SEISAN
EARTHQUAKE ANALYSIS SOFTWARE

FOR WINDOWS, SOLARIS, LINUX and MACOSX

Version 13.02

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The photo on the cover show the seismic test site in Peters backyard, December 2023 Photograph: P. Voss.

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Chapter 1

Introduction

The SEISAN seismic analysis system is a complete set of programs and a simple database for analyzing earthquakes from analog and digital data. With SEISAN it is possible using local and global earthquakes to enter phase readings manually or pick them with a cursor, locate events, edit events, determine spectral parameters, seismic moment, azimuth of arrival from 3-component stations and plot epicenters. The system consists of a set of programs tied to the same database. Using the search programs it is possible to use different criteria to search the database for particular events and work with this subset without extracting the events. Most of the programs can operate both in a conventional way (using a single file with many events), or in a database manner. Additionally, SEISAN contains some integrated research type programs like coda Q, synthetic modeling, moment tenesor inversion and a complete system for seismic hazard calculation.

The data is organized in a database like structure using the file system. The smallest basic unit is a file (the S-file) containing original phase readings (arrival times, amplitude, period, azimuth, and apparent velocity) for one event. The name of that file is also the event ID, which is the key to all information about the event in the database. Although the database in reality only consists of a large number of sub-directories and files (all of which the user has access to), the intention is that by using the surrounding software, the user should rarely need to access the files directly, but rather do all work from the user's own directory. Included with SEISAN there is a test data set, a training document using the test data of many events and a tutorial using just the 2 events included with the software. In addtion, there is a document illustrating seismogram analysis using SEISAN. See chapter 5. To get an idea of how SEISAN works, new users can take a look at a SEISAN webinar that was arranged by IRIS in 2014 (see `https://www.youtube.com/watch?v=KJH3ktGL_K0` or file seisan_webinar_iris_2014.mov on the SEISAN ftp server).

SEISAN runs under Sun Solaris, Linux, MacOSX and Windows. The programs are mostly written in Fortran, a few in C and almost all source codes is given, so the user should be able to fix bugs and make modifications. The programs have been compiled and linked with system compilers and linkers on SUN, GNU compiler on Linux, Windows and MaxOSX. For graphics, X is used on Unix systems and DISLIN (www.dislin.de) used under Windows. No format conversion is needed to move data files (binary and ASCII) between the systems if one of the standard formats (SEISAN, GSE2.0, SEED, SAC, GURALP) is used. The GUI Seisan Explorer is written in Qt and is used on Linux, MacOSX and Windows.

BE AWARE: A SEISAN S-file must not contain symbols requiring 2 bytes or more (the case with some country letters). The system will crash.

This manual resides in the directory INF (see below), when the system has been implemented on your computer. The file is called `seisan.pdf` (Adobe PDF).

The SEISAN system is built of programs made by many different individuals without whom it would never have been possible to make SEISAN. Acknowledgement is made throughout this manual where appropriate or in the acknowledgement section at the end. SEISAN now contains so many programs that when a new version is released, it is not possible to check all the options in all programs and we rely on the user to help finding the bugs, please report!

SEISAN is freely available for all non-commercial use.

In this manual names of computer programs are given with capital letters, names of files and command line options are given by typewriter font.

1.1 Changes for the SEISAN version 13.02 (released 2023-12-06)

- Many bugs fixed.
- GMAP program now converts the place_names.eev file in DAT to KML.
- NETDET, real time event detection.
- GET_ARC_CHANNELS added, find the list of channels in an archive.
- WAV_ADD, adds waveform file names to a data base from a list in filenr.lis.
- SCPNOR, extracts Nordic files for events in SeisComp.
- HARNOR can now also read MT solutions from Gisolai as made by SeisComp.
- MAPG has many new options.
- EEV has an option to plot magnitude residuals, PMR
- EEV can delete several events, DM
- HYP can now use geolocation from file in DAT
- SPEC has new option for kappa.
- KAPPA, a new program for calculating kappa only.
- KAPP_SORT: analysis of kappa values.
- BACKUP_SFILES, automatic backup of an S-file data base.

1.2 Changes in the SEISAN version 12.0 (released 2021-06-08)

The major change added to SEISAN in version 12.0 is the new phase line format, please find detailed description in 1.2.1.

- Program NOR2NOR2, converts between new and old Nordic formats.
- NOR2QML - A online service to convert NORDIC format to and from QuakeML, see page 253. There is also a Java script included which does the same called nor2qml or qml2nor.
- SELECT has changed waveform name search to a general search of a text string in whole file, optionally case independent. Program SELECTC has now been removed since the new SELECT can do the same.
- HYP can optionally do a grid search (3D) at end of iterations to find if the solution is in a local minimum. If so it then starts again iterating from the global minimum. Controlled by RESET TEST parameters.
- A plugin for the iLoc program has been implemented, see page 123.
- The definition of archive with ARC_CHAN2 now makes it easier to setup virtual networks, and allows for definition of different archive paths, see ARC_ARCHIVE2.
- A new program CHANGE_RESP_NAMES to fix RESP file names for missing or wrong location and network codes.
- Automatic amplitude can now also be used in multi trace mode.
- SELECT can use moment tensor as selection criteria.
- HypoDD has been included, all platforms. A turorial is included.

- Program WAVASC has been added, makes 2 column ASCII file from any waveform file format.
- Program MERGE_S has been added to merge S-file catalogs and remove duplicate phases.
- Program IMSNOR has been added. program for converting IMS and ISF format files, more complete than NORIMS. It also supports the new ISF2 format.
- EEV option US added to make and update ID lines
- Program VELNOR has been added, for converting Velest cnv file to Nordic.
- Program PLOTPHASE to plot seismogram around P/S for quick inspection, command QP in EEV.
- Program AUTOREG can get all input from prompt line and can register one waveform file without filenr.lis.
- CONDET can now detect, extract waveform files and register events in S-file data base copy waveform files in one operation.
- Place name file for EPIMAP and MACROMAP has changed format.
- EEV has got a new command GEO to put place names into S-file using a placename file in DAT.
- A summary email can now be sent from EEV with command EMAILSUM using a different email list from EMAIL command. It can optionally automatically put in an epicenter map made with MAP or MAPG. MAP and MAPG several new options including plotteing rays traces.
- NORGMT has been replaced with a new program of the same name.
- SE does not need to be recompiled on Linux, a static version is supplied.
- A new program MAGRES to calculate average magnitude station residuals.
- A new program HYP_COUNT_PHASES to calculate number of rays in different layers.
- A new section on using HYP grid search for crustal structure, with example and help programs (see page 38.2).
- Calculation of RMS in HYP for back azimuth observations has changed such that residual equal to RESET TEST(52) is equivalent to 1 sec travel time residual, this was not correct before.
- Calculation of local magnitude now allows for additional near source correction.
- New command IM in EEV for changing the eventid information, like E.
- The quarry command now can also copy quarry information to the S-file.
- The DELS command has several new options.
- This version was compiled with gfortran/gcc version 4.8.5 20150623 (Red Hat 4.8.5-44) (GCC).

Older changes are listed in Appendic E.

1.2.1 A new Nordic Format, Nordic2

The Nordic2 format for parametric data is implemented from version 12 to overcome limitations with the previous Nordic format. The old Nordic format does not included network and location codes that are part of the data stream identification. More and more station use these codes and two different stations (digitizer and/or seismometer) can have the same station code and then have to be differentiated by network code and possibly location code. A significant weakness with the old Nordic format is that component codes are 2 letters, which in the new format (Nordic2) are 3. Another problem when data is merged from different sources is to know where the data come from. We have therefore, for each phase, included the possibility to include both agency and author of the phase.

To see how to migrate from Nordic to Nordic2 format, see end of this section.

The philosophy of the new format is that each type of observation used in S-files (phase, amplitude, coda, back azimuth) must occupy one line with a corresponding phase. This has been an optional case also before for amplitudes and back azimuth, now it is a must. The amplitude phase has the same name as before like IAML, the back azimuth (and apparent velocity) are BAZ, possibly with a phase name like BAZ-P to indicate the phase. The coda is END (IASPEI standard). Below is an example, the Appendix has the full description.

```
STAT COM NTLO IPHASE   W HHMM SS.SSS   PAR1  PAR2 AGA OPE  AIN  RES W  DIS CAZ7
BER  SHZ NS00 IP         1325 38.120      C       BER lo      -.9801061.00  11
ASK  SHZ NS00 ES         1325 48.070              BER jh      -1.021071.10   3
ASK  SHZ NS00  AMP       1325 48.070  333.3  2.20                    71.10   3
ASK  SHZ NS00  IAML      1325 50.900  111.0  0.30                    71.10   3
NRA0 SHZ BB01 IPn       A1326 19.090              NAO hhh 50.0-.05010368.0  72
NRA0 S Z       END       1326 19.090  333.0                 0.2  368.0  72
NRA0 S Z       BAZ-P     1326 19.090  256.9   6.9           0.1  368.0  72
MUD  BHZ DK00 IP         1326 38.120      C       DNK pv      -.9801061.00  11
MUD  BHE DK00 ES         1326 48.070              DNK pv      -1.021071.10   3
```

The new columns are NT and LO for network and location respectively. AGA and OPE are agency and operators. PAR1 and PAR2 are the observation associated with the phase which are:

Seismic phase: polarity
Amplitude: amplitude and period
END: coda length
BAZ: back azimuth and apparent velocity

The residual (RES) is now residual for the observation if any, degree for BAZ, seconds for phase, magnitude for amplitude and coda.

The user can select the format to use in SEISAN.DEF, parameter NORDIC_FORMAT. The default, for now, in the distribution is that the format is set to the old Nordic format (0) and everything will work as before. Setting to 1 old and new format can be read but new will be written (also in programs such as SELECT, SPLIT, ...) and setting to 2 only new for a can be used. It is recommended to use 0 or 2 to avoid mixing the format in one database, but 1 is needed for example to compare data in Nordic and Nordic2 format.

SEISAN can be hardcoded to work with new nordic format only; in `LIB/libsei.for` uncomment the two lines given at the end of the `get_seisan_def` subroutine and recmpile SEISAN.

It is possible to convert from new to old and vise versa by program `NOR2NOR2`.

The majority of programs have been changed to be able to work with the new format, if not it will be noted.

There are several programs that work with the SEISAN 4 character component names, particularly conversion programs. These have not been changed to 3 character components since they will also work with the 3 character components, leaving the 3rd character blank. When converting from 2 character to 3 character component codes, the 2nd character is left blank. Also many programs can only work with station and component and will not, at the moment, be converted to also use network and locations (e.g. CODAQ).

Old to new components, NT and LO in MULPLT
When old data is transferred to new format there is only component e.g. S Z and no location and network

code. If the original data has this information, MULPLT is still able to plot the phases since:

- if component code 2 is blank, no check for 2nd component charcter.
- check for location and network is disabled if they are both blank.

If new phases are read and NT or LO are present, the component code must then have 3 characters.

Response files. The SEISAN naming of response files does not have NTLO so they cannot distinguish same station names and different NTLO. This will probably also be fixed but for now the problem can be solved by using RESP response files.

As the Nordic2 format allows more complete mapping between the data streams and observations, it is recommended to convert complete databases. However, it is planned to continue to distribute SEISAN, which is able to use the old format to be backward compatible.

To convert from Nordic to Nordic2, the user should carefully check that no significant changes are introduced. This can be checked by comparing locations and magnitudes between the orignal Nordic and recomputed results after conversion to Nordic2 format. An additional complication is changes in HYPOCENTER, especially compared to quite old distributions. The user should carefully consider what needs to be checked, the following list provides a suggestion:

- make sure you have backup of the original database
- keep NORDIC_FORMAT set to 0, and use SELECT or COLLECT to create Nordic file
- check for changes because of HYPOCENTER, by relocating, then use program COMPARE_HYP or COMP_HYP to check for changes; if changes are significant this needs to be investigated before moving on
- next convert file from Nordic to Nordic2, using program NOR2NOR2, check with COMPARE_HYP or COMP_HYP
- set NORDIC_FORMAT to 1, and use HYPOCENTER to relocate
- compare to Nordic format data using COMPARE_HYP or COMP_HYP
- if significant changes, this needs to be investigated
- when it is verified that there are no significant differences (unlikely in first round), the output from HYPOCENTER in Nordic2 format can be split into an empty new database (see MAKEREA), which then replaces the original database (be careful about changing database folder name when replacing)
- set NORDIC_FORMAT to 2, which makes Nordic2 a must, Nordic will no longer be read; in case of different databases, different SEISAN.DEF files can be used; NORDIC_FORMAT=1 is not recommended

1.3 Information about SEISAN online

SEISAN homepage

The URL address where SEISAN and related software can be found is:
`http://seisan.info`

Here you can find information on the latest changes in SEISAN, access the online manual, download the software and much more.

SEISAN download server

Seisan is available from the following web server:
`https://www.geo.uib.no/seismo/SOFTWARE/SEISAN/`

SEISAN mailing lists

There is a mailing list, which is set-up to improve the exchange of information and questions on SEISAN. We strongly recommend that all users subscribe to the SEISAN list. The list is:

`seisan@uib.no`

The purpose of the list is:

To subscribe to the list, send an email to `seisan-join@uib.no` or to `seisan-request@uib.no` with subject/body subscribe.

Subscription can also be done online via `http://mailman.uib.no/listinfo/seisan`. As a member of the list, it is possible to look through the archive (since 2008) for questions and answers on SEISAN. Anyone is welcome to reply to questions and a response to a question should be send to the complete mailing list.

Chapter 2

Structure of SEISAN

2.1 Directories

The whole SEISAN system is located in subdirectories residing under the main directory SEISMO. For more details, see chapter 3 on installation. The system contains the following main subdirectories:

REA:	Earthquake readings and full epicenter solutions in a database
WOR:	The users work directory, initially empty
TMP	Temporal storage of files, initially empty
PRO:	Programs, source code and executables
LIB:	Libraries and subroutines
INC:	Include files for programs and subroutines in PRO and LIB
COM:	Command procedures
DAT:	Default and parameter files, e.g. station coordinates
WAV:	Digital waveform data files
CAL:	System calibration files
INF:	Documentation and information
ISO:	Macroseismic information
SUP:	Supplementary files and programs

In the following, the above subdirectories will mostly be called directories to avoid always referring to SEISMO. All directories use capital letters, however this only makes a difference in the Unix versions. The directory structure is used as a tree like structure for quick access to individual files in the REA directory, which therefore will appear as a simple database to the user. The next section is a description of the database directories; the other directories are described in chapter 44. Figure 2.1 shows the tree structure of SEISAN.

2.2 The database

The database of SEISAN consists of the two directories REA and WAV. The REA directory and its subdirectories contain readings and source information while all waveform data is normally in the directory WAV (see 2.2.2) with no subdirectories. Optionally WAV can also be divided into a similar subdirectory structure, see 2.2.2, which is useful when storing continuous data in particular. The DELET database contains all events deleted from any of the databases (here BERGE/BER and NAO). Filenames are identical between all platforms.

2.2.1 Phase data and hypocenters

The REA directory contains phase readings and derived source information like hypocenters, fault plane solutions etc. The REA directory has one or several subdirectories corresponding to separate databases (see Figure 2.1 for an example with two databases). The database names can have between 3 and 5 characters. If less than 5 characters are used, the character '_' is added in the file system to make it 5. The user does

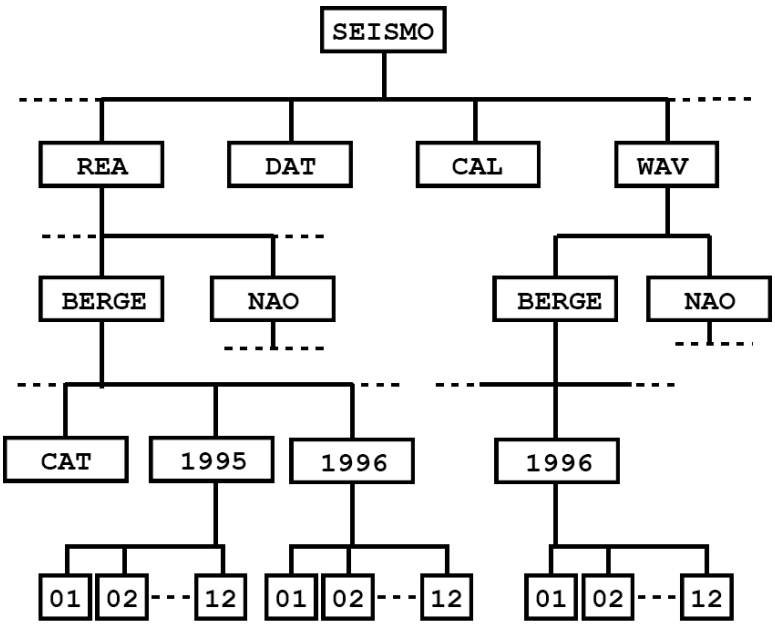


Figure 2.1: Structure of SEISAN. Note that BERGE under WAV is optional and DELET (not shown) under REA has a similar directory structure as e.g. NAO.

not have to put the '_' when running a program, they will be added by the software. If a directory is made manually, the '_' must be put in. It is assumed that a database is always present in the system. The name of the default database is given by an environmental variable (see section 3.2), however if not set, it will default to AGA for agency. Here, BER will be used as an example throughout the manual. A database has a duplicate storage of the events. For quick reference and interactive work the events are stored in single files (S-files) in yearly directories and monthly subdirectories. When new data is entered into the database, it comes in as individual event files. However, once the interactive work has finished, the single event files are overwritten with the final location and additionally stored in monthly files, which are only changed when updating (UPDATE command, see section 14). The monthly files, called CAT-files for catalog, are stored separately in the CAT directory and primarily used for quick searching and backup for the single files. In addition to the event data, there is also a LOG directory in each database to keep a log of the data processing, see section 14.

S-file database structure

The structure for the single file storage is as follows (Windows example):

\REA\BER__\	Main readings directory, all data
\REA\BER__\1999\	Data for 1999
\REA\BER__\1999\01\	Data for January 1999, each event in one file

On Unix, the last line would have been /REA/BER__/1999/01

The structure works back to year 0000. Each event contains original phase readings in the Nordic format (Appendix A.) which includes file names of all corresponding waveform files. One event is one file. Each event has an ID line. The ID line contains a unique ID, which will follow the event through all COLLECT and SPLIT operations (see section 12 and 13). The ID is directly correlated with the S-file name and after an update of the S-file, also with the origin time. The ID line also contains status information about the event like last action, when it was updated etc. The ID-number is normally fixed, which is useful if data is taken out from the database, processed on another computer and later put back into the database, since otherwise the ID of an event might be changed and the existing file would not be overwritten. An example of an S-file name is :

`27-1112-11L.S199401`

The S-files are used as input for the location program and, when making a permanent update, also for output, see 7. The letter in front of the "." indicates the event type and can be L, R or D for local, regional or distant event respectively. It is the same indicator as given in the header line of the S-file, see the Nordic format page 498. The remaining numbers give (in order) day, hr, min, sec, year and month.

As mentioned above, the system can contain many other databases, which may function exactly like the BER directory. A data base can be used to store a subset of data or data from different networks. Data can be moved between databases or in and out of the databases, for details, see description on EEV (5.4 and 5.5).

Monthly location files, the CAT directory

Events located in monthly files are in a directory called /SEISMO/REA/BER__/CAT in addition to the individual S-files. Additional databases like e.g. NAO will have epicenters stored under /SEISMO/REA/NAO__/CAT. The monthly epicenter files are called `199901.CAT` for e.g. January 1999. Although the files generated by SEISAN normally are monthly files, the CAT directory can also contain yearly files or any other time interval. The only rule is that the name of the file must give the year and month of the first event in the file. This is because the search program SELECT can use the CAT files to search requested time intervals (SELECT most often use the S-files for selection). If a user has a historical catalog, this can be added as an individual file. If the historical catalog starts in 1820, the file name would be `182001.CAT`. The files in CAT do not need to be continuous in time, but they must not have overlaps in time and each file must have data in chronological order. The format of the CAT files is the same as for the S-files. Additionally, CAT files can also be compact files, meaning just the header lines of the S-files (see also section 2.3).

2.2.2 Waveform data and formats

SEISAN works with various waveform formats including SEISAN, GSE2.0, SEED/MINISEED, GURALP GCF(single channel files), Helmberger format and SAC binary and SAC ASCII. The SEISAN format is

described in Appendix B, while for a format description of GSE and SAC the user is referred to GSETT-3 (1997) and Goldstein (1999), respectively. The SEED format is described in IRIS Consortium (1993). The GSE reading routines are based on the codeco routines written by Urs Kradolfer, Klaus Stammler and Karl Koch. The routines read GSE2.0 only, not GSE2.1. The format description of GSE2.0 is given in: `INF/structure-of-seisan.tex`. The different formats can be used in parallel by several programs. With MULPLT for example it is possible to plot data in the four formats at the same time. Other formats can be added by adding reading routines and adding the respective calls to `LIB/wave.for` . Note that SAC binary files can also be used on Windows from SEISAN version 8.2. To use other formats, a conversion program must be used first, see section 19.

Numbers smaller than 1.0 and real numbers

In general, binary waveform data is written as integers. However sometimes data can be smaller than 1.0. This can only be handled by SEISAN and SAC formats. In the SEISAN format, small numbers can be written by using the scaling constant (see SEISAN waveform format) so the small numbers are written as integers and the scaling constant is then used when reading the data. Most programs in SEISAN can read this data (like MULPLT) but few can write it. Currently WAVETOOL and SEISEI can write small numbers in SEISAN format. SAC small number data can also be read by most programs but probably only written by WAVETOOL. Several ASCII formats use real numbers so any size numbers can be written and read. The most important is the Helmberger format written by the the OutW command in MULPLT. Small numbers can be generated by SEISAN if date correct for a filter or corrected for reponse is written out.

In general it is recommended to keep the waveform data in one format only, mainly for simplicity and maintenance reasons. There may be different arguments for or against one or the other format depending on the user's preferences and requirements. SAC and GSE are widely used formats and therefore may be attractive. SEISAN is a multi-trace binary format with direct read access to individual traces. SAC is a single trace binary or ASCII format with a large number of header parameters. The SAC format is widely used in research-oriented programs. GSE is a multi-trace ASCII waveform format that includes various sub-formats. It is widely used for data exchange. Although the GSE format can keep any number of traces, it is recommended to include no more than 3 traces in a single file depending on the number of samples, since when reading a particular trace, the whole file may have to be read.

The MINISEED format is probably the best option since most data centers use it and almost all intrument manufactures will provide it. SEISAN cannot read SEED files using all options possible in SEED, but data from the largest data centers as well as many observatories have been used for testing. With respect to MINISEED, there are less problems since MINISEED is simpler than SEED. SEISAN can also write MININSEED (program WAVETOOL), but cannot write SEED (unless GSE2SEED is used). The WAV directory contains files with digital waveform data. The directory normally has no subdirectories or any other organization. However, in case of large databases, WAV can be subdivided, see below. In addition any directory can contain waveform data, it has to be specified in SEISAN.DEF (section 3.13).

The amount of data that can be stored is only limited by the disk size. The analysis system will always look in WAV for particular files if they are not in the user's own directory. Waveform files will automatically be transferred to WAV on initial registration into the database (see MULPLT). Registration is the process of automatically creating an S-file in the database with the name of the waveform file and header information. Phase pickings are done later. See section 8.

There is normally no requirement for particular filenames for the waveform files in WAV or elsewhere, however many programs will make file names like:

`yyyy-mm-dd-hhmm-ssT.NETWO_nnn` e.g. `1995-01-23-1230-20M.BERGE_013`

With the abbreviations yyyy: year, mm: month, dd: day, hh: hour, mm: minute, ss: second, T: file type indicator (normally M or S), NETWO: maximum 5 letter network code and nnn: number of channels.

Recommended file type indicators are:

S: Standard SEISAN
R: Resampled
A: Appended
M: Miniseed/SEED

WAV database: In case a large number of waveform data is stored, it might be an advantage to also split up the WAV directory in subdirectories. This is done in the same way as in the REA directory, e.g. waveform files for BER from July 1994 would be found in `WAV/BER__/1994/07`. Programs that use waveform

files will automatically search, in order, the current directory, TMP, WAV and the monthly WAV directory (TMP. see compression below). However, it is a requirement for all programs running outside EEV that the waveform data is in the default data base since only that one is searced. **When storing in the WAV database, it is a requirement that the waveform names by default start with either yymm (like 9902) ,yyyymmdd (like 19990101) or yyyy-mm (like 1999-02).** If this is not the case, the position in the file name of year (including century) and month must be specified in SEISAN.DEF, see parameter CONT_YEAR_MONTH_POSTION_FILE. In this case all the waveform files in the WAV structure must have the sane type file name.

The SEISAN binary waveform format is explained in Appendix B. The files are written and read with the same Fortran statements on all platforms, however the internal structure and byte order are different. As of SEISAN version 5.1, files written on either machine can be read on the other and there is no need for any conversion when the binary waveform files are moved between Sun, Linux, MaxOSX and Windows.

Compression of waveform data

Waveform files can be stored in compressed format. The compression must be done by the user. Programs that access the compressed waveform files copy the file to the TMP directory, and uncompress there. The uncompressed file remains afterwards and will be found the next time one of the programs is looking for the same waveform file. The content of the TMP directory has to be deleted manually. On Unix, you may automatically delete the content of the TMP directory by a cronjob, see manual pages on crontab. On Unix the compression formats supported include gzip, compress, bzip2 and zip. On Windows, only gzip is supported (gz files). In order for it to work, the command gunzip must working. This can be done with gzip which also can decompress. Fist install gzip if not there. Then create a bat file to be in you part (like in COM) with name gunzip.bat and content

gzip -d

With the introduction of SEED format, there is less need for external compression since the SEED data usually is compressed and therefore decompressed on the fly when read. Also now disk is usully not a problem when dealing with individual events.

Component codes

The SEISAN waveform format until version 8.2 has used 4 characters for the component code. SEISAN now follow the SEED component code (see Appendix A in the SEED manual: `http://www.fdsn.org/pdf/SEEDManual_V2.4.pdf`). In the format before 8.2, the first character indicates the type of sensor, for example 'B' for broadband, 'S' for short-period or 'L' for long−period. For acceleration data the first character has to be 'A' because SEISAN assumes that the corresponding response has been given as acceleration response. The fourth character has to give the channel orientation, 'Z' is used for vertical, 'E' for east-west and 'N' for north-south. Other orientation of the horizontal components is possible in GSE, SEED and SEISAN are not understood by SEISAN. If data are rotated, 'T' is used for transverse and 'R' for radial. The second and third characters can be chosen by the user. From SEISAN version 8.2, only 3 characters are used, the first 2 and the last. These 3 characters are then defined according to the SEED standard. SEED location codes and network codes are now also stored in the SEISAN format and are displayed when plotting the traces with MULPLT. From SEISAN version 12, several program will use location and network codes, particualrly if the new format, Nordic2, used. The component code is part of the response filename and is used to find the response corresponding to a given station and component. The network code is not part of the response files except for the SEED response files so if using a SEED response file, network and location codes must match. Program WAVFIX can be used to change station and/or component codes for most formats (but not yet network and location codes.

The Nordic format only has space for two characters for the component code. The definition in SEISAN is that these are the first and fourth character of the waveform component code. This means that the relation between the component code in the Nordic file and the waveform data is non-unique. In the the new format, Nordic2, there is room for 3 char componenet code and location and netwotk codes. D The GSE and SEED waveform formats have three characters for the channel code, see GSETT-3 (1997) and IRIS Consortium (1993) for the detailed definition of the component codes. SEISAN, when reading waveform data in either GSE or SEED format internally keeps the first two characters and moves the third to fourth, so for example 'BHZ' becomes 'BH Z', however the user will only see the name as BHZ in many programs. Data files in SEED also have a location code, which allows to distinguish for example between two 'BHZ' components (for example a 30 second and 120 second sensor with the same sampling rate and high gain) at the same

site. Z. When converting between SEISAN and SEED/MiniSEED, station, network and location codes are preserved while SAC and GSE only partly can store this information. SAC has more than four characters for the component code and sacsei.def parameter file in DAT has to be used to define the conversion. However, normally SAC data will have three character component codes as well. Conversion of component codes from SEISAN to SAC is also defined in sacsei.def.

When converting between SEISAN and other waveform formats, component conversion is defined in the respective definition files, see section on conversion programs.

2.2.3 Continuous waveform data

In SEISAN one can plot or extract continous data from either a standard SEISAN database (internally many different formats) or from a BUD or a SeiscomP archive (internal format MiniSeed. The archive option is the most common way to use continous data in SEISAN. It is easy to convert most format to MiniSeed with WAVETOOL and the use any group of MiniSeed files to create the archive with program DATASELECT (included in SUP), see section 'getting data into the data base' See also page 66.

Continous data in a BUD or SeiscomP archive

SEISAN reading BUD and SeisComp archives

SEISAN is able to read miniseed from a BUD and SeisComp (SDS) archives data structure. The reading routines using Chad Trabant software have been implemented by Ruben Luis. Reading continuous data: This works just like reading SEISAN continuous data, except there are no S-files, only the archive files. All the same functions are available:
Plotting, zooming and extracting segments and registering events.
Read archive data as an event from eev:
A reference to a segment is made in the s-file and it is treated as if it was a file. When a keyword for archive (ARC) is found, the reading is directed to the archive instead of to a file. The archive reference is e.g.

```
ARC STAT  COM NT LO YYYY MMDD HHMM SS   DUR
ARC ROSA  BHZ PM    2010 1011 0100 00 14400                                    6
```

where ARC indicate archive, STAT is station code, COM is component, LO is location code YYYY MMDD HHMM SS is start time and DUR is duration in secs.
Thus the segment in archive with given start time and duration is considered a file. If later plots require less data than the segment referenced, the whole segment is still read, like reading the whole trace in a file in archive with given start time and duration. A mixture of archive references and file names can be used.
The archive reference can also use wildcards to reference many channels, like e.g. just writing ARC and the rest of the line blank, all channels in the archive will be selected.
Station is blank or *, component, network and location are blank: All channels defined in SEISAN.DEF will be plotted with start time and duration given in ARC line (if not blank, see next option). If a component is given, only that component will be selected. If a network is given, only that network will be chosen. If a location code is given, only channels with that location code is selected.

Start time and or durations blank: Start time will be origin time - a time given in SEISAN.DEF (ARC_START), duration will be a time given in SEISAN.DEF (ARC_DURATION).

Station is P: For phase reading - All channels for all stations listed in the S-file found in the archive will be plotted. There is no requirement for the station to have any other information than the station name, component code is not used. So a new station can easily be added. Example:

```
ARC STAT  COM NT LO YYYY MMDD HHMM SS   DUR
ARC P               2010 1011 0100 00 14400                                    6
```

Station begins with _ indicates virtual network as defined in SEISAN.DEF. This can also be inserted with arc command in EEV. Example of link to virtual network named _CTBTO in sfile, below format line:

```
ARC STAT  COM NT LO YYYY MMDD HHMM SS   DUR
ARC _CTBTO          2010 1011 0100 00 14400                                    6
```

Plotting all stations without an archive reference line: If parameter ARC_BY_DEFAULT in SEISAN.DEF is set to 1, all channels in the archive will be selected.

NOTE: An ARC line can be inserted/edited in the S-file from EEV by command arc.

The archive is defined in SEISAN.DEF where each channel is defined by ether an ARC_CHAN2 line (from version 12) or an ARC_CHAN line (still possible, this was the only option prior to version 12). ARC_CHAN2 makes it easier to define virtual networks, which with ARC_CHAN have to be defined through ARC_VIRTUAL_NETWORK lines. Another improvement is that with ARC_CHAN2 it is possible to specify the archive with variables that are defined through ARC_ARCHIVE2 lines.

Here is an example of using the ARC_CHAN2 definition and definition of the nnsn_eida archive variable:

```
ARC_ARCHIVE2                          nnsn_eida /home/seismo/WAV/SLARCHIVE
-------------------------------------------------------------------------------------------------------
--------- explanation arc_chan2       S    C  N L  Def Start    Stop     Archive   Vnet1 Vnet2 Vnet3 V
-------------------------------------------------------------------------------------------------------
ARC_CHAN2                             ASK  HHZNS00 1.0 20181106          nnsn_eida _SW   _SN   _NNSN
ARC_CHAN2                             ASK  HHNNS00 1.0 20181106          nnsn_eida _SW   _SN   _NNSN
ARC_CHAN2                             ASK  HHENS00 1.0 20181106          nnsn_eida _SW   _SN   _NNSN
ARC_CHAN2                             ASK  EHZNS00 1.0          20181106 nnsn_eida _SW   _SN   _NNSN
ARC_CHAN2                             ASK  EHNNS00 1.0          20181106 nnsn_eida _SW   _SN   _NNSN
ARC_CHAN2                             ASK  EHENS00 1.0          20181106 nnsn_eida _SW   _SN   _NNSN
```

The columns in the ARC_CHAN2 line contain:
41-52: station, component, network and location
54-56: start date as yyyymmdd
58-65: stop date as yyyymmdd
67-74: archive name that is pointing to archive path
76-84: name of virtual network that station is part of
86-90:name of virtual network that station is part of
92-96:name of virtual network that station is part of
98-102: name of virtual network that station is part of
104-108: name of virtual network that station is part of
110-114: name of virtual network that station is part of
116-120: name of virtual network that station is part of

The ARC_ARCHIVE2 line gives the archive name (41-49) and the respective archive path (51-). One can add several ARC_ARCHIVE2 lines.

When defining a channel using a `ARC_CHAN` text string: SSSSSCCCNNLL, where SSSSS is the station, CCC is the component, NN the network and LL the location. These lines can be generated with program sample_read_wav, which will make a list of all channels in a given set of files (it thus requires to have one of several single files with the channels needed).. An alterentive is to use program GET_ARC_CHANNELS which will scan an archvie to list the channels in SEISAN.DEF format. See section 'Waveform file management tools'.

The directory of the archive is given by `ARC_ARCHIVE`, see e.g.:

```
ARC_CHAN                              PMOZ BHZPM
ARC_CHAN                              PMOZ BHNPM
ARC_CHAN                              PMOZ BHEPM
ARC_CHAN                              SFJD LHZIU10
ARC_CHAN                              SFJD LHNIU10
ARC_CHAN                              SFJD LHEIU10
ARC_ARCHIVE                           /uibsan/home/s2000/BUDARC
ARC_DURATION                          10000.0
ARC_START_TIME                        5000.0
ARC_TYPE                              1.0
ARC_BY_DEFAULT                        0.0
```

where each channel is defined as well as the location of the archive. The specification is the same for both BUD and SeisComp archives. ONLY one archive type can be used at the same time and the archive type, ARC_TYPE is given in SEISAN.DEF.
Groups of channels can be defined as virtual networks. The virtual network names will be shown in the station selection when using 'arc' option in MULPLT. The definition is done in SEISAN.DEF:

```
ARC_VIRTUAL_NETWORK                    _NO       BER  HHZNS00
ARC_VIRTUAL_NETWORK                    _NO       BER  HHNNS00
ARC_VIRTUAL_NETWORK                    _NO       BER  HHENS00
```

The virtual network name has to start with a '_' to make them visible as such in the station selection.
Archive reading works on both Linux and Windows.

Continous data in a SEISAN database

In SEISAN continuous data has no special format. Continuous data is simply ordinary waveform files that follow each other in time. In order to treat the data as continuous, the data can be put into a SEISAN continuous data base. Such a data base is made as follows:

- For each waveform file from a station or network, an S-file is created. The S-files only contain reference to the waveform file(s). Program AUTOREG can be used to create the S-files.
- The waveform data is optionally put into the corresponding waveform station directories, however they can also be in WAV or working directory. For large data sets it is strongly recommended to use the WAV database structure.
- The continuous databases are defined in SEISAN.DEF in DAT.

If e.g. data is to be stored from 3 different stations (three componet files), create 3 databases under WAV and REA with the name of the stations (program MAKEREA). If the continuous data consist of 20-minute files, this would mean about 2200 files pr month, which is a reasonable number. It is now possible for some programs (MULPLT, WAVETOOL) to get access to any or all of the traces in the continuous data base and plot and extract data. If the continuous data is archived from a real-time system it is best to have one database per station as it will at times be necessary to backfill gaps as data may not have arrived in real-time.

Note that waveform files in a SEISAN continuous structure must contain the year and month which is used to located the corresponding year-month structure. The default start of the file names accepted are:

ccmm ccyy-mm ccyymm

where cc is century, yy is year and mm is month. If year and month are placed diffenrently in the file name, their location must tbe specified in SEISAN.DEF, parmeter CONT_YEAR_MONTH_POSTION_FILE.

It is also possible to store the data without having a database for each station:

- Alternative 1: If the 3 stations have waveform files starting at about the same time and the same duration, they can be merged to 9 channel files and only one continuous data base is made. This may work well for data from a temporary deploymeny where all data is there when the data is put into database.
- Alternative 2: If the 3 stations have waveform files starting at about the same time and the same duration, the 3 waveform files can be listed in the S-file and only one data base is needed.
- Alternative 3: If the files are in individual channel files, 9 waveform files can be listed in the S-file and only one continuous database is needed.

The waveform files in a continuous data base can have different formats for different stations and one S-file can refer to more than one waveform file, provided they start at about the same time and have the same duration.

A simpler way to use smaller quantities of continuous data is to make a list of these files with DIRF and an application program can then use that list to work with the data. Currently two programs have special options for this kind of continuous data. The MULPLT program will plot data from several files as if it was one file in one continues trace the RESAMP program will resample the data from several files and put it into one output file.

2.3 File types used with SEISAN

A description of the different file types is given below with typical names. Most names must be exactly as specified, others can be given names. However it is VERY important that no name including full path is more than 80 characters long. Until now this has not been a problem, however it has to be considered when SEISAN is installed.

IT IS EXTREMELY IMPORTANT THAT NO ASCII FILES CONTAIN TABS, USE BLANKS INSTEAD, A TAB WILL SCREW UP FORMATTING. SIMLARLY NON STANDARD ASCII CHARACTERS (MULTIBYTE) CANNOT BE USED.

A file with non standard characters can be cleaned with program REMOVE_TAB which will replace the characters with blanks.

The basic unit is a file in the Nordic format, (see Appendix A). For practical purposes 3 descriptive names are used for Nordic files:

S-file: Single event file with phase readings, with or without source parameters such as location and magnitude. In the database these files are named with the extension: .Syyymm This is the standard type of file in e.g. the `BER__/1998/08/`. An example is `11-1234-11L.S199808`.

CAT-file: A catalog file containing many S-files with location or just a catalog of hypocenters, a compact file, see below. This is the standard type of file in e.g. the `/REA/BER/CAT` directory. An example is `199801.CAT`. This file format is also output from several programs like SELECT and COLLECT. There is a blank line between events.

Compact file: This is a CAT-file with only the source information. One event is represented with one line, (the header line in the S-file). There is no blank line between events. A compact file can be generated by either COLLECT or NORHEAD (earlier called COMPACT).

In addition there are the following types of files:

SEISAN waveform file: Waveform data can be stored in SEISAN, GSE, SEED, MiniSEED, Guralp, Helmberger and SAC format, see section 2.2.2. An example of a name is `1992-01-11-2233-22S.BERGE_011`.

Response file: File giving the response of a given channel at a given station. They are typically generated with the RESP program, see description of CAL directory, section 41. This is the standard type of file in the CAL directory. An example of a name is `ODDA_S__Z. 1999-05-01-0000_SEI`. However, SEED and SAC response files extracted with rdseed or made with other programs can also be used.

File listing: This is just a file with a list of numbered files. The file name is always `filenr.lis`, and it is generated with the DIRF program, see 15.

Index file: This file contains a listing of absolute paths to a series of S-files. The index file can be used as input instead of the CAT-files to several programs. Several programs generate index files as e.g. select and eev. The index file has the same format as the `filenr.lis` files described above and can be generated with the dirf command using S-files. The index file name must contain a '.'. An example is shown below:

1. \SEISMO\REA\TEST_\1993\09\29-2228-26D.S199309
2. \SEISMO\REA\TEST_\1994\06\16-1841-57D.S199406
3. \SEISMO\REA\TEST_\1996\06\03-1955-40D.S199606

2.4 Upper and lower case

Upper and lower case file names only makes a difference on SUN, Linux and MacOSX. The intention is that all permanent data file names used by SEISAN should be in upper case (e.g. S-files, crustal model file, directories (e.g. REA) while temporary files should be in lower case (e.g. print.out). Programs are also in lower case. It should then be a bit more difficult to delete the permanent files. NOTE THAT THROUGHOUT THIS MANUAL, PROGRAM NAMES ARE GIVEN IN UPPER CASE TO INDICATE THAT THEY ARE NAMES, HOWEVER WHEN USING THE PROGRAMS, LOWER CASE MUST BE USED ON LINUX. In program MULPLT, commands are case dependent.

2.5 Moving data between Sun, Linux, MacOSX and Windows

All S-files and file names are identical on the three platforms. To move many events (S-files) from one system to another, make a COLLECT (section 12) on the original system and a SPLIT (section 13) on the receiving system. As mentioned in section 2.3, the SEISAN binary waveform files have different internal structure if written on Sun, Linux, MacOSX or Windows, but this is corrected for in the reading routine, so files can be copied directly. GSE files can be copied directly since they are ASCII files. SEED/MINISEED files can be used directly on all platforms.

The only other files that are different are the binary earth model files `IASP91_`*`platform`*`.HED` and `IASP91_`*`platform`*`.TBL` in the DAT directory (where platform is either linux, macosx or windows). The platform is included in the filename. The files cannot be moved, but are easily regenerated with the IASP91 programs, see section 30 and 8.8 in the Hypocenter manual.

Chapter 3

Installation

SEISAN has been tested and compiled for Windows 10, Linux and MacOSX. If you wish to run SEISAN on Solaris, please note that not all programs will work. The SEISAN GUI "Seisan Exporer" is provided for Windows and Linux , it has not been tested for MacOSX.

Upgrade from previous versions

Before you start, take a backup copy of your DAT directory. Note that when you upgrade, many parameter files will be overwritten so make sure old parameter files are copied before putting in a new version of SEISAN. The most important are in DAT: `STATION0.HYP, SEISAN.DEF, MULPLT.DEF`. Also the Unix setup file SEISAN.csh and SEISAN.bash is overwritten. You may also want to keep copies of PRO, LIB and INC to keep a copy of the old source code, especially if you have done any modifications to the code. You can keep almost all of your parameter files, only `SEISAN.DEF` has been changed. Check this file and change to your system. Some individual program parameter files like for SPEC have changed.

How to get SEISAN

SEISAN can be downloaded using a browser from
`https://www.geo.uib.no/seismo/SOFTWARE/SEISAN/`

The web site will at least contain the following files:

`seisan_X.Y_.unix.tar.gz`	a compressed tar file, whole distribution with executables and test data, X.Y stands for the latest distribution number and Unix for the respective Unix system (linux or macosx).
`seisan._X.Y.exe`	Windows distribution an install file
`seisan_X.Y.pdf`	The SEISAN manual, Adobe PDF
`seitrain_X_Y.pdf`	SEISAN training course
`testdata_X.Y.tar.gz`	SEISAN data for the training course

Section 3.11 gives additional information about modifications and recompilation.

3.1 Quick start with test data

When you have installed SEISAN a quick way to make sure it works ok is to use the four test events that are included in the distribution. Use the EEV program to open the events and plot the waveforms. On a command line type
`eev 199606`
to see the 2 events from year 1996 and
`eev 202102`
to see the 2 events from year 2021.
Note, the 1996 events are in the old Nordic format and the 2001 events are in the new Nordic format.
In EEV use 't' to view the sfile and 'po' to plot the waveform data. If this works SEISAN is most likely installed ok. If the default data base is not TEST, run EEV with:

`eev 202102 TEST`
If this does not work, please see the instructions below.

3.2 Linux

Linux: The programs in the distribution have been compiled under Red Hat Enterprise Linux using the GNU compilers gcc and gfortran. It is recommended to recompile the programs, since otherwise the programs might not run on your Linux distribution. In the Redhat distribution of Linux the Fortran compiler is not part of the standard distribution, it has to be installed (see your Linux manual for instructions). THE USER ACCOUNT MUST BE SET UP TO USE csh, tcsh (use SEISAN.csh) or bash (use SEISAN.bash), in order for the SEISAN scripts to work. Note that in the following SEISAN.csh stands for both SEISAN.csh and SEISAN.bash. Otherwise the scripts need to be adopted to the shell used.

Instructions

The first step is to install the distribution, the procedure is the same for all Unix platforms.

1. Get tar.gz file

Copy the distribution file for your platform through FTP or from the web site to the SEISAN top directory, this could be a directory `seismo` under the home directory.

2. Decompress

`gunzip seisan_`*`version`*`_`*`system`*`.tar.gz`

There should now be the uncompressed file in your directory (without `.gz`).

3. Install SEISAN

`tar xvf seisan_`*`version`*`_`*`system`*`.tar`

Check that the SEISAN directories have been created.

If SEISAN has been installed without executable files, they can all be generated with the command 'make all' from the PRO directory. On Linux/MacOSX it requires the GNU Fortran compiler gfortran. See also section on compilation (3.11).

4. Regenreate the IASP travel time tables

On at 64 bit computer the IASP files in DAT must be regenerated if you have the files from a 32 bit computer, with the programs `REMODL` and `SETBRN` otherwise `HYP` will crash. First run REMODL, then SETBRN. The program do not require any input.

5. Set system parameters

If you are doing an update, some of the following settings can be skipped.

Activate SEISAN:

csh/tcsh shell :
In your .cshrc file, the aliases and paths used by SEISAN are defined by adding the line
`source /home/seismo/COM/SEISAN.csh`
where `../seismo` is the directory below which SEISAN has been installed. The `SEISAN.csh` script file assumes that you are running either csh or tcsh as your shell.

bash shell :
If you are using the bash shell add this line to your `.bashrc` file :
`. /home/seismo/COM/SEISAN.bash`
bash might include a `select` system program, if that is the case on your pc you also need to add this line in your `.bashrc` file :
`alias select="/home/seismo/PRO/select"`
to use the SEISAN SELECT program.
If you are using another shell you need to modify the script accordingly or change the shell. It is assumed that X-windows is installed.

SEISAN path for programs:
In order for programs and subroutines to know the path to the SEISAN program directory, this must be defined in the file SEISA.csh or SEISAN.bash in COM. Edit that file and set the environmental variable SEISAN_TOP to the name of the top directory, meaning the directory structure below and including seismo e.g. /top/users/seismo. This variable is then used to set the path to SEISAN directories.

SEISAN path for databases, parameter files etc:
The SEISAN database can be under the same top directory as programs, however it can also be different. This is practical if several users have their own databases, but use the same software. Set environmental variable SEISAN_TOP to top directory e.g. /top/users/seismo.

SEISAN default database:
To locate the default database directory set environmental variable DEF_BASE in SEISAN.csh. If not set, the name TEST is used since the distribution comes with some test data alreaded installled in TEST. The data bases are found under SEISAN_TOP.

SEISAN editor used in EEV:
The default editor is vi, any other editor can be set with the environmental variable SEISAN_EDITOR.

SEISAN calibration file directory:
By default, calibration files are in CAL, but they can be in a directory set with variable LOCAL_CAL. The directory name must be complete like /home/users/calibration/

SEISARCH
Gives the architecture, can be either linux32, linux64, macosx or windows. Used in Makefile when compiling.

SACLIB
Specify path and filename to SAC libraries, only needed when you compile programs (Unix) and you have the libraries installed on your system.

Printer for Postscript plots:
The hard copy files from programs are sent to the printer from within the programs using the standard lpr command. In the SEISAN.csh file, define lpr using the standard environmental variable PRINTER. Remember that the printer must accept Postscript. PostScript files can also be viewed and printed on most printers outside SEISAN using GhostView, however in that cases files cannot be printed from within a program.

Scaling for Postscript plots:
By default, plots will be in A4 size. This can be changed by setting the environmental variables SEISAN_PSSCALE_X and SEISAN_PSSCALE_Y. The default for A4 size is 1.0 for both variables. For Letter size the Y-scaling can be set to 0.9.

Seisan Extension:
User specific code can be implemented by making use of the environmental variable SEISAN_EXTENSION. The idea is that programs read this variable, if set to the user specific string, the user's source code will be used instead of the default. An example could be the computation of error ellipses. Currently used codes are: BGS.

6. Testdata The testdata set can be extracted from the file `testdata_X.Y.tar.Z`. Use programs uncompress and tar to extract the data in the SEISAN top directory (keep subdirectory structure). SEISAN has 4 test events always installed with the software (from June 1996 and Febrary 2021) so it is always possible to test SEISAN without installing test data. See the SEISAN tutorial, which only uses the 2 test events.

NOTE: All test data except the 2 events from 2021, are in Nordic format.

Dimensions

Most dimensions are set in file `seidim.inc` in the INC directory. In order to change dimensions, first change in the include file and then recompile the whole SEISAN distribution. The most important dimensions are:

Number of points in one trace	2 400 000
Number of points in memory buffer	30 000 000
Number of lines in NORDIC format file	20 000
Maximum number of traces in one plot	1 800
Maximum number of events in one month	200 000
Maximum number of calibration files	4 000
Maximum number of epicenters in epimap	90 000
Maximum number of lines in index file made with dirf:	200000

SEISAN has been tested with much larger dimensions, like 10 000 000 for number of points in one trace, however large dimensions might slow down the speed due to swapping (particularly if memory is not large) so a smaller dimension has been chosen. For continuous data, SEISAN works with many files so smaller dimensions can be used. For the PC version, dimensions may be different from above, check `seidim.inc`.

Note: In case programs don't work, you might have to recompile, see section 3.11.

Ubuntu 16.04: you might need a extra library to run SEISAN, run: `sudo apt-get install libgfortran3`
Some Ubuntu users are missing the `libg2c.so.0` library file, it can be installed with the command:
`sudo apt-get install gcc`
If this does not work, also try:
`sudo apt-get install libg2c0`

On a 64 bit computer the IASP files in DAT must be regenerated if you have the files from a 32 bit computer, with the programs `REMODL` and `SETBRN` otherwise `HYP` will crash.

Multiple users on Linux/Unix

If two or more users are working with EEV at the same time with the same user, there is a risk that the S-file names are being mixed up so an event from one year suddenly gets the S-file name from another year. This is caused by both users using the same environmental variable for the S-file (should be changed !). The solution is that each users has his/her own account, which in any case is the most convenient. From version 12 there is a lock file so if two users use EEV in the same directory, a wardning is given. More details under EEV.

3.3 MacOSX

The MacOSX version does not come pre-compiled, and will have to be compiled by the user. Please see section 3.11 and 3.11.2 for details.

3.4 Cygwin

As alternative to running SEISAN directly under Windows, it can also be compiled and used under Cygwin. The cygwin website `http://www.cygwin.com` explains:

"Cygwin is a Linux-like environment for Windows. It consists of two parts:

- A DLL (cygwin1.dll) which acts as a Linux API emulation layer providing substantial Linux API functionality.
- A collection of tools which provide Linux look and feel. The Cygwin DLL currently works with all recent, commercially released x86 32 bit and 64 bit versions of Windows, with the exception of Windows CE."

It is attractive to use SEISAN with Cygwin as it looks like the Unix version. Under Cygwin SEISAN uses X graphics, which requires the Cygwin X server (part of Cygwin). The compilation under Cygwin is like Linux, which means on the software side there are fewer differences to take care of.

Cygwin can be downloaded and installed from the website. However, to be able to compile SEISAN a number of non-default packages have to be included:

- Devel: gcc-g++ (and associated packages)
- Devel: gfortran
- Devel: make
- Libs: libncurses-devel
- Shells: tcsh
- X11: xorg-x11-base
- X11: xorg-x11-deve

We also recommend to install:

- Editors: vim

- Utils: diffutils

The choice of packages is done through the Cygwin installation tool. With some of the packages, additional required packages will be selected by default and must be installed.

To install SEISAN under Cygwin, use the Linux distribution and set SEISARCH to 'linux32' or 'linux64'. You have to compile as described for Linux below.

Under Cygwin, you can use csh or tcsh, which will allow to use the SEISAN.csh. If your default is bash, '(t)csh' can be started from the command line. The X server is started using command 'startx' from the Cygwin prompt. See the Cygwin documentation for more details.

Cygwin has not been tested on latest versions of SEISAN.

3.5 Windows

It is assumed that you transferred the Windows distribution from Internet to a directory on the PC. In the following, it is assumed that you install on disk drive C. The windows graphics work with any resolution, small fonts should be used, however, SEISAN is designed to work with 1024x768 or more.

Using install script

Click on seisan_v?.?.?_windows.msi and follow the instructions, use all defaults. If you later want to change some environmental variables, see instructions below. If SEISAN already is installed, a window comes up for a possible upgrade or removal of SEISAN. A new version cannot be installed witout removing the old one. SEISAN is now completely installed. Optionally, some parmeters can be set, se below. The general non system specific parameters are the same as under Linux.

OPTIONAL: Change environmental variables SEISAN_EDITOR, SEISAN_PSSCALE_X, SEISAN_PSSCALE_Y and DEF_BASE (see UNIX section for definition) using control panel - system - advanced and select environmental variables. The defaults are respectively SEISMO, notepad, A4 and TEST. SEISAN_TOP would be set as `set SEISAN_TOP=\SEISMO`, but could also be e.g. `test\best\analysis` or `d:\seisan`. Note there is one blank character at the end and the first character MUST be "\" or the second ":". If no seismo directory, it could e.g. be just E:.

Optional: If you want to recompile, you need the Fortran Gnu compilers installed, see section on compilation below.

Printer:

It is assumed that a Postscript printer is connected to the PC, either directly or by a network. When a program sends a plot to the printer, it issues the command SEISANPR. In the COM directory, there is a file called SEISANPR.BAT containing the print command. Several suggestions are made in that file, the default is to use `COPY filename PRN`. If you do not have a PostScript printer, it is possible to view and print PostScript files with GhostViev, a public domain software available from many sites, e.g. . Other software is also awailable to view PostScript files.

`http://www.cs.wisc.edu/~ghost/gsview/get47.htm`

Testdata:

The testdata set can be extracted from the file seisan_test_data.tar.gz with for example the WinZIP program. Extract the data to the SEISAN top directory. To use the test data base as the default DEF_BASE must be set to TEST (done by default during installation). Note that the dataset is in the old Nordic format, use the NOR2NOR2 program to convert to Nordic2 format.

Running SEISAN on networked PC's

SEISAN on one PC can be accessed from another PC. This can be an advantage if several users share the same data base. On the client PC, name the server PC disk where seisan is installed e.g. Z:. Then `set seisan_top=z:\.`

Potential problems

Program takes a long time to load: If the program is large, it might use disk swap files, which can take a lot of time. Reduce array size (seidim.inc in INC) and recompile.

Commands like P or L do not work in EEV. If swapping takes place, some damaged swap files or other files might remain which prevents the program from starting. Clean disk with command SCANDISK.

Graphics problem: Graphics programs write text to a console window. If there is a program crash, the error message goes to the console window, which then disappears.

3.6 Python

Python is currently only used with two program in SEISAN, MOPAD (making moment tensor plots) and SPECTRO (making spectrograms) so if any of these program are to be used, Python must be installed. Most Linux systems will have Python installed, else follow standard instructions on Python home page and install. SEISAN currently uses version 2.7 of Python. Make sure you include Python in the path. For running MOPAD, two extra libraries are needed. In Windows they are install like this:

pip install numpy
pip install matplotlib

For SPECTROGRAM, more libraries and Obspy are needed. On Windows this is done as follows:

pip install scipy
pip install lxml sqlalchemy
pip install pyreadline ipython
pip install flake8 nose mock
pip install obspy

In windows, Python files must be recognized as a Python programs so environmental variable PATHTEXT must have .PY if not already there.

On Linux, follow instruction on ObsPy home page https://github.com/obspy/ob1Gspy/wiki

3.7 Google Earth

GoogleEarth is currently used with the GMAP program and from EEV. It is also an option to plot automatically with Google Earth when locting from EEV or SE. Googel Earth can be downloaded from http://earth.google.com/download-earth.html. In order to use the automatic plotting in connection with location, Google Earth must be in the path. This is normally the case for Linux but not for Windows. check where googleEarth is installed, a typical location is c:\program files\google\google earth pro\client;

goto edit environmental variables
add the install location to the path

3.8 Database directories for your own system, MAKEREA

When you want to use SEISAN with your own data, the necessary directory structure must first be created and your own station coordinates and crustal model must be defined. Both REA and WAV directory structures are created with the program MAKEREA. The program asks for database name (must be 1-5 letters and UPPER CASE), start time (year and month), end time (year and month) and the structure to create (REA or WAV). An output will then show the names of directories created. If a directory already exists, a message will be given. It is possible to create both structures at a time, since the program after finishing asks if the respective other structure should be created.

3.9 Default parameter files for the main programs

Once you start locating events, the location program HYP will look for an input file with station coordinates, location parameters and crustal model. This file is located in the DAT directory and called `STATION0.HYP`. To edit the file, move to the DAT directory by using command DA and edit the file. For more information about this file, see section 7. If you want to keep the original file for test purposes, first copy it to a file with another name.

When plotting epicenters (command MAP (no questions) or EPIMAP (user sepcify)) input files with map-contours for the EPIMAP program are used (type *.MAP). These files are also located in the DAT directory. If you want to use more detailed map contours, you must get hold of your own data and put them

into file called e.g. MYMAP.MAP. In the DAT directory there are three sets of contours: WORLD.MAP (high resolution) WORLD_LOW.MAP (low resolution) and EUROPE.MAP . Detailed map files in SEISAN format for the whole world is found at the SEISAN web site.

The plotting program MULPLT can use a default file for those stations, which are to be routinely plotted, as well as other default information. This is defined in `MULPLT.DEF` in DAT, see example file. `MULPLT.DEF` also defines which keys are assigned to which phases and what character is used for the mouse. An example is given in DAT, see also example in 8.

Both the `MULPLT.DEF` and `STATION0.HYP` can also be in the working directory. Programs always look there first and on a multi-user system, this enables different users to have their own setup. It also makes it possible to work with different setups by just changing directory.

The AUTOPIC PROGRAM requires AUTOPIC.INP in the DAT directory.

Most SEISAN program use the `SEISAN.DEF` file (in DAT, see section 3.13) where many general parameters are set.

The bulletin program requires a front page with whatever you like and some set for fonts can be made. The text of this page is located in the BUL.INP file in the DAT directory.

3.10 Color settings

All programs using color can use a color definition file called COLOR.DEF. The file can be located in the current working directory or in DAT. Programs will first look in the working directory, then in DAT. If no COLOR.DEF file is given, default is used. Be careful with color setting, unexpected results might occur, like getting a blank screen when plotting white traces on a white background. Several color settings are universal like setting colors for titles, however several color settings are specific for particular programs, see example file below. Since colors can also be used for the Postscript file, there is an option for using color on the screen but not for Postscript, since it is more likely that the user will have a color screen than a color Postscript plotter. Sending a color plot file to a black and white laser printer results in a plot with gray tones.

The COLOR.DEF file:

This file is for defining SEISAN color objects and for setting the size(of full screen) of the graphics window for individual programs. If no file available, default colors, as given at end of line below, will be used. The entries can come in any order, however the keyword MUST appear as shown below. If an object color is not defined, it will retain its default value. If a black or white background and no colors are chosen, all colors will be reset accordingly.

```
This file is for defining SEISAN color objects. If no file available,
default colors will be used. The entries can come in any order, however the
keword MUST appear as shown below. If a object color is not defined,
it will retain its default value. If a black or white background and no
colors are chosen, all colors will be reset accordingly.
Since verison 9.0, the size of the window (% of full screen) for most graphics
programs is also set in this file.

The color codes are:

1: blue   2: green   3: red   4: yellow   5: white   6: black

color_screen            1   ! 0: no colors, 1: colors
color_hard_copy         0   ! ------------------------
color_back              5   ! background color
color_trace             6   ! seismic traces, map contours
color_pic               3   ! phase picking
color_zoom              2   ! zoo lines in mulplt
color_def               6   ! default color
color_frame             1   ! frames like epimap map frames, mulplt
```

```
color_title             6   ! titles on top of plots
color_spec              1   ! spectras
color_axis_not          3   ! axis notations
color_epi               3   ! epicenters
color_station           3   ! seismic stations
color_map_contour       1   ! epimap contours
color_map_grid          6   ! Lat-long/(x,y) grid
color_label_grid        6   ! Grid labels for map
color_symbol_key        6   ! Diagram key.
color_prompt            1   ! Prompt text.
color_section           3   ! section outline in epimap
color_bval_np           2   ! bvalue, number of events
color_bval_ac           1   ! ------, accumulated ---
color_bval_line         1   ! ------, lsq line
color_box               5   ! box for interactive input
color_box_letter        6   ! letters in --------------
color_foc_dilat         3   ! focmec dilatation
color_foc_comp          1   ! focmec compression
color_foc_p             2   ! focmec P-axis
color_foc_t             3   ! focmec T-axis
color_foc_plane         1   ! focmec fault planes
color_syn               1   ! synthetic picks, blue
size_bvalue            50
size_sample_graphics   80
size_catstat           60
size_codaq             70
size_corr               0   ! not implemeted
size_epimap            70
size_fk                60
size_focmec            70
size_lsq               60
size_mag               60
size of mulplt          0   ! set in MULPLT.DEF
size_presp             65
size_rmsdep            50
size_spec              80
size_ttplot            60
size_wad_plot          60
```

3.11 Compiling SEISAN programs

This section describes how to compile SEISAN or individual SEISAN programs. In the following subsections guidelines for indivudual operating systems are given.

The SEISAN distribution for all platforms includes the executables. Therefore in general it is often not necessary to recompile. In the case of Linux, it is often nescessary to rcompile since since different flavors of Linux behave differently. However, you may have the source distribution or you might want to modify some of the programs for your own needs or remove bugs and will have to compile programs.

The SEISAN programs on all platforms can be compiled using the `make` utility. On all platforms there is a '`Makefile`' in both the `PRO` and `LIB` directories and the `Makefile` is the same for all operating systems supported. The file might not need any modification, however the following parameters must be set correctly:

`SEISARCH` (environmental variable): This variable is used as keyword for the compilation, and can be `linux32`, `linux64`, `macosx`, `macosxppc` or `windows`. While the gfortran option should work on all platforms, the other keywords allow to have specific compile options. The keywords are also used to define which

programs are compiled and installed in addition to the default list of programs. See chapter 7 for differences between the platforms. (**Note:** Without setting `SEISARCH`, the compilation will not work since `make` will not know what `SEISARCH` is). On Linux/Unix system `SEISARCH` is set in the files `SEISAN.csh` or `SEISAN.bash` in `COM` while on Windows it is set in the `Makefile` itself or it can be set manually as an environmental variable. Most of the programs are the same on all platforms, but not all.

The compilation can now be started from the `PRO` directory by starting '`make all`'. From the `Makefile` in the `PRO` directory, the `Makefile` in the LIB directory is started to create the object libraries. A SEISAN archive in LIB for SEISAN routines is created, '`seisan.a`. If You want to use SEISAN subroutines in your own programs you can link to that. Finally all programs are compiled.

Single programs can be recompiled by starting '`make program`' . If you do changes in the LIB directory you need to compile using '`make all`', which will also create the archive file. Then you can recompile individual programs in `PRO` as explained above.

Note that on all platforms the Chad Trabant MiniSeed library is used (new from version 9.0) and it is put into seisan.a. In the distribution they are located in file `libmseed.c` in LIB and 4 include files in `INC` (see `seisan.all` in `INF`). The `libmseed.c` file contains all subroutines in the original Trabant distribution and all include files from Trabant distribution are in INC. The current version of the Trabant distribution is 2.6.1. If you want to use different version, the same process as described above must be done.

Seisan Explorer

The compilation of the SEISAN GUI Seisan Explorer is described in the following subsections.

The source code se-source.tar.gz is found in SUP directory.

IASP91

If the computation of IASP91 traveltimes does not work after compilation, first run program REMODL, then program SETBRN to fix the files.

3.11.1 Linux

Compilers used for SEISAN (other version may also work):
Linux 64 bit: Gfortran
Linux 32 bit: Gfortran

Compiler installation:

For Linux/Unix, compilers are usually installed when the operating system is installed.

If graphics programs do no link on Linux/Unix systems, check that you have X11 libraries in
`$LD_LIBRARY_PATH`
You can check what is there by command

```
echo $LD_LIBRARY_PATH
```

SUSE

When compiling SEISAN on SUSE Linux it has been suggested to use the following compiler options '`-malign-double -finit-local-zero`' in addition to the ones already used. Testing this on Redhat Linux produced very large executables, but it may be worth trying on SUSE.

Ubuntu

On Ubuntu one might need to add these libraries in order to compile SEISAN:

```
sudo apt-get install gfortran
sudo apt-get install libgfortran3
sudo apt-get install libx11-dev
```

On Ubuntu version 20.04 we have seen compilation errors like "error: ld terminated with signal 11", the solution was to install/reinstall these libraties:

```
sudo apt purge binutils
sudo apt remove make
sudo apt autoremove
sudo apt install build-essential
sudo apt install gfortran
```

and then make clear and make all in LIB and then in PRO

Seisan Explorer

The source code se-source.tar.gz is found in SUP directory.
The GUI Seisan Explorer can be compiled on Linux. SEISAN must be fully installed on the computer before Seisan Explorer can be compiled. To compile Seisan Explorer on a Linux system, the Qt 5 framework is needed. This can be downloaded from https://www.qt.io/developers (if not already installed on your system). The qmake program is a part of the Qt framework. You need qmake in your path. Alternatively, you can specify full path to qmake.

Building Seisan Explorer:
1: Move into the directory containing the SE source code.
2: Copy the SEISAN library `seisan.a` from `$SEISAN_TOP/LIB` to the `linux` subfolder.
3: Run `qmake se.pro` to build the makefile.
4: Run `make` to build the executable named `se`.
5: Copy the `se` to the `$SEISAN_TOP/PRO` folder.

Step 3 and 4 is not needed if Qt Creator is used.

3.11.2 MacOSX

The compilation of SEISAN on a Mac is basically the same as for Solaris/Linux, in `COM/SEISAN.bash` or `COM/SEISAN.csh`, set SEISARCH to '`macosx`' (Intel-based=newer Macs) or '`macosxppc`' (PowerPC based).

You may also need to change the line `$(fc) seed.for` to `$(fc) -fno-range-check seed.for` in `LIB/Makefile`

If you have gcc/gfortran 4+ installed and your Mac is Intel-based, you should now be able to compile. You also need X-windows, which should be preinstalled or on the installation disk for OSX 10.5 and higher (for earlier versions, they can be downloaded and installed).

New Mac computers are 64 bit, this URL is also showing how to tell if you Intel based is 32 bit: `http://support.apple.com/kb/ht3696`.

Additional hints on MacOSX 10

In order to compile and link Seisan off the source distribution, you need to have gcc/gfortran and Xcode installed.

We recommend you install the following:

brew package manager: Copy the following line in the Terminal and press Enter: /usr/bin/ruby -e "$(curl -fsSL https://raw.githubusercontent.com/Homebrew /install/master/install)"

gcc compilers: Upon successful installation of brew, execute "brew install gcc" from the terminal.

XCODE: Either install it from the Mac store under

`https://itunes.apple.com/us/app/xcode/id4977998x5?ls=1&mt=12#`

or from the terminal when you are automatically asked for it.

X11 Quartz: Download the dmg-file, doubleclick and install:

`https://dl.bintray.com/xquartz/legacy-downloads/SL/XQuartz-2.7.8.dmg`

The compilation procedure is the same as for Linux. However, for more details see INF/readme_macosx.txt.

Seisan Explorer
The GUI Seisan Explorer have not been tested on Mac!

3.11.3 Windows

Compiler installation: For Windows, the gcc/gfortran compiler is found at `http://sourceforge.net/projects/mingw/`. The Fortran compiler and the MinGW development toolkit must be installed. SEISAN can be compiled using the GW shell where the path to compilers is known. If you want to compile outside the GW shell (in the DOS window) in the same way as under Linux/Unix, the compilers must be defined outside the shell by adding c:\mingw\bin and c:\mingw\msys\1.0\bin to the path (assuming MinGW installation under c:\mingw). Make sure path to SEISAN COM and PRO directoris come before path to MinGW since

MinGW has some commands identical to SEISAN like pr and test. Putting in the path to MinGW also has the advantage of getting Linux commands in the DOS window like ls, tar, grep etc.

For the Windows platform, a graphics library and an include file is used from the DISLIN software (new from version 9.0). Files dislin.h and dismg.a are located in INC and LIB, respectively. See `http://www.dislin.de/` for more information.

Compilers used for SEISAN:
Windows: Gfortran under MinGW

Seisan Explorer

The GUI Seisan Explorer can be compiled on Windows. SEISAN must be fully installed on the computer before Seisan Explorer can be compiled. To compile Seisan Explorer on a Windows system, the Qt 5 framework is needed. This can be downloaded from https://www.qt.io/developers. The qmake program is a part of the Qt framework. You need qmake in your path. Alternatively, you can specify full path to qmake.

Building Seisan Explorer:
1: Move into the directory containing the SE source code.
2: Copy the SEISAN library `seisan.a` from `LIB` to the `windows` subfolder.
3: Run `qmake se.pro` to build the makefile.
4: Run `make` to build the executable named `se`.
5: Copy the files `se` to the `PRO` folder.
6. Create a shortcut to 'se.exe' on your desktop if needed.

Step 3 and 4 is not needed if Qt Creator is used.

3.12 Program Version

The version number of this SEISAN distribution is given on the front page of this manual. All individual programs have a version number and a date of the last changes. This will help the users and developers to find out which version is in use and from which date. This is particular useful when bugs are reported. In case major bugs have been fixed, the new versions (same version number, different date) of the individual program will be available on the anonymous ftp site and a message will be sent to the seisan mailing list.

In all programs you can obtain the version number by starting a program with '`−version`' as argument. For example `collect −version` will show you the version and date of your COLLECT program.

3.13 Setting general SEISAN defaults, `SEISAN.DEF`

There are several parameters which are common for several programs which are set in the file `SEISAN.DEF`. This file can be in your local directory or the DAT directory. The system will first look in the local directory, but normally the file is in the DAT directory. The file does not have to be there since there are defaults for all parameters, but the parameters might need to be set. It is also possible to include a file with settings by putting the '@' symbol in front of the additional file name to be read, e.g. '@additional.def', which can be useful for the extensive archive configuration.

The format of the file is as shown below:

```
This file is for defaults for SEISAN and called SEISAN.DEF. The name must
be in upper case on Linux. The following shows the parameters which can be set.
The file can contain any lines in any order, only the lines with
recognized keywords and a non blank field under Par 1 will be read. The
comments have no importance.

*********NEVER USE TABS IN THIS FILE, IT WILL NOT WORK*****************

KEYWORD............Comments.............Par 1.....Par 2

#
```

```
#   general SEISAN
#

NORDIC_FORMAT                           0.0
SEISAN_LOGGING                          1.0
CURSOR            0: default, 1: cross 0.0
#FONT                                   -adobe-courier-bold-r-normal--24-240-75-75-m-150-iso8859-1
SEISAN AGENCY                           XXX

#
# waveform files location and other waveform stuf
#

WAVEFORM_BASE      Waveform bases
WAVEFORM_DIRS      Waveform drectory    /net/seismo/seismo/WOR/seisnet
MERGE_WAVEFORM     Code for merging wa  NSN
COPY_WAV_DIR       Copy when register
CONFIRMATION       Confirm when delete

#
#   seisan cont data base
#

CONT_BASE          REA continuous base  RUND
CONT_BASE          REA continuous base  JMI
CONT_BASE          REA continuous base  NSS
CONT_BEFORE        start min before     20.
CONT_AFTER         start min after      1.

#
# position in file name for continous files where year yyyy and month mm starts
#

CONT_YEAR_MONTH_POSTION_FILE

#
# archive
#
ARC_ARCHIVE2                            test      ./archive
ARC_ARCHIVE2                            test2     ./archive2

-------------------------------------------------------------------------------------------------------
--------- explanation arc_chan2         S    C  N L  Def Start    Stop     Archive   Vnet1 Vnet2 Vnet3 V
-------------------------------------------------------------------------------------------------------
ARC_CHAN2                               SFJD LHZIU10 1.0                  test      _NA
ARC_CHAN2                               KBS  LHZGE10 1.0                  test      _NA
ARC_CHAN2                               DAG  LHZGE   1.0                  test      _NA
ARC_CHAN2                               TULEGLHZDK   1.0                  test      _NA
ARC_CHAN2                               BSD  LHZDK   1.0                  test      _NA
ARC_CHAN2                               BORG LHZII10 1.0 20020101 20150202 test      _NA

# old definition
#ARC_CHAN                                SFJD LHZIU10
#ARC_CHAN                                KBS  LHZGE10
```

```
#ARC_CHAN                                DAG  LHZGE
#ARC_CHAN                                TULEGLHZDK
#ARC_CHAN                                BSD  LHZDK
#ARC_CHAN                                BORG LHZII10        20020101  20150202
#ARC_ARCHIVE                             ./archive

ARC_DURATION                            10000.0
ARC_START_TIME                          100.0
ARC_TYPE                                1.0
ARC_BY_DEFAULT                          0.0

#
# load additional settings
#
@additional.def

#
# virtual networks                      NAME      SCNL
# several networks can be defined
#

ARC_VIRTUAL_NETWORK                     _DK       BSD  LHZDK
ARC_VIRTUAL_NETWORK                     _NO       KBS  LHZGE10

#
#
# PREM velocity and density model, Q model not known, Q is average along path,
# not Q in layer. Q might be distance dependent. Kappas are low values.
#

SPEC KAPPA p and kappa s                0.01        0.02
SPEC Q BELOW 1 HZ, P,S                  1.0         1.0
#
#                                      depth  vp   vs  Q0p  Qal  Q0s  Qal dens
SPEC MODEL h,vp,vs,qp,qap,qs,qas,d      3.0  5.8  3.2  500. 0.7  400. 0.7  2.6
SPEC MODEL h,vp,vs,qp,qap,qs,qas,d      15.0 6.8  3.9  500. 0.7  400. 0.7  2.9
SPEC MODEL h,vp,vs,qp,qap,qs,qas,d      24.0 8.1  4.5  500. 0.7  400. 0.7  3.4
SPEC MODEL h,vp,vs,qp,qap,qs,qas,d      80.0 8.1  4.5  500. 0.7  400. 0.7  3.4
SPEC MODEL h,vp,vs,qp,qap,qs,qas,d      171. 8.0  4.4  500. 0.7  400. 0.7  3.4
SPEC MODEL h,vp,vs,qp,qap,qs,qas,d      220. 8.6  4.6  500. 0.7  400. 0.7  3.4
SPEC MODEL h,vp,vs,qp,qap,qs,qas,d      271. 8.7  4.7  500. 0.7  400. 0.7  3.5
SPEC MODEL h,vp,vs,qp,qap,qs,qas,d      371. 8.9  4.8  500. 0.7  400. 0.7  3.5
SPEC MODEL h,vp,vs,qp,qap,qs,qas,d      400. 9.1  4.9  500. 0.7  400. 0.7  3.7
SPEC MODEL h,vp,vs,qp,qap,qs,qas,d      471. 9.5  5.1  500. 0.7  400. 0.7  3.8
SPEC MODEL h,vp,vs,qp,qap,qs,qas,d      571. 10.0 5.4  500. 0.7  400. 0.7  3.9
SPEC MODEL h,vp,vs,qp,qap,qs,qas,d      600. 10.2 5.5  500. 0.7  400. 0.7  4.0
SPEC MODEL h,vp,vs,qp,qap,qs,qas,d      670. 10.3 5.6  500. 0.7  400. 0.7  4.0
SPEC MODEL h,vp,vs,qp,qap,qs,qas,d      771. 11.1 6.2  500. 0.7  400. 0.7  4.4
SPEC MODEL h,vp,vs,qp,qap,qs,qas,d      871. 11.2 6.3  500. 0.7  400. 0.7  4.5

#
#   for geometrical spreading
#
```

```
SPECTRAL GEO_DEPTHS                     10.0       14.0
HERKIJ_DISTANCE                         100.0

#
#  for FOCMEC
#

FOCMEC MAXSOL      max solutions        125.

#
#   for MAP, MAPG program and map option in EEV, also GMT
#

MAP_LAT_BORDER     dist from center       3.0
MAP_LON_BORDER          "                 6.0
MAP_LAT_LON_DIV    lat-long divisions     1.0              2.0
EPIMAP_STATIONS    plot stations
EPIMAP_MAP_FILE    name of map          WORLD
EPIMAP_PROJECTION  number                 3.
EPIMAP_LOCALITY_FILE                    \seismo\DAT\place_names.eev
EPIMAP_PLOT_LOCALITY                    0.0
GMT_GRIDFILE                            c:\a\gmt\newbathy.grd
GMT_LOCALITY_FILE                       \seismo\DAT\place_names.eev

#
#   EMAIL
#

MAILX COMMAND                           /usr/bin/mailx
#
# format of long mail 0: nordic, 2: nordic2
#
ALERT_EMAIL_FORMAT                      0
#
#  emails to send whole file
#
ALERT EMAIL                             seismo@a.b.c
ALERT_EMAIL_NETDET
#
# emails and parameters for  summary file
#
EMAIL_SUMMARY_NETDET
EMAIL SUMMARY                           seismo2a.b.c
EMAIL_SUMMARY_TITLE                     Seismological Institute
EMAIL_SUMMARY_MAP                       2.0
MAILX_COMMAND_MAP                       mpack -s "Earthquake report" -d summary.out -c image/jpeg map.j
 EMAIL SYSTEM                            transfer_to_edu_server.sh

#
#   EEV related, see also EPIMAP_LOCALITY_file
#

EEV_COMMENT        Comment for EEV      Depth has benn fixed to 10 km
EEV_COMMENT        Comment for EEV      Depth has been fixed to 20 km
```

```
REG_KEEP_AUTO      Keep phases when reg    1.
TEXT_PRINT         Print command s-file nenscript -Psps
AUTO_PROCESS       Run prog. when reg.

#
# Parameters for plotting type P(icture) files in EEV
#

PLOT_PDF_COMMAND       for linux        evince
#PLOT_PDF_COMMAND       for windows      start acrord32.exe
PLOT_PICTURE_COMMAND   for linux        display
#PLOT_PICTURE_COMMAND   for windows      \Programfiler\irfanview\i_view32
PLOT_PS_COMMAND         for windows     gswin32
#PLOT_PS_COMMAND         for linux       gs

#
#   hypocenter
#

HIGH_ACCURACY      Set high accuracy

#
# order to select magnitudes as given here from top (high priortiy) to bottom (low priority)
#

MAGNITUDE_ORDER                        WGCM
MAGNITUDE_ORDER                        LBER
MAGNITUDE_ORDER                        WBER

#
# parameters for gmap used within eev
#

GMAP_DIR                               c:/seismo/WOR
GMAP_TYPE                              MAP          [MAP, SATELLITE, HYBRID, TERRAIN]
#GMAP_SIZE                              2.0  2.0
GMAP_ICON_QUAKE                        http://maps.google.com/mapfiles/kml/pal2/icon26.png
GMAP_ICON_EXPLOSION                    http://maps.google.com/mapfiles/kml/shapes/star.png
GMAP_ICON_PROB_EXPL                    http://maps.google.com/mapfiles/kml/shapes/open-diamond.png
GMAP_ICON_OTHER_EVENTS                 http://maps.google.com/mapfiles/kml/shapes/square.png
GMAP_ICON_MSIZE                        0.5
GMAP_ICON_XSIZE                        0.2
GMAP_ICON_YSIZE                        0.5
#GMAP_APPEND_KML                        <!-- lines to be appended to the gmap.kml file : -->
GMAP_APPEND_KML                        <ScreenOverlay id="LOGO">
GMAP_APPEND_KML                        <name>Info and links</name>
GMAP_APPEND_KML                        <description> <![CDATA[
GMAP_APPEND_KML                        Data is in Nordic format. The format is <br>
GMAP_APPEND_KML                        described in the Seisan manual at UIB.<br>
GMAP_APPEND_KML                        UIB:  http://www.geo.uib.no/seismo/<br> ]]>
GMAP_APPEND_KML                        </description>
GMAP_APPEND_KML                        <Icon>
GMAP_APPEND_KML                         <href>http://seis.geus.net/geus.png</href>
GMAP_APPEND_KML                        </Icon>
```

```
GMAP_APPEND_KML                          <overlayXY x="0" y="1" xunits="fraction" yunits="fraction"/>
GMAP_APPEND_KML                          <screenXY x="-0.01" y="0.99" xunits="fraction" yunits="fraction"
GMAP_APPEND_KML                          <rotationXY x="0" y="0" xunits="fraction" yunits="fraction"/>
GMAP_APPEND_KML                          <size x="0.1" y="0.1" xunits="fraction" yunits="fraction"/>
GMAP_APPEND_KML                          </ScreenOverlay>
#GMAP_APPEND_KML                         <!-- end of appended lines -->

#
# parameters for automatic gmap
#

GMAP_AUTO      0: no, 1:yes              1.0
GMAP_AUTO_ICON_EVENT                     http://maps.google.com/mapfiles/kml/pal2/icon26.png
GMAP_AUTO_ICON_COLOR                     ff0000ff
GMAP_AUTO_ICON_MSIZE                     0.5
GMAP_AUTO_ICON_XSIZE                     0.2
GMAP_AUTO_ICON_YSIZE                     0.5
GMAP_AUTO_LOOKAT_ALTITUDE                2000000.0
GMAP_AUTO_SHOW_STAT  0: no, 1:yes        1.
GMAP_AUTO_ERROR_ELLIPSE  0: no, 1:yes    1.
GMAP_AUTO_STAT_SIZE                      1.1
GMAP_AUTO_STAT_URL                       http://maps.google.com/mapfiles/kml/shapes/triangle.png
GMAP_AUTO_STAT_RESIDAL_GOOD              0.5
GMAP_AUTO_STAT_RESIDUAL_BAD              1.5
GMAP_AUTO_STAT_COLOR_GOOD                ff00ff00
GMAP_AUTO_STAT_COLOR_OK                  ff00ffff
GMAP_AUTO_STAT_COLOR_BAD                 ff0000ff
GMAP_AUTO_SHOW_OLD_LOCATION 0:no,1:yes   1.
GMAP_AUTO_OLD_LOCATION_COLOR             ffff0000
GMAP_AUTO_SHOW_PATH   0: no, 1:yes       1.
GMAP_AUTO_PATH_COLOR                     ff929292
GMAP_AUTO_PATH_WIDTH                     2.5
GMAP_AUTO_FILE_ACTION  0: no, 1:yes      0.
GMAP_AUTO_ACTION                         cp gmap.cur.kml /inetpub/www/html/seismo/nnsn
# e.g. GMAP_AUTO_ACTION    ncftpput -u seismo -p passwd ftp.server /home/seismo/www gmap.cur.kml
#
#
#
#EOF SEISAN.DEF
```

The parameters are:

ALERT EMAIL: Give email addresses (more than one are given by repeating the key word with one new address per line) to which email command in EEV will send.

ALERT_EMAIL_NETDET: mail address where whole file is sent from netdet.

ALERT_EMAIL_FORMAT: format of mail, defualt 0 is nordic, 2 is nordic2

EMAIL SUMMARY: Give email addresses (more than one are given by repeating the key word with one new address per line) to which emailisum command in EEV will send.

EMAIL_SUMMARY_NETDET: Mail address for summary file from netdet

EMAIL_SUMMAY_TITLE: Title to put into summary email.

EMAIL_SUMMARY_MAP: Optionally put a map in summary email: 0.0: no map, 1.0: epimap type, 2.0: GMT type.

MAILX_COMMAND_MAP: The mail command when sending a map, see EEV for an example.

EMAIL SYSTEM: System command to perform after using email command in EEV, if blank, no command is executed

AUTO_PROCESS: Set to 1. to run REG_AUTO_PROCESS.

CONFIRMATION: Level of confirmation required for example when deleting files, 0.=no confirmation and 1.=always confirm. (at the moment only used in eev)

CONT_BASE: Waveform database to be searched (there can be several). The base is selected as a default in base selection box in MULPLT if flag is 1.0. Example:

```
CONT_BASE selected by default          ESK            1.
CONT_BASE not sel by default           EDI            0.
```

CONT_YEAR_MONTH_POSTION_FILE: File name of file in continuous data base: First parmeter is the start position in the file name of the 4 digit year and second paramter is the start position of the 2 digit month. This paramter is also used for normal waveform files referenced in the S-file.

ARC_ARCHIVE: Path to BUD or SeiscomP archive

ARC_ARCHIVE2: Name and path to BUD or SeiscomP archive

ARC_TYPE: Type of archive, 0: BUD, 1: SeisComP

ARC_START_TIME: Deafault time(sec) to start before origin time

ARC_DURATION: Duration of segment(sec)

ARC_BY_DEFAULT: 0: not used, 1: Plot whole archive even when no archive has been specified in S-file, 2: Same as 1 but only stations with readings

ARC_CHAN: BUD or SeiscomP data that MULPLT will plot, given by station code, channel name, network code and location id.Optionally, the archive channel specification lines can have a time interval of validity. This is to avoid unnecessary checking of archive files if the archive has channels from different time periods. The format is: yyyymmddhh for both start and end time, only as much info as needed has to be specified. If start time is blank, start time is very early, if end time is blank, no end time. The start end end times are written in columns 61-70 and 71-80 respectively.

CONT_BEFORE: Minutes to read into the memory before the required start time (must be at least the length of a waveform file)

CONT_AFTER: Minutes to read into the memory after the data that is plotted

CONT_YEAR_MONTH_POSTION_FILE: Position in cont file name where year yyyy and month mm starts, all files must have the same format.

COPY_WAV_DIR: Normally, waveform files are copied to WAV when registering an event. If this parameter is set, waveform files can be copied to the WAV data base specified. Max 5 characters.

CURSOR: Select cursor: 0. for pointer, 1 for cross and 2 for crosshair (Unix only, on PC only pointer is available)).

EEV_COMMENT: Comments entered can then be used with EEV command ic. There can be any number of comments, max length 40 chars.

EPIMAP_MAP_FILE: The map coordinates file to use with MAP option in EEV and the MAP program.

EPIMAP_PROJECTION: The projection number used by EPIMAP with MAP option in EEV and program MAP, see EPIMAP program for choices.

EPIMAP_STATIONS: One letter indicator for plotting stations, in first column. See EPIMAP program for codes. A is all. Used with Map option in EEV as well as MAP program.

EPIMAP_PLOT_LOCALITY: 0.0: do not plot locality, 1.0: plot locality

EPIMAP_LOCALITY_FILE: File name to geographical locations file to use, absolute path.

GMT_GRIDFILE: File location and name of GMT gridfile used by MSAPG.

GMT_LOCALITY_FILE: The place name file used by MAPG.

FOCMEC MAXSOL: Maximum number of solutions in FOCMEC grid search, default is 100, however, it may be required to allow for more solutions.

FONT: Select font available on X system. To check available fonts use command 'xlsfonts' or 'xfontsel' and 'xfd -fn *font*' to display a font. (Unix only)

HIGH_ACCURACY: Setting it to 1.0 enables high accuracy operation. This parameter affects programs MULPLT, HYP and UPDATE

HYPO71_OFFSET: Apply offset in degree to station and epicenter locations, required for example when not all stations are either east or west of 0 longitude.

MAGNITUDE_ORDER: A list of magnitude type and agency (e.g., LBER for ML from agency BER) can be given to specify the order of magnitudes for selection. The order is given by listing different magnitudes

from top to bottom, where the magnitude at the top has highest priority and the bottom one the lowest. It is possible to leave either magnitude or agency blank in which case the blank represents a wildcard. This parameter is currently used by the program norcsv only.

MAILX COMMAND: Full path to mailx command (Unix only), which is used by email command in EEV.

MAP_LAT_BORDER, MAP_LON_BORDER: These parameters are used with command MAPi, MAPG and in EEV, which plot a map centered on current epicenter. The two parameters give the distance in degrees from the epicenter that the map should be plotted. If both set to '0.' EEV will ask for the parameters. Parameter is the same as EPIMAP_LAT_BORDER and EPIMAP_LON_BORDER

EPIMAP_LAT_BORDER and EPIMAP_LON_BORDER: Same as MAP_.....

MAP_LAT_LON_DIV: Divisions for lat and long for EPIMAP when used in EEV. MERGE_WAVEFORM: The network code given to waveform files merged with MULPLT when running from EEV. See MULPLT and EEV. Also used in WAVETOOL and SEISEI. Max 5 characters.

SPECTRAL_GEO_DEPTHS and HERKIJ_DISTANCE. See MULPLT spectral section for explanation. Parameters used to calculate geometrical spreading.

SPEC KAPPA: P and S kappa values, respectively, used with spec model.

SPEC Q BELOW 1 HZ: P and S values (X) for how Q is a function of frequency below the paramter value X. The Q-function is as follows: if X=0.0 then Q=Q0*f**qalpha. If X larger than 0.0, then Q=Q0*(1+f/X)**qalpha whwere f is frequency. These parameters are only active if the spec model is used, the default is X=1.0. The default is thus no frequecy dependense below 1 Hz. See also MULPLT, MULPLT.DEF and AUTOMAG.

SPEC MODEL: Gives depth, p-velocity, s-velocity, qp0, qpalpha, qs0, qsalpha and density. One line per layer in incresing depths. Format after column 40 is 8f5.0

REG_AUTO_PROCESS: Name of program to run when registering event.

REG_KEEP_AUTO: If flag set to 1.0, keep automatic pics when registering event from EEV.

TEXT_PRINT: Printer command used to print an S-file from EEV.

WAVEFORM BASE: Name of waveform data base to be searched. Normally this is a 1-5 letter data base name. The name must be written as shown above under Par1. Not needed for the default data base. The data base must have standard WAV year-month structure. It is intended to be used if for some reason the user wants to store waveform files in an alterenve WAV structure instead of the the one corresponding to the S-file data base. If a waveform file is not found in the base corresponding to the S-file base, WAVEFORM_BASE's will be searched.

WAVEFORM_DIRS: The complete path to directories where the system should look for waveform files. Searched last.

OUTPUT_DIR: Output Directory for SEISAN commands results. Default "./"

SEISAN_LOGGING: Command to turn logging on or off (1. or 0.0). Default is on.

SEISAN AGENCY: Agency used by some programs, 3 letters. Currently used by AUTOMAG and MACROIN.

PLOT_PDF_COMMAND: Command to plot a PDF file. Command can be 40 characters.

PLOT_PICTURE_COMMAND: Command to plot a picture file like a png file. Could be display on Linux. Command can be 40 characters.

INTERNET_BROWSER: Location and place of browser

HELP_DIR: Directory of help files, usually INF

GMAP_DIR: The directory on your computer system where `gmap.html` is copied to when gmap is called in eev , see also section 10.5.

GMAP_TYPE: The type of background map used by Google Maps when gmap.html is opened in a browser options are :MAP, SATELLITE or HYBRID, TERRAIN.

GMAP_ICON_QUAKE: The gmap program used this parameter to defines the icon uses to illustrate an earthquake in Google Earth.

GMAP_ICON_EXPLOSION: The gmap program used this parameter to defines the icon uses to illustrate an explosion in Google Earth.

GMAP_ICON_PROB_EXPL: The gmap program used this parameter to defines the icon uses to illustrate a probable explosion in Google Earth.

GMAP_ICON_OTHER_EVENTS: The gmap program used this parameter to defines the icon uses to illustrate all other events in Google Earth.

GMAP_ICON_MSIZE: The gmap program will plot all events with a magnitude smaller than this with the size/scale of this value.

GMAP_ICON_XSIZE: The gmap program scale the epicenter icons with the formula : scale=GMAP_ICON_XSIZE * Magnitude ** GMAP_ICON_YSIZE

GMAP_ICON_YSIZE: See GMAP_ICON_XSIZE

GMAP_APPEND_KML: With this parameter you can append yor own Google Earth KML code the the output file of gmap. Note, there can only be 100 GMAP_APPEND_KML lines and the KML code must be given between character no. 41 and no. 120.

GMAP_AUTO: To enable of disable the automatic generation of kml files, use 0.0 to disable or 1.0 to enable

GMAP_AUTO_ICON_EVENT: Link to icon used to display epicenter of current event

GMAP_AUTO_ICON_COLOR: color of epicenter icon e.g. ff0000ff

GMAP_AUTO_ICON_MSIZE: The magnitude is set to this values, if it is smaller or missing, e.g. 0.5

GMAP_AUTO_ICON_XSIZE: The size of the epicenter icon is given by this formula: size=GMAP_AUTO_ICON_XSIZE * Magnitude ** GMAP_AUTO_ICON_YSIZE

GMAP_AUTO_ICON_YSIZE: See GMAP_AUTO_ICON_XSIZE

GMAP_AUTO_LOOKAT_ALTITUDE: Altitude from where the epicenter is viewed, default is 2000000.0 meter.

GMAP_AUTO_SHOW_STAT: To show the used station, use 0.0 to disable or 1.0 to enable

GMAP_AUTO_ERROR_ELLIPSE: To show the error ellipse, use 0.0 to disable or 1.0 to enable

GMAP_AUTO_ELLIPSE_COLOR: Set color of ellipse line, default ff000000

GMAP_AUTO_ELLIPSE_WIDTH: Set width of ellipse line, default 2.0

GMAP_AUTO_STAT_SIZE: Size of used stations e.g. 1.1

GMAP_AUTO_STAT_RESIDAL_GOOD: Good travel time residuals are defined below this absolute value in seconds, e.g. 0.5

GMAP_AUTO_STAT_RESIDUAL_BAD: Bad travel time residuals are defined above this absolute value in seconds, e.g. 1.5

GMAP_AUTO_STAT_COLOR_GOOD: Color of good travel time residuals, e.g. ff00ff00

GMAP_AUTO_STAT_COLOR_OK: Color of travel time residuals between good and bad values, e.g. ff00ffff

GMAP_AUTO_STAT_COLOR_BAD: Color of bad travel time residuals, e.g. ff0000ff GMAP_AUTO_SHOW_OLD_LOCAT To show the old epicenter og the current event, use 0.0 to disable or 1.0 to enable

GMAP_AUTO_OLD_LOCATION_COLOR: Color of old epicenter, e.g. ffff0000

GMAP_AUTO_SHOW_PATH: To show the raypath, use 0.0 to disable or 1.0 to enable

GMAP_AUTO_PATH_COLOR: Color of raypath, e.g. ff929292

GMAP_AUTO_PATH_WIDTH: Width of raypath, e.g. 2.5

GMAP_AUTO_FILE_ACTION: To make a system call at the end of each gmap automatic calls, use 0.0 to disable or 1.0 to enable

GMAP_AUTO_ACTION: System call to be executed, e.g. cp gmap.cur.kml /home/seismo/www or ncftpput -u seismo -p passwd ftp.server /home/seismo/www gmap.cur.kml

3.14 Format description in parmater files

Since most SEISAN programs are written in Fortran, the format descriptions follow the Fortran convention. The following are the main format descriptors:

In: Integer format: E.g. I5 means an integer with 5 digits normally right justified. A completely blank field will be read as zero. Examples:

```
123456..    (Position)
  1100      read as 1100
    11      read as 11
            read as 0
```

Fn.k: Real number format: E.g. f7.3 is a real number occupying 7 places like 111.111 and the decimal point is 3 places from the right. Any real number can occupy the 7 places like

```
1234567     (Position)
  1.1
1.1
   1.1
```

All of these will be read as 1.1. If there is no decimal place given, it is automatically put k places from the right. Like the number 1234 read with f4.2 will be read as 12.34. nX . Spaces. Like 5x means 5 spaces.
An: Character format: Like A5 means reading 5 characters
Combining format specifications, example

```
1234567890123456789 position 2f5.1,1x,a4,2x,i2
11.1 12.1 text 12
```

Do not use tabulator instead of blanks

Chapter 4

Seisan Explorer User Guide

This chapter referes to Seisan Explorer (SE) Version 2.7.4, compiled with Qt Version 5.12.2

The core part of the SE code is written by Øyind Natvik, Department of Earth Science, University of Bergen, Norway. The statistical functions are mainly written by Peter Voss.

Introduction

Seisan Explorer (hereafter called SE) is a new graphical user interface for SEISAN written in C++/QT. It is supported on Windows, Linux and UNIX platforms. In its current version, it replaces the old SEISAN graphical interface for Windows, but the intention is that SE will be the main graphical user interface for SEISAN through which most of the current processing by `EEV` and `MULPLT` will take place. However, remaking `MULPLT` requires a large effort so the current `MULPLT` is used for now. In the following description, it is assumed that the user is familiar with SEISAN.

Problems

Please report bugs and questions to `seisan@geo.uib.no`

Installation:

Windows:

SE is installed together with Seisan.

Linux:

SE can be compiled on Linux/UNIX platforms. Please see section 3.11. However in latest version, it is precompiled.

NOTE: xterm must be installed for mulplt and map to be working.

Mac:

SE has not been tested or compiled on Mac.

Memory requirements:

When opening a database, SE will load the contents of all S-files into memory. Opening a database of 100.000 events will require 350+ megabytes of memory

SE works with the new Nordic format, Nordic2.

Parameter files for SE

SE uses the same parameter files as the rest of SEISAN whenever a corresponding program is called. The parameter file SEISAN.DEF is the only one used by SE directly while MULPLT.DEF and STATIONx.HYP are raed when respective options are used. SE will first look for the file in the SE work directoy, which might not be the the directory from which you started SE, but the directory specified as the SE work directory, see later. If the file is not found in the the SE work directory, it will be read from DAT. The STATIONx.HYP is treated the same way as it is ingrated with SE. MULPLT is a program running outside SE so MULPLT.DEF will first be read from directory where SE is started and then from DAT if not there..

How SE works:

Starting SE:

SE can be started in two ways: Clicking on the icon in Windows or givng the command se on the prompt line (Windows and Linux). When using the command line option, arguments can be used like for EEV:

se ,, Working with a local data base

se start date Using default data base from start date and +30 days

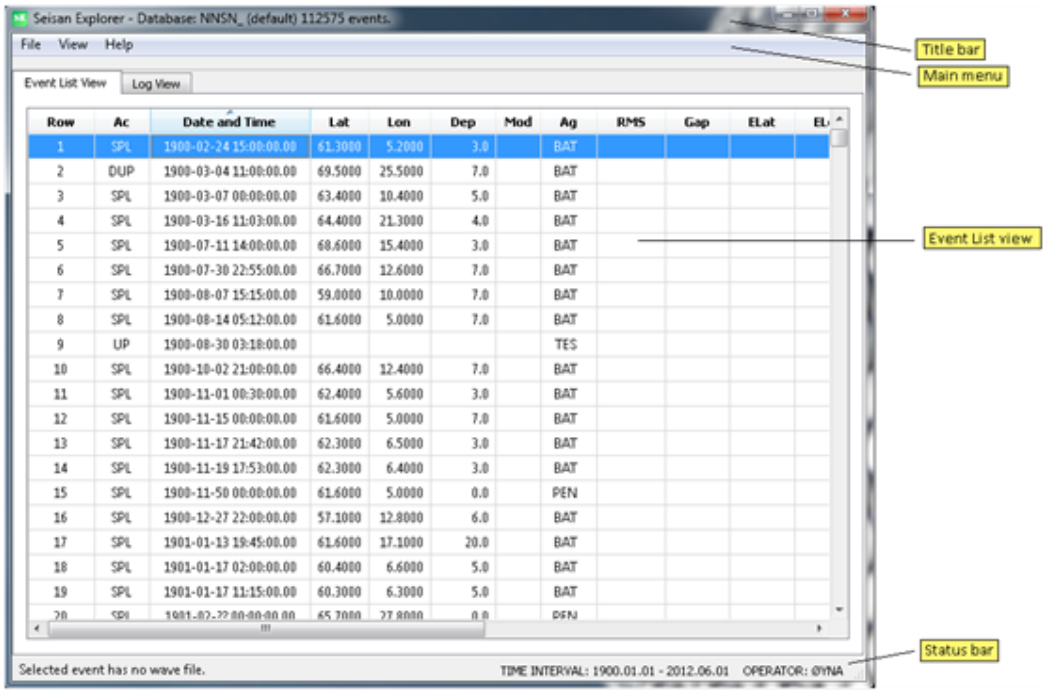


Figure 4.1: Basic Event List view with status bars.

se start date intereval ———————— + interval days

se start date data base interval ———————— using given data base

e.g. se 20110122 TRO 10 will load data from data base TRO for the time interval January 22, 2011 and the next 10 days.

To get the options, write se help.

SE loads S-files from a SEISAN database. Only the S-files that falls within a user specified time interval are read. You may also load an index file or a local database. In this case, the currently set time interval is ignored, and time interval is adjusted automatically to fit the loaded data All information in the S-files is stored in memory for fast access. SE is dimensioned for up to one million events. In contrast to `EEV`, SE can read in data for several months or years, thereby giving the user the opportunity to work with large datasets without any artificial time boundaries. A subset of the data in each S-file is displayed in rows in the Event List view as demonstrated on the front page and in Figure 4.1.

When a database has been loaded, the user can select one or several events for further action, a bit like EEV. The Event List view columns can to a certain degree be customized (EventList/Select Columns). A Log view is available where most system messages are shown.

An overview of the SE application:

The application can present two views, the Event List view and the Log view. The Event List view is shown in the figure below. The program also has a title bar at the top and a status bar at the bottom. The title bar shows the currently opened database and the number of events loaded.

The left part of the status bar shows messages. Status bar messages will only be displayed for a few seconds and then disappear since they might soon be replaces by another message. The right part of the status bar shows permanent information which is the current time interval and the current operator code.

The Event List view

When a database is loaded into SE, the Event List view will be populated (see Figure 4.1), and the first event will automatically be selected. To navigate, use mouse, arrow keys or the scroll bars. Click on an event to select it. Several events can be selected as needed using standard selection procedures. Some items in the event list view may be displayed with a grey background colour. This indicates that additional information will pop up if hovering over these items with the mouse pointer.

In the Event List view you can:

- Perform actions with selected events.
- Search for an event by time: From Event List view, just start typing the desired date (type as `yyyymmddhhmmss`), and the event nearest in time will be the selected. Press `Enter` when finished searching.
- Navigate to a particular row number by typing `0` followed by the row number (what in `EEV` was called event number) and press `Enter`.
- Navigate between selected events using the commands `N` (next), and `Shift+N` (previous).
- Search event(s) by time association: Use shortcut `A` and all events associated with each other within given time window (default 200 seconds) are selected.

Executing actions. Right-click inside the Event List view to bring up the Event List menu. The menu shows all available actions and their corresponding shortcuts. The current actions are:

- Add line: Gives a submenu for A: Add ARC lien, H: Add hypocenter line.
- Associate events (shift A): Find events occurring within a given time interval (default 200s).
- Copy to file (C): Copy highlighted events to file `se-select.out.out` (located in work directory).
- Delete (D): Delete the selected S-files.
- Duplicate (Shift+D): Duplicate an event file.
- Edit comment lines (Shift+C): Edit comment lines in S-file.
- Edit `STATIONx.HYP` file (Shift+S): The STATION file associated with current event (default) or any other station file can be edited.
- Edit with text editor (E): Edit the S-file.
- EEV (<): Launch EEV with current event. Some EEV commands will be disabled and it is not possible to move to another event is EEV.
- Locate (L): Locate current event with HYP. A locater window will pop up..
- Merge (M): Merge one or more events into a destination event. Note: To mark events for merging, first mark the destination event. Then mark one or more events while holding down the `Ctrl` key.
- Plot with mulplt (P): `MULPLT` is started in all default mode so no questions are asked. Results of picks are put back in S-file and SE.
- Plot with mulplt (show plot menu) (Shift-P): The mulplt plot menu will be shown so all defaults is not used.
- Reload event (ctl R). In case of changes, reload S-file.
- Register (R): Register event. Similar questions will come up as in EEV.
- Set distance indicator (Shift+R): Changes the distance indicator in SE and the S-file
- Set event indicator (ctrl E)
- Set model indicator (ctrl M)
- Show with Google Earth (Shift+G): Creates a KML file to be used with Google Earth. Google Earth has to be launched manually with the KML file. An Internet connection is required.

- Show with map (Shift M): The selected events are written out in a file called map.out in working directoy and the events are plotted with SEISAN program MAP (=automatic EPIMAP). MAP can be replaced with any other mapping program you have, it runs with command map map.out.
- Show with Seismicity Viewer (V): Opens the Seismicity Viewer with the selected events.

Other actions:

- Mark/unmark event (ctrl X)
- Unmark all (alt x)
- Refresh view (F5): Refreshes the current Event List view. Does not reload the database.
- Load event file into Explorer (F3): Reads a single S-file into SE. The S-file must belong to the currently opened database, but it can be outside of the current time interval.
- Unload event from Explorer (F4): Unloads an event from SE. This action does not remove the event from the SEISAN database.
- Select all events, (Ctrl+A). Select all events in view.
- Set filter (Ctrl+F): Apply a filter to the event list.

Note that most actions are disabled while SE is busy loading a database.
Sorting data in the Event List view.
The default sorting is by date/time. However, the eventlist can also be sorted by the contents of any other column to sort by this column. Simply click on the header of any column and all events displayed are in the order of the clicked column. The order can also be reversed by clicking the header again. E.g. clicking twice on the depth column will order events by increasing depth. Columns with text will be sorted alphabetically.
Event List menu
Under this menu we find options for dealing with the Event List view . They are:

- Set filter. This means setting criteria for selection of a subset of the Event List View, see details below. E.g., all events larger than a particular magnitude can be selected and only those will then appear in the Event List view.
- Remove filter. Return to the original unfiltered view.
- Select columns. Select columns to show.
- Auto resize columns. Automatically resize the column widths (based on what is currently visible in the view).

The event selection filter
SE has an event selection filter similar to SELECT, but with many more options. Since the selection is done with data in memory, it is very fast compared to any other method of event selection. After a selection is made, the selected events are shown in the Event List View, and further processing can be done with these events. Selections are made using logical expressions built from tokens.
The selection filter has two parts, one filter to include events, and one filter to exclude events. When applying the selection filter, the include expression is executed first and will return a list of all events that matches that expression. Next, the exclude filter will be applied if it has been defined. The exclude filter will be applied only to the result of the include filter, thereby reducing the resulting event list further. This can e.g. be used to select all events between 4 and 8 in magnitude but exclude events with magnitude 5 to 6. Both filters are defined in the same way with logical expressions. See examples below.
To createa filter, press Ctrl-F, or use the Event List menu to bring up the filter dialog (see figure 4.2). Click the Edit buttons to bring up the expression builder.

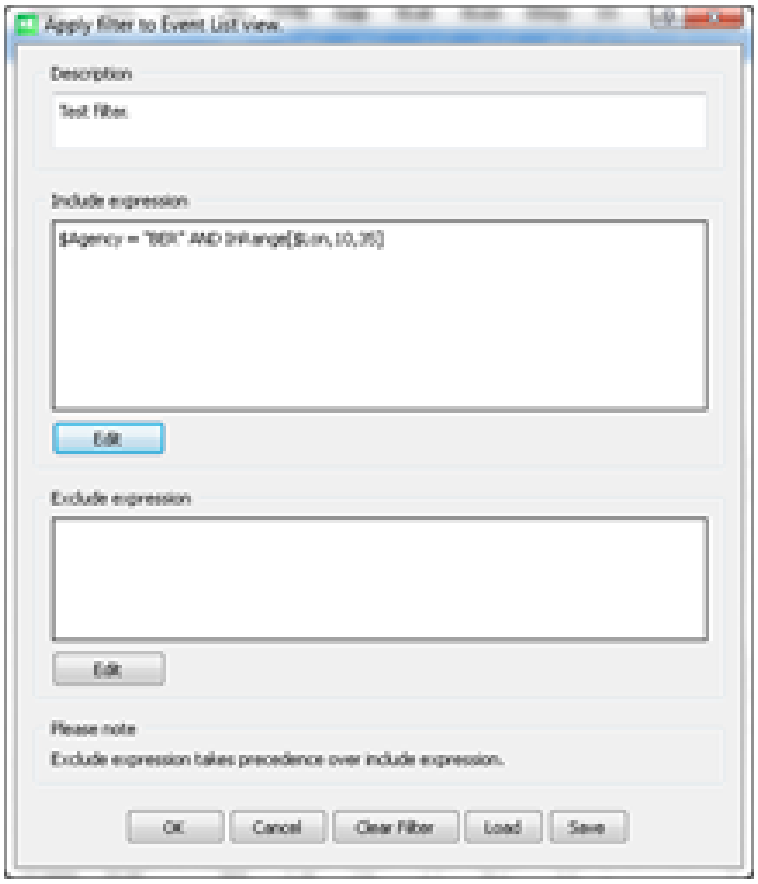


Figure 4.2: Filter dialog.

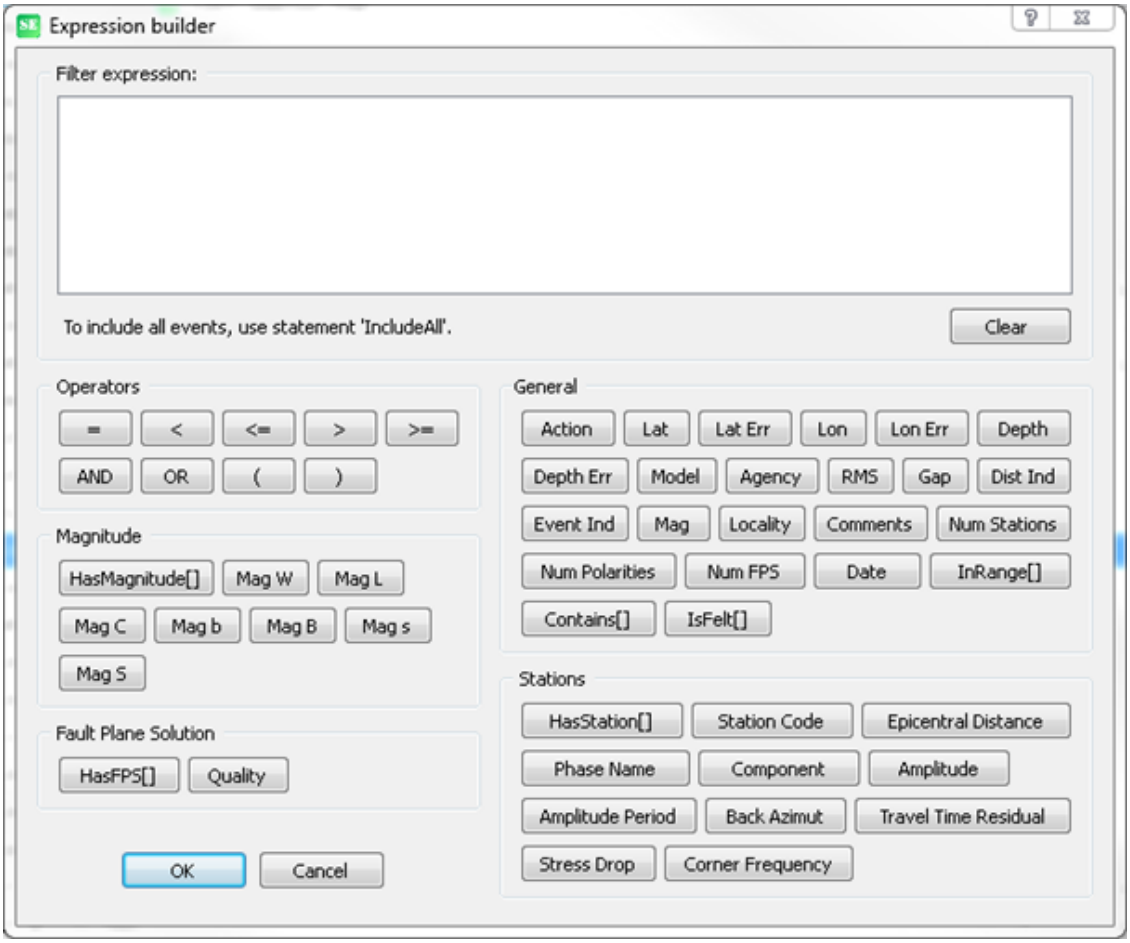


Figure 4.3: Expression builder.

The expression builder is used to define the include/exclude expressions. In expression builder, you may get explanation and examples for each token by right-clicking the token button. An include expression is mandatory. The use of an exclude expression is usually optional. When you are done creating and testing the filter, you may save the filter to a .flt file. The filter can then be loaded again later as needed. The filter's description is also saved.

The following token types are used in expressions:

- Properties
- Operators
- Values
- Functions

Properties:
These are properties in the S-file, like latitude, agency and magnitudes. Property names always start with a dollar sign, like `$Agency`.

Values:
Values are numbers or strings.

Operators:
The following logical operators are supported: =, <, <=, >, >=, AND, OR. In addition parentheses are also supported.

Functions:
Functions take a set of parameters. The return value is the logical value 'true' or 'false'. All functions take their parameters inside square brackets.

An example of a simple expression is

```
$Lat > 55 AND $Lat < 70 AND $Mag > 2
```

which selects events between 55 and 70 degrees N and with magnitude larger than 2.

An example of an expression with a function is

```
$Agency = "ber" AND InRange[$Lat,30,60]
```

which selects all events with agency 'ber' and latitude from 30 to 60.

Rules for writing a valid expression:

- The expression generally has to be constructed by one or more logical statements of type `$property = value`. The statements must be bound together by AND/OR operators to form an expression that evaluates to true or false when executed.
- Spaces are needed around all tokens (except for the right/left parenthesis).
- Capitalization of the expression is generally not important, so `$agency = "ber"` is eqal to `$AGENCY = "BER"`.
- String values are treated in a case-insensitive way.
- String values must be enclosed in double quotes.
- Decimal numbers are not required to have a decimal point. So '10.0' can be written as '10'.
- Arguments to functions are separated by commas.
- A function may take a logical expression as an argument. These expressions must adhere to the same rules as a normal expression. view.

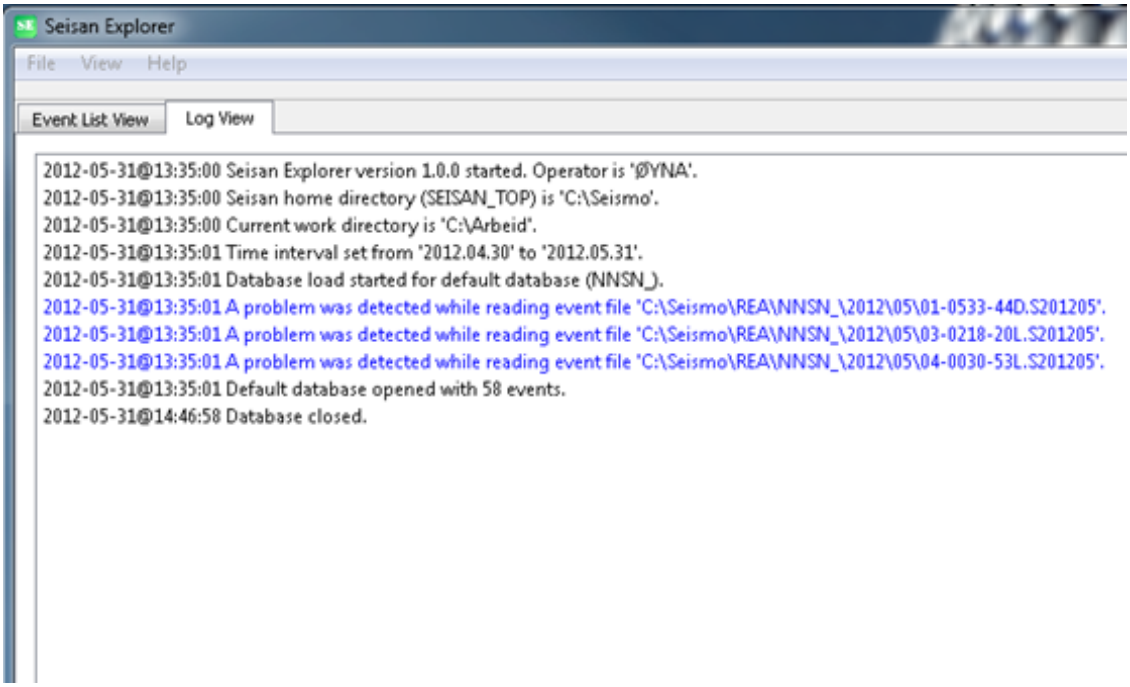


Figure 4.4: The Log view.

The expression builder will check the expression for errors when pressing the OK button. If any errors are detected, an error message will appear, and the error will have to be corrected.

There is a special keyword 'IncludeAll', that can be used in the include filter to include all events. If this keyword is used then an exclude expression is mandatory. Also note that this keyword must be used alone. It cannot be combined with other tokens.

Magnitudes in selection filter.

Since most events has several types of magnitudes, it can sometimes be difficult to select on magnitude criteria. SEISAN therefore optionally has a unique magnitude (or main magnitude) for each event called M. M is assigned to one of the magnitudes given for the event according to criteria for event type and event agency as set up in SEISAN.DEF. The selection criteria can use either the unique magnitude or a combination of magnitudes types and magnitude agencies.

The Log view.

The Log view (Figure 4.4) shows all important messages from SE. Information messages are black, warnings are blue, and errors are in red colour. Every time an error occurs, it will be logged here, and SE will automatically switch to the Log view to make the user aware of the error. The log view has a menu that can be activated by right-clicking anywhere in the view.

The menu has commands for common tasks such as clearing the view, or saving it to a file. If the Log view holds lines with errors/warnings for S-files, then it is possible to edit these S-files directly from the log view by right-clicking the line.

The work directory.

SE will always use a specific work directory where the log file and all output is written, e.g. from hypocenter locations. This work directory is independent from where SE is started, whether from the desktop or a particular directory. The work directory is by default WOR, but an alternative directory can be set (File/Set Work Directory). The work directory is also the local directory where MULPLT will look for waveform files irrespective of from which directory SE has been started. The current work directory is shown in the Log view when SE is started. Multiple running copies of SE should not share the same work directory. Therefore - when SE starts up - it will look for the existence of a lock file called se-workdir.lock in its work directory. If it does not exist, then it will be created to signal that directory is now in use. If it exists, then this may indicate that another user is currently using the work directory. In this case a dialog

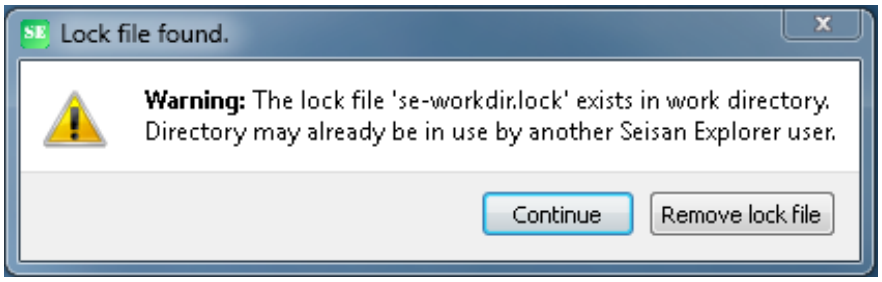


Figure 4.5: Warning (work directory may be in use).

box with a warning appears (see Figure 4.5). The user will be allowed to remove the lock file (if he is sure that none else is actually using the work directory), or select a new work directory, or exit the program. Any lock file created by SE will automatically be deleted when the program is closed. If SE should crash, then the lock file will be left in the work directory. In this case it can safely be deleted manually.

Multiple running copies of SE should not share the same work directory. Therefore - when SE starts up - it will look for the existence of a lock file called `se-workdir.lock` in its work directory. If it does not exist, then it will be created to signal that directory is now in use. If it exists, then this may indicate that another user is currently using the work directory. In this case a dialog box with a warning appears (see Figure 4.5).

The user will be allowed to remove the lock file (if he is sure that none else is actually using the work directory), or continue to select a new work directory. Any lock file created by SE will automatically be deleted when the program is closed. If SE should crash, then the lock file will be left in the work directory. In this case it can safely be removed manually.

Open a database.

Databases are opened under File/Open. The choices are: Default Database (as set by `DEF_BASE`), `Local Database, Database, Catalog File` and `Index File`. The 'Database' option will open a dialog box showing the REA directory with all databases (standard 5 letter directories), and one can be selected. A new option - compared to EEV - is that a database (the year month structure) can be located under any directory, not just REA. It can be selected by navigating the file system from the dialog box. This arbitrary structure must have corresponding waveform files in WAV, SE working directory or a named directory (see SEISAN.DEF) and cannot use the WAV structure since it is not placed in a standard REA structure.

The 'Catalog File' option makes it possible to open a catalog file. SE will extract the S-Files inside the cat-file to a user-selectable folder, and then open the folder as a local database. When closing the database, user will be prompted to save any changes back to the catalog file. The folder will not be automatically removed when the database is closed. It will have to be deleted manually.

SE can be configured to automatically open the last used database on start-up (see File/Configure).

Local data base in SE, access to EEV and reading waveform files.

Case 1: Default working directory

The default working directory in SE (example Windows) is \seismo \WOR \. A local data base can then be opened in any other directory. The waveform files must then be in WAV or WOR. If they are in the local data base directory, they can be found if parameter WAVEFORM_DIRS is set in SEISAN.DEF like

WAVEFORM_DIRS Waveform directory \seismo \wor \test

where the location of the waveform files are given as \seismo \wor \test , which also can be the local data base directory.

EEV will not work since EEV will look in SE working directory.

Case 2: Directory with local data base is set as SE working directory

In SE the working directory can be set under file $->$ File/Set Work Directory... When set to the directory of the local data base, EEV will work and waveform files will be found if in WAV or local data base directory. WAVEFORM_DIRS does not need to be set. However, no other local data base can be opened (a bug to be fixed).

Setting a time interval.

When a database is being opened, SE will suggest a default time interval. The default time interval has an `End date` equal to the current date, and the `Start date` is set to the current date minus 30 days (this

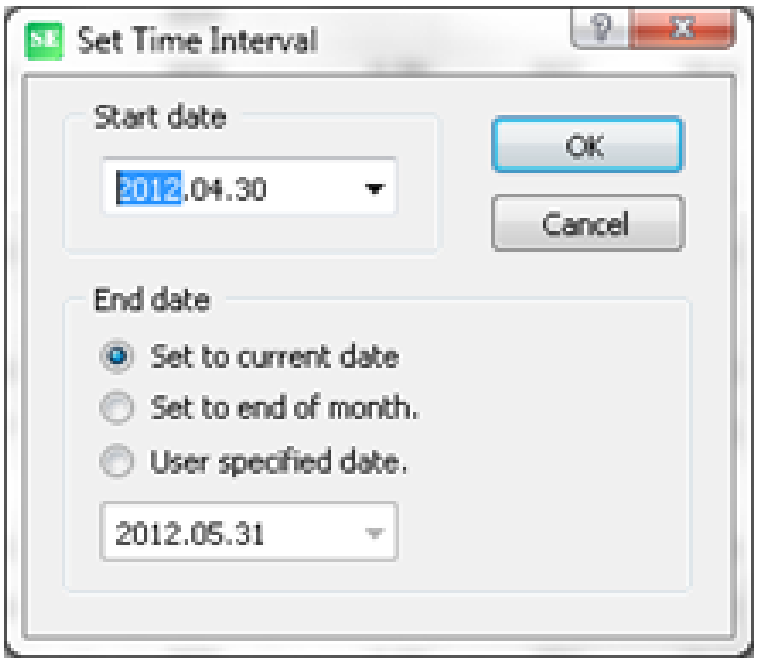


Figure 4.6: Set time interval.

value is user configurable). Both start-date and end-date can be modified by the user (see Figure 4.6). The default time span between start-date and end-date can be set under File/Configure. The time interval can be changed at any time by pressing `ctrl-t` or using the main menu (`File/Set Time Interval`). If the time interval is changed when a database is open, then the user will be prompted to reload the database.

Special functions have been written for SE, see below. To add new functions the two functions Sample function A and Sample function B can be used. Add changed in the source code of `sample_function_A.cpp` or `sample_function_B.cpp` and recompile. If you wish to change the widget we recommend to use Qt Creator, see `http://qt-project.org/wiki/Category:Tools::QtCreator`. Sample function A show how to get values in the event list. Sample function B show how to use the plotting widget QCustomPlot (see also `http://www.workslikeclockwork.com/index.php/components/qt-plotting-widget/`).

Functions

The functions are operations dealing will all data in the Event View, and not the data manually selected. The functions are:

With the function Gutenberg-Richter relation a histogram showing the number of events in selected magnitude intervals can be plotted. Furthermore, the b-value can be computed from the incremental and cumulative values using linear regression. An example is seen in figure 4.7.

With the function Poisson distribution, it can be tested whether or not the earthquakes in the event list are Poisson distributed. The function plot a histogram of the number of earthquakes in yearly intervals, and its coorsponding Poisson distribution. An example is seen in figure 4.8.

With the function Completeness check the years of completeness for selected magnitude intervals can be estimated. The output of the analysis done with this function is stored in the function `se-completeness.out`. An example is seen in figure 4.9.

With the function Weichert method, the b-value can be estimated. This function use the file `se-completeness.out` as input (see 4.9). An example is seen in figure 4.10.

With the function Tempo-spatial hypocenter distribution, the latitude or longitude or depth of the events in the event list can be plotted over time. An example is seen in figure 4.11

With the function change-event-type the events in the event list can be changed to E-explosion or P-possibel explosion or V-volcanic or Q-known earthquake. An example is seen in figure 4.12

With the function change-model-indicator the earth model of events in the event list can be changed. An example is seen in figure 4.13

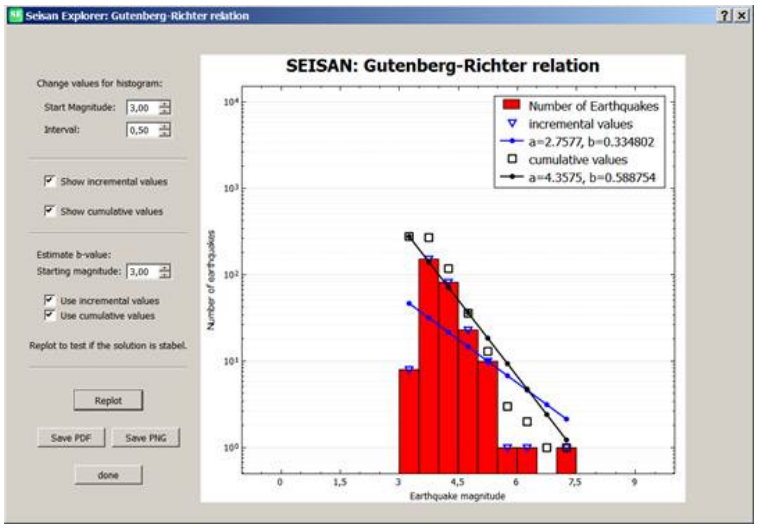


Figure 4.7: se-gutenberg-richter

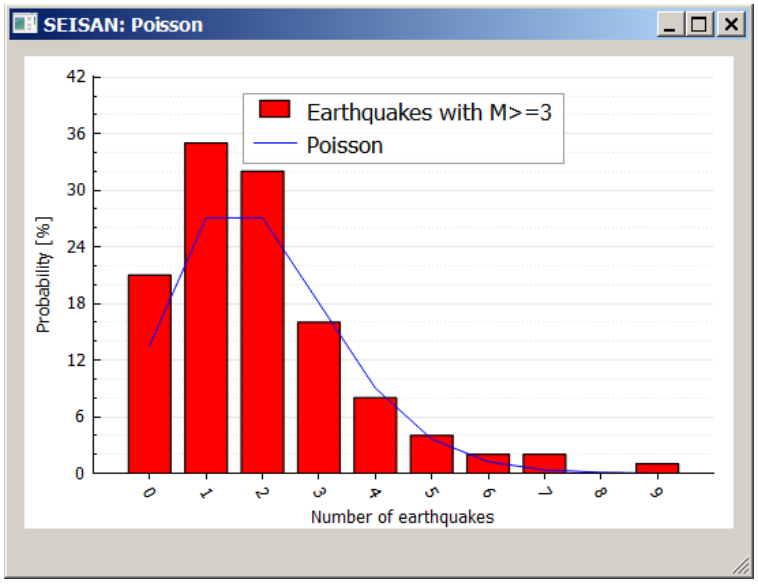


Figure 4.8: se-poisson

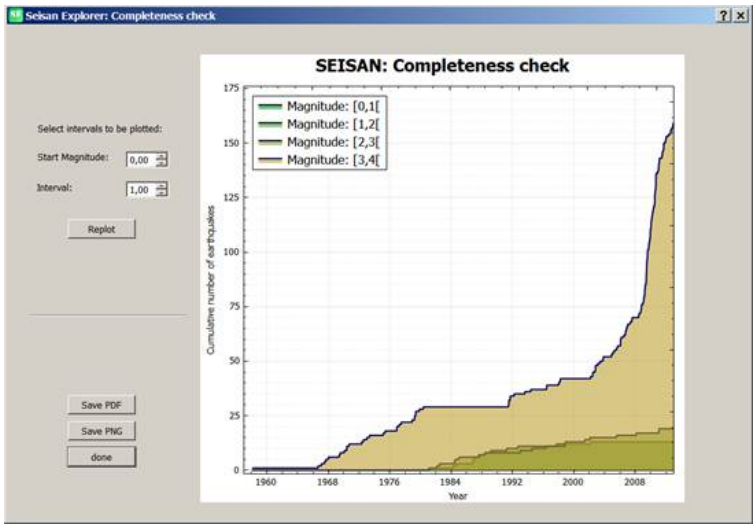


Figure 4.9: se-completeness

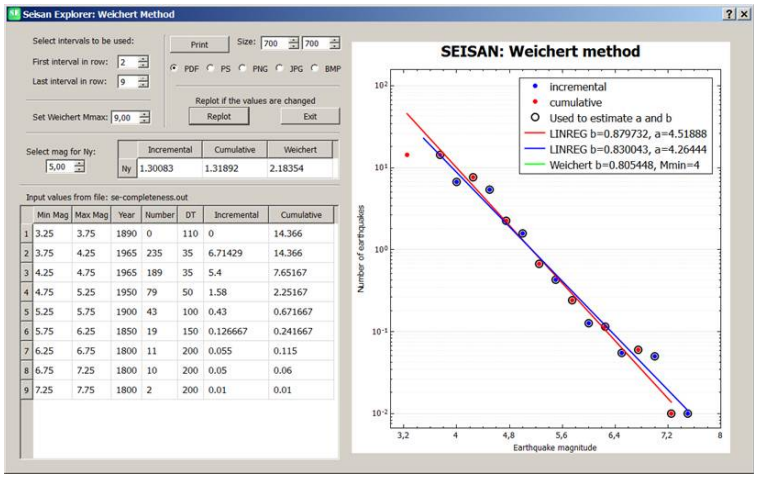


Figure 4.10: se-weichert-method

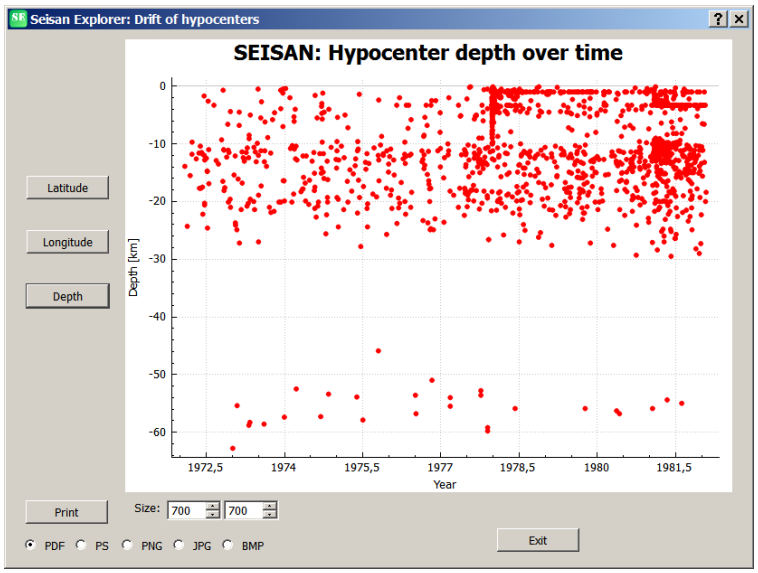


Figure 4.11: Tempo-spatial hypocenter distribution.

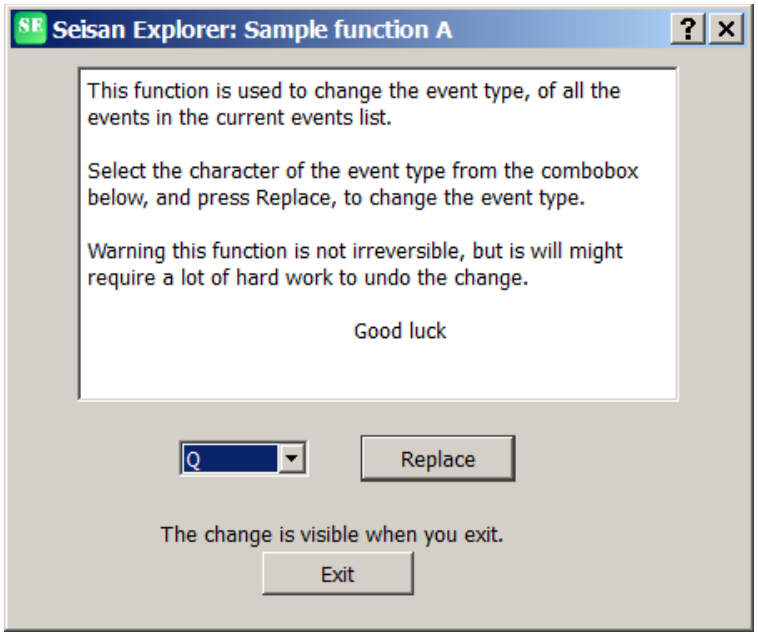


Figure 4.12: These event types are available "E","P","V","Q" and blank, here the "Q" is shown. se-change-event-type

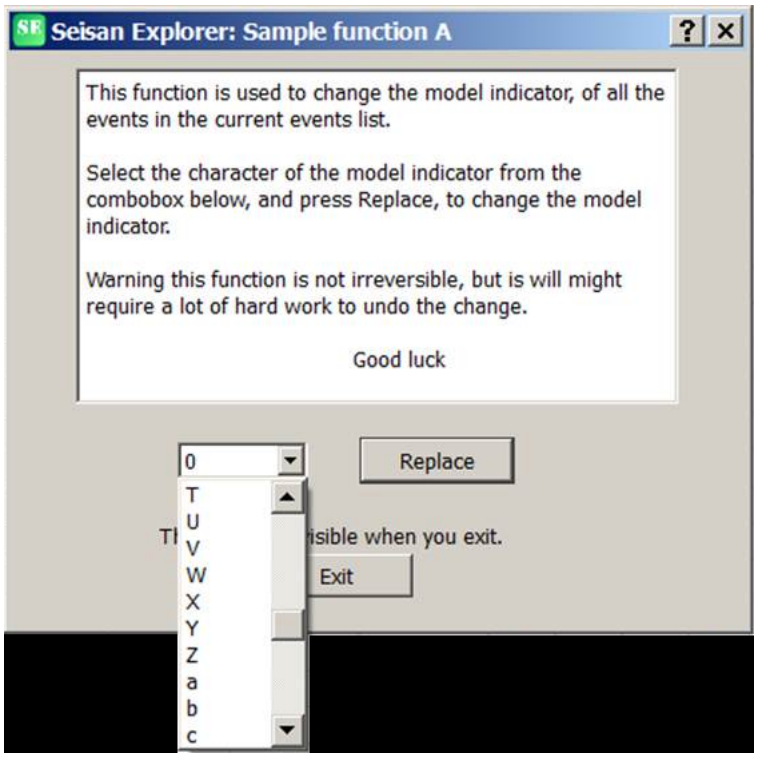


Figure 4.13: se-change-model-indicator

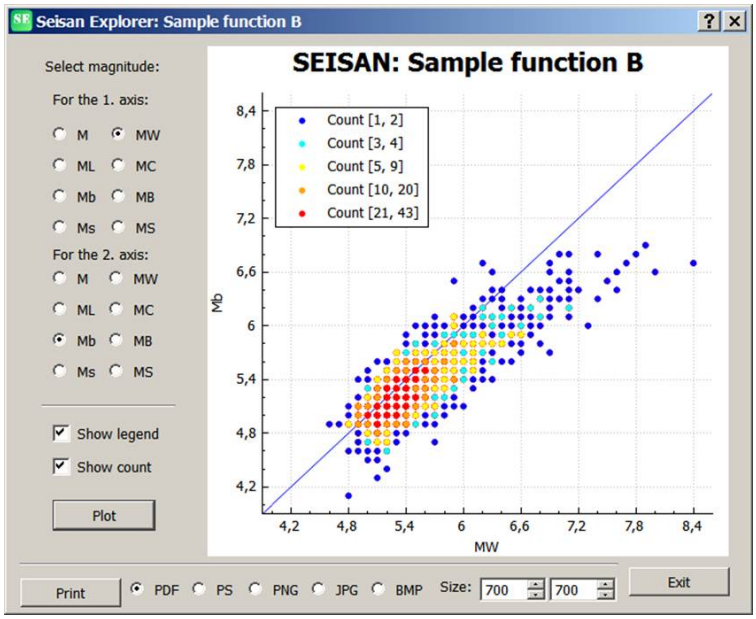


Figure 4.14: se-mag-vs-mag

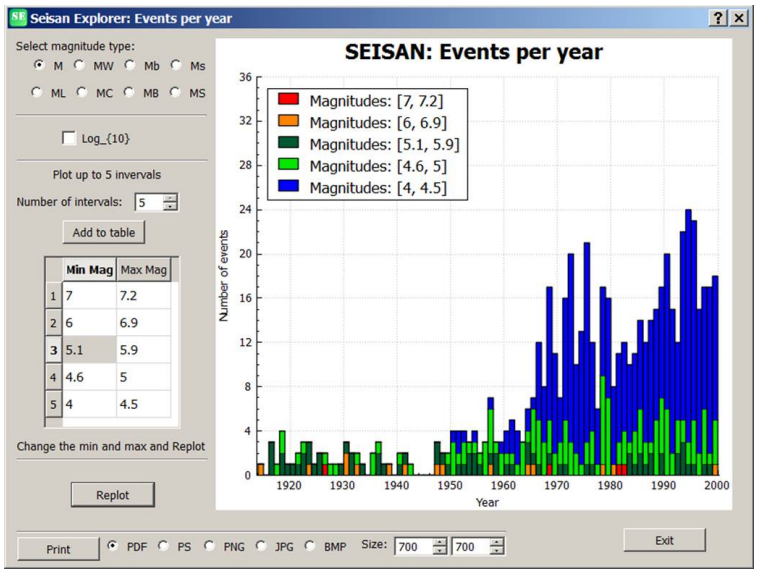


Figure 4.15: se-events-per-year

With the function mag-vs-mag magnitudes can be compared. An example is seen in figure 4.14

With the function events-per-year the number of events per year can be plotted in selected intervals. An example is seen in figure 4.15

With the function Time of day the number of events in the event list can be plottes with respect to the hypocenter time. An example is seen in figure 4.16

With the function Time of day versus time of year one can check, if e.g. there is an encreasing number of explosions at noon in a specific period. An example is seen in figure 4.17

With the function Time of day versus distance one can check if e.g. a mining area is making explosions. An example is seen in figure 4.18

With the function Simple Waveform Viewer waveform files in the Ascii Helmberger format. Use OutW command in MULPLT to generate waveform data file `mulplt.wav` in Ascii Helmberger format. An example is seen in figure 4.19

4.1 SE Locator

SE has got a completely new interface for locating events in SEISAN version 11.0. While previously, location was done in a separate program, the location routine (still using HYP) has been integrated into SE. This makes it possible to get a more user friendly graphical output from the locater, which can stay open while other activities take place. The locater can be started in two ways:

From the main event list, location is still started with command 'l', and a new window pops up.

Plotting in MULPLT, multi trace mode,' l' can also be used as before, but now the locater window comes up.

Figure 4.20 shows an example

Main locator window

When the Locator window pops up, a location has already been made and the results of the location is shown. These results are the same as given when locating with EEV, however more results are shown than locating with EEV, where one has to look in the print.out file to see all results. The results are latitude, longitude, depth, origin time (all with errors). Dx(km), Dy(km), Dz (km) and Dot (sec) are the difference in location from previous solution in longitude, latitude, depth and origin time. The GAP and number of stations (NSt) are also shown. The upper right corner shows the magnitude/settings window, see below.

Update and event selection

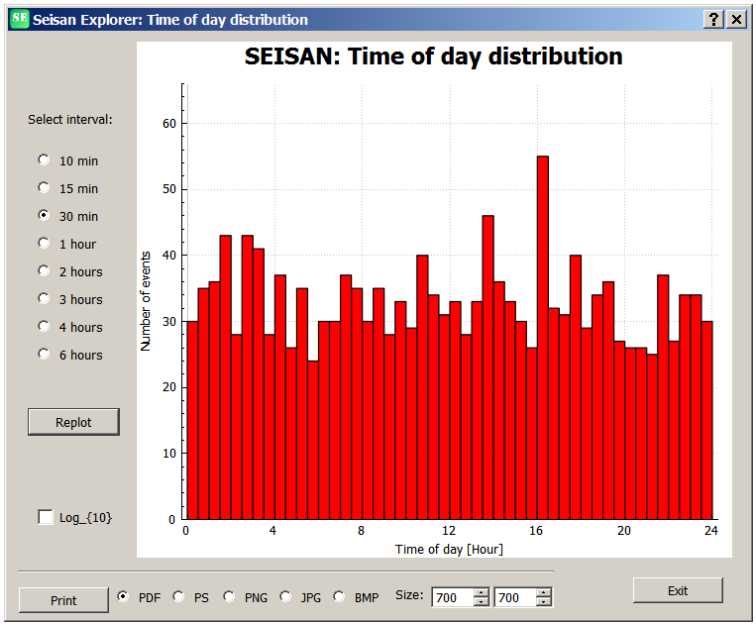


Figure 4.16: se-time-of-day

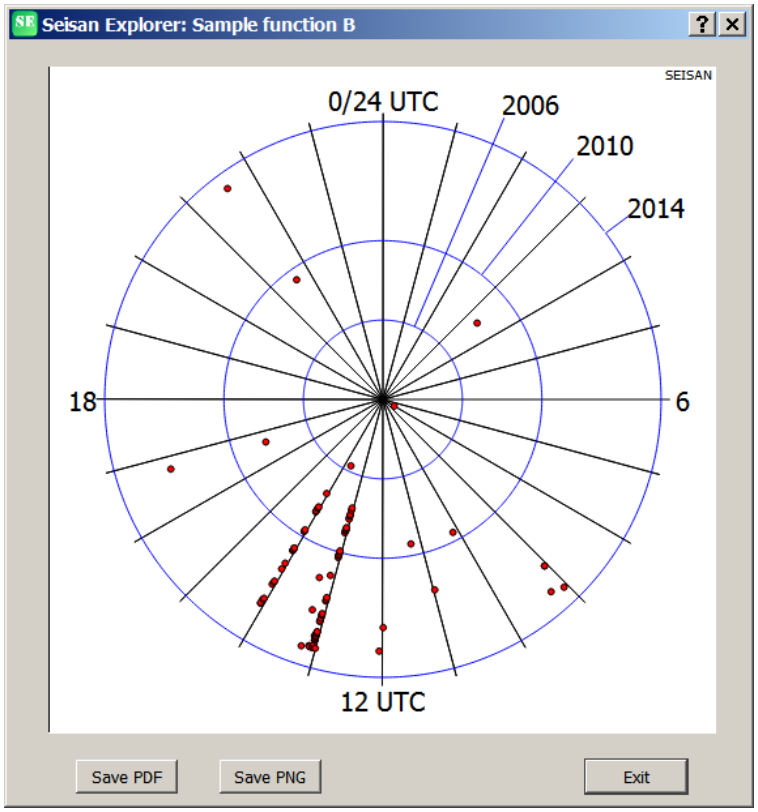


Figure 4.17: Time of day vs time of year

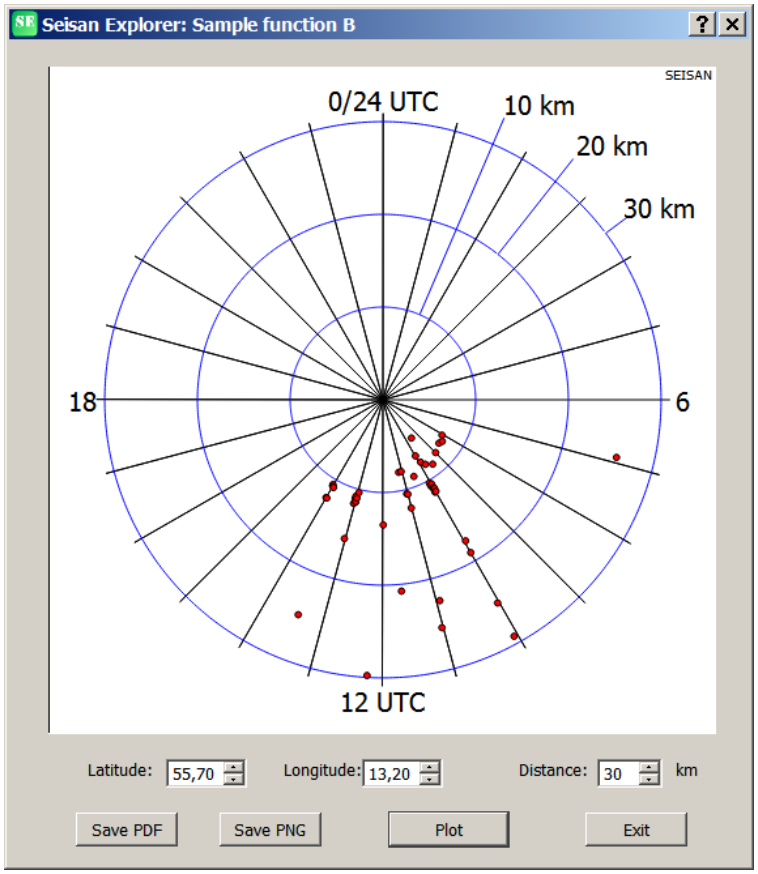


Figure 4.18: Time of day vs distance

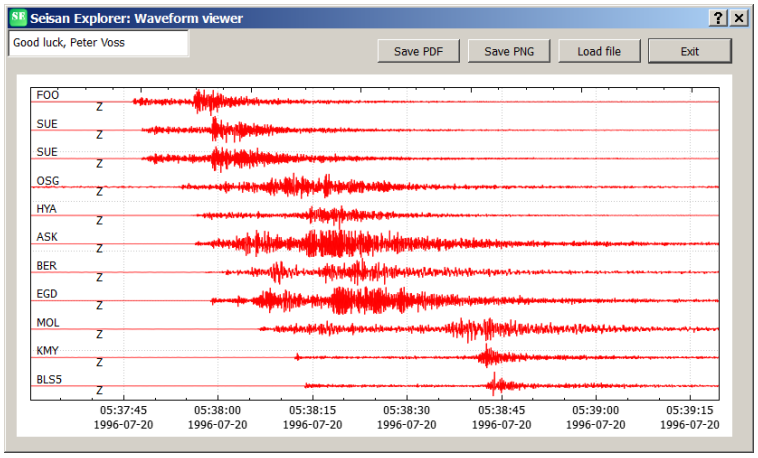


Figure 4.19: Simple Waveform Viewer

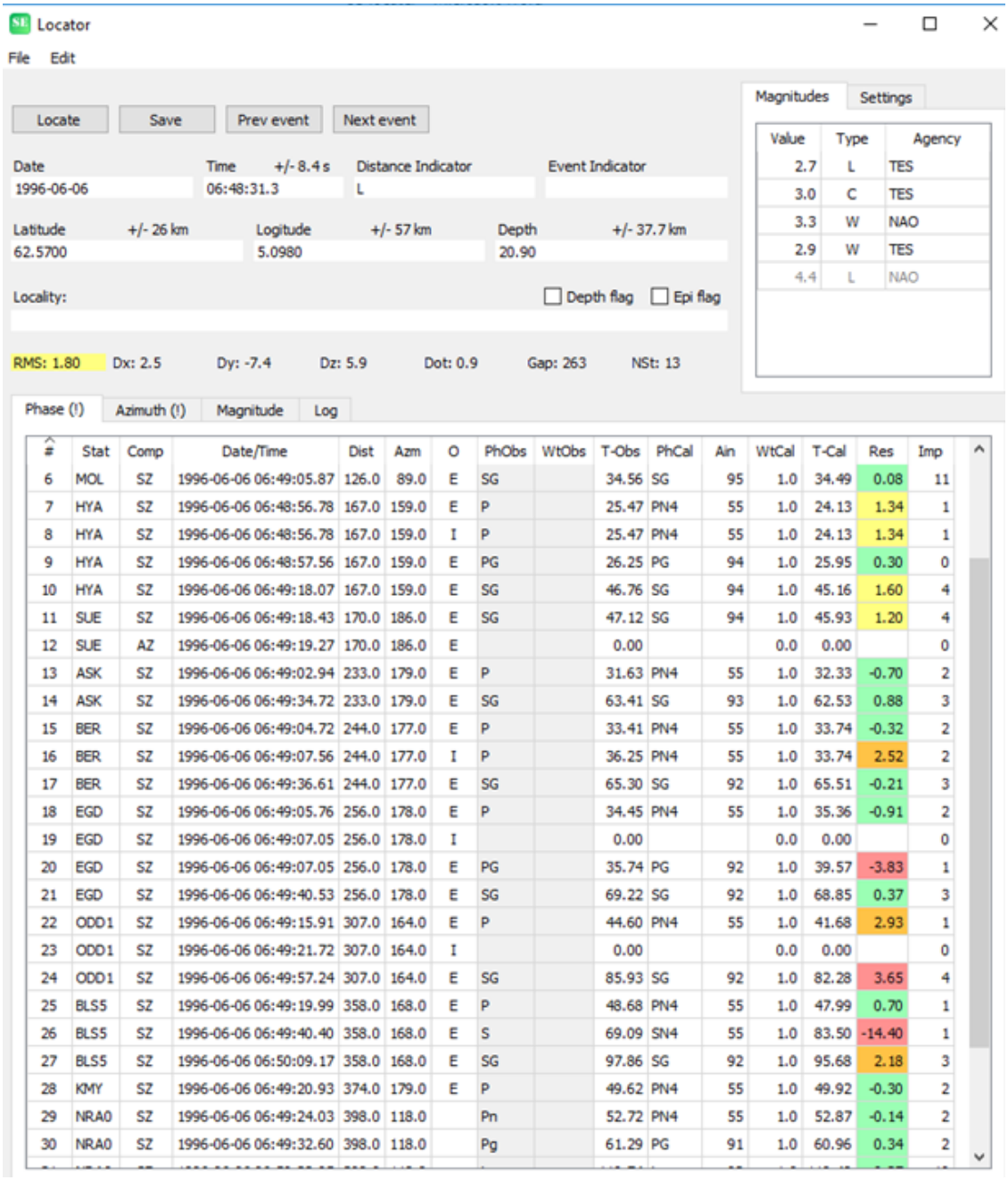


Figure 4.20: Example of locating an event, the locator window.

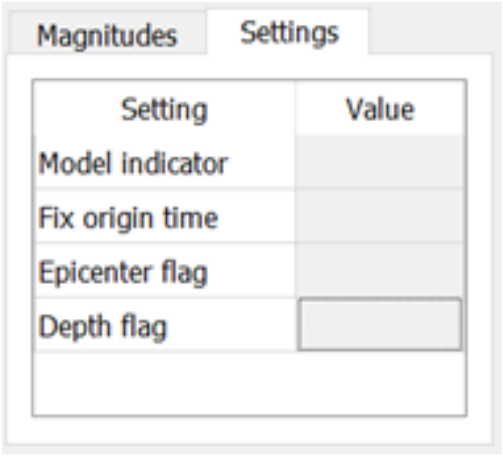


Figure 4.21: The options under Settings in the magnitude box.

The location, as shown in the locater window, must be saved (use button Save) in order for the results to saved in the data base (S-file). It is thus possible to do test without committing the results to the data base. In the Locator window, it is also possible to go to next and previous event without returning to the main window. However, when going to next event or previous event, no location is done and the data shown is taken from the S-file. Locate must be pressed to locate.

There is also an option for Save and Rename under File tab. This option will update the S-file name and the ID line to correspond to the origin time. Outside SE this can only be done with program UPDATE, see UPDATE to see why this is done. Option 'u' in EEV is not changing the filename and ID, only updating result in S-file.

Under the tab Edit, it is possible to copy the epicentre location to the paste buffer for use elsewhere.

Using the locater window as an editor

Several parameters in the locater window can be edited to facilitate simple changes and tests. Many of these fields are outlined with gray like the phases and the input phase weight. In addition, the following can be edited: latitude, longitude, depth, origin time, distance indicator and event indicator. The fix depth and fix epicentre flags can be set with tick boxes. More options are available in Settings seen in the magnitude box, see Figure 4.21

Travel times and residuals

The residuals are color coded. The limits are hardwired and the intention is that they should be user settable in the next version. The limits are:

0.0-0.99	Green
1.0-1.99	Yellow
2.0-2.99	Orange
>3.0	Red

RMS is color coded in a similar way. If any problem with the phases, the name of the Phase shows an exclamation sign (!) as shown above. This is also the case with Magnitude and Azimuth tabs.

Abbreviations are: Stat: Station code, Comp: the two letter component code from S-file, Dist: epicentral distance in km, Azm: Azimuth, O: Onset (I, E or blank), PhObs: Phase observed, WtObs: Weight observed, blank or 0 means full weight, 1 is 0.75 , 2 is 0.5, 3 is 0.25, 4 is zero weight, 9 means using S-P (all are HYPO71 style weights), T-obs: Observed travel time, PhCal: Phase calculated (the one the program calculate as the fastest), Ain: Angle of incidence at the source, WtCal: Weight used by the program (from 0.0 to 1.0), T-cal: Travel time calculated, Res: Residual=T-Obs - T-Cal and Imp: Importance of phase in the solution calculated as a percentage, importance of all phases should add up to 100

Magnitudes

The average magnitudes are shown in the Locator window, upper right and corner. All magnitudes available for the event are shown so magnitudes on additional header lines are included. The magnitudes are sorted in importance as specified in parameter file SEISAN.DEF. The magnitudes not calculated by SEISAN

are shown with less contrast than the magnitudes calculated by SEISAN. The 3. magnitude on the header line, which might not be calculated by SEISAN, is considered a SEISAN magnitude. This magnitude is often put in an external reliable reference magnitude. The magnitudes not calculated by SEISAN (not including 3. Magnitude) area t ten of the list.

For each magnitude calculated by SEISAN, it is possible to show the individual station magnitudes with the magnitude residual by pressing the Magnitude tab. See Figure 4.22.

The magnitude window show all the input used for calculating the magnitudes: Amplitude, period, coda and seismic moment (log value) as given in the S-file. Similar to the travel time residuals, the magnitude residuals are color coded in order to quickly find deviating magnitudes which could indicate bad readings or wrong calibration file. The limits are:

0.0-0.19	Green
0.2-0.39	Yellow
0.4-0.79	Orange
>0.8	Red

Additional abbreviations: MagType: Magnitude type, Amp: Amplitude (nm or nm/s), Coda: coda length(s), Moment: Log seismic moment (dyn cm) and Mag: Magnitude.

Azimuth (backazimuth)

If backazimuths are available, they can be seen in the Azimuth tab. See Figure 4.23

In this tab, only the weight observed (WtObs) values can be edited. The residuals are color coded. The limits are:

0-5	Green
5-10	Yellow
10-20	Orange
>20	Red

Additional abbreviations: BazObs: backazimuth observed, AppVel: Apparent velocity (km/s) and BazCal: Calculated backazimuth.

Log tab

This tab will automatically come up if the location routine returns a message (like a missing station, errors in station file or if the event cannot be located). In the last case, it is often useful to check the `print.out` file to get an explanation for why the location was not possible.

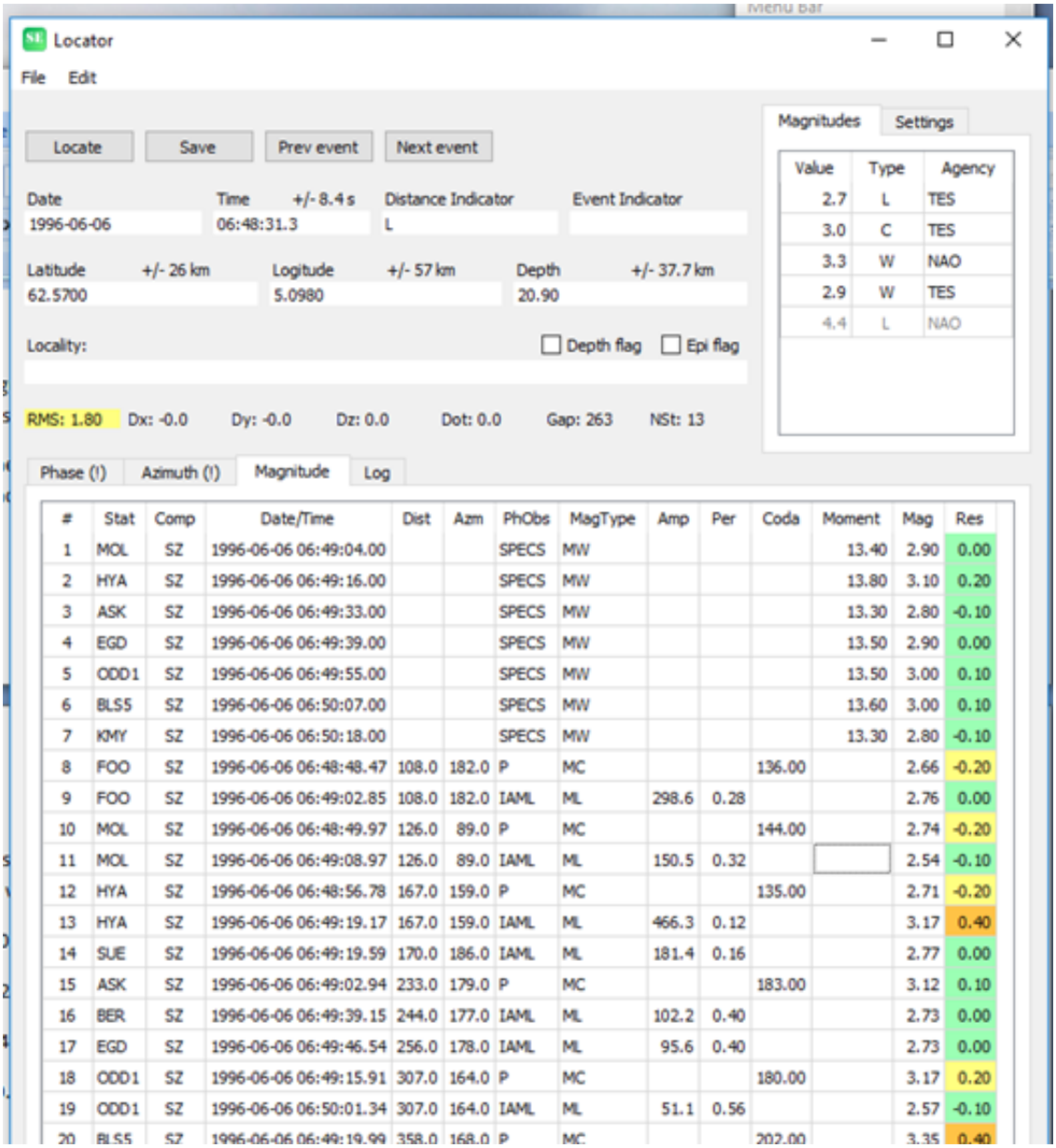


Figure 4.22: The magnitude window with magnitudes per channel, corresponding input data and magnitude residuals.

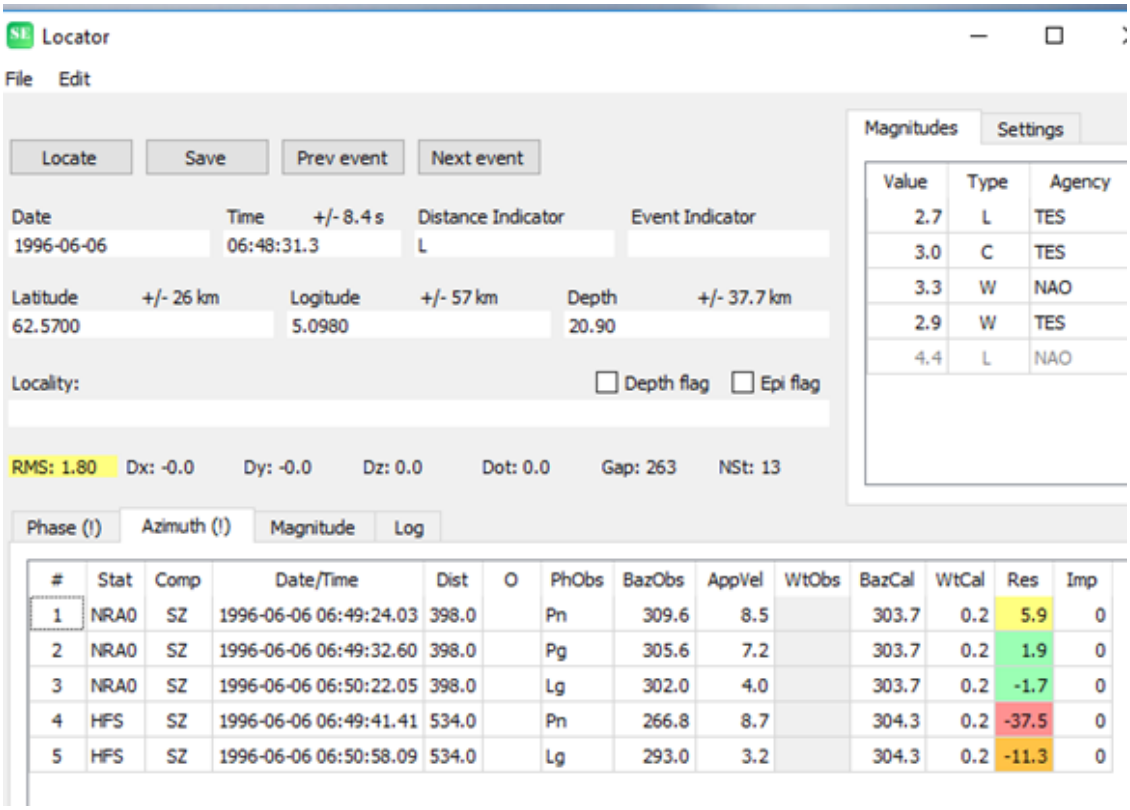


Figure 4.23: The Azimuth (backazimuth) tab.

Chapter 5

Using SEISAN

Once the system has been installed, it is ready to use. Usually all work should be done in the WOR directory or on a multi user system from your own directory. To move to WOR, type WO. Unless you have to do system work, it will not be necessary to move to any other directories. However to do so, just type the first two letters of the directory name like DA to move to the DAT directory. On a PC the Notepad editor is default (invoked with command Notepad from prompt), and on Linux it is the vi editor.

The system has two basic modes of operation. The first is to work interactively with the database. That means jumping around from event to event, plotting, interactive phase picking, locating, deleting, typing, editing or appending events (S-files). This mode is invoked with the command EEV, which uses several programs, controlled by a driver program and is intended for testing and editing of single events. Once the input data seems OK, the second mode of operation can be used.

The second mode is more like traditional data analysis where single programs are made to work on the whole or part of the database. In this mode the updated S-files and CAT-files are created. Examples are also plotting of epicenters, waveform data or searching for data fulfilling certain criteria.

The system comes with a test data set from different networks, mainly the Norwegian National Network for the time period 1990 to 2011. The data has waveform data in different formats. The data set includes events from both local and teleseismic distances. The installation of test data is separate from installation of SEISAN. However, two of the events, from June 1996, are always installed as part of the software installation.

If you want to try the system, go directly to section 5.4 to get a feeling for how the system works. You can then work directly with the data from the years 1996 and 2021.

User guide

A short user guide is found in the following section 5.1.

Tutorial

The document 'SEISAN tutorial' is an introductory tutorial for new SEISAN users. It does not require installation any test data since only the test data included with SEISAN is used. It is given as a PDF document in INF. Or here:
`http://seisan.info/seisan-tutorial.pdf`

Computer exercises

The document 'Introduction to SEISAN and Computer exercises in processing earthquake data' which is a more complete tutorial for both new users as well as experienced users, is included in the distribution. The testdata used in the exercises need to be installed, see chapter 3. It covers a lot more topics than the tutorial. The document is given as PDF file (`seitrain.pdf`) in the INF directory. Or here:
`https://www.geo.uib.no/seismo/SOFTWARE/SEISAN/seitrain.pdf`

WEBINAR

To get an idea of how SEISAN works, new users can take a look at a SEISAN webinar that was arranged by IRIS in 2014 (see `https://www.youtube.com/watch?v=KJH3ktGL_K0` or fileseisan_webinar_iris_2014.mov on the SEISAN ftp server).

Illustration of earthquake ananlysis using SEISAN

SEISAN also has a document illustrating the steps involved when analyzing seismic records. This is more a demonstration than a course. Examples are given for local, regional and teleseismic earth-

quakes. This is done by giving representative screen plots together with explanatory texts that follow the figures. This document is part of the New Manual of Seismological Observatory Practice manual (http://bib.telegrafenberg.de/publizieren/vertrieb/nmsop/). All the data used are also included with the test data. In SEISAN, the document is found in INF: nmsop_is11.7_seisan.pdf. Or here:
`http://seisan.info/INF/nmsop_is11.7_seisan.pdf`

SEISAN problems

Some of the most common problems have been collected in the index under the header "Problem" and in section 5.11.

5.1 Short user guide

The SEISAN manual has been divided into sections describing the individual programs. However, many tasks require the use of many programs and it is not always easy to find what can be done and which programs to use. The following section intends to give an overview of some general problems that SEISAN can work with and a list of programs to use. The following tasks have been identified:

- Routine processing: Phase picking, hypocenter location and magnitudes
- Determination of source parameters: Fault plane solution, stress drop, etc
- Determination of back azimuth and apprent velocity using arrays and networks
- Crustal structure: Velocities, layer thickness and attenuation
- Seismic catalogs: ISC data, database management, completeness, statistics, etc
- Seismic hazard: Attenuation, catalogs, and soil response

5.1.1 Routine processing

The main work of a seismic observatory is to quickly process and organize incoming data from different sources. SEISAN has a simple time ordered database (see later section) and a set of programs for these tasks. The most important programs are:

EEV and SE: The EEV and SE programs are the interactive programs for working with single events in the database. The programs are used to navigate in the database to find a given event as well as for housekeeping (splitting, merging and deleting events). Once an event has been selected, a large number of options are available like phase picking, earthquake location, fault plane solution, macroseismic information etc. All results of the interactive processing are stored in the database (S-files). EEV and SE have similar optionss and it is possible to use EEV options from SE. EEV is working from the prompt line while SE is using a graphical interface.

MULPLT: This is the general plotting and signal analysis program and can be used to pick phases and amplitudes, correct for instrument response, produce Wood-Anderson seismograms for determining Ml, simulate WWSSN SP and LP records, determine azimuth of arrival for 3 component stations, make spectrograms, rotate seismograms, display theoretical arrival times for IASP91 phases to help identifying global phases and do spectral analysis. And more. MULPLT can be used from EEV and SE or as a stand-alone program.

FK and PFIT Determining apparent velocity and back azimuth using an array of a local /regional network.

HYP: This is the general program for hypocenter location and is based on HYPOCENTER (Lienert et al., 1986; Lienert and Havskov, 1995). The program can use nearly all common crustal and global phases (8 character ISC codes), locate teleseismic events using the IASP91 model and use observed azimuth and apparent velocity. The program can therefore be used with all types of input data whether from single stations or arrays. HYP can be used from EEV or as a stand-alone program. HYP is integrated into SE proving a superior interface giving more feedback and options to the user, than the prompt operation. Apparent velocity is currently only used for starting location.

EPIMAP: This is the general hypocenter plotting program for making epicenter maps and hypocenter profiles. The hypocenters can be plotted with elliptical error ellipses and EPIMAP can also be used for interactive selection of events in polygon areas. For plotting hypocenters, there is also an interface to GMT. MAP is a simple version of EPIMAP requiring no input of parameters, just the Nordic file with the hypocenters. A simlar program using GMT is MAPG. Fault plane solution can also be plotted.

BUL: The function of this program is to produce a bulletin. The user can tailor the appearance to local needs and the program can produce bulletins of hypocenters only or both hypocenters and phase readings.

In addition to the above programs, several programs are available for database creation, input and output of large data sets and conversion and manipulation of waveform data.

In order to get an idea of how routine processing works, some examples of routine processing will be given below.

Case A: Telemetry network with 32 channel central recording

The network generates waveform event files, which are transferred to SEISAN. The tasks are:

1: Convert waveform files to SEISAN format or any of the other formats used by SEISAN. It is likely that the format is MiniSEED in which case no conversion is needed. (many events can be converted in one operation). Inspect events with MULPLT. From MULPLT, false triggers are deleted and real events are put into the database. Events are at this stage identified as local, regional or distant. Phase picks can be done at this stage, but is usually done later.

2: Interactive phase picking, earthquake location, magnitude etc done with EEV oe SE. Automatic phase picking is also possible at this stage.

3: Database is updated (UPDATE for many events, outside EEV or SE or oen by one in EEV or SE) once a suitable interval has been processed interactively, usually a month. Updating means permanently storing the updated or newly calcualted hypocenters etc in the database.

4: Make hypocenter maps with EPIMAP, MAP or MAPG.

5: Produce a bulletin with BUL.

Case B: 3 telemetry networks and one broad band station

The routine is the same as above except for one additional step between 1 and 2. Since several data sets are available, some of the detections from different networks or the broad band station might correspond to the same event. There are now two options. The first is to merge the waveform files for corresponding events and then put the events into the database. The second option is to put all real events into the database and then do the merging from EEV or SE.

Case C: A mix of stations and networks and additional phase readings

The steps are as in case B except that before step 2, the additional phase data is put into the database. In this case the merging of events must be done with EEV

Case D: A network recording all data in continuous mode into a SEISAN continuous data base or now more likely a SeisComP continuous data base.. In addition, there is likely to be network wide triggering put into SEISAN. In this case it is a question of inspecting the triggers with EEV or SE/MULPLT as above and possibly extract additional data out of the continuous data base and put it into the event data base. another option, which now is becomming more common is to put a reference into the S-file where to find the data in the continuous data SeisComP database so it is possible to plot the corresponding waveform data without having any event waveform files.

Example of using EEV for interactive processing:

Find event in default database nearest the given date and time: EEV 1999020303

Once EEV is started, an EEV prompt is given and different EEV options are available. Examples are: E: Edit event, P: Plot event, L: Locate event, F: Make fault plane solution, d2201: Find event nearest day 22 at 01 hour, MAP: Start EPIMAP to show earthquake location and SAC: Start SAC processing of event using all parameter and waveform data from SEISAN database.

The above examples have mostly described the interactive processing of single events. However, once the data is in the database, operations can be done on the whole database, for any time interval or for events fulfilling certain criteria (like magnitude, area etc). Examples are relocating events, extracting data and determining coda Q.

5.1.2 Source parameters

The routine processing normally produces magnitudes and hypocenters. The fault plane solution can be determined using polarities and one event (Snoke et. al., 1984). Composite fault plane solutions can also be made. In addtion there are 3 more programs for makeing fault plane solutions, 2 of which also can use amplitude ratios. A second way of determining fault plane solution is to synthetically model the waveforms using the modeling programs. In addition, seismic moment, stress drop and seismic source radius can be determined by doing spectral analysis or spectral modeling. This can also be done automatically with AUTOSIG, AUTO and AUTOMAG.

The full wave modeling programs integrated with SEISAN, are written by Bouchon (1981) and Herrmann (Herrmann,1996). The ray-tracing program is based on WKBJ and written by Chapman et al. (1988) and integrated with SEISAN by Valerie Maupin. All the above programs are executed from EEV in order to use known source parameters.

Momnet tensor inversion can be made in EEV using the Dreger (2003) programs.

5.1.3 Crustal structure and Q

A large database can be a good source of information for determining structural parameters and SEISAN provides several programs to determine the crustal structure and Q. Using seismic arrival times, it is possible to invert for the crustal structure using the VELEST program (Kissling et al., 1994). It is also possible to do forward modeling using the location program for a large number earthquakes, since it at the end of a run, a summary of average station travel time residuals and event RMS is given. A special option of HYP is to locate a data set with all permutation of a given range of models in order to find the model giving the lowest RMS.

Deep earthquakes under a local network produce clear phase conversion at crustal interfaces (Chiu et al., 1986). They can be modeled with one of the full wave modeling programs both with respect to amplitude and arrival time.

Attenuation can be determined using the coda Q method for local earthquakes (CODAQ). The coda Q program will calculate q for a series of events and stations at given frequencies. Average values are calculated and a q vs f curve is fitted to the calculated values. The principle for calculation is the standard coda q method, whereby a coda window is bandpass filtered, an envelope fitted and the coda q at the corresponding frequency calculated (Havskov et al., 1989). The SPEC program will determine Q by calculating spectral ratios or the near surface a ttenuation using the spectral decay method. An alternative is to use spectral modeling where Q, stress drop and seismic moment are modeled simultaneously. The AUTOMAG program can do a grid search for find the best attenuation parameters that will fit a series of eartquakes.

5.1.4 Magnitudes in SEISAN

Magnitudes are dealt with in many different programs in SEISAN and this section intends to give an overview.

SEISAN can calculate most standard international magnitudes: Local magnitude Ml, coda magnitude Mc, body wave magnitudes mb and mB (broadband), surface wave magnitudes Ms and MS (broad band) and moment magnitude Mw. The magnitudes are calculated in HYP as median of the station magntudes. Optionally, also averages can be calculated. For more details on the parameters used and the exact formulas, see program HYP.

Parameters for magnitudes

The input parameters used for calculating magnitudes are amplitudes and periods, code length and seismic moment M0. Amplitude and coda length can be obtained manually from MULPLT while automatic amplitudes for Ml can be obtained with programs EEV (command am running AUTOMAG), programs AUTOSIG and AUTOMAG. Seismic moments are obtained from spectra manually with MULPLT or automatically with AUTOSIG and AUTOMAG. Moments can also be obtained from moment tensor inversion using EEV. The amplitudes are stored as phases with the following names Ml: IAML mb IAmb mB IVmB BB Ms IAMs 20 MS IVMs BB

While the moments obtained by spectral analysis are stored in the SPEC lines and in the MOM lines for moment obtained by moment tensor inversion. While the magnitudes are calculated for all channels, only the average magnitude is stored on the header lines (except for Mw from spectral analysis, where

magnitudes corresponding to each moment is stored on the SPEC line). The parameters to calculated Ml and Mc are given in STATION0.HYP file. The parameters for calculating spectral magnitude are given in MULPLT.DEF and/or SEISAN.DEF. Parameters for calculating Mw from moment tensor inversion is generated by EEV (using the model in STATION0.HYP) and stored in the S-file. The remaining magnitudes have fixed parameters.

Changing Ml and Mc parameters will result in new magnitudes being calculated with the next update of the S-file. For the spectral magnitudes, only changes caused by hypocentral distance, density and velocity will affect the recalculation of magnitude. If the attenuation change, the spectra must be recalculated.

Storing magnitudes

Magnitudes are written on the type one header line. On the main first header line there is room for 3 magnitudes, see example below

```
1998 812 1410 26.8 L  36.755-121.462  8.0FFBGS  4 1.3 4.6LTES 4.9WTES 5.0WHRV
```

where magnitude is given by type (e.g. L for Ml), size and a 3 letter agency. When the location program HYP is operated, the magnitudes are overwritten EXCEPT for the 3. magnitude on the header line which never will be deleted by any program. The intention with this is to be able to store an external reference magnitude. If more than 3 magnitudes are calculated (2 if a magnitude in 3. position), a new type one line is written with exactly the same origin time and location agency

```
1998  812 1410 27.0 L  36.755-121.462  8.0FFBGS  4 1.7 4.6LTES 4.7CTES 5.0WHRV1
1998  812 1410 27.0 L                        BGS        4.9WTES                1
```

There is thus room for only 6 magnitudes calculated by SEISAN. More magnitudes can be stored on more type 1 lines which must have different location agency and/or origin time compared to the first header line.

Searching for events using magnitude criteria

Program SELECT can search for a combination of magnitudes of different type, size and agency. SELECT can also optionally search for magnitudes on all header lines. SeisanEplorer (SE) can also search for a magnitude combination, but only among the 6 prime magnitudes. Manipulating magnitudes

There can be a need to convert one magnitude to another. The MAG program can make magnitude relations (also using all header lines). This magnitude relation can then be used, also by MAG, to convert one magnitude to another and write it back to the S-file. Since some programs (like EPIMAP) uses the magnitude in the first position on the header line, MAG can also be used to move any one of the magnitudes to that position. Program NORHEAD can move magnitudes from following header lines up to empty magnitude spaces on the first line. Program REPORT can move magnitudes around on the header line according to user choices. This moving around of magnitudes is now not needed for some programs. There is now a magnitude in SEISAN simply called M, which is unique magnitude returned according to priorities given in SEISAN.DEF

```
MAGNITUDE_ORDER                                                    WGCM
MAGNITUDE_ORDER                                                    LBER
MAGNITUDE_ORDER                                                    WBER
```

where the order to select magnitudes as given here from top (high priority) to bottom (low priority). Only a few programs use this facility: SE, CLUSTER and ASSO. Plotting magnitude information

Magnitude sizes are plotted on all epicentral and hypocentral plotting programs. Relations between magnitudes can be plotted with MAG, b-value can be calculated and plotted with SE (standard method and Wiechert method) and BVALUE. A completeness check can be plotted with SE.

Other programs using magnitudes

NORHEAD can take magnitudes from following header lines and move them up to empty magnitude spaces on first line.

CLUSTER cleans a catalog for foreshocks and aftershocks, partly based on magnitudes. ASSO is a program that merges events in two catalogs based on both time and magnitudes.

Calculating magnitude relations

The Ml attenuation function can be calculated by inverting amplitude reading from many events suing program MAG2. A coda wave relation can be made with MAG. Attenuation to be used with spectral Mw

can be determined using QLG, SPEC and CODAQ. QLG is the recommended program. AUTOMAG can also be made to make some initial tests for the best Q to fit the Brune spectrum.

The magnitude implementation in SEISAN has been adjusted (version 8.3) to the new IASPEI standard.

Amplitude based magnitude identification

Over the years there has been different ways of identifying the amplitudes used for magnitudes. Originally, amplitudes were not identified with any specific magnitude and only the period and distance was used to find out which kind of magnitude should be calculated, like Ml or Ms. Later different amplitude type phase names were used to identify which type of magnitude should be calculated and now only one IASPEI name is used for the amplitude phase name. However, SEISAN is backwards compatible and will use all the old amplitude phase identifiers. Below is given all identifiers used.

Local magnitude ML:

- Period range: T < 5 s
- Distance range: distance < TEST(57)
- No depth range, distance is the hypocentral distance
- Phases accepted: Blank, L, S, Sg, SG, AMPL, AML, AMP and IAML (standard)

Body wave magnitude mb:

- Period range: 0.2 s < T < 3 s
- Distance range: TEST(113) < distance < 100°, before version 10.5 the lower distance was TEST(57)
- Depth range is handled by the attenuation function, SEISAN has two attenuation functions TEST(108) is used to specify which one is used. Default TEST(108) is 0 the Gutenberg and Richter (1956) attenuation function as recommended by IASPEI.
- Phases accepted: Blank, P, AMPB, AMB, AMPb, AMb, AMP, IAmb (standard)

Surface wave magnitude Ms (Ms_20):

- Period range: T > 10 s
- Distance range: TEST(114) ≤ distance ≤ 160°, before version 10.5 there was no distance limits. TEST(114) is 20° by default
- Depth < TEST(115), before version 10.5 there was no depth limit. TEST(115) is 60 km by default
- Phases accepted: Blank, AMPS, AMS, AMP, IAMs_20 (standard)

Broad band body wave magnitude mB (mB_BB):

- Period range: 0.2 s < T < 30 s
- Distance range: TEST(113) < distance < 100°, before version 10.5 the lower limit of distance was TEST(57). TEST(113) is 20° by default
- Depth: All depths values are accepted.
- Phases accepted: IVmB_BB

Broad band surface magnitude MS (Ms_BB):

- Period range: 3 s <T < 60 s
- Distance range: 2° ≤ distance ≤ 160°
- Depth < TEST(115), before version 10.5 there was no depth limit. TEST(115) is 60 km by default
- Phases accepted: IVMs_BB (standard)

Several parameters used for magnitude determination is controlled by the TEST values set in the STATION0.HYP (local events), STATIOND.HYP (distant event) or other model dependent STATION file. See the HYP chapter 7.1 for default TEST values. The above values are:
TEST(57) 1500km
TEST(113) 20°
TEST(114) 20°
TEST(115) 60 km

The underlined values are hardcoded in SEISAN.

Example showing mb, mB, Ms and MS amplitude and period readings with estimated magnitudes, on the BSD station respectively:

```
 In old Nordic:

 2015 1117 0710 30.8 D  39.919  20.421136.3  DNK 21 0.6 6.5sDNK 6.1SDNK 5.8bDNK1
 STAT SP IPHASW D HRMM SECON CODA AMPLIT PERI AZIMU VELO AIN AR TRES W  DIS CAZ7
 BSD  HZ  IAmb     714 18.53       194.3 0.98                            1739 348
 BSD  HZ  IVmB_BB  714 14.54      2995.7 3.96                            1739 348
 BSD  HZ  IAMs_20  722 15.83     97917.0 18.0                            1739 348
 BSD  HZ  IVMs_BB  722 13.06     43913.8 12.3                            1739 348

 In new Nordic2:

 2015 1117  710 30.8 D  39.919  20.421136.3  DNK 210.60 6.5sDNK 6.1SDNK 5.8bDNK1
 STAT COM NTLO IPHASE   W HHMM SS.SSS   PAR1  PAR2 AGA OPE  AIN  RES W  DIS CAZ7
 BSD  HHZ DK00  IAmb       714 18.530  194.3  0.98 DNK pv              1739 348
 BSD  HHZ DK00  IVmB_BB    714 14.540 2995.7  3.96 DNK pv              1739 348
 BSD  HHZ DK00  IAMs_20    722 15.83097917.0  18.0 DNK pv              1739 348
 BSD  HHZ DK00  IVMs_BB    722 13.06043913.8  12.3 DNK pv              1739 348

Hyp output:
 BSD  HZ    dist:    1740.0   amp:         194.3 T:   1.0   mb =   5.4
 BSD  HZ    dist:    1740.0   amp:        2995.7 T:   4.0   mB =   5.7
 BSD  HZ    dist:    1740.0   amp:       97917.0 T:  18.0   Ms =   6.0
 BSD  HZ    dist:    1740.0   amp:       43913.8 T:  12.3   MS =   6.1
```

5.1.5 Catalog and database work

Once a large database has been created, several programs are used to manipulate and analyze the data. The catalog can be searched for a large number of parameters. Selection criteria are: Magnitude range, magnitude types, event types (e.g. local, distant, volcanic, explosion), latitude, longitude and depth range, RMS of travel time residuals, number of stations used in the location, felt events, number of polarities, presence of certain stations etc. Events can also be selected in an area with the program used for hypocentral plots. SE has an even more sufisticated search facility

A very useful source of data is the ISC. Data from ISC CD ROM's can be read and converted to SEISAN format (hypocenters and phase data) and put into a database. However CD's are little used now and a better way is to download the data in ISF format (soon ISF2 format) and convert to SEISAN with IMSNOR. The data can then be used for e.g. seismic hazard, fault plane solution or it can be relocated. A general task with catalogs is to homogenize magnitudes. Magnitude relations between e.g. Mb and Ms or Ms from one agency to Ms from another agency can be done with the program MAG. The program will also convert one magnitude to another once the linear regression has been determined. Hypocenters from different agencies can be compared with COMPARE_HYP. This program can also be used to compare hypocenters and magnitudes from two files containing the same events but eg located with different models.

Event statistics can be made with STATIS and b-values calculated with BVALUEi (good functioon for that also in SE). The number of events as a function of time is plotted with CATSTAT.

5.1.6 Seismic hazard

Probabilistic earthquake hazard computations is done, using the EQRISK program (McGuire, 1976) or the CRISIS2012 program (Ordaz, 1991, 1999). EQRISK computes seismic hazard in terms of probabilities of exceedence vs earthquake intensity measures such as peak ground acceleration (PGA), for a given site or a grid of sites for up to eight different return periods. The site amplification is calculated with the SPEC program. This is used for making spectra of many seismic signals in a semiautomatic manner. The program is intended for two purposes: (1) making relative spectra for a series of pairs of stations terminated by the average spectra, (2) Making a series of spectra for a number of stations and events. The spectra can be corrected for distance, q, and instrument response.
This section involves a large number of programs and a more detailed description is given in section 33.

5.2 Getting data into the database

The first requirement for interactive work with the event editor EEV or SE is to get the data into the database.

There are two ways to get data into the database, as described in section 5.2.1 and 5.2.3. It is of course possible to make the individual S-files directly in the REA directories with the editor. This would be rather slow, and be against the philosophy of the system. However, it is mentioned in order to point out how simple the database structure is.

The SEISAN system can be used with or without digital data, the only difference to the directory structure is that the WAV and CAL directories are present when using digital waveform data. However the way of getting data into the database differs in the two cases and will be described separately.

5.2.1 System with digital data

This means that the original data is individual digital event waveform files generated by some data acquisition system. The waveform data can be stored in SEISAN, MiniSeed, GSE and SAC format as single or multi trace files. The files that are used in conjunction with the database are normally stored in WAV but can also be in the user's directory, e.g. WOR. The normal scenario would be that multiplexed files would be transferred from a digital field station, demultiplexed and converted to SEISAN or other waveform format, preferably MiniSeed. Programs are provided to convert from most of the popular waveform formats like MINISEED, GSE and from commercial recorders. It is most practical to initially put the files in WOR, check the events for false triggers, save the true events in WAV, make the corresponding S-file and a hardcopy of the digital data.
All of this can be done with the program MULPLT. The program plots channels from a single waveform file. The user can then interactively decide if this is an event to keep, in which case an S-file is created in the database and the event is moved to WAV.

Alternatively, all new waveform files can be auto-registered into the database (AUTOREG) and all checking takes place from EEV or SE.

When digital data is the input to the analysis system, MULPLT is the program to use to get data into the database. From there on further analysis can be done with EEV (picking phases, locating and editing). MULPLT is also the program used with EEV. For more details on MULPLT, see detailed description in section 8.

Metadata: SEED or dataless SEED

See also chapter 2.2.3.
To get SEED or dataless SEED metadata into a SEISAN database, you need the RDSEED program from GitHub. SEISAN include an old version of RDSEED, find the newest at:
`https://github.com/iris-edu-legacy/rdseed` See also End of Life Notice from IRIS: `https://ds.iris.edu/ds/nodes/dmc/software/downloads/rdseed/`

First you need to extract the Staion information from the SEED or dataless SEED file, use the command:
`rdseed -S -f <file>`

Then you need to extract the response information from the SEED or dataless SEED file, use the command:
`rdseed -R -f <file>`

Now you must list the response file, use the command:
`dirf RESP.*`

Then you run the program RDSEED2SEISAN, this program give a output file `rdseed.STATION0.HYP` with station coordiantes that you can add to your STATION0.HYP file in the DAT folder. And it gives a output file `rdseed.SEISAN.DEF` with `ARC_CHAN` lines that can be added to you SEISAN.DEF file in DAT, if you wish to store the data in an archive (e.g. BUD or SCP).

Finally you must move the RESP file to the CAL folder.

Waveform data: SEED or miniseed data

To get SEED or miniseed waveform data into a SEISAN database, you need the RDSEED program from IRIS (see URL above). And the DATASELECT program from IRIS if you wish to use an archive for the data:
`https://seiscode.iris.washington.edu/`

First you need to extract the miniseed data from the SEED, use the command:
`rdseed -o 4 -f <file>`

Then you need to send the data to the archive defined in the SEISAN.DEF file.
This is done using the program DATASELECT that you need to download from: `https://seiscode.iris.washington.edu/projects/dataselect/wiki`
An older version of DATASELECT is found in the SUB folder.
For a SeiscomP archive, use the command for waveform data:
`dataselect -A archive-path/%Y/%n/%s/%c.D/%n.%s.%l.%c.D.%Y.%j mini.seed`
For other types of data use: E:Detection data, L:Log data, T:Timing data, C:Calibration data, R:Response data, O:Opaque data. See `http://www.seiscomp3.org/doc/jakarta/current/apps/slarchive.html`. For a BUD archive, use the command:
`dataselect -BUD archive-path mini.seed`
Where `archive-path` must be the same path as `ARC_ARCHIVE` that is defined in `SEISAN.DAT`.

To plot the archived waveform data use the command textttarc in eev, before you call MULPLT

5.2.2 Instrument response

The response information gives the gain of a channel in counts/m and to get the correct ground displacement, the count values must be divided by the response values.

The response files can be located in CAL, or, if many files are available optionally also in a subdirectory structure.

The response files can be generated with RESP. Response files can also be imported in SEED format and SAC format can also be used.

For details, see section 41

5.2.3 System without digital data

In this case the user would get phase data from other sources, e.g. analog seismograms or files with readings from other stations and agencies. These files are assumed to be written in Nordic Format. Conversion can be done from other formats like ISC, NEIC and HYPO71.

If a user already has a file with one or several events in Nordic Format, this file can be split up into single files which are copied (from any directory) into the database by using the command SPLIT. Creating a new file in Nordic Format can also be done with the program NEWEVE (use command NEWEVE).

The SPLIT program then reads the NEWEVE output file and writes out single S-files with correct names either in the current directory (default) or in the database specified (BER or another). The reason that the database specifically must be given is that the user should not accidentally put data into the database (see section 13).

5.2.4 Getting data from ISC into SEISAN

ISC provides access to its data via the web page www.isc.ac.uk. SEISAN has facilities for converting ISC output from either the bulletin data base which contains all data (readings etc) or just the catalog which just has the main information corresponding to the SEISAN header line.

Search complete ISC bulletin

Go to Search the ISC Bulletin/Bulletin search Select criteria, like area, time etc. Note that if phase output is chosen, too much data could result and not all is output, so do not choose too much data. You now see output on the screen like

Search summary:
Database: ISC Bulletin
Search type: Global search
Start date: 2014-03-31 00:00:00
End date: 2014-03-31 02:00:00
Events found: 98

```
DATA_TYPE BULLETIN IMS1.0:short
ISC Bulletin
Event 604511947 Morocco

   Date       Time        Err   RMS Latitude Longitude  Smaj  Smin  Az Depth   Err Ndef Nsta Gap  mdist
2014/03/31 00:01:58.20   2.96 0.710  33.3883   -5.0333  27.8  24.0 158   0.0f        23      305   4.52
 (PRXIMO)
2014/03/31 00:01:58.22   0.82 1.030  33.3370   -4.9830   5.7   4.0  73   1.2   5.5   25      122   0.31
2014/03/31 00:01:59.20   1.07 0.400  33.3270   -4.8900   5.0   2.4  73  31.0f        25   17 152   0.57
2014/03/31 00:01:56.55   1.17 1.752  33.4408   -4.8850 5.539 3.543  86   8.1  10.2   68   41  80   0.43
 (#PRIME)

Magnitude  Err Nsta Author      OrigID
mb     3.3 0.3    5 MDD       07221203
ML     2.0           INMG      07894096

Sta     Dist  EvAz Phase        Time      TRes  Azim AzRes   Slow   SRes Def   SNR       Amp   Per Qual
CZD     0.43 197.8 Pg       00:02:05.057   0.1                          T__                        __
CZD     0.43 197.8 Sg       00:02:09.642  -1.0                          T__                        __
MD31    0.58 169.5 Pg       00:02:08.037   0.2                          T__                        __
MD31    0.58 169.5 Sg       00:02:14.202  -1.2                          T__                        __
MDT     0.67 159.5 Pg       00:02:09.692   0.3                          T__                        __
MDT     0.67 159.5 Sg       00:02:16.808  -1.3                          T__                        __
RSA     1.64 331.9 Pb       00:02:27.239   0.2                          T__                        __
```

Save the screen output in a text file by copying and pasting using e.g. notepad or vi. In this example we put it into file isc.txt but it could be any name. With some browsers, there might be an option to copy directly to a text file. The default format on the screen is the IMS1.0 short format which is the same as the IASPEI seismic format. There will soon be a more extensive ISF format called ISF2 which also contains componenes. This can be used by the program IMSNOR. SEISAN cannot read QuakeML format directly but QuakeML can be converted to Nordic format (old) with QML2NOR.

Convert with program IMSNOR:

The previous program used is NORIMS, still included, but it does not make as complete conversion as IMSNOR and it does not convert isf2. Details of IMSNOR is found in the section on conversion programs.

Search for events only

An event catalog is available under Bulletin seach/Event catalog. The criteria is much the same as above but the output format is different. SEISAN only supports CSV format. The following shows an example output.

Search summary:
Database: ISC Bulletin
Search type: Global search
Start date: 2014-03-31 00:00:00
End date: 2014-03-31 01:00:00
Events found: 37

```
DATA_TYPE EVENT_CATALOGUE
ISC Bulletin
--EVENT--|--------------------ORIGIN (PRIME HYPOCENTRE)-------------------|------MAGNITUDES-----...
  EVENTID,AUTHOR   ,DATE      ,TIME       ,LAT     ,LON      ,DEPTH,DEPFIX,AUTHOR   ,TYPE  ,MAG
604511947,ISC      ,2014-03-31,00:01:56.55, 33.4408,  -4.8850,  8.1,      ,MDD      ,mb    , 3.3,INMG
606581842,JMA      ,2014-03-31,00:02:31.30, 37.0400, 140.5100,  8.0,      ,JMA      ,M     , 1.6,
606581843,JMA      ,2014-03-31,00:03:45.10, 34.0400, 135.3200,  7.0,      ,JMA      ,M     , 0.5,
608276337,ROM      ,2014-03-31,00:04:01.93, 42.7815,  12.5628, 10.2,      ,ROM      ,ML    , 1.2,
607475289,ATH      ,2014-03-31,00:08:47.54, 38.4053,  21.9940,  7.8,      ,ATH      ,ML    , 1.4,
608873452,ISK      ,2014-03-31,00:09:47.90, 37.0850,  36.7560,  5.4,      ,ISK      ,ML    , 2.2,
607122021,TRN      ,2014-03-31,00:12:09.08, 17.4540, -61.9990, 24.4,      ,TRN      ,MD    , 2.7,
608276338,ROM      ,2014-03-31,00:12:55.66, 38.0828,  15.0768, 10.8,      ,ROM      ,ML    , 1.4,
606581844,JMA      ,2014-03-31,00:21:07.70, 35.5700, 139.3500,114.0,      ,JMA      ,M     , 2.1,
606442363,NNC      ,2014-03-31,00:23:17.31, 43.1481,  78.3658,  0.0,      ,NNC      ,mpv   , 2.5,
608276339,ROM      ,2014-03-31,00:23:35.47, 43.5047,  12.3582,  8.9,      ,ROM      ,ML    , 1.5,
606581845,JMA      ,2014-03-31,00:24:13.50, 35.6600, 140.9700, 18.0,      ,JMA      ,M     , 3.4,
607764104,RSNC     ,2014-03-31,00:25:32.90,  6.8670, -73.3360,122.0,      ,RSNC     ,ML    , 2.3,
607475290,ATH      ,2014-03-31,00:26:19.97, 38.1553,  20.3230,  6.2,      ,ATH      ,ML    , 1.7,
606581846,JMA      ,2014-03-31,00:26:37.90, 35.6500, 140.9600, 17.0,      ,JMA      ,M     , 2.1,
608276340,ROM      ,2014-03-31,00:26:58.27, 44.2772,  10.7885,  7.8,      ,ROM      ,ML    , 1.6,GEN
609917823,WEL      ,2014-03-31,00:27:07.25,-39.0091, 176.1862, 63.9,      ,WEL      ,M     , 2.6,WEL
606480609,TAP      ,2014-03-31,00:29:40.18, 25.0880, 121.7750,134.4,      ,TAP      ,ML    , 2.4,
607475291,ATH      ,2014-03-31,00:30:29.77, 38.3278,  20.4308, 10.2,      ,ATH      ,ML    , 1.4,
609526285,NNC      ,2014-03-31,00:30:40.55, 43.4595,  82.6685,  0.0,      ,NNC      ,mb    , 3.0,NNC
608481909,OTT      ,2014-03-31,00:34:19.87, 48.1538, -71.3242, 18.0,TRUE  ,OTT      ,MN    , 2.2,
609917824,WEL      ,2014-03-31,00:38:17.91,-39.4474, 175.7489, 18.5,      ,WEL      ,M     , 1.6,WEL
606581847,JMA      ,2014-03-31,00:39:38   , 28.2000, 129.5200, 19.0,      ,JMA      ,M     , 1.6,
606581848,JMA      ,2014-03-31,00:39:46.80, 36.9200, 141.4200, 35.0,      ,JMA      ,M     , 3.0,
606480610,TAP      ,2014-03-31,00:41:09.35, 23.9710, 122.2890, 27.9,      ,TAP      ,ML    , 2.2,
609085866,HEL      ,2014-03-31,00:41:42.30, 67.8960,  20.1110,  0.0,TRUE  ,HEL      ,ML    , 1.3,
606480611,TAP      ,2014-03-31,00:43:32.19, 23.8510, 120.9700, 14.6,      ,TAP      ,ML    , 0.8,
606581849,JMA      ,2014-03-31,00:45:43   , 36.6800, 140.6700, 10.0,      ,JMA      ,M     , 2.9,
607122022,TRN      ,2014-03-31,00:50:15.59, 17.4570, -61.2240,  8.2,      ,TRN      ,MD    , 3.2,
604374637,NEIC     ,2014-03-31,00:54:02.52, 36.8190, -97.6002,  5.0,      ,TUL      ,ML    , 2.7
604400815,ISC      ,2014-03-31,00:54:46.13,-32.9133,-178.5392, 35.0,TRUE  ,IDC      ,mb    , 4.6,IDC
606581850,JMA      ,2014-03-31,00:55:13.90, 40.2200, 141.7400, 18.0,      ,JMA      ,M     , 0.9,
608276341,ROM      ,2014-03-31,00:56:12.26, 43.4783,  12.4072,  8.5,      ,ROM      ,ML    , 0.7,
605641204,ISC      ,2014-03-31,00:58:01.66, 33.9061,-117.9448, 16.3,      ,ANF      ,ML    , 2.4,PAS
608276342,ROM      ,2014-03-31,00:59:45.31, 43.3403,  12.5418,  9.4,      ,ROM      ,Md    , 1.5,
609849728,NEIC     ,2014-03-31,00:59:50.25, 33.9112,-117.9444, 16.9,      ,PAS      ,ML    , 2.3
606581851,JMA      ,2014-03-31,00:59:53.90, 37.5100, 141.3500, 37.0,      ,JMA      ,M     , 2.2,
```

```
STOP

International Seismological Centre
Pipers Lane, Thatcham, Berkshire
United Kingdom RG19 4NS
+44 (0)1635 861022, voice; +44 (0)1635 872351, fax
admin isc.ac.uk, e-mail
```

Save the output in a text file like above, here we use isc.csv, but it can be any name. Convert to SEISAN with program ISCCSV2NOR

```
C:\seismo\WOR>isccsv2nor
 Input file
isc.csv
 Number of events          37
 Output file name is csvnor.out
```

The output file has this content

```
 2014 0331 0001 56.5 L  33.440  -4.885  8.1  MDD        3.3bINM 2.0L           1
 2014 0331 0002 31.3 L  37.040 140.510  8.0  JMA        1.6                    1
 2014 0331 0003 45.1 L  34.040 135.320  7.0  JMA        0.5                    1
 2014 0331 0004 01.9 L  42.781  12.562 10.2  ROM        1.2L                   1
 2014 0331 0008 47.5 L  38.405  21.994  7.8  ATH        1.4L                   1
 2014 0331 0009 47.9 L  37.085  36.756  5.4  ISK        2.2L                   1
 2014 0331 0012 09.0 L  17.454 -61.999 24.4  TRN        2.7D                   1
 2014 0331 0012 55.6 L  38.082  15.076 10.8  ROM        1.4L                   1
 2014 0331 0021 07.7 L  35.570 139.350114.0  JMA        2.1                    1
 2014 0331 0023 17.3 L  43.148  78.365  0.0  NNC        2.5p                   1
 2014 0331 0023 35.4 L  43.504  12.358  8.9  ROM        1.5L                   1
 2014 0331 0024 13.5 L  35.660 140.970 18.0  JMA        3.4                    1
 2014 0331 0025 32.9 L   6.867 -73.336122.0  RSN        2.3L                   1
 2014 0331 0026 19.9 L  38.155  20.323  6.2  ATH        1.7L                   1
 2014 0331 0026 37.9 L  35.650 140.960 17.0  JMA        2.1                    1
 2014 0331 0026 58.2 L  44.277  10.788  7.8  ROM        1.6LGEN 1.6l           1
 2014 0331 0027 07.2 L -39.009 176.186 63.9  WEL        2.6 WEL 2.8LWEL 2.6L   1
 2014 0331 0029 40.1 L  25.088 121.775134.4  TAP        2.4L                   1
 2014 0331 0030 29.7 L  38.327  20.430 10.2  ATH        1.4L                   1
 2014 0331 0030 40.5 L  43.459  82.668  0.0  NNC        3.0bNNC 2.8p           1
 2014 0331 0034 19.8 L  48.153 -71.324 18.0F OTT        2.2N                   1
 2014 0331 0038 17.9 L -39.447 175.748 18.5  WEL        1.6 WEL 1.8LWEL 1.6L   1
 2014 0331 0039 38   L  28.200 129.520 19.0  JMA        1.6                    1
 2014 0331 0039 46.8 L  36.920 141.420 35.0  JMA        3.0                    1
 2014 0331 0041 09.3 L  23.971 122.289 27.9  TAP        2.2L                   1
 2014 0331 0041 42.3 L  67.896  20.111  0.0F HEL        1.3L                   1
 2014 0331 0043 32.1 L  23.851 120.970 14.6  TAP        0.8L                   1
 2014 0331 0045 43   L  36.680 140.670 10.0  JMA        2.9                    1
 2014 0331 0050 15.5 L  17.457 -61.224  8.2  TRN        3.2D                   1
 2014 0331 0054 02.5 L  36.819 -97.600  5.0  TUL        2.7L                   1
 2014 0331 0054 46.1 L -32.913-178.539 35.0F IDC        4.6bIDC 4.8xIDC 4.1xIDC1
 2014 0331 0055 13.9 L  40.220 141.740 18.0  JMA        0.9                    1
 2014 0331 0056 12.2 L  43.478  12.407  8.5  ROM        0.7L                   1
 2014 0331 0058 01.6 L  33.906-117.944 16.3  ANF        2.4LPAS 2.3L           1
 2014 0331 0059 45.3 L  43.340  12.541  9.4  ROM        1.5d                   1
```

```
 2014 0331 0059 50.2 L  33.911-117.944 16.9  PAS        2.3L                    1
 2014 0331 0059 53.9 L  37.510 141.350 37.0  JMA        2.2                     1
```

This file is a compact file, however program SPLIT can also work on compact files if there is a need to put the data into a data base.

5.2.5 Getting data from USGS or EMSC into SEISAN, get_web_locations

Written by Terje Utheim, University of Bergen.

The purpose of this program is to download hypocenter information from international data centers. The program has now been implemented for USGS and EMSC.

The program downloads the data to a SEISAN data base in a Nordic format file in Nordic or Nordic2 format. The program downloads a file from the web site called
get_web_locations_EMSC.txt or get_web_locations_USGS.txt
from which it picks up relevant information for the S-file. The download might have data from several other sources which are entered into the S-file. The list of USGS sources can be found at
`https://earthquake.usgs.gov/data/comcat/contributor/`.
The source 'us' is translated into USG in the S-file but the others are left as they are, e.g. 'ak' is Alaska earthquake Center'.

The input magntude types from the text file are converted to SEISAN magnitude types as follows:

```
mb b
ML L
mB B
Ms s
MS S
MW W
Mc C
mw W
mww W
ww W
wr W
ml L
md C
```

The program has several options:

Set limits for minimum and maximum depths and minimum magnitude

Set time interval for download

Run once for the given parameters from command line

Run at given time intervals to always maintain the local data base. If a new location of the same event is found, the old event is replaced.

The program has no parameter files, all options are given as options on the prompt line.

```
Typing get_web_locations  -h the following options/info  are shown (platform dependent)

SEISAN_TOP.................................: /home/seismo

Valid program options, int is integer, float is a floating point number and text is an ascii string:

-h show this help info
-fm int     SEISAN format: 1-old, 2-new (default: 1)
-ag int     Agency to query: 0-USGS,1-EMSC (default: 0)
-loop int  1-loop forever, 0-one query (0=default)
-tsrt int minutes back, start-time.
```

```
                (Number of minutes to start from current time)
-tstp int minutes back, stop-time.
                Number of minutes to stop from current time. This should not
                be too close to real time in order for the data center
                to calculate the hypocenter. 50 minutes is a reasonable number.
                These two parameters are only used if the program runs
                continuously. The interval of looking for data is tstp-tsrt.
-mag float minimum magnitude
                The minimum magnitude to be included. The magnitude is the
                first found in case there are several types of magnitudes.
                If no magnitude is given, all magnitude events are used.
-mind text minimum depth (default: 0)
-maxd text maximum depth (default: 800)
-db text SEISAN database name, max 5 characters
-srt text start-time, format: 2018-02-20T03:45:00
-end text end-time, format: 2018-02-22T08:23:00
                Start and stop time for a one time extract. Cannot be used
                at the same time as tsrt and tstp.

To run the program in a continuous loop, the following parameters
MUST be specified:

-loop 1
-tsrt t1 (start time, number of minutes back in time)
-tstp t1 (stop time, number of minutes back in time)

Example 1: Collecting data continuously from command line:

get_web_locations  -loop 1 -tsrt 60 -tstp 55 -mag 3.0 -db TERJE

The program will query data from 60 minutes ago until 50 minutes
back in time from now.
The program will then sleep for 60 - 50 = 10 minutes and start again.
Minimum magnitude is 3.0 and the data is written to the data base TERJE.
It is created if not existing.

-srt and -end cannot be specified when running in loop mode.


The next lines are output from the program so that the
user can see the progress.

start_time: 2021-03-19T15:50:02
end_time  : 2021-03-19T15:55:02
web_agency: 0
web_agency: USGS
sleep 300  5



start_time: 2021-03-19T15:55:13
end_time  : 2021-03-19T16:00:13
web_agency: 0
web_agency: USGS
```

```
sleep 300  5

.
.
.
.
.
start_time: 2021-03-19T16:26:23
end_time  : 2021-03-19T16:31:23
web_agency: 0
web_agency: USGS
sleep 300  5



start_time: 2021-03-19T16:31:33
end_time  : 2021-03-19T16:36:33
web_agency: 0
web_agency: USGS
/home/seismo/sei11/REA/TERJE/2021 does not exist, create it
/home/seismo/sei11/REA/TERJE/2021/03 does not exist, create it
sleep 300  5

s-file generated

 2021  319 1633 14.8 D  -7.723 118.701 10.0  USG                          4.7bUSG1
 WEB event-id: us7000dl0y                                                       3
 LOCALITY: 81 km N of Bima, Indonesia                                           3
 ACTION:NEW 21-03-19 17:31 OP:SEIS STATUS:               ID:20210319163314     I
 STAT SP IPHASW D HRMM SECON CODA AMPLIT PERI AZIMU VELO AIN AR TRES W  DIS CAZ7



Example 2:" one time" data collections with no options

get_web_locations -db TEST -srt 2018-01-01T00:00:00 -end 2018-01-10T23:59:00



Example 3: Request events from EMSC, from a specific time-window,
magnitudes higher than 6.0, Nordic2 SEISAN format, database EMSC

get_web_locations -ag 1 -srt 2021-03-20T00:00:00 -end 2021-03-21T15:00:00 -mag 6.0 -fm 2 -db EMSC

SEISAN_TOP.................................: /home/seismo/sei11
web_agency: 1
web_agency: EMSC
/home/seismo/sei11/REA/EMSC_/2021/03 does not exist, create it

Response from EMSC in your current catalog temporary file get_web_locations_EMSC.txt.

#EventID | Time | Latitude | Longitude | Depth/km | Author | Catalog | Contributor | ContributorID | Ma
20210320_0000081|2021-03-20T09:09:46.5Z|38.52|141.55|60.0|EMSC|EMSC-RTS|EMSC|961496|mw|7.0|EMSC|NEAR EA
20210320_0000043|2021-03-20T05:19:31.3Z|-59.65|150.21|10.0|EMSC|EMSC-RTS|EMSC|961440|mw|6.1|EMSC|WEST O
```

```
Running eev:

eev 202103 EMSC

 2021  3 Reading events from base EMSC_  2
#    1 20 Mar 2021  5:19 31  D -59.650 150.210 10.0  N      6.1WEMC      ?
#    2 20 Mar 2021  9: 9 46  D  38.520 141.550 60.0  N      7.0WEMC      ? 1
#    1 20 Mar 2021  5:19 31  D -59.650 150.210 10.0  N      6.1WEMC      ? t

 File name: /home/seismo/sei11/REA/EMSC_/2021/03/20-0519-31D.S202103
2021  320  519 31.3 D -59.650 150.210 10.0  EMC                        6.1WEMC1
WEB event-id: 20210320_0000043                                             3
LOCALITY: WEST OF MACQUARIE ISLAND                                         3
ACTION:NEW 21-03-20 15:36 OP:SEIS STATUS:               ID:20210320051931     I
STAT COM NTLO IPHASE   W HHMM SS.SSS   PAR1  PAR2 AGA OPE  AIN  RES W  DIS CAZ7

#    1 20 Mar 2021  5:19 31  D -59.650 150.210 10.0  N      6.1WEMC      ? 2
#    2 20 Mar 2021  9: 9 46  D  38.520 141.550 60.0  N      7.0WEMC      ? t

 File name: /home/seismo/sei11/REA/EMSC_/2021/03/20-0909-46D.S202103
2021  320  9 9 46.5 D  38.520 141.550 60.0  EMC                        7.0WEMC1
WEB event-id: 20210320_0000081                                             3
LOCALITY: NEAR EAST COAST OF HONSHU, JAPAN                                 3
ACTION:NEW 21-03-20 15:36 OP:SEIS STATUS:               ID:20210320090946     I
STAT COM NTLO IPHASE   W HHMM SS.SSS   PAR1  PAR2 AGA OPE  AIN  RES W  DIS CAZ7

#    2 20 Mar 2021  9: 9 46  D  38.520 141.550 60.0  N      7.0WEMC      ? q




Example :  Continuous mode as cron job on a Linux system

The setup below will start every hour at 0 minutes in a bash environment
0  * * * * /home/seismo/get_web_locations/cron_restart.bash  2.0 MYDB 0 800 2 1 >/dev/null 2>&1

The setup below will start every hour at 0 minutes in a csh environment
0  * * * * /home/seismo/get_web_locations/cron_restart.csh  2.0 MYDB 0 800 2 1 >/dev/null 2>&1


The script files are in /home/seismo/get_web_locations

cron_restart.bash file


#!/bin/bash
rm -f /home/seismo/get_web_locations/prog.log
source /home/seismo/sei11/COM/SEISAN.bash
echo MAG: $1 DBASE: $2 MIN_DEPTH: $3 MAX_DEPTH: $4 START_HOUR: $5 STOP_HOUR: $6 AGENCY: $7 FORMAT: $8
start_time=‘date "+%Y-%m-%dT%H:%M:00" --date -$5hour‘
stopp_time=‘date "+%Y-%m-%dT%H:%M:00" --date -$6hour‘
echo $start_time
echo $stopp_time
```

```
cd /home/seismo/get_web_locations
/home/seismo/PRO/get_web_locations -mag $1 -db $2 -mind $3 -maxd $4 -srt "$start_time" -end "$stopp_time

The script expects the arguments in defined sequence:

arg.1 minimum magnitude
arg.2 SEISAN database, max 5 characters. If not existing it will be created
arg.3 minimum depth in km
arg.4 maximum depth in km
arg.5 start hour, for example 2, 2 hours back in time from now
arg.6 stop hour, for example 1, 1 hour back in time from now
arg.7 agency from where to send the request
arg.8 format, old or new SEISAN format.

The directory /home/seismo/get_web_locations is where data is downloaded and the
log written, can be any directory.

cron_restart.csh

#!/bin/csh
rm -f /home/seismo/get_web_locations/prog.log
source /home/seismo/COM/.SEISAN
echo MAG: $1 DBASE: $2 MIN_DEPTH: $3 MAX_DEPTH: $4 START_HOUR: $5 STOP_HOUR: $6 AGENCY: $7 FORMAT $8
set start_time=‘date --utc "+%Y-%m-%dT%H:%M:00" --date -$5hour‘
set stopp_time=‘date --utc "+%Y-%m-%dT%H:%M:00" --date -$6hour‘
echo $start_time
echo $stopp_time
cd /home/seismo/get_web_locations
/home/seismo/PRO/get_web_locations -mag $1 -db $2 -mind $3 -maxd $4 -srt "$start_time" -end "$stopp_time
```

5.3 Data base tools, security and backup

5.3.1 Database security

Duplicate ID:

Since the database consists of single files with names corresponding to time down to the second as well as the event type (L, R or D) it will sometimes happen that two events will get the same name. Thus copying in a new event with the same name could overwrite the existing event, and the user would never know. In SEISAN, from version 5.0, some security has been put in. New data can enter the database with 4 programs: SPLIT, EEV, MULPLT and AUTOREG. With all programs, the user will be prompted if a new event is about to overwrite an existing event. Both SPLIT and EEV have the possibility to create alternative ID's if the user wants both the new and old event, while MULPLT and AUTOREG just offers the possibility to skip a double event. If a new ID is created, an attempt will be made to use a time one second later. If that also corresponds to an existing event, the next second is attempted etc. This allows for 60 events to be registered in the database with the same minute and event type. If an event has got the ID changed, the header line in the file is NOT changed, however the ID line is of course changed. This will be indicated on the ID line with a 'd' at the end of the ID number.

Deleting events:

Event here means S-file in the database. Events are only deleted when using EEV, either with the EEV delete command D or the EEV append command A. In both cases, the deleted event is stored in the DELET database before being deleted from whatever database. Even if the system contains many databases, there is only one DELET database. This means that deleted events from different databases are mixed in DELET. In order to restore an event, enter DELET database with EEV and copy the deleted event back with the C

command. It is up to the user to manually clean up the DELET database.
There is one more final security. If an event has been deleted from a database, but an UPDATE has not yet been made, the event might be in the CAT part of the database and can be extracted by SELECT or the editor.

5.3.2 Data base tools, content and checks

Content of data bases, program BASE:

In the REA directory, a binary file called REA.LOG contains information about number of events in all data bases. Initially the file has no information, but each time programs EEV, HYP, UPD, CHECK_BASE or COLLECT are executed, the information is updated for the months accessed. The information can be displayed with program BASE, which first shows available data bases and the user, can then select one to get info for particular months. Make sure to use right case for data base names, always in upper case on Unix systems.

Check for data base related errors, program CHECK_BASE

The data base depends on error free S-files and that there is a correspondence between the S-file name and the event ID. This should normally be ok, however errors can occur during editing or there can be program crashed producing errors. The program reads the data base and checks for:

Missing ID lines: If ID line is missing, it can be put in with command us, doing an UPDATE, using UPD or command us in EEV.

No correspondence between ID line and S-file name: A serious error has occurred. Thsi can only be checked if using a daat base and not with a CAT file. Try to find out what is correct, the ID or the file name. An UPDATEi, UPD or us in EEV cures the problem, however data might be lost.

Missing type 1 of first line for event: Note that many programs reading from the data base will automatically correctt for this. So if a collect.out file is made, the 1 might be missing in the data base, but not in collect.out.

Error in S-file: All parameters are checked and files with non standard parameters are indicated. The error can be a number in a wrong position. The errors should be corrected.

Dulicate phase names: The phases are compared and events where two phases of type P or S that have the first two letters identical, will be flagged if from the same station. The 2.letter will be converted to upper case, e.g. Pg and PG will be considered the same phase.

For all the above cases, an index file is generated with bad S-files and EEV can the be used directly with the index file to access the bad S-files. THIS ONLY WORKS WITH ONE DATA BASE AT A TIME.

The program can also run on a single CAT file like collect.out. Since a CAT does not belong to a data base, it might no be possible to make an index file. The program will attempt to make an index file using the base name given as input to program and the ID lines for each event. If no ID line the origin time will be used. If data comes from another agency, this will mostly not work since the user might not have that data base. In that case, split the CAT file to some data base (also local) do the check_base on that.

It is recommended to run check_base in case of system crash or as a security, just before an UPDATE.

Example run:

```
c:\jens>check_base
Give file name or data base name, file name must have a .
Enter to search for all data bases

  Number of data bases          13
 DELET EMSC_ ISC__ JMI__ LICO_ LIGL_ LIGR_ LMK__ NSS__ RUND_ TEST_ TIR__ USGS_

  Base name(s), * is all, ,, is local, else, one pr line, return for no more
TIR

  Start time
2018
  End time, return for end of month
```

```
  Check data base (c) or only update statistics for program base(u)
c
  2018  1 Reading events from base TIR__  85
  2018  1 1 1356 26.8 L  39.965  19.726 5.10  TIR    .24 3.4LTIR         3.4LTIR1
  2018  1 1 2216 13.7 L  41.099  22.719 24.9  TIR    .37 3.5LTIR         3.5LTIR1
.
.
  2018  131 21 2 34.2 L  40.077  20.406 26.3  TIR    .20 1.7LTIR 2.7CTIR 1.7LTIR1

  Number of events without id-lines:                    0
  Number of events with wrong id   :                    0
  Number of events with missing type 1:                 0
  Number of events with other errors in file:           0


  Output file name is:                                 check_base.out
  Index file with events with no id lines:             index_no_id.out
  Index file with events with wrong id line:           index_bad_id.out
  Index file with events with wrong type 1:            index_no_type_one.out
  Index file with events with other errors in S-file: index_bad_s.out
```

5.3.3 Backup of S-file data base

The program collects all S-files in a given time interval for a given data base and optionally compresses the output file. The input is only from the prompt:

```
options: -start_time: time to start yyymmddhhmmss, at least yyyy,

                        if not given, use 1900

          -end_time  : time to end, if not given, use current time

          -base_name : data base, if not given use default data base

          -out       : directory ending with / where files are written

                       if not given, working directory is used

          -compress  : name of compress program, if blank no compression
```

If using all defults, the program will collect all data in the default data base from 1900 to the current date and write a file with a name like

backup-sfiles.TEST_.20230630090515

The program can be operated manually. However, it is intended to be used with a cron job to automatically backup an S-file data base. In COM, there is an example script to be used for a cron job, e.g.

```
#!/bin/csh
#
#  directory where backup_sfiles is running and backup
#  files are written by default
#
cd /home/seismo/backup_sfiles
```

```
#
#   define env variables
#
source /home/seismo/COM/SEISAN.csh
#
#  start backup_sfiles
#
/home/seismo/PRO/backup_sfiles -start_time 200201 -base_name ISC  >/dev/null
#
#  all in default data base compressed
#
#/home/seismo/PRO/backup_sfiles -compress gzip   >/dev/null
#
#
```

5.3.4 High accuracy in SEISAN

SEISAN can use higher accuracy than the default. The goal is to have an accuracy of 1 ms in time and 1 m in location.

In order to write out the high accuracy numbers, a new parameter has been added to `SEISAN.DEF`. The parameter is HIGH_ACCURACY. Setting it to 1.0 enables high accuracy operation. This parameter affects the programs MULPLT, FK, HYP and UPDATE.

Station locations: The station file looks like before except that in order to get higher accuracy of station locations, the minutes of latitude and longitude are specified without the point. E.g. the minutes 22.122 can now be written as 22122 in the same columns as before while if the point is given, only 2 decimals can be used as 22.12. This changes do not affect any old station coordinates. Programs reading station coordinates, will use high accuracy input if available.

EPIMAP will always read in high accuracy mode, if any high accuracy data is present, whether station locations or hypocenters.

FK will always read high accuracy station coordinates, if available and FK can therefore now be used with very small arrays.

Programs with output affected by high accuracy mode:

MULPLT will write the phase readings as f6.3 instead of f5.2 like e.g. 11.234 instead of 11.23. For normal use, this is not needed and the files look better if high accuracy mode is not used. In new Nordic format, Nordic2, seconds are always written with 3 decimals.

HYP and UPDATE writes an extra high accuracy hypocenter line which has been given type H. An example is

```
 1996  6 3 2006 35.5 D  46.787 153.722 33.0  TES 15 1.9 3.4STES 5.8BTES 5.6BPDE1
 1996  6 3 2006 35.511  46.78711  153.72245   33.011  1.923                    H

The format is
Column
1 -15      As type 1 line
16         Free
17         Seconds, f6.3
23         Free
24-32      Latitude, f9.5
33         Free
34-44      Longitude, f10.5
44         Free
45-52      Depth, f8.3
53         Free
54-59      RMS, f6.3
```

```
60-79       Free
80          H
```

5.4 Interactive work with earthquake locations, EEV command

The idea of SEISAN for interactive work is that the user should be able to easily jump from event to event and run several different programs with one event without restarting every time. This is done with the command EEV (see below). In this interactive mode, events are picked, edited, located, moved, deleted etc. until a satisfactory solution is found. In the interactive mode, NO UPDATING of the location in the permanent output CAT directory is done since it is too easy in interactive mode to accidentally change something. The permanent updating of CAT directories can only be done for one or several months at a time (see UPDATE command) in order to ensure that nothing is forgotten within a month. Thsi also updates the S-files. Updating single events can also be done in EEV.

Once the events have been updated, further work can be done (like searching for specific events or making a bulletin) using single programs which read directly from the database. Most of the analysis programs will also work without using the database structure that is e.g. searching in single file with many events. For more details of the analysis programs, see chapter 6.

5.5 How EEV works

It is now assumed that data has been entered into the database. The fundamental tool for the database is then the EEV program, which mostly works within the limits of one month in the standard database or with whatever the user has of S-files in his own directory. SE works in a similar way but with a graphical user interface. Optionally, EEV can also work with several months. A special option is to use a list of files in an INDEX file, see end of this section and SELECT program. Some of the commands available within EEV are also available within programs. See below for more details on EEV.

The EEV program reads the file names of all S-files in the database monthly directory (or local directory or index file), positions the pointer at the first event and asks for a command to be performed for the current event or to find another event. If the command is to use a program, control is handed over to that program, which on completion hands control back to EEV. In this way, many different independent programs can be used from within EEV, e.g. several different location programs can be installed.

Two people can wotk in the same directory with the same data base. This can potentially create a problem if working on the same event. When EEV starts, it will create a lock file eev.lock and when it closes, the file is deleted. If a lock file is found in the directory when eev starts up, a warning is given:

```
 **********************************WARNING************************************
 ** Another EEV user in same directory or EEV  was not properly terminated **
```

EEV can be started in several ways:

EEV with one month in default database: EEV yyyymm.
E.g. EEV 199201 would work on January 1992 on the standard BER database. It is here also possible to give a more precise start time like EEV 1992011520 to start with the first event at or after January 15 at 20 hrs.

EEV with one month in alternative database: EEV yyyymm BASE.
BASE is the database. To work on the NAO base, the command would be EEV 199201 NAO.

EEV with several months in default database: EEV yyyymm YYYYMM
yyyymm is start year and month and YYYYMM is end year and month.

EEV with several months in alternative database: EEV yyyymm YYYYMM BASE
yyyymm is start year and month and YYYYMM is end year and month.

EEV to work with events is local directory: EEV
Only the S-files in local directory will be used.

EEV to work with an index file: `EEV index.out`
EEV can work with an index file and the command would be `EEV index.out`, where `index.out` is the index

file name (can have any name as long as it contains a '.' except when used with HYP). For information on index files, see 11.

Databases can have 1-5 letter names and the user specify 1-5 letters. The real names in the directory structure are always 5 letters so if the user specifies e.g. a base name of BA, the real name will be BA___ . The full 5-letter name can also be used.

The commands in EEV mainly use only one letter unless a date or a number has to be given. To get a short explanation, type ? and you will get:

```
------------------------------------------------------------------------
 Help on EEV, all commands are given in lower case
 ------------------------------------------------------------------------

*** Basic commands

 Q:        Quit EEV
 ?         Print this help file

*** Navigation in EEV

 B:        Back one event
 #xx:      Go to event # xx, also works without the #
 Dxxxxxx:  Go to first event on date xx, hour xx, min xx
 Eyyyymm:  Let EEV session end with year yyyy and month mm
 Jyyyymm BAS:Jump to year yy and month mm in base BAS
 Sxxxxxx:  Search for next two events which are within xxxxxx seconds. If time
           is blank, a default of 180 secs is used
 SS:       Find next unprocessed event in base

*** Event information

 EP:       Edit print.out file from last location
 T:        Type event
 TT:       Type only header line of event
 W:        Show location of waveform files listed in s-file

*** File operation like copy, delete, email etc.

 Axx:      Append event # xx to current event, original event
           remains
 AA:       Append current event to next event, original event remains
 C:        Copy event to another data base or to current directory
 CM:       Copy out several events to eev.out
 D:        Delete current event, you will be prompted to confirm
 DM:       Delete many events, no backup
 DUP:      Duplicate current event in data base, different id
 EMAIL:    Send S-file as email as defined in SEISAN.DEF
 EMAILSUM: Send a summary email as defined in SEISAN.DEF
 NEW:      Add a new event to data base
 PRINT:    Print S-file on printer
 R:        Rename event type, must be L, R or D
 PUT:      Register event
 REG:      Register event
 US        Synchronize s-file name and ID with origin time
           and make an ID line if not there
```

```
*** File modification and edit, add data

 COMMENT:  Write comment lines in S-file
 COM:      Same as COMMENT
 COMF:     Add one or several felt information lines
 COML:     Add one geographical location line
 COMP:     Write province comment line in S-file
 COMT:     Write intensity comment line in S-file
 DD:       Duplicate header line in S_file
 DELS:     Delete specific phase lines in S-file, like P-phases
 E:        Edit S-file
 EXP:      Enter explosion information
 FIX:      Fix, unfix or set fixed depth
 FIXE:     Fix or unfix epicenter
 FIXO:     Fix or unfix origin time
 GEO:      Put in nearest geographical location with distance
 GXXXXX:   Get data from same event in data base XXXXXX like gISC
 GI:       Same as gISC
 GP:       Same as gPDE
 GE:       Same as gEMSC
 GU:       Same as gUSGS
 IC:       Insert comment as specified in SEISAN.DEF
 ID:       Change event type like P or E
 INPUTEPI: Input hypocenter and origin time in S-file from st. input
 INPUTONE: Input an additional type one line (hypocenter line)
 INPUTFPS: Input complete fault plane solution line
 INPUTMAG: Input 3. magnitude on header line
 IM:       --------------------------------
 IFP:      Input fault plane solution strike, dip, rake, Ag., Prog, Q.
 INPUTX:   Input of xnear and xfar, RESET TEST 107 must be 1.0
 M:        Input model indicator on header line
 MTD:      Delete all mt and synt lines
 MTE:      Edit MT parameters in S-file
 QUARRY:   Insert quarry info from quarry.dat in DAT
 STD:      Set or unset start location depth flag, also set depth
 STE:      Set or unset start location epicenter flag

*** Archive and waveform files

 ARC:      Add an archive line
 ARC _:    Add an virtual network archive line using the name given
           after the _ like: ARC _GSN
 ARCDEL:   Delete all archive lines
 ARX:      Extract waveform file from archive and put in S-file
 W:        Show location of waveforms listed in s-file


*** Hypocenter location

 EP:       Edit print.out filef from last location
 EH:       Edit hyp.out file --------------------
 GRID:     Locate by grid search
 GHYP:     Show Google map or Earth (or not) at each location with HYP
```

```
 FIX:       Fix, unfix or set fixed depth
 FIXE:      Fix or unfix epicenter
 FIXO:      Fix or unfix origin time
 H:         Locate with Hypoinverse
 HYPO71:    Locate with Hypo71 (linux only)
 INPUTX:    Input of xnear and xfar, RESET TEST 107 must be 1.0
 L:         Locate event, will also calculate magnitude if not
            locatable but distance is present, Hypocenter
 LR:        Reject outliers and locate, see also command UR
 LL:        Locate current and next event together
 Lxx:       Locate current and event xx together
 M:         Input model indicator on header line
 U(PDATE): Updates S-file with hypocenter etc.
 UR:        Reject outliers and update S-file with hypocenter etc.
 US         Synchronize s-file name and ID with origin time
            and make an ID line if not there


*** Plot signals and time sequece analysis

 P:         Plot event, also make hard copies and pic phases
 PO:        Plot event with defaults, multi trace mode
 POL:       Plot vertical channels P onset with polarities
 POO:       Plot event with defaults, single trace mode
 PB:        Plot Bouch synthetics
 PH:        Plot Herrmann synthetics
 PW:        Plot wkbj synthetics
 PM:        Plot moment tensor synthetics
 PD:        Plot extracted data file for moment tensor, mulplt.wav
 PG:        Ploty Greens's functions when doing MT
 QP:        Plot seismogram around P/S for quick inspection
 SAC:       Run SAC, Linux only

*** Plot epicenter

 GMAP:      Make epicenter map with Google Map
 MAP:       Make a map of current location with EPIMAP
 MAPF:      Makes a map like the MAP command showing fps if there
 MAPG:      Makes a GMT map like the MAP command
 MAPGF:     Makes a GMT map like the MAP command showing fps if there

*** Plot spectra, magnitudes vs distance, wadati, picture etc

 PMM:       Plot moment vs time
 PML:       Plot Ml vs distance
 PMR:       Plot magnitude residual vs distance, only Nordic2
 PP:        Plot picture file in PIC or in local dir
 PS:        Plot spectra and WA picks made with command AM
 PSPEC:     Same as PS
 RMSDEP:    Calculates and plots RMS as a function of depth
 WAD:       Make a wadati diagram
 PF(IT):    Get back azimuth and app. Velocity for network P-arrival, plot
 TTPLOT:    Make travel time plot
```

```
*** Automatic routines for picks, amplitudes and spectra

 AMPRATIO: Automatic amplitudes for ratio used with fps
 AR:       Same as above
 AUTOSIG:  Automatic processing with autosig
 AUTOMAG:  Automatic magnitude Ml and Mw, all defaults
 AM:       Same as automag
 AMI:      Automag with questions about window lengths
 AUTOPHASE Automatice phase picking with Lomax routine in AUTOPHASE
 AP:       Same as autophase
 Z:        Auto pic current event, if readings available, new pics
           will be added with a flag

*** Fault plane solution, plot, manipulation

 F:        Make a fault plane solution with FOCMEC
 F_OLD:    Old ------, before 2017
 FH:       Make a fault plane solution with HASH
 FI:       Make a fault plane solution with PINV
 FP:       Make a fault plane solution with FPFIT
 FPFIT:    -----------------------------------
 FO:       Plot all fault plane solutions, no questions, with polarities
 FOO       Plot all fault plane solutions, no polarities plotted or needed
 FM:       Plot moment tensor solution with mopad
 FQ:       Enter quality and position prime fps at top
 FD(IF):   Compare P and T axis from two different fps
 INPUTFPS: Input complete fault plane solution line
 IFP:      Input fault plane solution strike, dip, rake, Ag., Prog, Q.
 MAPF:     Makes a map like the MAP command showing fps if there
 MAPGF:    Makes a GMT map like the MAP command showing fps if there
 POL:      Plot vertical channels P onset with polarities

*** Moment tensor

 MTP:      Make Moment Tensor (MT) parameters
 MTG:      Make Green's function for MT
 MTI:      Invert for MT solution
 FM:       Plot moment tensor solution with Mopad
 MTD:      Delete all MT and synt lines
 MTE:      Edit MT parameters in S-file
 INVRAD:   Make moment tensor inversion with Invrad
 PM:       Plot moment tensor synthetics with original data
 PD:       Plot extracted data file for moment tensor, mulplt.wav
 PG:       Plot Greens's functions when doing MT

*** Synthetic seismogram and travel times

 BOUCH:    Run Bouchon's modeling program
 BOUSEI:   Make SEISAN file from Bouchon synthetic file
 HERRMANN: Run Herrmann's modelling program (not PC)
 HERSEI:   Make SEISAN file from Herrmann synthetic file
 IASP:     Generate arrival times using IASPEI91 tables
 SYNT:     Make parameters for synthetic modelling
 WKBJ:     Make synthetic seismograms with WKBJ program
```

```
*** Macroseismic information

 MAC:      Input macroseismic information
 MACROMAP: Make a GMT based map of felt information, Unix only
 EM:       Edit ISO file in ISO directory
 COMF:     Add one or several felt information lines
 COMT:     Write intensity comment line in S-file

*** Explosion information

 EXP:      Enter explosion information
 QUARRY:   Insert quarry info from quarry.dat in DAT

*** Other commands

 O:        Operating system command, e.g. ols is ls, ocd test is cd test
           do not currently work on command with prompt input like epimap and
           collect
 USERCOM:  Start user defined command as 'usercom -sfile <sfile-name> '
 TEST:     Start program TEST_PROG with s-file name as argument
 MODELS:   List MODEL.DEF file in DAT
 UP:       Update list of S-files in memory

*** end of file

 jh mar 10  2023
```

Note: Command letters can be upper or lower case.

Comments to commands:

#XXX : Go to event by number. When giving a number, only give the number of digits needed, no formatting. Thus e.g. to find event 7 or 777, write 7 or 777 respectively. If there is not an event corresponding to the parameter specified, EEV will go back to event #1. In the number command, # can be omitted.

Axxx: Append another event to current event. The event specified is appended to current event. All header and lines in both files are saved and put in order in the current event. The main first header is from the current event. The ID line for the appended event is saved as a comment line. The user will be questioned if the appended event is to be deleted.

AA: Same as above using next event.

ARC: Adds an archive line so event can be plotted, see SEISAN.DEF for defaults to set. Use 'ARC _VNET' (where VNET is an example of virtual network) to create ARC line with the virtual network.

ARC _: Adds an archive line for the virtual network name given after the _ like ARC _GSN for the GSN virtual network.

ARCDEL: Deletes all ARC lines in the S-file

ARX: Extract waveform file corresponding to S-file and adds thew waveform file name to the S-file. See program GET_ARC for details.

AMPRATIO or AR: Run program AUTORATIO 25 to measure P and S amplitudes to be used as amplitude ratios in FOCMEC and HASH.

AUTOSIG: Automatic processing with autosig program.

AUTOMAG and AM: Automatic amplitude for Ml and automatic spectral analysis. Only S-waves are used and fixed windows are used.The results are overwriting result in S-file. For more details see program AUTOMAG.

AMI: AUTOMAG, but questions about spectral window and window for Ml are asked. Type of spectrum (P or S) is also asked.

AUTOPHASE and AP: Automatic phase picking with Lomax picker.

AUTORATIO and AR: Automatically calculates amplitudes from spectra and time domain for use with FOCMEC.

B: Back one event

BOUCH: Run Bouchon's modeling program

BOUSEI: Make SEISAN file from Bouchon synthetic file

C: Copy events

There are two options, copy the event to another database given by a 1-5 letter name (upper case) or to a file EEV.OUT in your working directory. Several files can be extracted within one EEV session to the same EEV.OUT file. A new EEV session deletes the previous eev.out file. The C option can be used to recover files from the DELET database of deleted events. In addition to making the EEV.OUT file, an index file is also made called indexeev.out. THIS FILE IS NOT DELETED WHEN EEV STARTS UP since the intention is to be able to use EEV to make an index file of interesting events from several months. You can then start eev with the selected events with command EEV eevindex.out. Note: The other data base can also be a local data base ",," in which case EEV should not operate on the same local data base.

CM: Copy many files to eev.out. The copying starts at current file and the user is asked for the number of files to copy.

COMMENT: Comment are written into S-file, terminated by a blank line.

COM: Same as COMMENT

COMF: Add one or several felt information lines

COML: Add one geographical location line

COMP: Write province comment line in S-file

COMT: Write intensity comment line in S-file

DXXXXX; The D-command is used to jump to another event at a given date and time, normally only day is used: The hour can optionally be specified. E.g. d2205 will find the event nearest in time after day 22 at 05 hours. If both day and hour is used 4 digits MUST be given e.g. 0708. Highest accuracy is the nearest minute.

D: Delete event You are asked for confirmation. After the event has been deleted, all S-file names are read in again and all event numbers after the deleted event are therefore changed. **The deleted event is automatically saved in the DELET database**. If the event is present in the CAT file, it remains there until the next update is done, see UPDATE command in 14.

DM: Delete many events starting with the current event. The events are NOT backed up in DELET data basea .

DELS: Delete specific phase lines in S-file, like P-phases. This is the simplest way to delete large specific part of an s-file.

DD: Duplicates the header line

DUP: Duplicates an event in the database. The duplicated event has an ID, which is one second different from the original event. The command can be used to split an event in two and then manually deleting phase lines in each.

E: Edit the event. As default on Linux vi is used and on PC Notepad is used. The editor can be changed, see section 3. When control goes back to EEV, the file is checked for possible typing errors or other format problems. If a problem is encountered, the line with the problem is displayed with an indication of where the mistake might be, and the user is returned to the editor. Alternatively the error can be ignored. The file is also checked for missing ID and consistency between file name and ID. Problem: Some editors will keep a backup copy of the original file so 2 files might be present with one e.g. with the additional extension .BAK. EEV (from version 7.2) will only use the original file, but there is no check on what backup files might accumulate.

EM: Edit ISO file in ISO directory. The ISO file name must be listed in the S-file.

EMAIL: Send s-file as email using mailx program defined in SEISAN.DEF (variable MAILX COMMAND) (Linux only) for the addresses defined in SEISAN.DEF (variable ALERT EMAIL). The EMAIL command can optionally be used to perform a system command. The system command is defined in SEISAN.DEF variable EMAIL SYSTEM. If blank, no commands is executed. An example script below (Linux) is to send the S-file nor2nor2.out to a web ftp server:

```
#!/bin/bash
HOST=ftp.geo.edu.al
USER=seisan@geo.edu.al
PASSWORD=xxxxx
ftp -inv $HOST <<EOF
user $USER $PASSWORD
put nor2nor2.out
bye
EOF
```

IN SEISAN version before 12.0, the current S-file was sent. Now with 2 formats, the S-file is by default converted to Nordic format (the original format) so the same format (in nor2nor2.out file) is used whether the user is using Nordic or Nordic2 format. Noridc2 format can also be used by setting parameter ALERT_EMAIL_FORMAT to 2 in SEISAN.DEF.

EMAILSUM: Send summary of s-file as email using mailx program defined in SEISAN.DEF (variable MAILX COMMAND) (Linux only) for the addresses defined in SEISAN.DEF (variable EMAIL SUMMARY). An example is shown below:

```
Info sent by Departamenti i Sizmologjise (IGJEUM)
Magnitude:           1.6 ML
Date and time UTC:   2021-01-02 02:02:58
Location:            40.681 N  20.753 W
Depth:               5.8 km
Region:              4 km SE of Maliq
```

The Region is taken from the Locality: line. If a felt report is there it will be added from the FELTINFO: line. The region is put in with GEO command, see that.

The title in the header is from SEISAN.DEF parameter EMAIL_SUMMARY_TITLE.

The command can optionally generate an epicenter map and embed it into the email. To do so set parameter EMAIL_SUMMARY_MAP in SEISAN.DEF.

0: No map

1: map with EPIMAP (MAP command is used)

2: map with GMT (MAPG command is used)

In this case a different email command is used, set by parameter MAILX_COMMAND_MAP in SEISAN.DEF.

A typical example (Linux) is shown below:

mpack -s "Earthquake report" -d summary.out -c image/jpeg map.jpg From:alert.tir@gmail.com

Eartheqake report is the title, the summary file made by EEV is summary.out, the jpg image file is map.jpg and the From is to indicate an alternative sender, not needed if systems email is ok.

EEV genrates the PS file from MAP or MAPG and it is converted to jpg with hardwired command (in EEV, file `eev_sub.for` in the LIB folder) to make the map file map.jpg

gmt psconvert epimap.eps -Tj -Fmap

in case of epimap. So GMT must be installed, it is needed anyway for MAPG. For info on the geographical localities files used, see MAP and MAPG.

Eyyyymm: Giving this command will make the current EEV session end with year yyyy and month mm within the same data base. When EEV gets to the end of the month, pressing return will move EEV to the first event of the following month instead of to the first event of the same month.

EP: Edit the print.out file, useful to see what happens if something wrong with location or no location.

EXP: Input of explosion information. This command creates 3 new lines (see format description in Appendix A) and changes the main header line event type to explosion (E). The user is asked for location, time, charge and comments. The explosion agency is used to classify types of sites and can be used by SELECT for searching. If no event is available, a new event must be created with EEV command NEW.-

F: Make a fault plane solution. The program uses polarities. See section 23.1 for more details.

F_OLD: Use the old version of Focmec, before SEISAN version 10.6.

FO: Just plot a solution in S-file. It must have data so it can be located. Polarities are shown.

FOO: Plot solutions even if no phases in S-file. Polarities are not plotted.

FD: Calculate the difference in orientation of P and T axis of any two fps

FI: Fault plane solution using PINV

FH: Fault plane solution using HASH.

FP: Fault plane solution using FPFIT.

FM: Plot moment tensor solution with Mopad.

FQ: Enter quality of fault plane solution. It is also possible to order the solutions so the prime comes first.

FIX: Fix or unfix depth. It is also possible to give the depth.

FIXE: Fix or unfix epicenter

FIXO: Fix or unfix origin time

GMAP: Make an epicenter map of current event using Google Map. It is also possible to make maps with many epicenters using GMAP outside EEV, see section 10.5 for more details.

MAPG: Makes a GMT map like the MAP command using the GMT software.

GHYP: Show Google map or Earth (or not) at each location with HYP. The Google Earth option requires Google Earth to be installed and in the path.

GRID:. Hypocenter is started up and will ask for the grid: Latitude and longitude range and grid spacing. A maximum of 71 points can be used in each direction. The point with the lowest RMS is found and the corresponding location and residual is printed on the screen. It is now optionally possible to plot the contours on the screen. The map coordinates used are as defined in `SEISAN.DEF`. Note that the grid search is using exactly the same parameters as Hypocenter. This includes all weights and phase types. The depth is fixed to the depth given in the S-file header line. For more details and an example, see application note `epi.pdf` in INF.

GEO: Find the nearest location and calculates the distance and direction in terms of N, SE etc. The information can optionally be put into the Locality line in S-file. The locations are found in place_names.eev in DAT. It contains 256 global locations. You can put in your own instead. One can plot the place_names in Google Earth with the GMAP program.

GETXXXXX: Get data from same event in data base XXXXXX like gISC.

gi: short for getISC ge: short for gEMSC gu: short for gUSGS

The command searches the XXXXX data base for all events +/- minutes around the current event in EEC. The search window can interactively be increased or decreased. An event to be inserted in the the current events can then be selected by a number. Thre are several options for inserting:

Put in header line as #1 line: The header from the XXXXX data base file is overwrting the header in the current file and filename and ID are corrected accordingly, like if event was R and inserted event is D, then event becomes D. This option is intnded to be used when the user wants to fix the hypopcenter to an agency hypocenter in case not enough data is available to make a reliable solution. This is often the case for distant events. Use commands fix and fixe to fix hypocenter.

Put in header as line nr 2: This option is used when a reference hypoocenter and magnitude is recorded in file, e.g. from ISC.

Put in whole file: The file in EEV has the main header and all headers and phase lines are added from external event.

Put in whole file but delete duplicate phases. Duplicate phases are defined as having same phase name, station and component codes and to be within 0.1 s of the reference phase.

Put in whole file but weight out all inserted phases. This option allows the user to relocate and checking residual, decide which phase to include.

NOTE that to automatically obtain a SEISAN data base of EMSC or USGS hypocenters, the program get_web_locations can be used.

Below is an examaple. For each event time difference DT in minutes and distance DDIS in km is given.

```
#    4  1 Jan 2021  3:55 21  L  38.393  22.245 0.00    2.2  3.2LTIR   8  ? ge
 Window is  40 minutes
 2021  1 Reading events from base EMSC_  6818
------DT--DDIS-------------------------------------------------------------------------------
  1  -11 11615 2021  1 1  343 49.0 D -24.130 -67.420234.0  GUC                       3.2LGUC
  2   -2   926 2021  1 1  352 54.0 D  45.390  16.150 10.0  EMC                       3.6LEMC
```

```
  3    0    18 2021  1 1  355 20.2 D  38.380  22.030  9.0  EMC                        3.5LEMC
 EEV           2021  1 1  355 21.0 L  38.393  22.245 0.00  TIR  8 2.2 3.2LTIR 4.4WTIR
  4    7   964 2021  1 1  4 2 32.0 D  45.630  15.800 12.0  EMC                        2.3LEMC
  5    9 11082 2021  1 1  4 5 16.6 D  -0.190 124.460 55.0  GFZ                        4.6bGFZ
------DT--DDIS-------------------------------------------------------------------------------
 Chose one event number to include or increase(+) or decrease(-) window, enter to stop
3

 Following event is selected:
     2021  1 1  355 20.2 D  38.380  22.030  9.0  EMC                        3.5LEMC

 Options:
 Do nothing, return to EEV,              Enter
 Put in header line as #1 line:              1
 Put in header line as #2 line:              2
 Put in whole file                           3
 Put in whole file, delete duplicate phases: 4
 Put in whole file, weight out inserted ---: 5
```

H: Locate with Hypoinverse, no database update is made, no Nordic output format file.

HERRMAN: Herrmann's modeling programs, only on Sun, might work on Linux, not tested.

HERSEI: Make a SEISAN waveform file from output of Herrmann modeling, only tested on Sun.

IASP: Generate a file with theoretical arrival times for the current event for stations listed in S-file. . The command will only work if the event has an epicenter and origin time in header line or a subsequent type 1 line, see also HERSEI: Make a SEISAN waveform file from output of Herrmann modeling, only tested on Sun.

HYPO71: Locate with HYPO71. The database is not updated (not well tested on PC).

IASP: Generate a file with theoretical arrival times for the current event for stations listed in S-file. . The command will only work if the event has an epicenter and origin time in header line or a subsequent type 1 line, see also INPUTEPI and INPUTONE. These theoretical times will then be displayed with mulplt, the next time command P is used in EEV. The theoretical times are listed in file iasp.out. See section 30.4 for more information. The command can also be used directly from MULPLT and in this case theoretical travel times are calculated for all stations in waveform file(s).

IC: Enter one of predefined comments. The comments are given in SEISAN.DEF and any number of comments can be predefined. Example:

```
 7  1 Jan 2015 13:35 39  LQ 78.312   7.560 15.0    0.9 2.0LBER    8  ? ic
```

Predefined comments are:

---

1 Calculated depth is 0km, fixed to 10km due to uncertain depth
2 Calculated depth is 31km, fixed to 10km due to uncertain depth
3 Calculated depth is > 31km, fixed to 10km due to uncertain depth
4 Probable explosion due to spectrogram and waveform
5 Induced event rapported on lkab.com,
6 Probably explosion at Rana Gruber, Storforshei
7 Probably explosion at Titania
8 Probably explosion at Norsk Stein
9 Probably explosion at Slovaag, Sogn & Fjoradn
10 Probably explosion at Eikefet quarry

---

enter number

ID: Change the event id like E or P

INPUTONE: Makes an additional type one line (hypocenter line) in the file. Enter the data exactly under the columns indicated. The line will be entered exactly as written, so it is possible to enter any part of the information.

INPUTEPI: Works like INPUTONE, except that it overwrites information on the first header line if non-blank information is given. Use INPUTEPI to add information to the first header line like e.g. the depth. If existing nonblank characters on the line are to be replaced by blanks (e.g. remove a magnitude), use underscore "_".

INPUTX: Makes a comment line with xnear, xfar and start depth values. Note that RESET TEST(107) must be set for this option to work.

INPUTFPS: Input complete fault plane solution line

IFP: Input fault plane solution strike, dip, rake, agency, program used and quality of solutio.

INVRAD: Runs the moment tensor inversion program, see section 23.7.

Jyyyymm BAS: This command makes it possible to change month and database during an EEV session by giving a new year yyyy and month mm and optionally a new database BAS. If no database is given, the same database is assumed.

L: Locate event with HYPOCENTER (same as HYP). The location does not update the S-file.

LR: Reject outliers and locate. Outliers remain in file. Can be removed with command UR. see HYPOCENTER section for more details.

Lxx: Locate current event with event number xx. This is used to check if two events belong together.

LL: Locate current and following event together.

M: Input or remove model indicator on header lien.

MAC: Enter macroseismic information, you will be prompted for all information. For details of the type of information, see definition of Nordic format, Appendix A.

MACROMAP: Felt information is read from a file with macroseismic information and plotted with GMT. The file name of the file with macroseimic observations is given in the S-file.

MAP: Start EPIMAP program to produce a map of current location. If a location is given in the S-file, this location is plotted, otherwise the event is located if possible and the resulting location used for plotting. The parameters for generating the map are set in the `SEISAN.DEF` file (see 3.13).

MAPF: The same as MAP but in addion the first fault plane solution found in file will be plotted. Ther eis no requirement that there are polarities.

MODELS: Lists `MODEL.DEF` file in DAT that assigns names to single characters in `STATIONx.HYP` file.

MTP: Make Moment Tensor (MT) parameters, input wav file must tbe made first.

MTG: Make Green's function for MT. MTP first.

MTI: Invert for MT solution. MTG first.

MTD: Delete all mt and synt lines.

MTE: Edit MT parameters in S-file. A menu comes up and different parameters can be edited.

NEW: Creates a new event in the database. The user is asked to give date and time and the event is created in the current monthly database.

O: Give a command to the operating system. This is a very useful command, since it is possible to do almost anything without leaving EEV, including starting a new session of EEV !! E.g. the command ols on Sun and odir on PC would make a directory listing. The name and path of the current s-file is copied to a file named `eev.cur.sfile`, this makes it easy to write your own programs to handel seisan data.

PB: Plot Bouch syntheticsi, autimatic with MULPLT

PH: Plot Herrmann synthetics, ————————

PW: Plot wkbj synthetics, ————————-

PM: Plot moment tensor synthetics

PD: Plot extracted data file for moment tensor, mulplt.wav

PG: Plot Greens's functions when doing MT

PF or PFIT: Calculate the apparent velocity and back azimuth using the P-arrival times stored in the S-file. The calculation is done by a free standing program PFIT, which also can be called outside eev. It is assumed that the arriving wave can be approximated with a plane wave so this option is intended to be used with events which are far away relative to the size of the network which then can be considered a seismic array. The station coordinates are taken from the default station file and there is no correction for station elevation. When starting the pfit option, the user will be given a choice of reference station and maximum

distance from the reference station. Linear distances will then be calculated from the reference station and possible results will be associated with the reference station. All P-phases given as P, Pn, PN, Pg, PG, PKP, PB and Pb will be used and it is up to the user to ensure that the event file only contains the phases to be used. The output is displayed on the screen and the linear fit can be shown on a plot, which also can be used to interactively check individual station values, see example below.

Example run of PFIT

```
 Give reference station, enter for using first station in list
HYA
 Maximum distance from reference station, default is 1000 km

 2007  1 5 1652 23.3 D  55.991-159.065 13.5  BER 19 1.2 5.3SBER 5.5BBER 5.4BPDE

 Stations available: 18  Stations used: 14
 Stat      Delta t  Latitude Longitude         x         y
 HYA         0.000    61.165     6.182     0.000     0.000
 LOF       -44.970    68.132    13.541   394.668   774.733
 MOR8      -34.220    66.285    14.732   458.521   569.318
 NSS       -23.720    64.531    11.967   310.275   374.227
 MOL        -9.540    62.570     7.547    73.220   156.192
 DOMB       -6.840    62.073     9.112   157.158   100.965
 ASK         0.810    60.472     5.201   -52.618   -77.095
 RUND        4.060    60.414     5.367   -43.680   -83.581
 BER         4.820    60.384     5.335   -45.414   -86.880
 EGD         3.270    60.270     5.223   -51.403   -99.501
 ODD1        5.600    59.911     6.627    23.891  -139.457
 BLS5        9.920    59.423     6.456    14.712  -193.739
 KONO        9.630    59.649     9.598   183.221  -168.571
 SNART      18.280    58.339     7.210    55.130  -314.293

 Reference station is: HYA

 Back azimuth =358.8  Apparent velocity =19.81  corr =-0.99  rms =   0.03
```

Relative to the reference station, the above output gives relative P-times and relative x and y-coordinates (km). It is also seen that only 14 station were available within 1000 km from the reference station HYA. These results are also available in an output file `array.out`. See also array processing section 6.29 on FK-analysis.

PMM: Plot moment as a function of time. The values are taken from the SPEC lines. The intention is to get an idea if the attenuation is correct by seeing the trend. If the line has a negative slope, then the Q value is too and vise versa. On top of the plot the corresponding Q correction needed to make the moment distance independent is shown. It is calculated at a third of the corner frequency. This value is only an indication. On the plot it is possible to click on a symbold to get the corresponding channel used.

PML: Plot Ml as a function of distance. The plot can be used to judge any diance biars in the magnitude calculations. On the plot it is possible to click on a symbold to get the corresponding channel used.

PMR: Plot magnitude residual as a function of distance. The plot can be used to judge any diance biars in the magnitude calculations. On the plot it is possible to click on a symbold to get the corresponding channel used.

PUT: Register event. This option is mainly meant to be used with the SEISNET data collection system. The command cleans up the S-file for all SEISNET operations. It removes commented out ID-lines and copies the waveform files given for the event from the current directory to WAV. The command is equivalent to the register command in MULPLT. If events are auto registered with AUTOREG, the command can be used to clean up and inspect incoming data without using MULPLT directly.

P: Plot event with MULPLT

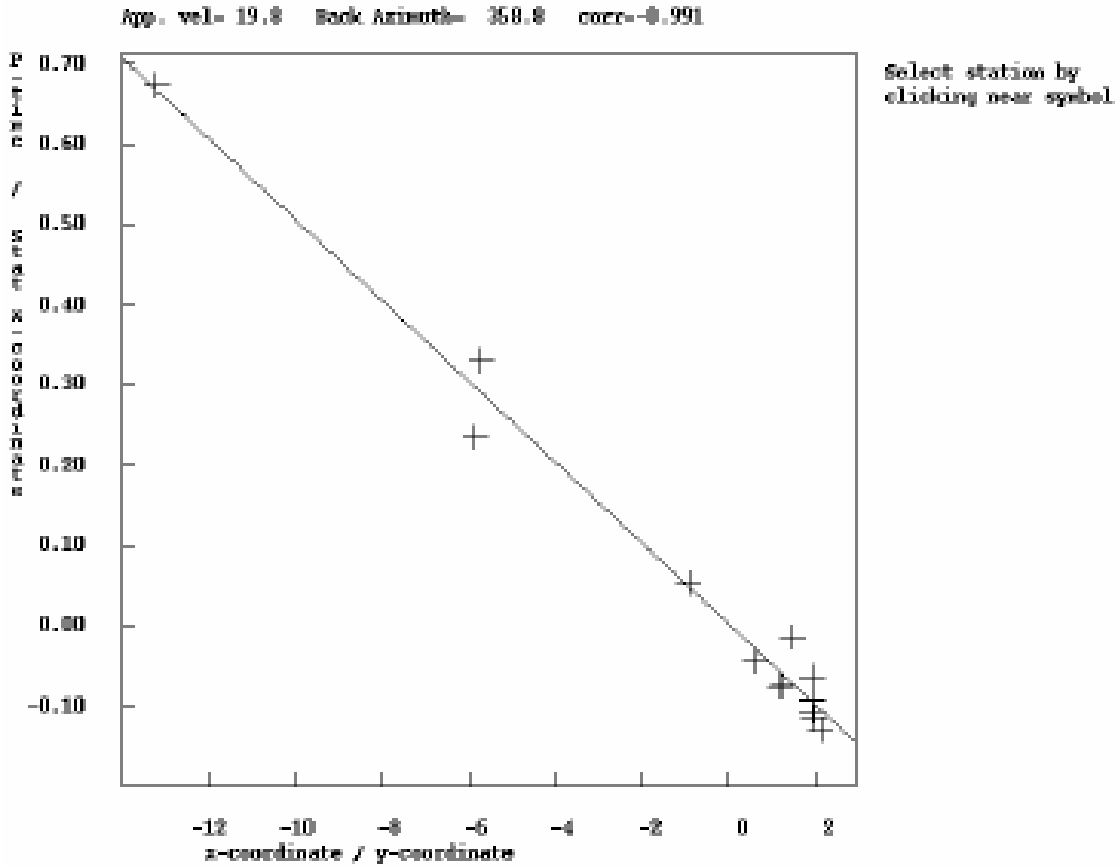


Figure 5.1: The linear fit of P-arrival times to a plane wave. For more details, see Havskov and Ottemöller (2010).

PO: Use MULPLT with defaults. This means that no questions will be asked and the plot appears in multi trace mode with default channels and default filters as given in the `MULPLT.DEF` file in DAT. Useful option for routine inspection of raw data.

POO: Same as PO with the difference that the user enters MULPLT single mode directly.

POL: Plot vertical channels P onset with polarities using program PLOTPOLARITY 24. The polarity picks can be chenged.

PP: Plot picture files with file names stored on type P-lines. The picture files must be in working directory or PIC directory. Several files can be defined in the S-file and the user will be prompted for which one to plot. The system command used for displaying the file must be defined in SEISAN.DEF, parameter PLOT_PICTURE_COMMAND bitmap types and PLOT_PDF_COMMAND for PDF files. An example is found for test event JUNE 3, 1996 at 19:55.

PRINT: The current S-file is printed on the default printer, to set up printer command, see `SEISAN.DEF` (section 3.13).

PS: Plot spectra and WA picks made with AM command. The bad fits that the user wants to deselect can be deleted interactively.

Q: Quit EEV

QP: Make a 'quick plot' to see short seismograms around phase picks using program PLOTPHASE. Picks can be changed, and filters can be applied. 24

QUARRYCHECK: Calculate distance between epicentre and quarry locations given in quarry.dat in DAT. If distance is less than maximum distance xx as given in quarry.dat, the quarry is listed. The file looks like this:

```
50.
 67.851   20.156 Kiruna (SWE), usual time 23:00
 67.630   20.990 Svappavaara, Kiruna (SWE)
 67.073   20.954 Gallivare (SWE)
 67.201   20.711 Gallivare (SWE)
 67.560   30.430 Kovdor (RUS)
```

The number 50 is the maximum distance.

After giving the command you get e.g. this:

```
      dist     lat      lon
#  1  16.8  60.852    5.078 Sloevaag (NOR)
#  2  40.7  60.547    4.988 Merkesvik (NOR)
#  3  47.3  60.704    5.559 Eikefet (NOR)
       Number to include in s-file, enter for none
```

It is now possible to select a site and put the info into the s-file as a comment.

REG: Same as PUT.

R: Rename event type - Giving an event a new type requires changing the header in the S-file and the S-file name. All this is done with R-command. You are prompted for a new type (can be the same in which case nothing is done). A new S-file is made and the old deleted. The CAT-file is NOT changed so if no UPDATE is done, the event there will remain with wrong type. Event types are L: Local event, R: Regional event and D: Distant event. Change events id - By adding a second charater to the event type the event id will be changed too. E.g. changing the event to a local explosion one must type LE. Use LB, lb or l_ to replace the E with a blank. Standard event id's are: E = Explosion, P = Probable explosion, V = Volcanic and Q = Confirmed earthquake

RMSDEP: Calculates and plots RMS as a function of depth for current event. Note: Program starts by reading STATION0.HYP so if current events uses e.g. STATION1.HYP, STATION0.HYP must be there also.

SAC: Convert all data to SAC format and starts the SAC processing system (not distributed with SEISAN, must be obtained separately), not on PC.

Sxxxxxx: Search for next pairs of events separated in time by xxxxxx secs (max 999999). If no value is given, 180 secs is used. The command is intended for finding events to be merged after putting together two different data sets with SPLIT. If a new time instead of the default 180 is entered, it will remain in effect for the whole EEV session. NOTE, that the search starts with the current event, so after using S, one return to go to the next event must be given to start a new search.

STE: Set or unset the start location flag for epicenter

STD: Set or unset the start location flag for depth. The dept can also be entered.

SYNT: Make parameters for synthetic modelling, similar format as used for MT.

SS: Find next unprocessed event in database. Events, which have status in ID line as follows: SPL: split with SPLIT program, HYP: auto-located with HYP, NEW: new event from EEV or ARG: registered by AUTOREG. The idea is that when new unprocessed data have entered the database by one of these programs, it should be easy for the operator to find the event. In EEV, an N near the end of the prompt line indicates an event with this status.

T: Type event.

TT: Type only header of event.

TEST: Start program TEST_PROG with the argument of the current file. The intention with this command is to simplify testing a program with events accessed by EEV. TEST then excutes the command 'test_proge current-sfile-name'

TTPLOT: The program reads P and S-arrival times from S-file and makes a travel time plots. The program is useful for checking readings, see section 30.4. The lines connect the computed first arrivals for P and S, respectively.

UPDATE or just U: Updates (overwrite) S-file with hypocenter, magnitudes, residuals etc. Note that the CAT file IS NOT UPDATED . This can only be done with stand-alone command UPDATE, see section 14.

UP: Update EEV event list. All S-file names are read in again. Is useful if data arrives during an EEV session, like when using Copy command from another data base.

UR: Reject outliers and update S-file with hypocenter etc. Outliers are removed. See Hypocenter section for more details.

US: Synchronize S-file name and ID with origin time. Will also make an ID line if not there.

USERCOM: Starts user defined program with command `usercom -sfile <sfile-name>`, where usercom is the command name. This command is useful for example if you want to start your program to create a report based on the S-file, from EEV. Note: the usercom is not a SEISAN program but a program named USERCOM which will look for the argument -sfile. See also command TEST.

W: Check if event has waveform files. If so, check in which directory they are if present on the system. The search will start in current directory, then WAV followed by all directories defined with keyword WAVEFORM_BASE in `SEISAN.DEF` in DAT.

WAD: The program reads the data for the event and then asks if all phases are going to be used or only phases of the same type like Pg and Sg. Ideally, only phases of the same type should be used, however in practice it might be interesting so see all data, it might give an idea about phase identification. The Wadati parameters will now be calculated and shown on the screen. Optionally a plot can now be made. The plot shows the Wadati diagram. On the left is shown all stations with corresponding S-P times. Any station on the plot can be identified with the cursor. Point the cursor near a symbol and click and the station data will be shown in the upper right hand corner. This facility is used to identify bad picks. The plot output file is called `wad_plot.eps`.

WKBJ: Make synthetic seismograms with WKBJ program. See program for details.

Z: Automatic phase picking. A waveform file must be present. See also the AUTO program section 21.

Below is shown a session with EEV on PC.

Example of using EEV for November 1993

```
eev 199311

1993 11 Reading events for base AGA          18
#    1  2 Nov 1993 17:06 48 L   60.443    4.512  2.0  1.5 N 1.8CBER    6  ?
#    2  5 Nov 1993 22:37 21 D                                          1  ?
#    3  5 Nov 1993 22:37 23 D                                          1  ?
#    4  5 Nov   93 22:39  2 L                                             ?
#    5  5 Nov   93 22:40 58 L                                             ?
#    6  7 Nov 1993 23:40 43 L   67.837   20.059 15.0  0.7  2.5CBER     7  ?
#    7  7 Nov 1993 23:43 17 L   66.307    6.919 31.0  1.4  3.1CBER     8  ? 17
#   17 19 Nov 1993 01:45 29 D   70.069  139.780   .1  0.1               7  ? t

File name: \seismo\REA\AGA__\1993\11\19 0145-29D.S199302
1993 1119 0145 29.0 D  70.069 139.780   .1  BER  7  .1                          1
                .19     999.9   821.9999.9   .3206E+06   .2536E+07   .2639E+08E
ACTION:UPD 97 03 25 21:28 OP:jh   STATUS:               ID:19931119014529     I
93111901.K41                                                                  6
  93 1119  153  6.5 D                                                         1
9311 19 0153 06S.NSN_09                                                       6
STAT SP IPHASW D HRMM SECON CODA AMPLIT PERI AZIMU VELO SNR AR TRES W  DIS CAZ7
KBS  SZ EP        151 54.8                                      13.4 0 3365 161
TRO  SZ EP        153 03.0                                        .010 4420 169
MOL  SZ EP        153 50.51                                       .010 5070 165
ASK  SZ EP        154 04.0                                        .010 5262 164
BER  SZ EP        154 05.0                                        .110 5274 165
EGD  SZ EP        154 05.5                                        .110 5285 165
KONO BZ EP   9    153 49.21                                     25.5 0 5413 167


#   17 19 Nov 1993 01:45 29 D   70.069  139.780   .1                    7  ?
#   18 21 Nov 1993 01:53 56 L   60.184    4.965 15.0  N 0.5  2.6CBER    11  ?
 1993 11 Reading events for base AGA          18
    1  2 Nov 1993 17:06 48 L   60.443    4.512  2.0     2.2  1.8CBER     6  ? q
```

In the above example (PC), the month has 18 events. For each event, vital information is displayed: Date, type, hypocenter, RMS, first magnitude and number of stations (number in S-file which might be larger than number used for location as given in S-file header line after a location). In this way the user can quickly search for events wanted and get important information without looking at all the details. The first event in the list is newly entered into the database as indicated with the N near the end of the line. In the above example, a return was made to go to next event until event #7 after which a jump was made to event 17. For this event, all parameter data was displayed with the 't' command. A return was made to event 18, another return and the event list was read in again and event #1 again became the current event. Note that not all events had a location.

Below are shown examples of the commands (C)opy, (D)ate, a(S)sociate and (A)ppend. Comment are preceded by '!' and written in bold. The database is EAF. The example use the old Nordic format.

```
EEV 199405 EAF

1994  5 Reading events for base EAF         613   ! the month has 613 events
#    1  1 May 1994  1:18  8 D                                              ?
#    2  1 May 1994 11:37  6 L                                              ?
#    3  1 May 1994 12:00 33 D   36.607   68.449 15.0  2.4    ! go to day 20 ? d20
#  366 20 May 1994  5: 2  8 R                                              ? c
                                          ! copy an event to working dir.
 Copy event: Other database, give 1-5 letter name
             Working directory in file eev.out: return

#  366 20 May 1994  5: 2  8 R                                            ?
#  367 20 May 1994 10:59 32 D      ! jump to 530                         ? 530
#  530 26 May 1994  8:55 11 D      ! look for time association            ? s

  549 27 May 1994  9:27 41 L                                        Associated
  548 27 May 1994  9:27  1 L       ! append to next event            ? aa
 Event #  549 appended to event #  548   Appended event still present
 Do you want to delete appended event(y/n=return)y   ! delete appended event

Backup copy saved as: \seismo\REA\DELET\1994\05\27 0927-41L.S199405 ! del. ev. save
Deleted file          \seismo\REA\EAF__\1994\05\27 0927-41L.S199405 ! app.ev. del.
1994 05 Reading events for base EAF         612    ! event list updated
#  548 27 May 1994  9:27  1 L                    ! jump to 222            ? 222
#  222 12 May 1994 23:28 10 L                    ! change event type      ? r

 Change event type to L,R or D ?r

New file       \seismo\REA\EAF__\1994\05\12 2328-10R.S199405
Deleted file:  \seismo\REA\EAF__\1994\05\12 2328-10L.S199405
Reading events for base EAF         612
#  222 12 May 1994 23:28 10 R                                          ?
#  223 13 May 1994  1: 1 37 L                                          ?
#  224 13 May 1994  1:16 44 L                                          ? q

Stop   Program terminated.
```

****

When the interactive location is finished, the database should be updated, see section 7.

****

Using EEV on a subset of events or using alternative databases:

Since the EEV procedure or the HYP program will work on an index file, the user can create a subset of his own interesting events to work with by creating his own index file with just these events. The index file can be created by searching through the database using SELECT or it can be created manually with the C-command in EEV.

Local database:

If data is extracted by using the COLLECT or SELECT and then split up again using SPLIT, it is possible to keep all files in a working directory by not specifying database when splitting up. Another simple way is to use the Copy function in EEV and copy directly from a named data base to the local data base. Programs will then look for S-files in the current directory instead of in the database.

In addition to working with index files, there is also the possibility of storing data in different databases. By default, the data is always stored in the default data base set by DEF_BASE, here BER. However, the user can also create another database structure (file structure) with another name and programs and procedures will work on that database too. There are some restrictions: The new database, which is a subdirectory

under SEISMO/REA, just like BER, MUST have a 1-5 letter name. Currently, the alternative database is used in our Institute to store data from other agencies like NAO, which in some cases are copied to our own database (C-command under EEV). The name DELET is reserved for the DELET database, which is always present.

5.6 Working with catalogs

It is often convenient to have multiple solutions of hypocenters in the database S-files or the CAT-files. Typically data has been entered from different sources and merged to form a single catalog. The first hypocenter line in the file is then considered the prime hypocenter estimate and this is the one used by e.g. EPIMAP to plot the hypocenters. The order of the hypocenters can be rearranged by CAT_AGA. Several programs use all the hypocenter lines. The magnitude correlation program will search any hypocenter line and the database selection program SELECT will optionally also use all the hypocenter lines. When the data base is updated with a new location and magnitude (UPDATE, section 14), it is only the first hypocenter line which is overwritten. If there is a magnitude in the 3 position, it is left unchanged unless it has the same agency as used for updating. This is useful in normal observatory practice, where it is common to put in some external agency magnitude which then must be left unchanged. If more magnitudes than 3 are calculated, they will be placed on a subsequent hypocenter line identified by having the same year, month, day and hypocenter agency as given on the first line. In order to merge different catalogs, it might be an advantage to put all the data into a complete database where each event is one file, even when only hypocenters are available. This is done by first splitting up the catalogs with SPLIT and then using EEV to merge the events. Since there is no requirement for monthly directories to have data, this methodology can also work for historical catalogs. The data can then subsequently be put into the CAT database without relocation using the UPD command.

5.6.1 Explosions in SEISAN

Many catalogs are contaminated by explosions and in SEISAN, explosions can be dealt with in several ways. In the data base, confirmed explosion are marked with E and probable explosions with P. These indicators are mostly put in when the operator first registers the event. However, there is also a possibility to automatically identify events which are probable explosions. This is done with program EXFILTER (section 37). In the data base S-files, there is a special format for recording explosion information (command EXP in EEV). The explosion site there can be assigned a three letter code, which can be used by SELECT to find explosions from specific sites. In this format it is also possible to store the explosion charge and explosion location and origin time separately from the calculated location and origin time. In EEV, the command QUARRYCHECK, will look for known quarries near the epicenter in the S-file.

5.7 Printing

All SEISAN programs, that produce graphical output, also generate Postscript files with the file suffix eps (note this was plt before version 8.1). These can be directly sent to a Postscript printer. It seems that programs like Microsoft Word don't like the SEISAN Postscript and you will need to convert your files to another Postscript, this can be done for example with the program ghostscript using pswrite as output device.

Note: On Solaris 7, both the lpr and the lp command for sending files to the printer, don't create a copy of the file before sending it (bug in Solaris). This means that a plot file can be overwritten before being sent to the printer. Therefore when SEISAN on Unix is sending plots, the system waits for 5 seconds after a file is sent to the plotter before continuing. This is most important when plotting continuous data or a large number of files with MULPLT.

5.8 General Work with SEISAN

Once data is in the database and the routine analysis has been finished by running UPDATE (final epicenters recorded in CAT and the S-files), it is possible to go on with general work with the data. This means searching the database, making a bulletin or plotting the epicenters. It is also possible to use some of the more specialized tools of SEISAN which include working on subsets of data or creating other databases, see 5.5. For general use, the basic philosophy is that the user should not enter the REA directories. All commands and programs should be used from the user's own directory or the WOR directory. To access part of the main database, the programs always ask for start and end date as follows:

19880602011001	: including from or to the second
198806020110	: including from or to the minute
1988060201	: including from or to the hour
19880602	: including from or to the day
198806	: including from or to the month
1988	: including from or to the year
BLANK	: only used as end date, means to end of month

Note that the end time is inclusive, this means that e.g. 198806 includes all of June 1988.

Thus most programs will work from any given date-time to any other given date-time. Programs that work directly on the S-files in the database (e.g. COLLECT) can work with any time interval in which the database structure has been created. THERE IS NO REQUIREMENT THAT THERE IS DATA IN THE INDIVIDUAL MONTHLY DIRECTORIES, ONLY THAT THEY EXIST. There are usually 4 options for database, either the standard base (often by default), the user's own subset of the standard base (an INDEX file or S-files in local directory) or another database. If the user has his own database specified by an INDEX file, the event ID's must be in that INDEX file. Since the index file gives complete file name of event files, the index file can work on a subset of the main database.

Note that most of the programs are used as stand-alone programs, disregarding the database structure. If one for example prefers to have all events gathered in one file rather than split into many files and directories most programs will therefore work.

5.9 Graphics in SEISAN

Most programs in SEISAN producing graphics on the screen use the SEISAN graphics system (see also chapter 44). This produces fast and low quality graphics both on the screen and similar PostScript output files. Most of these plots are not suitable for publication and many programs therefore also create output ASCII files of the main results, which then can be put into more professional plotting routines. The GMT (Generic mapping Tools) system is one of the more widely used plotting systems used in seismology. Several programs in SEISAN therefore produce output that can be used with GMT or makes plots directly in GMT. From version 8.0 of SEISAN, a script is included (GMTXY, manual in INF) which will produce nice xy-graphics from specially made output files. So far only programs SPEC, CATSTAT and LSQ produce these output files, the intention is to include this feature in more SEISAN programs.

If there is a need to produce better quality graphics there are several possibilities:

Maps: MAPG, map with GMT 5, GMT must be installed, works on all platforms.

W_EMAP: Windows based mapping system

Seismograms: TRACEPLOT (before GMT 5 based)

XY-plots: GMTXY (before GMT 5 based)

Maps: create GMT input files with SEIGMT

Volcanic event distribution: VOLCSTAT

Pregenerated graphics files

Files of the type e.g. png can be stored in the PIC directory or in working directory. The file names can be listed in the S-file in type P-lines and then plotted directly from EEV with command PP. The command to display picture files on a particular system must be defined in SEISAN.DEF.

5.10 Logging in SEISAN

This part describes how logging is handled in SEISAN. Logging is turned off by setting SEISAN_LOGGING to 0.0 in SEISAN.DEF.

Logging is performed by:

- EEV
- MULPLT continuoues

EEV:
Logging in EEV is done with respect to each event:

- When comment is inserted (COM command)
- When event is registered (REG or PUT command)
- When event is updated (UPDATE command)
- When event is duplicated (DUP command)
- When event is moved or copied to another database (C command)
- When event type is changed (R command)
- When sfile has been edited (E command)
- When event is deleted (D command)

For each event a log file is created in the LOG folder in the database folder. The log file name is linked to the sfile name, like:

```
S-file:   /seisan/REA/TEST_/1996/06/06-0648-30R.S199606
Log file: /seisan/REA/TEST_/LOG/1996/06/06-0648-30R.S199606.LOG
```

To see the content of the current log file type `log` in EEV.

The log file contain information on when a change was done, who the operator was and what the action was. The sfile is listed in the log file to show changes.

MULPLT cont mode:

Logging in MULPLT cont mode is described on page 130, the log files are stored in the LOG folder in the database folder.

5.11 Known problems in SEISAN

This list describe some of the known problems in SEISAN:

1: Azimuthal of arrival (h command in MULPLT single trace), channels with orientation code 1 and 2 are handled as N and E. If the orientation of 1 and 2 is off North and East the estimated azimuth will be wrong.

2: Particle motion (PartM or P command in MULPLT multi trace) will not work with channels that has orientation code 1 and 2.

3: If waveform data from a three component sensor is rotated it is assumed that the response is the same on all three rotated channels (Z,R,T).

4: If MULPLT gives the following error: "`--fonts-- ERROR: Unable to get font`" on Linux, it means that the default font used in SEISAN is not installed.
The solution is to install the default font `-adobe-courier-bold-r-normal--12-120-75-75-m-70-iso8859-1` or to use an other font
Linux users can check which fonts they have installed with the command textttxlsfonts
See `FONT` under `SEISAN.DEF` see page 27.

5: AUTOREG crash with the message
texttttAt line 356 of file autoreg.for
`Fortran runtime error: Bad value during integer read`
This is because the waveform filename have characters in the filename where AUTOREG assumes an integer, like:
`2019-03-10-1819-M.DATA`, solution is to rename file to:
`2019-03-10-1819-00M.DATA`

6: EEV crash with the message like:
`At line 1657 of file tau.for unit = 22, file = IASP91_linux.HED`
`Fortran runtime error: End of file` This is because the computer is not able to read the IASP91 model files. The solution is to first run the program `REMODL` and then `SETBRN`, thereafter copy the `IASP91_linux.HED` and `IASP91_linux.TBL` to the DAT folder.

7: EEV gives lots of message like:
`Bad sqrt argument: NaN.`
`More than150 arrivals found` This is because the computer is not reading the IASP91 model files correctly. The solution is to first run the program `REMODL` and then `SETBRN`, thereafter copy the `IASP91_linux.HED` and `IASP91_linux.TBL` to the DAT folder.

8: Fonts might not work using SEISAN with X2Go
For X2Go windows clients the problem might be solved by installing the `x2goclient-4.0.1.3+build2-extrafonts-set`
package (suggested JAN 2022).

ients

Other known problems are listed in the index.

Chapter 6

Description of Programs and Commands

This section gives user manuals for programs and command procedures used with SEISAN. Not all are as detailed as one could want, however many questions from programs should be self-explanatory. Most programs will produce output files with the extension .out and proceeding by the name of the program. E.g. output from collect, will be `collect.out`. Running a program twice will erase the earlier output files. If these files are to be used later, remember to rename them before running a program again. There are several programs, which have separate manuals in the INF directory.

Chapter 7

Hypocenter location programs: HYPOCENTER, HYPO71 and HYPOINVERSE

7.1 The hypocenter program, HYP

The hypocenter program is a modified version of HYPOCENTER (Lienert et al., 1986; Lienert, 1991; Lienert and Havskov, 1995). The main modifications are that it can accept more phases, locate teleseismic events and use input in Nordic format directly from the database. A detailed manual (earlier version, `hypocent.pdf`) and some of the later changes
(`hypocent_latest.pdf`) is given in INF directory. The input parameter file with station coordinates, model etc. is `STATION0.HYP`, see later. The station file has all the stations currently registered at ISC so the user migh want to use a smaller set of stations.

7.1.1 Phases

Local crustal phases:

The program will accept P, Pg, Pn, S, Sg, Sn, Pb, Sb, Rg, T and Lg phases and when locating teleseismic events most of the IASPEI phases (see below). If only P or S is given, the fastest phase is used as in the original version of the program. The phase used by the program is indcated in output, see later.

Pb, Pn, Sb and Sn phases

If Pb and Pn phases (and Sn and Sn) are used as input, the depth will be kept below Conrad and Moho, respectively provided RESET TEST(47) is set to 1.0. If the test parameter is set to 0.0 (default) the phases will ttreatred like first arrivals.

Duplicate phases

In SEISAN before version 12.0 duplicate phases would not be used. From verison 12.0 thay are used and it up to the user to remove them.

7.1.2 Azimuth and single station location

The program also uses observed station azimuths as given in the Nordic Format. Station azimuths can be obtained with either 3-component stations or array stations or by using a local network as an array (see EEV pfit option) This means that the program can locate with one station if it has at least two phases like P, S and azimuth. Azimuth residuals contribute to the overall rms, see TEST(52) and section on weight. In order to locate with one station, azimuth and P and S, TEST(56) MUST be set to 1. Note that the depth then will be fixed to the starting depth. So if the starting depth is larger than the hypocentral distance, no solution is possible and the starting depth must be set to a value smaller then the hypocentral distance.

This can be done in the `STATION0.HYP` file or individually in the S-file. Known problem: If Azimuth on one station and P and S on another station, HYP might not locate properly.

NOTE: XNEAR must be larger than the distance to the station. If TEST(58) is set to a value lower than the apparent velocity associated with the backazimuth, no location will be made.

7.1.3 Magnitudes

The phase readings for magnitude determination is described on page 64.

In SEISAN version 8.3, there are substantial changes in the way amplitudes are read and two new magnitude scales have been added (broad band body and surface wave magnitudes). Furthermore, the Richter attenuation curve is now used be default for the body wave magnitude. The phase names used for amplitudes have also changed. These changes are due to the new standards for magnitude calculation approved by the IASPEI. For more on the application of the different magnitude scales, see Havskov and Ottemöller (2010).

Magnitudes are calculated using coda, amplitude and spectral level. Parameters are given in the station file using the RESET TEST variables. For magnitude based on amplitude, the amplitude must be given in nanometers or nm/s in the input file (SEISAN standard).

Local magnitude Ml

The formula used to calculate local magnitude is

$$Ml = a * log_{10}(amp) + b * log_{10}(dist) + c * dist + d$$

where a,b,c,d are constants, log_{10} is logarithm to the base 10, amp is maximum ground amplitude (zero−peak) in nm and dist is hypocentral distance in km (RESET TEST 75-78). The default constants used, if not set in STATION0.HYP, are for California (Hutton and Boore, 1987) which gives the following relation

$$Ml = log_{10}(amp) + 1.11log_{10}(dist) + 0.00189dist - 2.09$$

It is here assumed that the gain of the Wood-Anderson instrument is 2080. An amplitude of $1mm$ of the Wood Anderson seismogram is then $10^6nm/2080$ and inserting this amplitude above together with a distance of 100 km gives magnitude 3 as originally defined by Richter. If using the default STATION0.HYP, distributed with SEISAN, the Ml parameters are for Norway. It is assumed that the maximum amplitude is picked on a seismogram simulating the original Wood-Anderson seismogram, see program MULPLT. SEISAN uses hypocentral distance, while the original Ml scale used epicentral distance (no deep earthquakes in California). We use hypocentral distance so Ml also can be used for deep earthquakes, but the user should be aware that the Ml relation for deep earthquakes might be different from the relation for shallow earthquakes.

Local magnitudes are only calculated for events with epicentral distance LESS THAN TEST(57) (default 1500 km) and if the period is less than 5.0 secs. All amplitudes for the phases 'L', 'S ', Sg, SG, AMP, and AML, AMPL, IAML or blank are used. This means that if an amplitude is picked on both Lg and Sg, both will be used. The period is not used. The many possible phase names is a result of changes over time and thus to ensure that Ml is calculated correctly with older data. From version 8.3, MULPLT produces the standard IASPEI name IAML.

At very short distance, the traditional Ml scale may not be valid and it is possible to include additional terms in the Ml calculation (Luckett et al., 2018).

$$Ml = a * log_{10}(amp) + b * log_{10}(dist) + c * dist + e * exp(-f * dist) + d$$

The values for e and f are given by TEST(xx) and TEST(yy), respectively.

Local magnitude Mw;

The mb(Pn/Sn) scale has recently been defined for the North Atlantic region (Kim and Ottemöller, 2017; Kim et al., 2020). This scale is based on Pn and Sn amplitudes measured, just like ML amplitudes, on the Wood-Anderson simulated trace. The reason for introducing this scale was that in many regions ML is defined to correct for attenuation in continental crust where Sg/Lg are typically the phases with largest

amplitudes. However, these are not propagating in Oceanic crust and amplitudes need to be measured from Pn or Sn phases. As the scale is calibrated against GCMT MW, we label it Mw in SEISAN

The Mw scale in SEISAN is implemented as described in Kim and Ottemöller (2017), given by

$$MN = log_{10}(amp) - alog_{10}(100/dist) + S + E + b$$

where the amplitude is in units of nm and measured on Pn or Sn on the WA simulated trace, dist is in km, S and E are the station and event (or source region) correction terms. For the North Atlantic, a = 1.86 and b = 1.62.

The scale is activated with RESET TEST(117).

The scale is defined in `mbn.par`, an example based on Kim and Ottemöller (2017); Kim et al. (2020) is:

```
#
# definition of scale for Pn and Sn
# MN = log10(A) - a log10(ref/dist) + S + E + b
#                                     a         ref       b
SCALE MBPN                            +1.861    100.      1.618
SCALE MBSN                            +2.176    100.      1.426

#
# group velocity windows for Pn and Sn
#
GROUP VEL PN                          5.0       9.0
GROUP VEL SN                          2.0       5.0

#
# station corrections (S)
#                                     Pn        Sn
STATION CORRECTION  ARE0               0.168     0.168
STATION CORRECTION  BJO1              -0.217    -0.088
STATION CORRECTION  DAG               -0.285    -0.166
STATION CORRECTION  DBG                0.101    -0.052
STATION CORRECTION  HAMF               0.143     0.094
STATION CORRECTION  HOPEN             -0.348    -0.332
STATION CORRECTION  HSPB               0.047     0.086
STATION CORRECTION  JMIC              -0.308     0.143
STATION CORRECTION  KBS               -0.072     0.001
STATION CORRECTION  KEV                0.191     0.133
STATION CORRECTION  KTK1               0.072     0.155
STATION CORRECTION  LOF                0.153    -0.140
STATION CORRECTION  MOR8               0.065    -0.137
STATION CORRECTION  NOR                0.120     0.145
STATION CORRECTION  NSS               -0.046    -0.298
STATION CORRECTION  SCO                0.331     0.343
STATION CORRECTION  SPA0              -0.259    -0.086
STATION CORRECTION  STEI               0.023     0.002
STATION CORRECTION  TRO                0.120     0.028

#
# event corrections E
#                   name of area       minlon maxlin minlat maxlat Pn    Sn
SOURCE CORRECTION   Gakkel Ridge       -10.0   10.0   82.0   85.0 -0.090-0.082
SOURCE CORRECTION   Spitsbergen  TF    -10.0   10.0   79.7   82.0 -0.194-0.352
SOURCE CORRECTION   Molloy FZ            0.0   10.0   77.0   79.7 -0.047-0.118
SOURCE CORRECTION   Knipovich Ridge      0.0   11.0   73.0   77.0 +0.215+0.215
SOURCE CORRECTION   Mohns Ridge         -4.2    8.0   71.0   73.0 +0.043+0.277
SOURCE CORRECTION   Jan Mayen TF       -14.0   -4.2   70.0   72.0 -0.260-0.077
SOURCE CORRECTION   Kolbeinsey Ridge   -20.0  -14.0   69.3   71.0 +0.274+0.379
```

Coda magnitude Mc

The coda magnitude is calculated using

$$Mc = a * log_{10}(coda) + b * dist + c$$

where coda is coda length in secs and a,b and are constants (RESET TEST 7-9). If 'a' is given as a negative number, the following formula will be used

$$Mc = abs(a) * log_{10}(coda) * log_{10}(coda) + b * dist + c$$

If both Mc and Ml are calculated, Ml is written first on the header line.
Coda magnitude is only calculated if the epicentral distance is less than TEST(57).
Surface wave magnitude Ms
Ms is calculated using the standard

$$Ms = log_{10}(amp/T) + 1.66log_{10}(dist) + 3.3$$

where T is period. Amplitude is in micrometer and distance in degrees, however in the Nordic format nm and km are used and the program converts. Ms is only calculated if the period is larger than 10.0 seconds in which case the program automatically assumes that Ms is the wanted magnitude. The phase used can be AMS, AMPS, AMP or blank. The current version of MULPLT produces the standard IASPEI name IAMs_20. The many possible phase names are a result of changes over time and thus to ensure that Ms is calculated correctly with older data. It is assumed that the amplitude has been picked on a WWSSN standard LP trace and that the period is in the range $18 - 22s$ (see program MULPLT). Ms will be calculated even if the period is outside this range, but it will not be correct according to the standard. The distance range is between TEST(114) and 100 deg. before version 10.5, there were no distance limits. TEST(114)=20 deg by default. Depth must be less than TEST(115). Before version 10.5, there were no depth limit. TEST(115) is 60 km by default.

Broadband surface wave magnitude MS (IASPEI code MS_BB, but SEISAN uses MS for simplicity, new from SEISAN version 8.3)

MS is calculated using the standard

$$MS = log_{10}(amp/T)_{max} + 1.66log_{10}(dist) + 3.3$$

or

$$MS = log_{10}(V_{max}/2\pi) + 1.66log_{10}(dist) + 3.3$$

where V_{max} is the maximum velocity. The IASPEI definition is to use velocity and the period is thus not needed but read for information. The velocity is in micrometer/s and distance in degrees, however in the Nordic format nm/s and km are used and the program converts when calculating magnitudes. MS is only calculated if the period is larger than 3 seconds and less then 60 seconds, distance must be larger than or equal to 222 km (2 degrees) and less or equal to 160 degrees. The depth must be less than TEST(115) (default 60 km). Before version 10.5, there was no check of depth. The phase used to report the amplitude and period must be called IVMs_BB which the current version of MULPLT produces. The biggest advantage using MS compared to Ms, is that any period in the range $2 - 60s$ can be used.

Body wave magnitude mb
mb is calculated using

$$mb = log_{10}(amp/T) + Q(dist, depth)$$

where Q is a hardwired function of distance and depth and amp is the amplitude in nm. There are two possibilities: The default (set by REST TEST(108) is the standard Gutenberg and Richter (1956) curve while alternatively the Veith-Clawson curve can be used (Veith and Clawson, 1972). Before SEISAN version 8.3, Veith-Clawson was always used. mb is only calculated if the epicentral distance is less than or equal to 100 degrees and larger than or equal to TEST(113), default 20 deg (IASPEI standard and SEISAN default is 20 degrees).Before version 10.5, the lower distance was TEST(57) (default 1500 km). The period must be smaller than 3s and larger then 0.2 s and the phase is P, AMP, AMb, AMB, AMPB, AMPb, blank character or IAmb. The current version of MULPLT produces the standard IASPEI name IAmb. The many possible phase names are a result of changes over time and thus to ensure that mb is calculated correctly with older data.

Broad band body wave magnitude mB (new from SEISAN version 8.3)

The broad band magnitude mB (official IASPEI name is mB_BB) is calculated using

$$mB = log_{10}(amp/T)_{max} + Q(dist, depth)$$

or

$$mB = log_{10}(V_{max}/2\pi) + Q(dist, depth)$$

where V_{max} is the maximum velocity and Q is a hardwired function of distance and depth. The IASPEI standard is to use velocity and SEISAN store the velocity in nm/s. There are two possibilities for the atteneuation function: The default (set by RESET TEST(108) is the standard Gutenberg and Richter (1956) curve while alternatively the Veith-Clawson curve can be used (Veith and Clawson, 1972). mB is only calculated if the epicentral distance is less than or equal to 100 degrees and larger than or equal to TEST(113) (IASPEI standard and SEISAN default 2 degrees. Before version 10.5, the lower limit was TEST(57), default 1500 km) and the period is larger than 0.2s and less than 30s and the phase name is IVmB_BB . The current version of MULPLT produces the standard IASPEI name IVmB_BB. The biggest advantage using mB compared to mb, is that the mB scale does not saturate before magnitude 8.

Moment magnitude Mw

Mw is calculated as

$$Mw = 2/3 * \Big(log_{10}(moment) - 9.1\Big)$$

where moment is in Nm (see also section 8.12). When an event is relocated, the moment is also recalculated according to revised hypocentral distance. Mw is only calculated from moment as given on the SPEC lines, see MULPLT.

NOTE: If an amplitude has a given period between 5 and 10 secs, it is not used for Ml and mb magnitude calculation, see above. If an event is not located, there will normally be no magnitude calculation and all magnitude and distance information is deleted from the output S-file (`hyp.out`) except, the magnitude in the 3rd position on the header line if it has an agency different from the default agency. The only exception is that if a coda is given, the epicentral distance is retained and coda magnitude will therefore be calculated. This means that for events, which cannot be located, it is still possible to calculate coda magnitudes by manually entering the epicentral distance on the line containing the coda length.

On the first header line, there is room for 3 magnitudes. If there is a magnitude in the 3rd position, it is not overwritten unless the default agency is overwritten, so there will often only be room for 2 calculated magnitudes on the first header line. If more magnitudes are calculated, they will be written on a subsequent hypocenter line, which is identified by having the same year, month, day and hypocenter agency as the first header line. This means that there is room for a total of 6 magnitudes, which can each, be updated when relocating. Hypocenter info and all 6 magnitudes can be printed out on one line with program REPORT.

All magnitudes can have a station dependent correction given in the station file. This correction does not affect the Mc in `print.out` file. Mb and mB use the same correction and Ms and MS use the same correction. Only calculate magnitude: If TEST(106) is set to 1.0, only magnitudes are calculated, provided a distance is given.

NOTE*********

Amplitude phases and coda length (END-phase) can be given weight 4 and the corresponding magnitude is not calcualted. Other weights cannot be used. If Nordic format is used without amplitude phase like coda on phase line, a weight 4 on the P will not affect the weight of the coda magnitude.

7.1.4 Use of S-P and L-S differences

Uncertainty in absolute times often makes it necessary to be able to use the difference in time between two arrivals such as P and S or P and Lg. If no absolute times are available, the calculated origin time will be close to that at the first arrival station and is of course meaningless. However, a perfectly good epicenter and depth can still be obtained from P-S or P-Lg differences alone. To enable this feature, set the weight for the P phase input record to 9. This P is then assigned a weight of 0, effectively disabling its use. However, a time residual and azimuth, etc., will still be calculated for it, enabling an assessment to be made of its

absolute time. A search will then be made of the entire input phase set for an S or Lg phase at the same station. If such a phase is found, its variables are used to store the observed and calculated difference times and their derivatives, and it's weight (0-4) is used for the difference phase. DON'T SET IT TO 9!! If two or more such phases (e.g., SN, SG, LG, etc.) are found, all their differences with the P time will be used instead of their absolute times. Blanks will appear beneath 'hrmn' in the residual summary for all such phases, while the observed and calculated difference times with the first P will appear beneath 't-obs' and 't-cal'.

NOTE: Difference with Rg has not been implmented, could be done if need be.

NB. There must be at least one phase with absolute time to get a location.

7.1.5 Global event location

When locating globally, the program uses the IASPEI91 travel time software described by Buland and Chapman (1983) and Kennett and Engdahl (1991). The global model is used if the distance indicator in the S-file is D. If the distance idicator is R, the local model is used unless there are distant stations (distance larger then TEST(57) in which case the global model is used.

HYP evaluates all the IASPEI91 phases (up to 60) at each delta, and searches for the phase specified in the 4-character phase identifier. If no phase is found, the phase is given a weight of -1, which effectively removes it from the phase set. If a phase is labeled as 'P ', 'S ', 'PKP ' or 'SKS ', and this phase is not in the IASPEI91 list, the first arrival phase having P or S as its first letter is used, or PKP, SKS as its first 3 letters. In addition, include the PKiK phases in this search for 'PKP ' and 'SKiK' phases in the search for 'SKP '. The IASPEI91 phase set currently includes: P, Pdiff, PKP, PKiKP, pP, pPdiff, pPKP, pPKiKP, Sp, sPdiff, sPKP, sPKiKP, PP, P'P', S, Sdiff, SKS, sP, pSdiff, pSKS, Ss, sSdiff, sSKS, SS, S'S', PS, PKS, SP, SKP, SKiKP, PcP, PcS, ScP, ScS, PKKP, PKKS, SKKP, and SKKS.

Long phase names:

Normally SEISAN and the Nordic format assume up to 4 character phase names. However, when working with global phases, the phase name length can in a few cases be up to the ISC standard of 8 characters. The program then uses column 9 for weight (normally blank) and column 11-18 for the phase. In this case it is not possible to give a polarity.

In the new Nordic format, Nordic2, there is always room for 8 characters and a polarity can be stored.

```
old:

 STAT SP IPHASW D HRMM SECON CODA AMPLIT PERI AZIMU VELO AIN AR TRES W  DIS CAZ7
 KTK1 SZ3 sPKiKP   654  2.96

new:

 STAT COM NTLO IPHASE   W HHMM SS.SSS   PAR1  PAR2 AGA OPE  AIN  RES W  DIS CAZ7
 KTK1 S Z       sPKiKP  3   654  2.960      D
```

7.1.6 Criteria for a solution and weighting

The cases where a solution will not be attempted are as follows:

1. Multiple phases at two stations, but no azimuths. This is a non-unique case, even though four different arrivals are present.
2. Less than three phases from three different stations and no azimuths.
3. A single phase at one station with an azimuth.

Note that if phases are weighted out due to large distance or a bad fit during the first iteration, there might not be a location even if more than 3 stations are available.

Weighting:

A number of different weights may be used to calculate the solution.

1. User specified weights: These are calculated using the HYPO71 style weight number 0 to 4, read with each phase, where 0 corresponds to w1=1.0, 1 to w1=0.75, 2 to w1=0.5, 3 to w1=0.25 and 4 to w1=0. Uncertain time is 9 meaning that absolute time is not used, see also use of S-P times on previous page.

2. Distance weighting: This is given by the formula w2=(xfar-delta)(xfar-xnear) where delta is the distance (km) of the event from the station and xnear and xfar are read from the station file, `STATION0.HYP`.

3. Bisquare weighting: This scheme, described by Anderson (1982) calculates residual weights, see details in HYP manual.

4 Azimuth weighting: Azimuth residuals are divided by test(52), which is the error in azimuth that corresponds to a one-second error in arrival time. For example, if test(52)=5 (default), a phase residual of 5 degrees will become a residual of 1 (5/test(52)) in the parameter corrections and rms calculation.

All the above weights are multiplied together to calculate the weight used in the inversion. If the user-specified weight, w1, is changed by (2) or (3) above, changed to zero by the consistency check, or set to -1 because the phase is not recognized, an asterisk will appear after the final weight in the residual printout.

7.1.7 Eliminating outliers

Outliers can be hard to spot since the residuals from one or several outliers tend to be distributed over all residuals. The problem is particularly large when dealing with automatic picks (A in column 16 (old format) or 26 in (Nordic2 format) of phase line) where gross mistakes, like picking P at S, can occur. One possibility is to use residual weighting but often more drastic means are needed. Fernando Carrilho (IPMA) has made an algorithm for HYP which effectively finds and remove and/or weight out large outliers. Only P and S-phases will be checked. The procedure works for both local and distant events although it is mainly meant to be used with local events. The principle is the following:

Run the location in a loop (iterations) of a maximum of 15 steps

For each step:

- Weight out residuals larger then 99

- S-phase: If residual larger than 1.5*rms and larger than RESET TEST(109) it is weighted out. If in a following iteration it is smaller than 1.5*rms, and smaller then RESET TEST(109), it is included again. If 1.5*rms is less than 0.6 and the residual is less than 1.0, the data is always used. Default value of RESET TEST(109) is 0.8.

- P-phase: Same as for the S-phase but only after the 2. iteration.

The loop will be terminated if any of 2 conditions are met:

- rms is less than 0.3 and iteration is more then 5.

- Change in rms from one step to the next is less than 0.05 and iteration is larger than 4.

The phases with high residuals are now weighted out. They can also be removed from the S-file if the residuals are larger than a user defined value given in RESET TEST(110) (default value of 3), however this is only possible for the phases flagged as automatic.

There is also an option for keeping only the phase with the lowest residual if the same phase has been picked on several components of the same station. Phases will be deleted for both manual and automatic phase picks. Set RESET TEST(111)=1.0. Default value is 1.0.

There is an option for testing for Sg phases. If RESET TEST(112) is set to 1.0, there will be an additional iteration loop, where all S- phases which are only labeled S have been changed to Sg. At the end, the data set with the highest number of accepted phases will be used and all S's will be S or Sg. The phases which already have two letters like SG or SN will not be changed. This option will not be used for distant or regional events.

The default values are the ones best fitting automatic operation using AUTOPIC in the Portuguese network. Increasing the values of test(109) and test(110) will increase the number of accepted phases.

7.1.8 Determining which travel time software is used

The parameter test(57) is used to determine whether a layered model or IASPEI91 software is used to calculate the travel times and their derivatives. For the initial starting location, the distances from each

station are calculated and IASPEI91 is used if any of them exceed test(57). However, this can be overridden by the distance indicator in column 22 of the Nordic header record. If this is L, a crustal model is used regardless of distance, whereas if it is D, IASPEI91 is used, while R has no effect i.e., test(57) is still used. So if either a crustal model or IASPEI91 tables are wanted, use either L or D respectively.

7.1.9 Starting location

The program uses a starting location algorithm (reset test(56)) which tests the rms of all starting locations and select the minimum rms solution, see HYP manual.

User defined start location: If an S is written in the input S-file at column 45 of the epicenter line, the location starts at the location (epicenter) given on the header line. If an S is written in column 44 on header line, the depth iteration will start at depth given on the header line. If N is written in column 45, the nearest station will be used irrespective of global settings.

Starting depth:

If no event specific start depth is given in S-file, the starting depth is taken from the first number on the control line (see later) in the HYPO71 style. However, there is often problems obtaining a reliable depth due to local minima. This can be manually checked with program RMSDEP from EEV. HYP can also be set up to locate the same event starting with a range of different start depths, and then choose the one with the lowest RMS. This can significantly improve the reliability of depth determination. Selecting 3 to 5 different start depth is often enough. This option is set on the control line in the station file.

Fixing location:

Using F instead of S, fixes the position (depth and location).

Do not locate event:

If a * is written in column 45, the event is not located, can be used if an external location is to be kept unchanged.

Only calculate magntudes and update spectral values

Set TEST(106) to 1.0

Fixing origin time:

Using an F in column 11 of header line will fix the origin time given on the header line.

If both depth and location are fixed, but not the origin time, new origin time and residuals will be calculated. This can be useful when working with readings from a few stations which should be checked against known locations. If e.g. distant events are read, it is often the practice to put in the PDE location on the header line and calculate residuals relative to the observations. When the UPDATE is made, the agency of the location is NOT changed, assuming that if both depth and epicenter are fixed, the hypocenter must come from an external agency.

7.1.10 Station travel time delay and magnitude correction

On the station line in STATION0.HYP, there is room for travel time delay and magnitude corrections, see section 'Station and model files' below. The P delay is in column 28-33 and the S-delay in column 34-38. Both numbers are real numbers, format f6.2,f5.2. In previous versions of SEISAN, the S-delay was the P-delay*1.78. The S-delay has been put into the previously used space for coda magnitude correction assuming there is no longer a need for that. The delay is subtracted from the phase reading.

The magnitude corrections for Ml, mb or mB, Ms or MS and Mw are in the following 4 columns and the corrections are added to the calculated magnitude. Format 4f5.1.

7.1.11 Putting in geographical location

Geographical locations are stored in a file place_names.eev located in DAT or local directory. This file is mainly intended to use with EEV where geographical location can be entered with the geo command, see EEV. The same file can also be used with HYP to input a geographical locaton with every location. The information is put into the LOCALITY line, see exmaple below:

LOCALITY: 101 km N of Bergen 3

The locality file is always read when HYP starts up but only used if RESET TEST(124) is set to 1.0. There is only one LOCALITY line in S-file so a new location will overwrite the line and if it is not there it will be created.

7.1.12 Preventing a local minimum

For some data, the iterations will stop in a local minimum. This can partly be checked with the DRMS output in the print.out file. The DRMS output gives the RMS in 6 points around the hypocenter at distance DRMS. DRMS is set with RESET TEST (13). In order to check for a local minimum, a more extensive grids search can be done. This is done by using RESET TEST 119-121. Setting these parameters, a grid search can be done in 3D around the hypocenter in a user selected grid size. The grid search is done after the last iteration. If a point is found with a lower RMS than given by the iterative process, a new iterative process is started with that point as start location. The grid search can be particularly useful for local earthquakes, however, in the current implementation it is also done for distant earthquakes using the same parameters. Note that using a large grid might significantly slow down the processing time.

When using the grid search option for start location, an extra ouput is given in the print.out file:

Grid rms smaller than solution rms 1.953 3.391

Hypocentral dist. (km) from epicenter to grid point min. 28.3

Depth change 10.00

Iterate again with new start location: 62.303 5.760 15.0

This information gives how far away the minimum is and what the RMS is.

The most likely local minimum is happening for the depth. The start depth (on control line in STATION0.HYP) is therefore important and should be what is expected for the area. If there is a large variation in depths, like in a subduction zone, and the network is small, it might be an advantage to use several start depths. This can be done in two ways:

1: Set a range of start depths on the control line. In this case a complete location is done with each start depth. Setting many depth will increase the processing time proportionally.

2: Set RESET TEST(96) to 1.0. With this parameter set, the program will, once a location is found, look for the depth with the smallest RMS using the loction found. A new location is now made with the a start depth location at the minimum rms depth. This procedure is fast since the mimumum RMS depth is found with a fixed epicenter and no new location is found, however, since a new location is not found, it will not always work as well as option 1. The procedure for this option is to start with a depth 3 times the current depth (set to at least 40km) and then calculate rms in 40 steps from that depth to the surface. In SEISAN before version 12.0, the procedure was to start with current depth and the go in steps of 10 to the surface but this did not work well with shallow earthquakes.

7.1.13 Alternative model

By default, an event is located using the `STATION0.HYP` input file. However, each event can use its own model (with all the location parameters) which is specified with one character in column 21 on the Nordic input file header line. The model then has a corresponding name. If e.g. the model is called W, the corresponding input station file will be called `STATIONW.HYP`. It is therefore possible to have as many different station files, as there are printable characters. Note that if a different model x has been specified and is not present, the program will stop with the message "`STATIONx.HYP does not exist`". The file `MODEL.DEF` in DAT can be used to assign the single character a name, which can be listed from EEV. The format in `MODEL.DEF` is one line per model, the model indicator is given in column 1, column 2 is blank and the model name is given in columns 3 to 80. The MODEL.DEF is for information only.

7.1.14 Location by grid search

Hypocenter can also locate an event by grid search. This can be quite time consuming but illustrates well the problem with local minima. Grid search can only be done for one event at a time using EEV command 'grid'.

Hypocenter is started up and will ask for the grid: Latitude and longitude range and grid spacing. A maximum of 71 points can be used in each direction. The point with the lowest RMS is found and the corresponding location and residual is printed on the screen. It is now optionally possible to plot the contours on the screen. The map coordinates used are as defined in SEISAN.DEF. Note that the grid search is using exactly the same parameters as Hypocenter. This includes all weights and phase types. The depth is fixxed to the depth given in the S-file header line. For more details and an example, see application note epi.pdf in INF.

7.1.15 Using HYP to determine crustal structure

HYP has an option to locate a data set for a large number of different models and then determined which model gives the lowest average RMS for the data set. This might be a useful option, particularly when a sparse data set is available. In order to use this option, an additional input parameter file `h_models.par` is given. When this file is in the working directory, HYP will switch to multiple model mode SO ONLY HAVE THIS FILE IN WORKING DIRECTORY IF MULTIPLE MODEL MODE IS INTENDED. For more details and an example, see chapter 38.

7.1.16 Running HYP

The program is started with command HYP from the prompt line (interactive mode) or with 'L' in EEV or SE. HYP can also be started with an argument like `hyp input.dat`, where `input.dat` is an S-file. The first event in the S-file will then be located without further user interaction. Other prompt options (mainly used in connection with EEV) are

-seisanexp Use with SE

-update Stop at end of run, ask if update and overwrite input file

-op XXX Operator XXX to use in -update option chosen

Below follows an example of running outside EEV, explanations are in lower case. Note that the `STATION0.HYP` file MUST be present in the DAT directory for HYP to know that it is working with a SEISAN database. If not present, HYP will only ask for an input file name, see HYP manual.

```
HYP
Arrival time data input, select one:

  SEISAN database or                              : RETURN
  Alternative database, give 1-5 letter code      :
  Local index file, name must start with index or :
  Local database, write ,, or                     :
  File name for one file in NORDIC format         :

                 Your answer here  determines  the input
source. A return means that you work directly on the BER database. A 1-5 letter
code gives name of database, e.g. NAO. An index file or the name of a readings
file  is used when you want to work on specific subsets.
                   Local database is S-files in local directory.

 Start Time           (YYYYMMDDHHMMSS) : 199012
 End Time, RETURN is to end of month   : 19901205
           Standard formatted time input.

 Interactive operation (N/Y=return)
                 If N, whole time interval or file is located, one line output pr event.


#  1   1992 12 3 0137 40.3 NPHS=   12  T Q L #XXX
#  2   1992 12 3 0237 43.3 NPHS=   14  T Q L #XXX  l   ! now locate
here comes location, see HYP manual*****************************
#  2   1992 12 3 0237 43.3 NPHS=   14  T Q L #XXX  q   ! stop


 PRINT OUTPUT IN FILE print.out
 CAT-FILE IN FILE hyp.out
 Summary file in hypsum.out
```

In interactive mode, as shown above, event date is printed out for each event and action is taken as in EEV for the options available. If HYP run on a single file, the options above are available meaning that HYP can select and locate different events in a single file using the event number. If HYP runs on a database, the EEV options D and B are also available, but not shown. If the option of no interactive input is chosen, the program will locate from beginning to end without any more user interaction. This is a useful option for testing a subset of the database with different models etc. without changing the database. Note that the input file or database is never overwritten by HYP.

ALL TYPE ONE LINES WITH SAME AGENCY AS GIVEN IN `STATIONX.HYP` FILE WILL BE DELETED SO THERE WILL NEVER BE MORE THAN ONE TYPE 1 LINE IN OUTPUT WITH CURRENT AGENCY (except possibly a second magnitude line with a different type magnitude as given on main header line).

Problems: Sometimes HYP will not locate an event, look in the `print.out` file to see what happened. In EEV this can be done with command ep. In some cases, the initial location was put beyond the limits set by the parameters. If e.g. an event is defined as a local event and no readings are to be used further away than 2000 km (distance weighting, see following table or TEST(41)) then no location will be attempted. Try to change the event type to D and see if the event locates. In a few other cases it might be an advantage to use a starting location.

7.1.17 Station and model files

Station input is given in near standard HYPO71 format in the file `STATION0.HYP` in directory DAT. If however the user wants to try a different model without changing the standard model in DAT, this is possible by having a `STATION0.HYP` file in the working directory, since the program always looks there first for the `STATION0.HYP` file (see example at end of this section). Another possibility is to use another model for just one event by setting a flag in the phase input file, see below.

The station file included with SEISAN usually includes the complete ISC station list. The ISC station list can be downloaded from ISC and converted to SEISAN format with program ISCSTA in order to make updates. To update the station list from ISC, open the ISC webpage in a browser, open the link to the c̈omplete liständ copy and paste the list into a file (wthout the html code), run ISCSTA on this file.
ISCSTA can also select out of the large station file (in ISC or SEISAN format) all strations corresponding to events in a CAT file so it is possible to make a much smaller station file for the users data.

Below is an example of a `STATION0.HYP` file. The format is close to the HYPO71 format with one extra line at the bottom. In addion, 5 letter station codes can be used. The test parameters 2-13 are as in HYPO71, see also HYPOCENTER manual section 4.1.2.

Comments are given after !'s

```
RESET TEST(01)=0.3
RESET TEST(03)=0.6
RESET TEST(06)=0.1
RESET TEST(07)= 3.0
RESET TEST(08)=2.6
RESET TEST(09)=0.001
RESET TEST(11)=50.0
RESET TEST(13)=5.0
RESET TEST(50)=1.0
                                ! one and only one blank line here
  UPP 5951.50N 1737.60E  14     ! station lines
  COP 5541.00N 1226.00E  13
  KBS 7855.08N 1155.44E  46
  EBH 5614890N  330490W 375     ! high accuracy lat-lon
  OSG 6029.80N  252.55E-100
  01A06049.43N 1049.95E 426
 BERGE6057.12N 1133.15E 100     ! 5 char station name
-BEBGE6157.12N 1133.15E1100     ! 5 char station name and at 1100 m
                                  depth

...

                                ! one and only one blank line here
  6.2       0.0         !      ! model lines
  6.6      12.0
  7.1      23.0           3.8      2.2       200.0     300.0 **
  8.05     31.0      N  ! N  indicates location of Moho
  8.25     50.0
  8.5      80.0         !
15.  600. 1300. 1.73    5  5.0  10.0     ! control parameters
BER                     ! Reporting agency    (a3)
```

Format of the station line is 2x,a4,i2,f5.3,a1,i3,f5.3,a1,i4,f6.2,5f5.2,9f6.2,2a2 or 1x,a5 .... if the station has 5 characters. The content is:
station code 4-5 chars (see above)
latitude in degrees
latitude in min
north or south (N or S)

longitude in degrees
longitude in minutes
east or west (E or W)
altitude in m, in some rare cases, the station is deeper than 1000 m in which case the minus sign has to be put in column 1
P-delay in secs, S-delay in secs. Since it is a delay, it is subtracted from the arrival time. NOTE. The S-delay is in the former position of the Mc correction.
Magnitude corrections for the magnitudes: Ml, mb or mB, Ms or MS and Mw
Spherical harmonic station corrections Network and Location codes

NOTE: Network and location are new from version 12 and are only used with new Nordic format, Nordic2. The are located in column 113-116. If the station file has network and location and the S-files does not have it, the station will be selected anyway. So network and location is really only needed if two station have the the same station code but different location or network.

NOTE: The format for the minutes is f5.3. Normally minutes are given as e.g. 20.22, however if a higher accuracy is needed, it can be written without the point as 20222 meaning 20.222 ccording to the format f5.3. See also section 5.3.5.

The command GET_STAT (get_stat <station-code>) can be used to check that a station is present in the station file and that the coordinates are correct.i An example is

```
c:\seismo\WOR>get_stat BER
 BER     60.3838    5.3338        50
```

The magnitude residuals are added to magnitudes calculated for each station but the result is only seen in the final average magnitude. If the magnitude correction is set to 99.0, the magnitude is not used in the average. The magnitude corrections for mb and mB are the same and similarly also for Ms and MS.
Format of model line: 3f7.3,a1,3f7.2. The information is:
P- velocity (km/sec)
Depth to interface (km)
S- velocity (not needed). If no S-velocity is given, the S-velocity is calculated from the P-velocity using the given Vp/Vs ratio.
Interface indicator: N: Moho, B: Conrad
Density (g/cm**3)(not needed)
Qp (not needed)
Qs (not needed)

Density and Q is only used by modeling programs and moment tensor inversion. In this way the station file is a complete model file for making synthtic seismgrams. NB: Moho cannot be the last layer, there MUST be one layer below interface marked with N.

The line with ** indicates optional Vs, density, Qp and Qs. This is information only used with modeling, see section 29. Format for additional info is 25x,4f10.1.

Format of control line: 3f5.0,f5.2,i5,2f5.1 Information is:
start depth in km, used if no range of start depths specified (see below)
xnear: distance at which distance weighting start
xfar: distance at which distance weighting is zero, beyond xfar, the phase is not used (local events only)
Vp/Vs ratio
number of start depths
start depth of range of start depths
increment in start depths
NB: If these parameters are used, the fixed initial start depth is not used
The input at the bottom is reporting agency used for both hypocenter and magnitudes.

Since the program locates distant events, max distance, reset test(41) must be set to a large value. To avoid that local events move out in the blue, the parameters xnear and xfar must be set not larger than 2000 to 3000 km. Xnear and xfar are only used for local events (flag L) and regional events if the local crustal model is used.

7.1.18 RESET TEST parameters

HYP will assign reasonable default values for RESET TEST parameter. Below is shown a summary. For full details see HYP manual. The number to the left is the control parameter and D indicates the default value. The most important parameter are given in bold.

2:	Step length damping control, D: 500.0.
7-9:	Duration magnitude coefficients used for calculating the coda magnitude, as MAG = TEST(7) + TEST(8) * LOG(T) + TEST(9) * DELTA where T is the coda length in seconds, DELTA is the hypocentral distance in km. D: 7: -0.87, 8: 2.0, 9: 0.0035 (Lee et al., 1972) If test(8) is negative, its positive value will be used and log(T) will be squared. Note however, that the individual stations magnitude values printed out during the run of HYP still will be using the unsquared log(T).
11:	Maximum no of iterations in the least-squares rms minimization, D: 99.0
13:	Increment in km for auxiliary rms, D: 20.0 km. To disable (save some computation time), set to 0.0.
30:	Initial damping factor, D: 0.005
31:	Max degs of freedom: Set to 3 for determining origin time and hypocenter, set to 2 for fixed depth solution (depth on phase headers), -2 fix all events to starting depth in `STATION0.HYP`, 1 to fix all hypocenters to value on phase headers, 0 to fix hypocenters and origin times to values on phase headers. D:3.0
32:	Magnitude of parameter changes (km) below which convergence is assumed, D: 0.05
34:	Minimum spread to normalize residuals, D: 0.1, do not change
35:	Bisquare weighting width, D: 4.685, do not change
36:	RMS residual low limit for bisquare weighting for local events, D: 0.0
37:	Maximum number of increases in damping before fixing depth, D: 10.0
38:	Least squares errors (0.0), damped least squares errors (1.0) with initial test(30) damping value, D: 0.0
39:	Factor by which damping is increased when RMS increases, D: 4.0
40:	Depth origin of coordinate system, 0: sea level, 1:maximum elevation station in station list, D: 0.0
41:	Maximum distance (km) from nearest station at which hypocentral solutions will be generated, D: 20000.
43:	Maximum rms for an event to be used in average station residual calculation - doesn't affect the final hypocenter solution, D:1.5
44:	Rg phase velocity in km/sec, D: 3.0
45:	Minimum rms difference between the location on the header line and the new location for the event to be used for average difference in location, D: 50.0
46:	Minimum number of non zereo weight phases for event ot be included in average difference in location, D: 3.0
47:	Prevent depth to go below Moho and Conrad for n and b phases respectively, 1: enabled, 0: disabled, D: 0.0
49:	T-phase velocity, D: 1.48 km/sec
50:	Flag for using azimuth phases, 0 disables. Disabling the azimuths also means that they are not used for a starting location. A better solution will often be to set the azimuth error, TEST(52) to a large value, effectively disabling them.D: 1.0 (enabled).
51:	Lg phase velocity in km/sec, D: 3.5.
52:	Relative weighting of error in azimuth used in azimuth inversion (degrees). The default value of 10 means that an error of 10 degrees will give the same contribution to the rms residual as a travel time error of 1 sec, D: 5.0

53:	Critical distance phases moved to by start loc. if Pn or Sn, D: 130.0 km
56:	A value of 1.0 enables the starting location algorithm, STARTLOC. Estimates are then obtained from apparent velocity, distance, azimuths, etc. If test(56)=0.0 epicenter is taken 0.2 km from the first arrival station. D: 1.0 MUST BE SET TO 1.0 TO LOCATE WITH ONE STATION ONLY.
57:	Distance (geocentric km) beyond which IASPEI91 tables are used to calculate travel times for regional events. Can be overridden by the distance letter L in the Nordic format. D: 1500 km
58:	Maximum apparent velocity (km/sec) for phase data to be used. This option was added to selectively disable some of the PKP phases, which have large errors due to their steep angle of incidence. Their velocities were almost always ¿ 25 km/s, D: 100.0 (effectively disabled)
59:	Critical distance for PKP core phases to be used in starting location, D: 13000 km
60:	Seconds by which the arrival time difference between two adjacent stations can exceed the travel time between them. Setting this to 0 disables the initial consistency check. D: 5.0
61:	Multiple of apparent velocity regression residual rms at which arrival times are weighted to zero during start location determination. Reducing this value will cause arrivals to be rejected when they do not conform to the plane wave set of arrivals which is characteristic of distant events. Unless you are getting a lot of messages ' xxx removed: Apparent velocity deviation =..', in the output, it is recommend against changing this default value. However, you can disable this feature by setting test(61)=0.0, D: 2.0
62:	Use of IASP91 phases.0: Only calculate 'basic' phases, 1: calculate all, D: 1.0
63:	Types of phases used when calculating travel times and their derivatives and resulting residuals and rms. The default value of 0 means that all 8 letters of the phase ID are matched. However, first arrivals are used before and after the critical distance for N and G phases, respectively. 0: match 4 char. phase ID in phase, 2nd letter is case insensitive 1 use minimum time for 1st letter phase 2 use refracted 'n' phases, set other phases weighted to 0 3 use surface 'g' phases 4 use Conrad 'b' phases 5 use only minimum time P, Pn, Pg and pP phases no PKP's, all other phases weighted to 0 D: 0.0
64:	Allow temporary increase in RMS by this factor, D: 2.0
65:	Number of iterations for which increased rms is allowed, D: 3.0
66:	Print out of travel time calculation errors (1=y,0=n), D: 0.0
67:	Recognize blank phases as P (y=1,n=0), D: 0.0
68:	Apparent P-velocity(km/sec) to calculate start depth from pP-P, D: 5.0
69:	Distance (deg) beyond which PKiKP or PKP is used as first arrival instead of Pdif D: 110.0
70:	Maximum depth that the hypocenter is allowed to move to, D: 700 km
71:	Sort output according to distance,(y=1,n=0), D: 1.0
72:	Auto phase identification for distant events (y=1,n=0), D: 0.0
73:	Number of iterations with first P's before autophase id., D: 3.0
74:	Print input phase data in `print.out` (y=1,n=0), 0.0

75-78	Ml magnitude coefficients. Ml = TEST(75)*log10(amp) + TEST(76)*log10(dist) + TEST(77)*dist + TEST(78) where amp is amplitude in nm and dist hypocentral distance in km. The defaults are Ml = 1.0 * log10(amp) + 1.11*log10(dist) + 0.00189*dist - 2.09 which is close to the original Richter definition (Hutton and Boore, 1987).
79:	Minimum number of stations to attempt a solution,D: 1.0
80:	Minimum number of phases (azimuth is counted as a phase) to attempt a solution, D: 3.0
81:	Disable location of local events if 0.0, D: 1.0
82:	Disable location of regional events if 0.0, D: 1.0
83:	Disable location of distant events if 0.0, D: 1.0
84:	Disable ellipticity correction for distant events if 0.0, D: 1.0
85:	A priori error(sec) of local events. This affects the error estimates, particularly when few stations are present. D: 0.1. See TEST(91) for distant eqrtquakes.
86:	Number of degrees of freedom in estimating test(85) for loc. ev., D: 8.0
87:	Confidence level that the solution will lie outside the confidence ellipse defined by the covariance matrix . The default value corresponds to 90 %confidence., D: 0.1
88:	RMS residual(sec) at which residual weighting is applied for distant events. Set to 0.0 to disable. D: 10000.0
89:	Use depth phases (y=1,n=0), D: 1.0
90:	Use of core phases (y=1,n=0), D: 1.0
91:	Same as TEST(85) for distant events,D 1.0
92:	Number of degrees of freedom for test(91), D: 8.0
93:	Output longitude to always be positive (y=1,n=0), 0.0
94:	Value of residual below which zero weight phases (w=4) is used again, D. 0.0
95:	Disable use of core phases between 135 and 150 deg, 1: disabled, 0: enabled, D: 0.0
96:	Variation of depth to find minimum rms, 1: enabled, 0: disabled, D: 0.0
97:	Minute error correction 1: enabled, 0: disabled, D: 0.0
98:	Enable spherical harmonic station corrections, 1: enabled, 0: disabled, D:0.0
99-101:	Lg, Rg and T weights put in permanently: D: 1.0,1.0,0.0
99:	Lg phase weight: multiplied by phase weight. D: 1.0
100	Rg phase weight: multiplied by phase weight. D: 1.0
101	T phase weight: multiplied by phase weight. D: 0.0
102	Not used
103:	Minimum number of depth phases for starting depth, D: 1.0
104:	Minimum distance of epicenter from array for distant events, D: 30.0 deg.
105:	Enable gradient model, not yet implemented
106:	Only calculate magnitudes and update spectral values, 1: enabled, 0: disabled, D: 0.0
107:	Use xnear and xfar from sfile, 0: disabled (xnear and xfar from `STATION0.HYP` file), 1 enabled, D:0.0 (see format description)
108:	mb attenuation curve, 0.0 Richter, 1.0 Veith and Clawson, D: 0.0
109	In reject mode, if residual is larger than this, it is weighted out. D: 0.8
110	In reject mode, in final run, phases with residual larger this and automatic, are removed. D: 3.0.
111	In reject mode, if several phases from same station, only keep the one with lowest residual if test is 1.0. D: 1.0
112	In reject mode, set this to 1.0 ito enable testing for Sg when rejecting phases, default 0.0.
113	Shortest distance for calculating mb and Mb. D: 2224 km (20 deg)

114	Shortest distance for calculating Ms. D: 2224 km (20 deg)
115	Maximum depth for calculating Ms and MS. D: 60.0 km
116	Average magnitude is simple average (0.0) or median (1.0) D: 0.0
117	Use Mw (mb(Pn/Sn)) magnitude instead or ML if events are in defined areas D: 0.0
118	Decides if a local minimum should be searched for after iterations ends. If an RMS with lower rms than the iterated solution is found, new iterations will be done with that solution as a starting epicenter. If zero, grid search is not done, if positive number grid search is done with that number used as grid size (km).i D. 0.0
119	The number of gridpoints in one quadrant so the grid will be +/-test(119) on each side. D: 10.0
120	Decides if depth grid search for a local minimum like test 118. test 118 and 120 can be combined. The value is the size of the depth step (km). D: 0.0 no grid search.
121	The number of steps in depth grid search. D: 10
122-123	Additional parameters for Ml scale that change calculation for short distance. Ml = TEST(75)*log10(amp) + TEST(76)*log10(dist) + TEST(77)*dist + TEST(122)*exp(-TEST(123)*dist) + TEST(78). D:0.0 and 0.0
124	Put in geographical information after a location, 1.0 to enable. D: 0.0

The test parameter defaults are set in file hyposub1.for in LIB.

7.1.19 HYP output

Output from the program is a CAT-file (`hyp.out`) and the original HYPOCENTER print file (`print.out`) with more detailed information. The `hyp.out` file can be plotted directly using EPIMAP or MAP. In addition, there is also the HYPO71 style summary file, hypsum.out. NOTE: In `print.out` and hypsum.out, year is only given with 2 digits. Magnitude in hypsum.out and `print.out` are only coda magnitude and will be different from same magnitude in `hyp.out` if a magnitude correction has been used.

When HYP is executed from EEV, the `print.out` file has no station listing. In all other cases, there is a station listing.

Some explanation is given below, for details see HYP manual

The output in `print.out` first shows the content of the TEST parameters in the `STATION0.HYP` file. After that comes some routine output from the starting location algorithm. Then follows the output from the iterations, which should be self-explanatory. The location is then given on one line containing origin time, latitude longitude (deg min), depth, number of phases, the number of degrees of freedom in the spatial solution (maximum 3), rms damping and errors, error estimates, resolution matrix. Last are the station lines with the following abbreviations:

```
stn  : Station
dist : Distance in km
azm  : Azimuth at the source
ain  : Angle of incidence at the source
phs  : Phase specified by user
calcphs: Phase used by program
w    : Input weight
hrmn : Hour minute
t-sec: Arrival time sec
t-obs: Observed travel time
t-cal: Calculated travel time
res  : Residual
wt   : Weight usedi by program, normalized to 1.0
di   : importance of phase in %
     : network and locaiton, no header
```

An example of output on screen is given below

```
  date hrmn   sec      lat      long depth   no m    rms  damp erln erlt erdp
16 1 1  029  9.85 6749.40N  20 21.0E  15.0    8 3   0.53 0.000 54.9 42.6118.6
 stn   dist   azm  ain w phas    calcphs hrmn tsec  t-obs  t-cal    res   wt di
 KIF    137   7.6 55.1 0 P       PN4      029 29.9  20.05  21.06  -1.01 1.00 16
 KIF    137   7.6        BAZ                       169.2  188.0 -18.82 0.20  9
 KIF    137   7.6 55.1 0 S       SN4      029 46.4  36.55  36.64  -0.09 1.00 29
 HEF    152  63.2 55.1 0 P       PN4      029 32.5  22.61  22.93  -0.32 1.00 12
 KTK1   178  40.5 55.1 0 P       PN4      029 36.2  26.36  26.07   0.29 1.00  4
 STEI   215 275.5 55.1 0 P       PN4      029 40.3  30.50  30.66  -0.16 1.00 10
 FAUS   221 259.5 55.1 0 P       PN4      029 40.9  31.09  31.38  -0.30 1.00 16
 ARA0   283  45.3 55.1 0 P       PN4      029 50.6  40.75  39.16   1.59 1.00  4

 KTK1 HZ   hdist:     178.6   amp:           2.5 T:   0.2   ml =   0.9
 ARA0 HZ   hdist:     283.4   amp:           2.2 T:   0.8   ml =   1.2
 2016  1 1 0029  9.9 L  67.823  20.349 15.0  RRR  6 0.5 1.0LRRR
 OLD:  1 1 0029  8.6 L  67.854  20.249  0.0  BER  6 0.6 1.0LBER

In case of Nordic2 format, it would  be


  date hrmn   sec      lat      long depth   no m    rms  damp erln erlt erdp
16 1 1  029  9.60 6747.52N  20 25.9E  15.0    8 3   0.59 0.000 45.2 20.4 95.9
 stn   dist   azm  ain w phas    calcphs hrmn tsec  t-obs  t-cal    res   wt di
 KIF    140   6.1 55.1 0 P       PN4      029 29.9  20.30  21.44  -1.14 1.00 29 FI00
 KIF    140   6.1        BAZ-P                     169.2  186.4 -17.22 0.20  5 FI00
 KIF    140   6.1 55.1 0 S       SN4      029 46.4  36.80  37.30  -0.50 1.00 26 FI00
 HEF    151  61.5 55.1 0 P       PN4      029 32.5  22.86  22.74   0.11 1.00  9 FI00
 KTK1   178  39.0 55.1 0 P       PN4      029 36.2  26.61  26.13   0.48 1.00  4 NS00
 STEI   219 276.4 55.1 0 P       PN4      029 40.3  30.75  31.13  -0.39 1.00 10 NS00
 FAUS   224 260.6 55.1 0 P       PN4      029 40.9  31.34  31.73  -0.40 1.00 12 NS00
 ARA0   283  44.3 55.1 0 P       PN4      029 50.6  41.00  39.16   1.84 1.00  5 NO00

 KTK1 HZ   hdist:     178.6   amp:           2.5 T:   0.2   ml =   0.9
 ARA0 HZ   hdist:     283.4   amp:           2.2 T:   0.8   ml =   1.2
 2016  1 1 0029  9.6 L  67.792  20.432 15.0  RRR  6 0.6 1.0LRRR
 OLD:  1 1  029  8.6 L  67.854  20.249 0.00  BER  6 .60 1.0LBER
```

BAZ means there is a back azimut for station KIF. For the Nordic2 format, it is shown that the BAZ is on the P. In addion, KIF has NTLO shown at the end of the line. At the end of listin is shown the original data (OLD) and the new hypocenter so it is easy to compare the effect of changing someting. In the print.out file there are details of the difference between the two hypocenters.

A station weight wt=-1 means that the phase travel time could not be calculated. The output phases can be e.g. PN2, where 2 means that the phase calculated has been refracted in layer 2 and PN5 refracted in layer 5. The input phase is then just P and a local model is used.

To get a statistics of which phases the program has used, run the program HYP_COUNT_PHASES. It uses the print.out file to count all types of local phases like PG, PN2 etc. For an example see, section "Inversion of travel time..."

Any change in the input phase ID is signified by an asterisk (*) before the phase ID.

If amplitudes are available, Ml, Mb. Mw or Ms will be calculated, and all stations calculating Ml, Mb, Mw or MS will additionally be displayed at the end of the interactive printout.

Change of day:

If the origin time of the located event occur on the day before the time in the header line, the time in the header line is changed to the previous day and all phase arrivals are changed accordingly. This means that some hour values will be more than 23 since phase arrival times refer to the main header.

Seismic moments etc: After locating an event, HYP will check if there is spectral information (Moment etc, see MULPLT) available in the S-file and average values will be calculated and written into the output file.

7.1.20 Problems

If no location or an obviously wrong location is obtained, check `print.out`. Common problems are:

- Wrong location: Program gets into a local minimum. Use the individual event start location option ('S' in header line). If the problem happen often, try either option for start location (nearest station or start location routine). If dept is the problem, try a range of start depths (set in `STATION0.HYP`)

- No location: The program iterates outside the maximum distance set for a local or regional event (RESET TEST 57) or the initial start location is outside limits. Use a fixed start location or check readings to get a better start location.

7.2 The Hypoinverse program, HYPINV

The latest version of Hypoinverse-2000 program (version 1.40, 2014) has been implemented in SEISAN to be use within EEV and as standalone. The original program has not been changed except to increase number of stations (25k). The original manual is found in `INF`. The main program has been given the name HYPINV (original version was HYP in conflict with HYP for HYPOCENTER) and can be run according to the original manual (Klein, 2014) and will not be described here. With a new driver program HYPINV_SEISAN, Hypoinverse can be run using Nordic files as input and output. Only the archive format for input and output is used directly with Hypoinverse.

The program does not work well at large distances ($> 1000km$) so use it only for local earthquakes.

If original data, station and control files are available, it is just typing HYPINV and the program will run according to the manual. If none of these files are available, they can be made with the conversion programs, see below.

HYPINV can be operated in 3 ways:

Alternative 1: Manually do all steps:

1: Convert a `CAT` file a Hypoinverse input file with the program NORHIN, e.g. `norhin collect.out`. The input file in Nordic format is converted to a file `norhin.out` in Hypoinverse format. The following limitations and additions apply:

- Only local events with at least 3 stations will be converted.

- Since HYPOINVERSE only use first arrivals, all P and S phases will be converted to P or S, like PG to P. There is then the possibility that there will be e.g. two P's if the original data has e.g. Pg and Pn.
- The S-P time cannot be used by HYPOINVERSE. The weigh 9 will result in zero weight on the P but the corresponding S-time will be used so it should manually be weighed out.
- Lg and Rg phases are not used.
- Polarity and coda length are transferred.
- The hypocenter location is transferred to the norhin.out file but not the magnitudes.
- A fixed depth in input file is transferred to `norhin.out`. HYPOINVERSE cannot fix depth at zero, must be at least 0.01 km. If put to 0.000, depth is not fixed. If event qualifier is P or E, the depth is fixed in output file to 0.01 km.
- In order to recover the original component names, the two letter component code is put in at available places in the archive format (columns 87 and 109). This information is written out again by Hypoinverse.
- The event id (minus year) is saved on the hypoinverse header line in the field for id. It is later used for conversion back to Nordic format.

2. Make the control files with the program MAKEHIN. This creates the instruction file `hypinst`, station file `hypinv.sta` and model file `hypinv.mod`. These files are standard HYPOINVERSE files. The information is taken from the `STATION0.HYP` file in either the working directory or `DAT`. MAKEHIN cannot work with an alternative `STATIONx.HYP` file. If the `hypinv.sta` or hypinst files are present, they will not be generated. This allows for changes in the Hypocenter parameters to be used in subsequent runs. On the other hand, if the `STATION0.HYP` file is changed, the `hypinst` and `hypinv.sta` files must be deleted before the changes in `STATION0.HYP` will be used. The following parameters are partly generated from `STATION0.HYP`:

- Vp/Vs
- Start depth
- Minimum number of stations, however less than 3 is not allowed.
- Distance weighting starts at iteration 4, starts at HYPOCENTER parameter xnear and is zero at approximately xfar. However that assumes that xnear is further away than the second closest station. Hypoinverse parameter DISCUT is set to xnear, DISW1 is set to 1, and DISW2 = xfar/xnear. See Hypoinverse manual for details.

3. Type HYPINV and the program runs. There is a one-line output per event on the screen and the full output is in a file called `print.out`.

The output file from HYPINV is now `hypinv.out` and it can be converted back to Nordic format with program HINNOR, however, some of the original information is lost (like e.g. amplitudes). To avoid this, see alternative 2. HINNOR transfers the following information:

- Hypocenter with rms.
- Error line with gap and erz (vertical error) and erh (horizontal error). The Nordic values erlat and erlon are both replaced by erh.
- Magnitudes L and C in Hyoinverse file. If program HYPIN_SEISAN is used, the magnitudes are overwritten with the original values.
- Residuals.
- Distances, Hypinverse will give 999 if more than 1000 km.

- Angle of incidence.
- Azimuth.
- Weights used.
- Polarity.
- Coda length.

Alternative 2: Run the whole process using the driver program HYPINV_SEISAN. The program does the following:

- Run NORHIN
- Run MAKEHIN
- Run HINNOR
- Generate an output file in Nordic format `hypinv_seisan.out` that contains the new HYPINV location with corresponding residuals etc as well as all the original information in the Nordic input file like amplitudes, spectral information etc. The only thing lost is the original P and S phase names. All the R and D events skipped by NORHIN are put back in. To keep track of the events, the ID is used. The ID line will get the action flag HIN. The original magnitudes, agencies and number of stations are kept.

Using alternative 2 makes it very easy since Nordic file is both input and output.
Alternative 3: Running HYPINV from EEV using the command H. The steps are:

- EEV runs HYPINV_SEISAN using current s-file.
- The `print.out` file is printed on the screen.
- The user is asked if the data base should be updated with the combined file `hypinv_seisan.out`.

It is thus possible to use HYPINV to update the data base of local events with the limitations mentioned under alternative 1.

Note: Hypoinverse use residual weighing by default so rms and errors might be smaller than locating with Hypocenter.

Magnitudes

No magnitudes are transferred from Nordic files to Hypoinverse files. Coda magnitude is calculated with Hypoinverse using the Hypoinverse default relations. If the magnitudes have to be updated due to significantly changed location, it must be done with SEISAN EEV command 'u' and with the hypocenter fixed so the original HYPINV location is preserved.

How to run Hypoinverse with other parameters

Hypoinverse has many options of which the multiple models might be the most interesting. Generate the standard input files as in alternative 1 and then modify them according to the Hypoinverse manual. Then run HYPINV directly or, as the hypinst file is not changed if it exists, using alternative 2 or 3.

sectionHYP_ISC (Unix and Linux only)

Program written by **Richard Luckett**

ISC has for many years used a standard procedure to locate earthquakes and the ISC locations have often been used as a reference. The earth model used is the Bullen tables. ISC has recently rewritten the old location program and it was therefore possible to also port it to SEISAN. The purpose is that it should be possible to compare standard ISC locations with location using other programs and models. The implementation in SEISAN was done using the standard hyp program where only the location routines have been changed. The program then behaves almost identical to HYP and uses the same format input and output files.

Parameter files: STASTION0.HYP is used for station coordinates, magnitude scales and agency code. The crustal model information is not used and only the RESET TEST parameters related to magnitude are

used. In addition, there is a new parameter file (in DAT) `iscloc.def` with parameters specific for the ISC location routines, see file for explanation of parameters.

Input data files: Just like for HYP

Output files: Hyp.out is like before, `print.out` is different.

Not all crustal phases used with HYP may be available. The weights used in SEISAN do not apply since the program uses residual weighing only, see parameter file.

Magnitudes are calculated exactly like in SEISAN.

In eev, the command to locate with HYP_ISC is 'il'.

For more information about the ISC location program, see `http://www.isc.ac.uk/Documents/Location/`

7.3 Plugin for the iLoc location algorithm, ILOC_SEISAN (Linux only)

A plugin for version 2.04 of the iLoc program, written by **István Bondár** (Bondár and Storchak, 2011), has been implemented in SEISAN to be used within EEV or as stand-alone. The purpose of the plugin is to have the possibility of event location with a regional 3-dimentional velocity model. Since iLoc use the Regional Seismic Travel Time (RSTT) (Myers et al., 2010) velocity model as part of its event location it serves this purpose.

iLoc must be installed on the system used and the program `iloc` must be in the path. iloc is not included in SEISAN.

One only need to compile iLoc with the ISF I/O option to be used with SEISAN. RSTT is part of iLoc and is required. See the iLoc installation instructions: `http://www.seismology.hu/index.php/en/home/iloc`

Note, only stations registrated to the ISC are included in iLoc. Otherwise one must add used stations to the file `isc_stalist` in the iLoc aux_data folder. If your stations have been registreated at the ISC recently, download a new station file at: `ftp://ftp.isc.ac.uk/pub/iscloc/isc_stalist`
If iLoc does not have the station information it will type: textttReadISF: missing station STATIONCODE

There are three ways of using iLoc in SEISAN:

1 From EEV; in EEV type:
`iloc`
The process here is similar to the the stand-alone gien below, but the user will have the option to save the output in the database.

2 Stand-alone, type:
`iloc_seisan <sfilename> <operator_id>`
The program ILOC_SEISAN will read the sfile, convert the sfile to isf format, using the ISFNOR program (output filename: `norisf.out`). Next the iLoc program is executed, it reads the isf file. If data are not ok for hypocenter inversion iLoc will end. If data are ok for hypocenter inversion result is printed on the terminal and written as isf format in the file `iloc-out.isf`.

3 In a loop over many events:
Make a index.out file with SELECT program, run the program ILOC_LOOP. ILOC_LOOP will read all sfiles in index.out and add the iLoc solutiuon to the sfiles if a solution was found.

Below is the first header lines of an sfile that includes the iLoc hypocenter solution. The two last type L lines are from iLoc:

```
 2016 0229 2320 01.8 LE 67.177  20.623  0.1F UPP  9 0.2 1.5LUPP                1
 LOCALITY: 612636992 Sweden                                                   3
 2016 0229 2320 02.67   67.1608    20.6182    0.0   f 0.45  INTAR ILOC         L
 GAP 79 E 0.98 j  4.2 i  3.9 A 82 s  16 d  26m  0.04M  3.87 INTAR ILOC         L
```

The agency code is from the enviromental variable AGENCY or if that is not used from the station file, e.g. STATION0.HYP.

The format of the first type L line is the same as the type H line described in Appendix X. The format of the following comment line is:

```
1:4 ' GAP'
5:7 Gap in azimuthal coverage (degrees), i3
8:9 ' E'
10:14 Origin time error (seconds) f5.2
15:16 ' j'
17:21 Semi-major axis of 90% ellipse or its estimate (km), f5.1
22:23 ' i'
24:28 Semi-minor axis of 90% ellipse or its estimate (km), f5.1
29:30 ' A'
31:33 Strike of error ellipse clock-wise form North (degrees), i3
34:35 ' s'
36:39 Number of defining stations, i4
40:41 ' d'
42:45 Number of defining phases, i4
46 m
47:52 Distance to closest station (degrees), f6.2
53 M
54:59 Distance to furthest station (degrees), f6.2
60 Free
61:65 Agency, a5
66 Free
67:73 'ILOC   ' Method used, a7
74:79 Free
80 '3'
```

7.4 Plugin for the NonLinLoc location algorithm, NLL_SEISAN (Linux only)

ONLY IN ALPHA VERSION AND ONLY TESTED ON LINUX

A plugin for version 7.00 of the NonLinLoc (Non-Linar Location) program, written by **Anthony Lomax** (Lomax et al., 2009), has been implemented in SEISAN to be used within EEV or as stand-alone. The purpose of the plugin is to have the possibility of event location with a 3-dimentional velocity model.

Chapter 8

Trace plotting, phase picking and spectral analysis, MULPLT

This program is the general plotting and signal analysis program. The program is capable of doing general phase picking, correct for instrument response, and produce Wood-Anderson seismograms for determining Ml, synthetic traces for Mb and Ms, determine azimuth of arrival for 3 component stations, do spectral analysis and particle motion. The program can also read in theoretical arrival times for global phases for help in identifying phases. If a quick location is needed based on a waveform file only, mulplt can both pick the phases and locate the event. MULPLT operates either as a database independent program (started with command MULPLT) or in connection with the database (started from EEV with command P or PO). If the program works independently of EEV, it will create an output file mulplt.out in Nordic format with the readings and results of spectral analysis. This file can directly be used with e.g. HYP. MULPLT reads and plots one channel at a time. This can be very time consuming when replotting traces and from SEISAN version 8.2, a certain number traces are kept in a memory buffer in order to speed up replotting and reprocessing The data is stored in one large array the size of which is determined at the time of compilation so for systems with many or long traces, it might have to be larger and for systems with little memory it might have to be smaller. The dimension is set in file seidim.inc in directory ./INC using variable max_mem_sample. A typical value is 30 000 000.

Note on Seed/Miniseed reading

The routines will put in zeros for gaps

If an overlap occurs, the block with the overlap will be discarded and zeros inserted.

If a block is out of time sequence, the block will be discarded, this is like a large negative overlap.

The channel start time will be considered the time of the first block found for that channel. If a block then occurs before the start time the block will be discarded.

Starting MULPLT from prompt line

Giving the command `mulplt -h`, will show the basic options:

```
The MULPLT program - for plotting earthquake data

Usage: mulplt [options]
       enter input

## Options ##
  -help        Print this list
  -h           Same as -help
  -plotdefault Will plot data directly with default values
  -qdp         Same as -plotdefault
  -po          Same as -plotdefault
  -version     SEISAN version
```

```
Examples:
      1)  mulplt
          enter values
      2)  mulplt -plotdefault -sfile /home/seismo/REA/TEST_/1996/06/03-1955-40D.S199606
```

Giving command `mulplt`, the question is

```
Filename, number, filenr.lis (all)
Continuous SEISAN data base: cont
Large SEED volume: conts
Archive: arc
Make a choice
```

Filename, number, filenr.lis(all): The program asks for a file name or file number of a waveform file. To use the number, it is assumed that a list of files has first been created and numbered in a file `filenr.lis` using command DIRF, see section 15. By giving the number, the file corresponding to the selected number is used. By giving a ?, the list with numbers is displayed and a new number can be given. If many files are to be plotted with one command (hard copy only), give `filenr.lis` for file name and all events in FILENR.LIS will be plotted. There will only be one question about filter and then all events are plotted with all channels and the chosen filter.

Cont: Plot from a continuous data base. The program will use all data bases defined in `SEISAN.DEF`. A question will be given for absolute start time and window length. See also 8.5. Conts: Plot from a large SEED volume. A SEED file too large to be read in can be plotted in parts. A question will be given for file name or number. The file is then read and available data is displayed. Start time and window length is then entered.

arc: Plot from a BUD or SeisComp archive

Plot from a continuous archive. The program will use all channels defined in `SEISAN.DEF`. A question will be given for absolute start time and window length. See also 8.5. Then follows a display showing all stations and virtual networks that are defined in SEISAN.DEF before a channel selection is made. It is possible to combine selection of stations with one or more virtual networks. MULPLT removes duplicates in case a station should be selected more than once. See also secion 'Working with many channels in MULPLT' a bit later.

8.1 MULPLT main functions

The program has 7 main functions irrespective of type of input as illustrated below with the questions given by the program:

```
Plot options:          Interactive picking          Return
                       Multi trace plot on screen, def (0)
                       Multi trace plot on screen      (1)
                       Multi trace plot on screen+laser(2)
                       Multi trace plot on laser       (3)
                       Continuous on screen            (4)
                       Continuous on screen + laser    (5)
                       Continuous on laser             (6)
                       Stop                            (9)
```

Return:	Picking phases, spectral analysis and 3 component analysis
0:	Initial plotting of new waveform data and registration in database using predefined defaults. Phase picking.
1:	Initial plotting of new waveform data and registration in database, or general plotting of multi-trace data. Phase picking. In this mode, the user is asked to select which channels to work with and a graphical window will be shown for selection. If more than 250 channels are available, selection will have to be made on several screens. A maximum of 1000 channels can be used. Optionally, channels can be shown in alphabetical order (see `MULPLT.DEF`).
2:	Same as 1, only hardcopies may be made at the same time.
3:	Making hardcopies of many waveform files with one command. No screen output.
4,5,6:	Plotting one channel continuously like on a seismogram with several traces from left to right on top of each other. One channel can be selected. Time windows can be selected for event extraction.

For continuous data, see 2.2.2 and 8.5.

Commands f and q: With a plot on the screen, q will always quit mulplt. F will, in single trace mode, bring up the next channel, in multi trace mode bring up the next event whether input is from a filenr.lis or EEV.

Option 0 is particular useful for checking many new events, since the program does not ask question about station choice (uses definition in `MULPLT.DEF` file in DAT, or working directory) and typing f (when the plot is on the screen) automatically goes to the next file in `filenr.lis`.

If option 1,2 or 3 is used, a display will show the available channels and the user can click to select. If MULPLT is operated from EEV, a * in a channel box will indicate that readings are available. NOTE: The channel will be marked if only the orientation code is matching. When the channel selection is shown, it is possible to quit the program with q or continue with f.

If option 4,5 or 6 is selected, continuous data is plotted, see below.

Running MULPLT using command MULPLT, the program asks for a file name or file number of a waveform file. To use the number, it is assumed that a list of interesting files has first been created and numbered in a file `filenr.lis` using command DIRF, see section 15. By giving the number, the file corresponding to the number is used. By giving a ?, the list with numbers is displayed and a new number can be given. If many files are to be plotted with one command (hard copy only), give `filenr.lis` for file name and all events in FILENR.LIS will be plotted. There will only be one question about filter and then all events are plotted with all channels and the chosen filter.

Hardcopies assume a PostScript printer. For each event plotted, a plot-file called `mulplt.eps` is generated. The plot files are sent directly to the printer from within the program with the seisan print command as soon as the plot is finished for one event but before the program is finished. In Unix, this is lpr or lp while on PC, the command is given in a .bat file in COM (see installation section). This means that the same plot-file is overwritten for each event plot. For setting up the printer, see installation, chapter 3.

In multitrace mode, many traces (number limited by the SEISAN system definitions, see chapter 3) can be plotted. If the plot is made via EEV, all picks are also displayed.

Location of waveform file:

Mulplt will search in current directory first. If not found there, the WAV directory is searched. If the `SEISAN.DEF` file has been set up, MULPLT will thereafter try to locate the waveform file in one of the databases or specific directory given in the `SEISAN.DEF` file (located in DAT or working directory).

Format of waveform files: MULPLT can, on all platforms, use SEISAN, GSE, SAC ASCII and binary, GURALP (one channel files), HelmMberger Format and SEED. If started from EEV, files in different formats

can be used at the same time.

Time gaps in waveform files:

Only SEED format has running time headers and therefore the only format where a possible time gap, in one file, can exist. SEISAN will replace missing data intervals with zeros. For a SEISAN continuous data base, it is assumed that a gap of less than 2 s between files is not a gap. Larger gaps will be replaced by zeros.

8.2 Use of MULPLT from EEV and SE

In order to process events more easily, EEV and SE and MULPLT have been tightly integrated. When MULPLT is called from EEV or SE, command f will plot the next event in the database, to go back to the same event in EEV, use quit. The event can be plotted with default parameters from EEV using PO. If PO has been selected, the f command in MULPLT multi trace mode will show the plot of the next event with default options. This is a fast way of plotting waveform files going through S-files in a database. The command poo does the same as po except that you start in single trace mode. In SE, command P corresponds to PO in EEV.

If several waveform files are available, the user will graphically be shown the files and can select one or several Files can optionally be displayed in alphabetical order (see `MULPLT.DEF`). If more than 75 files, several selection screens will be shown. A maximum of 1000 files can be used if the PO option has been used, all default channels will be used.

Plotting from EEV or SE, a file with a list of waveform files can also be used as input. The filename must end with _LIST. The filename could be e.g. 2002-02-02-1310-20S.BER_LIST. The format is the filenr.lis format so the file can be created with DIRF. The _LIST file can be in local directory, WAV or any other directory as specified for normal waveform files. The intention with the list option is to be able group many waveform files in one group without the need to merge the files or list them all in the S-file. The limit of number of files in the _LIST files is 1000 and up to 10 _LIST files can be used for the same event. There is currently no automated facility to create and include _LIST files in the S-file.

Components: The picks in the S-file are plotted on respective traces if both the station name and component matches. The waveform file has in general a 3 letter component code. Nordic2 also has 3 letter component code while the old Nordic format S-file only has 2 so here only the first and last letters are checked for matching. Similarly, when writing a pick to the S-file, in Nordic2 all 3 are writen to the S-file, but in old Nordic only first and 3. letters are used. In case there are no compoenet code in S-file, the readings in the S-file are shown on all componenets. If any subsquent readigs are done, the component code of the first channel used will be assigned to all readings for that station.

8.3 Working with many channels in MULPLT

Many networks have several hundreds of channels which quickly becomes difficult to work with. MULPLT has several options to facilitate working with many channels, whether working with an archive, SEISAN continuous data base (cont base), individual files or a combination. Note that MULPLT is setup to handle up to 1000 channels. Some of the options are:

Limit the number of channels on one screen (all input): The number of channels per screen is parameter NCHAN PER SCREEN in MULPLT.DEF. From each screen, channels can be selected and the user can go forward to the next screen with TAB. It is not possible to go backwards. If there is a need to temporarily see all channels on one screen, command N in multitrace mode will do that. This can be useful if the Out function (writing out a file of what is seen on the screen) is used. Alternatively, when registering an event from an archive or a cont base, the extracted file can have all channels irrespective of what is seen on the screen.

Set default stations to be plotted in default mode (all input): The stations are defined in MULPLT.DEF and only those stations will be plotted in default mode.

Plotting only stations with readings or only Z-channels (all input): When the channel selection screen comes up, there is an option to select only stations with readings (Picked or p). Since then channel selection screen only has 250 channels, there might be up to 4 channel selection screens and the next screen

is chosen with f. If however F is pressed, only channels with readings are also selected for the remaining channels without the following screens being shown. Similarly the command for only Z-channels are z and F, respectively, to get all Z-channels for the whole data set.

Plotting only stations within a given distance, radius, from a user selectable point, the midpoint (all input): Since most events with large networks are only recorded with the nearest stations, this option is very effective in limiting the chosen data to the most important stations. There are several options for selecting midpoint and radius using parameter MULPLT AREA in MULPLT.DEF:

1: Midpoint from epicenter in S-file, radius from MULPLT.DEF

2: Midpoint from epicenter in S-file, radius asked at start of MULPLT

3: Midpoint and radius from MULPLT.DEF

4: Midpoint from MULPLT.DEF, radius asked at start of MULPLT

5: Midpoint and radius asked at start of MULPLT

6: Midpoint from a station in MULPLT.DEF, radius from MULPLT.DEF

7: Midpoint station asked at start of MULPLT, radius from MULPLT.DEF

8: Both midpoint station and radius asked at start of MULPLT

In addition, in multitrace mode, the radius can be changed (command R) and a center station can be entered (command S). If command S is given and there is no radius defined, the user will also be asked for radius.

Plotting stations from an archive: A large number channels can be specified in the archive (currently max 3000). All channels will initially be available to the the user and the starts times etc. read in. This can take some time, so in order to avoid first reading the channels and then selecting channels present with data, it is possible to preselect which channels should be checked (first station selection screen when using arc). A furhter reduction in the number of channels to check is to use the option above for distance to a station or a point. This distance check is done before the channles are checked.

Archive referencing in S-files is described in section 2.2.3. An example of an archive reference line is:

```
ARC STAT  COM NT LO YYYY MMDD HHMM SS   DUR
ARC BORG  LHZ II 10 2011 0129 0650 00  3600                                        6
```

which is referring to one channel (station STAT, component COM, network NT, date-time and duration DUR (s)). With many channels, this referencing becomes a bit cumbersome and some wild cards can then be used:

If the station name begins with _ the ARC line is a link to a virtual network.

Station is blank or *, component, network and location are blank: All channels defined in SEISAN.DEF will be plotted with start time and duration given in ARC line (if not blank, see next option). If a component is given, only that component will be selected. If a network is given, only that network will be chosen. If a location code is given, only channels with that location code is selected.

Start time and or durations blank: Start time will be origin time - a time given in SEISAN.DEF (ARC_START), duration will be a time given in SEISAN.DEF (ARC_DURATION).

Station is P: All channels for all stations listed in the S-file found in the archive will be plotted. There is no requirement for the station to have any other information than the station name, component code is not used. So a new station can easily be added.

Plotting all stations without an archive reference line: If parameter ARC_BY_DEFAULT in SEISAN.DEF is set to 1, all channels in the archive will be selected. Setting it to 2, only stations with readings are plotted.

NOTE: An ARC line can be inserted/edited in the S-file from EEV by command arc. If there is ARC line(s) in the S-file, these will determine what is plotted and not the parameters in SEISAN.DEF. If .e.g. the station name in ARC line is X, no channels will be plotted (assuming there is no station with name X) and only otyher possible waveform file names will be used.

Optionally, the archive channel specification lines can have a time interval of validity. This is to avoid unnecessary checking of archive files if the archive has channels from different time periods. The format is: yyyymmddhh for both start and end time, only as much info as needed has to be specified. If start time is blank, start time is very early, if end time is blank, no end time. The start end end times are written in columns 61-70 and 71-80 respectively.

How to specify many channels in a separate file, the _LIST file: In some formats, a waveform file can only have one channel (e.g. SAC). Referencing hundreds of waveform files (or ARC references) in an S-file is not practical. These file names can be collected in a separate file in filenr.lis format. The file name must end with _LIST like e.g. 2012-12-01-1044-22.BERGEN_LIST and the filename is referenced as a waveform file in the S-file and also stored in the usual place of the waveform files. Up to 10 _LIST files can be referenced in the S-file so a large network can be broken up in regions, each with a _LIST file, which then can be selected separately in the file selection screen. There is no specific software, except DIRF, to create _LIST files.

8.4 Continuous plotting of one channel

This option is used to plot one channel in a multi line display and can therefore simulate a helicorder plot. This is a very different option from the plotting from a continuous data base (see 8.5). Interactive processing is not possible in this mode except for selecting time windows for event extraction, see below. Note that this does not work for continuous data in the archive structure.

Using this option the program asks for the following input:

Low and high cut for filter: Give values or return for no filter. A band pass cannot always be used with a low frequency low cut(filter unstable) so if e.g. a LP record is to be simulated, use filter limit 0 to 0.1 Hz. The zero means it is a low pass filter, not bandpass. A filter 10 to 0 would mean a high pass filter.

Seconds pr line: Number of seconds on each line.

End time: This question only appear if plotting from EEV. The list of files is then the list of events belonging to the data base used. Give end time as e.g. 2000050203

Max count: The absolute maximum count to be used for full scale. Since many lines and possibly many pagers are plotted, it is not possible to use autoscaling, and like on a seismogram, a fixed value must be set.

Lines pr page: Number of lines per page.

Station code: Station code (max 5 characters)

Componet code: The component code, max 4 characters. NOTE, since componenet codes are 3 characters, the first 2 and the 3. must be used. Like BH Z for BHZ. Some very old SEISAN waveform format files might have 4 characters.

MULPLT will plot from the first file given from the `filenr.lis` file and then continue to plot as long as more file names are given in `filenr.lis`. Alternatively if plotting from EEV, it will start with the current event and continue until the end time. So if a month of data files are given, a month of seismograms will be displayed. There is no requirement that the input files follow each other in time (no time gaps) since each file is plotted on the page where it belongs in time. However, the files must be time ordered. The continuous option can therefore be used to check availability and timing of continuous data. Discrete events can also be plotted in this mode if one want to get a display of when the events occurred. However, if filtering, it is assumed that the files follow each other in time since a few points are carried over from one file to the next to make the filtering continuous. Figure 8.5 shows an example.

Selecting time windows for event extraction in continuous one channel mode:

To extract events shown in the continuous plot one can mark a given time window by typing 's' and 'e' at the start and end of the required time window (see Figure 8.1). Selected time windows are, when plotting is finished, written to the file mulplt.ext and to the screen as wavetool command lines. By executing `mulplt.ext` (type `sh ./mulplt.ext` or `source mulplt.exe` in UNIX, on PC the name will be `mulplt.ext.bat` so just typing the name `mulplt.ext` will start the extract process) the time windows given in `mulplt.ext`, are extracted from the continuous database defined in `SEISAN.DEF`. The data files are extracted in the local directory. These files can now be registrated in a REA database with autoreg. One cannot delete a "Start" or "End" time mark. So, if another time window is required pick the new window and delete the line in `mulplt.ext` with the old time window before data is extracted.

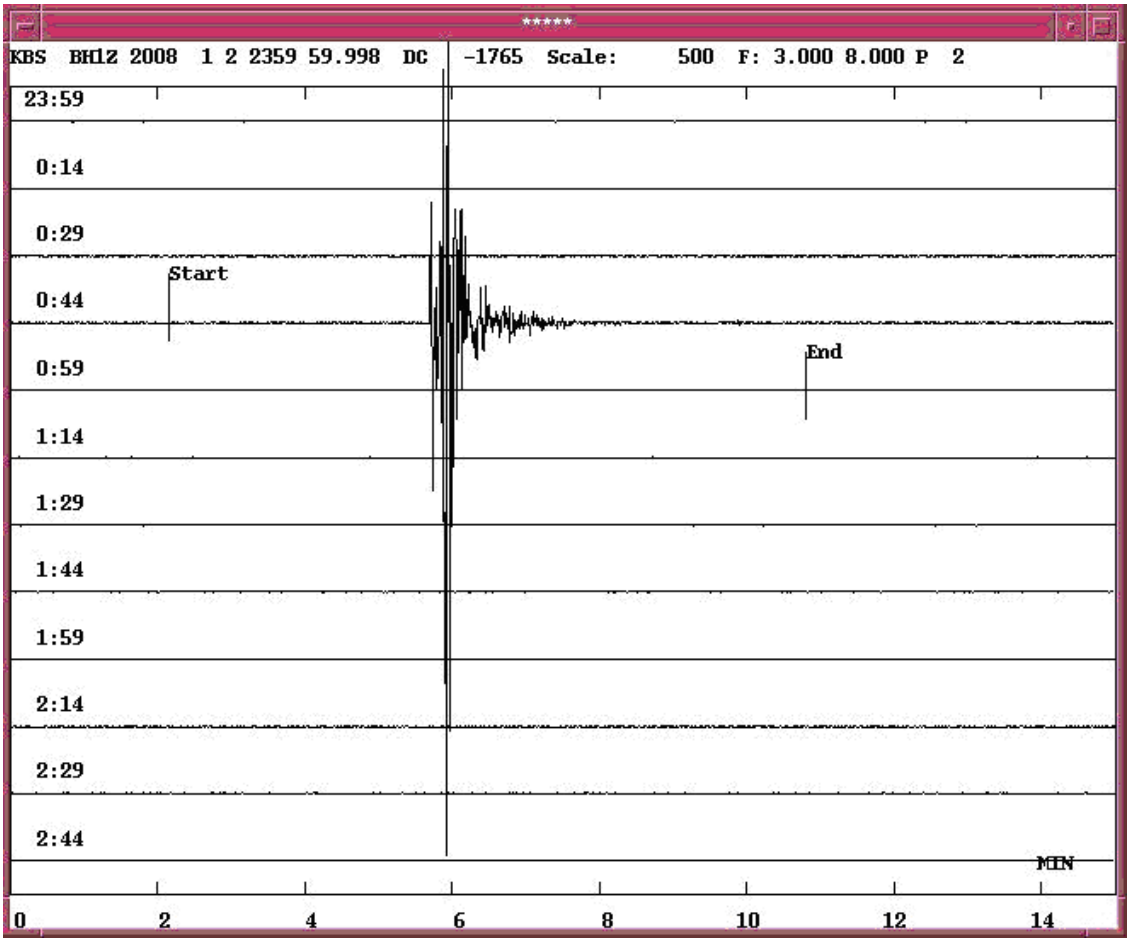


Figure 8.1: Example of time marks at the "Start" and "End" of an event recorded at the KBS station. The time marks is witten to the file `mulplt.ext` for data to be extracted and processed. Type "s" and "e" to add time marks.

The time marks is written to the file mulplt.ext for data to be extracted and processed. Type "s" and "e" to add time marks.

If the `SEISAN_LOGGING` parameter is set to 1 in `SEISAN.DEF` the analysis done with this option, will be saved in a log file in `REA/BASE_/LOG/YEAR/MM`. `BASE_` is the default database, `YEAR` and `MM` is the year and month the analysis was done. The log files are named `mulplt.cont.data-time.log`, where date-time is the time of the analysis. Logging is on by default.

8.5 Commands in MULPLT, overview

When the trace(s) are on the screen and the cursor is displayed, then several options are available. Most options can be displayed by pressing the MENU button in the upper right hand corner. Pressing MENU again removes the option boxes. Commands can be given by either pressing a letter or clicking on a box in the menu (Figure 8.6). By pressing ? or clicking on the Help button, the following help menu will be displayed:

Help on MULPLT

```
MULPLT has 3 modes:

  multi trace mode:  Displaying many traces, some picking options
```

```
  single trace mode: One trace, all picking options
  all channel mode:  All channels for selected stations


Most commands are given by pressing one key, however several commands can
also be given by clicking in the appropriate menu box on top of the screen.
If the full menu is not displayed, select the menu on top right part of the
screen. The following commands are available, first given by the single
letter command and if also available as a mouse click, the letters in the
menu box is shown. COMMANDS ARE CASE SENSITIVE.

Channel selection: In multitrace mode, one or several channels can be
selected by clicking on the station code. Several channels can be selected
by first clicking on first channel with left mouse button and then cliking
on last chanel with right mouse button.  If only one channel is selected,
and toggl (t) to single trace mode is done, a new toggl in single trace mode
will display all previous channels again.  For the channels selected in
multi channel mode, it is possible to change to single station 3-component
mode with y and back again with y. If all channels from all stations shown in
multi trace mode are desired, press u, back again with u or y.
From single channel mode it is also possible to go to all channel mode for that
station with y and back again with y.
Two channels can be plotted on same trace with different colors. If the channel
below is to be plotted on top the one above, the channel below is selected by putting cursor on
channel and pressing & and then r for repolot.


Zooming:  Select a window with the mouse and a zoomed window
          will appear below in single mode and replace the plot
          in multi mode. In Single mode, it is also possible replot
          the zoomed window in place of the original by placing the
          cursor above the trace when selecting the zoom window. This
          makes it possible to zoom in the zoomed window. In order to
          go back to the original window in multi mode, do an opposite
          zoom, meaning picking the last point first.
          In multi mode: First left click gives start of zoom window. If
                followed by a left click, end of window is selected
                independent of mouse position. If first click is right
                click, start of window is selected.


a:        Read amplitude. Position cursor at the top of
          a wave and press a.  Position cursor at the
          bottom of the wave and press a. Amplitude(0-p) and
          period are now stored. These values will be stored
          with the amplitude  phase selected. Amplitude and period are
          displayed.

A:        Automatic amplitude reading.


b:        Filter 5-10 hz, see below

B: Back   Go back one trace in single trace mode
```

```
          From eev, multi: Go back one event
          Continous data base: Go back one window

c:        Read coda.

C:        Read end of coda automatically

d:        Delete phase. Position cursor near phase and press d.

d: Del W: Delete waveform file(s), cursor outside area of trace plot, file(s)
          must be in working directory, else no files displayed. If done
          from EEV, only file names in S-file are deleted.

D: Del S: Delete S-file if operated from EEV, multi mode

e:        Phase E

E:        Call external program (defined in MULPLT.DEF) to compute spectrogram.
          Only in multi trace mode

f: Next:  Single: Go to next channel
          Multi, One event: Go to next event
          multi, continous data base: Go to next window

F: FK:    FK analysis of array data

g: Groun: Make a ground motion seismogram(s).

h: Azim:  Make 3 component analysis (single mode ONLY) to
          determine azimuth of arrival. Select a window around
          the P-phase on the Z-component. Azimuth and apparent
          velocity  will enter the S-file with the next phase
          reading.

i:        Phase I

I: Iasp   Calculate IASPEI synthetic arrival times, which are then
          displayed, multitrace only. For teleseismic events
          the IASP91 tables are used, while for local events
          the model defined in STATION0.HYP is used.
          If I is pressed again the synthetic arrivales are removed
          and the iasp.out file is deleted.

j: mb:    Generate a synthetic SP seismogram for reading amplitudes
          for determining mb.

J: mB:    Generate a synthetic BB velocity seismogram for reading
          amplitudes for determining mB.

k: Ms:    Generate a synthetic LP seismogram for reading amplitudes
          for determining Ms.

K: MS:    Generate a synthetic BB velocity seismogram for reading
          amplitudes for determining MS.
```

```
l: Locat: Locate event, only multi trace mode

m:        Filter 15-24 hz, see below

M: Merge: Merge waveform file, mulplt called from EEV, only if files are
          In working directory.

n:        Filter 10- 15 hz, see below.

N:        Toggle multiple windows to show all traces in one screen or
          one of the multiple windows.

o: Oth C: Select other channels

O: Out:   Makes an output waveform file of current
          data on screen. Only multi mode. Response info not saved.
          Standard name with YYYY_MM... is used, name is written in
          text window.

p: Regis: PUT (Register) event in database, you will be
          prompted for event type and waveform file will be copied
          to WAV.

P: PartM  Particle motion plot, requires the three components in
          multi trace plot

q: Quit:  Quit program

r: Plot:  Replot same event, useful when screen is cluttered
          up with e.g. many picks. Also used when a replot is
          wanted with new parameters e.g. filter.

R:        Change radius from epicenter or other selected point from
          which to select stations.

s: Spec   Make a spectrum, single mode ONLY. Press s, select
          window with cursor, answer questions and the spectrum
          will appear below with noise spectrum.

s:        Make a spectrogram of all traces, multi trace mode only.

S:        Same as s without the noise spectrum, singel trace.

S:        Select station for area selection, only multi trace mode.

t: Toggl: Toggle between multi and single mode

T: OutW:  Output file mulplt.wav of what is on screen

U: Rotat: Rotate components. Backazimuth is calculated from location
          in header or as a second option, taken from observed + azimuth
          residual for respective station. R is plotted instead of N and
          T instead of E. Combining 3 component option (h) with u, the
```

```
          user is asked for the backazimuth angle.

v:        Filter 1-5 Hz, see below.

y: AllC:  Toggle to and from all channel mode. Either all channels
          seen, one after the other or channels selected.

Y:        Pick a theoretical phase if displayed. Place cursor
          where the phase might be. Press y and the program will
          select nearest synthetic phase.

w: WA:    Remove system response and display synthetic
          Wood-Anderson ground motion in nanometers (nm)
          on next plot (using R or zoom).

W: Oth W: Select other waveform file, same event

z:        Filter 0.001 to 0.1, see below
x:        Filter 0.1 to 1.0 Hz, see below
Z: <W>    Increase window length in plotting from a continous data base
X: >W<    Decrease window lenght when plotting from a continous data base

>: Print: Will make a hardcopy of all channels of current event with
          the last selected filter, only in multitrace mode.

<:        Same as D

*: Scale: Fixed scaling of trace amplitudes.

Up and down arrows: Increase and decrease amplitude
Right and left mouse click: ----------------------
    In multitrace mode, the cursor must be between the
       top frame and the menus or below lower x-axis
    In single trace mode, the cursor must be below upper trace window
    Remember, space bar is the same as left mouse click

Horizontal arrows: Scroll

_: Dist:  Select plotting channels in distance order.

:  Resp:  Plot response file, single trace mode only.

TAB: NextW: Next window if multiple windows

Filter options: The fixed filters (4/8 pole Butterworth) are placed
on keys z,x,v,b,n,m with the following frequencies:

z: 01-.1: 0.01 -  0.1 Hz  Pressing key once gives a 4 pole filter one way
x: .1-1.: 0.10 -  1.0 Hz  Pressing the key twice, and the filter also
v: 1 - 5:  1.0 -  5.0 Hz  go the other way and it is now an 8 pole filter.
;  2 - 4:  2.0 -  4.0 Hz
b: 5-10 :  5.0 - 10.0 Hz  From menu, only 4 pole filters are used.
n: 10-15: 10.0 - 15.0 Hz
m: 15-23: 15.0 - 23.0 Hz
```

```
.: Filt: Variable filter, question of filter limits is given in text
         window.
,: FixF  Fix filter. If pressed aftrer selecting as filter, the filter
         remains fixed until pressing ',' again.
'        Variable filter also with number of poles
&        Overlay, see in beginning of help section.
Phase picking: This is possible in both modes. In Single mode, the phases
               defined are shown on top with some of the options, while
               they are not shown in Multi mode, but have the same
               definitions.

Combining options: Note that you can select several options together.
               E.g. V and S will first filter the signal and then
               make the spectrum.

Saving observations: When you go to the next trace or another event (F),
               the readings are saved in the S-file. They are also
               saved when you pick the next trace in Multi mode.

               This is also true for spectral parameters and azimuth
               determination.
                                                        jh 24-09-2021
```

Filters in MULPLT

All filters in MULPLT are Butterworth filters in time domain. When a filter is selected. using a hotkey or from the menu, the filter is only run one way, forward in time, and the number of poles is then 4. This will make a small phase delay where the first onset might appear a bit later, so if possible, read on unfiltered traces. If a 2 way filter is desired, press the filter key twice and the filter will also run backwards in time and the filter will be similar to an 8 poles filter. This gives theoretically a zero phase shift filter, however in practice, some of the onset energy is seen well before the first arrival, so it seems to distort the arrival times much more than using the 4 pole filter. When the program asks for a non fixed filter like when using the "." (Filt) command, the filter is always 4 poles by default. However, it is now also possible to interactively select number of poles and number of passes (1: forwards, 2: both ways) using the ' command. Press ' and the user is asked for filter frequencies, number of poles (less than 10, but more then 4 and the filter might become unstable for high sample rates) and number of passes. In addition LP (low pass), HP (high pass) and BR (band reject) filters can be used. E.g for a 5-10 Hz filter some of the choices are:

```
5 10        4 pole band pass, command .
0 10        4 pole low pass, command .
10 0        4 pole high pass, command .
-5 10       4 pole band reject, command .
5 10 2      2 pole band pass, command '
```

WHEN PLOTTING, THE FILTER LIMITS, NUMBER OF POLES AND NUMBER OF PASSES IS WRITTEN ON THE SCREEN.

For band pass filters, the number of poles for both frequencies is the same. When doing spectral analysis or response removal and specifying a filter before, the filtering is done in time domain and the filter has the number of poles specified by the user, default 4. NOTE:When reading polarities, DO NOT USE FILTER, if possible.

Filtering and instrument correction: Since filtering is done in time domain, there is an added stability filter in frequency domain to avoid low frequency blow up. This filter is a 4 pole HP filter at 1/5 the filter low frequency corner.

Filter limitations: For frequencies below 0.5 Hz, only 4 pole BP and BR filters can be used. If the user try to select another number of poles, the number of poles is set to 4.

Filtered output: Extracting data with WAVETOOL, option 'Out'. It is only possible to use 4 pole BP filters, forward in time, using any other filter and the data is not filtered. Using option OutW any filter can be used but then only Ascii Helmberger format is possible. WAVETOOL can then convert to any other desired format.

Prior to version 9.1 MULPLT used a 4 pole Butterworth filter in time domain and an 8 pole Butterworth filter in frequency domain. The filters in frequency domain were use in connection with instrument response correction and spectral analysis. It has turned out that the frequency domain filters distorted the signal in some cases, particularly for narrow band and low frequencies. Therefore, frequency domain filters are no longer generally used. The change in filter setup, might change Ml magnitudes by 0.05 to 0.1 depending on which filter (if any) was used.

Displayeing epicentral or hypocentral distance

There is an option in MULPLT.DEF to plot epicentral or hypocentral distance on multi trace plots. The distanc is shown just after the DC and is given in km. The option is set with parameter PLOT DISTANCE. The default is not to plot distance.

Displaying uncertain time

In each trace header in the SEISAN waveform file, there is a flag to indicate if the time might be uncertain (see Appendix B). If that flag has been set, the message 'UNCERTAIN TIME' will be displayed on top of the trace. Currently this flag is only put into the waveform files if the data comes from a SEISLOG system that has detected a timing error or if the data is converted from SEED/MiniSEED data. Simlarly plotting SEED/MiniSeed data, uncertain time will be displayed if that flag is set in any block in the time window read in for a particular trace.

Below is some more detailed description of some of the options. The one letter command is given with the menu command in parenthesis:

To apply filters, first make a selection of options (filter, window, channel selection) and then execute by pressing R(Plot) (or selecting a zoom window). Figure 8.2 shows an example.

Single trace mode:

In this mode, one trace is initially displayed on top of the screen, see example on Figure 8.7. The traces used are the ones earlier selected and will be displayed one by one. Several options are now possible as can be seen on the menu. Normally no hardcopies are made in single trace mode since it is intended for fast routine work. However, by starting MULPLT in multitrace mode (option 2) and then go to single trace mode (command T(Toggl)), hard copy files are made.

Multitrace mode:

In this mode hard copies can be made. If option 2 is used, both screen plot and hard copy files are made. If replot is made, only the last plot is available in the hard copy file. If option 3 is used, which is only hardcopy, there will be additional questions about, window length, start time, scaling and filters. If the scaling is set so that the plot occupies more than one page, several pages will be printed. If in this mode, `filenr.lis` is given as file name, the program assumes that all the files should be plotted and the only questions will be about the scaling and filters. All channels in each file will be plotted. This option is useful for plotting a large number of events with a single command.

All channel mode

In this mode, all channels for selected stations are displayed in a new window. This mode is particularly useful for working with three component data. By selecting one or several stations in multrace mode, all components for those stations will be displayed in new window by pressing y or ALLC on menu. Similarly in single trace mode, prsssing y or ALLC will display all channels for that station. The user can then go back to e.g. multitrace window and select another station to work with in three component mode.

Multiple screens in multitrace mode

If many channels are available (like more than 30), it might be difficult to distinguish all and the channels can be displayed in multiple screens. The number of channels per screen is set in `MULPLT.DEF`. The number of windows or screens for a particular data set is given in top left hand corner as e.g. 'Win 2 of 7' meaning current window is number 2 of 7 windows. To move to the next window, use TAB or NextW in menu. In each window, normal operation can be done. Channels selected will be kept. Using a large data set, the user can then view each window separately, select the channels of interest and when all channels have been viewed, only the selected channels will remain for display. It is possible to togle between showing all channels and multiple screens by pressing N.

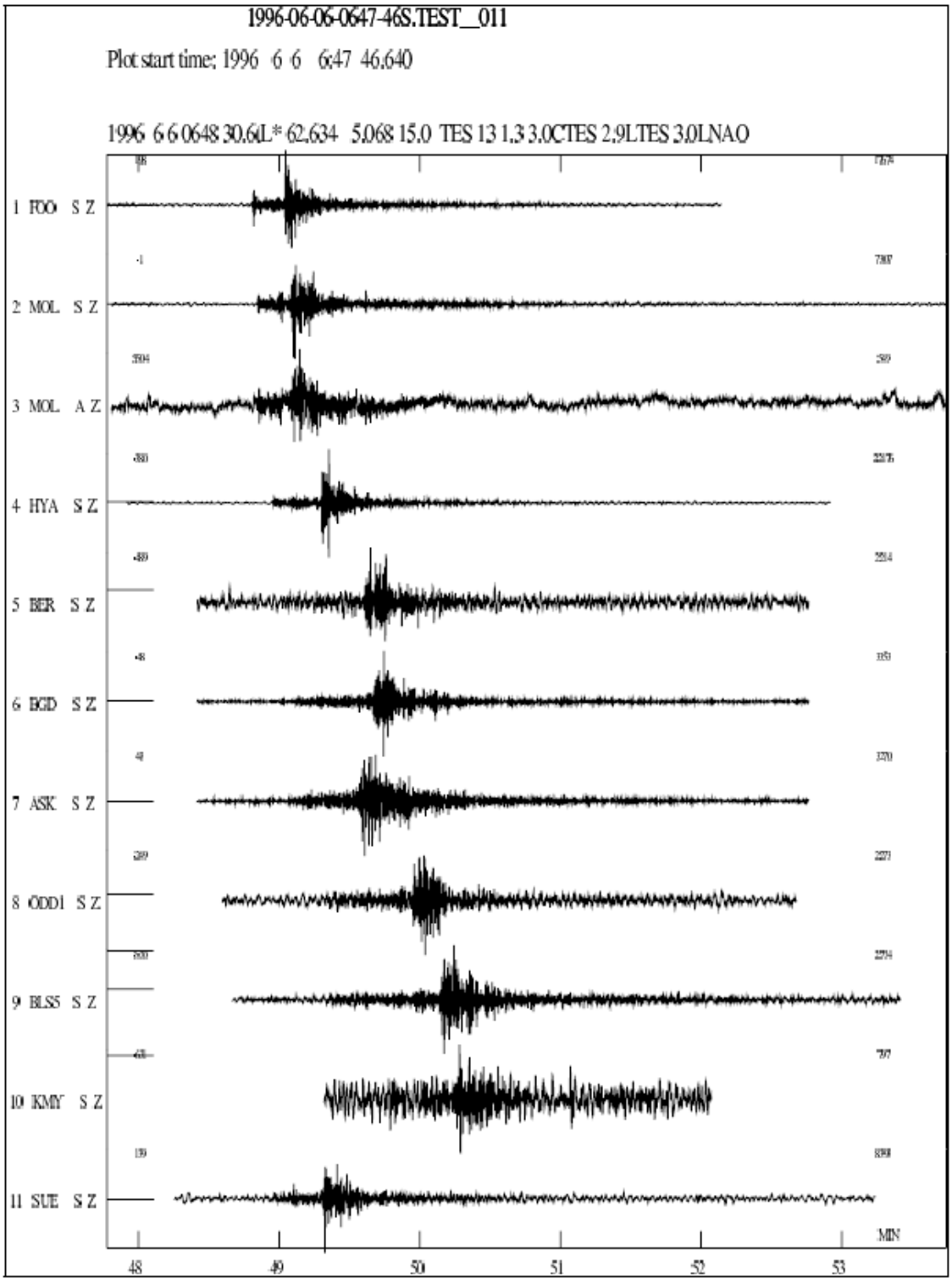


Figure 8.2: An example of using MULPLT in multitrace plot mode. Notice that start and stop times are different for different channels. The horizontal line at the start of the plot is the DC level. The small number above each trace to the right is the max absolute count with the DC-level subtracted and the small number to the left above the trace is the DC level. If plotting from EEV, the phase picks available are shown.

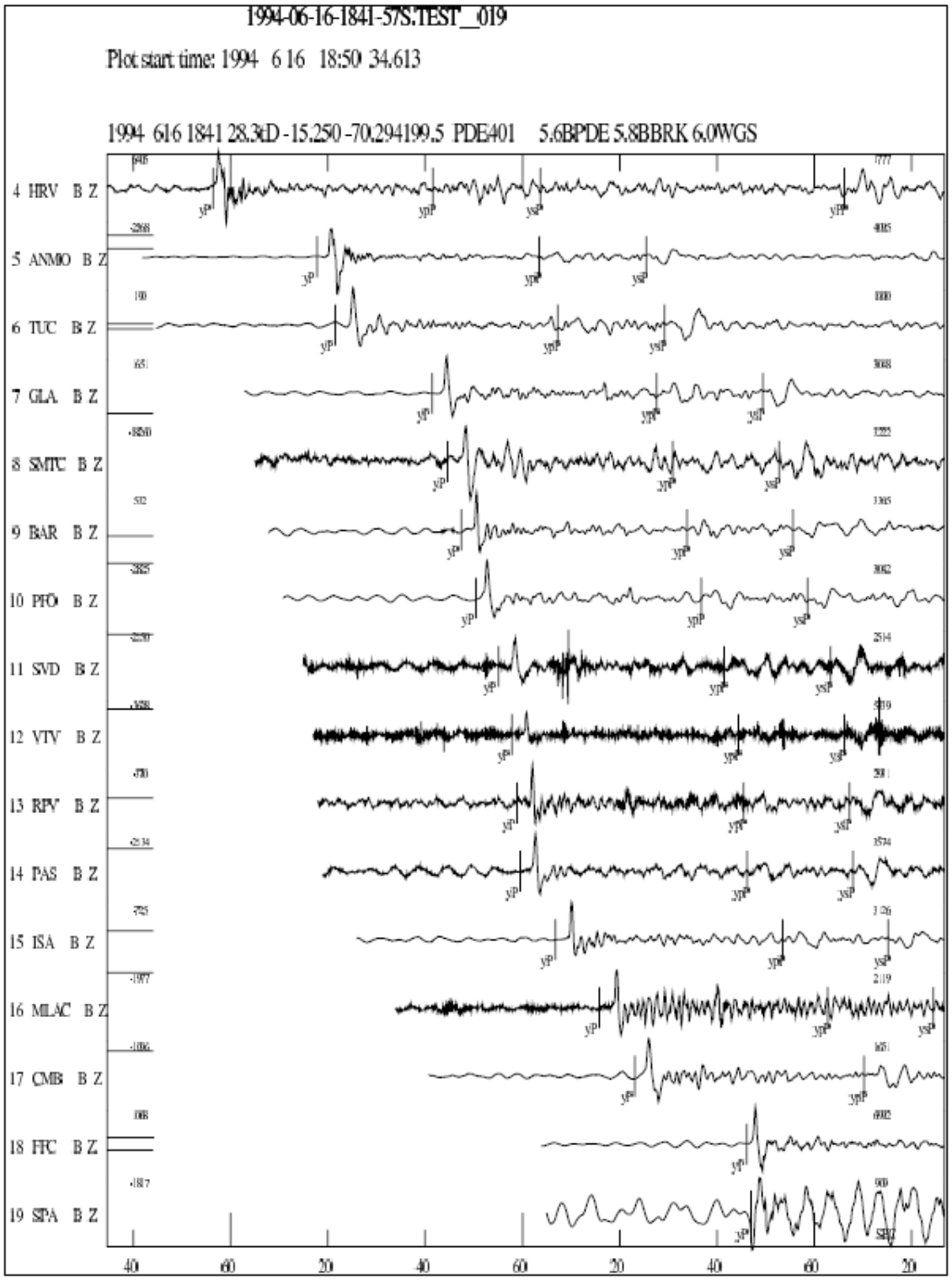


Figure 8.3: Examples of MULPLT with theoretical arrival times of some global phases. Short period seismograms are shown. The theoretical phases are marked with onset y below the trace and the read phases are marked normally above the trace.

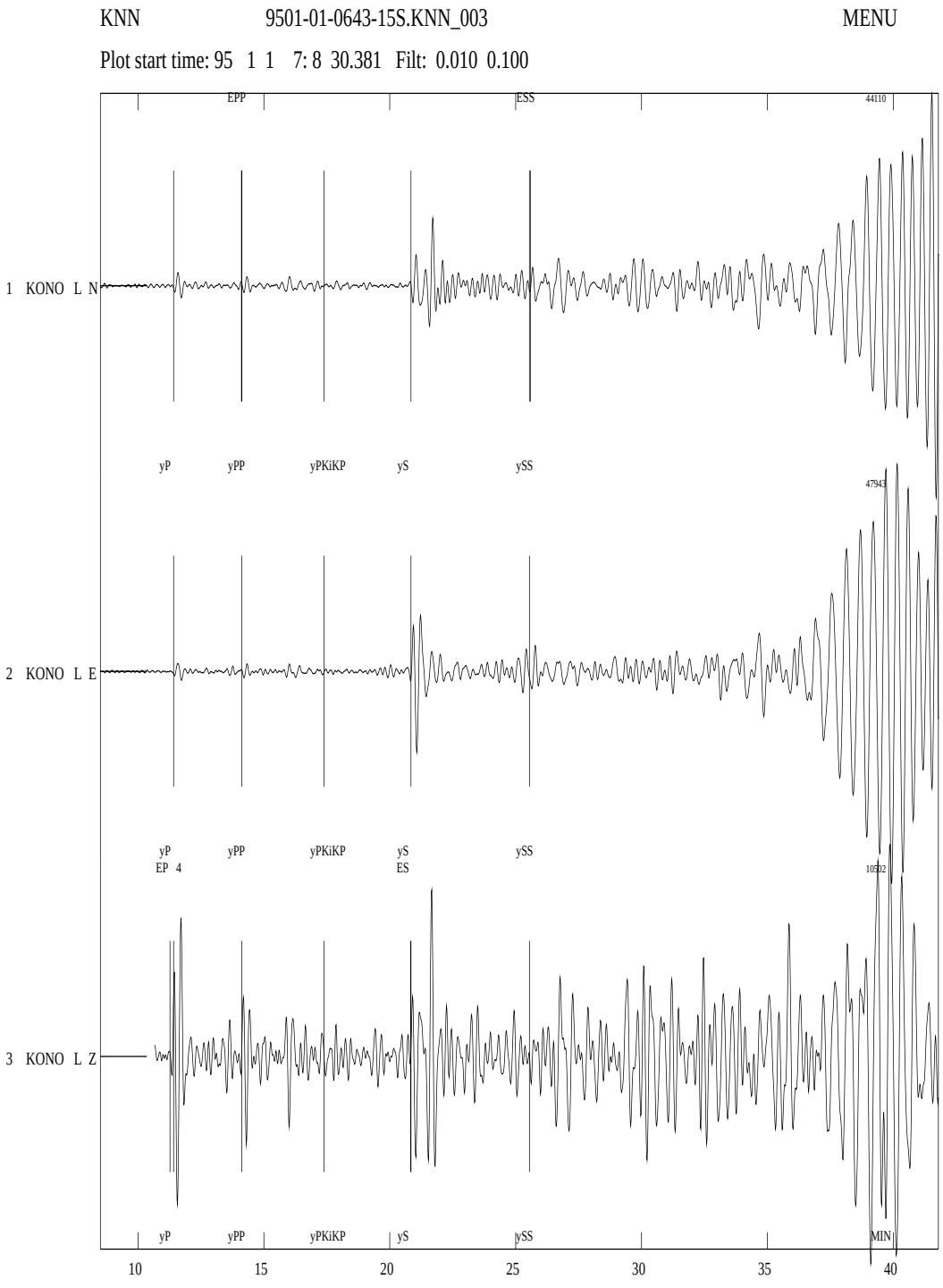


Figure 8.4: Example of MULPLT with theoretical arrival times showing global phases on a long period seismogram. The filter used from 0.01 to 0.1 Hz. Without filtering, almost nothing would have been seen on this broadband station.

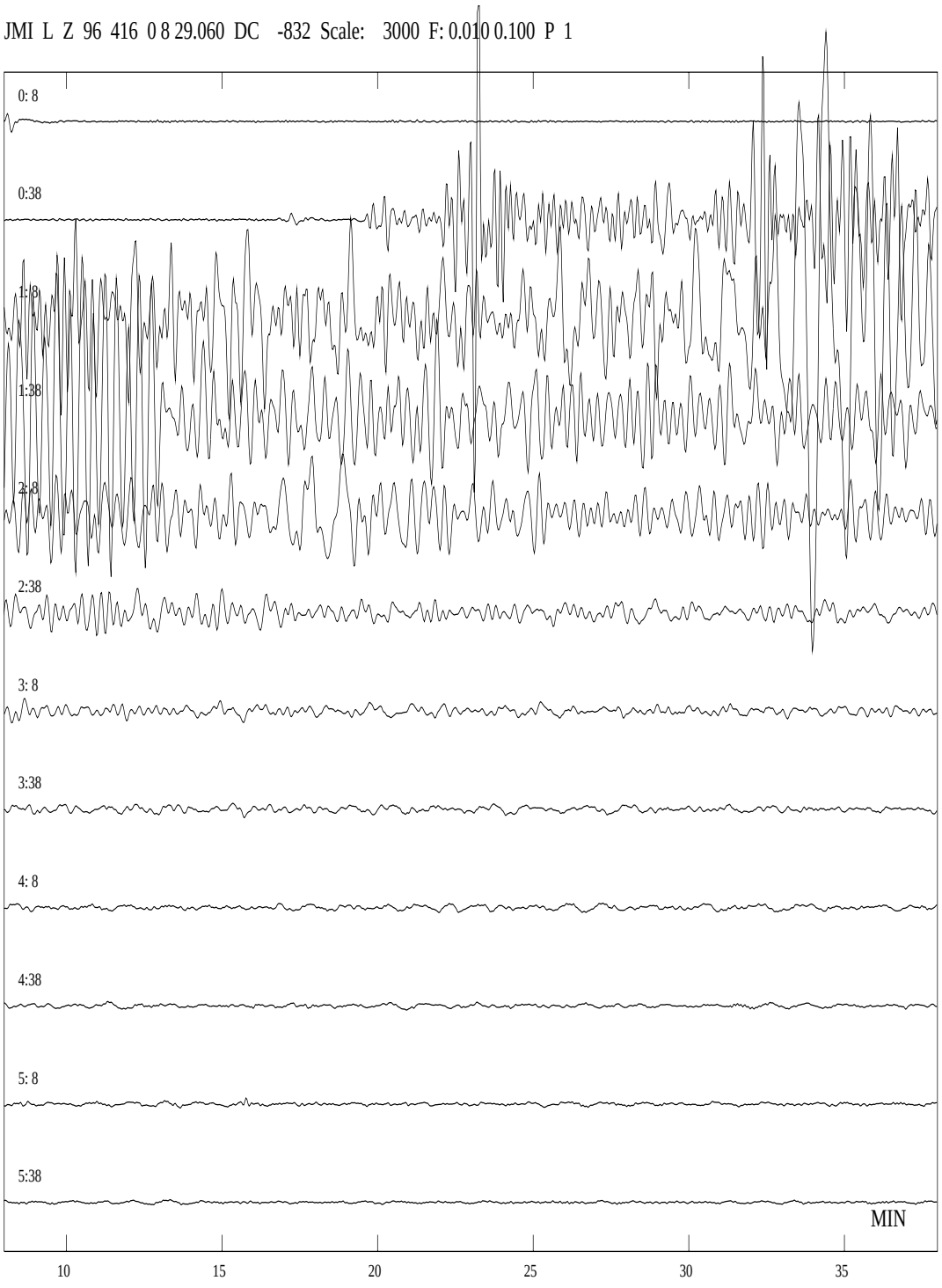


Figure 8.5: MULPLT in continous mode.
The plot shows 6 hours of long period data. The scale is 3000 counts between the traces and the filter used is from 0.01 to 0.1 Hz. The trace start time in hours and minutes is given on top of each trace. On the header line, P1 means the first page and DC is the DC level subtracted. Note that the numbers on the time scale at the bottom only are valid for the first trace unless all traces are 60 sec or 60 min long.

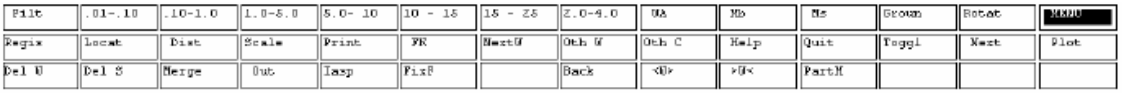


Figure 8.6: Example of the menu, which can be displayed on top of the plot. The current one might have different options.

Plotting stations in a given distance range When many stations are available, it might be useful to only plot the stations nearest the epicenter or a particular location. For this option to work, parameter MULPLT AREA in MULPLT.DEF must be set to a value larger than 0.0. For more information, see section Working with many channels in MULPLT"

Channel order in multitrace mode:

Channels are plotted by epicentral distance or in alphabetical order according to station name, see parameter NSORT_DISTANCE and CHANNEL SORTING in `MULPLT.DEF`. They can also be plotted in the order they are stored in the waveform file(s). By setting the channel order parameter in the `MULPLT.DEF` file, it is possible to plot the channels in distance or time order. If MULPLT is started from EEV (and NSORT_DISTANCE is set), the channels will be plotted in epicentral distance order unless the station if is not in the station file . If the event does not have an epicenter the location of the station with the first pick will be used as the epicenter for the ordering. Since there is no consideration for channels for the same station, the channels for one station, will be plotted in the same order as given in the waveform file. Ordering can be turned on with the key "-" or pressing (Dist). In this case distances are computed based on epicenter and station locations. If set in the `MULPLT.DEF` file, it is set when MULPLT starts up. It cannot be turned off for a given event when set from MULPLT but the flag is returned to the default value for the next event.

Plotting from continuous data base or archive

If a continuous data base is set up (see section 2.2.3), it is then possible to plot all traces from the continuous data base with MULPLT. When MULPLT starts up, use option cont and the user is prompted for a start time and interval. MULPLT will now check all continuous data bases for available data in required interval and display the available data. The forward (next) or back option will display previous or next window respectively. There is an 25 % overlap between windows. If no data is available for the whole window, no trace is shown. If the beginning and the end is available, a line will join the two segments. If only end or beginning is available, only the available data is shown. All normal operation can be done on the window plotted so it is possible to e.g. extract data. If the register option is used, the whole window is extracted from the continuous data base as one file, copied to WAV and the S-file created.

8.6 Registering new events into SEISAN

Mulplt is the main tool for checking and putting new events into SEISAN. New events with waveform data can appear in two ways in SEISAN:

1. Unprocessed waveform files are available in a work directory and have to be inspected and possibly put into the database. No S-files have been made.

2. Raw data has already been put into a SEISAN database with S-files and corresponding waveform files in some work directory, the data has not been checked. This process has most likely been done with the automatic data collection software SEISNET (Ottemöller and Havskov, 1999), or other similar programs like RTQUAKE (similar to SeisComP and and SC2SEI (gets data form SeisComP), see ftp://ftp.geo.uib.no/pub/seismo/SOFTWARE/. However, events can also have been auto registered with program AUTOREG.

3. Registering from continuous data: SEISAN continuous data base, BUD or SeisComp archives or a large SEED file.

In both cases above, the aim is to inspect an event and decide if the event is real and should be put into the database using option 'p'. All work must be done from the directory where the raw waveform files are

located. The process of putting an event into the database results in creating the S-file (option1), giving the event identifiers and copying the waveform files of registered events to the waveform directory.By pushing p(Regis), the user will be prompted for distance indicator, which has to be L, R or D for local, regional or distant event. It is possible here to enter 2 characters like LE or LV for local explosion or local volcanic event. The event type or event ID can be any character. Four characters are predefined and should only be used if the following definition correspond: P(probable explosion), E(explosion), Q(confirmed earthquake) or V(Volcanic event). If the user enter L, R or D in lower case, the case will automatically be changed to upper case. The same also happends with E, P, Q and V. A third cahracter can optionally be entered for the model indcator which is put into column 21 of the header line. The volcanic events have a sub classification which can be entered when registering an event as volcanic, see section 39. The process of registering the event into the database implies that a new S-file is created or registered and in the S-file. An operator ID will be asked and the operator ID will be put on the ID-line. The question about operator will only be asked for the first event since it is assumed that all subsequent events are put into the same database by the same operator. The event ID, can later be used with the SELECT program to select out particular event types. When first putting an event into the database, the user is also prompted for database.

Option (1)

Data is available as waveform files only and a list of files must be made first with DIRF. Main option 0, 1 or 2 can be used for plotting. The 'p' option creates the S-file and copies the waveform file to the WAV directory. The waveform file remains in the working directory. Unwanted waveform files can also be deleted so that when all events have been put in, only waveform files of 'real' events remain in working directory. These can then be plotted with one run of MULPLT, see section 8.1.

Option (2)

Data is available already in a database, however since the data has not been inspected, the waveform files are still in a work directory. In EEV, the first unprocessed event in the month is found with command 'ss' and MULPLT is started with command 'po' to invoke all defaults. If the event is to remain in the database, it must be registered with option 'p'. The process and the questions are the same as in option (1) except that the S-file is not created since it is already there. The S-file is cleaned for all processing information from SEISNET if present. This normally also includes automatic phase picks. However, they can be kept if parameter REG_KEEP_AUTO is set in the `SEISAN.DEF` file. The status of the files also changes to being newly registered as under option (1) (see definition of processing codes in Appendix 1) and waveform file(s) copied to WAV. Before registering, it might be an advantage to merge waveform files and delete unwanted files (could be false triggers), see section 8.5. Files can only be merged and deleted in working directory with commands Delw and Merge (Menu). Delw command only deletes the waveform file names in the S-file. In this process of putting new events into the database, it is also an advantage to delete unwanted events. This is done with option 'S'(Del S)'. The S-file is deleted, but the waveform files remain in the working directory.

Option (3)

When reading continuous data, an output file can be made with the Out option and that output file can be registered. However, it is also possible to do this in a single operation using the Register option like above. The selected time window is then extracted, the waveform file copied to WAV and the S-file registration made. In addition to the questions above, additional questions are given:

Output channels on screen: s

No output, just register: n

No output, jusr ARC line: a

Output all channels: enter

These option are intended to be used with routine operation when many channels are present and the user only view a few, like all vertical channels, but want to extract (and register a file with all channels). For ARC archive, the user might want to work directly with the archive from EEV and thus not extract out a waveform file but only create a reference to the archive.

Preprocessing of data while registering new events, option (1)

Normally a series of events are registered first and MULPLT terminated. Then EEV or SE is started up for interactive picking and location. However, if preliminary processing is desired while registering the event, this is also possible.

Phase picks: If phases are picked before the event is registered, these readings are saved in the database

at the time of registration. After the event has been registered, MULPLT automatically goes to the next event in FILENR.LIS and no more phase picking can be done.

Processing with a given program: Optionally MULPLT can, after registration, start any program processing the newly registered event. E.g. the AUTOPIC program can be started or a program reading amplitudes etc. The program name is defined in `MULPLT.DEF`.

Locating the event: As the final step after registration, the event can optionally be located and the location optionally placed in the database.

The above options have been put in on the suggestion of Brian Baptie, who is using it for rapid processing of volcanic events, where in most cases the operator only wants to look at the event once.

8.7 Phase picking, amplitude, weight and polarity

Picking phases:

The plot will display any pick present in the database (current S-file). To pick new phases, position cursor at phase, and press the key as indicated on top of the screen (if in Single mode). E.g. pressing 1 will read IP. Pressing the same key again with the cursor at a different place will delete the old one (indicated with a D) and display the new one. Additional default phases, which can be picked, are i for I ans e for E (note upper or lower case). Keys for phases have default definitions, but can be redefined using the file `MULPLT.DEF`, see below. The end of the coda is picked as a phase (END) and the program calculates coda length IF AND ONLY IF A P-READING IS PRESENT.

Picking amplitudes:

Position the cursor at the bottom or top of a wave and press a, then at the other extreme (bottom or top) and press a (do not use upper case, see below). There is no requirement for going left to right or top to bottom, it can be done in any order as long as the two extremes are marked. At each press, a cross is marking where the pick was made. In case a filter, like WA, MS or Mb is applied, the program will associate the amplitude with the respective amplitude phase (IAML, IAMs_20,IVmB_BB, IVMs_BB or IAmb). Amplitude and period are calculated and stored with the phase. Otherwise, if none of these filters are applied, a menu pops up and the user needs to select an amplitude phases name phase name to which the amplitude and period readings are associated. If an attempt is made to pick amplitude on a trace which is not in nm or nm/s, the reading must be confirmed since SEISAN assumes all amplitudes to be in nm or nm/s (see section on instrument correction). If no amplitude phase is picked, no amplitude is stored. The amplitudes are always assumed to come in pairs so if e.g. 3 amplitude values have been picked, and the user tries to pick a phase or quit the program, it will appear frozen since the program is still waiting for the next amplitude measurement. It is always the last pair of amplitude measurements, which are used. Amplitudes can be picked on both corrected and uncorrected traces.

If A is pressed instead of a, the amplitude is read and marked automatically. It works in most cases, but sometimes two subsequent peaks are not correctly chosen and the amplitude reading has to be done manually. The method is to find the absolute extreme and then the largest amplitude before or after is selected in order to obtain the peak to peak amplitude, from which the amplitude is calculated by dividing by 2. For more information, see. ../LIB/auto_amp.for.

Manual and automatic amplitude picking can be done in both single trace and multi trace mode. In multi trace mode the amplitude will be picked at the trace nearest the cursor.

Component names when picking phases:

In the old Nordic format S-file (the default), the component only has 2 letters while in the waveform file it has 3 letters (in old SEISAN waveform files it can be 4, but rarely used). There must therefore be a unique translation between the two. This definition is given in the subroutine componen.for in LIB. Most common combinations are now defined, however if a new one is defined in the waveform file which does not exist in componen.for, the first and last letter of the input component will be used. If e.g. an input component is called SHZ, then the code in the S-file will be SZ. This means that picks for stations with components, which do not differ in first and last character, cannot be separated in the S-file. Component names for rotated channels will be e.g. SR and ST for short period radial and transverse components respectively.

In the new Nordic format, Nordic2, there is room for 3 character component names and in addtion

network and locateion codes are stored. So there is no problem with identifying a channel. The complete station, component, network and location codes will be use to identify a reading.

Reading polarity:

If the cursor is above or below the trace at a distance marked by horizontal tics on the sides of the plot, the first motion is also picked and displayed when the next phase is picked. So if e.g. picking a P with dilatation, put cursor below the line and pick P. Do not use a filter if possible. Note that if you delete the phase later, the polarity is also deleted.

Assigning weight:

A phase can be assigned a weight. Move the cursor close to a pick and press one of the keys 0-9 in UPPER case thus using e.g. !"# (default, can also be changed), and a HYPO style weight is assigned and displayed. Although weights 0 to 9 can be put in, HYP only uses 0-4 and 9 (see section 7.1). Phases with associated amplitude, period, azimuth or apparent velocity are displayed with a hat below on the phase indicator line. The default keys for the weights might not be correct on all keyboards, if not, set keys in `MULPLT.DEF` using the parameter `PHASE WEIGHT KEY`.

The keys are defined as follows

Weight	Linux	Windows
1	!	!
2	@	"
3	#	#
4	$	$
5	%	%
6	^	&
7	&	/
8	*	(
9	(	)
0	)	=

Automatic determination of coda length (C or c):

The coda length can be quite variable among different operators and a function has been made to automatically determine the coda length. The signal is bandpass filtered and the end of the coda is determined by a standard STA/LTA procedure. The parameters are set in the `MULPLT.DEF` file. Press C to find coda length automatically or c to determine manually. If parameter CODA AUTO is set in `MULPLT.DEF`, c is used.

In old Nordic format the position of the coda can only be determined if a P-phase is present sienc the coda lenght (time between coda pick and P) is stored together with the P. The location of the pick is indicated with Coda on the plot.

In new Nordic format, Nordic2, the coda can be picked even when there is no P since the coda is now an independent phase called END (IASPEI convention, indicating end of earthquake signal). However, the coda length is only given (on phase line END) if there is a P.

From SEISAN version 12, coda is no longer stored with the P but with the phase END. However, magnitude is still calculated when coda is stored with the P.

Below is shown an example of old and new format, Nordic2.

Old:

```
 STAT SP IPHASW D HRMM SECON CODA AMPLIT PERI AZIMU VELO AIN AR TRES W  DIS CAZ7
 ASK  SZ IP        337 56.25  88                           62   0.38010  171 140
```

New Nordic2:

```
 STAT COM NTLO IPHASE   W HHMM SS.SSS   PAR1  PAR2 AGA OPE  AIN  RES W  DIS CAZ7
 ASK  S Z      IP         337 56.250               RRR dd  62.00.38010  171 140
 ASK  S Z       END       339 24.680   88.0                             171 140
```

8.8 Theoretical arrival times for global and local phases and location

In order to assist in identifying seismic phases, there is an option for displaying the theoretical arrival times of several global (using IASP91) and regional phases while picking phases (using ttlocal based on layered model in STATION0.HYP). The steps to do so are the following:

1 Before entering MULPLT from EEV, the theoretical travel times can be calculated for the current event. This assumes that the origin time and hypocenter is given in the header line or a subsequent type one line. If not, enter manually (from e.g. PDE) or use the EEV command INPUTEPI or INPUTONE. Then proceed to calculate the theoretical arrival times using EEV command IASP with the IASPEI91 traveltime tables (for more details, see section 30.5). The same command is also available inside MULPLT in multitrace mode. All arrival times (or a subset, see 30.5) for all stations in current S-file will now be calculated with program IASP if call from EEV. If call from MULPLT times will be calculated for all stations in waveform file(s). In both cases, the times are stored in file iasp.out (no importance for the user, just for information). See Figure 8.2 for an example in multitrace mode. Note that very many theoretical phases can be generated if the S-file has many stations. MULPLT will stop if more phases are used than the dimensions are set up for (include file seidim.inc), and you must use fewer phases (a warning is given when 500 phases are generated) or set up SEISAN with larger dimensions, see section 3. Theoretical local crustal phases for the current model can be calculated with program WKBJ and displayed, see section 29. Theoretical phases can also be calculated when using the location option, see next section.

2 When a trace is displayed on the screen, all theoretical phases inside the time window will be shown. To distinguish the theoretical phases, they are prefixed with a y and displayed below the trace (normal phases have I, E or blank and are displayed above the trace). Position cursor where you see a phase which you think corresponds to a theoretical phase and press y. The nearest theoretical phase will now be placed at that position with a prefix E. Only theoretical phases selected in this way will be written in the S-file. Note that the phase names can be up to 8 characters long, see Appendix 1 for the definition of long phase names when using old Nordic format.

If the phases fit badly, start looking at the P-phase. If that does not fit the theoretical P-phase, change the origin time in the S-file so that the P-arrival fits, and recalculate the theoretical phases.

PROBLEM: In multitrace mode, only one theoretical phase can be picked. Replot must be made before picking the next.

Locate earthquake

If several phases have been read and saved in the S-file, the event can, in multitrace mode, be located with command l (Locat), just as in EEV. The screen is cleared and the usual location rolls over the screen. When the location is finished, the plot will reappear and the calculated travel times will be displayed as synthetic phases (see previous section). In this way it is possible to immediately visualize the differences between the read and calculated phases. The output files are `hyp.out` and `print.out` as usual.

8.9 Instrument correction and magnitudes Ml, mb and Ms

The correction for instrument response is done by taking the spectrum of the selected window of the trace, dividing with the response function and converting back to the time domain. Any filtering specified is done in the time domain. Filtering is needed in most cases. The steps are:

Optionally filter in time domain

Remove DC

Apply sine taper on 10 percent of the signal so 5 percent in each end

Do FFT

NOTE: The taper will reduce the amplitude of the signal in the beginning and end of the signal. So to get a correct amplitude, make sure the amplitude you want to pick is not at the extreme beginning or end of the signal (5 percent).

If data has been high pass filtered in time domain at frequency flow, then Frequency domain 4 pole low pass Butterworth filter is added at frequency flow/5. This is for stability.

Correct for response

Do inverse FFT

Ground motion

Option g(Groun) removes the effect of the instrument and displays a ground motion seismogram. After selecting g and the zoom window, there is a question of which type of seismogram to calculate: Displacement (d), Velocity (v) or Acceleration (a). The corrected trace is shown below in nanometers(nm), nm/sec or nm/(sec*sec) (if response information is available). Note that this might produce strange seismograms, since e.g. a SP seismograph has very low gain at low frequencies so noise might be amplified very strongly. It is therefore recommended to also do some filtering when using the g option.

Amplitude for determining Ml (also Mn)

For the w(WA)-option (Wood Anderson), the trace is corrected for the instrument to produce displacement. The displacement trace is then multiplied with the response of the Wood-Anderson instrument to produce a signal to look exactly like it would have been seen on a Wood-Anderson seismograph. The maximum amplitude (nm) is read and saved to the S-file with name IAML. The Wood-Anderson response (PAZ) is hardwired in SEISAN and it is similar to a 2 pole Butterworth high-pass filter at 3 Hz. In SEISAN versions prior to 8.3, a fixed 8 pole bandpass filter was used (1.25 Hz - 20 Hz). Filtering is done in the frequency domain. For noisy traces it might also be required to put a filter at the high end. This can be specified in the `MULPLT.DEF` file. Unfortunately, the correct low cut filter with 2 poles will often result in the seismogram blowing up at low frequencies and might be quite useless for earthquakes with magnitude below 2.0 - 2.5 So in addition to the PAZ filter, a fixed bandpass filter can be added (see `MULPLT.DEF`). In the standard distribution of SEISAN, this additional filter is not set A filter 1.25 - 20 Hz is recommended. Other filters at a higher frequency should only be used for small events (M<1). An extra filter should only be used if it is estimated that the maximum amplitude of the Wood Anderson signal is above the high pass filter limit. NOTE: In SEISAN version 7.1.1 and earlier, the low cut filter was set by mistake to 0.8 Hz. Repicking amplitudes with the correct filter might change magnitudes of larger events slightly.

Amplitudes for Ml are normally picked from the S/Lg wave, either vertical or horizontal channels depending how the magnitude scale is defined. For Mn, the amplitudes are read from either Pn or Sn, which ever is the largest.

Displaying response information

The response function for the current channel can be shown with option ':' (Resp), see Figure 8.11. If no response function is given, a message is shown. If the response function is taken from the waveform file header instead of from the CAL directory, a message is given. This can only be done with very old waveform files in SEISAN format.

Amplitude for determining mb:

Determining mb assumes that the maximum amplitudes are measured on classical 1 Hz WWSSN instruments having a peak gain around 1.5 Hz. This in reality means a band limited measurement. To pick ground amplitudes for determining Mb on instruments with a broader or more narrow frequency band, like most high frequency SP instruments, some filtering must first be done. Using the j(mb)-option, the trace is corrected for the instrument to produce displacement. The displacement trace is then multiplied with the response of the SP WWSSN instrument to produce a signal to look exactly like it would have been seen on a SP WWSSN seismograph. The unit of the amplitudes seen on the screen is nm, however the amplitude will only represent the ground motion correctly at the frequency of the maximum gain at 1.5 Hz and for all other frequencies, the true ground motion will be larger than seen on the screen. The maximum amplitude is now picked and displayed below the trace with the corresponding period.The amplitude corrected for the gain relative to the gain at 1.5 Hz is also shown and written to the S-file with name IAmb. This means that the amplitude written to the S-file generally will be larger than the amplitude displayed on the plot. The SP WWSSN response (PAZ) is hardwired in SEISAN and cannot be modified with filters.

In SEISAN version to 8.2.1, the default filters used to simulate SP WWSSN were, by mistake, in the band 0.9 (2 pole) to 1.8 Hz (3 poles). This will result in slightly wrong magnitudes unless the user had put in correct new filter contants... Prior to SEISAN version 8.2, the default filters used were 0.5 Hz (8 pole) and 5.0 Hz (8 pole filter), which was close to the correct values. No correction for relative gain was used in SEISAN versions prior to 8.3.. All of these changes could have resulted in smaller errors in mb, which only

can be corrected by repicking the amplitudes.

Amplitude for determining mB

Amplitude for mB is defined as the maximum velocity on a wide band instrument (0.2 -30 sec or 0.033 - 5 Hz). The maximum amplitude Vmax is measured on a velocity trace. Using the J(mB) option, a velocity trace (nm/s) in the frequency band 0.033 - 5 Hz is displayed. The maximum amplitude in nm/s (irrespective of frequency) is picked and displayed below the trace. This amplitude is now written to the S-file with phase name IVmB_BB. In principle, mB can be calculated using any instrument, but in practice it can only be used if the P-signal is seen clearly on an unfiltered broad band velocity record. The Butterworth filter 0.033 - 5 Hz , 8 poles, is hardwired and it cannot be modified with additional filters.

Amplitude for determining Ms:

The attenuation function for determining Ms assumes that the amplitudes are measured on classical LP WWSSN instruments having a peak gain around 15 second. To pick ground amplitudes for determining Ms on instruments with a broader or more narrow frequency band, like most broad band instruments, some filtering must first be done. Using the k(Ms)-option, the trace is corrected for the instrument to produce displacement. The displacement trace is then multiplied with the response of the LP WWSSN instrument to produce a signal to look exactly like it would have been seen on a LP WWSSN seismograph. The unit of the amplitudes seen on the screen is nm, however the amplitude will only represent the ground motion correctly at the frequency of the maximum gain at 15 seconds and for all other periods, the true ground motion will be larger than seen on the screen. The maximum amplitude is now picked and displayed below the trace. This amplitude is then corrected for the gain relative to the gain at 15 seconds, shown on the screen and written to the S-file with name IAMs_20. This means that the amplitude written to the S-file generally will be larger than the amplitude displayed on the plot. The LP WWSSN response (PAZ) is hardwired in SEISAN and no additional filters can be used.

The attenuation function for determining Ms assumes that the amplitudes are measured in the period range 18 - 22 sec and it is up to the user to make sure that the the amplitude is in the correct range..

For SEISAN 8.2.1, the default filters used were in the band 0.038 (2 pole) to 0.1 Hz (1 pole). Prior to SEISAN 8.2 default filters were 0.042 to 0.063 Hz (8 pole filter). No correction for relative gain was used in SEISAN versions prior to 8.3. These changes might have resulted in small errors in Ms and can only be corrected by repicking the amplitudes.

Amplitude for determining MS

Amplitude for MS is defined as the maximum velocity on a wide band instrument (3 -60 sec or 0.017 - 0.3 Hz). Using the K(MS) option, a velocity trace (nm/s) in the frequency band 0.017 - 0.3 Hz is displayed. The maximum amplitude in nm/s (irrespective of frequency) is picked and displayed below the trace and written to the S-file with phase name IVMs_BB. In principle, MS can be calculated using any instrument, but in practice it can only be used if the surface wave is seen clearly on an unfiltered broad band velocity record. The big advantage with using MS is to avoid the 18-22 s limitation needed for Ms. The Butterworth filter 0.017 - 0.3 Hz , 8 poles, is hardwired and cannot be modified with additional filters.

Problem: If a long trace (large number of samples) is used, the instrument correction might fail (funny result seen) due to numerical overflow in the spectral conversion. Choose a shorter window.

8.10 Determine azimuth of arrival (3 comp or array) and component rotation

Azimuth of arrival (back azimuth) from 3-component stations, h(Azim)

If a 3 component station is available, the azimuth of arrival can be determined using the method developed by Roberts et al. (1989). Display any of the 3 components and press h (Azim). Then select a zoom window around the P-arrival of a few secs duration for the analysis. The 3 components will now be displayed below in order Z, N and E and the calculated azimuth, apparent velocity and correlation will be displayed at the bottom line. In order to check the stability of the estimate, try different windows and filters. Often, a filter must be used to get reliable results. The displayed azimuth and apparent velocity is only saved in the S-file when an associated phase is picked. THAT PHASE MUST BE PICKED ON THE SINGLE UPPER TRACE SEEN ON THE SAME SCREEN. If there is none, use I or E. The velocity estimate is not very reliable and is dependent on the local velocities. In order to calculate the apparent velocity, the P-velocity of the top

layer must be given. The default value is 5.0 km/sec, but another value can be set in the `MULPLT.DEF` file. To get a good estimate, the correlation coefficient should be as high as possible and positive. The quality of the obtained azimuth can be tested by locating the event with the calculated azimuth weighted out and observe the azimuth residual.

The output is different in new and old Nordic format, see exaple below:

```
old:

 STAT SP IPHASW D HRMM SECON CODA AMPLIT PERI AZIMU VELO AIN AR TRES W  DIS CAZ7
 ASK  EZ EP        916 40.94                   37.3  9.2 111           29.9 205
 ASK  EZ E         916 41.96                   41.8  7.8

new:

 STAT COM NTLO IPHASE   W HHMM SS.SSS   PAR1  PAR2 AGA OPE  AIN  RES W  DIS CAZ7
 ASK  EHZ      EP          916 40.940                     111.0-1.0510 29.9 205
 ASK  EHZ       BAZ-P      916 40.942   37.3   9.3 BER jh
 ASK  EHZ       BAZ        916 41.962   41.8   7.8 BER jh
```

Two back azimuths (BAZ) have been picked, one associated with the P and one a bit after the P. In the old format, the one picked with the P is also stored with the P-phase line since there is space on every phase line for BAZ while the one picked later is put on a new phase line and marked with E.

In the new format, Nordic2, the 3 observations are on separate lines and the phase picked with the P is identified as BAZ-P and the BAZ pick with E is marked as BAZ and no phase. The advantage of 3 lines is that each observation can be changed independtenly of the others.

Figure 8.10 shows an example.

Azimuth and apparent velocity from array data, FK analysis f(FK)

Using this command, the traces seen on the screen will be put into the FK program and an FK plot will be displayed. The azimuth and apparent velocity with the highest correlation is selected by the program, however any other value can be manually selected. The values will ONLY enter the S-file if associated with a phase in the same way as amplitudes are picked. For more details, see section 40.

Rotated seismograms

Option U(Rotat) will rotate the horizontal components for the next plot if the two horizontal components are available. The rotation will display the radial component instead of the N-component and the transverse component instead of the E-component. The back-azimuth used is displayed above the trace. All channels will be displayed rotated until u(Rotat) is pressed again This means that phases can be picked and spectra made with the rotated channel. When picking phases on rotated signals, these will appear in the S-file with components R or T instead of N and E respectively. This also means that only if the rotated signals are shown, will the phases read on rotated channels appear on the plot. The station back-azimuth is obtained in the following way: If a hypocenter is given in the header line, the angles are calculated using the current `STATIONx.HYP` file. If no hypocenter is available, the angle will be read from the S-file under column observed azimuth (47-51) (if not blank) and the azimuth residual will be added. This option permits the user to first determine the azimuth with the 3-component option and then rotate the signals with the determined azimuth. Finally, if no observed azimuth is available, the event to station azimuth + 180 deg. will be used if available (column 77-79). If no back-azimuth can be found, no rotation is done and an angle of 999 deg. is displayed. If in single trace mode and choosing the 3-component option AND the rotate option, the user will be prompted for a rotation angle and the rotated channels will be shown in the usual 3-component plot, however, the azimuth determined is done with the unrotated channels.

PROBLEM: In general, the R-channel will use the response of the N-channel and the T-channel will use the response of the E-channel so for instrument response removal to be correct, the 2 channels must have the same response curve.

8.11 Data manipulation commands

Select other channels: o(Oth)

The channel selection menu comes up again.

Go back one channel in single trace mode, go back one event in multitrace mode if MULPLT is started from EEV: B(Back)

Select other waveform files from S-file: W(OthW)

If more than one waveform file available for the event, one or several others can be selected.

Delete waveform files:

This can only be done in multitrace mode: The command is d(DelW) and the cursor must be above the top frame of the plot. There are two possibilities:

1 Input is from `filenr.lis`: The current file is deleted and if in default mode, the plot moves on to the next event.

2 MULPLT is started from EEV: If only one waveform file is available, the program proceeds as under (1). The waveform file is deleted and the waveform file entry in the S-file remains. However, if more than one waveform file is available, the user can use a menu to select which files to delete. Only the waveform file entries in the S-file are deleted, the waveform files remain. This option is mostly used with SEISNET.

Delete S-files D(Del S)

This command deletes the current S-file. It can only be used if MULPLT is called from EEV. No waveform files are deleted.

Merge waveform files given in S-file M(Merge)

The files will be merged to one waveform file and the old individual file names removed from the S-file and replaced by the new file name of the merged file. The original waveform files remain. Files to be merged will be shown on a menu. Mostly used with SEISNET. The user MUST have files in working directory. If files are in the data base, they will not be shown on the merge menu.

Overlay two channels: It is sometimes practical to be able to overlay 2 or more channels. The channels to be overlaid must follow each other on the screen (sorting might influence that). Move the cursor to the channel name of the lower of the two channels, press & and the channel is marked with a cross. When doing replot, that channel will be plotted in red on top of channel above. Both channels will be autoscaled, but if absolute scaling is used, the real difference in amplitude is seen. Overlay cannot be deselected without leaving MULPLT. This option is particularly useful when comparing real and synthetic seismograms results from moment tensor inversion, see that section later.

Output of binary waveform file, O(Out)

It is often useful to be able to select part of a waveform file and save it. The Out option makes an output file of the traces AS DISPLAYED ON THE SCREEN with exactly the same channels, and time window in a file with a standard SEISAN waveform name. The output format is by default SEISAN, even if some input files have a different format. A different output format can be selected in MULPLT.DEF, parameter MULPLT WAV OUT FORMAT. The network code in the file name will ALWAYS be the station code if all channels are from the same station. Otherwise the network code has the default name MERGE. Alternatively the parameter MERGE_WAVEFORM can be set in `SEISAN.DEF`. The data is output exactly as displayed on the last screen, so if filtering or instrument response has been made, the output file will also be filtered or instrument corrected WITH SOME RESTRICTIONS: Not all response, channel or filter combinations are possible. Only 4 pole band pass filters can be used, no rotated channels and none of the magnitude simulated traces like Wood Anderson for Ml. if you want exactly what is seen on the screen for all combinations, use option `OutW`. If any filtering or instrument response correction has been done, a note will be inserted in the SEISAN waveform header so the user can see that this is no longer the original data. The note could be e.g. ‘ Displacement 1.250- 20.0 Hz’ indicating that output has been filtered and converted to displacement (nm). Note that numbers have been scaled so only if the SEISAN file is read with standard SEISAN routines, will the numbers be correct. If the output file is converted to ASCII by SEIASC, the number shown must be multiplied with a given scaling factor, see SEISAN binary format description (Appendix B). There is no response information in the header other than the short text. Since the station code is still the same, it is

technically possible to correct for the response again using the response information in the CAL directory, **however, be aware that this will give wrong results**.

Option `OutW`: This option will output the signal exactly as seen on the screen with all the selected filter and response combinations. It also handle rotated channels. The output file name is `mulplt.wav` and it is an ASCII file with real numbers in Helmberger format (readable by SEISAN). To make the file, press `OutW` and wait for message '`mulplt.wav written`' in top right of the screen. For many channels and high sample rate it could take some time since the output is Ascii. If the traces in the window do not start and stop and stop at the ends, then dc levels will be added so all channels in the output file has same start and stop timers. Format description is found in section moment tensor inversion.

Output of ASCII waveform file

This option only works if parameter SPECTRAL_OUTPUT has been set in `MULPLT.DEF`. The output file signal.out contains the last data displayed in the single trace zoom window (in ASCII and real numbers). This option is a another way (see option O(Out) above) of getting an output file that has been filtered or instrument response corrected. The main difference is that this file is only for one trace written in ASCII.

Fixed scaling

Normally all traces are plotted with autoscaling. However, it is sometimes useful to be able to scale the traces with a fixed scale in order to e.g. compare traces or override the autoscale in case a spike distorts the autoscaling. Option *(Scale) will prompt the user for a maximum count to use for the scaling of all traces.

Example of using MULPLT on Linux:

Comments are given with ! in front

This example shows how running MULPLT from EEV would look.

```
/top/seismo/REA/BER__/1991/01/01 0557 12L.S199101 ! S-file name
Read header from file /top/seismo/WAV/9101-01-0557-12.WNN_13

 Plot options:     Interactive picking          Return  ! first choice
                   Multi trace plot on screen, def (0)
                   Multi trace plot on screen      (1)
                   Multi trace plot on screen+laser(2)
                   Multi trace plot on laser       (3)
                   Multi trace plot on laser       (3)
                   Continuous on screen            (4)
                   Continuous on screen + laser    (5)
                   Continuous on laser             (6)
                   Stop                            (9)
                       ! now comes a menu for selection and then
                       ! the plot appear in Single mode since a
                       ! return was made
```

The next example shows how to plot many events in one go, first make a list with DIRF.

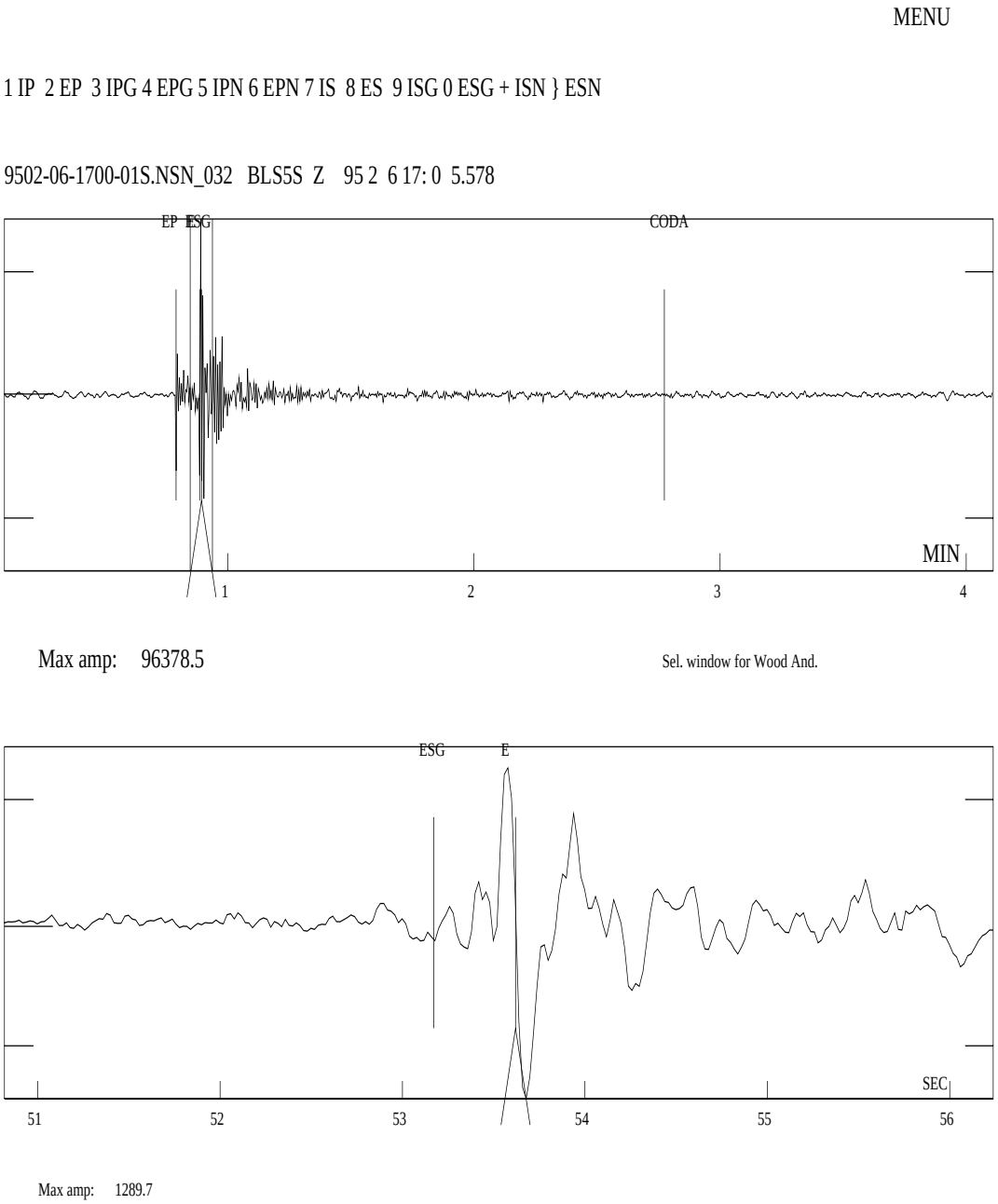


Figure 8.7: Using MULPLT for picking phases. The top shows the original trace and the bottom the zoomed part. Note that the amplitude has been associated with the phase E and not the ESg. This means that if the S-phase is deleted, the amplitude will remain. In the new Nordic format, Nordic2, amplitudes are always stored on separate phase lines.

```
dirf 9101-10*                       ! events from January 10, 1991
#  1  9101-10-0915-15S.KMY_03
#  2  9101-10-1510-55S.NSS_12
#  3  9101-10-2333-44S.NNN_11

mulplt
file name, number, filenr.lis for all
filenr.lis             ! plot all events in filenr.lis
 Resolution in cm/sec, 0: plot all on one page (default)
0                      ! scale will be different for each plot!!!
Read header from file:9101-10-0915-15S.KMY_03
 Page           1
 Channel:           1

Plotfile sent
Read header from file:9101-10-1510-55S.NSS_12       ! next event in list
 Page           1
 Channel:           1
 Channel:           2
 Channel:           3
 Channel:           4
 Channel:           5
 Channel:           6
 Channel:           7
 Channel:           8
 Channel:           9
 Channel:          10
 Channel:          11
 Channel:          12

Read header from file:9101-10-2333-44S.NNN_11
 Page           1
 Channel:           1

 ! etc.


Plotfile sent
Read header from file:9101-10-1510-55S.NSS_12       ! next event in list
 Page           1
 Channel:           1
 Channel:           2
 Channel:           3
 Channel:           4
 Channel:           5
 Channel:           6
 Channel:           7
 Channel:           8
 Channel:           9
 Channel:          10
 Channel:          11
 Channel:          12

Read header from file:9101-10-2333-44S.NNN_11
 Page           1
 Channel:           1

 ! etc.
```

8.12 Spectral analysis, s(Spec)

The spectral analysis option for local and teleseismic events is selected in single trace mode. The spectral analysis is based on the Brune (1970) model and various assumptions about the geometrical spreading and anelastic attenuation. The steps in the analysis is:

1.Remove DC
2.Apply sine taper on 10 percent of the signal in each end
3.Do FFT
4.Do attenuation correction
5.Correct for response

The theoretical displacement spectrum d(f)(Brune, 1970) is:

$$d(f) = G(r,h) * D(f) * Moment * KK/(1 + f**2/f0**2) * (4 * \pi * DE * V**3))$$

where G(r,h) is geometrical spreading, r is epicentral distance, h is hypocentral depth, D(f) the diminution functiondue to anelastic attenuation, f is the frequency, DE the density, V the velocity at the source, f0 the corner frequency and KK a factor of 2.0*0.6 to correct for the free surface effect and radiation pattern.

The diminution function D(f) is written as

$$D(f) = P(f) * exp(-\pi * f * trtime/(q0 * f**qalpha))where$$

trtime is the travel time from the origin time to the start of the spectral window and

$$P(f) = exp(-\pi * kappa * f)$$

is meant to account for near surface losses (Singh et al., 1982) with the constant kappa having a value of the order 0.02 sec. Anelastic attenuation Q is assumed to be frequency dependent following the relation $Q = q0 * f**qalpha$. For f less than 1 Hz, Q is, by default, assumed frequncy independent with the value q0 (before Dec 2013 it was frequecy dependent for f less than 1 Hz which could lead to a small overestimation of seismic moments for events larger than 4.5. This change is also affects other programs using Q-correcion like SPEC, AUTOMAG and AUTOSIG).

Before version 12.1, the transion of Q from high to low frequencies as a function of frequecy was made with the function Q=Q0*(1+f)**qalpha. However, this has turned out not to be ideal since Q at 1Hz then would be 2Q0 althought following the the function Q=Q0*(1+f/X)**qalpha at higher frequecies and becoming contant at lower frequencies. So now there is no smooth function and Q=q0 below 1 Hz and Q0 at 1 Hz. This parameter is set in SEISAN.DEF . For teleseismic events, only t* is used and Q must be set to zero (not used). The t* parameter is then entered using the kappa variable and is usually set to 1.0 (same value is used for P and S). So kappa is no used for teleseismic events. The geometrical spreading has been defined to be dependent on the wave type with several possibilities, all made equivalent to a distance called geo_distance (GD) such that geometrical spreading is expressed as 1/GD. There are several possibilities for GD:

Local and regional events geometrical spreading

P-waves:

GD is the hypocentral distance $(HD) = sqrt(r * r + h * h)$ so body wave spreading is assumed.

S-waves:

The geometrical spreading has been made dependent on distance and depth. At short distances, the geometrical spreading is assumed to be body wave spreading. For distances beyond the Herrmann-Kijko distance (default of 100 km) and a shallow focus, the following relation is used:

$$G(r,h) = 1/r = 1/GDforr < 100km$$

$$G(r,h) = 1/sqrt(100 * r) = 1/GDforr > 100km$$

which is commonly used (Herrmann, 1985; Herrmann and Kijko, 1983). This relation assumes surface wave dispersion for epicentral distances larger than 100 km. In SEISAN 100 km is the default, however it can also be set to any other value by the parameter HERKIJ_DISTANCE (see later).

The above relation breaks down if the depth is large or comparable to the epicentral distance and in that case body wave spreading is again assumed. In order to get a smooth transition from surface wave to body wave spreading, it is assumed that the relation changes nearly linearly from surface wave spreading to body wave spreading between the depths GEO_DEPTH1 to GEO_DEPTH2. For depth less than GEO_DEPTH1(default 50 km), Herrmann-Kijko spreading is assumed, for depths larger than GEO_DEPTH2 (default 100 km), body wave spreading is assumed with the transition in between. In each case the geometrical spreading term is given as the equivalent GD, which is also recorded in the database. These 3 parameters can be used to change geometrical spreading. If e.g. HERKIJ_DISTANCE is 10 000 km, body wave spreading is always used. For more info, see (Havskov and Ottemöller, 2010).

Geometrical spreading for teleseismic events

The geometrical spreading is approximated with (Havskov and Ottemöller, 2010)

$$G(r) = 1/GDwhereGD = (27 + dist)/0.0048$$

where dist is epicentral distance in degrees. This approximation is only valid for depth is less then 100 km and dist larger than 30 degrees.

Attenuation and velocity specification for spectral analysis

The are 2 possibilities, use the values in MULPLT.DEF or use a spectral model in SEISAN.DEF.

Use the values given in MULPLT.DEF: Since only one value can be given for attenuation (Q and kappa), the same attenuation is used for P and S. Likewise, if the hypocenter changes depth, it will be the same fixed values for all attenuation and velocity parameters. For a particular fixed situation e.g. where the user always analyze shallow events and always is using the same type of spectrum (usually S), this is adequate. However in a situation with large depth variations, it is desirable to change all parameters as a function of depth. It might also be useful to change attenuation as a function of phase type although there often is little difference between P and S attenuation.

Use values in SEISAN.DEF: The spectral model is defined in SEISAN.DEF. In order to activate the model, set parameter SPECTRAL MODEL in MULPLT.DEF to 1.0, then the spectral model is used instead of the parameters in MULPLT.DEF. The model gives velocities (P and S), attenuation (P and S) at different depths as will as kappa for P and kappa for S and the behavior of Q below 1Hz (P and S).

The Q below 1 Hz parameter can now be set to any frequecy. If set to 1.0, the Q function is as above when using MULPLT.DEF parameters but if the frequecy is set to another valus, it is then the frequency f1 below which Q becomes constant with the value Q(f1). If the Q below 1Hz parameter is set to zero, the Q functions will not become constant at any frequecy..

Remember that the attenuation given at a particular depth is NOT the attenuation at that depth but the average between source and receiver. Values used will be interpolated between values in model and the values used will be show in the plot and stored in the S-file. If the spec model is used, it will be indicated on the plot (lower right hand corner). if a spec model is not there, MULPLT.DEF values will be used and also indicated on the plot.

From the spectral parameters, source radius and stress drop can be calculated as follows:

$$Sourceradius = 0.37 * V/f0$$

where f0 is the corner frequency and V the P or S-velocity at the source for P and S-spectra, respectively.

$$Stressdrop = 0.44 * Moment/(sourceradius) * *3$$

The spectral analysis is used in two ways. The first and most common is to make the attenuation and instrument corrected displacement spectrum and determine the flat spectral level OM0, and corner frequency f0 from which the seismic moment, source radius and stress drop can be calculated. The second option is to display the instrument corrected spectrum (displacement, velocity or acceleration) and model the spectrum for corner frequency and attenuation parameters. In this case no correction for attenuation should be made.

Spectral analysis to determine moment, source radius and stress drop:

Select the spectral option, s(Spec). Before the spectrum comes up, you will get a question of the type of spectrum wanted and a few other options.

Displacment: d Displacement spectrum
Velocity: v Velocity spectrum
Acceleration: a Aceeleration spectrum
Raw spectrum: r Spectrum without instrument correction
Change velocity: c Use other velocity for calcualation
Change density: e Use other density for calculation
Change moment: m Change moment (see modeling)
Noise Pow. spec: n Noise powe spectrum (see later)
Lin axis: l Change to linear axis
New spec f-lim: f Change frequecy limits for spectrum
Change spectrum: t Change to P or S spectrum if auto does not work
Autofit spectrum: s Make automatic spec fit

The most used possibilities are displacement (d), velocity (v) or acceleration (a). For determination of Moment etc, the displacement spectrum or the autofit option (see below) MUST be selected. Unless raw spectrum is selected, the spectrum will be instrument corrected. If no response file is available in CAL, a message will be displayed on the screen and the raw spectrum calculated. At this stage it is also possible to change the velocity from the `MULPLT.DEF` value or the moment to be used for spectral fitting as given in the S-file (see spectral fitting below). The velocity change is only affective for the current spectrum since the user might make both P and S spectra and it is up to the user to make sure that it is appropriate for P or S, however, the value is saved in the S-file. The density change is kept for the whole MULPLT session since there is no change with velocity and its value is also saved in the S-file. The spectrum shown will normally show both the spectrum from the selected time window as well as a noise spectrum from an identical length time window at the start of the trace. IF NO NOISE SPECTRUM is desired, select spectrum with capital S instead of s.

Option s, auto spectrum

If auto spectrum is chosen (s), an attempt will be made to fit the Brune spectrum to the observed spectrum. The program will first try to find the frequency range of acceptable S/N and then find the best fit by grid search and the fit will be shown on the spectrum as well as the frequency range used. The automatic frequency range determination can fail, particularly for small events so a check should be made if the spectrum fit looks 'reasonable' and that the frequency range is ok. Choosing a slightly different window might fix the problem. The initial frequency range is limited by the parameter SPECTRAL F-BAND set in MULPLT.DEF so changing this parameter might also help. Note that the automatic frequency range determination will fail if the noise window before the P is not as long as the analysis window chosen. Automtic spectra can also be done for the whole event with command automag in EEV, AUTOMAG and AUTO from the prompt line.

The spectral analysis produces two output files:

`com_spec.out`: The complex spectrum with some additional information needed for surface wave analysis, must be displacement spectrum.

`amp_spec.out` : The real spectrum given as frequencies and amplitudes. The files are only generated if parameter SPECTRAL_OUTPUT is set in `MULPLT.DEF`. Setting this parameter will also generate an ASCII waveform file with the input signal used.

Power spectra: The above spectra can also be displayed as power spectra if capital letters are used. Using e.g. 'V' instead of 'v' will show the power velocity spectrum.

When the spectrum comes up (see example in Figure 8.9 , the axis units are log amplitude in nanometers-sec (displacement) versus log frequency (Hz). The cursor can be used to select the level, corner frequency and slope by defining the spectrum with a 3 point selection. This 3-point selection is finished with f, q or r with the same meaning as in picking mode. The spectral values are displayed on the screen once q, f or r is pressed. The abbreviations are

General parameters

Vel:	Velocity used (km/sec) (Vp or Vs)
Dens:	Density (g/(cm**3)
Dist:	Hypocentral distance (km)
Depth	Hypocentral depth (km)
q0:	q0 for spectral amplitude correction
qalpha:	qalpha for spectral amplitude correction
k:	kappa
qi1Hz:	frequency where Q(f) changes to constant Q
spec model:	Spec model is used

NOTE: The veleocity is the velocity at the source, so if the dataset contains both shallow and deep earthquakes, a single velocity will be an approximation if the spec model is not used. There are two solutions to this problem if the values in MULPLT.DEF are used. A: Use different MULPLT.DEF for deep and shallow events. Since the the MULPLT.DEF used is taken from working directory if available, you can have different directories when working with different depth earthquakes. B: Use the general MULPLT.DEF in DAT and change the velocity after making the spectum in the S-file. At the next update, the moment etc will be recalculated with the new velocity. On top of the general parameter is indicated which kind of spectrum is assumed, P or S. In order for the program to automatically determine which kind of spectrum to assume, there must be a P or S reading displayed on the screen near the time window analyzed. The reading must be within 10 sec of the start of the window. If both a P and S-reading is within 10 secs, the nearest phase is chosen. If it cannot be determined which kind of phase is analyzed, the user will get a question to select type of phase (can also be changed later when spectral choices come up) The determination of which phase influences the further calculation of geometrical spreading and moment (uses P or S-velocity).

If f is selected, the spectral values together with calculated moment etc are stored in the S-file at the next key press (see parameters below). Spectral values in S-files accumulate, since no old values are deleted !!!. This is because the spectrum might be made under different conditions (start time, time window etc). The input parameters for the spectral analysis is given in file `MULPLT.DEF`, which can be in either DAT or the working directory, see below. Additional parameters for geometrical spreading are given in `SEISAN.DEF` in DAT.

The spectral parameters are calculated using the relations

$$Moment = 4 * pi * DE * V**3 * 10**OM/(G(r,h) * KK)$$

where V is the seismic wave velocity at the source (P or S if P or S-spectrum respectively) and OM the spectral flat level on the attenuation corrected displacement spectrum.

$$Momentmagnitude = 2/3 * log10(moment) - 6.06$$

which is equivalent to the relation

$$Momentmagnitude = 2/3 * log10(moment) - 10.73$$

if moment is in dynes-cm (Kanamori, 1977).

The moment is calculated in Nm, the source radius in km and the stress drop in bars. All results are written to the S-file. Below is an example if Nordic format is used:

```
SPEC ITK S  Z MO 13.0 ST  4.2 OM  1.5 f0 9.45 R   .22 AL 2.50 WI  4.0 MW  2.6 3
SPEC ITK S  Z K 0.002 T    7  GD   52 VP 6.00 DE 3.00 Q0   .0 QA 1.00 Q1  0.0 3
```

Note that no special line has been created in the Nordic format. Comment lines are used with SPEC at the start of the line followed by station and component. Only the first 4 characters of the 5 character station name is used. The station and component names are given at the start of the line. In case of a 5 character station name, the station name is shifted one character to the left. The information is:

MO:	log of moment, unit Newton*m
ST:	Stress drop in bars
OM:	log spectral level (nm-sec) not distance corrected
F0:	Corner frequency (Hz)
R :	Source radius (km)
AL:	Decay of log spectrum
WI:	Spectral window used (secs)
MW:	Moment magnitude
T :	Start time of window for spectrum in hr, min, sec
K:	Kappa
GD:	GEO_DISTANCE in km
VP or VS:	Velocity in km/sec at source for P and S-spectra respectively. The P or S in this line indicated if the spectrum is a P-spectrum or an S-spectrum. It MUST be P or S to be used for magnitude determination. A '?' is put in if MULPLT does not know which kind of spectrum is (no P or S reading near start of spectral window). This can be changed by editing the S-file afterwards.
DE:	Density in g/cm**3
Q0:	q0 in relation Q = q0 * f ** qalpha
QA:	qalpha
Q1:	frequency where Q(f) changes to constant Q

Note: Before version 10.1, VS was written instead of Q1. However, VS was not used for anything. Note: The component codes have not been adjusted for SEED so the location code is not included.

Note: In earlier versions (before version 7.0), the field for kappa was used for the travel time to start of window. This can be calculated from origin time and the start time of the window.

In Nordic2 format, a special spectral line (type S) has been made and now there is also room for network and location. Example below:

```
AV-SD MO 13.1 0.3 ST  4.0 6.0 F0 5.13 3.3 R 0.364.181 AL 2.0  0.0 MW 2.70 0.2 S
STA  COM NTLO  OM  F0 AL     T  WI   GD  MO ST   R   K   VX  DE  Q0  QA Q1  MWS
FOO  HHZ      1.811.12.0 1242620.047.6012.6 110.12.0003.60S3.00 4400.701.0 2.4S
HYA  HHZ      2.03.902.0 1244820.0123.013.32.00.34.0003.60S3.00 4400.701.0 2.8S
AKN  HHZ      1.96.342.0 1245320.0140.013.27.80.21.0003.60S3.00 4400.701.0 2.8S
ASK  HHZ      1.92.982.0 1245720.0161.013.30.90.45.0003.60S3.00 4400.701.0 2.8S
```

Now the spectral information is on one line and there is an explanatory line above with the same abbreviations as in Nordic format except VX which now indicates P or S velocity. SEISAN can read both new and old format independent of whether Nordic or Nordic2 format is used but will only write S-lines if Nordic2 format is used. This should ensure backwards compability.

NOTE: MOMENT IS NOT CALCULATED IF THE SPECTRUM IS NOT IN DISPLACEMENT.

When doing an UPDATE of the database or just a location with HYP, all distance dependent spectral values are recalculated and average values written into the output file. Mw will be calculated from the average value and written in the header line. **However, the original distance dependent Q and kappa correction is not changed**, since this correction was used to modify the spectrum used for reading parameters. Normally a small distance change has insignificant influence on the spectral level or the corner frequency so the Q-correction should be no problem. Spectra of the same type (P, S or ?) and from the same channel are overwritten. Only in case of UPDATE are the values written back into the database.

Display of spectral parameters: Program MAG can read and plot relations between spectral and source parameters. Program REPORT can read spectral parameters and combine in a table.

Potential problem with Q-correction: If the origin time in header is wrong, the Q-correction can be very wrong.

There must be a phase line in the S-file with component and distance corresponding to the spectra made in order for the spectral values to be calculated.

Spectral fitting

Once the spectrum has been shown (displacement, velocity or acceleration), a theoretical spectrum can be calculated and superimposed on the observed spectrum in order to forward model either source parameters or attenuation.

Another option (s: Plot stored fitted spectrum) if spectral analysis already has been done, is to plot the corresonding theoretical spectrum on top of the calculated spectrum. This option has the purpose to be able to check previously made spectra whether manual or automatic. The SPEC lines have all the information needed to make the theortical spectrum.

Entering constants and modeling: The modeling can only take place when the spectrum is seen on the screen.

Press S and a question will appear to enter the constants f0, k, Q0 and qa which are as defined above except qa is Qalpha. Once these parameters have been entered (terminate with return), the theoretical spectrum (displacement, velocity or acceleration depending on what is used for the spectrum) is calculated and superimposed on the observed spectrum. The parameters used or calculated are displayed. S or s can now be pressed again and a new theoretical spectrum calculated and plotted. To get out of the spectral fitting loop, type r or q as usual.

Which constants and parameters are used: The moment is taken from the last moment calculation made for thsi station, if any. If none, the moment is taken from the S-file if an average moment has been calculated (see UPDATE command). If no moment is available, it can also be entered the first time the spectrum is shown (option M). If no moment is available, no modelling can be done and a message is given. The distance and depth is likewise taken from the S-file. If no distance is available, no modelling can be done and a message is given. If all 4 parameters f0, k, Q, qa are entered, stress drop is calculated with the relation given above. If the corner frequency is given as zero, the user will be asked to enter the stress drop and the corner frequency is calculated from the stress drop. If Q is zero, no Q-correction is made. **IMPORTANT: The Q and qa used here are distinct from the Q0 and Qalpha used for making the amplitude spectrum and both should not be used when modeling since this would imply a Q-correction two times. The best way is to use Q0=0 and kappa=0, so that Q is only corrected for when modeling**. The distance used is everywhere is GEO_DISTANCE.

The spectral parameters shown are:

Moment:	Moment used
Geo dist:	Geo distance used
Stress drop:	Stress drop in bars
f0:	Corner frequency
k:	Constant used in diminution function
q:	q0 used in spectral fitting
qa:	qalpha used in spectral fitting

Power spectrum and noise spectrum

The 3 types of spectra (displacement, velocity and acceleration) can optionally be made as power spectra. Instead of selecting the type of spectrum by pressing d, v or a, just press the same characters in upper case and the power spectrum will be shown.

In seismic noise studies, the seismic background noise is often displayed as acceleration power spectral density in dB relative to ((1m/s**2)**2)/Hz. Instead of selecting d, v or a, press n instead. The plot shows the Peterson (1993) new global high and low noise models superimposed on the observed spectrum (Figure 8.8). When doing noise spectra, no attenuation correction is done. The normalization of the spectrum is as follows

$$P = |F^{DFT}|^2 \times \frac{\Delta t^2}{T} \times 2$$

where P is the Peterson Power spectrum, F^{DFT} is the discrete Fourier transform, Δt is the sample interval and T is the length of the time window. The factor 2 comes from the fact that only the positive frequencies are used so only half the energy is accounted for. The total power is proportional to the length of the time window since the noise is considered stationary, so by normalizing by T, the length of the time window should not influence the results. This noise option is a handy method of checking the noise characteristics

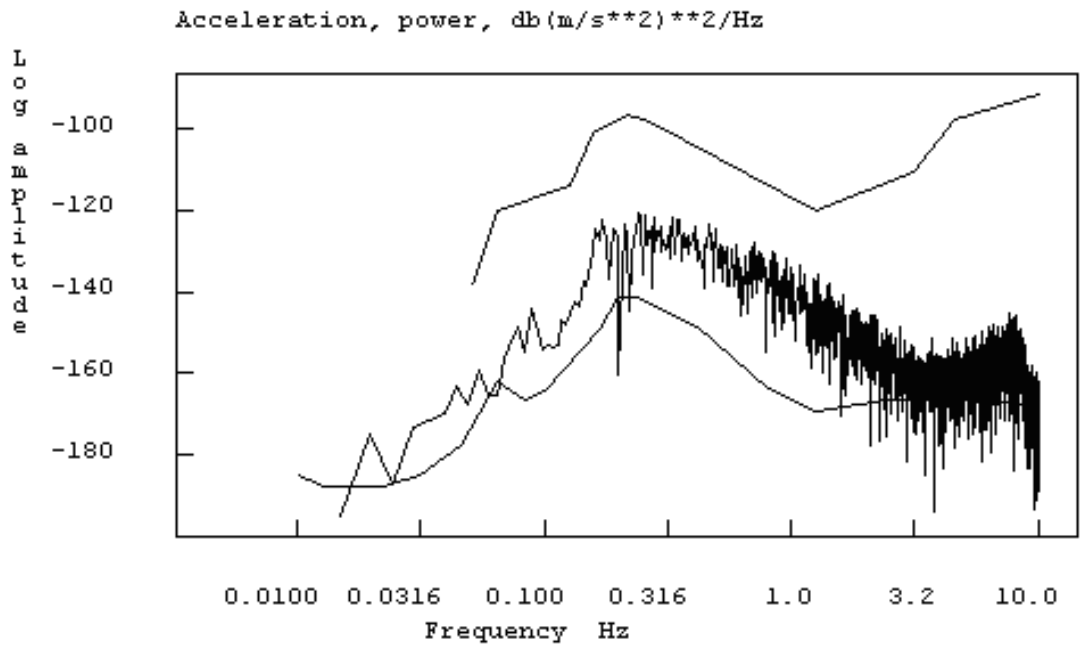


Figure 8.8: Example of a noise spectrum.

of a given seismic station and compare it to global standards. This kind of analysis can also be done with the SPEC program (section 32). For more information, see instrument.pdf in INF.

Problems: There is currently no check if a displacement seismogram has been calculated when calculating the spectral parameters. If spectral analysis is done outside EEV (output in MULPLT.OUT) or with EEV when there is no origin time and/or epicentral distance, the output results are wrong for moment etc. Before calculating moment etc, the S-file MUST HAVE BEEN UPDATED SINCE BOTH THE DISTANCE AND ORIGIN TIMES ARE USED. If the spectra get very high amplitude levels when correcting for instrument, this might be caused by correcting for Q. With a Q of 100 and a distance of 10 000 km, this gives a very large correction. The Q-correction can be disabled in the `MULPLT.DEF` file. If picks are made, but no readings appear in the S-file or readings appear with wrong component, the waveform file component might not have been defined in subroutine componen.for. If poles and zeros are used to remove the response, rotation cannot be used at the same time.

8.13 Spectrogram

SEISAN has two options for making spectrograms. The first is the built in SEISAN routines in MULPLT and the second is an ObsPy script. The first can make a spectrogram of all the traces seen in the multi trace window, while the second make of one trace with a fixed time window. A spectrogram makes a plot of the frequency content of a signal trace as a function of time and is useful to distinguish different kinds of seismic signals. It is often used to identify explosions, see examples below.

The built in program

In multi trace window, press 's' and a spectrogram appears for each trace. The signal is by default filtered before the spectrogram is made using the predefined filter in MULPLT.DEF given by parameter SPECTROGRAM FILTER. To disable the filter, put in 0.0 in the SEISAN.DEF. In spectrogram mode, the usual commands for picking phases, zoom and selecting other traces etc. is working. To return to normal plot, use replot. In order to do spectrograms with other filters, select filter (e.g. variable filter with '.') and press 's'. It is also possible to make spectrograms of instrument corrected signals. To e.g. make a spectrogram of acceleration, choose 'g' for ground motion, 's' for spectrogram and 'a' for acceleration. This can be done whether the current plot is a spectrogram or a trace plot. When a replot of the spectrogram is

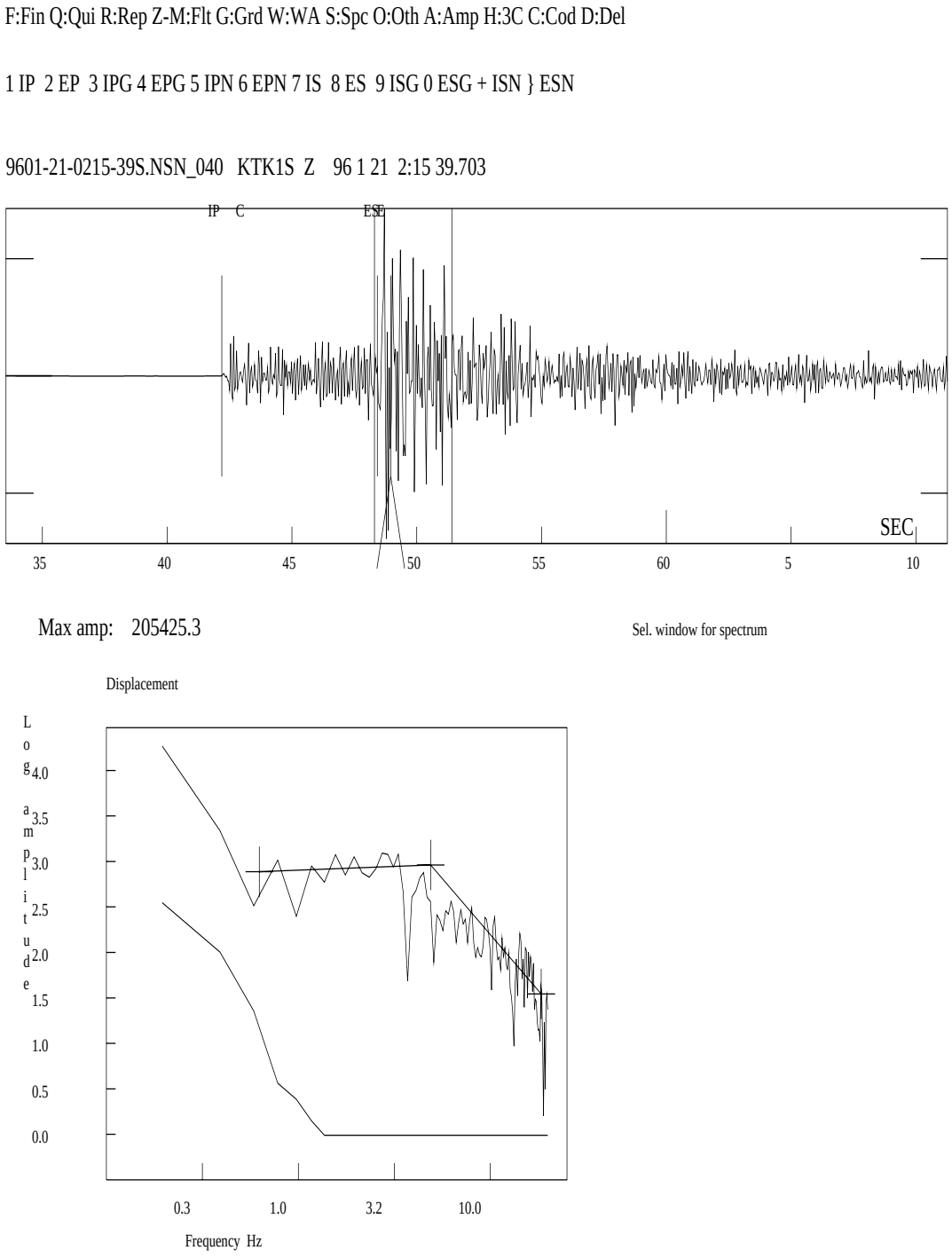


Figure 8.9: Spectral analysis
On top the original trace is seen and on the bottom the displacement spectrum (log -log, unit nm-sec and Hz). The level and slope has been indicated interactively. Note the noise spectrum at the bottom of the figure.

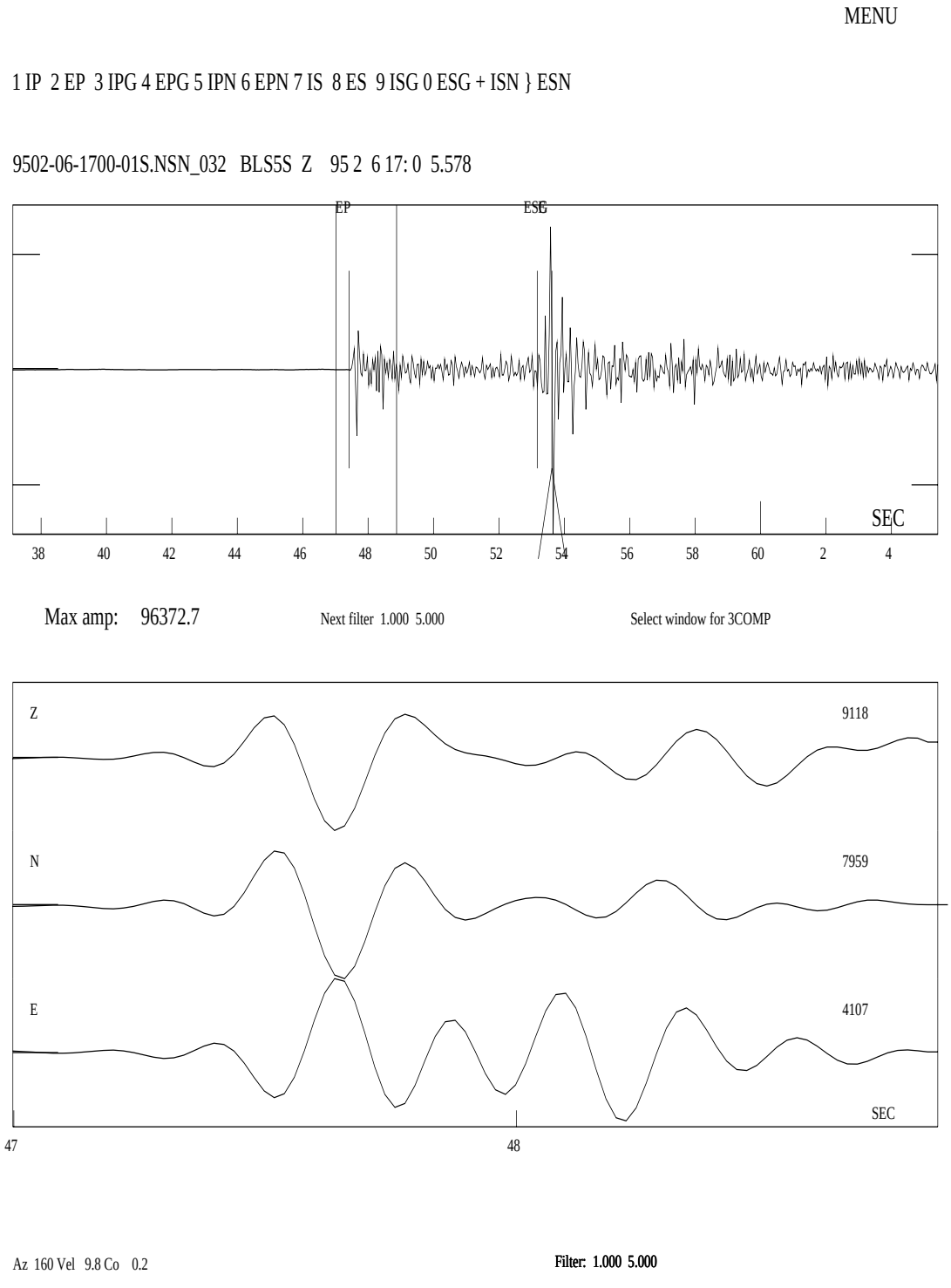


Figure 8.10: Three component analysis
On top the Z-channel is shown together with the window used for the 3 channels Z, N and E shown below. The signals below has been filtered between 1 and 5 Hz and the resulting azimuth of arrival is 160 degrees and a correlation coefficient of 0.2. The apparent velocity is 9.8 km/sec.

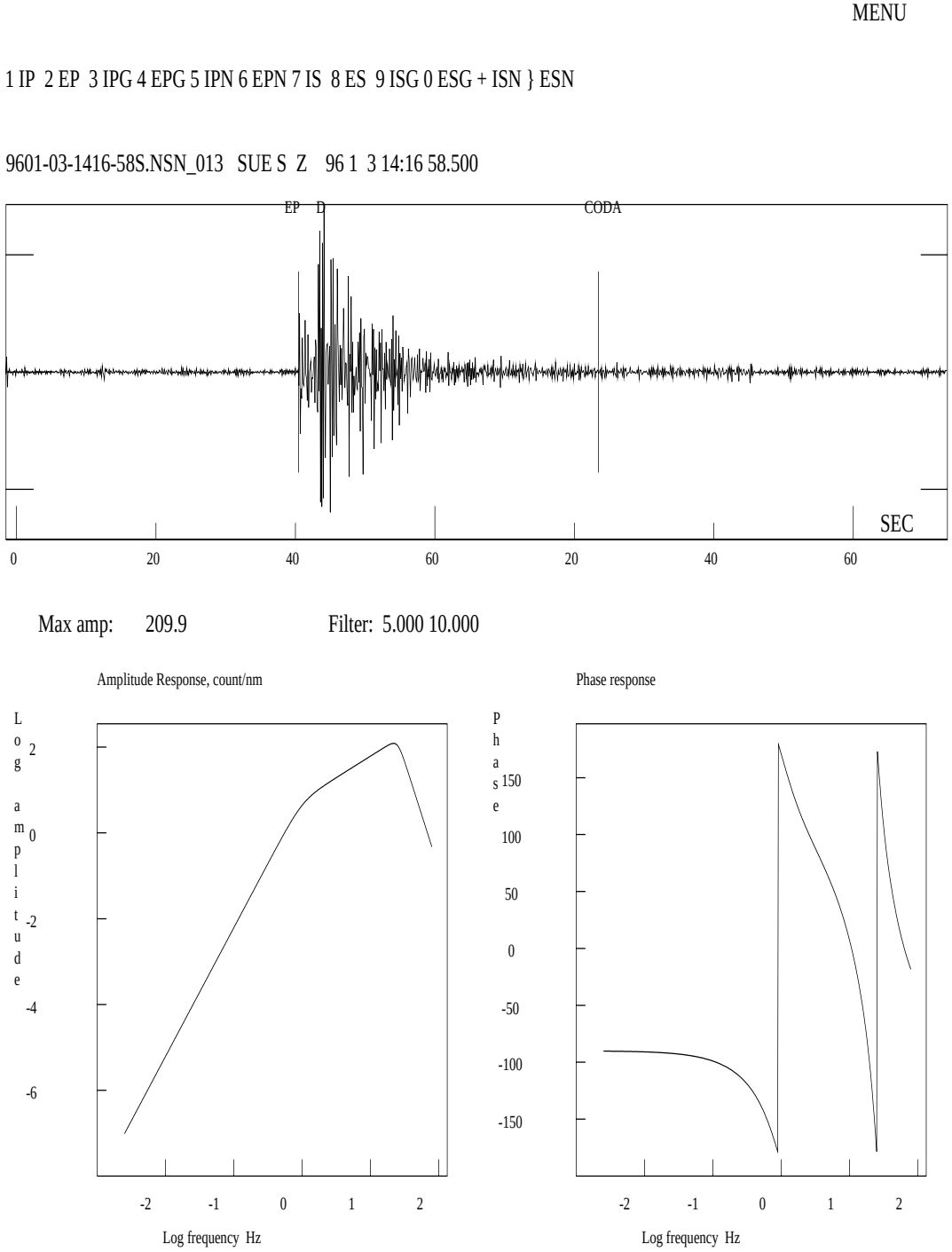


Figure 8.11: Plotting response curves
The figure shows the amplitude and phase response for station SUE, component S Z. The response is the one which will be used in analysis irrespective of whether it is taken from the file header or the CAL directory.

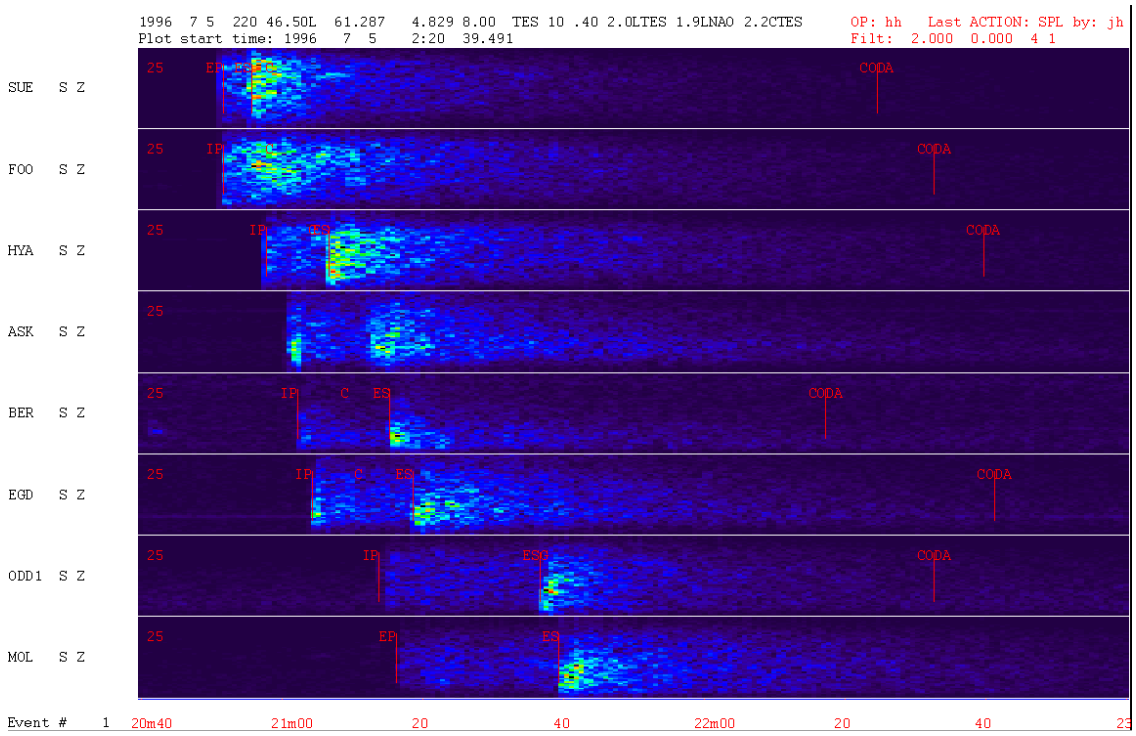


Figure 8.12: Multi trace spectrogram. The numbers to the left indicate Nyquist frquency for each trace. The filter used is indicated at the usual place above right. Dark blue is lowest amplitude and red is the highest amplitude

done, the default filter is removed like for a replot in traceplot mode.

Figure 8.12 shows an example of a a multi trace spectrogram. Note how clear the P and S-arrivals are seen on the plot. However, since the spectrograms are made doing spectral analysis in fixed time windows, the arrival times will not fit the spectrogram exactly. It would have been possible to smoothe the spectrograms (or make it contoured), see the ObsPy example. However without smoothing, we see the data as it is.

NOTE: The possible output file mulplt.eps does not contain the spectrogram. To get a plot file, use the ObsPy option.

ObsPy spectrogram

The ObsPy SPECTROGRAM program in SEISAN is based on Python routines from ObsPy (docs.obspy.org) **so both Python and ObsPy must be installed**, see installation section. In MULPLT, the spectrogram is made in multitrace mode: Put the curser on the trace you want to analyse at a position where the time series for the spectrogram should start. Press E (shift e) and the spectrogram will be plotted in a separate window (close the trace window if opened first). To continue with MULPLT, close the spectrogram window. The window length is by default 80 sec and a default high pass filter (2 Hz) with 2 poles is used before calculating the spectrogram. The reason for the filter is that most spectrograms are only interesting at the higher frequencies, particularly for explosion discrimination. Optionally a window with the filtered signal can also be plotted before the spectrogram comes up, see example below. The options are set up in MULPLT.DEF and the parameters used are:

```
SPECTROGRAM WINDOW                    60.0
SPECTROGRAM FILTER                     2.0
SPECTROGRAM PLOT TRACE                 0.0
```

The window can have any value up to 300 sec (hardwired value in MULPLT). The filter is always high pass and 2 poles. If no filter is to be used, set it to 0.0. If the trace is to be plotted, the parameter must be set to 1.0.

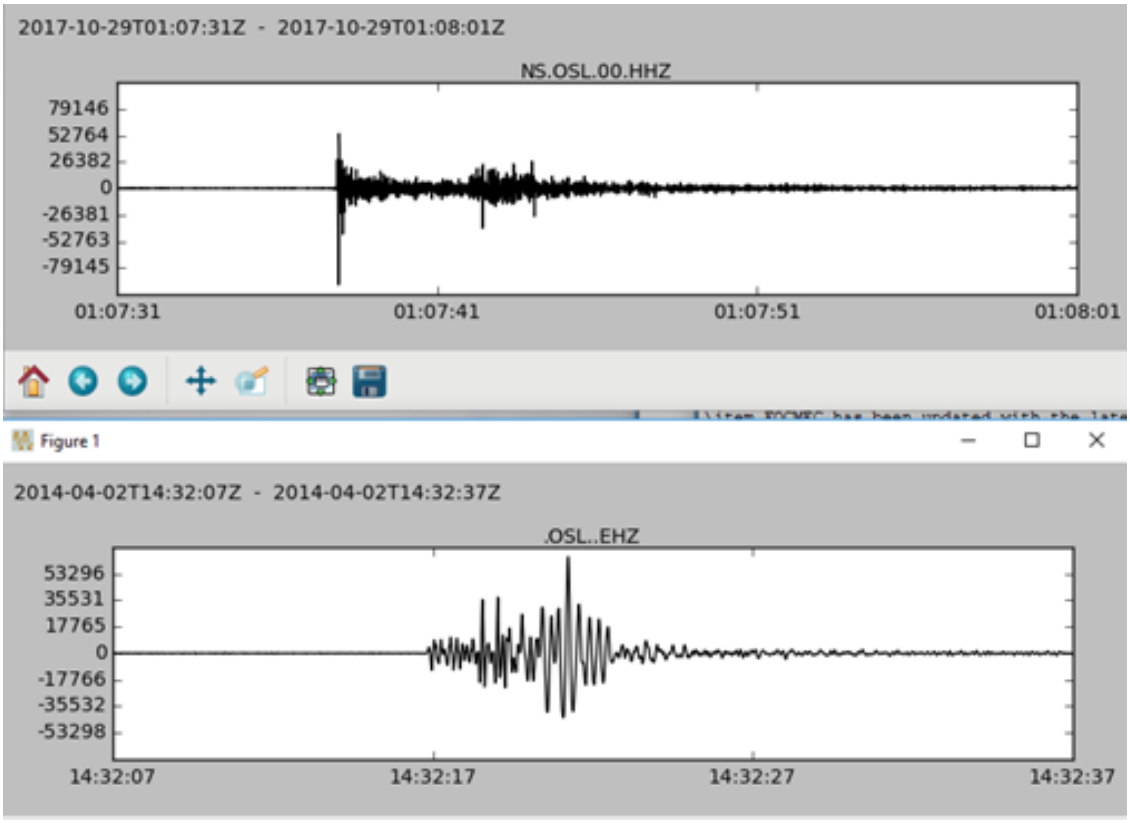


Figure 8.13: Top: Seismogram of an earthquake recorded at station OSL. Bottom seismogram of an explosion at the same station. Both seismograms plotted with SPECTROGRAM. The filter is 2 Hz.

The spectrogram program can also be operated as a free standing program. An example is:

```
spectrogram waveform.out 80 3 1
```

where the first argument is the file name, second is window length, third is filter and last is trace plotting options. All arguments must be there. In principle most waveform formats can be used (as implemented by ObsPy) but some versions of SEISAN waveform format might not work. The safest is to use MininSeed. If the waveform file contains several channels, the first one is used. Using the program independently from MULPLT, there is not the 300 s limitation.

If several tests are to be made with different window lengths and filters, the simplest way is to first make the output file waveform.out with MULPLT spectrogram option and then do the tests from the command line as the shown with the example above.

Figure 8.13 shows an example of an explosion and an earthquake at about the same location recorded at the same station . Figure 8.14 shows the corresponding spectrograms. It is clear from the seismogram which is the explosion due to the monochromatic waves (probably Rg) and the spectrograms also show more monochromatic content for the explosion than for the earthquake. Station OSL is close to the event and the explosion (epicentral distances 10-20 km). However, the same is seen for station SKAR 157-159 km away (Figure 8.15). This is a textbook example and not all explosions and earthquakes are so easily distinguished.

8.14 Particle motion plots

Particle motion plots can be made in multi trace mode when three components from one station are selected. The particle motion is plotted below the rescaled trace plot. The particle motion plots are made for the time window shown in the trace plot. The trace plot has all the normal functionality, so it is still possible to zoom and filter. The particle motion plots can be useful when determining phase types. No readings can

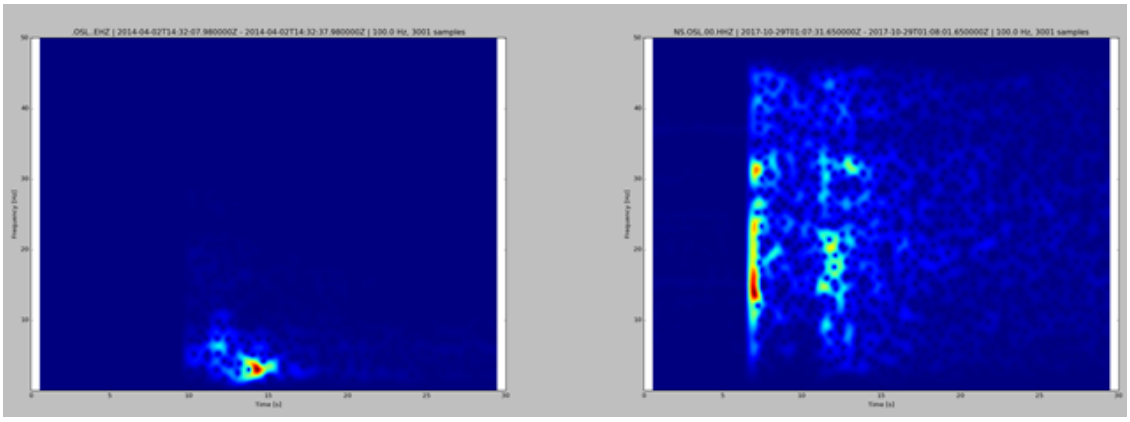


Figure 8.14: Spectrograms of the two signals from OSL, explosion left, earthquake right. Note the clear difference in frequency content.

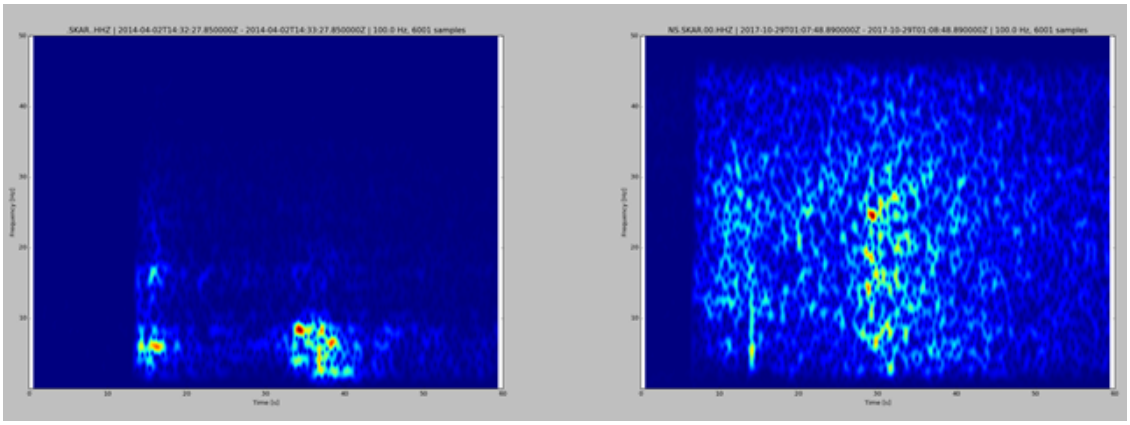


Figure 8.15: Spectrograms from station SKAR. Explosion to the left and earthquake to the right.

be made from the trace plots.

8.15 Setting MULPLT parameters, MULPLT.DEF

In the MULPLT.DEF and the SEISAN.DEF files, it is possible to set the various parameters for MULPLT. Nearly all parameters are set in the MULPLT.DEF except geometrical distance parameters, which are set in SEISAN.DEF since these parameters also are used by HYP. MULPLT will operate without DEF-files using hardwired defaults. The MULPLT.DEF can be located in the working directory and or in DAT. The if a DEF-file is present in the working directory, it overrides the file in DAT. In MULPLT.DEF, several groups of parameters can be set: The keyboard, default channels to use and analysis parameters (e.g. for spectral analysis). The parameters are identified by keywords, see example file below for explanation. Note that all numbers given in file are real and must be given a '.'

Example file:

This file is for defaults for MULPLT and called MULPLT.DEF. The name must be in upper case on SUN. The following shows the parameters, which can be set. The file can contain any number of lines in any order, only the lines with recognized keywords and a non blank field under Par 1 will be read. Numbers under Par1 and Par2 must be given as reals. The comments have no importance.

```
This file is for defaults for MULPLT and called MULPLT.DEF. The name must
be in upper case on Linux. The following shows the parameters which can be set.
The file can contain any lines in any order, only the lines with
recognized keywords and a non blank field under Par 1 will be read.  The two
parameters are in column 41-50 and 51-60, repectively. The
comments have no importance. Blank means default is used. The numbers in Par 1
and Par 2 are always real numbers and anc be placed anywhere withing the 10
fields.

KEYWORD............Comments.............Par 1.....Par 2

*** Screen appearance ***

X_SCREEN_SIZE      Size in pixels       90.0
NCHAN PER SCREEN   # chan pr screen
NSORT_DISTANCE     0: no, 1: yes
RESOLUTIONX        # points pl. screen  1500.0
RESOLUTIONHC       # points pl. hc      3000.0
PLOT DISTANCE      0: no 1: epi 2: hyp  1.0
#BANDPASS FILTER    Default filter       4.5       9.6
CHANNEL SORTING    Sort channels        1.0

*** Channel selection ***

#DEFAULT CHANNEL                         TRO       S  Z
MULPLT AREA                             0.0
MULPLT LAT LON                          60.0      5.0
MULPLT RADIUS                           2.0
MULPLT STAT                             BER

*** Key assignments, see also filters for processing        ****
*** Do not use keys with fixed assignment, 1 to + are free  ****

# Example of using 1 and 2 for P and S, uncomment to use
#PHASE NAME KEY     Phase key and phase  1         IP
#PHASE NAME KEY                          2         IS
```

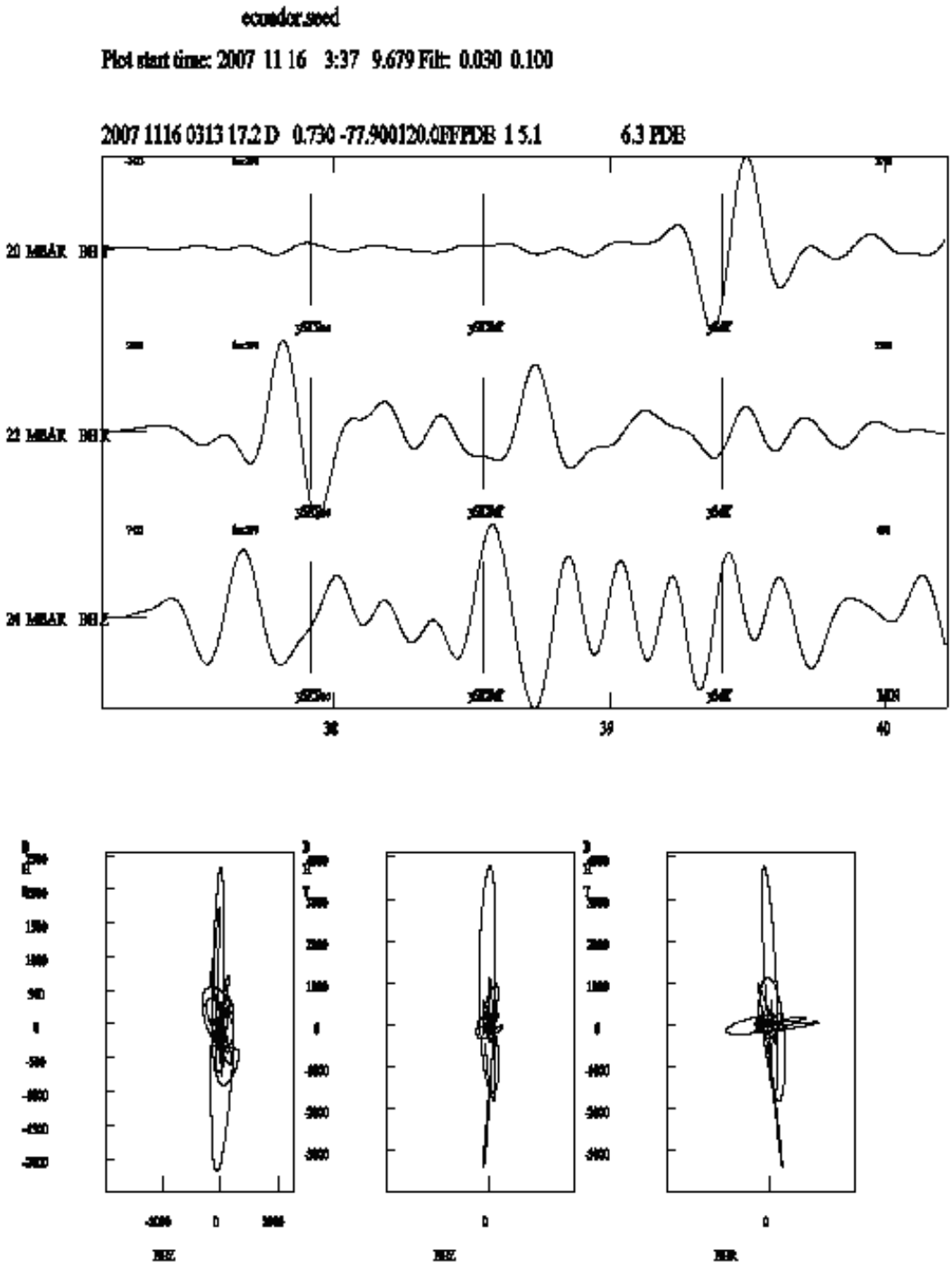


Figure 8.16: Example of particle motion plot.

```
PHASE WEIGHT KEY   Weight key and weight
PHASE MOUSE KEY    Mouse key character

*** Filters for processing ***

### Set Filter type 0 for bndpas 1 for recfil routine
FILTER TYPE                          0.0
FIX FILTER  Fix BANDPASS FILTER, 0, 1
### Setup user-defined filters
FILTER 1                             0.01      0.1
FILTER 2                             0.1       1.0
FILTER 3                             1.0       5.0
FILTER 4                             5.0       10.0
FILTER 5                             10.0      15.0
FILTER 6                             15.0      25.0
FILTER 7                             2.0       4.0

*** Spectral analysis ***

SPECTRAL Q0        Q0                440.0
SPECTRAL QALPHA    Q = Q0**Qalpha    0.70
SPECTRAL KAPPA
SPECTRAL P-VELOCITY P velocity       6.2
SPECTRAL S-VELOCITY S velocity       3.6
SPECTRAL DENSITY   Density
SPECTRAL MODEL      0 no 1 yes       1.0
SPECTRAL OUTPUT   Makes a file       1.0
SPECTRAL F-BAND   Spectral band to show 0.01      20.0

*** Spectrogram ***

SPECTROGRAM COMMAND                  spectrogram.py
SPECTROGRAM WINDOW                   60.0
SPECTROGRAM FILTER                   2.0
SPECTROGRAM PLOT TRACE               1.0

*** Three component analysis ***

3COMP VELOCITY     velocity for 3 comp

*** Magnitude ***

AUTOCODA FILTER                      0.1       10.0
AUTOCODA STA                         3.0
AUTOCODA RATIO                       1.2
CODA AUTO                            0.0
#ML LOW CUT AND POLES                 1.25      8.0
#ML HIGH CUT AND POLES                20.       8.0

*** Auto processing ***

AUTO_LOCATE        0,1,2       0,1,2    0.0       2.0
AUTO_PROCESS       0,1,2       name     0.0       ls
```

```
*** Format of waveform output ***

MULPLT WAV OUT FORMAT  Output format    SEISAN
```

All parameters are within column 41 and 60 and each occupying up to 10 characters.

NOTE: If any of the phase or weight keys are redefined, all previous defaults disappear.

DEFAULT CHANNEL: All channels are default if not given. For routine display, it is useful to only select some channels.

PHASE NAME KEY: The keys associated with given phases. Remember that I, E or a blank MUST be part of the name so it is not possible to chose a name like "P", it must then be " P" (note the blank in front of P). About 10 phase combinations are currently default as seen on the pick display. If a new phase key is selected, you must define all the keys you want to use for phases including all the predefined phases. The combined onset/phase key can be up to 9 characters.

PHASE WEIGHT KEY: The defaults are upper case 1,2,... to 0 for weights 1,2,... to 0 . Again, choosing just one other key, and all must be redefined. The symbol must be in column 41 and the weight in column 51. The weight is an integer 0, 1,2,3, 4 or 9.

PHASE MOUSE KEY: The default is blank. Normally no redefinition is needed since the mouse character is defined in SEISAN. The key can be defined as a character or the ASCII code written as a real number.

SPECTRAL P-VELOCITY: P-velocity in km/sec, default 6 km/sec

SPECTRAL S-VELOCITY: S-velocity in km/sec, default 3.5 km/sec Both above parameters must be set separately, the Vp/Vs in `STATION0.HYP` is not used to calculate one from the other. The values go into the S-file the first time spectra are calculated. if values are changed later in the `MULPLT.DEF` file, no change will be made in the S-file, old values remain.

SPECTRAL Q0: Q is defined as $q0 * f * *qalpha$, default 0 meaning no Q-correction. For f ¡ 1 Hz, Q=q0 (new from version 10.1).

SPECTRAL QALPHA : See above, default 1.0, NOTE: Q is only used when doing spectral analysis and has no effect on the displacement seismograms.

SPECTRAL DENSITY: Density for spectral analysis (g/cm**3), default 3.5 g/cm**3

SPECTRAL KAPPA: Near surface attenuation, default 0.0 meaning no attenuation. For teleseismic events, this is t*.

SPECTRAL GEO_DEPTHS: Depth range where geometrical spreading changes from surface wave to body wave spreading, S-waves only. Default 50 and 100 km. This is only used if distance is larger than HERKIJ_DISTANCE. THIS PARAMETER IS NOT SET IN `MULPLT.DEF`, BUT IN `SEISAN.DEF`, MENTIONED HERE SINCE IT IS IMPORTANT FOR SPECTRA.

SPECTROGRAM COMMAND: External command to compute spectrogram for single trace that can be started from MULPLT in multi trace mode (command 'E').

HERKIJ_DISTANCE: Epicentral distance at which geometrical spreading changes from body wave spreading to surface wave spreading, S-waves only. Default 100 km. THIS PARAMETER IS NOT SET IN `MULPLT.DEF`, BUT IN `SEISAN.DEF`, MENTIONED HERE SINCE IMPORTANT FOR SPECTRA

3COMPVELOCITY: Velocity used (km/sec) in 3 component azimuth analysis. Default is 5 km/sec.

CHANNEL SORTING: If set to 1.0, channels and filenames are sorted alphabetically, if 0.0, no sorting. Default = blank is sorting.

NCHAN PER SCREEN: The number of channels to be displayed per screen. Default = blank is 99 channels. It may conflict with **DEFAULT CHANNEL**.

NSORT_DISTANCE: If blank or zero, channels are plotted in the order as they appear in the waveform file or in alphabetical order if flag CHANNEL SORTING is set. If set to 1.0, the channels are plotted in distance order with respect to the epicenter or if no epicenter is given with respect to the location of the station that has the first pick. If not plotted from EEV, 1.0 will indicate sorting in waveform file header time order. Default 0.

X_SCREEN_SIZE: Size of initial X-window in % of total screen. Default 90 %.

RESOLUTIONX and RESOLUTIONHC is the number of points plotted on the screen or laser printer respectively. If e.g. 1000 points are plotted, this means that the remaining points are skipped although some primitive smoothing is done. Choosing too few points can lead to funny looking seismograms with aliasing effects and using all points will slow down the plotting. Resolutionx is for the screen and resolutionhc for the hardcopy. NOTE: If using MULPLT mode where both screen and hardcopy is used, it is the hardcopy resolution, which is used for both. Default 1000 and 3000 respectively.

PLOT DISTANCE: If set to 1.0 plot epicentral distance, if set to 2.0 plot hypocentral distance an dif set to 0.0, do not plot distance. Distance is only plotted on multi trace plots, just after the DC. Distance is in km.

SPECTRAL F-BAND: Spectral range (Hz) used for spectral plots. Default values are 0.05 to 20.0 Hz.

AUTO_PROCESS: Immediately following registration, MULPLT can run any program specified here. Since the event name has been put into memory, the program can operate on the newly registered S-file. Parameter one has the options: 0: Do not auto process, 2: Ask the user if autoprocess, 3: Autoprocess without asking the user. Parameter 2 gives the name of the process to run. The name is limited to 10 characters. Default, no auto processing.

AUTO_LOCATE: Immediately following registration, MULPLT can locate the newly registered event and put the location into the database. Parameter one has the options: 0: Do not locate, 1: Ask the user if locate, 2: Locate without asking the user. Parameter 2: 0: Do not save in database, 1: Ask if saving in database, 2: Automatically save in database. Default, no auto locate.

SPECTRAL OUTPUT: If parameter set to 1, two output files are created for each signal spectrum. `com_spec.out` is the complex spectrum and `amp_spec.out` is the real spectrum. Default 0.0. In addition, the single trace zoom window is saved in signal.out.

FILTER: Change definition of filters 1 to 7. The settings affect both the shortcut keys and the menu boxes.

MULPLT WAV OUT FORMAT: The output format when using Out function, default is SEISAN. The options are the same as available in WAVETOOL.

ML LOW CUT AND POLES and ML HIGH CUT AND POLES: Filter band for Wood Anderson additional filter. Recommanded values are 1.25 Hz to 20 Hz and 4 poles. Note, poles are always 4 whatever is specified.

BANDPASS FILTER: When using all defaults from EEV (option PO), a bandpass filter can be set. Default is no filter. The parameters are lowcut and highcut for parameter one and two respectively. 4 poles only.

FIX FILTER: When using alldefaults from EEV (option PO), a bandpass filter can be set, see parameter BANDPASS FILTER. The filter can be fixed with parameter FIX FILTER: 1.0 =fix filter, 0=no fix. Fixing means that in all operation the filter will remain.

CODA AUTO: Enable automatic coda determination (YES or NO). Default is NO. If enabled, auto coda is read with c instead of C.

AUTOCODA FILTER : Filter band for automatic coda: Default 5 to 10 Hz.

AUTOCODA STA: Auto coda short term average: Default 5.0 secs.

AUTOCODA RATIO : Autocoda ratio. Default 1.5.

MULPLT AREA : Options for plotting stations in a given distance from a midpoint. 0: do not select option (default) 1: midpoint from s-filei epicenter, radius from MULPLT.DEF, 2: midpoint from MULPLT.DEF, radius interactive 3: midpoint and radius from MULPLT.DEF, 4: midpoint from MULPLT.DEF, radius interactive, 5: midpoint and radius interactive, 6: Midpoint from a station in MULPLT.DEF, radius from MULPLT.DEF 7: Midpoint station asked at start of MULPLT, radius from MULPLT.DEF 8: Both midpoint station and radius asked at start of MULPLT

MULPLT LAT LON : Midpoint

MULPLT STAT : Station for midpoint

MULPLT RADIUS : Radius in degrees

SPECTROGRAM COMMAND: name of spectrogram program

SPECTROGRAM WINDOW: window lenght of spectrogram

SPECTROGRAM FILTER: frequency of high pass filter for spectrogram, if zero no filter is used

SPECTROGRAM PLOT TRACE: if zero, no plot, if 1.0 plot trace

Chapter 9

Distance trace plot with GMT, TRACE_PLOT (Unix only)

TRACE_PLOT is a simple program to create a distance trace plot using GMT version before 5 programs (Generic Mapping Tools, `http://gmt.soest.hawaii.edu/`). The axes of the plot are time and distance, and the traces are centered on the respective epicentral distance. The input to the program is a single event in Nordic format (S-file). From the S-file, the program reads the origin time, epicenter location and the names of the associated waveform files. TRACE_PLOT reads the waveform data and writes the x-y coordinates of the lines in the plot to a file that is then used as input to the GMT program psxy. The TRACE_PLOT program removes the DC from the data and as an option can apply a band-pass filter. The output of the program is a Postscript file (`trace_plot.ps`) and a batch file that can be modified and used to rerun the GMT programs (`trace_plot.bat`). The parameters are set in the `trace_plot.par` file, which can be located either in the DAT or in the working directory. An example is seen in Figure 9.1 .

The parameters in `trace_plot.par` are:

FILTER: The pass-band filter limits can be specified through the FILTER parameter.
DISTANCE: The distance range (y-axis) for the plot.
TIME: The time range in seconds (x-axis).
AMPLITUDE_SCALE: The amplitudes are scaled for every trace individually, by [amplitude/(max amplitude) * AMPLITUDE_SCALE].
STATION_SFILE_ONLY: This variable can be set to 1.0 to only plot traces that are listed in the S-file, the default is 0., which plots all traces without checking if they are present in the S-file.
TIME_ORIGIN: In the current version, the origin of the time axis corresponds to the origin time of the event.
COMPONENT: This can be used to select components for plotting, in case no component is defined, TRACE_PLOT will show all vertical component traces.

Example of `trace_plot.par`:

```
KEYWORD.............Comments..............Par 1.....Par 2

FILTER              filter range          0.1       5.0
DISTANCE            dist range            0.        440.
TIME                time window           0.        250.
AMPLITUDE_SCALE     amplitude/max*scale   15.
STATION_SFILE_ONLY  0. if any station     0.
                    1. if station has
                       to be in s-file
TIME_ORIGIN         1.=origin time        1.
                    0.=file start time
COMPONENT                                 BH Z
COMPONENT                                 HH Z
```

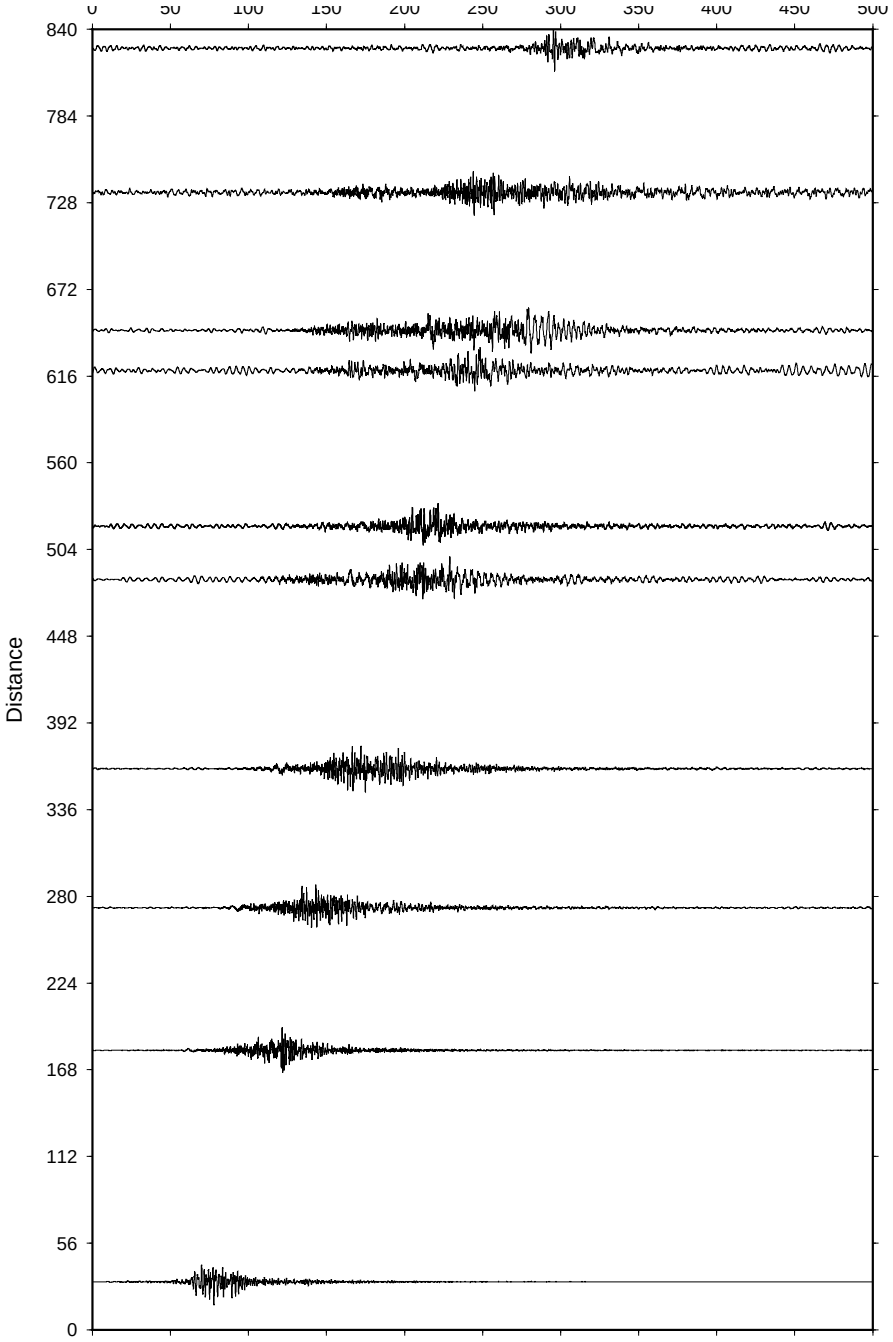


Figure 9.1: Example of TRACE_PLOT output.

Chapter 10

Plotting epicenters

In SEISAN there are several different programs for plotting epicenters, EPIMAP, W_EMAP and GMAP, MAPG and MAP. EPIMAP is the basic program for plotting epicenters in SEISAN and is the program that is called from EEV, when you type `map`. Program MAP is an automatic version of EPIMAP and does not require input parameters either than the hypocenter file. MAPG is a similar program to MAP using GMT. W_EMAP is a windows based program. GMAP is linked to the Google Earth and Google Map Internet mapping tool.

10.1 EPIMAP

The command for plotting epicenters is EPIMAP ¡file¿, where the optional file is a file with EPIMAP commands. If file is not given, the user will be prompted for the input. The program can plot land contours, epicenters, macroseismic intensities, stations and level contours as well as depth profiles. It is possible to zoom in on selected areas (option by **Mario Villagrán**). The program has been much revised by **Jim Bolton**.

Optionally the program can be started with flag n like epimap map.inp n to not plot info on left side. This option is intended for making a map without the interactive options plotted.

Input files: Land contours and other contours

The program will look for all files ending with .MAP located in the DAT directory. The user can then choose any one or a combination of files. The users own contour files (e.g. faults) can be added to the DAT directory. A very detailed world map is available on the SEISAN CD and on the SEISAN web site. Areas can be selected out of these files with program SELMAP.

Stations

Epimap will look in `STATION0.HYP` for station coordinates. It will search first in the working directory, then in DAT.

Epicenters

The user will be prompted for epicenter input files. The format can be Nordic or Nordic compact. Magnitudes are plotted proportional with symbol size unless the ellipticity option is selected in which case the error ellipses are plotted (if smaller than 100 km). Fault plane solutions can optionally be plotted instead of error ellipses. The first fault plan esolution found in file will be used. Name of intensity files (SEISAN standard format, see Appendix A) are also entered here. The file name must have the 3 letters 'mac' after the '.' See also section 42.

Input files for EPIMAP can be made e.g. with the COLLECT command which collects S-files into one file or with the SELECT command selecting data from the database using several criteria. HYP also generates a CAT-file (`hyp.out`) which may be used as input to EPIMAP.

Macoseismic information

EPIMAP can plot SEISAN macroseismic observations, see section 42.

Magnitudes

The program will read all 3 magnitudes (magnitude1, magnitude2 and magnitude3) in the header line. It will use the first non-zero magnitude in the order magnitude1, magnitude3 and magnitude2. Epimap

will search the first header line only. If it is desired to use a particular magnitude from any header line for plotting, use MAG program first to select particular magnitude type which is then placed in first header line magnitude position one. Program NORHEAD can move magnitudes from following header lines to the first line. Program REPORT can move magnitudes around on the header line.

A typical run is as follows, comment after !:

```
Projection menu
===============

   1: POLAR STEREOGRAPHIC     conformal, azimuthal
   2: ORTHOGRAPHIC            view from infinity, azimuthal
   3: MERCATOR                cylindrical, conformal
   4: LAMBERT EQUAL AREA      azimuthal
   5: GNOMONIC                Great Circles are straight lines
   6: AZIMUTHAL EQUIDISTANT   distance from origin is to SCALE$
   7: STEREOGRAPHIC           conformal, azimuthal
   8: EQUIDISTANT CYLINDRICAL
   9: OBLIQUE MERCATOR        cylindrical, conformal
  10: MOLLWEIDE ELLIPTICAL    pseudocylindrical, equal area
  11: SANSON'S SINUSOIDAL     pseudocylindrical, equal Area

Please enter projection number   :  3
Enter latitude  range of the map :  60 70    ! N  positive
Enter longitude range of the map :  0 30     ! E  positive

Center of geographical map space is ( 65.0,  15.0) degrees.
         ! can be used e.g. to make an accurate MERCATOR at high latitude
 Press <return> to accept these as the reference latitude
 longitude for the projection or <N>o to enter your own
co ordinates :

 Enter latitude of any grid line and also the grid spacing
:  60 2      ! possible to have grid spacing at any value
 Enter longitude of any grid line and also the grid spacing
:  0 4

DO YOU WANT THE EVENTS NUMERATED? (Y/N=RETURN)
  ! a sequential number will be plotted besides each hypocenter, the     !
corresponding hypocenters are found in output file epimap.out.

Plot title (max 60 chars), or press <return> for none:
Plot error ellipses: e or fps: f (n=return)?:       ! from HYP or fps programs
File name for contour levels, or press <return> for none: ! format below
Plot place names (P) or                             ! file format below
Plot all (a) or some (s) stations with a label, ! if s, question given about
                               ! which station, give in UPPER CASE all stations
without a label (X), or none <return>
...Enter in uppercase if you wish the symbols to be filled
and this facility is available...     ! only filled out in Postscript
:

Available colour index values are:
           1) Blue
           2) Green
```

```
           3) Red
           4) Yellow
           5) White
           6) Black (default)


 Enter epicenter filename and colour index,
 separated by a blank, otherwise press <return>
collect.out 2              ! plot first file green

 Input file is Nordic      ! full Nordic format of input file

 Enter epicenter filename and colour index,
 separated by a blank, otherwise press <return>
select.out  3              ! plot second file red

 Input file is Compact     ! compact file format of input file


 Enter epicenter filename and colour index,
 separated by a blank, otherwise press <return>

 Enter the following in uppercase if you wish the symbols
 to be filled and this facility is available...
 By default, symbols will be plotted according to
 magnitude, do you wish them to be plotted according
 to magnitude range ?

==== Loading Epicenters...

! now comes the plot, see below for options

 Earthquake locations inside the window are in epimap.out
 Coordinates of the surrounding area are in epimap.cor
 Area selected epicenters are in epimap.are
 Plot file is called epimap.eps
```

Interactive options:

When the plot is shown, there appears in the lower left-hand corner a menu of several options:

Q: Quit
P: Profile
A: Area
Z: Zoom

Press one of the letters to continue.

P: Profile

One or several depth section windows can now be selected with the cursor. First move the cursor to where the section shall start (from where distances are calculated), press any character to select point, move cursor to end of profile, press any character to select. A line between the two points is now plotted. Move the cursor to a point on the side of the line and press any character. A rectangle defined by the three points is now drawn, which defines the area used for the section. If more than one section is wanted (up to 9), press the number of sections instead. The selected number of profile boxes will now be plotted, all the same size. Pressing any character will draw the depth sections auto scaled, while PRESSING THE CHARACTER F, THE X AND Y SCALES ARE EQUAL and determined by the horizontal extension. When the first section

appears, you can either press q to quit or any other character to plot next profile or, if the last profile, replot epicenter map and select new sections. IF YOU WANT ALL SECTIONS TO REMAIN IN PLOT FILE, QUIT AFTER PLOTTING THE LAST PROFILE. The plot file always stores what has been plotted so far, and is overwritten when a replot is made. It is also possible to plot a previously defined profile by entering O. The parameters are then taken from file profile.out. This file stores the last parameters selected by EPIMAP, but can also be edited by the user.

A: Area

Select, by clicking with the cursor, at least 3 points defining a polygon within which epicenters are selected. A new plot is made enclosing only the polygon and showing the epicenters within the polygon. The corresponding epicenters (S-files) are in file epimap.are. Known bug: Sometimes epicenters are still left outside, SELECT can be used instead.

Z: Zoom

Similar to Area, however a rectangle is selected by defining just the 2 diagonal corners. Note, you can also zoom out by selcting zoom points at extreme corners of the plot outside the map.

MAP files The map files consist of blocks of coordinate pairs. Each block starts with the number of pairs in the block. The format of the header line is i4 and the following lines 10f8.3. Thus each block can at most have 9999 pairs.

Plotting place names If option P is used when the program asks for place names or station codes, the user will be prompted for one or several files with place names. The place name file format is:

name latitude_degrees longitude degrees

eg:

```
 55.94422  3.20096    Edingburgh
```

The first 24 characters are for the latitude and longitude. The text must begin in column 25 or later.

NOTE: The format changed with SEISAN version 12.0.

An example of a place name file is place_names.macro located in DAT.

Epimap contour file

EPIMAP has a simple contouring routine accepting a regular spaced grid. Below is an example (output from EQRSEI). The top part of the file is just comments, the data starts at "Fields to use". The data must come in longitude, latitude pairs (+ value of contour) in order as shown below. The contour value is plotted exactly as shown below. E. g. the value 117 is plotted as __117____ where "_" is blank. By specifying ____117.0_, the value would be plotted as 117.0 and moved one space to the left on the plot. The example below is from an older version of SEISAN which had a program for making hazard maps. Currently the only program for making a contour file is HYP when it is used for making a gridsearch. In the DAT directory, there is an example of a gridsearch.out file made with HYP.

NB: In the input file shown below, the FIRST COLUMN MUST BE blank.

```
This file is input for epimap contour plotting. The input of
parameters must appear as listed below with the actual data
starting after the line Fields to use. There can be any
number of header lines. The contour values plotted are
plotted with the number of decimals given below. The last
part of the file is the actual longitudes, latitudes and
levels. Color use is optional and the field can be left
blank, the codes are as follows:

1: blue   2: green   3: red   4: yellow   5: white   6: black

Fields to use                          I.........I.........I.........I
Contour level to plot and color           117           2.0
Contour level to plot and color           119           3.0
Contour level to plot and color           121
Contour level to plot and color           123
Contour level to plot and color           125
```

```
 Contour level to plot and color           127
 Contour level to plot and color           129
 Contour level to plot and color           131
 Contour level to plot and color           133
 Contour level to plot and color           135
    5.00000    40.0000    117.620
    6.00000    40.0000    118.490
    7.00000    40.0000    119.080
    8.00000    40.0000    119.390
    9.00000    40.0000    119.390
   10.00000    40.0000    119.080
    11.0000    40.0000    118.490
    12.0000    40.0000    117.630
    13.0000    40.0000    116.510
    14.0000    40.0000    115.180
    5.00000    41.0000    119.680
    6.00000    41.0000    120.620
    7.00000    41.0000    121.260
    8.00000    41.0000    121.600
    etc
```

EPIMAP output files:

`epimap.out`: Gives a numbered list of all events within main window. This can be used in connection with the number option.

`epimap.cor` and `epimap.are`: If option A (selecting area) has been used, the coordinates of the corners will be given in `epimap.cor` and the complete events (S-files) within the selected area, in `epimap.are`.

`epimap.are`: Events selected with area function.

`epimap.num`: A compact file of `epimap.out` with the numbers plotted.

`epimap.eps`: Postscript plot file of epicenters and possible profiles. If only one profile has been selected, all is on one page. If several profiles are selected, there will be two profiles per page up to a maximum of 6 pages (one with map and 5 with profiles).

`epimap.inp`: This file is storing all input parameters of the run and can be used to run epimap again without entering any parameters. The file can be edited if a run has to be repeated with e.g. a new epicenter file. The file can have any name so several predefined plot definitions can be stored and thereby automate map production.

`profile.out`: The file stores the parameters used with the profiles. The file is overwritten for each new profile parameter selection. An example is:

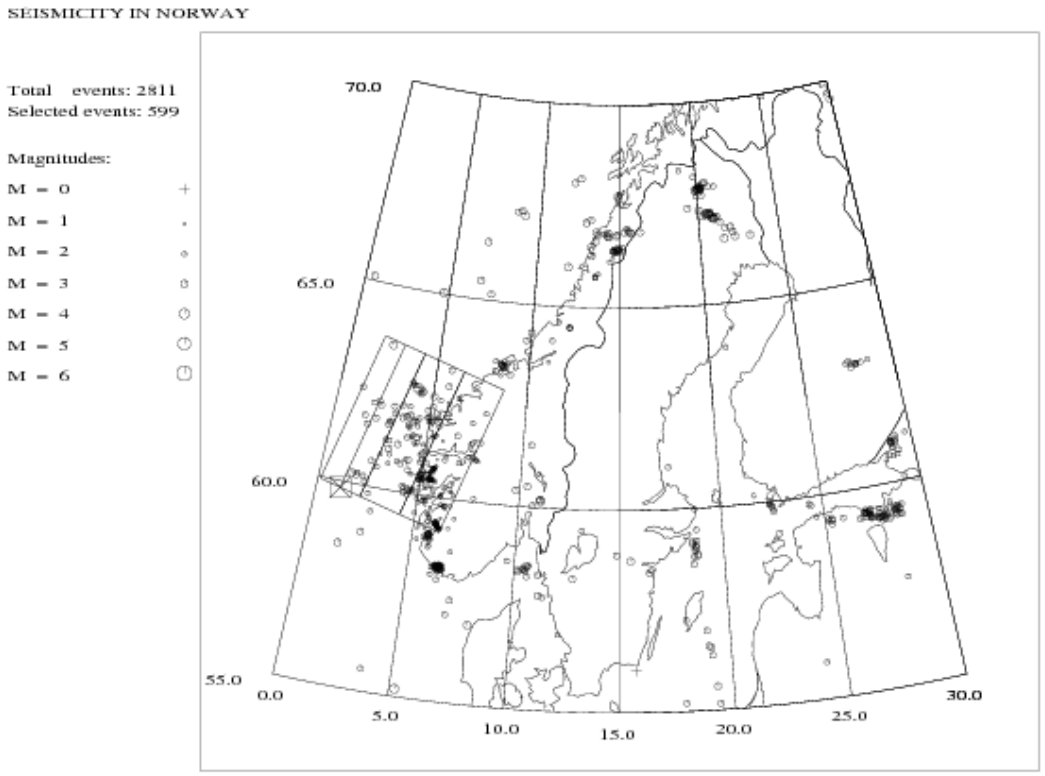
```
 17.99949 -71.54082  18.99619 -71.55782  18.44856 -71.99660
     42.7
        1
  18.0063782      -71.0928040
  17.9925880      -71.9888306
  18.9893341      -72.0058365
  19.0030403      -71.1098099
```

The first line gives latitude and longitude of the 3 points used for selecting profile (see explanation for interactive section), next line the azimuth calculated for the profile. The third line gives the number of profiles. The following 4 lines are the coordinates (lat,lon) of the map of the profile. The file can be used to repeat the same profile as in an earlier run or to predefine a more exact profile than can be selected with the cursor. The file can also be used to plot the location of the profile with other programs.

`profile.num`: Output of distance and depth of the profile in km. Distance is only correct in unzoomed plots.

Problems: Known bug: When selecting events with polygon, sometimes some events remain outside

Figure 10.1 and Figure 10.2 shows examples of plots made with EPIMAP.



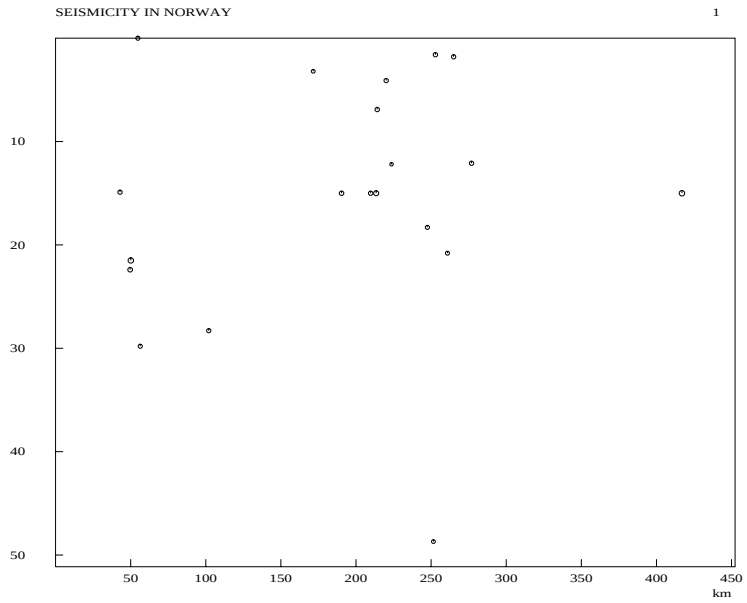


Figure 10.1: An example of using EPIMAP. The top shows epicenters plotted and the bottom the first of a series of profiles. The frames on the top plot show the location of the profiles. Top left shows how many events there are in the input file and how many are plotted. Events not plotted is either because they are outside the map or because the event has no location.

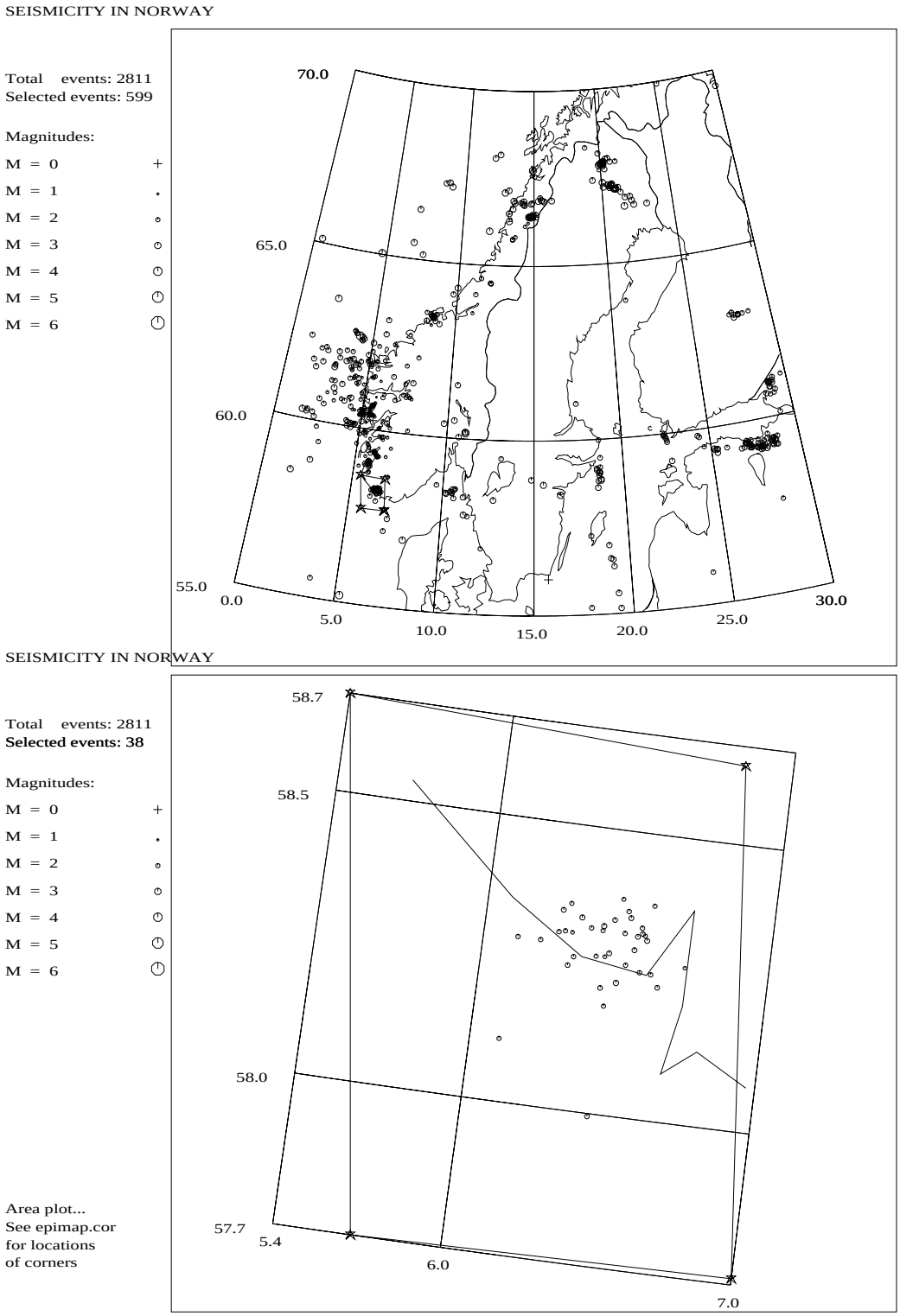


Figure 10.2: An example of using EPIMAP with area selection. The top plot shows where the area is selected, while the bottom plot shows the selected area.

10.2 MAP, running EPIMAP without questions

The many options in EPIMAP are often not needed, and a bit cumbersome for routine use, so the wrapper program, MAP, will automatically calculate the input parameters and start EPIMAP. To run the program type

map file-name

where file-name can be an s-file or a compact file. If no file name is given, MAP will ask for a file name.

Some optional flags are available:

s: plot stations as triangles

S: ——— with stations code above

f: plot fault plane solutions

m: plot epicenter symbol according to magnitude range

l: plot localities names

r: plot rays

Program MAP gets its few input parameters from SEISAN.DEF using most of the same parameters as used with the EEV option map. The parameters used are:

EPIMAP_STATIONS : plot stations from STATION0.HYP . Options are: blank: no stations plotted, a: all stations with station coded plotted, x: all stations without station code plotted. NOTE: Option s (plot some stations) cannot be used.

EPIMAP_MAP_FILE : name of map file, if blank use WORLD

EPIMAP_PROJECTION : projection number, if 0, use Mercator = 3

EPIMAP_LOCALITY_FILE: name of geogrpghic localities with names to be plotted

The program will determine the area of the map from the data file and add 0.5 degree in all directions. The latitude-longitude grid will have 5 lines for both latitude and longitude, however the smallest spacing is one degree. The commands used for the plot are given in map.inp. the file can be edited to change parameters and the plot remade with command epimap map.inp.

Ray path option

The rays are generated from the stations in the S-files. Only stations with given phases are used and only with given weights so e.g. all P-phase rays can be plotted. The epicenter coordinates are taken from the S-files and the station coordinates from the STATION0.HYP. The additional question is:

Enter phases to use for ray paths, one per line, terminate with enter Only the chars given will be used so entring e.g. P, all P-type phases will be used

P

Minimum output weight for phase-stat to be used, enter for non zero weight phases

When using the r-option, epicenters are always plotted, also epicenters without rays. Stations are only plotted if s or S option is used and only the stations used are plotted. When plotting rays, only option S works so using s will also plot station codes (a design problem of EPIMAP). If a map is needed withwout station codes, use MAPG.

The map outline is adjusted to include all stations used. The ray paths in epimap format are stored in file epimap.ray.

The rays are plotted as straight lines so no allowence for earth curvature while in GMAP they are plotted correctly. For small areas it makes no difference.

10.3 W_EMAP, Version Windows based map program

Program and documentation by **Fernando Carrilho**, The Portuguese Institute for Sea and Atmosphere, I. P. (IPMA, IP).

Program must be installed in addition to SEISAN.

This program was developed to be used on seismic routine processing. Its main features are the capability of allowing visualization of epicentre locations, seismic stations, error ellipses, coastlines, macroseismic data, focal mechanisms (one or many) and simplified tectonics. From the previous public version (4.1), some bugs were corrected and new features added. In particular: cartographic deformation is taken into account in error ellipses and station-epicentral path draws; some bugs on printing were corrected; compacted seisan files

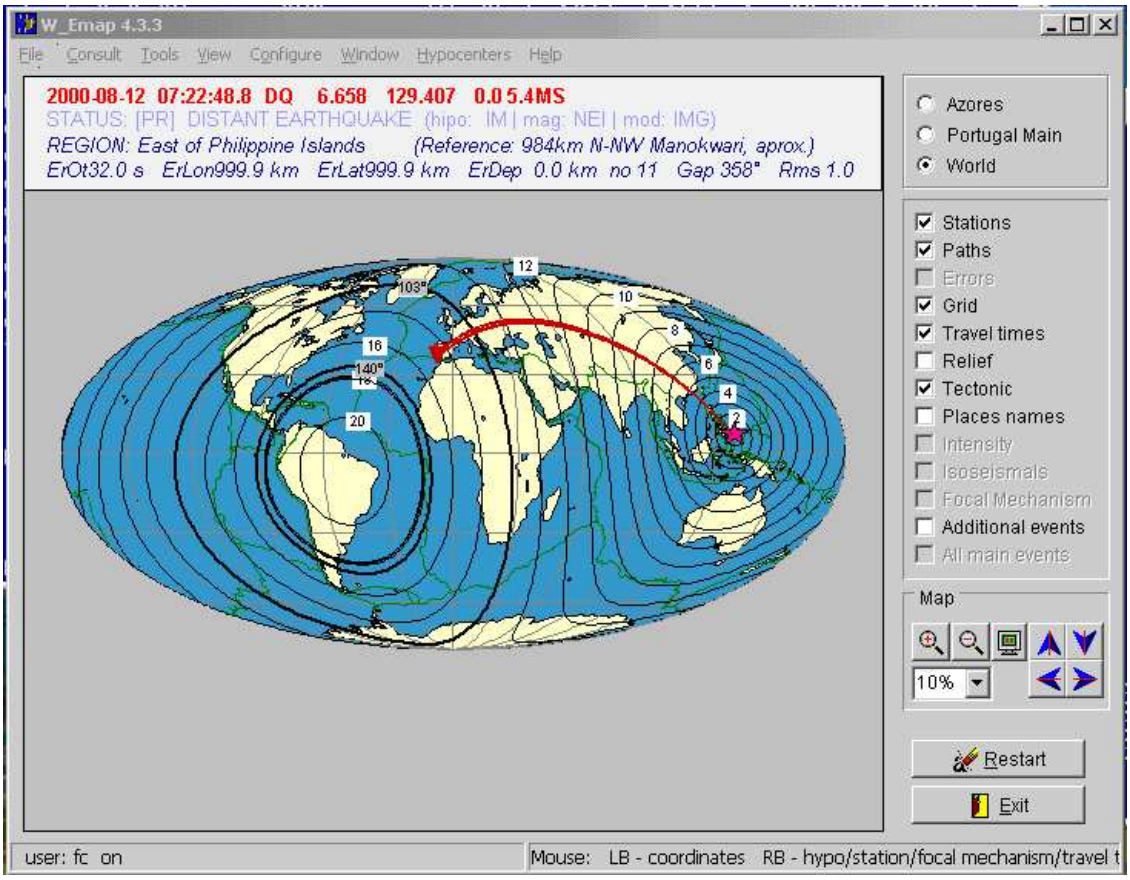


Figure 10.3: Example for plot using w_emap (example not latest version).

can be used within 'additional events' representation; travel time curves can now be displayed; simplified relief can be displayed (if available as a MAP file); more than one file can be used for each category layer (coastlines, tectonic, relief and places names).

The program can be integrated within the SEISAN environment, since it uses SEISAN parameter files, macrosseismic files, MAP files and station/model files.

If the program is called from EEV or from the command line as W_EMAP, then it displays information contained in `hyp.out` file, generated by the HYPOCENT (Lienert, 1994) location program, included in SEISAN, in the settable working directory.

During the first run, user is driven to edit the configuration file w_emap.def that is created in the users personal directory (SEISAN_TOP/DAT/users/¡username¿), where most of the program parameters can be changed.

The program can automatically detect changes in the `hyp.out` file so the user doesn't need to restart the program each time the epicentre changes.

The program can also display epicentres contained in any SEISAN parameter file, where the user may choose between one single epicentre and all epicentres at the same time. Double clicking the right mouse button will change the active epicentre to the one picked.

Multi-user individual configurations (color schemes, additional event files, tectonic files, coastline files, relief files, cartographic projections, etc.) are supported. The program also has an option for Google Earth and Google map. Installation

All the files are included in the distribution file w_emap.exe. To install it, you just execute this install script and make sure W_EMAP is installed under SEISMO_TOP (Usually the seismo folder). The manual will only be found in INF after installation. The current version of W_EMAP is 4.8.2 but the manual has not been updated since version 4.6. An important new option is be able to directly plot a file with many hypocenters

with the command w_emap filename. Known problem: Thre must be a type 7 line in S-file in order to be able to plot a focal mechanism. Some versions of w_emap plot some of the fault plane solutions with inverted colors.

10.4 MAPG, a simple automatic GMT map

The program can make a standard GMT plot of epicenters, stations, ray traces and fault plane solutions. The input can be standard input from a file, data base or index file. All scaling is done automaticallyi. Both standard s-files and compact files can be input. If the program is started without argument, it will ask for input data and whether stations and/or fault plane solutions should be plotted. The program uses the standard SEIGMT program to prepare the data for GMT and the stations plotted are therefore the stations found in the input data and not all possible stations in the area. The program can also be started with input on the prompt line, but then only with input from a file like

mapg select.out

With input from the prompt line there is also more options like

mapg select.out f s

which will plot fault plane solutions and stations. All options are:

s: plot stations as triangles

S: ——— with station code above

-s or -S: as above with station file following

f: plot fault plane solutions, size proportional with magnitude

F ——————————, size constant

-m: plot epicenter symbol with constant size, default is proportional to magintude optionally add size in cm

l: plot localities names

L: plot localities with names and symbols

R: plot rays

t: no topography

u: user gives area, question asked later

e: do not plot epicenter

rf, rh, rl or rc: high to low resolution

c: do not plot coast line

-c: fill landmass with color from next argument e.g. -c blue

The rays are generated from the stations in the S-files. Only stations with given phases are used and only with given weights so e.g. all P-phase rays can be plotted. The epicenter coordinates are taken from the S-files and the station coordinates from the STATION0.HYP. The additional question is:

Enter phases to use for ray paths, one per line, terminate with enter Only the chars given will be used so entring e.g. P, all P-type phases will be used

P

Minimum output weight for phase-stat to be used, enter for non zero weight phases

When using the R -option, epicenters are always plotted, also epicenters without rays. Stations are only plotted if s or S options is used and only the stations used are plotted. The map outline is adjusted to include all stations used. The ray paths in GMT format are stored in file mapg.ray.

The output is a PostScript file mapg.ps and a script file mapg.gmt. The script file can be used to do modifications to the plot that is not possible with the program. Some modifications are obvious but others require knowledge of GMT. On Linux, the file can be executed by command 'source mapg.gmt'. On windows, rename file to e.g. m.bat and execute by typing 'm'. Do not use name mapg.bat since the program would no longer run by using the mapg command, only the script if started from directory with the script.

Some parameters for the program is set in SEISAN.DEF:

PLOT_PS_COMMAND: The command used for displaying the ps file, usully GhostScript. In Windows, a free software pstopdf and be used to convert to PDF so the command could be the following commands put into a BAT file.

pstopdf -i

figure.pdf

GMT_GRIDFILE: The GMT grid file used. A reasonably detailed world file is found at
ftp://ftp.geo.uib.no/pub/seismo/SOFTWARE/GMTEXAMPLES/DATA/newbathy.grd

GMT_LOCALITY_FILE, see above. Format is the same as otjher locations files in SEISAN. Latitude, longitude and name, 2f12.3,a

MAP_LAT_BORDER and MAP_LON_BORDER, the same a sfor EPIMAP, distance to map center (deg) when only one epicenter.

The map projection is hardwired to Mercator. The maximum horizontal size is 17 cm. The horizontal size will be reduced if the vertical size is more than 1.5 times the horizontal size. The minimum lat-lon division is 0.25 deg. The title is hardwired to Epicenters, can be changed in script.

The program uses latest version of GMT.

```
An example run is

c:\seismo\WOR>mapg t.out R

  Options, some by interactive input or as arguments
  The first argument is filenme so e.g. mapg select.out f l

  s: plot stations as triangles
  S: --------- with station code above
  -s or -S: as above with station file following
  f: plot fault plane solutions, size proportional with magnitude
  F  -------------------------, size constant
  -m: plot epicenter symbol with constant size,
      default is proportional to magintude
      optionally add size in cm
  l: plot localities names
  L: plot localities with names and symbols
  R: plot rays
  t: no topography
  u: user gives area, question asked later
  e: do not plot epicenter
  rf, rh, rl or rc: high to low resolution
  -c: fill landmass with color from next argument
      e.g. -c blue

 Enter phases to use for ray paths, one per line, terminate with enter
 Only the chars given will be used so entring e.g. P, all P-type phases will be used
P
S

 Minimum output weight for phase-stat to be used, enter for non zero weight phases

 1996 0606 0648 27.2 L  62.916   4.491 34.3  BER  6 .30 3.2LBER 2.6CBER 3.0LNAO
 1996 0606 0648 35.5 L  62.658   5.449 0.00  BER  9 3.3 3.1LBER         3.0LNAO
 1996  6 6  649  2.8 L  60.678   3.180 15.0  BER  6 5.8 2.1LBER 2.6WBER 3.0LNAO
 1996 0607 1325 37.3 L  60.899   4.782 12.0F BER  3 6.2 3.4LBER
 1996  6 7 1325 37.3 L  60.899   4.782 12.0F BER  3 6.2 3.4LBER
 1996 0625 0337 33.6 R  61.595   3.730 0.00  BER 12 .20 4.9CBER         3.2LNAO
 1996  625  337 38.9JL  61.476   3.952 1.60  BER  9 1.9 3.4LBER 2.7SBER 3.2LNAO
End of s-file
Grid file to use: c:\a\gmt\newbathy.grd
  Nordic input file
  Return to use largest magnitude, or enter magnitude order (e.g. CLBSW)
```

```
  scale: size = mag * scale (for example 0.01)
 Input file is Nordic.
 Number of events:                                7
 Number of events with fault plane solution:     3
  epicenter location input file for GMT psxy/psxyz: gmtxy.out/gmtxyz.out
  epicenter locations with day counter from first event gmtdays.out
  station location input file for GMT psxy: gmtstxy.out
  time and magnitude to be used with GMT psxy: gmttime.out
  travel path input file for GMT psxy (option -M): gmtpath.out
  Coordinates are given as longitude - latitude
  input file for psmeca (Aki and Richards convention): psmeca.out

 Number of events in input file          7
 Number of events with location          7
Lattitude range to use    59.0   63.3
Longitude range to use     2.4    8.0
Grid size in lat and lon:   1.00  2.00

c:\seismo\WOR>pstopdf -i mapg.ps -o figure.pdf

c:\seismo\WOR>figure.pdf

 Number of events in input file or data base          7
 Number of rays generated     36
 Number of stations used for rays    10
 File with ray paths is mapg.ray
 File with stations used for rays is gmtstxy.out
 Output of events in input file with location: mapg.out
 Output of postscript file with map: mapg.ps
 Output of gmt script: mapg.gmt

c:\seismo\WOR>
```

Normally the size of the plot in lat long is determied from the data in the epicenter file. However, the u-option can override that and the user is asked for lat lon range. An alternative station file can be given with option -s or _S so specific stations can be plotted instead of the stations corresponging to the content of the CAT file. Whhen option e is used, the map is sclaed by the epicenters is CAT file, but not plotted so this option can be used to plot only stations.

NOTE: first argument is ALWAYS a CAT file, whether used or not.

If an input CAT file is only header lines, station names and cocrdinates must come from a separate file.

Most of the output is self explanatory. Only events with locations are used so number of events plotted might be different from number of events in input file. The events used are output in mapg.out. An example plot is seen in Figure 10.4.

The script file (Windows) corresponding to the above run is:

```
REM
REM   Set font, size and color of title
REM
gmt gmtset  FONT_TITLE = 14p,Helvetica,black
REM
REM   Cut out desired area from grid file, area is 1.500/7.600/57.00/63.100
REM
gmt grdcut c:\a\gmt\newbathy.grd -R1.500/7.600/57.00/63.100             -Gmapg.grid
```

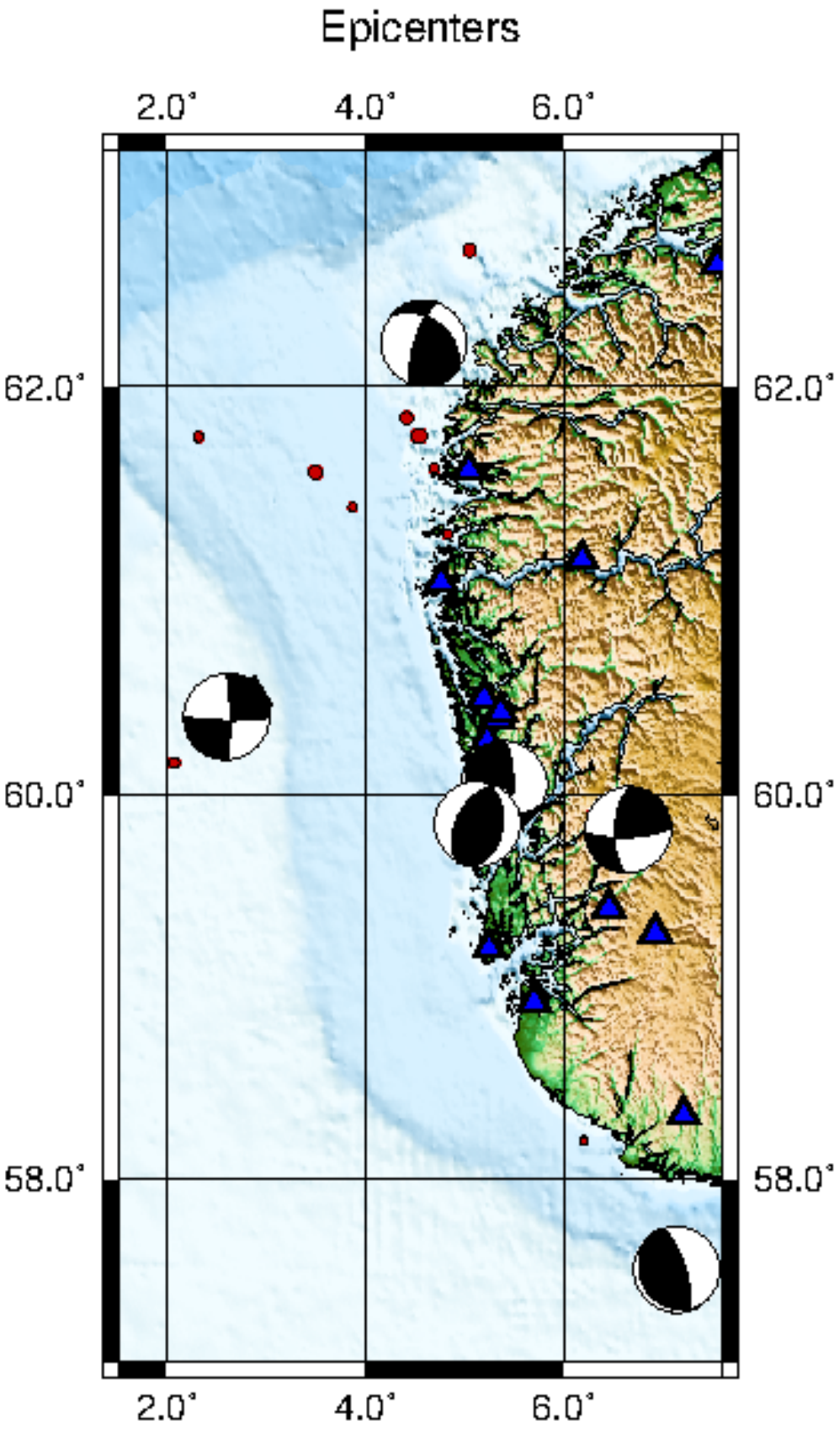


Figure 10.4: An example GMT plot

```
REM
REM   Make color table, global colors
REM
gmt makecpt -Cglobe -T-8500/8500/50 -Z > mapg.cpt
REM
REM   Plot base map, midpoint is 60.05/4.55/         horizontal size in cm is 07
REM   Longitude and latitude grids are:    2.00   2.00
REM
gmt psbasemap -Bxa002.00g002.00 -Bya002.00g002.00 -B+t"Epicenters" -JM60.05/4.55/07c -R1.500/7.600/57.0
REM
REM    Compute directional gradients from a grid
REM
gmt grdgradient mapg.grid -Nt1 -A225 -Gmapg.gradient
REM
REM   Make the map
REM
gmt grdimage -JM60.05/4.55/07c -R1.500/7.600/57.00/63.100             mapg.grid  -Imapg.gradient  -O -K
REM
REM   Plot coast line
REM
gmt pscoast -JM60.05/4.55/07c -B -R1.500/7.600/57.00/63.100             -Dh -N1/1.00p,- -K -O -W >> mapg
REM
REM   Plot epicenters, size proportinal to magnitude
REM
gmt psxy gmtxy.out -R -J -Sc -G200/0/0 -W0.3 -O -K >> mapg.ps
REM
REM   Plot stations, blue triangles, size 0.4
REM
gmt psxy gmtstxy.out -R -J -St0.4 -Gblue -W1 -O -K >> mapg.ps
REM
REM   Plot fault plane solutions, -1 to avoid date on top of
REM   of fps, 1.0 is size proportinal to magnitude, to make
REM   fixed size, add parameter -M
REM
gmt psmeca psmeca.out -R -J -V -Sa1.0/-1 -M -P -O >> mapg.ps
REM
REM
REM
REM   Plot map on screen
REM
gswin32 mapg.ps
```

In Linux REM is replaced by #.

10.5 GMAP, Plotting epicentres with Google maps or Google Earth

Google maps and Google Earth seem to quickly establish themselves as commonly used mapping tools. GMAP provides the conversion from Nordic format (s-files) to the input format required by these systems, which is the Keyhole Markup Language (KML). GMAP also convert SEISAN station and polygon files. The input format of Google Earth is described on `http://earth.google.com/kml/`. GMAP required Google Earth installed on your system to plot the output file. Download Google Earth here `http://earth.google.com/download-earth.html` (note the terms and conditions on `http://pack.google.com/intl/en/eula_`

print_us.html). To change the color codes se e.g. http://html-color-codes.info/. See also chapter 3.7.

GMAP can run in three modes:

- The simple GMAP - runs in the browser with Google Map
- The advanced GMAP - runs in the desktop version of Google Earth
- The automatic GMAP - runs in the desktop version of Google Earth

The three modes are described below.

10.5.1 The simple GMAP

Type gmap in eev, a file gmap.html is created and copied to you GMAP_DIR directory. When you open the gmap.html with your browser, you will be redirected to Google Maps and a green arrow will show the epicentre. The following parameters in SEISAN.DEF are used: GMAP_DIR /home/seismo/www
GMAP_TYPE MAP [MAP, SATELLITE, HYBRID or TERRAIN]
GMAP_TYPE determines which type of map Google MAPS will use, you can choose between: MAP, SATELLITE, HYBRID and TERRAIN.

10.5.2 The advanced GMAP

This mode of GMAP is a command line version, that convert SEISAN s-files to input files for Google Earth. It also convert SEISAN STATIONx.HYP files, polygone files and place_names.eev (see GEO command in EEV).

- Type gmap on the command line to start gmap.
- Type gmap -help to see the options.
- Type gmap -stat to convert a SEISAN station files to kml.
- Type gmap -poly to convert a SEISAN polygon files to kml.
- Type gmap -place_names to convert a place_names.eev file to kml.

In gmap you can:

1. Set the colour of the icons.
2. Show the error ellipse.
3. Show events as a animation over time.
4. Set the scale of the icons (default: scale=0.2*mag**0.5).
5. Set the type of icon used for earthquakes, explosions, probable explosions and for other events.
6. Include or exclude the S-file.
7. Rename the output file.
8. Append text in KML format to the output file (See SEISAN.DEF parameters below).

Example:

1. Use select to grap data from your Seisan database.
2. Run the GMAP program:

```
unix:/home/seismo/WOR: gmap
 INPUT FILE NAME
select.out
Title:
West Greenland [2000;2008]

Number of Earthquakes : 945 Explosions : 0 Probable Explosions : 2 Other events : 2
Output file is
gmap.kml
```

3. In Google Earth open the output file gmap.kml. See Fig. 10.5.

To make an animation for events over time use the -timespan flag. As an example explosions in the south of Norway from 1983 to 2007 can be downloaded here: `http://seis.geus.net/ber-exp.kml` Press the play button at the time slider at the top of the Google Earth. Use the ruler to control how the animation is displayed (speed, days shown, etc.).

GMAP parameters added to `SEISAN.DEF`: Icon used for earthquake, explosion, probable explosion and other events:

```
GMAP_ICON_QUAKE                 http://maps.google.com/mapfiles/kml/pal2/icon26.png
GMAP_ICON_EXPLOSION             http://maps.google.com/mapfiles/kml/shapes/star.png
GMAP_ICON_PROB_EXPL             http://maps.google.com/mapfiles/kml/shapes/open-diamond.png
GMAP_ICON_OTHER_EVENTS          http://maps.google.com/mapfiles/kml/shapes/square.png
```

Events with magnitude smaller than GMAP_ICON_MSIZE will be plottet with size of GMAP_ICON_MSIZE:

```
GMAP_ICON_MSIZE                 0.5
```

The scale of the earthquake icons is give by GMAP_ICON_XSIZE*magnitude**GMAP_ICON_YSIZE:

```
GMAP_ICON_XSIZE                 0.2
GMAP_ICON_YSIZE                 0.5
```

The scale of other events is furthermore multiplied by 2 Text can be added to the KML file, see this example, note the text must be placed from character no 41 to no 120:

```
#GMAP_APPEND_KML                 <!-- lines to be appended to the gmap.kml file : -->
GMAP_APPEND_KML                 <ScreenOverlay id="LOGO">
GMAP_APPEND_KML                 <name>Info and links</name>
GMAP_APPEND_KML                 <description> <![CDATA[
GMAP_APPEND_KML                 Data is in Nordic format. The format is <br>
GMAP_APPEND_KML                 described in the Seisan manual at UIB.<br>
GMAP_APPEND_KML                 UIB:  http://www.geo.uib.no/seismo/<br> ]]>
GMAP_APPEND_KML                 </description>
GMAP_APPEND_KML                 <Icon>
GMAP_APPEND_KML                  <href>http://seis.geus.net/geus.png</href>
GMAP_APPEND_KML                 </Icon>
GMAP_APPEND_KML                 <overlayXY x="0" y="1" xunits="fraction" yunits="fraction"/>
GMAP_APPEND_KML                 <screenXY x="-0.01" y="0.99" xunits="fraction" yunits="fraction"/>
GMAP_APPEND_KML                 <rotationXY x="0" y="0" xunits="fraction" yunits="fraction"/>
GMAP_APPEND_KML                 <size x="0.1" y="0.1" xunits="fraction" yunits="fraction"/>
GMAP_APPEND_KML                 </ScreenOverlay>
```

GMAP -help:

```
unix:/home/seismo/WOR$ gmap -help

  The GMAP program converts Nordic format to the KML format.
  The output file gmap.kml can be opened with Google Earth.
```

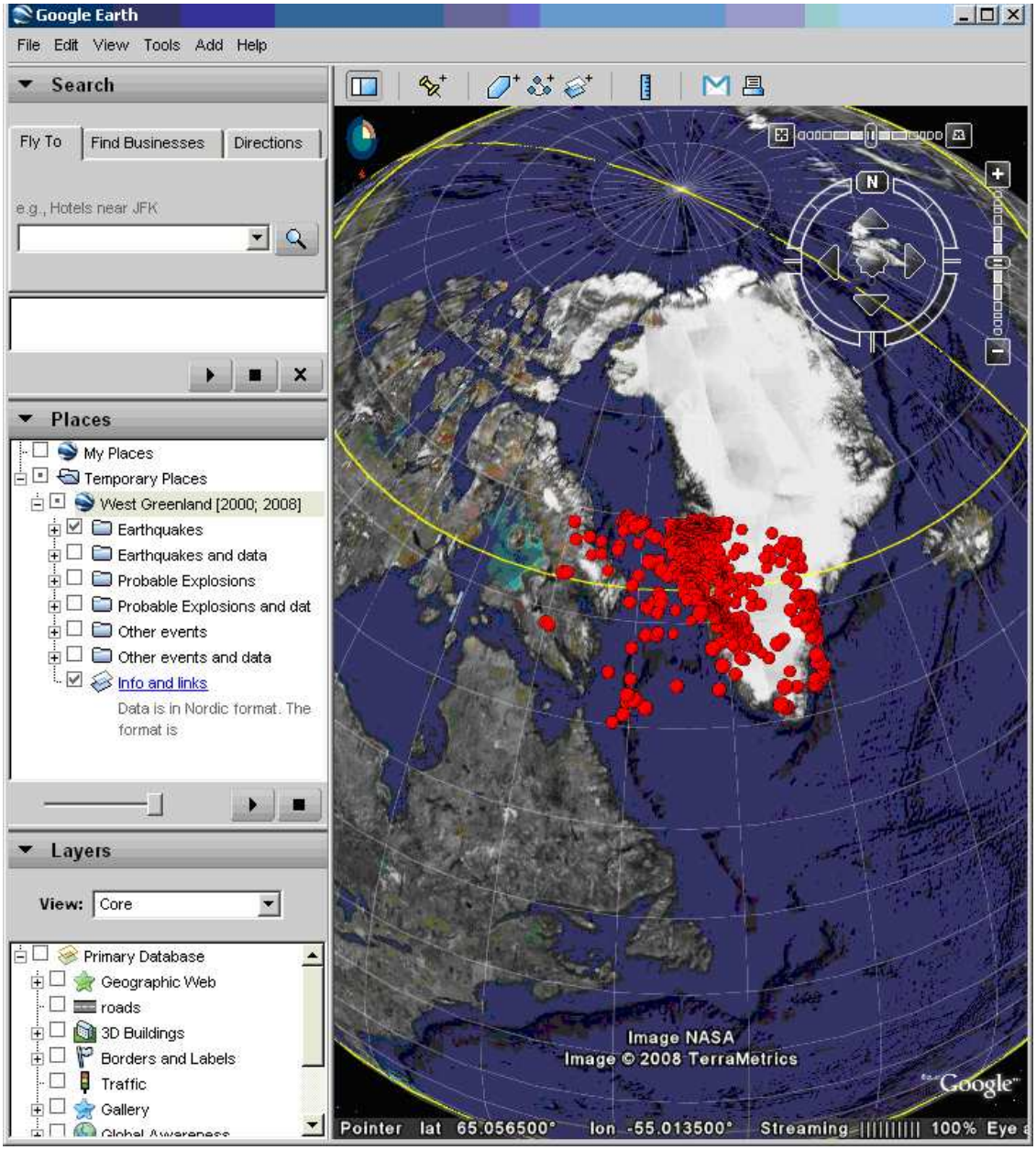


Figure 10.5: Example of mapping with gmap. Events in West Greenland. Note the folder and the subfolders in the `Places` window.

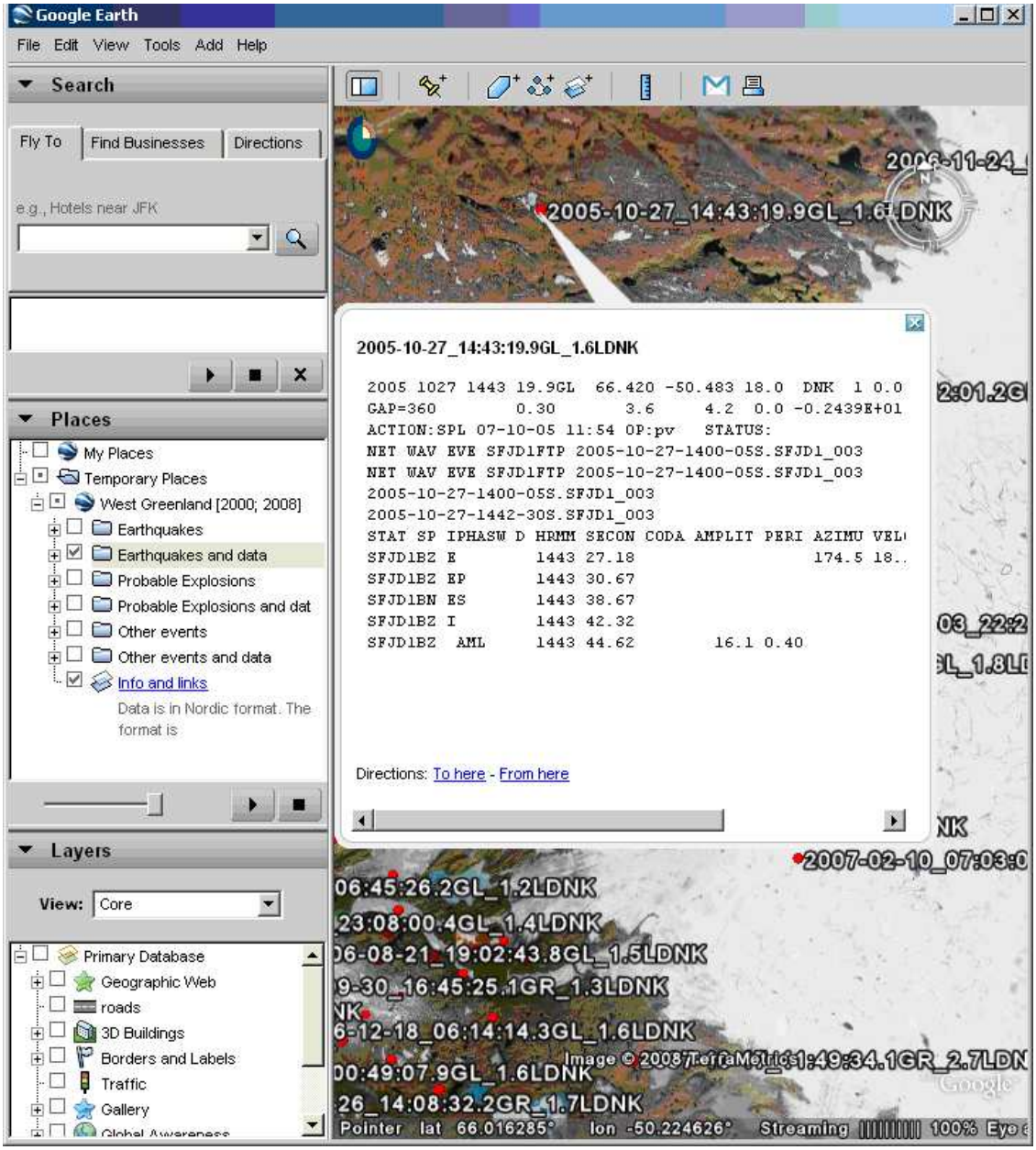


Figure 10.6: If the `Earthquakes and data` folder is selected in the `Places` window S-files can be shown.

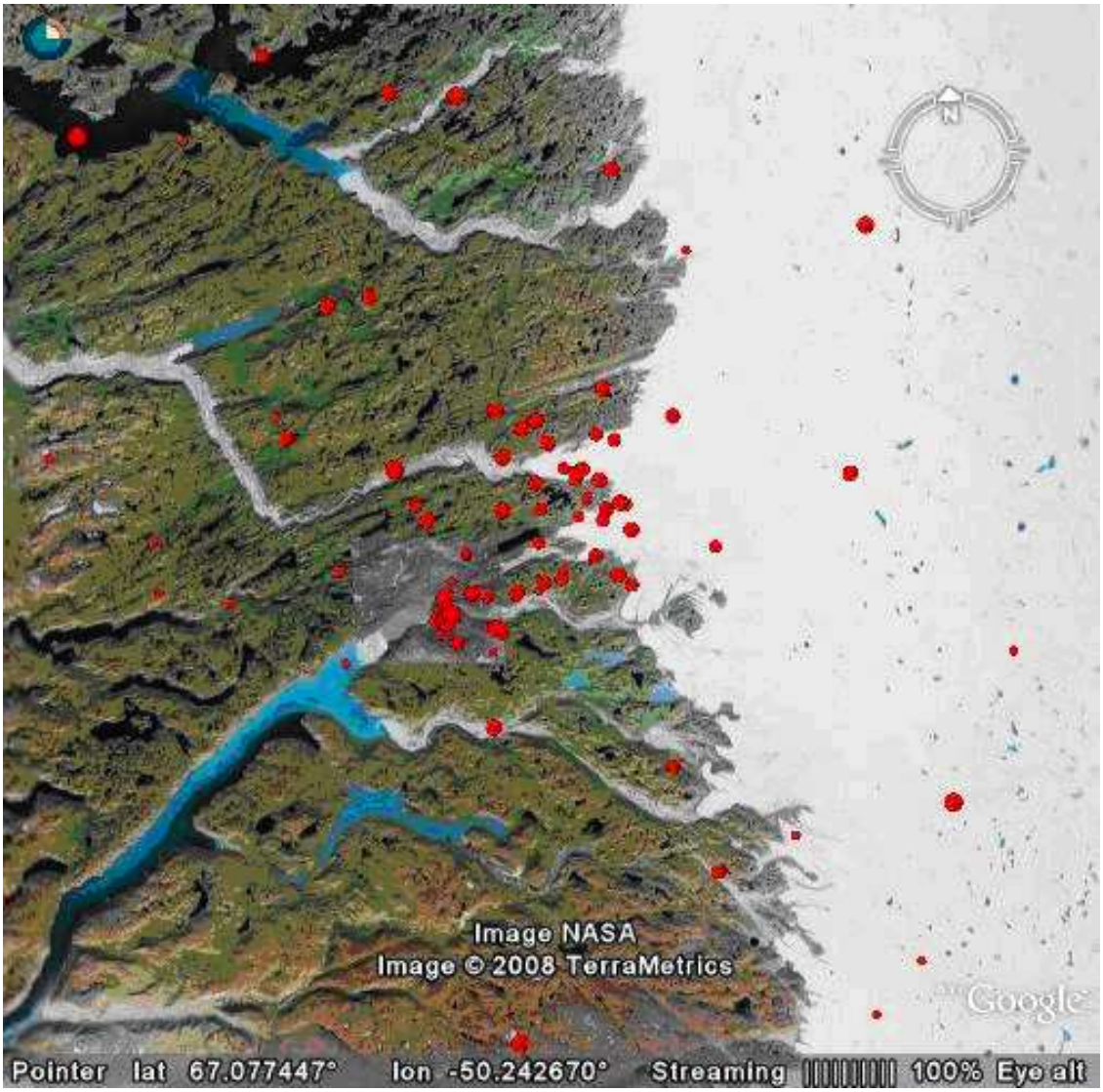


Figure 10.7: A map can be saved as raster file (File-Save-Save Image).

```
The program prompts for a input file in nordic format, the
input file can be compact.
The program also convert SEISAN station and polygon files.

Usage: gmap [options]
       input file
       Title used for kml folder

## Options ##
  -help         Print this list
  -h            Same as -help
  -color        Define color of epicenters [blue/green/yellow/
                black/white]. Default color is red
                To uses other colors see describtion below
  -timespan     Events gets timetag scroll in time domain
  -nodata       kml file will only contain header infomation
  -errorellipse kml file will include error ellipse
  -ellipsecolor Define color of ellipse in 8 digit hex code
  -ellipsewidth Define width of the ellipse line, in pixels
  -stat         Station locations given in STATION?.HYP files
                is converted to KML, output is gmapstat.kml
                To change color/scale/icon edit gmapstat.kml
                and change the content of Style Id=stat
  -poly         SEISAN polygon files like DAT/SALVADOR.MAP
                is converted to KML, output is gmappoly.kml
                To change color/width edit gmappoly.kml and
                change the content of Style Id=poly
  -out_file     Define name of output file (default is gmap.kml)
  -verbose      Be more verbose
  -version      Seisan version

Scale:
The scale of the icons is set by the SEISAN.DEF
parameters GMAP_ICON_MSIZE, GMAP_ICON_XSIZE and
GMAP_ICON_YSIZE, see the manual for details.

Color:
Color and opacity (alpha) values are expressed in
hexadecimal notation. The range of values for any
one color is 0 to 255 (00 to ff). For alpha, 00 is
fully transparent and ff is fully opaque. The order
of expression is aabbggrr, where aa=alpha (00 to ff);
bb=blue (00 to ff); gg=green (00 to ff);
rr=red (00 to ff).For example, if you want to apply
a blue color with 50 percent opacity to an overlay,
you would specify the following:
<color>7fff0000</color>, where alpha=0x7f, blue=0xff,
green=0x00, and red=0x00. See also:
http://code.google.com/apis/kml/
documentation/kml_tags_21.html#color

Examples:
          gmap -color blue -nodata -errorellise
          gmap -timespan -color 7eee00ee
          echo "collect.out\nDK events\n" | gmap -out_file dk.kml
```

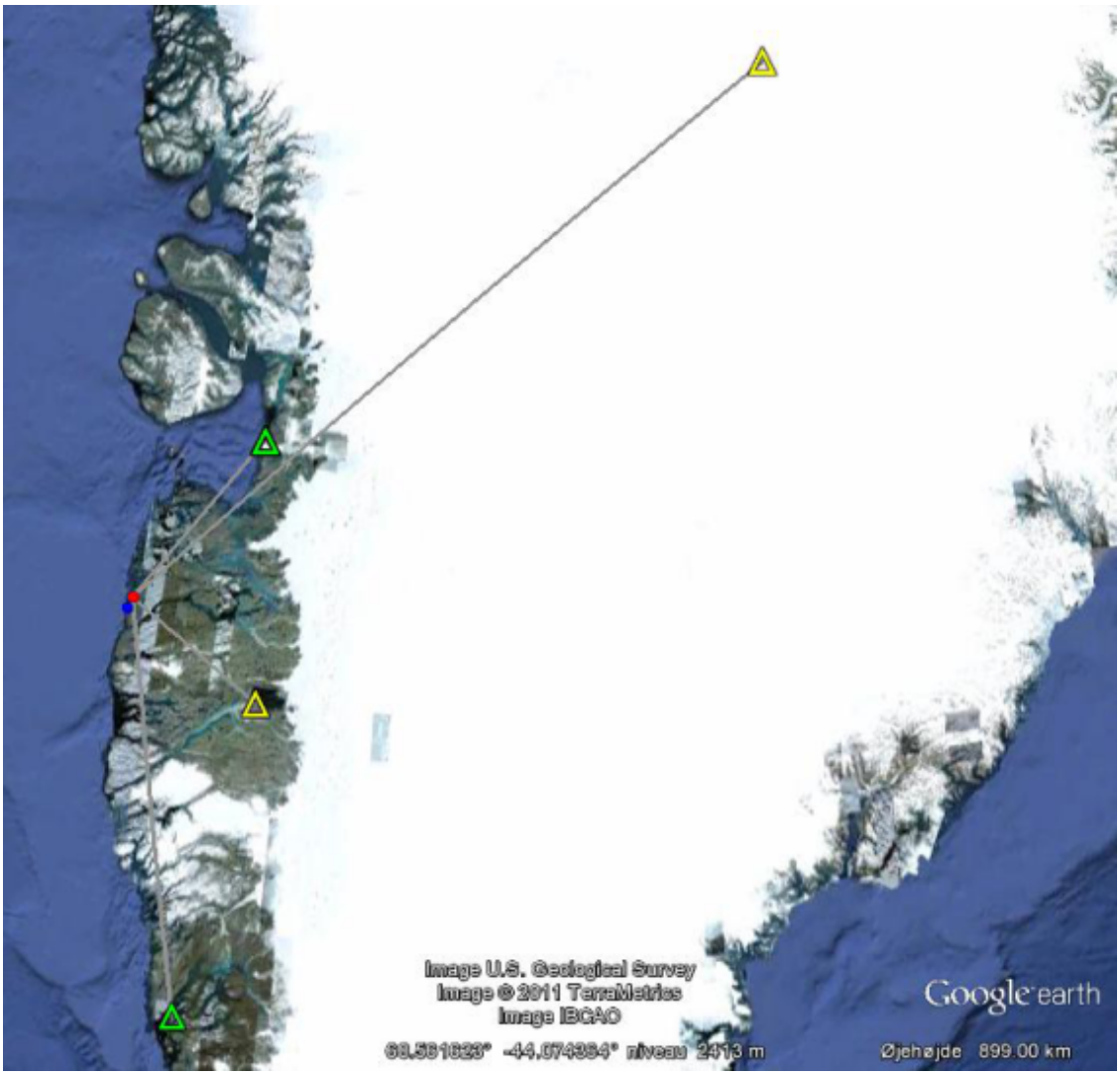


Figure 10.8: Example of automatic mapping with gmap. Earthquake in West Greenland. Blue dot is the old location and the red dot is the current location. Green and yellow stations are stations with good and ok residuals, respectively.

10.5.3 The automatic GMAP

There are two way to make maps with Google Earth or Google Maps from EEV automatic.

One way is to call GHYP in EEV, this will start Google Earth or Google Maps (in a browser) automaticly for each of the following events. Note, that Google Earth will reload every new event but Google Maps will open a new browser tab for every new event (tested in Chrome).

The other way is to enable the GMAP_AUTO parameter in SEISAN.DEF, this will enable a function in the HYP program, that makes a KML file that Google Earth can load automatically when e.g. an event is located in EEV. See describsion below.

Start EEV and locate an event. In the directory a new file `gmap.cur.kml` will appear, this file can be opened with Google Earth and it will show the location of the current event and the used stations and the raypaths.

The color of the stations is given by the travel time residual as green, yellow or red, for: residuals$< 0.5s$, $0.5s =<$residual$=< 1,5s$ or residual$> 1.5s$, respectively.

To enable the automatic generation of Google Earth input files, add these parameters to your `SEISAN.DEF`

file:

```
GMAP_AUTO      0: no, 1:yes            1.0
GMAP_AUTO_ICON_EVENT                   http://maps.google.com/mapfiles/kml/pal2/icon26.png
GMAP_AUTO_ICON_COLOR                   ff0000ff
GMAP_AUTO_ICON_MSIZE                   0.5
GMAP_AUTO_ICON_XSIZE                   0.2
GMAP_AUTO_ICON_YSIZE                   0.5
GMAP_AUTO_LOOKAT_ALTITUDE              2000000.0
GMAP_AUTO_SHOW_STAT  0: no, 1:yes      1.
GMAP_AUTO_ERROR_ELLIPSE  0: no, 1:yes  1.
GMAP_AUTO_ELLIPSE_COLOR                ff00ff00
GMAP_AUTO_ELLIPSE_WIDTH                12.43
GMAP_AUTO_STAT_SIZE                    1.1
GMAP_AUTO_STAT_URL                     http://maps.google.com/mapfiles/kml/shapes/triangle.png
GMAP_AUTO_STAT_RESIDAL_GOOD            0.5
GMAP_AUTO_STAT_RESIDUAL_BAD            1.5
GMAP_AUTO_STAT_COLOR_GOOD              ff00ff00
GMAP_AUTO_STAT_COLOR_OK                ff00ffff
GMAP_AUTO_STAT_COLOR_BAD               ff0000ff
GMAP_AUTO_SHOW_OLD_LOCATION 0:no,1:yes 1.
GMAP_AUTO_OLD_LOCATION_COLOR           ffff0000
GMAP_AUTO_SHOW_PATH   0: no, 1:yes     1.
GMAP_AUTO_PATH_COLOR                   ff929292
GMAP_AUTO_PATH_WIDTH                   2.5
GMAP_AUTO_FILE_ACTION  0: no, 1:yes    0.
GMAP_AUTO_ACTION                       cp gmap.cur.kml /inetpub/www/html/seismo/nnsn
```

You can change the parameters to adjust the output file `gmap.cur.kml` for your system, see definition here 3.13.

Inorder to run the display in a realtime mode, you must have an other KML file that makes Google Earth reload the `gmap.cur.kml` file at short intervals. Such file could look like:

```
<?xml version='1.0' encoding='UTF-8'?>
<kml xmlns="http://www.opengis.net/kml/2.2">
<Folder>
<!-- Link to GMAP file on Computer: -->
<NetworkLink>
<name><B>SEISAN current event</B></name>
<!-- To turn flyToView on/off use:1/0 -->
<flyToView>0</flyToView>
<Link>
<href>C:/seismo/WOR/gmap.cur.kml</href>
<refreshMode>onInterval</refreshMode>
<refreshInterval>3</refreshInterval>
</Link>
</NetworkLink>
<!-- Example: Link to GMAP file on the Internet:
<NetworkLink>
<name><B>DNK events NOV 2011</B></name>
<Link>
<href>http://seis.geus.net/quakes/dnk-2011-11.kml</href>
<refreshMode>onInterval</refreshMode>
<refreshInterval>3600</refreshInterval>
</Link>
</NetworkLink>
-->
</Folder>
</kml>
```

In this example the `gmap.cur.kml` file is reloaded every 3 second from a local `C:\seismo\WOR` directory on a windows pc. And below is an other KML file is reloaded at 60min intervals from the Internet.

The above file is named `gmap-automatic.kml` and is found in the DAT directory.

10.6 SEIS2VIEWER, Plotting hypocentres in 3D

The program is written by **Ruben Soares Luís** (ruben.so.luis@gmail.com) and use the SeismicityViewer50 program by **Anthony Lomax**. To program has been aliased to smap.

Overview

seis2viewer is a wrapper for the application SeismicityViewer, developed by Anthony Lomax for rapid mapping of seismic events. SeismicityViewer displays hypocenter locations in 3D as well as station locations and P/S residuals. Geographic and geologic features can also be displayed as well as focal mechanisms. Please find details here:

`http://alomax.free.fr/seismicity/`

seis2viewer has been created to take information from a nordic file from Seisan and convert it in a format usable by SeismicityViewer 5.0 (NLLoc Format). It automatically launches Seismicity Viewer, generating a set of files required for its operation.

In its current version, seis2viewer allows the visualization of hypocenters and magnitudes in SeismicityViewer 5.0. Other information, such as station locations, P and S residuals, etc. is not displayed.

Configuration

1: **Configuration Files:**

- `seis2viewer.def`: seis2viewer uses a **single** configuration file: `seis2viewer.def`, which may contain references to other files containing information on maps, elevation, localities, etc. The file `seis2viewer.def` is actually passed directly to Seismicity Viewer adding only a reference to an automatically created file. This operation is transparent to the user. As such, the configurations can be obtained from the Seismicity Viewer 5.0 website: `http://alomax.free.fr/seismicity/` The seis2viewer.def can be in local directory or DAT. The program will operate without the def file.
- Other files: `seis2viewer.def` may reference other files containing map information, elevation data, locality names, etc. These files should follow the definitions presented in the Seismicity Viewer 5.0 website.

2: **Installation**

seis2viewer is distributed as a single .jar file (`seis2viewer.jar`), containing all the necessary classes to work, including Seismicity Viewer 5.0. This file is placed in the PRO directory of seisan. To facilitate the usage of seis2viewer, an executable script file to call seis2viewer has been created, smap. As an example, the executable script should contain the following line:

```
java -jar $SEISAN_TOP/PRO/seis2viewer.jar $1        (for unix/linux)
java -jar %SEISAN_TOP%/PRO/seis2viewer.jar %1%      (for windows)
```

The configuration file, `seis2viewer.def`, and any other required files should be placed in the DAT directory of seisan. Alternatively, the user may have its configurations on the working directory. the configuration file refers to a more detailed map file, europe.xyz, which will be plotted superimposed on the built in word map (can be turned on and off on the plot). The location of this file must be given an absolute path. In the example file, the path is given for Windows as

```
seismicity.lines.gray = C:/\seismo/\DAT/\europe.xyz
```

where the '/' is needed under Windows. The user must adjust this line to the local environment. Detailed map files in xyz format, using standard SEISAN MAP files, can be made with program SELMAP.

2: **Automatically Generated Files** seis2viewer generates a set of files to be used by Seismicity Viewer 5.0. Although these files are, in principle, irrelevant to the user, it is nevertheless important to mention them for reference purposes.

- `input-file.hyp`: This file contains a translation of the event file selected by the user for visualization in NonLinLoc format, appropriate for Seismicity Viewer. Input-file is the input file name without extension.
- `input-file.hdr`: This is an automatically generated grid file for the area surrounding the events to be visualized. It is only created if the maximum distance in longitude or latitude between events is less than 8 degrees.

Usage

seis2viewer can be used directly with a nordic file containing one or more events (e.g. `select.out`) as:

```
java -jar %SEISAN_TOP%/PRO/seis2viewer.jar select.out    (windows)
java -jar $SEISAN_TOP/PRO/seis2viewer.jar select.out     (unix/linux)
```

or using the command '`smap`')

```
smap select.out
```

seis2viewer can also be called directly from eev, as an external program, using the prefix 'o' as:

```
osmap
```

In this case, smap will try to find the file eev.cur.out, which is automatically generated by eev and contains a reference to the event that is currently under work.

Seis2viewer will use a global mode if the distance between events is more than 8 degrees. The global mode can be forced with the flag -gl (but not with command smap, use complete command like

```
java -jar  C:\Seismo\PRO\seis2viewer.jar -gl select.out
```

Seis2viewer noramlly requires a Nordic file for input and will only plot the header line hypocenter. To plot all hypocenter lines in the s-file, use option -ia. This option can also be used to plot a compact file (ooly header lines, no space between lines).

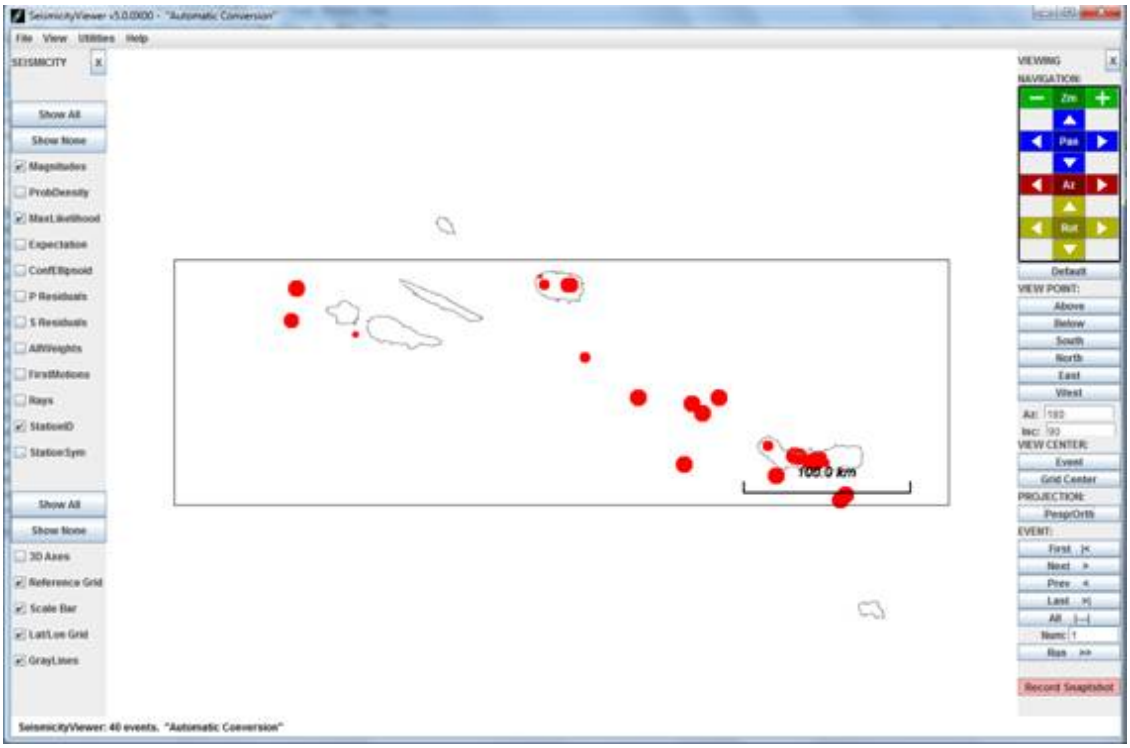


Figure 10.9: Epicenter map by SEIS2VIEWER.

Chapter 11

Searching in the database, SELECT and others

There are several program to search the data base or search in files. The most important is SELECT when working from the prompt. The most sophisticated search can be made with SeisanExplorer (see SE section). SE and SELECT have overlapping functions and both have options not found in the other.

11.1 SELECT

Whenever selective search and extraction is wanted SELECT is used. The program can run on the CAT database, single CAT files (Nordic or Nordic compact) or the S-file data base. The output file, `select.out`, will also be in Nordic format. Since the input CAT database can contain both normal and compact files, the output will always be a normal file with blank lines between events. If however the input is one compact file, the output will also be a compact file. Note: If SELECT is used on the CAT database (normal operation), you need to UPDATE your S-file database in order to transfer changes from the S-files to the CAT database. Select can work with input in 3 different ways:

1. The user is asked for selections
2. The selection parameters are in a file
3. Parameters are given on the prompt line

The program is started by typing SELECT (parameters from screen), SELECT 'input file' (parameters from input file) or SELECT -options. A typical user interactive run is shown below. Comments following !

```
POSSIBLE INPUT IS:
     STANDARD CAT DATABASE: RETURN
     ALTERNATIVE DATABASE, GIVE 1-5 LETTER CODE:
     FILENAME FOR ONE FILE, MUST BE 6 OR MORE CHARACTERS:
     Type of base: CAT (c) or Sfiles (s) (enter):
c
 Updating database TEST_              ! standard base
 The database TEST_ has  10 files
 The first file starts: 199309
 The  last file starts: 199909

  Start time (blank is 1980), yyyymmddhhmmss: 199309! time range
  End time, enter for 2025                  : 199607

             PARAMETERS
```

```
    1   - Fault Plane Solution
    2   - Earthquake Felt
    3   - Magnitude Type(s)
    4   - Distance ID(s)
    5   - Event ID(s)
    6   - Magnitude Limits
    7   - Latitude Limits
    8   - Longitude Limits
    9   - Depth Limits
    10  - RMS Limits
    11  - Number of Stations Limits
    12  - Hypocenter Errors Latitude Limits
    13  - Hypocenter Errors Longitude Limits
    14  - Hypocenter Errors Depth Limits
    15  - Minimum Number of Polarities
    16  - Hypocenter Agencies
    17  - Magnitude Agencies
    18  - Station Codes, components and distance range
    19  - Polygon
    20  - Use all header lines
    21  - Search for text string in S-file
    22  - Gap range
    23  - Phases
    24  - Volcanic subclasses
    25  - Moment tensor solution


SELECT NUMBER TO CHANGE PARAMETER, RETURN TO SEARCH: 6
Minimum Magnitude, return for default:   5
Maximum Magnitude, return for default:   7

          PARAMETERS

    1   - Fault Plane Solution
    2   - Earthquake Felt
    3   - Magnitude Type(s)
    4   - Distance ID(s)
    5   - Event ID(s)
    6   - Magnitude Limits                          5.0        7.0
    7   - Latitude Limits
    8   - Longitude Limits
    9   - Depth Limits
    10  - RMS Limits
    11  - Number of Stations Limits
    12  - Hypocenter Errors Latitude Limits
    13  - Hypocenter Errors Longitude Limits
    14  - Hypocenter Errors Depth Limits
    15  - Minimum Number of Polarities
    16  - Hypocenter Agencies
    17  - Magnitude Agencies
    18  - Station Codes, components and distance range
    19  - Polygon
    20  - Use all header lines
```

```
     21  - Look for wave form file names
     22  - Gap range
     23  - Phases
     24  - Volcanic subclasses
     25  - Moment tnesor solution

 Ok. Input realized successfully.
 SELECT NUMBER TO CHANGE PARAMETER, RETURN TO SEARCH:
199309.CAT  No of events:     1  Selected:     1  Selected total:     1
199406.CAT  No of events:     1  Selected:     1  Selected total:     2
199410.CAT  No of events:     1  Selected:     0  Selected total:     2
199508.CAT  No of events:     1  Selected:     0  Selected total:     2
199511.CAT  No of events:     1  Selected:     0  Selected total:     2
199606.CAT  No of events:     6  Selected:     3  Selected total:     5
199607.CAT  No of events:     5  Selected:     1  Selected total:     6

 TOTAL NUMBER OF EVENTS IN TIME INTERVAL   16
 NUMBER OF DISTANT EVENTS   - - - - -      7
 NUMBER OF REGIONAL EVENTS  - - - - -      0
 NUMBER OF LOCAL EVENTS     - - - - -      9
 -------------------------------------------------
 NUMBER OF EVENTS SELECTED **************   6
 NUMBER OF WAVEFORM FILES SELECTED         9
 NUMBER OF INDEXES SELECTED                6
 SELECTED EARTHQUAKES ARE IN FILE: select.out
 LOCAL INDEX FILE IN:              index.out
 NAMES FOR WAVEFORM FILES IN FILE: waveform_names.out
 SELECT COMMANDS IN FILE:          select.inp
```

Note above, that the second time the menu is shown, the choice of magnitude limits is shown. For each CAT file in the catalog, the number of events in file, number of events selected from that file and the accumulated number are listed. The last file might not show the correct number of events in file since SELECT might stop before reading the whole file if the end time is in the middle of the file. If start time is blank, 1980 is used. The end time can also be blank, and 2025 is used. This option is useful when selection on whole data base or whole file.

NOTE on time interval: If selecting from S-files or the CAT data base, selection will stop when one event reach the time limit so a wrong time in S-file could stop search. When selection from a file, all events in file will be checked so there is no requirement for correct time order.

Index.out file: It contains the indexes of files selected and can be used to access theses file only like eev index.out. NOTE that the index file will only contain events which have an ID line since ID line is used to create the reference.

11.1.1 Input parameters for SELECT

In the input database (or file) a time window must always be given. If no more selection is done, all data in time window is selected. Further selection can be done by choosing a number and giving parameters. The chosen parameters are then shown on the next parameter selection menu as shown above for magnitude. Parameters can be reentered. Parameters not entered will have no influence in the selection. If several parameters (numbered selections below) are entered, conditions for all must be true for the event to be selected. Within each numbered selection, usually only one of the entered conditions must be fulfilled for the event to be selected. If e.g. Ml and Mb are selected, events, which have either magnitude, will be selected. When no more parameters are desired, press enter.

1. - Fault Plane Solution
   Selects events with a fault plane solution (F- line in S-file). There will also be the question: "Give quality, e.g. A or ABC, enter for all", in this way different qualities can be selected.

2. - Earthquake Felt
   Events felt indicated by a type 2 line

3. - Magnitude Type(s)
   Normally, all magnitudes for one event are searched to see if any magnitude fits the selection criteria. With option 3 it is possible to use one or a combination of magnitude types e.g. L and B. If magnitudes without type are to be selected, use underscore "_" for magnitude type. If there is no magnitude in the first magnitude position, chose "N" for one of the magnitude types to be able to select the other 2 magnitudes on the line. Magnitude types are: C: Coda magnitude, L: Local magnitude, b: mb, B: mB, s: Ms, S: MB and W: Moment magnitude. N: Find events with no magnitude in first position. An event is selected if any one of the types of magntudes are found. Magnitudes are only searched on first header line unless "Use all header lines is set".

4. - Distance ID(s)
   Restricting the search to be for one or a combination of the distance id's L, R and D.

5. - Event ID(s)
   Restricting the search to one or a combination of event id's, e.g. E and V for explosion and volcanic events. The letters used for selection are not limited to the examples shown above, they are however the ones used currently. It is thus e.g. possibly to label events as X for unknown type (column 23 in header line) and then later on select out all those events by specifying X for event ID. For the 3 questions about types, up to 5 letters can be used. The currently most used codes are: B: Blank (no ID), E: Explosion, P: Probable explosion, V: Volcanic, S: Sonic boom, Q: Earthquakes. For a full list, see the Nordic format in Appendix. If no selection is given, all events are selected. If e.g. Q is used as input, only events with Q ID are selected. If B is selected, only events with no ID are selected. So if all earthquakes and volcanic events are to be selected, use QV. Without the Q, only volcanic events are selected. In most cases no ID is also earthquakes, but they have not been marded as so. In this case, in order to get all earthquakes, use BQ. Selection is made if either one of criteria is met.

   Note: Before october, 2018, using Q was equivalent to using BQ and there was no possibility to select Q or no ID only.

6. - Magnitude Limits
   Range of magnitudes to select. Note that if no magnitude type is given, the extreme of all magnitude types reported is used. Magnitudes are only searched on first header line unless Üse all header lines is set:

7. - Latitude Limits
   Range of latitude. NOTE: If no latitude or longitude values are chosen, SELECT will include an event even when it is not located if the remaining criteria are OK. If it is required that only located events are searched for, enter at least one value like an upper latitude limit of 95. If ONLY events with no locations are wanted, enter 99 as lower latitude limit. This option is intended to find all events not located in a file or data base.

8. - Longitude Limits
   Range of longitude.

9. - Depth Limits
   Range of depths.

10. - RMS Limits
    Range of rms travel time residuals.

11. - Number of Stations Limits
    Range of number of stations. This option can be combined with option CODAQ to seach for a number of stations in a given distance range.

12. - Hypocenter Errors Latitude Limits
    Range of hypocenter latitude errors. Works only if error line (E-type) is present in S-file. Currently error lines are generated by HYP and the ISC conversion program ISCNOR. There should only be one error line in file associated with the prime solution in first header line. However, if more than one error line is present, all are checked and if one fulfills the selection criteria, the event can be selected.

13. - Hypocenter Errors Longitude Limits, See 12.

14. - Hypocenter Errors Depth Limits, See 12.

15. - Minimum Number of Polarities, only P-phases are used
    Counts all polarities, useful to find potential events for fault plane solutions.

16. - Hypocenter Agencies
    Selects events only with given hypocenter agencies as indicated on header line.

17. - Magnitude Agencies
    Select only events with given magnitude agencies as indicated on header line. Magnitudes are only searched on first header line unless Üse all header lines is set.

18. - Station Codes, components, distance range and phase
    Selects only events with given stations, component, distance range and phase. A formatted help line comes up for selecting items. Any one or a combination can be selected, however, a station code or component code must be selected. The phase can be 8 characters long. The distance can be hypocentral or epicentral. Distances are integers right justified.

19. - Polygon
    Selects events within a given polygon of at least 3 latitude-longitude pairs.

20. - Use all header lines
    All header lines are searched for relevant information

21. Search for text string in S-file
    Search the database for any text string in any line of the S-file. The search is normally case sensitive, but if the search string is terminated with 'case' like 'bergencase', then the search is case independent. The search string can be 80 chars long plus 4 if termniated with 'case'. It is thus possible to make a seach including the line type in character 80.

22. - Gap range
    The range of gap as given on the E-line (normally 2. header line). Only hypocenters calculated with SEISAN version 7.0 have gap.

23. - Phase
    Look for events with particular phases. Up to 6, 8 character phase names can be selected. The event is selected if at least one of the phases is present for the event. For a more selective selection based on phase, see option 18.

24. - Volcanic subclasses
    Search for events of given subclasses given by up to 10 codes. Any code can be given, however, normally they will be as defined in VOLCANO.DEF. The program searches for lines starting with 'VOLC MAIN'.

25. - Moment tensor solution
    Search for events with a moment tensor solution as indicated by M-lines.

11.1.2 Option for codaq

A special option is to make a file used for input to CODAQ using option 18. The station name CODAQ is selcted and all stations present within the specified distance range are seleted and the output is written in file index.codaq which then contains the event-station combinations used as input to CODAQ. For componet selection, only the orientation code can be used. In addtion to to Z, N or E, also A can be used. This will select all 3 components for a selected station. In example below, all components for stations with 100 km are selected.

```
STAT CO Mindis Maxdis Phas All stat hdist->FF
CODAQ A      0    100
```

The CODAQ option can also be used to select events in given distance range with a given number of stations if the number of station option is also used.

Spectral paramter selection

There is no direct option to select events with spectral parameters except to select local events withe MW and assumed they have been calculated with spectra. A posibility is to use MAG where events can be output having particular spectral parameters. Another option is to use SeisanExplorer. /IndexSearch for spectral parameters

11.1.3 Historical data

When working with historical data, it can be useful to work with catalogs of several centuries. The century is available in the Nordic Format, so catalogs can go back to year 0. Output:

`select.out`: A CAT-file or compact file (depending on input) of selected events.

`index.out`: A list of event id's of selected events can be used with EEV or other programs accepting index files. This could be used e.g. to work on only distant events in the database by first selecting all distant events and then working with these directly in the database using command EEV index.out. Index files can have any name (must contain a '.') so different subsets can be available with different index files.

`Waveform_names.out`: A list of corresponding waveform files. It is mainly intended for copying to or from tape specific waveform files. It has the format of the `filenr.lis` files and can be used directly with e.g. MULPLT. See also program get_wav for selecting waveform files from the database.

`select.inp`: A file with all the parameters used for the run. The file can be renamed, edited and used as input for select. This is particularly an advantage if a complex set of selection parameters are used and the selection is wanted again with just a small change. An example file is shown below

```
Base or file name            : TEST_
Start time                   : 19930300000000
End time                     : 19961231235959
Minimum number of stations   :              0
Maximum number of stations   :            999
Minimum latitude             :        -90.000
Maximum latitude             :         90.000
Minimum longitude            :       -360.000
Maximum longitude            :        360.000
Minimum magnitude            :          5.000
Maximum magnitude            :          7.000
Magnitude agencies           :
Hypocenter agencies          :
Minimum rms                  :          0.000
Maximum rms                  :        999.000
Minimum depth                :        -99.000
Maximum depth                :      99999.000
Minimum error in latitude    :          0.000
Maximum error in latitude    :      99999.000
```

```
Minimum error in longitude   :          0.000
Maximum error in longitude   :      99999.000
Minimum error in depth       :        -99.000
Maximum error in depth       :      99999.000
Magnitude types (L,C,B,S,W)  :
Distance (ID) types (L,R,D)  :
Event types (e.g. E,V,P)     :
Minimum number of polarities :              0
Felt earthquakes             :              F
Fault plane solution         :              F
Check all header lines       :              F
Waveform files to check      :
Minimum gap                  :          0.000
Maximum gap                  :        360.000
Phases                       : P   SSS PP
Volcanic subclasses          :
Stat., comp. dist range, phase (1x,a5,a2,2i7,1x,a4) one pr line, end blank line:
STAT CO Mindis Maxdis Phas All stat hdist->TT
BER  SZ      1    999 P

Polygon points (lat,lon), one pair pr line, end with blank line :
```

Note: The TT at STAT line indicates that all stations must be present (True) and hypocentral distance is used (True)

11.1.4 Select with input from the prompt line

This option is particular useful when using select with automated operations and has been made specifically to deal with extracting data out of the data bases using WEB based software. This option do not have all of the above options. The following are implemented:

-base :	5 letter data base
-seisweb:	if set, WEB output parameters
-time :	time interval (2 variables)
-web_out:	complete path to where data is placed, only active if seisweb set. 3 files are made: `web_out.id` : id's, like `index.out` without `web_out.all` : like `select.out` `web_out.head` : header lines
-area :	lat-lon grid, minlat,maxlat,minlon,maxlon
-depth :	depth range, mindepth,maxdepth
-mag :	magnitude range, minmag,maxmag
-nstat :	range of number of stations, min,max
-gap :	range of gap, min,max
-rms :	range of rms, min,max
-magtypes :	up to 5 mag types, one string, e.g L
-disttype :	distance type, e.g D
-eventtype :	event type, e.g. E

Problems: An event might be found and listed in `index.out`, but when looking for it with EEV, it is not there. This can happen if an event has been deleted with EEV and no UPDATE has been made, so that the event is still present in the CAT part of the database.

11.2 Getstressdrop

Written by Bladimir Moreno, August, 2014, bladimir@cenais.cu

This is a program to search in a SEISAN Nordic file (S-file) for the calculated stress drop, make average stress drop and Mw for each event using all channels or selected channels as well as average for the whole data set of several events. Only channels with a stress drop of 1 bar or more is used and the upper limit of stress drop to use in average is user selectable. The output is the average stressdrop for each event versus magnitude Mw, average stressdrop for the whole data set and a statistics of the stress drop distribution. In addition events can be selected in a lat-lon polygon.

NOTE: Only works with Nordic format spec lines.

In SEISAN stress drops are calculated with either MULPLT in a manual or semiautomatic way, automatically with AUTOSIG and automatically with AUTOMAG (a simplified AUTOSIG) either directly or through EEV command `av`. In each S-file, the average stress drop (as well as the average of other source parameters) is calculated when the event is updated, irrespective of the value of the stressdrop. The stressdrop is a good indicator of the quality of the spectral fitting and stress drops less 1 and higher than 200 bars usually indicate an unreliable spectrum. The program GETSTRESSDROP will therefore be useful for making reliable average stress drops using only the best data and channels.

The user calls the program with command line arguments. The first argument is obligatory and the rest are optional. The program is called in the following way:

`getstressdrop <nordic.inp> [ -c <stress_cut> ] [ -s <stationslist_file.inp> ] [ -p <points_polygon.inp`
`]`

`Nordic.inp`: an S-file, any name.

`stress_cut`: the maximum stress drop to consider in the searching process.

`stations.lis`: a file (any name) with the station-channels list, with the same format as written in the line SPEC of the S-FILES format, see example later.

`points_polygon.inp`: a file (any name) with longitude, latitude pairs. The last point of the polygon must be equal to the first (close polygon), see example below.

```
20.0 -76.7
20.0 -75.0
19.5 -75
19.5 -76.7
20.0 -76.7
```

Output `getstressdrop_histo.out`: number of stressdrops in steps of 10 bars, can be plotted with LSQ.

`getstressdrop_mw.out`: list of earthquake magnitudes Mw versus stressdrop, can be plotted with LSQ.

Example run

```
getstressdrop eev.out
1996  6 6 0648 23.8 L  63.005   3.955  8.0  TES  5 2.9 2.8LTES 2.7WTES 3.0LNAO1
SPEC FOO S  Z MO 13.5 ST 26.2 OM  1.5 f0 12.7 R0.1754 AL 0.00 WI 10.0 MW  2.9 3
SPECHASK S  Z MO 12.9 ST  7.7 OM  0.7 f0 13.0 R0.1713 AL 0.00 WI 10.0 MW  2.6 3
SPEC EGD S  Z MO 12.9 ST 24.1 OM  0.6 f0 20.0 R0.1114 AL 0.00 WI 10.0 MW  2.5 3
SPEC ASK S  Z MO 13.0 ST113.0 OM  1.7 f0 17.5 R0.0738 AL 0.00 WI 20.0 MW  2.6 3
SPEC EGD S  Z MO 13.1 ST 35.7 OM  1.8 f0 10.9 R0.1185 AL 0.00 WI 20.0 MW  2.7 3
SPEC BLS5S  Z MO 13.2 ST  5.8 OM  1.8 f0 5.66 R0.2281 AL 0.00 WI 20.0 MW  2.7 3
1996  6 7 1325 29.2 L  59.846   5.130 12.0F TES 12 0.6 1.9LTES 2.2CTES 2.0LNAO1
SPEC EGD S  Z MO 12.0 ST 12.8 OM  1.1 f0 20.0 R0.0690 AL 0.00 WI 20.0 MW  1.9 3
SPEC KMY S  Z MO 12.2 ST 23.5 OM  1.2 f0 20.0 R0.0690 AL 0.00 WI 20.0 MW  2.1 3
SPECHASK S  Z MO 12.2 ST 23.5 OM  1.2 f0 20.0 R0.0690 AL 0.00 WI 20.0 MW  2.1 3
SPEC ODD1S  Z MO 12.3 ST 27.8 OM  1.2 f0 20.0 R0.0690 AL 0.00 WI 20.0 MW  2.2 3
SPEC BLS5S  Z MO 12.2 ST 23.1 OM  1.1 f0 20.0 R0.0690 AL 0.00 WI 20.0 MW  2.1 3
SPEC SUE S  Z MO 12.4 ST 32.8 OM  1.1 f0 20.0 R0.0690 AL 0.00 WI 20.0 MW  2.2 3
SPEC HYA S  Z MO 12.3 ST 29.3 OM  1.0 f0 20.0 R0.0690 AL 0.00 WI 20.0 MW  2.2 3
SPEC FOO S  Z MO 12.5 ST 23.9 OM  1.1 f0 16.4 R0.0842 AL 0.00 WI 20.0 MW  2.3 3
```

```
Average stress drop for 2 earthquakes selected:   30.0
Total number of channels used: 14
File with stress drop histogram is getstressdrop_hist.out
File with stress drop as a function of magnitude mw is getstressdrop_mw.out
```

Each selected channel is printed out and in the end there is information of the total number of events and channels used.

An example of a channel selection file stat is:

```
HASK1S  Z
 HYA S  Z
```

It could also be written

```
HASK1S  Z
HYA S  Z
```

Note that station names with 5 characters on SPEC line uses the 5. character on the line for the first character in station name.

Stress drop versus magnitude can give an indication if stress drops are reliable. According to the theory of self similarity (see e.g. Havskov and Ottemöller (2010)), stress drops should be magnitude independent. For small earthquakes ($M < 3$) it might be difficult to get a reliable corner frequency, it will often be to small due to near surface attenuation (kappa, see MULPLT section). This results in smaller stress drops for smaller events than larger events. It is therefore useful to plot the stress drop versus magnitude. Figure 11.1 shows an example made with program LSQ.

It is seen that there is only a slight tendency to increasing stress drop with magnitude indicating reliable stress drops.

The distribution of stress drops can also be plotted with LSQ. Figure 11.2 shows an example of the data from 11.1.

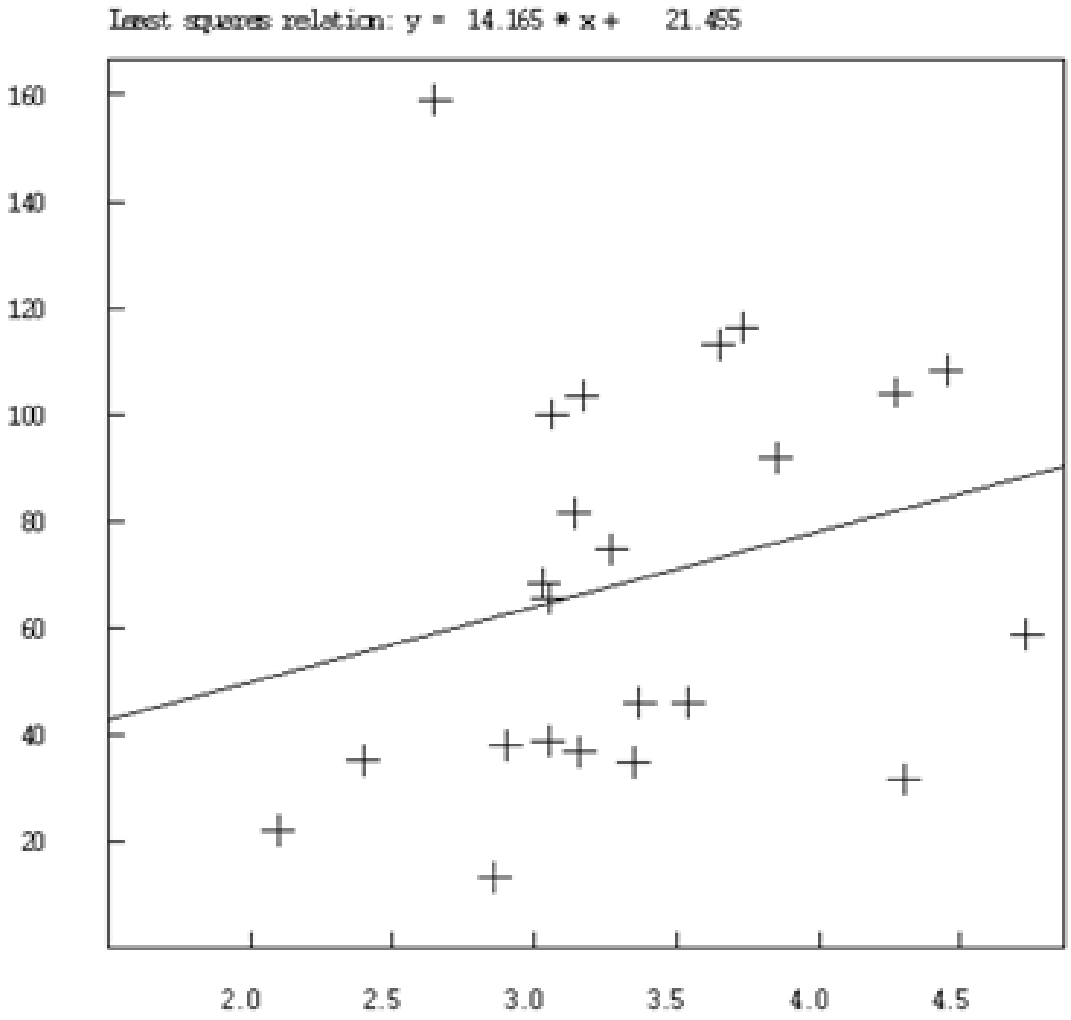


Figure 11.1: Stress drop versus Mw for 23 events.

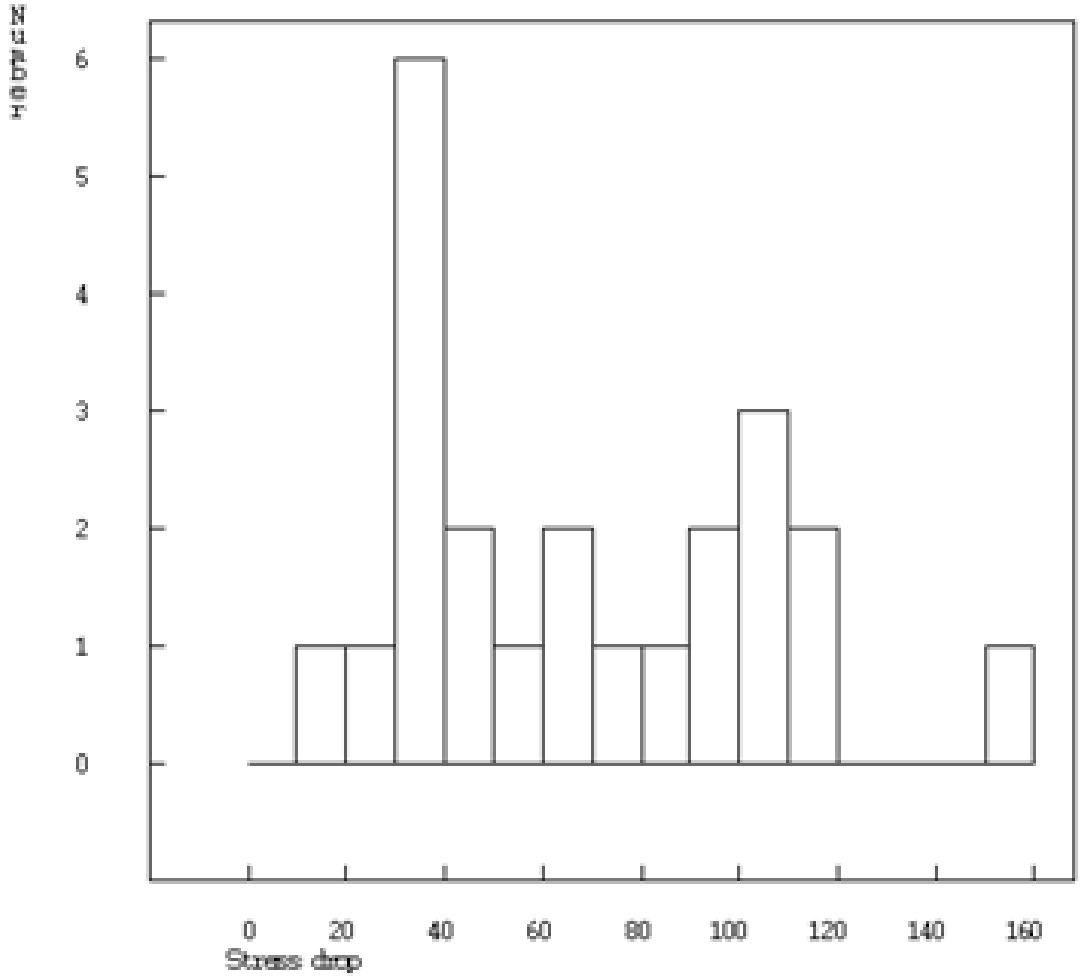


Figure 11.2: Histogram of stress drops.

Chapter 12

Extracting events from the database, COLLECT

The command COLLECT is used for collecting many event files from the database S-files into a single file. This may be split into individual event files later using SPLIT. The file can be used for exchanging data with other agencies or be used with the epicenter plotting program. The questions are:

```
Base  name, ,, for local directory, name of index file
or return for default base:

Start time                          :
End time, return for end of month:
Compact output file (Y/N=default)
```

If a local data base is input, default start time is 1980 and default end time 2015. In this way it is fast to collect all data from a local data base. At the end, the program will give statistics of collected data, and file name. For getting data out of the database represented by the monthly CAT files, use SELECT. If an update has been made, SELECT will always be the fastest program to use. COLLECT and SELECT are the only programs that can make a CAT file from the individual S-files. Program input can also be on the prompt line, below is an example:

```
collect -start_time 19910912 -end_time 19911015 -base_name BER -compact
```

This means that a CAT-file (default) is collected from BER and is written in compact format (-compact has no arguments). The time interval is between 19910912 and 19911015. Only start_time is required, the other arguments are optional. The syntax is: -"keyword" value -"keyword" value etc.

Chapter 13

Inserting events into the database, SPLIT

The program splits up a multiple event S-file in Nordic format (usually made by COLLECT or NEWEVE) or compact file to single files in the database or in the users own directory. Type SPLIT to start program and questions are:

```
 INPUT FILE NAME                          !  Give file name
COLLECT.OUT                               !  File name
 INPUT BASE NAME:                         !  Indicate which type
   BER FOR STANDARD DATABASE:            !  - database
   THREE LETTER CODE FOR OTHER BASE
   RETURN FOR SPLIT UP IN LOCAL DIRECTORY
BER                                       !  Choice was standard base
   OPERATOR ID, MAX 4 CHARS               !  Operator id logged in file
jh

1988  2  5  13:51 35.0  L       RECORDS:  4 ! Listing of events split up
File already exists, options are:         ! try to make a file with same
                                          !  id
Ignore (leave old event):              Return
Ignore all                             I
Overwrite duplicate:                   O
Overwrite all duplicates               A
Create a new event, different ID:      N
Create new events for ALL duplicates: * O

1988  2  5  14:15 25.2  D       RECORDS:  4
1988  2  5  19: 4 10.0  D       RECORDS:  3

1992 11  1   1:32  1.0  D       RECORDS: 55


NUMBER OF LOCAL EVENTS:       1            ! Statistics of events
NUMBER OF REGIONAL EVENTS:    0            ! - split up
NUMBER OF DISTANT EVENTS:     2
NUMBER OF EXPLOSIONS:         0
NUMBER OF PROB. EXPLOSIONS    0

TOTAL NUMBER OF EVENTS:       3
```

```
TOTAL NUMBER OF RECORDS:     14

FORTRAN STOP
```

In the above example, there was already an event in the database with the same file name and therefore the same id. It is up to the user to decide if this is the same event in which case it should be ignored or if it is a new event which happens to have the same id (start time or origin time to the same second and same event type). In case of a new event, a new id with one second different will be tried. Sometimes it can be desirable to overwrite the whole database event by event. If e.g. a station code is wrong in all events, this can be corrected by making a collect to extract all events, edit the `collect.out` file using a global substitute, and finally use split to put the events back in. In that case the option of overwriting all should be chosen.

Compact files can also be split up. Since this is unusual to do, the user will be prompted 2 times to confirm the split up. Since there is no ID line in a compact file, the database name will be generated from the header time. This option to be able to split up compact files has been made to facilitate work with seismic catalogs where it is often desirable to be able to access individual events even when no readings are available.

Chapter 14

Updating final locations in database, UPDATE and UPD

UPDATE

Both the monthly epicenter files in \SEISMO\REA\BER__\CAT and the updated S-files are generated with program UPDATE which is a special version of HYP. Type UPDATE to start the program and there will be questions about time period and database. The program will also ask for operator ID (4 chars), which is stored in the updated log file and the S-file, see below.
By updating, both the S-files and the CAT-files in the CAT-directory are updated. The reason for updating both at the same time is to ensure that there is a correspondence between the two.

The program will go through as many months as specified by the user. When the program is running, one line will be printed out for each event. The S-files will be overwritten with the updated location, residuals etc. At the same time, a monthly CAT file is created in the CAT directory containing all events, also events not located. If a monthly file is already present, it is overwritten.

Update can also work on a local database. The S-files are updated as described above. Since there is no CAT database, the Update program makes a CAT file in the local directory called hyp.cat with events in chronological order.

The ID line is updated with the action UPD.

The update process can also change all S-file names according to the origin time and the ID's are changed correspondingly. This is done in order for the database to be in chronological order according to origin time and not the more random times used when the events were first registered into the database. E.g. a teleseismic event is put in with the ID corresponding to the recording time, when located, the origin time is many minutes before and it will appear too late in the database). Even if the event is marked not to be located with a * in header line column 45, the ID will still be updated (same for program UPD). Like with the SPLIT program, if two events of the same type (L, R or D) have the same origin time to the second, one second is added to the file name part indicating seconds (see also section 13). The event will also be in chronological order in the CAT database.

*****VERY IMPORTANT ******

By default, the ID and file name are not changed by using the UPDATE program. However, optionally this can be done. The user gets the qustion:

Keep sfile name and ID (default=enter) or synchronize sfile name and ID with origin time (s)

By synchronizing, the S-filename and ID is synchonized to the origin time. If no origin time, the earliest time of the phases is used. At the same time an S is put in on the ID line column 76 to indicate event has been synchornized (this was L in version 11 and before). The S will remain for all future updates so it only indicates that the event has been synchronized at some time. To find out when, see the history of the ID lines. The S is only used for information. When the file has been syncronized, the action is set to UPS.

This is VERY important in case data is taken out of the database for some special analysis and then put back in to overwrite the original data. If the ID is the same, the correct event will be replaced.

NOTE: When an update takes place, the old location, magnitudes (except 3. if a different agency from the default agency), residuals etc are removed. If an event cannot be located, the old location etc is lost.

This is intentional since the updated database should represent the data available. If a location should be retained, special flags must be set, see section 7, "Fixing location" (a '*' in column 45 in header line).

In order to keep track of how and when the database has been updated, every run of UPDATE creates a log file of the update process. This file is located in a subdirectory of the database directory (default BER__). If e.g. updating REA, the logfiles will be in ../REA/BER__/LOG/ (unix). Filenames are similar to S-files. Below is an example of a logfile with name `01-0000-00L.S199606`:

```
1996 06 kk   99-09-08 14:30 03-1955-35D. 25-0337-29L.     6
1996 06 jh   98-09-08 14:29 03-1955-40D. 25-0337-31L.     5
```

The content is as follows: date and time of file updated, operator ID, time of update, event id of first and last event of the month, number of events for month. The example above shows that June 96 has been updated 2 times, the last time on September 10, 1999. For each update, one line is added to the top of the file, so the update history is saved.

Note: If the command UPDATE(U) is used from EEV, only one S-file is updated (name stays the same), and a general update should be made.
UPDATE recalculate moments if distances (or depths) change, however it does not change the Vp or Vs velocities used if a change is made in MULPLT.DEF.

Problem: If UPDATE crash, there will not be a correspondence between S-files and the CAT data base: Redo UPDATE.

UPD

The command UPD is very similar to the UPDATE command, however there is no modification of the S-file except the ID line. The program can optionally synchonize the S-filename and ID with the origin time in the same ways as UPDATE. The only difference is that the action is US instead of UPS to indcate that no relocaiton has been made. The program is used to simply move single S-files into the monthly CAT-files without relocating. It is mainly used to manipulate database events already processed. E. g. if ISC data a available and it is desirable to have it in individual files to be able to use EEV, the same data can then be copied into the CAT part of the database using UPD without modifying the original solutions. The data must be in the CAT part of the database in order for SELECT to work fast. KNOWN BUG: On Sun OS, it seems that UPD can only operate on up to a 4 year time period.

Chapter 15

Using `filenr.lis`, DIRF and DELF

DIRF

The DIRF command is a useful program for making a file with a numbered list of files from a directory. The command makes a file with file name `filenr.lis` e.g. when working with many waveform files with long names, a DIRF is first made, and subsequent programs then get file names from `filenr.lis`, either by using the whole list, or just a given number. This is handled with routine filename (in LIB). Below are some examples of using DIRF with SEISAN data files.

```
dirf 9101-10*
#  1  9101-10-0915-15S.KMY_01
#  2  9101-10-1510-55S.N2F_08
#  3  9101-10-2333-44S.N3F_06


dirf 9101-10-0915-15S.KMY_01 9101-10-2333-44S.N3F_06

#  1  9101-10-0915-15S.KMY_01
#  2  9101-10-2333-44S.N3F_06
```

The wildcard '*' above indicates that all files from the 10'th is wanted. Many programs use the same subroutine to get the file name from `filenr.lis`. This means that most programs using `filenr.lis` assume that if a name given is less than or equal to 4 characters, it is a number so file names less than 5 characters cannot be used when the program asks for "Filename or number". For a very long listing it might be an advantage to only get the first or the last 20 files and dirf has the corresponding options -head and -tail respectively. This argument must be the first argument like dirf -tail *.txt.

DIRF is dimensioned to a maximum of 99999 files.

DELF

DELF is a simple program that allows the user to delete a file that is listed in a `filenr.lis` file or another index file. First run DIRF to list the files that you want to delete. Then start DELF and choose the number of the file to delete, '?' shows the contents of `filenr.lis`. In addition, DELF also has an option to delete all the files in the `filenr.lis` or index file. This is a useful option if selected files in a data has to be deleted. If e.g. all S-files from a particular agency has to be removed, run SELECT first and then DELF.

Chapter 16

Making a bulletin, BUL

The bulletin program BUL is intended for writing seismic bulletins in a nice format. The output is written to a PostScript file.

Input files:

1. A monthly data file: This file can be made by COLLECT or SELECT
2. `BUL.INP` : This file must be in DAT or in the local directory. In this file the layout of the front pages are decided, as well as the font selection for the main bulletin. There are ample comments in the file on how the commands are written.

Some special format features:

Type 3 line: If the first 5 columns in a type 3 line are:" Bul:", then the rest of the line is interpreted as text line that is written in the bulletin. In this way comments to certain earthquakes can be written into the bulletin. Type 2 line: Maximum intensity and casualty/damage reports are included in the bulletin if found in the S-file.

How to run the program:

Type `bul -h` this gives you a list of the different options like this:

Options:

-frontpage:	Only frontages are printed.
-nofrontpage:	No frontages are printed. ll
-onlyhypo:	Only hypocenter solutions are printed.
-minmag x.x :	Only hypocenter solutions with magnitude than the requested are printed.

The last option may be used in cases where the number of earthquakes is very high, so that it is preferable to report phases only for events above a given magnitude.

You can also run the program without any options, in which case the default values used are:

i) All phases are reported.

ii) Front pages are printed.

You will always be asked for the name of the S-file.

Output file:

The output file is called `bul.ps` and is a PostScript file that you can print. Optionally, a limited number of pages can be selected from the `bul.ps` file for printing. The header page is still included and the page numbers correspond to the original page numbers.

Chapter 17

Reports and statistics

SEISAN has several programs for extracting and writing out data for plotting or printing statistics, most of which will be listed in this section.

17.1 REPORT, extract data from CAT file

The program extracts parameter data from all header lines in a CAT file and rearranges the data in a table. In additions, there is an option to rearrange order and location of magnitudes on the header line. Below is an example of a run where the input CAT file is called `collect.out` :

```
report collect.out

Below is shown parameters which can be chosen for output.
 A return will chose all, placing any character under a field
 will chose that parameter in the output. Each field starts
 with a capital letter and ends within the following blank.
 The order of the output can be changed by placing a number
 under the field and fields will be written out in the order
 of the numbers. E after time, lat, lon and dep are errors,
 L E is distance and event id s, F is both fix flags and A is
 agency for magnitude.
 The following example shows that Mc, Depth(Dep) and Time with
 error are selected and written out in given order.
Date TimeE L E LatE LonE Dep E F Aga Nsta Rms Gap McA MlA MwA MbA MsA MWA Fp Spec Macro Loca
     30  45              20                       10

Date TimeE L E LatE LonE Dep E F Aga Nsta Rms Gap McA MlA MwA MbA MsA MWA Fp Spec Macro Loca
x              x    x    x           x       x                          x
 Number of output fields           8

 Number of events                                    12
 Number of events with spectra:                       1
 Number of events with fault plane solution:          3
 Number of events with error estimates:              16
 Number of events with mc             :              10
 Number of events with ml             :              10
 Number of events with mb             :               8
 Number of events with ms             :               5
 Number of events with mw             :              12
```

```
Output report file is report.out
Output nordic file is report_n.out
Output of choices used in report.inp
```

The `report.inp` is a file with the choices used. Report can use that file (or a file with the same format and a different name) as second argument:

`report collect.out report.inp`

in order to use a fixed set of choices.

Content of `report.out`

```
Year Date Latitud Longitud Depth NST GAP   Ml STRIK  DIP RAKE
1996  6 3  47.776  153.222   0.1  12 348
1996  6 6  62.652    4.940  15.0  13 270  2.9    28   61  -41
1996  6 6  62.634    5.068  15.0  13      2.9
1996  6 6  62.652    4.940  15.0  13 270  2.9    28   61  -41
1996  6 7  59.841    5.127  12.0  12      1.9     8   41   75
1996  610 -13.481  167.130 200.1 301
1996  625  61.656    3.363  14.9  35      3.2
1996  7 5  61.282    4.825   7.1  10      2.0
1996  713  61.416    3.870  12.1   9      1.5
1996  718  60.156    2.070  15.0   9      1.8
1996  718  51.438  157.737  29.9  18
1996  726  61.755    2.293  22.1   9      1.8
```

The file `report_n.out` contains the input data with the only difference that the magnitudes have been moved around on the header line. This can be practical for later plotting with EPIMAP. If no magnitude selection has been made, the magnitudes will come in the order Mc, Ml and Mb. If no magnitude of that type is available, the output field is blank. The magnitude selected is the first to occur of the corresponding type. If other magnitudes are to be selected, numbers can be used to select any 3 magnitudes in any order. If it is important to select magnitudes by agency also, use program MAG. REPORT can also give a numbered output by adding the second or third argument `-n`.

17.2 NORHEAD, making a compact Nordic file from a Nordic file

You must give arguments: First is input file, optional second is output file, if an optional second or third argument is -mag, magnitudes from following header lines are moved up to empty magnitude spaces on first line. The program was earlier called COMPACT (version 7.2 and earlier).

17.3 STATIS, statistics of databases

This is a simple program for making statistics of stations used in the database or in a file. The program will ask the following questions:

1. Information about which stations should be searched for in the database. There are several options for entry:
   - a: Give a filename with the stations listed one per line. The format is a5. The file name MUST have a '.' not to be confused with option (b) below.
   - b: Give stations, one pr line, enter to finish, enter for def file statis.def
   - c: Just make a return and the stations given in file statis.def will be used. The file has one station per line an dcan be located in either the working directory or DAT.
2. Standard questions about base or filename and time interval

3. Question about counting all phases. This means counting the occurrence of a station for each phase for that particular station. This can give the total number of phases read at a particular station in a given time interval which can be more than the number of events. If not counting all phases, the program gives the number of events recorded at the station.

The output from the program could be as follows:

```
Station     Local Ev.   Local S.  Distant E  Distant S
   KONO          0                    21          8
   KMY          24         10          6          0
   ODD           0
   EGD          28          0          3          1
   ASK          29          0          3          0
   HYA          16          1                     0
   SUE          16          4          2          0
   FOO          18          1          3          0
   NRAO         86          9          0
   MOL          38         17         14          1
   NSS           9          6          7          0
   MOR           0
   LOF          25         13         12          0
   TRO          12          2         13          1
   BJO           0
   KBS           3          2          8          6
   JMI          16          0
   KTK1         22          1          2          0
   ARAO         66          6          0

NET  NWAW
NSN   147
JMI    21
KNN    10
W_L     2
W_E     1
W_S     2

Number of events selected with given stations     222
Number of events selected with more than ---       98
Number of events with no phases                     0
Number of events with waveforms                   168
Number of events with only waveforms                0
Number of events with 2 or more waveforms           9
Total number of waveform files                    183
Total number of local events                      200
Total number of regional events                     0
Total number of distant events                     34
Total number of events                            234
Total number of records                          2830

Output files are: statis.out
                  statab.out (station statistics only)
```

The top part shows the event statistics by station. Local Ev is number of local events (readings if so specified above) (type L and R) at the station, Local S means number of local events ONLY recorded at that station, Distant E and distant S is the same for distant events (type D). The middle parts shows the number

of waveform files NWAV from different networks NET as indicated by the first 3 letters of the waveform file name after the "." At the bottom is a summary statistics most of which should be self-explanatory. The information about ".. more than given stations" means that in addition to the stations searched for, the event had additional stations not used in the statistics.

17.4 CATSTAT, statistics of catalogs

This program calculates the yearly, monthly and daily number of events from a given earthquake catalogue and plots the results (written by **Mario Villagrán**). The input is a standard Nordic file containing only the header lines (compact file). The output is given in three different files with following default file names:

`catyear.out` : Output catalogue of the yearly number of events. This file contains two columns of data corresponding to year and the number of events.

`catmonth.out` : Output catalogue of the monthly number of events. This file contains three columns of data, corresponding to the year, month and the number of events, respectively.

`catday.out` : Output catalogue of the daily number of events. This file contains four columns of data corresponding to the year, month, day and the number of events, respectively.

`cathour.out` : Hourly distribution of events within a day interval.

In addition, a series of files with gmt in name give similar output for use with gmtxy (only Unix). The output files can then be used for plotting the histograms for the desired time interval at yearly, monthly or daily intervals. If desired, the corresponding histograms can be plotted interactively on the screen or can be printed. Several other routine programs such as grapher, xyplot, gnuplot or GMT, etc., can also be used for this purpose. The general purpose of this program is to evaluate the catalogue completeness. When run for different magnitude intervals, one can detect the magnitude thresholds above which the catalogue can be considered complete.

17.5 SWARM, finding earthquake swarms

The program is used to identify seismic swarms in a catalog. Input to the program is a CAT file with many events and some manually entered parameters. Output is identified swarms. The output file swarm.out contains all swarms organized as 'events'. In the header line is given the center for area identified and the 'magnitude' is the number of events in the area divided by 10. The rest of the line is information from first event in swarm.

Principle of selection:

The area is divided into a lat-lon grid. Around each grid point, there is a cell with radius small_r. The program first checks the number of events in each cell for the whole catalog. It then checks each cell to find which has more than the minimum number of events to constitute a swarm under the condition that enough events are within the required time window. For each time window, with enough events, a swarm is declared so a swarm lasting e.g. twice the time window will be declared as two swarms. An additional condition is that the number of events is larger than the normalized background activity. The normalized activity is calculated as the activity in the large cell normalized for area to the small cell, and normalized in time to the window for the swarm.

17.6 STATSTAT, number of events per seismic station in catalog

The program reads Nordic file input data and writes out text files giving the number of events per station.

17.7 LSQ, plotting a linear relation or a curve

A simple program to make and plot a least squares or maximum likelihood relation between

two parameters, plot a curve using the xy parameters or plot a hsitogram using the xy parameters. Input is from a file with two columns x and y. The program also calculates average and standard deviation of the two data sets. If a linear fit is made, the program also makes an output used with GMT in order to make nice plots. The PostScript output file is `lsq.eps` and the GMT file is `lsq_gmt.out`. In order to produce the GMT plot (only Unix), use command `gmtxy lsq_gmt.out`. The curve can be plotted with points only, lines joining the points with points plotted or just lines between points. X and y-axis for the curve plotting can be linear or logaritmic.

For plotting histograms, the input data must be equally spaced in x like e.g.

0 4
10 22
20 11
30 4
40 2
50 0

Examples of plots are found under program GETSTRESSDROP

Chapter 18

Waveform file management tools

This section describes the programs used for modifying and checking waveform files. The most important features are to add or subtract channels and modify headers and convert format.. A special program in this group is GET_WAV which checks data bases for availability of waveform files. New from version 7.1 is that SEISAN also can handle other waveform formats, however not all programs can work with all formats. This will be indicated with each program.

The most important program is WAVETOOL which can convert to and from many formats, do instrument corrections and extract data from continous data bases (SEISAM and archive type) and large MSEED volumes. Another important program is WAVFIX which can correct binar waveform files (SEISAN or MSEED formats) for many parameters.

The following programs are available:

APPEND:	Append two or more waveform files following each other in time
AUTOREG:	Automatically register events
CONGAP:	Check completeness of continuous waveform database
CONNOI and EVANOI:	Compute noise power spectral density and evaluate out to produce plots
DATABASE2MSEED:	Convert waveform data to miniseed based on parametric database
GET_WAV:	Check for available waveform files
GET_ARC:	Extract wav files from archive and register in S-file
GET_ARC_CHANNELS:	Get a list of all channels in an archive
MSCUT:	Cuts MiniSEED files into 1 hr or shorter files
RDSEED_MANY:	Simple way to chop up a seed volume
SEIASC:	Convert SEISAN waveform files between ASCII and binary form
SEICUT:	Extract an interval of a waveform file
SEIDEL:	Splitting up a SEISAN waveform file in 2
SEISEI:	Split and merge SEISAN, GSE, SAC and MiniSEED waveform files
P_ALIGN:	Time shifting waveform data to align P or S-phase arrival times
WAVETOOL:	Extract waveform data
WAVFIX:	Fix waveform file header time correction, make standard file names, change headers etc.
WAV_ADD	Add wavform filenames to S-files.
WAVFULLNAME	Print full file name including path for waveform file.

18.1 APPEND, Append two or more waveform files

The program uses a `filenr.lis` input file. All files are read, and then written out as one new file. The maximum number of channels is max_chan_out which is set as a parameter (currently 7). Only the first max_chan_out channels are used or less if fewer channels in file. A blank line followed by a new group of files will make a new output file. There is also a question of how many files should be megerd at a time so e.g. every 10 files will be mergged. This is independent of the option with blank lines. The output file cannot have more than standard SEISAN dimension number of samples (more than 2 400 000, see file `../INC/seidim.inc` for exact number) per channel.

It is assumed that all channels have the same sample rate and that files follow each other in time.

Input format can be many but output format is SEISAN.

18.2 AUTOREG, automatic registering of events

When a large number of waveform files are available and it is known that they are real events, it might be an advantage to automatically register them into a database. Remember, the database must be made beforehand with MAKEREA. If the filename follows the SEISAN filename convention, the date and time used to generate the S-file are taken from the filename. Otherwise, the file is read to get the date and time from waveform headers. Obviously, the first option is faster. It is possible to register events both to the default database, any other database or the local directory. To run the program, make a `filenr.lis` of the waveform files and run AUTOREG. It is possible to put blank lines into the `filenr.lis` to separate into events, in case there is more than one waveform file from the same event. All waveform files before a blank line are put together into one S-file. Alternatively, one waveform file can be given on the prompt line and then no filenr.lis is needed. Optionally, the waveform files can also be moved or copied to WAV or a WAV database subdirectory (including year and month). This can either be the default parameter COPY_WAV_DIR (in `SEISAN.DEF`) if different from blank. COPY_WAV_DIR should be the same as the data base used by the S-files. However an optionally data base directory entered interactively if COPY_WAV_DIR is set to blank. AUTOREG can also be operated entirely or partly with flags on the prompt line. The flags are:

-file : file name of a single file to register, can be filenr.lis for many

-op : operator

-copy: flag to indicate if copy or move wav files: b for blank, no move or copy, c is copy and m is move

-base: data base for s-files, b for blank for default

-wbase: base for waveform files b for default WAV. If blank, the data base given in SEISAN.DEF will be used.

-model : x model flag for STATIOx.HYP

You can run AUTOREG with any number of flags, parameters not given with the flags will be asked for.

```
c:\seismo\WOR>autoreg
  Event type for all events: Local:    L (default)
                             Regional: R
                             Distant:  D
r
  Move (m) or copy (c) waveform files to WAV (enter=n) ?
c
  Enter wav base to copy/move to, enter for WAV main folder
TEST
 Files will be copied to default WAV base: TEST_
  Operator, max 3 chars
jh
 2004-05-11-0050-42S.NSN___013
  sfile: c:\seismo\REA\TEST_\2004\05\11-0050-42R.S200405

 File already registered, options are:
 Ignore (leave old event):            Return
```

```
 Ignore all                            I
 Overwrite duplicate:                  O
 Overwite all duplicates:              A
 Create a new event, different ID:     N
 Create new events for ALL duplicates: *o

  Sure you want to overwrite(y/n)
y
 c:\seismo\REA\TEST_\2004\05\11-0050-42R.S200405

 copy 2004-05-11-0050-42S.NSN___013 c:\seismo\WAV\TEST_\2004\05\
        1 file(s) copied.
  File transferred to WAV base TEST_ **********
 2004-07-05-1809-44S.NNN___010
  sfile: c:\seismo\REA\TEST_\2004\07\05-1809-44R.S200407

 c:\seismo\REA\TEST_\2004\07\05-1809-44R.S200407

 copy 2004-07-05-1809-44S.NNN___010 c:\seismo\WAV\TEST_\2004\07\
        1 file(s) copied.
  File transferred to WAV base TEST_ **********
```

Now comes a listing of waveform file names and S-file names. The program will check if the event is already registered and the same options are available as in program SPLIT (section 13). Since AUTOREG automatically creates S-files for all events in `filenr.lis`, they will all be given an event type.

18.3 CONGAP, check completeness of continuous waveform database

This program checks for completeness of continuous data for a given time interval. The program reads the waveform data to see what data are available and checks for gaps, defined by a constant amplitude value (e.g. 0). The input can come either from an input file (`congap.par`) or the command line.

Parameters in the input file are:

CONT BASE:	name of database, you can have more than one
START DATE:	start time and date of interval to be read (yyyymmddhhmmss)
STOP DATE:	stop time and date of interval to be read (yyyymmddhhmmss)
INTERVAL:	duration of intervals read at a time in minutes (e.g. 60. for one hour)

When started from the command line, the same parameters can be given:

```
congap -start <yyyymmddhhmmss> -stop <yyyymmddhhmmss> -cbase <text> -interval <number>
```

The output file (`congap.out`) looks like this:

```
EDI   HHZ 20080101 0000 0.00   3600.00   3600.00
EDI   HHN 20080101 0000 0.00   3600.00   3600.00
EDI   HHE 20080101 0000 0.00   3600.00   3600.00
EDI   HHZ 20080101 0100 0.00   3600.00   3600.00
EDI   HHN 20080101 0100 0.00   3600.00   3600.00
EDI   HHE 20080101 0100 0.00   3600.00   3600.00
...
```

The fields are station and component code, date and time, expected duration and actual time with data. The output file can be used to produce plots showing data completeness (tool for this not included). When the program runs it also produces a summary output at the end, where the last column gives the percantage of data completeness, and the actual and expected times are in seconds:

```
-------------------------------------------
 # stat comp       actual     expected     %
-------------------------------------------
 1 EDI   HHZ     86400.00     86400.00 100.0
 2 EDI   HHN     86400.00     86400.00 100.0
 3 EDI   HHE     86400.00     86400.00 100.0
-------------------------------------------
```

18.4 CONNOI and EVANOI, noise power spectral density

These two programs with the help of GMT allow to produce noise power spectral density (PSD) plots similar to the ones produced by the PQLX software. CONNOI is the tool that reads the continuous database and produces output files that are evaluated by EVANOI. The computation of the noise PSD follows the method described by McNamara and Buland (2004).

To run CONNOI on a SEISAN continuous database BER use for example:

```
connoi -start 20100501 -stop 20100502 -cbase BER
```

To run CONNOI on an archive structure BER use for example:

```
connoi -start 20100501 -stop 20100502 -arc BER
```

In both examples BER is the database, you can also specify 'def' and the program will take all default continuous databases or archives defined in SEISAN.DEF. The default output filename is connoi.out.

Example of output:

```
stat comp date and time       duration frequency noise PSD
-------------------------------------------------------------
BER   HHZ 20100501 0000 0.00   3600.00  0.00200    -159.14
BER   HHZ 20100501 0000 0.00   3600.00  0.00204    -159.14
BER   HHZ 20100501 0000 0.00   3600.00  0.00209    -159.14
...
```

The output from CONNOI can then be used as input to EVANOI. You can enter station and component, give a time interval, select a time of day interval, and chose a reference station. EVANOI produces GMT plotting scripts files that are named after the station. Then simply run the script file to get a plot.

You can also output the data in a compact format using the -compact option. This output does not work with EVANOI, but it is fairly easy to read in your own scripts. An example output :

```
CONNOI: NF= 500 START=2008120101   STOP=2008120103   DURATION= 60.0min, SPACING= 50.%
STATN CMP yyyymmdd HHMMSS.FF   SPECLEN  -2.69897 -2.68955 -2.68014 ...
BER   HHZ 20100501 0100 0.00   3600.00   -102.94  -102.94  -102.94 ...
BER   HHN 20100501 0100 0.00   3600.00   -117.85  -117.85  -117.85 ...
BER   HHE 20100501 0100 0.00   3600.00   -115.81  -115.81  -115.81 ...
VASAV BHZ 20100501 0100 0.00   3600.00   -134.16  -134.16  -134.16 ...
VASAV BHN 20100501 0100 0.00   3600.00   -131.06  -131.06  -131.06 ...
VASAV BHE 20100501 0100 0.00   3600.00   -124.60  -124.60  -124.60 ...
...
```

By default, CONNOI calculates spectra every 30 minutes, with each spectra calculated over a 60-minute interval. You can change this using the -spectlen and -spectspace options, where -spectlen gives the interval over which to calculate the spectra (in minutes) and -spectspace gives the spacing between spectra with respect to -spectlen (1.0 for no overlap, 0.5 for 50% overlap, etc). For example:

```
connoi -start 20100501 -stop 20100502 -cbase BER -spectlen 60 -spectspace 1.
```

will calculate spectra over a 60-minute interval, spaced every 60 minutes (no overlap). Finally, you can calculate the spectra for a single channel of a single station using the -sgram option. This option always uses the -compact output format and sets spectspace to 1.0. For example:

```
connoi -start 20100501 -stop 20100502 -cbase BER -sgram TOTI BHZ
```

18.5 DATABASE2MSEED, convert database to miniseed

This program can be used to convert the waveform data that is linked to from a parametric database to miniseed format. The user is asked to enter the database name, and start and end time for the operation.

One should do a small test with a copy of parts of the database before runnung it through the complete database.

18.6 WAVETOOL, extract and convert waveform data

The program was called extract in SEISAN 7.2 and earlier. The program extracts all or selected time sections of waveform data, optionally applies some signal processing and then creates the output file(s). The input formats supported are SEISAN, SEED, MINISEED, GSE, HELMBERGER (only made by MULPLT), GURALP (one channel files) and SAC (all platforms)and output formats are SEISAN, MINISEED, GSE and SAC (all platforms)and SEED on Linux. The program can be used as a conversion program between these formats, instead of using e.g. SACSEI. It would also be possible to convert for example SAC and GSE files to SEISAN in one go. When creating GSE, MINISEED or SAC files, the respective format code is added to the filenames. The program can also extract data from a SEISAN continuous data base or a large SEED file.

File name convention for output files:

In interactive mode, the output file name is SEISAN by default since

there is no question about file name.

No output file name given: wavetool.out for SEISAN output file

wavetool.out_SEED for SEED output file

wavetool.out_MSEED for MSEED output file

wavetool.out_GSE for GSE output file

Output file name given as SEISAN: SEISAN name for SEISAN output file SEISAN_name_SEED for SEED output file SEISAN_name_MSEED for MSEED output file SEISAN_name_GSE for GSE output file

No output file name given and output format is SAC:

SEISAN_name_component_SAC

Output name given: That name is used exactly as specified. There

is no check if file exists and there is no

ending indicating format

Ouput of one channel files with SEISAN names: The channel code is added

to avoid overwrite of different channels

from the same station

Output format is SEISAN and ouput file exists: _SEI is added to file name

Note that for MINISEED writing, only Steim1 compression is used. Integer format is also possible, but requires a parameter change in WAVETOOL and recompilation.

There are two input options: (1) a single S-file or a list of S-files created with DIRF (is also an index file), which points to the waveform data or a `filenr.lis` type of file that gives the waveform file names; (2) a waveform file or a list of waveform files. The program can be started either interactively, without arguments, or non-interactive by specifying the commands as arguments.

Filtering: WAVETOOL only supports band pass filters hardwired to 4 poles and one pass (forwards). So if WAVETOOL is started from MULPLT to extract data as seen on the screen, the filter constants will ONLY be passed to WAVETOOL if 4 poles and band pass.

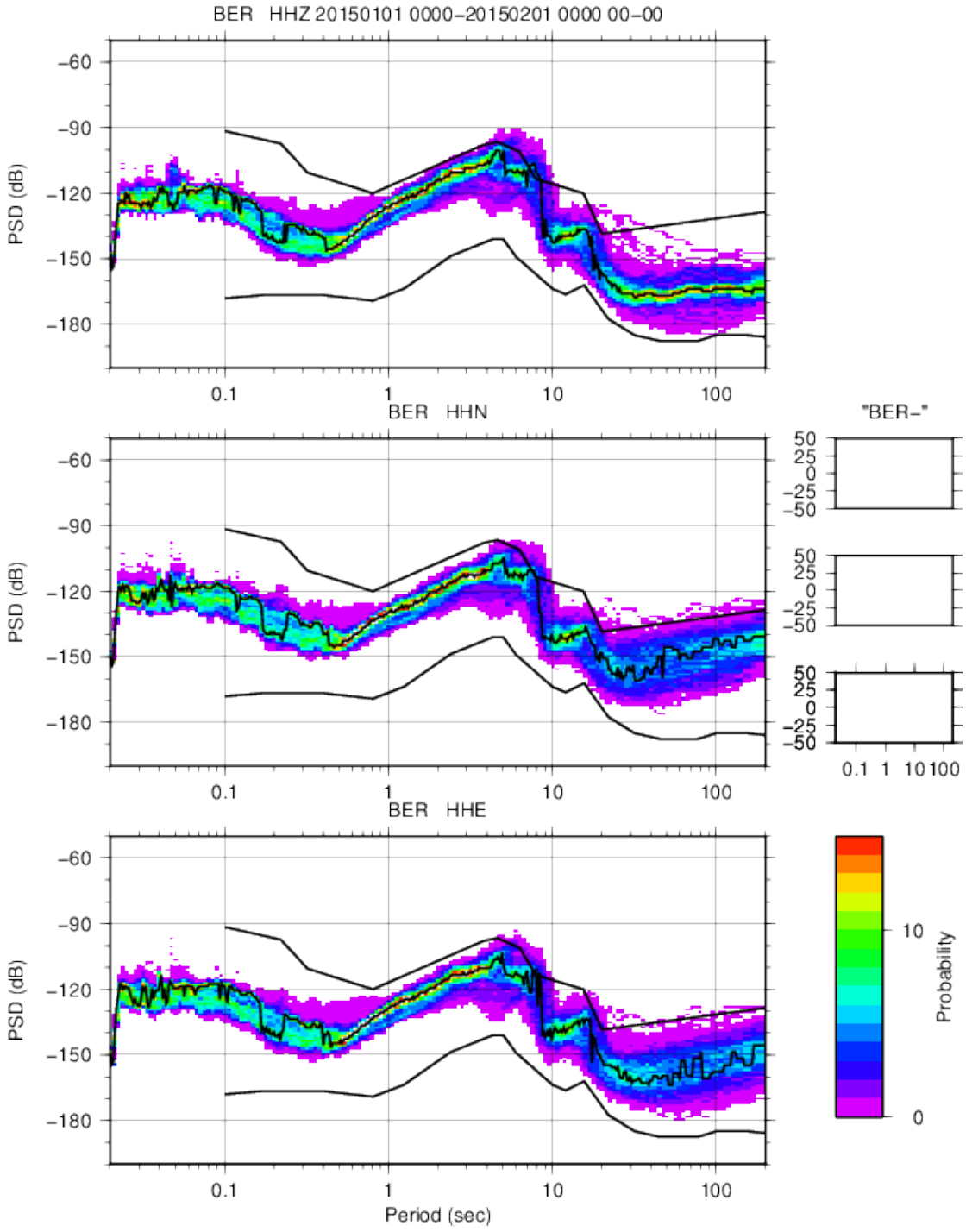


Figure 18.1: Example of plot created using CONNOI and EVANOI. The plot shows noise PDFs for station BER for three components in January 2015.

The arguments are: `-sfile <sfile-name>` : The S-file name of the event you want to extract waveform data from.

-wav_files <file-name>: Extract from a list of waveform files in `filenr.lis` format. Input from S-file will be ignored. This option merges all files from list (if within a 'reasonable time window') and program is then partly doing what SEISEI is doing. If file-name is given as 'SEISAN', then the output file name follows SEISAN convention.

-wav_in_file: input waveform file.

-maxpoints : Skip points to get approximately maxpoints

-wav_out_file <file-name>: Name of waveform output file, not used if output format is SAC.

-start <time>: Start time can be used to set start time the same for all channels instead of using chansel file, time can be absolute or relative to beginning of the first trace. Options are Start time relative earliest channnel, Abs start time string yy...s.sss for all channels.If ABS time used, string MUST contain a '.'.Abs start time string yyyymmddhhmmss (integer), used to define cont start time.

-duration <time>: Select duration of time window in seconds if -start is used.

-interactive : enable interactive mode

-cbase: name of file with selected continuous databases,all bases is default

-command_file: give arguments to wavetool in a file rather than on the command line (used by Seisweb)

-cwav: Input is from the SEISAN continuous data base, useful for extracting intervals

-cseed: Input from large SEED file, similar to -cwav -wav_in_file <file-name>: Input of one waveform file

-arc: Input from BUD or SeisComp archive.

-sfile <file-name>: Input of S-file name

-format <output format>: The output formats supported are SEISAN, SAC, GSE (GSECM6) and GSEINT. In case of SEISAN or GSE, multi-trace files including all selected traces are created, while for SAC, single trace files are generated. SEED is also possible on Linux.

-chansel <file-name>: Input file to select channels and time windows. The first line contains number of channels. The following lines give station code, start time (both absolute and relative to earliest trace allowed) and duration. If start time and duration are set to 0, complete traces are selected.

-chan_out_file: file name of file with channel description if this option is given, program terminates after writing out the file.

-chandef <file-name>: change station and/or channel names following standard also used in the conversion programs, for example:

```
Header line text (29 chars) ... NetCd (5 Chars), comment in next line

 chan stati  comi stato  como, In and Out definitions
             p0          HH Z
             p1          HH N
             p2          HH E
```

-ground : compute displacement, velocity or acceleration (1,2,3)

-seed_location: seed location code NOT USED.

-rsam: comput 1 min rsam data.

Example

Select the first three complete traces

```
3
1 0 0.0
2 0 0.0
3 0 0.0
```

Use absolute start time, and duration of 180 seconds

```
3
1 19991001124500.000 180
2 19991001124500.000 180
3 19991001124500.000 180
```

Use relative start time of 60 seconds from beginning of earliest trace, and 300 seconds duration

```
   3
1 60 300
2 60 300
3 60 300
```

The program assumes that a large number is absolute time.

`-chan_out_file <file-name>` : Name of text file containing a list of available channels from a list of waveform files. If wav_out_file is not specified, program terminates after creating the list.

Example

```
 1 KBS   BV Z  1996  6  3 20  2 18.991  6000   20.000 2666.400  299.950
 2 LOF   S  Z  1996  6  3 20  5  5.531  5800   50.000 2832.940  115.980
 3 MOL   S  Z  1996  6  3 20  5 24.984 10000   50.000 2852.393  199.980
 4 FOO   S  Z  1996  6  3 20  5 34.156  9650   50.000 2861.565  192.980
 5 HYA   S  Z  1996  6  3 20  5 36.078  9900   50.000 2863.487  197.980
```

`-filter <flow> <fhigh>` : bandpass filter limits

If a filter is used, a 4 pole Butterworth filter is used one way. No other filters are possible. Filter in WAVETOOL

`-ground <1,2,3>` : compute displacement, velocity or acceleration (1,2,3)

`-ichan <id>` : select one channel only

`-interactive` : Flag to specify non-interactive use, in which case the program does not ask any questions (for example given by SEISAN-autodrm interface), default is interactive.

`-seisweb` : Flag to indicate that the program is started by SEISWEB.

`-maxpoints <number>` : Number specifies the total number of points desired for the total time window covering all selected traces. This option is meant to reduce the number of points to what is needed to visual correctly plot the traces. When plotting the trace using a number of pixels, which is smaller than the number of points on the trace, samples are plotted on top of each other for one time sample. This results in the maximum and minimum being plotted at the same place on the x-axis. The idea now is to reduce the trace to these maxima and minima only. Then using twice the number of samples than pixels will allow to visually correctly show the trace. Note that this is not a resample routine. Option mainly used with SEISWEB.

`-stat_out` : write out station location file, simple xy output file (`station_list.out`)

`-rsam` : convert data to RSAM (1-minute absolute average), which is commonly used in volcano seismology

`-resp_out` : write out list of all response files for channels given in waveform files (`respfile_list.out`)

Intercative input

The interactive input has less options as the mon interactive input, however the option are as above. The questions are:

Filename of s-file or waveform file, number or filenr.lis Maximum number of points in output trace, return for all same as -maxpoints Ground motion output (dis = 1, vel = 2, acc = 3, none = return) Filter low and high, return for no filter Select all data, y=return,n If answer is n, then the following 2 questions come: Number of channels to read Channel number, start time and window

Output formats (SEISAN, GSE (def=CM6), GSEINT, SAC, MSEED) Default is SEISAN=return

Another way of extracting waveform data is using MULPLT where many traces can be extracted as a binary SEISAN file (using WAVETOOL in the background) or a single trace as an ASCII file.

Accuracy of extracted data

If the data is filtered or corrected for instrument response, the number out can be less than one and an output file of zeros can be made. If the output format is SEISAN, the values will always be scaled to avoid this and the appropriate scaling factor is included in the waveform file. Subsequently reading of these files in SEISAN will produce the correct values. For this reason, it is advised to use SEISAN as output format when filtering or correcting for instrument response. SAC data can have values less than 1.0 so only if written in SAC or SEISAN will the values be correctly represented. If a more specific combination of filters and and response removal is required (like making a Wood Anderson trace with an addtional fileter) it can only be done for one event using the MULPLT OutW option which creates an ASCII Helmerger file which then can be converted with WAVETOOL to any other format. SAC input data is checked for max values. If smnaller

then 10, output will be scaled in SEISAN format. Note: Parameter MERGE_WAVFORM in `SEISAN.DEF` sets the network extension of extracted files.

18.7 GET_ARC, extract waveform files from the archive corresponding to S-files and register the name in the S-file.

The program uses an S-file as input (one or many files). The stations to select from the archive can be user specified, all stations with readings, all stations in archive or all stations in a given distance from the epicenter. All channels for each station are automatically selected and there is no option for selecting e.g. all Z-channels. The output file get_arc.out contains the input data with the waveform file line added. If the process is done twice and the same waveform file name is created, it will only be recorded once in the S-file. The output file must be split into the data base and possibly overwrite existing S-files. The program can also be run with arguments for the operator and file e.g. get_arc collect.out bb. This option is used when the program is called from EEV with commend ARX.

```
Example run

get_arc
Give operator
jh
 Give input file
collect.out
 Interval in number of seconds before and after origin time
 Default (enter) is 30 and 300
50 500
 Extract stations with readings:                  enter
        all channels in archive:                      a
        for given stations interactively:             s
        for stations in a file:                       f
        for stations at given distance to epicenter:  d
        for stations to given distance to given point:p
a

********* Event    1   2011  129 10 0  0.0 L
 wavetool -start 20110129095910 -arc  -duration      550.0 -wav_out_file SEISAN -cbase cbase.inp -forma
 Number of archive channels defined           3
  Total duration:   551.050476
  Output waveform file name is 2011-01-29-0959-09M.NSN___003
 Extracted file 2011-01-29-0959-09M.NSN___003
  End of s-file

 Number of events in input file           1
 Number of events skipped                 0
 Output file name is get_arc.out
```

In details, the options are: Default: Use stations with readings. If a station has more than one reading, it is only selected once.

a: All channels in archive. If a very large network, this option might select too much.

s: For given stations. Give station codes, one per line.

f: For given stations. Give stations from a file, one per line.

d: Use all stations in archive within a given distance. If there is no epicenter, the stations in S-file will be used. If no stations in S-file, all station in archive will be used.

p: Use all stations at a given distance from a point. The user will be asked for the latitude and longitude of point and distance.

18.8 GET_ARC_CHANNELS, get a listing of all channels in an archive for SEISAN.DEF

In order to use continuous data form an archive, all the channels must be listed in SEISAN.DEF in a particular format. For a large archive, this can be a cumbersome job and we therefore have this program to automatically generate the lines needed in SEISAN.DEF using the information available in the archive (SeisComP type). The first step is to get a list of all the day files in the archive. In Linux this can be done with command (executed in archive top directory)

ls -R ¿ archive.list

where all info is redirected to a file with any name, here archive.list. This can take some time for a large archive. The file can look like this

```
.:
2019
2020
2021
2022

./2019:
HA
HC
HI
HL
HP
HT

./2019/HA:
ATAL
ATHU
AXAR
FYLH
KALE
KARY
LAKA
LOUT
MAGU
MAKR
SNT5
STFN
VILL

./2019/HA/ATAL:
HHE.D
HHN.D
HHZ.D
MME.D
MMN.D
MMZ.D
SOH.L
```

```
./2019/HA/ATAL/HHE.D:
HA.ATAL..HHE.D.2019.225
HA.ATAL..HHE.D.2019.226
HA.ATAL..HHE.D.2019.227
HA.ATAL..HHE.D.2019.228
HA.ATAL..HHE.D.2019.229
.
.
```

GET_ARC_CHANNELS is now started and an example run is:

```
  Input file name
archive.list
 Output format, arc_chan (def=enter) or arc_chan2(=2)

 Which channels like HHE or **Z, enter for all, else one per line
 * is wild card
**Z

 Which networks, enter for all, else one per line

 Which stations, enter for all, else one per line

 ATAL  HHZ HA           2019         225        2019         363
 ATAL  MMZ HA           2019         225        2019         363
 ATHU  HHZ HA           2019           1        2019         365
 AXAR  HHZ HA           2019           1        2019         365
 AXAR  MMZ HA           2019         202        2019         365
 FYLH  HHZ HA           2019         202        2019         246
 FYLH  MMZ HA           2019         202        2019         246
 KALE  HHZ HA           2019           1        2019         365
 Number of channels            8
 Output file is get_arc_channels.out
```

The user can select two formats ARC or ARC2. There are also options for selecting out particular stations, channels or networks. If choosing ARC2, the ARC2 line archive identification will be given the name arc_loc, later to be associated in SEISAN.DEF with the location of the archive. The start and end time for each channel is determined from first and last channel found in the archive. Files with channel code LOG are ignored.

18.9 GET_WAV, get listing of available waveform and response files

The program uses a CAT file as input and checks for availability of all waveform files listed. For each channel, there is a check on existence of corresponding response files. A typical run is shown below:

```
get_wav
 INPUT FILE NAME
select.out
 Where to copy files to, default . on Linux and blank on Windows

 Full path name : /net/seismo/users/jens/TD/WAV/1996-06-03-2002-18S.TEST__012
 Full path name : /net/seismo/users/jens/TD/WAV/1996-06-03-1917-52S.TEST__002
```

```
Full path name : /net/seismo/users/jens/TD/WAV/1996-06-06-0647-46S.TEST__011
Full path name : /net/seismo/users/jens/TD/WAV/1996-06-07-1324-51S.TEST__009
Full path name : /net/seismo/users/jens/TD/WAV/1996-06-10-0105-42S.TEST__014
Full path name : /net/seismo/users/jens/TD/WAV/1996-06-23-0126-27S.TEST__013
Full path name : /net/seismo/users/jens/TD/WAV/1996-06-23-0059-47S.TEST__001
Full path name : /net/seismo/users/jens/TD/WAV/1996-06-25-0336-34S.TEST__032

 Total number of events 6
 Number of events without waveform files 0
 Number of waveform files 8
 Number of waveform files present 8
 Number of waveform files missing 0
 Number of cal files found 28
 Maximum number of cal files missing 29
 Output file with events is get_wav.out
 Output file with waveform file names is copy_wav.out
 Output file with cal files is copy_cal.out
 Output file with waveform file names missing is copy_wav_missing.out
 Output s-file with waveform file names missing is copy_wav_missing_sfile.out
 Output file with missing calibration channels is copy_cal_missing.out
```

The 'where to copy' option can be used to write the complete path to where files are copied. This option is only used for waveform files, not calibration files. Note: On PC the files `copy_wav` and `copy_cal` have names `copy_wav.bat` and `copy_cal.bat`, respectively

In the above example, a `select.out` was used. For each file, it is checked if the waveform and response files are available in the system. All waveform data bases and directories specified in `SEISAN.DEF` are searched. Calibration files are seached for in working directory and CAL. In order to extract the waveform files corresponding to the input CAT file, the output file `copy_wav.out` can be used to copy the files out of the data base to working directory. On Unix, just source the `copy_wav.out` file, on Windows, change the file to a `.bat` file (e.g. `copy_get_wav.out wav.bat`) and run it. For the calibration files there is similarly a file called `copy_cal.out`.

MSCUT chop up MiniSEED files

The program cuts up MiniSEED files into 1 hour, 15 minutes or x minutes files. Where 60 modulo x is equal to zero. Note that mscut is splitting miniseed files at block level and not at the first sample in the new minute, in order to keep the original header information. To compile the program, the miniseed library ***libmseed*** by **Chad Trabant** is required. The options are

-H	Cut into one hour files (default)
-Q	Cut into 15 min files
-D	Cut into files with a duration defined by minutes 60 modulo the number of minutes must be zero.
-V	Report program version
-h	Show this usage message
-v	Be more verbose, multiple flags can be used
-p	Print details of header, multiple flags can be used
-s	Print a basic summary after processing a file
-r bytes	Specify record length in bytes, required if no Blockette 1000
file	File of Mini-SEED records

18.10 RDSEED_MANY, chop up seed file

The program reads a large SEED volume and divides it up into several files of the same size. It calls rdseed, so rdseed must be installed. Rdseed can do the same, but RDSEED_MANY is simpler to use.
Example:

rdseed_many
Seed file name
test.seed
start time YYYY,MM,DD,HH,MM
2005 01 01 01 01
Interval in minutes
20
Number of intervals to extract
200

The output format is SAC, other format require a change of the program.

18.11 SEIASC, converting SEISAN waveform files to or from ASCII

A simple program to make an ASCII equivalent of a binary SEISAN file, or vice versa. It is the same call to use the program both ways. By using a `filenr.lis` file as input, many files are converted and the original filenames are kept with the addition of an A for ASCII or B for binary. If the files are converted back, the A or B is removed.
The program is useful for manually editing a waveform file or checking the content in case of problems. The program is also useful for moving binary files between different types of computer platforms (moved as ASCII files, not needed between platforms running SEISAN). Between PC, Sun, Linux and MacOSX, SEISAN programs will automatically adjust for differences in binary structure. The header format is exactly like the binary SEISAN files and the sample values are written in multicolumn format.

Works ONLY with SEISAN format

18.12 SEICUT, extract part of a waveform file

A simple program to extract out a section of a waveform file (any seisan primary format). A similar job can be done with wavetool. Syntax is:

`seicut filename yyyymmddhhmmss.s interval`

The first sample to use is the first sample found before the start time, the output time interval (in seconds) will be the time from first to last sample, so if e.g. one second of data is asked for at a sample rate of 100 Hz, the time interval in header will be 0.99 sec and the number of samples output will be 100. If the interval is not available in any of the channels, the program will stop. The output file name will use a network code reflecting station code of first channel in input file and 'CUT' is added to the end of the file name. The same time window must be available in all channels.

18.13 SEIDEL, splitting a SEISAN binary file into 2 files

The program splits up waveform file into 2 files. Input can be file or list of files (`filenr.lis` created with DIRF). The questions are:

```
Filename, ?, number or filenr.lis for all
filenr.lis
No of channels to remove
3
Channels to remove
1 3 6
```

The program will generate 2 new files, one with the channels removed and one with the remaining channels. The original file is still present.

Works ONLY with SEISAN format

18.14 SEISEI, splitting and merging SEISAN readable binary files

The program can merge several SEISAN, MiniSEED, SAC etc waveform files to one file or take one SEISAN, GSE or MiniSEED file and split it into single channel files. The program is intended for editing waveform files and merging files from different networks to one file. In order to use SEISEI for merging files, a DIRF must be made to make a `filenr.lis` file containing the files to be merged. The program will sequentially read `filenr.lis` and merge files which have start times within the time interval specified (3 minutes default). Once a gap of more than 3 minutes occur, a new output file is made. Merging to a new file can be forced by editing `filenr.lis` so the groups of files to be merged are separated by a blank line, however, within the group, the time difference can still only be the given time interval.

If two channels to be merged have the same station and channel codes and the same start time, the second occurrence will be ignored. If the station and channel codes are the same, but start time different, the user will be asked to confirm merging.

The program can also split up a multichannel file to files with only one channel. This can be used to remove unwanted channels by deleting selected channels and merging again. When the file is split up, the channel component is added to the file name. A `filenr.lis` file can also be used for splitting many files in one go. If a file is only to be split into only 2 files, it is more convenient to use the program SEIDEL (only works on SEISAN format), see above. SEISEI is also used in connection with MULPLT for merging files automatically based on waveform file names in an S-file.

Note: The network extension of merged files will be set by default to the value of parameter MERGE_WAVEFORM in `SEISAN.DEF`.

18.15 P_ALIGN: Time shifting waveform data to align on P or S-phase arrival times.

If one wishes to compare signals (align in time) from different earthquakes observed at the same station, the P_ALIGN program can be used. The program works by time shifting the waveform header times to a common time and then putting all the new waveform file names into an S-file. First use e.g. the SELECT program to extract information of earthquakes in a defined area that have been observed by a given station, and use GET_WAV to copy the waveform files to your working directory. Then execute P_ALIGN. The input is the Nordic file (e.g. `select.out`) and the station name for data to be compared. The output is:

- Waveform files with time shifted headers, all have the same time, but station names are labeled STA01, STA02 etc in the same order as given in input file. Only first 3 letters of station code is used.
- `tsd.out` : A file in Nordic format with the new waveform file names of the time shifted data. This file can be split and then used with EEV for plotting all traces. It can be split into a local data base or any other data base. Or copy `tsd.out` to a file e.g. named `27-1200-00L.S207011` and then start EEV.

The waveforms in the output file `tsd.out` can also be plotted with the command `mulplt -sfile tsd.out`.

The arrival time of the selected phase in the new waveform files is the pseudo date and time: 2070-11-27 12:00.

Note: The station name is renamed in the output. If there are more than one P-phase observation for a single event (e.g. Pn and Pg, or P read on two different channels) it is the first P that is time shifted. The program can only time shift 99 waveform files and they have to be in SEISAN format. The waveform file must be present in the working directory.

Figure 18.2 show an example.

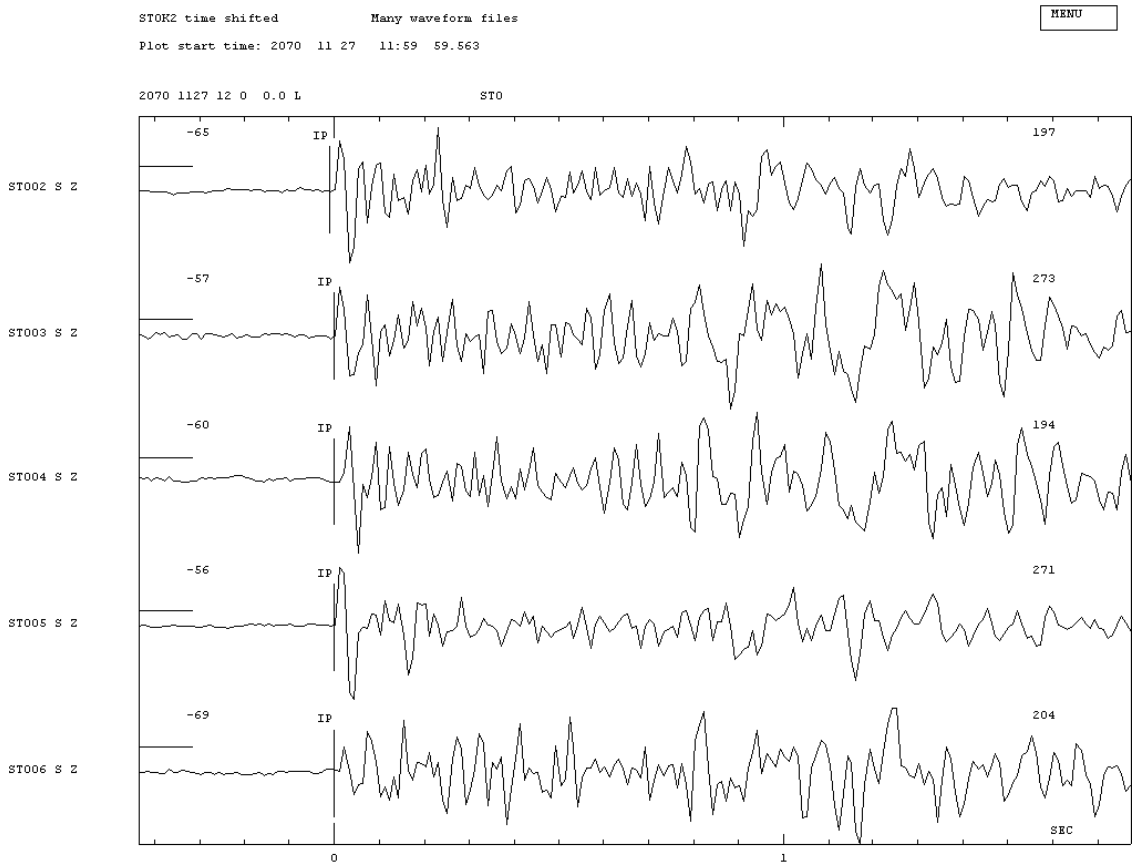


Figure 18.2: Example of aligning traces from 5 events for the same station. Note that the alignment is critically dependent on the original P-picks.

18.16 WAVFIX, fixing time correction and channel names in waveform file headers and make standard file names

The input format can be any SEISAN readable format like SEISAN and MIniSeed. The outpur format is only MiniSeed.

It can easily happen that a waveform file has a wrong time in the headers, or that individual channels have wrong timing, for example introduced by different delays in the acquisition system that are not accounted for . WAVFIX can change all header times with a given constant time delay, or correct individual channels as specified in a parameter file (`wavfix.tim`). In addition, the file name will also be changed to reflect the header time change. Waveform file names were shorter in SEISAN version 6.0 so when using older files, the user might want to use standard file names. In cases where only channel names or timing of individual channels are changed, the filename can be kept the same. In this case a temporary file is created, which is later renamed to the original name.

WAVFIX can also change polarity. This is done by setting the output channel and station codes to the same as the input values in `wavfix.def`.

In case channel names are to be changed, this can also be done with WAVFIX. A definition file is needed for changing station, component or both. The parameter file name is `wavfix.def` and an example is given in DAT. For definition of the `wavfix.def`, see next section 19 on "Conversion programs definition file".

WAVFIX can change header times and/or file names for one or many files. Before running the program, a list of file names must be made with DIRF. Below is an example where the header time is changed by 120 secs. No `wavfix.def` file is present (current or DAT directory).

To correct the timing of individual channels, you need to create the file `wavfix.tim` in either the DAT or working directory. WAVFIX checks if the file is present and applies the correction from the file as default. The format of this file is as follows:

Column 1-5: station code
Column 7-10: component code
Column 12-25: start date and time for time correction (can be empty)
Column 27-39: end date and time for time correction (can be empty)
Column 41:60: time correction to be added

NOTE: The file must have 3 header lines of any content before the station lines as shown below.

Example:

```
wavfix time correction applied to individual components
stat  comp start time     end time       correction in
a5    a4   yyyymmddhhmmss yyyymmddhhmmss seconds f20.3
-----|----|--------------|--------------|--------------------
TEST  SH Z 19500101120000 19600101120000 -0.015
```

File names of waveform files can be given to WAVFIX directly, from a `filenr.lis` file or from a Nordic format file. In case you choose the Nordic input, the waveform file names will be changed in the Nordic file (output file nordic.fix). This option is useful if you are correcting file names, since the entries in the S-files are otherwise not fixed.

ONLY the first waveform filename in the Noridc files is used.

WAVFIX will also take input from the prompt. Writing wavfix -help gives

```
wavfix -help
wavfix
usage: wavfix -infile <infile> [-uncertain_time -polarity] [-time_correction <x in seconds> ]
-uncertain_time   add uncertain time flag to all channel headers
-polarity         change polarity
-time_correction  apply time correction of x seconds
```

The uncwrtain time option does not seem to work for MiniSeed output.

Example of running WAVFIX

```
No wavfix.def file, will use internal information for channel codes
 This program will change header times in all headers
 with the same amount. The waveform file name will be
 changed at the same time and adjusted to the standard
 name.
 If no time correction is given, only the waveform
 names are adjusted.
 In addition, channels names can be changed if a
 wavfix.def file is available

 Time correction in seconds, return for no correction
 Input options: (1) filenr.lis or waveform file name
                (2) Nordic file
Filename or number, filenr.lis for all
Input file name: 1994-06-16-1841-57S.TEST__019
Output file name 1994-06-16-1843-57S._____019

Input file name: 1994-10-04-1324-00S.TEST__016
Output file name 1994-10-04-1326-00S._____016

Input file name: 1994-10-04-1324-24S.TEST__016
Output file name 1994-10-04-1326-24S._____016
```

18.17 WAV_ADD, add waveform file names to S-files

A common task is that you have a data base of S-files in one place and the corresponding waveform files at another place and there is a need to put the waveform file names into the S-files. This can easily be done by editing if only a few files but for many files a program is needed. WAV_ADD uses as input a filenr.lis of the waveform files and some input of the S-files. The S-file input can be a data base or a file etc. For each event, the time in every waveform file (the channel with the earliest time) is compared to the origin time and if within a given time limit, the wavform file name is added to the event. It is thus possible that several waveform file names are added to the same event or that a wavform file name is added to several events. There is no requirement for the name of the wavform files since the time of the waweform file start is read from the wavform file itself. Note however, tha tid the waveform file are to stored in a WAV data base, the file names must be standard. Since all wavform files are compared to all events there is no requirement that the waveform file names are in any order in filenr.lis.

An output file is written with all the events in the input and with the added waveform file names. The waveform file names of waveform files not associated with an event are wrtten out in a file with filnr.lis format and can potentially be used with AUTOREG to create events in the corresponding data base.

Files with errrors are also listed in an output file.

A procdure could be:

Collect all S-files from data base using COLLECT

Make dirf of waveform file names

Run WAV_ADD and check the output file for associations. If too many or too few, test with a another time difference.

Once output is ok put data back into data base with SPLIT.

Possibely make new events with waveform files not associated.

18.18 WAVFULLNAME

Prints full filename including path for a waveform file by searching directories and databases specified in `SEISAN.DEF`. Filename is to be given on prompt line, e.g. `wavfullname 1996-06-13-1248-15S.NSN__003`.

Chapter 19

File conversion and modification programs

There are mainly two types of files to convert, parameter files with readings and related parameters and binary waveform files.

The conversion to Nordic format from some other format will in many cases be to Nordic format and not to Nordic2 since many formats now are rarely used. The most used programs convert to Nordic2 like IMSNOR. If the program converts to Nordic format and you need Nordic2, use program NOR2NOR2 to get Nordic2 format.

19.1 Parameter files

ALBNOR:	Albania bulletin data to Nordic
CAT_AGA:	Records the S-file header lines according to agency
DELS:	Deletes specific parts of an S-file
EDRNOR:	Converts USGS monthly bulletins (EDR files) to Nordic format
GIINOR:	Converts from Geophysical Institute of Israel parameter format to Nordic
GSRNOR:	Converts from geophysicl surver of russia to nordic
HARNOR:	Converts standard Harvard CMT solutions to Nordic format, also from gisola
HYPNOR:	Converts from Hypo71 readings files to Nordic format files
HINNOR:	Similar to HYPNOR for Hypoinverse files, archive format
HSUMNOR:	Converts from Hypo71 summary file format to SEISAN format
ISCNOR:	Converts from ISC 96 column format to Nordic format
ISCCSV2NOR:	Converts ISC csv foromat catalog to nordic
ISCSTA:	Converts ISC station list to SEISAN station listoptionally selecting specific stations.
ISFNOR:	Converts between ISF1.0 and Nordic
IMSNOR	Converts from IMS, GSE and ISF to Nordic
KINNOR:	Converts from Kinemetrics to NORDIC
NORCSV:	Converts from NORDIC to CSV format using MAGNITUDE_ORDER given in SEISAN.DEF to setup priority of magnitudes.
NORGSE:	Converts between Nordic format and GSE parametric format
NORHIN:	Converts from Nordic format to Hypoinverse archive format
NORIMS:	Converts from Nordic to and from IMS1.0
NORHYP:	Converts from Nordic to HYPO71 format
NOR2NOR2:	Converts NORDIC phase readings to and from old style to new style introduced in 2021
NOR2QML:	Converts NORDIC to and from QuakeML
PDENOR:	Converts a PDE bulletin file to NORDIC format
RSANOR:	Converts Andalucian Seismic Network data to NORDIC format
SEIGMT:	Converts from NORDIC file to input for GMT
SELMAP:	Selects out a part of a MAP file, also creates file for SeismicityViewer
STASEI:	USGS station file or ISC station file to SEISAN
USGSNOR:	USGS/NEIC CDROM catalog conversion to NORDIC format

ALBNOR, Albania bulletin data to Nordic

The program converts many different Albania bulletin formats to Nordic format. The program gives these formats:

0: hypoinverse 1: 2012-2014 2: 1995-2005 3: 2008-2009 4: 2007 5: jun-aug-2008

For more information, see program comments.

CAT_AGA, reordering of CAT file header lines

When plotting hypocenters or doing seismic hazard work, it is the first header line in an S-file or CAT-file

that is used since it is assumed that it is the prime estimate. When making compact files it is also the first header line, which is used. However, there can be a need for resorting the many type 1 header lines for one or several events so that they are ordered according to agency. It could e.g. be needed to put priority on all the ISC solutions, which then should be the first line in the file. CAT_AGA will reorder the type 1 lines in a CAT file according to the order in which the agencies (3 character codes) are given by the user. If there are many agencies, they can be given in an input file named `cat_aga.par`, format is one agency per line in the first 3 columns. If the file is not present, the program will ask the user to enter the agencies manually. Optionally, also hypocenter type M lines can be used as type 1 lines. The output file `cat_aga.out` will contain the sorted events.

DELS, deletes parts of S-file

DELS, program to delete specific lines in an S-file with one or many events

There is often a need to delete particular parts of an event file like the spectral lines or the P-phases etc. Below is an example run.

```
 C:\\seismo\\WOR>dels

 Give input file

hyp.out

 Give line to delete or keep, terminate with enter
 1: Lines with P-phase             Not delete
 2: Lines with S-phase             Not delete
 3: Lines with SPEC-phase          Not delete
 4: Lines with IAML-phase          Not delete
 5: Lines with IASP-AMP phase      Not delete
 6: Lines with AM, AT and AS phase Not delete
 7: Lines with END phase           Not delete
 8: Lines with BAZ phase           Not delete
 9: Lines with any phase           Not delete
10: Lines with fp solutions        Not delete
11: Phases with given stations     Not delete
```

Any combination of options can be selected or deselected. The output is in file dels.out. If used withing EEV, it is used with current event S-file. Note: Option 11 can use several stations and all phases for those stations are deleted, however not SPEC phases.

A special option is 99. This will write out IAML amplitudes for Z, N and E if all three present. Output file is `dels_amp.out`. The program can also be used with arguments

First argument is file name

Second argument is optionally 'overwrite' meaning that input file will be overwritten, can only be used with a file with one event, if more program stops. Third argument is operator

The last two arguments are used with EEV, command dels in EEV.

EDRNOR: USGS monthly bulletins (EDR files) to Nordic format

Program to convert USGS weekly EDR files (ftp://hazards.cr.usgs.gov/weekly/mchedr*) to Nordic format. The program is written by **Mohammad Raeesi** (email Mohammad.Raeesi@student.uib.no).

ISCCSV2NOR: ISC CSV catalog to Nordic format

Program converts csv ascii format to nordic format, csv is used by ISC for catalog data. Only the first 3 magnitudes are used, if a magnitude type in input is b1, output type is x.

GIINOR, Geophysical Institute of Israel to SEISAN

The input files are the bulletin type files.

GSRNOR, Geophysical Survery of Russia to Nordic

Program to convert data from Geophysical Survey of Russian Academy of Science to SEISAN Nordic format.

The program uses 2-3 input files:

1

Output from hypo71 program (Russian version): Arrival times with weights, location, Russian magnitude based on P-waves, crustal model number used, polarity, gap, error, rms.

2

Arr file: this file has amplitudes of P, S and for Ml in units of um*100, Ml for each station (used to calculate average Ml) and component codes. The P amplitudes are labeled AMP-P, S amplitudes AMP-S and amplitudes for Ml is labeled the standard IAML. All are converted to nm. The magnitudes from P amplitude are not given a type since not recognized by SEISAN. The time for the P and S amplitudes are given as the corresponding P and S-times plus 2 sec so as not to be plotted on top of P or S. In any case, the picking time for the amplitudes is not known.

3

A file filenr.lis with a list of corresponding waveform files. The file must have SEISAN style names which are used to get the file start time for comparison with the event origin time. It must also have the correct component codes. This can be done with program WAVFIX. This file is optional but needed if waveform file names should be integrated in the S-file.

The two first input files must be in chronological order and contain the same events, else the program stops. This is checked by comparing the P-times in the two files and if not within 1 s for corresponding stations, the program stops with an error message.

The program first reads the hypo file, then the arr-file and combines the two. Finally the waveform files names are put in. The names are put in if the waveform file name start time is within xx seconds of the origin time. The default is 600 s, but any value can be chosen by the user. If too larger, the waveform file might be put into more than one S-file and if too small there might not be correspondence.

If an event has depth zero, it is assumed to be an explosion and marked with an E in column 23 on the header line. The model number, if available in hypo file, is given in column 21 on the header line.

Energy class is given in a comment line.

S-files which are not assigned a waveform file name are listed at the end. Likewise for waveform files that are not put into S-files. So it can be checked if there is a correspondence between events and waveform files and if waveform files are missing

The agency is assumed to be GS and the operator is asked for. In the output file, the Ml magnitude is duplicated in the 3. position on the header line so it will remain at the next update. The header line is also duplicated using agency ORG so the original location can be compared to a future calculated location on the header line. An example of the output is seen below:

```
2020  9 1 1738 58.26L  44.010  39.302 10.5  GS   4 .33 2.1LGS  2.1 GS  2.1LGS 1
GAP=237                   2.6     2.6  1.1                                  E
2020  9 1 1738 58.2 L  44.010  39.302 10.5  ORG  4 .33 2.1LORG 2.1 ORG        1
2020-09-01-1736-59M.TEST__012                                                6
Magnitude Mp:    2.1                                                         3
Energy class:    5.3                                                         3
ACTION:H71 20-11-09 18:57 OP:jh   STATUS:               ID:20200901173858     I
STAT SP IPHASW D HRMM SECON CODA AMPLIT PERI AZIMU VELO AIN AR TRES W  DIS CAZ7
GOYR EZ EP   3   1739  4.38                                    0.830   26.9  13
GOYR EN IS   1   1739  7.22                                    -.220   26.9  13
GUZR SZ IP   0   1739 10.43                                    0.250   65.6  91
GUZR SN IS   1   1739 18.83                                    -.080   65.6  91
VSLR EZ IP   1   1739 13.12                                    -.420   84.9 136
VSLR EN ES   2   1739 24.98                                    0.250   84.9 136
GRYR EZ IP   1   1739 22.90                                    -.020    144  85
GRYR EN IS   1   1739 40.52                                    -.430    144  85
GOYR EZ  AMP-P   1739  6.38        40.0 0.72                           26.9  13
GOYR EN  IAML    1739  6.57       150.0 0.92                           26.9  13
GOYR EE  AMP-S   1739  9.22       160.0 0.62                           26.9  13
GUZR SZ  AMP-P   1739 12.44        10.0 0.20                           65.6  91
```

```
 VSLR EZ  AMP-P   1739 15.13        30.0 0.78                          84.9 136
 GUZR SN  IAML    1739 18.19        50.0 0.32                          65.6  91
 GUZR SN  AMP-S   1739 20.83        50.0 0.48                          65.6  91
 GRYR EZ  AMP-P   1739 24.91        10.0 0.30                           144  85
 VSLR EE  AMP-S   1739 26.98        80.0 0.44                          84.9 136
 VSLR EE  IAML    1739 26.20        90.0 0.36                          84.9 136
 GRYR EE  IAML    1739 39.66        40.0 0.28                           144  85
 GRYR EE  AMP-S   1739 42.53        40.0 0.30                           144  85

 2020  9 2 12 2  7.76LE 44.225  40.278 0.00  GS   6 .39 2.3LGS  2.8 GS  2.3LGS 1
 GAP=189                  1.3     1.30.340                                  E
 2020  9 2 12 2  7.7 LE 44.225  40.278 0.00  ORG  6 .39 2.3LORG 2.8 ORG       1
 2020-09-02-1159-59M.TEST__018                                              6
 Magnitude Mp:    2.8                                                       3
 Energy class:    7.2                                                       3
 ACTION:H71 20-11-09 18:57 OP:jh   STATUS:               ID:20200902120207     I
 STAT SP IPHASW D HRMM SECON CODA AMPLIT PERI AZIMU VELO AIN AR TRES W  DIS CAZ7
 GUZR SZ IP   0   12 2 13.49                                    0.060   28.5 207
 GUZR SN IS   1   12 2 18.02                                    0.430   28.5 207
 RPOR EZ IP   0   12 2 18.96                                    0.280   58.4 181
 RPOR EN IS   1   12 2 26.25                                    -.440   58.4 181
 GRYR EZ IP   0   12 2 20.27                                    0.210   66.3 101
 GRYR EN ES   2   12 2 29.14                                    0.060   66.3 101
 GOYR EZ IP   1   12 2 21.16                                    0.080   72.1 272
 GOYR EN ES   2   12 2 30.53                                    -.310   72.1 272
 SHA1 EZ EP   2   12 2 40.12                                    -1.39    198 106
 SHA1 EN ES   2   12 3  5.13                                    -1.05    198 106
 KBZ  BZ EP   3   12 2 43.80                                    -.100    217 105
 KBZ  BN ES   3   12 3  9.42                                    -.890    217 105
 GUZR SZ  AMP-P   12 2 15.49       140.0 0.60                          28.5 207
 GUZR SE  AMP-S   12 2 20.02       640.0 0.48                          28.5 207
 RPOR EZ  AMP-P   12 2 20.96        60.0 0.54                          58.4 181
 GUZR SE  IAML    12 2 19.42      1350.0 0.92                          28.5 207
 GRYR EZ  AMP-P   12 2 22.28        40.0 0.60                          66.3 101
 GOYR EZ  AMP-P   12 2 23.17        80.0 0.56                          72.1 272
 RPOR EE  IAML    12 2 25.41       280.0 0.38                          58.4 181
 RPOR EE  AMP-S   12 2 28.26       420.0 0.62                          58.4 181
 GRYR EE  IAML    12 2 28.35       210.0 0.84                          66.3 101
 GRYR EE  AMP-S   12 2 31.14       140.0 0.88                          66.3 101
 GOYR EE  AMP-S   12 2 32.54       370.0 0.66                          72.1 272
 GOYR EE  IAML    12 2 34.59       350.0 0.76                          72.1 272
 SHA1 EZ  AMP-P   12 2 42.13        40.0 0.34                           198 106
 KBZ  BZ  AMP-P   12 2 45.81      1740.0 0.55                           217 105
 SHA1 EN  AMP-S   12 3  7.13       220.0 0.52                           198 106
 SHA1 EN  IAML    12 3  6.13       210.0 0.60                           198 106
 KBZ  B1  AMP-S   12 3 11.43      4900.0 0.60                           217 105
 KBZ  B1  IAML    12 3 11.31      6310.0 1.00                           217 105
```

Below is shown an example run:

```
c:\seismo\WOR\gsrnor
 Give input hypo file
sep.bin
 Give input arr file
```

```
sep.arr
 Give operator, max 3 chars
jh
 Time difference in secs for wav file to be include in s-file, def 600s (enter)

 Number of waveform files          35


 Model number           6
 Number of phases found in hypo file           50
 Waveform file added 2020-09-01-0049-29M.TEST__075
 2020  9 1  059  6.06L  43.997  39.142 7.59  GS  25 1.0 3.4LGS  4.9 GS  3.4LGS

 Model number           8
 Number of phases found in hypo file            6
 Waveform file added 2020-09-01-1038-00M.TEST__009
 2020  9 1 1040 31.78LE 44.808  37.642 0.00  GS   3 .28 3.4LGS  2.0 GS  3.4LGS
.
.
.
.
.

 Model number           8
 Number of phases found in hypo file            8
 Waveform file added 2020-09-23-1034-59M.TEST__012
 2020  923 1037 19.38LE 44.835  37.638 0.00  GS   4 .29 3.1LGS  2.2 GS  3.1LGS

 Number of waveform files not used           13
 File not used: 2020-09-08-1104-59M.TEST__009
 File not used: 2020-09-15-1025-59M.TEST__012
 File not used: 2020-09-29-0423-59M.TEST__015

 Number of events without waveform file           2
 Events which did not get a waveform file name

 2020  9 3 1046 45.6
 2020  916 2157  0.2

 Output file name is gsrnor.out


************************************************
Special option for rewriting SAC response files
************************************************

The GSR response files are not written in a standard way as used by SEISAN so they have to be rewritten

A GSR response could have the name GOYR_EHZ_2017jul14.sac while the corresponding name in SEISAN is GOY
The GSR file looks like

# Station GOYR
# Channel EHZ
# Location ??
```

```
# Network OBN
# Time 2017.07.14 00:00:00
ZEROS 3
POLES 6
-2.9102  0
-1.5196  0
-176.198 -420.291
-176.198 +420.291
-336.6282 -84.213
-336.6282 +84.213

CONSTANT  1.548e19
```

HARNOR, Harvard to Nordic

The standard moment tensor solutions given by Harvard (`http://www.globalcmt.org/CMTsearch.html`) are converted to Nordic format. Strike, dip, rake and moment tensor solution is written out. In addtion, also solution from Gisola cab be converted. The programs can use 4 different input formats:
Standard format: Default format on screen
Full format: Full format on screen
ndk format: File format for downloaded file
gis format from Gisola Gisola Isola The screen formats have the disadvantage that only a limited number of events can be downloaded and captured in one screen so if a lot of events are required, the best alternative is to download a file with all events in ndk format, and then, after conversion, select the desired events.
The ndk format and the full format both give both the hypocenter calculated with arrival times (main header line) and the centroid hypocenter and origin time (MT line), while the standard format does not give the hypocenter calculated with arrival times, so the first header line gives the centroid location. For that reason, it is recommended to use the full format if a screen format is used.
The ndk format does not give Mw which is then calculated from the moment. All formats have additional information not carried over to SEISAN.

HINOR, Hypoinvers archive format to Nordic

The input files are the archive type. For details, see HYPINV program.

HYPNOR, converting HYPO71 files to Nordic files

Input is just filename of HYPO71 file. A similar program for HYPOINVERSE files is HINNOR.

HINNOR, converts from Hypoinverse to NORDIC format

This program works like HYPNOR.

HSUMNOR, HYPO71 summary file format to NORDIC format

Note that the program only converts to header lines.

ISCNOR, converting ISC bulletin file to Nordic format

This program works with the ISC fixed 96-column format as e.g. distributed on CDROM (files of type FFB). The program can select out subsets of ISC data using a latitude-longitude window, depth and prime magnitude. Any of the magnitudes Ms and mb are used. Before 1978, there was only mb on the CD's. More detailed selection can be done on the output file later with SELECT. Since the amount of data is very large it is also possible to write out only the hypocenters. Note that ISC now writes in ISF format also, which can be converted with ISFNOR or IMSNOR.

Newer CD's have compressed data and cannot be used directly. files must be copied to disk first, decompressed and then handled as single files.

The program will first check if a file with agency codes called agency.isc is present. If so the station codes are read from this file (same format as files on CDROM). The program will also check the beginning of the data input file for a possible list of agencies and station coordinates. If present, the stations coordinates are read and converted to SEISAN format and additional codes read in. The agency codes are needed in order to identify in plain text the various agencies used.

Principles in conversion:

Phases:	The phases out can be either the phase ID's sent to ISC or the ISC reinterpreted phases (given with a number code in the input file). If the user supplied phases are used, parenthesizes are removed, and if P/PKP etc is given, it is replaced by P.
Times:	If day is incremented relative to origin time day, it is carried into the hours, which can be more than 24.
Agency:	It is assumed that it is the same agency for hypocenter and first magnitude. Magnitude is checked for agency, if blank, it is assumed also to be the same as for hypocenter. Only first 3 characters of code is used.
Stations:	Only first 4 characters of code are used.
Depth:	If no error on depth, a depth fix flag is set.
First motion:	Only C or D are used, ISC codes J and B are ignored.
Hypocenter orders:	ISC put the best solution last, here the order is reversed, and the prime estimate is first.
Duration magnitude:	Change D to C for type.
Distance indicator:	If station furthest away is less than 1000 km indicator is L, between 1000 and 3000 km indicator is R and if more than 3000 km indicator is D. If no stations are present the type is set to D.

In order to relocate an event and compare to ISC location, the ISC reidentified phases must be used (option 2, see below). This has the disadvantage that phases not used by ISC (mainly S-phases of local earthquakes) are weighted out in the output file. If option 3 is used, the ISC identified phases are selected if there and if no ISC identification is given, the local reported phase is used. The output file for option 2 and 3 looks the same except that for option 2, the user-defined phases are weighted out. The residuals given in the output file are always relative to the ISC identified phases.

Running ISCNOR:

Below is an example of a run where a latitude - longitude window has been used.

```
 Phases selected can be:
   User reported phases (default=return)          : 1
   ISC identified phases only                     : 2
   ISC identified phases and user reported phases
       when not identified by ISC                 : 3
3
 Output: All hypocenters and phases : Return
         All hypocenters            : 1
         Prime hypocenter           : 2

 Latitude range, return for all
60.2 70.5

 Longitude range, return for all
10, 20

 Depth range, return for all

Magnitude range, return for all

Write selected events on screen (y/n=return)

 No agency.isc file present
 If ISC CDROM, give drive letter, else return
d
```

```
Give first year and month, e.g. 199501 198601
Give  last year and month, e.g. 199602 198602

 Now opening d:\1986\198601.FFB
 Number of agencies in input file        244

etc, for each month


        493 events converted
 Output file name is iscnor.out
 File with stations is isc.sta
```

The file input can be from a CDROM as in the example above. In that case, the whole CDROM can be read or a smaller time interval can be given. The input can also be from a single file and the program will then ask for the next file when the first has been converted. If many files are to be converted, a list of file names can be made with DIRF and `filenr.lis` entered as an input file name. The Nordic format output file is `iscnor.out` and the station list is in `isc.sta` which has the format used by SEISAN. Optionally, output can also be in the original isc format, however that requires setting a flag in the program and recompiling, see program source code.

ISCSTA, selecting stations in the complete ISC station file

The complete station list in the ISC list is very large and it is often an advantage to use a smaller subset, although HYP can use the whole list. The program can select out subsets of stations in both SEISAN and the latest ISC format as found on the ISC home page. The program will read an S-file, find how many different stations there are and select those stations out of a station file, which can either be in SEISAN format or ISC format (automatically determined). The output is in SEISAN format. If no S-file is given the input station file is assumed to be in ISC format and the whole file will be converted to SEISAN format. Optionally, the output can be in high accuracy format, but that is generally only needed for very small networks or small arrays. The latest version of the program supports 5 letter station codes. As of April, 2020, the ISC list contains more then 27000 stations. Hypocenter can work withe 30000 stations.

NOTE: The ISC file must only have the stations so remove any text before or after the list.

```
Start of station list:



034A   Hebbronville                                    27.06470  -98.68330     155.0
       Texas,U.S.A.

035A   Encino                                          26.93790  -98.10230      29.0
       Texas,U.S.A.

035Z   Hargill                                         26.46300  -98.06831      19.0
       Texas,U.S.A.

058A   Arcadia                                         27.05690  -81.80490      15.0
       Florida,U.S.A.

059A   Moore Haven                                     26.96710  -81.14400      11.0
       Florida,U.S.A.

059Z   Ave Maria                                       26.33730  -81.44320       8.0
       Florida,U.S.A.
```

```
060A   Indiantown                                      27.03610  -80.36180       9.0
       Florida,U.S.A.
```

KINNOR, Kinemetrics to NORDIC

Converts .PCK file output of EDPPICK to file in SEISAN format. Many events are converted from one file. The program is based on program from Kinemetrics by **Christopher S. Lim**. For info on how conversion is made, see program source code.

ISFNOR, ISF1.0 to and from Nordic

The ISF format is used by the ISC and is an extension to the IMS format. The program is based on the routines provided by the ISC for reading and writing ISF, and the SEISAN standard routines for reading and writing Nordic data. The program converts in both directions. All possible information is converted. Information on the ISF format can be found on the ISC website (`http://www.isc.ac.uk`). It is recommended to use ISF format for data exchange with ISC.

There is also the newer program IMSNOR which converts from IMS, GSE and ISF to Nordic format. It has been adapted a bit closer to how seisan works than ISFNOR.

NORIMS, IMS1.0 to NORDIC format.

The IMS1.0 (International Monitoring System) is a new version of the GSE format and very similar. The program can partly be used for the new ISF (IASPEI Seismic Format) which will include all of the IMS format an additional information needed by ISC and NEIC. The program and the following description is by **Mario Villagrán**. The program works with the IMS1.0:SHORT format (phase-readings/origin files) and the program works both ways.

IMS1.0:SHORT ⇒ Nordic

Nordic ⇒ IMS1.0:SHORT

The IMS1.0:SHORT format is exactly the one used at the IDC International Data Center (Vienna, Austria). In addition some features used by the ISC International Data Center and the Spanish NDC National Data Center had been added. Magnitudes in IMS format use many characters, the Nordic format allows only one; the following rule is followed:

IMS Nordic
For mb → 'b'
For MS → 'S'
For ML → 'L'
For MD → 'C'
For Ml → 'l'
For MN → 'N'
For mblg→ 'G'
For ms → 's'
For MB → 'B'

The maximum likelihood magnitudes mb1, mb1mx, ms1, ms1mx, etc are pending. IDC still does not have documentation and they may be changed.

Single measurements of magnitude/station are parsed as comment lines (type 3) starting with symbol "$". When importing data from IMS format, only the "Event IDC" number is parsed and included into a comment line (type 3) of Nordic, together with the ellipse dimensions orientation and the mb standard deviation.

All parameter values read that exceed field limits of Nordic (Amplitude, velocity, snr, etc) have been set to the maximum or minimum possible, example: if snr > 999.9 then snr=999. For conversion from Nordic to IMS it is necessary to use both the `hyp.out` and `print.out` files; The reason is that IMS includes many parameters that need to be searched in both files.

When converting to IMS format, the user can specify the start numbering for the first event and phase in the file; ignoring will assume (1,1). It is optionally also possible to set the no location flag in the output header lines.

Comments in the IMS input phase data is ignored.

IMSNOR, IMS, GSE and ISF to Nordic format

Program for reading GSE, IMS and ISF bulletin event files and converting to Nordic format. The intention is that it will replace NORIMS which is doing an incomplete conversion. The program also has

several adoptions for SEISAN.

The data from the input file is modified to make it possible to use the data in SEISAN. The source of this data format is mainly CTBTO and ISC. CTBTO is using only the defined IMS or GSE format data while ISC has extended the format to cover other types of data using the ISF format. The program can read both and it is particularly useful for ISC data.

Assumptions and limitations

All events are assumed regional

The file must have headers like 'Magnitude' so when selecting data at ISC, clik on field 'Output headers'

Input files have no component in ISF format but when ISF2 format is released, it sometimes has componenet. MULPLT has been modified to plot phases without component.

All error parameters are not read, to be fixed.

If felt information in a commant line, it will be included (first 80 chars) and a type 2 is created.

Amplitudes are a bit of a mess since very many amplitudes do not use IASPEI standard names or standard methods for measuring and they are therefore useless for further use. The following describe how amplitudes are treated:

All amplitudes which cannot be identified are labeled A-xxx where xx is the phase it came from like A-Pn. If a time is associated with the amplitude, that time is used. If amplitude is associated with a phase, the time from the phase is used so it is possible to see where the amplitude came from.

IASP amplitude phases are used unchanged, seem to be standard.

L, LR is a Raleigh wave, amplitude associated with LR and is assumed to be Ms_20.

LQ amplitudes are not associated with a magnitude scale and labeled A.

MLR is non standard, seems to be the same as LR and treated the same way.

M and AMl is the same as obove.

Amplitude on a phase line is made into a new line. The time is the same so it is possible to see which phase it was associated with. If possible, it is given and IASPEI standard name (from indication at end of line), if not it is named Ai-xxx.

Amplitude for Ms and Mb are only convered to IAMb if it has been used to calculte magnitude, else it is reported as A-xxx.

Ml amplitudes from CTBTO are calculated in a non standard way and cannot be used, give very wrong Ml, labeled A. This might also be the case from other array stations like NORSAR, Norway. No check for other array stations.

Many amplitudes, even on Sg or Lg, are not standard and not labeled IAML. Seems some could be mm WA. If amplitude on P and distance larger than 20 deg, assume IAmb. Some amplitudes have no phase and no time, no time also in S-file.

ONLY IAML are accepted.

Amplitudes are mm WA for Nanometrics in Albania system so converted to nm.

Back azimuth

Back Azimuth (BAZ) is put on separate line in order to be able to put in weight. This is needed for ISC where many BAZ values are wrong. ISC does not use BAZ so the ISC observations are identified with no BAZ residual. This has the unfortunate effect that good BAZ are not used, like for NORSAR array or locally determined by 3 components sensors. IMS BAZ is not weighted out since there is a residual. The BAZ is given the name of the phase it was associated with like BAZ-PKP (limited to 8 character length).

Phases

Phases not used by SEISAN are given weight zero, like LR and LQ. More must be added to the list (hardwired).

Phases not used by ISC, as indicated by no residual, is given weight zero. If there is a residual but ISC is not using the phase due to large residual (the phase has no time dfining flag), the phase is included with weight 3 if the residual is less than 5s. The exception is when ISC does not process the event and use the agency supplied locations. Then there are no residuals. This is identified by 'Event not reviewed by the ISC' which is also given in S-files as a comment. In these cases strange phases might not be weighted out.

For data after the date when ISC has processed the event, there is no flag telling if ISC has processed or not. The file is therefore first read to find last date of ISC revision. After that date the event are treated as if not processed by ISC.

In ISF2, there can also be component, network, location, phase agency, phase operator. However, network often wrong so not used.

At ISC, the incoming phases are reinterpreted. This is particularly unfortunate for crustal phases, like Pn, which then no longer is Pn as a refracted phase but rather a direct phase. However, for events not processed by ISC, the original phase names remain. This will create an inhomogeneous data base for user who want to process data located by ISC and located by a local agency. Consequently all Pb, Pn, Sb and Sn phases have benn changed to P and S. Pg/Sg are also chenged to P and S. THIS PHASE CHANGE IS DONE FOR ALL EVENTS, ALSO EVENTS NOT PROCESSED BY ISC since it seems that picking of n,g and b-phases is not consistent. This unfortunate situation with the ISC reinterpretations has been created by the way the AK1535 software works according to Dmitry Storchak at the ISC (personal communication):

" Regarding the crustal phases, it is true that Pn, in its IASPEI standard understanding ¡http://www.isc.ac.uk/standards/p is also the P-wave that bottoms in the uppermost mantle. The working group (which included yourself) has decided at the time that we must follow the ak135 notation, simply because the corresponding code did not differentiate between the classical Pn travelling as a headwave alongside the Moho and the branch of direct P that leaves a source in the uppermost mantle (400km), bottoms no deeper than that and eventually going up towards a station. I recall that Peter Bormann wasn't particularly easy about it, but connection with ak135 and corresponding software was dearer, so he reluctantly agreed."

Hypocenters

Hypocenters are ordered according to a hardwired table in program. The same order is used for the magnitudes. However, the prime solution (ISC or the last in the list) always come first since residuals are referred to that solution. The priority is: ISC, NEI, GCM, IDC. The list is hardwired in routines sort_source_info.

Relocating ISC events gives higher rms with SEISAN. Part of the problem is that epicentral distance is different, at certain distances up to 100 km. The travel time model is also different. Using residual weighting gives similar rms to ISC, might be what ISC is using.

Fault plane solutions

Fault plane solutions are also ordered, different table. The priority is: GCM, NEI and ISC.

Magnitudes

Only standard magnitudes are put on header lines, same order as for hypocenters. The first 5 magnitudes are put on first hypcenter, the rest distributed among following hypocenters and if more put in as comments. The first magnitude is repeated in 3. position on header line, therefore only 5 different. Non standard magnitudes are listed in comments.

Macroseismic data is not included, but if event is felt, it is marked with a blank type 2 line.

Event type

IMS use the folloing characters to define event types:

The leading characters are

s = suspected
k = known
f = felt (implies known)
d = damaging (implies felt and known)

The trailing characters are

c = meteoritic event
m = mining explosion
e = earthquake
n = nuclear explosion
h = chemical explosion
r = rock burst
i = induced event
x = experimental explosion
l = landslide

In SEISAN they are converted to event types using the 2 or one letter(s):

se to E = mining explosion
n to E = nuclear explosion
sh to P = probable explosion

ke to Q = known earthquake
se to ' ' = probably earthquake
sl or kl to L = probably or know landslide
si or ki to I = probably or known induced event
f or d indicated as a felt event (type 2 line)
All remaining IMS types are ignored (blank)

To run the program type imsnor and you get question about the input file. When writing the output file the main header is duplicated.

Optinally you have the following arguments:
-infile: name of input file
-agency: the agency code given to the prime hypocenter and magnitude if they are blank.
-def_dup: the agency code given to the duplicated prime hypocenter and magnitude.
-dist_indicator: distance indcator. By default the distance indcator is R, can be set here.

NORCSV, NORDIC to CSV format

The program converts the date and time, hypocenter location and magnitude to a simple CSV file that can be loaded into spreadsheet software. An example of a line is

2012/01/06,06:16:26.80, 76.191, 9.870, 10.0, 2.3,CBER

where the columns are date, time, latitude, longitude, depth, magnitude and magnitude type. The magnitude with type of the highest priority is selected as given by the magnitude order in SEISAN.DEF. For example ML from your agency may be given priority over MC, or you may prefer your ML over that from another angency.

NORGSE, NORDIC from and to GSE parametric format

The program (written by **Mario Villagrán**) converts parametric data between Nordic and GSE2 format. It can be used interactively or by giving the options as arguments. Type `norgse -help` to see the options.

NORHIN, From Nordic to Hypoinverse archive format

The program is started by typing `norhin input-file`. The output file is norhin.out. For more details, see program HYPINV. indexHYPINV

NOR2NOR2 Converts NORDIC phase readings to and from old style to new style introduced in 2021. The program is started by typing `nor2nor2` or by typing

```
nor2nor2 -format 2 -file input-file [-aga xyz] [-ope abc]
```

Where if format is 1 the program converts from new format to old format, and if format is 2 the program converts from old format to new format. Using the aga flag one can add the agency id on the phase readings in the new format. Using the ope flag one can add the operator id on the phase readings in the new format. The output file is `nor2nor2.out`.

NOR2QML From Nordic to and from Qml. The program has many options, see below. To simplify, there are two scripts:

NOR2QML filename
QML2NOR filename

They have some fixed options so if only converting one file in working directory, they are the easiest to use.

NORHYP, From Nordic to HYPO71 format (SUN and PC)

The program is written by **F. Courboulex**. The program asks for the input file name and the output file name is `norhyp.out`.

NOTE, the program expect there to be a type 7 line for each event, else it will not output anything.

PDENOR, converting PDE bulletin file to NORDIC format

PDE distributes bulletins on e-mail, both a monthly bulletin and a weekly bulletin (different formats). The program converts one of these files to Nordic format and put the file into a standard SEISAN database called PDE for the monthly files and PDEWE for the weekly files. This database must have been created before running the program. Both CAT and S-files are made and SELECT and EEV can be used afterwards. Files can be received by email or picked up at hazards.cr.usgs.gov, dir pde for monthly files and weekly for weekly files, must be ehdf type.

RSANOR

Program converts between format used by "Red Sismologica de Andalucia" and a few others in Spain.

NOR2QML

NOR2QML is an program that enables conversion of parametric data in NORDIC format into QuakeML and QuakeML to NORDIC format.

The program is described in detail in section 19.1.1.

An online NOR2QML service that enables conversion of parametric data in NORDIC format into QuakeML and QuakeML to NORDIC format is found at `http://nnsn.geo.uib.no/nor2qml/`

Nordic → QuakeML

Convertsion from Nordic format to QuakeML is found at `http://fnsn.geo.uib.no/seis2qml/sfile-to-quakeml`. Here one needs to select a file in Nordic format on the local harddisk, next select "UPLOAD ALL". A new window will open where one can choose QuakeML version, prefix and autority ID. Autority ID is important if the data will be made public.
Next choose "GENERATE XML".
Type in a filename for the QuakeML file that is generated and select "SAVE FILE".

QuakeML → Nordic

Conversion from QuakeML to NORDIC format is found at `http://nnsn.geo.uib.no/seis2qml/quakeml-to-sfile/web-service`.
There are three options:
1: "Web-Service link" provide conversion from third party QuakeML web services. Type in the URL from a web service in the box (see "Click here for an example") and select "GENERATE".
2: "XML text" converts plain text QuakeML into Nordic format. Paste the QuakeML format into the box and select "GENERATE". In the new window enter name of output file and select "SAVE FILE", below is the Nordic format shown.
3: "XML file" converts QuakeML files the Nordic format, select a QuakeML file on the local harddisk and select "UPLOAD". In the new window enter name of output file and select "SAVE FILE", below is the Nordic format shown.

Please report bugs to the developer, Christian Rønnevik, University of Bergen.

SEIGMT, Nordic to GMT input

The program SEIGMT reads information from Nordic or compact files and writes the parametric data to files that can be used as input for GMT(Generic Mapping Tools, `http://gmt.soest.hawaii.edu/`). The user can choose a scaling for the magnitudes and also select a magnitude type order. The scaling option is useful if you wish to scale the symbol size of your epicenters with magnitude. The magnitude type order defines, which magnitude should be taken in case several magnitudes have been determined for one event. If you don't give a magnitude order, the program chooses the largest magnitude.

The files written by SEIGMT are:

`gmtxy.out` - event locations, to be plotted with psxy
`gmtxyz.out` - event locations and depths, to be plotted with psxy
`gmtstxy.out` - station coordinates (longitude, latitude and station code)
`gmtpath.out` - travel path data, to be plotted with psxy
`psmeca.out` - fault plane solutions, to be plotted with psmeca (Aki and Richards convention)

SELMAP, selecting a subsection of a MAP file

The program can retrieve parts of a large MAP file written in SEISAN map format. On the SEISAN web site or on the SEISAN CDROM, very detailed global mapfiles are available in SEISAN format. The file originally comes from the USGS. SELMAP can select out part of a MAP file in a latitude-longitude grid. The MAP files consist of several small segments and a segment is selected if at least one point is inside the specified grid. The program also creates an output file in xyz format for the Lomax SeismiciyViewer. The program can output a smaller number of points than available in the input file by using the parameter skip.

STASEI

Converts the official global station file from USGS (comma format) or ISC global station file to SEISAN station format (same as HYPO71 format with SEISAN extension for 5 letter station codes). A list of most global stations are now found on the SEISAN CD. It seesm that the USGS format is no longer used.

USGSNOR, USGS catalog to NORDIC format

The program converts USGS CDROM hypocenters to NORDIC format. Most of the information is used.

If more than 3 magnitudes are available, only the 3 first are used. The number of stations is included when available. The depth is indicated as fixed in all cases where the operator has been used (A,N,G). Macroseismic information is included with max intensity. The residual standard deviation is put into rms column. Event types are set to R. Magnitude types are converted as follows:

UK is made blank
b is replaced by B
s is replaced by S
D is replaced by C
w is replaced by W

19.1.1 Nordic to QuakeML converter

Author Christian Rønnevik

This application is a convertion tool between the Nordic format and QuakeML. The tool is preconfigured to reading (s-files) and producing earthquake event data (event parameters) in QuakeML. By configuring arguments the tool can also convert QuakeML data into a collection of s-files from both a XML file and a web-service. The program works with Nordic and Nordic2 formats. When converting from Nordic to qml, the program will automatically detects if the input file is in Nordic or Nordic2 format. When converting the other way, the used must specify a flag to tell which format is desired. Nordic is default.

The source code i found at https://github.com/cronnevik/nor2qml

1. How to run the application
2. Configure IDs for QuakeML output
3. Configure to convert from QuakeML to Nordic
4. Arguments

The two first sections describe the conversion from the Nordic format to QuakeML. The third section gives an explain on how to enable conversion from QuakeML to the Nordic format. The fourth section gives an overview of all the possible arguments that can be used within this application along with default values for each argument.

How to run the application

Make sure that you have java installed. Check by typing "java -version" into the terminal.

Run without options in the SEISAN environment:

Two scripts (in COM) have been made to facilitate the simplest way of converting. The scripts are:

norqml filename.out

to convert filename.out to qml. The output filename is nor2qml.xml.

qmlnor filename.xml

to convert from qml to Nordic. The output filename is sfile.out.

In addition an alias has been defined for nor2qml (java -jar $ SEISAN_TOP/PRO/nor2qml.jar) to make it easier to used the converter with all options, see below. The default is to convert to Nordic format. If you need Nordic2 format, either run the complete Java command with flags as described below or change the script in COM.

Input

The application has a built-in file scanner, which is designed to identifying s-files within in SEISAN catalog structures. Hence, a folder will only be scanned if the folder name follows the convention of a catalog name with underscore ("_") at the end, for example the catalog name "NNSN_". The file scanner will also search through folders with a folder name of numbers, which is true for the catalog's subsequent folders of year and month. Examples of valid input for folders are:

```
" Folder (whole catalog): "<path to seisan>/SEISMO/REA/NNSN_"
" Folder (specific year): "<path to seisan>/SEISMO/REA/NNSN_/2014"
" Folder (specific month): "<path to seisan>/SEISMO/REA/NNSN_/2014/09"
```

During file scan, only files that has the extension starting with "S" will be read. However, if the given input path is pointing at a single file, the application can read any file regardless of extension or filename. Hence, following examples of file input can be used:

```
" File (particular file): "<path to seisan>/SEISMO/REA/NNSN_/2014/09/01-2050-05L.S201409"
" File (particular file): "<path to any folder>/testfile.out"
```

Output

The output argument has a default value of the path where the application (jar file) is located. If you are running the converter through the seisan structure it is recommended to specify another path for the output. The ouput value should the complete path with a filename and extension at the end of the path. If converting from Nordic to QuakeML, please give the "xml" extension. If converting from QuakeML, you are more free to chose extension, but as a guideline you can use the ".out" extension. Example for running the application

```
In SEISAN environment

nor2qml --input="/home/SEISMO/REA/NNSN_/2014/09" -output="/home/my-name/qml201409.xml"

In Java environment

java -jar nor2qml.jar --input="/home/SEISMO/REA/NNSN_/2014/09" -output="/home/my-name/qml201409.xml"
```

Configure ID generation

Within QuakeML, each entity has a public ID for identifying each resource given. This may for instance be a particular event, origin, magnitude, or amplitude. The resource IDs is crucial for linking these entities. The application has a build-in ID generator that follows the QuakeML standard of resource identifiers. By default, these identifiers are built by some predefined values and attributes given by the event itself. The attributes taken from the events are fixed, but two of the predefined values can be overwritten by providing arguments. Since the application provide default values, the conversion can take place without specifying these arguments, but it is recommended that you at least give a value for the authority ID as this will link the resource to your institution. Before explaining which arguments to use, a brief overview of the resource identifiers by QuakeML is given.

```
[smi|quakeml]:<authority-id>/<resource-id>[#<local-id>]
```

More explicitly the id follow this schema pattern:

```
( smi | quakeml ) : [ \w\d ] [ \w\d \?\.\?\(\) ' ] { 2 , } / [ \w\d \?\.\?\(\) ' ] [ \w\d \?\.\?\(\) \+
```

The two first part of this identifier is configurable in the application by the arguments prefix and agency. To see a list and description of all the available arguments, please see the arguments section below.

Prefix

The prefix argument takes a sting value that should be either "smi" or "quakeml". To apply this argument, simple attach –prefix="smi" or –prefix="quakeml" when running the application. "smi" stands for seismological meta-information.

Agency

Similarly, the authority-id can be configured by attaching –agency="¡your authority-id¿", which should be at least 3 characters with the first charcter as alphanumeric, while subsequent characters can be alphanum or from the following list:

```
-,  _,  ., ~ , *, ', (, ).
```

The agency-id should follow this form:

```
<top-level domain>.<organisation/institution>[.<sub-unit of organisation>]
```

An example can be "no.uib.nnsn", where "no" (Norway) is the top-level country domain, "uib" (University of Bergen) is the organisation and "nnsn" (Norwegian National Seismic Network) is the sub-unit of the organisation.

Example with ID generation

Running the application for an s-file within the NNSN catalog could then look like this:

```
In SEISAN evironment

nor2qml --input="/SEISMO/REA/NNSN_/2014/09" -output="/home/my-name/qml201409.xml" --prefex="smi" --agen

IN Java environment

java -jar nor2qml.jar --input="/SEISMO/REA/NNSN_/2014/09" -output="/home/my-name/qml201409.xml" --prefe
```

Configure to convert from QuakeML to Nordic

Conversion from QuakeML to the Nordic format can be achieved from two different sources, a XML file or a web-service.

QuakeML file to Nordic

To convert a QuakeML file to the Nordic format, three arguments is required: convert, input and output arguments. For SEISAN environment, the convert argument is already predefined and can thus be omitted. Description about the input and output parameters are given in the section above on how to run the application. For Java environment, the convert argument is by default set to "q" (meaning QuakeML), specifying the output format. Similarity "s" can be given to point to s-file output in the Nordic format. Thus, in order to convert to Nordic, attach –convert="s" to the command. The order of arguments does not matter.

The full command would then looks like:

```
For SEISAN environment:

nor2qml --input="<path to file>" --output="sfiles.out" --convert="s"

For Java environment:

java -jar nor2qml.jar --convert="s" --input="<path to file>" --output="<path to file>"
```

QuakeML web-service to Nordic

Configuring to read from a QuakeML web-service requires four arguments: output, convert, source and url. Both output and convert are set in a similar fashion as for converting a QuakeML file (see previous section). The source parameter is telling the application that it should fetch data from either a file or an external web-service. The default source value is file. To fetch data from a web-service, attach -source="ws" to the command. As a web-service is an external source, an internet connection is required to make use of this command. In addition to source, an URL to the web-service is also required and should be given in with the URL parameter , by attaching -url="¡path to web-service¿".

The full command would then looks like:

```
For SEISAN environment

nor2qml --output="sfiles.out" --convert="s" --source="ws" --url="<path to web-service>"

For Java environment

java -jar nor2qml.jar --output="sfiles.out" --convert="s" --source="ws" --url="<path to web-service>"
```

Arguments
General Arguments

Key	Value type	Default value	Description
–convert	”q” or ”s” (type String)	”q”	Specify to which format the files should be converted to. ”q” means convert from s-files to QuakeML, while ”s” means convert QuakeML to s-files.
–input	Path (type String). The value must be enclosed with ””.	Current path	Select where the input files are. If no path is specified, the program will search the current folder for files to be converted.
–output	Path (type String). The value must be enclosed with ””.	Current path	Select where the converted file should be placed. If no path is specified, the program will create a single file in the current folder with the filename and extension to either ”quakeml.xml” or ”sfile.out” based on the conversion type.

QuakeML specific arguments

Key	Value type	Default value	Description
–version	”nordic”, ”nordic2””, 1.2” or ”2.0”	”1.2”	Specifying the QuakeML version output.
–prefix	String that should be ”smi” or ”quakeml”	”smi”	Specifying the prefix of generation of IDs
–agency	String	”authorityid”	Specifying the agency for generation of IDs (e.g. ”no.nnsn”)
–source	String that should be ”file” or ”ws”	”file”	Specify if the source is a file or a web-service (ws)
–url	String (mandatory if source is ws). The value must be enclosed with ””.		Specifying the url if the source is a web-service

References

[1] https://quake.ethz.ch/quakeml/docs/REC?action=AttachFile&do=view&target=QuakeML-BED-20130214b.pdf

19.2 Waveform conversion programs

This group of programs are mostly converting waveform files from some format to SEISAN although a few also convert from SEISAN to some other, mostly standard, formats. Most programs convert from binary to binary formats.
Many instruments come with conversion programs to some standard format like PCSUDS or MINISEED, and these have often been used to convert to SEISAN instead of writing programs reading the original files directly. Many such conversion programs work on PC so the corresponding SEISAN programs only work on PC. However, since the PC files can be read directly on Sun, this should not present a problem. Many programs have VERY LITTLE documentation, look in source codes for more information.

The number of programs are forever increasing with new recorders coming onto the market and new formats coming in use and others going out of use and it is becoming increasingly difficult to keep track of it all. For this release of SEISAN it has not been possible to test all programs on all platforms. An attempt has been made to standardize the programs. A general problem is that many seismic recorders and formats

do not provide proper identification of the channels. In the worst cases, there are no station codes, only channel numbers and in very many cases, there is no room for proper component information. This is being taken care of by having a definition file, and only one format for the definition file is used, see below. This is also used with program WAVFIX.
Most programs work in the standard way with a `filenr.lis` file as input (made with DIRF).
The response information is seldom in the original files and in most conversion programs, the response information is taken from the CAL directory. If no response information is available, a message will be given. For each program, a comment will be given as to the status of testing and on which platforms they operate. If the channel definition file option is implemented, the array dimensions will be SEISAN standard.
The program SEIPITSA might be an easy way to convert between 1-column ASCII data and SEISAN (see below).

When converting between the major analysis format (MiniSEED, SEISAN, SAC and GSE) mostly using program WAVETOOL, only SEISAN and MiniSEED will preserve the network and location codes as well as the flag for uncertain timing since the other formats only partly have room for this information.

Conversion programs definition file

The conversion programs use a common format for the definition file for naming station and channels. The definition file is named programname.def as e.g. sudsei.def. The definition file can be in the working directory or the DAT directory. The conversion program will first look in the working directory for the file and then in DAT. The conversion of codes can take place in 2 ways (see below for details): (1) An input station and component code is converted to an output station code and component, (2) an input channel number is assigned a station and component code. The advantage of (1) is that the conversion is independent of the channel number or order, however, the user must then know the default station and component names generated by the conversion program.

Default assignment of station code and component:
This is very much dependent on the conversion program used since some data files have complete

information and others very little, see description of individual programs in manual or at start of source codes. In all cases, the conversion program will make both station and component codes based on what is available of information in the input files. IT IS THESE CODES THAT are used for input code as described below. In order to find out what they are, it is easiest to run the conversion program once (without a def file) and see what codes the program assign. Alternatively, some of the programs have documentation in the manual. Some of the station codes might be instrument serial numbers, which are not always known. Therefore, running a test might be the best way to find out.
In addition to converting channel codes, the def file can also give SEISAN waveform file header information and network code as it appears in the file name. If no network code is given, the network code will be the station code of the first channel.

Principle of conversion in order of precedence:

1. Both station and component given on input: Converted to what is given for output station and component.

2. If both are not present, the channel number is used.

```
Header line text (29 char)... NetCd (5 chars), Comment for next line
Header for REFTEK             NEWNT
chan stati  comi stato  como, In and output definitions, comment for next line
   1 BO11   S  Z BOM    B  Z
     BO12   S  N BOM    B  N
     BO13   S  E BOM    B  E
```

The first line is just a comment line, must be there in any format. Here it shows where the network code is positioned as indicated by NetCd.

The second line gives the header information for the SEISAN main header, which are the first 29 characters. The file name network code is also given and is here NEWNT. Format a29,1x,a5.

The third line is just comment to indicate the position of the columns in the following lines (max 200). A line must be there. The abbreviations are:

chan: Channel number, optional unless no input station and component given.
stati: Input station code, 1-5 chars
comi: Input component code, 4 characters
stato: Output station code, 1-5 characters
como: Outut component code, 4 characters. First character MUST be S, L, B, A, or I, last character MUST be Z, N or E, all upper case.

Format i5,1x,a5,2x,a4,1x,a5,2x,a4
The conversion programs are listed below

AFADSEI:	AFAD acceleration records to SEISAN
AHSEI:	AH ASCII to Seisan, little tested
ARCSEI:	Reftek archive to Seisan, windows only
ASCSEI:	ASCII to SEISAN
BGISEI:	Beijing Geodevice Institue to SEISAN
CITSEI:	CityShark to SEISAN
CNVSSA:	Kinemetrics SSA to Kinemetrics Dataseis
CNVSSR:	Kinemetrics SSR to Kinemetrics Dataseis
DELS:	Deletes specific parts of an S-file
DIMASSEI:	USGS Dimas to Seisan
DRSEI:	Sprengnether recorders to SEISAN
GIISEI:	Geophysical Institute of Israel to SEISAN
GSRSEI:	GeoSig to SEISAN
GSESEI:	See WAVETOOL
GSERESP:	Conversion between GSE and SEISAN response files
GURSEI:	Güralp to SEISAN
GCF2MSD_MANY:	Run Guralp gcf2msd many times from files in a file structure
IRISEI:	From IRIS ASCII to SEISAN
ISMSEI:	ISMES to SEISAN
KACSEI:	Kinemetrics ASCII acceleration to SEISAN
KINSEI:	Kinemetrics Dataseis to SEISAN
K2SEI:	Kinemetrics K2 to SEISAN
LEESEI:	Willy Lee system to SEISAN
LENPCQ:	Converts from Lennartz to PCEQ to PCEQ format
LENSEI:	Lennarts ASCII to SEISAN
M88SEI:	Lennartz MARS88 to SEISAN
NANSEI:	Converts from Nanometrics to SEISAN or MSEED
NEISEI:	Converts from NEIC CDROM waveform data to SEISAN
NRWSEI:	Geol. Survey. of Northrhine-Westphalia format to SEISAN format
OS9SEI:	Converts SEISLOG files to SEISAN waveform files
PITSA:	Conversion programs described with program PITSA
PCQSEI:	Converts from PCEQ to SEISAN
PDASEI:	Geotech Instruments PDAS to SEISAN
PSNSEI:	Public Seismic Networks to SEISAN
QNXSEI:	SEISLOG QNX to SEISAN
RDSEED:	IRIS program to read SEED volumes
RSASEI:	Conversion from Andalucian Seismic network to SEISAN
RT_SEIS:	Reftek Passcal format to SEISAN conversion
SEI2PSXY:	Convert waveform data to trace input for psxy
SEIM88A:	Conversion from SEISAN to MARS88 ASCII format
SEISAN2MSEED:	From SEISAN to MiniSEED
SEISAF:	SEISAN to SESAME ASCII
SEIPITSA:	SEISAN $\Leftrightarrow$ PITSA ASCII
SGRSEI:	SeisGram to SEISAN
SISSEI:	Sismalp format to SEISAN format
SILSEI:	SIL network ASCII files to SEISAN
SUDSEI:	PCSUDS to SEISAN
TERSEI:	Terra ASCII to SEISAN
VELNOR:	Velest CNV to Nordic
WGSSEI:	WGSN format to SEISAN
WAVASC	Waveform file to 2 column ASCI file

For each program, a summary of capabilities is mentioned: The platforms available (all for all or specific name), channel definition file available (chan. def. yes or no) and if the program will look for response files

in the CAL directory to insert in the headers (resp. yes or no).
If you do not find the conversion program here, look on the ORFEUS website for other programs that might convert to one of the formats used above.
(`http://orfeus.knmi.nl/other.services/conversion.shtml`).

AFADSEI, AFAD acceleration to SEISAN or MiniSeed all, chan. def. yes, resp yes

Converts from AFAD ASCII acceleration to SEISAN or MiniSeed. . Components are hardwired to HN Z etc. Assume 3 channels files only, all channels same sample rate and number of samples. Input values are in gal, the output is in 1/10 000 gal or 0.001 mm/s2, station code is taken from file (a number). There is an output file with hypocenter info from input files as well as the waveform file name. For echa channel a response file is written in SEISAN format.

AHSEI, AH ASCII to SEISAN all, chan. def. yes, resp yes

Converts AH ASCII files to Seisan format.

ARCSEI, Reftek archive to SEISAN (windows only)

ARCSEI is a program to automate the extraction of data from a RefTek data archive and the conversion to SEISAN format. The program works interactively and with a simple text interface that asks the user to enter the details for the data extract. Based on the user selected criteria the program (1) extracts the data from the archive in Passcal format using ARCFETCH, (2) converts the Passcal data files to SEISAN format using RT_SEIS, and (3) merges the SEISAN files if merging is activated by the user, using SEISEI. The program is written in Fortran and works on Windows only.

The ARCSEI program can be used in various ways:

- to extract a single time window from one or several stations
- to extract several time windows from one or several stations
- to extract sequential time windows from one or several stations

The ARCFETCH and RT_SEIS programs, both part of the RefTek software package, have to be installed (see RefTek documentation) and the PATH variable set to include the directory where the programs are stored. It is assumed that the RefTek data archive exists and that the user is familiar with the content of the archive. The archive content can be shown with the command ARCINFO. To test that the program is installed correctly, open the Windows command tool (from the menu, or by selecting Start . Run . cmd) and type ARCSEI <RETURN>.

The definition file: `arcsei.def`

The purpose of the definition file is to set some parameters needed to run ARCSEI, however, the program also works without. The arcsei.def file can either be stored in the seismo/DAT directory, or the current working directory. The program first checks in the current directory. The arcsei.def file should be adjusted to the user's set-up, before ARCSEI is started.

The parameters are:

ARCHIVE:	The path of the RefTek data archive, can also be entered manually at run time.
OUTPATH:	The directory in which the SEISAN files are to be stored. The default is '.\' (the current directory).
MERGE:	Select if SEISAN files from several stations for the same time interval should be merged (Y), or not (N).
NETWORK_CODE:	Network code used in case SEISAN files are merged.
CHANNEL:	Data channel in RefTek archive consisting of the unit, stream and channel (unit,stream,channel). The * can be used as wildcard to select all streams or channels, BUT not to select all units (since ARCFETCH is used in cooked mode, which means that the time interval extracted matches the input start- and end-time.

Example of the `arcsei.def` file

```
KEYWORD.............Comments..............Par1.........................
```

```
ARCHIVE            Path to archive      G:\CTBTO\ARCHIVE
OUTPATH            Path to put          C:\test
                   converted SEISAN
                   files
MERGE              Y or N for           Y
                   merging Seisan files
NETWORK_CODE       used for merging     ARCSE
CHANNEL            Name of channel      8020,1,*
CHANNEL            Name of channel      8021,1,*
CHANNEL            Name of channel      8022,1,*
CHANNEL            Name of channel      8023,1,*
CHANNEL            Name of channel      8024,1,*
CHANNEL            Name of channel      8025,1,*
CHANNEL            Name of channel      8028,1,*
```

How to run the program:
ARCSEI is started from the Windows Command Tool (cmd) by typing

```
arcsei <RETURN>

 ARCSEI - DATA EXTRACTION FROM REFTEK ARCHIVE AND CONVERSION TO SEISAN FORMAT

 SEISAN FILES ARE MOVED TO DIRECTORY: C:\test

 ENTER ARCHIVE, OR <RETURN> TO USE DEAULT (default: G:\CTBTO\ARCHIVE)

Return to accept default, which is set in the arcsei.def file, or give the archive path.

     AVAILABLE CHANNELS ARE:
     8020,1,*
     8021,1,*
     8022,1,*
     8023,1,*
     8024,1,*
     8025,1,*
     8028,1,*

 ENTER CHANNEL SELECTION (UNIT,STREAM,CHANNEL)
       OR TYPE ALL TO USE ALL AVAILABLE CHANNELS
```

Type channel and <RETURN>, if defined in arcsei.def channels are listed, otherwise an example is shown. The channel is given as unit,stream,channel. Wildcards can be used for stream and channel, but not for the unit.

```
NEXT CHANNEL OR RETURN TO CONTINUE
```

Additional channels can be entered, to continue press <RETURN>.

```
ENTER START-TIME (YEAR:DAY-OF-YEAR:HOUR:MINUTE:SECOND)
          EXAMPLES: 2000:200:12
                    2000:200:12:15
                    2000:200:12:33:15
```

Type start time as year:day-of-year:hour:minute:second. Minute and second can be omitted.

```
NEXT START-TIME OR RETURN TO CONTINUE
```

Additional start times can be entered, to continue press <RETURN>.

```
ENTER END TIME USING ONE OF 3 OPTIONS:
- ABSOLUTE TIME AS YYYY:DDD:HH:MM:SS (LIKE START-TIME)
- +SECONDS FOR TIME INTERVAL (e.g. +300)
- ++SECONDS FOR MULTIPLE INTERVALS(CONTINUOUS EXTRACT, e.g. ++300)
```

Specify the end time, either in the same style as for the start time (only if one start time), or in some cases more useful, the desired time window in seconds, by entering +seconds. If sequential time windows are to be extracted, use ++ seconds. The user is then asked how many time windows should be extracted. It is thus possible e.g. to extract 10 consecutive windows of 600 seconds. Only if sequential extract windows specified:

```
ENTER NUMBER OF CONTINUOUS WINDOWS
```

After the program has finished, the data in SEISAN format can be found in either the current directory (default) or in the OUTPATH directory if the variable is specified in `arcsei.def`. The temporarily created files are deleted automatically.

How it works

ARCSEI reads the user input that specifies what should be extracted from the RefTek archive and then calls the programs ARCFETCH, RT_SEIS and SEISEI. For temporary data storage ARCSEI creates the directory arcsei_temp under the current directory. The arcsei_temp directory is automatically deleted upon program completion.

1. Create empty arcsei_temp directory
2. Arcfetch

   The arcfetch program performs the data extraction from the RefTek archive. A complete list of the command line input of arcfetch can be obtained by starting the program without additional options. ARCSEI starts arcfetch in the following way:

   arcfetch archive channel,start-time,end-time -o OUTPATH -c

   Where:

   -o OUTPATH: Specifies the output path for arcfetch, always arcsei_temp
   -c: Specifies cooked mode, which means that the time interval extracted matches the input start- and end-time (this is not the case, when not running in cooked mode)

   Example:

   ```
   arcfetch G:
   ARCHIVE 8020,1,*,2000:200:12,+10 -oarcsei_temp -c
   ```

3. rt_seis

   RT_SEIS converts all files with the suffix 'rt' in arcsei_temp to SEISAN format. RT_SEIS reads the `RTU.INI` file for station definition, if the environmental variable RTU is set to point to the `RTU.INI` file (see RT_SEIS section below).

4. SEISEI

   SEISEI, if merge is selected, merges all SEISAN files in the arcsei_temp directory.

5. move

   Finally all files (single or merged) are moved to the OUTPATH directory or the current directory if OUTPATH is not defined. In case multiple stations are selected, ARCSEI runs steps (1) and (2) in a loop, before the data is merged and moved. In case several time windows are selected, ARCSEI runs steps (1) to (4) in a loop, and in addition a second loop over multiple station (1) and (2). If sequential time windows are specified, ARCSEI computes multiple start times and works as if these time windows were user specified. All, def. File yes, resp yes

ASCSEI, ASCII to SEISAN all, chan. def. yes, resp yes

Converts a single column file to a one channel SEISAN file. Date, time, sample rate (number of samples per second), station and component must be entered manually. The user is ask for a scale factor, normally it is 1.0. If input numbers are smaller than 1.0, a scale factor must be used since numbers are written out as integers. The input file must contain only a column of numbers and no headers.

Example:

```
linux$ head data.txt
       -1646
       -1722
       -2138
        -942
        -734
        -272
        -652
       -1736
        -102
         755
linux$ ascsei
 File name, # or filenr.lis for all
data.txt
 data.txt
 year,month,day,hour,min,sec
2017,02,22,11,30,05.12
 sample rate
20
 station, max 5 chars
JENS
 component, max 4 chars
BH Z
  Enter scale factor, return for no scaling

 Number of samples in file:       144132
 Outfile name: 2017-02-22-1130-05S.JENS__001_BZ
 JENS                           1117  53  2 22 11 30  5.120  7206.550
  No response file for this channel --------
 JENS BH Z117  53  2 22 11 30  5.120   20.00 144132
```

BGISEI, Beijing GEODEVICE FORMAT (BGI) to SEISAN. Linux, PC, chan. def. yes, resp yes

The program to convert waveform files from BGI to SEISAN format is called BGISEI. The instrument response in the original files is not used. The program has only been tested with data recorded in Cuba. The program is written by **Bladimir Moreno**.

CITSEI, CityShark to SEISAN all, chan. def. yes, resp yes

Converts from CityShark ASCII to SEISAN. Components S Z, S N, S E are assumed for the 3 channels. Assume 3 channels files only, all channels same sample rate and number of samples.

CNVSSA and CNVSSR Kinemetrics accelerometers to Kinemetrics Dataseis PC

The programs are supplied by Kinemetrics to convert from SSA and SSR formats to Kinemetrics Dataseis. To further convert to SEISAN, use program KINSEI. Only PC executable programs are available. The data is 16 bit.

CSS

At the moment there is no direct conversion from CSS to SEISAN. It is possible to convert CSS data to SAC or GSE using other tools like codeco, Geotool and SAC, and then convert to SEISAN format.

DELS, deletes parts of S-file

DELS, program to delete specific lines in an S-file with one or many events

There is often a need to delete particular parts of an event file like the spectral lines or the P-phases etc. Below is an example run.

```
 C:\\seismo\\WOR>dels

 Give input file

hyp.out

 Give line to delete or keep, terminate with enter
 1: Lines with P-phase             Not delete
 2: Lines with S-phase             Not delete
 3: Lines with SPEC-phase          Not delete
 4: Lines with IAML-phase          Not delete
 5: Lines with IASP-AMP phase      Not delete
 6: Lines with AM, AT and AS phase Not delete
 7: Lines with END phase           Not delete
 8: Lines with BAZ phase           Not delete
 9: Lines with any phase           Not delete
10: Lines with fp solutions        Not delete
11: Phases with given stations     Not delete
```

Any combination of options can be selected or deselected. The output is in file dels.out. If used withing EEV, it is used with current event S-file. Note: Option 11 can use several stations and all phases for those stations are deleted, however not SPEC phases.

A special option is 99. This will write out IAML amplitudes for Z, N and E if all three present. Output file is `dels_amp.out`. The program can also be used with arguments

First argument is file name

Second argument is optionally 'overwrite' meaning that input file will be overwritten, can only be used with a file with one event, if more program stops. Third argument is operator

The last two arguments are used with EEV, command dels in EEV.

DIMASSEI, USGS DIMAS to SEISAN all, chan. def. yes, resp yes

Converts Dimas files to Seisan format.

DRSEI, Sprengnether data recorders to SEISAN all, chan. def. yes, resp yes

Converts Sprengnether DR3024 and DR3016 to SEISAN format. These two formats are slightly different, but the program makes the adjustment. Only essential information is read in and only 4 lowest digits of serial number are used. If station codes are set up, these are used, else the serial numbers are used for station codes.

GIISEI, Geophysical Institute of Israel to SEISAN all, chan. def. yes, resp yes

Converts Geophysical Institute of Israel imported DAQ files to SEISAN format. The initial station codes are as defined in file, can be converted with the normal .def file. If 4.th character of station name indicates component (N or E), that is blanked out and transferred to 4.th character of component name BEFORE using the def file conversions.

GURSEI, Güralp to SEISAN all, chan. def. yes, resp yes

Converts Güralp GCF files to SEISAN format, only works with one channel data. Maximum number of samples as defined in seisan, at least 1 200 000, channels codes can be defined using the gursei.def definition file. If no definition file, the station name is the first 4 letters from internal station name and the component is BH Z. If a file name indicates that the file is thought to be from AFAD, no def file is used since it is assumed that intern codes are correct. .

GCF2MSD_MANY

Runs Güralp gcf2msd many times from files in a file structure. It is only tested for one particular structure with 15 min files, so the program has to be adopted to other structures. Requires program gcf2msd from Güralp.

GSERESP, conversion between GSE and SEISAN response files all

The program provides conversion between SEISAN, GSE1 and GSE2 response files. The response can be given in frequency, amplitude and phase (FAP) triplets or in poles and zeros (PAZ). Since the number of values in the GSE format is unlimited the conversion from SEISAN to GSE only changes the format, whereas converting from GSE to SEISAN, if the number of FAP triplets is more than 30 or the number of poles and zeros larger than 37, the response in SEISAN format will be approximated by 30 FAP triplets. The output files in SEISAN format will have the default SEISAN response filenames (see RESP program and SEISAN response format). Output files in GSE format will include the station name, the component, number 1 or 2 for GSE1 and GSE2 respectively and end on '.CAL' (e.g. MOR_SHZ2.CAL (GSE2), KONO_BZ_1.CAL (GSE1).

GSRSEI, GeoSig to SEISAN all, chan. def. yes, resp yes

Converts from GBV recorders to SEISAN. GeoSig was earlier GeoSys. Before version 8.1, there was a bug in program so start time was wrong by the amount of the prevent time.

IRISEI, IRIS ASCII to SEISAN all, chan. def. no, resp yes

The input format is the variable ASCII download format used on the GSN Quanterra stations. The format is used in connection with SEISNET. The program only works if input file has more than 1000 samples. ISMSEI, ISMES to SEISAN PC, chan. def. no, resp no ISMES is an Italian seismic recorder. This is the first version of the program made by IIEES in Iran. The program can convert one file with up to 3 channels.

KACSEI: Kinemetrics ASCII acceleration to SEISAN all, chan. def. yes, resp yes

Kinemetrics ASCII film record acceleration files (type *.v1) to SEISAN. It is assumed that:

- channel 1 is N, 2 is Z and 3 is E
- there are always 3 channels in file
- input values are in 1/10 g, the output is in 1/1 000 000 g
- station code is taken from file name as given in first line of input file
- the 3 channels can have different number of samples, however it is assumed that they all start at the same time

KINSEI, Kinemetrics DATASEIS to SEISAN PC, chan. def. yes, resp yes

The program takes the station code from the input files. The component codes are also taken from the input file as far as Z, N and is E is concerned, but the first letter is always set to S, like 'S Z'. The program is also used if CNVSSR or CNVSSA have been used first.

K2SEI, Kinemetrics K2 to SEISAN PC,Linux, chan. def. yes, resp yes

Program for K2 binary files. The program works by first converting the binary files to ASCII by internally running the Kinemetrics program kw2asc (PC only). If no definition file is present, channel 1-3 will be A Z, A N and A E. If more channels they will be called A 04, A 05, etc.

LEESEI, Willy Lee binary files to SEISAN PC, chan. def. no, resp no

The number of channels is fixed to 16 and the time information is not read, it must be entered when converting the file.

LENSEI, Lennartz ASCII to SEISAN all, chan. def. yes, resp yes

LENPCQ, converting Lennartz to PCEQ format PC

Only executable code for this program and only PC (made by the Royal Belgian Observatory). The format is used by an older version Lennartz tape recorder. The output files have the same names as the input files and are placed in a directory c:
qcoda, WHICH MUST BE THERE.

M88SEI, Lennartz MARS88 to SEISAN all, chan. def. yes, resp yes

NANSEI, Nanometrics to SEISAN or mSEED PC, Sun, chan. def. yes, resp no
The program converts from the Y-file format to SEISAN waveform format or MSEED. This is done by first making an ASCII file with Nanometrics y5dump program (done internally in NANSEI). NOTE: The y5dump program requires some special Nanometrics libraries (Solarisi, only available in older versions of SEISAN) or *.DLL files (PC), which are included and installed with SEISAN (see installation section). These libraries are not available un Linux. The program converts single channel files only.

NEISEI, NEIC digital data to SEISAN PC, chan. def. no, resp no
NEIC earthquake digital data comes on CDROM. The data is extracted with a program coming with the data and then converted to SEISAN binary waveform data. The response information is given as poles and zeros in the SEISAN waveform file header.

OS9SEI, converting SEISLOG files to SEISAN PC, SUN, chan. def. no, resp yes
The program takes a SEISLOG ASCII (downloaded in CMP6 format) or binary file and converts to a SEISAN file. The input can be several files from a `filenr.lis` or an ASCII downloaded file either compressed or uncompressed. The program will look for the calibration file in the CAL directory and add it to the SEISAN file, or give a message if it is not there. The program will work with SEISLOG files recorded under operating system OS9 or QNX up to version 7.6. For QNX version 7.0, use program QNXSEI.

PCQSEI, converting PCEQ format to SEISAN PC, chan. def. yes, resp no
PCEQ format to SEISAN. Earlier used with IASPEI software libraries.

PDASEI, converting PDAS files to SEISAN all, chan. def. yes, resp yes
The program converts a single channel PDAS file to a single channel file in SEISAN format. Several of these files can then be merged with SEISEI. PDASEI in previous SEISAN versions (before version 6.0) only worked with PDAS in 16-bit format, so if 32 bit or gain ranged format was input, the output would have been in error. The current version of PDASEI should be able to convert all 3 types of input files. A description of the PDAS format is found in the PDASEI program.

PSNSEI, Public Seismic Networks to SEISAN all, chan. def. yes, resp yes
The Public Seismic Network recording system makes one file pr channel. Since component is not well defined, several files from the same recording system might get the same SEISAN file name. Do some testing when setting up the recording system. The one component files can be assembled into multichannel files with SEISEI. There might be a newer version of PSN format not supported.

QNXSEI, SEISLOG QNX version to SEISAN all, chan. def. no, resp yes
This program works as OS9SEI except that it does not read the ASCII files. The program must be used with Seislog 8.0. The program is currently the only program that put in the time synchronization flag in SEISAN waveform files except for data logging programs under Seislog Windows. See format description in Appendix B. The program recalculates the sample rate based on the time in the first blocks in the file and the last blocks in the file (each block is one second long). For very long files, this might be of importance since the digitizer might not have exactly the nominal sample rate.

RSASEI, Andalucian Seismic Network to SEISAN all, chan. def. yes, resp yes
Conversion of network and broad band files to SEISAN format. Covers several versions of the DTS format also used by other institutions in Spain. Not tested on Linux.

RT_SEIS, Reftek Passcal to SEISAN PC, chan. def. no, resp no
The RT_SEIS program converts Reftek Passcal format to SEISAN. This program is provided by Refraction Technology Inc. The program does not use the `filenr.lis` as input file. To see the options of RT_SEIS, start the program without any arguments. In order to make use of the `RTU.INI` definition file, the environmental variable RTU needs to be set to for example c:
seismo
dat (see RefTek documentation for more details). This file can be used to set station names for respective unit IDs.

Example of `RTU.INI`:

[8020]
Station=SB00
Network=CTBTO
CH1Band=
CH1Type=
CH1Axis=a

CH1Loc =
CH2Band=
CH2Type=
CH2Axis=b
CH2Loc=
CH3Band=
CH3Type=
CH3Axis=c
CH3Loc =
[8021]
Station=SB01
Network=CTBTO
CH1Band=
...

SEI2PSXY

Converts waveform file to GMT psxy trace plotting ASCII file. The output files have one line for each sample giving the date and time and amplitude value, e.g.:
2005/06/16T00:59:59.51 -40.0000

Each trace will have its own file and the output names are given for each like
Output file name: 2005-07-31-1544-10S.STOK__003_STOK__S__Z
Output file name: 2005-07-31-1544-10S.STOK__003_STOK__S__N
Output file name: 2005-07-31-1544-10S.STOK__003_STOK__S__E

To plot the trace data with psxy, use projection '-JX<xsize>T<ysize>' and option '-R' giving time range in the same style as the data. To plot the data the gmtdefaults should be set to 'gmtset INPUT_DATE_FORMAT yyyy/mm/dd INPUT_CLOCK_FORMAT hh:mm:ss.xx'. See psxy man pages for more details.

SGRSEI PC, chan. def. yes, resp yes

SeisGram binary to SEISAN. Only 3 component data has been tested. Channel order is assumed to be Z, N, E. The input real values have been multiplied by 100 000 before being converted to integers. Program little tested.

SEED

The Standard for Exchange of Earthquake Data (SEED) format is defined by the Federation of Digital Seismographic Networks (FDSN). The rdseed program is distributed with SEISAN to extract data from SEED volumes. RDSEED is an IRIS program to read SEED volumes. The program provides conversions to SAC (ASCII and binary), AH, CSS and miniseed. It is described in the file 'rdseed.txt' in the INF directory. Updated versions of rdseed will be available at `http://www.iris.washington.edu/pub/programs`. A PC version (rdseed.exe) is distributed with SEISAN CD (also on home page). SEED volumes contain the complete response information, details on how to convert the SEED response to GSE response format can be found in Havskov and Alguacil (2004).

SEIM88A, conversion from SEISAN to MARS88 ASCII format all, chan. def. no, resp no

The program converts SEISAN waveform files to Lennartz-ASCII MARS88 format. The program will write one file per channel. Output files are either mars.xxx if a single file is converted or marsxxx.yyy if the '`filenr.lis`' file is used as input.

SEIPITSA all, chan. def. yes, resp yes

The program converts from SEISAN to PITSA ASCII format and back. The ASCII format has one file per channel. The user will be asked for a name of the output file-system. If a single file is converted, the channel number will be added to the output file-system name (e.g. data.001). If the '`filenr.lis`' file is used the filenumber will be added to the file-system name (e.g. pitsa001.004, first file and fourth channel). The program is no longer used for conversion when PITSA is started from EEV, but might be useful, since it creates one column ASCII data and can easily be modified.

SEISAF, SEISAN to SESAME ASCII all, chan. def. no, resp no

The 3 first channels in SEISAN file are read. There is no check if from same station. It is assumed that the order in SEISAN file is Z,N,E, that all 3 channels have the same start time, number of samples and sample

rate. These values are taken from the first trace.

SEISAN2MSEED All chan.def. no resp no

By **Chad Trabant**, IRIS Data Management Center

Program developed at IRIS to convert from SEISAN to mseed, all platforms and all mseed formats. This program can be used as alternative to converting data with wavetool, advantage is that SEISAN2MSEED supports STEIM2 compression.

Source code can be found at `https://seiscode.iris.washington.edu/projects/seisan2mseed`

SYNOPSIS

seisan2mseed [options] file1 [file2 file3 ...]

Seisan2mseed converts SeisAn waveform data files to Mini-SEED. One or more input files may be specified on the command line. If an input file name is prefixed with an '@' character or explicitly named '`filenr.lis`' the file is assumed to contain a list of input data files, see LIST FILES below. The default translation of SeisAn components to SEED channel codes is as follows: a 3 character SEED channel is composed of the first, second and fourth characters of the component; furthermore if the second character is a space and the first and fourth are not spaces an 'H' is substituted for the 2nd character (i.e. 'S_Z' → 'SHZ'). The default SEED location code is '00', if the third character of the SeisAn component is not a space it will be placed in the first character of the SEED location code. Other translations may be explicitly specified using the -T command line option. If the input file name is a standard SeisAn file name the default output file name will be the same with the 'S' at character 19 replaced by an 'M'. Otherwise the output file name is the input file name with a "_MSEED" suffix. The output data may be redirected to a single file or stdout using the -o option.

OPTIONS

"-V "

Print program version and exit.

"-h "

Print program usage and exit.

"-v "

Be more verbose. This flag can be used multiple times ("-v -v" or "-vv") for more verbosity.

"-S "

Include SEED blockette 100 in each output record with the sample rate in floating point format. The basic format for storing sample rates in SEED data records is a rational approximation (numerator/denominator). Precision will be lost if a given sample rate cannot be well approximated. This option should be used in those cases.

"-B "

Buffer all input data into memory before packing it into Mini-SEED records. The host computer must have enough memory to store all of the data. By default the program will flush it's data buffers after each input block is read. An output file must be specified with the -o option when using this option.

"-n Inetcode P"

Specify the SEED network code to use, if not specified the network code will be blank. It is highly recommended to specify a network code.

"-l Iloccode P"

Specify the SEED location code to use, if not specified the location code will be blank.

"-r Ibytes P"

Specify the Mini-SEED record length in Ibytes P, default is 4096.

"-e Iencoding P"

Specify the Mini-SEED data encoding format, default is 11 (Steim-2 compression). Other supported encoding formats include 10 (Steim-1 compression), 1 (16-bit 3 integers) and 3 (32-bit integers). The 16-bit integers encoding should only be used if all data samples can be represented in 16 bits.

"-b Ibyteorder P"

Specify the Mini-SEED byte order, default is 1 (big-endian or most significant byte first). The other option is 0 (little-endian or least significant byte first). It is highly recommended to always create big-endian SEED.

"-o Ioutfile P"

Write all Mini-SEED records to Ioutfile P, if Ioutfile P is a single dash (-) then all Mini-SEED output will go to stdout. All diagnostic output from the program is written to stderr and should never get mixed with

data going to stdout.
"-T Icomp=chan P"
Specify an explicit SeisAn component to SEED channel mapping, this option may be used several times (e.g. "-T SBIZ=SHZ -T SBIN=SHN -T SBIE=SHE"). Spaces in components must be quoted, i.e. "-T 'S Z'=SHZ".
LIST FILES
If an input file is prefixed with an '@' character the file is assumed to contain a list of file for input. As a special case an input file named '`filenr.lis`' is always assumed to be a list file. Multiple list files can be combined with multiple input files on the command line.
The last, space separated field on each line is assumed to be the file name to be read. This accommodates both simple text, with one file per line, or the formats created by the SeisAn dirf command (`filenr.lis`).
An example of a simple text list:
2003-06-20-0643-41S.EDI___003
2005-07-23-1452-04S.CER___030
An example of an equivalent list in the dirf (`filenr.lis`) format:
1 2003-06-20-0643-41S.EDI___003
2 2005-07-23-1452-04S.CER___030

SILSEI all, chan. def. no, resp no

Conversion from the Icelandic SIL system to SEISAN. Only conversion from ASCII files.

SISSEI, Sismalp to SEISAN all, chan. def. yes, resp yes

The program converts from Sismalp to SEISAN. Sismalp is a French field recording system. The input consists of 2 files pr event, a header file and a data file. It is assumed that the Sismalp ndx files have the same file name as the header file except for the file extension. It is also assumed that the file names are 12 characters long.

SUDSEI, PCSUDS to SEISAN PC, chan. def. yes, resp yes

The program converts from PCSUDS to SEISAN. This is done by first running the program SUD2ASC (included) and then converting to SEISAN. The SUD2ASC program and test data was supplied by REFTEK through the distribution of PC-SUDS Utilities by Banfill (1996).

TERSEI, Terra ASCII to SEISAN all, chan. def. yes, resp yes

Program converts from Terra Technology ASCII files to SEISAN. Only tested with 1-3 channel files

VELSEI, Velest CNV to Nordic

An example of the input format is seen below:

```
191213  043 55.85 41.4825N  19.6017E  26.19 -99.00     98      0.09
AB18P1  3.99AB26P0  4.07AB06P0  4.08AB30P0  4.22AB10P0  4.74AB10S0  9.01
AB17P0  4.78AB09P0  4.85AB09S1  9.21AB03P1  5.95AB03S2 11.12AB02P0  6.02
AB01P1  6.27AB13P1  7.12
191213  131 28.93 41.4204N  19.5849E  10.39 -99.00     93      0.08
AB26P1  1.91AB18P3  2.04AB30P0  2.05AB06P0  2.18AB09P1  2.22AB10P0  2.26
AB17P0  2.54AB02P1  3.66AB03P1  3.68AB01P1  3.93AB13P2  4.54
```

WGSSEI to SEISAN all, chan. def. yes, resp yes

Program converts from WGSN files to SEISAN. The format is used on IRIS stations as processing format. Little tested.

WAVASC, ASCII file from any WAV file

Program to convert any seisan waveform file to a 2 column ASCII file. One file will be made per channel as well as one file for all the converted data. The start of the converted file looks as follows:

```
 COCO  BH E 10 II 2007  928 1345  31.440   42953  40.000
    31.440     1874.00
    31.465     1787.00
```

```
31.490     2159.00
31.515     3002.00
```

where the header has station, component, location, network, time, number of samples and sample rate. The following times are referred to the minute in the header.

the channel output filename is like

2007-09-28-1345-31A.COCO_BH_E

where a stands for ASCII

The input can be an s-file where all waveform files in s-file will be used or it can be a waveform file or a filenr.lis of waveform files.

Chapter 20

Signal processing programs

The SAC software is interfaced to SEISAN and can be started directly from EEV. This is done since SAC has functions that SEISAN does not have. It only operates on Unix.

20.1 SAC2000

SAC2000 (seismic analysis code) is currently developed by **Lee Minner** and **Peter Goldstein** (Goldstein, 1999). SAC is not distributed with SEISAN, information on SAC can be obtained from the SAC homepage (`http://www-ep.es.llnl.gov/www-ep/esd/seismic/sac.html`). The main features of SAC include general arithmetic operations, Fourier transforms, three spectral estimation techniques, IIR and FIR filtering, signal stacking, decimation, interpolation, correlation, and seismic phase picking. SAC also contains an extensive graphics capability. With SAC it is possible to write macros, which helps to process large amounts of data. The SAC format is used in several research oriented programs. SAC can be started from EEV using the command 'sac'. EEV will start the WAVETOOL program to convert the data to SAC and then execute the command sac. In case your sac executable is called sac2000, it is necessary to rename it (to sac) or alternatively to create a link in either the SEISAN PRO directory or the SAC bin directory. This is done for example by the command :

```
ln -s /sac/bin/sac2000 /sac/bin/sac
```

Since the SAC format is a single trace format, the SEISAN multichannel files are split into single trace files. The station and component names are included in the file name and the suffix 'SAC' is added to all SAC files. For both systems, waveform data can be converted to the respective format outside EEV using WAVETOOL, GSESEI or SACSEI, and the programs can be started without using EEV.

Chapter 21

Automatic routines in SEISAN

The section describes the routines in SEISAN that can be used for analysing data automatic.

21.1 AUTOPIC and AUTO

AUTOPIC is a tool to automatically pick phases on events registered into the database. AUTOPICK can also be used for many events in connection with program AUTO, see below.

If an event file (S-file) has any readings, the AUTOPIC program will not reread in order to not destroy old picks. The automatic readings in the file are marked with an A after the weight column to indicate automatic pick. Each pick is evaluated by using the signal to noise ratio and an indication of the quality is given with the weight. The program will run on all waveform files given in an S-file. Each time the program runs, there is a file called autopic.out containing information about the run. If there are any 3-component stations, an azimuth will also be calculated, and the S-phase will be more reliable. The AUTOPIC program can also be used from EEV by typing Z (will run program AUTOPIC). When it is used from EEV, there is always an output in the S-file, which will be grouped at the bottom of the file, making it possible to compare manual and automatic readings. THE S-FILE MUST THEN BE EDITED MANUALLY IN ORDER TO REMOVE DOUBLE READINGS. The program requires an input parameter file in the working directory or DAT with the name AUTOPIC.INP. The program will first look in the working directory. The parameters in that file are explained below. NOTE: The file is formatted, data must be in columns exactly as shwown and no tabs must be used. The program uses a 4-pole filter running one way. This might result in phases being picked a bit late. However, it seems more accurate than the earlier version where the filter run both ways and picks were often far too early. The program is made mainly by Bent Ruud. For more information about how it works, see Ruud et al. (1988); Ruud and Husebye (1992). Description of parameters

```
-----------------------------------------------------------------
%
% Input parameters common to all filters:
%
% LWIND  : used to define step length (DELTA=WINDOW/LWIND)
% ISHIFT : defines time shift between STA and LTA window (ISHIFT*DELTA)
%          Delay for LTA window (15 * 0.1) ==> 1.5 sec. after STA window.
% ISIGMA : defines fall-off rate of LTA window (larger values - longer windows)
%          LTA(i) = (1 - 2^(isigma)) * LTA(i-1) + 2^(-isigma) * STA(j)
% COHMIN : Polarization threshold.
%          Minimum coherence (see thresh_1 and thresh_2)
% NDMIN  : Mimimum number of consecutive triggered windows in a detection
% SVELO  : S-wave velocity of the medium below the station (used for 3-comp)
% NFILT  : number of filters
% CRAT   : Ratio for calculation of coda duration ( range 1 - 4), if 0,
%          no calculation
```

```
% LWIN   : Window used in coda duration routines (range 20 - 50 seconds)
% THRES  : Quality threshold (range 2 - 5). Used on the maximum to average
%          amplitude ratio in order to sort out the most noisy traces.
% MAXWIN : Maximum window from start of trace to be used (sec). If zero
%          the whole trace is used, if too long also whole trace is
%          used.
%
% Input parameters defined for each filter:
%
% WINDOW : length of the moving time window (sec)
% F1     : lower cutoff frequency (Hz) of band pass filter
% F2     : higher cutoff frequency (Hz) of band pass filter
% THRSH1 : STA/LTA threshold for polarized signals
% THRSH2 : STA/LTA threshold for unpolarized signals
%          If coherence > cohmin then detection is made on thresh_1
%          If coherence < cohmin then detection is made on  thresh_2
%
% Output parameters:
%
% D    : day of year
% H    : hour
% M    : minute
% SEC  : second
% DUR  : duration, i.e. time in detection state (sec)
% FRQ  : centre frequency of filter giving the best detection (Hz)
% SNR  : signal to noise ratio (SNR=STA/LTA)
% STA  : short time average (root mean square of amplitude)
% NT   : total number of triggered time windows in the detection
% NH   : number of windows with best SNR on one of the horizontal comp.
% NV   : number of windows with best SNR on the vertical comp.
% NC   : number of windows with acceptable polarization
% Q    : quality class, 1(best) - 4(worst)
% PS   : P/S wave discriminator, 0(S) - 10(P)
% AZI  : backazimuth in degrees measured from North through East
% DA   : variability in azimuth (deg)
% VEL  : apparent velocity (km/s)
% DV   : variability in apparent velocity (km/s)
%
% Note : azimuth and apparent velocity calculations are based on the
%        assumption of P-wave, so that these variables should be
%        neglected for S-waves.
%                                                              jh aug 22
```

Example of input file AUTOPIC.INP

```
% This is the parameterfile needed by program: --- AUTOPIC ---
%
% The following rules apply:
% 1. All lines with % in the first column are comment lines
% 2. Lines with a blank in column 1 are read for fixed parameters.
% 3. All lines starting with "filter_x", where x is a number,
%    are read for filter variable parameters
% 4. All lines with * in the first column are read for stations to process
% 5. A breif explanation of all parameters is given in the manual and file
%    AUTOPIC.INF in INF.
```

```
%
% FIXED PARAMETERS THAT ARE USED THROUGHOUT THE PROGRAM
% ------------------------------------------------------------------------
% Lwind Ishift Isigma Cohmin  Ndmin  Svelo  Nfilt   Crat   Lwin  Thres MaxWin
%     !      !      !      !      !      !      !      !      !      !      !
% ------------------------------------------------------------------------
    4.0   30.0   06.0    0.1    3.0   2.75    4.0    1.6   30.0    3.0  180.0
%
%
% PARAMETERS THAT ARE FILTER DEPENDANT
% ------------------------------------------------------------------------
%Filter_nr    Window        F1        F2    Thrsh1    Thrsh2
%        !         !         !         !         !         !
% ------------------------------------------------------------------------
filter_1         0.8       2.0       4.0      2.30      3.0
filter_2         0.6       5.0      10.0      2.30      3.00
filter_3         0.4       8.0      16.0      2.30      3.00
filter_4         2.0       0.5       2.0      4.0       5.0
%
%
% STATIONS TO USE IN THE PROCESSING
% ------------------------------------------------------------------------
*SUE  S  Z 3 component
*BER  S  Z
*HYA  S  Z
*KMY  S  Z 3 component
*ODD1 S  Z 3 component
*BLS5 S  Z 3 component
*ESG  S  Z
*EGD  S  Z
*KTK1 S  Z 3 component
*NSS  S  Z 3 component
*MOL  S  Z 3 component
*MOL  S  A 3 component
*JNW  S  Z
*JNE  S  Z
*FRO  S  Z
*JMI  S  Z 3 component
*ASK1 S  Z 3 component
*ASK  S  Z 3 component
*MOR7 S  Z 3 component
*MOR8 S  Z 3 component
*LOF  S  Z 3 component
*LOF  A  Z 3 component
*OSG  S  Z 3 component
*TRO  S  Z 3 component
*FOO  S  Z 3 component
*ALVN S  Z 3 component
*UGA  S  Z 3 component
*ENT  A  Z 3 component
```

AUTO

A Program for automatic processing: Phase picking, location, magnitude and fault plane solution determination.

This program run the picking program AUTOPHASE first (optionally AUTOPIC), locates events with or without outlier removal with HYP and then determines magnitudes with AUTOMAG. Automatic amplitudes for fault plane solutions can be done optionally with AUTORATIO. Fault plane solutions can also be done optionally with FPFIT or HASH, note velocty is the hardwired option. The default is to do AUTOPHASE, HYP with outlier removal and AUTOMAG using default parameters. Individual steps, like doing magnitudes, can optionally be deselected and some non default parameters for AUTOMAG can be selected. All changes are made using arguments, see list below. Thus the program can also be used to do any one of the operations. However to do only e.g. magnitudes, a more rational choice would be to use AUTOMAG only. Similarly for doing only locations, it is more logical to use HYP. The input can be all SEISAN types: a file, a data base or an index file. Outlier removal by HYP can be deselected. An alternative to outlier removal by HYP is to use the HYP option for residual weighting. For more detail of the individual programs, see program descriptions elsewhere in SEISAN manual. There are always two output files: auto.out: all events with the final results with updated values of location and magnitude. auto.log: a summary of what has been done to each event. If input is from a data base or index file, the results are also written back to the data base, overwriting what was there from before. The ID line is not updated by AUTO. When picking automatically, a few bad picks can throw the solution off so for a local event, the distance might wrongly be very large. It is then important that the range used for distance weighting in HYP is large so the initial wrong location can be made and the outlier rejection gets a chance to eliminate bad picks. Doing fault plane solution is only recommend with very good data. It is then important to use at least the default values set for both minimum number of polarities and maximum az gap. Note the gap is not the gap as in a hypocenter solutions but the gap when polarities are plotted on the projection on the focal sphere.

See list of argument below

```
 Examples of argument use:

auto          : pick phases, locate and do magnitudes
auto l m      : only pick phases with AUTOPHASE
auto j l m    : only pick phases with AUTOPIC
auto i l       : only do magnitudes
auto s 30     : all defaults except that spectral window for magnitude is 30 s
auto l m i f  : only do fault plane solutions with FPFIT
auto l m i ar h f: automatic amplitudes and fault plane solution with HASH

Writing auto help will give all the possible arguments:

c:\seismo\PRO>auto help
 Write auto help to get list of arguments. If no
 arguments, all defaults are used. This is autophase,
 location with outlier rejection and ML and spectral Mw

  s xxx : do spectrum for Mw, xxx is window length, default
          is 20 s. if 0, no spectrum. Default is spectrum

  w xxx : amplitude for Ml, xxx is window length
          if zero, no amplitude. Default is do amplitude
          default window length is 50 s

  n or e: use N or E component for magnitude, respectively.
          Default is Z

  p     : use P for Mw, default is S

  l     : do not locate, def. is to locate with rejection
          if magnitudes are done, location is also done
```

```
          after determination of amps and spectra in order
          to update magnitudes on header line

  r     : do not remove outliers when locating

  m     : no magnitude, default is to do magnitude

  i     : no phase pick, default is to do phase pick

  j     : if phase pick, use autopic, default is autophase

  ar    : do autoratio, default is not to do

  af  xx xx  : filter for autoratio, default is 2-4 Hz

  ad  xx   : max distance for autoratio, def 100km

  at  xx  : time window for autoratio, def 2 s

  ag  xx   : ground motion for autoratio, def 0 for none

  az    : if given, use z for s in autoratio

  f     : do fault plane solution with fpfit, def.  is not

  h     : do fault plane solution with hash, def.  is not

  n     : minimum number of polarities for fps, default 10

  g     : maximum gap for fps, default 180
```

When using amplitude ratios for fps, velecity is the harwired default.

21.2 AUTOPHASE, automatic phase picking

By T. Utheim, University of Bergen.

The AUTOPHASE program is part of the RTQUAKE real-time earthquake detection (Utheim et al., 2014). The AUTOPHASE (hereafter AP) is a stand-alone phase-picker routine that is used for automatic phase-picking in RTQUAKE and can also be used as an option in SEISAN from the EEV program. The routine is based on the FilterPicker algorithm (Lomax et al., 2012), but with several modifications and additions. However, the original picking algorithm is unchanged.

The FilterPicker (hereafter FP) implementation in both RTQUAKE and SEISAN checks each component of a waveform for possible phase-picks. All channels in the waveform file are checked and there is no possibility to unselect channels. Each component may have several suggested phases given by the time of occurrence. Each component may also have a suggested first movement indicated for each pick. There can thus be many picks for each channel.

The following rules apply for selecting P and S phases among the suggested picks:

For one station there will only be one P and one S-phase selected.

P is only accepted on vertical components.

S is only accepted on vertical components if the station does not have horizontal components so S is in general only accepted on horizontal components. If several picks are found on a horizontal component, it is assumed that the first is P. The S is then selected on the first of the following picks that has a time-difference

greater than a default value MINDIFF (1.5 seconds) set in the program. This is to avoid picking secondary P phases as S phases. This rule is also used if picking S on Z-components.

If S-phases are found on two different horizontal channels, the first arriving one is used.

If only one pick on a horizontal component, no S is selected.

First movement are included in the S-file only for vertical channels.

If the event is defined as distant (D) in the SEISAN S-file, only P phases are picked.

S-phases are given a weight of 3.

Running AUTOPHASE AP is started from within the SEISAN EEV program with the command 'ap'. This command converts all associated waveform files (can be different formats) to one MiniSeed file seed.out, which is then used as input to AUTOPHASE. The S-file and corresponding waveform files are used as input to the AP. All old readings are deleted and replaced by the new readings from AP. All phases are marked with A for automatic. AUTOPHASE can also be operated outside EEV with the command:

Autophase -sfile xxx -wavefile yyy

where xxx is a single event S-file and yyy is one waveform file in MiniSeed format. AP can only work with one S-file.

AUTOPHASE also has other options not used in SEISAN, see RTQUAKE manual:
`ftp://ftp.geo.uib.no/pub/seismo/SOFTWARE/RTQUAKE/`

Parameters

AUTOPHASE has no parameter file since it seems that the default parameter work will in most cases. Default FilterPicker parameters are set at the top in the source program under the comment:

"Default FilterPicker parameters" and can be changed by the user. See M. Vassallo and Lomax (2012) for documentation. The program must be recompiled.

`#define Picker_FW 300.0` Longest period for a set of filtered signals from the differential signal of the raw broadband input trace (300 multiplied by sample rate)

`#define Picker_LTW 500.0` Time scale used for accumulating time-averaged statistics of the input raw signal (500 multiplied by sample rate)

`#define Picker_TH1 10.0` Trigger threshold used for event declaration. A trigger is declared when the summary CF (characteristic function) exceeds Picker_TH1

`#define Picker_TH2 10.0` A pick is declared if and when, within a window of predefined time width, Picker_TUP after trigger time, the integral summary CF (characteristic function) exceeds the value: Picker_TH2 multiplied by Picker_TUP (see below).

`#define Picker_TUP 20.0` Time window used for pick validation (20 multiplied by sample rate).

Default time-difference MINDEF is set to:

MINDEF = 1.5

Coda is computed for vertical components only, and only for events marked local (L) or regional (R) in the s-file. Computation of coda can be turned off by changing the SETCODA switch in the source code to zero, and recompiling. Default is SETCODA=1. The coda is computed by comparing a long-term average of the signal before the P phase with long-term averages after the P-phase divided by a factor.

Example: The AUTOPHASE picker is started from EEV with the command: ap

```
#   13  9 Dec 2015 08:03 54  LM-22.259 -66.832  0.0  N 1.2 2.3WBER   11  ? ap
The waveform file is converted to miniseed file: seed.out
wavetool -sfile /home/seismo/snew/REA/TST__/2015/12/09-0804-18R.S201512 -format MSEED -wav_out_file seed
  Number of wav-files           1
  Number of wav-files present           1
 /home/seismo/snew/WAV/TST__/2015/12/2015  MINISEED
  Total number of channels available:          42
  Total duration:   323.599976

  Output waveform file name is seed.out
Here the autophase routine is started with s-file and seed.out file as input:
autophase -sfile /home/seismo/snew/REA/TST__/2015/12/09-0804-18R.S201512 -wavefile seed.out
SEISAN_TOP.....................: /home/seismo/snew
wfilename: seed.out
```

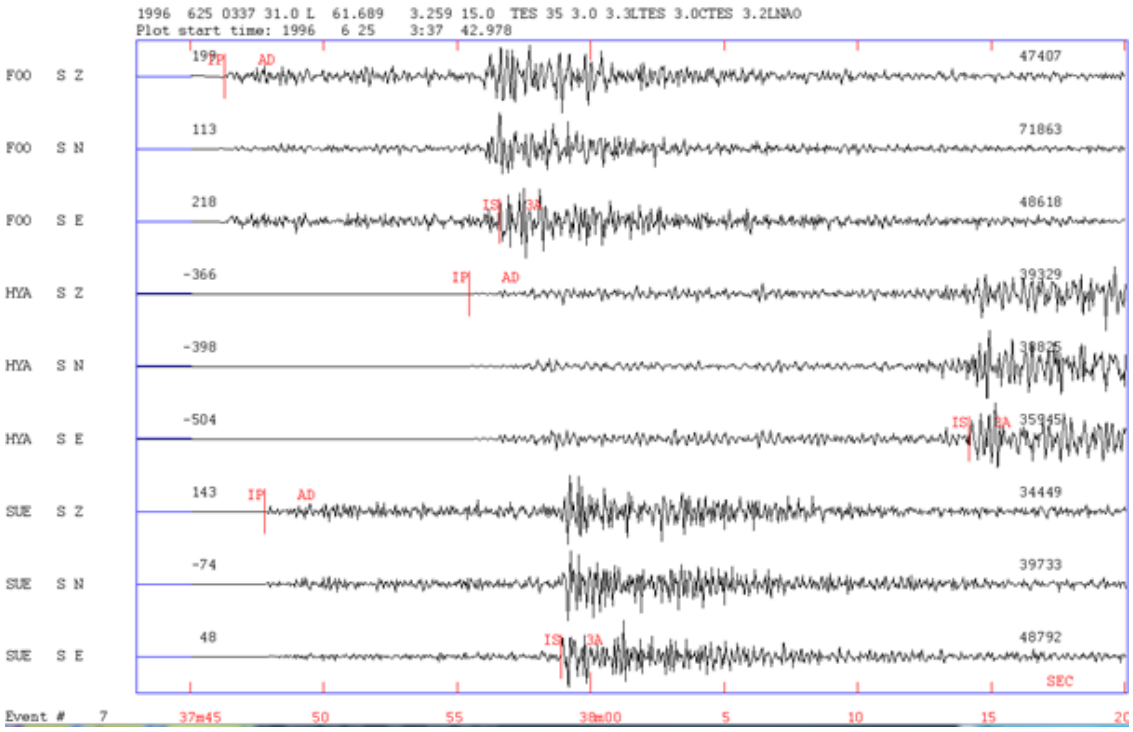


Figure 21.1: Examples of automatic picks on a "good" event.

```
All picks found are listed below in the format:
STATION-NAME      DATE      TIME       TIME-DIFFERENCE TO NEXT PICK ON SAME COMPONENT
CX_PB16__00_BHZ 09/12/15 08:05:04.499        (1 pick only)
CX_PB11__00_BHZ 09/12/15 08:04:49.150 39.85  (2 picks, time-diff. to 2. pick:39.85 seconds)
CX_PB11__00_BHN 09/12/15 08:04:49.349 39.30
CX_PB11__00_BHE 09/12/15 08:04:49.349 39.55
CX_PB08__00_BHZ 09/12/15 08:04:43.769
CX_PB08__00_BHN 09/12/15 08:04:43.819 35.35
CX_PB08__00_BHE 09/12/15 08:04:43.919 35.40
CX_PB01__00_BHZ 09/12/15 08:04:38.269
CX_PB01__00_BHN 09/12/15 08:04:38.569 31.25
CX_PB01__00_BHE 09/12/15 08:04:38.569 31.95
CX_PB07__00_BHZ 09/12/15 08:04:39.019
CX_PB07__00_BHN 09/12/15 08:04:38.969
CX_PB07__00_BHE 09/12/15 08:04:39.069
CX_PB09__00_BHZ 09/12/15 08:04:33.650
CX_PB09__00_BHN 09/12/15 08:04:33.999
CX_PB09__00_BHE 09/12/15 08:04:33.799
CX_PB03__00_BHZ 09/12/15 08:04:37.569
CX_PB03__00_BHN 09/12/15 08:04:37.469
CX_PB03__00_BHE 09/12/15 08:04:37.469
CX_PB04__00_BHZ 09/12/15 08:04:41.369
CX_PB04__00_BHN 09/12/15 08:04:41.669
CX_PB04__00_BHE 09/12/15 08:04:41.619  0.90
CX_PB06__00_BHZ 09/12/15 08:04:36.519
CX_PB06__00_BHN 09/12/15 08:04:36.919 30.15
CX_PB06__00_BHE 09/12/15 08:04:36.769
```

```
CX_PB05__00_BHZ 09/12/15 08:04:42.619
CX_PB05__00_BHN 09/12/15 08:04:43.069
CX_PB05__00_BHE 09/12/15 08:04:42.769
CX_PB15__00_BHZ 09/12/15 08:04:37.869  1.20 30.50 (3 picks,and 2 time-differences)
CX_PB15__00_BHN 09/12/15 08:04:37.669 31.65
CX_PB15__00_BHE 09/12/15 08:04:38.169 31.30
CX_PB10__00_BHE 09/12/15 08:04:48.500
------------------------------------------------------------------------
SELECTED PICKS:
------------------------------------------------------------------------
Below the selected picks from the picks above. As seen below, there are picks on both
horizontal components on stations PB11,PB08,PB01 and PB15:
  0 PB16  BHZ   P 09/12/15 08:05:04.499
  6 PB11  BHZ   P 09/12/15 08:04:49.150
  7 PB11  BHN                           S 09/12/15 08:05:28.649
  8 PB11  BHE                           S 09/12/15 08:05:28.899
  9 PB08  BHZ   P 09/12/15 08:04:43.769 C
 10 PB08  BHN                           S 09/12/15 08:05:19.169
 11 PB08  BHE                           S 09/12/15 08:05:19.319
 12 PB01  BHZ   P 09/12/15 08:04:38.269
 13 PB01  BHN                           S 09/12/15 08:05:09.819
 14 PB01  BHE                           S 09/12/15 08:05:10.519
 15 PB07  BHZ   P 09/12/15 08:04:39.019
 18 PB09  BHZ   P 09/12/15 08:04:33.650 C
 21 PB03  BHZ   P 09/12/15 08:04:37.569
 24 PB04  BHZ   P 09/12/15 08:04:41.369
 27 PB06  BHZ   P 09/12/15 08:04:36.519
 28 PB06  BHN                           S 09/12/15 08:05:07.069
 30 PB05  BHZ   P 09/12/15 08:04:42.619
 33 PB15  BHZ   P 09/12/15 08:04:37.869
 34 PB15  BHN                           S 09/12/15 08:05:09.319
 35 PB15  BHE                           S 09/12/15 08:05:09.469
------------------------------------------------------------------------------------------
In the next step of selection the first of the 2 S-phases on the horizontal components
are selected while the last are deleted:
  0 PB16  BHZ   P 09/12/15 08:05:04.499
  6 PB11  BHZ   P 09/12/15 08:04:49.150
  7 PB11  BHN                           S 09/12/15 08:05:28.649
  9 PB08  BHZ   P 09/12/15 08:04:43.769 C
 10 PB08  BHN                           S 09/12/15 08:05:19.169
 12 PB01  BHZ   P 09/12/15 08:04:38.269
 13 PB01  BHN                           S 09/12/15 08:05:09.819
 15 PB07  BHZ   P 09/12/15 08:04:39.019
 18 PB09  BHZ   P 09/12/15 08:04:33.650 C
 21 PB03  BHZ   P 09/12/15 08:04:37.569
 24 PB04  BHZ   P 09/12/15 08:04:41.369
 27 PB06  BHZ   P 09/12/15 08:04:36.519
 28 PB06  BHN                           S 09/12/15 08:05:07.069
 30 PB05  BHZ   P 09/12/15 08:04:42.619
 33 PB15  BHZ   P 09/12/15 08:04:37.869
 34 PB15  BHN                           S 09/12/15 08:05:09.319
------------------------------------------------------------------------
Create s-file: /home/seismo/snew/REA/TST__/2015/12/09-0804-18R.S201512
------------------------------------------------------------------------
```

```
The autophase routine will also indicate first movement of p-phases when found. This can
be seen on station PB08 BZ and PB09 BZ below:
 0  2015 12 9 0803 54.7 LM-22.259 -66.832  0.0  BER 11 1.2 2.3WBER                1
 1  SPEC AVERAGE  MO 12.5 ST  2.2 OM  1.3 f0 6.48 R1.2239 AL 0.00 WI 20.0 MW  2.3 3
 2  SPEC SD       MO  0.7 ST  1.8 OM  0.7 f0 2.58 R2.8040 AL      WI      MW  0.5 3
 3  GAP=282        2.48      27.2    73.7 98.6 -0.1631E+04  0.5338E+04 -0.1724E+04E
 4  SPEC PB09BH Z MO 12.1 ST  1.5 OM  0.9 f0 8.00 R0.1480 AL-0.00 WI 20.0 MW  2.0 3
 5  SPEC PB09BH Z T 8 5 5 K 0.020 GD  159 VS 3.20 DE 2.60 Q0400.0 QA 0.70 Q1 1.00 3
 6  SPEC PB03BH Z MO 12.3 ST  2.6 OM  1.1 f0 8.00 R0.1480 AL-0.00 WI 20.0 MW  2.1 3
 7  SPEC PB03BH Z T 8 519 K 0.020 GD  173 VS 3.20 DE 2.60 Q0400.0 QA 0.70 Q1 1.00 3
 8  SPEC PB01BH Z MO 12.4 ST  3.4 OM  1.2 f0 8.00 R0.1480 AL-0.00 WI 20.0 MW  2.2 3
 9  SPEC PB01BH Z T 8 5 8 K 0.020 GD  174 VS 3.20 DE 2.60 Q0400.0 QA 0.70 Q1 1.00 3
10  SPEC PB07BH Z MO 12.2 ST  1.1 OM  1.0 f0 6.36 R0.1862 AL-0.00 WI 20.0 MW  2.1 3
11  SPEC PB07BH Z T 8 524 K 0.020 GD  179 VS 3.20 DE 2.60 Q0400.0 QA 0.70 Q1 1.00 3
12  SPEC PB08BH Z MO 14.4 ST0.002 OM  3.2 f00.137 R8.6423 AL-0.00 WI 20.0 MW  3.6 3
13  SPEC PB08BH Z T 8 517 K 0.020 GD  183 VS 3.20 DE 2.60 Q0400.0 QA 0.70 Q1 1.00 3
14  SPEC PB04BH Z MO 12.2 ST  2.2 OM  1.0 f0 8.00 R0.1480 AL-0.00 WI 20.0 MW  2.1 3
15  SPEC PB04BH Z T 8 530 K 0.020 GD  184 VS 3.20 DE 2.60 Q0400.0 QA 0.70 Q1 1.00 3
16  SPEC PB05BH Z MO 11.9 ST0.335 OM  0.7 f0 5.32 R0.2226 AL-0.00 WI 20.0 MW  1.9 3
17  SPEC PB05BH Z T 8 534 K 0.020 GD  187 VS 3.20 DE 2.60 Q0400.0 QA 0.70 Q1 1.00 3
18  SPEC PB11BH Z MO 12.7 ST  6.1 OM  1.4 f0 8.00 R0.1480 AL-0.00 WI 20.0 MW  2.4 3
19  SPEC PB11BH Z T 8 527 K 0.020 GD  200 VS 3.20 DE 2.60 Q0400.0 QA 0.70 Q1 1.00 3
20  2015-12-09-0803-18.TST___054_00_01                                          6
21  ACTION:NEW 15-12-09 08:04 OP:SEIS STATUS:               ID:20151209080418     I
22  STAT SP IPHASW D HRMM SECON CODA AMPLIT PERI AZIMU VELO AIN AR TRES W  DIS CAZ7
23  PB16 BZ IP    A   8 5  4.49  120
24  PB11 BZ IP    A   8 4 49.15  132
25  PB08 BZ IP    AC  8 4 43.76  105
26  PB01 BZ IP    A   8 4 38.26  125
27  PB07 BZ IP    A   8 4 39. 1  122
28  PB09 BZ IP    AC  8 4 33.65  121
29  PB03 BZ IP    A   8 4 37.56  113
30  PB04 BZ IP    A   8 4 41.36   89
31  PB06 BZ IP    A   8 4 36.51   86
32  PB05 BZ IP    A   8 4 42.61   87
33  PB15 BZ IP    A   8 4 37.86   94
34  PB11 BN IS   3A   8 5 28.64
35  PB08 BN IS   3A   8 5 19.16
36  PB01 BN IS   3A   8 5  9.81
37  PB06 BN IS   3A   8 5  7. 6
38  PB15 BN IS   3A   8 5  9.31
#   13  9 Dec 2015 08:03 54  LM-22.259 -66.832  0.0  N 1.2 2.3WBER   11  ?
```

21.3 AUTOSIG

AUTOSIG is a program to perform some automatic processing. The program includes routines for P-phase picking, determination of signal duration, amplitude determination, determination of spectral parameters (Ottemöller and Havskov, 2003) and determination of distance type (local, teleseismic, noise). The program can still do with improvement. The input to the program can be either a parametric Nordic file (with one or several events) or waveform files. In both these cases, the output is written to the `autosig.out` file. Additional output files are `autosig.trace` and `autosig.err`, which will help to find potential problems. Alternatively, the program can also be started from EEV; the output is then directly written to the S-file.

The input parameters are defined in the file `autosig.par`, which is located either in the DAT or the working directory.

Following are descriptions of the automatic processing routines:

P-phase picking:

The phase picking is based on changes in the STA/LTA ratio. A band pass filter can be specified. The routine gives options to enhance the changes in the signal before computing the STA/LTA ratio. It is recommended to first remove the linear trend and then to compute the characteristic function which is given by y**2+k*(dy/dt)**2, which enhances changes in both amplitude and frequency content. Then the STA/LTA ratio is computed to detect changes in the signal. The routine can also compute the squared STA/LTA. When a change is detected (STA/LTA ratio above trigger level), it is tested whether the signal spectral amplitudes are significantly higher (factor of 2 in amplitude) than the pre-signal noise spectral amplitudes. This is done to avoid triggering on spikes.

Signal duration:

The signal duration is determined by comparing the signal amplitudes with the amplitudes of the pre-signal noise. The duration is determined by the point from which the ratio of these amplitudes is lower than a given value. A filter is applied if specified in the parameter file.

Amplitude:

Routine finds maximum amplitude between two peaks.

Spectral parameters:

The routine computes the displacement amplitude spectrum for P or S waves (see section 8.12) and, using either a converging grid search or a genetic algorithm determines the seismic moment and the corner frequency by minimizing the difference between observed and synthetic source spectra. The frequency band is determined by comparison with the pre-signal spectrum. The grid search is generally more cost effective and produces better results. The method is described in Ottemöller and Havskov (2003). The displacement spectrum is corrected for geometrical spreading and attenuation (both along the travel path and near surface). Therefore, the hypocentral distance has to be known. The time domain window for extracting the data from the trace can be given by either a group velocity (Vg=distance/travel time) window or a fixed window in seconds around the phase pick.

Distance type:

The routine determines whether the signal is from a local or teleseismic event, or noise. If signal spectral amplitudes are not significantly higher than pre-signal noise amplitudes, it is assumed that the signal is noise. Otherwise the amplitudes at two selected frequencies given by 'DIST FREQ SELECT' are compared, the rules are (f1<f2):

Spec signal amp(f1) - Spec noise amp(f1) > Spec signal amp(f2) - Spec noise amp(f2): teleseismic
Spec signal amp(f2) > Spec noise amp(f2): local

There are a few command line options that can be used to run autosig in non-interactive mode, syntax is

`autosig -infile <filename> [-spec on/off -phase on/off -clear on/off]`

where

-spec on/off: determine spectral parameters if option given
-clear on/off: remove phases from input S-file before start if option given
-phase on/off: detect phases if option given
-infile <file>: give name of input file, either S-file or waveform file
-help: get help

Note: When running the program the first time and the hypocenter location is not known, the determination of spectral parameters is not done. To run the determination of spectral parameters, the hypocenter location has to be given in the S-file.

The meaning of most parameters in the parameter file is clear from the keyword. The spectral parameters are as described in the MULPLT section. Other parameters that need explanation are:

AUTO PHASE, AUTO SPECTRUM and AUTO AMPLITUDE: Logical flag to activate phase picking, spectral analysis and amplitude reading, respectively (1. for true)

GA POPULATION SIZE: Number of elements in the population, used only if SEARCH ALGORITHM is 1.

GA GENERATIONS: Number of generations in one run, used only if SEARCH ALGORITHM is 1.

Note: Increasing GA POPULATION SIZE and GA GENERATIONS will increase the computation time.

GRID NLOOP: Number of loops in converging grid search for spectral parameters, used only if SEARCH ALGORITHM is 2. Resolution increases with every loop.

NGRID FREQUENCY: Number of grid points in search for corner frequency, used only if SEARCH ALGORITHM is 2.

NGRID SPECTRAL AMP: Number of grid points in search for spectral amplitude, used only if SEARCH ALGORITHM is 2.

NORM: Norm for computation of residuals in spectral fitting can be set, however, tests show that 1 or 2 produce the same result, and generally default of 1 can be used.

SEARCH ALGORITHM: Defines whether genetic algorithm (1) or converging grid search (2) should be used. Converging grid search is recommended.

SELECT PHASE: Defines, which phase to use for spectral analysis, choices are: 0 for P by AUTOSIG, 1 for computed P arrival for given location, 2 for computed S arrival, 3 for P from s-file, 4 for S from s-file or 5 for S or P from s-file.

SEPCTRUM F LOW: Lower limit of frequency band to be used.

SPECDURATION CHOICE: The time window for computation of the spectrum can be given either as a time window starting from the phase onset (0.) or can be defined by a group velocity window (1.).

SPECTRUM P LENGTH: Duration in seconds of signal starting from P arrival.

SPECTRUM S LENGTH: Duration in seconds of signal starting from S arrival.

SPECTRUM PRE LENGTH: Duration in seconds of signal to be included prior to phase arrival.

GROUP VEL WINDOW P: Range of group velocities defining time window to be used for P spectrum. Time window is given by (distance/group velocity)

GROUP VEL WINDOW S: Range of group velocities defining time window to be used for S spectrum. Time window is given by (distance/group velocity)

STALTA NREC/REC: There are two STA/LTA algorithms, recursive (0.) and non-recursive (1.).

STATION LINE: One line with processing parameters for phase detection is given for each channel. The parameters are (also see example below):

STAT - station name
COMP - component name
STA - duration of STA
LTA - duration of LTA
RATIO - trigger ratio
MINCOD - minimum coda required for trigger
DTRLE - de-trigger level
FILL - bandpass filter low cut
FILH - bandpass filter high cut

Example of the parameter file `autosig.par`:

```
#
KEYWORD.............Comments.............Par 1.....Par 2

#
# spectral parameters
#
SPECTRAL S-Q0       Q0                    440.0
SPECTRAL P-Q0       Q0                    85.0
SPECTRAL S-QALPHA   Q = Q0**Qalpha        0.70
SPECTRAL P-QALPHA   Q = Q0**Qalpha        0.70
SPECTRAL KAPPA                            0.02
SPECTRAL P-VELOCITY P velocity            6.2
SPECTRAL S-VELOCITY S velocity            3.6
SPECTRAL DENSITY    Density               2.8

#
# auto signal processing parameters
```

```
#
REMOVE MEAN          1. for true          0.
REMOVE TREND         1. for true          1.
CHAR FUNCT           1. for true          1.
K IN CHAR FUNCT      K IN X=Y^2+K*Y'^2.   3.
STALTA NREC/REC      rec 0./ non-rec 1.   1.
STALTA SQUARE/ABS    square 1.            1.
AUTOCODA SQUARE/ABS  square 1.            0.
AUTO PHASE           1. for true          0.
                     only if no phase
AUTO SPECTRUM        1. for true          1.
AUTO AMPLITUDE       1. for true          1.
AUTO LOCATE          1. for true          0.

NORM                                      1.
SEARCH ALGORITHM     1.=GA 2.=GRID        2.
#
# window selection
#
SPECTRUM P LENGTH    in seconds           5.
SPECTRUM S LENGTH    in seconds           2.
SPECTRUM PRE LENGTH  in seconds           .5
GROUP VEL WINDOW P                        5.0       6.5
GROUP VEL WINDOW S                        2.7       3.7
SPECDURATION CHOICE  0:SPEC. P/S LEN.     1.
                     1:GROUP VEL W. P/S

#
# select phase
#
SELECT PHASE         0:auto  P            2.
                     1:synth P
                     2:synth S
                     3:P from file only
                     4:S from file only
                     5:S or P from file
     --- for 3-5, if no phase and AUTO PHASE is 1. use auto phase pick ---
DIST FREQ SELECT                          1.        10.

#
# parameters used in the genetic algorithm searching for spectral parameters
#
GA POPULATION SIZE                        50.
GA GENERATIONS                            250.

#
# grid dimension in case of grid search
#
GRID NLOOP                                5.
NGRID FREQUENCY                           100.
NGRID SPECTRAL AMP                        100.

#
# low filter limit to use for auto spectrum
```

```
SEPCTRUM F LOW                          .05

#
# parameters controlling output
#
CREATE WAVEOUT                          1.
SPEC OVERWRITE                          0.
PHASE OVERWRITE                         0.

#
# station parameters
#
#       STAT- COMP -sta-- -lta-- -ratio mincod -dtrle fill filh
STATION MOL   S  Z    3.0   20.0   10.0    2.5    1.5  5.0 10.0
STATION MOL   B  Z    3.0   20.0   10.0    2.5    1.5  5.0 10.0
STATION HYA   S  Z    3.0   20.0   10.0    2.5    1.5  5.0 10.0
STATION LSA   L  Z    3.0   20.0   10.0   10.0 9999.0 00.1 10.1
STATION CHTO  L  Z    3.0   20.0   10.0   10.0 9999.0 00.1 10.1
STATION XAN   L  Z    3.0   20.0   10.0   10.0 9999.0 00.1 10.1
```

21.4 AUTOMAG

Program to make automatic readings of WA amplitudes and make spectral fitting for channels for one or several events in an S-file. This is a simplified version of AUTOSIG and the program does not require any parameter file. The program will, by default, process Z channels for which the stations has a P or S reading and the window following the S-phase will be used. Optionally P can be used for spectra and N and E channels can also be used. A check is made for P-window length so if the window will include the S-waves, no spectrum is made. If only a P-phase available, the S-phase time will be calculated from the P-phase arrival time. If the epicentral distance is more than 500 km, the S-phase is assumed to be the Lg phase and an Lg velocity of 3.5 km is used. However if the depth is more then 50 km, S is assumed. In any case, if an S is present, the observed S-time is used.

The program can be used stand alone or in EEV with command automag(am) or command ami (input of parameters).

********** The agnecy used is taken from SEISAN.DEF **********

A special option is to do a grid search for the best Q-parmeters that fit the Brune spectrum using one or several events.

If the S-file has distances, both Ml and Mw can be calcculated. The parameter for Ml is taken from STATION0.HYP in local directory or in DAT. If not found, the standard Hutton and Boore(1987) values are used. The additional filter limits for Ml (if any) are taken from MULPLT.DEF, in local directory or DAT. If not filters in MULPLT.DEF, no filters are set. If a filter is used, the amplitudes read are corrected for the gain of the filter at the determined peiod.

The average Ml and Mw are shown on screen after one run. In order to get the average Ml and Mw in the S-file after using AUTOMAG, an update must be made. However each value is printed out and can also be shown with program PLOTSPEC (see later).

The program has a lot of output on screen when running. This can mostly be used to check why a particualr spectrum or amplitude operation failed.

Program input

Interactive input: Give s-file name, spec window and wa window, if zero window length, the corresponding operation is not done, give frequecy range for spectral fit, give channel names. If station is called ALL, all Z-channels from all stations with readings (P or S) are used. Alterentively other components can be used for all stations. If not using option ALL, the user must give each channel in which case any channel can be used. Give if P or S-spectrum.

If the spectral window is given, data outside this window will not be used. However, the signal to noise ratio is still check so the actual spactral range might be smaller than the spcified range.

Input from prompt, options are:

S-file name: If only S-file name, all stations are used and default values of window lengths are applied.

s xxx : where xxx is spectral window

w xxx : where xxx is wa window

p : P-spectrum (S is default)

n : use north-south component

e : use east-west component

overwrite : If given, input file will be overwritten, but automag.out also made. Option can only be used with one event. Used with EEV.

grid : Grid search, see below

Examples, input file is sfile:

Automag sfile s 10 : Makes S-spectra only, with 10 s window length

Automag sfile s 10 p : Makes P-spectra only, with 10 s window length

Automag sfile w 30 : Makes wa operation only with window length of 50

Automag sfile s 10 w 30 : Do both

Automag sfile s 10 w 30 n : Do both but use NS channel

Automag sfile s 10 w 30 overwrite : Do both and overwrite sfile

Automag grid : Do grid search, other options cannot be used, see below

Channels to process: If interactive option, each channel must be giveni o rthe ALL option used. If non interactive: Stations with P and/or S readings are selected if station has a reading on one of the channels.

Before running AUTOMAG, it might be an advantage to remeove all old amplitude and spectral values from the input file. This can be done with program DELS or command DELS in EEV.

Location of waveform data: AUTOMAG will look for waveform files in the standard SEISAN way: Local directory, WAV, default data base under WAV (file names must be standard SEISAN) or in any other directory specified in SEISAN.DEF. NOTE that to use another WAV data base than the the default data base when AUTOMAG is running outside EEV, the data base name must be given in SEISAN.DEF, paramter WAVEFORM_BASE.

Program flow:

Read RESET TEST value for Ml in STATION0.HYP in local directory or DAT

Read filter values for Ml

Read S-file with readings and location

Get waveform files from S-file

Enter or find station and component for instrument correction

Find S/Lg-time or P-time from readings

Select out a time window from waveform channel starting a bit before the P or S-time (see below)

Find channel number in waveform file(s) corresponding to desired channel

Read the P/S-time window from waveform channel, default 50 s, starting 4 s before P/S. If S/Lg has been calcualted from P, extra time is allowed before S calculated as distance(km)/100.

Read response file

Prepare response removal, different filters and poles and zeros used for Wood-Anderson response

Correct for instrument response

Automatically pick maximum amplitude and corresponding period. The amplitude is checked for s/n by taking the spectral level around the pick period and time in the S-signal and comparing it to the spectral level in same frequency band at the start of the trace. s/n must be at least 2.

Correct for additional filter if chosen

Write out results in internal s-file, overwrite old results

Do the automatic spectral fitting using a time window of 20 s starting 4 s before the P/S. Grid search is used

Write results in internal S-file, overwrite old results

Write results in automag.out

Write channels processed in automag.list, used for plotting with plotspec

Grid search

This option allows the spectral fitting to do a grid search for the best fitting Q0, Qalpha and kappa. The user will be asked for input file name, grid parameters, spectral window, frequency range and stations. For each group of events in input file, the average residual will be calculated and the results output in file automag_grid.out in order of increasing average residual, see example below. The parameter used in one run is output in automag.par, see example later. The fit can be made with many traces from many events; up to 4000 spectra can be used for each attenuation combination in the grid search. Both P and S-waves can be used. In order to not include very bad results, the results from spectra resulting in a stress drop not in the range 1-150 bar, will not be included in the average. This means that the only data where sterss drop can be calculated will be used and the events should therefore be updated before using automag.

Q0, qalpha and kappa will play off each other, therefore a comparable fit might be obtained with a different combinations and it might not be easy find the one to use. Low Q0 and high qalpha as well as high Q0 and low qalpha might be combinations giving similar fit. However, the lower Q0 will generally give a higher spectral level and therefore a higher magnitude. Similarly, kappa also plays off with Q0, but to a lesser degree. Hence, for any given Q0 and qalpha, there is generally a best kappa in the range 0.01 to 0.05. In order to limit number of parameters, an initial value of kappa= 0.02 can be used. For the qalpha parameter, the best fits are usually obtained for qalpha in the range 0.3 to 0.9. For Q0, the values with a good fit are often in the range 100-400, depending on qalpha. A good fit to the Brune spectrum does not automatically indicate correct attenuation parameters, since the spectrum could have another shape than the theoretical shape, but at least it gives an indication of possible values. equency range can in most cases be default. However, sometimes the antialias filter cut off the signal in the high end (not corrected by SEISAN) which will give a bad fit so a high cut should be selected. Check first with MULPLT how it looks or run for one event and plot all spectra with PLOTSPEC.

The frequecy below 1 Hz at which Q becomes constant cannot be searched for and is a fixed parameter set in SEISAN.DEF. The default value is 1.0 Hz.

There is thus many combinations that give a similar residual and it might be difficult to chose. One option is to average all Q-results with the lowest residual. This can be done with the AVQ program. The program will read all Q-results from automag_grid.out and average the results over a given user specified number of results. This process is then done for all the results in a running average so it is possible to get an idea of how the parameters change with increasing residual. For details on how AVQ calculates the average, see the AVQ program under section CODAQ. An example of running the program is shown below. It is important that curves that are averaged using the same kappa since the averaging does not take kappa into account. AVQ will also make a plot showing the Q-relations for the Q-curves averaged (the first avarage) as well as the average curve.

Example of running the AUTOMAG program:
automag grid
Give input S-file
dels.out
Give spec window, enter for def (20)
25
Give spectral range, enter for 0.05-srate/2.5
give max distance, enter for all
Start q0, step Q0 and number of steps
50 50 10
Start qalpha, step qalpha and number of steps
0.3 0.1 9
Start kappa, step kappa and number of steps
0.03 0.0 1
Number of tests is: 90
Continue(n/y=enter)
Station code and component (e.g. BER BHZ), end with blank
Station code and component (e.g. BER BHZ), end with blank Giving station code ALL : Use all Z channels with readings Giving station code ALL C : Use all C channels with readings
ALL
P or S-spectrum=default (enter)

Output file for the above input:

```
q0=  50.0 qa= 0.500 ka= 0.030 nf=     5 re= 0.081 mw=  3.46 f0=  4.19 st=  42.0
q0=  50.0 qa= 0.600 ka= 0.030 nf=     8 re= 0.092 mw=  3.41 f0=  4.18 st=  31.8
q0= 100.0 qa= 0.900 ka= 0.030 nf=    50 re= 0.095 mw=  3.24 f0=  5.11 st=  26.4
q0= 150.0 qa= 0.900 ka= 0.030 nf=    49 re= 0.095 mw=  3.17 f0=  4.01 st=   9.3
q0= 100.0 qa= 1.000 ka= 0.030 nf=    51 re= 0.096 mw=  3.25 f0=  4.18 st=  13.1
q0=  50.0 qa= 0.300 ka= 0.030 nf=     4 re= 0.096 mw=  3.48 f0=  5.80 st=  45.3
q0= 200.0 qa= 0.800 ka= 0.030 nf=    47 re= 0.097 mw=  3.11 f0=  4.23 st=   9.0
q0= 300.0 qa= 1.100 ka= 0.030 nf=    33 re= 0.097 mw=  3.17 f0=  3.42 st=   5.4
q0= 400.0 qa= 1.000 ka= 0.030 nf=    33 re= 0.097 mw=  3.15 f0=  3.51 st=   5.4
q0= 500.0 qa= 0.900 ka= 0.030 nf=    33 re= 0.097 mw=  3.14 f0=  3.58 st=   5.5
q0= 150.0 qa= 0.800 ka= 0.030 nf=    49 re= 0.097 mw=  3.16 f0=  4.90 st=  16.4
q0= 100.0 qa= 0.800 ka= 0.030 nf=    43 re= 0.097 mw=  3.22 f0=  5.94 st=  34.9
q0= 150.0 qa= 0.600 ka= 0.030 nf=    43 re= 0.097 mw=  3.20 f0=  5.82 st=  35.6
q0= 350.0 qa= 1.100 ka= 0.030 nf=    33 re= 0.097 mw=  3.16 f0=  3.38 st=   5.2
q0= 450.0 qa= 1.000 ka= 0.030 nf=    33 re= 0.097 mw=  3.15 f0=  3.47 st=   5.2
q0=  50.0 qa= 1.000 ka= 0.030 nf=    37 re= 0.097 mw=  3.35 f0=  6.22 st=  55.2
q0= 300.0 qa= 0.800 ka= 0.030 nf=    41 re= 0.097 mw=  3.12 f0=  3.71 st=   6.3
....
....
q0= 400.0 qa= 0.400 ka= 0.030 nf=    45 re= 0.103 mw=  3.05 f0=  4.36 st=   9.0
q0= 400.0 qa= 0.500 ka= 0.030 nf=    42 re= 0.103 mw=  3.08 f0=  4.15 st=   8.0
q0= 350.0 qa= 0.600 ka= 0.030 nf=    42 re= 0.103 mw=  3.09 f0=  4.27 st=   8.3
q0= 500.0 qa= 0.500 ka= 0.030 nf=    41 re= 0.104 mw=  3.09 f0=  3.97 st=   6.9
q0= 450.0 qa= 0.500 ka= 0.030 nf=    42 re= 0.104 mw=  3.08 f0=  4.17 st=   7.6
q0= 150.0 qa= 0.300 ka= 0.030 nf=    24 re= 0.104 mw=  3.34 f0=  4.19 st=  21.1
q0= 500.0 qa= 0.400 ka= 0.030 nf=    41 re= 0.105 mw=  3.08 f0=  4.12 st=   7.6
q0= 200.0 qa= 0.300 ka= 0.030 nf=    37 re= 0.106 mw=  3.18 f0=  5.38 st=  29.6
q0= 100.0 qa= 0.400 ka= 0.030 nf=    19 re= 0.108 mw=  3.34 f0=  4.16 st=  27.0
q0= 100.0 qa= 0.300 ka= 0.030 nf=    13 re= 0.109 mw=  3.32 f0=  4.54 st=  28.4
q0= 100.0 qa= 0.500 ka= 0.030 nf=    20 re= 0.112 mw=  3.33 f0=  4.69 st=  30.1
q0=  50.0 qa= 0.800 ka= 0.030 nf=    13 re= 0.112 mw=  3.26 f0=  6.09 st=  58.0
q0= 100.0 qa= 0.600 ka= 0.030 nf=    25 re= 0.112 mw=  3.26 f0=  5.31 st=  32.5
q0=  50.0 qa= 0.400 ka= 0.030 nf=     4 re= 0.114 mw=  3.47 f0=  6.04 st=  51.2


nf is the number of fits for each test, mw is average Mw,  f0 is average
corner frequency and st the average stress drop.
```

How to find the best Q-parmeters, use of program AVQ

```
avq
 File name, enter for automag_grid.out

 Min number of fits to use in average, enter for 1

q0=  50.0 qa= 0.500 ka= 0.030 nf=     5 re= 0.081 mw=  3.46 f0=  4.19 st=  42.0
q0=  50.0 qa= 0.600 ka= 0.030 nf=     8 re= 0.092 mw=  3.41 f0=  4.18 st=  31.8
q0= 100.0 qa= 0.900 ka= 0.030 nf=    50 re= 0.095 mw=  3.24 f0=  5.11 st=  26.4
q0= 150.0 qa= 0.900 ka= 0.030 nf=    49 re= 0.095 mw=  3.17 f0=  4.01 st=   9.3
q0= 100.0 qa= 1.000 ka= 0.030 nf=    51 re= 0.096 mw=  3.25 f0=  4.18 st=  13.1
q0=  50.0 qa= 0.300 ka= 0.030 nf=     4 re= 0.096 mw=  3.48 f0=  5.80 st=  45.3
q0= 200.0 qa= 0.800 ka= 0.030 nf=    47 re= 0.097 mw=  3.11 f0=  4.23 st=   9.0
```

```
q0= 300.0 qa= 1.100 ka= 0.030 nf=    33 re= 0.097 mw=  3.17 f0=  3.42 st=   5.4
q0= 400.0 qa= 1.000 ka= 0.030 nf=    33 re= 0.097 mw=  3.15 f0=  3.51 st=   5.4
q0= 500.0 qa= 0.900 ka= 0.030 nf=    33 re= 0.097 mw=  3.14 f0=  3.58 st=   5.5
...
...
q0= 500.0 qa= 0.400 ka= 0.030 nf=    41 re= 0.105 mw=  3.08 f0=  4.12 st=   7.6
q0= 200.0 qa= 0.300 ka= 0.030 nf=    37 re= 0.106 mw=  3.18 f0=  5.38 st=  29.6
q0= 100.0 qa= 0.400 ka= 0.030 nf=    19 re= 0.108 mw=  3.34 f0=  4.16 st=  27.0
q0= 100.0 qa= 0.300 ka= 0.030 nf=    13 re= 0.109 mw=  3.32 f0=  4.54 st=  28.4
q0= 100.0 qa= 0.500 ka= 0.030 nf=    20 re= 0.112 mw=  3.33 f0=  4.69 st=  30.1
q0=  50.0 qa= 0.800 ka= 0.030 nf=    13 re= 0.112 mw=  3.26 f0=  6.09 st=  58.0
q0= 100.0 qa= 0.600 ka= 0.030 nf=    25 re= 0.112 mw=  3.26 f0=  5.31 st=  32.5
q0=  50.0 qa= 0.400 ka= 0.030 nf=     4 re= 0.114 mw=  3.47 f0=  6.04 st=  51.2

  Number of curves to average:          90
 Running average over how many, enter for average of all?
20

Q0=  155.1 qalpha=  0.83 res= 0.096 mw=  3.22 f0=  4.31 avst=  18.4
Q0=  161.2 qalpha=  0.85 res= 0.097 mw=  3.20 f0=  4.28 avst=  16.6
Q0=  164.2 qalpha=  0.87 res= 0.097 mw=  3.19 f0=  4.26 avst=  15.4
Q0=  176.7 qalpha=  0.86 res= 0.097 mw=  3.18 f0=  4.18 avst=  14.4
Q0=  183.2 qalpha=  0.86 res= 0.097 mw=  3.18 f0=  4.16 avst=  14.2
Q0=  196.3 qalpha=  0.81 res= 0.097 mw=  3.18 f0=  4.22 avst=  14.7
Q0=  202.8 qalpha=  0.84 res= 0.097 mw=  3.16 f0=  4.10 avst=  12.7
...
...
Q0=  243.4 qalpha=  0.55 res= 0.102 mw=  3.13 f0=  4.52 avst=  14.2
Q0=  243.2 qalpha=  0.54 res= 0.102 mw=  3.13 f0=  4.54 avst=  14.2
Q0=  238.8 qalpha=  0.53 res= 0.102 mw=  3.14 f0=  4.50 avst=  14.4
Q0=  241.0 qalpha=  0.54 res= 0.102 mw=  3.13 f0=  4.47 avst=  14.0
Q0=  234.1 qalpha=  0.53 res= 0.103 mw=  3.14 f0=  4.53 avst=  15.0
Q0=  222.7 qalpha=  0.52 res= 0.103 mw=  3.15 f0=  4.52 avst=  15.9
Q0=  216.9 qalpha=  0.53 res= 0.103 mw=  3.16 f0=  4.49 avst=  16.2
Q0=  206.6 qalpha=  0.52 res= 0.104 mw=  3.17 f0=  4.51 avst=  17.3
Q0=  192.4 qalpha=  0.55 res= 0.104 mw=  3.18 f0=  4.56 avst=  19.2
Q0=  182.1 qalpha=  0.56 res= 0.105 mw=  3.18 f0=  4.58 avst=  20.0
Q0=  186.4 qalpha=  0.54 res= 0.106 mw=  3.20 f0=  4.59 avst=  20.8
```

It is seen that the average parameters, including residual, mw and corner frequecy now is a slowly varying function of the average residual. It is also seen that a high Q0 and a high qalpha give a better fit than a low q0 and a low qalpha. If some test have few good fits, they can be eliminated by usin the parameter " Min number of fits to use in average". In this example, 20 could have been used.

Example of the output automag.par file

```
 Ml constants:          1.000000  1.11 Component used:           Z
 Spectrum type:            S
 Spec dur. wa. window:         20.0    50.0
 Filter:                       0.05    0.00
 Max distance:               10000.0
 Start Q0, delQ,  nQ           100.0    50.0      15
 Start Qa, delQa, nQa           0.10    0.10      11
```

```
 Start ka, delka, nka          0.030   0.000       1
```

Hardwired parameters set in start of program
Default WA window: 50 s
Start 4 s before the S-time
Initial frequency range for spectral analysis: 0.05 to (sample rate)/2.5
WA period must be less than 5 s for results to be saved
Corner frequency must be larger than 0.05 for data to be used
The residual of the spectral fit must be smaller than 0.3 for spectral fit to be used
The Lg-velocy is 3.5 km/s
When doing grid search, the stress drop must be in the range 1-150 for the event to be used.
Parameters from parameter files

Q, kappa, density and velocity come from the spec model in SEISAN.DEF. If no spec model available, the model is taken from MULPLT.DEF. Notice that the frequecy dependence of Q from frequency lower than 1 Hz can only be set with the spectral model parameters in in SEISAN.DEF. See also MULPLT and SEISAN.DFF. if the parameter form MULPLT.DEF are used, Q is assumed constant=q0 below 1 Hz.

For explantion of the output of spectral parameters in the S-file, see MULPLT, spectral section.
The Ml constant are taken form STATION0.HYP
The Ml filter constants are taken from MULPLT.DEF
The spectra for one event can be plotted after running AUTOMAG, see program PLOSPEC.

21.5 PLOTSPEC

The program PLOTSPEC is plotting of spectra generated by AUTOMAG.

The command AM in EEV automatically generates the spectra for the corresponding event and read the maximum WA amplitudes. The automatic obtained parameters, within the error limits defined in AUTOMAG, are then saved in the S-file. In some cases, both the automatic spectral analysis and the automatic amplitude can fail. The spectra most often fail because the automatically determined frequency interval has been wrongly selected. The automatic amplitude can fail if the signal to noise ratio is high so amplitudes are determine in the noise. Manual analysis of course spot these problems at once but for the automatic analysis it is hard to judge if a deviating magnitude is real or caused by wrong analysis. PLOTSPEC can therefore plot all the accepted results for the automatic analysis for one event and it is easy to judge the results (see Figure 21.2). Determinations considered in error can then be deleted on the plot and will, when finishing the program, also be deleted in the S-file. The command in EEV to plot is PS.

Program operation

AUTOMAG generates a series of output files intended for plotting with names like BKS.BH_Z.noise, BKS.BH_Z.obs, BKS.BH_Z.synth. The station and component information for all accepted determinations are stored in the file AUTOMAG.list, see example below showing entries for the first 5 channels in Figure 21.2:

```
1996  625 0337 31.1 L  61.687   3.283 15.0  TES 31 2.0 3.3LTES 3.0CTES 3.2LNAO
FOO  S  Z
Ml=3.4 A=  1425 T=0.24
f= 0.09-20.00
Mw=3.5
 1996  625 0337 31.1 L  61.687   3.283 15.0  TES 31 2.0 3.3LTES 3.0CTES 3.2LNAO
SUE  S  Z
Ml=3.4 A=  1094 T=0.20
f= 0.49-20.00
Mw=3.3
 1996  625 0337 31.1 L  61.687   3.283 15.0  TES 31 2.0 3.3LTES 3.0CTES 3.2LNAO
OSG  S  Z
```

```
Ml=3.5 A=   941 T=3.58


 1996  625 0337 31.1 L  61.687   3.283 15.0  TES 31 2.0 3.3LTES 3.0CTES 3.2LNAO
HYA  S  Z
Ml=3.8 A=  1146 T=0.32
f= 0.09-20.00
Mw=3.6

f= 1.82-20.00
Mw=3.2
```

The first line is the header line from the S-file so it does not reflect the magnitudes calculated automatically until an update has been made. Second line is the station and component. Third line is local magnitude and corresponding amplitude (nm) and period(s). Fourth line the frequency interval used for the spectral fitting and the fifth line the moment magnitude. Values that could not be determined are left blank.

The plot has room for 15 pairs of spectra/WA traces. The fitted spectrum is plotted in red and for the WA trace, the trace between the two extremes used for the amplitude observation, is plotted in red. If either the spectrum or the WA-trace is not used for a particular component, the corresponding part of the plot is left blank. If there are more then 15 component plots, several pages can be plotted.

To delete a value, put the cursor in the corresponding plot square and press d. A diagonal line will appear in plot to indicate that a value is to be deleted. When terminating the program, the user will have to confirm the delete of all. There is no undelete option for single channels.

NOTE. Both spectral information and WA amplitudes can be deleted from the s-file with command DELS.

PLOTSPEC is intended to be used from EEV but it will also work outside EEV by giving command PLOTSPEC. The program will then look for the latest AUTOMAG.list in working directory and plot spectra for the FIRST event ONLY. If AUTOMAG has been used with many events, some of the results for the first event might have been overwritten if the same STAT-COMP is used in several events and will not be plotted. PLOTSPEC has one optional argument which is the S-file to use.

21.6 Detection program for continuous data, CONDET

The CONDET program is a detection program works on data that is organized in a SEISAN continuous database or a BUD or SeisComp archive. It performs a detection process similar to real-time processing systems, but of course the data is already there. The program works in two steps, first to run a detector on a single channel, and second to detect events that are on more than a minimum number of stations. Optionally, the detected events can be extracted, registered and copied into a data base. Possible applications are processing of data from a temporary deployment (e.g., aftershock monitoring, where continuous were recorded without event detection) and adjustment of detection parameters used in real-time monitoring.

The program has three built-in detection algorithms: 1) standard squared STA/LTA, 2) Carl Johnson's detector (that is for example used in the Earthworm processing system (`http://folkworm.ceri.memphis.edu/ew-doc/`) and 3) correlation with master event. The program writes out a list of detections (file `condet.out`, which gives station name, component code, trigger time and trigger duration), but also a batch file that can be used to extract the corresponding event data from the continuous data (file extract.batch). Note that wavetool by default takes data from all continuous databases listed in `SEISAN.DEF`.

Running step by step, first station detection, then event detection

When started without any command line options, the program works on all stations/databases given by the STATION parameter. The output file has detections from all stations, and the extract.batch file has extract commands for all detections. This is all required if only one station is available. For more than one station, it is possible to search for times at which more than a minimum number of stations have triggered. This is done by starting the program with the command line argument '-net'. In this mode, the output file `condet.out` from the first run is used and the file extract.batch is overwritten. The extract script can now be used to get data for the network detected events. The script can be sources in Unix, under windows

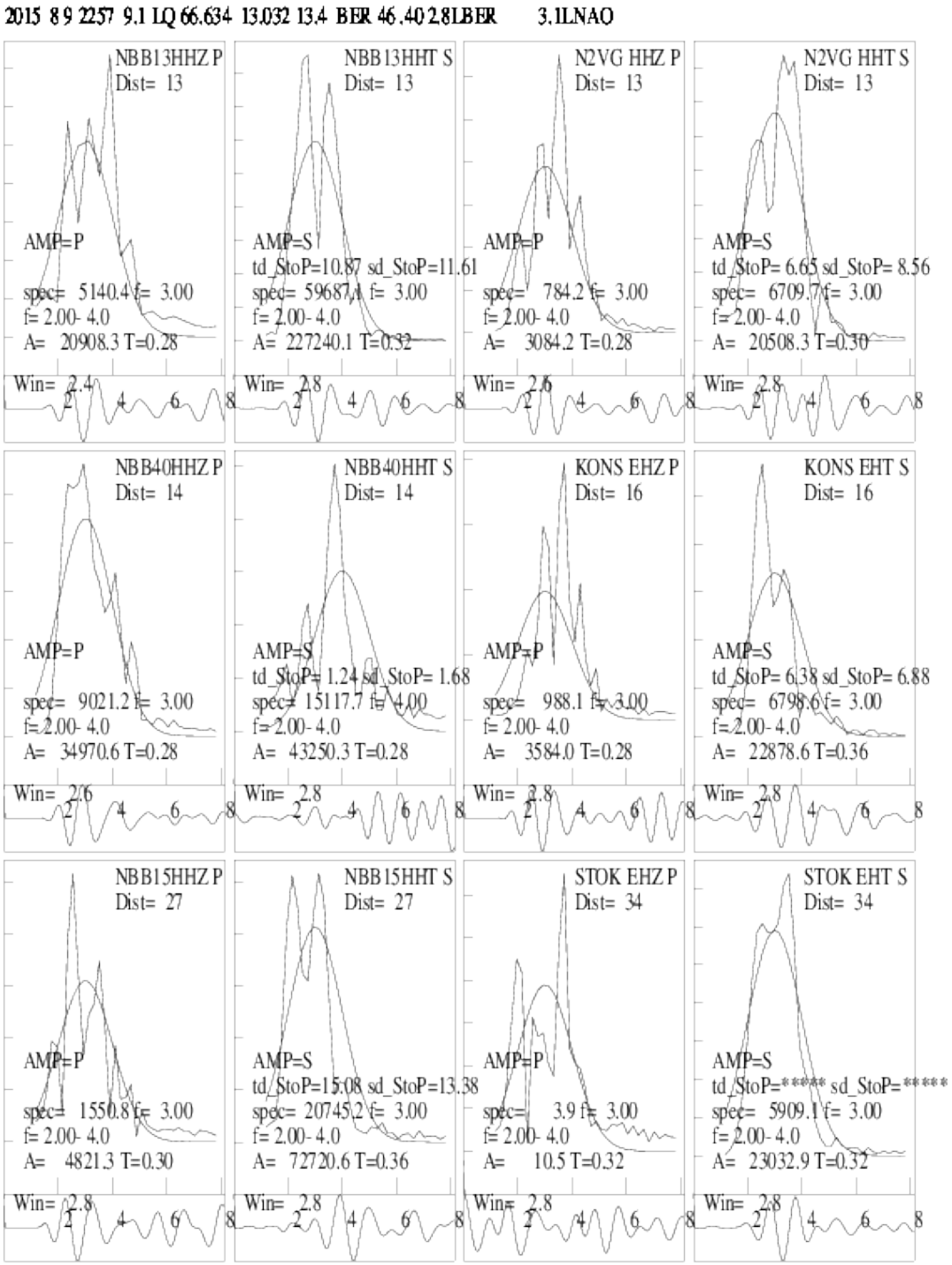


Figure 21.2: Plot using program PLOTSEC. The WA amplitude for OSG and spectral estimate for LOF have been deleted. The automatic fits are plotted in red. This event is found in the TEST_ database.

run comman in script or rename script to extract.bat and then run it. Condet is intended to run without questions and the parameter file condet.par must be in working directory or DAT. An example of condet.par is in DAT.

Running the whole process from station detection, event detecion, wave extraction and event registration.

The parameters in condet.par can be set up to run all or part of the detection process. This means that it is possible to detect the events, make the s-files and copy the waveform files to WAV with one command. This is partly done by running AUTORG from CONDET. This option can e.g. be useful for a network running SeisComP to get all CONDET detections into a database for daily processing.

Below is an example:

```
~/WOR/condet
 Give operator
jh
  Start time (yyyymmdd...), at least yyyymmdd
20210318
  Stop time (yyyymmdd...), at least yyyymmdd, blank is end of day
2021031803

....
....
....


       5 events detected within   50.0s on   3+ stations

Number of detections on all stations   81

YEAR MODA HR MM SEC NDET
2021 0318 00:05  30   12
2021 0318 01:57  21    3
2021 0318 02:03  25    3
2021 0318 02:40   3    4
2021 0318 03:12  36   11
```

A lot of listing comes out while running like missing channels. At the end there is a summary of what has been detected. In this case there were 81 detection on all stations and 5 events with more then 3 detections in window.

The input parameters are given in `condet.par`:

STATION: give continuous database name, station and component code. If an archive, the data base name is not used.

```
STATION                                LICOC       LICO  HH Z
STATION                                LIGLC       LIGL  HH Z
```

The BASE TYP is SEISAN (blank), Archive (arc)

```
BASE TYPE                              arc
STATION                                LIGLC       LIGL  HH Z
```

START DATE and STOP DATE: give time interval, can be larger than data availability

```
START DATE          yyyymmddhhmmss        200802270000
STOP DATE           yyyymmddhhmmss        200803122359
```

WAVEOUT: Set to 1. to write out waveform files with the original data and trigger channels.
EXTRACT DURATION: Length of extraction window in seconds, used in `extract.batch`
PRE EVENT TIME: Time to start extract before detection time in seconds, used in `extract.batch`

INTERVAL: Length of data segment read at a time. The default is 60 minutes.

DET ALGORITHM: choices for the detection algorithm are STA for squared STA/LTA, COR for correlation and CAR for Carl Johnson's detection algorithm

MIN TRIG DURATION: Minimum duration the trigger level needs to be exceeded for
MIN TRIG INTERVAL: Only allow for one detection within this time, given in seconds
FILTER LOW: Low cut for bandpass filter
FILTER HIGH: High cut for bandpass filter
If DET ALGORITHM is STA:
STA LENGTH: Short term duration in seconds
LTA LENGTH: Long term duration in seconds
TRIGGER RATIO: Ratio of STA/LTA required for trigger
DETRIGGER RATIO: Ratio to detrigger
FREEZE LTA: LTA can be frozen at time STA/LTA goes above TRIGGER RATIO, 1.=to freeze
If DET ALGORITHM is CAR, see Earthworm documentation for details:
CARL RATIO
CARL QUIET
If DET ALGORITHM is COR:
CORRELATION MIN: Minimum correlation between waveforms of master event and the data required for a trigger
MASTER WAVEFORM: Name of waveform file that is used as master event, the master event is cross-correlated against the continuous waveform data
Network detection parameters:
NET MIN DET: Minimum of detections required from different stations with time window given by
NET WINDOW SEC: Time window for network detection in seconds. NET MAX DELT SEC: Allows the user to specify the maximum time allowed between arrivals on two consecutive stations (in addition to the overall time window for all arrivals given in the preexisting NET WINDOW SEC NET MIN RATIO: Gives the minimum STA/LTA ratio to keep. This lets one use a low STA/LTA ratio in CONDET and then to explore which STA/LTA level to reject during the much faster "CONDET -NET" phase. EXTRACT DURATION: Duration(sec) of extract.
Extra parameters needed for automated operation

```
#
#  parameter needed if net detection
#  else not

NET DETECTION  0: no 1: yes             1.0
#
#  paramter needed if waw extraction,
#  else not
#
WAV EXTRACT 0: no extract, 1: extract   1.0
#
#  parameter need if s-files made after extraction
#  else not
#
MAKE SFILE 0: no, 1: yes                1.0
#
#   following 3 can be omited if all default
#
BASE SFILE, base for s-files, blank def
COPY WAV, move(m),copy(c), not(' ')     c
WAV BASE, ' ' WAV, or 5 letter
```

NET DETECTION: If set to 1.0, net detection will be run after station detection and there is no need to run again with -net flag.

WAV EXTRACT: if 1.0, wavforms will be extracted to working directory, one each time an event is found and the batch file is not used.

MAKE SFILE: An s-file in the data base is made.

BASE SFILE: The data base for the s-files, if blank, the default data base is used. A local data base ',,' can also be used.

COPY WAV: Optionally copy extracted waveform files to WAV. If blank, no copy, if m, file is moved and if c file is copied.

WAV BASE: If blank, copy to WAV, else to data base given. NOTE, the parameter COPY_WAV_DIR in SEISAN.DEF is not used, data base must be given here.

21.7 NETDET, event detection and location in real time or offline

Introduction

NETDET is a program for event detection and location of events. It can process data in near realtime from archived data streams (few minutes delay) or on time intervals given by the user. The program CONDET can detect and write out events from a SEISAN continuous data base but not in real time. Program NETDET does a similar job, but in near real time. While CONDET can use both archives and SEISAN style continuous data bases, NETDET can only use the SDS (SeisComP) or BUD archives and it can only use one archive. The only trigger option is STA/LTA. The program is intended to run on a Linux system and the included scripts for operation are for Linux but it can also work on Windows, however it has not been tested for realtime operation. The program can write out S-files and waveform files for triggered events, optionally repick phases with AUTOPIC and calculate magnitudes with AUTOMAG. The automatically located events can be display automatically on a map. A detected event can optionally be classified as a distant event if the signal to noise ratio of the triggers in the default frequency band 7-14 Hz is below 2 for 75% of the triggers. The frequency band can be be set in the parameter file. If set to 0.0 0.0, no distant event check is made. For a distant event no automatic picks and magnitudes can be made, however a location can optionally be made.

Requirements:

- Linux computer
- SEISAN
- Data in SDS or BUD archives
- Linux clock is synchronized using e.g. NTP
- Optimal: Google Earth
- Optimal: The Generic Mapping Tool (GMT)

How it works

Real time operation: The programs starts with getting the current GMT time from the operating computer and will then start reading data some minutes after real time as specified in the parameter file. Data availability in the archive is normally delayed a few minutes relative to real time, typically 2-5 minutes depending on where the data comes from. In addition, when an event is detected, a waveform file can be written so the longer that is, the longer delay is needed. If an ARC reference is used in the S-file, no waveform file is written out, so a shorter delay can be used.

One minute of data is read from all channels and used for detection. For each channel, triggers are found and stored in a ring buffer. The triggering is done using STA/LTA on filtered data. The trigger parameters

are then minimum STA/LTA ratio, minimum duration of trigger and minimum time since previous trigger for the same channel.

Optionally 3 different channel trigger sets can be used so the same data can be tested with e.g. 3 different filters and trigger ratios. All triggers for the different trigger sets are store in the same trigger ring buffer. For more details, see section on parameter file. In most operations only one trigger set would be used.

Once all channels have been processed for a one minute time window, the triggers for all trigger sets are checked for network detection (number of triggers in the array propagation window). If there are multiple triggers for the same station within the array propagation window, only the first one is used. The triggers do not have to be within the same minute just read in, since an event cannot be declared before the array propagation time has passed after the first trigger. If an event is declared, a corresponding S-file can be written out, if specified in parameter file. The S-file can be written in a specified data base. The S-file will by default have the ARC reference for the trigger time of the earliest trigger. However, a waveform file can also be written out (locally, in WAV or in WAV data base) and referenced in the S-file, in which case the ARC reference is deleted. The network code is given by parameter MERGE_WAVEFORM in SEISAN.DEF. The trigger times are written in the S-file and in this way one can see which channesl are triggering and where. A detected event will be classified as a distant event if the signal to noise ratio of the triggers in the frequency band 7-14 Hz is below 2 for 75

If the option to use AUTOPIC is used (if parmeter set and if enough triggers), by default no trigger times are written out since now the automatic picks from AUTOMAG are shown. However, if the AUTOPIC parameter is set to 2.0, the trigger times are kept as phase x. Optionally the event can be located (using the program HYP in reject mode), and optionally the magnitudes for local events can be calculated with

AUTOMAG program (Ml and Mw). Optionally, the phases for a local events can be repicked with AUTOPIC which often will give more phases and will in addition pick S-phases. Finally there is an option for sending out an email in case an event triggers with either a minimum number of stations, a location and/or a given minimum magnitude. These last options are not excecuted if the event is distant since the location often is not reliable and automag is not used for distant events.

NOTE THAT IN ALL CASES WHERE MINIMUM NUMBER OF STATIONS IS USED AS CRITERIA FOR AN OPERATION, IT IS THE MINIMUM NUMBER OF TRIGGERS AND NOT THE NUMBER OF STATION AFTER USING AUTOPIC THAT IS USED.

Real time operation can work in the background (cron job) or be started from the prompt. In that case the window cannot be closed. Several instances of NETDET can be started as cron jobs, each with a different parameter file.

After the network detection, the next minute is read and the process continues.

Temporary files are stored in the netdet directory. If not in real time and no directory given in parameter file, output is in working directory. If netdet dir is given in parameter file, then the temporary file are there. If running a cron job, a netdet directory must be given in the start script. This becomes the working directory. Then if a netdet dir is given in the parameter file, it must be the same. In the netdet directory there will be a file called parfile.err (like netdet.err) with messagaes of errors.

Other files made are parfile.now and parfile.html used for monitoring, also in the netdet directory. These file are only made if realtime operation.

Offline operation: In this case the user must give start time and end time and the program goes through the data base in given interval in a similar way as CONDET. There is then no option for sending email but S-files will always be output in one file, netdet.out, in addition to optional output in data base of S-files and WAV-files. The location and magnitude is only calculated for events going to the data base. The offline operation is useful for testing trigger parameters or for processing data which is not available in real time like aftershock data from a field experiment.

Installation

NETDET and corresponding scripts are part of SEISAN. The only additional requirement is that the directory SEISAN_TOP/CRON is created. The data bases for writing S-files and WAV files must be created manually. The script for starting NETDET has two versions, netdet_start.csh and netdet_start.bash and the relevant one must be edited to fit your environment. It can be given any name.

Data source

The data can come from a local SeisComP system or the data can be pulled from an available SeedLink server into a local archive using slarchive. `https://ds.iris.edu/ds/nodes/dmc/software/downloads/`

`slarchive/`

How to check trigger operation

When starting NETDET in real time mode from a terminal window, there will be a running output showing the readings each minute. If there is a crash or other malfunction, it will be shown. There is also a parameter in the parameter file that turns on debug details of the triggering process. The files are netdet_debug_trig.out and netdet_debug_sta_lta.out. The latter will only written if a specific station has been defined in the parameter file. Debug output is turned of in realtime mode to avoid filling up the disk. So to test for the best trigger parameters, the program can be operated in offline mode, as described above, and it can then be verified which parameter best trigger on known events in the given data interval.

Examples of netdet_debug_trig.out

In this file, a line is written each time one minute of data is read for one channel. When reading starts for the next minute, the message 'Read next minute' is given. If there is a trigger, a message 'Trigger now' is given. The trigger is then checked for duration, and if ok, the message 'Trigger ok with ratio and duration' is given and the trigger is accepted and put into trigger ring buffer. The trigger time is given as well as which parameter set is used (e.g. filt=2). When the detrigger takes place, a message is also given 'Detrigger now.' which can be due to ratio or duration. This message might come in the following minute.

Example with 3 filter sets and no events declared

```
DOMB  HHZ NS00 2022 01-01 12:59:40.0  100.0 10001
************************************************
HYA   HHZ NS00 2022 01-01 12:59:40.0  100.0 10001
************************************************
KMY   HHZ NS00 2022 01-01 12:59:40.0  100.0 10001
************************************************
SUE   HHZ NS00 2022 01-01 12:59:40.0  100.0 10001
************************************************
ODD1  HHZ NS00 2022 01-01 12:59:40.0  100.0 10001
************************************************
FOO   HHZ NS00 2022 01-01 12:59:40.0  100.0 10001
************************************************
HOMB  HHZ NS00 2022 01-01 12:59:40.0  100.0 10001
READ next minute  ******************************
************************************************
************************************************
ASK   HHZ NS00 2022 01-01 13:00:40.0  100.0 10001
Trigger now *************   01 13:01: 9.3  filt=2
Trigger ok with ratio and duration   ************
TRIGGER ACCEPTED *******************************
ASK   HHZ 2022 01-01 13:01: 9.3

Detrigger now due to ratio  01 13:01:29.4
Trigger now *************   01 13:01:59.4  filt=2
Trigger now *************   01 13:01: 7.1  filt=3
Trigger ok with ratio and duration   ************
TRIGGER ACCEPTED *******************************
ASK   HHZ 2022 01-01 13:01: 7.1
```

When an even is detected, the message 'NEW EVENT' is printed out together with the number of stations triggering. After that follows the content of the entire trigger buffer at that time where the trigger time, station, trigger status and filter set used are shown. Trigger status 0 means that the trigger has not yet been associated with a trigger from another station, 1 means that it has been associated but maybe not used and 2 means it is a duplicate and not used. In the example below, 3 stations triggered occurred within the array propagation window starting at (hour:minute:second) 13:04:19.7, on 1 January 2022. The first station is HYA, the next is ASK with trigger set 3, the next 2 from ASK are duplicates and not used and the third one used is DOMB.

```
SUE   HHZ NS00 2022 01-01 13:05:40.0  100.0 10001
***********************************************
ODD1  HHZ NS00 2022 01-01 13:05:40.0  100.0 10001
***********************************************
FOO   HHZ NS00 2022 01-01 13:05:40.0  100.0 10001
***********************************************
HOMB  HHZ NS00 2022 01-01 13:05:40.0  100.0 10001

NEW EVENT
2022 01-01 13:04:19.7  ndet=  3
2022 01-01 13:01:57.0 ASK   trig=2 filt=3
2022 01-01 13:01:58.5 FOO   trig=1 filt=3
2022 01-01 13:01:59.1 FOO   trig=2 filt=2
2022 01-01 13:01:59.3 FOO   trig=2 filt=1
2022 01-01 13:01:59.4 ASK   trig=1 filt=2
2022 01-01 13:02:30.8 HYA   trig=1 filt=3
2022 01-01 13:03: 4.0 ASK   trig=1 filt=3
2022 01-01 13:03:23.1 FOO   trig=1 filt=3
2022 01-01 13:03:31.6 ODD1  trig=1 filt=1
2022 01-01 13:03:31.7 ODD1  trig=2 filt=2
2022 01-01 13:03:43.3 ASK   trig=2 filt=3
2022 01-01 13:03:45.3 ASK   trig=2 filt=2
2022 01-01 13:04:19.7 HYA   trig=1 filt=3
2022 01-01 13:04:22.7 ASK   trig=1 filt=3
2022 01-01 13:04:22.9 ASK   trig=2 filt=2
2022 01-01 13:04:31.7 ASK   trig=2 filt=1
2022 01-01 13:04:56.8 DOMB  trig=1 filt=3
2022 01-01 13:06:46.4 ASK   trig=0 filt=3
2022 01-01 13:06:47.1 ASK   trig=0 filt=2
2022 01-01 13:06:48.8 DOMB  trig=0 filt=3
READ next minute  ******************************
***********************************************
```

The detailed triggering can also be check for one station and output is in file netdet_debug_sta_lta.out. For this to be written out, a station code must given in the parameter file in addition to setting the debug flag. An example is shown below.

```
BLS5  HHZ 01 13:05:50.0 STA=         1.2 LTA=         1.2 R=         1.0 Trig=                  F Fil
BLS5  HHZ 01 13:05:51.0 STA=         1.3 LTA=         1.2 R=         1.0 Trig=                  F Fil
BLS5  HHZ 01 13:05:52.0 STA=         1.4 LTA=         1.2 R=         1.1 Trig=                  F Fil
BLS5  HHZ 01 13:05:53.0 STA=         1.5 LTA=         1.2 R=         1.2 Trig=                  F Fil
BLS5  HHZ 01 13:05:54.0 STA=         2.0 LTA=         1.2 R=         1.6 Trig=                  F Fil
BLS5  HHZ 01 13:05:55.0 STA=         2.1 LTA=         1.3 R=         1.7 Trig=                  F Fil
BLS5  HHZ 01 13:05:56.0 STA=         1.6 LTA=         1.2 R=         1.3 Trig=                  F Fil
BLS5  HHZ 01 13:05:57.0 STA=         1.5 LTA=         1.2 R=         1.2 Trig=                  F Fil
BLS5  HHZ 01 13:05:58.0 STA=         1.3 LTA=         1.2 R=         1.0 Trig=                  F Fil
BLS5  HHZ 01 13:05:59.0 STA=         1.1 LTA=         1.2 R=         0.9 Trig=                  F Fil
BLS5  HHZ 01 13:06: 0.0 STA=         0.9 LTA=         1.2 R=         0.7 Trig=                  F Fil
BLS5  HHZ 01 13:05: 0.0 STA=         0.5 LTA=         0.5 R=         0.9 Trig=                  F Fil
BLS5  HHZ 01 13:05: 1.0 STA=         0.4 LTA=         0.5 R=         0.8 Trig=                  F Fil
BLS5  HHZ 01 13:05: 2.0 STA=         0.5 LTA=         0.5 R=         0.9 Trig=                  F Fil
BLS5  HHZ 01 13:05: 3.0 STA=         0.5 LTA=         0.5 R=         0.9 Trig=                  F Fil
BLS5  HHZ 01 13:05: 4.0 STA=         0.5 LTA=         0.5 R=         0.9 Trig=                  F Fil
BLS5  HHZ 01 13:05: 5.0 STA=         0.4 LTA=         0.5 R=         0.8 Trig=                  F Fil
BLS5  HHZ 01 13:05: 6.0 STA=         0.5 LTA=         0.5 R=         0.9 Trig=                  F Fil
```

```
BLS5  HHZ 01 13:05: 7.0 STA=         0.5 LTA=         0.5 R=         0.9 Trig=                    F Fi
BLS5  HHZ 01 13:05: 8.0 STA=         0.5 LTA=         0.5 R=         0.9 Trig=                    F Fi
```

For this particular station, for each second STA, LTA, trigger ratio (R), trigger status and parameter set is shown.

Sending email

The conditions for sending an email are minimum number of stations and/or minimum magnitude but there is no requirement for a location being present. However if magnitude is present, it is assumed that there is a location. If minimum magnitude is set to -1000.0, then only the requirement of minimum number of stations (triggers) is used since minimum magnitude is initilized to -999. The command for sending email as well as the email addresses to send to is defined in SEISAN.DEF. The command is the same as the one used by EEV while the email addresses are specified separately with the keyword ALERT_EMAIL_NETDET for sending the whole file and EMAIL_SUMMARY_NETDET for sending the summary file. An E-mail is not send if a distant event.

Output of S-file

In offline mode, all trigger S-files are written to one CAT file netdet.out. This is also the case if individual S-files are written. However, in real time operation, nothing is written to netdet.out since that file could be accumulating for a long time and eventually become very big. So only S-files are written to the data base which can be a local data base or a normal data base. The location and operator of readings will have the agency of the institution as given in netdet.par and the operator is net. In the S-file, the trigger times are labelled IP and can be used to make an initial location.

Running netdet

Offline mode: Just start NETDET with command netdet and you will asked for a time interval. NETDET will then start with the default parameter file netdet.par. Alternatively you can start with another parameter file with command netdet -parfile xx.par where xx.par is the parameter file. The parameter file must end with '.par'. The parameter file must be in local directory or DAT.

Real time interactive: Start by typing 'netdet realtime' and the program starts. There will be output for every minute on the screen. Here also an alternative parameter file can be chosen.

Cron job in the background: A script e.g. netdet_start located in COM is used to start NETDET. Use either the csh or bash version to make this file. It checks if NETDET is running and if not, it starts NETDET. For a cron job, the parameter file must be in DAT.

The parameter file name must be given, even if the default name, in order to distinguish different NETDET cron jobs. Note that the netdet_start has been renamed to the name without extension.

The csh scrip starting NETDET is

```
#!/bin/csh
#
#  directory where netdet is running, also set in netdet.par
#
cd /home/seismo/netdet
#
# start netdet if it is not running
# the file must be edited for your environment
#
#
# check if netdet is running
#
set check=‘ps ax | grep -v grep | grep "netdet realtime -parfile netdet.par" | wc -l‘

if ($check > 0) then
/usr/bin/echo "netdet with parameter file netdet.par is running"
else
/usr/bin/echo "netdet is not running, start again"
#
#   define env variables
```

```
#
source /home/s2000/seismo/COM/SEISAN.csh
#
#  start netdet
#
/home/seismo/PRO/netdet realtime -parfile netdet.par >/dev/null
#
#  send mail that it has been started
#
#/usr/bin/echo "netdet has been started" | /usr/bin/mailx -s "netdet startet"  mail.adr@gmail.com
#
/usr/bin/date >> /home/seismo/CRON/netdet.log
/usr/bin/echo "netdet started:" >> /home/seismo/CRON/netdet.log
/usr/bin/echo "netdet.par" >>/home/seismo/CRON/netdet.log
/usr/bin/echo " "
endif
```

In this script, a mail is sent to a user to inform that NETDET has started. Both the mail command and the mail address are hardwired and must be edited for your own system. If NETDET crashes, the user will then be informed within 5 min (example above) when NETDET starts again.

If you want to run 2 jobs at the same time, make another netdet_start with a different name and hardwire the new name of the parameter file like e.g. n.par. An example crontab file is then

```
#
*5/ * * * * /home/seismo/COM/netdet\_start2 > /dev/null 2>&1
*5/ * * * * /home/seismo/COM/netdet\_start1   /dev/null 2>&1
```

The netdet.log file only contains the start time of the cron jobs for all jobs running like

```
Fri Jan 21 18:55:46 CET 2022
netdet started:
netdet.par
Sat Jan 22 08:45:42 CET 2022
netdet started:
ne.par
Mon Jan 24 10:17:09 CET 2022
netdet started:
netdet.par
```

Example of the bash file for starting netdet

```
#!/bin/bash
#
#  directory where netdet is running, also set in netdet.par
#
cd /home/seismo/netdet
#
# start netdet if it is not running
#
#
# check if netdet is running
#
if ps ax | grep -v grep | grep "netdet realtime -parfile netdet.par"
then
/usr/bin/echo "netdet is running"
```

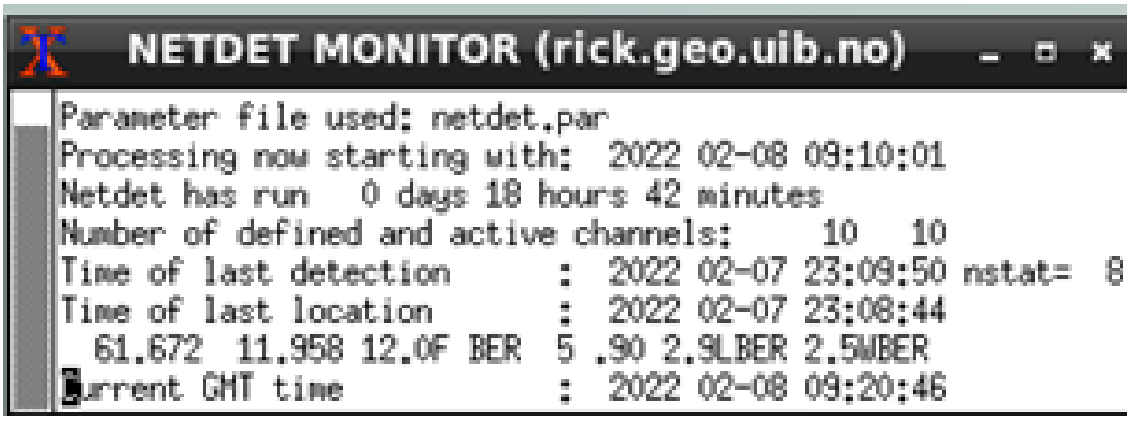


Figure 21.3: Status in the NETDET MONITOR.

```
else
/usr/bin/echo "netdet is not running, start again"

#
#   define env variables
#
source /home/seismo/COM/SEISAN.bash
#
#  start netdet
#
/home/seismo/PRO/netdet realtime -parfile netdet.par >/dev/null
#
#  send mail that it has been started
#
/usr/bin/echo "netdet has been started" | /usr/bin/mailx -s "netdet startet"  mail.adr@gmail.com
#
/usr/bin/echo "netdet started:" >> /home/seismo/CRON/netdet.log
/usr/bin/echo "netdet.par" >>/home/seismo/CRON/netdet.log
/usr/bin/date >> /home/seismo/CRON/netdet.log
fi
#
```

Monitoring realtime netdet

A script will start a small monitoring window (requires X-windows). Type netdet_monitor and you get:

For netdet with parameter file n.par type `netdet n`.

The window will stay up as long as the screen is on. The lines show the parameter file used, the time of the current data being processed, how long NETDET has been running,the number of channels defined for triggering, the number of channels actually received, the time of the last detection with number of stations triggering, the time of the last location, the last location and magnitude and the current GMT time. The number of active channels could be less than the number of defined channels if a station is out or the time delay is larger than given in parameter file. If NETDET stops running, the message NETDET IS NOT RUNNING will appear on the top. When a new detection occurs, a beep will sound. By default, the window corresponding to netdet.par is shown. If another process using parameter file n.par is used, type netdet_monitor n to get up a window for that process. It is also possible to get up the same data in a non graphics window. Then use command netdet_display for netdet.par or netdet_display n for n.par. The same data is also visible with a browser The html file netdet used for displaying the statuss in a browser is described in the section below named 'NETDET in a browser' .

If data is written out to a data base, and EEV is active, one can check for new events in the data base

with EEV command up.

In case we see that the process starts frequently, then something is wrong. To find the problem, either run NETDET offline for the same time period or use interactive NETDET.

NETDET cronjobs running can be found with command netdet_check, which also can be used to stop a job.

```
**********netdet jobs running**********

 1  netdet realtime -parfile netdet.par
 2  netdet realtime -parfile n.par

Delete job, enter which one, enter to stop
```

```
Changing the parameters
```

If the parameters have to be changed while in real time operation, first change the parameter file and the stop NETDET with netdet_check. NETDET will then start up again at the time given in the crontab file.

Parameter file

The parameter file can be located in local directory or in DAT. The file name must end with '.par' and the default name is netdet.par. If the parameter file is in the local directory (where NETDET is started), that file will be used instead of file in DAT. The parameters will be written out on the screen when NETDET is started so that is a way of checking that they have been entered correctly.

The channels of the network must be defined in SEISAN.DEF and it is important that both location and network codes are correct and identical in SEISAN.DEF and netdet.par.

Channels to be written out can be given separately (CHAN OUT parameter). If none are given, all channels defined in SEISAN.DEF are written out.

The channel detection can be made with up to 3 different sets of trigger parameters, namely filter, STA, LTA, minimum trigger duration, minimum trigger interval, trigger ratio and detrigger ratio. The number of trigger sets are defined by how many filter sets are given since the most common parameter to set differently is the filter. So if e.g. 2 sets will be used with only the filter as a difference, only the two filters are given and other parameters will be given identical to the parameters for the first filter. In general, one trigger set is used.

The parameter file is intended to be self-explanatory, an example is shown below.

```
#
# netdet.par: netdet input parameter file, comments can be added to this file,
#              but the comments must not match a KEYWORD
#
#
#

KEYWORD............Comments.............Par 1.....Par 2
#
#   the network agency and operator, 3 chars
#
#.....................................1.........2........
AGENCY                                  TES       jh
#.....................................xxxxxxxxxxxxxxxxxx
#
#   directory for netdet temporary files,
#   must be given also in netdet_start
#   script, 40 chars
#   if not given, WOR will be used
#
#.....................................1.................................
```

```
NETDET DIR                              /home/s2000/seismo/netdet
#.....................................xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
#
#   Debug and station to debug. Set
#   debug to 1.0 if debugging. Station
#   can be blank if no STA/LTA output
#   for that station. Debug will be
#   turned off in real time mode.
#
#.....................................1.........2.......
DEBUG                                   0.0       FOO
#.....................................xxxxxxxxxxxxxxxxxx

#
# Channels used for triggering
#
# station, component, network, location
#
#.....................................1.........2.......
CHANNEL TRIG                            ASK       HHZNS00
CHANNEL TRIG                            BER       HHZNS00
CHANNEL TRIG                            BLS5      HHZNS00
CHANNEL TRIG                            DOMB      HHZNS00
CHANNEL TRIG                            HYA       HHZNS00
CHANNEL TRIG                            KMY       HHZNS00
CHANNEL TRIG                            SUE       HHZNS00
CHANNEL TRIG                            ODD1      HHZNS00
CHANNEL TRIG                            FOO       HHZNS00
CHANNEL TRIG                            HOMB      HHZNS00
#
# Channels used for output, if none, all
# in achive will be used
#
# station, component, network, location
#
#.....................................1.........2.......
#CHANNEL OUT                             ASK       HHZNS00
#CHANNEL OUT                             BER       HHZNS00
#CHANNEL OUT                             BLS5      HHZNS00
#.....................................xxxxxxxxxxxxxxxxx



#
########################################
#  delay to start data collection
#  relative to GMT, usually minimum
#  300 s
########################################
#
#.....................................1.........
REAL TIME DELAY                         600.0
#.....................................xxxxxxxxxx
#
```

```
########################################
# channel trigger parameters
########################################
#
# length of short term average
#
#.....................................1.........2.........3.........
STA LENGTH         in seconds           03.
#.....................................xxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
#
# length of long term average
#
#.....................................1.........2.........3.........
LTA LENGTH         in seconds           300.
#.....................................xxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
#
# minimum trigger duration
#
#.....................................1.........2.........3.........
MIN TRIG DURATION  in seconds           5.
#.....................................xxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
#
# time to next trigger must be least
# this number
#
#.....................................1.........
MIN TRIG INTERVAL                       30.
#.....................................xxxxxxxxxx
#
# frequency limits of filter, 0 for
# no filter
#
#.....................................1.........2........3.........
FILTER LOW                              2.0
FILTER HIGH                             7.0
#.....................................xxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
#
# trigger and detrigger ratios
#
#.....................................1.........
TRIGGER RATIO                           3.
DETRIGGER RATIO                         2.
#.....................................xxxxxxxxxx
#
# keep LTA during trigger flag up,
# currently not implemented.
# 1.0 keep LTA, blank or 0.0 do not use
#
#.....................................1.........
FREEZE LTA                              0.
#.....................................xxxxxxxxxx
#
########################################
# network detection
```

```
########################################
#
# minimum number of detections in array
# propagation window
#
#.....................................1.........
NET MIN DET                           3.
#.....................................xxxxxxxxxx
#
# arrary propagation window
#
#.....................................1.........
NET WINDOW SEC                        50.
#.....................................xxxxxxxxxx
#
# filter band for detecing distant
# event. if blank, 7-14Hz is used, if
# 0.0 0.0, no test for distant event.
#.....................................1........ 2........
FILTER DISTANT                        0.0       0.0
#.....................................xxxxxxxxxxxxxxxxxx
#
########################################
# waveform data extraction
########################################
#
# extract waveform blank or 0.0: no, 1: yes
# if blank or 0.0, an ARC reference is made,
# the ARC reference is removed if 1.0.
# WAV files can be made even if S-files
# are not made. waveform files are made
# in current directory. can be moved
# or copied elsewhere, see COPY WAV.
#
#.....................................1.........
WAV EXTRACT                           1.0
#.....................................xxxxxxxxxx
#
# pre event time when extracting or
# setting ARC reference
#
#.....................................1.........
PRE EVENT TIME                        60.
#.....................................xxxxxxxxxx
#
# duration if extraction, also duration
# for ARC reference
#
#.....................................1.........
EXTRACT DURATION                      300.
#.....................................xxxxxxxxxx
#
#  if a wav file extract, where to copy
#  or move the file as given by COPY WAV
```

```
#  blank: working directory
#  m: move file, c: copy file
#
#.....................................1.........
COPY WAV                              m
#.....................................xxxxxxxxxx
#
#  where to write WAV file if move or copy
#  blank: WAV directory
#  1-5 letter:  WAV data base directory
#
#.....................................1.........
WAV BASE                              TEST
#.....................................xxxxxxxxxx
#
########################################
# making S-files
########################################
#
#  parameter needed if s-files are made
#  in addition to a cat file with all
#  events. the cat file is not made in
#  real time mode so in that case
#  the  S-file flag must be set to
#  get S-files.
#  0.0 or blank: no S-files
#  1.0 : make S-files
#
#.....................................1.........
MAKE SFILE                            1.0
#.....................................xxxxxxxxxx
#
#  base for S-files.
#  blank     : def base
#  1-5 letter: data base
#  ,,        : local data base
#
#.....................................1.........
BASE SFILE                            TEST
#.....................................xxxxxxxxxx
#
########################################
# Real time location and email
########################################
#
#  pick phases with AUTOPIC (1.0), if
#  not netdet triggers are used.
#
#.....................................1........
AUTOPIC                               1.0
#.....................................xxxxxxxxx
#
#  min. number of stats. for location
#  of local events
```

```
#
#.....................................1.........
MIN STAT LOCATION LOCAL                 4.00
#.....................................xxxxxxxxxx
#
#  min. number of stats. for location
#  of distant events
#
#.....................................1.........
MIN STAT LOCATION DIST                  99.0
#.....................................xxxxxxxxxx
#
#
#  fix location depth:
#  blank or < 0: do not fix
#  if ge 0.0   :  fix to that depth
#
#.....................................1........
FIX DEPTH                               12.0
#.....................................xxxxxxxx
#
#  min. number of station for email
#
#.....................................1.........
MIN STAT EMAIL                          99.0
#.....................................xxxxxxxxxx
#
#  excute a command after location,
#  like making a map
#
#.....................................1............................
COMMAND
#.....................................xxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
#
#  min. magnitude for email in addition
#  to minimum number of stationss. If
#  magnitude not used, set to -1000,
#  then only number of stations is
#  used. More mail parameters in
#  SEISAN.DEF
#
#.....................................1.........
MIN MAG EMAIL                           2.0
#.....................................xxxxxxxxxx
#
########################################
#  the end
########################################
```

SLARCHIVE example

In this part an example is given on how to run the SLARCHIVE program as a cron job on a linux server. SLARCHIVA can e.g. be downloaded from

`https://ds.iris.edu/ds/nodes/dmc/software/downloads/slarchive/`

One can as an alternative to the example below e.g. use a seiscomp server.

The example below shown how to stream data from IRIS and GEOFON. Here SLARCHIVE from IRIS is installed in the folder /home/seismo/PRO.

Setup the cron job to make sure SLARCHIVE is running and check every 5 minute, by adding this line to the users crontab:

```
*/5 * * * * /home/seismo/COM/autorun-slarchive.sh 2>&1
```

This is the script autorun-slarchive.sh used to run SLARCHIVE, it will restart SLARCHIVE if it has stopped. The script is here given using the SH shell, other shells will work too:

```
#!/usr/bin/sh
#
echo This script will dump mseed data from several seedlink servers to a SDS archive, in real time.
echo The script makes sure that all subscripts are running at all times. See crontab.
echo ----
date
echo $0
uname -a
echo ----

#
SLA="Slarchive IRIS"
SSH="slarchive -k 704"
SSH_PID="‘ps -efa | grep "$SSH" | grep -v grep | tr -s ’ ’ ’ ’ | cut -d ’ ’ -f 3‘"
if [ $SSH_PID ]; then
echo $SLA is running
else
date
echo $SLA is NOT running, starting $SLA ...
/home/seismo/PRO/slarchive -k 704 -l /home/seismo/DAT/streamlist.iris -SDS /home/seismo/archive rtserve
fi
#

SLA="Slarchive GEOFON"
SSH="slarchive -k 705"
SSH_PID="‘ps -efa | grep "$SSH" | grep -v grep | tr -s ’ ’ ’ ’ | cut -d ’ ’ -f 3‘"
if [ $SSH_PID ]; then
echo $SLA is running
else
date
echo $SLA is NOT running, starting $SLA ...
/home/seismo/PRO/slarchive -k 705 -l /home/seismo/DAT/streamlist.geofon -SDS /home/seismo/archive 139.1
fi

##
echo ------------------------------------------------------------------
echo REMEMBER TO remove old archive files, if needed
#/usr/bin/find /home/seismo/SDS/2022 -type f -mtime +26 -exec rm {} \;
#echo remove old archive folders
#/usr/bin/find /home/ seismo/SDS/2022 -type d -empty -delete
#echo Done $0
echo ------------------------------------------------------------------

exit 0
```

```
#EOF
```

The two input files giving the network and station codes requested from the IRIS and GEOFON seedlink servers:

```
NU BILN
NU CARN
NU RIBN
TC DRK0
TC PTJ1
TC TCS1
TC TRT2
SV CEDA
SV CNCH

NU ACON
NU BLUN
NU BOAB
NU ESPN
```

Add other stations or seedlings servers to improve the monitoring in your area.

Fit the paths given above so that they fit your system.

Once the cron job is started, data will be found in the /home/seismo/SDS folder.

Find more information on SLARCHIVE at:

`https://ds.iris.edu/ds/nodes/dmc/software/downloads/slarchive/2-2/manual/`

NETDET in a browser

NETDET will create a netdet.html file in the working folder. The html file is updated every minute with new information on the last detection.

An example on the NETDET html file is seen in a browser above. In addition the html file can display the epicentre on a map, but his requires that a command program or script is executed by NETDET (see COMMAND in the parameter file). In the example below, found in COM, is shown an example of a Linux script using SEISAN and GMT to create the map file.

```
COMMAND                                /home/seismo/COM/plot-netdet.gmt
#.....................................xxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
```

The script plot-netdet.gmt is found in COM and is as follows:

```
#!/bin/ksh
#
# script to map epicenters from the SEISAN netdet program
# works with GMT - The Generic Mapping Tools, Version 6.1.1
# (c) 2022 peter voss
#

cd /home/seismo/netdet
echo $0 > plot-netdet.log
date >> plot-netdet.log

echo run seigmt
printf "hyp.out\n\n0.1\n" | seigmt
echo done seigmt



AP="-R-100.0/-75.0/5.0/18.0 -JM9c"
```

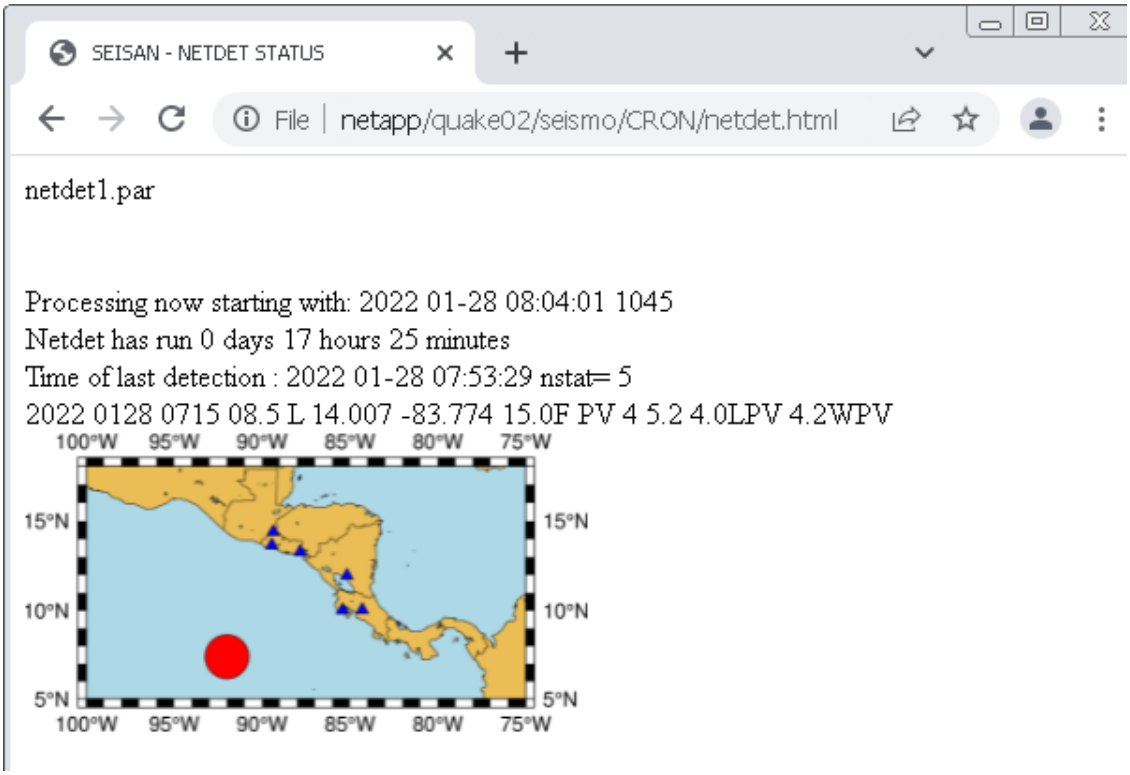


Figure 21.4: NETDET Status in a browser.

```
gmt begin netdet_map png
    gmt coast -Wthinnest -Dl -N1 $AP -B -Slightblue -Glightbrown --FORMAT_GEO_MAP=dddF
    gmt plot gmtstxy.out -St0.3 -Wthinnest -Gblue
    gmt plot gmtxy.out  -Sc -Wthinnest -Gred
gmt end

echo ------------------------------ >> plot-netdet.log

#EOF
```

Execute the code and inspect the file netdet_map.png with a image viewer. If the map does not show the area of your network, change the area in the AP line, where

```
AP="-Rminlon/maxlon/minlat/maxlat -JM9c"
```

Further details on the GMT commands are given in the GMT documentation, see https://docs.generic-mapping-tools.org

21.8 SCPNOR, getting detections from SeisComp in real time or manually

SCPNOR The program SCPNOR has the purpose to extract event parameter data from SeisComP (SCP) and put them into Nordic format. The program can operate in two ways:

(1) Extract events at a given time interval and output the events in one file and/or in a SEISAN data base.

(2) Extract events from the current time and a given time back in time (instant-time), the instant option.

This option can be set up as a cron job and can therefore maintain a SEISAN data base of SCP events close to real time depending on the cron parameters set up. In this mode, the program can optionally also maintain a second SEISAN data base with only the events instant-time back. This option can be use to e.g. a web page which should only use data for a limited time back. In order to keep track of what already has been copied, a file scpnor.instant in the working directory will keep track of what already has been copied.

Requirements:

- Linux computer
- SEISAN
- Acces to SeisComP program and data base

If operating close to real time like getting data every 2 minutes, SCP can make several solutions before the final solution. Within the time window defined as instant-time back, all duplicate solutions will be deleted.

Plotting waveforms and getting waveform files

The data from SCP available in a SEISAN data base can be plotted provided the SCP archive is available to SEISAN and the channel parameters are set up in SEISAN.DEF for plotting with or without the ARC line in the s-file. The ARC line can optionally be written in the S-file. If just a file of events has been obtained, the corresponding waveform files can be extracted with program GET_ARC and a new cat file is made with links to the extracted waveform files.

A more complete option for getting data files from SCP is the SC2SEI system found at https://www.geo.uib.no/seismo/SOF

Program operation

The program is first getting the event IDs from SCP in the given time interval, using SCP command scevtls, and thus creating a file newids.txt. Using that list, parameter information is extracted to file event using a modified version of SCP command scbulletin. The modified program is scbul4.py for SCP version 4 and 5 and scbul3.py for SCP version 3, both are included in PRO. These scripts must be executable. The SCP id is stored in the S-file.

The output from the bulletin program is then converted to Nordic format. The program uses a parameter file, see an example later. The program can only operate if there is access to SCP commands and the SCP relation data base data base of parameters.

Program operation The program is first getting the event IDs from SCP in the given time interval, using SCP command scevtls, and thus creating a file newids.txt. Using that list, parameter information is extracted to file event using a modified version of SCP command scbulletin. The modified program is scbul4.py for SCP version 4 and 5 and scbul3.py for SCP version 3, both are included in PRO. The SCP id is stored in the S-file. The output from the bulletin program is then converted to Nordic format. The program uses a parameter file, see an example later. The program can only operate if there is access to SCP commands and the SCP relation data base data base of parameters.

Example option 1

```
scpnor
seiscomp version   4
sql user:          seiscomp
sql pass:          xxx1922scmp
sql ip  :          localhost
sql data base      seiscomp
make s-file        T
insert ARC line    T
wa gain            2800.0
sfile data base    SCP
sfile 2. data base SCP2
agency operator    SCP sc
instant time back  1440.0
```

```
Give start time, at least year, yyymmddhhmmss
20230115
 Give end time, at least year, month and day, yyyymmddhhmmss
 or give number of hours from start like 2 or 0.2
24
begin: "2023-01-15 00:00:00"
end:   "2023-01-16 00:00:00"
scevtls -d mysql://seiscomp:xxx1922scmp@localhost/seiscomp --begin "2023-01-15 00:00:00" --end "2023-01
 Number of event ids           5
scbul4.py -d mysql://seiscomp:xxx1922scmp@localhost/seiscomp -E nsn2023azyq -3 -e -p > event
  first sfile:   /home/seiscomp/seismo/REA/SCP__/2023/01/15-0404-21L.S202301
scbul4.py -d mysql://seiscomp:xxx1922scmp@localhost/seiscomp -E nsn2023baau -3 -e -p > event
  first sfile:   /home/seiscomp/seismo/REA/SCP__/2023/01/15-0505-49L.S202301
scbul4.py -d mysql://seiscomp:xxx1922scmp@localhost/seiscomp -E nsn2023bbct -3 -e -p > event
  first sfile:   /home/seiscomp/seismo/REA/SCP__/2023/01/15-2000-06L.S202301
scbul4.py -d mysql://seiscomp:xxx1922scmp@localhost/seiscomp -E nsn2023bbfv -3 -e -p > event
  first sfile:   /home/seiscomp/seismo/REA/SCP__/2023/01/15-2103-07L.S202301
scbul4.py -d mysql://seiscomp:xxx1922scmp@localhost/seiscomp -E nsn2023bbhp -3 -e -p > event
  first sfile:   /home/seiscomp/seismo/REA/SCP__/2023/01/15-2203-02L.S202301
```

In this example, data is collected for 24h and 5 events were found. The first output is a summary of the parameter file. Although a second data base is defined, no data is collected for the second data base since the instant option is not used. Output is in scpnor.out and data base SEISAN SCP.

Example option 2

```
scpnor instant
seiscomp version   4
sql user:          seiscomp
sql pass:          xxx1922scmp
sql ip  :          localhost
sql data base      seiscomp
make s-file        T
insert ARC line    T
wa gain            2800.0
sfile data base    SCP
sfile 2. data base SCP2
agency operator    SCP sc
instant time back  1440.0

 number of instant events           3
begin: "2023-02-15 13:19:00"
end:   "2023-02-16 13:24:00"
scevtls -d mysql://seiscomp:xxx1922scmp@localhost/seiscomp --begin "2023-02-15 13:19:00" --end "2023-02
 Number of event ids           3
scbul4.py -d mysql://seiscomp:xxx1922scmp@localhost/seiscomp -E nsn2023dgmv -3 -e -p > event
 sfile already written
scbul4.py -d mysql://seiscomp:xxx1922scmp@localhost/seiscomp -E nsn2023dgrj -3 -e -p > event
 sfile already written
scbul4.py -d mysql://seiscomp:xxx1922scmp@localhost/seiscomp -E nsn2023dgun -3 -e -p > event
 sfile already written
```

In this example, data will be collected for the last 24 h. There were already 3 events collected before and the 3 checked are the same so nothing is copied to the SEISAN data bases. However, the 3 events are listed in scpnor.out.

Data converted

SCPNOR reads most if the data in the SCP output file event. For magnitudes, only amplitudes for ML and Mb are transferred. For the IAML amplitudes, they are converted from mm Wood Anderson to nm. SCP by default uses the wrong Wood Anderson gain of 2800 (see SCP setup) but can also use the correct 2080 (Uhrhammer and Collins,1990) In the SCPNOR parameter file, the gain used by SCP can be set in the SCP configuration. SCP does not give a period for IAML and since SEISAN needs a period to judge if the reading is within a correct period range, a fixed period of 1.0 s is used.

Example of a script for the cron job. It could be started e.g. every 5 minutes.

```
#!/bin/bash
#
#   directory where scpnor is running
#
cd /home/seiscomp/seismo/scpnor
#
#
#   define env variables
#
source /home/seiscomp/.bashrc
#
#  start scpnor
#
/home/seiscomp/seismo/PRO/scpnor instant  >/dev/null
#
#  put info in log file
#
/usr/bin/date > /home/seiscomp/seismo/scpnor/scpnor.log
/usr/bin/echo "scpnor started:" >> /home/seiscomp/seismo/scpnor/scpnor.log
```

Parameter file scpnor.par

The parameter file is intended to be self-explanatory. It can be placed in working directory or DAT. An example is seen below:

```
#
#   parameter file for scpnor
#
#   KEYWORD identifies the parameter and up to 2 parameters
#   can be given. They are given in column 41 to 50 and
#   51 to 60 respectively. Numbers can be anywhere in the
#   fields but characters must start in 41 or 51
#   respectively. If blank, a default is used.
#
KEYWORD.....Comments.....Par 1.....Par 2
#
#
########################################
#.....................................
#
#   SeisComp version, 3, 4 or 5
#   4 is default and also works with 5
#
#.....................................1.........2........
SEISCOMP VERSION                      4
```

```
#.....................................xxxxxxxxxxxxxxxxxx
#
#   the network agency and operator,
#   3 chars, default SCP and sc
#
#.....................................1.........2........
AGENCY
#.....................................xxxxxxxxxxxxxxxxxx
#
#
#######################################
#  parameter for sql data base
#######################################
#
#.............................................
#
#  sql user name
#
#.....................................1.........
SQL USER                              seiscomp
#.....................................xxxxxxxxxx
#
# sql password
#
#.....................................1.........................
SQL PASS                              xxx1922scmp
#.....................................xxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
#
# sql data base
#
#.....................................1.........................
SQL DATABASE                          seiscomp
#.....................................xxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
#
# sql ip number
#
#.....................................1.........................
SQL IP                                localhost
#.....................................xxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
#
# in instant mode, give number of
# minutes back from real time (UTC)
# from which to start data collection
#
#.....................................1........
INSTANT TIME BACK                     1440.0
#.....................................xxxxxxxx
#
# put 1.0 if making an S-file, else 0.0
#
#.....................................1.........
MAKE SFILE                            1.0
#.....................................xxxxxxxxxx
#
```

```
#  base for S-files.
#  blank     : def base
#  1-5 letter: data base
#  ,,        : local data base
#  this base is used with instant
#  operation  where data is added
#  INSTAT TIME BACK
#  or for normal operation when
#  instant is not selected. All
#  data collected is stored here.
#
#.....................................1.........
BASE SFILE                            SCP
#.....................................xxxxxxxxxx
#
# insert ARC line (1.0), default is no
# ARC line (blank or 0.0)
#
#.....................................1.........
INSERT ARC LINE                       1.0
#.....................................xxxxxxxxxx
#
# seiscomp wood anderson gain, default
# is 2800 (blank) or 2080

#.....................................1.........
WOOD ANDERSON GAIN
#.....................................xxxxxxxxxx
#
#  for instant operation only:
#  second base for S-files where only
#  s-files for instant time back are
#  kept.
#
#  blank     : no second base
#  1-5 letter: data base
#  ,,        : local data base
#
#.....................................1.........
SECOND BASE SFILE                     SCP2
#.....................................xxxxxxxxxx
#
#
########################################
#  the end
########q################################
```

Chapter 22

Calculating b-value, BVALUE

BVALUE is a program to make b-value plots using a NORDIC input file (also compact). The magnitude is selected among all magnitudes on all header lines, but when the first is found, no more are searched for. So only one value is used for each event. A magnitude agency can be specified for the magnitude selection.

Magnitudes can be in the range -2 to 8.

A postscript plot file is generated.

The questions are:

```
 Input file name, select.out or collect.out are defaults
    ! Give filename or return
 Which magnitude type, C,L,B,W or S, return for no type
    ! C: coda, L: Ml, B: mb and S: surface wave magnitude, W: Moment mag.
         blank: no magnitude type
 Magnitude agency, enter for any

 Output:
 Number of events selected from file:    91
Duration of catalog in years: 0.502

    ! Output number of events selected and duration of catalog
 New input:
 Magnitude step 1.0, 0.5, 0.25, 0.2 or 0.1
    ! Magnitude step for summing number of events, MUST be one of the above.
 Magnitude range m1,m2 for b value and fixed b-value
    ! Range for calculating b value, and the fixed b-value for which a-value
is calculated. The a value is calculated as the average of N(i) + bfix * mag(i),
where N(i) is the accumulated number of events at magnitude
mag(i) and bfix is the fixed bvalue.

 Output is now:
      n    m1    m2 maxl a maxl b   sd  lsq a  lsq b   cor    rms   bfix   afix   sd
     52    2.0  4.0 3.25     0.68 0.46   3.77   0.93  0.93   0.14    1.0   4.02 0.16
 Normalized         3.55                4.07                            4.32
 Normalized m1      2.19                2.21                            2.32
 Norm. lin. m1     154.9               162.2                           208.9

! Normalized means normalized to one year (m=0), Normalized m1 (m=m1)
and Norm. lin. m1 is just antilog the previous. So in the above example,
it is expected that 162.2 earthquakes occur larger than or equal to 2
```

```
in one year (least squares relation).


   mag  nmag  cmag
    0.4     1    91
    0.6     1    90
    0.8     3    89
    1.0     6    86
    1.2     6    80
    1.4     7    74
    1.6     4    67
    1.8    11    63
    2.0     8    52
    2.2    11    44
    2.4     6    33
    2.6     7    27
    2.8     5    20
    3.0     4    15
    3.2     7    11
    3.4

 n: Number of values used
 m1 and m2: Magnitude range used for b value calculation
 maxl a and b: Maximum likelihood a and b
 sd: Standard deviation
 lsq a and b: Least squares a and b ( the one plotted)
 cor and rms: Correlation coefficient and rms of above
 bfix: fixed b-value given at input
 afix: a-value for above
 sd: standard deviation for above
 mag: magnitude
 nmag: number of events within mag interval
 cmag: cumulated number of events

 Questions:

 Plot(y/n)
   ! This will make a plot and a postscript plot file.
     Note that only the last plot on screen is saved. The plot
     must be sent manually to the printer.

 Which b-value 1: Least squares (default)
               2: Fixed bvalue
               3: Maximum likelihood
   ! Choice of b-value to plot

 Run again with other parameters (y/n)
   ! Another step length or range can be selected

The final output is:

Output file in bvalue.out
Last plot in file bvalue.eps
```

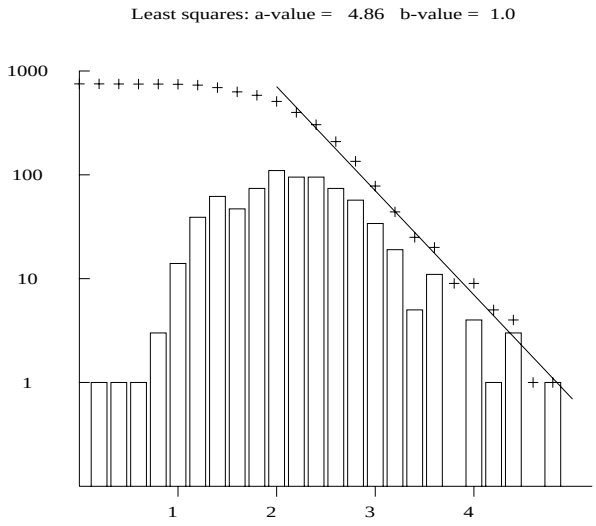


Figure 22.1: An example of a b-value plot. The bars are number of events and crosses the accumulated number of events.

The output file bvalue.out contains the same information in the same format as shown in the example above. The file can be used with other plotting programs to make 'nicer looking' b-value plots. An example is shown in Figure 22.1.

Chapter 23

Fault plane solution

SEISAN includes five programs for estimating the fault plane solution, FOCMEC, FPFIT, HASH (called hash_seisan),EBEL and PINV. The programs are described below, they can all be called from EEV. Fault plane solutions can be plotted with EPIMAP (new from version 9.0), W_EMAP (Windows only) and FOC (see below).
Apart from MULPLT, polarities and amplitude ratios can be read in a more efficient way with the programs PLOTPOLARITY, AUTORATIO and PLOTRATIO.
The program GMTNOR also makes output which can be used with GMT. In EEV fault plane solutions can be added manually to an event with commands inputfps or ifp.

23.1 FOCMEC

The program can be used to determine double couple earthquake focal mechanisms using polarities and/or amplitude ratios for both local and global earthquakes. The program also provides an interactive graphical display. The existing solution can be plotted without any station data or location being available, however if existing polarities should be plotted, the event must be locatable in order to calculate angles of incidence. Several solutions can be plotted on the same figure in order to compare solutions.

****

Changes to Focmec

****

SEISAN used the 2001 version of Focmec and has now updated to the 2017 version and this has implied some significant changes. Polarity weight can now be used. When using polarity weight, each wrong polarity does not count as one but as the normalized (to 1.0) amplitude. This is done in order to give less weight to polarities near the nodal planes. The number of wrong polarities to use for an accepted solution is therefore a real number and calculated as the sum of the weights. In an extreme case, all polarities could be wrong but the sum of the polarities less than 1.0 but generally, according to Snoke, polarity weight improves the reliability of a solution. Amplitude ratios are calculated as before but counted differently in case of observations near a nodal plane where the calculated ratios could be extreme as indicated by N&D in the output (nominator and denominator both below a given threshold, now hardwired to 0.1 for both P and S, before it was 0.05 and 0.15, repsectively). In the old version of Focmec, these ratios were simply discarded so. E.g. if 8 out of 10 ratios were indicated by N&D, and one error was accepted, only one of the 2 remaining rations had to be ok for the solution to be accepted. In the new version, every N&D ratio is counted as an error so it is more difficult to get an accepted solution, however unrealistic ratios are not accepted.

NOTE: The old version of FOCMEC is included. Running from EEV, the command is f_old and running from the prompt it is focmec_old.

The SEISAN program FOCMEC provides the interface between the database and the program that determines focal mechanisms, which in SEISAN is the program FOCMEC_EXE. This program is written by Arthur Snoke (Snoke et al., 1984) and distributed as part of the FOCMEC package (`http://www.iris.edu/`

pub/programs/focmec/). FOCMEC_EXE is identical to FOCMEC in Snoke's package and can be easily upgraded (unless formats are changed). Generally the user will use FOCMEC when working with SEISAN data, however, it is also possible to run the original version (see documentation by Snoke: INF/focmec.pdf). Before FOCMEC_EXE is started the user can optionally change the inputfile `focmec.run`.

The program works with polarities and amplitude ratios. See the MULPLT section on how to read polarities and amplitudes. Note that since amplitude ratios are used, there is no need to correct for instrument response provided the response is the same for the different components (within 5-10 %).

23.1.1 Use of amplitudes

Amplitude ratios are computed from amplitude readings given in the S-file. While amplitude ratios can provide additional constraint on the solution, they should be used with caution. Ideally, the solution should be well constrained by polarities only, and then amplitude ratios can provide confirmation of a solution or help to select one of several equally good solutions. The principle behind the amplitude ratio method is that the effect of geometrical spreading will cancel out when forming the amplitude ratios of S and P waves (or SV/SH) of the same phase type, e.g. Pg and Sg. This leaves the following corrections to be made on the amplitudes before the ratios are calculated.

- Calculate angle of incidence at the station and correct for the free surface effect.
- For local earthquakes, use the calculated travel time for a particular phase to correct for Q. Different Q for P and S can be used and the frequency used is the frequency of the maximum amplitude phase.
- For distant earthquakes, correct for t^*. Different t^* for P and S can be used. The frequency used is the frequency of the maximum amplitude phase.

Different values can be set in file FOCMEC.DEF, which can be located in DAT or working directory.

If there is no definition of Q in FOCMEC.DEF or the file is not there then the attenuation parameters have default values of:

$Q = 100 \times f^{1.0}$	for P and S-waves
$t^* = 1.0$	for P-waves
$t^* = 4.0$	for S-waves

For amplitudes, a model and vpvs are needed. They are dfined in STATION0.HYP.

The observations to be made are:

- Rotate the seismogram (if three component record) to get R and T components.
- Read maximum amplitude P-phase and corresponding period on Z, phase P.
- Read the maximum amplitude S-phase (same type) and corresponding period on Z, phase (SV).
- Read the maximum amplitude S-phase (same type) and corresponding period on H, phase (SH).

The wave type Pg/Sg or Pn/Sn has to be given when the amplitude is read. When reading on uncorrected seismograms, MULPLT will want a confirmation that the user wants to save uncorrected amplitudes, since, normally, all amplitude observations in an S-file are in nm. It is possible to filter the signals provided the same filter is used for P and S. Ideally, the amplitude observation should be made at a frequency below the earthquake corner frequency and consequently also the filter high cut frequency should be below the corner frequency.

It is also possible to read amplitudes on the radial component. However, SV amplitudes and phases change rapidly around the critical angle and the amplitudes can therefore be unreliable (see INF/focmec.pdf for details). So, although SEISAN will use the amplitudes read on the radial component, it is in general not recommended to use them. Assuming reading on only Z and H, the following amplitude ratios are calculated:

- SV/P

- SH/P
- SV/SH

In reality, the data only provides 2 independent ratios so ideally only 2 should be used. Since it is hard to know which 2 are the most reliable, SEISAN uses all.

The most reliable amplitudes are P on Z and SH on T so if enough data is available, try not to use SV. However, if only Z-channels are available, SV on Z has to be used.

Unwanted amplitudes can be weighted out with wight 4 in S-file.

FOCMEC also uses polarities on S-waves but this has not been implemented in SEISAN since S-polarities seldom are seen clearly. However, they cab be used by editing the focmec.dat file.

Phase names in SEISAN used for amplitudes for FOCMEC have the names AMPG, AMSG, AMPN and AMSN for direct and first arrival (refracted), respectively. For local earthquakes both PG and PN types can be used while for distant earthquakes only PN types can be used.

23.1.2 Automatic reading of amplitudes

Amplitudes (only g-phases) can be read automatically using program AUTORATIO which is implemented in EEV with command ar. Both time domain and frequency domain amplitudes can be read and they have different phase names from the manually determined amplitude phases names so fault plane solution can be made with one of the kind of amplitudes. For details, see AUTORATIO program.

23.1.3 Polarity selection

Any P-phase (first letter of phase name is P) with a polarity (C or D) is used, like P, Pg, PP etc.

FOCMEC can also use polarities of SV and SH, but this has not been implemented in SEISAN.

Automatic polarity determination

Program AUTOPHASE (command ap in EEV) read phase arrivals and polarities. In general it is not recommened to use automatic polarities unless P-phases are very clear. See program AUTOPHASE.

Checking and modifying polarities

Once polarities and/or P-phases are stored in the S-file, the graphical program PLOTPOLARITY (EEV command pol) can modify, add and remove polarities. See PLOTPOLARITY for more details.

23.1.4 Local earthquakes

Any P-phase can be used like Pn and Pg. When few polarities are available, it is an advantage to use both Pg and Pn since these phases have different angles of incidence. Polarities associated with other phases are not used. There is no check if a P-phase has been duplicated.

Amplitude ratios must be determined from the same wave type for example Pg and Sg and the program will only form amplitude ratios from the same wave types. While in principle it should be possible to use ratios determined from refracted waves, generally ratios determined only from direct waves are used since they are easier to identify and have larger amplitudes than refracted arrivals. Particularly the Sn is difficult to identify. This means that the amplitudes readings most often will be made within what is considered the maximum amplitude in the Pg and Sg wave trains. However, the polarity might be read on the first arrival which can be Pn or another refracted arrival.

Distant earthquakes

Polarities of any P-phase can be used (but not pP since first letter is not P). Using amplitudes require events with clear P and S phases and usually this means reading on broad band records. The amplitude phase names AMPN/SN are used to indicate first arrivals.

23.1.5 Program operation

The program makes a grid-search and finds how many polarities and amplitude ratios fit each possible solution. All solutions with less than a given number of wrong polarities and/or amplitude ratios within given error limits, are then written out and can be plotted. With a cursor, the user can then select the

preferred solution, which can be stored in the input file or the database. The program is intended to work from within EEV (option F), however it can also work independently (see below). The program uses an input file called `focmec.inp` (automatically generated). This is a Nordic format file. Direct waves have angle > 90 and refracted arrivals angle < 90 degrees. If the angle is > 90, the polarity is plotted at an azimuth+180. If the user wants to use FOCMEC as a freestanding program, the angle of incidence information may have to be put in manually in a standard CAT-file, which is then renamed focmec.inp. This can be done automatically by FOCMEC if a `hyp.out` and corresponding print.out file is available. FOCMEC can also be used to convert angles, like dip, strike and rake to T and P-axis, simply say 'focmec a', where argument a stands for angles and you will be prompted for input.

NOTE that the number of polarity errros is an integer number if no relative weighting of polarities is used and a real number if relative weighting is used, see intro for FOCMEC above and/or FOCMEC manual in DAT.

When the program runs, all amplitude information and corresponding corrections are listed. First there is a question of which type of amplitudes to be used. In the example below, automatic amplitudes are chosen.

```
Number of polarities:            7
Amplitude types:   Manual:       0   Automatic:   10   Spectral:    10

Amplitude to use:  Manual(1), Automatic(2), Spectral(3) ?
2


 Q: Local: Qp= 142.0**0.71  Qs= 142.0** 0.7   Global: t*(P)=1.10  t*(S)=4.20

 STAT  C PH       AMP    PER TRTIME   QCOR ANGINC ANGEMG Fcor   AZ  DIST
 FOO   Z PG      2883   0.28   13.4    1.5    119     40  1.5   83    77
 FOO   T SG     23712   0.24   23.4    2.2    119     40  2.0   83    77
 SUE   Z PG      1448   0.28   13.8    1.6    118     41  1.4  129    81
 SUE   T SG     24591   0.32   24.0    2.1    118     41  2.0  129    81
 OSG   Z PG       734   0.29   18.2    1.8    106     46  1.3  199   120
 OSG   T SG     11610   0.25   31.6    2.8    106     46  2.0  199   120
 HYA   Z PG      1090   0.28   21.0    2.0    102     47  1.3  105   144
 HYA   T SG     12161   0.28   36.6    3.2    102     47  2.0  105   144
 MOL   Z PG       505   0.24   32.2    2.9     94     48  1.3   59   238
 MOL   T SG      2866   0.28   56.1    6.0     94     48  2.0   59   238

 STAT  Ratio type  T     Amp 1    Amp 2  Fcor LogRat
 FOO   SH(T)/P(Z)  H     23712     2883   0.7   0.93
 SUE   SH(T)/P(Z)  H     24591     1448   0.7   1.22
 OSG   SH(T)/P(Z)  H     11610      734   0.7   1.23
 HYA   SH(T)/P(Z)  H     12161     1090   0.7   1.08
 MOL   SH(T)/P(Z)  H      2866      505   0.6   0.87

 total obs =  12  gap in az = 220.0  gap in ain =  60.0
```

The abbreviations are STAT: Station code, C: Component, PH: Phase, AMP: Amplitude in count, PER: Period in sec, TRTIME: Travel time in sec, QCOR: Log Q-correction, ANGINC: Angle of incidence at the source, ANGEMG: Angle of emergence at the station, Fcorr: Free surface correction for this amplitude, Az: Azimuth from the event to the station, DIST: Epicentral distance in km., Ratio type (see text), T: indicator of ratio type, Amp1 and Amp2: The two amplitudes (count) in the ratio, Fcor is the free surface correction in the amplitude ratio (to be multiplied with ratio) and LogRat is the logarithm of the corrected amplitude ratio used. Total obs: Total number of ratios and polarities, gap in az: the gap of no observations (amplitude

and polarity), should be less then 180 deg, gap in ain (amplitude and polarity): gap in angle of incidence, should be as small as possible.

Following, the user get the choices:

```
Stop                        (0)
Plot saved solution(s)      (1)
Plot new solutions          (2)
Plot selected solution      (3)
Find new solutions          (4)
-1, -2, -3 also plot station
```

1. This is the solution(s) already stored in the data base (S-file). See secetion "Storing and selecting fault plane solutions" below.

2. Plotting new solution after having used option 4

3. Plotting the selected solution after using option 4
   Using e.g. -1 instead of 1, also plots the stations to help identify them on the plot, see Figure 23.1

4. Starting a search for new solutions

   Option 4 gives the following information and questions:

   ```
   There are   7 polarity readings
   Use realtive weight, y/n=default
   Maximum number of allowed polarity errors, enter for 1
   ```

   Depending on number of data values, 0-5 is a good answer.

   If relative weighting is used, the question about number of polarity errors is:

   Realtive weight, number of polarity errors, can be a fractional number, enter for 1.0

   Relative weighting will give more solutions since the numbers summed are smaller than 1.0. So for a good solution, 0.5 miught be a good number to use.

   Equivalent for ratios to 'Maximum number of polarity errors', however, error is defined by amplitude ratio error. Number of errors depends on number of observations. For 5 observations 0-1 errors is reasonable.

   ```
   Maximum amplitude ratio error,  enter for default of .2
   ```

   Give maximum allowed difference between observed and computed log amplitude ratio, default is 0.2, which often is a good value.

   ```
   Degree increment in search, enter for default 2
   ```

The program will now start the searching and write out on the screen (and in a file) the solutions which fit the requirement of number of misfits. The maximum number of solutions is limited to 100 as a default, or to the value defined by 'FOCMEC MAXSOL' in `SEISAN.DEF`. At the end, the number of acceptable solutions is written out as well as the minimum number of bad fits. This can then be used for the next search. Now option 0 to 4 can be used again.

When plotting the solution with option 2, the cursor comes up. Also, the solutions will be printed in text form to the screen, see Figure 23.1.

The abbreviations are Pol: Number of polarity errors for P note it is a real number, SV(not used) and SH(not used), AccR/TotR: Number of accepted to total number of ratio errors, RMS RErr: The RMS error for the ratios used, AbsMaxDiff: The maximum error. See also FOCMEC manual.

The polarities and amplitude ratios can be plotted on the focal sphere using the same convention as the original FOCMEC program, which is:

o = compression
Δ = dilatation
V = amplitude ratio SV/P
S = amplitude ratio SV/SH
H = amplitude ratio SH/P

The user can select a preferred solution by moving the cursor near one of the letters T or P (T and P axis). By pressing T, the program will find the nearest T axis (same for P and nearest P-axis) and corresponding fault plane solution, which can be stored in the database and/or plotted with option 3. If no solution is to be selected, press q for quit. If a solution has been selected, the user will be asked if it is to be saved or not after selecting option 0. The saved solution goes into the focmec.out and from there into the S-file (type F-line) in the database if FOCMEC is operated from EEV and the solutiosn will also be written to fps.out.

When working from EEV, the event will always be located before the FOCMEC program starts up. In the Nordic format the solution is stored simply as strike, dip, rake and number of bad polarities (3f10.1,I5). Aki and Richards convention is used. In addition, the name FOCMEC will be written near the end of the line to indicate that the fault plane solution was made by FOCMEC. The line type is F.

The following files are created:

`focmec.dat`: Input parameters to FOCMEC_EXE.
`focmec.log`: Log of the FOCMEC_EXE run.
`focmec.lst`: More details on solutions
`focmec.out`: Gives input parameters and solutions
`focmec.eps`: A Postscript plot file of LATEST plot
`focmec.run`: Run parameters for FOCMEC_EXE, you can re-run FOCMEC by 'focmec_exe ¡ focmec.run'

23.1.6 Making synthetic amplitudes and polarities to test FOCMEC and HASH

A synthetic input can be generated for FOCMEC. The purpose is, for a given fault plane solution with a given set of stations, to test how well 'correct amplitudes and polarities' can be inverted to the known fault plane solution. The procedure is: 1: Select an event with a set of observations and a fault plane solution.

2: Write SYNTET in the F-line in S-file where method is given, using e.g. FOCMEC, this is FOCMEC, replace with SYNTET. 3: Run FOCMEC from EEV. The synthetic polarities and amplitudes will then be generated for the same observations as given in the S-file. These observations are normally written out to the file focmec.dat as polarities and corrected amplitudes. The focmec.dat is then input to the original FOCMEC. The synthetic observations are now made by correcting the focmec.dat file to the theoretical polarities and amplitude ratios corresponding to the SYNTET fault plane solutions. The theoretical values are therefore at the source and not affected by Q and free surface. The original observations in the S-file are not changed. 4: Do the inversion in the normal way.

Since the theoretical values are generated by FOCMEC routines, FOCMEC should exactly return the SYNTET solution. However depending on the number and types of observations, this might not be the case. Before making the solution with FOCMEC, it is possible to edit the focmec.dat file to introduce errors or remove observations in order to test the sensitivity of the solution to errors in input or insufficient input.

All promt line options for FOCMEC:

```
a: Calculate angles
o: Plot saved solution, no questions
p: Just run foc preparation
d: Use auto amp as default, use velocity
pd: Options p and d above
s: Calculate thoretical amplitudes from fps
None: Fault plane solution after using HYP
```

Theroretical amplitudes: Used to calculate amplitudes on the focal sphere for a given fault plane solution, example:

```
c:\Seismo\PRO>focmec s
```

```
 strike,dip,rake
30 40 50
 Enter az and ain, enter to stop
22 33
p-amp=  0.0301 sv-amp=  0.6091 sh-amp= -0.3259
log ratios, sv/p, sh/p and sh/sv  2.0272  1.7556  0.2716
P-polarity is: C

 Enter az and ain, enter to stop
```

For this option, vpvs is hardwired to 1.74. There is no Q-correction or free surface correction, it is just the amplitude on the focal sphere.

Computer limitations: Total number of polarities must be less than the dimension of array DATA (parameter max_data) for Nordic data (see file `seidim.inc` in INC directory).

Figure 23.1 shows an example of a fault plane solution calculated with FOCMEC.

23.2 FPFIT

This well known program, written by Reasenberg and Oppenheimer (1985), uses polarities to find one or several fps's (see manual fpfit.pdf in INF). Quoting the manual "Program FPFIT finds the double couple fault plane solution (source model) that best fits a given set of observed first motion polarities for an earthquake. The inversion is accomplished through a two stage grid search procedure that finds the source model minimizing a normalized, weighted sum of first motion polarity discrepancies". The weighted sum is expressed through the F-factor (0-1) given as output in S-file. A value below 0.5 is a good fit and a value of 1.0 is means a perfect misfit. A station distribution ratio STDR is calculated. Quoting the manual "The station distribution ratio is $0.0 < \text{STDR} < 1.0$. This quantity is sensitive to the distribution of the data on the focal sphere, relative to the radiation pattern. When this ratio has a low value (say, $\text{STDR} < 0.5$), then a relatively large number of the data lie near nodal planes in the solution. Such a solution is less robust than one for which $\text{STDR} > 0.5$, and, consequently, should be scrutinized closely and possibly rejected". This value is also written to the S-file. One advantage with FPFIT compared to FOCMEC is that formal errors are estimated and usually only one solution is given. The software is found at `http://earthquake.usgs.gov/research/software/`

The original program FPFIT is left unchanged except for a minor gfortran adaption, however it has changed name to fpgit_org. FPFITi_ORG is an interactive program with many options for parameters stored in a parameter file and different data input formats can be used. In the SEISAN implementation, this has been simplified and a SEISAN driver program FPFIT is used. This program converts the observations to an input file in hypo71 format, fpfit.dat, makes a parameter file with preset parameters, fpfit.inp and a run file fpfit.run to run the program. After running FPFIT (either free standing or through EEV with command fp), it is possible to run the original program directly with command fpfit_org and test different FPFIT parameters, using fpfit.inp as a starting parameter file (default). It is then possible to interactively get information about the different parameters. The hardwired parameters essentially use default settings, ensure the use of all data (e.g. no magnitude-distance restrictions) with the same weigh on all data. In addition, the following is set:

- Search in as fine a grid as the program allows, one deg for fine search.
- Search for multiple solutions, not just the best. Gives an idea of uncertainty.
- Minimum number of polarities to attempt a solution is 6.

Run the program: In EEV, use command fp, first solution is written to S-file. The previous solution of FPFIT will be overwritten. FPFIT in SEISAN implementation can work with both global and local data,

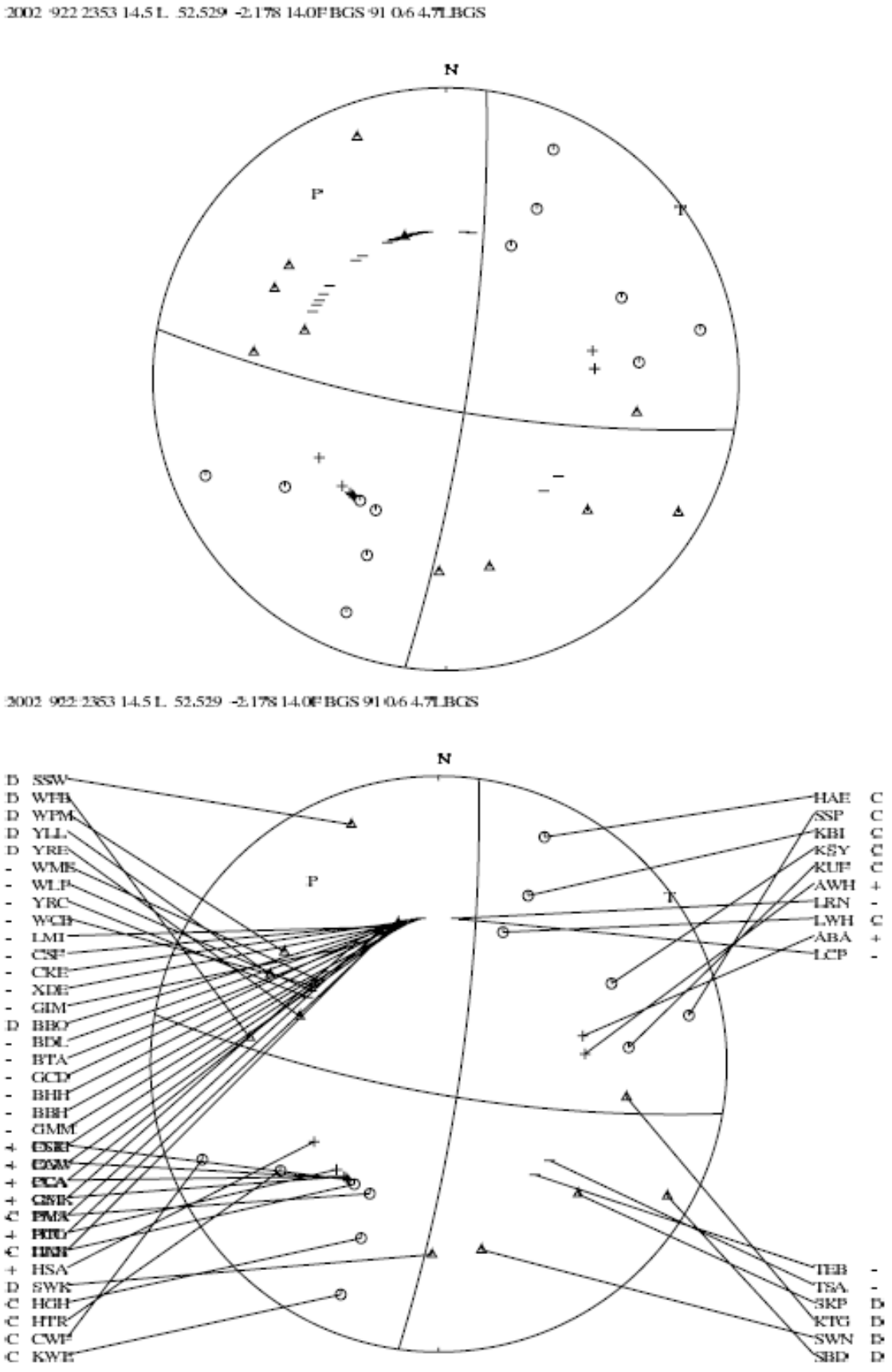


Figure 23.1: Top: An example of a fault plane solution plot. Symbols are explained in the text. Bottom: A fault plane solution also showing the stations with corresponding polarities.

while the original FPFIT only works with local data. Outside EEV. See section on composite fault plane solution.

Output files:	
fpfit.out	Details of inversion. In the FPFIT manual, this file is called "Statistical summary file"
fpfit.fps	The fps solution etc. In the FPFIT manual, this file is called "Extended hypocenter summary card file"
fpfit.pol	Station and polarities used, see FPFIT manual
fps.out	The fps in SEISAN format in a cat file

**********NOTE********** IN the FPFIT outptut on screen from FPFIT_ORG, strike is downdip azimuth so to get the standard notation as used in SEISAN, 90 degrees is subtracted. **********

Note: There is no check if polarities are read on Z-channel but it is required that the phase is P.

23.3 HASH

NOTE: internally in SEISAN, the program is called HASH_SEISAN to avoid conflict with bash command hash.

This program (Hardebeck and Shearer, 2002, 2003) determines fault plane solutions using P-polarities and amplitude ratios as input, just like the FOCMEC program. The P-amplitude used by the program is the theroretical radial amplitude and that was obtained by reading (Hardebeck and Shearer, 2003) $A_P = \sqrt{(}A_r^2 + A_z^2)$ and the S-amplitude $A_S = \sqrt{(}A_{sv}^2 + A_{sh}^2)$ where A is amplitude, r is radial (on rotated seismogram) and z is vertical. The S used was the maximum S on any of the rotated components or Z. This was then compared to the theoretical amplitude $A_S = \sqrt{(}A_{sv}^2 + A_{sh}^2)$ where sv is SV, and sh is SH. This approximation apparently worked well. The free surface and attenuation correction is not built in, but was replaced by a fixed factor per station, which had to be determined independently. In order to simplify the input, the free surface and attenuation corrected amplitude ratios from FOCMEC are used as input for HASH. The program was modified to use only SH and by using the free surface corrected P on the Z-component, the true P-amplitude is used. Thus only one amplitude ratio is used for each station (SH to P). HASH returns solutions with less than a given number of polarity errors and average amplitude errors less than a given limit. If no solutions are found, error limits are increased and normally many solutions are returned. Using this, an estimate of the best solution is made and likely errors calculated. The advantage with HASH is that it finds one or a few best solutions, while for FOCMEC the user must select one among many. Also HASH will not completely change the solution by one wrong amplitude ratio, since the average of the amplitude errors is used as selection criteria and not a single amplitude. FOCMEC does not give any estimate of the errors in the solution. HASH calculates an estimated error; however that requires an input where each event has been located with e.g. 10 different likely input models and all data is used as input in order to get estimate of fault plane solution uncertainties generated from the model. This was not done in the SEISAN implementation so only the error estimated from the spread in solutions is used. This might lead to smaller error estimates as compared to the original HASH implementation. The SEISAN HASH implementation is a simplified implementation compared to the original HASH with many parameters hardwired, see hash_seisan.for for implementation details and changes. Like FPFIT, the F-fit function is calculated (called weighted fraction of polarity misfits) and similarly the station distribution ratio (see FPFIT). Both values are given in S-file as well as the average amplitude error. For more information, see the HASH manual hash.pdf and FPFIT manual fpfit.pdf in INF. The software is found at `http://earthquake.usgs.gov/research/software/index.php`. HASH does not estimate errors in strike, dip and rake but errors in fault plane and auxiliary plane (degrees). HASH, like FOCMEC uses the Vp Vs velocity ratio to calculate amplitudes. In versions of SEISAN before

10.6, this was hardwired to 1.74. Now it is read from the input file focmec.dat also used with FOCMEC. This ratio is in turn read from STATION0.HYP.

23.3.1 Running HASH from EEV

Polarities and amplitudes are picked like for FOCMEC. When running the program, the amplitudes are corrected like for FOCMEC (actually done by FOCMEC) so the Q-correction will use the Q-relation given in focmec.def (see FOCMEC description above). The same output, as for FOCMEC, with the available amplitudes, their ratios and corrections will be shown and the control is the handed over to HASH. The questions are:

```
  Grid angle for focal mech. search, enter for def 2           Comment: Smallest is 2

  Max number of polarity errors, default is  0                 Comment: Default
0
  Max average error in amp rat, log10, def 0.1                 Comment: default 0.1 selected

  Enter angle for computing mechanisms probability, def is 60  Comment. Default 60 deg. Sel.

  Enter probability threshold for multiples, def is 0.1        Comment: Default 0.1 selected
```

Now is following the FOCMEC amplitude information, not shown ...

```
 Number of polarities is                      :    11
 Number of amplitude ratios is                :     5
 Minimum number of polarity misfits overall   :     0
 Minimum average amplitude error overall      :  0.13
 New number of pol. misfits inc. extra is     :     1
 New average amp limit inc. extra             :  0.23
 Minimum average amplitude error for pol ok   :  0.27
 New average amp limit is                     :  0.37
 Number of solutions found                        92

 Strike,dip,rake               197.3    66.5  -157.4
 Fault+aux plane uncertainty    23.2    10.3
 ================================
```

Explanations of input:

The "mechanism probability" is the probability that the real mechanism is "close" to the preferred mechanism, within "angle for computing mechanisms probability" where angle define "close." If there are clustered outliers, alternative solutions (or "multiples") are found based on those outliers. You can set the minimum probability for the multiples (i.e. ignore multiples with a low probability.)

23.3.2 Explanations of output

`Minimum number of polarity misfits overall`: Minimum number of wrong polarities for anyone of the grid points disregarding amplitude fit. This is the number of polarity errors to find a solution without amplitudes.
`Minimum average amplitude error overall`: The minimum average log error for any grid point disregarding errors in polarity.
`New number of pol. misfits inc. extra is`: The new limit for polarity errors.
`New average amp limit inc. extra`: Based on the above, a new amplitude ratio error limit is set.
`Minimum average amplitude error for pol ok`: The new error limit considering polarities within limit.
`New average amp limit is`: In order to get sufficient solutions, the amplitude error limit is increased to this value.

Output files: Hash_seisan.out: A summary of the solutions(s).
Fps.out: The solution(s) in SEISAN format.

Storing and selecting fault plane solutions: Format errors estimates and quality.

The fault plane solutions are stored in the S-file. Different programs give somewhat different parameters and sometimes the same output field is used for different parameters. Some programs give strike of dip instead of strike of fault plane, but values used in SEISAN are converted to strike of fault plane. Each program is indicated with its own name like "`HASH      F`" at the end of the F-line. If no characters are written in the blank space, any new solution will overwrite the old one. However if anything is written like "`HASH     1F`", any new solution will create a new line in S-file. This is also the case if a quality indicator is written (see below). An example is:

```
  158.0      53.1    -156.4  7.0  3.8      0.30 0.57 0.76      FCF HASH     F
39.2900   66.3900  -63.6500                          0.13  2 1 FCF FOCMEC   F
   42.0      68.0     -62.0  7.0  5.0  3.0  0.1  0.2           FCF FPFIT  A F
   18.7      67.8     -63.3                                 4   FCF PINV     F
```

In this example, there are 4 solutions made by the 4 programs and the solution made by FPFIT has been selected as a prime solution with quality A. The content and format is:

```
Type F Line (Optional): Fault plane solution

Columns Format Description

  1:30 3F10.0 Strike, dip and rake, Aki convention
 31:45 4F5.1  Error in strike dip and rake (HASH), error in fault plane and aux. plane (FPFIT)
 46:50 F5.1   Fit error:  FPFIT and HASH (F-fit)
 51:55 F5.1   Station distribution ratio (FPFIT, HASH)
 56:60 F5.1   Amplitude ratio fit (HASH, FOCMEC)
 61:62 I2     Number of bad polarities (FOCMEC, PINV)
 64.65 I2     Number of bad amplitude  ratios (FOCMEC)
 67:69 A3     Agency code
 71:77 A7     Program used
 78:78 A1     Quality of solution, A (best), B C or D (worst), added manually
 79:79 A1     Blank, can be used by user
 80:80 A1     F
```

`Quality indicator`: The indicator can be any character, but usually A to F is used with A as the best. It is up to the user to manually assign a quality indicator. Events can later be selected based on quality indicator. Programs SELECT and FOC use quality indicators. The quality indicator as well as the selection of the prime solution can be select by command fq in eev. An example is given below:

Fault plane solutions for this event 1 180.3 55.1 -123.7 5.0 4.4 0.04 0.67 0.38 SJA HASH A 2 6.1000 48.4400 -48.0700 2 SJA FOCMEC 3 191.0 51.0 -110.0 SJA DREGER 4 185.0 48.0 -121.0 HRV CMT A Give fps number to be prime solution, enter for no change

23.4 PINV

This program makes a preliminary best fault plane solution based on polarities and is intended as a help to other methods of fault plane solution. The original program was written by Suetsugu and some information is found in (Suetsugu, 1998). A copy of this report, which also gives general information about fault plane solutions, is available as foc.pdf at `http://iisee.kenken.go.jp/lna/?mod=view&cid=S0-250-2007`

To run the program from EEV:

Command `pi` will locate the current event and then start PINV (stands for P-inversion). PINV is hardwired to use hyp.out as input file and it will use all polarities from P-phases (capital P as the first letter). The result of the inversion is written out on the screen and in file pinv.out. The strike, dip and

rake and number of wrong polarities is also written to the S-file provided at least 5 polarities are available, however PINV will make an inversion with any number of polarities and write the result to the screen. In the S-file, the result is written as an OF-line giving the source of the inversion as PINV. A new inversion will overwrite the previous solution. This means that a PINV solution will be additional to the solution given by the F-line and therefore not considered as prime. It is also possible to directly compare the solution to the solution obtained by FOCMEC.

To run program outside EEV.

The program can run with one or many events (composite solution). First locate event(s) with HYP, then give command pinv and the inversion is made. All polarities in the hyp.out file are used. The result only goes the screen, hyp.out, fps.out and pinv.out.

Principle of operation:

Moment tensor inversion can be done most simply using amplitudes as observed on the focal sphere. In PINV, polarities are considered to be amplitudes of +1 or -1 corresponding to compression and dilation, respectively. This is a gross oversimplification since there will be large variation of real amplitudes over the focal sphere. This input data of amplitudes is then inverted to get the moment tensor under the restriction of finding a single double couple. Despite the simplification, the advantage of this method is that it very quickly gives a best approximation to the fault plane solution. This best solution, particularly with few data, might be just one of many possible (see FOCMEC), but it serves to give an idea of a possible best solution and it is in general consistent with the observations (Suetsugu, 1998). Unfortunately PINV does not give an error estimate to judge how reliable the solution is. It is therefore not recommended to use PINV to obtain prime fault plane solution, but rather as a help to select a solution when using FOCMEC unless much well distributed data is available. In some cases, FOCMEC will find a solution where all polarities fit, while PINV will get a similar solution with some polarity errors. This can be explained by PINV using the assumption of +1 and -1 amplitudes and thus an overall fit to amplitudes near nodal planes might be difficult. The original input to the PINV program has an option to give zero amplitude of observations judged nodal, however in our experience it is hard to judge if a first polarity is nodal or just has a small amplitude du to path (e.g. Pn) so this option has not be included.

An example of a run is:

```
Number of data used for inversion=  8
Absolute pseudorank tolerance     0.001210          Pseudorank   5
Strike, dip, rake           72.3      38.9      34.6
Consistent data:     8
Inconsistent data:   0
```

There were 8 observation which all fitted. The pseudorank indicates how many parameters can be determined in the inversion. In this case 5 since there are 8 observations. If less than 5 observations, the pseudorank will be less than 5. The Absolute pseudorank tolerance is a measure of the fit.

23.5 Fault plane solution program to use and some advice

The different programs all have advantages and disadvantages. FOCMEC uses the most data since it can use more amplitude ratios than HASH but it might be difficult to find the 'correct' solution since a small change in input limits might make a large change in output. If a few of the amplitude ratios are very wrong, an unrealistic high ratio limit must be used and many errors allowed. This problem is avoided by using HASH since the limit is the average amplitude ratio error and not the number of errors. If only working with polarities, all 4 programs can be used. PINV gives a very quick solution which can be used as an indication of a possible best solution, however for final results one of the other 3 programs should be used. It is often a good idea to compare the results from the different programs. Ideally they should all give the same result, but there will be difference due to different methods used and different data, however if solutions are very different, the solution might not be very stable.

Polarities are often not very clear so in general, when using FOCMEC, one should allow for polarity errors. Even if polarities are very clear, there might be errors since the theortical ray calculated by HYP does not correspond to the observed ray. This can be due to a wrong model or a wrong hypocentral depth.

If e.g. the program calculates that the first arrival is Pg, but the arrival is very emergent, the first arrival might be a refracted arrival due to wrong model or depth. In some cases a clear Pg arrival might be seen a bit later and can be used instead.

In some cases due to incorrect model, the hypocenter must be fixed to a depth different from what it locates to naturally in order to get a solution.

Note that in order to compare FOCMEC and HASH, amplitudes should only be used on Z and T since HASH cannot use amplitude on Z. In anay case, these amplitudes are the most reliable. In HASH, the number of solutions will depend mainly on the error limit given for the amplitude ratios. If very few solution are found, the solution might be less reliable so increase the limit then. A few hundred solutions is a good number. The results from two solutions can be compared with EEV command 'fd' which calcultes the difference it P and T orientations. It is easy to compare the solutions. Run each program in EEV, then plot using command fo. Each solutions will be plotted in a different color, see Figure 23.3. If doing composite solutions, use program FOC with input from fps.out.

23.6 Composite fault plane solution using any of the programs FOCMEC, FPFIT, HASH and PINV

For some small networks, the number of stations is too small to make a fault plane solution using polarities from a single event and even using amplitudes, there might not be enough data. Under the assumption that the underlying stress field will generate events with similar fault plane solutions, a group of events can be used together to make one fault plane solution which will represent an average of the supposedly similar solutions. The advantage of using several events with different azimuths and angles of incidence is that the observations will be well spread out on the focal sphere. The four fault plane solution programs in SEISAN can all be used to make a composite solution and both polarities and amplitudes can be used. The procedure is similar for all programs:

1: Select the events to be used together in one file using e.g. SELECT or the graphical options in EPIMAP.

2: Locate the events with HYP. There are now two output files, hyp.out and print.out available for input to the fault plane solution programs. The fps program must be executed in the directory of the print.out and hyp.out. Once the fault plane solution has been made, the solution is available with the first event in hyp.out.

3: Do the fault plane solution:

- FOCMEC: Run with command 'focmec'.
- FPFIT. Run with command 'fptfit'.
- HASH: Run with command 'hash_seisan'.
- PINV: Run with command 'pinv'.

Plot the composite fault plane solution: The solution can be plotted with command 'focmec o'. Only polarities will be plotted. The solution can also be plotted with plotfoc using hyp.out as input. In thsi case no polarities are shown. The solution with the first event in hyp.out is used. No agency is written for the composite solution. A previous solution without agency and quality is overwritten. If all 4 programs have been used, all 4 solutions will be present in hyp.out and plotted together. It is possible to plot stations corresponding with all polarities with program focmec. Then type 'focmec' and when the menu 0-4 comes up, chose -1.

The solution(s) will also be written to the cat-file fps.out in standard SEISAN format. For each run of a program, the solutions accumulate in fps.out. This can be used to compare solutions from different programs, see FOC. The solution can also be plotted with PLOTFOC. An example of the plot with FOCMEC is seen in Figure 23.1.

Finally the solutions will also be written to hyp.out and can be plotte with PLOTFOC, however in that case only the mechanisms are shown.

NOTE: All fault plane solutions made from the different programs are accumulated in file fps.out.

When the first event has been read in, general questions comes up. The all events are read in and after last event, there is info on the toal number of data, see example below:

```
4: c:\FPS>focmec


 Number of polarities:           10
 Amplitude types:   Manual:       4   Automatic:    0   Spectral:     0

 Amplitude to use:  Manual(1), Automatic(2), Spectral(3) ?
 1

  PCNG  use P-travel time to calculate S-travel time

  Q: Local: Qp= 470.0**0.70  Qs= 470.0** 0.7   Global: t*(P)=1.10  t*(S)=4.20

  STAT  C PH       AMP    PER TRTIME   QCOR ANGINC ANGEMG Fcor   AZ  DIST
  MESC  Z PG 103600000   0.14    1.4    1.0    128     20  1.9   54     3
  MESC  T SG 117800000   0.38    2.5    1.0    128     20  2.0   54     3
  VIF   Z PG   8745000   0.25    1.5    1.0    119     22  1.8  132     4
  VIF   T SG  22300000   0.21    2.7    1.0    119     22  2.0  132     4
  PMAT  Z PG  28400000   0.14    1.4    1.0    119     22  1.8    8     4
  PMAT  T SG  49800000   0.24    2.4    1.0    119     22  2.0    8     4
  PCNG  Z PG  17900000   0.14    2.0    1.0    107     25  1.8   96     7
  PCNG  T SG  29500000   0.34    3.5    1.0    107     25  2.0   96     7

  STAT  Ratio type  T     Amp 1    Amp 2  Fcor LogRat
  MESC  SH(T)/P(Z)  H 117800000103600000   0.9   0.03
  VIF   SH(T)/P(Z)  H  22300000  8745000   0.9   0.37
  PMAT  SH(T)/P(Z)  H  49800000 28400000   0.9   0.21
  PCNG  SH(T)/P(Z)  H  29500000 17900000   0.9   0.17
 .
 .
 .
 .
 .
 .
  Q: Local: Qp= 470.0**0.70  Qs= 470.0** 0.7   Global: t*(P)=1.10  t*(S)=4.20

  STAT  C PH       AMP    PER TRTIME   QCOR ANGINC ANGEMG Fcor   AZ  DIST
  MESC  Z PG  45300000   0.14    1.7    1.0    135     18  1.9   51     4
  MESC  T SG  36300000   0.17    2.9    1.0    135     18  2.0   51     4
  VIF   Z PG   1916000   0.21    1.7    1.0    132     19  1.9  125     4
  VIF   T SG  11700000   0.21    2.9    1.0    132     19  2.0  125     4
  PMAT  Z PG   3320000   0.10    1.6    1.0    128     20  1.9   11     5
  PMAT  T SG   8508000   0.07    2.8    1.0    128     20  2.0   11     5
  PCNG  Z PG   4310000   0.15    2.1    1.0    117     23  1.8   92     7
  PCNG  T SG   8371000   0.28    3.7    1.0    117     23  2.0   92     7


  STAT  Ratio type  T     Amp 1    Amp 2  Fcor LogRat
```

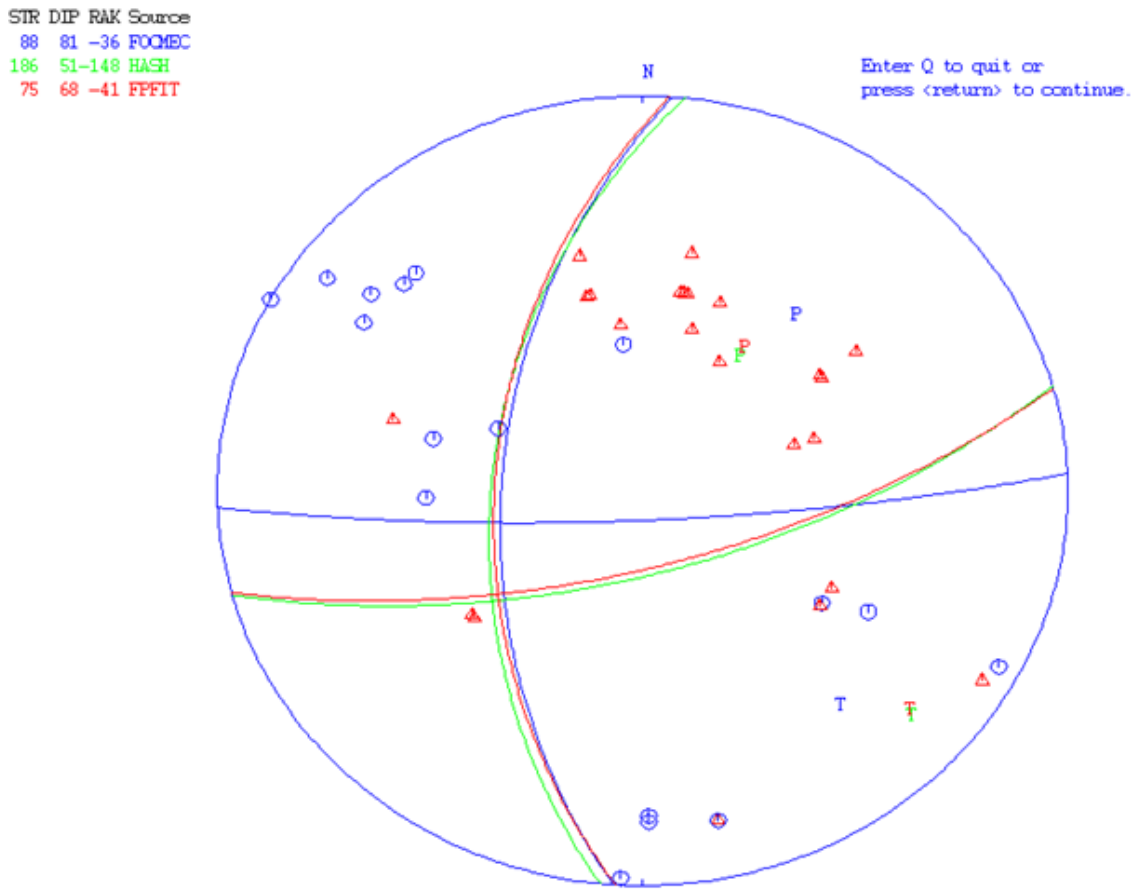


Figure 23.2: Composite solutions using 5 events and the 3 programs FOCMEC, FPFIT and HASH. Only polarities are used.

```
MESC  SH(T)/P(Z)  H  36300000 45300000   0.9  -0.12
VIF   SH(T)/P(Z)  H  11700000  1916000   0.9   0.76
PMAT  SH(T)/P(Z)  H   8508000  3320000   0.9   0.38
PCNG  SH(T)/P(Z)  H   8371000  4310000   0.9   0.25

total obs = 126  gap in az =  56.0  gap in ain =  22.0

 Stop                    (0)
 Plot saved solution(s)  (1)
 Plot new solutions      (2)
 Plot selected solution  (3)
 Find new solutions      (4)
 -1, -2, -3 also plot station
```

Figure 23.2 shows an example using polarities from 5 events.

23.7 Moment tensor inversion program, INVRAD

The program is written by John Ebel (Ebel and Bonjer, 1990) for moment tensor inversion for very local events. The program uses instrument-corrected amplitudes of the direct (upgoing) phases of P, SV and SH

phases and makes a linear inversion for the moment tensor. The program then finds the largest double couple component of the traceless moment tensor. For more details see file invrad.txt in the INF directory.
The original program has been slightly modified in input and output to be integrated with EEV in SEISAN. The steps to get the fault plane solution are:

Select the event from EEV

1. Plot each trace and select preferably the first clear amplitude of the direct wave. Mark the amplitude as usual and associate the amplitude with amplitude phases AMPG or AMSG (direct phases). This will create a separate line with amplitude readings only. The polarity must also be indicated on a separate phase , which must be Pg or Sg since the inversion program uses the polarity of the amplitude. The amplitudes MUST be picked on instrument corrected traces if all instruments do not have the same response function. At least 5 amplitudes must be selected. S phases picked on vertical or radial components will be considered SV while S-amplitudes picked on transverse components will be considered SH. Phases picked on NS or EW component cannot be used. If these new phases are not to be used for location, they can be weighted out.

2. Update event with command update to make distance and azimuths available.

3. Use command INVRAD to do the inversion. This command does several things hidden for the user:

   - Creates the model input file for INVRAD called invrad.mod. This file is created from the STATION0.HYP file, either from the current directory or DAT.
   - Creates the data input file for INVRAD called invrad.inp. This file is made from the current database file (S-file) by extracting all amplitudes associated with Pg and Sg amplitudes and converts to P, SV or SH amplitudes in microns. The depth of the event is taken from the S-file header and the estimated error is fixed to 0.1 micron.
   - Runs the INVRAD program which produces the invrad.out file
   - Reads the invrad.out file to get the fault plane solutions which overwrite the current fault plane solution in the S-file. If you do not want to get the current solution overwritten, put a character in column 79 on the solution, see also focmec program.

The fault plane solution can then be plotted with FOCMEC.

23.8 Plotting fault plane solutions

There a many ways of plotting fault plane solutions in SEISAN: Through EEV (a single event), program FOC (many events), program PLOTFOC (single event without station information), program MOPAD which also can plot a moment tensor solution, program EPIMAP (many events), option MAPS in EEV (one event on a map) and W_EMAP (many events). The input file is in all cases a CAT-file. In addition, using program SEIGMT, a file to be used with GMT is prepared, however the use must make his own script. Only through EEV is it also possible to plot the observations.

Data can also be exported in GMT format with programs SEIGMT and MOPAD.

Using EEV

Command fo will plot all events in S-file. This can be a useful ways of comparing solutions obtained by different programs, see Figure 23.3. It is a requrement that the event can be located and polarities will be shown, not amplitudes. Command foo will work as fo but no polarities are shown. There is no requirement for the event to be located so foo can be used if an S-file only has a header line and fault plae solution(s).

Command fh will plot a moment tensor solution with MOPAD program.

Using FOC

See under FOC for how to run the program.

The plot is seen in Figure 23.4.

Using PLOTFOC The program asks for input of

W_EMAP (Windows only) plots the solutions as seen in Figure 23.5. In this case the simplest is to give command w_emap file, where file is the CAT file with fault plane solutions. See W_emap manual in INF.

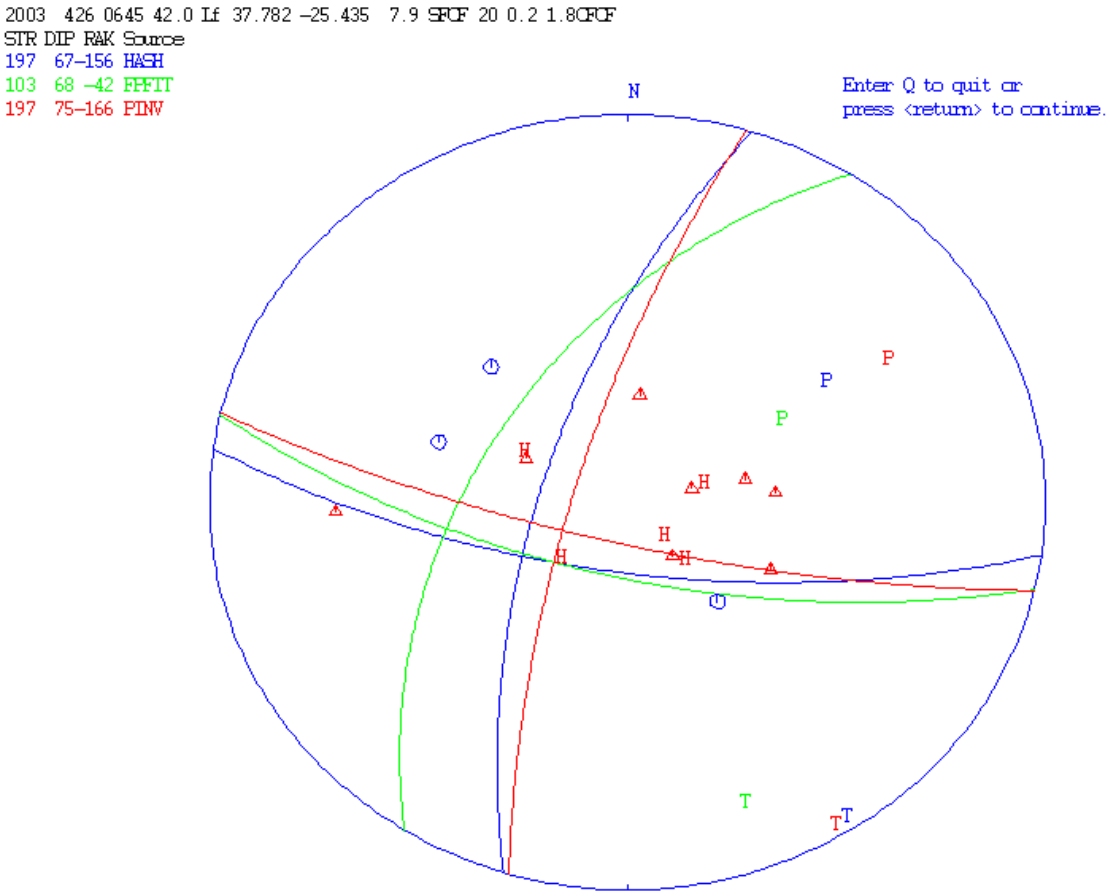


Figure 23.3: Compare fault plane solutions from different programs. For explanation of symbols, see FOCMEC.

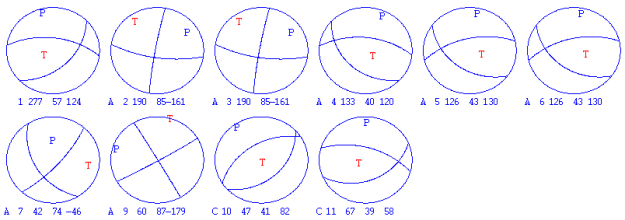


Figure 23.4: Example of plotting many solutions. Each solution is given with number, the fault plane solution and the quality (A-E). Up to 24 solutions can be plotted on one page.

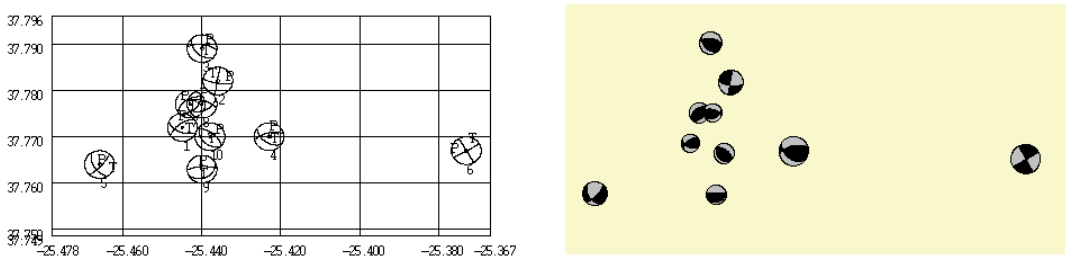


Figure 23.5: Plotting many fault plane solutions. Left: Using W_EMAP. Notice that the colors in the solutions are inverted compared to normal practice. Right: Using EPIMAP. The data for the two plots is the same.

NOTE: Some versions of W_EMAP plots some of the fault plane solutions with inverted color e.g. inverse fault becomes a normal fault).

The EPIMAP plot for the same events is shown in Figure 23.5. See EPIMAP for more explanation. EPIMAP can also plot the fault plane solutions in a section, the solutions are still seen in the horizontal plane.

23.9 FOC: Plot many FPS, stress inversion and Rose diagram

The SLICK program

This program is part of the Slick package doing the following quoting the author Michael (1984) "The slick package uses fault slip data (either field observations or from focal mechanism) to find the stress tensor that best explains the observations. Inputs are the orientation and slip direction of a set of fault planes. Outputs are the orientation and shape of the stress ellipsoid, including confidence regions, and statistics used to judge the success of the inversion. This method uses the linear inversion algorithm and non-parametric bootstrap statistics". The software is available at `http://earthquake.usgs.gov/research/software/index.php`.

In SEISAN, only the inversion part has been implemented so the error analysis is missing. Program SLICK can be run as a separate program, but is normally run as part of FOC which prepares the input for SLICK and plots the output. The method is explained in Michael (1984) where also examples are given with data available at the above web site. Running SLICK: slick "file", where "file" is a file with strike of dip, dip and rake. An example input file is:

```
Strik dp     Dip    Rake
   203.0    51.0   137.0
   280.0    85.0  -161.0
    ...
```

Note that in SEISAN, strike of fault plane is used so the strike of the dip is strike of the fault plane+90 degrees. The output is "file.oput" which gives the found stress tensor and the fit to the data, for details see Michael (1984). The stress tensor has a corresponding slip angle, (average slip) and for each event the difference in slip angle for the individual event and the average slip is calculated as well as the average difference and standard deviation. When running SLICK with FOC, an input file foc.slick is made for selected events (making the corrections to strike of slip) and the output file is foc.slick.oput. FOC also plots the direction of maximum compressive stress s1, minimum compress stress s3 and null axis s2. In the example below s1 has max value of 0.68 and strike and dip are 19 and 34 respectively. S3 has strike and dip of (113, 5) and s2 (-149, 56) respectively. The average fit angle is 59 with a standard deviation of 51, a bad fit.

```
stress tensor is:
```

```
-0.290526  0.236582  -0.146602
0.236582  0.293028  -0.438347
-0.146602  -0.438347  -0.00250278
eigenvalue   vector: E,N,UP,direction,plunge
0.686771  -0.273399  -0.784281  0.556917  19.205739  33.820430
-0.37516  -0.917882  0.385856  0.0927811  112.725966  5.320093
-0.31161  0.287656  0.485818  0.82537  -149.270892  55.589101
variance= 0.283314
phi value= 0.940156

dip direction, dip, rake, fit angle, mag tau
  203.0     51.0    137.0    166.4    0.11
  280.0     85.0   -161.0    167.9    0.19
   ...
   13.9     68.1    -85.7     11.0    0.46
   14.0     70.0   -130.0     33.3    0.48
fit angle mean= 59.156784 standard deviation= 51.527176
for f=0.8 I= -2.242677 , std. dev.= 1.609795 D norm= 0.248640
avg tau=xx , std. dev.= xx
```

For a complete stress analysis it is recommended to also do the error analysis using the complete slick package or e.g. the program ZMAP (not a SEISAN program, uses MATLAB, found at `http://www.earthquake.ethz.ch/software/zmap/ftp`). FOC writes a file which is formatted for input to ZMAP. However doing stress analysis as implemented in SEISAN gives a good impression of the consistency of the fault plane solutions in a particular area. It is recommended that at least 10 events are used for inversion.

FOC program

FOC is a program doing different things with fault plane solutions given in a CAT-file: Converting data to other formats, plotting many solutions, running the SLICK program and displaying the results, plot P and T axis for many events and make statistics of polarities. The input is:

```
foc
 Give input file
collect.out
 Quality, ABC.., up to 5 chars, enter for all
AB                                          Comment: Different qualities can be selected
 Cumulative(c) or individual misfit(def)    Comment: See later

 Plot all solutions selected (Y=enter/n)    Comment: Analysis can be done without plotting all
N
```

The plot of the many fault plane solutions is seen in Figure 23.4. After plotting the fault plane solutions, a plot comes up plotting the location of the P and T axis and the results from SLICK, see Figure 23.6.

Output files:

Foc.out: P and T axis for all events, can be used as input to make rose diagrams.

Foc_events.out: The events used based on quality selection

Foc_pol.out: Statistics of polarities:

```
Stat     C    D
AZ05     3    2
MESC    18   60
VIF0     5    2
MIRA    10   32
VIF     44   19
LFA     52   18
PRCH    36    6
```

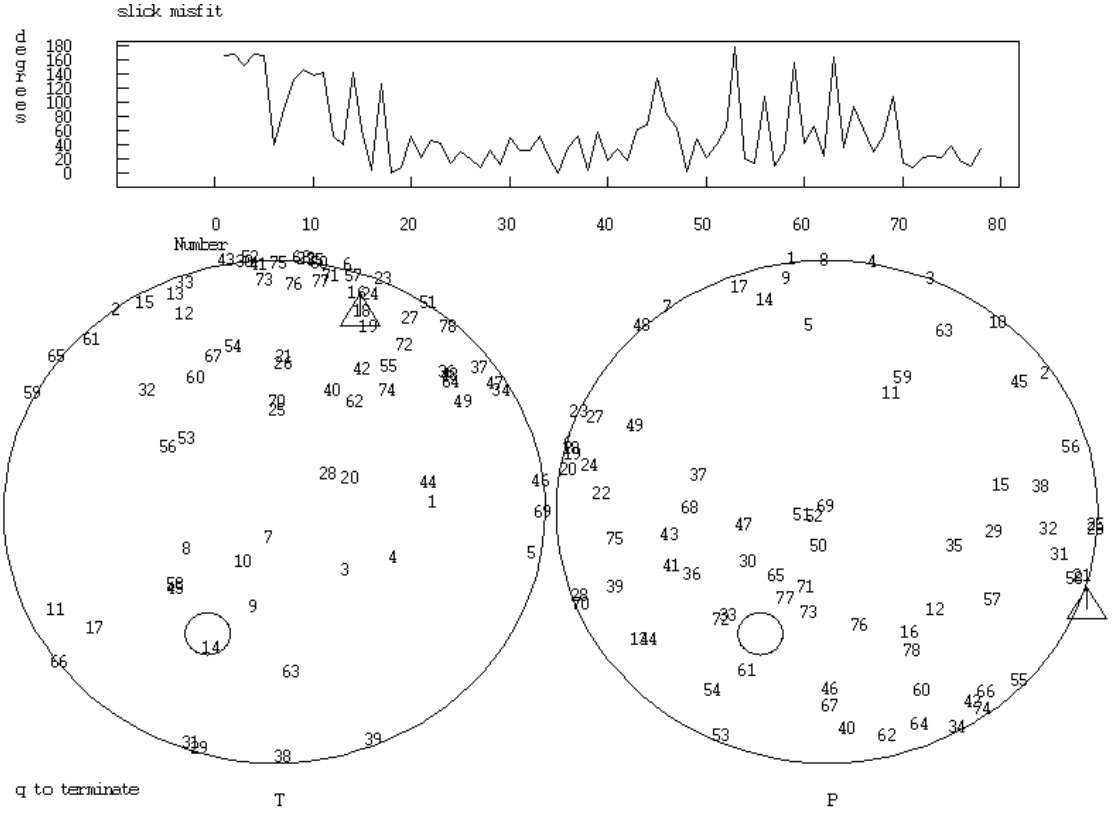


Figure 23.6: Left: The position of the T-axis given by the event numbers. The triangle is the SLICK minimum compressive stress direction and the circle is the null axis. Right: Corresponding for P-axis and the triangle is now the maximum compressive stress direction. Top: The misfit for each event as a function of event number. This figure can also show the cumulative misfit, see example run of FOC.

```
PVER    26    3
FRA0     0    2
AZ07     1    1
.
.
SET2     3    0
PSAN     1    3
 Sum of maximum number of polarities         570
 Sum of minimum number of polarities         158
```

For each station the different polarities are counted and a sum of the consistent polarities are given at the end. Foc.zmap: Input file in format used by ZMAP, notice direction of slip is used instead of strike of fault, see SLICK.
Foc.slick and foc.slick.oput: See SLICK.

NOTE: FOC uses the first instance of the fault plane solution found in file for a particular event.

23.10 PLOTFOC, plotting fault plane solution without need for station informtion

The program can plot all fault plane solution in an S-file without any need for location, polarities or any other station information. The plot looks like the plot for FOCMEC. The program can be started without argument and the user is asked for the name of the S-file or CAT-file. The program can also be started with the input file as argument. If the input file contains several events, it is possible to plot one event at a time, one after the other. Optionally, all events can be plotted superimposed. This can be used for comparing the fault plane solution from two different events, superimposed. Plotting fault plane solutions side by side can be done with program FOC. The program can also be started form EEV with command 'foo'. In this case only one event can be plotted.

The plot will list number of polarities and azimutal gap of the polarities. The azimutal gap is calcualted taking into account the azimuths as plotted on the focal sphere.

23.11 MOPAD, plotting a moment tensor solution and more

A Python program for plotting the focal sphere of seismic sources, both pure double couple and non DC sources described with the moment tensor. The program is made by Krieger and Heimann (2012) and available at `http://www.larskrieger.de/mopad/`. The program is included with SEISAN and started with command mopad. The program has many options for plotting and manipulating seismic sources using either the moment tensor or the strike, dip rake as input. For examples see http://www.larskrieger.de/mopad/. To see the options type mopad -h. MOPAD is the only program in SEISAN that can plot moment tensor solutions. It is implemented in EEV (command fm) with the only option of plotting the moment tensor solution as given in the S-file.

See Figure 23.7 for an example. The corresponding S-file is

```
 1976  1 1  129 53.4 D -29.250-176.960 47.8  HRV        7.3WHRV 6.2bHRV        1
 ACTION:SPL 17-06-02 19:06 OP:ff   STATUS:               ID:19760101012953     I
      202.       30.       93.                                    HRV HARVAR A F
 1976  1 1  129 53.4   -29.250-176.960 47.8  HRV        7.3WHRV       GlobCMT  M
 MT  7.680  0.090 -7.770  1.390  4.520 -3.260HRVS19 0.956E+20         GlobCMT  M
```

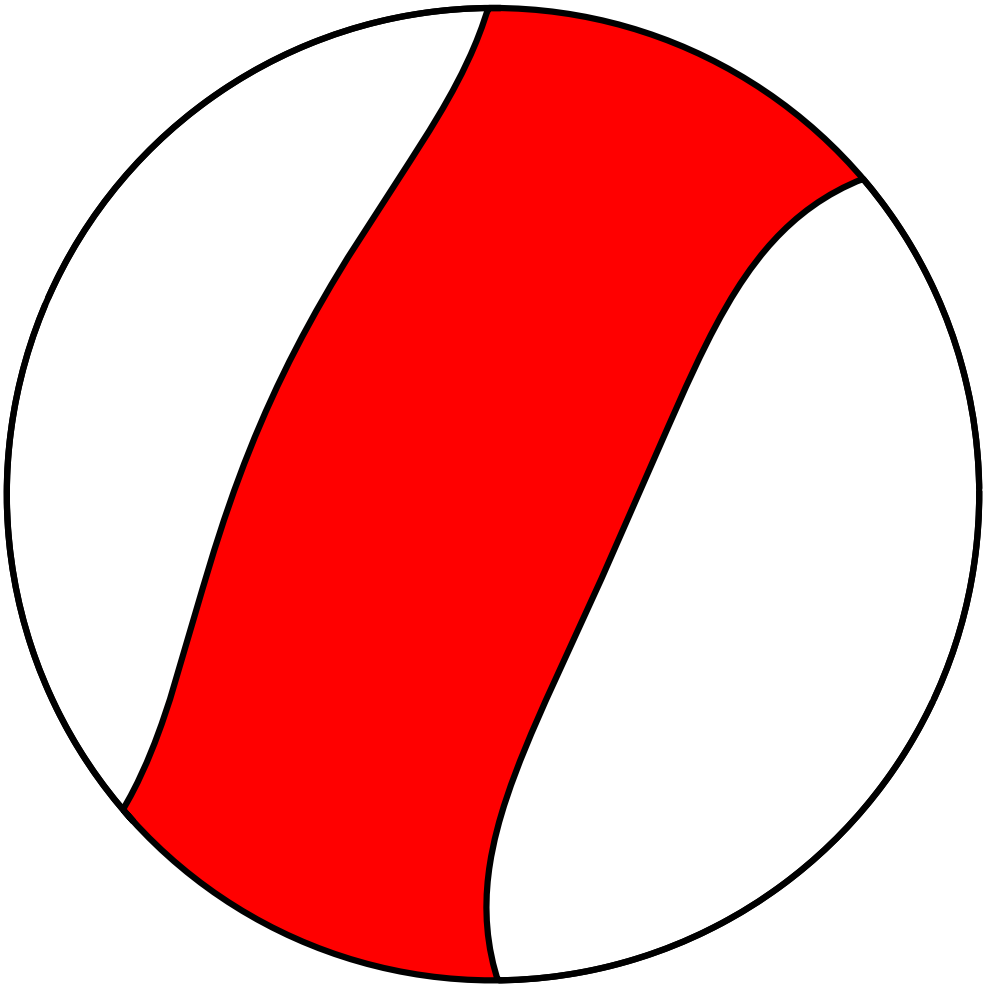


Figure 23.7: Example of plotting the focal sphere of a moment tnesor solution

Chapter 24

Quick plotting and changing of phases and polarities, PLOTPHASE and PLOTPOLARITY

PLOTPHASE and PLOTPOLARITY are two programs for relatively quick and dirty plotting of short data segments. The purpose of these tools is to efficiently display observations that are stored in the sfile. They also allow to make simple adjustments. Both tools can be started from the command line or EEV (commands QP and POL).

PLOTPHASE takes the s-file name as input and plots a time window of data around all phase picks found in the s-file. The user specifies the window length. The tool allows to change picks, apply filters (given by characters that are the same as defaults in MULPLT), go forward or back to start if many channels. All commands are displayed on the screen (Figure 24.1). To start from the command line, use e.g.:

```
plotphase 09-2257-08L.S201508
```

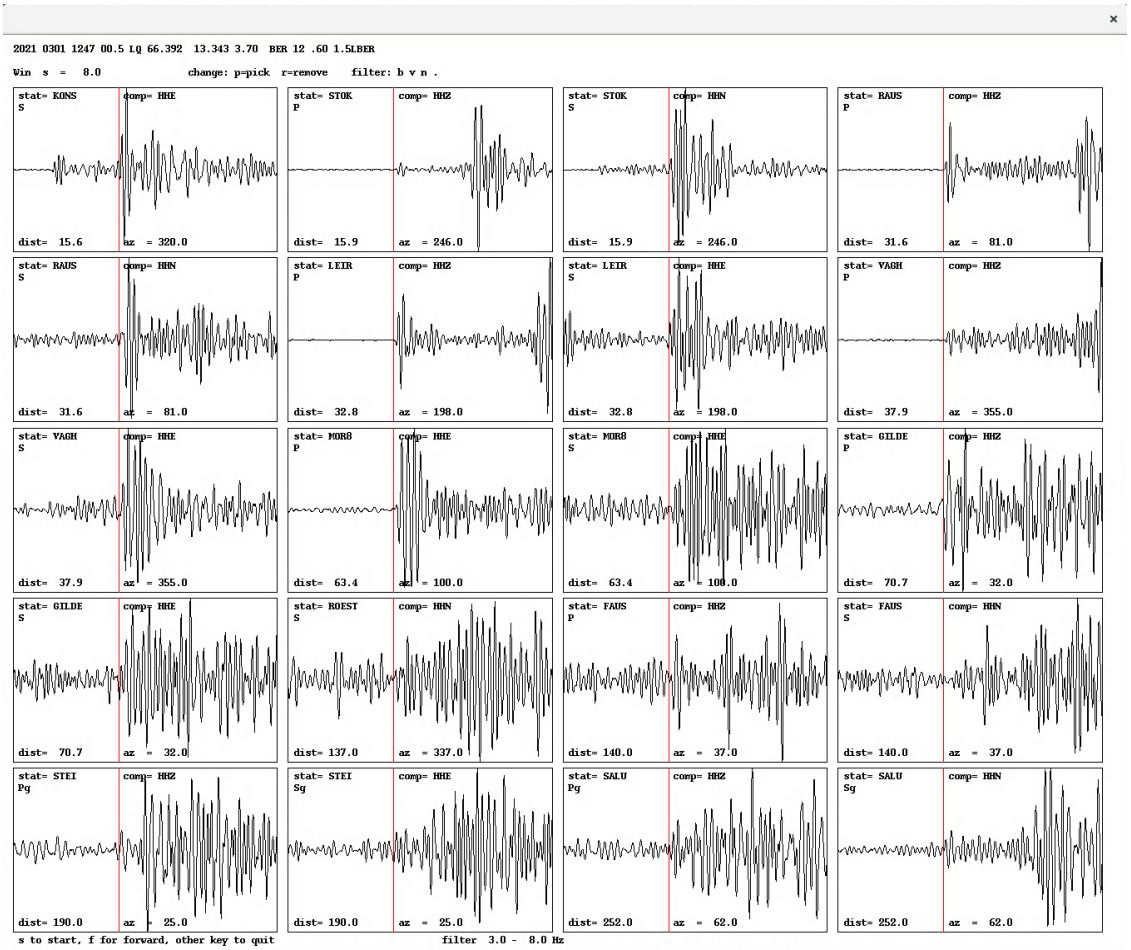


Figure 24.1: Sample plot of PLOTPHASE.

PLOTPOLARITY takes the s-file name as input and makes a plot of P-wave onset with polarity readings if available. The program provides an efficient way to plot and change polarities used to determine fault plane solution. Only vertical channels of data are shown. If changes are done, the program will save, if the user wants to, these back to the s-file. The plots can extend over several pages when there are many traces. PLOTPOLARITY can be started from EEV using command 'pol', or from the command line using either, e.g.:

```
plotpolarity 09-2257-08L.S201508
```

to plot traces which have polarities in s-file already, or with:

```
plotpolarity 09-2257-08L.S201508 all
```

to plot all vertical channel data. This is the default option when starting the program from EEV.
The program asks for some input at the startup:

```
  total window duration (default 1s):
2
```

This is the total window duration that will be displayed around the P arrival, which is taken from the s-file.

```
  P-onset position as percentage of total duration (10-90; def 50 = middle):
60
```

This number gives the position of the P arrival within the time window as percentage of the total window. Setting this to 0 would mean that the signal starts from the P arrival, 50 means that P will be in the center of the window, and so on. Numbers less than 10 and greater than 90 will be reset to 10 and 90, respectively. One typically wants enough pre-phase time to see how the signal is changing.

```
  window length in seconds for averaging (default is 0)
```

This allows to average the samples for the given time period starting the given length prior to the time of a sample. The averaging will act as a filter without a phase response, and can be looked at for noisy signals, best only to confirm if the signal seen on original trace is still the same when applying averaging filter.
Next the plot comes up, and the polarities can be inspected and changed, using keys c=compression, d=dilatation and r=remove. In case of a change, a message is written to the terminal, and the graphics are updated. For each trace, the station name is shown together with the the phase, the polarity (empty if not available), the distance and azimuth. The graphics are written to a Postscript file polarity.eps, an example is given in Figure 24.2.

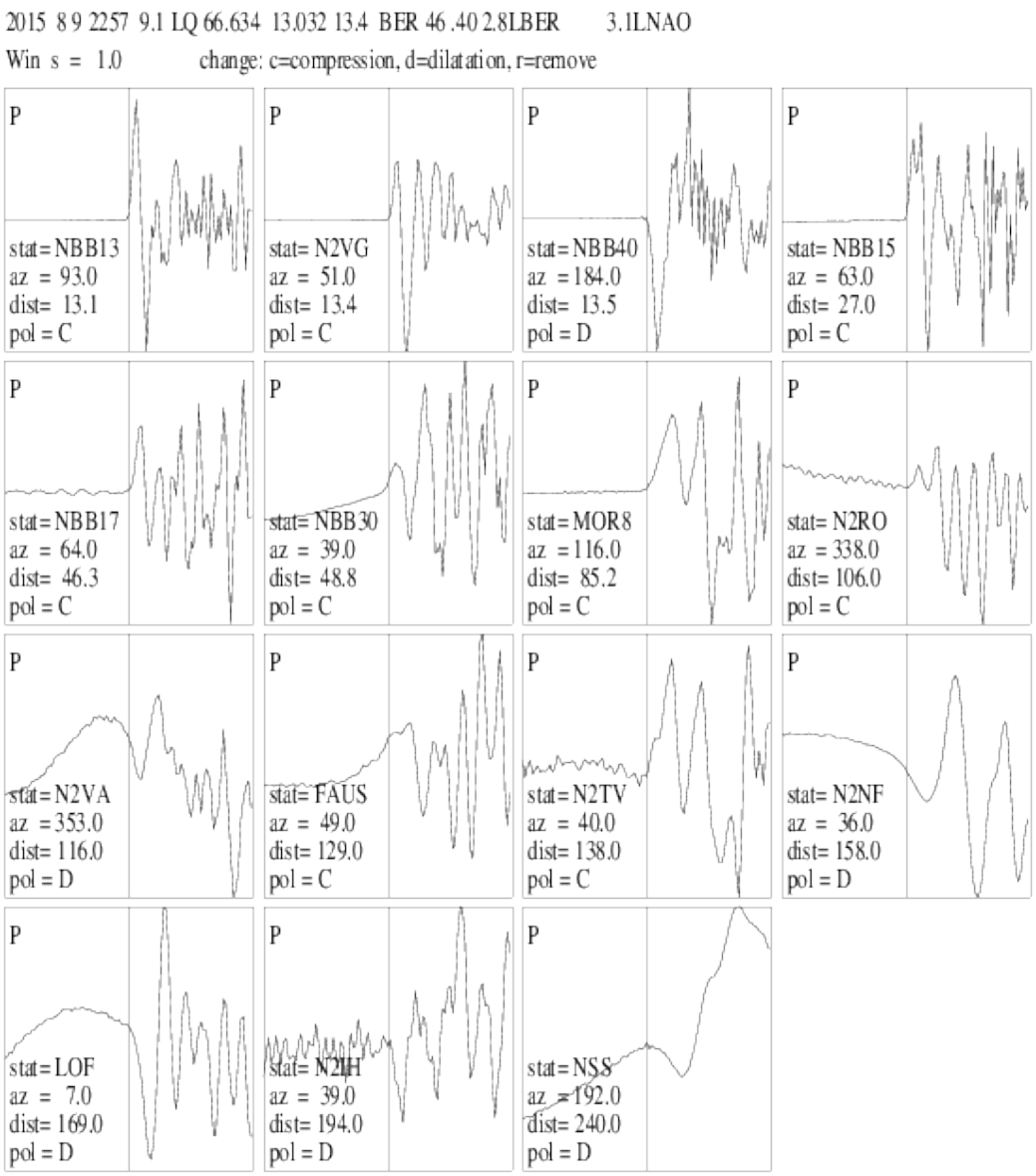


Figure 24.2: Sample plot of PLOTPOLARITY.

Chapter 25

Measuring amplitude ratios, AUTORATIO

The program runs on an s-file and measures P and S amplitude in both time and frequency domain. The measurements are done for a number of frequency bands and the results are obtained by averaging. The results can be used with FOCMEC and HASH to determine the fault plane solution. Data windows are selected based on the arrival time picks in the file and have a user selectable length (default 2 sec). The program adds 20% of time as pre-phase time. AUTORATIO can convert to displacement or velocity units and allows for filtering of the data. The user can set a maximum hypocentral distance, default is 100 km. While the program would work with Pg/Sg or Pn/Sn, it is probably wise to work with short distances and direct phases only. The results are written to the autoratio.nor output file in Nordic format. If called from EEV (command ar), the results are written directly to the s-file. Another output file, autoratio.out, lists all the amplitude readings.

The data processing steps are as follow, first for P, then S signal:

- Read the complete trace, for P this is the vertical channel, for S the horizontal channels are read and rotated into radial and transverse using the computed back azimuth
- Taper and remove DC, possibly filter and convert to ground motion
- Select time window
- Read amplitude of time domain data: P on Z, SV on Z and SH on T.
- Apply FFT to compute spectra
- Read spectral amplitude by fitting with Gaussian curve
- Do the above for different frequency bands and average
- Write out the results

The following amplitude names are used in the Nordic output file:

- ATPG: amplitude Pg time domain
- ATSG: amplitude Sg time domain
- ASPG: amplitude Pg spectral domain
- ASSG: amplitude Sg specrtal domain

The following amplitude names are used in the Nordic output file:

- StoPt: Sg to Pg ratio time domain

- StoPs: Sg to Pg ratio spectral domain

There are thus 2 S-amplitudes and one P-amplitude and the fault plane solution program will make 3 amplitude ratios, see FOCMEC and HASH. The least reliable S is probably S on Z. The program has a parameter s_on_z which can be set to not reading SV on Z. The program must then be recompiled.

NOTE: Each time the prgrom runs, all old automatic amplitudes are deleted. Manual amplitude pics are not deleted.

25.1 Plotting amplitude ratios, PLOTRATIO

This program plots the output from AUTORATIO. It shows the time domain traces and spectra for P and S, respectively, together with the amplitude measures and ratios described in the AURORATIO section. An example is given in Figure 25.1.

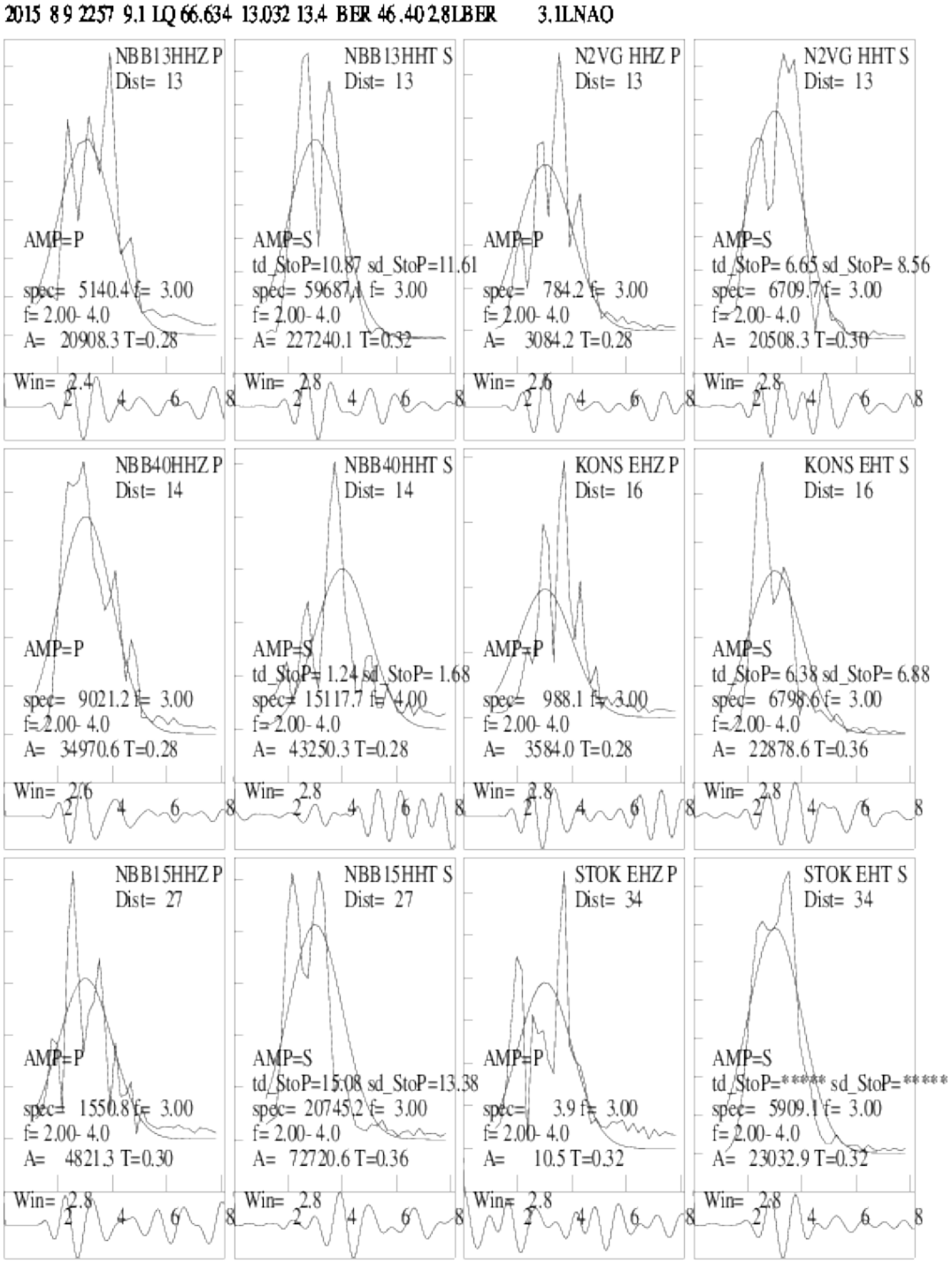


Figure 25.1: Sample plot of PLOTRATIO.

Chapter 26

Waveform inversion

26.1 Moment Tensor inversion in SEISAN

Introduction

The moment tensor inversion for regional earthquakes implemented in SEISAN uses the well tested Dreger code (Dreger, 2003).The software has been integrated into SEISAN to take advantage of all the parameters already being part of the SEISAN data base like response, hypocenter and station parameters as well as SEISAN's ability to do instrument correction and filtering. All operations take place through EEV including an optional search for the best hypocentral depth. A tutorial for the original Dreger software including basic information on the principles of the software is found in INF, `mt_dreger.pdf`.

What data to use

The program works for regional distances (up to 2000−3000 km) where the model can be approximated by flat parallel layers., The inversion will generally work best for events large enough to produce low frequency signals (f<0.1 Hz) which means surface or sometimes S-waves (at short distances or for deep events). However theoretically there is no lower magnitude limit since the source time function is a point source. A simple test to see if the data potentially can be used at low frequencies, is to apply a filter 0.01 to 0.1 Hz and see if there is a clear signal. A more quantitative test is to make spectral analysis of the S and/or surface waves to observe where the signal to noise ratio approaches 1. There are examples of inversions of small near events (m=2−3) with frequencies as high as 3 Hz. However, this is not what generally can be expected to work. It is possible to use any or all of the components Z, R and T, however the T-component is often the most important. It is recommended to use at least 4 stations with at least 6 seismograms, however that is rarely enough to get a reliable solution. Real signals are often more complicated and of longer duration than the synthetic signals, so it is easier to fit signals with a few simple pulses.

Use velocity or displacement

Our tests show that it does not make much difference for good data. In some cases it might be easier to get stable velocity traces than displacement traces since the effect of the enhancement of low frequency noise from the conversion to displacement is avoided. Whatever is selected in MULPLT is what is used by all programs. There is a check that there is no discrepancy between the data and the Green's function in terms of displacement and velocity.

Technical steps to do MT

Step 1 Select channels to analyze and write out a rotated instrument corrected data file in Helmberger format which is used to make input files to the Dreger program. Note, that all filters used must be 4 pole bandpass Butterworth filters, either one way or two ways. Although MULPLT can generate other filters, they can currently not be used for MT inversion.

- Make sure the event is well located and all response files are available. If doubt about depth, fix it in S-filer header line.
- Start EEV.
- Plot data filtered, it is easier if filter is fixed.

- Select channels desired for analysis. Select as many channels as possibly can be used. It is possible later to deselect without going back to MULPLT. NOTE: You can only make a data set of the channels seen on the screen! See below how to deal with many channels.
- Select a time windo starting about 30 s before the first P and lasting for about 10 min, but at least long enough to get all waves to use for analysis.
- Rotate channels (if 2 horizontals), check that all channels are rotated (no back azimuths of 999).
- Select filter band and plot signals instrument corrected and filtered. Start with just filtering the signals e.g. in band 0.01 to 0.1, this gives an idea of which channels have good low frequency signals. A good filter to use is often 0.03 to 0.1 Hz. For small events, a filter of 0.5 to 1.0 might have to be used Inspect the signals to see if they look reasonable. E.g., the instrument corrected amplitudes should not be very different. At this stage errors in the response files or bad data might be detected. If so correct data and select again. A wrong response can seriously affect the solution.
- When signals look ok and are displayed instrument corrected, filtered and rotated, press button `OutW`, and wait for message in to right hand corner 'File `mulplt.wav finished`'. The Ascii file `mulplt.wav` has now been written out. It can take some time since it is an Ascii format of real numbers (see below). In a multi-trace window there can be missing data in front of the signals and at the end of the signals for some channels. These gaps are filled out with the DC level.
- Quit MULPLT.

How to deal with many channels: By default, MULPLT shows 99 channels per screen, but this is often reduced to a smaller number by setting parameter `NCHAN PER SCREEN` in `MULPLT.DEF` to a number like 24. So if e.g. 100 channels are available, the data will be shown on several screens. The procedure is then:

- Select channels to use on each screen. If no channels are selected on a screen, all will be used.
- When the selection is finished and if there are more channels than fitting on one screen, press N. This will plot all channels on one screen and a file with all channels desired can be made. Pressing N again brings back the original number of channels per screen.

At this stage, a file with possible data for analysis has been written out with the original sample rate, instrument corrected (units nm or nm/s) and filtered. The two first letters in the component names has been replaced by RR to indicate reprocessed data. The file can be plotted with MULPLT or from EEV with command pd.

Step 2 Create parameters needed for MT

The generation of the Greens function needs a series of parameters including the crustal model, which might be the most critical input. The model used will be taken from the `STATIONx.HYP` file so it will be possible to use a station file different from the default by either working in a local directory with a local `STATION0.HYP` or having a `STATIONx.HYP` in DAT, where x corresponds to the model ID given in the S-file. Note that a `STATIONx.HYP` file can contain Q and density, but often does not and then default values are used. All parameters will be written in the S-file in the SYNT format (including extra mt-variables), see section on synthetic seismograms and the example below. The stations selected for analysis will be the stations given in the `mulplt.wav` file as made under step 1. Default values are given for many parameters. In order to generate parameters, in EEV:

- Give command mtp (p for parameter). All needed parameters are now stored in S-file as well as parameters for the synthetic seismogram programs, since many of these parameters are the same. An example of the parameters is given below. At this time a backup file of `mulplt.wav` is made for future reference. The name is `yyyy-mmdd-hrmm-ss.mulplt.wav`.
- Edit the S-file to change default parameters to desired values, see example below. Often a first test can be made with the default values. By default, modeling is only done for one depth, but it is possible to test a range of depths by editing the parameter file. It is however recommended to use the default depth from the S-file for the initial test.

NOTE: Command `mtp` does not overwrite any parameters already in S-file. If a completely new set of parameters is needed, all the old ones can be deleted in the S-file or by using command `mtd`.

Step 3 Generate and inspect unfiltered Greens functions.

The Greens functions should now be generated with the parameters given in S-file. In EEV:

- Give command `mtg` (g for Green's functions). This makes Helmerger format files all.green$$$ with all the time series Greens functions needed for the given data set and the requested depths $$$. By default only one depth is used. This might take some time (minutes) depending on number of points used, however the time is independent of the number of stations used. The default is to generate a 512 point time series which by default is 512 secs long. NOTE: All previous Greens function files are deleted before the new ones are made.

- Plot the Greens functions with command `pg` (g for Green). It is useful to check if the Greens functions look "reasonable". NOTE: If Greens functions for several depths have been made, only the Greens function with the largest depth can be plotted in this way (file all.green). The other ones must be plotted directly with MULPLT outside EEV. For component codes, see Dreger documentation in SEISAN. Note that the transverse components TSS and TDS have no P-waves so they appear to start later. Not all models and distances might produce reasonable signals, there should at least there should be some resemblance with the data signals. Note that the signals, starting at the origin time (read from S-file) have been time shifted with the reduction velocity to appear to arrive at similar times. At this stage it might be decided that a different time window or sample rate is needed. Then edit S-file and redo step 3.

Step 4 Decide on time window length for analysis.

The Green's functions are typically generated for 512 secs (sample rate 1.0) and typically a smaller window around the signals is used like 200-400 s (default 257 s). From the Greens functions signal, it can be seen how long a minimum window is needed. The window should be longer than the signals. Before inversion, the signals are also time shifted (like the Greens functions are already) with the reduction velocity in order to make the data file smaller.

- Edit S-file and adjust parameter `MT-NP-USE` to desired length.

Note that the all the Green's function files and the time shifted data files do not have accurate absolute time due to time shifting.

Step 5 Make the inversion

The desired time windows from all.green$$$ are filtered by the selected filter and written out. The filtered time shifted window from `mulplt.wav` are now selected, filtered by a (desired sample rate)/5 Hz antialias filter and resampled to the desired sample rate and written out. The inversion is now performed. All this is done in EEV. NOTE: All data files from previous inversion are deleted before the data selection.

- In EEV, give command `mti` (i for inversion).

The inversion is now done and the results given on the screen. If a range of depths have been selected, inversion will be done for each depth and the inversion will be repeated for the depth with the best fit so this becomes the last inversion, which can be save in S-file. A table of fit parameter (VR) and depth is displayed together with corresponding fault plane solution. If results are good (see later), they can optionally be saved in the S-file. Note particularly the value of Zcor which is how many samples the data has to be shifted to fit with the Greens function.

Step 6 Check results

See Dreger documentation in INF for the explanation of the output. The variance reduction (VR) is shown for each station as well as for all stations. A low value indicates a bad fit and a negative VR might indicate inverted polarity. The most important check is to see how the synthetic seismograms fit the observed seismograms.

- In EEV, give command `pm`. The plot of overlaid seismograms is now shown. They should be similar. Plot also with fixed scale to see the absolute difference between the traces.

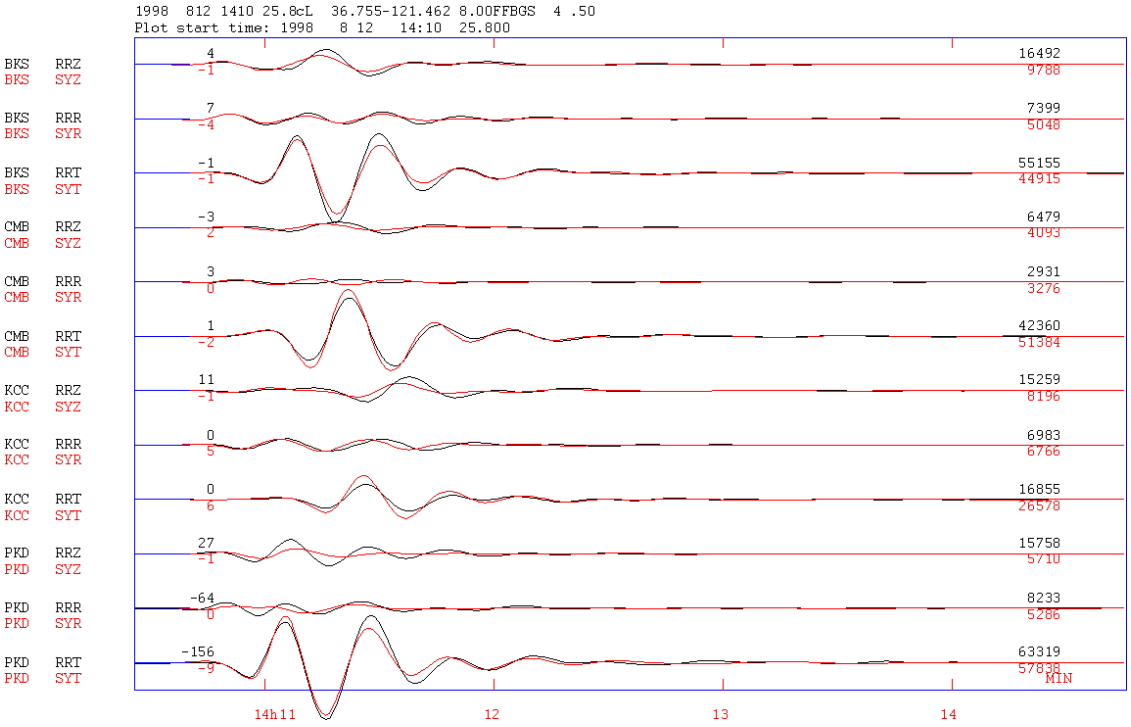


Figure 26.1: Plot of original filtered instrument corrected data (blue) compared to the synthetic seismograms (red). The filter used is 0.02 to 0.05 Hz. The plot is made with a fixed scale of 30 000. Note how the T-components dominate the solution. The data is the Dreger test data included in the SEISAN training data. Note that when plotting a file in Helmberger format, the overlay function (see MULPLT section) is turned on automatically for channels starting with SY.

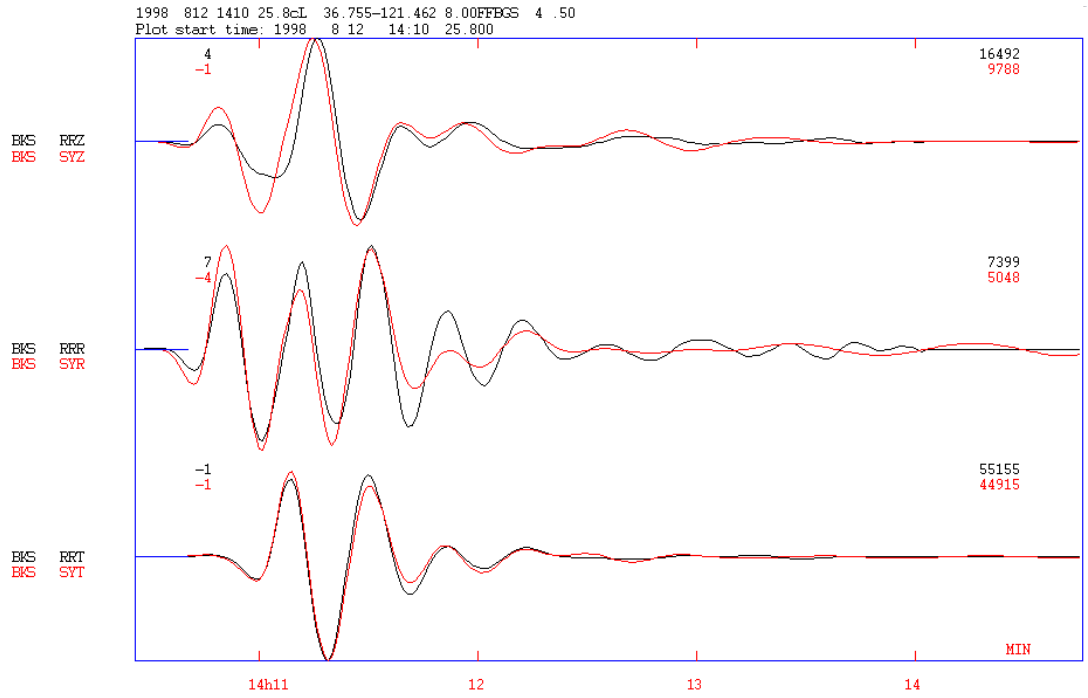


Figure 26.2: Same data as shown in previous figure but only for station BKS. The data is now auto scaled. The fit on all channels is quite good. Notice the small amplitude of the radial component.

The fault plane solution can be plotted (if saved in step 5) with command `fo`. Compare to any solution from other sources (if given in S-file, see section 23 on fps in SEISAN).

In the above plots, the original data has been shifted corresponding to the value of Zcor. This means that, for a positive Zcor, the last Zcor data sample on the trace has no data and is replaced by zeros. Similarly if Zcor is negative the first Zcor samples are zero.

Judging the results

See the Dreger documentation for a discussion. Generally the variance reduction VR should be as high as possible. A bad fit could give an unrealistic moment (and Mw) so that is also an indicator of the quality. A good fit is not a guarantee for correct results. If e.g. the gap is large, there might not be sufficiently different data to give a reliable solution, even if the fit is good. The quality given has been assigned by Dreger as follows

```
 0 < VR <   20  Quality = 0
20 < VR <   40  Quality = 1
40 < VR <   60  Quality = 2
60 < VR <   80  Quality = 3
80 < VR <  100  Quality = 4
```

It is necessary to check the solution against the P polarities to confirm that they generally match the solution as wrong alignment can result in inverted solutions. However, it is not to be expected that all the synthetic polarities fit the observed polarities since the fault plane solution from MT (measures overall slip) might be different from fault plane solution with polarities (measures the slip of the initial rupture). Use command fo to plot the solution together with observed polarities recorded in the S-file.

Example of a run of the inversion

```
#    2 12 Aug 1998 14:10 25  L  36.755-121.462 8.00FF  .50     BGS    4  ? mti

***Event to invert***: C:\Seismo\\REA\TEST_\1998\08\12-1410-00L.S199808

Inversion in:             displacement
Number of stations:              4
Number of points to use:       250
Depth:                           8.0
Sample rate:                 1.000
Reduction velocity:              8.0
Filter:                      0.020   0.050

Skip for down sampling for PKD    20
Skip for down sampling for BKS    20
Skip for down sampling for CMB    20
Skip for down sampling for KCC    20

PKD   Distance(km)=   122.0 ShiftVel(s)=     0.1  Offset(sample)=    0
BKS   Distance(km)=   142.0 ShiftVel(s)=     2.5  Offset(sample)=    0
CMB   Distance(km)=   171.0 ShiftVel(s)=     6.2  Offset(sample)=    0
KCC   Distance(km)=   201.0 ShiftVel(s)=     9.9  Offset(sample)=    0

Writing PKD__.green            ShiftVel: Shift in s due to reduction velocity
Writing BKS__.green            Offset:  Zcor parameter in S-file
Writing CMB__.green
Writing KCC__.green

Output from tdmt_invc:         See Dreger manual for following output

Depth=8
```

```
Station Information
Station(0): PKD__.data  R=122.0km  AZI=137.0  W=1.000  Zcor=14
Station(1): BKS__.data  R=142.0km  AZI=331.0  W=1.164  Zcor=13
Station(2): CMB__.data  R=171.0km  AZI=34.0  W=1.402  Zcor=13
Station(3): KCC__.data  R=201.0km  AZI=71.0  W=1.648  Zcor=12
Mo=4.12984e+023
Mw=5.0
Strike=223 ; 130
Rake=18 ; 172
Dip=83; 72
Pdc=98
Pclvd=2
Piso=0
Station(0)=78.607796  4.95437e+010
Station(1)=82.944862  3.37622e+010
Station(2)=82.605667  1.91152e+010
Station(3)=56.903259  6.36377e+009
VAR=7.48972e+006
VR=79.39  (UNWEIGHTED)
VR=79.00  (WEIGHTED)
Var/Pdc=7.668e+004
Quality=3

Update event with new mt solution(n=enter/y) ?
```

How and where parameters are changed for making tests

After the first parameter file in the S-file has been made, these parameters can only be changed by manually editing the S-file or deleting part or all of the parameters in the S-file and running command `mtp` again. Possible changes:

- New model: Delete in S-file, edit station file and run `mtp`. Or correct directly in S-file. However if a new model results in new distances and azimuths, then the station lines should also be deleted before using `mtp`. Similarly with the depth line if depth changes.
- New depth: If location is unchanged, only change depth in parameter file and start with step 3.
- Range of depths: Edit S-file depth line.
- New event location: Delete station lines in sfile and start with step 2.
- Take out some stations: Change the ID in the first station line (the one with mt specific parameters), e.g. write xSTATION instead of STATION. Then run inversion again, step 5.
- Take out components for a station: Edit the field `MT-COMP: TRZ`, see below. Then run inversion again, step 5.
- Change filter: A new data selection in MULPLT must be made with the new filter and the new filter must be written into the S-file. There is a check if filter in S-file corresponds to filter in data file. Then continue with inversion, step 5.
- Add a completely new station: Start from the beginning, this requires complete data selection and computation of Green's functions. The simplest is to delete all parameters with mtd.
- Change from displacement to velocity: Start from the beginning.
- Change sample rate: Change in S-file and start from step 3 making Greens functions. Remember to change the number of points for inversion correspondingly, that is e.g., if sample rate is doubled, number of points must also be doubled to analyze the same length time window.

- Change reduction velocity. Change in S-file and ideally start from step 3. However, starting from step 4 gives the same result provided the time window is long enough, see also below.
- Adjust time shifts: Zcor gives the number of samples the data automatically has been shifted to correlate with the Greens function. Check how the synthetic seismograms fit the observed seismograms. This number can be adjusted in the s-file. The number should be Zcor plus or minus a few data points. If zero, the automatic correlation is used. *If real data is seen to the left of the synthetics, reduce Zcor and increase if the data is to the right of the synthetics* (indicated on top of plot as D̈ata left. -Zxor̀). Zcor can be positive or negative.
- In general, if deleting a line with parameters, they can be regenerated by command mtp.

The most common editing in the S-file can be done with command mte in EEV. The command shows:

```
 Edit MT station lines
NUM STAT ACTIVE COMP ZCOR-SFIL ZCOR-AUTO DIST  AZ
  1 PKD       1  TRZ         0        40  122 137
  2 BKS       0  TRZ         0         0  142 331
  3 CMB       1  TRZ         0        39  171  34
  4 KCC       1  TRZ         0        38  201  71
 Enter station number to flip if station is used or not
 Enter station number and components to use, e.g. 4 TZ
 Enter station number and new zcor, e.g. 3 33
 Enter to terminate
```

With this command it is possible to very quickly weight out or in a station, select components and change zcor.

If a range of depths is used or the new mt solution is updated, the mt is written to a file named `psmeca.in` that can be used to plot the mt solution with the GMT program `psmeca`. With the command
`psmeca psmeca.in -R10/80/0/42 -JX16/-20 -Sd0.3 -Gred -P -B10f5:"Variance reduction":/1:Depth: > mt.ps`
the double couple part was plottes in figure 26.3. Using `-Sm0.3` will show the mt.

Summary of mt related commands in EEV

- mtp Make parameters
- mtd Delete all parameters
- mte Edit parameters in S-file
- mtg Make Greens functions
- mti Make inversion
- pm Plot observed and synthetics
- pd Plot mulplt.wav
- pg Plot greens functions
- fo Plot fault plane solutions

Influence of parameters

Filters: Try to find a filter giving a good signal to noise ratio. There can be substantially difference using different filters.

Reduction velocity: It has little influence on the results except that Zcor changes due to relative change in arrival times. It is normally selected to include signals before the P arrival and to include all surface waves. Even different reduction velocity for real and Greens function data does not matter. The use of reduction

velocity only has the purpose of reducing the length of the traces by putting events close in time. This is particularly important when using events in with a wide distance range.

Time window: The most important is that the time window includes the whole time signal to be inverted. The time window actually used by the program will depend on how close it is to a 2^n number.
The correlation is done only with 2^n samples. The number of samples selected for correlation can be both larger and smaller than the number of samples in the data file. E.g. if number of samples is between 90 and 181, 128 samples will be used and if between 182 and 362, 256 samples is used etc.
The inversion also seems to use a 2^n number and there can, in a few cases, be a radical difference between using e.g. 256 and 257 points in calculating the fit VR, but apparently not the solution itself. The default number of samples to use is therefore 257. So if the number of samples is near a 2^n number, use a number a bit larger than 2^n. This change in fit is not generally observed, in most cases VR is not affected.
Inspect the Greens function file all.green (command pd) or use MULPLT with all.green$$$ to see how long the Green function signal is and similarly look at the data files. The time shifted data files are STAT.data and can be plotted with MULPLT.

Sample rate: Seems to have little influence if well above the frequencies of analyzed data. One or two Hz seems ok for data where the inversion is made for frequencies below 0.1 Hz. For 1 Hz data 4−8 Hz or similar (depending on sample rate of original data).

Number of stations and components: It is often difficult to get good results with all stations and components. Start with a few stations (even one god one) and gradually add data. Note that changing station configuration also can change the time shift between synthetic seismograms and the data. It is important to have as small a location gap as possible.

Zcor: Zcor is calculated by correlating the Greens functions with the data and the synthetic seismograms might need a correction as observed from the overlay seismograms. The Zcor time shift will change with different solutions so there is no final Zcor that will work in all cases. Small changes in Zcor can significantly improve the results. In the worst case, Zcor might have to be large enough to reverse the polarity of a signal or even larger if e.g. P has been correlated with S (small events at higher frequencies). The automatic correlation is what creates most problems.

What can go wrong

- Very bad fit. This can be caused by the correlation not working well, Signals might be shifted several cycles. Try using a different time window, particularly a longer one. This can also be cause by a bug which results in a factor 2 wrong sample rate. it is clearly seen whan comparing the synthetics and real data. Just run again usually fixes the problem:
- Crash of inversion program. This might be caused by correlation not working. Zcor for a particular station might have a value of millions. Do not use the particular station.
- Deselecting components does not always seem to work, then use all 3 component or deselect station.
- The invasion does not start. Use `Ctrl+c` and start again.

Rerunning a previously analyzed event

The S-filer contains all a parameters used including the start time and duration of the data file so it is possible to extract the same data file for the same channels again. The Green's functions must be regenerated by command mtg. If the user does not delete the backup files (see above) the data file is available as backup file and a question will be given if the previous data file should be used.

Running the programs independently of EEV

Once a first run has been made, the programs can be run independently of EEV using the original parameter files. This can be an advantage if the user wants to change some of the hardwired parameters. However, this can only be done for one depth.

`FKRPROG_SEISAN`: The only parameters which might be tested are the group velocities. Dreger is vague about what they should be but their values seem to have some influence on the Greens function. It is also possible to edit other parameters independently like the model.

- Edit the `green.par$$$` file ($$$ is depth).

- Run program `fkrprog_seisan`: `fkrprog_seisan < green.par$$$`
- Convert to time domain by running `vwint_seisan`

`TDMT_INVC_SEISAN`: The only parameter that cannot be tested through EEV is to make the analysis window smaller than the data window. This sometime improves the results.

- Edit parameter file `mt_inv.in`
- Run `TDMT_INVC`: `tdmt_invc_seisan`

Running in this way, the synthetic file readable by SEISAN is not generated and cannot be updated with the results.

Example of parameters in S-file

```
 SYNT: MODEL--:     THICK        VP        VS      DENS        QP        QS    3
 SYNT: MODEL--:     1.000     3.200     1.500     2.280   600.000   300.000    3
 SYNT: MODEL--:     2.000     4.500     2.400     2.280   600.000   300.000    3
 SYNT: MODEL--:     1.000     4.800     2.780     2.580   600.000   300.000    3
 SYNT: MODEL--:     1.000     5.510     3.180     2.580   600.000   300.000    3
 SYNT: MODEL--:    12.000     6.210     3.400     2.680   600.000   300.000    3
 SYNT: MODEL--:     8.000     6.890     3.980     3.000   600.000   300.000 N  3
 SYNT: MODEL--:    60.000     7.830     4.520     3.260   600.000   300.000    3
 SYNT: MODEL--:    50.000     8.000     4.600     3.260   600.000   300.000    3
 SYNT: ST-D-RK:      48.0      85.0      -1.0                                  3
 SYNT: DEPTH--:      10.0         5       5.0                                  3
 SYNT: NPOINTS:       512 MT-NP-USE       280                                  3
 SYNT: TIMES--:     TOTAL    60.000   INITIAL     0.000  SY-TRACE    60.000    3
 SYNT: BOUPAR-:     800.0      2000     0.010                                  3
 SYNT: PHASES-:        Pg        Sg       PmP       SmS       SmP              3
 SYNT: DT-Tsou:     0.050      .100   MT_RATE       1.0                        3
 SYNT: MTSTART: 1998-0812-0410-00.0 MT-WINDOW     305.0                        3
 SYNT: MT-D-V-: displacement                                                   3
 SYNT: REDVELO:    0.0000 MT-REDVL:       8.0                                 3
 SYNT: COMPON-:    RADIAL                                                      3
 SYNT: STAT-AT:  no                                                            3
 SYNT: MT-FILT:     0.015     0.030         4         1                        3
 SYNT: NSTAT--:         4-------------------------------------------------------3
 SYNT: NEW STAT:-------------------------------------------------------------3
 SYNT: STATION: PKD  S  Z  DISTANC:     122.0 MTOFFSET:        22 MT-COMP: TRZ 3
 SYNT: STATION: PKD        AZIMUTH:     137.0 BAZIMUTH:     317.8              3
 SYNT: NEW STAT:-------------------------------------------------------------3
 SYNT: STATION: BKS  S  Z  DISTANC:     142.0 MTOFFSET:         0 MT-COMP: TRZ 3
 SYNT: STATION: BKS        AZIMUTH:     331.0 BAZIMUTH:     151.0              3
 SYNT: NEW STAT:-------------------------------------------------------------3
 SYNT: STATION: CMB  S  Z  DISTANC:     171.0 MTOFFSET:         0 MT-COMP: TRZ 3
 SYNT: STATION: CMB        AZIMUTH:      34.0 BAZIMUTH:     214.1              3
 SYNT: NEW STAT:-------------------------------------------------------------3
 SYNT: STATION: KCC  S  Z  DISTANC:     201.0 MTOFFSET:         0 MT-COMP: TRZ 3
 SYNT: STATION: KCC        AZIMUTH:      71.0 BAZIMUTH:     252.3              3
```

Most of the parameters are explained under synthetic seismograms. The new ones used only for mt and other important ones are:
`DEPTH--`: The first number is start depth, the following number of depth to test and the last number is the increment in depth. The default is one depth only. `MT-NP-USE`: Number of points for the inversion, default 257. The number does not have to be 2^n but it seems that, in some cases, a number a bit larger than 2^n is

better than 2^n or a bit smaller.
NPOINTS: Number of points in time domain used to make Greens function, default 512. This number must be 2^n.
MTSTART: Start time of data window used. MT-WINDOW: Length (s) of data window used. MT-RATE: Sample rate to use. This rate will be used for Greens function generation and the observed data will be down-sampled to this rate. *NOTE: The rate must have value so only skipping samples in the data can be done.* So the rate 1 can nearly always be used while rate 3 rarely can be used. The time window for the Greens function will then be NPOINTS/MT-RATE. Default 1.0 samples/s.
MT-REDVL: Reduction velocity, default 8 km/s.
MT-FILT: Filters to use for both data and Greens functions.
MTOFFSET: Offset in samples for the data relative to the Greens function. Default 0.
MT_COMP: Indicate which component to be used. By default all 3 are used, but any combination can be selected. T, R and Z can come in any order but must be within column 76:78.

Technical notes

The Dreger MT inversion essentially consists of a Green's function generation program, `fkrprog` (in SEISAN called `fkrprog_seisan`), several data manipulation programs and scripts using SAC to prepare data for the inversion program `tdmt_invc` (in SEISAN called `tdmt_invc_seisan`). The two key programs have been left nearly unchanged (all changes are clearly marked in programs) while the data manipulation programs mostly have been replaced by standard SEISAN functions (mostly within EEV) and one modified Dreger program `wvint9` (now called `wvint_seisan`) so only 3 programs have been added to SEISAN. A significant change is that Dreger uses cm as a unit while SEISAN uses nm, so software has been changed to nm like elsewhere in SEISAN. The Dreger code has no provision for using less than 3 channels. However, undocumented information indicates that if a data channel has zeros, it is not used and this is how it is implemented in SEISAN. In some cases it does not seem to work well, should be investigated more. The data and Greens functions in Dregers software are using the Helmberger format, a simple Ascii format without reference to time and channel name. SEISAN will, for simplicity use the same format, but it has been extended to also include channel information, absolute time and an ID of the event being processed (the S-file name), see example below.

```
       3   0.020  0.050 4 1 C:\Seismo\\REA\TEST_\1998\08\12-1410-00L.S199808
(7e14.5) displacement
     0.0000e+00     0.0000e+00      0  0  0.00
     120     0.100  0.0000e+00 PKD   RR T 1998  812 1410   5.983
   0.48303E+01   0.48328E+01   0.48315E+01   0.48305E+01   0.48293E+01   0.48275E+01   0.48261E+01
   0.48247E+01   0.48264E+01   0.48257E+01   0.48229E+01   0.48237E+01   0.48236E+01   0.48208E+01
   0.48195E+01   0.48179E+01   0.48153E+01   0.48138E+01   0.48090E+01   0.48077E+01   0.48043E+01
```

The two first lines are main headers. The first line has number of channels in file (format i8) and has been extended with, filter band, number of poles and passes and S-file name. Only the number of channels is required information for plotting. The second line gives format of data, extended with help text which in this case is information that file is in displacement (nm). The following two lines are channel headers for each channel. The first channel header has undocumented information. The second channel header has number of samples in channel (i8), sample interval(s)(f10.3), undocumented and starting from column 32, the station code, channel code and start time.

The program flow in SEISAN is

- Plot, rotate, filter and instrument correct signals. This generates an output file `mulplt.wav`. A parameter is set in MULPLT to enables the output. This file has not been re-sampled.
- Make parameters in S-file (command `mtp`): Parameters are selected from `mulplt.wav` (stations to use, filter and whether displacement or velocity), from s-file (depth, distances and azimuths), from station file (model) and some are hardwired. The operation takes place in EEV. At this point the backup data file is made.

- Generate the 10 Greens functions (command `mtg`): All old Green's functions are deleted and parameter files to `fkrprog_seisan` (`green.par$$$`, $$$ is depth) are made from the S-file (inside EEV), `fkrprog_seisan` is run giving an output file with frequency domain Greens functions `green.out`. This file is converted to a Greens function time domain files, `all.green`, with `wvint_seisan` (modified version of original program `wvint9`). Since it is assumed there is no explosive component, only 8 of the 10 greens function are written out in time domain (as the original program). `all.green` is in Helmberger format. Information of using displacement or velocity is read from S-file.

- Make inversion (command `mti`). In EEV, same length time windows, one for each station, are extracted from `all.green` and `seisan_mt.out`. Names are `STA.green` and `STA.data`. The old `STA.green` and sta.data are deleted first. The Greens function files are antialias filtered with a LP filter of 4 poles at (desired sample rate)/5 Hz (not sure it is needed), re-sampled and time shifted, all in EEV. If a channel has been deselected or not available, zeros are written out. The Greens functions are band-pass filtered and anti alias filtered with same filters as used for the data. The parameter file (`mt_inv.in`) for the inversion program `tdmt_invc_seisan` is made (in EEV) and the inversion program started from EEV. The inversion program makes an output file with signals and synthetics (`synt.out`) which is converted to Helmberger format file `synt_seis.out` in EEV. Command `pm` will plot this directly in EEV. File `mt_inv_redi.out` (as the original) has details of the results and is read by EEV to optionally get results back into the S-file.

Fkrprog_seisan: The parameter file format has been changed to include station names and the s-file name.
Tdmt_invc_seisan: The program has minor changes to accept new Helmberger format (it also reads the original format). It did not work properly under Windows with more then 450 points, so memory allocation was doubled to fix this. The plotting routine has been simplified to only write original and synthetic seismograms.

To get correct overlay, the channels must be sorted alphabetically. MULPLT turns on sorting (normally set in MULPLT.DEF) if the filename is synt_seis.out.

The SEISAN implementation is dimensioned to max 99 stations.

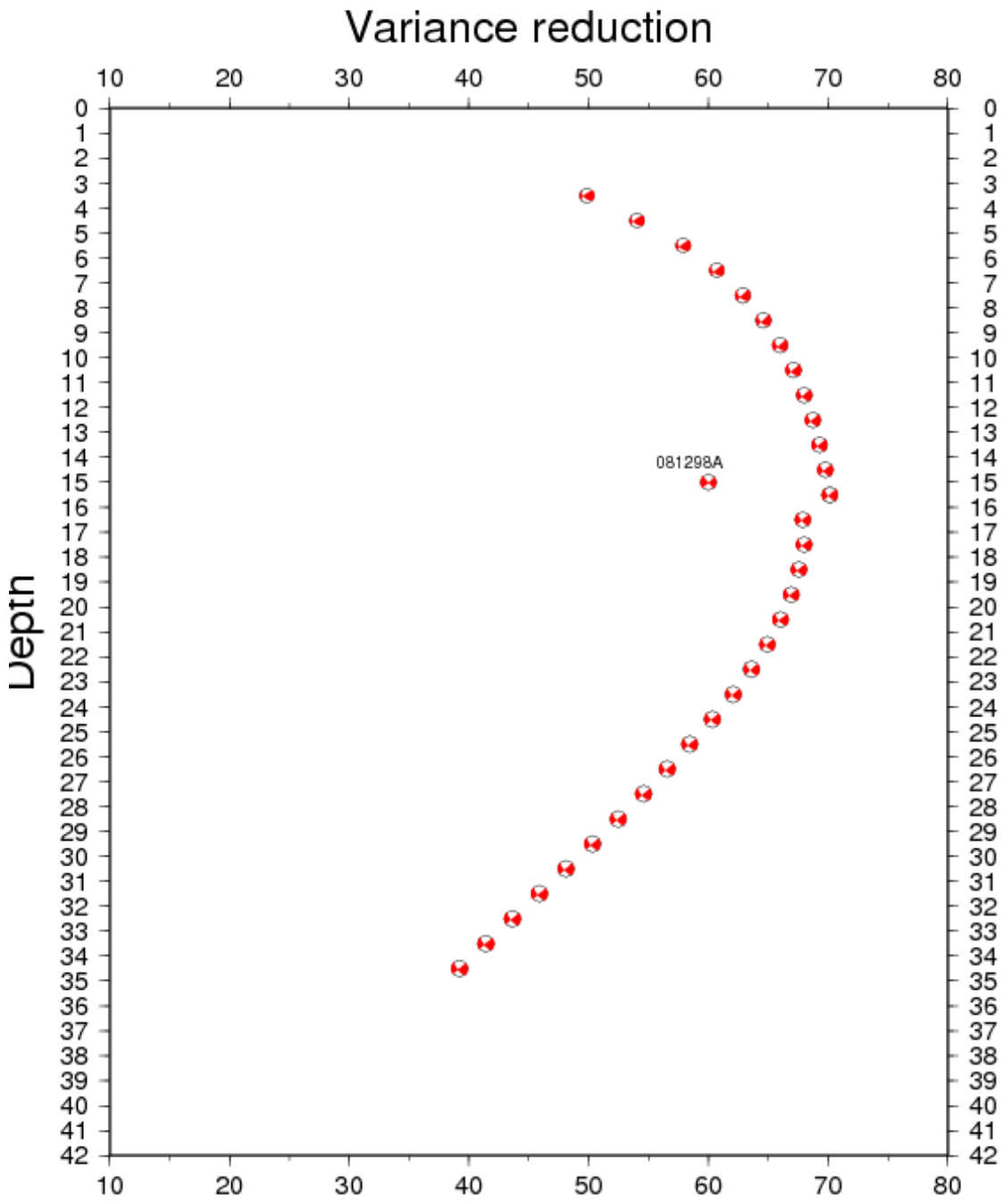


Figure 26.3: The double couple part of the moment tensor solution shown with respect to the variance reduction at different depths. The GCMT solution is also shown with arbitrary variance reduction. This figure was made with the GMT program psmeca, see text.

Chapter 27

Calculation of coda q, CODAQ, and related programs

This chapter contains the main program CODAQ to calculate coda Q, program CODAQ_AREA to sort output from CODAQ into areal bins, CODAQ_POLYGON to average in a polygon and a help program AVQ to average Q-relations.

27.1 Codaq

The program will calculate coda Q (hereafter called Q) for a series of events and stations at given frequencies. On completion, the average values are calculated and a Q vs f curve is fitted to the calculated values. The program will also plot the individual events and filtered coda windows.

The principle for calculation is the standard coda Q method, whereby a coda window is bandpass filtered, an envelope fitted and the coda Q at the corresponding frequency calculated. The envelope is calculated RMS value of the filtered signal using a 5 cycle window. The program used here is the one described in Havskov et al. (1989) and in more details in Havskov et al. (2016). The program can only operate in connection with the SEISAN format S-files. The program can use all waveform file types accepted by SEISAN and there can be more than one waveform file in the S-file. The program will also take advantage of the SEISAN database structure.

NOTE From SEISAN version 10.6, the error calculations in CODAQ has changed. Luis Matias pointed out that they seemed too small and indicated how to do it correctly (see https://en.wikipedia.org/wiki/Propagation_of_uncerta Consequently, most errros have incrased and this also affected the calcualted of Qzero and Qalpha (see later for definition). So rerunning CODAQ with identical data might give differenr results from verison 10.6 as comparesd to earlier versions.

27.1.1 Input

The calculations are controlled by a parameter file called codaq.par and the actual event-station combinations to use are given in `codaq.inp`. Example files are in DAT, and with the test data set and the example files in DAT, a test run can be done. An example of a parameter file is shown below:

```
------------------------------------------------------------------
start in s times and Vp/Vs ratio (optionally)
2.0
absolute start time (sec)
0
window length (sec)
20
spreading parameter
1.0
```

```
constant v in q = q0*f**v
1.0
minimum signal to noise ratio
2
Noise window in front of signal and length of RMS noise window
15,5
minimum correlation coefficient
0.50
maximum counts to use
64000
number of frequencies and number of octaves (optional)
3
frequencies and bands (optional if octave given)
4,2
8,4
16,8
default stations(1. line) and components (2. line), 30a5
HYA  ASK  SUE
S  Z S  Z S  N
--------------------------------------------------------------------
```

Start in s-times and Vp/Vs ratio (optinal): Normally the coda window starts at twice the S-travel time from the origin, this factor can be varied and might be chosen differently in special cases. Note that the S-time is calculated from the P-time so a P-time must be present. This also means that if a Pn is used, the coda window will start at 2 times the Sn travel time, which might be substantially different from 2 times the Sg travel time. e S-time is calcualted from the P-time using and Vp/Vs = 1.78. Optionally, the user can select an Vp/Vs ratio to be used. This parmeter is optional so parameter files prior to version 8.3 can be used.

Absolute start time: If 0.0, above parameter is used. However if different from zero, an absolute start time relative to the origin time is used for the start of the coda window. This might be useful since different start times (meaning different lapse times) might produce different q-values. To use this parameter, one must be certain to choose it long enough which can be checked with the plots. If the absolute start time is smaller than (Start in s-times) multiplied by the s travel time, the station will be skipped and a message given.

Window length: This is the coda window length in secs. Use at least 20 secs to get stable results.

Spreading parameter: The geometrical spreading parameter used in q-fit, normally 1.0 is used.

Constant v in $q = q0 * f * *v$: For all $q(f)$ values, $q0$ is calculated using a fixed v, use e.g. 1.0. This parameter has no influence on the individual q calculations.

Minimum signal to noise ratio: In order to accept a q value for the average, the signal to noise ratio must be above this value. The signal to noise ratio is calculated using the last tRMS (see next parameters) secs of the filtered coda window and the first tRMS secs of the data file window. If the data file starts with noise or in the P signal, the s/n ratio will be in error. A reasonable value is 5.0.

Maximum counts to use: If the count value in a coda window is above this value, the window is not used. The intention is to avoid using clipped values. From SEISAN version 7.2, there is also an automatic checking for clipped values in addition to 'maximum counts'.

Noise window in front of signal and length of noise window, tnoise and tRMS: The first number is the number of seconds of noise to plot in front of the signal. In previous versions, 15 secs was hardwired, but sometimes there was not 15 secs of noise before the P. The second number is the length of the noise window used for calculation of the signal to noise ratio. This was earlier hardwired to 5 secs.

Minimum correlation coefficient: In order to use the q value in the average, the correlation coefficient of the coda q fit must be larger than or equal to this value. NOTE. Correlation values are in reality negative, but are always referred to as positive in the following. An acceptable value depends on the data, try to use a value higher than 0.5 (in reality -0.5)

Number of frequencies and number of octaves: Number of frequencies to use, maximum 10, 5 is a good number. The number of octaves for the filter can also be given, then all filters have the same bandwidth.

Frequencies and bands: The corresponding center frequencies and frequency bands. The frequency band should increase with increasing frequency to avoid ringing. E.g. 8,4 means that the signal is filtered between 6 and 10 Hz. It is advisable to use constant relative bandwidth filtering, to get an equal amount of energy into each band. The relative bandwidth is defined as $RBW = (f_u - f_l)/f_o$ where f_u and f_l are upper and lower frequency limit respectively. Such a filter would be e.g. 4 ± 1, 8 ± 2. 16 ± 4. The frequency representing the energy in a particular filter band, is the geometric center frequency calculated as $f_c = sqrt f_u f_l$. Since the user probably wants to calculate coda Q at the given frequency, the normal option (new in SEISAN7.2) is that f_u and f_l are calculated such that the given bandwidth (e.g. 4 Hz) is used, but the actual f_u and f_l will give the specified central frequency. It is still possible to calculate as before, where f_u and f_l will be exactly as specified (but the geometrical center frequency will not correspond to specified center frequency) by giving the bandwidth as a negative number. The filter width should be at least one octave like 2-4 and 8-16. The number of octaves can be given with number of frequencies so then there is no need to calcule the correct bands. It is recommended to use a 1-2 octave filter and when using the option of specifying octaves, the geometric center frequency is always used. At ther end of the calculations, the octaves and filter bands is written out. Default stations: The stations and components that will be used if not specified in the `codaq.inp` file. The stations are on the first line and the components on the second line. A maximum of 300 channels can be used. THE 2 LINES MUST BE THERE CONTAIN AT LEAST SOME BLANK CHARACTERS, if not, stations will not be read from `codaq.inp` file and the program will crash.

Use of components; Component blank: Note that the program will use the first available component for the given station in waveform file. The compoent actually selected will be shown in output and on plot. Component with orientation e.g. Z: First Z-channel for station is se—lelected.

After reading the parameter file, the program will by default use the `codaq.inp` file to get the event station information. However, any other name can be used if specified interactively, see below. The station codes can have up to 5 characters.

The `codaq.inp` file will consist of a series of lines each giving an event identifier (an INDEX file). An easy way to generate the file is using the SELECT program. The file can also be generated with EEV using the (C)opy option making a file called indexeev.out. An example, where default stations are used, is shown below:

```
 1  /top/seismo/seismo/REA/BER__/1992/06/16-0343-38L.S199206
 3  /top/seismo/seismo/REA/BER__/1992/06/16-1311-58L.S199206
 7  /top/seismo/seismo/REA/BER__/1992/06/30-1504-30L.S199206
```

Since the above example only uses the default stations given in `codaq.par` there are no stations in the input file. Below is an example where particular stations and components have been selected with particular events, for this to work the station line and component line in `codaq.par` MUST be blank. Component lines can be blank or only with orientation.

```
    1 /top/seismo/seismo/REA/BER__/1992/06/16-0343-38L.S199206
HYA  KMY  BER  ASK  TRO
S  Z S  E B  E S  Z S  Z
    3 /top/seismo/seismo/REA/BER__/1992/06/16-1311-58L.S199206
HYA
   Z
    7 /top/seismo/seismo/REA/BER__/1992/06/30-1504-30L.S199206
HYA  EGD
S  E    Z
```

Note that the numbers to the left originate from the index file and do not have any importance. The long name with the directory structure, is the name of the pick file (S-file) in the database, if the S-file is in the local directory, it can have just the event id, in this example starting with 30-....The waveform file name is in the S-file. Following the S-file name is, (like in the parameter file), first a line with station codes followed by a line of component codes. Like in the parameter file, if a component is not given, the

first compoent with given station name will be chosen. THE COMPONENT LINE MUST BE THERE, EVEN IF BLANK. Since it can be quite a lot of work to generate this file manually with both stations and components, SELECT has an option to generate it, see SELECT. SELECT is able to make an output file with all event-station combination within a given range. However, SELECT will give incomplete component names since not complete in S-file. It is possible to use one or three components. The file from SELECT is called index.codaq.

Below is an example of a `codaq.inp` file, where it is assumed that the S-files are the current directory. This file can also be generated with DIRF.

```
       16-0343-38L.S199206
HYA  KMY  BER  ASK  TRO

       16-1311-58L.S199206
HYA
S  E
       30-1504-30L.S199206
HYA  EGD
S  N S  E
```

In the above examples, all results from one run are averaged. However it can sometimes be desirable to run several datasets and get individual results from each. There is therefore the option of running one set of events with many different sets of stations and for each set, the reults are written out separately. Typically in a large area, one would want to get codaq for each station or small groups of stations using a large earthquake set. This can be done using several sets of default stations, see example below.

```
SUE  KMY
S  Z S Z
ASK
S  Z
ODD1
S  Z
SUE
S  Z
```

In this example, the first dataset has two stations, the others only one. The summary output for each dataset is given in file codaq.summary . An example is seen below, for abbreviations, see later:

```
SUE  S  Z KMY  S  Z
ntotal=   37  q0= 71  sd= 25  v= 1.19  sd= 0.14  cor= 0.99
ASK  S  Z
ntotal=   10  q0= 54  sd= 22  v= 1.19  sd= 0.19  cor= 0.98
ODD1 S  Z
ntotal=   11  q0= 61  sd= 19  v= 1.25  sd= 0.13  cor= 0.99
SUE  S  Z
ntotal=   20  q0= 54  sd= 26  v= 1.27  sd= 0.19  cor= 0.98
```

Average coda Q is also calculated for each station or channel. The default is to calculate average for all components for each station. The output is given in file codaq.channel and also with more details in codaq1.out. Optionally the averages can be made for each channel if codaq is called with the argument -c. An example of an output file with channel averages is seen below.

```
PIL   BH Z n=    4 q10= 1066  q0=147  sd=  5  v= 0.86  sd= 0.01  cor= 1.00
PIL   BH N n=    5 q10= 1012  q0= 87  sd= 25  v= 1.06  sd= 0.12  cor= 0.99
PIL   BH E n=    5 q10=  995  q0= 66  sd=  9  v= 1.18  sd= 0.08  cor= 1.00
```

```
YJI   BH Z n=   11 q10= 1033  q0=113  sd=  5  v= 0.96  sd= 0.03  cor= 1.00
YJI   BH N n=    3 q10=  965  q0=107  sd= 33  v= 0.96  sd= 0.13  cor= 0.99
```

Q10 is Q at 10 Hz.

27.1.2 Program operation

The program first reads the parameter file, default `codaq.par` which must be in your current directory. It then reads the `codaq.inp` file with the events to analyze (also in current directory). The S-file names given here can, as shown in the examples above, be in the database or elsewhere, e.g. in your local directory. In the S-file, the name of the waveform file is given. If more than one waveform file is given, all files will be searched for the specified station and component. The program will first look in the current directory, and then in WAV and thereafter in the WAV database and other directories as given in the `SEISAN.DEF` file in DAT. The program can therefore work without moving the data from the database, however you can also move both the S- files and waveform files to your local directory. Remember that the S-files must be updated in order to have origin time, since the program uses the origin time and P arrival times from the S-files.

Running the program:

```
Type codaq, the program asks about output:

0: Only q is calculated, ente ris 0 for default
1: Q is calculated and a plot on the tek screen is shown
2: Q                                                    ,
   and at the same time hard copy plots are made.
3: Q is calculated and hard copy plots are made, but
   no screen plot.

Parameter file, name codaq.par is default (return)
   Just hit return if default file, otherwise give name.

File with event stations, codaq.inp is default (return)
   Just hit return if default file, otherwise give name.
```

The program will now start to run. Alterantively, the progran can be started with arguments on the promt line:

`codaq n parameter-file data-file`

or alternatively when doing channel averages

`codaq -c n parameter-file data-file`

and no questions are asked. n is the choice 0 to 3 above.

If no plot is chosen, one line will appear on the screen for each station used and one for each frequency. The program will start a new page for each new event. If you are plotting on the screen, you will therefore have to hit return to get the next plot. The screen might not have been filled out if there are few data.

All questions will appear in the text window. At the end, a summary is given, which is the same as logged in the output file `codaq.out`.

The abbreviations are:

H:	Focal depth
M:	Magnitude
TP:	P travel time
TC:	Start time of coda window relative to origin time
F:	Frequency
Q:	Corresponding coda q, if 0 value is > 10000 or negative
S/N:	Signal to noise ratio AV
Q:	Average q
SD:	Standard deviation for average
NT:	Total number of q values at all frequencies
N:	Number of q values at given frequency
q:	Average of q values
1/q:	q is calculated as 1/q averages, probably the best to use
f:1/q:	Q values calculated using the relation derived from the 1/q averages q = q0*f**v obtained with the average 1/q-values
cq0:	Constant q0 obtained using the fixed user selected v
v:	Constant v determined
cor:	Correlation coefficient on determining q vs f
corr:	Average correlation coefficients of individual codaq calculations when fitting the envelope, both average and standard deviation is given

If a station is not present or no P is read, a message will be given. The program will search for the first P arrival time in the S-file. If several are present for the same station, it will use the first.

27.1.3 Output files

codaq.out

A file called `codaq.out` is generated. It contains a copy of the parameter file, one line for each event station combination accepted by the program (correlation and s/n ratio) and the average q values. The q values are averaged directly (indicated by q) and $1/q$ are averaged (indicated by $1/q$). At the end are the fits to the $q = q0 * f * *v$ relation. A summary of codaq.out is given in codaq1.out This relation is calulated using the average Q-values for each frequency and each average is weighted by the number of observations used to calculate the average.

codaq.area

Output of codaq midpoints, codaq.area. For each accepted Q value, the midpoint between the station and the event together with the corresponding Q and frequency is saved in the file, see example below

```
2009 117201030 LYN   BH Z  34.58 112.67    1.0   91.2    1.1   10.0   37.5   38.8
2009 117201030 LYN   BH Z  34.58 112.67    2.0  223.9    2.7   10.0   37.5   38.8
2009 117201030 LYN   BH Z  34.58 112.67    4.0  444.0    6.9   10.0   37.5   38.8
2009 117201030 LYN   BH Z  34.58 112.67    8.0  833.4   11.9   10.0   37.5   38.8
2009 117201030 LYN   BH Z  34.58 112.67   16.0 1324.1   16.6   10.0   37.5   38.8
2009 117201030 LYN   BH N  34.58 112.67    1.0  132.2    2.0   10.0   37.5   38.8
2009 117201030 LYN   BH N  34.58 112.67    2.0  255.3    4.7   10.0   37.5   38.8
2009 117201030 LYN   BH N  34.58 112.67    4.0  374.2    4.6   10.0   37.5   38.8
2009 117201030 LYN   BH N  34.58 112.67    8.0  683.0    8.3   10.0   37.5   38.8
2009 117201030 LYN   BH N  34.58 112.67   16.0 1252.1   14.9   10.0   37.5   38.8
2009 117201030 LYN   BH E  34.58 112.67    1.0   92.0    0.6   10.0   37.5   38.8
2009 117201030 LYN   BH E  34.58 112.67    2.0  156.8    1.5   10.0   37.5   38.8
2009 117201030 LYN   BH E  34.58 112.67    4.0  330.3    4.2   10.0   37.5   38.8
2009 117201030 LYN   BH E  34.58 112.67    8.0  652.5    7.4   10.0   37.5   38.8
2009 117201030 LYN   BH E  34.58 112.67   16.0 1167.3   13.8   10.0   37.5   38.8
2009 3 11636 0 YMG   BH Z  39.43 112.73    1.0   70.0    0.4   13.3    0.0   13.3
```

The content is: Event date, station code, component,lat -lon of midpoint, frequency, Q, sd in Q, depth, epicentral distance and hypocentral distance. This information can be used to plot the areal variation in Q and SEISAN provides one such program, CODAQ_AREA, see below. It can also be used for statistics with QSTAT, see below.

codaq.index

A file called `codaq.index` is created. This index file contains all the events accepted for calculating the codaq values and can therefore e.g. be used for making an epicenter map of events actually used (use collect with the index file)

codaq1.out

Output file `codaq1.out` contains the same output as `codaq.out` except there is no `print out` for each event. Additionally it has the average results for each station/component.

Example of `codaq.out`:

```
start in s-times                              2.00
absolute start time (sec)                     0.00
window length (sec)                          15.00
spreading parameter                           1.00
constant v in q = q0*f**v                     1.00
minimum signal to noise ratio                 5.00
noise window in front of signal and len      15.00      5.00
minimum correlation coefficient               0.50
maximum counts to use                       500000
ASK  SUE  KMY  EGD  HYA
S  Z S  Z S  Z S  Z S  Z
 \SEISMO\WAV\1996-06-07-1324-51S.TEST__009
 \SEISMO\WAV\1996-06-07-1324-51S.TEST__009
 \SEISMO\WAV\1996-06-07-1324-51S.TEST__009
  1996 6 7132458 KMY   tc  41.3  f 16.0  s/n 37.4  Q 1077  corr -0.55  rms 0.30
 \SEISMO\WAV\1996-06-07-1324-51S.TEST__009
 \SEISMO\WAV\1996-06-07-1324-51S.TEST__009
 \SEISMO\WAV\1996-06-25-0336-34S.TEST__032
  1996 625 33715 ASK   tc  87.2  f  4.0  s/n121.9  Q  340  corr -0.60  rms 0.19
  1996 625 33715 ASK   tc  87.2  f  8.0  s/n 72.5  Q  551  corr -0.56  rms 0.28
 \SEISMO\WAV\1996-06-25-0336-34S.TEST__032
  1996 625 337 5 SUE   tc  57.3  f  4.0  s/n 96.9  Q  193  corr -0.61  rms 0.34
 \SEISMO\WAV\1996-06-25-0336-34S.TEST__032
  1996 625 33730 KMY   tc 143.5  f  8.0  s/n 13.6  Q  506  corr -0.61  rms 0.27
 \SEISMO\WAV\1996-06-25-0336-34S.TEST__032
 \SEISMO\WAV\1996-06-25-0336-34S.TEST__032
  1996 625 33653 HYA   tc  84.4  f  2.0  s/n 51.5  Q  288  corr -0.54  rms 0.12
  1996 625 33653 HYA   tc  84.4  f  4.0  s/n239.5  Q  427  corr -0.56  rms 0.17
  1996 625 33653 HYA   tc  84.4  f  8.0  s/n112.1  Q  504  corr -0.61  rms 0.27

 Freq      2.00     4.00     8.00    16.00
 Band      1.00     2.00     4.00     8.00

        AV Q  SD AV Q  SD AV Q  SD AV Q  SD

 NT=  8    N=  1    N=  3    N=  3    N=  1    N=
    q    288   0  320 118  520  27 1077   0
  1/q    288   0  287 123  519  26 1077   0
f:1/q    206  91  333 147  537 237  867 382

    q   cq0= 84  sd= 37  q0=143  sd= 49  v= 0.65  sd= 0.16  cor= 0.94
```

```
 1/q   cq0= 82  sd= 38  q0=128  sd= 57  v= 0.69  sd= 0.20  cor= 0.93

 Corr: 0.540.00 0.590.03 0.590.03 0.550.00

 Average lapse time with sd       83.704498       29.501974
```

Above, the one line per q calculations is showing results from different stations. Only the traces selected (fulfilling selection criteria) are shown. The time indicated, is the start time in the waveform file for that particular station. In general, the start time for each channel of digital data would be different. If some data is missing, it is also show in the `codaq.out` file. Corr is the average correlation coefficient (with standard deviation) for the data selected for that frequency. The average lapse time is the average of the tc - values.

codaqxx.statis

Q-values at each frequency xx is given in file codaq08.statis for e.g. 8 Hz. The file can be used to plot the results with other programs.

codaq.summary

the files give a summary of the runs, e.g.

ntotal= 1096 q0= 68 sd= 3 v= 0.95 sd= 0.02 cor= 1.00

codaq.channel

The file gives the average values for each station, see example below:

```
LYN        n=   21 q10=  622  q0= 64  sd=  4  v= 0.99  sd= 0.03  cor= 1.00
YMG        n=   88 q10=  570  q0= 68  sd=  6  v= 0.92  sd= 0.04  cor= 1.00
DAX        n=   16 q10=  701  q0= 78  sd=  7  v= 0.95  sd= 0.04  cor= 1.00
TIY        n=   38 q10=  668  q0= 81  sd=  9  v= 0.92  sd= 0.06  cor= 0.99
XAX        n=   40 q10=  605  q0= 67  sd= 10  v= 0.95  sd= 0.07  cor= 0.99
LIF        n=   50 q10=  719  q0= 57  sd=  3  v= 1.10  sd= 0.03  cor= 1.00
HEYT       n=   12 q10=  676  q0= 77  sd= 18  v= 0.94  sd= 0.12  cor= 0.98
KEL        n=   34 q10=  666  q0= 60  sd=  6  v= 1.05  sd= 0.05  cor= 1.00
DOS        n=  105 q10=  629  q0= 63  sd=  4  v= 1.00  sd= 0.04  cor= 1.00
TAG        n=   24 q10=  694  q0= 73  sd=  8  v= 0.98  sd= 0.06  cor= 0.99
JIC        n=   90 q10=  663  q0= 79  sd=  5  v= 0.92  sd= 0.03  cor= 1.00
SZZ        n=   72 q10=  617  q0= 80  sd=  4  v= 0.89  sd= 0.03  cor= 1.00
HSH        n=  114 q10=  511  q0= 78  sd=  2  v= 0.82  sd= 0.01  cor= 1.00
HZH        n=   16 q10=  698  q0= 75  sd=  5  v= 0.97  sd= 0.03  cor= 1.00
JIN        n=   10 q10=  706  q0= 74  sd=  6  v= 0.98  sd= 0.04  cor= 1.00
GUJ        n=   12 q10=  756  q0= 71  sd= 14  v= 1.03  sd= 0.10  cor= 0.99
LIS        n=    4 q10=  651  q0=125  sd=  0  v= 0.72  sd= 0.00  cor= 1.00
XIY        n=   11 q10=  492  q0= 61  sd= 22  v= 0.91  sd= 0.16  cor= 0.96
YUQ        n=   52 q10=  598  q0= 62  sd=  5  v= 0.98  sd= 0.04  cor= 1.00
YAY        n=   81 q10=  621  q0= 66  sd=  5  v= 0.98  sd= 0.04  cor= 1.00
HMA        n=   22 q10=  638  q0= 76  sd=  3  v= 0.92  sd= 0.02  cor= 1.00
```

codaq.area.nor This file gives the midpoint coordinates in Nordic format so ready to plot with epimap and other mapping programs. Example below.

```
 1999  210 1052 56.0 L  38.946  -9.168                3.0XXXX               1
 1999  210 1052 56.0 L  38.946  -9.168                3.0XXXX               1
 1999  210 1052 56.0 L  38.946  -9.168                3.0XXXX               1
 1999  210 1052 56.0 L  38.946  -9.168                3.0XXXX               1
 1999  210 1052 56.0 L  39.092  -9.118                3.0XXXX               1
 1999  210 1052 56.0 L  39.092  -9.118                3.0XXXX               1
 1999  210 1052 56.0 L  39.092  -9.118                3.0XXXX               1
 1999  210 1052 56.0 L  39.092  -9.118                3.0XXXX               1
```

codaq.map

This file is a MAP type file containing just two points for each contour, the epicenter and the station location for accepted Q-values. The file can be used with EPIMAP to plot a line between the station and the epicenter. Am example is:

```
 2
43.980  39.267  43.936  39.481
 2
43.980  39.267  43.936  39.481
 2
43.980  39.267  43.936  39.481
 2
43.980  39.267  43.936  39.481
 2
43.980  39.267  43.936  39.481
 2
43.980  39.267  43.936  39.481
 2
43.697  40.333  43.700  40.265
 2
43.697  40.333  43.700  40.265
```

In the DAT directory, there is an example `codaq.par` and `codaq.inp` set up to run on PC assuming that SEISAN has been installed under
seismo. If installed differently, edit the `codaq.inp` file to reflect the installation. For Unix testing, the `codaq.inp` MUST be edited to reflect the installation path or the file is regenerated using EEV as described above.

27.1.4 General recommendations and example of test data

Coda window should be at least 30 seconds, minimum correlation coefficient larger than 0.6. For comparing coda values in different regions, ALL processing parameters must be identical including lapse time. In Havskov et al. (2016) the effect of the different parameters is investigated and a set of recomendations are given. The parmerters found in the example file in DAT are the parmeter used in Havskov et al. (2016). In DAT there is also an input file codaq.inp using available data in the test data base. The input file has been created with program SELECT (option 18, station code= CODAQ, distance range 0 to 100 km). The start of the file is

```
    1  /seismo/REA/TEST_/1990/12/13-1109-19L.S199012
SUE  SUE  SUE  ODD1 ODD1 ODD1 ASK  ASK  ASK
   Z    N    E    Z    N    E    Z    N    E
    2  /seismo/REA/TEST_/1995/08/22-0141-06L.S199508
OSG  OSG  OSG
   Z    N    E
    3  /seismo/REA/TEST_/1995/11/20-0401-59L.S199511
EGD  EGD  EGD  BER  BER  BER  ASK  ASK  ASK  ODD1 ODD1 ODD1 BLS5 BLS5 BLS5 KMY  KMY  KMY
   Z    N    E    Z    N    E    Z    N    E    Z    N    E    Z    N    E    Z    N    E
    4  /seismo/REA/TEST_/1996/06/07-1325-29L.S199606
```

which assumes that the test data base is installed under seismo. In a standard Windows installation, that would work. Under Linux it must be change to something like /home/seismo.... Alternatively create the file with SELECT.

Figure 27.1 gives an example of a codaq plot. There are no options for the codaq plots and the length of the window is always the first 200 secs from the original trace. If origin time or coda window is outside

this 200-sec window and data is available, the program continues, but the coda window is not plotted on the figure.

27.2 Program CODAQ_AREA

CODAQ outputs the Q-values at midpoints between station and events. Using these values directly will often not show consistent results so some averring is needed. CODAQ_AREA reads this output and, at each frequency, average Q-values in user defined lat-lon bins. In each bin, provided there is enough data, the Q relation

Q =Q0*f**qalpha

is also calculated. If little data is available, Q0 can additionally be calculated for fixed qalpha given by the user. Results are also made for f=10 Hz, Q10, since this might show the differences between areas more clearly. The values in each bin is listed in an output file which can be displayed to get an approximate idea of the areal Q-distribution. In addition, a contoured map is made with EPIMAP of Q0 or Q10 and started from CODAQ_AREA. Optionally it can be deselected with parameter *Extrapolate', see below.

Input files: It is assumed that codaq.area and codaq1.out exist so these names are hardwired. Codaq1.out is used to get the frequencies available for the data set.

The interactive options are: Min no for grid average, min no of freq for Q0 calculation: Minimum number of values in a grid point for average to be calculated

Constant qalpha in Q=Q0*f**qalpha relation, 0 means do not use: Q0, can optional be calculated with a fixed qalpha. This can be useful when there is little data and it is expected that qalpha does not vary a lot over a region.

Print numbers of observations for each Q0: 1 else 0: When printing out the Q0, it is also possible to print out the total number of observations used for calculating Q0. This is all results for all frequencies.

Extrapolate q0 or q10 for plot, 0=no, 1=yes, -1= do no plot contours: When making the contours, it is possible to extrapolate the Q0 or Q10 values to bins with no data. This is done by averaging the values for the bins around. This process is done several times to fill the complete grid so in gridpoints more than 2 away from grids with data, all values will be constant.

Plot Q0 (0) or q10 (1): Plot Q0 or Q10

Latitude range and grid size: It can be a fraction of a degree but Q0 does not have resolutions better than one degree.

Longitude range and grid size: ———————

The interactive options can be stored in a file called codaq_area.inp. If the file is present, input will be read from that file and no questions asked. An example of the file is:

```
Minimum number for grid average
3
Minimum number of frequencies for Q0 calculation
4
Constant qalpha in Q=Q0*f**qalpha relation, 0 means do not use
0.0
Print numbers of observations for each Q0 (1), else 0
0
Extrapolate q0 or q10 for plot, 0=not, 1=yes
1
Plot Q0 (0) or q10 (1)
0
Latitude range and delta
34 44 1
Longitude range and delta
-12,-2 1
```

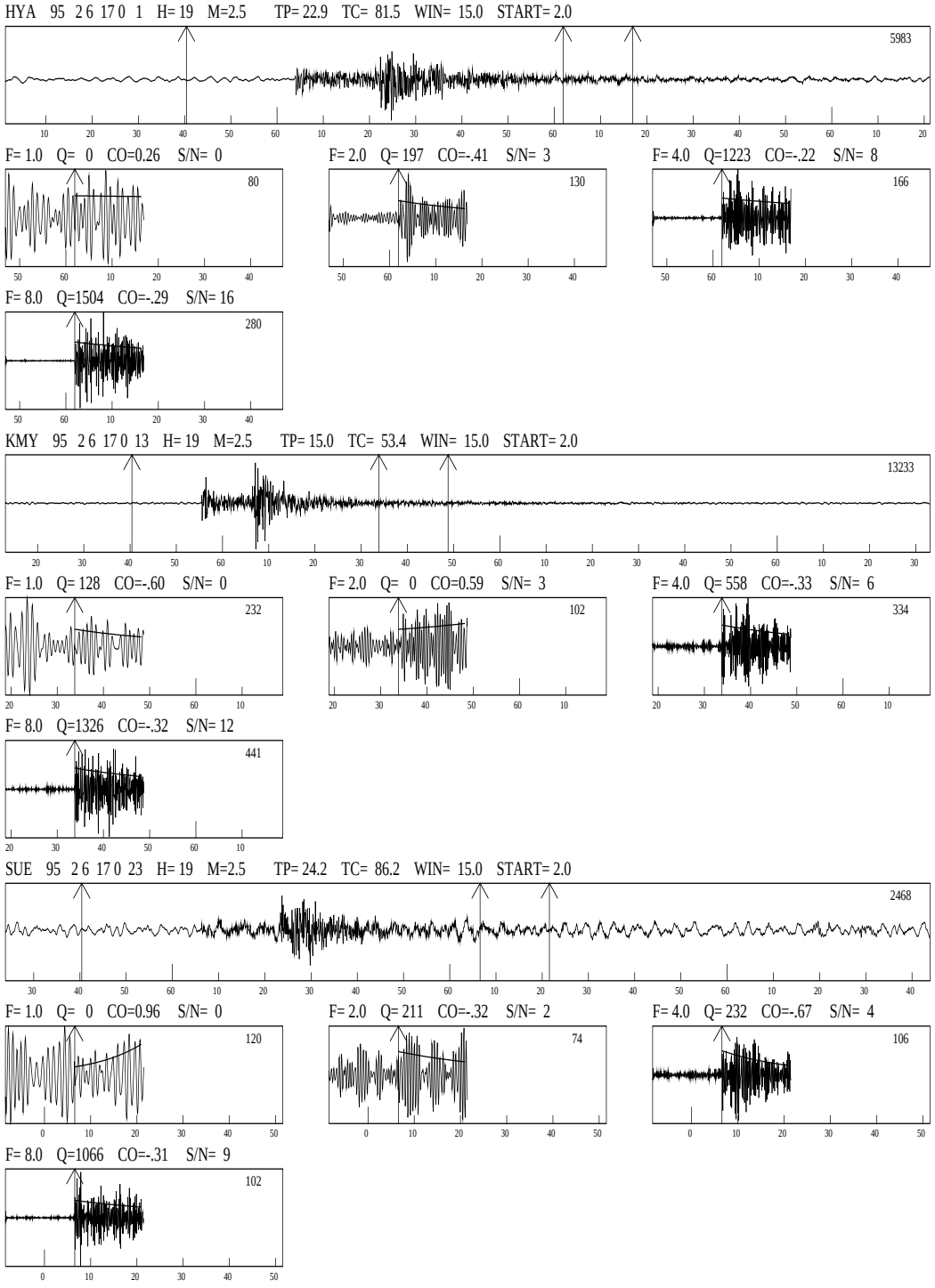


Figure 27.1: An example of a coda Q plot. On top is shown the original trace and below the filtered coda windows. Note that 15 secs of noise are shown in front of the selected filtered coda window. The first 5 secs of the noise shown is used for calculating the S/N ratio. On each filtered plot is given F: Center frequency, Q: Q-value, zero means no Q-value could be calculated, S/N: Signal to noise ratio.

The comments between the lines with numbers are just for information but there must be a line. This example file is also in DAT.

Example run with input from parameter file so no questions:

```
C:\>codaq\_area
Frequencies    1.00    2.00    4.00    8.00   16.00
 Min no for grid average, min no of freq for Q0 calculation           3           4
 Constant in Q-relation, print number of observations   0.00000000              0
 Extrapolate, plot Q0           0           0
 Lat range and delta   34.0000000       44.0000000       1.00000000
 Lon range and delta  -14.0000000      -2.00000000       1.00000000
 Number of q-data in input file        4581
 Number of q-data inside grid          4581



Range of Q values to plot    58.4   310.7
 Writing codaq\_area\_epimap.inp
....
....   epimap output
....

 File with area grid:    codaq\_area.out
 File with grid points: codaq\_grid.out
 File with epimap commands: codaq\_area\_epimap.inp
```

Example of the areal output file coda_area.out showing the lat-lon bins, note the midpoint of the bin is used:

```
 freq=   1.00000000
      -13.5 -12.5 -11.5 -10.5  -9.5  -8.5  -7.5  -6.5  -5.5  -4.5  -3.5  -2.5
  43.5     0     0     0     0     0     0     0     0     0     0     0     0
  42.5     0     0     0     0     0     0     0     0     0     0     0     0
  41.5     0     0     0     0     0     0     0     0     0     0     0     0
  40.5     0     0     0     0     0     0     0     0     0     0     0     0
  39.5     0     0     0     0    81    93     0     0     0     0     0     0
  38.5     0     0     0     0   136   114     0     0   196     0     0     0
  37.5     0     0     0     0     0     0     0     0     0    88    94     0
  36.5     0     0    97     0     0   141     0    83   124     0   103     0
  35.5     0     0     0   134     0     0     0     0   107     0     0     0
  34.5     0     0     0     0     0     0     0     0    89     0     0     0
 freq=   2.00000000
      -13.5 -12.5 -11.5 -10.5  -9.5  -8.5  -7.5  -6.5  -5.5  -4.5  -3.5  -2.5
  43.5     0     0     0     0     0     0   256     0     0     0     0     0
  42.5     0     0     0     0   323     0     0   227     0     0     0     0
  41.5     0     0     0     0     0   394   150     0     0     0     0     0
  40.5     0     0     0     0     0   112     0     0     0     0     0     0
  39.5     0     0     0     0   221   227     0     0     0     0     0     0
  38.5     0     0     0     0   256   338   303     0     0     0     0     0
  37.5     0     0     0     0     0   245   273     0     0   126   125     0
  36.5     0   219   141     0     0   156     0   133   155     0   135     0
  35.5     0     0     0   155     0     0     0     0   155     0     0     0
  34.5     0     0     0     0     0     0     0     0   128     0     0     0
 freq=   4.00000000
```

```
      -13.5 -12.5 -11.5 -10.5  -9.5  -8.5  -7.5  -6.5  -5.5  -4.5  -3.5  -2.5
 43.5     0     0     0     0     0     0   487     0     0     0     0     0
 42.5     0     0     0     0   619     0     0   411     0     0     0     0
 41.5     0     0     0     0     0   640   485   565     0     0     0     0
 40.5     0     0     0     0     0   502   546     0     0     0     0     0
 39.5     0     0     0     0   556   531     0     0     0     0     0     0
 38.5     0     0     0     0   503   560   540     0     0   623     0     0
 37.5     0     0     0     0   319   500   505     0   265   235   207     0
 36.5     0   287   210   384   280   303   287   196   211     0   204     0
 35.5     0     0     0   273     0     0   207     0   233     0     0     0
 34.5     0     0     0     0     0     0     0     0   209     0     0     0
freq=   8.00000000
      -13.5 -12.5 -11.5 -10.5  -9.5  -8.5  -7.5  -6.5  -5.5  -4.5  -3.5  -2.5
 43.5     0     0     0     0     0   790   803     0     0     0     0     0
 42.5     0     0     0     0   921  1121     0   712     0     0     0     0
 41.5     0     0     0     0     0   859   896   808     0     0     0     0
 40.5     0     0     0     0     0   732   797     0     0     0     0     0
 39.5     0     0     0     0   948   880   667     0     0     0   808     0
 38.5     0     0     0     0   884   897   836     0  1002  1028     0     0
 37.5     0     0     0     0   622   812   899   970   774   463   379     0
 36.5     0   486   386   604   569   607   577     0     0     0   358     0
 35.5     0     0     0   492     0     0     0     0   754     0     0     0
 34.5     0     0     0     0     0     0     0     0   518     0     0     0
freq=   16.0000000
      -13.5 -12.5 -11.5 -10.5  -9.5  -8.5  -7.5  -6.5  -5.5  -4.5  -3.5  -2.5
 43.5     0     0     0     0     0  1238  1306  1342     0     0     0     0
 42.5     0     0     0     0  1362  1574     0  1216     0     0     0     0
 41.5     0     0     0     0     0     0  1499  1302     0     0     0     0
 40.5     0     0     0     0     0     0  1451     0     0     0     0     0
 39.5     0     0     0     0  1558  1376     0     0     0     0     0     0
 38.5     0     0     0     0  1534  1375  1295  1442     0  1537     0     0
 37.5     0     0     0     0  1413  1306  1366  1418     0   970   805     0
 36.5     0     0     0     0  1007  1427     0     0     0     0     0     0
 35.5     0     0     0  1188     0     0     0     0     0     0     0     0
 34.5     0     0     0     0     0     0     0     0   989     0     0     0
Q0
      -13.5 -12.5 -11.5 -10.5  -9.5  -8.5  -7.5  -6.5  -5.5  -4.5  -3.5  -2.5
 43.5     0     0     0     0     0     0   160     0     0     0     0     0
 42.5     0     0     0     0   226     0     0   133     0     0     0     0
 41.5     0     0     0     0     0   256   129     0     0     0     0     0
 40.5     0     0     0     0     0    58     0     0     0     0     0     0
 39.5     0     0     0     0   103   126     0     0     0     0     0     0
 38.5     0     0     0     0   142   162   193     0   196   266     0     0
 37.5     0     0     0     0    69   169   166   310     0    85    77     0
 36.5     0   114    83     0     0    87     0     0     0     0    83     0
 35.5     0     0     0   118     0     0     0     0    93     0     0     0
 34.5     0     0     0     0     0     0     0     0    72     0     0     0
Q10
      -13.5 -12.5 -11.5 -10.5  -9.5  -8.5  -7.5  -6.5  -5.5  -4.5  -3.5  -2.5
 43.5     0     0     0     0     0     0   923     0     0     0     0     0
 42.5     0     0     0     0  1032     0     0   841     0     0     0     0
 41.5     0     0     0     0     0  1115  1005     0     0     0     0     0
 40.5     0     0     0     0     0  1468     0     0     0     0     0     0
 39.5     0     0     0     0  1061   965     0     0     0     0     0     0
```

```
 38.5     0     0     0     0  1035  1034   962     0  1193  1150     0     0
 37.5     0     0     0     0   848   933  1006  1096     0   522   457     0
 36.5     0   559   440     0     0   857     0     0     0     0   417     0
 35.5     0     0     0   747     0     0     0     0   561     0     0     0
 34.5     0     0     0     0     0     0     0     0   590     0     0     0
Qalpha
      -13.5 -12.5 -11.5 -10.5  -9.5  -8.5  -7.5  -6.5  -5.5  -4.5  -3.5  -2.5
 43.5  0.00  0.00  0.00  0.00  0.00  0.00  0.76  0.00  0.00  0.00  0.00  0.00
 42.5  0.00  0.00  0.00  0.00  0.66  0.00  0.00  0.80  0.00  0.00  0.00  0.00
 41.5  0.00  0.00  0.00  0.00  0.00  0.64  0.89  0.00  0.00  0.00  0.00  0.00
 40.5  0.00  0.00  0.00  0.00  0.00  1.40  0.00  0.00  0.00  0.00  0.00  0.00
 39.5  0.00  0.00  0.00  0.00  1.01  0.88  0.00  0.00  0.00  0.00  0.00  0.00
 38.5  0.00  0.00  0.00  0.00  0.86  0.80  0.70  0.00  0.78  0.64  0.00  0.00
 37.5  0.00  0.00  0.00  0.00  1.08  0.74  0.78  0.55  0.00  0.79  0.77  0.00
 36.5  0.00  0.69  0.72  0.00  0.00  0.99  0.00  0.00  0.00  0.00  0.70  0.00
 35.5  0.00  0.00  0.00  0.80  0.00  0.00  0.00  0.00  0.78  0.00  0.00  0.00
 34.5  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.91  0.00  0.00  0.00
```

Output file codaq_grid.out contains details of the averages in each bin see part of file below:

```
freq=   1.00000000
   34.500   -13.500       0.0       0.0         0
   34.500   -12.500       0.0       0.0         0
   34.500   -11.500       0.0       0.0         0
   34.500   -10.500       0.0       0.0         0
   34.500    -9.500       0.0       0.0         0
   34.500    -8.500       0.0       0.0         0
   34.500    -7.500       0.0       0.0         0
   34.500    -6.500       0.0       0.0         2
   34.500    -5.500      89.5      21.1        81
   34.500    -4.500       0.0       0.0         0
   34.500    -3.500       0.0       0.0         0
   34.500    -2.500       0.0       0.0         0
   35.500   -13.500       0.0       0.0         0
   35.500   -12.500       0.0       0.0         0
   35.500   -11.500       0.0       0.0         0
   35.500   -10.500     134.9      13.7         3
   35.500    -9.500       0.0       0.0         0
   35.500    -8.500       0.0       0.0         0
   35.500    -7.500       0.0       0.0         0
   35.500    -6.500       0.0       0.0         0
   35.500    -5.500     107.8      15.8         4
   35.500    -4.500       0.0       0.0         0
   35.500    -3.500       0.0       0.0         0
   35.500    -2.500       0.0       0.0         0
   36.500   -13.500       0.0       0.0         0
   36.500   -12.500       0.0       0.0         1
   36.500   -11.500      97.4      49.9         5
   36.500   -10.500       0.0       0.0         0
   36.500    -9.500       0.0       0.0         0
   ....
   41.500    -2.500       0.0       0.0         0
   42.500   -13.500       0.0       0.0         0
   42.500   -12.500       0.0       0.0         0
   42.500   -11.500       0.0       0.0         0
```

```
   42.500   -10.500       0.0       0.0         0
   42.500    -9.500       0.0       0.0         0
   42.500    -8.500       0.0       0.0         0
   42.500    -7.500       0.0       0.0         0
   42.500    -6.500       0.0       0.0         0
   42.500    -5.500       0.0       0.0         0
   42.500    -4.500       0.0       0.0         0
   42.500    -3.500       0.0       0.0         0
   42.500    -2.500       0.0       0.0         0
   43.500   -13.500       0.0       0.0         0
   43.500   -12.500       0.0       0.0         0
   43.500   -11.500       0.0       0.0         0
   43.500   -10.500       0.0       0.0         0
   43.500    -9.500       0.0       0.0         0
   43.500    -8.500       0.0       0.0         0
   43.500    -7.500       0.0       0.0         0
   43.500    -6.500       0.0       0.0         0
   43.500    -5.500       0.0       0.0         0
   43.500    -4.500       0.0       0.0         0
   43.500    -3.500       0.0       0.0         0
   43.500    -2.500       0.0       0.0         0
freq=   2.00000000
   34.500   -13.500       0.0       0.0         0
   34.500   -12.500       0.0       0.0         0
   34.500   -11.500       0.0       0.0         0
   34.500   -10.500       0.0       0.0         0
   34.500    -9.500       0.0       0.0         0
   34.500    -8.500       0.0       0.0         0
   34.500    -7.500       0.0       0.0         0
   34.500    -6.500       0.0       0.0         2
   34.500    -5.500     129.0      23.5       114
   34.500    -4.500       0.0       0.0         0
   34.500    -3.500       0.0       0.0         0
   34.500    -2.500       0.0       0.0         0
   35.500   -13.500       0.0       0.0         0
   35.500   -12.500       0.0       0.0         0
   35.500   -11.500       0.0       0.0         1
   35.500   -10.500     155.4      26.0        23
   35.500    -9.500       0.0       0.0         1
   35.500    -8.500       0.0       0.0         0
   35.500    -7.500       0.0       0.0         0
   35.500    -6.500       0.0       0.0         0
   35.500    -5.500     155.6      13.4        11
   35.500    -4.500       0.0       0.0         0
   35.500    -3.500       0.0       0.0         0
   35.500    -2.500       0.0       0.0         0
   36.500   -13.500       0.0       0.0         0
   36.500   -12.500     219.2     106.5         5
   36.500   -11.500     141.4      30.3         7
   36.500   -10.500       0.0       0.0         0
```

The output is: Bin midpoint, average Q, standard deviation in average and number of points in bin. Finally a plot is made with contours of Q, see Figure 27.2.

The map with the contours is produced automatically from the input. The projection is Mercator

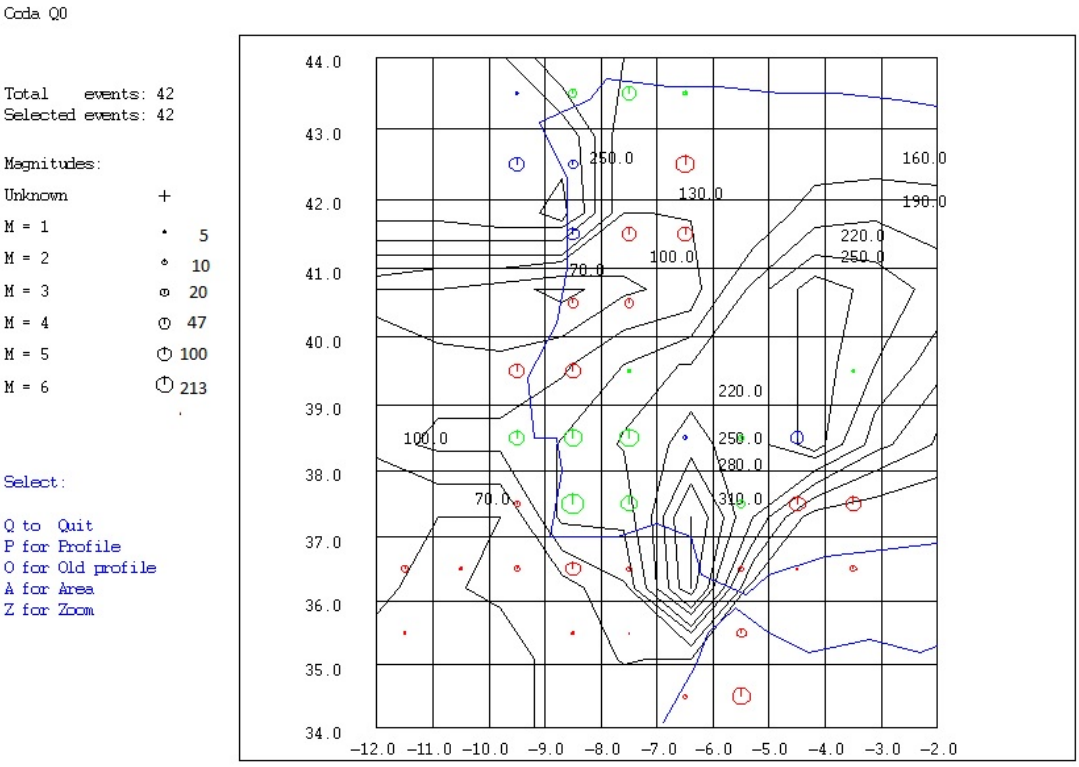


Figure 27.2: Map with contours. The 'epicenter' symbols show gridpoints with data and the size of the symbols show the total number of Q-results for that gridpoint, the number are shown to the left (not shown in real plot, have been put in manually). The color of the symbols indicate Q-values where the range of Q-values have been divided by 3 so blue is highest Q, green is average and red the smallest.

and the land contour is WORLD.MAP in DAT. Another map file can be used by setting parameter EPIMAP_MAP_FILE in SEISAN.DEF. The commands for running EPIMAP are in output file codaq_area_epimap.inp, so this file can also be modified to change map projection etc (see EPIMAP) and the plot regenerated by giving command

epimap codaq_area_epimap.inp

27.3 Program CODAQ_POLYGON

Using EPIMAP, it is possible to select out events in a polygon when plotting the codaQ midpoints (or other epicentres). It is then possible to calculate the average Q in that area using the program CODAQ_POLYGON. The input polygon coordinates are assumed to be present in file epimap.cor, the one created by EPIMAP when selecting in a polygon. The codaQ values in the midpoints are supposed to be present in file codaq.area and no questions are asked. File coda1.out is also used as input and must be present. A depth range can be specified. The data in the polygon file is written out in a file POLYGON.MAP so it can be plotted again with EPIMAP. The POLYGON.MAP file is appended to so if CODAQ_AREA is used several times with different polygon areas, they will all be stored in POLYGON.MAP read for plotting with EPIMAP. It is up to the user to ensure the POLYGON.MAP is empty if a new series of polygons are stored.

The section of the codaq.area corresponding to the polygon area is output in codaq_polygon.area and it can be used with QSTAT for statistics of the data in the polygon area.

Example run

```
codaq_polygon


c:\jens\Q-port\ALL>codaq_polygon
Frequencies    1.00    2.00    4.00    8.00   16.00

 Depth range to use, enter to use all

Number of points defining polygon:     7
 f=   1.00000000

 f=   2.00000000
   216.   269.   308.
 f=   4.00000000
   696.   450.   602.   776.   677.   494.   614.   489.   707.   643.
   764.   687.   649.   573.   816.   841.   834.   518.   536.   524.
   786.
 f=   8.00000000
  1366.   878.   968.  1295.   803.   999.   979.   967.  1155.  1080.
   940.  1110.  1042.   994.   992.   999.  1023.  1020.  1009.   853.
  1177.  1007.  1316.  1186.   777.   898.   959.  1052.  1097.   945.
  1030.  1206.  1123.  1008.  1140.  1062.  1455.  1029.  1125.   809.
  1298.   871.  1386.  1231.  1175.  1100.   771.  1171.   891.   897.
   740.  1286.  1352.  1108.  1037.  1240.
 f=   16.0000000
  1667.  1514.  1648.  1638.  1898.  1777.  1381.  1667.  1620.  1810.
  1220.  1251.  1543.  1344.  1436.  1520.  1772.  1575.  1586.  1455.
  1666.  1534.  1491.  1696.  1514.  1575.  1690.  1597.  1352.  1450.
  1358.  1672.  1674.  1514.  1633.  1543.  1392.  1552.  1619.  1474.
  1647.  1425.  1510.  1456.  1374.  1391.  1389.  1366.  1657.  1449.
  1342.  1689.  1238.  1667.  2297.  1573.  1972.  1463.  1405.  1449.
Number of Q-midpoints within polygon:      140
f= 2.0  av= 259.0  sd=  46.9  n=    3
```

```
f= 4.0  av= 628.9  sd= 119.7  n=   21
f= 8.0  av=1035.7  sd= 163.2  n=   56
f=16.0  av=1531.8  sd= 167.4  n=   60

q0=  172.7  sd 38.8    qalpha= 0.81  sd 0.10   q10=1107.8  sd=182.1   corr= 0.98  rms= 0.00  nf= 4

 Use all data, no weight
q0=  166.0  sd 36.8    qalpha= 0.84  sd 0.12   q10=1151.4  sd=188.4  corr= 0.98  rms= 0.00  nf= 4

 Append to POLYGON.MAP (n/y=default)


 Accumulated polygon coordinates in POLYGON.MAP
 Area file selected is codaq_polygon.area
 oUput file is codaq_polygon.out
```

For each frequency, all the Q-values are printed so it is possible to get an idea of the variation of the values. The averages are calculated for each frequency if 2 or more values are available. The Q-realtion is then

calculated if averages are available for at least 3 frequecies. Finally, a Q-relation is calculated if also one value is available, but then there is no weighting with the standard deviations of the averages.

How to calculate coda Q in polygon areas

Calculate coda Q in large area of interest.

indexCoda Q in a polygon Plot all the midpoints between station end events with EPIMAP using command map codaq.area.nor . The input epicentre file is codaq.area.nor which is output from CODAQ.

Do the following for each polygon area:

With EPIMAP, use polygon function to select an area. Terminate EPIMAP.

Run codaq_polygon to calculate coda Q for that area, the polygon outline is stored in file

POLYGON.MAP for later plotting.

After e.g. 5 runs, the 5 areas are stored in POLYGON.MAP and the Q-relations have been printed out.

27.4 Program QSTAT

This program also use the codaq.area to make statistics etc. After running CODAQ, codaq.area contains all individule coda Q determinations. The program first finds all the stations which has contributed to the calculations and makes an output file qstat.stat with station codes and station coordiantes (require STATION0.HYP) so a map can be made with the 'good' stations. If a station is not found in STATION0.HYP, the lat-lon will be 0.0 0.0 in output file. Then a plot is made with Q as a function of distance for each frequecy and a histogram is made with the the distribution of Q values for each frequency. The latter is intended to be illustrate the spred in the Q values and is useful when comparing Q from different areas. Note that the number of values for each frequency are not absolute, but scaled to fit the plot. The number of values for each frequency is indicated on the plot.

27.5 Program AVQ, average Q-relations

Q as a function of frequency is usually described as

$q = q0 * f * *v$

If several such relations are to be averaged, it is not just a question of averaging the parameters. In program AVQ, the averaging is done in the following way:

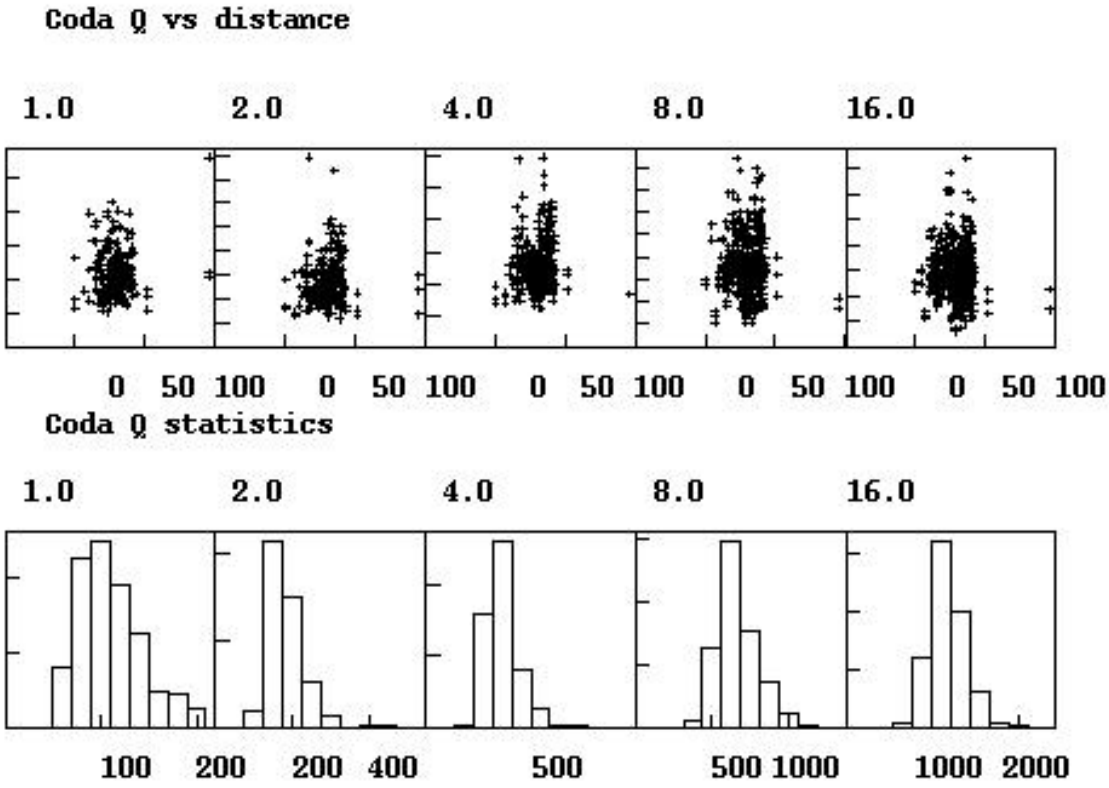


Figure 27.3: The top plot shows Coda Q as a function of epicentral distance and the bottom plot shows the distribution of individual Q-values for each frequency. n is the number of Q-values for each frequency

-For each relation, 1/Q is calculated at the frequencies 1, 2, 4, 8 and 16 Hz. -At each frequency, average 1/Q is calculated using the number of observations in the original determination of Q for a particular relation as weight. -A new least squares determination of v in $q0$ is made with the Q-values.

The program uses an input file with q0, v and number of observations, one relation (free format) per line. An example of a run is seen below:

```
C:\seismo\wor>avq
 File name, enter for automag_grid.out
input.txt
 Q0,alpha,n   100.000000      0.500000000             100
 Q0,alpha,n   150.000000      0.300000012              50
 Q0,alpha,n   200.000000      0.200000003              10
 Q0,alpha,n   170.000000      0.400000006              22
 Q0,alpha,n   250.000000      0.150000006               5
 Q0,alpha,n   80.0000000      0.800000012              10
  Number of curves to average:           6
 Running average over how many, enter for average of all?

 Q0,alpha,corr   119.819160      0.437137932      0.999868274

 Output of plot in avq.eps
```

and the plot seen in figure 27.4 comes up.

The program also has a special input to be used with AUTOMAG, which can output Q-relations found by grid search, see AUTOMAG for more details. These relations can be averaged over a number of relations. However, here that option is not used.

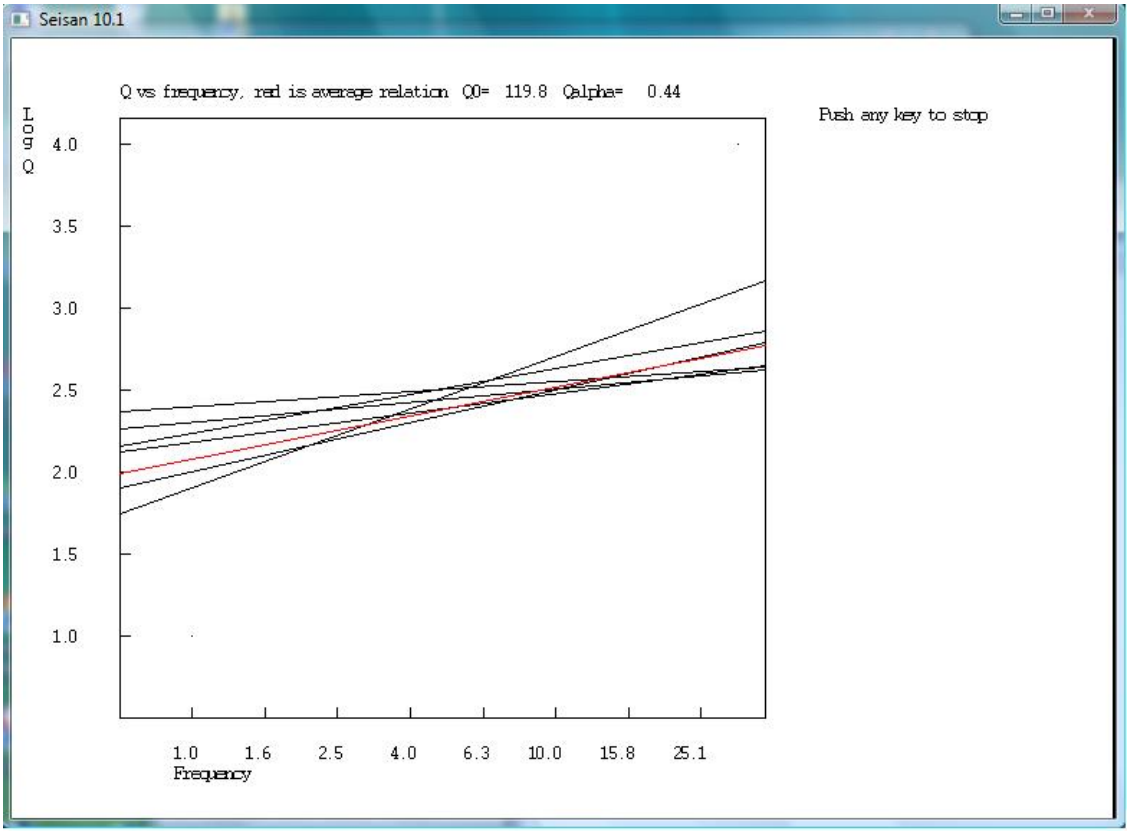


Figure 27.4: Figure AVQ: The figure shows the Q-relations to be averaged and the average Q-relation (red).

Chapter 28

Merge events in SEISAN and compare catalogs

The programs described in this chapter are used for merging events in SEISAN as well as for comparing two catalogs.

28.1 Merge events near in time ASSOCI

The program will check if two events are close together in time and merge the events if requested. This is partly an alternative to use append in EEV. The program asks for maximum time difference between events to associate. The user will then be asked if events should be physically associated or not. The program is useful when merging a large number of events.

NOTE: The times used for comparison is the origin time in an s-file and the data base file name for a data base. There be a large difference between the origin time and datta base s-file name, so if critical, do an update first with UPDATE and synchonize the file names.

The program has two alternatives for merging:

1. Merge events in same data base: One event is compared to the next event in the same data base. If they are close enough in time, the two events are merged and the program moves on to the next event. If 3 events are close in time, only the 2 first are merged. In order to also merge the third, the program has to be run again.

2. Merge events from a file into the data base: This option makes it possible to merge from another data base (use SELECT or COLLECT to create a file) without first completely mixing the two. The event from the file will be merged with as many files from the data base as fit the time difference criteria. So e.g. 2 events from the data base can both get the same event from the file included.

   At the end of the run, three files are output (associ_rest.out, associ_merg.out and associ_base.out) with events from file which were not merged, events that were merged and events from data base that were appended too, respectively. These can then be put into another data base with split, if desired. This function can also be used to separate the input file in two files.

   Note: When merging within one data base, the first event will get the next one merged into it. If merging from file into a data base, the event in the data base will by default always be the first and keep the main header. This thus a safe method when you want to keep the main header uncheged in the data base. Optionally you can decide to always put the header from the file first.

Putting new data in a data base where locations are available in one place and waveform files have to be merged in:

Use AUTOREG to make a data base with s-files with only waveform file names. This is done by using the option to copy or move waveform files to the WAV structure and the s-files will be made in a data base of the same name.

Use ASSOCI to merge in the s-files with locations and phases from a file and use the option to put the headers from the file first.

If the event files are put into the data base first, then the s-files from AUTOREG will also go into the data base (with opeion to move or copy waveform files the WAV data base) and ASSOCE will have to merge files which all are in the data base. Then there is no control whinch header comes first.

28.2 Merge events near in time and delete duplicate phases, MERGE_S

This program works in a similar way as ASSOCI, however with a better control of the merging.

The program can merge two files or a data base and a file. The two inputs are main input and merge input. The main input can be a data base or a file while merge input only can be a file. The merge input file is merged into the main input and the merged file written to an output file. None of the inputs are changed.

Events from the merge file is compared to events in the main input and merged if within user given time difference.

Duplicate phases are deleted if from same station with a time difference of less than 0.1 s. There is no check for component since some input sources, like from ISC, have no component. The user can specify if the phase from main input or merge input will be deleted. Normally the whole phase name is compared, but there is an option to use only the first letter. This can be used if two agencies use different upper and lower case like PN or Pn so only the first letter can be compared. However, this does not apply to SPEC phases since only used in SEISAN and we do not want to confuse S with SPEC.

For spectral phases, also component is used since that is always given. The spectral averages are taken from the main input. If no averages in main but in merge, they are taken from the merge input. So spectral averages might not be a correct representation of SPEC lines are merged, but that will be fixed with next update.

The first header and ID line will come from the main input file. The Id line from the merge file is converted to a comment line.

The merge event can be merged into several main events if the time differece allow this.

The locality line from main is kept and if there is a locality line in merge file, it is renamed from LOCALITY: to MER-LOCA:

Both inputs must be in chronological order, if not the program stops. Input from a data base (or using e.g. a collect from a data base) might therefore require can update with new ID lines.

Input can be old or Nordic2 format but output is the one set up by the SEISAN.DEF.

There is no check for distance id.

All events from main input is written out again and events from merge file that does not match in time can optionally be put in main output file or in a separate file.

All the events from repective input files that have a time match are wrttien out again in separate files with added name 'used'. These two files will then have the same events from two different sources and can e.g. be used to compare location for the same events from two different sources either by plotting with EPIMAP or using COMPARE_HYP.

Example run:

```
c:\seismo\WOR>merge_s
  Main data base or file to merge into - select one:

     SEISAN default data base or                      :Enter
     Alternative data base, give 1-5 letter code or   :
     Local index file, name must start with index or  :
     Local data base, write ,, or                     :
     Filename for one file, min. 6 chars or with a .  :
collect.out
  File to be merged into main
epi.out
  Max time difference for event to be appended, def(enter)=50s
20
```

```
  Delete duplicate phases: 0=no, 1: from merge file (default enter), 2:from main file

  Put all events from file to merge in output file y,n=default (enter)

  Compare whole phase name (enter) or only first letter (f)

Main:  1996  7 1  142 19.8 L  Merge:  1996  7 1  144 19.8 L dif=         -120.0
Main:  1996  7 1  759 36.0 L  Merge:  1996  7 1  144 19.8 L dif=        22516.2
Main:  1996  7 1  759 36.0 L  Merge:  1996  7 1  759 38.0 L dif=           -2.0 *Appended*
Main:  1996  7 1  8 3 16.1 L  Merge:  1996  7 1  759 38.0 L dif=          218.1
Main:  1996  7 1  8 3 16.1 L  Merge:  1996  7 1  8 3 16.1 L dif=            0.0 *Appended*
Main:  1996  7 1 1040 53.8 L  Merge:  1996  7 1  8 3 16.1 L dif=         9457.7
Main:  1996  7 1 1040 53.8 L  Merge:  1996  7 1 1044 45.3 L dif=         -231.5
Main:  1996  7 1 1044 55.3 L  Merge:  1996  7 1 1044 45.3 L dif=           10.0 *Appended*
End of s-file

 Number of events in main input file or data base           5
 Number of events in merge input file                       4
 Number of events appended                                  3
 Number of deleted phases                                  32
 Output file name is append_s.out
 Output file of not appended events is append_s_not.out
 Output file of events used from main is merge_s_main_used.out
 Output file of events used from merge is merge_s_merge_used.out
c:\seismo\WOR>
```

Note how the reading advances in each file one by one and each line compares two events with the difference given. The time differences are are calculated from the first header line for each event.

28.3 Merge events near in time, distance, depth and magnitude ASSO

The purpose of ASSO is to merge events which potentially are the same. In contrast to the ASSOCI program, ASSO will use more parameters to determine if events are identical: Time difference, magnitude difference, epicentral distance and depth distance. The ASSOCI program only uses time difference. The parameters can be magnitude dependent. The program requires an input parameter file asso.def which can be placed in working directory or DAT. An example is given in DAT and seen below.

If the event has no location or magnitude, it will not be considered as a possible duplicate event and will be included as it is.

The magnitude used are selected among all prime magnitudes in the file (the 6 magnitudes on main header line, can be 2 lines if more than 3 magnitudes). The magnitudes can be given an order of priority in SEISAN.DEF:

```
 KEYWORD............Comments.............Par 1.....Par 2
 MAGNITUDE_ORDER                         LBER
 MAGNITUDE_ORDER                         LNAO
```

In this example, LBER (local magnitude calculated by BER) is first chosen, if not there, LNAO and if not there either, the first magnitude found in file. If no order is given in SEISAN.DEF, the magnitude used will be the first found for the event, irrespective of type or agency. It is possible to leave either magnitude or agency blank in which case the blank represents a wildcard.

Potentially all events can be a main shock so all combinations, within the time limit, will be searched. However, one an event has been selected to be a duplicate, it cannot be used again for either main shock or duplicate.

Input:

A SEISAN data base. The data base is not modified by ASSO.

Output:

All duplicate events will be merged with the Main event. The largest event will be listed first. The output file with merged events is in asso.out. Optionally, a debug output can be made, either on screen or in a file (see asso.def). An example is seen below

```
Main : 1995 1120  4 1 59.1  60.1   5.4   1.5 2.0 LTES
Main : 1996  6 3 1955 35.7  47.8 153.2   0.1 4.8 STES
Asso : 1996  6 3 1955 37.9  47.8 153.2   0.1 4.8 STES  M0.7 T  46   2 D  38   0
Asso : 1996  6 3 1955 57.9  47.8 153.2   0.1 4.8 STES  M0.7 T  46  22 D  38   0
Main : 1996  6 3 1955 39.4  47.9 153.2   0.1 5.6 bPDE
Main : 1996  6 6  648 30.4  62.6   5.1  15.0 2.9 LTES
Asso : 1996  6 6  648 30.4  62.6   5.1  15.0 2.9 LTES  M0.5 T   9   0 D  21   0
Main : 1996  6 7 1325 29.2  59.8   5.1  12.0 1.9 LTES
Main : 1996  623  117 57.8  51.7 160.0  30.7 3.5 sTES
Main : 1996  623  117 57.8  51.6 159.6  33.0 5.8 bTES
Main : 1996  625  337 31.7  61.6   3.3  34.8 3.5 CTES
Asso : 1996  625  337 31.0  61.7   3.3  15.0 3.3 LTES  M0.6 T  22   0 D  26  10
Main : 1996  7 5  220 45.9  61.3   4.8   0.0 2.7 CTES
```

Each potential main (Main) event is listed. To be considered potential main event, it must have both location and magnitude. If a duplicate event is found (Asso), it is shown with the parameters: M: The interpolated maximum magnitude difference used, T: The interpolated maximum time difference (sec) used and the actual time difference(sec), D: The interpolated maximum distance (km) used and the actual distance. In the above example, the lower magnitude difference limit for the first associated shown is 0.7, the limit in distance is 38 km and in time difference 46 sec. The Main event is listed first, then all associated events so the list as shown above might not be in chronological order if there is an event within the accepted time range which do not fulfill the other criteria. In the above example, the Main event (1996 6 3 1955 35.7) has been merged with the 2 following events shown. But in between there is event (1996 6 3 1955 39.4 47.9 153.2 0.1 5.6 bPDE) which has a too large magnitude to be merged with the Main event, so this will then appear out of order and will be a potential new Main event. Once an event has been merged with a Main event, it will not be merged with another Main event.

Merging across day boundaries: This usually does not create problems. If the first event is before midnight and the second event after midnight, phase readings from the second event might have 24 h added if the readings are from the second day. However in some cases, ASSO will select the first event after midnight and the second event before midnight due to the magnitude size. In this case the header cannot refer to the earlier phase times since they cannot be negative and the phases for the second event are not merged. A message will be given.

Example of a asso.def file

```
This file is parameter file for asso. The file can be in working directory
or DAT.
Only the lines with recognized keywords and a non blank field
under Par 1 will be read. The comments have no importance. Lines with
keywords MAGS MDIF DIST TIME must come grouped
together in increasing magnitude order. Parameters for these lines are:
Reference magnitude, minimum magnitude difference of corresponding
event to merge, distance(km) and time(sec).
All number must be real numbers. Columns Par 1-Par 4 start in
columns 41,51,61 and 71 respectively.
All keywords in capital letters.
"Hypocentral" distance is calculated assuming main shock is at depth h1
and associated event at depth h2, epicentral distance at dist so
```

```
hypocentral distance is = sqrt(dist*dist+(h2-h1)*(h2-h1)).

If and event has no depth (field is blank), the depth is set tp 20 km.


If event is larger than largest event in table, largest event is used.
If event is smaller than smallest event in table, even is not used as
main event.
Values used are interpolated.
The values shown in debug output are the interpolated values.
The MAGS MDIF DIST TIME are mag of main shock, corresponding maximum
mag difference of associated event, maximum distance (km) and time(sec)
differences.

The MAX DEPT DIFFERENCE will consider only events with a depth
difference less than MAX DEPT DIFFERENCE as possible associated events.

The largest of the associated events is written out first

KEYWORD.............Comments..............Par 1.....Par 2.....Par 3.....Par4.....
HYPOCENTRAL DIST   1.0 yes, 0.0 no      0.0
MAX DEPTH DIFF     Difference in depth  50.0
DEBUG OUT 0.0 none, 1.0 screen 2.0 file 1.0
#                                       MAG       MAG DIFF  DIST DIFF TIME DIFF

MAGS MDIF DIST TIME   Mag. dep. par.    2.5       0.5       19.5      6.0
MAGS MDIF DIST TIME   Mag. dep. par.    3.0       0.5       22.5      10.0
MAGS MDIF DIST TIME   Mag. dep. par.    3.5       0.6       26.0      22.0
MAGS MDIF DIST TIME   Mag. dep. par.    4.0       0.6       30.0      30.0
MAGS MDIF DIST TIME   Mag. dep. par.    4.5       0.7       35.0      40.0
MAGS MDIF DIST TIME   Mag. dep. par.    5.0       0.7       40.0      50.0
MAGS MDIF DIST TIME   Mag. dep. par.    5.5       0.8       47.0      60.0
MAGS MDIF DIST TIME   Mag. dep. par.    6.0       0.8       54.0      70.0
MAGS MDIF DIST TIME   Mag. dep. par.    6.5       0.9       61.0      75.0
MAGS MDIF DIST TIME   Mag. dep. par.    7.0       0.9       70.0      80.0
MAGS MDIF DIST TIME   Mag. dep. par.    7.5       1.0       81.0      90.0
MAGS MDIF DIST TIME   Mag. dep. par.    8.0       1.0       94.0      90.0
MAGS MDIF DIST TIME   Mag. dep. par.    8.5       1.0       110.0     100.0
```

28.4 Catalogue merging and comparison with `merge_seisan.pl`

This program was provided by Frederik Tilmann, (tilmann at gfz-potsdam.de) (c) 2002-2011.

`merge_seisan.pl` is a 'swiss-army knife' command line tool for catalogue merging and comparison. Unlike ASSO and ASSOCIATE, it operates always on two catalogues (either a catalogue file or extracted from the database). Its uses are

- Event association, for example search for events present in both catalogues and display them side by side (or to select only events exclusive to one of the catalogues)
- Merging information in two catalogues, for example to create a catalogue with Mw and focal mechanisms taken from one catalog (e.g. globalCMT), and hypocenter from another catalogue (e.g. one based on local network relocation).
- Comparison, i.e. generate output suitable for making histograms or map view comparisons of the locations in two catalogues, or calculate bias vectors between two catalogues.

Usage: `merge_seisan.pl [options] cat1 cat2 > out.nor`

```
Usage: merge_seisan.pl [options] cat1 cat2 > out.nor

Reads two CAT Files or Sfiles in nordic format and associates events,
merging the information and respective files.  Merged events have information
from both files interspersed. Both files must be sorted.  Also each event
of the first set can only be associated with at most one event of the second set,
and vice versa.

cat1 and cat2 can be one of the following:

<file.nor>    The filename of a file in Nordic format

DBASE         If cat1 is three to five letters long and a file of the same
              name does not exist the corresponding catalogues is created on
              the fly from the S-files in the respectiv database. If the code
      DBASE or D is used, use the current database

-             read from standard in (only one - is allowed, of course)

Options:

Method of association:

-I            associate events by ID (default)
-T=tol        associate events within (tol) s of each other

-D=<dist>[h]  Maximum epicentral distance in km. If h is appended then the hypocentral
              distance is used instead.

-D can be combined with -T but cannot be used on its own (both conditions need to be fulfilled).
 It also cannot be used with -I option



Output control

-S=I,-i     Only output associated events (Intersection)

-S=U,-u     Output all events (Union)

-S=A        Output only events in A (only makes sense when combined with -b or -B option)
-S=B        Ouptut only events in B

-S=~A       Output only events not in A (i.e. only in B, only makes sense with -B option)
-S=~B       Output only events not in B (i.e. only in A, only makes sense with -A option)


-s          Show different sets side-by-side (split screen)

-A          For associated events, only show event from first set
-B          For associated events, only show event from second set

-b=1,2,m    For associated events, take all header lines of the type listed from second
```

```
            set, all other headerlines from first set (implies -A).  If the second set
            does not have the required headerline, they will not be included in the output
            (i.e., specified header lines will never be taken from first set if there is
            an event association)

            1...9,F,E,I,H :  the corresponding header lines (Note that line type 4 refers
                             to phase pick lines, even if they have a blank in column 80
            o:            :  Origin time (from type 1 line only)
            e:            :  Epicentral coordinates (from type 1 only)
            d:            :  Depth (from type 1 line only)
            m             :  copy all magnitude information into header line
            mW,mL,mb,mS   :  only copy designated magnitudes (note that magnitudes are copied
                             into the same slot unless option -M is set

-a=1,2,..   Like -b, but copy information from first set to 2nd set, implies -B (not
            implemented yet)

-m=1,2,..   Like -b, but add header lines to existing header lines, effectively merging
            the information in both files. Other header lines are taken from A (implies -A).

-M          Find named slot for copied magnitudes (only relevant if -b={mW,ML,mb,mS} is set
            Both type and agency need to match; otherwise the first empty slot is occupied, or
            the last slot is overwritten)

-d=xyz      Plot differences in hypocentre (in km) (loc2-loc1)
-d=gmt      Plot differences in epicentre as gmt-style multi-segment file (for input into psxy)
-d=gmtd     Plot differences in hypocentre as gmt-style multi-segment file.  This is similar
            to the output of -d=gmt, but insted of just latitude and longitude include latitude,
            longitude and depth (for pre-processing with awk before passing to psxy)
-d=bias[:<minerr>][:covscale]
            Calculate bias vector between the two sets (i.e. the vector that needs to be
            added to loc1 locations to make them coincide with loc2 locations on average).
            The calculation weighs pairings according to their horizontal errors and an error
            estimate is provided for the resulting bias vector.  For combined error estimates
            less than 1 km (or <minerr>) if set, the weighing is applied assuming the error
            is 1 km (minerr).   The calculation assumes the area of interest is small such
            that all calculations ignore spherical geometry.  The average latitude of the
            events is used to determine the latitude for the spherical to Cartesian
            conversion.

            Example Output (actual output without line number)

            1 Bias (set B - set A) #eq: 58
            2 (Lon,Lat,Dep) = (  0.01,  0.04, -8.21 )
            3 (R,THETA,Z)   = ( 4.427799,  19.4, -8.209310 )
            4 (X,Y,Z) (km)  = ( 1.470831, 4.176369, -8.209310 )
            5 (EX,EY,EZ)    = ( 0.147675, 0.159429, 0.339260 )
            6 CXX,CXY,CXZ,CYY,CYZ,CZZ = 0.0218079551088708, -0.000638279192795213,
                          -0.000749725773138676, 0.0254174912655165, 0.00139172909726588,
                           0.115097515525919
            7 96.1097639008737 2.39858930837142 1.47083143290329 4.17636917834104
                           0.0897062757410673 0.0968460018196738 -0.0271104591760068

            2 Average shift of events in B with associated events in A in deg latitude, deg
```

```
  longitude and depth (km)
3 As line 2, but horizontal shift is expressed in terms of a distance R (km)and
  a direction theta (deg)
4 As line 2, but horizontal distances expressed in km rather than degree
5 Formal errors of the mean shift in km. Note that this is the error of the mean
  and not the standard deviation.
  The formal location errors and covariance matrices of the catalogue events are
  taken into account in this calculation
6 Input line for gmt commandpsvelo.  psvelo expects errors to be specified for
  68% confidence intervals.
  If covariances are given for a different confidence interval, then they are
  divided by covscale prior to working out the quantities for psvelo (the error
  and covariance output lines are always left unchanged).  You can use the
  following table:

Input file
Confidence    covscale
68%           1.0
90%           2.71    [ Value for NEIC and JHD Oxford ]
95.4%         4.0
99%           6.63
99.73%        9.00

[Defaults: minerr=1.0 ; covscale=2.71 (Native Confidence Interval 90%)]


 Note: all -d options require -i option

Author: F. Tilmann (tilmann at gfz-potsdam.de)  (c) 2002-2011
```

Examples

1. `merge_seisan.pl -s -S=U -T=4 -D=50 cat1.nor cat2.nor`
   Display events in both catalogues. The left side (cols 1-80) shows events from the first catalogue, and the right side (cols 83-163) shows events from the second one. Where an event in the first catalogue is within 4 s and 50 km epicentral distance of an event in the second catalogue, the events are displayed side-by-side where corresponding header lines are matched up.
   `merge_seisan.pl -s -S=U -T=4 -D=50 DBASE cat2.nor` does the same as above but the first catalogue is compiled from all the events in the current database. Instead of `DBASE`, it is also possible to give an explicit database code.

2. `merge_seisan.pl -M -T=10 -i -b=F,mW local.nor cmt.nor > local-with-cmt-mech.nor` If cmt.nor is a nordic file with the CMT focal mechanism represented by a 'F' type header line, and magnitude mW set, then the focal mechanism and magnitude information from cmt.nor is combined with all other parameters from local.nor. The -M option forces the mW magnitude to be entered into an empty magnitude slot if available (association requires a time-difference of less than 10 s).

3. `merge_seisan.pl -T=10 -i -d=gmt global.nor local.nor > lines.xy` produces a multi-segment file suitable as input to gmt command `psxy` with `-m` option which will then draw the line connecting the epicentres of associated events in the two catalogues.

4. `merge_seisan.pl -T=10 -i -d=xyz global.nor local.nor > bias.xyz` produces a file suitable for plotting a histogram of the difference between locations in both catalogues.

5. `merge_seisan.pl -T=10 -i -d=bias global.nor local.nor > lines.xy` works out the mean shift between events that are present in both catalogues (see usage information above for explanation of output format).

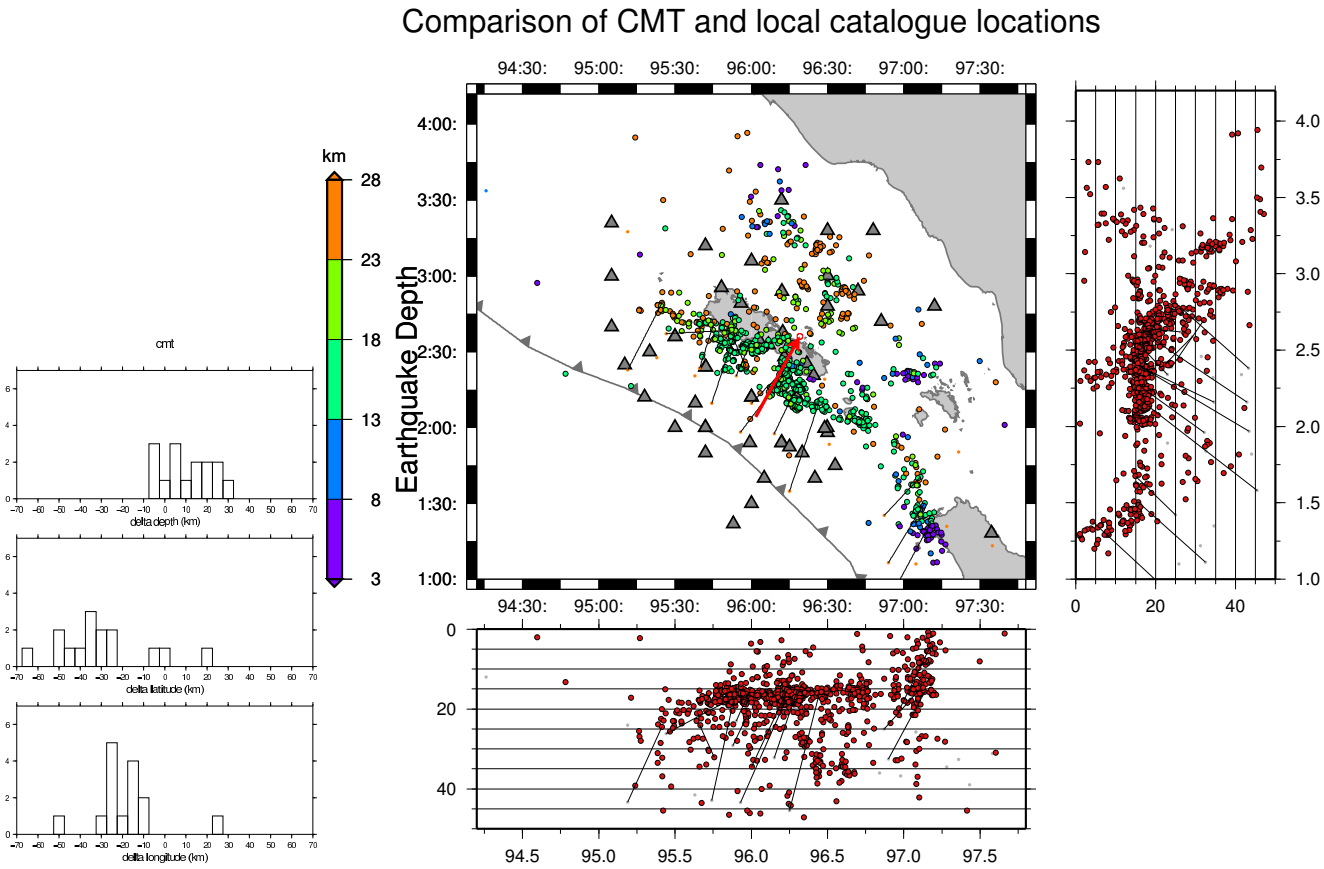


Figure 28.1: (Left) Histogram of the offsets between locations in the GCMT catalogue and a catalogue based on an OBS/land deployment offshore Nortern Sumatra (Tilmann et al., 2010), generated using the `-d=xyz` option and GMT `pshistogram`. (Right) Map and cross-sectional views. Large rimmed circles are events in the local catalogue, and small borderless circles are locations in the GCMT catalogue. Lines connect associated events (drawn using `-d=gmtd` option and GMT `psxy`). The red arrow points in the direction of the average shift between CMT and local locations, with the little red circle showing the formal uncertainty of the average shift vector (generated using `-d=bias` option and GMT `psvelo`). Its absolute size is only meaningful if the formal errors of the contributing locations are all realistic. The plots show the tendency of CMT centroids in subduction zones to be located seaward off and deeper than their actual location.

28.5 COMPARE_HYP, compare hypocenters of two cat-files

This program compares hypocenters. The hypcenters can be either from one file (option 1) with several hyopocenters for each event and the hupocenters to compare are selected by agency code. The intention with this option is to comapare hypocenters from different agencies stored in same s-file. An example is a download from ISC.

Or (option 2) the program compares two Nordic event files with the same events in both. The intention with this second option is to be able to see the effect of locating the same data set using a different model and or different magnitude scales.

Options 2

The input requires two files: The first file is the reference and the second file is the modified reference file. The compared content is origin time, rms, hypocenter and magnitudes. For each parameter, the average difference with standard deviations is calculated. The difference is calculated as the value in the reference minus the value in the modified file. In order to compare the files, they must have the same number of events and it is assumed that the events are the same and come in the same order, however the only thing checked is that the files contain the same number of events. If an event has no data (no hypocenter), the event

is skipped. The the list of skipped events is given in a file compare_hyp.skip. The number of magnitudes for each event does not have to be the same so not all events need to have magnitudes. Only magnitudes available in both data sets are compared and listed. The magnitudes are always listed in order Ml, Mc, Mb, MB, Ms, MS, Mw. For the magnitudes there is no check if the agency is the same. If a magnitude appears 2 times, the last one will be used. Note that magnitude in position 3 on header line will not be overwritten when relocating unless it has the agency identical to the agency in the STATION0.HYP file, this can create problems when comparing so make sure the agency in that position corresponds to the agency used when locating.

SO IF ALL MAGNITUDES DO NOt HAVE THE SAME AGENCY, THE COMPARISON WILL NOT BE ACCURATE SINCE MAGNITUDES FORM DIFFERENT AGENCIES COULD BE COMPARED.

There is no check if epicenter is fixed since normally this is what will be compared. Since the depth very often is fixed, fixed depths are not used for comparison.

The output is a file called compare_hyp.out. It lists each event with the data from the reference event and the difference with the relocated event. Events with a difference of more than user defined values for the parameters, have their differences marked with a star, see example below. Events with less than a given number of stations are skipped. Events with no RMS are skipped. Events with flag set for no location are skipped. The skipped events are listed in file compare_hyp.skip. An example run is shown below. The default minimum differences used indicating with a star are 5 km in lat-lon and depth, 1 s in origin time, 0.5 s in rms and 0.2 magnitude units.

Example run

```
c:\seismo\wor>compare\_hyp
 Give input file 1, the reference, or single input file
eev.out
 Give input file 2, the file to compare
 If blank (enter) only one file is used
hyp.out
 2016  721 1517 46.7 D  41.340  44.040  5.0F SC3 20 1.5 4.2LSC3 5.7BSC3 4.3bSC3
 2016  721 1628 47.7 D -23.860-175.560 10.0F SC3 43 1.9 6.0LSC3 5.8BSC3 5.3bSC3
 2016  721 23 9  3.5 D  40.780-124.070 10.0F SC3 33 2.0 4.9LSC3 4.9BSC3 4.7bSC3
 2016  722  040 26.3 D  39.360  25.970  7.0  SC3 34 1.4 3.1LSC3 3.0SSC3
 2016  722 1131 49.5 D  19.900 120.900 10.0FSSC3 17 1.8 5.1BSC3 4.7bSC3
 2016  722 2140 10.2 D  42.400  35.210 23.0  SC3 49 1.0 4.4LSC3 3.9SSC3 4.6BSC3
 2016  722 2344 57.8 D  36.940  26.680  8.0  SC3 15 1.0 2.7LSC3
 2016  723  1 0 20.0 D  47.680 147.050395.0  SC3214 1.0 6.9LSC3 5.7BSC3 5.7bSC3
 2016  723  226 20.3 D  -7.410 128.920132.0  SC3 19 1.1 5.4LSC3 5.3BSC3 5.0bSC3
 2016  723  252 12.1 D  30.140 142.110 61.0  SC3 14 0.7 4.9LSC3 4.9BSC3 4.8bSC3
 2016  723  741 45.1 D  -6.710 101.270 10.0F SC3 83 1.5 6.0LSC3 5.8BSC3 5.3bSC3
  End of s-file
 2016  721 1517 46.5 D  41.342  44.053  5.0F SC3 20 1.6 4.2LSC3 4.6bSC3
 2016  721 1628 47.6 D -23.873-175.548 10.0F SC3 43 1.8 6.1LSC3 5.2bSC3 5.9BSC3
 2016  721 2309  3.2 D  40.770-124.070 10.0F SC3 33 2.0 4.9LSC3 5.0bSC3 5.1BSC3
 2016  722 0040 27.1 D  39.365  25.988  7.3  SC3 25 1.4 3.0LSC3
 2016  722 1131 49.4 D  19.911 120.895 10.0FSSC3 17 1.7 4.7bSC3 5.3BSC3
 2016  722 2140 11.9 D  42.343  35.206 22.2  SC3 42 1.3 4.4LSC3-4.1SSC3
 2016  722 2344 58.5 D  36.951  26.683 10.5  SC3 13 0.9 2.7LSC3
 2016  723 0100 19.3 D  47.772 147.040385.8  SC3214 0.8 7.3LSC3 5.4bSC3 5.6BSC3
 2016  723 0226 20.3 D  -7.409 128.924135.3  SC3 19 1.1 5.6LSC3 4.8bSC3 5.0BSC3
 2016  723 0252 12.1 D  30.140 142.097 61.9  SC3 14 0.7 5.1LSC3 4.4bSC3 4.9BSC3
 2016  723 0741 45.1 D  -6.701 101.262 10.0F SC3 83 1.5 6.1LSC3 5.2bSC3 5.9BSC3
  End of s-file

 Min difference to mark, lat-lon, depth, origin, rms, mag
```

```
 Defaults (enter) are 5km, 5km, 1s, 0.5s, 0.2s

 Min number of stations to compare, def 0

          Origin time RMS     Lat      Lon Depth          Ml   Mb   MB
  Average diff    0.4 0.0  -0.005   -0.001   0.5        -0.1  0.1 -0.0
  Standard dev    1.0 0.1   0.033    0.010   4.5         0.1  0.3  0.2
  Number of values     10              11     6          10    8    7


 Output file name is compare_hyp.out
 Output of events deviating is compare_hyp_dev.out
 Output of events ok is compare_hyp_ok.out
```

The last two files can be used to plot bad and good events repectively.

In textttcompare_hyp.out, all the input headers are listed for the two files and at the end a summary of the differences is given. In the example above, note that there were 11 events. Five events had fixed depth so only 6 were used for depth comparison. For RMS, only 10 out of the 11 has an RMS. Also note that not all events had all the magnitude types. This example is comparing locations done with SeisComp3 and SEISAN.

NOTE: If RMS is 0.0, it is assumed there is no rms and it is not used. Below is shown the output file.

```
  #      Origin time RMS     Lat      Lon Depth    N     Ml   Mb   MB
  1 20160721151746.7 1.5  41.340   44.040   5.0   20    4.2  4.3
                0.2-0.1  -0.002   -0.013              0.0 -0.3*
  2 20160721162847.7 1.9 -23.860 -175.560  10.0   43    6.0  5.3  5.8
                0.1 0.1   0.013   -0.012             -0.1  0.1 -0.1
  3 20160721230903.5 2.0  40.780 -124.070  10.0   33    4.9  4.7  4.9
                0.3 0.0   0.010    0.000              0.0 -0.3*-0.2
  4 20160722004026.3 1.4  39.360   25.970   7.0   34    3.1
               -0.8 0.0  -0.005   -0.018  -0.3         0.1
  5 20160722113149.5 1.8  19.900  120.900  10.0   17         4.7  5.1
                0.1 0.1  -0.011    0.005                   0.0 -0.2*
  6 20160722214010.2 1.0  42.400   35.210  23.0   49    4.4
               -1.7*0.3   0.057*   0.004   0.8         0.0
  7 20160722234457.8 1.0  36.940   26.680   8.0   15    2.7
               -0.7 0.1  -0.011   -0.003  -2.5         0.0
  8 20160723010020.0 1.0  47.680  147.050 395.0  214    6.9  5.7  5.7
                0.7 0.2  -0.092*   0.010   9.2*       -0.4* 0.3* 0.1
  9 20160723022620.3 1.1  -7.410  128.920 132.0   19    5.4  5.0  5.3
                0.0 0.0  -0.001   -0.004  -3.3        -0.2  0.2  0.3*
 10 20160723025212.1 0.7  30.140  142.110  61.0   14    4.9  4.8  4.9
                0.0 0.0   0.000    0.013  -0.9        -0.2  0.4* 0.0
 11 20160723074145.1 1.5  -6.710  101.270  10.0   83    6.0  5.3  5.8
                0.0 0.0  -0.009    0.008              -0.1  0.1 -0.1

          Origin time RMS     Lat      Lon Depth          Ml   Mb   MB   MS
  Average diff    0.4 0.0  -0.005   -0.001   0.5        -0.1  0.1 -0.0
  Standard dev    1.0 0.1   0.033    0.010   4.5         0.1  0.3  0.2
  Number of values                    11     6          10    8    7
```

For each event, the difference in value is shown. Note that the difference value has a star behind it if it exceeds the user specified values. The event numbers are also listed.

Option 1, a single file

Comparison of hypocenters is done between the hypocenters listed for the same event in the s-file. The hypocenters are selected based on user specified agencies. There is no comparuison of magnitudes. An output file of the events having hypocenters from specified agencies i made. In addion 2 compact file are made of the hypocenters and magnitudes from each of the two agencies making it possible to e.g. plot the hypocenters separately for the two agencies. Only magnitudes from corresponding agencies are selected, they are limited to 3. The output of the comparison in the standard output file as for option 2. is the rsame as for option 2. Below is an example run.

```
compare_hyp
 Give input file 1, the reference, or single input file
test.out
 Give input file 2, the file to compare
 If blank (enter) only one file is used

 Give reference agency
ISC
 Give agency to compare to
TIR
  1982  3 9 2311 34.9 R  39.825  19.879 12.7  ISC 67 1.8 4.5bISC 4.3SISC 4.5sISC1
  1983  3 3  931 16.2 R  40.155  19.797 9.00F ISC 97 2.1 4.5bISC 4.4SISC 4.5bISC1
  1995  524  340 27.8 RQ 39.711  20.437 7.00  ISC 36 1.7 3.6bISC 3.5bNEI 3.6bISC1
  1999  112  726 11.0 RQ 40.024  20.528 10.0  ISC108 1.7 4.1bISC 4.0bNEI 4.1bISC1
  1999  3 9  341  5.1 R  39.195  20.812 9.50  ISC 59 1.8 3.6bISC 3.8bNEI 3.6bISC1
  1999  3 9  523  3.1 R  39.171  20.846 31.8  ISC 65 1.7 3.7bISC 4.0bNEI 3.7sISC1
  1999  412 1716 28.0 R  40.413  21.450 13.2  ISC 86 1.8 3.7bISC 3.9LPDG 3.7bISC1
  1999  424  723 18.9 RQ 41.448  19.536 20.4  ISC118 2.4 4.2bISC 4.0bNEI 4.2bISC1
.
.
.
           Origin time   RMS     Lat      Lon Depth
   Average diff   -0.6   1.1  -0.089    0.053  -0.5
   Standard dev    4.8   0.5   0.299    0.272  11.0
   Number of values       75              106    99

 Output file name is compare_hyp.out
 File with events with both agencies is compare_hyp_both.out
 File with only events from ISC is ISC.out
 File with only events from TIR is TIR.out
```

28.6 COMP_HYP, compare hypocenters of two Nordic files

This program is similar to COMPARE_HYP, but simpler, in that it compares two Nordic files and writes out differences. Typical application is that one wishes to see how changes in velocity model, station coordinates, software version, format changes etc affect the location results. Here is an example of how the program runs:

```
  Program to compare hypocenters from two Nordic files
  Name of first Nordic file, reference data
select.out
  Name of second Nordic file
hyp.out
  Enter minimum numbers to select event with significant change : distance (km)/depth (km)/rms
10 10 .5
```

```
 2021  1 1 17 3 56.3 LQ 78.559 -18.893 15.0F BER 10 .90 3.9wBER         3.2LNAO
 2021 0101 1703 56.4 LQ 78.555 -18.862 15.0F BER 10 1.6 3.9wBER         3.2LNAO
 change epicentre,depth,rms:     0.8  0.0   0.7
 2021  1 3 1842  9.5 LQ 77.328   7.938 24.2  BER 10 .70 3.3wBER         2.3LNAO
 2021 0103 1842 09.5 LQ 77.328   7.938 24.2  BER 10 1.3 3.3wBER         2.3LNAO
 change epicentre,depth,rms:     0.0  0.0   0.6
 2021  113 2025 25.8 LQ 73.515   7.829 27.3  BER 12 .50 3.5wBER         2.6LNAO
 2021 0113 2025 25.8 LQ 73.515   7.829 27.3  BER 12 1.2 3.5wBER         2.6LNAO
 change epicentre,depth,rms:     0.0  0.0   0.7
 2021  113 2224 34.1 LQ 73.592   7.963 10.0F BER 36 1.0 4.0wBER         3.1LNAO
 2021 0113 2224 34.1 LQ 73.592   7.963 10.0F BER 36 1.5 4.0wBER         3.1LNAO
 change epicentre,depth,rms:     0.0  0.0   0.5
 2021  114  012 53.6 LQ 73.617   8.383 10.0F BER 30 1.2 3.8wBER         3.1LNAO
 2021 0114 0012 53.6 LQ 73.618   8.387 10.0F BER 30 2.0 3.8wBER         3.1LNAO
 change epicentre,depth,rms:     0.2  0.0   0.8
 2021  114  025  1.8 LQ 79.718   3.795 23.0  BER 13 1.0 3.8wBER         3.3LNAO
 2021 0114 0025 01.8 LQ 79.718   3.795 23.0  BER 13 1.7 3.8wBER         3.3LNAO
 change epicentre,depth,rms:     0.0  0.0   0.7
 2021  117 1229  3.1 LQ 73.454   7.847 10.0F BER 22 .90 3.9wBER         3.1LNAO
 2021 0117 1229 03.1 LQ 73.454   7.847 10.0F BER 22 1.5 3.9wBER         3.1LNAO
 change epicentre,depth,rms:     0.0  0.0   0.6
 2021  122  4 8  6.1 LQ 77.441   7.562 19.1  BER  8 .80 3.6wBER         2.3LNAO
 2021 0122 0408 06.1 LQ 77.441   7.562 19.1  BER  8 1.4 3.6wBER         2.3LNAO
 change epicentre,depth,rms:     0.0  0.0   0.6
 2021  122  424 24.6 LQ 77.404   7.517 22.7  BER  9 .60 3.7wBER         2.7LNAO
 2021 0122 0424 24.6 LQ 77.404   7.517 22.7  BER  9 1.2 3.7wBER         2.7LNAO
 change epicentre,depth,rms:     0.0  0.0   0.6
 2021  124  7 3  0.3 LQ 73.522   7.917 10.0F BER 20 .90 3.9wBER         2.2LNAO
 2021 0124 0703 00.3 LQ 73.522   7.917 10.0F BER 20 1.6 3.9wBER         2.2LNAO
 change epicentre,depth,rms:     0.0  0.0   0.7
End of s-file
 the standard deviation of the difference to the  reference for the 3 parameters is:    epicenter:    0

 Number of events in input file          34
 Output file names are:
     comp_hyp.out: list with changes of all events
     comp_hyp_change.out: list of events that changed
     comp_hyp_events_changed.out: nordic format
     comp_hyp_events_unchanged.out: nordic format
```

In this example the files select.out and hyp.out were compared. A number of output files are generated.

Chapter 29

Making synthetic seismograms

BOUCH and BOUSEI, HERRMANN and HERRSEI and WKBJ are all programs which is used for generating synthetic seismograms.

The full wave modeling programs are written by Bouchon and Herrmann, and for WKBJ, Chapman and Valerie Maupin. Valerie Maupin has integrated WKBJ for SEISAN and written the routines that makes it possible to use specific phases. She has also made many improvements in the original installation of BOUCH and HERRMANN and written a large part of this chapter.

Bouchon:

The Bouchon program is somewhat modified for SEISAN. The theory, which is quite straight forward, is given in a series of papers (e.g. Bouchon (1981)). It is based on a discrete wave number representation of the wave fields. Basically, the source is repeated periodically in space, so that integration over the k-domain is replaced by a series. This implies that the periodicity of the source, L (in km), should be large enough so that the information from fictitious sources does not arrive during the time interval of interest. Roughly r < L/2, sqrt((L-r)**2+Z**2) > Vp*t where r is the epicentral distance and Vp is the highest P-wave velocity of the model, t is the travel time and Z the hypocentral depth. Only layered (horizontal, parallel) earth model is used. The earthquake source cannot be in the bottom layer or at the surface.

There are 2 programs, BOUCH and BOUSEI. BOUCH computes the frequency response given the model, the source depth, the focal mechanism, the receiver locations and the orientations of the two horizontal components. BOUSEI takes the output file from BOUCH, multiplies it by the source spectrum and uses an FFT to get the synthetic ground motion (displacement, velocity or acceleration). The user must provide the source function (see below) and the original waveform files must be available in WAV or working directory if a file containing both real and synthetic signal is to be generated. Otherwise, only synthetic data will be seen in the output file.

Herrmann:

The Herrmann programs HERRMANN and HERSEI work the same way as BOUCHON and BOUSEI respectively. The major difference is that once HERRMANN has been executed, HERSEI can be executed with different fault plane solutions to obtain the time series, while for the Bouchon programs, both programs must be run again. The Herrmann programs are thus faster for testing many different fault plane solutions.

The description in the following is for the Bouchon programs, but the steps are the same for HERRMANN.

WKBJ:

As opposed to the seismograms calculated with the Bouchon and Herrmann programs, the WKBJ synthetic seismograms contain only the number of phases selected by the user. The execution time for one run of the program is very short. In addition to making the synthetic seismograms, the program calculates the arrival times of these phases, and write them both on the screen and in the iasp.out file for later plotting (see MULPLT). This is intended to be a tool to help identify phases on the data or on the Herrmann or Bouchon synthetic seismograms: it can by no means replace these two programs, which are much better than WKBJ to model the frequency-dependent character of crustal phases at regional distance.

WKBJ seismograms have been introduced in seismology by Chapman (1978). More details on the method can be found in Dey-Sarkar and Chapman (1978) and in Chapman and Orcutt (1985). The core of the present program is a code written by Chapman et al. (1988) and is part of the seismological software distributed

freely by IASPEI. The synthetic seismograms are given in displacement. Although their spectra contain low frequencies, one should bear in mind that they represent a high-frequency approximation of the wave field. They include a number of non-physical phases due to truncation of the integrals in slowness p. For the most interesting crustal phases, the epicentral distance is usually much larger than the source depth, and these phases interfere with the physical phases and modify their amplitudes.

The head waves on an interface appear automatically as a by-product of the reflected phases, as soon as the epicentral distance is larger than critical. That means for example that the Pn phase appears automatically on the synthetic seismogram as a by-product of the PmP phase. In order to synthesize or calculate the arrival time of a Pn or Sn phase, you must then specify 'PmP' or 'SmS' (see below).

For a receiver at the free surface, the synthetic seismograms must include the free surface reflection coefficient to yield correct amplitude and waveform for the different phases. For S phases, at epicentral distances larger than critical, this includes automatically the SP phase (a P phase which propagates horizontally along the free surface, and which originates from the critical conversion of S to P at the free surface). The critical distance is of the order of the source depth for the Sg phase, and its SP phase usually appears as a large arrival between the P and S wave. The SP phases are physical, but the amplitude of their high frequency part is overestimated with WKBJ. If one wishes to suppress them from the synthetic seismograms, one may optionally do so. With this option, the surface reflection coefficient is omitted and the synthetic seismograms contain only the upgoing wavefield, that is the wavefield one would get in a borehole, after filtering out the downgoing wavefield. Let us note that this option may strongly modify the amplitudes and waveforms of the different phases compared with those at the free surface.

In addition to the synthetic seismograms, the program calculates the arrival times of the phases you have specified, and write them in the iasp.out file. These times are calculated by interpolation in epicentral distance of the values tabulated in wkbj.tab. For sources close to an interface (in practice for Pg and Sg phases and the source under an interface), there is a limited epicentral distance range in which an arrival time can be calculated. For example, the maximum epicentral distance for Pg is about 250km for a source 0.1 km under Moho in the default SEISAN model. In order to increase the maximal epicentral distance, you may move the source away from the interface, or you may increase the number of ray parameters used in program wkbj_or.for (parameter 'nnpp') called from wkbj.for.

All three programs are hardwired to use triangular sources.

Running the programs

The programs require input about distances, azimuths, depth, crustal model, fault plane solution, time window, number of points and some modeling parameters. Almost all of these parameters are available within SEISAN. The programs have therefore been modified to use an S-file (Nordic format) as input file with additional information about time window, number of points to model and crustal model. A special format has been used to keep the modeling information separate from other information in the file (see below for an example). The steps to model a particular event are as follows:

Problem Bouchon: Use fewer layers, ideally just a halfspace under the deepest ray. The programs seems to become unstable if too many layer are used there.

Step 1

Edit the event in EEV and mark the stations wanted for modeling with a minuscule s in column 1, ONLY mark the station once. Exit from editor and, within EEV, give the command "synt". This will generate all the necessary default input parameters for modeling, which are stored as comment-lines starting with SYNT in the S-file (see below). At the same time, the s's used as markers are removed. Any old modeling information present will remain and override the defaults.However, in case the F-flag is set for the DEPTH parameter, distances and azimuths will be reset according to the current location.

Step 2

Edit event again and check if default parameters are ok (see explanation below).

Step 3

Run one of the programs BOUCH, HERRMANN or WKBJ. These are known commands in EEV. BOUCH: The program will now run for a certain amount of time depending on number of points required. At the standard output, the input parameters used will be printed out and for each frequency, the number of terms in wave number integration is printed out. If the limit of the number of terms is reached, something is wrong, try other parameters. The limit is 2. BOUPAR parameter, currently set at default value of 2000. The speed of this output (NPOINT/2+1 lines) gives a good indication of how long time it will take.

HERRMANN: Takes longer than BOUCH.
WKBJ: Very fast.

Step 4

Generate the seismograms. BOUCH: Use program BOUSEI. The program is interactively asking the seismogram type (displacement, velocity or acceleration). BOUSEI will generate a file bousei.out in SEISAN format containing both original and synthetic traces. The number of traces is determined by the specifications for each station, see below. Output file is `bousei.out`.
HERRMANN: Use program HERSEI, similar to BOUSEI. Output file is `hersei.out`.
WKBJ: The first command WKBJ also makes the seismograms. Output file is `wkbjsei.out`.

In all cases it is possible to shift the original trace relative to the synthetic trace and the program will ask, for each channel, how much it should be shifted. A positive value shifts the real trace up in time (to the left). The default is to shift the trace the amount of the P-travel time residual of the first P found in the S-file for that station in order to line up the P - phases. NOTE: These phases MUST be the same phase types in order to be lined up. If the first modeled phase is Pn and the first observed phase given in the S-file is Pg, there will be a no alignment. The amplitudes for Bouchon are in nm, nm/sec or nm/sec*sec (hopefully !!) assuming a seismic moment of 10 **22 dyne-cm. The output file will normally contain both the original and synthetic traces. However, if no waveform file is available (in local or WAV directory), the output file will contain an empty channel where the original data should have been. The specifications in the `hyp.out` file determine which traces from the modeled stations are included in the output file. If the specification after STATION is only component (e.g. S), then all 3 channels are shown. If a particular channel is given (e.g. S N), then only that channel is shown. Only one or 3 channels can be displayed.
All output traces are given in Z, N and E or Z, R and T depending on the parameter file (see below). The channel names are SH, SB and SW for Herrmann, Bouchon and WKBJ respectively.

Step 5

Plot the traces with mulplt. This can be done within EEV using the command pw, ph or pb for WKBJ, Herrmann or Bouchon respectively. Since there is no instrument correction, it is a good idea to plot both the modeled and observed signals narrow band pass filtered. E.g. for regional events 0.1-1 Hz and for small local events 2- 5 Hz (depending on sample rate).

shows an example of the modeling.

Note: The whole modeling process can be done entirely within EEV and it is intended to be done so. Since the modeling requires updated distances, depths etc when changing model etc, it cannot take its input from the location in the S-file, which only changes when doing an update (see UPDATE program). So when running from within EEV, a location will always be done first to get an updated S-file (in this case the `hyp.out` file) and this is the reason that the modelling programs use the `hyp.out` file instead of the S-file for input. This also means that the modeling program can be run separately from any `hyp.out` file, however it is then up to the user to keep it updated.

The modeling parameters

Below is shown an example of part of an S-file prepared for modeling. The file is one of the events in the test data set and by using EEV to find the event, modeling can start immediately. All parameters have been set automatically.

```
1996  6 7 1325 29.1 L* 59.841   5.127 12.0F BER 12 1.1 2.2CBER 1.9LBER 2.0LNAO1
1996  6 7 1325 29.1 L*                     BER        2.0WBER                1
      8.3      41.0      74.7     1                                          F
1996-06-07-1324-51S.TEST__009                                               6
     535  SOUTHERN NORWAY                                                   3
depth fixed to 12 km, rms lowest with near station (less than 110 km) location3
fault plane solution ok within 10 deg                                       3
SYNT: MODEL--:     THICK        VP        VS      DENS        QP        QS    3
SYNT: MODEL--:    12.000     6.200     3.563     2.600     0.000     0.000    3
SYNT: MODEL--:    11.000     6.600     3.793     2.800     0.000     0.000    3
SYNT: MODEL--:     8.000     7.100     4.080     3.000     0.000     0.000 B  3
SYNT: MODEL--:    19.000     8.050     4.626     3.200     0.000     0.000 N  3
SYNT: MODEL--:    30.000     8.250     4.741     3.400     0.000     0.000    3
```

```
SYNT: MODEL--:    50.000     8.500     4.885     3.600     0.000     0.000    3
SYNT: ST-D-RK:      8.3      41.0      74.7                                    3
SYNT: DEPTH--:     12.0                                                       3
SYNT: NPOINTS:      512                                                       3
SYNT: TIMES--:    TOTAL    60.000   INITIAL     0.000  SY-TRACE    60.000    3
SYNT: BOUPAR-:    800.0      2000     0.010                                   3
SYNT: PHASES-:       Pg        Sg       PmP       SmS       SmP              3
SYNT: DT-Tsou:    0.050      .100                                            3
SYNT: REDVELO:   0.0000                                                      3
SYNT: COMPON-:   RADIAL                                                      3
SYNT: STAT-AT:  no                                                           3
SYNT: NSTAT--:         3-----------------------------------------------------3
SYNT: NEW STAT:------------------------------------------------------------3
SYNT: STATION: EGD  S  Z  DISTANC:      49.0                                 3
SYNT: STATION: EGD        AZIMUTH:       9.0 BAZIMUTH:     189.2             3
SYNT: NEW STAT:------------------------------------------------------------3
SYNT: STATION: KMY  S  Z  DISTANC:      71.0                                 3
SYNT: STATION: KMY        AZIMUTH:     172.0 BAZIMUTH:     352.7             3
SYNT: NEW STAT:------------------------------------------------------------3
SYNT: STATION: ASK  S  Z  DISTANC:      72.0                                 3
SYNT: STATION: ASK        AZIMUTH:       5.0 BAZIMUTH:     185.1             3
STAT SP IPHASW D HRMM SECON CODA AMPLIT PERI AZIMU VELO SNR AR TRES W  DIS CAZ7
EGD  SZ IP     C 1325 35.95   93                                -1.110   48   6
EGD  SZ ES       1325 42.03                                      -1.010   48   6
BER  SZ IP     C 1325 38.12   55                                -1.010   62  11
BER  SZ ES       1325 45.44                                      -1.110   62  11
BER  SZ E        1325 46.71        31.7  0.2                             62  11
ASK  SZ EP     D 1325 39.59   68                                -0.910   70   3
ASK  SZ ES       1325 48.07                                      -0.810   70   3
ASK  SZ E        1325 50.90       111.0  0.3                             70   3
KMY  SZ IP     C 1325 40.26   62                                -0.410   71 175
KMY  SZ ES       1325 48.74                                      -0.410   71 175
KMY  SZ E        1325 48.92        83.6  0.2                             71 175
```

MODEL: The model to be used. THICK is layer thickness, VP is Vp velocity, VS is Vs velocity, DENS is density and QP and QS, are P and S q-values respectively. The model, velocities and Q-values are taken from the `STATION0.HYP` file with first choice from current directory and second choice from DAT directory (like the HYP program). The S-velocities are calculated using the Vp/Vs ratio given there. Moho is indicated with N at the end of the line with the first mantle layer. A Q of zero means infinite Q. The densities are approximate values and should be modified. See below for maximum number of layers.

ST-D-RK: Strike dip and rake is taken from an existing fault plane solution for the given event (F-line) if it exists, otherwise arbitrary values are supplied. (0,0,0) is an explosion. The convention is Aki and Richards.

DEPTH: Focal depth is taken from the current solution. The second field can optionally have the letter F (right justified). If this flag is set, the user can give the synt command to update all distances and azimuths used for modeling which will correspond to the latest location determined as e.g. a result of a changed fixed depth or a changed model. The intention with this flag is that the user should be able to set a fixed depth in the S-file header line, give the synt command to update the parameters for modeling corresponding to this depth and then model.

NPOINTS: Number of points to model, 512 is set as default, must be 2**N. Used by BOUCH and HERRMAN only.

TIMES–: Three different times:

TOTAL: The total time window for generating data and synthetic seismograms for all channels, see also REDVELO.

INITIAL: The initial time of the earliest trace in the output file, with reference to the source origin time.

The synthetics at the station with smallest epicentral distance automatically start also at this initial time.
SY-TRACE: The duration of the synthetic seismogram for each channel, might have different start times, see REDVELO.

DT-Tsou: Sampling interval (used for WKBJ seismograms only), and half-duration of the source used for all three programs. In all programs, the source is triangular, however BOUCH can optionally use several sources, see below.

REDVELO: Reduction velocity to calculate the initial times at subsequent distances (put 0. for no reduction velocity). NOTE: Seems to not be correctly implemented so use 0 always.

PHASES-: The names in format A4 (right justified) of the phases to be synthesized with WKBJ. The phases may be given in any order, with a maximum of 6 phases per line, and there may be several "SYNT: PHASES-" lines.

Possible phases:

Pg (direct P from source to receiver)
Sg (direct S)
PmP (includes automatically Pn at distances larger than critical)
pPmP (includes automatically pPn at distances larger than critical)
sPmP (includes automatically sPn at distances larger than critical)
SmS, pSmS, sSmS (includes automatically Sn, pSn, sSn at distances larger than critical)
SmP, PmS
P1P, P2P, S1S, etc: the same as PmP, SmS etc, but on interface number 1, 2, etc.
(The free surface gets interface number 0 in the convention taken here. Thus in HYP, PN2 is the same as P1N here. There associated head waves are labeled Pn1, Pn2, Sn1, etc.

COMPON-: RADIAL for radial-transverse components, NORTH for North-South, East-West components.

STAT-AT: Is "not free" or "NOT FREE" anywhere within column 16 to 25: Optional line. If this option is chosen, the WKBJ synthetic seismograms are calculated omitting the reflection coefficient at the free surface, at the receiver location.

BOUPAR: Modeling parameters L, Nt and e. L is length of periodicity (should be a few times the hypocentral distance), Nt is maximum number of terms in wave number summation and e is the value used in truncating the summation. Increasing e and decreasing Nt will speed up convergence, but the results might be unreliable. If Nt is reached, the results are unreliable.

NEW STAT: Comment line

STATION: Station to be modeled with component(s) to be displayed. The S means that short period instruments are used. The default is S, so if e.g. BH is used, S must be chaged to BH, else the waveform data is not found. If no component is given, all 3 components are assumed. The other option is to indicate a component (e.g. Z) and only that component will be displayed (see also description of BOUSEI). DISTANC is epicentral distance used, this distance is taken from the current location, AZIMUTH is azimuth from the source to the station taken from current location, BAZIMUTH is the back azimuth at the station, calculated by EEV, used to rotate if so specified. Each new station isrepresented by the above 3 lines.

The source time function

The time duration of the triangular source time function for Bouchon is given as Tsou above, and is also used in WKBJ and Herrmann.

Hints on modeling

Event 199606071325 in the test data set is set up with modeling parameters and can be tested immediately.

The model

The standard model given in `STATION0.HYP` might be too detailed for most cases and should be simplified to include 3-4 layers by just editing the S-file, this also speeds up modeling. However, if you located the event with one model and model with another, the distances and residuals might not fit. A solution could be to have a `STATION0.HYP` in the local directory with the simplified model.

Alignment of P and S

If the distance calculated by HYP is not correct as indicated by P and S residuals, the synthetic and observed signals will not be aligned. The distance for that station can then be changed manually in the S-file under DIST and/or delays can be applied when generating the seismograms. For line up, it is important

that the correct first arrival is included in phase list (WKBJ), see what is identified by HYP. If PN2, then P1N must be given for WKBJ.

Testing different parameters

There is no need to go back to EEV to test for the parameters that do not change the location. Thus to test for different fault plane solutions, time windows, number of points, edit the `hyp.out` directly and rerun. However, if depth or model is changed, relocation must be made. To test for different depths, locate with fixed depths, see HYP.

NOTE: THE SOURCE AND RECEIVER CANNOT BE AT THE SAME DEPTH (BOUCH AND HERRMANN) AND IN NO CASES CAN THE SOURCE BE AT DEPTH ZERO.

Running time

This depends mostly on the number of points and to some degree on number of layers. The number of stations has an insignificant effect on running time.

Program limitations: HERRMANN and WKBJ is set up with max 20 layers and Bouchon with 20 layers. Maximum of 32 stations Change programs and recompile if more layers are needed. Bouchon is compiled for 2048 frequencies (4096) points.

Computer notes:

The original Bouchon program BOUCH is almost unchanged. The only modification is that it uses a subroutine to generate its original input file bouch.inp from the `hyp.out` file. This file still remains after running BOUCH for debugging purposes. The output from BOUCH is bouch.out, which in turn is input to BOUSEI.

Herrmann:

The Herrmann waveform modeling is based on a concept where the synthetic seismograms are computed through a sequence of four distinct processes (programs).

1. The program "hspec8" will calculate the medium response for 10 basic Green's functions, where the response is given in frequency - wavenumber domain F(f,k).

2. The program "rhwvinta" will integrate and take the medium response from F(f,k) $\rightarrow$ F(f,r)

3. The program "rhfoc10" will convolve the response function with a source time function and with inverse Fourier transform take F(f,r) $\rightarrow$ F(t,r)

4. The program "mech" will construct a 3 component synthetic seismogram given a focal mechanism.

Herrmann's programs originally had several optional source time functions, however, a triangular source has been hardwired (for all 3 programs) so it is easier to compare the results. The original options can be reactivated by editing the program.

The programs HERRMANN and HERSEI run these 4 programs in an automated sequence.

All References, a detailed manual, source code and parameters as well as other related programs: "Computer Programs in Seismology", Volumes I - VIII. By Robert B. Herrmann, Saint Louis University, Saint Louis, Missouri.

WKBJ:

Input file `hyp.out`, read by "WKBJ.

Output file `iasp.out`, written by "WKBJ". Contains the arrival times of
the different phases at the stations, in SEISAN format.

Output file `wkbjsei.out`, written by WKBJ in the SYNTSEL.FOR subroutines. A waveform file (SEISAN type) containing the data and the synthetics, which can be plotted using "mulplt". Note that there is a code for each synthetic seismogram giving the modeling method (SH: Herrmann, SB: Bouchon, SW: WKBJ), and the component (Z, R, T, N or E).

INTERMEDIATE FILES

`wkbj.inp`, created by WKBJ for input to WKBJ_OR. The same information as in `hyp.out`, in a WKBJ_OR format.

`wkbj.tab`, output from WKBJ_OR, reprocessed by WKBJ. Contains tables as a function of ray parameter.

`wkbj.out`, output from WKBJ_OR, reprocessed by WKBJ. Contains the Green functions.

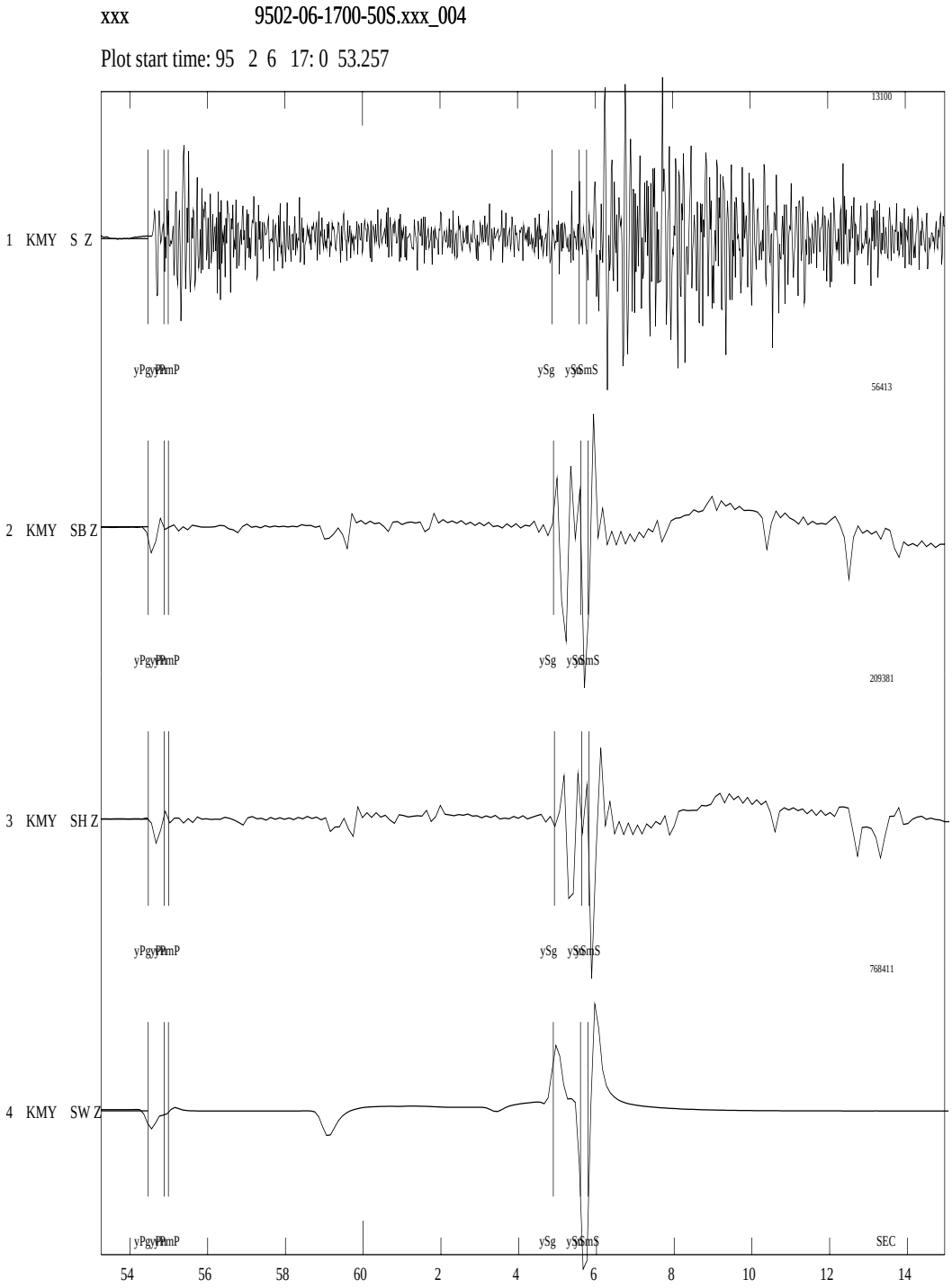


Figure 29.1: An example of synthetic seismograms using Bouchon(2), Herrmann (3) and WKBJ (4). The original seismogram is shown in channel 1. All synthetics are displacement. Also shown are the theoretical travel times calculated by WKBJ.

Chapter 30

Calculation and plotting of travel times

In SEISAN, travel times are generated from a flat crustal model or using the IASP91 global travel time model. It can often be useful to generate travel times for given distances and two programs are supplied to do these calculations. TTIM will calculate travel times for global phases at one given distance and depth and TTLAYER, will calculate a travel time table (layered flat model) for a given depth and a distance range. A special version of TTIM called IASP is used in connection with EEV and MULPLT.

30.1 IASPEI travel time software, program TTIM

This program can be used for calculating global travel times, see below for details on phases calculated. The program assumes that you have the travel time tables in the working directory or in DAT, see computer notes below on how to generate these file if not already there. The same files are also used by HYPOCENTER.

After starting the program, the first two questions 'do you want xxxxx' relate to range summaries, etc., that are normally not required and can be answered with n(no) followed by ENTER. The program then asks 'Enter phases, one per line...' You can then enter a specific phase, or a keyword defined as follows:

All	gives all phases
P	gives P-up, P, Pdiff, PKP, and Pkikp
P+	gives P-up, P, Pdiff, PKP, Pkikp, PcP, Pp, Ppdiff, PPKP, PPKIKP, Sp, Spdiff, SPKP, and SPKIKP
S+	gives S-up, S, Sdiff, SKS, Ss, Ssdiff, SSKS, Ps, Psdiff, and PSKS
basic	gives P+ and S+ as well as ScP, SKP, PKKP, SKKP, PP, and P'P'

Writing all individual phases, separate by ENTER, terminating the list with an additional ENTER. The program will then enter a loop where phase times are calculated for new distances entered on request. The program is terminated for a particular distance by entering -1, and a new depth can be used, or the program can be terminated by entering -1 again.

A special version of this program used in connection with MULPLT and EEV is IASP. When used from MULPLT, it will use an input file with stations to use called iasp.inp. The file contains station codes of all station in waveform file(s). If no iasp.inp preesent, it will use all stations in S-file.

In order to generate the earth model files IASP91.HED and IASP91.TBL, first run program REMODL, then program SETBRN. The program REMODL has the earth model hardwired. Note: These binary files CANNOT be moved between platforms. They are included with SEISAN for each respective distribution. If lost, they must be regenerated on the same platform.
For more information about IASP91 programs, see HYPOCENTER manual by **B. Lienert**.

On at 64 bit computer the IASP files must be regenerated is you have the files from a 32 bit computer, with the programs `REMODL` and `SETBRN`.

30.2 Calculation of travel times for layer and gradient model, TTLAYER

The TTLAYER program is written by Barry Lienert to calculate travel times for both layer and gradient model. In this version the program only works for zero depth, and therefore might not be very useful. The program reads a set of velocities and depths from an input file in '`STATION0.HYP`' format and calculates travel times for P and S velocities for a set of uniform-velocity layers, using the HYPOCENTER dtdx2 routine and also for a set of uniform gradient layers, using dtdxg, a new routine written to have the same input arguments as dtdx2.
The routine to calculate travel times for a gradient model uses an adapted version of Fred Klein's TTCAL routine, which he uses in his program TTGEN to generate a table of values from which to interpolate travel times and their derivatives in HYPOINVERSE.
The program is easy to run and the output can be plotted with some standard xy plotting tool.

30.3 Calculating of local phases: TTLOCAL

Program to calculate travel times for given stations and hypocenter location at local distances. The program uses the HYPOCENTER travel time calculations. By default, the model used is from STATION0.HYP, unless another model is selected in the s-file.

The program operates in two modes:

With MULPLT

If iasp.inp is present, and there are no arguments, arrival times for stations in iasp.inp are calculated and put in file iasp.out to be used with MULPLT. The iasp.inp contains the stations in the waveform file. It is thus possible to calculate theoretical arrival times without any picks in the S-file. The iasp.inp is generated by MULPLT when the user asks for synthetic phases (MULPLT IASP option). The phases calculated are first and possibly second arrivals. For short distances there would only be first arrivals like Pg. Although refracted arrivals might be present, they are not calculated since they are unlikely to be seen. For larger distances both refracted P and PG are calculated like PN3 and PG. PN and PB are not specifically calculated but will appear as one of the PNX. When running the program, an output is also give on the text screen:

```
1 FNA     230.977905     N4   35.8533058
1 FNA     230.977905     G    38.0395508
2 IGT     308.198364     N4   45.9507637
2 IGT     308.198364     G    50.4460907
3 MRVN    293.900574     N4   44.1098595
3 MRVN    293.900574     G    48.1656075
4 PUK     46.8152657     G    8.61053467
5 SCTE    248.730225     N4   38.1072121
5 SCTE    248.730225     G    40.8507156
6 TIR     104.178276     G    17.6073112
7 KBN     212.190460     N4   33.3805771
7 KBN     212.190460     G    35.0128403
8 PHP     106.046379     G    17.9404621
9 SGRT    303.668915     N4   45.3243828
9 SGRT    303.668915     G    49.6978455
```

This gives the station, epicentral distance, type of phase and travel time for the P-phase. The travel times for the S-phases are calculated using the Vp/VS ratio given in the station file and NOT by using a possible S-velocity model in the station file.

Free standing program for calculation of theoretical arrival times for station given in an S-file To operate in this mode, the command ttlocal sfile is given. The program calculates theoretical arrivals for the phases given in the s-file and write the output file with the original arrival times replaced by the theoretical times. All weights etc are kept. N and B-phases are used if given in S-file and specified in station file. A possible

S-velocity model is ignored. Relocating the output file should give same locations as given in input file with zero residuals. In this mode there can be many events in the input s-file. The station file used is the one from the first event. Optionally the arrival times can be have added noise if a second argument is used like e.g. ttlocal collect.out 2.0 where input file is collect out and random noise is added. The noise generator is the Fortran RAND function which gives random numbers from 0-1 so in the example we would get random numbers between 0 and 2. The nose added to the arrival times for P is then between -1 and 1. The noise added to the S is multiplied with Vp/Vs.

The output file is ttlocal.out

30.4 Plotting of travel times, TTPLOT

Program to plot observed and calculated travel times (Figure 30.1). The input to the program is an s-file, which has an indicator to a model file (`STATION?.HYP`) and the travel time observations. The program is started by 'ttplot <sfile-name>'. At the start, TTPLOT relocates the event and calculates distances using the HYPOCENTER program. It then plots all observations with a '+' symbol and the theoretical travel times that are calculated by the program for the first P and S arrivals and the g-phases with solid lines. The program can be useful in routine processing to visualize large residuals, which otherwise are seen from the location program output. The program can also be started from EEV using option 'ttplot'. It is possible to click on symbols, which will bring up station code, phase, observed travel time and residual on the rigth. The output files are:

`ttplot.out` - gives station code, phase name, distance, observed travel times and residual.

`ttplot.eps` - Postscript version of plot.

30.5 IASP, travel times for MULPLT

This program is a special version of IASP91 to be used in connection with EEV and MULPLT. Giving command iasp from the EEV prompt (or from within MULPLT), the program will read the current active S-file, and for each station, calculate possible IASP91 phases and arrival times relative to the hypocenter and origin time given in S-file. The origin information can be obtained from two places in the S-file: (1) The header lines are searched for hypocenter lines and the first found after the main header will be used, (2) If no secondary header lines, the main header line is used. The intention of this order is that it is possible to put in a PDE solution in a secondary header line (option INPUTONE in EEV) so that theoretical travel times are calculated relative to a fixed solution and not the temporary solution made by the local agency.

The IASP91 tables can be found in the local directory or DAT and have the same names as used in HYP and TTIM. The program generates an output file iasp.out in Nordic format. This file is read by MULPLT and the theoretical phases displayed on the screen. The number of phases calculated can be very large making it hard to see which phase is which. IASP therefore has a definition file, IASP.DEF, where phases to be written out are given. The file can be in the working directory or in DAT. If no definition file is available, all phases will be written to the iasp.out file. Below is an example of a IASP.DEF file.

```
This file contain the definitions of phases to be used when calculating
synthetic phases to be plotted with mulplt. There is one phase pr line
and each phase is preceded with the keyword IASP-PHASE. Only lines with this
keyword will be read. The defined phase then follows in column 13 to 20.
If no phases are defined, all ISPEI91 phases will be used.

Phase ID    Phase---
--------------------
IASP-PHASE  P
IASP-PHASE  PP
IASP-PHASE  PPP
IASP-PHASE  PKP
IASP-PHASE  pP
```

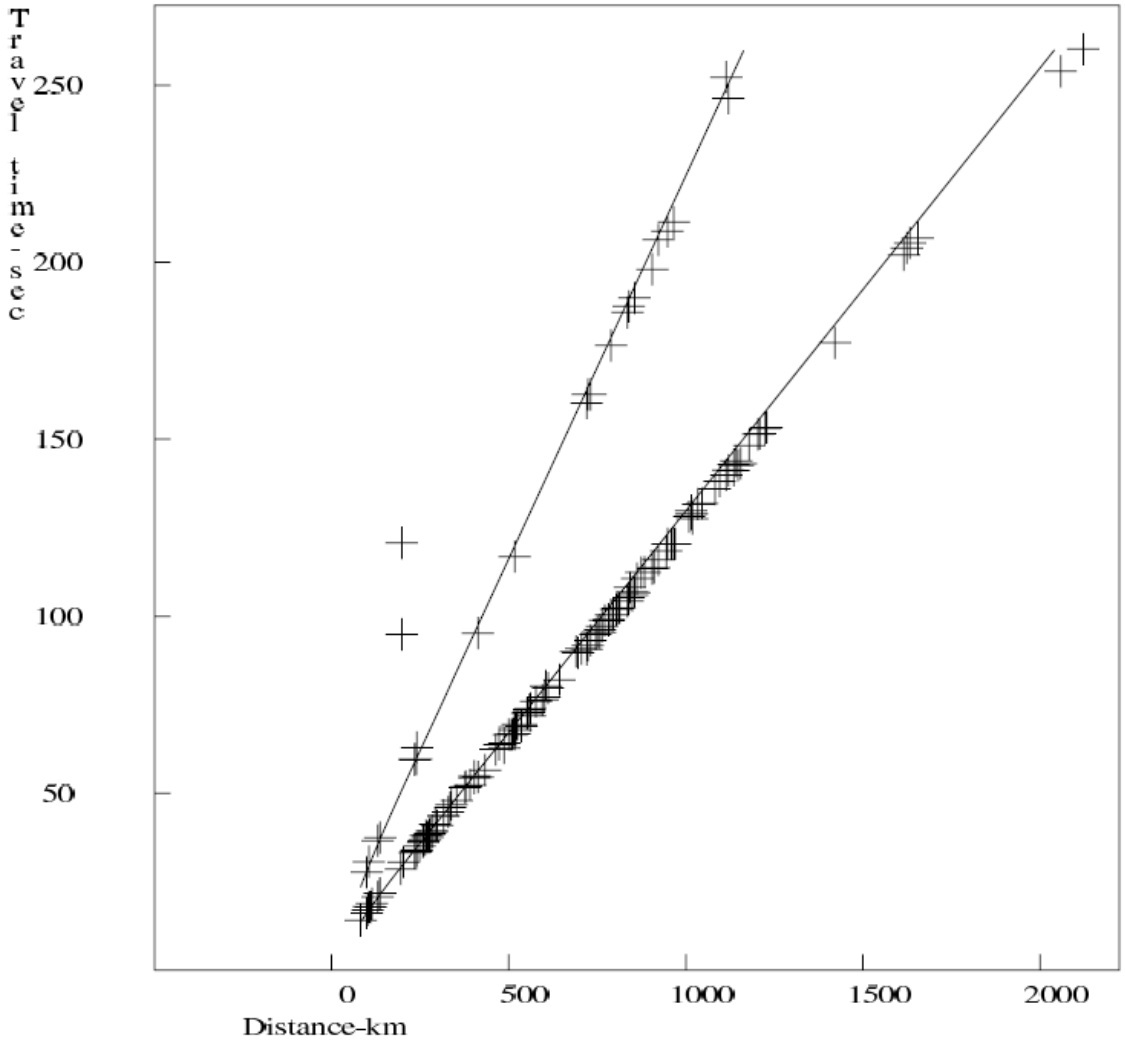


Figure 30.1: Example of travel time plot. Both P and S observed travel times are plotted with "+" symbol. Calculated times are shown by the solid lines, the lower one gives the first P arrivals, the upper line gives first S arrivals. The two outliers are observations from a station with incorrect timing. In thsi plot the g-phases are not shown

```
IASP-PHASE  sP
IASP-PHASE  PcP
IASP-PHASE  S
IASP-PHASE  SS
IASP-PHASE  SSS
IASP-PHASE  SKS
IASP-PHASE  ScS
IASP-PHASE  PS
IASP-PHASE  SP
IASP-PHASE  ScP
```

Notice that the definition file might prevent display of phases expected. In the axample above, e.g. Pg would not be seen so it is important to set up the definition file for the phases wanted. Fort local earthqukes, it is not enough to write P or S since these phase are named Pn, Pg, Pb, Sn, Sg and Sb so these phases names must be written like that.

Chapter 31

Wadati

This is a program to make Wadati diagrams and apparent velocity from a Nordic file with one or many events. The apparent velocity is calculated from the arrival times and the calculated epicentral distances as given in the S-file. The apparent velocity is thus approximate and affected by the location.
The purpose of the program is to calculate Vp/Vs values for individual events and calculate the average for a group of events. In addition, the program can calculate the apparent velocity for each event based on P or S-times. Wadati diagrams with plot can also be calculated directly from EEV.

The information can be used to obtain a first impression of crustal parameters. For each calculation, events can be selected based on: Minimum number of stations, maximum rms of the fit (S-P vs P, or arrival times), and minimum correlation coefficient of the fit. For the apparent velocity calculation, the data can also be selected in distance and azimuth ranges.

The output gives:

T0 :	Wadati calculated origin time
N :	Number of stations used for Vp/Vs
VPS :	Vp/Vs ratio
NP :	Number of stations for P- velocity
NS :	Number of stations for S-velocity
AVSP:	Average S-P times with sd
AVDI:	Average distance with sd

The average Vp/Vs is calculated for the whole data set. Individual Vp/Vs values outside the range 1.53 to 1.93 are excluded. An output file wadati.out is generated. A minimum of 3 stations is required for an event to be used. Only same type phases are used (like PG and SG).

Example of a run to calculate Vp/Vs

```
Input file name
collect.out
 Wadati (1), apparent velocity (2) or both (3) ?
1
 Wadati parameters:  Minimum number of stations
3
 Maximum rms
1
 Minimum correlation coefficient
0.9
 1994  616 1841 28.3 No data for Wadati
 1994 10 4 1322 55.8 No data for Wadati
 1995  822 0141  5.3 T0:  141   8.1 N:    8 VPS:  1.84 RMS:   1.19 CORR:  0.997
 1995 1120 0401 58.9 T0:  4 1  59.5 N:    7 VPS:  1.76 RMS:   0.87 CORR:  0.995
 1996  6 3 1955 35.6 No data for Wadati
 1996  6 3 1955 35.6 No data for Wadati
 1996  6 3 1955 40.1 No data for Wadati
```

```
 1996  6 6 0648 29.8 T0:  648   1.1 N:   22 VPS:  1.51 RMS:  11.00 CORR:  0.380
 1996  6 6 0648 30.6 T0:  648  38.7 N:    3 VPS:  2.16 RMS:   0.80 CORR:  1.000
 1996  6 6 0648 29.8 No data for Wadati
 1996  6 7 1325 28.5 T0: 1325  28.1 N:    9 VPS:  1.72 RMS:   1.06 CORR:  0.973
 1996  6 7 1325 29.1 T0: 1325  28.1 N:    9 VPS:  1.72 RMS:   1.06 CORR:  0.973
 1996  610  1 4 47.0 No data for Wadati
 1996  610  1 4 47.0 No data for Wadati
 1996  623 0117 57.8 No data for Wadati
 1996  623 0117 58.1 No data for Wadati
 1996  625 0337 31.7 T0:  337  33.1 N:   21 VPS:  1.75 RMS:   1.36 CORR:  0.999
 1996  7 5 0220 46.5 T0:  220  45.8 N:    6 VPS:  1.76 RMS:   0.28 CORR:  0.999
 1996  713 0556 46.0 No data for Wadati
 1996  718 0946 51.4 No data for Wadati
 1996  718 2255  6.0 No data for Wadati
 1996  726 0742 12.0 T0:  742  11.8 N:    6 VPS:  1.74 RMS:   0.47 CORR:  0.993

 Number of events for which vp/vs were calculated            9
 Number of events selected for average                       3


 Average VP/VS =  1.75  SD=  0.01 N=    3
```

Example of a run to calculate apparent velocity

```
Input file name
collect.out
 Wadati (1), apparent velocity (2) or both (3) ?
2
 Apparent velocity parameters:  Distance range
50 200  Azimuth range
0 180
 Minimum number of stations
2
 Maximum rms
1
AVSP:  30.212.7  AVDI: 152.0  30.7 NP:    4 VP :  6.95 RMS:   0.20 CORR:  1.000
                 AVDI: 143.3  31.1 NS:    3 VS :  3.82 RMS:   0.25 CORR:  1.000
AVSP:  23.0 9.5  AVDI: 158.7  26.6 NP:    3 VP :  6.76 RMS:   0.00 CORR:  1.000
                 AVDI:  90.5  35.8 NS:    6 VS :  3.72 RMS:   1.79 CORR:  0.998
                 AVDI:  89.0  35.6 NS:    6 VS :  3.69 RMS:   2.78 CORR:  0.996
AVSP:  50.536.0  AVDI: 145.8  40.8 NP:    6 VP :  7.60 RMS:   0.42 CORR:  1.000
                 AVDI: 116.3  38.2 NS:    3 VS :  3.97 RMS:   0.04 CORR:  1.000
                 AVDI: 118.8  45.6 NS:    4 VS :  3.61 RMS:   0.66 CORR:  1.000
AVSP:  14.4 7.5  AVDI: 106.0  39.2 NP:    5 VP :  6.75 RMS:   0.94 CORR:  0.999
                 AVDI: 111.7  37.7 NS:    6 VS :  3.82 RMS:   0.97 CORR:  0.999
AVSP:  14.4 7.5  AVDI: 176.7   1.5 NP:    3 VP :  5.13 RMS:   0.07 CORR:  1.000
                 AVDI: 178.0   2.9 NS:    4 VS :  2.80 RMS:   1.06 CORR:  0.859
AVSP:  22.0 5.7  AVDI: 150.0   4.2 NP:    2 VP : 10.17 RMS:   0.00 CORR:  0.000

 Output file is wadati.out
```

Chapter 32

Calculating spectra and attenuation

This chapter uses spectral anlysis to calculate varios parameters. The SPEC program has many options and can do graphics. The KAPPA program only calculates kappa (can also be done with SPEC) and the KAPPA_SORT program do various manipulations of the output from kappa calculation.

32.1 Spec program

The SPEC program is used for making spectra of many seismic signals in a semiautomatic manner. It can be used for several investigations:

A: Making a large series of signal spectra, which can be corrected for instrument and path.

Average spectra are calculated. There are two options for further processing the calculated spectra:
Option (1): Calculate acceleration density spectra which are plotted compared to the Peterson noise model.
Option(2): Using the slope of the flat part of the displacement spectra to calculate the near surface attenuation kappa (see 8.12.

B: Making relative spectra of seismic events or background noise in order to determine the soil response. When using relative spectra of horizontal versus vertical components, this is referred to as the Nakamura method (Nakamura, 1989).

C: Making relative spectra of signals from two stations in order to determine Q. The program makes output files for generating GMT plots in addition to standard SEISAN plots.

Note: Parameter file has changed between SEISAN 7.2 and 8.0 (number of windows and overlap has been added).

The program can technically operate in two ways: (1) Making relative spectra of a series of pairs of stations terminated by the average spectra, (2) Making a series of spectra for a number of stations and events. The spectra can be corrected for distance, Q, and instrument response. In addition, the spectral levels can be expressed in moment or moment magnitude calculated in the same way and with the same units as in MULPLT. All relevant parameters are taken from the CAT files, the CAL files and the input parameter file for SPEC. Window selection for the spectra can be specified to be related to the P, S arrival times or the earthquake origin time and it is thus possible to automatically make e.g. S-wave spectra of a large set of stations and events. Optionally, noise spectra, can be calculated together with the signal spectra. The noise window is selected at the start of the waveform file.
Before the program is started up, the input files must be prepared. The program need two input files. The parameter file (default spec.par) gives the parameters to use and the list of stations to process. The event file (default spec.inp) is a CAT file with events to use or a `filenr.lis` type file with waveform file names (can only be used if no readings are needed, like for Nakamura studies). An example of a spec.par and spec.inp file is found in DAT. These files can be used immediately with the test data set.

The program produces several output files. The main output is in `spec.out` with the parameters used, the station event combinations used and error messages. The other files are giving output of most graphs shown. These ASCII output files can be used in other plotting programs, however they have been specifically formatted for the SEISAN GMTXY plotting script. Note that the numerical values given for the spectral

output given in those files is the same that appear on the plots and the values are linear. So if a spctrum has been instrument corrected and smoothed, that is what is given. Similarly if a relative spectrum is used. The number of files depends on number of stations used. Examples of files could be

`spec_all_ASK__S__Z.out`	All spectra from ASK, S Z
`spec_all_BER__S__Z.out`	All spectra from BER, S Z
`spec_all_gmt.out`	All spectra from ASK and BER
`spec_ave_ASK__S__Z.out`	Average spectrum from ASK, S Z
`spec_ave_BER__S__Z.out`	Average spectrum from BER, Z Z

In order to plot these files with GMTXY (only Unix), give e.g. command

`gmtxy spec_all_ASK__S__Z.out`

There is one more output file, spec_amp.out, which gives the log log spectra of of all traces calculated (possibly instrument corrected) before smoothing takes place.

Limitations of amount of data: The program is set up to handle 300 spectra of up to 30000 points each for one run. The dimensions can be increased in spec.for, however the program must then be recompiled. The spectral windows are 10% tapered. The analyzed signals will be checked for clipping and rejected if clipped. A message is then given in spec.out

The program is tarted with command spec. it can also be started with arguments:

-par file: give parameter file

-cat file: give cat file

-batch: no plot

if no par and cat files are given, the default names are assumed so only the argument -batch can be used.

The `spec.par` file: The file contains alternate lines of parameter names and parameter values, and must contain the number of lines shown in the example below.

```
selection criteria 1: P, 2: S, 3: S from P, 4: abs
2
start
1
window length, # of windows,overlap
5.0,1,1
number of times to smooth
5
gain factor of channel 1
1
noise spectrum 0: n 1: y
1
make relative spectras 1: y, 0; n
1
plot pics
1
frequency band to use
1.0 7.0
response removal: 0: none, 1: displ., 2: vel., 3: accel. 4. noise pow. 5. kappa
0
rotate: 0: no, 1: yes
0
q0, qalpha and kappa
-1.0,0,0
distance correction
1
minimum correlation and minimum sn for kappa
0.5  2.0
velocity and density
0.0 0.0
```

```
magnitude spectrum
0
stations and components, format a5,1x,a4,1x,a5,1x,a4
FOO   S  Z SUE   S  Z
```

The parameters:

Selection criteria: Determines how the start of the time window is selected. 1: Start with the P-arrival time, 2: Start with the S-arrival time, 3: Start with the S-arrival time calculated from the P-arrival time assuming a P to S velocity ratio of 1.78, 4: Start with 'start' (see next parameter) seconds after the origin time as given in the CAT file header. This option can be used if no readings are available in the CAT file. When using a P or S-time for start of window, the program uses the first P or S phase found in the CAT file for a given station. Component is of no importance here, so there is only a need for e.g. one P-time for the station being processed if 3 component data is used. This is also the case when rotating the signal, see below. However, on the trace plots, only readings on those components shown will be seen on the plots.

Start: If the selection criterion is 1,2 or 3, this is the number of P or S travel times (from the origin) used to find start time of window. Use 1.0 if the window shall start exactly at the phase time picked. If selection criteria is 4, start is the number of seconds after the origin time. Optionally, give a second input, number of seconds to start before the window.

Window length, #of windows, overlap:

- Window length: Window length in secs for both signal and noise (if selected).
- # of windows: If more than 1, spectra will be made in several windows following the first window and average spectra will be made. This option can only be used if selection criteria is 4. Used for noise studies or Nakamura studies.
- Overlap: Windows can overlap (factor < 1.0) exactly follow each other (factor=1.0) or have gaps (factor > 1.0). E.g. 0.9 is equal to 10 % overlap.

Number of times to smooth: Number of times to smooth, 0 means no smoothing.

Gain factor of channel 1: Factor that the spectral level for channel 1 is multiplied with. This can be used if the response shape is the same for the two channels and only the levels are different. If the shape is also different, set factor to 1 and use response removal below.

Noise spectrum: If 0, no noise spectrum, if 1, make noise spectrum. The noise window is taken from the beginning of the trace and the window length is the same as given above.

Make relative spectra: If zero, no relative spectra, if 1, make relative spectra. The relative spectra will appear one on each page, and the average relative spectrum on the last plot (see Figure 32.1). If no relative spectra are chosen, only one trace and one spectrum is shown per page and the average spectrum is shown on the final plot. MUST BE SET to 1 to calculate Q, see below.

Plot pics: If 1, the phase pics in the CAT file spec.inp will be plotted.

Frequency band used: Lower and upper frequency bands for the spectral plots.

Response removal:

If 0, no response is removed.

1: displacement

2: velocity

3: acceleration (units is nm, nm/s and nm/s*s)

4: Power spectral density in dB relative to ((1m/s**2)**2)/Hz. This option is used for seismic background noise studies.

5: Determine kappa. The flat part of the displacement spectrum (frequency below corner frequency) is approximated by a straight line and kappa calculated for each event and the average at the end (in spec.out file and on final plot). The spectrum will normally be corrected for Q, BUT NOT kappa. For more details, see (Havskov and Ottemöller, 2010).

6: Determine kappa. The flat part of the acceleration spectrum (frequency above corner frequency) is approximated by a straight line and kappa calculated for each event and the average at the end (in spec.out file and on final plot). The spectrum will normally be corrected for Q, BUT NOT kappa.

Make sure to set appropriate frequency limits and correct distance corrections. Can be used for both P and S-spectra.

A cal file for each channel must be available in the CAL directory (see section 4.6). For relative spectra, the response removal has no importance if the response is the same for the channels compared. A simple correction can be made with "Gain factor of channel 1" parameter above. NOTE: If moment or magnitude spectrum is made, response removal MUST be 1.

Rotate components: If 1, the horizontal components are rotated. This means that if the user has specified N or E, radial or transverse respectively will be used instead. The original data remain unchanged. If start time of spectra are chosen by using P or S, there must be a reading from those components if the pics are to be plotted. If the parameter is zero, no rotation is done. See also MULPLT for more details of rotation.

Q0, qalpha and kappa:

Q-correction:

Parameters in Q-relation Q = Q0**qalpha used for spectral correction (see also section on MULPLT for standard attenuation relations). Only used if response is removed. If first 2 parameters are 0,0, no Q-correction. New from SEISAN7.2 is that a kappa correction also can be used (see MULPLT spectral section). Note that from version 10.1, Q=Q0 for f ¡ 1 Hz.

Calculation of Q:

If Q0 and qalpha is set to -1,0, the relative spectra will be used to calculate q as a function of f (see standard relations in MULPLT section) and the plots will show q as a function of f. This can be used for both P-waves and S-waves. The distance correction MUST be set, S-velocity must be given (see below) and it is recommended to assume body wave spreading (amplitude proportional to 1/distance, factor is 1.0 below). If the response of the 2 stations is not identical, correction for response must also be made. There must be an origin time and phase readings for components used must be available in order to calculate Q. Q is calculated as pi * f * (t2-t1) / (ln(A2(f)/A1(f)) + alpha * ln(t2/t2)), where A1 and A2 are spectral levels at frequency f for the two stations, t1 and t2 are travel times and alpha is geometrical spreading exponent (1.0 is body wave spreading). Q values lower than 1 and higher than 5000 are not used, the Q(f) plot might then display a long straight line. The Q=Q0*f**qalpha is calculated from the 'good' values'.

Distance correction alpha: The spectral amplitudes are multiplied by R**(distance correction) if different from zero. This option MUST be set if moment or moment magnitude options (see below) are selected as well as calculation of Q. However, it can be used without instrumental correction. For body waves, use 1. Note that the geometrical spreading use here is simpler than used in MULPLT.

Minimum correlation coefficient and minimum signal to noise ratio for kappa and optional maximum hypocentral distance: The minimum correlation coefficient and signal to noise ratio for an event to be included in average kappa. The coefficients are from the linear fit to the flat part of the spectrum. The optional maximum hypocentral distance can be used to limit the data to e.g. 50 km. if used here, then the data in the input file does not have to be distance limitied.

Velocity and density: Velocity (km/sec) and density (g/cm*cm) used for calculating moment spectra. If set to 0,0, no moment spectra are calculated. See section on MULPLT for details of calculation.

Magnitude spectrum: If 1, the spectral level is converted to moment magnitude, see MULPLT for details of calculation.

Stations and components: Station-component pairs used, one pair per line, format (a5,1x,a4,1x,a5,1x,a4). If no relative spectrum is used, the first station-component on the line is used.

NOTE: Note for component, only the orientation need to be used like Z instead of S Z. This can be useful if the data contains different component codes for same data set like HH Z and S Z.

Calculation is done separately for each station so the the program stops between each and the average plots is shown unless option -batch is used.

Averaging in spec:

Q: For each frequency, the average linear 1/Q and corresponding sd is calculated. The upper and lower bounds are calculated by subtracting and adding the sd. These values are then converted back to Q and finally the log is taken. Only the 'good' individual values are used. There is a possibility that the lower bound becomes negative. In that case, the log Q is set to zero. Because the average is made in 1/Q, the upper and lower bounds curves will not be symmetric around the average Q-curve.

Power spectrum: For each frequency the dB values are averaged and upper and lower curves should be symmetric.

Kappa: Same as for Power spectrum.

Other spectra: The linear spectra or relative spectra are averaged. The sd used in the log spectra are calculated by subtracting log average spectrum from log(average spectrum + sd).

If many data sets are to be processed at the same time one can have one CAT file for each station or station pairs and optionally also a location for the corresponding waveform files. On the station line, the CAT file name is then given starting from column 25 and the directory of the waveform files starting at column 105. In the example below, the names of the CAT files all have the same name but they are in different directories but they could also have had different names and placed in the working directory. The specification of the waveform directory is needed if the waveform files are not in the working directory or the in WAV.

If cat files are given on the channel line, there is no question later of name for the cat file.

Example:

```
**************THIS OPTION HAS ONLY BEEN TESTED FOR KAPPA CALCUALTION***************

STAT  COMP STAT COMP    Abs location CAT file, start col 25                                  Directory for WAV files, start col 105
KTK1     Z              /home/seismo/WOR/jens/kappa/KTK1/spec.inp.q                          /home/seismo/WOR/jens/kappa/KTK1
KTK1     N              /home/seismo/WOR/jens/kappa/KTK1/spec.inp.q                          /home/seismo/WOR/jens/kappa/KTK1
KTK1     E              /home/seismo/WOR/jens/kappa/KTK1/spec.inp.q                          /home/seismo/WOR/jens/kappa/KTK1
ARA0     Z              /home/seismo/WOR/jens/kappa/ARA0/spec.inp.q                          /home/seismo/WOR/jens/kappa/ARA0
ARA0     N              /home/seismo/WOR/jens/kappa/ARA0/spec.inp.q                          /home/seismo/WOR/jens/kappa/ARA0
ARA0     E              /home/seismo/WOR/jens/kappa/ARA0/spec.inp.q                          /home/seismo/WOR/jens/kappa/ARA0
SKAR     Z              /home/seismo/WOR/jens/kappa/SKAR/spec.inp.q                          /home/seismo/WOR/jens/kappa/SKAR
SKAR     N              /home/seismo/WOR/jens/kappa/SKAR/spec.inp.q                          /home/seismo/WOR/jens/kappa/SKAR
SKAR     E              /home/seismo/WOR/jens/kappa/SKAR/spec.inp.q                          /home/seismo/WOR/jens/kappa/SKAR
LOF      Z              /home/seismo/WOR/jens/kappa/LOF/spec.inp.q                           /home/seismo/WOR/jens/kappa/LOF
LOF      N              /home/seismo/WOR/jens/kappa/LOF/spec.inp.q                           /home/seismo/WOR/jens/kappa/LOF
LOF      E              /home/seismo/WOR/jens/kappa/LOF/spec.inp.q                           /home/seismo/WOR/jens/kappa/LOF
```

In this example, it was desired to calculate kappa for many different stations and since only stations in a given distance were used, a separate CAT files was needed for each station. Since a complete specification is given to where the waveform files are located, there is no requirement of having the waveform data in the the currem directory, WAV or the defualt WAV data base.

If all data is in the default data base, a simpler way to calcualte kappa for many stations is setting a distance limit in spec.par

minimum correlation, minimum signal to noise ratio, max distance

0.0,2.0,50

and having a spec.inp with the station in many different distances. Then the channel part of the par file could be:

```
STAT  COMP STAT COMP
KTK1     Z
KTK1     N
KTK1     E
ARA0     Z
ARA0     N
ARA0     E
LOF      Z
LOF      N
LOF      E
STEI     Z
STEI     N
```

Normally, at the end of calculation, there is a plot of all the results. If calculation for many stations, the plot can be skipped if spec is started with option -batch. There is a summary output file for the kappa value for each station and component called spec_kappa_average.out. The content is station, component, kappa, sd of kappa and number of values.

```
KTK1    Z   0.031  0.013   31
```

```
KTK1    N   0.037  0.014   38
KTK1    E   0.025  0.013   43
ARA0    Z   0.001  0.015   16
ARA0    N   0.009  0.022   15
ARA0    E   0.014  0.016   15
SKAR    Z   0.040  0.014    2
SKAR    N   0.025  0.003    3
SKAR    E   0.027  0.003    3
LOF     Z   0.038  0.018   22
LOF     N   0.035  0.022   26
LOF     E   0.033  0.018   26
```

For kappa, there are also ouput files in Nordic format with average kappa at a particular station. The epicenter is the station coordinates and the magnitude is proportinal with kappa. The file can be plotted with map or mapg and also used for furhter ananlysis, see example next section.

Running the program:
The program gets the first pair of stations (or one station) from spec.par, calculates the spectra using the list of events in spec.inp and at the end of the station list, calculates the average spectral ratios for all pairs (max 100). All spectra are then shown on one plot together with averages and standard deviation. Then the next pair of stations is processed in the same way and the program continues until the end of file spec.par. Each pair of stations with signals and spectra is plotted on one page. If no relative spectra are made, the plots look similar except that only one station is shown. Hard copy plots are made for each page and sent to the printer if specified (see below). The hard copy postscript file is called `spec.eps` and when the program finishes, a file with the last plot is available on the disk. For each spectrum (relative or single), the average spectrum (or Q) is calculated both as an average of the log spectrum and as an average of the linear spectrum. There is no frequency weighting and since all values shown on the plot are used, the average value will be more representative of the high frequency part of the spectrum since there are more values. This can be regulated by choosing another frequency range. The average spectra shown on the last plot are log-averages. If option to calculate Q is used, the plots show 1/Q as a function of frequency instead of relative spectra (proportional to relative spectra). For each event, Q0 and qalpha are calculated.

When calculating kappa, the average spectrum do not have much physical meaning since the averages are made from absolute spectra of events that might have very different moments. So the kappa calculated from the average spectrum is not to be used.

Interactive output of level and frequency: With a spectral ratio (or Q) plot on the screen, position the cursor at the point of interest on the spectrum and click. The level and frequency will now be displayed on the right side of the plot.

The output file spec.out gives details of the run like averages and missing data. The output file spec_ave.out gives the x and y-values of the average spectrum IF IT HAS BEEN PLOTTED ON THE SCREEN. File spec_rel.out gives the values of the relative spectra.

There are 4 interactive input options:

0: All spectra are calculated but not sent to the plotter or screen except the last plot with the average spectra (sent to both screen and printer). Used for checking the files or making a final run. If no relative spectrum is chosen, no final plot is made. For each station and event combination, check lines are written out on the screen.

1: All plots are shown on the screen, but not sent to the laser printer.

2: All plots are shown on the screen and at the same time sent to the laser printer.

3: No plots are shown on the screen, all are sent to the laser printer. For each station event combination, check lines are written to the screen.

4: Only final plot on laser.

5: No plotting so no graphics window come up anytime. Can be used e.g. for batch mode.

How to run the program with only waveform files available: Two options:

(A) Using S-files

Step 1: Generate S-files in your local directory with AUTOREG,

Step 2: Make the spec.inp file with COLLECT.

(B) Using `filenr.lis`

Step 1 : Make a dirf of waveform files to use

Then use `filenr.lis` as input file name

With only waveform files and no readings in the spec.inp file, it is only possible to use option 4 (absolute time) for start criteria. Since the events have not been located, the "origin time" read from the S-files will be identical to the waveform file start time, so the parameter "start" can then be set to number of seconds after waveform file start time. Figure 32.1 shows an example.

32.2 Calculating kappa, KAPPA

This program calculates kappa from displacement or acceleration spectra. The program is a simplification and improvement of the kappa option in program SPEC. There is no option for graphics and no options for output file of the spectra, however the results are the same as in SPEC. Kappa is calculated from the P or S spectra and both displacement and acceleration can be used, but displacement is the most useful option. Kappa is calculated from the slope of the flat part of the displacement or acceleration spectrum. The effect of attenuation on the flat part of the spectrum can be described as

ln(A(f,t)) = ln(A0) + -pi*f(kappa+t/Q)

where A0 is the initial amplitude, A(f,t) the amplitude after the waves have traveled the time t, f is the frequency and Q(f) is the general frequency dependent Q.

It is generally assumed the distance is short enough (¡ 50km) so that the spectrum is not affected by Q so kappa simply can be calculated from the slope of the spectrum. However if Q is accurately known, the spectrum can be corrected for Q and larger distances might be used. When using displacement spectra, small events should be used in order to get a high corner frequency, Ml ¡ 1.5 will give a corner frequency generally above 20 Hz. The frequency range for analysis could then be 3-16 Hz. A lower frequency than 3 Hz is not recommended since the macroseismic noise will affect the signal to noise ratio.

When using acceleration spectra, there is the same restriction on distance if no Q-correction, however now larger events should be used to get a large enough s/n for the frequency range above the corner frequency. If larger distances are used, a Q correction can be applied or kappa values can be plotted as a function of distance to get kappa at zero distance. This what is done in many other studies but is not part of the program. Using program KAPP_SORT and the output file kappa_chan.all an output file of kappa vs hypocentral distance can be made and kappa at zero distance can be determined by a standard least squares program, like LSQ.

Input files: Parameter file: The parameter file (default kappa.par) gives the processing parameters and the channels to process. Events file: The events are given in an CAT S-file (default kappa.inp) and the file must have been updated to have distances. The waveform files listed in the Nordic file must be available in the directory where KAPPA is executed. The files can be in the working directory, WAV or default WAV data base. The program can also use the ARC references in the S-file but for a large archive this can be very slow. The solution can then be to extract relevant data (particular stations or stations less than a given distance) from the archive with program GET_ARC and use file get_arc.out as input file.

```
Example of a parameter file:

selection criteria 1: P, 2: S, 3: S from P
2
window length, pre window
7.0 1.0
number of times to smooth
0
frequency band to use
3.0 16.0
maximum hypocentral distance
50.0
response removal: 1: displ., 3: accel.
```

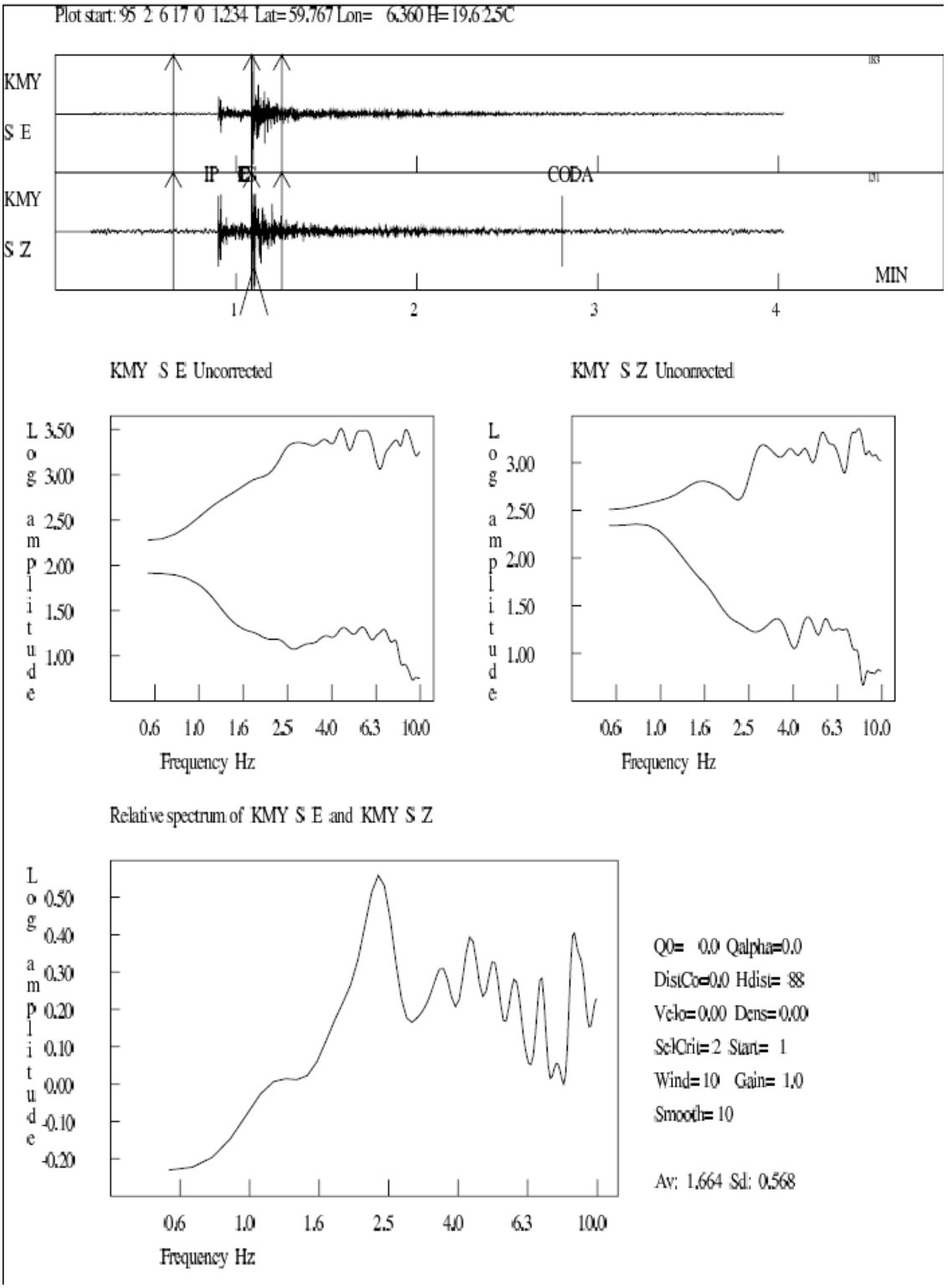


Figure 32.1: An example of using the SPEC program. On top the original traces are shown with windows chosen, in the middle the spectra of each channel and at the bottom, the relative spectrum. Lower right shows the input parameters used. In some cases (kappa and Q) the values calculated for this case are also shown.

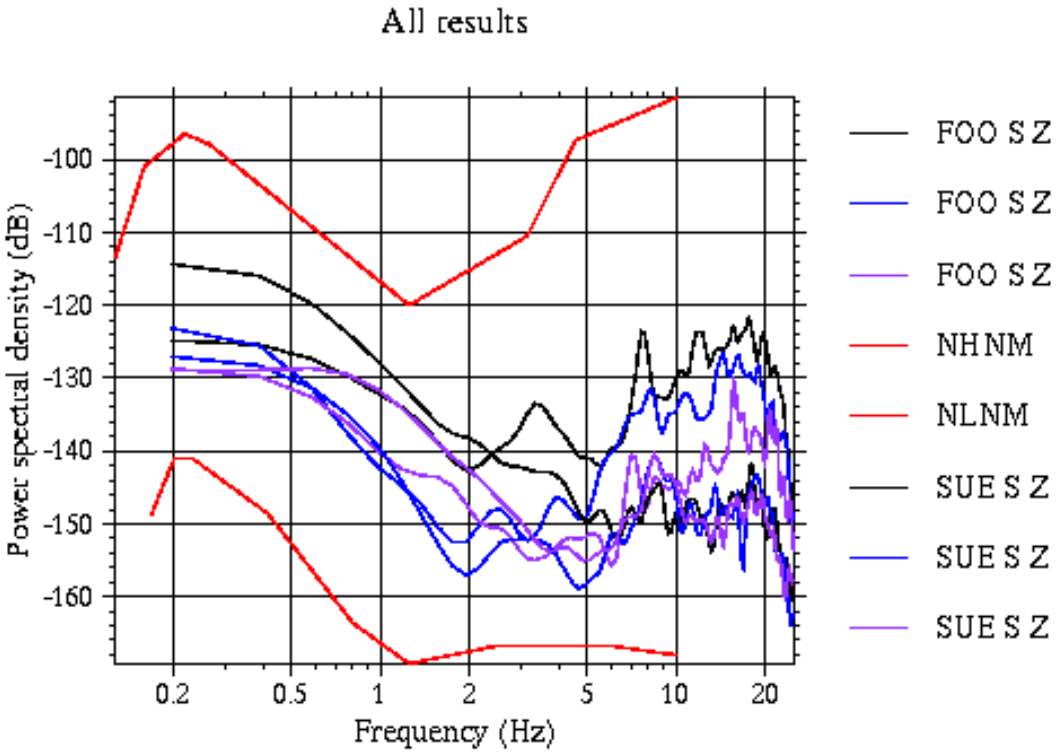


Figure 32.2: An example of a GMT plot. The figure shows an example of making noise spectra of several traces.

```
1
rotate: 0: no, 1: yes
0
q0, qalpha
0.0,0,0
minimum corr, min s/n ratio
0.0, 2.0
stations and components, format a5,1x,a4,1x,a5,1x,a4
KTK1     Z
KTK1     N
KTK1     E
ARA0     Z
ARA0     N
ARA0     E
LOF      Z
LOF      N
LOF      E
```

The parameters are:

Selection criteria: The phase to use. If no S, the time of S can be calculated from the P-time assuming a Vp/Vs ratio of 1.78.

Window length, pre window: The window (s) for the signal starting with P or S and the start of the time window before the phase. The total time window is then the sum of the two.

Number of times to smooth: The spectrum can be smoothed before calculating kappa, often it is not so no to change the slope.

Maximum hypocentral distance: maximum hypocentral distance (km).

Response removal: Displacement or acceleration.

Rotate: If rotate is selected, component N will be R and component E will be T. The output will still show Z, N and E.

q0, qalpha: Q0 and the exponent of the frequency dependence for spectral Q correction. Note that if qalpha is 1.0, kappa is not affected.

Minimum corr, min s/n ratio: The minimum absolute correlation coefficient for accepting the calculated kappa value. The minimum signal to nose ratio for accepting the kappa value. The s/n ratio is calculated using a 5 times smoothed signal and noise spectra and the ratio is checked for each spectral point. This comes in addition to the smoothing above.

Stations and components: For component at least the orientation must be given. The number of channels has no limits but the number of good kappa values is limited to 100000.

Output files:

Kappa.out: detailed output, also shown on screen. At the end is the overall average of all data for each channel.

Kappa_average.out: for each channel, average, sd and number of values. Example:

```
KTK1    Z   0.031  0.012   33
KTK1    N   0.037  0.013   39
KTK1    E   0.026  0.013   45
ARA0    Z  -0.001  0.014   17
ARA0    N   0.006  0.022   18
ARA0    E   0.011  0.017   17
LOF     Z   0.039  0.016   19
LOF     N   0.037  0.021   23
LOF     E   0.034  0.018   23
```

Kappa_chan.all: all individual kappa values with some extra information. Can be used as input for more analysis, see program KAPPA_SORT. Example:

```
KTK1     Z k=  0.020 h=    9.6 hd=  17.5 ed=  14.6 lt= 68.895 lo=  23.403 baz= 152.7 2013 1026 1722 51.
KTK1     Z k=  0.007 h=    3.0 hd=   8.0 ed=   7.4 lt= 69.076 lo=  23.279 baz=  11.3 2015 0214 0145 22.
KTK1     Z k=  0.044 h=    7.4 hd=  14.3 ed=  12.2 lt= 69.084 lo=  23.467 baz=  48.8 2015 0405 1120 55.
KTK1     Z k=  0.027 h=    6.1 hd=  21.0 ed=  20.1 lt= 68.833 lo=  23.308 baz= 170.2 2015 0501 1207 16.
KTK1     N k=  0.024 h=    9.6 hd=  17.5 ed=  14.6 lt= 68.895 lo=  23.403 baz= 152.7 2013 1026 1722 51.
KTK1     N k=  0.047 h=    3.0 hd=   8.0 ed=   7.4 lt= 69.076 lo=  23.279 baz=  11.3 2015 0214 0145 22.
KTK1     N k=  0.048 h=    7.4 hd=  14.3 ed=  12.2 lt= 69.084 lo=  23.467 baz=  48.8 2015 0405 1120 55.
KTK1     N k=  0.028 h=    6.1 hd=  21.0 ed=  20.1 lt= 68.833 lo=  23.308 baz= 170.2 2015 0501 1207 16.
KTK1     E k=  0.016 h=    9.6 hd=  17.5 ed=  14.6 lt= 68.895 lo=  23.403 baz= 152.7 2013 1026 1722 51.
```

The data are: station, component, kappa, depth, epicentral distance, hypocentral distance, latitude, longitude, back azimuth and origin time.

Kappa_event.z n e: Compact S-file with the events with ok kappa value for respective channel. It can be used to plot ok events for a particular component.

Kappa.z n e: Nordic format file with average kappa at a particular station. The epicenter is the station coordinate and the magnitude is proportional with kappa. The file can be plotted with MAP or MAPG and can also be used for further analysis, see example next section. Example:

2000 0101 0101 0.0 L 69.012 23.237 33 3.1 1

KTK1 Z 0.031 0.012 3

2000 0101 0101 0.0 L 69.535 25.506 17 -0.1 1

ARA0 Z -0.001 0.014 3

2000 0101 0101 0.0 L 68.132 13.540 19 3.9 1

LOF Z 0.039 0.016 3

In the header line is the number of kappa values in number of stations field (33), kappa multiplied by 100 (3.1) in magnitude field. The second line gives station, component, average kappa and sd. If plot with e.g. MAP, the stations are shown with magnitude symbol proportional with kappa.

Run the program:

Parameter file, kappa.par is default (return)

CAT File file with events, name kappa.inp is default (return)

Both parameter file and CAT file can have different names. The program has 3 optional arguments: -batch: no questions asked and it is assumed that input file names are kappa.par and kappa.inp.

-par: give parameter file

-cat: give CAT file

32.3 Sorting kappa values, KAPPA_SORT

The SPEC and KAPPA programs gives several kappa related outputs. KAPPA_SORT can further sort and analyze the data and prepare outputs that can be used for plotting the results. The main input file to the program is spec_kappa_chan.all (from SPEC) or kappa_chan.all (from KAPPA) that contains all the individual kappa results from each channel. The options are:

1: get all 3 components from same event, but only if all 3 are there the input file is hardwired to be kappa_chan.all or spec_kappa_chan.all. It will first look for kappa_chan.all and if not found look for spec_kappa_chan.all. For some analysis it is important to have only the data if available at all 3 channels. This is done every time the program runs. The output is in kappa_sort.out, example output:

```
KTK1     Z k=  0.020 h=    9.6 hd=  17.5 ed=  14.6 lt= 68.895 lo=  23.403 baz= 152.7 2013 1026
KTK1     N k=  0.024 h=    9.6 hd=  17.5 ed=  14.6 lt= 68.895 lo=  23.403 baz= 152.7 2013 1026
KTK1     E k=  0.016 h=    9.6 hd=  17.5 ed=  14.6 lt= 68.895 lo=  23.403 baz= 152.7 2013 1026
KTK1     Z k=  0.007 h=    3.0 hd=   8.0 ed=   7.4 lt= 69.076 lo=  23.279 baz=  11.3 2015 0214
KTK1     N k=  0.047 h=    3.0 hd=   8.0 ed=   7.4 lt= 69.076 lo=  23.279 baz=  11.3 2015 0214
KTK1     E k=  0.006 h=    3.0 hd=   8.0 ed=   7.4 lt= 69.076 lo=  23.279 baz=  11.3 2015 0214
KTK1     Z k=  0.044 h=    7.4 hd=  14.3 ed=  12.2 lt= 69.084 lo=  23.467 baz=  48.8 2015 0405
KTK1     N k=  0.048 h=    7.4 hd=  14.3 ed=  12.2 lt= 69.084 lo=  23.467 baz=  48.8 2015 0405
KTK1     E k=  0.024 h=    7.4 hd=  14.3 ed=  12.2 lt= 69.084 lo=  23.467 baz=  48.8 2015 0405
KTK1     Z k=  0.027 h=    6.1 hd=  21.0 ed=  20.1 lt= 68.833 lo=  23.308 baz= 170.2 2015 0501
KTK1     N k=  0.028 h=    6.1 hd=  21.0 ed=  20.1 lt= 68.833 lo=  23.308 baz= 170.2 2015 0501
KTK1     E k=  0.009 h=    6.1 hd=  21.0 ed=  20.1 lt= 68.833 lo=  23.308 baz= 170.2 2015 0501
LOF      Z k=  0.016 h=    6.5 hd=  27.5 ed=  26.7 lt= 68.025 lo=  12.967 baz= 243.5 2013 0116
LOF      N k=  0.015 h=    6.5 hd=  27.5 ed=  26.7 lt= 68.025 lo=  12.967 baz= 243.5 2013 0116
LOF      E k=  0.017 h=    6.5 hd=  27.5 ed=  26.7 lt= 68.025 lo=  12.967 baz= 243.5 2013 0116
LOF      Z k=  0.034 h=    3.7 hd=   8.1 ed=   7.2 lt= 68.120 lo=  13.369 baz= 259.1 2013 0124
LOF      N k=  0.077 h=    3.7 hd=   8.1 ed=   7.2 lt= 68.120 lo=  13.369 baz= 259.1 2013 0124
LOF      E k=  0.063 h=    3.7 hd=   8.1 ed=   7.2 lt= 68.120 lo=  13.369 baz= 259.1 2013 0124
```

2: optionally make xy files of kappa vs distance and depth for a particular Channel. These xy files can e.g. show if any bias of kappa with distance. Three files are made: kappa vs epi distance, kappa vs hyp distance and kappa vs depth. The files can be used e.g. with program LSQ.

3: optionally make a station file for GMT where kappa has been added to the station code. Input can be from an epimap.are where the spec kappa Nordic files have been use for plotting so kappa is included in the file (spec_kappa.z, spec_kappa.n or spec_kappa.e) or one of the three kappa Nordic files directly. The average for each componnt as well as the overall average is calculated. This can be to calcualte average kappa in a particular region selecte in EPIMAP using the Kappa Nordic file. Example of input in spec_kappa.z:

```
 2000 0101 0101  0.0 L  69.012  23.237           3     2.2                    1
 KTK1   Z   -0.022   0.013                                                    3

 2000 0101 0101  0.0 L  68.132  13.540           2     4.5                    1
 LOF    Z   -0.045   0.003                                                    3

 2000 0101 0101  0.0 L  67.930  15.242           2     5.1                    1
 STEI   Z   -0.051   0.023                                                    3

 2000 0101 0101  0.0 L  66.499  13.118         200     5.3                    1
 KONS   Z   -0.053   0.012                                                    3

 2000 0101 0101  0.0 L  66.333  13.018          47     5.4                    1
 STOK   Z   -0.054   0.016                                                    3
```

Kappa is given on second line and also on header line as a magnitude. Example of output GMT file is `kappa_station.gmt`:

```
23.237  69.012 KTK1  22
13.540  68.132 LOF   45
15.242  67.930 STEI  51
13.118  66.499 KONS  53
13.018  66.333 STOK  54
```

Chapter 33

Seismic risk related programs

This section is written by **M. B. Sørensen**, based on a previous version by **K. Atakan**. Extensive testing of the programs was done over the years by many users.

Introduction

Currently, the SEISAN package includes a series of stand-alone programs and Seisan Explorer (SE) functions that can be used in a number of tasks that are needed to perform seismic hazard analysis. The basic requirements for performing a probabilistic seismic hazard analysis (PSHA) may be summarized as follows:

- Collect the best possible earthquake catalog for the study area.
- Homogenize the earthquake catalogue and assess the completeness.
- Define the seismic source zones.
- Prepare input parameters from the earthquake catalogue for each source zone.
- Define ground motion prediction equations (GMPE) for the region.
- Compute hazard in terms of different ground motion parameters (e.g., peak ground acceleration (PGA), peak ground velocity (PGV) or spectral acceleration (SA) at different periods).
- Assess site effects.
- Prepare response spectra.

33.1 Useful programs for hazard

Following is a list of programs that may be useful during a PSHA study. Most of these programs are described in more detail in different sections of the SEISAN manual.

SELECT: Select a subset of earthquake data according to given criteria. This can be useful both in connection with initial quality testing of earthquake catalogs and for selecting events within a given source zone. SE has a similar but more advanced function.
CATSTAT: Program to compute and plot the yearly, monthly and daily number of events in addition to the time-of-day distribution of events from a given catalogue.
NORHEAD: The program can move magnitudes form following header lines to empty space on first header line.
CAT_AGA: Program to reorder the hypocenter lines in a CAT-file according to hypocenter agency, in order to put the prime estimate in the beginning.
CLUSTER: Program that searches for dependent events, defined through time, distance and depth windows, in a given CAT file.
ASSO: Program to merge events which are close in time, magnitude and space in a database. This program

is useful when merging catalogs to avoid double entries. ASSOCI will perform a similar search, but only based on the time difference between events. Furthermore, ASSOCI can only merge two events at a time. It is thus recommended to use ASSO rather than ASSOCI when merging catalogs for hazard assessment purposes.
EXFILTER: Identifies probable explosions, based on user-defined parameters involving time-of-day distribution and the mining locations. It can be used for catalogue clean-up and for discrimination between earthquakes and man-made explosions.
MAG: Magnitude regression and conversion program. Prepares a plot showing the data scatter and the best-fitted line for conversion between two magnitude types. Magnitude conversions can then be performed after a user defined priority list.
EPIMAP: Plots coastlines, national boundaries and earthquake epicenters. It is also possible to select a subset of earthquakes from a chosen polygon on the epicenter map.
BVALUE: Prepares magnitude-frequency of occurrence diagrams and computes a- and b-values with maximum likelihood and least square approximation. In addition, the threshold magnitude and the maximum observed magnitude can be obtained. It is generally recommended to use the Gutenberg-Richter or Weichert functions built into Seisan Explorer instead of BVALUE.
SPEC: Computes amplitude spectra for a given set of earthquake records and plots spectral ratios. It can be used to assess local site effects.
CRISIS2012: Computes seismic hazard in terms of the probability of exceedance vs. earthquake intensity measure. Any intensity measure can be provided through user defined ground motion prediction equations in addition to a large number of built-in relations. Epistemic uncertainty can be considered through the definition of a logic tree. Results can be provided as hazard maps or in terms of hazard curves for selected sites. The program can furthermore provide a deaggregation of the results. The program only runs under Windows and needs to be installed separately. Look for a MSI file in SUP.
SEISAN EXPLORER: A number of functions have been built into Seisan Explorer to aid the preparation of input to a PSHA:
- Function 'Gutenberg-Richter relation' allows for determining a- and b-values for a given catalog using different magnitude intervals and bin sizes (similar to the BVALUE program).
- Function 'Poisson distribution' allows for visually checking whether an earthquake catalog is Poisson distributed or not.
- Function 'Completeness check' provides a 'staircase plot' of the earthquake catalog, showing for different magnitude classes the cumulative number of events as a function of time. This plot allows for defining catalog completeness for different magnitude classes.
- Function 'Weichert method' allows for determining a- and b-values for a given catalog, accounting for varying catalog completeness for different magnitude classes.

Probabilistic seismic hazard computations are done using the Crisis2012 program. In addition, the programs listed above and a number of other programs that manipulate earthquake data within the SEISAN package are useful tools to assess the parameters that are needed to perform a seismic hazard analysis for an area of interest. Crisis2012 is developed by **Mario Ordaz** of the Institute of Engineering, UNAM (Ordaz, 1991, 1999).

Step by step procedure for seismic hazard analysis

Following is a summary of the steps that need to be completed in order to produce a seismic hazard map.

1. Compile a catalogue for the area of interest from local, regional and global sources. Most commonly, several catalogs are merged. After quality control of the individual catalogs (SELECT, CATSTAT and some of the Seisan Explorer tools can be useful for this) the catalogs can be merged using SPLIT and ASSO.

2. Evaluate the preliminary catalogue completeness by using the 'Catalog completeness' function of Seisan Explorer.

3. Convert magnitudes into one uniform magnitude, preferably to moment magnitude MW. To do this, regression curves must be prepared for different magnitude scales. Program MAG can be used for this purpose.

4. Clean up the catalogue for dependent events (i.e. induced seismicity, non-earthquakes, foreshocks, aftershocks, earthquake swarms). Here a search has to be made for clusters of events both in time and space. Program CLUSTER can be used for this purpose. The probable explosions may be removed by using the program EXFILTER. Following, the 'Poisson distribution' function of Seisan Explorer can be used to confirm that the cleaned catalog is Poisson distributed.

5. The evaluation of the catalogue completeness is dependent upon the clean-up process and the magnitude unification. It is therefore necessary that steps 2-4 be repeated until a reliable catalogue is prepared.

6. Delineate earthquake source zones for the area of interest. The zonation can be based on a seismicity map with the clean catalog and additional information from geology, geophysics, seismotectonics, paleoseismology etc. A seismicity map can be prepared using EPIMAP or GMAP (with Google Earth). Both programs have zooming and area selection procedures which can be used to define the source zone polygons.

7. For each earthquake source zone select the subset of events that fall in the chosen area. This can be done by using the SELECT program. Alternatively, EPIMAP can be used to draw polygons interactively on the screen and put the subset of events within this polygon into a file.

8. The seismicity within each source zone is assumed to be uniform following a Poisson distribution. This can be checked using the 'Poisson distribution' function of Seisan Explorer. For each source zone, the following parameters then need to be defined:
   - The a and b-value of the Gutenberg-Richter relation: these can be defined using the 'Weichert method' or 'Gutenberg-Richter relation' functions of Seisan Explorer or from BVALUE. When applying these programs, magnitude interval and bin sizes must be chosen critically, taking into account the catalogue completeness and the detection threshold.
   - Maximum expected magnitude with its standard deviation: This is usually inferred through other available information, such as geology, palaeoseismicity, or subjective judgment of the scientist.
   - Maximum observed magnitude: This is the largest magnitude observed within the catalogue time span.
   - Threshold magnitude: The so-called lower bound magnitude, which is chosen, based on engineering considerations. Usually magnitudes less than 4.0 are not considered engineering significant.

9. It should be assessed whether there are characteristic earthquakes in the region of interest. This can be done through careful examination of the catalogue and the active faults in the area. If characteristic earthquake sources are included in the analysis, it is important that the seismicity rate is reduced correspondingly in any area sources overlapping with the characteristic fault sources.

10. Ground motion prediction equations (attenuation relations), describing the level of ground shaking as a function of magnitude and distance, must be defined for each source zone. Such relations are based on empirical ground motion observations. If no suitable relations are available for the chosen study area and cannot be derived based on existing data, relations can be adopted from tectonically similar regions. In that case it is important to check the predictions of the chosen relations against available recordings from the study area. Many relations are defined for different types of ground conditions (rock, stiff soil, soft soil) and it is important that appropriate relations are chosen.

11. Run the CRISIS2012 program in order to set up a hazard model with the parameters determined in steps 6-10. The model can be defined through the graphical user interface of CRISIS2012. Optionally, a logic tree can be set up to account for epistemic uncertainty. Results can be displayed as hazard maps or hazard curves directly, or exported as ASCII files. There is also an option for deaggregating the results.

12. The local site conditions should be considered for critical sites. SPEC program can be used to obtain the amplification factors due to unconsolidated sediments. These factors can be used later to adjust the response spectra.

Many of the programs mentioned above are described individually throughout this manual at different sections. In the following the programs that are directly relevant to hazard computations and not described in other sections of the manual are explained in detail.

33.2 CRISIS2012

CRISIS2012 is a computer program to compute seismic hazard in extended regions. It was developed at the Institute of Engineering, UNAM, Mexico, by **Mario Ordaz**, **Armando Aguilar** and **Jorge Arboleda**.

Basic input data are: geometry of the sources, seismicity parameters of the sources, and ground motion prediction equations. In addition, the spectral ordinates, for which the hazard is calculated, must be defined together with the calculation grid and parameters related to the integration and display of results. Details about the use of CRISIS2012 are given in the separate CRISIS2012 manual PDF file contained in the MSI installation file in SUP.

CRISIS2012 is only available under Windows and needs to be installed separately. An MSI file is available in SUP. When opening the MSI file, an installation widow appears asking a number of questions in Spanish. The following choices should lead to successful installation of CRISIS2012:

1st window: Siguiente (next)

2nd window: Choose the location where CRISIS2012 should be installed (browse with 'Examinar').
Choose whether CRISIS2012 should be available for all users (Para todos los usuarios) or current user only (Solo para este usuario)
Siguiente (next)

3rd window: Siguiente (next)

4th window: Cerrar (close)

During the process, it may be necessary to update the .NET framework of the computer.

After installation, a number of files will be available at the location specified in the 2nd installation window. CRISIS2012 is launched through CRISIS 2012.exe . A comprehensive manual is found in CRISIS 2008 Manual.pdf and through the help function of CRISIS2012.

33.3 SEISAN EXPLORER:

The Seisan Explorer functions which are specifically relevant for seismic hazard assessment are described in the following. The user is referred to the separate section on Seisan Explorer for details on the general use of the program.

Function 'Gutenberg-Richter relation' allows for determining a- and b-values of the Gutenberg-Richter relation for a given catalog using different magnitude intervals and bin sizes. The Gutenberg-Richter relation states that

$$\log(N) = a - bM \tag{33.1}$$

where log is the base-10 logarithm and N is the number of events with magnitude M (or larger in case of regression on cumulative data, see below).

The user can choose which magnitude type to use (M is the first magnitude given for each event). The database is read, and a histogram is plotted showing the number of events in different magnitude bins. The minimum magnitude to be considered and the bin size can be chosen by the user. Optionally, the incremental number of events and the cumulative number of events above a given magnitude can be overlain as symbols. The a- and b-values can be determined by regression on either the incremental or the cumulative values. The starting magnitude is selected by the user and should be set such that only the complete part of the catalog is considered. It is also possible to set a maximum magnitude in the regression. The obtained a- and b-values are returned, and the fit is compared to the data in the plot.

Function 'Poisson distribution' allows for visually checking whether an earthquake catalog is Poisson distributed. The function reads the database and plots a histogram showing the number of 1-year intervals with a given number of earthquakes, as a function of the annual number of earthquakes. This histogram is compared to the theoretical Poisson distribution derived from

$$P(N = n) = \frac{\nu^n}{n!} e^{-\nu},$$

where n is the number of earthquakes for a given year and ν is the mean annual number of events. A good fit between the histogram and the theoretical curve indicates that the data fulfills the Poisson distribution.

Function 'Completeness check' allows for defining catalog completeness for different magnitude classes. The function provides a 'staircase plot' of the earthquake catalog, showing for different magnitude classes the cumulative number of events as a function of time. Assuming that the catalog is complete during the most recent part of the time interval, the user can search for a change in slope, indicating a change in seismicity rate. Such change is interpreted as a change in catalog completeness. The completeness time can thus be read as the time where the staircase plot changes slope for a given magnitude class and entered into a table. The plot can be zoomed by scrolling and moved by dragging with the mouse. The user can select the minimum magnitude to be considered and the magnitude interval for each curve. The entered completeness values are shown in the plot and saved to a file se-completeness.out, to be read by function 'Weichert method', when pushing 'Replot'.

Function 'Weichert method' allows for determining a- and b-values for a given catalog, accounting for varying catalog completeness for different magnitude classes following Weichert (1980). The magnitude classes and their corresponding completeness times are read from the file se-completeness.out, which is generated by function 'Completeness check'. The user can choose which magnitude classes to consider through 'Select intervals to be used'. The function performs a standard linear regression for the Gutenberg-Richter a- and b-values for the complete part of the catalog. In addition, a regression is performed following Weichert (1980). This regression returns the b-value, the Mmin value used and a value of Ny(M) for a magnitude selected by the user, defined through:

$$\log(Ny) = \log(Ny(M_{min})) + b(M_{min} - M), \tag{33.2}$$

where log is the base-10 logarithm and Ny(M) is the annual number of earthquakes with magnitude M.

33.4 CLUSTER

The purpose of CLUSTER is to find and remove dependent events (foreshocks, aftershocks and swarm events) from a catalog. In contrast to the old CLUSER in SEISAN before version 10.0, this completely new version will search for dependent events using more parameters: Time difference, epicentral distance and depth distance. These parameters can be magnitude dependent and can be different before and after the main event. The program requires an input parameter file cluster.def which can be placed in working directory or DAT. An example is given in DAT and seen below.

For declaring an event as a dependent event, the dependent event must be occur at less than a given time difference from the main event, it must be smaller than a specified magnitude (relative to the main event), the epicentral or hypocentral distance between main and dependent event must be less than a given value and the difference in hypocentral depth between the two events must be less than a given value. Hypocentral distance is calculated as the direct distance between main shock and dependent event.. The time and distance limits are generally magnitude dependent so larger values are used for larger events. Different magnitude dependence can be used before and after the main event.

If the event has no location or magnitude, it will not be considered as a possible dependent event and will be included in the list of main shocks.

The magnitude used is selected among all prime magnitudes in the file (the 6 magnitudes on main header line, can be 2 lines if more than 3 magnitudes). The magnitudes can be given an order of priority in SEISAN.DEF:

```
KEYWORD.....Comments.....Par 1.....Par 2
```

```
MAGNITUDE_ORDER                          LBER
MAGNITUDE_ORDER                          LNAO
```

In this example, LBER (local magnitude calculated by BER) is first chosen, if not there, LNAO and if not there either, the first magnitude found in file. If no order is given in SEISAN.DEF, the magnitude used will be the first found for the event, irrespective of type or agency. It is possible to leave either magnitude or agency blank in which case the blank represents a wildcard.

Potentially all events can be a mainshock so all combinations, within the time limit, will be searched. A search is first made after the main event (for aftershocks) and then before the main event (for foreshocks).

Input:

A file in Nordic format. If only header lines, there must be a blank line between events.

Output:

All dependent events will be removed and put out in a file called cluster_reject.out while the cleaned catalog will be in file cluster_use.out. Optionally, a debug output can be made, either on screen or in a file (see cluster.def). An example is seen below

```
Main : 2012  210 1222 22.3  66.4  14.2  14.0 0.9 LTES
Main : 2012  210 1316  8.1  66.3  14.9   0.0 1.1 LTES
Main : 2012  210 1356 25.0  71.2  -8.1  13.0 3.5 LTES
After: 2012  212 2332  7.8  71.2  -8.2  12.9 1.8 LTES  M2.5 T 22  2 D   26    3
After: 2012  213  853 34.5  71.0  -8.0  19.7 1.3 LTES  M2.5 T 22  2 D   26   19
After: 2012  216 1322  6.1  71.1  -7.7   0.1 1.5 LTES  M2.5 T 22  5 D   26   18
Fore : 2012  124  027 10.9  71.1  -8.0  43.2 2.3 LTES  M2.5 T 22 17 D   26   14
Fore : 2012  122 1248 16.6  71.1  -8.3  23.7 1.7 LTES  M2.5 T 22 19 D   26   12
Fore : 2012  120  128 10.3  71.1  -7.5  13.2 1.8 LTES  M2.5 T 22 21 D   26   22
Main : 2012  210 1543 54.2  73.3   7.8  15.0 2.8 LTES
Main : 2012  210 1549 52.9 -27.6-176.6  33.0 5.0 BNAO
Main : 2012  210 1654 31.8   2.2 122.2  33.0 5.4 BNAO
```

Each potential main (Main) event is listed. To be considered a potential main event, the event must have both location and magnitude. If a dependent event is found, its type is shown (After or Fore) with the parameters: M: The interpolated main shock magnitude used, T: The interpolated maximum time difference used and the actual time difference (days), D: The interpolated maximum distance (km) used and the actual distance. In the above example, the upper magnitude limit for dependent events is 2.5, main event is 3.5, the limit in distance is 26 km and in time 22 days. Directly following the Main event comes a listing of all dependent events. The next potential main event will then be the first unused event following the previous Main event and that Main event can then jump back in time since there might be several events following the previous Main event which were not declared as dependent events.

Example of a cluster.def file

```
This file is parameter file for cluster. The file can be in working
directory or DAT.
Only the lines with recognized keywords and a non blank field
under Par 1 will be read. The comments have no importance. Lines with
keywords MAGS AFTER DIST TIME and MAGS BEFORE DIST TIME must come grouped
together in increasing magnitude order. Parameters for these lines are:
Reference magnitude of main event, maximum magnitude of corresponding after/foreshock
                                    (AFTER/FORE), distance(km) and time(days).
All number must be real numbers. Columns Par 1-Par 4 start in
columns 41,51, 61 and 71.
All keywords in capital letters.
Hypocentral distance is calculated as the direct distance between main shock and
                                    dependent event.
Parameter values are interpolated for magnitudes between the ones given.
The values shown in debug output are the interpolated values.
```

```
If event is larger than largest event in table, the values for the largest event is
                                    used. If event is smaller than smallest event in
                                    table, no dependent events will be searched for.

The MAGS AFTER DIST TIME are magnitude of main shock, corresponding magnitude
of largest aftershock, distance and time. Similarly for the foreshocks.

The MAX DEPT DIFFERENCE will consider only events with a depth
difference less than MAX DEPT DIFFERENCE as a possible dependent event.


KEYWORD.............Comments..............Par 1.....Par 2.....Par 3.....Par4.....
HYPOCENTRAL DIST   1.0 yes, 0.0 no      0.0
MAX DEPTH DIFF     Difference in depth  50.0
DEBUG OUT 0.0 none, 1.0 screen 2.0 file 1.0

MAGS AFTER DIST TIME  Mag. dep. par.    2.5       1.5       19.5      6.0
MAGS AFTER DIST TIME  Mag. dep. par.    3.0       2.0       22.5      11.5
MAGS AFTER DIST TIME  Mag. dep. par.    3.5       2.5       26.0      22.0
MAGS AFTER DIST TIME  Mag. dep. par.    4.0       3.0       30.0      42.0
MAGS AFTER DIST TIME  Mag. dep. par.    4.5       3.5       35.0      83.0
MAGS AFTER DIST TIME  Mag. dep. par.    5.0       4.0       40.0      155.0
MAGS AFTER DIST TIME  Mag. dep. par.    5.5       4.5       47.0      290.0
MAGS AFTER DIST TIME  Mag. dep. par.    6.0       5.0       54.0      510.0
MAGS AFTER DIST TIME  Mag. dep. par.    6.5       5.5       61.0      790.0
MAGS AFTER DIST TIME  Mag. dep. par.    7.0       6.0       70.0      915.0
MAGS AFTER DIST TIME  Mag. dep. par.    7.5       6.5       81.0      960.0
MAGS AFTER DIST TIME  Mag. dep. par.    8.0       7.0       94.0      985.0
MAGS AFTER DIST TIME  Mag. dep. par.    8.5       7.5       110.0     1000.0

MAGS BEFORE DIST TIME  Mag. dep. par.   2.5       1.5       19.5      6.0
MAGS BEFORE DIST TIME  Mag. dep. par.   3.0       2.0       22.5      11.5
MAGS BEFORE DIST TIME  Mag. dep. par.   3.5       2.5       26.0      22.0
MAGS BEFORE DIST TIME  Mag. dep. par.   4.0       3.0       30.0      42.0
MAGS BEFORE DIST TIME  Mag. dep. par.   4.5       3.5       35.0      83.0
MAGS BEFORE DIST TIME  Mag. dep. par.   5.0       4.0       40.0      155.0
MAGS BEFORE DIST TIME  Mag. dep. par.   5.5       4.5       47.0      290.0
MAGS BEFORE DIST TIME  Mag. dep. par.   6.0       5.0       54.0      510.0
MAGS BEFORE DIST TIME  Mag. dep. par.   6.5       5.5       61.0      790.0
MAGS BEFORE DIST TIME  Mag. dep. par.   7.0       6.0       70.0      915.0
MAGS BEFORE DIST TIME  Mag. dep. par.   7.5       6.5       81.0      960.0
MAGS BEFORE DIST TIME  Mag. dep. par.   8.0       7.0       94.0      985.0
MAGS BEFORE DIST TIME  Mag. dep. par.   8.5       7.5       110.0     1000.0
```

There must be at least one "MAGS AFTER DIST TIME" line but "MAGS BEFORE DIST TIME" are not needed. In that case there will be no search for foreshocks.

Chapter 34

Magnitude and spectral relations, MAG

The MAG program calculates simple magnitude relations. The program has three functions: (1) Calculate parameters for a magnitude scale (Ml or Mc), (2) Calculate relation between two different magnitudes and/or spectral parameters and (3) Calculate a new magnitude as a function of an existing magnitude, a natural step following function (2). All three functions can be done at the same time. Function (3) can also be used for moving a particular magnitude type and/or agency to the first magnitude position in line 1 to be plotted with EPIMAP.

ALL HEADER LINES ARE SEARCHED FOR MAGNITUDE INFORMATION

Input: The data input is a CAT-file like one made with SELECT or COLLECT or it can be a compact file if only magnitude comparison is made. Optionally there can be a parameter file, which MUST be, called mag.par and MUST reside in the working directory. An example of the parameter file is found in DAT and also shown below. The parameter file is not needed for all operations, see details below.

1: Magnitude scales

Coda magnitude Mc: The coda magnitude scale used is

$$Mc = A * log(coda) + B * dist + C$$

where Mc is the coda magnitude, coda is the coda length in secs, dist is the hypocentral distance in km (calculated from epicentral distance and depth in CAT file) and A, B and C are constants to be determined. This is done in two ways

3d regression

$$m = A * log(coda) + B * dist + C$$

2d regression

$$m = A * (log(coda) + dist_coff * dist) + C$$

with B = A * dist_coff where dist_coff is given in the parameter file and m is the reference magnitude. SO B AND dist_coff ARE DIFFERENT. The CAT-file must contain coda readings, epicentral distances and a magnitude in the header line. A linear regression is then made between the known magnitude from a given agency and the observed coda lengths following the relations above. The user has the option to choose the type of magnitude to use in the regression. Usually Ml or Mb are used. All station-event combinations are used to determine simultaneously the 3 constants A, B and C. Since the data often is too bad to determine all 3 parameters at the same time, the program will also calculate just A and C using a fixed user supplied value for the distance correction to the coda. The constant dist_coff is given in the mag.par file as the second parameter under MAG_TYP_COF (see below). IN ORDER FOR THE CODA SCALE OPTION TO WORK, THE DISTANCE COEFFICIENT MUST BE DIFFERENT FROM ZERO.

Output: On the screen the constants will be printed out and a file mag_coda.out will contain pairs of values m and (log(coda) + dist_coff*dist), which can be used to plot the distance corrected coda relation. If results from the 3D is to be plotted, dist_coff must be calculated as dist_coff=B/A, put into mag.par and mag run again. On the other hand, if a best dist_cof has been found, B is calculated as B=A*dist_cod

A typical coda magnitude relation is :

$$Mc = 2.0 * log(coda) + 0.0035 * dist - 0.87$$

(Lee et al., 1972)

Local magnitude Ml:
The local magnitude scale is calculated by determining an amplitude attenuation scale using amplitudes and distances in CAT file. The parameters in the Ml magnitude scale are computed for every event individually, parameters are determined as averages of all events.

For each event (only type L and R are used) a,b,c are calculated if at least 3 stations are available using least squares regression as follows:

$$log(amp) = a * log(dist) + b * dist + c$$

The relation above can be derived from the standard geometrical spreading and attenuation relations:

$$amp = (dist * *a) * exp(pi * f * dist/(v * q))$$

where f is the frequency, v is the velocity and $q = q0 * f * *qalpha$. The relation can be rewritten

$$log(amp) = a * log(dist) + (pi * f * dist)/(v * q0 * f * *qalpha * 2.3)$$

Since $qalpha$ often is close to 1.0, the relation can be simplified to the frequency independent relation:

$$log(amp) = a * log(dist) + (pi * dist)/(v * q0 * 2.3)$$

If body wave spreading is assumed ($a = 1$), $q0 = 100$ and $v = 3.5km/sec$, the relation is

$$log(amp) = 1.0 * log(dist) + 0.004 * dist$$

which is comparable to the relation shown below for California.

Similarly to the coda relation, a 2D relation is also calculated

$$log(amp) - b * dist = a * log(dist)$$

where $b = dist_coff$ is fixed to the value given in the mag.par file (same parameter as used for coda). This gives a more stable solution, however b = dist_coff must be determined by trial and error or fixed using known values from e.g. q-studies.

The amplitudes are assumed to be ground displacements (in SEISAN they are ground displacements highpass filtered at 1.25 Hz to resemble Wood Anderson seismograms, see MULPLT). The distance ratio between stations with the maximum distance and minimum distance must be more than 3 for the event to be selected for analysis. It is assumed that a and b will be the same for all events, while c is different (magnitude dependent). At the end, the average constants a and b are calculated of all values a and b which are not deviating too much (a must be in the range 0 to -5, hardwired). Distance attenuation coefficients a and b are supposed to be negative since amplitude decrease with distance. To get the local magnitude scale

$$Ml = log(amp) - a * log(dist) - b * dist - C$$

the constant C must be determined by fixing the magnitude at some reference distance like the original Wood Anderson definition with $Ml = 3$ at $dist = 100km$ and $amp = 1/2200mm = 454nm$ (assuming gain of the Wood Anderson seismograph to be 2080, (Hutton and Boore, 1987). The determination of a and b

does not work well unless the observations are very good. The relation for California is (Hutton and Boore, 1987)

$$Ml = log(amp) + 1.1 * log(dist) + 0.00189 * dist - 2.09$$

Output: On the screen the constants will be printed out and a file mag_amp.out will contain the values of a, b and c.

2: Magnitude relations and/or spectral parameter relations

Linear regression (maximum likelihood) can be made between any two magnitudes and/or spectral parameters on any of the header lines of an event in a CAT-file or a compact file. The user is interactively prompted for the magnitude type and/or spectral parameters and agencies to compare. If none is given, no magnitude comparison will be made. If several magnitudes/spectral parameters fit the requirement, the last one is used. If e.g. the first header line has a BER Ml and the last header line also has a BER Ml, the last one will be used. Maximum likelihood linear fitting is used. It is assumed that both variables have normal and correlated errors. See subroutine maxlik.for in LIB for more info.

The following parameter can be selected:

Any magnitude and agency
Seismic moment(log)
Stress drop (log)
Corner frequency (log)
Source radius(log)
Spectral decay
Omega zero level (log)

If any of the spectral parameters are selected, or moment magnitude is without agency, there will be an additional question about which station and component. A blank return means the average will be used. With these parameter selections, it is possible to compare spectral parameters from any two channels, compare the average spectral parameter with the parameter from one channel etc.

Output: A plot will be shown on the screen with the observations and the least squares fit and the values are also printed out on the screen. It is now possibel to click on any symbol to get up the correponding date and time. This facility can be used to find bad magnitides. A file mag_mag.out contains the pairs of magnitudes used.

A file with heder lines, including extra magnitudes, and spectral parameter is mag_spec.out.

All the events used are output in a CAT file called mag_used.out so MAG can be used to select events with two particular parameters which both are there.

3: Magnitude conversions

If a relation between two magnitude scales is known, e.g. by using option 2 above, an output file can be made with the converted magnitudes. The relation to use is specified in the mag.par file. Several different input magnitude types and agencies can be used and the relation-agency used is given in a priority list in the mag.par file, see example below. It is here shown that if a BER Mc is available, this will be the first choice. If no BER Mc then BER Mb will be the next choice etc. The new magnitude will have type X and agency NEW. Output: The output file is mag_new.out and has the same format as the input file. On the header line, the old magnitudes are removed and in the first magnitude position will be the converted magnitude (NEW) while in the second magnitude position, the magnitude selected for conversion will be given. The third magnitude position is blanked out. The conversion option can also be used to move magnitudes around by using a 1 to 1 relation as shown in mag.par example.

Summary of output files:

`mag_amp.out` :	Details each event for amplitude regression.
`mag_coda.out` :	Magnitude vs coda, see text.
`mag_mag.out` :	Pairs of magnitudes used for regression.
`mag_new.out` :	Events with converted magnitudes only.
`mag_newa.out` :	All events, both converted and non converted (due to no correct input magnitude available).
`mag_spec.out` :	Summary of normal header line, all associated magnitudes and spectral parameters.
`mag_ml_inv.out` :	From Ml inversion

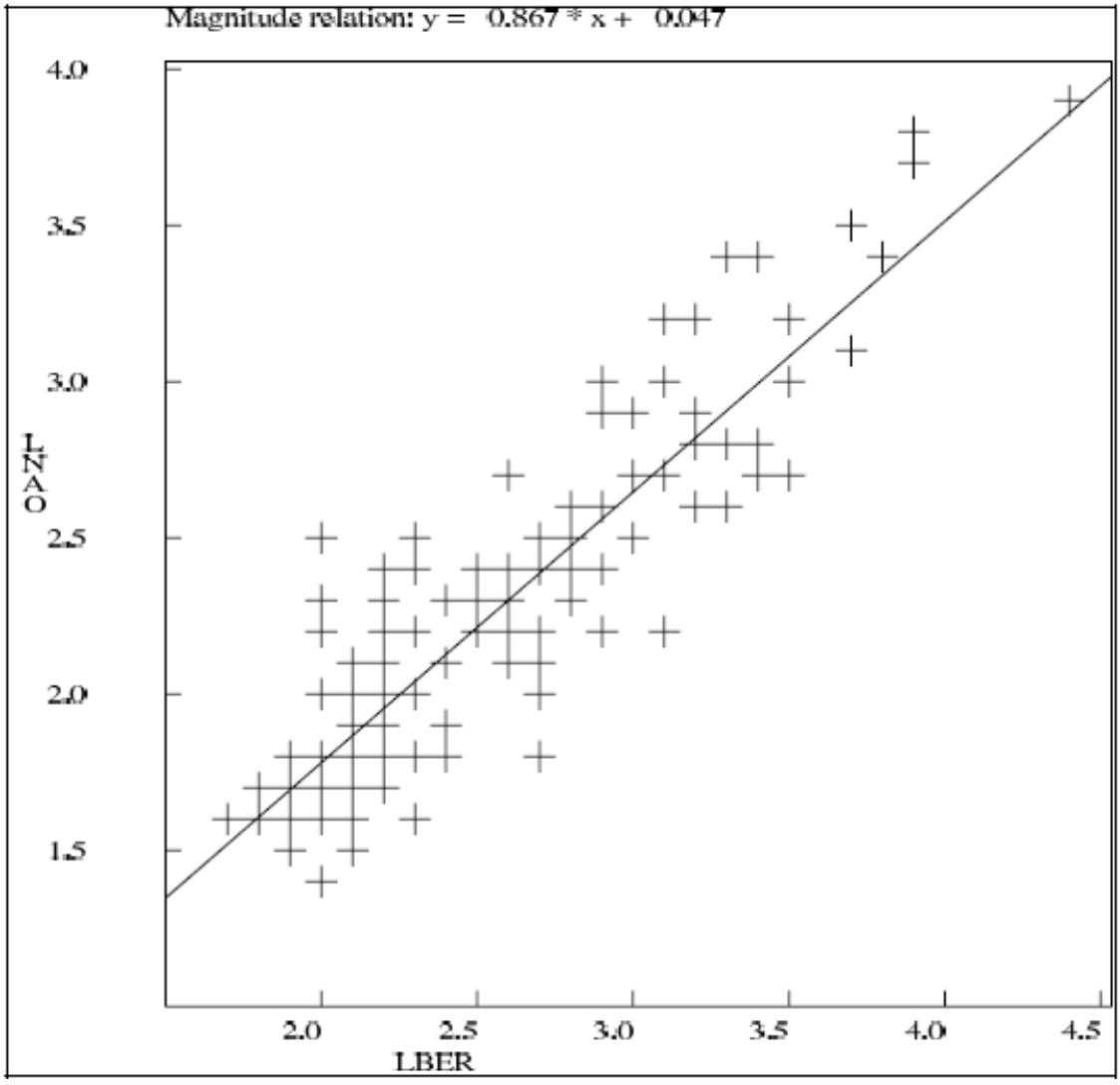


Figure 34.1: Example of using the MAG program. Relation between NORSAR and Bergen local magnitudes.

In DAT there is an example `mag.par` file.
An example of the `mag.par` parameter file:

```
This file is for parameters for MAG and called MAG.PAR. The name must
be in lower case on Sun. The following shows the parameters which can be set.
The file can contain any lines in any order, only the lines with
recognized keywords and a non blank field under Par 1 will be read. The
comments have no importance. The text fields are left justified, the
real numbers can be anywhere within the 10 columns of the parameter.
 MAGAGA is the magnitude type and agency to use for the converted magnitude.
 MAGREL gives the magnitude and agency to use for conversion e.g. LBER and
the parameters 2 and 3 gives the relationship:

magnitude out = magnitude in * par2 + par3

The magnitude conversion uses one of the MAGREL relationships, where the
priority is in the same order as found in the list.
```

SCREENOUT can be (Y)ES or (N)O, indicates if a line is printed on the screen
for each event.

When doing a magnitude regression on coda or amplitude, BAD STATION indicates
stations not to be used. MAG_TYP_COF is the magnitude type and agency to correlate
coda readings with and the second parameter is the distance correction
term used when calculating a coda magnitude relation with a fixed distance
term. The same parameter is also used for amplitude regression.

The input file can be either Nordic or compact Nordic, however if coda or
amplitudes are to be used, it must be NORDIC.

KEYWORD	Comments	Par.1	Par.2	Par.3
BAD STATION	Station not used for mag relation	BER		
BAD STATION	Station not used for mag relation	XXX		
BAD STATION	Station not used for mag relation	BER		
MAGAGA	Magnitude type and agency, new mag	XNEW		
MAGREL	Mag type, agency, a,b for new mag	CBER	1.0	2.0
MAGREL	Mag type, agency, a,b for new mag	BBER	1.0	2.0
MAGREL	Mag type, agency, a,b for new mag	SBER	1.0	2.0
MAGREL	Mag type, agency, a,b for new mag	WBER	1.0	2.0
SCREENOUT	Header line printed each event	N		
MAG_TYP_COF	Mag. type for corr., dist coff.	LNAO	0.002	

Chapter 35

ML inversion, MAG2

MAG2 is a program to invert for the local magnitude scale ML. The difference to the inversion done in MAG is that MAG2 inverts amplitudes from all events simultaneously for the scale and station corrections. The program can invert for different scale parameters depending on selected distance ranges. The reason for this is that it is known that the geometrical spreading is not the same for example between Pg and Pn. Some authors have suggested distance dependent scales, but most commonly a single scale is used for all distances for simplicity.

The general ML scale is given by

$$ML = log_{10}A + alog_{10}(R) + bR + S + c$$

where we measure the displacement amplitude A in nm, R is the hypocentral distance in km, S is the station correction of the individual stations, and c is a constant added to make the scale comparable to other places at a reference distance. The station corrections add up to 0. The region dependant parameters in the scale are a, accounting for geometrical spreading, and b, accounting for attenuation. The part $(alog_{10}(R) + bR + c)$ is commonly written as $(-log_{10}A0)$.

The program applies singular value decomposition using the Numerical Recipe (Press et al., 2003) routines to invert the observations for a, b and S. It then computes the parameter c based on the reference given through distance, amplitude and magnitude. This allows to calibrate scales between different regions so that they are the same at the reference distance. Commonly c is set such that 480 nm amplitude at 17 km gives ML=2 (this is equivalent to 1 mm on a Wood-Anderson seismograph giving ML=2 at 17 km (Hutton and Boore, 1987). The original definition was 480 nm at 100 km giving a ML=3 (equivalent to 1 mm on a Wood-Anderson seismograph at 100 km distance), however it is now considred that a shorter reference distance will give a more accurate scale. The inversion can be setup to invert for the geometrical spreading term a in the scale for up to three distance ranges. However, a single attenuation term b is used.

As input the program requires a parameter file mag2.par (or other name can be given as input) in the working directory, and a standard station file e.g. STATION0.HYP. Then the user only has to enter the input file of events in Nordic format, and if needed the name of the parameter file if different from mag2.par. A sample file, mag2.par, and an input file, mag2nor.cat, with events from Norway are in given in DAT.

The parameter file has the following settings given by keywords (any order):

INVERSION TYPE (f10.1) - 1. = singular value decomposition (no other choice yet)
DISTANCES (2f10.1) - distance range in km for observations to use
MINIMUM NUMBER OF OBS/EVEN (f10.1) - only events with more or equal number of observations are used
MIN DISTANCERANGE RATIO (f10.1) - minimum range required computed as ratio of distances defined by DISTANCES
ORIENTATION (f10.1) - use of components: 0. = horizontal and vertical, 1. = horizontal only, 2. = vertical only
SYNTHETIC (f10.1) - set to 1. for synthetic test, scale defined by FIX SCALE A and FIX SCALE B; 0. for inversion of data
NOISE (f10.1) - ratio of amplitude to be added as noise to synthetic test

FIX SCALE A (3f10.1) - set the fixed parameter a in scale, possible for the three distance ranges given by SCALE DISTANCE
FIX SCALE B (3f10.1) - set the fixed b parameter in scale, possible for the three distance ranges given by SCALE DISTANCE
FIX SITE (f10.1) - set to 1. to not invert for station corrections; 0. for default inversion for station corrections
IGNORE COMP (a4) - give component not to be used
IGNORE STAT (a5) - give station not to be used
REFERENCE DISTANCE, REFERENCE AMPLITUDE, REFERENCE MAGNITUDE (all f10.1) - setup of the reference, used to calculate parameter c, give amplitude as Wood Anderson amplitude in mm
SCALE DISTANCE (2f10.1) - give up to two distances which give the transition between the possibly three distance dependent scales; blank or numbers larger than maximum distance will give only one scale
RANGE A (3f10) - The parameter 'a' in the ML scale can be fixed to values given here. Three numbers have to be given, the first gives the start value, the second the end value and the third gives the spacing (e.g., .5,1.5,.1 means that mag2 inverts for 'a' values between .5 and 1.5 with .1 spacing); if this parameter is set, mag2 does run the invesion for the given (fixed) values of 'a'.

The program produces a number of output files:

mag2_amp_dis.out - amplitude versus distance for each event
mag2_amp_obs.out - list of observed amplitudes
mag2_events_read.out - listing of events that were read in
mag2_events_used.out - events used in Nordic format
mag2_evxy.out - coordinates of events used
mag2.out - general output file, lists data used and computed scale
mag2_paths.out - event-station path coordinates
mag2_station_hyp.out - hyp station file with scale and station corrections
mag2_stat_list.out - simple output of stations used
mag2_statxy.out - coordinates of stations used

The output file mag2.out will give some details on the input data, as number of stations, events and observations. It reports the reference used to fix the scale at the reference distance. Next it gives the scale, consisting of three parts if inversion is done for all possible segments. This will be given by a1, a2, a3, while b will be assumed to be the same. First the scale is presented to include the reference distance, second it is shown without the reference distance included with the scale. Then comes a section with the stations and the respective site terms, and finally the list of events with the source term inverted for.

The output file mag2.out for the example in the DAT directory should look like this:

```
 ML inversion output

 SVD inversion

 Total number of events:           69
 Total number of stations:           23
 Total number of observations:          600

 Reference distance  =    100.0000
 Reference amplitude =    1.000000
 Reference magnitude =    3.000000

 Ml = log A + a log(dist/refdist) + b (dist-refdist) + c + S
     a1=  0.84717 +/-  0.39844
     a2=  0.00000 +/-  0.00100
     a3=  0.00000 +/-  0.00100
     b =  0.00061 +/-  0.00136
     c =  0.31807 +/-  0.00000
```

```
 Ml = log A + a log(dist) + b (dist) + c + S
    a1 =  0.84717 +/-  0.39844
    a2 =  0.00000 +/-  0.00100
    a3 =  0.00000 +/-  0.00100
     b =  0.00061 +/-  0.00136
    c1 = -1.43679
    c2 =  0.25756
    c3 =  0.25756

Station #    1 STAV  -0.120  +/- 0.2612   58.935    5.702
Station #    2 BLS5  -0.044  +/- 0.2204   59.423    6.456
Station #    3 ODD1  -0.085  +/- 0.2125   59.912    6.628
...
 Average site term:   0.00
  Event #     1 2002051922484590  ML =  1.95 +/- 0.438
  Event #     2 2002052614481700  ML =  1.68 +/- 0.577
  Event #     3 2002063023341400  ML =  1.86 +/- 0.491
...
```

35.1 MAGSTAT

The program MAGSTAT can be used with MAG2 to produce statistics that allow to evaluate the magnitude scale. As input it takes a STATION file, as produced by MAG2, and a Nordic input file. Here, one can use any data set, or the events that were used in the MAG2 inversion.

This program is still under construction.

Chapter 36

MAGRES, calculate average magnitude residuals

The program MAGRES is used to calcualte average magnitude residuals for each station and component in a given data set. Currently the program only work with Nordic2 format, which has the magnitude residual in the S-file after it has been updated. So if data is in Nordic format, transfer to Nordic2 with NOR2NOR2, relocate the events and run the program. The progrsam is intended to check a data set for stations with a magnitude bias. In addition, if magnitudes are available on all 3 components, the average difference in magnitude between vertical and horizontal components, are calculated. This can be used to find if there is a bias using vertical compoent instead of horizontal component. This is mostly usweful for Ml.

The program has several options for making the comparison for a subset of data. This will come out in a separate file.

Below is an example:

```
magres
 Magnitude type: L, C, b, B, s, S or W
b
 Other selection criteria for 2. output: y/n=enter
y
 Average absolute residual range, enter for all
0.0 0.3
 Minimum number of residuals for average, enter for all
3
 Component to use, Z, N or E, if blank use all

 Accept blank component (y=enter/n)
y
 Only list first entry from a station(y/n=enter)

  Event data input - select one:

     SEISAN default data base or                    :Enter
     Alternative data base, give 1-5 letter code or  :
     Local index file, name must start with index or :
     Local data base, write ,, or                    :
     Filename for one file, min. 6 chars or with a . :

test.inp
```

```
 2016 0101 0200 40.5 RQ-50.622 139.549 15.3FFISC836 3.5 6.2sBER 6.1SBER 6.0bISC
 2016 0103 2305 18.9 RQ 24.831  93.605 31.0FFISC999 2.5 6.7LBER 6.2sBER 6.6bISC
 2016 0111 1638 08.0 R   3.802 126.840 22.0FFISC999 9.0 6.5sBER 6.9SBER 6.1bISC
 2016 0114 0325 27.6 R -19.711 -63.317 582.FFISC951 2.9 6.1LBER 6.0bBER 6.0bISC
 2016 0114 0325 31.4 RQ 42.044 142.697 31.0FFISC999 3.6 6.4sBER 6.6SBER 6.5bISC
 ..
 ..

 Residuals for magnitude type b

 STAT COM      N        AV      SD
 CASY BHZ      4      0.12    0.12
 FORT BHZ      3      0.17    0.29
 RPZ  HHZ      3      0.17    0.08
 THZ  HHZ      3      0.01    0.17
 ASAR          6     -0.61    0.23
 MORW BHZ      5      0.10    0.09
 VNDA          4     -0.65    0.54
 RK1H          2     -0.66    0.24
 SBA  S Z      2      0.23    0.31
 SBA  BHZ      1      0.03    0.00
 URZ           3     -0.32    0.26

 Average horizontal mag res minus mag res on Z for station MNK    -0.74

 Number of events in input file or data base          11
 Number of channels with mag        1905
 Number of stations with mag        1589
 Number of stations with magnitudes on Z,N and E           1
 Output file name is magres_all.out for all stations
 Output file name is magres_selected.out for selected stations
 Output of histogram, all residuals, is magres_histogram.out
 Output of residuals vs distance, all data is magres_distance.out
```

The output on the screen and file magres.out lists all residuals while the selected ones are in file magres_selected.out. An example of magres_selected.oput:

```
Residuals for magnitude type b

 STAT COM      N        AV      SD     LAT     LON   ELEVA
 CASY BHZ      4      0.12    0.12 -66.279 110.536 154.000
 FORT BHZ      3      0.17    0.29 -30.779 128.059 165.000
 RPZ  HHZ      3      0.17    0.08 -43.715 171.054 453.000
 THZ  HHZ      3      0.01    0.17 -41.763 172.905 747.000
 MORW BHZ      5      0.10    0.09 -29.068 116.040 296.000
 WRO  BHZ      4      0.08    0.21 -19.960 134.540 353.000
 WRA           7     -0.23    0.23 -19.943 134.339 419.000
 WRAB S Z      7     -0.05    0.12 -19.933 134.350 366.000
 CTAO S Z      6     -0.11    0.38 -20.088 146.254 357.000
 PSA00BHZ      6      0.09    0.14 -21.573 119.846 244.000
 OUENCBHZ      3      0.16    0.05 -22.418 166.842 115.000
 DZM          12     -0.05    0.34 -22.071 166.444 905.000
 MTN  BHZ      3      0.18    0.17 -12.844 131.133 137.000
 QSPA BHZ      3      0.02    0.20 -89.928 145.0002657.000
 BATI          8     -0.12    0.16 -10.207 123.663 356.000
```

```
MSVF S Z      4     -0.05    0.15 -17.733 178.050 783.000
JAGI BHZ      5     -0.00    0.28  -8.470 114.152 171.000
```

The file also has the location of the stations so it can be used for making a map with the residuals. The magres_distance.out lists the distance in km vs the residual. All data is used. Example:

```
2390.00000      0.230000004
2400.00000      0.319999993
2487.00000       9.00000036E-02
2728.00000       5.99999987E-02
3029.00000     -0.920000017
3097.00000      0.100000001
3142.00000     -0.660000026
3165.00000     -0.829999983
3238.00000       9.99999978E-03
```

Chapter 37

Explosion filtering, EXFILTER

The program EXFILTER is used to identify probable explosions in a catalog of seismic events. Man-made seismic events like quarry blasts, mining explosions and other explosions show a certain distribution in time and space. Therefore the method of explosion identification here is based on normalizing the time of day distribution of seismic event occurrence as a function of area. The program works on the following principle: Areas where explosions occur are defined. If an event is located in one of these areas, with a magnitude below a given maximum magnitude, with a depth less than a given maximum depth, within a given time of day interval and within a given year interval, it is identified and marked as probable explosion. The areas are defined by polygons of any shape. For definition of the filter areas, a list of mine locations (with consideration of location accuracy), locations of explosions and locations of event clusters (they might be clearly related to mine locations, but others might indicate unknown explosion sites) can be used. The next step is to define the parameters for each area to get a normal time of day distribution. They can be determined following the steps:

1) - get the time of day distribution of events (program CATSTAT)
   - select a time window of probable explosions
   - select events within time window of probable explosions

2) - get the distribution of magnitudes of events within time window of probable explosions (program BVALUE)
   - select the maximum magnitude

3) - test parameters defined with program EXFILTER for the defined area and adjust the parameters if the time of day distribution is not normal.

For more details, see Ottemöller (1995).
The program uses a parameter file, `EXFILTER.PAR` which MUST be located in the DAT directory.
An example of the parameter file `EXFILTER.PAR`

```
--------------Parameter file for program EXFILTER-----------------
-------------------------------------------------------------------
        This file must follow the following format rules: __________
1. Any number of comment lines
2. Any line with first character # defines the parameters of that area
3. Any line with first character * defines the parameters of exceptions within
   an already defined area. I.e. you can define an area around a volcano,
   and make an exception for that very small  area.
4. In the first line of each parameter set the parameters are:
    Maxdepth: Events with depth above this value are not explosions
    Maxmag  : Events with magnitude above this value are not explosions
    Lhour   : Lower limit of time interval for explosion time
```

```
    Hhour   : Upper limit of time interval for explosion time
    Btime   : Lower limit of yearly interval
    Etime   : Upper limit of yearly interval
    N       : Number of latitude longitude pairs in polygon
5. From the second line the lat long pairs are given
-----------------------------------------------------------------------
 Area------------Maxdepth Maxmag   Lhour   Hhour   Btime   Etime       N

# area 1           100.0     3.6      11      15  197001  200012      12
                   64.0    23.8    66.70   23.80   68.80   20.20   69.80    18.30
                   70.50   20.0    71.20   26.00   70.80   29.50   70.00    27.50
                   68.50   28.50   67.00   29.50   64.30   29.50   64.00    34.00

# area 2           100.0     3.8      15      20  197001  200012       4
                   67.90   17.80   68.80   20.20   66.70   23.80   66.50    21.00

# area 3           100.0     3.5       0       1  197001  200012       4
                   67.90   17.80   68.80   20.20   66.70   23.80   66.50    21.00

# area 4           100.0     4.0       2      17  197001  200012       4
                   68.50   28.50   68.50   36.00   67.00   36.00   67.00    29.50
```

The EXFILTER program searches for probable explosions using a catalog-file as input and marks events that might be explosions with 'P' as Event ID in the output file `exfilter.out`. Example of program run

```
<exfilter>

NUMBER OF AREAS: 55

 FILENAME... ?
june.cat
 ***********************************
 Number of probable explosions found: 90
 Output written in file: exfilter.out
 ***********************************
```

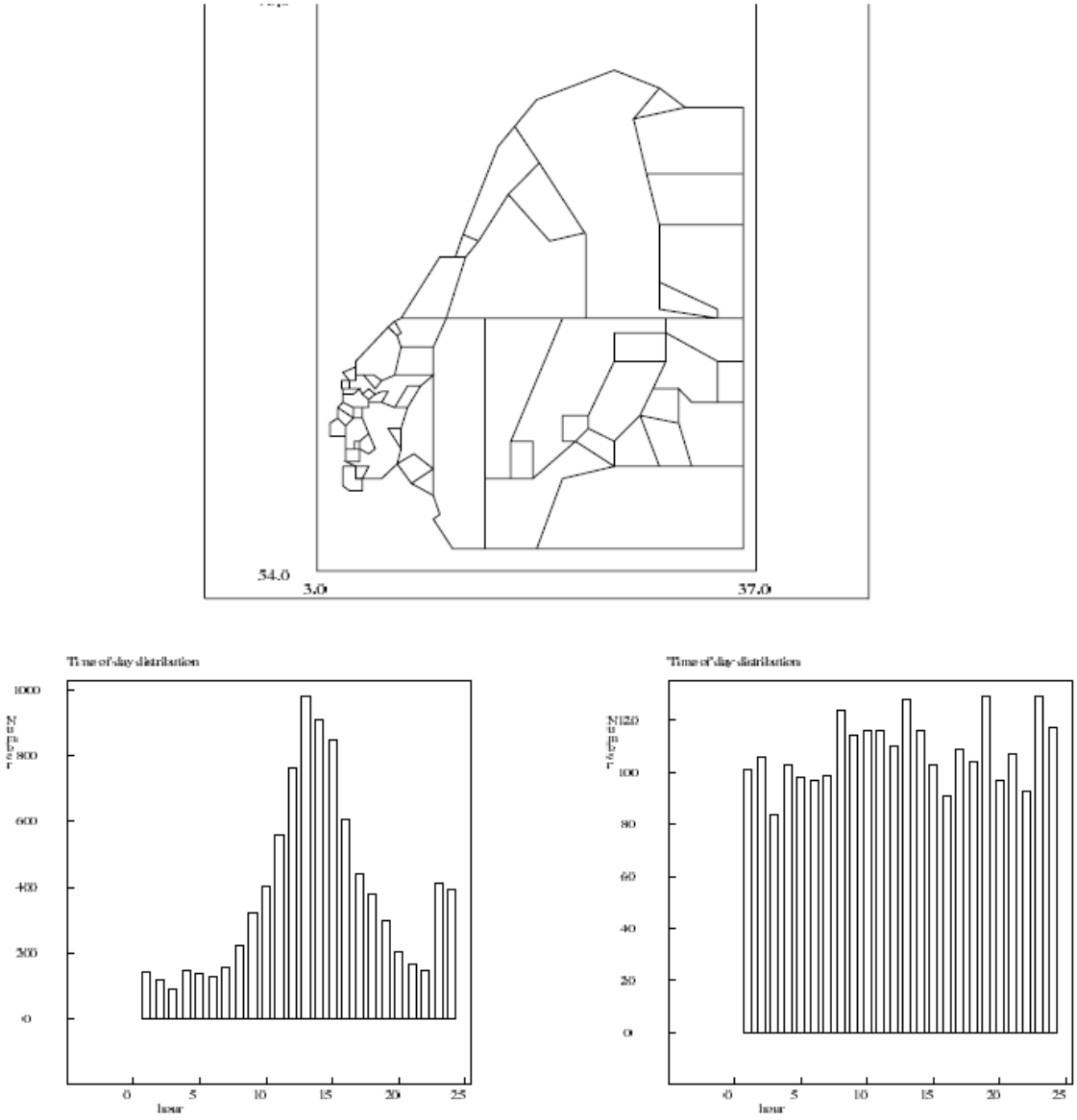


Figure 37.1: Figures that show how the exfilter works for events in Scandinavia:
The top figure shows the filter areas used for Scandinavia. The bottom right figure shows the time of day distribution for a 10 year Scandinavian catalog before filtering (made with CATSTAT) and the figure bottom left shows the distribution after filtering.

Chapter 38

Inversion of travel time data and joint hypocenter determination

38.1 VELEST

Introduction

The program VELEST is used to solve the coupled hypocenter velocity model problem for local earthquakes. It performs a simultaneous inversion for hypocenters and velocity model. The inversion is limited to first arriving phases. A detailed program description is given in the 'VELEST USER'S GUIDE' (Kissling, 1995). A recipe for preparing data and use of the inversion routine is presented in 'Initial reference models in local earthquake tomography' (Kissling et al., 1994). The two documents are available in one Postscript file in the INF directory, the filename is 'velest.ps'. The derived model can be used as an improved model for earthquake location or as a starting model for 3-D inversion. For a fixed velocity model and constant station corrections, VELEST in simultaneous mode performs the Joint-Hypocenter-Determination (JHD).

Before you start please see the two articles Kissling-1988.pdf and Kisslig-1994.pdf in the INF directory.

The original version of VELEST by Kissling is included in the Sun and Linux versions. A version modified to compile VELEST under Windows has been provided by Freddy Aldersons (e-mail: faldersons@earthlink.net). This Windows package is included in the file velest_pc_3.3.zip, which is located in the SUP directory. The files have to be extracted to the PRO directory.

The implementation of VELEST to SEISAN is given by the program VELMENU.

VELMENU provides:

- automatic format conversion to VELEST
- generation of parameter files using the SEISAN system
- execution of VELEST
- conversion back to SEISAN format

After preparing a dataset of local earthquake data, VELMENU can be used to work with the VELEST inversion routine. The first time VELMENU is used, all input files for the inversion with default parameters can be generated. These parameter files then can be changed interactively and the inversion started with VELMENU.

Running VELMENU

The program is started with 'velmenu'. After entering the filename of the earthquake data the menu of VELMENU appears.

Example of program run :

```
velmenu

File name of earthquake data in Nordic Format :
```

```
select.out

VELEST MENU
-----------

1. Create VELEST command file (vele\index{Velest.cmn}st.cmn)
2. Edit/change VELEST command file (velest.cmn)
3. Create station select file (selstat.lis)
4. Edit/change station select file (\index{Selstat.lis}selstat.lis)
5. Create model file
6. Edit/change model file
A. RUN VELEST
B. Edit inversion output file
C. Convert VELEST output to Nordic format and make diff-file
Q. End

Choice ?
```

The complete inversion-process of earthquake data in SEISAN format, including all conversions and preparation of parameter files, can be done with VELMENU. The steps are as follows:

1: Create VELEST command file (`velest.cmn`)
The user is asked for inversion or JHD and the appropriate parameters are set. The file `velest.cmn` is the central VELEST parameter file. To create it, the file of earthquake data is read to determine the parameters that depend on the data. These are the number of events and the center of Cartesian coordinate system, which is simply determined as the average of latitude and longitude of epicenter locations. The remaining parameters are set to default values.

3: Create station select file (`selstat.lis`)
For the inversion, VELEST will use phases from stations with an epicentral distance below a maximum distance only. In addition in VELMENU a selection of stations has to be used, only phases from stations given in the file `selstat.lis` will be used for inversion. When generating the file, the maximum distance between station and hypocenter (parameter 'dmax') is read from `velest.cmn` and the input data are scanned to get a list of stations, which are within the limit to any epicenter. Editing the file, stations can be added or removed. If all stations should be used for inversion, the parameter 'dmax' in the file `velest.cmn` has to be increased.

Example of `selstat.lis`:

```
#
# STATION SELECT FILE FOR PROGRAM VELEST
#
# STATIONS WILL BE USED IN THE VELEST
#      INVERSION PROGRAM
#
# COMMENT LINES START WITH
#
#
KONO
BER
NRAO
...
```

NOTE: The order of the stations is as given by the input data file. VELEST uses the last station as reference station, so you may want to change the order.

5: Create model file
The input model file 'model.inp' is created using the model as given in the '`STATION0.HYP`' file. The '`STATION0.HYP`' file, if available, will be read from the local directory, otherwise from the DAT directory. This might be a reasonable starting model, but of course the model file has to be changed.

A. RUN VELEST

Once the parameter files are created the inversion program can be started. The inversion study requires interactive changing of parameters, which is supported by VELMENU. All input parameter files can be changed from VELMENU. NOTE:, '... please accept the warning: To calculate a Minimum 1-D model a single or even a few VELEST runs are useless, as they normally do not provide any information on the model space!' (Kissling, 1995). The conversions and the inversion programs are started as one process.

Before the inversion routine is started the station locations will be converted from the `STATION0.HYP` file and the earthquake data in Nordic format will be converted to CNV (hypocenters and travel times) format. NOTE: VELEST does not support 5 character station codes, therefore in the conversion to VELEST, only the first 4 characters are used if the station code has 5 characters. In the conversion of the earthquake data only phase readings from stations included in the station selection file will be used. Arrivals with a time residual, given in the Nordic input file, above five seconds are omitted. Only the first arriving phase of P and S respectively are used. The hypocenter location given by the inversion will be determined by first arrivals only. The original data might include more phases like Pg, Sg or Lg. Therefore, to get a comparison of hypocenter locations between the HYP location program and VELEST, a Nordic file including the same data as the CNV file is created and the HYP program run on this file before VELEST is started. The HYP program can be skipped by pressing 'CTRL+C', while it is running.

The results of the inversion will be given in a text file that can be viewed within VELMENU. VELMENU provides an option to convert the VELEST output file with final hypocenter locations in CNV format back to Nordic format and to write a file that shows differences (`velout.dif`) in location and time between the two location routines, HYP and VELEST, based on the same input data.

Example of `velout.dif` :

```
differences: inversion output - SEISAN input
first line input, second line output, third line difference

 1984  8 5 0235 22.7 L  59.449   4.968  0.0  BER  9 1.3 1.9CBER 3.7BBER        1
 1984  8 5  235 22.1 L  59.458   5.140  0.1  BER  9                            1
time:   -0.6 latitude:   0.009 longitude:    0.172 depth:    0.1

 1984  8 6 0406 26.6 L  59.538   5.678  1.9  BER  9 1.8 1.7CBER 3.6BBER        1
 1984  8 6  4 6 26.6 L  59.505   5.655  6.2  BER  9                            1
time:    0.0 latitude:  -0.033 longitude:   -0.023 depth:    4.3
...
```

Files will be overwritten, when VELMENU is started again. To work with different datasets or parameter files it is recommended to work on different directories or to change the filenames, but note that the default filenames (see below) will be used in VELMENU.

Problems: VELEST skips events without phase readings and therefore the number of events read by VELEST will be different from the number given in the `velest.cmn` file. If this is the case VELEST stops with the message STOP: ...end...(VELEST was running with the SINGLE-EVENT-OPTION). Events without phase readings will not be listed in the invers.out file, and should be deleted from the input file.

Joint-Hypocenter-Determination (JHD)

VELEST for fixed velocities and station corrections can be used as a JHD routine. For JHD, VELMENU is used in the same way as described above for inversion. The only difference is that when generating the `velest.cmn` you have to choose JHD. The appropriate file for JHD is then generated. Some parameters in the '`velest.cmn` file are different, compared to the inversion. These are dmax, nsinv and invertratio, see 'VELEST USER'S GUIDE' for details. The output of final hypocenter locations as described above can be converted to Nordic format, but note that the JHD will be based on first arriving phases only.

Example of JHD:

```
File name of earthquake data in Nordic Format :
select.out

VELEST MENU
-----------

1. Create VELEST command file (velest.cmn)
...

Choice ?
1

Inversion or JHD (I / J) ?
j
Origin of cartesian coordinates :  59.394   -5.707
number of events:    61
```

Potential problem: We have seen cases where in JHD mode the depth parameter in the inversion is sensitive to invertratio, which when set to 1. in JHD means that VELEST inverts for station correction in every iteration. VELEST in this case worked better with an invertratio of larger than 1. See VELEST manual for details.

List of files generated by VELMENU / VELEST

`data.cnv`	earthquake data in CNV format, VELEST input, generated by VELMENU
`data.nor`	earthquake data in Nordic format, HYP input, generated by VELMENU
`fin_hyp.cnv`	final hypocenter locations in CNV format, VELEST output
`hyp.out`	earthquake data in Nordic format, HYP output
`hypsum.out`	HYP output file
`input.mod`	input model, VELEST input, generated by VELMENU
`invers.out`	documentation of inversion, VELEST output
`nor1.date`	earthquake data in Nordic format, VELMENU input
`print.out`	HYP output file
`selstat.lis`	selection of stations, generated by VELMENU
`sta_cor.out`	station corrections, VELEST output
`station.sta`	station locations, VELEST input, generated by VELMENU
`velout.dif`	difference file between HYP and VELEST location routine, VELMENU output
`velout.nor`	final hypocentre locations, same as `fin_hyp.cnv`, in Nordic format,

VELMENU output

velest.cmn	VELEST control file, VELEST input, generated by VELMENU

38.2 Grid search to obtain crustal structure

A simple way to estimate a crustal structure from travel time data is to use grid search. A grid search is performed by locating a set of events in a given area using many different crustal models which are varied in a systematic way and finding the model which gives the lowest average RMS for all events. HYP has an option to locate a data set for a large number of different models and then determine which model gives the lowest average RMS for the data set. This might be a useful option, particularly when a sparse data set is available. In order to use this option, an additional input parameter file h_models.par is used (see below for an example). When this file is in the working directory, HYP will switch to multiple model mode SO ONLY HAVE THIS FILE IN WORKING DIRECTORY IF MULTIPLE MODEL MODE IS INTENDED. When using this option, all events must use the same STATIONx.HYP file, otherwise the program fails.

The input MUST be from a single file, NOT from the data base. THE PROGRAM MUST RUN IN NON INTERACTIVE MODE.

Difference with VELEST

VELEST makes an inversion for velocity in a given fixed layer thickness model. This is fast and give a good average velocity since all data is used together. Many different layer thicknesses must be searched (kind of grid search) and it is up to the user how to do this and often a script is made by the user. A disadvantage with VELEST is that only first arrivals can be used and other arrivals must be filtered out. First arrivals are not always easy to identify, however, it is up to the user to do this independently of VELEST. With HYP grid search, all phases are used.

Example of doing grid search

An example is shown using data from Western Norway. A data set of 127 events has been selected (available in test data set under CATALOGS/wn-grid.cat), see Figure 38.1. In order to sample the area uniformly, and not use too much data, only the 18 red events in the center are used for the grid search.

The data is in Nordic2 format so parameter NORDIC FORMAT in SEISAN.DEF must be set to 2.0.

The model used for this data is the standard model used for continental Norway and has been developed with data from S. Norway.

```
Vp [km/s], Depth [km]
6.2          0.0
6.6         12.0
7.1         23.0
8.05        31.0
8.25        50.0
8.5         80.0
```

This model has been used for more than 30 years and there is no strong indication that it is wrong. So it should be interesting to see if it can be improved or if the grid search finds the same model.

The first step is to locate the test data set with the current model. The distance weighting was set to 200-250 km to only sample the area near the events. Then a check is made of which layers are sampled. This is done with program HYP_COUNT_PHASES. The program counts the phases used for location as they appear in the print.out file. The phases counted are local phases as identified by the program and not the phases given as input. Zero output weight phases are not counted. In addition the sum of the weights used for the phases are counted. Only phases for up to 9 layers are counted. The output will give an idea of how many rays sample different layers. The program is started and no questions are asked. It is assumed that the print.out is in current directory. For the above data set of 18 events, the run is

```
hyp_count_phases
Number of phases
   pg   pn2   pn3   pn4   pn5   pn6   pn7   pn8   pn9
  171    10     0    77     0     0     0     0     0
   sg   sn2   sn3   sn4   sn5   sn6   sn7   sn8   sn9
  173    10     0    67     0     0     0     0     0

Sum of phase weights
   pg   pn2   pn3   pn4   pn5   pn6   pn7   pn8   pn9
168.9  10.0   0.0  62.5   0.0   0.0   0.0   0.0   0.0
   sg   sn2   sn3   sn4   sn5   sn6   sn7   sn8   sn9
166.4  10.0   0.0  54.7   0.0   0.0   0.0   0.0   0.0
Output file is hyp_count_phases.out
```

pnx and snx are refracted phases for layer number x where the surface is layer 1 so the first refracted phase is pn2.

It is seen that there are mostly direct Pg and Sg and only a few refracted phases from layer 4 (see HYP program for explanation of phase names) which is Moho. There are no phases from deeper layers since the distance is limited to 250km so there is no reason to grid search for these layers.

Below is the h_model.par used for this test:

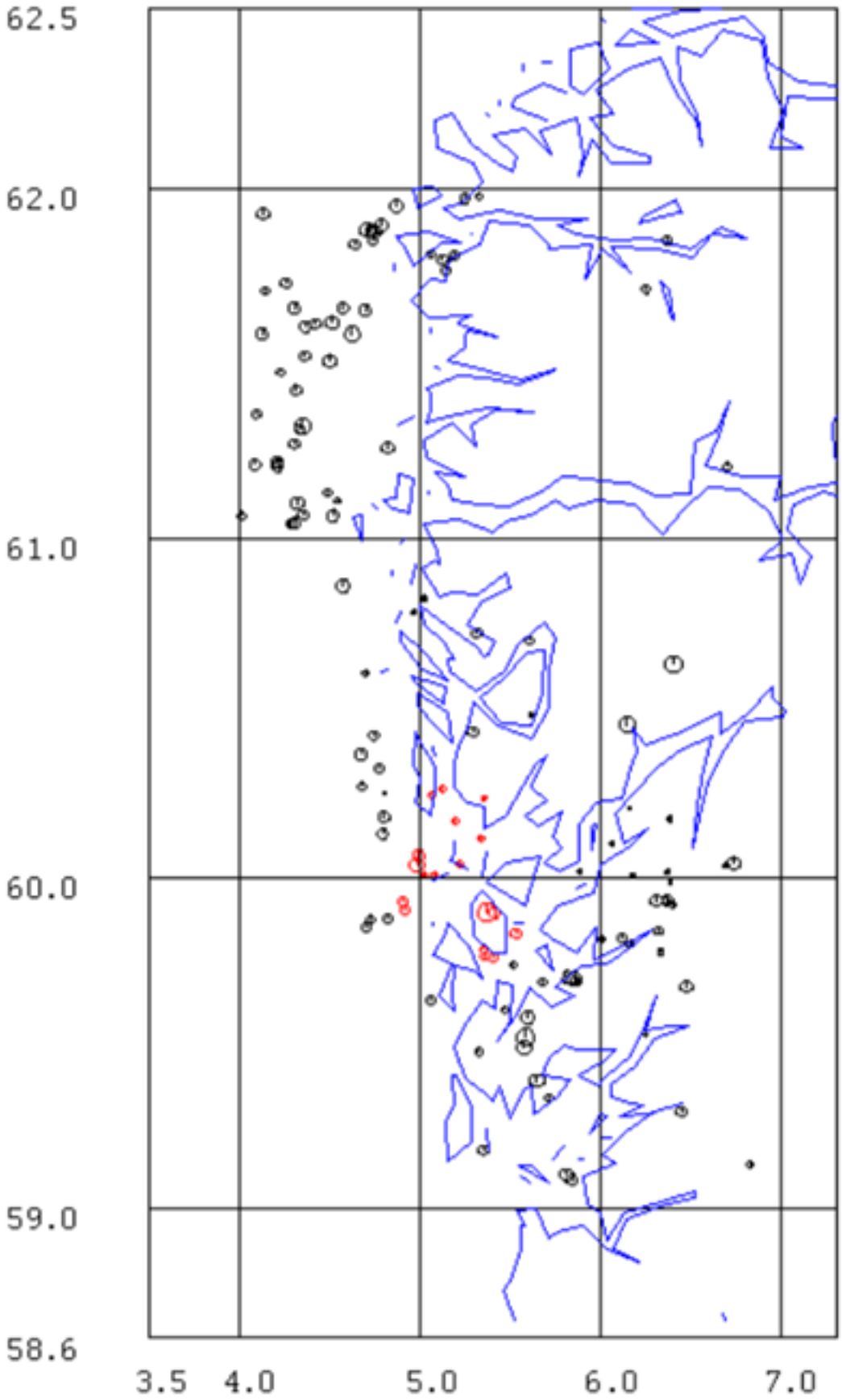


Figure 38.1: The total data set has 127 events (black and red). The red events in the center are used for the grid search.

```
layer # start vp delta vp # delta start h delta h # delta start vs delta vs # delta st. vp/vs del vp/vs
      1      5.6      0.2       4     0.0     1.0       1                                  1.70      0.02
      2      6.4      0.2       3     6.0     2.0       5
      3      6.9      0.2       5    16.0     2.0       6
      4     7.80      0.1       5    28.0     2.0       4
      4     8.25     0.05       1    50.0     1.0       1
```

The first line is info only. Layer # is also only for information. For each layer, there is a start P-velocity, (start vp), increment in velocity (delta vp) and number of increments (# delta). The following inputs are then the same for layer depths. Optionally also the S-velocities can be varied independently of the P-velocity, here the option is left blank to indicate that Vp/Vs is used to get the test S-velocity. The Vp/Vs ratio can also be searched for, if left blank, the ratio is taken from the station file. Vp/Vs and S-velocity cannot be searched for at the same time. There must be an entry for each layer even if no variation is used. An example input file is given in DAT. The parameters for location not set in h_model.par like Lg velocity remain unchanged.

Ideally, the whole possible model space should be searched in order to avoid possible local minima. In practice this will take too long so the model space can first be search with a larger spacing and then refined in a smaller range. In our case a rather fine grid was used and also the Vp/Vs was varied giving a total of 216000 models. There is a check in HYP that models do not overlap. With 18 events this takes about 24h on a standard PC. The model space searched is summarized below:

```
Vp range   Depth range   Vp/Vs range
5.6-6.2                  1.70-1.80
6.4-6.8      6-14
6.9-7.7     16-24
7.8-8.2     28-34
```

It is seen that he model space is searched quite extensively and hopefully including the range of possible models. The average RMS variation for these models (see below) is 0.3 to 1.2s so that many unlikely models are checked.

When HYP starts up, it will print out how many permutations are required so if more than a few thousand, reduce the number of models, of course depending on how many events are used. Using all parameters at the same time will often give too many combinations like searching for

Vp and Vs independently. In any case, it is an advantage to first try with just a few models to get a feeling for how sensitive the data is for model changes.

An output file h models.out is generated, see example below. For each model tested, one output line is given with the RMS and the model. In the example below only the last 5 models are shown. Since many models can have very similar average RMS, the best 30 models are printed at the end. These models are also printed out in the format used in STATION0.HYP.

Example of h_models.out with the 18 events

First is shown some lines from each test, in this case there were 216000. Then follows the best 30 models, both as one line and in format ready for the station file. The average hypocentral depth for the particular model is shown to get an idea of how much the depth depends on the model. Also shown is the range of RMS for all the test models. This gives an idea of the real variation between the models.

```
0.510 1.700 5.60 3.29 0.00 6.40 3.76  6.00 6.90 4.06 16.00 7.80 4.59 28.00 8.25 4.85 50.00  6.93
0.475 1.700 5.60 3.29 0.00 6.40 3.76  6.00 6.90 4.06 16.00 7.80 4.59 30.00 8.25 4.85 50.00  7.50
0.469 1.700 5.60 3.29 0.00 6.40 3.76  6.00 6.90 4.06 16.00 7.80 4.59 32.00 8.25 4.85 50.00  8.33
0.486 1.700 5.60 3.29 0.00 6.40 3.76  6.00 6.90 4.06 16.00 7.80 4.59 34.00 8.25 4.85 50.00  9.14
0.542 1.700 5.60 3.29 0.00 6.40 3.76  6.00 6.90 4.06 16.00 7.90 4.65 28.00 8.25
...
0.584 1.800 6.20 3.44 0.00 6.80 3.78 14.00 7.70 4.28 26.00 8.10 4.50 34.00 8.25 4.58 50.00 12.56
0.639 1.800 6.20 3.44 0.00 6.80 3.78 14.00 7.70 4.28 26.00 8.20 4.56 28.00 8.25 4.58 50.00 10.70
0.619 1.800 6.20 3.44 0.00 6.80 3.78 14.00 7.70 4.28 26.00 8.20 4.56 30.00 8.25 4.58 50.00 10.99
0.605 1.800 6.20 3.44 0.00 6.80 3.78 14.00 7.70 4.28 26.00 8.20 4.56 32.00 8.25 4.58 50.00 11.49
```

```
0.590 1.800 6.20 3.44 0.00 6.80 3.78 14.00 7.70 4.28 26.00 8.20 4.56 34.00 8.25 4.58 50.00 12.13

Minimum and maximum rms 0.337170064 1.21897244

The best models

  rms vp/vs   vp   vs    d   vp   vs     d   vp   vs     d   vp   vs     d   vp   vs     d  av-h
0.337 1.720 5.60 3.26 0.00 6.40 3.72  6.00 6.90 4.01 26.00 7.90 4.59 34.00 8.25 4.80 50.00 14.21
0.337 1.720 5.80 3.37 0.00 6.40 3.72  6.00 6.90 4.01 26.00 7.90 4.59 34.00 8.25 4.80 50.00 14.24
0.338 1.740 6.20 3.56 0.00 6.60 3.79 10.00 6.90 3.97 26.00 8.00 4.60 32.00 8.25 4.74 50.00 11.72
0.338 1.740 6.20 3.56 0.00 6.60 3.79 10.00 6.90 3.97 24.00 8.00 4.60 32.00 8.25 4.74 50.00 11.51
0.338 1.720 5.60 3.26 0.00 6.40 3.72  6.00 6.90 4.01 26.00 8.00 4.65 34.00 8.25 4.80 50.00 13.13
0.338 1.740 6.20 3.56 0.00 6.60 3.79 10.00 7.10 4.08 26.00 8.10 4.66 34.00 8.25 4.74 50.00 11.88
0.338 1.740 6.20 3.56 0.00 6.60 3.79 10.00 6.90 3.97 26.00 8.20 4.71 34.00 8.25 4.74 50.00 11.82
0.338 1.720 5.80 3.37 0.00 6.40 3.72  6.00 6.90 4.01 26.00 8.00 4.65 34.00 8.25 4.80 50.00 13.32
0.338 1.740 6.20 3.56 0.00 6.60 3.79 10.00 7.10 4.08 26.00 8.00 4.60 32.00 8.25 4.74 50.00 11.14
....
0.340 1.720 5.60 3.26 0.00 6.40 3.72  6.00 7.10 4.13 26.00 7.90 4.59 34.00 8.25 4.80 50.00 13.21
0.340 1.740 6.20 3.56 0.00 6.60 3.79 10.00 7.10 4.08 26.00 8.20 4.71 34.00 8.25 4.74 50.00 10.88
0.340 1.720 5.80 3.37 0.00 6.40 3.72  6.00 6.90 4.01 26.00 7.80 4.53 34.00 8.25 4.80 50.00 15.18
0.340 1.720 5.80 3.37 0.00 6.40 3.72  6.00 6.90 4.01 22.00 7.90 4.59 34.00 8.25 4.80 50.00 13.19
0.340 1.720 5.60 3.26 0.00 6.40 3.72  6.00 6.90 4.01 26.00 7.80 4.53 34.00 8.25 4.80 50.00 15.11

vp/vs=  1.720   rms= 0.337
   5.60   0.00   3.26
   6.40   6.00   3.72
   6.90  22.00   4.01
   7.90  34.00   4.59
   8.25  50.00   4.80

vp/vs=  1.720   rms= 0.337
   5.80   0.00   3.37
   6.40  10.00   3.72
   6.90  24.00   4.01
   7.90  34.00   4.59
   8.25  50.00   4.80
```

Evaluating the results

It is seen that for similar or same average RMS, there can be quite a bit of fluctuation in parameters where one parameter plays off another. In this case this is clearly seen in the velocity in first layer and the depth to the first layer so the data cannot distinguish between these models. Even if the models are similar, it is seen that the average hypocentral depths are affected by these small changes since the depth varies between 11 and 15km. So which model to choose? Program GRIDMIN calculates the average model for an RMS-range, below is an example using the above test.

```
gridmin
 rms range to average(r) or
 range determined by % increase in minimum rms(p=default)

 percentage
2
 Input file, def is h_models.out
test5
 Minimum rms is   0.337170064
Number of iterations           216000
```

```
Number of values in rms range     171
RMS range                       0.000   0.344
Vp/Vs    1.74   0.01

      Vp      SD      Vs      SD       H      SD
    6.08    0.20    3.50    0.10    0.00    0.00
    6.54    0.09    3.76    0.03    7.95    2.04
    7.02    0.16    4.04    0.10   24.48    1.93
    7.99    0.12    4.60    0.06   33.12    1.30
    8.25    0.00    4.75    0.04   50.00    0.00

 Averages for 30 best models

Vp/Vs    1.73

      Vp      SD      Vs      SD       H      SD
    5.99    0.25    3.45    0.12    0.00    0.00
    6.51    0.10    3.76    0.03    8.20    2.09
    6.96    0.11    4.02    0.06   25.07    1.44
    7.99    0.12    4.61    0.05   33.47    1.02
    8.25    0.00    4.76    0.03   50.00    0.00

Output file is gridmin.out
```

So here the 171 best models (the 2and H (km) is depth to interface. The standard deviation gives an idea of the variation and uncertainty of the parameters and it is seen that the velocities are quite stable while layer thickness is less so.

In this case 18 events were used. Below is shown a comparison of results if fewer events are used:
Abbreviations: N: number of events, RMS: average rms for best model or maximum
RMS for NS number of models averaged, Vp/Vs: best of average Vp/Vs, Sd: standard deviation
Vp-x: velocity in layer x, dx: depth to layer x, P: test with P-readings only.

```
N  RMS    NS Vp/Vs Sd  Vp-1 Sd Vp-2 sd    d1  sd Vp-2  sd   d3 sd  Vp4  sd   d3 sd
1  0.244     1.76      6.0      6.6      6.0      7.3     16.0     8.0     30.0
   0.260     1.76 0.00 6.0 0.2  6.6 0.0  7.2  1.6 7.3 0.1 17.6 1.5 8.0 0.1 32.0 1.0

2  0.186     1.74      6.2      6.6     14.0      7.3     24.0     7.8     32.0
   0.200 586 1.74      6.0 0.2  6.6 0.0  9.9  2.4 7.2 0.2 22.8 2.8 7.9 0.1 31.4 1.9

8  0.310     1.72      6.0      6.4      8.0      6.9     20.0     8.0     34.0
   0.320 280 1.72 0.01 5.9 0.2  6.4 0.1  7.8  2.3 7.1 0.2 23.4 2.4 7.9 0.1 33.1 1.2

18 0.337     1.72      5.6      6.4      6.0      6.9     26.0     7.9     34.0
   0.345 285 1.74 0.01 6.1 0.2  6.5 0.1  8.1  2.1 7.0 0.1 24.1 2.2 8.0 0.1 33.0 1.3

P  0.231               6.2      6.6     10.0      7.3     24.0     7.9     34.00
   0.240 210           6.2 0.1  6.6 0.0 10.4  2.0 7.1 0.2 24.0 2.4 7.9 0.1 33.0 1.2

Old model    1.74      6.2      6.6     12.0      7.1     23.0     8.1     31.0
New model    1.74      6.1      6.5      8.1      7.0     24.1     8.0     33.0
```

It is seen that all tests find similar models but 8 and 18 events give the most similar result. The last lines show the comparison with new and old model and the largest difference is the depth to the first layer. For the 18 events, using the new model, the average RMS has decreased from 0.374 to 0.335. Using all the 127 events give a similar RMS reduction (0.435 to 0.394s) so the new model also improved the RMS for events

not used for the grid search (except the 18 events), an indication that the model has been improved. The new model reduces the RMS of about 10

Since the readings have been done using the current model, there is a possibility that the readings are biased towards the current model. This is particularly the case for S-readings. A new grid search was done using only P-readings (see Table above) and the results are almost the same so it is conclude that there is not much bias. Note, there is no Vp/Vs search with P only.

Test with synthetic data

In order to test the sensitivity of the data set for different models, the grid search can be done with a test model using the theoretical arrival times for the phases picked but with arrival times

calculated with the test model. Different levels of noise can be added to the theoretical arrival times. The program used for this is TTLOCAl, also described elsewhere in the manual. The model is specified in STATIONx.HYP where x is taken for the first event in event file and station file can be in DAT or local directory. To get theoretical arrival times for data in file data.inp write

ttlocal data.inp 0.5

The 0.5 indicates the level of random noise added to the data. In this case +/-0.25s is added to the P-times and +/-0.25*Vp/Vs to the S-times. Vp/Vs is taken for the station file. The random noise is independent for P and S. All phase types and weights remain the same. Only phases P and S are modelled (P, Pg, Pb and Pn, same for S) so Lg and Rg are not changed. Testing with synthetic data gives an idea of how well the data can resolve a particular model with the given test data.

38.3 NOR2DD

originally by **Brian Baptie**, BGS

This program produces input for the Double Difference Program hypoDD (Waldhauser, 2001; Waldhauser and Ellsworth, 2002) from Nordic and `STATION0.HYP` files. The program also converts back from hypoDD output to Nordic format. The Nordic file name is entered when the program starts.

The program gives the option to use and P and S-phases, or only P or S, which means first arrivals (and not Pg, Pn, etc). When first arrivals only are used, the user can enter minimum distance for which Pn/Sn are valid, and maximum distance where Pg/Sg are expected. This has to be chosen based on the model and observations. For example, one may not want to include Pg when it appears as first arrival at 250 km distance, or one should not include Pn observed on continental crust at 25 km distance.

The user also can enter specific station weights.

The output files created are:

`phase.dat` : phase input data

`station.dat` : station coordinates

hypoDD is available from: `http://geopubs.wr.usgs.gov/open-file/of01-113/`

38.4 hypoDD

This program Waldhauser and Ellsworth (2000) is meant to improve relative locations in clusters of events. Quoting the manual (hypodd.pdf in INF):

"The DD technique (described in detail in Waldhauser and Ellsworth, 2000) takes advantage of the fact that if the hypocentral separation between two earthquakes is small compared to the event-station distance and the scale length of velocity heterogeneity, then the ray paths between the source region and a common station are similar along almost the entire ray path. In this case, the difference in travel times for two events observed at one station can be attributed to the spatial offset between the events with high accuracy."

Thus arrival time differences between stations is used. Data from catalogs or corss correlation can be used, here we will only illustrate the use of catalog data. For details, see the manual. hypoDD is installed in SEISAN and can also be obtained from http://geopubs.wr.usgs.gov/open-file/of01-113/. For simplicity, the program is called hypodd and not hypoDD. To run the program, the steps are:

1: Select a cluster of events.

2: Create an input file to hypodd program ph2dt with SEISAN program NOR2DD. NOR2DD takes a CAT file (like select.out) and makes a file phase.dat (default input file to PH2DT).

3: Created difference times with PH2DT (supplied with hypodd, included in SEISAN).

4: Run HYPODD.

5: Plot the new and original locations with EPIMAP, output is provided in Nordic format. Command is epimap hypodd.map

NOR2DD

The program takes an input CAT file and creates an output file phase.dat (default name) with the arrival times and hypocenter information:

```
# 2015  4 13 15 32 40.6 66.6120  13.3800  15.1  0.7 5.2 9.4 0.6    1
KONS    3.13  1.0 P
KONS    5.94  1.0 S
STOK    7.02  0.5 P
STOK   11.13  1.0 S
MOR8   19.50  1.0 S
FAUS   18.71  0.5 P
FAUS   33.65  1.0 S
STEI   42.45  1.0 S
```

The phases P and S are assumed to be first arrivals, whether Pg or Pn. There are 2 options for selecting phases, either use all phases P and S irrespective of given names so e.g. Pn becomes P or only use phases labeled P and S in input file. It is recommend to use all phases since phases labeled Pn and Pg most likely are first arrivals. Any double entry of a phase will be eliminated by giving the latest arrival phase zero weight. In this way a Pg following a Pn for the same station will be weighted out.

Optionally, phases from given stations can be given a different weight than given in the S-file. This can be used to remove station by giving weight 0 or lowering the weight. The weigh -9 can also be given to indicate that this station must be used in all cases (see hypodd manual).

The program also creates the station file for HYPODD using the STATION0.HYP (in local or DAT directory) with the default name station.dat:

```
 KONS   66.4990   13.1177
 STOK   66.3330   13.0177
 MOR8   66.2852   14.7317
 FAUS   67.3820   15.2877
 STEI   67.9300   15.2420
```

Once the location is made with HYPODD, the output locations can be converted to Nordic format with NOR2DD. It is assumed that the default file hypoDD.loc is used for the original locations and hypoDD.reloc is used for the relocations. The output file with the relocated events is called hypodd.out and the corresponding original locations is hypodd.org. Hypodd.org will usually contain fewer events than the original input in phase.dat since events are eliminated during the relocation process, see later.

Examples:

```
nor2dd
  Convert from Nordic to hypodd (1=enter) or hypodd to Nordic (2)

  Give input Nordic file
swarm.out
  Use any P and S-phase (enter) or only P and S (o)

  Stations and weights  0-1 or -9 to force use, enter to terminate
NBB13 0
```

```
  The input file had          388  events
  Output phases in file phase.dat
  Output of station list in station.dat



nor2dd
  Convert from Nordic to hypodd (1=enter) or hypodd to Nordic (2)
2
  Give input hypodd file, hypoDD.reloc is default (enter)

  Number of events in original file          39
  Number of events in relocated file           24
  Output file of relocated events is hypodd.out
  Output file of corresponding original events is hypodd.org
```

PH2DT

PH2DT find the stations pairs to be used. It has a default parameter file ph2dt.inp. The most important parameters are event separation and maximum distances. Since these parameters also can be set on the HYPODD parameter file, hypodd.inp , the simplest is to leave ph2dt with default parameters. That includes the default phase data file phase.dat and station.dat made with NOR2DD:

```
* ph2dt.inp - input control file for program ph2dt
* Input station file:
station.dat
* Input phase file:
phase.dat
*MINWGHT: min. pick weight allowed [0]
*MAXDIST: max. distance in km between event pair and stations [200]
*MAXSEP: max. hypocentral separation in km [10]
*MAXNGH: max. number of neighbors per event [10]
*MINLNK: min. number of links required to define a neighbor [8]
*MINOBS: min. number of links per pair saved [8]
*MAXOBS: max. number of links per pair saved [20]
*MINWGHT MAXDIST MAXSEP MAXNGH MINLNK MINOBS MAXOBS
   0      200      10      10     8      8     20
```

To run the program, write

```
ph2dt ph2dt.inp
```

HYPODD

The program has a large number of parameters and it can be a bit confusing to adjust for best performance, see manual for details. The most important seem to be the event separation WDCT (see example parameter file below and example runs), weight for P and S-data WTCTP and WTCTS, respectively and cut-off threshold for outliers WRCT. Inversion is normally with conjugate gradients but for a small data set (less than 40-50 events), least squares solution can be used. The parameter file must also be set up for the model used.

Running HYPODD

Hypodd hypodd.inp

For explanation of output, see hypodd manual. The program will, in the SEISAN version, also execute the NOR2DD program to generate, in Nordic format, the files hypodd.out and hypodd.org as describe under NOR2DD. The result can then be plotted immediately.

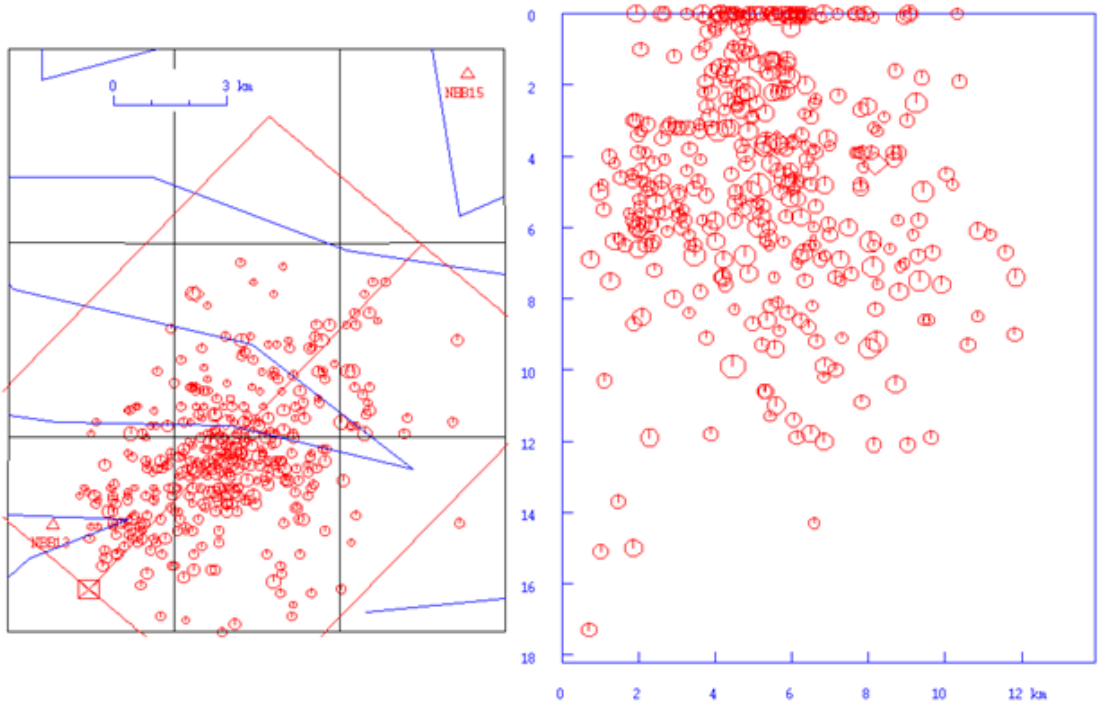


Figure 38.2: Dataset for testing HYPODD. To the left is seen the epicentres and to the right the depth profile taken from SW to NE as outlined on the left figure. There are 388 events.

38.4.1 hypoDD example

We will illustrate the use of HYPODD with an example data set from the Norwegian National Seismic network. The data consist of a swarm of event occurring mostly in 2016. All data and parameter files are available in the test data set under WOR/hypodd. The original data consists of 388 events located in an area of about 10km in diameter, see Figure 38.2.

Despite that two stations (NBB13 and NBB15) are within 5-10 km of the swarm, the epicentre pattern is diffuse. Likewise the depths, where many are at the unlikely depth of zero km. Some testing was done to obtain a best solution in terms of number of events remaining and RMS of travel time residuals, see Figure 38.3. The corresponding parameter file is listed below.

It is seen that the epicenters are now in 3 groups with the southernmost being the most clear. The depths are now much more clustered with the southernmost group the most concentrated. Nearly all zero depth events have been removed or relocated.

Now some of the parameters were then varied, one by one, to see the effect on the results.

Separation distance

One of the more sensitive parameters is the event separation distance (WDCT). For the reference solution, 2 km was used for the 2. set of parameters and 5 for the first set. However with such a small cluster, one could think that 1km would be more reasonable so this was tested for the 2. set of parameters, see Figure 38.2 for the result.

The clustering has not changed much but much less results are obtained. A test was also made with 4km (276 events), however clustering was much less clear. So it seems that the original 2km separation is ok. A test was also made to increase WDCT to 10km in first data set, but results were worse.

Number of iterations

The number of iterations should be enough that the RMS does not decrease anymore.

With fewer iterations, there were more events, but the clustering is less clear. More iterations were also tested, but with no significant difference. In this data set 8+8 iterations seems ok.

Maximum distance

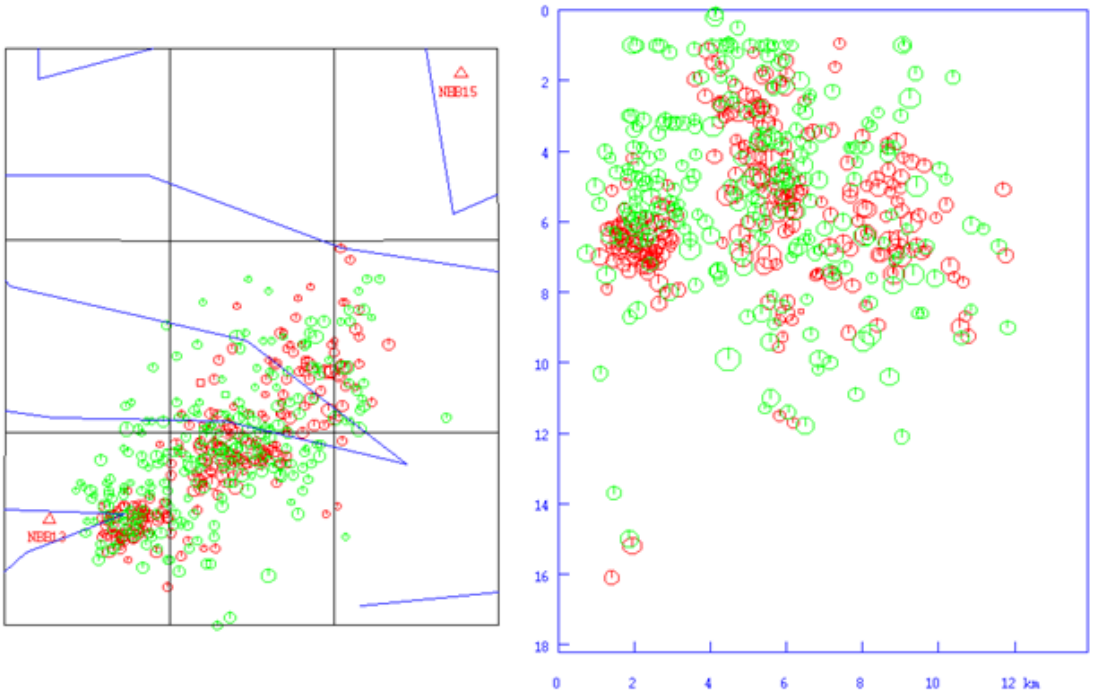


Figure 38.3: Results of the hypodd inversion with best parameters. The number of events have been reduced to 248. The red color indicates the original solutions and the green the hypodd solutions.

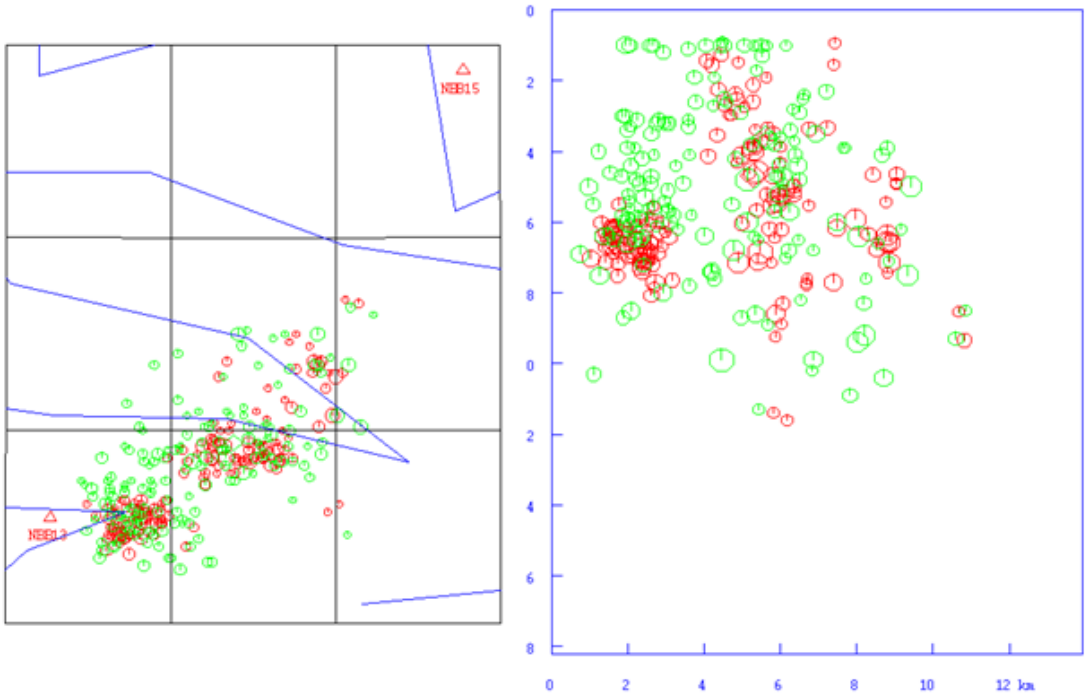


Figure 38.4: Testing with event separation distance of 1 km. There are 158 events.

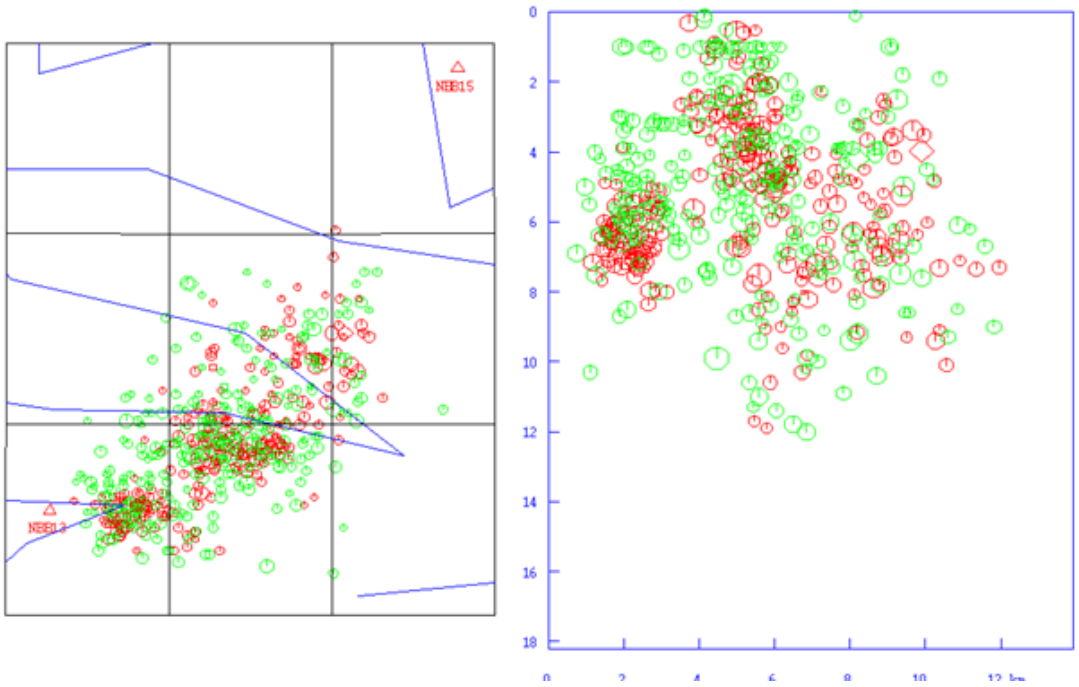


Figure 38.5: The number of iteration has been changed from 8+8 to 4+4. The number of events is 268.

In the standard parameter set the maximum distance it is set to 200km. Considering that far stations might have less clear arrivals than near station, using in shorter distance might improve the results. Testing with 80k max distance is seen in Figure 38.6. Only 4 iterations were needed in the 2. parameter set.

Clearly the clustering is less clear than when using standard parameters so larger distances should be used for this data set.

Importance of nearest station

Station NBB13 is very close to the southern cluster so a test was made weighting out the station (with NOR2DD).

The clustering is now less clear so one near stations can change results significantly. But the results are still better with HYPODD than using standard locations. NBB13 has readings for 292 events out of the original 388. However of the 248 events with the standard parameters, 225 events had station NBB13 so the staion is clearly important for the best solutions.

Other tests: Using only P resulted in fewer events (232) with more scatter, maybe not surprising. The outlier parameter WRCT did not affect the results much provided they were keeps within 'reasonable' limits as in our example.

These tests are mostly valid for the current data set, other data sets might require other parameters. But the test should give an indication of the importance of the different parameters. In many cases there is a trade-off between number of events which can be relocated and the demand for stricter parameters. For a better understanding, read the hypodd manual and paper.

Hypodd.inp file for the best solution.

```
* RELOC.INP:
*--- input file selection
* cross correlation diff times:
*catalog P diff times:
dt.ct
*
* event file:
event.sel
```

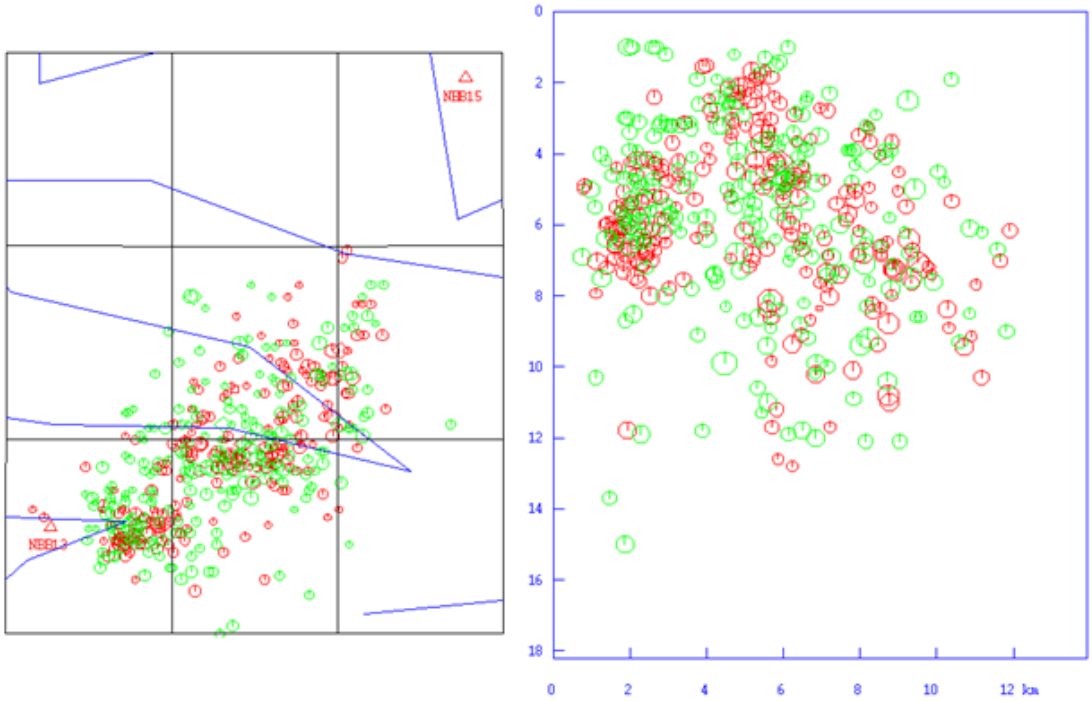


Figure 38.6: Testing with maximum distance of 80 km instead of 200 km. There are 231 events.

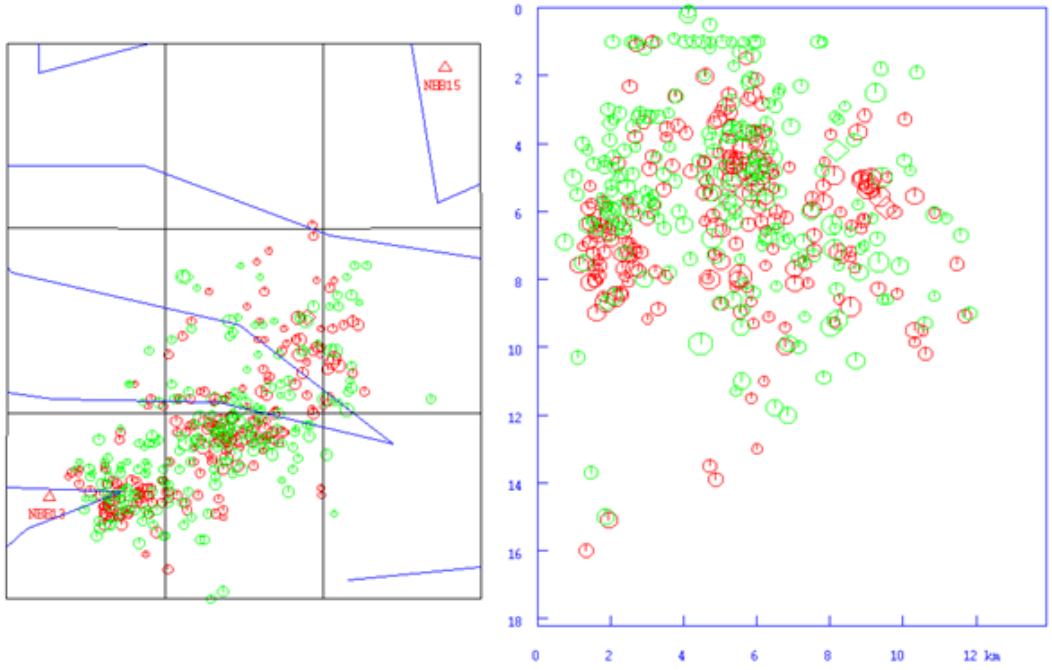


Figure 38.7: Results without using station NBB13. There were 212 events.

```
*
* station file:
station.dat
*
*--- output file selection
* original locations:
hypoDD.loc
* relocations:
hypoDD.reloc
* station information:
hypoDD.sta
* residual information:
hypoDD.res
* source paramater information:
hypoDD.src
*
*--- data type selection:
* IDAT:  0 = synthetics; 1= cross corr; 2= catalog; 3= cross & cat
* IPHA: 1= P; 2= S; 3= P&S
* DIST:max dist [km] between cluster centroid and station
* IDAT   IPHA   DIST
    2     3      200
*
*--- event clustering:
* OBSCC:    min # of obs/pair for crosstime data (0= no clustering)
* OBSCT:    min # of obs/pair for network data (0= no clustering)
* OBSCC  OBSCT
     0     0
*
*--- solution control:
* ISTART:   1 = from single source; 2 = from network sources
* ISOLV: 1 = SVD, 2=lsqr
* NSET:       number of sets of iteration with specifications following
*  ISTART  ISOLV  NSET
    2        2      2
*
*--- data weighting and re-weighting:
* NITER:  last iteration to used the following weights
* WTCCP, WTCCS: weight cross P, S
* WTCTP, WTCTS: weight catalog P, S
* WRCC, WRCT: residual threshold in sec for cross, catalog data
* WDCC, WDCT:   max dist [km] between cross, catalog linked pairs10:49 AM 24/02/2020
* DAMP:     damping (for lsqr only)
*       ---  CROSS DATA -----  ----CATALOG DATA ----
* NITER WTCCP WTCCS WRCC WDCC WTCTP WTCTS WRCT WDCT DAMP
   8    1      -9   -9   -9   1.00   0.5   5     5   20
   8    1      -9   -9   -9   1.00   0.2   2     2   20
*
*--- 1D model:
* NLAY: number of model layers
* RATIO: vp/vs ratio
* TOP: depths of top of layer (km)
* VEL:  layer velocities (km/s)
* NLAY  RATIO
```

```
   6     1.74
* TOP
0.0 12.0 23.0 31.0 50.0 80.0
* VEL
6.2 6.6 7.1 8.05 8.25  8.5
*
*--- event selection:
* CID:  cluster to be relocated (0 = all)
* ID: cuspids of event to be relocated (8 per line)
* CID
    1
* ID
```

38.5 NOR2SIMULPS, NOR2SIMULR

By **Felix Halpaap**, UIB

These programs produce input for the programs simulps and simulr from Nordic and `STATION0.HYP` files. The Nordic file has to be given as argument when running the program, example:

`nor2simulps select.out` `nor2simulr select.out`

The files created are:

`EQKS` : phase input data

`STNS` : station coordinates

38.6 NOR2JHD_PUJOL

By **Brian Baptie**, BGS

This program produces input for Pujol's JHD program (Pujol, 2003) from Nordic and `STATION0.HYP` files. The Nordic file has to be given as argument when running the program, example:

`nor2jhd_pujol select.out`

The files created are: `syn.times` : phase input data

`syn.vel` : velocity model

`stalist.elev` : station list

The inversion tool is available from:

ftp://beagle.ceri.memphis.edu/pub/pujol/JHD

`http://www.orfeus-eu.org/links/softwarelib.htm`

Chapter 39

Analysis of volcanic earthquakes

SEISAN is often used for volcanic monitoring. Many of the standard tools used in SEISAN can also be used for volcanic earthquakes, like epicenter location and magnitude. However, more special tool are also needed and below there is a description how this is done at the British Geological Survey (BGS).

Another description, made by Andrew Lockhart at the USGS, is given in a separate manual (`seisan_volcano.pdf` in INF or at `http://seis.geus.net/software/seisan/seisan_volcano.pdf`). This manual is a mini SEISAN manual detailing the steps under Windows.

Volcano monitoring at BGS

By **Brian Baptie**

Background

An important part of volcanic seismology and the seismic monitoring of active volcanoes is the correct recognition of the different types of seismic event generated by the volcanic activity. The principal event types include, volcano-tectonic events, caused by shear or tensile failure of rocks; long period events, generated by a volumetric source in a liquid; hybrid events; and volcanic tremor.

To be of value for volcanic monitoring, any database of seismic events should include the type or sub-class of individual events. This should allow users to then extract phase and location information over a selected time period for individual event types and calculate hourly and daily rates of event. Simple histogram plots showing the distribution of subclasses over time can be generated with the program VOLCSTAT. The progrm used GMT 6.1.1.

Initialization

The user should create a text file in the DAT directory called `VOLCANO.DEF` (an example is already in the directory). The format of this file will be one line of text (80A) followed by successive lines with the format "i2,1x,6A,1X,40a" for number, sub-class code and description. An example of the file is shown below. Comments are preceded with '!'.

```
Current volcano sub-classes:   ! Comment line 80 characters
1  vt     volcano-tectonic     ! Individual sub-class line
2  hybrid hybrid
3  lp     long-period
4  tremor volcanic tremor
5  rf     rockfall
6  un     unknown
7         QUIT                 ! The last line should contain
                                  this entry
```

Registering volcanic sub-classes

Registration should be carried out as normal in MULPLT. From multi-trace mode enter 'p' to create a new s-file for the event in the database. Answering 'LV' to the prompt for event type marks the event as a local volcanic in the headers. If the `VOLCANO.DEF` file has been set up correctly in the DAT directory, the information on the different sub-classes will be printed to the terminal. Choosing an appropriate number selects the volcanic sub-class. The sub-class code is then entered in the s-file.

Modification of the s-file to incorporate volcanic sub-classes

The volcanic sub-class information is stored in a type 3 line within the s-file, e.g.

```
 VOLC MAIN tremor 3

Columns 2:10  'VOLC MAIN'    : Header identifier
Columns 12:17    a6          : Sub-class flag
Column  80       '3'         : line type identifier
```

This allows the use of a maximum 6-character sub-class identifier, e.g. 'hybrid', which can then be searched for and selected.

VOLCSTAT: Creating histogram plots

The program reads S-files directly from the database, and creates input files as well as a GMT script to produce histogram plots of the distribution of subclasses over time. The user needs to enter database name, start and end time, and the subclasses that are to be plotted. An example of a plot is shown in Figure 39.1. The program supports 1-char subclass names only.

The following output files are created:

`volcstat.batch` - c-shell script to generate Postscript output using GMT
`volcstat_counts.ps` - Postscript output file
`volcstat_counts_<type>.out` - for each event, the Julian date is written out, one file per subclass
`volcstat_daily_<type>.out` - number of events per day, files written for each subclass
`volcstat_counts_total.out` - total event counts for each subclass

RSAM

1-minute RSAM data can be created with WAVETOOL.

Future Extensions:

It is intended that additional parameters can be included in the above structure to included routine measurements of the volcanic earthquakes. For example, signal duration, peak amplitude and mean frequency can be calculated for individual stations and included on additional type 3 lines with a volcanic identifier. Parameters on each channel can then be averaged an inserted on the volcanic header line.

The proposed format for these lines is as follows

```
column      format         description
2:5          a4              'VOLC'    Volcanic identifier
7:10         a4              station
12:15        a4              component
19:20        a2              'PA' field identifier
22:29        g8.3            peak amplitude
31:32        a2              'DU' field identifier
34:41        g8.3            signal duration
43:44        a2              'MF' field identifier
46:53        g8.3            mean frequency
55:56        a2              'SB' field identifier
58:65        g8.3            signal bandwidth
66:79                        blank
80           a1              '3' line type identifier.

For example

 VOLC MAIN tremor                                                          3
 VOLC KTK1 S  Z   PA .152E 06  DU    1.325 MF    2.472                    3
 VOLC KTK1 S  N   PA .167E 06  DU    1.997 MF    2.067                    3
 VOLC KTK1 S  E   PA .141E 06  DU    1.543 MF    1.998                    3
```

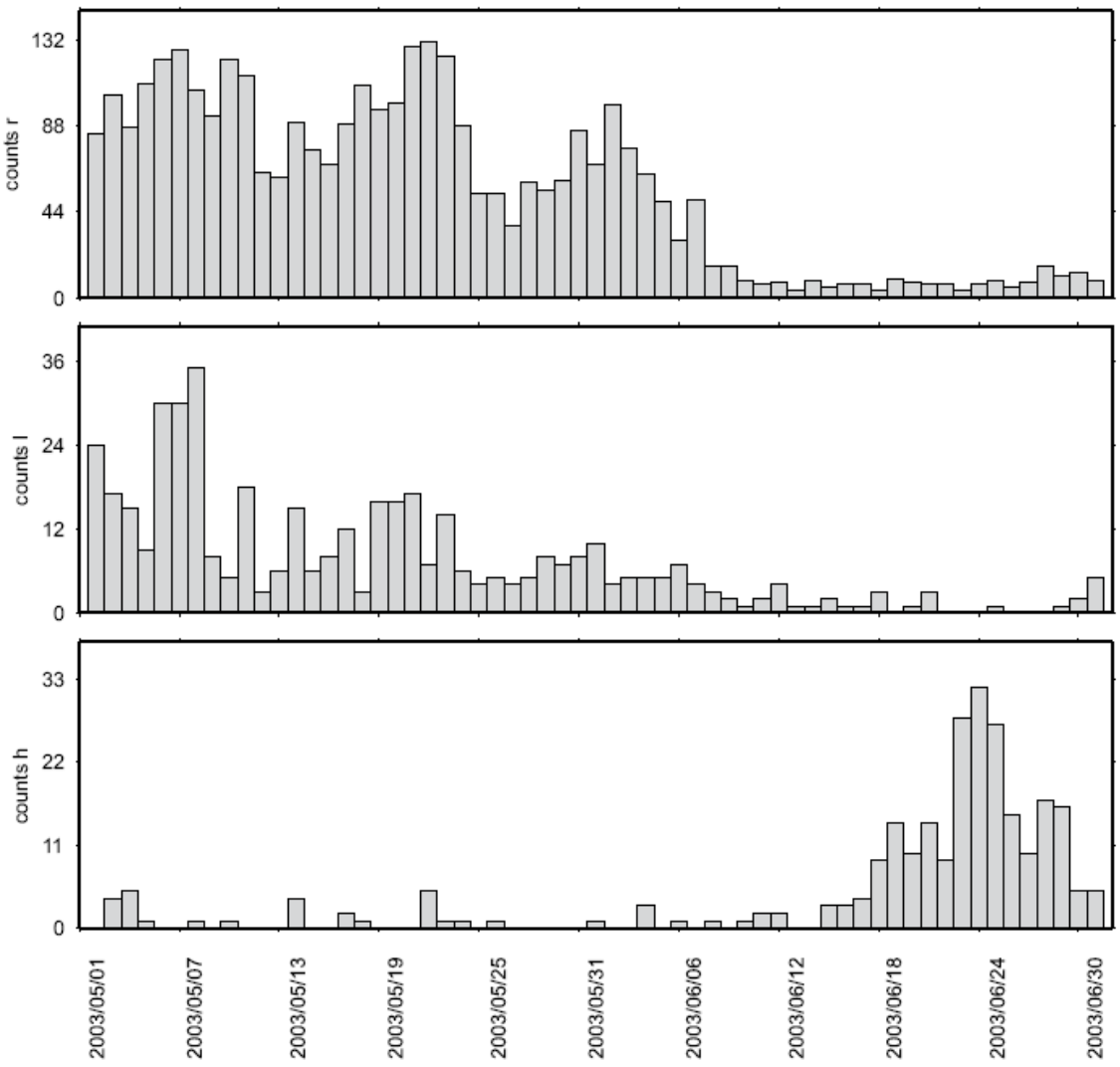


Figure 39.1: Bar diagrams showing distribution of events of different subclasses over time.

This method of inclusion of volcanic parameters should allow for future flexibility such as incorporation of an additional parameter fields in columns 66 to 79. Also the use of type 3 lines means that existing software, such as the update program, are unaffected by these lines.

Chapter 40

FK Analysis

The FK routines were provided by **Tormod Kværna** from NORSAR and implemented into SEISAN by **Andrius Pacesa**.

Some basics

The FK-analysis, more strictly slowness analysis, is a standard tool in seismic array processing. It is used to find the apparent velocity and back azimuth of an incoming wavefront. Apparent velocity can be used to identify the type of wave (P, S, Lg and etc.) and the approximate distance to the source can be determined for teleseimic events. Utilizing azimuth and distance to the source, one can define the approximate location of the signal source.

A description of frequency-wavenumber analysis - f̈-k analysis¨ may be found in Capon (1969). This method has been further developed to include wide-band analysis and maximum-likelihood estimation techniques - see Kvaerna and Doornbos (1986).

The principle of slowness analysis is beamforming in the frequency domain for a number of different slowness values and calculating the power for each beam. The beam power will be a maximum in case the slowness of the beam coincides with the slowness of the wavefront crossing an array. So the beam having the maximum power will indicate the slowness of the incoming signal.

Running the program

The FK program can be started directly with command fk or from MULPLT. The program expects that the file waveform.out with the seismic traces as input data, is available in the current directory. If the program is invoked directly, this file has to be created before using mulplt, selecting a window and creating the 'waveform.out' file.

In general it is more useful, to start the FK program from MULPLT since the input file needs to be created by mulplt. The result of the fk analysis can be saved to the S-file.

The steps are:

- start MULPLT
- select channels and a time window
- use option fk to start FK program (this option creates file 'waveform.out' and starts FK program), accept maximum or pick value with mouse

  The options in FK are:

  R-Redo: Repeat fk analysis with different parameters
  M-Mouse: 'm' or mouse click to pick values different from maximum
  S-Save and quit: save picked value to file and quit
  Q-Quit: quit

- use option 'save and quit' to save your result, so that it can be used by MULPLT
- back in MULPLT: pick phase on the first trace used, to store back azimuth and apparent velocity in the S-file

- in case of teleseismic events, the apparent velocity can be used for location, the fk analysis has to be done on the P phase

Note: The FK program only works by default with station file 'STATION0.HYP'. If coordinates are in e.g. STATIONt.HYP, the user will be asked to specify another station file letter, in this case 't'.

Example

Input:

```
 Enter lower frequency,<ENTER> for default value 1 Hz

 Enter higher frequency,<ENTER> for default value 5 Hz

 Enter max slowness, <ENTER> for default value 0.4 s/km

 Enter No of grid points, <ENTER> for default value 51

 Do you want to plot level numbers, N/Y, <ENTER>=Y

 It will take some time ...
 APPARENT VELOCITY  10.26   AZIMUTH          140
 NORM. POWER MAX     0.99   POWER MAX IN dB  72.44
 MAX X SLOWNESS      0.06   MAX Y SLOWNESS   -0.07
 LOW FREQUENCY       0.94   HIGH FREQUENCY    5.00
 QUALITY (1=best, 4=worst)  1
  Plot file is fk.eps
```

Example of output file fk.out:

```
 DATE, TIME AND WINDOW LENGTH     99 256  9 13 12  0 33.843     7.62
 APPARENT VELOCITY  10.26   AZIMUTH          140
 NORM. POWER MAX     0.99   POWER MAX IN dB  72.44
 MAX X SLOWNESS      0.06   MAX Y SLOWNESS   -0.07
 LOW FREQUENCY       0.94   HIGH FREQUENCY    5.00
 QUALITY (1=best, 4=worst)  1
 VALUES TO SAVE
 APPARENT VELOCITY  10.26   AZIMUTH          140
 Station     Long      Lat         Elev   Xcoord    Ycoord Zcoord
 NRA0 S  Z   11.54150  60.73533    300         0         0    300
 NRA1 S  Z   11.54233  60.73650    291        45       129    291
 NRA2 S  Z   11.54333  60.73433    311        99      -111    311
 NRD4 S  Z   11.56333  60.72717    379      1186      -907    379
 NRD5 S  Z   11.54750  60.72217    348       326     -1463    348
 NRD6 S  Z   11.52883  60.72334    352      -688     -1334    352
 NRD7 S  Z   11.51617  60.73017    337     -1377      -574    337
 NRD8 S  Z   11.51667  60.73900    301     -1349       407    301
 XSLOW   YSLOW  POWER
  0.40    0.40   0.05
  0.38    0.40   0.05
  0.37    0.40   0.05
  0.35    0.40   0.05
...
```

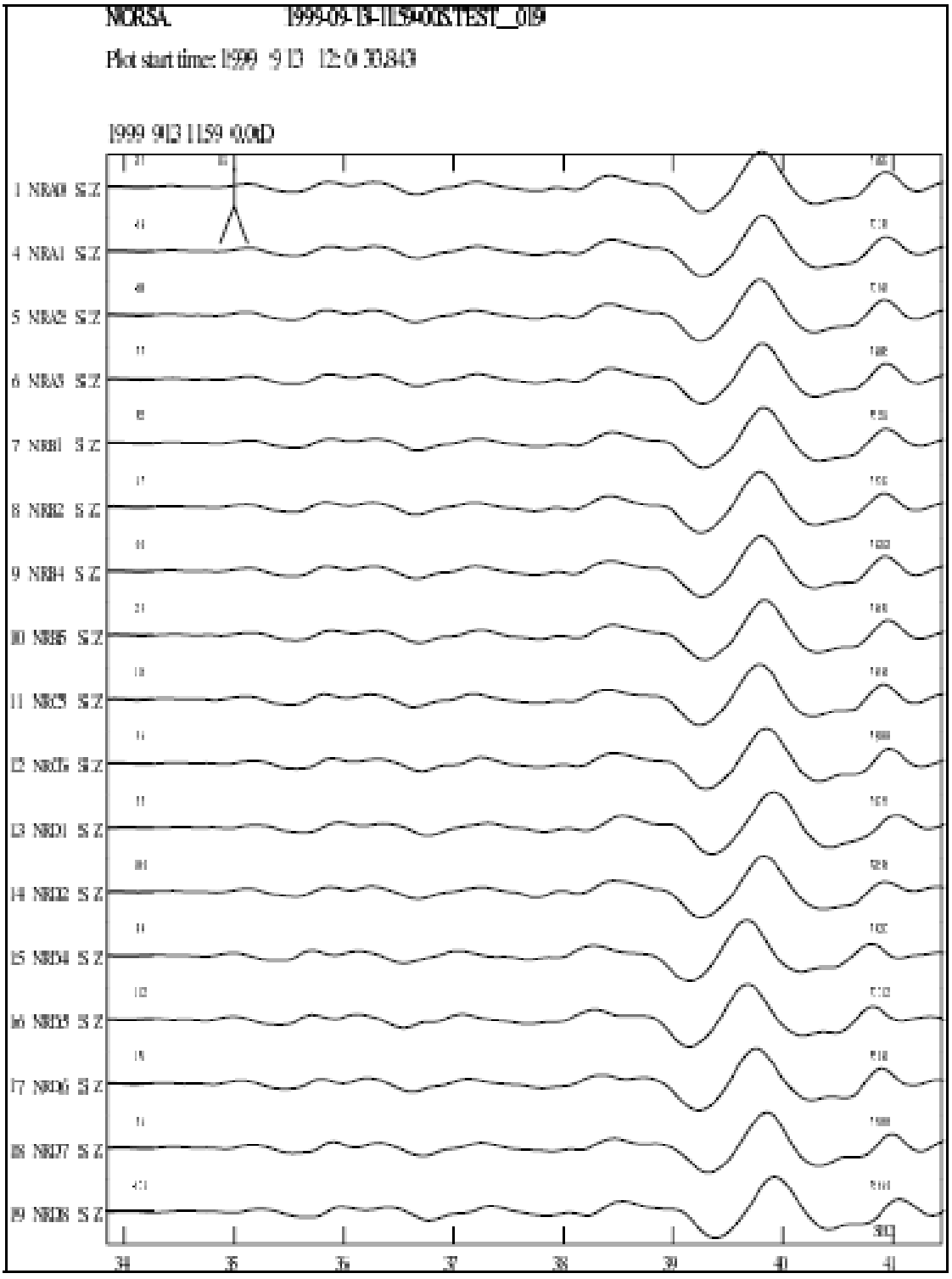


Figure 40.1: The FK program can be started from MULPLT. The traces shown were selected and used as input to the FK program. The result of the FK analysis is shown in Figure 40.2. The event shown here is part of the testdata set.

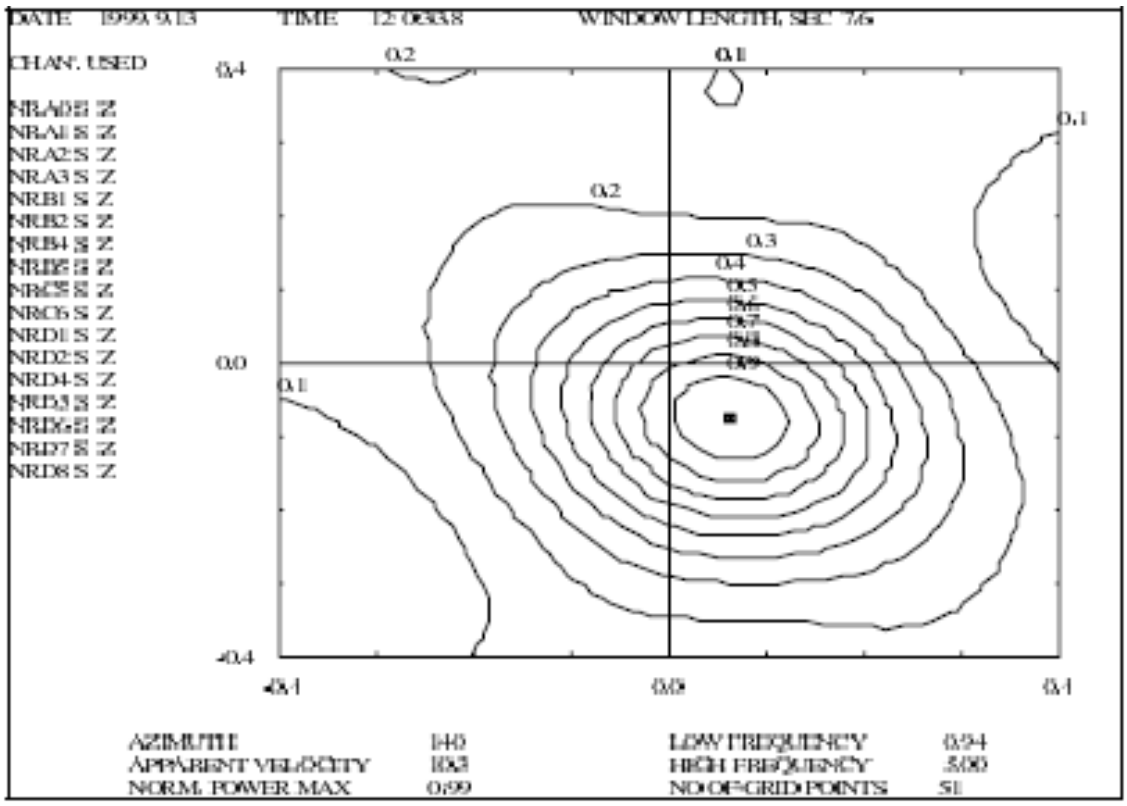


Figure 40.2: Output from the FK program. Contours and values are the normalized maximum power.

Chapter 41

Instrument response

In SEISAN the instrument response can be stored as pairs of frequency, amplitude and phase or as poles and zeros. The formats that can be used include GSE2, SEISAN, SAC and SEED. The SEISAN, SAC and GSE response formats are described in Appendix C. For a detailed description of the GSE format, the reader is referred to GSETT-3 (1997). The program RESP creates response files in SEISAN and GSE format. SEED format response files can be extracted from a SEED volume.

The response information gives the gain of a channel in counts/m and to get the correct ground displacement, the count values must be divided by the response values. In the current SEISAN system, only the programs MULPLT, WAVETOOL and SPEC use the response information when doing spectral analysis, generating Wood Anderson or ground motion traces. The programs will look first in the CAL (or alternative) directory for a valid response file and if not found there use the header information in the waveform file. A message will be given if the file header information is used.

If waveform files are generated on the SEISAN system from raw field station files or other input files without response information, the conversion programs (e.g. QNXSEI from a SEISLOG QNX system) will look in the CAL (or alternative) directory to find the response information to include with the Seisan waveform file. The response will be only put into the SEISAN waveform file, if the response is stored in SEISAN format. The response files are generated with RESP, see below and Appendix C.

The instrument response can be defined for each channel of digital data in either SEISAN, GSE, SAC or SEED (ascii version) response format.There are three places in the system where it can be stored. Often the instrument response is part of each channel header in the digital waveform file in SEISAN waveform format (see the Appendix B for format description). However, the instrument response is often not available at the moment the data arrives, or it is later discovered that the response given in the waveform file is wrong. There is therefore by default a directory CAL that contains one response file for each channel and for each date from which it is valid. Since the filenames contain the date from which a change in the response was made and the channel code and component code, a directory listing of CAL will give the history in chronological order of the response of a given channel. This is the most common way to use the response information in SEISAN. Response information can also be kept in any other directory specifiedwith the environmental variable LOCAL_CAL.The variable must beset with the full path to the directory e.g. /home/seismo/WOR/test/,or on PC, C:\seismo\new\cal\. On Sun it can be set in the SEISAN.csh file and under Windows by using the setting of environmental variables Control panel/system/advances/environmental variables. The variable can also be set from the keyboard (Linux/Sun: 'setenv LOCAL_CAL=directory', PC, 'set LOCAL_CAL=directory'. This is a useful option when testing response files. The file name of the SEISAN, GSE and SAC response files defines the start time of which they are valid. If the response of a station is changed, a new response file must be made with a new time stamp.
The SEED response files are named e.g.`RESP.IU.TRIS.10.BHZ` (see rdseed below), where the network, station, location and channel codes are part of the filename. When SEISAN looks for a SEED response files it will search for afile with a name matching the network, station, location and channel code of the data in memory.

The file name of the SEISAN, GSE and SAC response files defines the start time of which they are valid. If the response of a station is changed, a new response file must be made with a new time stamp.

The SEED response files are named e.g. `RESP.IU.TRIS.10.BHZ` (see rdseed below), where the network, station, location and channel codes are part of the filename. When SEISAN looks for a SEED response files it will search for a file with a name matching the network, station, location and channel code of the data in memory.
The RESP filename must match the waveform data, so if the waveform data does not include network code and location code, then filename must be e.g.: `RESP..BER..BHZ`
So if the location code in the waveform data is '–' then the RESP filename must include the '–', like e.g.: `RESP.NO.BER.--.BHZ`
And if the location code in the waveform data is empty ' ' then the RESP filename must be like:`RESP.DK.BSD..BHZ`

The SEED response files can include multiple changes of response and must have valid Start and End dates for the time of the data that are processed. For the current response the "End date" must be set to "No Ending Time".

The SEED response files are not alwasy written in the same way since the position of the columns of numbers can be different depending of the source of the RESP file. The most common format is created by RDSEED and this was the only format accepted by SEISAN until version 11.0. From version 11.0, SEISAN can also read other versions of RESP files.

SEISAN will use this scheme until it finds a valid response file:

1: Look for SEED response file in the current working directory.

2: Look for SEED response file in the CAL directory.

3: Look for a SEISAN, GSE or SAC response file in the current working directory.

4: SEISAN will check if the environmental variable LOCAL_CAL is set, if it is, SEISAN will look for a SEISAN, GSE or SAC response file in the LOCAL_CAL directory.

5: Look for a SEISAN, GSE or SAC response file in the CAL directory.

6: Look for a SEISAN, GSE or SAC response file in the CAL/STAT_ directory.

In the very unlikely case where a selected data window covers two different response files, the response file belonging to the first part of the data is used. In the very unlikely case where a selected data window covers two different response files, the response file belonging to the first part of the data is used.

The RESP program (section 41) can be used to generate the response files. The filenames for the response files are STATTCOMP.YYYY-MM-DD-hhmm_FOR where STATT is station code, COMP is component, YYYY is year, MM is month, DD is day, hh is hour, mm is minute and FOR is the format indicator which can be SEI or GSE. If FOR is not given, the format is SEISAN. An example is BER__S__Z.1999-05-05-1244.. You should take a backup of the response files before you run the program (see chapter 3). The response files can be located in CAL, or, if many files are available optionally also in a subdirectory structure. This optional structure simply consist of a subdirectory for each station and the subdirectory name must have 5 letters so base BER would have the name BER__. The system automatically locates the response files whether all are in CAL or in the subdirectory structure.

The response file can store the response in different ways:

1 SEISAN format:

   a Parameters used for calculating the response: Generator constant, filters etc. In addition, the response (amplitude and phase) at 30 frequencies is listed. In this case the response is calculated from the parameters.

   b Incomplete set of parameters or no parameters and the response at 30 frequencies. In this case the response is calculated by interpolation of the 30 values.

   c Poles and zeros: No discrete values are given and the response is calculated directly from the poles and zeros. The number of poles and zeros in the SEISAN format is limited.

2 GSE CAL2 format:

a Poles and zeros, number is unlimited, the response is directly calculated from the poles and zeros.

b Pairs of frequency amplitude phase, number of pairs is unlimited, the response is calculated by interpolation.

3 SEED

– Poles and zeros (only Transfer function type A (Laplace Transform (Rad/sec)), number of poles and zeros are unlimited, the response is directlycalculated from the poles and zeros. Only reads SEED response in ASCII format as written out by rdseed, not dataless SEED volumes. The command to extract the files is`rdseed −R −f seed_filename`. Standard filename such as`RESP.IU.TRIS.10.BHZ` are understood. Files are read from CAL directory. Note that if e.g. the horizontal channels are rotated the `−R` flag by `rdseed` will not provide this information.

4 SAC format:SEISAN can use SAC PAZ files as created by rdseed. The files have to be names in the standard SEISAN way, but have to end on `_SAC`.

NOTE: When rotating signals, it is in SEISAN assumed that the response is the same on all 3 channels. !!!! Response files can be plotted from MULPLT showing the actual response information that is used with a given trace. Response files can also be plotted directly with program PRESP, see below. All or a subset of the response files can be printed out in a table with program PR_RESP. The program must be executed from the directory with the response files. Make a listing (file filenr.lis) of files to print out with DIRF and run the program. It will produce an output file ready for printing. A response file can be plotted with the program PRESP. The program is started with commandpresp filename, where filename is the response file name. If no file name is given, the program asks for a filename, number or filenr.lis to plot all response files in the filenr.lsi file.. If a DIRF has been made and the list of files in filenr.lis is available, a response file can then be selected with a number. The program produces a PostScript output file with name `presp.eps`.

41.1 Create instrument response files, RESP

Introduction

The purpose of this program is to (1) Make Seisan or GSE2 response files, (2) Provide the engineer maintaining seismic instrumentation with a practical tool for calculating and checking response functions of the most common elements of a seismic system. The program can calculate response functions of velocity transducers, accelerometers, filters and amplifiers, input poles and zeros or tabulated values and multiply the combinations together to get complete system response functions. The program produces a table with the response function and a simple graphical expression of the response curve. For the purpose of checking measured values, a file with these values can be used as input and will be plotted together with the theoretical values. The program can calculate, acceleration, velocity or displacement response. Program PR_ RESP can make a table of many response files.

The instrument response

The seismic recording system can consist of seismic sensor, analog-digital converter, amplifier and filters. For a detailed discussion the user is referred to Scherbaum (1996). The combined response can be given in the frequency domain as frequency response function or in the Laplace domain as transfer function. The frequency response is given in pairs of frequency amplitude phase (FAP), while the transfer function is given as poles and zeros (PAZ). The combined frequency response is obtained through multiplication of the response from the individual components, while the transfer function is obtained by combing the PAZ from the components. Amplifiers and accelerometers are specified simply by a constant gain. Filters are assumed to be Butterworth. RESP can be used to write finite impulse response (FIR) coefficients (Scherbaum, 1996) that are used as anti-alias filters in most modern digitizers if GSE is used as output format. SEISAN has no capability to read the FIR filters or to correct for them. However, the FIR filters are part of a full description of the instrument response and should be at least included for information if possible.

The electrodynamic seismometer is assumed to have the following velocity frequency response:

$$T(\omega) = \frac{\omega^2}{\omega_0^2 - \omega^2 + i2\omega\omega_0 h}$$

which corresponds to the transfer function:

$$T(s) = \frac{-s^2}{\omega_0^2 + s^2 + 2s\omega_0 h}$$

where $s = i\omega$, ω is the angular frequency $2\pi f$ in Hz, ω_0 the resonance frequency of the seismometer, $i = \sqrt{-1}$ and h the damping (normally around 0.7).

NOTE: In the equation for the frequency response, the sign "+ 2*i*h.." was "-" before March 2000, so old parameter files may have to be regenerated. The sign depends on the definition of the signs in the Fourier transform and therefore may be different in different text books. It may even be wrong although it looks right, if a wrong Ansatz is done. Due to the wrong sign, the FAP values in the SEISAN response files were wrong, however the programs use the constants given in the files and the correct response is generated. If you have the instrument constants in your old response files and not just FAP, the old response files can be used.

The transformation from displacement to velocity or back is done by multiplying with i*..

In addition to or instead of using the equation above, values can also be entered as discrete values or as poles and zeros.

The SEISAN response function is calculated for 60 frequencies between 0.01 and 100 Hz and the steps between the frequencies are approximately logarithmic. The response function is normalised at 1.0 Hz (see Table 1) and the gain at 1.0 Hz is given separately.

NOTE: ALL UNITS ARE IN METERS, SECONDS OR G (9.8ms-2)

NOTE: It seems that although the GSE format is clearly defined, there has been different interpretations. This has also led to changes in SEISAN since the GSE response was introduced with SEISAN. For more details, see Appendix C.

Which format to use

SEISAN, since version 7.1, supports the GSE2 calibration format in addition to the SEISAN response file format. We recommend that you use the GSE2 format, since it presents one of the most widely used calibration formats. Storage of the response in terms of PAZ is recommended over FAP, since the PAZ representation describes the continuous transfer function. You may continue using existing SEISAN response files and add new files in GSE2 format, or replace the old SEISAN response files with new GSE2 files.

How to run the program

The program has quite a few options, which easily may lead to confusion. Before you start you should know which format you want to use (GSE2 or SEISAN) and whether you want to describe the response in terms of FAP or PAZ. The recommended choice is to use GSE2 and PAZ.

Type RESP to start the program. You will then get a series of questions as indicated below in upper case letters. All input is format free. A sample run is shown below.

CHOSE OUTPUT FORMAT: 0: NO OUTPUT FILE
1: SEISAN FAP
2: SEISAN PAZ
3: GSE2 FAP
4: GSE2 PAZ

Answer with 0-4, options 1-4 will create respective response files in selected format, option 0 will only calculate and show the response on the screen. SEISAN PAZ can only be used if number of poles and number of zeros are less than 38. If more are input, a table will be generated automatically in FAP format. A format with poles and zeros MUST BE USED if a mechnical displacment sensor is selectedor an accelerometer is selected which does not have first character A in component name (see later).

TYPE OF SENSOR: 1: NONE
2: SEISMOMETER
3: ACCELEROMETER 4: MECHANICAL DISPLACEMENT SEISMOMETER

Answer with 1, 2, 3 or 4. Number 1 is used when only calculation of filters or amplifiers are desired, 2 is a standard velocity transduceri, 3 a standard accelerometer and 4 is a mechnical diplacement sensor (normally a digitized record of a paper seismogram). If a seismic sensor is used, you will get additional questions on the constants of the sensor. If a seismometer is chosen, the following questions must be answered:

SEISMOMETER NATURAL PERIOD ?

This is measured in seconds. For most short period systems the value would be 1.0 second.

SEISMOMETER DAMPING RATIO ?

The damping ratio should ideally be 0.7. This depends on the damping resistance.

For both the electrodynamic seismometer and accelerometer, the following question is given:

SENSOR LOADED GENERATOR CONSTANT (V/M/S OR V/G) ?

This is the generator constant of the sensor in terms of volt per unit of of ground motion (meter/second or g). It is important to note that this is the loaded constant, which means the effective output of the sensor taking into account amplifier input and damping resistances.

For the mechanical sensor, the question is

SEISMOGRAPH GAIN in TIMES GAIN (M/M) ?

which is simply the mechnical gain.

Now comes questions about amplifier, filter and recording unit.

RECORDING MEDIA GAIN (COUNT/V OR M/V) ?

If you have a recording media, the gain can be given here, otherwise just enter 1.0

If the output format is GSE, the response is always calculated in displacement units, while for SEISAN output and seismometer or accelerometer, the following options appear:

TYPE OF RESPONSE: 1: DISPLACEMENT
2: VELOCITY
3: ACCELERATION

Normally for a seismometer, one wants to calculate the displacement response and for an accelerometer, the acceleration response. However it might sometimes be interesting to look at e.g. the velocity response for a seismometer (after all, the seismometer is normally a velocity transducer !!). Enter the appropriate number.

AMPLIFIER GAIN (DB) ?

This is the amplifier gain in dB. Since this question is only asked once, this gain must include gain of all units except the recorder (asked below). This could e.g. include gain of the VCO system.

NUMBER OF FILTERS (0-10), RETURN FOR NONE ?

Up to 10 filters can be specified. If you answer 0, no filters are used and no more questions on filters will appear. Otherwise one line of input must be given for each filter as follows:

FREQUENCY AND NUMBER OF POLES FOR EACH FILTER,
POLES NEGATIVE FOR HIGH PASS

Each line requires two numbers, the corner frequency of the filter and the number of poles. A high pass filter is given by letting number of poles be negative. It is not always easy to know whether a filter is e.g. one 2 pole or two 1 pole filters, the user needs to experiment with this.

FILE NAME FOR FILE WITH POLES AND ZEROS, RETURN FOR NO FILE

Here a file with poles and zeros can be entered. If seismometer constants have been chosen above, the values calculated with poles and zeros are multiplied with the values previously calculated. The free format file contains:

1. line: NP: Number of poles, NZ: Number of zeros, Norm: Normalization constant
Following NP lines contain one pair each of real and imaginary poles
Following NZ lines contain one pair each of real and imaginary zeros

NOTE: The unit of frequency is radian/s so if in Hz, multiply with 2π and normalization constant in $radian = (normalizationconstantinHz)2\pi^{(numberofpoles-numberofzeroes)}$.

The next 2 options are only shown if the output file is selected to be FAP:

FILE NAME FOR TABULATED VALUES, RETURN FOR NO FILE

Here a file with tabulated values are entered. If seismometer constants or poles and zeros have been chosen above, the tabulated values will be interpolated and multiplied with the values previously calculated for from above. The free format file contains:

1. line: N: Number of tabulated values, Norm: Normalization constant
Following N lines contain one each frequancy, amplitude and phase(deg)

GIVE FILE NAME FOR MEASURED VALUES, RETURN FOR NONE

Give file name for measured values. In most cases you have none so just make a return. The format of the input file is as follows:

frequency, amplitude, phase
frequency, amplitude, phase
etc.

e.g.

0.2,0.7,200
0.7,0.8,100
10.0,0.1,33

The file has no blank lines and can contain up to 60 data sets. It is important to note that the amplitude values should be NORMALIZED at 1.0 Hz.

Now there is no more input to the response parameters, and the output is:

GAIN FACTOR AT 1.0 HZ: 12345.6

This is the gain of the system at 1.0 Hz and is also the value for normalizing the response curve, that is, all calculated values are divided by this number. There is no unit for gain of an amplifier and for displacement response using a seismometer and drum recording. If the recording is digital, the unit would be counts/meter and for a velocity response counts/meter/second etc. If a file with poles and zeros is used without any other information, the normalization constant must have the unit of count/m, similar for the tabulated input.

Further output is given in a file called resp.out, see Table 1 for an example.

The response curves (amplitude and phase) are now printed/plotted on the screen. First comes the amplitude response (amplitude in db versus log frequency). By pushing return, the phase response is shown (phase shift (deg) versus log frequency). After the plots, the SEISAN calibration file can optionally be made, follow instructions, see example below. The response file MUST be calculated for the displacement response, and all calculation in SEISAN assume that response is calculated in counts/m.

After the SEISAN response file is made, the current parameters will be displayed and one or several can be changed without entering all again. Like if the gain has changed at a certain date, only change date and gain. This feature (new in SEISAN7.2) has been put in to be able to quickly make many similar response files, like when all files have to be put in for a network.

Comments to data for response files

Station and channel codes

It is important that the station and channel codes are made exactly as they appear in the waveform files. If not, SEISAN is not able to identify the channel.

Date

The date given here corresponds to the date from which the calibration information is valid. The SEISAN system will always look for the most recent calibration file relative to the date of the earthquake.

Latitude, longitude and elevation

These data are for information only, it is not used anywhere in SEISAN, so it does not have to be entered, however there is room for it in the SEISAN waveform file headers.

Comment

No information used by the system.

Plot

After the response file has been written out, a plot is made with PRESP of the file. There will also be a plotfile, `presp.eps`, which can be sent to the printer. The response file can store the response in different ways:

1. Parameters used for calculating the response: Generator constant, filters etc. In addition, the response (amplitude and phase) at 30 frequencies are listed. In this case the response is calculated from the parameters.

2. Incomplete set of parameters or no parameters and the response at 30 frequencies. In this case the response is calculated by interpolation of the 30 values.

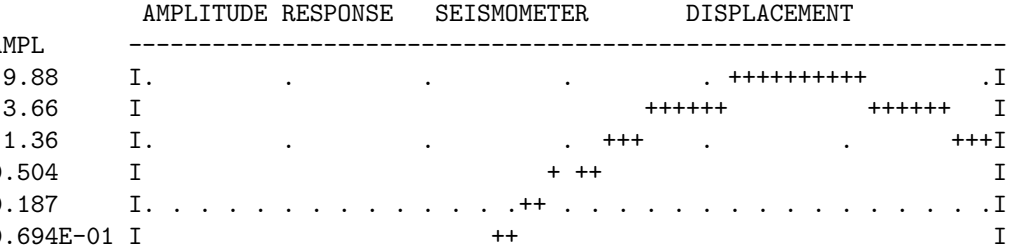
3. Poles and zeros: No discrete values are given and the response is calculated directly from the poles and zeros.

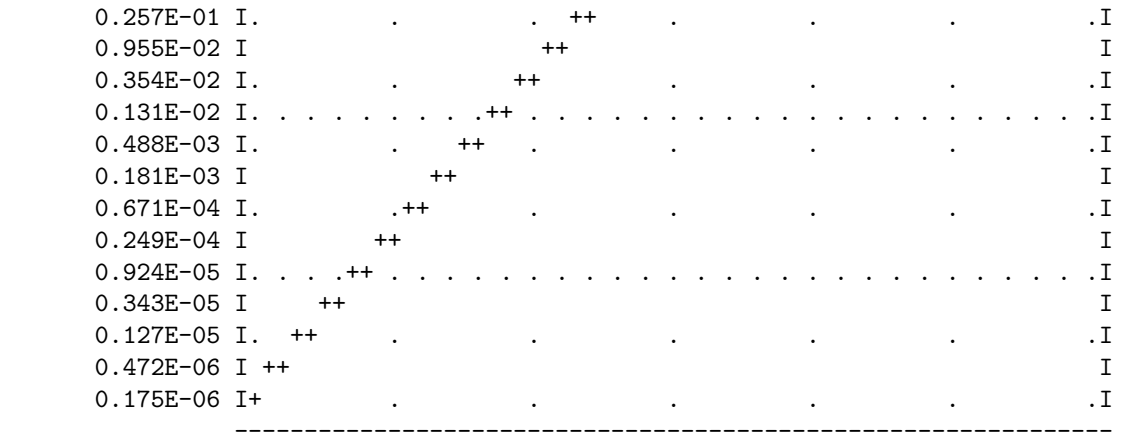
See also Appendix B for the SEISAN waveform file format and section 5.2.2.

IMPORTANT: PUT RESPONSE FILE IN CAL DIRECTORY OR ONE OF ITS STATION SUBDIRECTORIES. Response files can also be in working directory but this is not advisable except for testing.

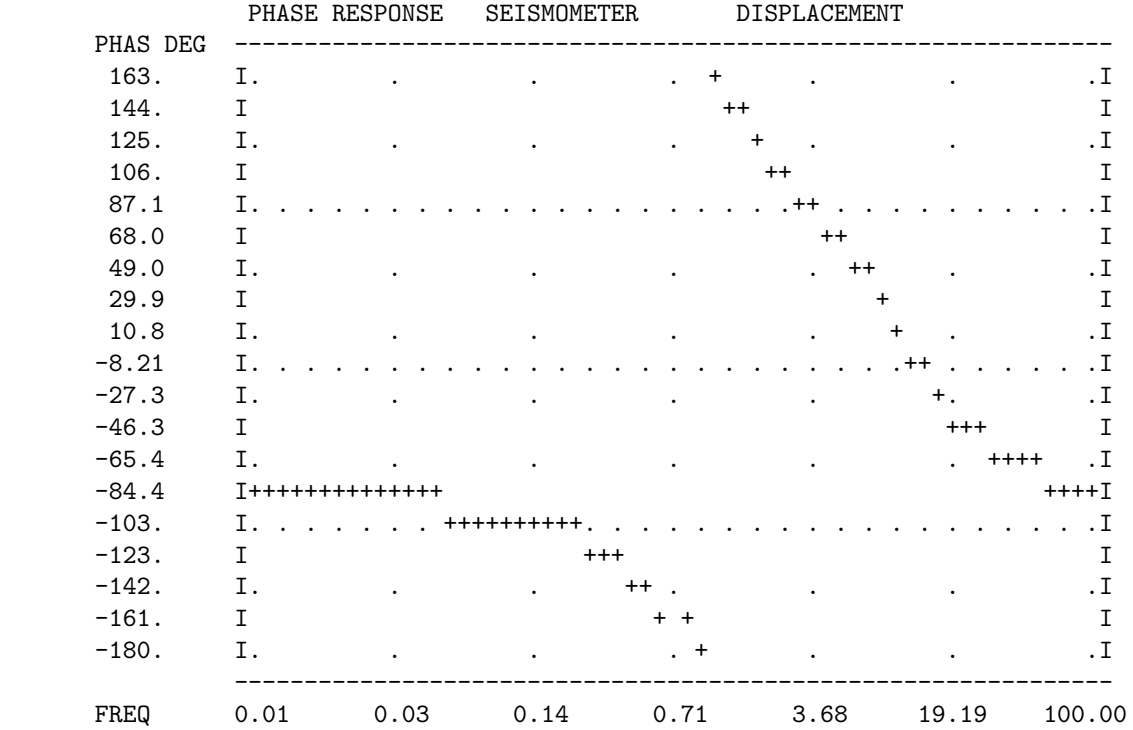
Example of running the program:

```
oxygen-(larso)23: resp

  RESP - PROGRAM TO CREATE RESPONSE FILES IN SEISAN
         OR GSE FORMAT. THE RESPONSE CAN BE CREATED
         AS POLES AND ZEROS (PAZ) OR FREQUENCY
         AMPLITUDE AND PHASE (FAP). THE SAME
         TRANSFER FUNCTION AND FILTERS ARE USED
         IN BOTH CASES.

  CHOSE OUTPUT FORMAT: 0: NO OUTPUT FILE
                       1: SEISAN FAP
                       2: SEISAN PAZ
                       3: GSE2 FAP
                       4: GSE2 PAZ
4
  TYPE OF SENSOR:       1: NONE
                        2: SEISMOMETER
                        3: ACCELEROMETER
2
  SEISMOMETER NATURAL PERIOD ?
1
  SEISMOMETER DAMPING RATIO ?
.7
  SENSOR LOADED GENERATOR CONSTANT (V/M/S OR V/G) ?
300
  RECORDING MEDIA GAIN (COUNT/V OR M/V) ?
2048
  AMPLIFIER GAIN (DB) ?
40
  NUMBER OF FILTERS (0-10), RETURN FOR NONE ?
1
  FREQUENCY AND NUMBER OF POLES FOR EACH FILTER,
  POLES NEGATIVE FOR HIGH PASS
10 2
  FILE NAME FOR FILE WITH POLES AND ZEROS, RETURN FOR NO FILE

  FILE NAME FOR MEASURED VALUES, RETURN FOR NO FILE
```






```
 GAIN FACTOR AT 1 HZ: 0.276E+09     RETURN FOR PHASE RESPONSE
```




```
 GSE RESPONSE FILE (Y/N=default)?y
 Enter station code. e.g. BERGE, max 5 chars
TEST
  Enter component (4 chars) e.g. SH Z
  First character is type, should be one of the following:
  E, S, H, B, M, L, U
  Second character is instrument code, should be one of the following:
  H, L, G, M, N
  Third character is not used, leave blank
  Last character is orientation, must be Z,N or E
S  Z
 Enter date as YYYYMMDDHHMMSS, at least up to the day  (e.g. 19880123):20000101
 Latitude (Up to 4 decimal places and - for south), return for none:
 Longitude (Up to 4 decimal places and - for west), return for none:
```

```
Enter elevation in meters (integer), return for none:
Enter comments, one line. e.g. amp type, sensor type return for none

Response file name is: TEST_S__Z.2000-01-01-0000_GSE


 RESPONSE CURVE IS IN FILE resp.out
```

Problem: The response file naming has not changed according to the SEED convention so location and network code cannot be entered using RESP, however they can be entered manually in response file (see response file format). This menas that e.g. SHZ must be entered as SH Z since only 3 of the 4 character are used. For older data in SEISAN format, all 4 characters can be used.

Examples of response files is given in Appendix C.

41.2 Examples of main response files from seismometers and accelerometer

Example of a Güralp DM 24 digitizer with CMG-40-1 (1 Hz)

Digitizer:

The sensitivity of the digitizer is given to $3.197 \mu V/count$. The SEISAN gain is in counts/V so

SEISAN recording media gain =1000000/3.197 = 312793 count/V

Sensor:

Sensitivity is 2 X 1001 V/m/s =2002 V/m/s

Making response file with parameters

For calculating with parameters, it is assumed that the free period is 1.0 s and damping is 0.7. Using the resp program answering as follows

Output format: 0 Only testing
Type of sensor: 1 It is a seismometer
Seismometer period: 1.0
Seismometer damping: 0.7
Generator constant: 2002
Recording media gain: 312793
Amplifier gain: 0 No amplifier
Number of filters: enter No filter
File with poles and zeroes: enter We use parameters now
File with tabulated values: enter
File with measured values enter

Then the plot below comes up

Making response file with poles and zeros

The poles and zeroes velocity response in units of Hz is given as

Poles
-0.707 0.707
-0.707 -0.707
-62.4 135.4
-62.4 -135.4
-350.0 0.0
-75.0 0.0

Zeros
0.0 0.0
0.0 0.0

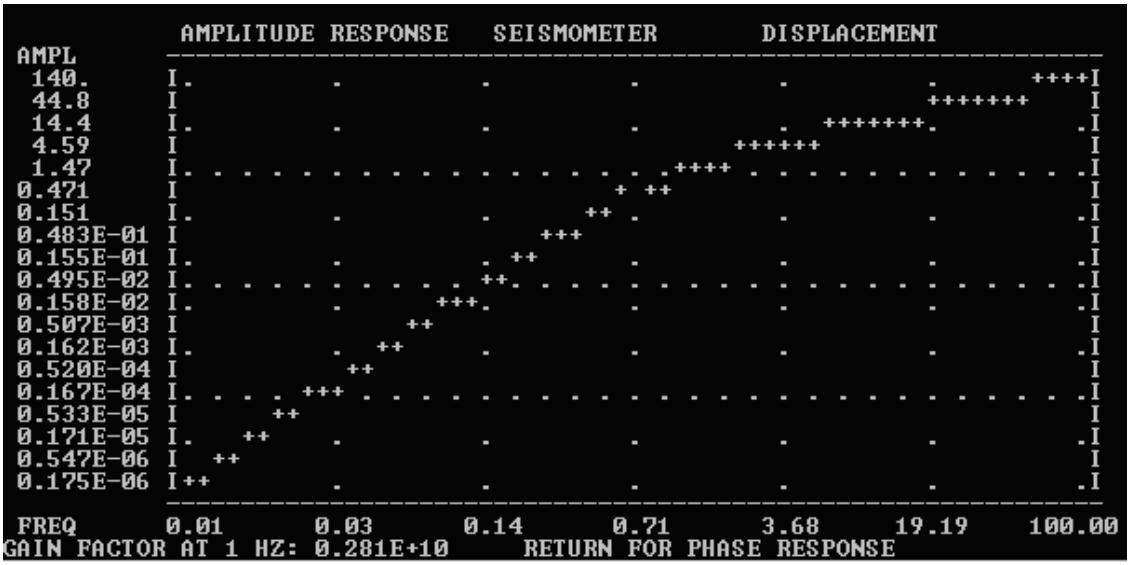


Figure 41.1: Making response file with parameters.

SEISAN units are radians/sec so poles and zero values are multiplied by 2π.
The normalization constant is given as 585.810^6. To convert to radian is done as follows
Normalization constant in radian $= 585.810^6(2\pi)^{(numberofpoles-numberofzeroes)} = 585.810^6(2\pi)^4 = 9.1210^{11}$.
SEISAN also uses displacement so one zero is added. The values are then
Poles
-4.442 4.442
-4.442 -4.442
-392.0 850.7
-392.0 -850.7
-2199.0 0.0
-475.0 0.0
Zeros
0.0 0.0
0.0 0.0
0.0 0.0
To get total constant (gain and normalization constant), we multiply by sensor gain and digitizer gain
Total normalization constant $= 9.1210^{11}x2002x312793 = 5.7110^{20}$
A SEISAN input file is then made
6 3 5.71e20 6 poles, 3 zeros and total gain constant
-4.442 4.442
-4.442 -4.442
-392.0 850.7
-392.0 -850.7
-2199.0 0.0
-475.0 0.0
0.0 0.0
0.0 0.0
0.0 0.0
The resp program now makes the SEISAN response file with this input as follows
Output format: 0 Only testing
Type of sensor: 0 Sensor response is in poles and zero file
Recording media gain: 1 Gain has been put into total gain constant
Amplifier gain: 0 No amplifier

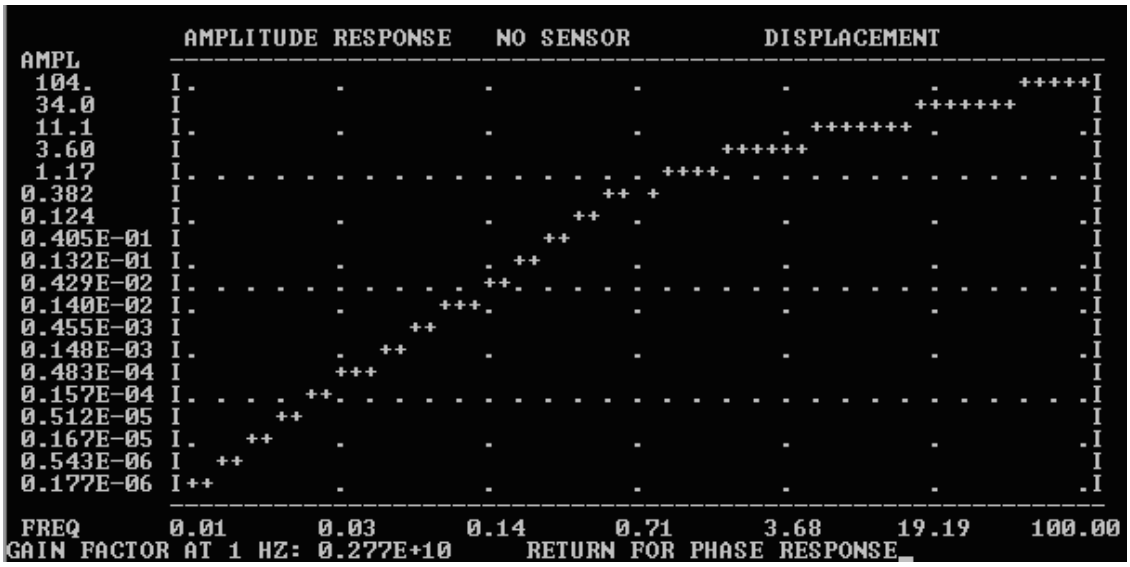


Figure 41.2: Making response file with poles and zeros.

Number of filters: enter No filter
File with poles and zeroes: `resp.inp` File with poles and zeros, can be any name
File with tabulated values: enter
File with measured values enter

Then the plot below comes up

It is seen that the two ways of making the response file gives almost the same result, however using poles and zeroes is the most accurate, particularly for active sensors. In both cases no consideration was made for antialias filters which normally can be disregarded if a modern sharp filter.

Example of a Gurlp DM 24 digitizer with CMG-5T accelerometer

The digitizer is the same as before

Using parameter format, SEISAN currently requires the component name to start with A. According to international standards, the component code for an accelerometer should be something like ENZ so a parameter format cannot be used if international coes are used and poles and zeroes must be used.

For the CMG-5T, the only information about the sensor is the sensitivity of 1V which is is equivalent to 0.970 m/s2 or 1.03 V/ms-2. In SEISAN parameter format this should be converted to V/g so sensitivity is then

9.81 (ms-2/g)/0.97(ms-2/V) = 10.1 V/g

Parameter format

The input is:

Output format: 1 parameter format
Type of sensor: 3 It is an accelerometer
Generator constant: 10.1
Recording media gain: 312793
Amplifier gain: 0 No amplifier
Number of filters: enter No filter
File with poles and zeroes: enter We use parameters now
File with tabulated values: enter
File with measured values enter

The plot below comes up

A response file can now be made with e.g. A Z as component code.

Poles and zeros

The displacement response for an accelerometer consists of 2 zeros and normalizarion constant of 1. The total gain constant is then

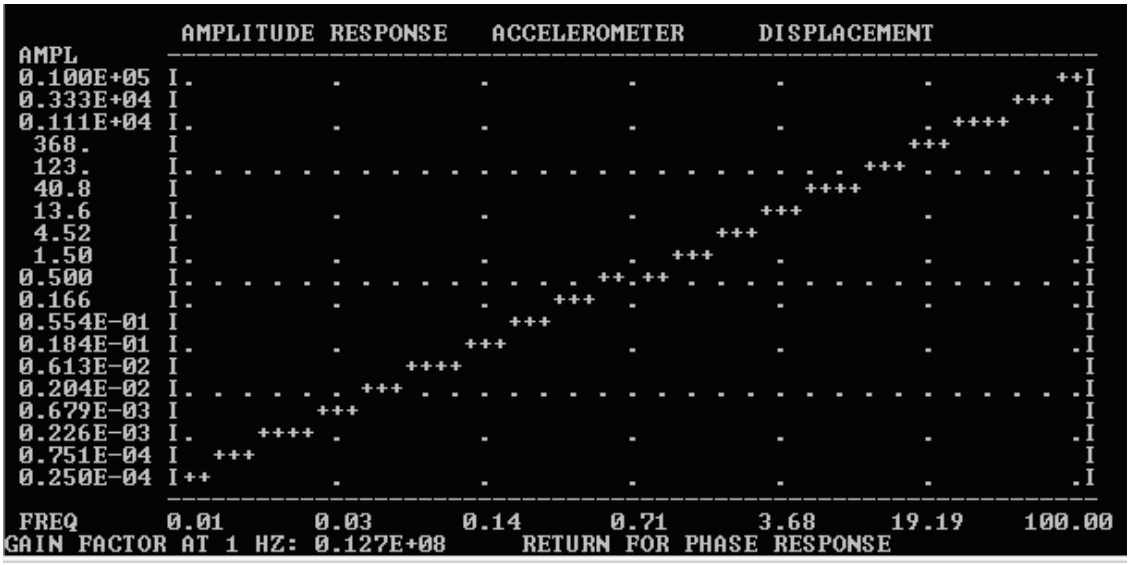


Figure 41.3: Making response file for an accelerometer woth parameters.

312793 x 1.03 = 322000
The generator constant is in V/ms-2 since the two zeros transform from acceleration to displacement.
So the input file e.g. resp.txt with poles and zeros is
0 2 322000
0 0
0 0
The manual input is
Output format: 2 PAZ in SEISAN format

Type of sensor: 1 It is give input resp file

Generator constant: 1.0 Given in resp input file

Recording media gain: 1.0 Given in resp input file

Amplifier gain: 0 No amplifier

Number of filters: enter No filter

File with poles and zeroes: resp.txt Use resp.txt input file

File with tabulated values: enter

File with measured values enter
The rest is the same
The response file would then be

```
TEST EN Z100   0  0  0  0  0  0.000                                          P

     0    2 0.3220E+06  0.000      0.000      0.000      0.000
```

Making a response file for a particular station

For a particular station, chose output format SEISAN PAZ or GSE2 PAZ and later answering yes to question of making the SEISAN response file (see SEISAN manual ??????????????). If e.g. the station has

station code TEST and component name S Z, the a response file valid from January 1, 2007 will have the name `TEST_S__Z.2007-01-00-0000_SEI`. In case of a SEISAN poles and zero file, the content is:

```
TEST S  Z107   0  1  0  0  0  0.000                                              P

     6    3 0.5710E+21 -4.442      4.442     -4.442     -4.442     -392.0
  850.7     -392.0     -850.7     -2199.      0.000     -475.0      0.000
  0.000      0.000      0.000      0.000      0.000      0.000
```

So the file could have been made without using resp.
Table 1 Example of `resp.out`:

```
SENSOR TYPE: SEISMOMETER       RESPONSE: DISPLACEMENT
SEISMOMETER PERIOD=    1.00000
GENERATOR CONSTANT=    300.000
DAMPING RATIO     =   0.700000
AMPLIFIER GAIN(DB)=    40.0000
RECORDING GAIN=        2048.00
FILTER CONSTANTS
F= 10.00   POLES=  2
GAIN AT 1 HZ=          2.75728E+08

F=  0.0050   T=  200.00    AMP=      0.000000    AMPDB=-135.1    PHAS=   -90.4
F=  0.0059   T=  169.49    AMP=      0.000000    AMPDB=-130.8    PHAS=   -90.5
F=  0.0070   T=  142.86    AMP=      0.000000    AMPDB=-126.4    PHAS=   -90.6
F=  0.0083   T=  120.48    AMP=      0.000001    AMPDB=-121.9    PHAS=   -90.7
F=  0.0098   T=  102.04    AMP=      0.000001    AMPDB=-117.6    PHAS=   -90.9
F=  0.0120   T=   83.33    AMP=      0.000002    AMPDB=-112.3    PHAS=   -91.1
F=  0.0140   T=   71.43    AMP=      0.000004    AMPDB=-108.3    PHAS=   -91.2
F=  0.3900   T=    2.56    AMP=      0.082352    AMPDB= -21.7    PHAS=  -125.9
F=  0.4600   T=    2.17    AMP=      0.133868    AMPDB= -17.5    PHAS=  -133.0
F=  0.5500   T=    1.82    AMP=      0.224204    AMPDB= -13.0    PHAS=  -142.3
F=  0.6500   T=    1.54    AMP=      0.356744    AMPDB=  -9.0    PHAS=  -152.9
F=  0.7700   T=    1.30    AMP=      0.554684    AMPDB=  -5.1    PHAS=  -165.6
F=  0.9100   T=    1.10    AMP=      0.820676    AMPDB=  -1.7    PHAS=  -179.7
F=  1.1000   T=    0.91    AMP=      1.198877    AMPDB=   1.6    PHAS=   163.3
F=  1.3000   T=    0.77    AMP=      1.580098    AMPDB=   4.0    PHAS=   148.6
F=  1.5000   T=    0.67    AMP=      1.933016    AMPDB=   5.7    PHAS=   137.0
F=  1.8000   T=    0.56    AMP=      2.420457    AMPDB=   7.7    PHAS=   123.6
F=  2.1000   T=    0.48    AMP=      2.877005    AMPDB=   9.2    PHAS=   113.5
F=  2.5000   T=    0.40    AMP=      3.460298    AMPDB=  10.8    PHAS=   103.0
F=  2.9000   T=    0.34    AMP=      4.027073    AMPDB=  12.1    PHAS=    94.6
F=  3.5000   T=    0.29    AMP=      4.855642    AMPDB=  13.7    PHAS=    84.1
```

FOR MORE DETAILS ON HOW TO UNDERSTAND GSE AND SEED RESPONSE PARAMETERS, SEE (Havskov and Alguacil, 2004), chapter 6.

41.3 SEED response

SEISAN can directly read SEED responses, which is poles and zeros, given as velocity response and transfer function types A (Laplace Transform in Rad/sec) and B (Analogue in 1/sec). Storage of response in one of these is the most common. The resp files can be created with rdseed from a full or dataless SEED volume (`rdseed -R -f seed_volume`). RDSEED creates files with the pattern `RESP.NC.STAT.LC.CHC`, where

NC=network code, STAT=station code, LC=location code (not used by SEISAN) and CHC=channel code. The resp files need to be stored in the CAL directory and SEISAN will find the correct file.
The RESP filename must match the waveform data, so if the waveform data does not include network code and location code, then filename must be e.g.: RESP..BER..BHZ
So if the location code in the waveform data is '–' then the RESP filename must include the '–', like e.g.: RESP.NO.BER.--.BHZ
And if the location code in the waveform data is empty ' ' then the RESP filename must be like:RESP.DK.BSD..BHZ

If there are many files to change, program CHANGE_RESP_NAME can be used:
- make a dirf of RESP files that all require the same change to location and network
- length of station name is unimportant
- questions of changing/adding location and/or network codes, to see codes, plot with MULPLT
- if file has one'.' for code, it will be replaced by '..', also when no change is indicated

The resp file can contain response information from several time intervals. SEISAN uses the date and time of the waveform data to find the corresponding instrument response.

SEED response files are given in stages, for example seismometer, digitizer and FIR filters are stored as individual stages. The overall response is made by combining all the stages. SEISAN uses the following blockets from the SEED resp file (for more details see IRIS Consortium (1993)):

B052F22 - start date
B052F23 - end date

B053F03 - transfer function type, A=Laplace Transform (Rad/sec), B=Analog (1/sec)

B053F07 - A0 normalization factor (A0 is checked against poles and zeros at normalization frequency and changed if not correct). The product of poles and zeros at the normalization frequency and A0 gives 1.

B053F08 - Normalization frequency

B053F10-13 - zeros, if transfer function type is B, normalization factor A0 is changed to (A0)/(2 pi) for each zero

B053F15-18 - poles, if transfer function type is B, normalization factor A0 is changed to (A0)*(2 pi) for each pole

B058F04 - gain

The overall gain factor is given by the product of normalization factors and gain factors from all stages. One zero is added to convert to displacement response. It is assumed that input units are V/m and output units are counts, no checks are done on input and output units.

41.4 SEED response to GSE, SEEDRESP2GSE

SEEDRESP2GSE converts SEED resp files as written out by rdseed to GSE format. The program only supports poles and zeroes and transfer function type Laplace Transform. The program asks for station and component names and a time. This is because the resp file could have data from several channels and cover several time intervals with different instrument configuration.

41.5 GSE response to SEED, GSERESP2SEED

GSERESP2SEED can be used to build dataless SEED volumes from a set of GSE calibration files. The conversion is based on the GSE2SEED program by **Reinould Sleeman** (email sleeman@knmi.nl). Input can be single filenames or a list of files given in `filenr.lis`. The program produces a single channel SEED volume for each channel given by a GSE response file. At the end of the output filename, GSE is replaced by SEED. Other tools have to be used to merge several channels into one SEED volume. If there are several GSE files for a channel from different time periods, a stop date has to be given in the CAL2 line of the respective GSE file. Station coordinates are taken from the STATION0.HYP file. The program can use the site name, if it is part of the GSE response file through a comment line as in the following example:

```
(GSE2SEED_SITENAME Charnwood Forest, Leicestershire, England, UK)
```

Chapter 42

Macroseismic data in SEISAN

Macrocosmic information in SEISAN are of 2 kinds. The summary information with maximum intensity, macroseismic epicenter etc has a special line in the S-file (see Appendix1) and the SELECT program can search for felt events. In addition, from SEISAN, version 8.1, a format has been defined to store macroseismic observations used to create e.g. maps with isoseismals. The observations files are stored in a local ISO format. For a format description and suggestion for file names, see Appendix A. There are currently no SEISAN programs that generates these files so they have to be made manually from the observations. The files in ISO are linked to the events as given by the S-file data base structure in the same way as waveform files are linked to the events. The line type is MACRO3 and an example is

```
 2007-01-21-1345-00.MACRO                                          MACRO3
```

Thus information about event source parameters and felt information is available together. An example of a file is

```
Brattvag, More og Romsdal     2007  121 1345  0 GMT 2007  121 1445  0 Local time
 Comment
    62.200     6.110  5.0 EMS 6150        ARSTA
    62.200     6.110  4.0 EMS 6150        ARSTA
    62.890     7.680  4.0 EMS 6480        BATNFJORDSARA
    62.500     6.680  6.0 EMS 6260        SKODJE
    62.460     6.130  6.0 EMS 6013        Alesund
    62.200     6.110  6.0 EMS 6150        ARSTA
    62.460     6.290  6.0 EMS 6017        ASESTRANDA
    62.460     6.010  4.0 EMS 6055        GODAY
    62.490     6.176  5.0 EMS 6057        ELLINGSAY
    62.430     6.180  4.0 EMS 6030        LANGEVAG
```

The file format is given in Appendix A. Program EPIMAP can plot the new files (use macroseismic file instead of a hypocenter file). The requirement is that the the first 3 letters after the '.' is mac or MAC (as example above). The intensities will be plotted as number on the map. A new Unix program can also be used with the data. Program MACROMAP can use the macroseismic observation file as input to create a map of the observations using GMT. The program generates a GMT script file, macromap.gmt, which then is executed from within the program to create a PostScript output file, macromap.ps. This file is then displayed, from within the program, with Unix command gv (GhostView). The program also runs under Windows, but does not plot.

The input can also be from a file made with macroquest (web based interactive program for input from the public, to be distributed with SEISAN CD). In addition to making the plot, a conversion from the web format to SEISAN format is made (output file macromap.out). This option requires an input file with postal codes in order to get location of the observations. MACROMAP can also be executed directly or

from eev. When executed directly from the prompt line, the options are: -macroinput file with macroseismic observations, SEISAN format, abs path or in ISO -placename optional additional file with place names, to be shown on map, abs path or in DAT, epimap format is used, -postfile optional file with postal code, abs path, used with web option If used with eev, the place name file must have name place_names.macro

An example of the postal code file is

```
Brattvag, More og Romsdal     2007  121 1345  0 GMT 2007  121 1445  0 Local time
 Comment
    62.200     6.110  5.0 EMS 6150        ARSTA
    62.200     6.110  4.0 EMS 6150        ARSTA
    62.890     7.680  4.0 EMS 6480        BATNFJORDSARA
    62.500     6.680  6.0 EMS 6260        SKODJE
    62.460     6.130  6.0 EMS 6013        Alesund
    62.200     6.110  6.0 EMS 6150        ARSTA
    62.460     6.290  6.0 EMS 6017        ASESTRANDA
    62.460     6.010  4.0 EMS 6055        GODAY
    62.490     6.176  5.0 EMS 6057        ELLINGSAY
    62.430     6.180  4.0 EMS 6030        LANGEVAG
```

The content is postal code, latitude, longitude and location. The format is a10,ff10.3,2x,a30. the postal code does not have to be a number, but can be any string.

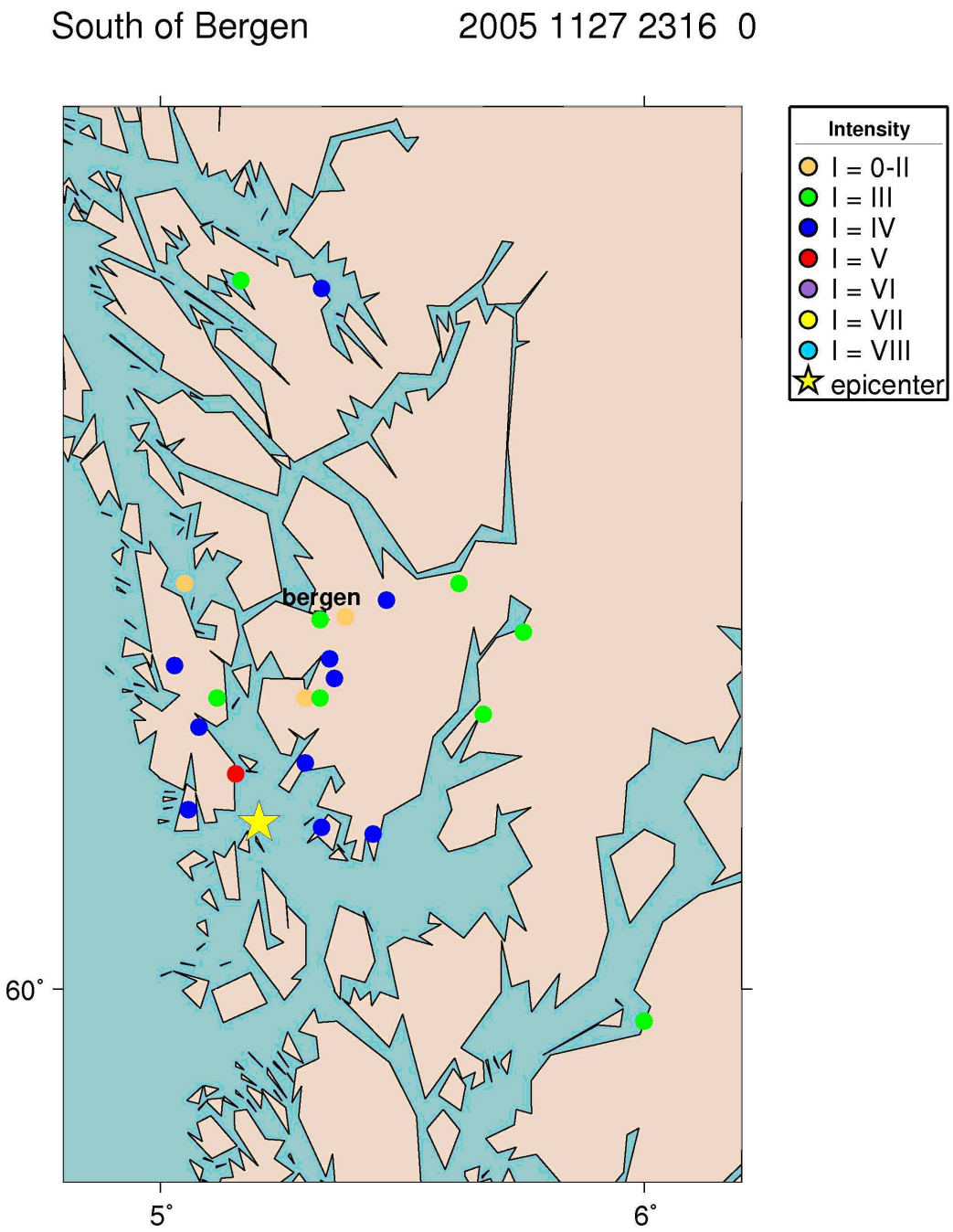


Figure 42.1: Macroseismic map made with MACROMAP using EEV. The epicenter, taken from the S-file, is shown with the star.

Chapter 43

Correlation of waveform signals, CORR and detection of event clusters XCLUST

The cross-correlation function provides a measure of similarity between signals. In seismology cross-correlation can be used to measure the similarity of waveforms between seismic events and in case of similarity to determine relative arrival times of a seismic wave between two events. Waveform similarity is caused by proximity in hypocenter location and similarity in focal mechanism between two events. Cross correlation can be computed with the program CORR and the output be processed with program XCLUST to detect groups of similar events.

CORR

The program CORR computes correlation and can be used to measure relative arrival times. It also can be used to determine correlation of a master event with continuous data and extract event based data. The output of maximum correlation for a station recording different events can be used to identify event clusters within the data set, this can be done using the program XCLUST. The cross-correlation function of signals x and y is computed in the time domain as:

$$r_{xy}(i) = \frac{\sum_{j=1}^{n} x_j y_{(j+i-1)}}{\sqrt{\sum_{j=1}^{n} x_j^2} \sqrt{\sum_{j=1}^{n} y_{j+i-1}^2}}$$

Phase arrivals

Phase arrivals of similar events can be determined accurately through cross-correlation. P and S arrivals can be determined independently. The procedure starts by selecting and picking phases for a master event that is representative for the group of events. Analysis of this event needs to be done accurately as it is the basis for the subsequent analysis. Phases of the other events in the group can be determined through cross-correlation of either the complete trace or a selected phase window with the master event. To pre-select a time window, manual identification of the phase for subsequent events is required prior to running CORR. This may be necessary for example if the waveform file contains several events. The phase arrival time is given by the maximum of the cross-correlation function that needs to exceed a minimum threshold. The arrival time is written out as absolute time. Filtering is applied to the signals if selected for both master and subsequent events, this may be necessary especially when dealing with events of different size. The filtering introduces a phase shift, which is applied to both signals. However, the absolute phase arrival for the subsequent event is consistent with the master event picked time.

The calculation of the relative phase time (dt) is done by taking the travel time for the master event (AT1 -OT1) (where AT is arrival time and OT origin time) minus the travel time of the other event (CAT -OT2), where CAT is the time corresponding to the maximum amplitude in the cross correlation function. The output file dt.cc can be used with the double difference location program HYPODD.

Cross correlation matrix

In this mode the cross-correlation is computed between the same stations for all pairs of events (that fulfill the criteria for maximum distance between the events, and event and station). The resulting cross-correlation matrix (for each station containing $\sum_i^n (i-1)$ values, where n is the number of events) can be used to identify groups of similar events using the program XCLUST.

Continuous mode

The main objective of running CORR in this mode is to identify a master waveform signal in a continuous data stream, given by waveform data files. The times when correlation is higher than the selected threshold level are written out, and can be visualized by splitting the corr.out file and using EEV and MULPLT. In addition, it is possible to cut out individual event files (see CONTINUOUS EXTRACT parameter).

Input file

Input to the program is given through the file corr.inp. A sample file is given in the DAT directory; the data used in the example are part of the test data set (TEST database 2003/06, see training document). The program is run by command corr in the same directory as corr.inp and the s-files. The waveform files can be in any SEISAN standard place. All standard waveform formats can be used.

The parameters in `corr.inp` are as follows:

Event file names:

SFILE MASTER:	sfile name of master event, remove or comment out this parameter to run program in group identification mode to determine cross-correlation matrix between all events and identify group of similar events
SFILE EVENT:	sfile name of events that will be either cross-correlated among themselves, or compared to the master event, there can be several of these.
SFILE INDEXFILE:	textttfilenr.lis file can be used to give S-file names instead of listing them with 'SFILE EVENT'

General parameters:

INTERACTIVE:	set to 1. for interactive use where graphics are displayed on the screen, which is useful for testing; or set to 0. for non-interactive run
CC MATRIX WINDOW:	time interval in seconds to use in computation of cross-correlation matrix instead of the duration given for each station given on STATION line, if different from 0.; full trace is used if EVENT SELCRIT is set to 0.
CONTINUOUS MODE:	write out all detection times for correlation above threshold if set to 1.; otherwise only phase for maximum correlation CONTINUOUS EXTRACT: extract event waveform files for correlation above threshold, 0. for no extract, 1. to extract single channel used, 2. extract all channels
EVENT SELCRIT:	cross-correlation with the master signal can be computed either for the complete trace of the subsequent event (0.) or the same part of the signal (either P or S) as for the master event (1.) including the pre signal part and of the same duration as defined in STATION line
FILTER:	this parameter allows to enable (1.) or disable (0.) filtering as defined for each channel with parameter line
STATION FIX DEPTH:	allows to fix depth to given value in corr.out, which can be useful if data is input to location program; set to 999. to disable
MAX DIFF TIME:	maximum difference in seconds from average of correlated stations average, used to exclude relative times that are too large and could be due to cycle skipping.
MAX EVENT DISTANCE:	maximum distance between event pair to compute correlation
MAX STAT DISTANCE:	maximum distance between event and station
MIN CORR:	minimum correlation required either for grouping or phase identification
MIN CORR CHAN:	number of stations required for event pair to be correlated.
N DOUBLE SRATE:	if sampling rate is to be increased give factor n to double sampling rate n times, 0. for none, this makes it possible to get phase reading with resolution greater than sampling interval
PRE SIGNAL:	duration of signal to include before phase arrival if used
SINGLE BIT:	the data can be reduced to 1 bit; reduce to 0 (-) and 1 (+) if set to 1, full data if set to 0.
START LATITUDE and START LONGITUDE:	these can be set to write values to corr.out, which is in Nordic format and can be used as input for location programs; this can be used if all events analyzed belong to one cluster and the same starting location is to be used for all of them; set to 999. to disable
TRACE OUTPUT:	flag to write corr.trace output file (1. for true)
WAVE CORR OUT:	CORR can write out cross-correlation function and input traces to waveform output files of the selected duration, to disable set this parameter to 0., 1. for full data or 2. for reduced data, where 1 for data ¿ MIN CORRELATION, otherwise 0
WAVENAME OUT:	CORR writes out waveform filenames to corr.out, it is possible to either keep original waveform names (0.) or put corr output file names (1.), which after SPLIT of corr.,out allows inspection of the results using eev and mulplt

Station parameters:

STATION: one line for configuration of each channel

- STAT, COMP: station and component codes
- SELCRIT: 1=P, 2=S, 4=full trace
- DURATION: signal duration in seconds if (selcrit¡4) starting from either P or S
- FLOW, FHIGH: filter limits for bandpass filter, can be; can be disabled by FILTER (see above)

Example of STATION line:

```
KEYWORD...STAT......COMP......SELCRIT...DURATION..FLOW......FHIGH.....
--- p ---
STATION   PCA       S  Z      1.        6.        3.        8.
--- s ---
STATION   EDI       S  E      2.        5.        3.        8.
```

Output files:

`corr.out`: This is the main output file. The file is in Nordic format and contains the phase readings if run in phase detection mode and can be used with the SEISAN location programs directly. In continuous mode, the file can contain more than one phase reading per channel. In group identification mode the file contains the event list, cross-correlation matrix and suggested groups of similar events.
`corr.trace`: This files gives details of program run and can provide information on cause of errors. dt.cc: Input file for hypodd giving relative phase times and correlation (see hypodd manual for details), e.g.

```
#    1    2 0.0
GMK   -0.136 0.940 P
GMK   -0.136 0.977 S
PCA   -0.142 0.963 P
PCA   -0.142 0.967 S
PCO   -0.152 0.968 P
PCO   -0.152 0.952 S
```

`cc_pairs.out`: List of event pairs giving, index and s-file of first event, index and s-file of second event, number of stations and average correlation of all stations. This file is used as input to XCLUST.

```
1 05-0028-32L.S200405    2 05-0413-55L.S200405   4 0.934
1 05-0028-32L.S200405    3 05-1644-21L.S200405   2 0.838
1 05-0028-32L.S200405    4 05-2102-06L.S200405   1 0.844
1 05-0028-32L.S200405    5 05-2143-52L.S200405   3 0.905
1 05-0028-32L.S200405    6 06-2136-12L.S200405   3 0.880
1 05-0028-32L.S200405    7 06-2301-54L.S200405   4 0.901
```

XCLUST

XCLUST is a simple program for cluster analysis of output from program CORR (`cc_pairs.out`) to identify groups of similar events. This is done in a rather simple approach:

- sort event pairs with descending correlation
- find group
  - start with highest correlation
  - add events that are linked into group this group in several loops over all pairs until no more events can be added to group; link into group is given by one of the events in the pair being correlated with any of the events in the cluster

- continue to find next group

Visual inspection of the waveforms is highly recommended to confirm the clustering results.

Input file: `xclust.par`

This is the file for the main parameters, which are:
MINIMUM CORRELATION: minimum correlation required for pair to be used
MINIMUM STATIONS: minimum number of correlated stations required for pair to be used
MINIMUM PERGROUP: minimum number of events required to make a group
TRACE OUTPUT; flag to write trace output file (1. for true)

Output files:

`xclust.trace`: gives some details of what the program does, useful for debugging
`xclust.out`: gives list of events for each cluster and for each event the number of links with other events in that cluster

```
=============
 group:     1 number of events:      20
-------------
  event links
-------------
      5     7
     11     8
      6     5
      2     7
      1     6
      7     9
...
```

`Index.xxx`: Index file where xxx refers to number of cluster. This file can be used with eev (e.g. `eev index.001`) to work on a specific cluster.

Chapter 44

Programming in SEISAN and list of files in SEISAN distribution

This chapter gives a bit more technical details of SEISAN starting with a short programmers guide with description of sample and test programs.

44.1 Programmers guide and some test programs

SEISAN is conglomerate of programs and subroutines and it can be difficult to find out which routines to use and how to start a new SEISAN program. The most common method is to use an existing program and modify it. The intention with this section is to make it easier by providing a few sample programs which then can be modified to do specific tasks. The most common subroutines in LIB, which might be useful in other programs, are listed in Appendix D. The compilation of existing SEISAN programs has been described in section 3.11 and details of the commands are found in the Makefiles. In this distribution, sample programs have been included, which each illustrate the used of some SEISAN features. All programs are included in the Makefiles and can therefore be compiled directly, modified and recompiled.

Reading and writing S-files

A basic operation is to be able to read and write S-files, since all parameters are contained in the S-files. Starting with version 7.2, a new library (`rea.for`) and include block (`rea.inc` for definition of variables) has been included to make it easier to read and write data into S-files. Earlier, S-files were only read and written as text strings and individual parameters were then read/written to the text strings. Now the new routines do it all. These routines are now used in a few programs, but will be included whenever a program is substantially modified. The sample program is called `sample_read_write_s.for`. The program illustrates how to read all parameters in an S-file, make modifications and write out the file again. The program can be useful, if the user needs a program where special parameters are needed for a particular analysis or for output in another format. This program is written in Fortran.

The program can read from a file or a data base and therefore illustrates the different posibilities in SEISAN.

There is also a program available to read and write S-files in C. `sample_read_write_s_c.cpp`. The program will use the seisan fortran routines to read and write, and the data is placed into a C structure. This C-struction is equivalent with the correspondiong REA.INC common block in Fortran. In c++, the definitions are found in textttrea_c.h in INC but the definition of the variables are in rea.inc. All the c++ subroutines used are found in the main program. This program only read and write an S-file with one or many events. You need to compile `sample_read_write_s_c.cpp` in the PRO folder, it is not part of the standard compilation since additional libraries might be needed.

Putting two S-files into memory at the same time, sample_rea_to_rea2.

Sometimes it is useful to have two s-files with all parameters in memory at the same time for different manipulations. Normally the rea.inc struction is used for one file. However, there is also a rea2.inc structure containing the same element as the rea structure, but all names are now rea2_.... In rea2.for there are several

subroutines that copy between rea and rea2 and the sample program illustrates this. The program operation is:

Data from 2 different s-files are read, one event at a time in each.

The two files are merged together, file 1 is inserted into file 2, so file 2 main header remins.

Id line from file 1 is converted to a comment line.

Locality line is only kept from file2, from file 1, it is converted to a comment.

If duplicate phases are found, they are deleted from file 1.

Reading and writing waveform files: SAMPLE_READ_WAV, SAMPLE_READ_CONT, SAMPLE_READ_ARC, SAMPLE_READ_WRITE_SEED, SAMPLE_WRITE_WAV

In SEISAN, waveform files can be in SEISAN, SAC, MiniSeed/SEED, Guralp or GSE format. SEISAN format is slightly different depending on which compute platform it is written and byte swapping has to be done in some cases. In order to automatically handle the reading of waveform files, irrespective of format and computer platform, a set of standard routines are used (waveform.for) and an include block where all parameters and data end up (`waveform.inc`). The sample reading program is called `sample_read_wav.for`.There is a similar program SAMPLE_WRITE_WAV for writing SEISAN waveform files.

The program illustrates how to read many waveform files belonging to one event as if it was one file, irrespective of format. It also demonstrates how to read just one waveform file. There is an output file which gives a listing of all different channels found in all the files read. Thsi listing is in the format used for defining channels in an achive. There is no detail on how to write a SEISAN binary file in this program, but some info is given under the format description in Appendix B and the program `tsig.for` described below illustrates a simple write. The sample program sample_read_cont illustrates how to extract out a time segment of the continuous data base. The program also shows how to write a Seisan file with all headers. The program is started from the command prompt:

sample_read_cont start_time interval

where start time is yyyymmddhhmmss and interval is interval in minutes.

There is a similar program for reading data from archives, sample_read_arc.

sample_read_write_seed interval

This program can read and write seed files using Chad and Rubens routines. it works independently of SEISAN subroutines.

There is also a routine in Java available to read all SEISAN binary formats. The program is called SFORMAT (written by T. Utheim). Similarly there is a sample program to read all SEISAN binary formats in Perl (written by Angel Rodriguez). The program is called `seibinasc.pl` and you need a Perl interpreter to run it. Before starting the program, a DIRF must first be made of waveform input files. The output is identical to a SEISAN ASCII file as made by SEIASC.

The sample write program is called `sample_write_wav.for`. It is a simple example of writing a straight line. The output formay is SEISAN.

Correction for instrument response, sample_instrument_correction

This program will mainly demonstrate how to make instrument correction, but is also demonstrates several other standard subroutine calls in SEISAN. The operations are:

Read S-file with readings and location

Get wave form files from S-file

Enter station and component for instrument correction

Find S-time from readings

Select out a time window for waveform channel around S-time

Find channel number in waveform file(s) corresponding to desired channel

Read the S-time window from waveform channel

Read response file

Prepare response removal, different filters and poles and zeros possible, the example is Wood-Anderson response

Correct for instrument response

Write out corrected data in an ASCII file in Helberger format

Automatically pick maximum amplitude and corresponding period

Write out results

Graphics in SEISAN

SEISAN uses a set of graphics routines, which are identical in call on all 3 platforms . These routines then call low level routines which are platform dependent (X on Unix and Windows calls on PC). The programmer only has to use the high level routines. The routines also generate a PostScript output if a given parameter is set. The program is called `sample_grapichs.for`. The program illustrates how to initiate graphics, make a few simple calls, get up and use the mouse and make a hard copy file. Most of the general graphics routines are located in file `seiplot.for` and common variables in `seiplot.inc`. The program can be useful for testing functionality of the mouse.

Program LSQ is a simple example of how to make xy-graphics. It also shows how to make the output files for gmtxy. In order to find more info (apart from manual in INF) on gmtxy, see file `gmt.for` in LIB and `gmt_xy_par` in INF.

Program for UDP communication SAMPLE_UDP_MESSAGE

This program shows how to communicate between two program using UDP signalling. It is so far only used in MULPLT to communicate with SE.

Program to make test signals, TSIG:

It is often useful to be able to work with controlled waveform data so a program making test signals is included. The program makes several traces, all with same length and sample rate and trace 1 is the sum of all traces. For each trace selected, the parameters selected are: Frequency, amplitude (remember this is integer numbers in file so use at least 1000), phase, delay (delay time when the signal appears on trace relative to start of trace, the data before is zero) and damping. The damping is used to simulate seismometer damping or simple a damped signal and has a similar physical meaning as the seismometer damping constant, but period is not recalculated to simulate changing period with damping. Zero damping is no damping.

An additional trace can be made with a Brune displacement pulse generated with parameters corner frequency (f0), Q and kappa (see MULPLT) and travel time. Travel time is used for Q-correction and also places the pulse at travel time distance from the origin (start of trace), so length of trace must be longer than travel time. If zero q and kappa, no attenuation is used. The program also write an S-file with relevant parameters. The program illustrates a simple writing of a SEISAN waveform file.

Java programs in SEISAN

The Java programs are each given as a Jar-file, the jar-files are located in the PRO directory. The jar-file contains all the Java source code, the Java classes and the project file so a user can decompress the jar file, change the script and make a new version of the program. The programs are started using a script file in the COM directory and no classpath has to be set, when SEISAN has been correctly installed.

44.2 Routines for Geodetic computations (WGS84)

The SEISAN software libaray include two subroutines for geodetic computations using the WGS84 ellipsoid:

vincenty_forward(lon,lat,azi,dist) and vincenty_inverse(lo,la,lo2,la2)

vincenty_forward(lon,lat,azi,dist) computes the lat and lon for a point at an azimuth and distance (meter) from the point given by input lon and lat. Output lon and lat are returned at the position of input lon and lat.

vincenty_inverse(lo,la,lo2,la2) computes the azimuth, back-azumith and distance between the two points lo,la,lo2,la2. Outout azimuth, back-azumith and distance (meters) are returned at the position of lo,la,lo2.

The code is based on the code at `http://www.ngs.noaa.gov/PC_PROD/Inv_Fwd/` see also `http://www.movable-type.co.uk/scripts/latlong-vincenty.html`

Please check for bugs before use.

Example:

```
C program example that show how to call the Vincenty routines:
      double precision lo,la,azi,dist,lo2,la2
      real lon,lat
      lon=12.8833
      lat=56.54
      azi=0.0D0
      dist=111000.0D0   ! meters
```

```
      lo=DBLE(lon)
      la=DBLE(lat)
      lo2=DBLE(lon)
      la2=DBLE(lat)
      write(*,*)"lonlat:",lo,la
      do i=1,3
        write(*,*)"FORWARD:"
        lo=DBLE(lon)
        la=DBLE(lat)
        write(*,*)"Input [lon,lat,azi,dist]:",lo,la,azi,dist
        write(*,*)"Input: lo1 la1 lo2 la2:",lo,la,lo2,la2
        call vincenty_inverse(lo,la,lo2,la2)
        write(*,*)"Output: [azi,baz,dist]",lo,la,lo2
        azi=azi+DBLE(90.0)
        write(*,*)"-----------------------------------"
      enddo
      end
C End of example
```

44.3 CONTENTS OF PRO, LIB, INC, INF, COM, DAT, SUP, ISO and PIC DIRECTORIES

The PRO, LIB, INC and COM directories contain software, the DAT directory parameter files for operating the SEISAN system and INF contains documentation and manuals. All files are listed and explained in the file `seisan.all` in the INF directory.

The most common subrouties from LIB are listed in Appendix D.

The ISO directory contains macroseismic information.

The program CHECK can check if a distribution is complete. Run CHECK and use option 'basic'. The content of the distribution is compared to the `seisan.all` file in the INF directory.

The `seisan.all` file also list programs no longer compiled, but with source code included in case there should be a future need for these programs

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Appendix A

The Nordic format

The main purpose of the Nordic format is to provide parametric data on seismic events. In SEISAN the Nordic format is also used to link events to waveform data etc.

The Nordic format has 2 versions, Nordic and from SEISAN version 12.0, also Nordic2. Nordic2 has more parameters, however SEISAN operated on both formats.

Each line is always 80 characters long and the last character defines the type of line.

The definition of each type of line is given below under the "FORMAT DESCRIPTION".

Free columns are included for two purposes:

1. To obtain a readable format
2. To have some space for possible future extensions

Here are a few examples on the format:

Nordic2 format:

```
1996  6 7 1325 29.2 L  59.846   5.130 12.0F TES 12 .60 1.9LTES 2.2CTES 2.0LNAO1
GAP=177        2.78       4.5    12.80.000  0.2239E+02  0.6258E+03 -0.2817E+03E
1996  6 7 1325 30.5 L  59.763   5.396 29.2  NAO  2 1.0                 2.0LNAO1
      8.3      41.0      74.7     1                                        F
1996-06-07-1324-51S.TEST__009                                             6
ACTION:SPL 14-12-11 12:04 OP:jh   STATUS:               ID:19960607132529 L   I
STAT COM NTLO IPHASE   W HHMM SS.SSS   PAR1  PAR2 AGA OPE  AIN  RES W  DIS CAZ7
EGD  HHZ NS   IP       4 1325 35.950      C       BER jh 120.0-1.131047.70   6
EGD  HHZ NS    END       1325 35.950  111.0       BER jh       0.0   47.70   6
EGD  HHZ NS    AMP       1325 35.950   11.1  33.3 BER jh             47.70   6
EGD  HHN NS   ES         1325 42.030              BER jh  70.0-.8901047.70   6
BER  BHZ NS00 IP         1325 38.120      C       kkk AUT     -.9801061.00  11
BER  BHZ NS00  END       1325 38.120   55.0       BER jh        4.8  61.00  11
BER  BHN NS00 ES         1325 45.440              BER jh  70.0-.9901061.00  11
BER  BHZ NS00  IAML     A1325 46.710   31.7  0.20 BER jh       0.4   61.00  11
KMY  BHZ NS10 IP         1325 40.260      C       PPP Ajh 70.0 .3301070.90 175
KMY  BHZ NS10  END       1325 40.260   62.0       BER jh             70.90 175
KMY  BHN NS10 ES         1325 48.740              BER jh   70.0.3001070.90 175
KMY  BHZ NS10  IAML      1325 48.920   83.6  0.20 BER jh             70.90 175
ASK  SHZ NS   EP       2 1325 39.590      D                   -1.031071.10   3
ASK  SHZ NS    END       1325 39.590   68.0                         71.10   3
ASK  SHZ NS   ES         1325 48.070                          -1.021071.10   3
ASK  SHZ NS    AMP       1325 48.070  333.3  2.20                 71.10   3
ASK  SHZ NS    IAML      1325 50.900  111.0  0.30                 71.10   3
NRA0 S Z       Pn       A1326 19.090                      50.0-.05010368.0  72
```

```
NRA0 S Z       END       1326 19.090  333.0                        368.0  72
NRA0 S Z       BAZ-P     1326 19.090  256.9   6.9                0.  368.0  72
NRA0 S Z       Pg        1326 27.940                           -.64010368.0  72
NRA0 S Z       BAZ       1326 27.940  253.0   7.3                -3.  368.0  72
NRA0 S Z       Lg        1327 10.540                           -.89010368.0  72
NRA0 S Z       BAZ       1327 10.540  266.6   4.1                9.  368.0  72
```

Notes:
Coda has in Nordic2 phase name END
So far the Nordic2 format only affects type phase lines. SPEC lines also have a new format using Type S lines which can be read also when using Nordic format.

Nordic format:

```
1996  6 3 1955 35.5 D  47.760 153.227  0.0  TES 12 1.1         5.6WHRV 5.6bPDE1
GAP=348        2.88     999.9   999.9999.9 -0.1404E+08 -0.3810E+08  0.1205E+09E
1996 0603 1955 31.8 D  46.787153.722  33.0  PDE        5.6bPDE                1
ACTION:SPL 08-10-02 10:19 OP:jh   STATUS:               ID:19960603195540     I
1996-06-03-2002-18S.TEST__012                                                 6
1996-06-03-1917-52S.TEST__002                                                 6
STAT SP IPHASW D HRMM SECON CODA AMPLIT PERI AZIMU VELO AIN AR TRES W  DIS CAZ7
KBS  BZ EP       20 4 40.63                              23   -1.3210 5724 351
TRO  SZ EP       20 5 32.5                               21    1.7510 6471 343
LOF  SZ IP     C 20 5 46.68                              21   -0.1110 6729 344
JNW  SZ EP       20 5 49.5                               21    1.1910 6755 353
JMI  LZ I        20 8 27.35                                     6768 353
JMI  LZ I        2014 41.56                                     6768 353
JMI  LZ I        2021 25.49                                     6768 353
MOL  SZ IP     C 20 6 25.49                              19   -1.7410 7408 343
FOO  SZ EP       20 6 35.99                              19    0.1210 7559 344
HYA  SZ EP       20 6 36.91                              19   -0.1410 7580 343
SUE  SZ IP     C 20 6 39.07                              19   -0.2810 7621 344
KONO BZ IP     C 20 6 40.72                              19   -0.7010 7657 341
ASK  SZ EP   9   20 6 37.24                              19   -4.94 0 7671 344
BER  SZ EP   9   20 6 37.43                              19   -5.16 0 7678 344
EGD  SZ EP   9   20 6 38.42                              19   -4.95 0 7692 344
ODD1 SZ EP       20 6 45.57                              19    1.7310 7699 343
BLS5 SZ EP       20 6 46.33                              19   -0.5010 7753 343
```

Below are examples of how the last free columns of type phase lines are used in e.g. the Nordic Databank in Helsinki and in Bergen:

```
1985 510 21 5 16.1 LE 60.240 6.170 30.0F BER  6 2.3 3.8LNAO 4.0bPDE 3.2sISC  1
               1.5     0.5   0.9    5.0             0.4                     5
8505210425.WNN                                                               6
ACTION:UPD 93-07-09 09:40 OP:jens STATUS:               ID:19920101080359    I
STAT SP IPHASW D HRMM SECON CODA AMPLIT PERI AZIMU VELO AIN AR TRES W  DIS CAZ7
STAT SP IPHASW D HRMM SECON CODA AMPLIT PERI AZIMU VELO AIN AR TRES W  DIS CAZ7
8505210425.WNN                                                                6
ACTION:UPD 93-07-09 09:40 OP:jens STATUS:               ID:19920101080359    I
STAT SP IPHASW D HRMM SECON CODA AMPLIT PERI AZIMU VELO AIN AR TRES W  DIS CAZ7
NRSA SZ IPN  1 D 2105 13.44 0345 1234.6 1.33 245.2 08.6  22  2 -0.7 9  555 235
BER  SZ IPG  2 U 2105 25.41  200
HYA  SZ ISG  1   2105 33.1
```

```
 ODD  SZ IP   3   2105 20.1   250
 ODD  SZ EPG      2105 22.9
 ODD  SZ  LG      2105 55.8
```

Note in the below example the fault plane solution line(F) and the HYP error line(E)

```
 1993 1028 0800 26.4 L 57.518 7.119 18.8  BER  6  .6 2.6CBER                  1
 GAP=201        1.20    6.4   7.0    6.8   .3359E+01  -.2719E+00      .3054E+02E
      93.2      74.8     -48.2     2                                        F
 ACTION:SPL 95-01-08 09:40 OP:jh   STATUS:               ID:19931028080019     I
 9310-28-0800-19S.NSN__17                                                   6
 STAT SP IPHASW D HRMM SECON CODA AMPLIT PERI AZIMU VELO AIN AR TRES W  DIS CAZ7
 BLS5 SZ EP     D 8  0 56.80  129                                 -.110  216 349
 BLS5 SZ ESG      8  1 23.59                                     -.910  216 349
 BLS5 SZ EP       8  0 56.80  129                                 -.110  216 349
 BLS5 SZ ESG      8  1 23.59                                     -.910  216 349
```

```
Note:
Location parameters in phase lines under Type 7 is:
AR  : Azimuth residual when using azimuth information in locations
TRES: Travel time residual
W   : Actual weight used for location ( inc. e.g. distance weight), i2
DIS : Epicentral distance in km
CAZ : Azimuth from event to station

--------------------------------------------------------------------------------
Note: Type 1 line must be the first, all phase type lines should be together and
the last line must be blank
--------------------------------------------------------------------------------
```

FORMAT DESCRIPTION, Type descriptions:
The details on the type lines is given below, the title us the used types is:

```
--------------------------------------------------------------------------------
Type 1 line: Hypocenter line
Type 2 line: Macroseismic information
Type 3 line: Comments
Type Phase lines Nordic2
Type Phase lines Nordic pre v12.0
Type 5 line: Error estimates of previous line, not used by any SEISAN programs.
Type 6 line: Waveform data file name or link to where waveform data is found.
Type 7 line: Title line for phases, fixed text, different for Nordic and Nordic2 format.
Type E line: Hypocenter error estimate of prime hypocenter, only one E-line in S-file
Type F line: Fault plane solution
Type H line: High accuracy hypocenter line
Type I line: ID line
Type M line: Moment tensor solution
Type P line: Picture file name
Type S line: Spectral parameters (new from verision 12)
Type E13 and EC3 line: Explosion information
Type MACRO3 line: File name of macroseismic observations in ISO directory
--------------------------------------------------------------------------------
```

FORMAT DESCRIPTION, Type details:

Type 1 line - Hypocenter line:

Columns	Format	Description	Comments
1		Free	
2- 5	I4	Year	
6	A1	Can optinally be location program code if not Hyopocenter (blank)	
7- 8	I2	Month	
9-10	I2	Day of Month	
11		Fix o. time	Normally blank, an F fixes origin time
12-13	I2	Hour	
14-15	I2	Minutes	
16		Free	
17-20	F4.1	Seconds	
21		Location model indicator	Any character
22	A1	Distance Indicator	L = Local, R = Regional, D = Distant, etc.
23	A1	Event ID	E = Confirmed explosion P = Probable explosion V = Volcanic Q = Confirmed earthquake ' ' = Presumed earthquake L = Landslide (was X) S = Acoustic signal I = triggered or induced O = confirmed other event C = Cryogenic event (e.g. ice quake) G = Glacial earthquake (subset of C) U = Unknown event type
24-30	F7.3	Latitude	Degrees (+ N)
31-38	F8.3	Longitude	Degrees (+ E)
39-43	F5.1	Depth	Km
44	A1	Depth Indicator	F = Fixed, S = Starting value
45	A1	Locating indicator	----------, * do not locate
46-48	A3	Hypocenter Reporting Agency	
49-51		Number of Stations Used	
52-55		RMS of Time Residuals	
56-59	F4.1	Magnitude No. 1	
60	A1	Type of Magnitude L=ML, b=mb, B=mB, s=Ms, S=MS, W=MW, G=MbLg (not used by SEISAN), C=Mc	
61-63	A3	Magnitude Reporting Agency	
64-67	F4.1	Magnitude No. 2	
68	A1	Type of Magnitude	
69-71	A3	Magnitude Reporting Agency	
72-75	F4.1	Magnitude No. 3	
76	A1	Type of Magnitude	
77-79	A3	Magnitude Reporting Agency	
80	A1	Type of this line ("1"), can be blank if first line of event	

If more than 3 magnitudes need to be associated with the hypocenter in the first line, a subsequent additional type one line can be written with the same year, month, day until event ID and hypocenter agency. The magnitudes on this line will then be associated with the main header line and there is then room for 6 magnitudes.

```
Column number example:
         1         2         3         4         5         6         7         8
12345678901234567890123456789012345678901234567890123456789012345678901234567890
 1996  6 3 1955 35.5 D  47.760 153.227  0.0  TES 12 1.1         5.6WHRV 5.6bPDE1
```

Type 2 line - Macroseismic information:

1-5		Blank
6-20	a	Any descriptive text
21		Free
22	a1	Diastrophism code (PDE type) F = Surface faulting U = Uplift or subsidence D = Faulting and Uplift/Subsidence
23	a1	Tsunami code (PDE type) T = Tsunami generated Q = Possible tsunami
24	a1	Seiche code (PDE type) S = Seiche Q = Possible seiche
25	a1	Cultural effects (PDE type) C = Casualties reported D = Damage reported F = Earthquake was felt H = Earthquake was heard
26	a1	Unusual events (PDE type) L = Liquefaction G = Geysir/fumerol S = Landslides/Avalanches B = Sand blows C = Cracking in the ground (not normal faulting). V = Visual phenomena O = Olfactory phenomena M = More than one of the above observed.
27		Free
28-29	i2	Max Intensity
30	a1	Max Intensity qualifier (+ or - indicating more precicely the intensity)
31-32	a2	Intensity scale (ISC type defintions) MM = Modified Mercalli RF = Rossi Forel CS = Mercalli - Cancani - Seberg SK = Medevev - Sponheur - Karnik33 Free
34-39	f6.2	Macroseismic latitude (Decimal)
40		Free
41-47	f7.2	Macroseismic longitude (Decimal)
48		Free
49-51	f3.1	Macroseismic magnitude
52	a1	Type of magnitudeI = Magnitude based on maximum Intensity. A = Magnitude based on felt area. R = Magnitude based on radius of felt area. * = Magnitude calculated by use of special formulas

```
                          developed by some person for a certain area.
                          Further info should be given on line 3.
 53-56 f4.2    Logarithm (base 10) of radius of felt area.
 57-61 f5.2    Logarithm (base 10) of area (km**2) number 1 where
                       earthquake was felt exceeding a given intensity.
 62-63 i2      Intensity boardering the area number 1.
 64-68 f5.2    Logarithm (base 10) of area (km**2) number 2 where
                       earthquake was felt exceeding a given intensity.
 69-70 i2      Intensity boardering the area number 2.71 Free
 72    a1      Quality rank of the report (A, B, C, D) 73-75 a3 Reporting agency
 76-79         Free
 80    a1      Type of this line ("2")


Type 3 line - Comments:
-----------------------

Columns Format Description  Comments

  1            Free
  2-79 A       Text       Anything (ASCII printable characters https://en.wikipedia.org/wiki/ASCII)
 80    A1      Type of this line ("3")

Examples:

 This type of line can be used to specify xnear, xfar and the starting depth for use with
HYPOCENTER. For example

 XNEAR  200.0 XFAR  400.0 SDEP   15.0                                              3

   8-13  f6.1  Xnear
  20-25  f6.1  Xfar
  32-36  f5.1  Starting depth


Type Phase lines Nordic2:
-------------------------

Type Phase lines has blank last char.

Columns Format Description Comments
1 Free
2- 6  A5 Station Name
7-9   A3 Component, eg SHZ
10       Free
11-12 A2 Network code
13-14 A2 Location
15       Free
16    A1 Quality Indicator I, E, etc.
17-24 A8 Phase ID PN, PG, LG, P, S, etc.
25    I1 Weighting Indicator (1-4) 0 or blank= full weight, 1=75%, 2=50%,
         3=25%,4=0%, 9: no weight, time (e.g. P-S).
26       Free or flag A to indicate automatic pick, removed when picking
27-28 I2 Hour Hour can be up to 48 to indicate next day
```

```
29-30 I2 Minutes
31       Free
32-37 F6.0 Seconds
38-44    Parameter 1. If a phase, it is polarity in column 44
                      If phase END for coda, it is duration(s)(F)
                      If amplitude phase, it is amplitude (G7)
                          Amplitude is(Zero-Peak) in units of nm,
                          nm/s, nm/s^2 or counts.
                      If back azimuth phase (BAZ), it a back azimuth (F)
45-50    Parameter 2  If a phase or END, it is blank
                      If an amplitude, it is period (F)
                      If back azimuth phase, it is apparent velocity(km/s)
51         Free
52-54 A3   Agency
55         Free
56-58 A3   Operator
59         Free
60-63 F4.0 Angle of incidence
64-68 F5.1 Residual, can be travel time, back azimuth or magnitude
69-70 I2   Weight used, like 05 is 0.5
71-75 F5.0 Epicentral distance(km)
76 Free
77-79 I3   Azimuth at source
80 A1 Type of this line (" ")


Type Phase lines Nordic pre v12.0:
----------------------------------

Type Phase lines has blank last char (in pre v12.0 manuals these lines could also be Type 4).

Columns Format Description  Comments

  1 Free
  2- 6 A5 Station Name  Blank = End of readings = end of event
  7 A1 Instrument Type S = SP, I = IP, L = LP etc
  8 A1 Component  Z, N, E ,T, R, 1, 2
  9 Free or weight, see note below
 10 A1 Quality Indicator  I, E, etc.
 11-14 A2 Phase ID  PN, PG, LG, P, S, etc. **
 15 I1 Weighting Indicator (1-4) 0 or blank= full weight, 1=75%, 2=50%, 3=25%,4=0%, 9: no weight, use di
            time (e.g. P-S).
 16 Free or flag A to indicate automartic pick, removed when picking
 17 A1 First Motion  C, D
 18 Note: Currently 15 to 18 can also be used for phase assuming
           column 11-14 is not blank. See note ** below.
 19-20 I2 Hour  Hour can be up to 48 to
            indicate next day

 21-22 I2 Minutes
 23-28 F6.0 Seconds
 29 Free
 30-33 I4 Duration (to noise)  Seconds
 34-40 g7.1 Amplitude (Zero-Peak) in units of nm, nm/s, nm/s^2 or counts.
```

```
 41 Free
 42-45 F4.0 Period  Seconds
 46 Free
 47-51 F5.0 Direction of Approach, back azimuth  Degrees
 52 Free
 53-56 F4.0 Phase Velocity  Km/second
 57-60 F4.0 Angle of incidence (was Signal to noise ratio before version 8.0)
 61-63 I3 Back azimuth residual
 64-68 F5.1 Travel time residual
 69-70 I2 Weight
 71-75 F5.0 Epicentral distance(km)
 76 Free
 77-79 I3 Azimuth at source
 80 A1  Type of this line (" ").

NB: Epicentral distance: Had format I5 before version 7.2. All old lines can
be read with format F5.0 with same results, but now distance can also be
e.g. 1.23 km which cannot be read by earlier versions. However, an UPDATE
would fix that.


  ** Long phase names: An 8 character phase can be used in column 11-18. There
is then not room for polarity information. The weight is then put into column 9.
This format is recognized by HYP and MULPLT.

Type phase  cards should be followed by a Blank Card (Type 0)


Type 5 line - Error estimates:
------------------------------

Error estimates of previous line, not used by any SEISAN program.

Columns Format Description  Comments
  1 Free
  2-79 Error estimates in same format as previous line, normallytype 4
 80 A1 Type of this line ("5")


Type 6 line - Waveform data:
----------------------------

Gives waveform data file name or link to where waveform data is found.
This is mostly a file name but can also be a reference to a position
in an archive.

Columns Format Description  Comments
  1 Free
  2-79  Name of  file or archive reference, a-format,
 80     Type of this line ("6")

Example:
 1996-06-07-1324-51S.TEST__009                                          6

Archive reference:
```

```
Example:
 ARC STAT  COM NT LO YYYY MMDD HHMM SS   DUR                                  3
 ARC ROSA  BHZ PM    2010 1011 0100 00 14400                                  6
 ARC _GSN            2010 1011 0100 00 14400                                  6

Columns Format Description  Comments
  1    Free
 2-04  Must be the keyword ARC
 5     Free
 6-10  Station (a5)
 11    Free
 12-14 Compoent (a3)
 15    Free
 16-17 network  (a2)
 18    Free
 19-20 Location (a2)
 21    Free
 22-38 Year,month,day,hour.min,sec (i4,1x,2i2,1x,2i2,1x,i2)
 39    Free
 40-44 Duration of extract (s), (i5)
 46-79 Free
 80    Type of this line ("6")

 If first station char is _ the following string defines a virtual network
 code, see _GSN above. If it is a * all stations are read.


Type 7 line - Title line for phases, fixed text
-----------------------

Columns Format Description  Comments

  1 Free
  2-79 A Help lines to place the numbers in right positions
 80 A1 Type of this line ("7")

Example Nordic2 format:
 STAT COM NTLO IPHASE   W HHMM SS.SSS   PAR1  PAR2 AGA OPE  AIN  RES W  DIS CAZ7

Example Nordic format:
 STAT SP IPHASW D HRMM SECON CODA AMPLIT PERI AZIMU VELO AIN AR TRES W  DIS CAZ7


Type E line - Error estimate of hypocenter:
-------------------------------------------

Before version 12.0 there was only one E-line in S-file which could only belong to
the main hypocenter.
In order to know which E-line belongs to which 1-line, the location program indicator
and the agency must match. If only one E-line and no agency, it is assumed
it belongs to the main hypocenter. This ensures backwards compatibility. Multiple
E-lines can be used in both Nordic and Nordic2 format.
```

```
Columns Format Description

1 Free
2 - 5 A4 The text GAP=
6 - 8 I3 Gap
10:10 A1 Location program indicator, blank for Hypocenter (new from version 12)
11:11 Free
12:14 A3 Agency (new from version 12)
15-20 F6.2 Origin time error
25-30 F6.1 Latitude (y) error
31-32 Free
33-38 F6.1 Longitude (x) error (km)
39-43 F5.1 Depth (z) error (km)
44-55 E12.4 Covariance (x,y) km*km
56-67 E12.4 Covarience (x,z) km*km
68-79 E14.4 Covariance (y,z) km*km


Type F line - Fault plane solution:
-----------------------------------

Columns Format Description

1:30  3F10.0 Strike, dip and rake, Aki convention
31:45 3F5.1 Error in strike dip and rake (HASH), error in fault plane and
            aux. plane (FPFIT)
46:50 F5.1 Fit error: FPFIT and HASH (F-fit)
51:55 F5.1 Station distribution ratio (FPFIT, HASH)
56:60 F5.1 Amplitude ratio fit (HASH, FOCMEC)
61:62 I2 Number of bad polarities (FOCMEC, PINV)
64.65 I2 Number of bad amplitude ratios (FOCMEC)
67:69 A3 Agency code
71:77 A7 Program used
78:78 A1 Quality of solution, A (best), B C or D (worst), added manually
79:79 A1 Blank, can be used by user
80:80 A1 F


Type H line - High accuracy hypocenter line:
--------------------------------------------

The S-file can include a type=H line for each hypocenter (new from version 12).
Prior to version 12.0 only one type=H line was allowed in SEISAN.
The H line gives the same solution as the type=1 line, but with higher accuracy.
In order to know which H-line belongs to which 1-line, the location program indicator
and the agency must match. If only one H-line and no agency, it is assumed
it belongs to the main hypocenter. This ensures backwards compatibility.
Multiple H-lines can be used in both Nordic and Nordic2 format.

Columns

  1:55 As type 1 line including program used in column 6 (new from version 12)
 16 Free
 17 Seconds, f6.3
```

```
 23 Free
 24:32 Latitude, f9.5
 33 Free
 34:43 Longitude, f10.5
 44 Free
 45:52 Depth, f8.3
 53 Free
 54:59 RMS, f6.3
 61:63 Agency, A3 (new from version 12)
 62:79 Free
 80 H


Type I Line, ID line:
---------------------

Columns Format description1 Free

  2:8 Help text for the action indicator
  9:11  Last action done, so far defined

           ARG: AUTO Register, AUTOREG
           ARX: From ARC extract
           DPH: Phases deleted with DELS
           DUP: Duplicated event
           HIN: Updated with HYPOINVERSE
           NEW: New event
           REE: Register from EEV
           REG: Register
           SPL: Split
           UPD: Update with HYP
           UP : Update with HYP only from EEV
 12 Free
 13:26 Date and time of last action
 27 Free
 28:30 Help text for operator
 36:42 Help text for status
 43:56 Status flags, not yet defined
 57 Free
 58:60 Help text for ID
 61:74 ID, year to second
 75 If d, this indicate that a new file id had to be created which was
        one or more seconds different from an existing ID to avoid overwrite.
 76 Indicate if ID has been synchronized with origin time.
        Blank means not syncronized, S means synchonized. In version 11 and before
        this was L. Only for information.


Type M line - Moment tensor solution:
-------------------------------------

Note: the type M lines are pairs of lines with one line that gives the hypocenter
time, and one line that gives the moment tensor values:
```

```
The first moment tensor line:
Columns Format Description
  1:1          Free
  2: 5   I4    Year
  7: 8   I2    Month
  9:10   I2    Day of Month
 12:13   I2    Hour
 14:15   I2    Minutes
 17:20   F4.1  Seconds
 24:30   F7.3  Latitude                       Degrees (+ N)
 31:38   F8.3  Longitude                      Degrees (+ E)
 39:43   F5.1  Depth                          Km
 46:48   A3    Reporting Agency
 56:59  F4.1   Magnitude
 60     A1     Type of Magnitude L=ML, b=mb, B=mB, s=Ms, S=MS, W=MW,
 61:63  A3     Magnitude Reporting Agency
 71:77  A7     Method used
 78:78  A1     Quality of solution, A (best), B C or D (worst), added manually
 79:79  A1     Blank, can be used by user
 80:A1         M

The second moment tensor line:
Columns Format Description
  1:1          Free
  2:3   A2     MT
  4:9   F6.3   Mrr or Mzz [Nm] divided by exponential
 11:16  F6.3   Mtt or Mxx [Nm]        ------
 18:23  F6.3   Mpp or Myy [Nm]        ------
 25:30  F6.3   Mrt or Mzx [Nm]        ------
 32:37  F6.3   Mrp or Mzy [Nm]        ------
 39:44  F6.3   Mtp or Mxy [Nm]        ------
 46:48  A3     Reporting Agency
 49:49  A1     MT coordinate system (S=spherical, C=Cartesian)
 50:51  i2     Exponental
 53:62  G6.3   Scalar Moment [Nm]
 71:77  A7     Method used
 78:78  A1     Quality of solution, A (best), B C or D (worst), added manually
 79:79  A1     Blank, can be used by user
 80:80  A1     M

All moment values must be multiplied by the exponent


Type P line - Picture file name:
--------------------------------

These lines are used to link to pictures in e.g. png/jpg format.

  1:1          Free
  2:79         File name
  80:80        P


Type S line - Specrtral information:
```

S lines are generated by AUTOMAG and MULPLT. This format will
only be generated with SEISAN version 12.0, however version 12.0 will
also read the old spectral format.

Columns	Format	Abbreviation	Description
1			Free
2- 6	A5	STA	Station
7- 9	A3	COM	Component
10-11	A2	NT	Network
12 13	A2	LO	Location
14			Free
15-18	F	OM	Log Omega0
19-22	F	F0	Corner frequency(Hz)
23-25	F	AL	Spectral slope
26-31	3i2	T	Hour Min Sec for start of spectrum
32-35	F	WI	Window length(s)
36-40	F	GD	Geo-distance(km)
41-44	F	MO	Log moment
45-47	F	ST	Stress drop(bar)
48-51	F	R	Source radius(km)
52-55	F	K	Kappa
56-59	F	V	Velocity at source(km/s)
60-60	A	X	Type of spectrum,, P or S
61-64	F	DE	Density at source (g/cm*cm*cm)
65-68	F	Q0	Q0
69-72	F	QA	Q-alpha
73-75	F	Q1	Frequency(Hz) below which Q(f) changes to constant Q
76-79	F	MW	Moment magnitude

There is also an explanatory type S-line, for abbreviations, see above

```
STA  COM NTLO  OM  F0 AL     T  WI   GD  MO ST   R   K   VX  DE  Q0  QA Q1  MWS
```

There is an average spctral S-line

```
AV-SD MO 12.4 0.1 ST  0.0 0.0 F0 1.10.046 R 0.082.045 AL 2.0  0.0 MW 2.20 0.1 S
```

identified by AV-SD. Abbreviations are the same as above and the extra number after
each value is standard deviation.

Type E13 and EC3 line - Explosion information:

Example

```
1980 0124 0927 CHARGE(T): 0.5 E13  LE Haakonsvern,  HAA underwater explosion  E13 EC3
```

Information on explsion site, time and agency, same format as a type 1 line,
no magnitudesused, last 3 columns must be E13
EC3 Information on charge and site

```
Columns
  2:11 Info text
 11:12 Blank
 13:22 Charge in tons, f10.3
 23:77 Any information, a
 78:80 EC3


Type MACRO3 line: File name of macroseismic observations:
----------------------------------------------------------

The files are located in the ISO directory.

Example:

1980-03-14-0456-05.MACRO MACRO3

An example of the file is:

Sunnfjord 1980 314 456 5 GMT 1980 314 556 5 Local time
 Comment
60.500 5.270 1.0 EMS 5088 MJOELKERAAEN
60.560 5.260 1.0 EMS 5100 ISDALSTOE
60.570 5.050 1.0 EMS 5112 ROSSLAND

1.  Line
Location, GMT time, Local time. Format a30,i4,1x,2i2,1x,2i2,1x,i2,'
GMT',1x,i4,1x,2i2,1x,2i2,1x,i2,1x,'Local time'
2.  Line Comments
3.  Line Observations: Latitude, Longitude,intensity, code for scale,
postal code or similar, location,Format 2f10.4,f5.1,1x,a3,1x,a10,2x,a.
Note the postal code is an ascii string and left justified (a10).


Type 3 line giving xnear/xfar:
------------------------------

Definition of xnear and xfar to be used with HYPOCENTER.

Example
XNEAR 1000.0 XFAR 2000.0 3
Columns
  8-13: xnear value
 20-25: xfar value


Type 3 line with locality:
--------------------------

Example

 LOCALITY: atlantic ocean                                              3
```

```
Type 3 line with  felt information:
-----------------------------------

Example

 FELTINFO: cracks in the ground at xx                                  3
```

Appendix B

The SEISAN waveform file format

The file is written from Fortran as an unformatted file. This means that the file contains additional characters (not described below, see end of this Appendix) between each block, which must be taken into account if the file is read as a binary file. If read as Fortran unformatted, the content will appear as described below. However, the internal structure is different on Sun, Linux and PC. SEISAN automatically corrects for these differences. The SEISAN ASCII format has identical headers to the binary files, however the binary samples are written as formatted integers, one channel at the time just like the in the binary format.

```
 EVENT FILE HEADER

 CONTAINS MINIMUM 12 ASCII STRINGS OF 80 BYTES.
 ALL FORMATS I OR A UNLESS OTHERWISE SPECIFIED.

line 1
   1     1: FREE
   2    30: NETWORK NAME,
             COULD E.G. BE WESTERN NORWAY NETWORK
  31    33: NUMBER OF CHANNELS, MAX 999
  34    36: YEAR-1900, e.g. 101 for 2001 (I3)
  37
  38    40: DOY
  41
  42    43: MONTH
  44
  45    46: DAY
  47
  48    49: HR
  50
  51    52: MIN
  53
  54    59: SEC, FORMAT F6.3
  60
  61    69: TOTAL TIME WINDOW (SECS), FORMAT F9.3
  70    80: FREE
  71
  72
  73    80: FREE

                                                                |
 line 2
   1    80: FREE
```

```
                                                                |
line 3
  1
  2     5: STATION CODE (A4), first 4 characters
  6     7: FIRST two COMPONENT CODES (A2), SEED style
  8      : NOT USED
  9      : LAST COMPONENT CODE (A1), SEED style
 10      : STATION CODE (A1), LAST CHARACTER IF 5 CHARACTER STATION CODE
 11    17: START TIME RELATIVE TO EVENT FILE TIME (SECS) F7.2
 18      : BLANK
 19    26: STATION DATA INTERVAL LENGTH (SECS)  F8.2
 27    52: SECOND CHANNEL
 53    78: THIRD  CHANNEL
 79    80: BLANK                                                 |
                                                                 |

line 4-XX, where XX depends on number of channels, however, XX
           is at least 12 so there might be some blank lines.
  1    80: THREE MORE CHANNELS (SAME FORMAT AS line 3)
                                                                |

EVENT FILE CHANNEL HEADER

HEADER IS 1040 BYTES LONG, WRITTEN AS ONE VARIABLE DEFINED AS
CHARACTER*1040
THE PARAMETERS ARE WRITTEN FORMATTED WITH INTERNAL WRITE INTO
1040 BYTE TEXT STRING.
FORMAT IS ALWAY I FORMAT UNLESS OTHERWISE SPECIFIED

  1     5: STATION CODE (A5)
  6     7: FIRST TWO COMPONENT CODES (A2), SEED style
  8      : FIRST LOCATION CODE (A1), SEED style
  9      : LAST COMPONENT CODE (A1), SEED style

 10    12: YEAR - 1900, e.g. 101 for 2001, (I3)
 13      : SECOND LOCATION CODE (A1), SEED style
 14    16: DOY
 17      : FIRST NETWORK CODE (A1), SEED style
 18    19: MONTH
 20      : SECOND NETWORK CODE (A1), SEED style
 21    22: DAY
 23
 24    25: HR
 26
 27    28: MIN
 29      : TIMING INDICATOR, BLANK: TIME IS OK, E: UNCERATIAN TIME
 30    35: SECOND (F6.3)
 36
 37    43: SAMPLE RATE  (F7.2 or any f-format)
 44    50: NUMBER OF SAMPLES (I7)
 51
 52    59: LATITUDE (F8.4), optional
 60
 61    69: LONGITUDE (F9.4), optional
```

```
 70
 71    75: ELEVATION (METERS), optional
 76      : Indicate gain factor: Blank: No gain factor, G: Gain factor in
         column 148 to 159
 77      : 2 OR 4 FOR 2 OR 4 BYTE INTEGER, BLANK IS 2 BYTE
 78      : P: Poles and zeros used for response info, blank: Seismometer
              period etc used for response info. See below for details.
           T: Use up to 30 tabulated values irrespective of what is given
              below. If less than 30, blank characters must be given.
 79      : C: a combination of table, poles and zeros or instrument
              constants have been used, for information only. Value in 78
              must then be T.
           F: Force use of header response, e.g. generated by MULPLT. Only
              gain at 1 hz is correct and 78 must be set to T.
 80 -  80: FREE
 148- 159: Normally comment, if 76 set to G, this is a gain factor,
           format G12.7. All samples read from channel are multipled
           by this factor when read by routine seisinc. Used when data
           is stored in units of e.g. nm where values can be less than 1.
           Currently  generated by MULPLT when option OUT is used to
           extract part of a waveform file. Alse program WAVETOOL will
           generate these files (used with Out option). Some conversion
           programs may also write this.
 81 - 160: COMMENT LINE DESCRIBING THE SYSTEM RESPONSE (A80)

If character 78 is blank, option 1:

161 - 240: (10G8.3) 1. SEISMOMETER PERIOD
                    2. FRACTION OF CRITICAL DAMPING
                    3. SEISMOMETER GENERATOR CONSTANT (V/m/s) or
                       ACCELEROMETER SENSITIVITY (V/G)
                    4. AMPLIFIER GAIN
                    5. RECORDING MEDIA GAIN (I.E. 2048 COUNTS/VOLT)
                    6. GAIN AT 1.0 HZ, UNITS: COUNTS/METER
                    7. CUTOFF FREQUENCY FOR FILTER1 (HZ)
                    8. # OF POLES FOR FILTER1 (NEGATIVE FOR HIGHPASS)
                    9. CUTOFF FREQUENCY FOR FILTER2 (HZ)
                   10. # OF POLES FOR FILTER2 (NEGATIVE FOR HIGHPASS)
241 - 320: (10G8.3) FREQUENCIES AND #'S OF POLES FOR FIVE MORE FILTERS
321 -1040: RESPONSE CURVES (9(10G8.3) FREQ., AMPL. (REL. 1.0 HZ) AND PHASE,
           WRITTEN IN GROUPS OF 10 FREQUENCIES, 10 AMPLITUDES AND 10 PHASES

 If character 78 is P, option 2:

 161 - 182 (1X,2I5,G11.4) 1. NUMBER OF POLES
                          2. NUMBER OF ZEROS
                          3. NORMALIZATION CONSTANT, COUNTS/M
 183 - 240 (5G11.4)       2 Poles in pairs of real and imaginary parts
 241 -1040 (G11.4)        Remaining poles and zeros. 7 values are written
                          and then 3 spaces are left blank, see example
                          below.
```

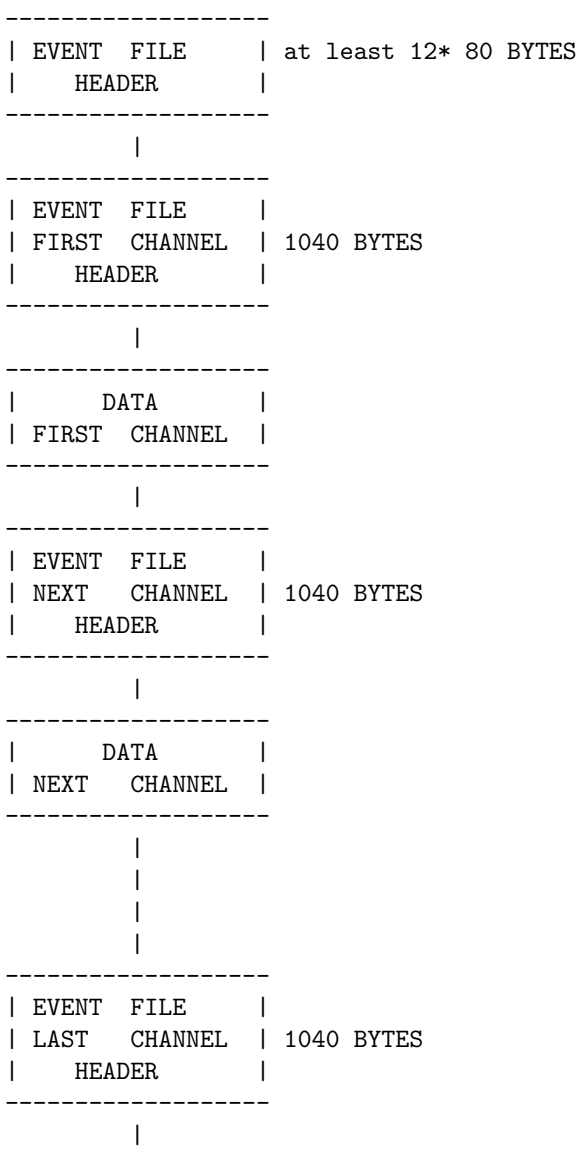
For each pole or zero, there are two real numbers representing the real and imaginary part of the pole or

zero, thus the number of poles is half the number of values written. First all the poles are written in pairs of real and imaginary parts, then follow the zeros. There is room for a total of 37 poles and zeros (74 pairs). The poles and zeros are written in a simulated line mode to make it easier to read, thus the 3 blanks after writing 7 values. It is assumed that the response is in displacment with units of counts/m.

```
SLR  L  E 86 199  7 18 15  6 35.960   1.000   1320                          4P

    11    5  .2760E+11  .3770      .1830      .3770      .1830      .6540
  .0000       .2320      .0000      .2320      .0000      .2320      .0000
  .3280       .0000      .3280      .0000      .3280      .0000      .2140E 01
  .0000       .2140E 01  .0000      .0000      .0000      .0000      .0000
  .0000       .0000      .0000      .0000      .0000      .0000
```

NOTE: The component information in character 6 IS VERY IMPORTANT. It MUST be A if an accelerometer is used, any other character assumes a velocity transducer. This is only relevant however if option 1 is used where response values will be calculated from the free period etc. If option 1 with discrete values or poles and zeros are used, the first component character can be anything.



```
-------------------
|      DATA       |
| LAST   CHANNEL  |
-------------------
```

To write a SEISAN file: If main headers are called mhead, channel header chead, data is data (integer), there is nchan channels and each has nsamp samples, then the file is written as

```
Do i=1,12
  Write(1) mhead(i)
Enddo
Do k=1,nchan
  Write(1) chead
  Write(1) (data(i),i=1,nsmap)
Enddo
```

This example only works up to 30 channels when writing main header. For more channels, see e.g. program SEISEI how to do it.

Details of binary file structure

When Fortran writes a files opened with "form=unformatted", additional data is added to the file to serve as record separators which have to be taken into account if the file is read from a C-program or if read binary from a Fortran program. Unfortunately, the number of and meaning of these additional characters are compiler dependent. On Sun, Linux, MaxOSX and PC from version 7.0 (using Digital Fortran), every write is preceded and terminated with 4 additional bytes giving the number of bytes in the write. On the PC, Seisan version 6.0 and earlier using Microsoft Fortran, the first 2 bytes in the file are the ASCII character "KP". Every write is preceded and terminated with one byte giving the number of bytes in the write. If the write contains more than 128 bytes, it is blocked in records of 128 bytes, each with the start and end byte which in this case is the number 128. Each record is thus 130 bytes long. All of these additional bytes are transparent to the user if the file is read as an unformatted file. However, since the structure is different on Sun, Linux, MacOSX and PC, a file written as unformatted on Sun, Linux or MacOSX cannot be read as unformatted on PC or vice versa. . The files are very easy to write and read on the same computer but difficult to read if written on a different computer. To further complicate matters, the byte order is different on Sun and PC. With 64 bit systems, 8 bytes is used to define number of bytes written. This type of file can also be read with SEISAN, but so far only data written on Linux have been tested for reading on all systems. This means that version 7.0 can read all earlier waveform files on all platforms from all platforms. However, files written on version 7.0 PC cannot be read by any earlier versions of Seisan without modifying the earlier seisan version. In SEISAN, all files are written as unformatted files. In order to read the files independently of where they were written, the reading routine (buf_read in seisinc, in LIB) reads the file from Fortran as a direct access file with a record length of 2048 bytes. The additional bytes are thrown away, the relevant bytes fished out and swapped if the file is written on a different computer than where it is read. Since there is no information stored in the header of the file giving the byte address of each channel, the routine must read the first file-header, calculate how many bytes there are down to where the next channel starts, jump down and repeat the process until the desired channel is reached (this is also how SUDS files are read). However, compared to reading the file as unformatted, only a fraction of the file is read to fish out a particular channel. Once the channel header has been read, the start address is stored in the subroutine so any subsequent access to that channel is very fast. Overall, random access to SEISAN waveform files is much faster with the binary read than the previous (version 5.0 and earlier) unformatted read. Only in the case where the whole file is read is the unformatted read faster.

PC file structure Up to and inluding version 6.0	Sun and Linux file structure PC structure from version 7.0
----------	----------

```
one byte: K indicates start of file             4 bytes: # of bytes following
----------------------------------------        ----------------------------
one byte: # of bytes following                  one block of data
----------------------------------------        ----------------------------
128 bytes or less of data                       4 bytes: # bytes in prev. write
----------------------------------------        ----------------------------
one byte: # of bytes in previous record         4 bytes: # of bytes following
----------------------------------------        ----------------------------
one byte: # of bytes in following record        one block of data
----------------------------------------        ----------------------------
128 bytes or less of data                       ........
.....                                           ........
.....                                           ........

For 64 bit systems, the above 4 byte numbers are 8 byte numbers.
```

From version 7.0,the Linux and PC file structures are exactly the same. On Sun the structure is the same except that the bytes are swapped. This is used by SEISAN to find out where the file was written. Since there is always 80 characters in the first write, character one in the Linux and PC file will be the character P (which is represented by 80) while on Sun character 4 is P.

Appendix C

Response file formats used in SEISAN

SEISAN can use either SEISAN response format or GSE response format or SAC response format or RESP response format. The detailed SEISAN format is given here as well as the parts of the GSE format and SAC format used in SEISAN. Please see the SEED manual for details on the RESP response file format.

See also chapter 5.2.2.

C.1 SEISAN response format

There are three SEISAN response formats. The instrument response can either be presented as (1) instruments constants, (2) pairs of frequency amplitude and phase or as (3) poles and zeros.

```
Line 1
   1     5: STATION CODE (A5)
   6     9: COMPONENT (A4), E.G. SZ L : SZ LOW GAIN, AN: ACCELERATION NS
  10      : CENTURY, 0: 1900, 1:2000
  11    12: YEAR
  14    16: DOY
  18    19: MONTH
  21    22: DAY
  24    25: HR
  27    28: MIN
  30    35: SECOND (F6.3)
  52    59: LATITUDE (F8.4), optional
  61    69: LONGITUDE (F9.4), optional
  71    75: ELEVATION (METERS), optional
  78      : P: Poles and zeros
            Blank: Seismometer period etc used for response info. See below for
                   details.
            T: Use up to 30 tabulated values irrespective of what is given
               below. If less than 30, blank characters must be given.
  79      : C: a combination of table, poles and zeros or instrument
               constants have been used, for information only. Value in 78
               must then be T.
            F: Force use of header response. Only
               gain at 1 hz is correct and 78 must be set to T.

Line 2
   1   80: COMMENT LINE DESCRIBING THE SYSTEM RESPONSE (A80)
```

```
OPTION 1

If character 78 is blank, option 1:

Line 3
  1 - 80: (10G8.3)   1. SEISMOMETER PERIOD
                     2. FRACTION OF CRITICAL DAMPING
                     3. SEISMOMETER GENERATOR CONSTANT (V/m/s) or
                        ACCELEROMETER SENSITIVITY (V/G)
                     4. AMPLIFIER GAIN
                     5. RECORDING MEDIA GAIN (I.E. 2048 COUNTS/VOLT)
                     6. GAIN AT 1.0 HZ, UNITS: COUNTS/METER
                     7. CUTOFF FREQUENCY FOR FILTER1 (HZ)
                     8. # OF POLES FOR FILTER1 (NEGATIVE FOR HIGHPASS)
                     9. CUTOFF FREQUENCY FOR FILTER2 (HZ)
                    10. # OF POLES FOR FILTER2 (NEGATIVE FOR HIGHPASS)

Line 4
  1 - 80: (10G8.3) FREQUENCIES AND #'S OF POLES FOR FIVE MORE FILTERS


Lines 5-13: RESPONSE CURVE in 3 blocks of 3 lines
  1 - 80: (10G8.3) FREQ.
  1 - 80: (10G8.3) AMPL. (REL. 1.0 HZ)
  1 - 80: (10G8.3) PHASE,

The are only for info in option 1


OPTION 2
If character 78 is T, use tablated values, format as in option 1


OPTION 3
If character 78 is P, option 2:

Line 3
  1 - 22:   (1X,2I5,G11.4) 1. NUMBER OF POLES
                           2. NUMBER OF ZEROS
                            3. NORMALIZATION CONSTANT, COUNTS/M
  23 - 80 (5G11.4)         2 Poles in pairs of real and imaginary parts

Lines 4-13
  1 - 80: (G11.4) Remaining poles and zeros. 7 values are written
                           and then 3 spaces are left blank.
```

Example of SEISAN FAP response file

```
KBS  B  Z100   1  1  1  0  0  0.000

360.    .700    .260E+04  0.    .419E+06.684E+10  0.       0.000  0.       0.000
  0.        0.00  0.        0.00  0.        0.00  0.        0.00  0.        0.00
.500E-02.700E-02.980E-02.140E-01.190E-01.270E-01.370E-01.520E-01.730E-01.100
.480E-02.694E-02.978E-02.140E-01.190E-01.270E-01.370E-01.520E-01.730E-01.100
 138.366 123.400 113.340 106.128 101.813  98.283  96.034  94.289  93.054  92.229
```

```
.140    .200    .280    .390    .550    .770    1.10    1.50    2.10    2.90
.140    .200    .280    .390    .550    .770    1.10    1.50    2.10    2.90
  91.592  91.114  90.796  90.571  90.405  90.289  90.203  90.149  90.106  90.077
4.10    5.80    8.10    11.0    16.0    22.0    31.0    43.0    60.0    85.0
4.10    5.80    8.10    11.0    16.0    22.0    31.0    43.0    60.0    85.0
  90.054  90.038  90.028  90.020  90.014  90.010  90.007  90.005  90.004  90.003
```

Example of SEISAN PAZ response file using the same constants as above

```
KBS  B  Z100   1  1  1  0  0  0.000                                          P

     2    3 0.1089E+10-0.1222E-01 0.1246E-01-0.1222E-01-0.1246E-01     0.
     0.         0.         0.         0.         0.         0.         0.
     0.         0.         0.         0.         0.         0.         0.
     0.
```

C.2 GSE response format

Below is an example of a GSE response file generated by RESP for the same parameters as used for the SEISAN file above. The GSE response format is rather complex, and can contain parts that will not be understood by SEISAN.

Below follows an example of the GSE response using FAP. The first line gives station and sensor type. The numbers following are gain in nm/c (0.15) at reference period (1. seconds), sample rate (20) and date. The following line (FAP2) gives a gain factor (1.) and the output units (V for Volts). Finally follows the frequency, gain and phase triplets.

```
CAL2 KBS   B Z      STS-1    0.15E+00      1.   20.00000 2003/ 1/ 1  0: 0
FAP2  1 V               60
    0.00500  0.48047733E-02  138
    0.00590  0.57846815E-02  130
    0.00700  0.69361408E-02  123
    0.00830  0.82667302E-02  117
    0.00980  0.97841555E-02  113
    0.01200  0.11995634E-01  108
    0.01400  0.14000172E-01  106
...
   60.00000  0.59999992E+02   90
   71.00000  0.70999992E+02   90
   85.00000  0.84999992E+02   90
  100.00000  0.99999985E+02   90
```

In the poles and zero representation, the file looks like:

```
CAL2 KBS   B Z      STS-1    0.15E+00      1.   20.00000 2003/ 1/ 1  0: 0
PAZ2  1 V  0.26000000E-05               2   3 Laplace transform
 -0.12217305E-01  0.12464144E-01
 -0.12217305E-01 -0.12464144E-01
  0.00000000E+00  0.00000000E+00
  0.00000000E+00  0.00000000E+00
  0.00000000E+00  0.00000000E+00
DIG2  2  0.41900000E+06    20.00000 quanterra
```

The first line is the same as before. The PAZ2 lines has the following meaning: Normalization constant of seismometer and filter (0.26e-5), number of poles and zeroes (2 and 3), and the type of response (Laplace transform). The DIG2 line has the gain of amplifier and AD converter combined (0.419e6 c/V) and sample rate.

In the simplest case, the response is given by the PAZ and a scaling factor. It is common (like in SEED) to have two scaling constants, one that normalizes the PAZ to amplitude 1 at a calibration period, and another constant that gives the amplitudes in the physical units. This is NOT the case with the GSE2 format. The GSE2 response for PAZ normally contains at least two parts, the CAL2 line and a PAZ2 line. The scaling factor should scale the PAZ to output/input units, NOT normalize. In the CAL2 line, the system sensitivity at a calibration period is given in units input/output, but is generally not needed. The total response is given by the PAZ, multiplied with the PAZ2 scaling factor, or the product of several stages.

This is how SEISAN reads the response, however, if it finds that the PAZ2 gives normalized values at the calibration period, the response is multiplied with the sensitivity given in the CAL2 line (this is done because such GSE files have been seen).

FIR filters can be specified in GSE as an additional stage and can be written out by the RESP program. An example is given below. The FIR filter coefficients are required to completely describe the instrumentation. However, they are not used in SEISAN.

```
FIR2 3 0.10E+01 3 0.030 A 180
0.18067658E-06 0.88848173E-06 0.24195760E-05  0.37699938E-05 0.32037496E-06
 -0.18581748E-04 -0.69605186E-04 -0.16990304E-03 -0.32499805E-03 -0.51408820E-03
 -0.68242848E-03 -0.75194239E-03 -0.65436028E-03 -0.37627667E-03  0.94138085E-05
0.35409257E-03 0.49653835E-03 0.35531260E-03 -0.29224902E-05 -0.37382543E-03
...
```

C.3 SAC format

Below is an exampel of the SAC response file format. Note that if zeros are zreo, there is no need to write them. The response must be in displacment with unit meters.

```
ZEROS 3
POLES 4
-0.0123  0.0123
-0.0123  -0.0123
-39.1800  49.1200
-39.1800  -49.1200
CONSTANT 3.832338e+12
```

Note that the response file names must follow SEISAN response file file names with SAC at the end like e.g. KEV__B__Z.2000-10-10-0000_SAC.

C.4 RESP format

The RESP files are obtained from a SEED file by the rdseed program when the R flag is set. See the chapter 41.3 for details.

Note: RESP files will not include all metadata stored in the SEED file, e.g. a rotation of the horizontal channels.

Appendix D

Some general subroutines in SEISAN in LIB

Subroutines in SEISAN are located in different files and it is not always easy to find what is available. Consequently there are some duplication. The following is a list of some of the commmon routines and their location. Very technical routines have not been listed. Some much used routines are not listed since they are found together in a file like routines for waveform handling in `LIB/wave.for`. There are also many routines in main programs which might be useful, they are not listed here. Most entries are subroutines but there are also a few functions. See also `INF/seisan.all` for a list of all subroutine files in `LIB`.

Table D.1: Statistics

Name	Description	Location
r4sort	sorting	tau
r8sort	sorting double precision numbers	hypoloc1
hpsort	sorting	general
qsort	sorting	quarrycheck
mdian	calculate median	general
sei rand	random number generator	general
lin_interp	linear interpolation	genenral
lsqlin	linear regression	lsqlin
sdv	standard deviation	lsqlin
maxlik	maximum likelihood linear fitting	maxlik
fit	least squares with chi square	general

Table D.2: Numerical

Name	Description	Location
integrate	integration based on trapezoid rule	auto_proc
rtr	remove linear lsq trend	auto_proc
differentiate	differentiate	auto_proc
char_fu	calculate characteristic function	auto_proc
normalize_signal	normalize a signal	auto_proc
bcd	bcd byte to number	bcd
bndpas	butterworth filter, time domain	bndpas
recfil	many filter types, type domain	recfil
bworth	butterworth filter, freq. domain	sys_resp
pazresp	poles and zeros reponse	sys_resp
mpolys	multiply two polynomials	recfil
ctpoly	CONVERT ROOT DESCRIPTION TO POLYNOMIAL DESCRIPTION	recfil
bessel	generate bessel system function	recfil
delip	matrix normalization	delip
xy_ellipse	ellipsoide error and the orientation from the north	err_ellipse
ellipse_x	major axis lengths and orientations from covariance matrix	err_ellipse
fft	fft	fft
reakft	ftt real numbers ??	sig_spec
real2fft	two dim fft ??	sig_spec
four1	ftt ??	sig_spec
dyadic	calculate dyadic of eigenvectors	fmap_subs
matsum	calculate matrix sum	fmap_subs
remove_dc	remove dc	remove_dc
rotate	rotate matrix	remove_dc
rotate	rotate a 3-vector represented in cartesian coordinates	hyposub1
scmxmn	extremal values of the time series	sacsubf
jacobi	eigenvalues and eigenvectors of a real symmetric matrix	sacsubf
eigsrt	sorts the eigenvalues	sacsubf
eigen	eigenvalues and eigenvectors of a real symmetric matrix	hyposub2
GMPRD	matrix multiplication	focmec_exe_sub
imtql2	find eighe values and vectors	focmec_exe_sub
dec_to_bin	convert real number to binary	ga_lib
bin_to_dec	convert binary to decimal number	ga_lib
minv	svd of partial derivative matrix	hyposub2
polos	finds if point inside a polygon	polos
qdis	pythagorean distance calculation	quarrycheck
smooth	smooth data	sig_spec
prepare	pad and taper	sig_spec
taper	taper	sig_spec
precoh1	azimuth and vel. from 3 comp .	sig_spec
cross	cross correlation	sig_spec
crosscorr	————	sig_spec
cor_time	————, time domain	sig_spec
cor_freq	————, freq ——	sig_spec
correl	correlation ???	sig_spec
rotate_comp	signal rotation	sig_spec
check_clipped	check if clipped signal	sig_spec
check4gap	find gaps in data	sig_spec
svbksbx	solves the equation A * X = B	svd
svdcmpx	—— complex ??	svd
svdvar	covariance of a matrix	svd
lubksbx	linear equation problem ???	svd
ludcmpx	———— ???	svd
pythag	pythagoras ???	svd

Table D.3: Character handling

Name	Description	Location
SEI UPC	convert any lower case to upper	libsei
upper	convert to upper case	quarrycheck
trimlen	characters in string, ignore blank	quarrycheck
trimbeg	first not blank char in string	quarrycheck
text_to_array	read numbers in text string into integer array	ga_lib
casefold	convert to capital	codecoutil
ucase	lower case to upper case	hyposub1
lcase	upper case to lower case	hyposub4
SEI LEFT	left justify a text string	libsei
SEI CLEN	lenght of text string	libsei
r_index	find character in text, starting search from last character	libsei
swap4	swap 4 byte data	swap
swap4_one	swap 4 byte data, one value	swap
swap2	swap 2 byte data	swap
swap2_one	swap 2 byte data, one value	swap
text_sort	sort text strings	text_sort
check_whole	check string for spaces	isf_isc

Table D.4: Input output see also rea and wave

Name	Description	Location
SEI CMD PRO	get text from input	libsei
SEI CMD SET	get argument from command line, possibely execute it	libsei
SEI GET FILE	open file in current or alt. directory	libsei
SEI GET VALUES	get values from input string	libsei
SEI INTEGER	get integer from a text string	libsei
SEI OPEN	open file on next availabel unit	libsei
get_seisan_def	read SEISAN.DEF	libsei
file_ready	check if file is opened already and wait until it is closed	libsei

Table D.5: SEISAN specific

Name	Description	Location
iasp91_filename	set name of iasp91 files	general
topdir	get top dir name	general
get_env_op	get operator id	general
get_operator	——— interactively	eev_sub
get_env_event	get event name	general
put_env_event	put event name	general
put_env_base	put base name in memory	general
put_env_seistop	put seisan top ———	general
put_env_op	put operator id ——-	general
get_env_base	get base name from —-	general
get_env_cal	get alt. CAL dir ——	general
get_def_base	get def. base ———	general
get_env_string	get any string ———	general
put_env_string	put any string ———	general
put_seisan_message	put a seisan message	seis_mes
get_seisan_message	get a seisan message	seis_mes
get_agency	get agency from ——-	general
send_plot	send plot to laser	general
dir_char	directory separation char	general
uncompress	check if file is compressed and uncompress	general
sort_event	sort an s-file acor. to distance	general
get_agency_hyp	return agency in station file	general
get_baz	calculate station back azimuth for stations in waveform header	get_baz
component	convert from 2 to 4 char component	componen
findchan	find channel number corresponding to a station and component	findchan
filename	get filename seisan way	filename
init_networ	start UDP communication	network
send_udp_message	send UDP message	network
get_udp_message	receive UDP message	network
close_network	close UDP communication	network
ms_sleep	sleep function	networtk
number_of_events	count number of events in a CAT file	general

Table D.6: S-files see rea for general routines

Name	Description	Location
check_s	check s-file for erros	check_s
read_s_file_e	open and read s-file, close, for eev	check_s
write_s_file_e	write s-file, ——-	check_s
auto_tr	get trace file names from s-file	auto_tr
auto_filename	———————	autofil
findevin	finds an event in list of events	findevin
get_fstart	find start of s-file name and check name	findevin
merge_f	merge two s-files	merge_f
nortype	find if compact or normal d-file	nortype
rea_xxx	different routines	rea
sfilname	make s-file name	sfilname
stat_loc	find coordinates of a given station	stat_loc
stat_loc_many	——— of many stations	stat_loc

Table D.7: Timing rotines

Name	Description	Location
abstim	converts a data base timestring to abs time	abstim
etoh	epoch time to human time	sacsubf
htoe	calendar date to epoch time since January 1, 1970	sacsubf
dtoepo	convert julian date to epoch time	sacsubf
julian	calculates julian day	codecoutil
mnthdy	YEAR and DOY, return MONTH and DAY	sacsubf
systime	get system time	systime
datetimex	get date and time	systime
TIMSEC	time in year to double precision seconds after 1.1.0000	timerout
SECTIM	seconds after 1.1.0000 to date and time	timerout
DTE	day-of-year to date (month,day)	timerout
TIMDIF	time-difference in seconds of two two input dates and time	timerout
TIMADD	Adds seconds to date, and returns the new date	timerout
MONTH_DAY	number of days in a month from month and year	timerout
leap_year	find leap year	timerout

Table D.8: General seismological

Name	Description	Location
autoamp	peak to peak amplitde and period	autoamp
find_coda	find signal duration	auto_proc
auto_coda	————————	auto_coda
compute_brune	calcualte brune spectrum	auto_proc
freq_event_type	determine if local or distance ev.	auto_proc
m0dcf	decompose moment tensor into various representations	fmap_subs
pcnts	percentages of double-couple, CLVD & iso in seismic source	fmap_subs
m0find	find scalar moment	fmap_subs
ptfind	find P & T vectors	fmap_subs
mtsrce	set up moment tensor components from input moment tensor representation	fmap_subs
fpsol	calculate strike, dip & slip of fault solutions from the P & T vectors	fmap_subs
plaz	calculate plunge & azimuth of eigenvectors in degrees	fmap_subs
mdcmp	calculate components of an arbitrary moment tensor	fmap_subs
AN2DSR	dip, strike and rake - A&R convention from A and N	focmec_exe_sub
AN2MOM	moment tensor element from A and N	————————
ANTPIN	other representations of fault planes	——
DSRIN	————————————-	————————
PTTPIN	———————— from T and P	————————
GDMOT	ground displacement of incident P	——
grndmtn	vertical and radial grond disp. amp.	————————
mb_att	mb attenuation curves veith et all	m_att
mbb_att	———————— gutenberg-richter	———
plot_foc	plotting focal mechanism	plot_foc
fps_gap	find az gap in polarity data	plot_foc
fps_gap_all	find az gap in polarity and amplitude data	plot_foc
p_t_gap	calculate difference in P and T axis between two fault plane solutions	eev_sub

Table D.9: Coordinate handling

Name	Description	Location
fold	geographic to geocentric coordinates	hyposub1
unfold	geocentric to geographic coordiantes	hyposub1
cvrtop	convert from rectangular to polar coordinates	hyposub1
delaz	calculate the distance in km and azimuths	hyposub1
distaz	angular distance, azimuth and back-azimuth between two points	hyposub1
cart	geographical location to geocentric cartesian coordinates	hyposub1
geog	geocentric cartesian coordinates to a geographical location	hyposub1
latlon	Find a point on a sphere at a given distance and azimuth from an. point	hyposub1
azibazi	calculate distance, azimuth and back azimuth	azibazi

Table D.10: Plotting, see seiplot for most general routines

Name	Description	Location
fcircl	Plot a filled circle	plot_foc
draw_circle	draw a circle	plot_foc
draw_triangle	draw a triangle	plot_foc
xy_plot	general xy-plot	xy_plot
xy_plot_line	make a line in xy_plot	xy_plot

Table D.11: Waveform handling, see wave for most general routines

Name	Description	Location
seisinc	read a seisan format file	seisinc
shead	make seisan waveform channel header	shead
sheads	——main and channel heders	sheads

Table D.12: Routines for logging

Name	Description	Location
get_log_file_name	This subroutine creates the name of the log file from the name of the sfile	seisan_logging
create_log_file	This subroutine creates a log file (is it does not exist), name=sfilename.LOG	seisan_logging
show_log_file	This subroutine sends the content of the logfile to the screen	seisan_logging
sfile_to_log_file	This subroutine adds the sfile to the end of the log file	seisan_logging
move_log_file	This subroutine add actions to the log file	seisan_logging
get_log_time	This subroutine returns a string used to timestamp the log	seisan_logging
message_to_log_file	This subroutine added a message in the logfile	seisan_logging
pick_to_log_file	This subroutine adds the character used to pick phases etc.	seisan_logging
string_to_log_file	This subroutine add a string to the logfile	seisan_logging

Appendix E

Changelog

This appendix list the changes that have been added to SEISAN since version 8.2.
Please note that most changes are also notes in the header of the source code.

E.1 Changes in the SEISAN version 11 (2018-06-07)

- SEISAN EXPLORER has seen a major upgrade with the location interface and the integration with MULPLT. It is now possible to work with picking phases in MULPLT and immdiately see the results in the location window. In addtion there are other major changes.
- Bug in MULPLT Continous on screen has been fixed, the bug was introduced in version 10.5
- MSCUT: Can now be used to cut large miniseed files into files with a shorter duration in minutes, where 60 modulo duration is equal to zero.
- EEV has new options: ste and std for setting and unsetting start flags, ep to see the print.out file
- EEV can plot fault plane solution on a map option MAPF
- Include program MOPAD to plot moment tensor solutions, option fm in EEV
- A new program PLOTFOC to plot fault plane solutions from a CAT-file without need for relocating event. Also in EEV with command 'foo'.
- A new option in EEV to compare the P and T axis of two fault plane solutions, fd
- A new version of the AUTO program that can run anyone or a combination of the programs AUTOPHASE, AUTOPIC, HYP, AUTOMAG, AUTORATIO, FPFIT and HASH in loop of many events
- FOCMEC has been updated with the latest FOCMEC program from Snoke and it can now used relative polarity weight and has a better treatment of amplitudes near nodal planes. The old version can still be used (f_old) in EEV.
- A new sample program, SAMPLE_READ_WRITE_S_C, writen in c++, can read and write S-files in C++ and provides a structure with all the variables.
- An updated Seisan_explorer with graphical locate interface.
- Specctrograms can be made from MULPLT or with program SPECTROGRAM, see section 8.13.
- A new progrm MAP which runs EPIMAP without questions, only the input file.
- A new progrm MAPG which makes a map in GMT without questions, only the input file or data base is needed. Also plots fault plane solutions. Also works with command MAPG in EEV.

- New options in EEV: STE: Set or unset start loction, STD. Set or unset start location depth, FIXO: Fix origin time.
- A new program, GET_WEB_LOCATIONs to download hypocenter information from web sites, so far implemented with USGS.
- New magnitude scale MN or mb(Pn/Sn) for Pn and Sn at regional scale is implemented.

E.2 Changes in SEISAN version 10.5 (2016-11-18)

- GMAP: The color and width of the error ellipses can now be set, see page 188
- MULPLT multi trace mode: A label is now showing the id of the OP and the last action and the id of the OP preforming the action. The label is not shown if MULPLT_MULTI_LABEL is zero in MULPLT.DEF
- MULPLT multi trace mode: If one right click on station/channel code, MULPLT will now select all stations/channels plotted above, if one did not left click on one of the station/channels above.
- MULPLT: If NSORT_DISTANCE is set in MULPLT.DEF, all stations are plotted in distance order after epicenter, subsidiary after location of station with first phase pick.
- GMAP: Fix bug setting default MSIZE, fix bug when sorting event id Q
- Logging: One can now turn logging off; set `SEISAN_LOGGING` to 0.0 in `SEISAN.DEF`
- FOCMEC can generate theoretical amplitudes and polaritites for testing.
- A new program, COMPARE_HYP has been added. The program compares hypocenters and magnitudes from two data sets of idential evenrs and calculates average differences. Used e.g. to evaluate effect of changing a model or location program.

E.3 SEISAN version 10.4.1 (2016-06-08)

- Fixing reading of SEED files on Windows
- Updating the sfiles is now possible from MULPLT, option appears after locate command
- A new section has been added to the manual regarding response files
- The order of which a respose file is found has been changed. SEISAN will now first look for a SEED RESP file that is valid for the selected data, before it looks for a matching SEISAN/SAC/GSE response file. Previously, SEED RESP files was checked last. The change in order is due to the addition of SEED network and location codes and sinces RESP files include an expiere date, which SEISAN/SAC/GSE response files does not.
- DATASELECT added to distribution (see SUP folder), DATASELECT is replacing MSROUTER since IRIS is no longer supporting MSROUTER (to use DATASELECT see page 67).

E.4 SEISAN version 10.4 (2016-03-31)

- SEISAN can now also read SEED real numbers, but not write SEED real numbers
- HYP has a new option for finding and eliminating travel time outliers, EEV commands lr and ur
- Logging of MULPLT continuous mode, see page 130
- Logging of EEV commands:(see page 98)

  - When comment is inserted (COM command)
  - When event is registered (REG or PUT command)
  - When event is updated (UPDATE command)
  - When event is duplicated (DUP command)
  - When event is moved or copied to another database (C command)
  - When event type is changed (R command)
  - When sfile has been edited (E command)
  - When event is deleted (D command)
- Iasp command in MULPLT use local model
- Iasp all available waveform channels used
- Definition of virtual networks for archive in SEISAN.DEF
- Call to (external) spectrogram from MULPLT (command 'E')
- GSERESP2SEED added to distriburion
- MSROUTER added to distribution
- New option in CODAQ and new coda Q analysis program
- GET_STAT command to print station coordinates
- New Locator in SEISAN EXPLORER
- Update CODAQ
- New program to analyze coda Q results, QSTAT
- AUTOREG now runs with flag to set location model indicator
- Magnitude calculation has changed a bit in terms of distance limits, so a few magnitudes might have changed
- New program GET_ARC to extract waveform files from an archive based on S-files and add the waveform name to the S-file.
- New option arx in EEV to use GET_ARC
- New program ARC_DEL that will remove ARC lines in sfiles
- New option arcdel in EEV to use ARC_DEL
- New option in EEV to add ARC lines in sfiles for virtual nets, see ARC _
- New options in EEV to enter one of a set of fixed comments, command ic.
- New command in EEV to fix, unfix of enter fixed depth, fix
- Mulplt command u for rotate is now U.
- MULPLT can now go from one station to the next in three channel mode.
- New command in EEV to plot in single channel mode using all defaults, poo.
- New programs to convert Nordic input to simulps and simulr
- New version of WAVFIX that accept all SEISAN used waveform formats and write out in MiniSeed

E.5 SEISAN version 10.3 (2015-01-17)

Changes since version 10.1:

- Latest version of HYPOINVERSE now works
- new version of CODAQ which can work weithe severl data sets

NOTE: Version 10.2 was only distributed under Windows so most changes to version 10.2 are also changes to 10.3

E.6 SEISAN version 10.2 (2014-09-20)

Changes since version 10.2:

- Changes to program AUTOMAG to refine grid search
- New program GETSTRESSDROP to extract and analyse stress drops for S-files
- Seitrain and Seisan tutorial now include SeisanExplorer
- SeisanExplorer can make a simple waveform plot
- SeisanExplorer plots time of day distributions, see page 52
- Program LSQ can now also plot histograms
- Program P_ALIGN can now time shift with respect to both P or S phases, see page 237
- A few minor bugfixes
- A major problem with SE and spectral values fixed
- Latest version of Hypoinverse now works

Note: Version 10.2 was only relased for Windows.

E.7 SEISAN version 10.1 (2014-06-19)

Changes since version 10.1:

- Plot picture files from EEV with command pp. Try with earthquake on June 3rd 1996 in TEST base. Files are in PIC or local directory. A new linetype P is used in S-file for the file name. In SEISAN.DEF PLOT_PICTURE_COMMAND must be set.
- Plot pdf files from EEV with command pp. Files are in PIC or local directory. A new linetype P is used in S-file for the file name. In SEISAN.DEF PLOT_PDF_COMMAND must be set.
- A new command em in EEV will edit an ISO file listed in the S-file.
- A new program plotspec, called from EEV with command ps, will plot all spectra made with AUTOMAG in EEV. Bad fits can be deleted interactively.
- MULPLT will select possible arc channels before reading them.
- Q correction in most programs have been changed to optionally be frequency independent set q0 for f below a given frequency, usually 1 Hz.
- New Perl script (textttmerge_seisan.pl) to associte CAT files, many new options compared to ASSOCI and ASSOCIATE.

- Program LSQ can now also plot curves from xy-data.
- A new program ISCCSVC2NOR to convert ISC CSV catalog data to Nordic format.
- WAVETOOL: new option to convert station and channel names of miniseed files
- Data in SeisComP archives with quality make M, R or E, is now read, if D is not present

E.8 SEISAN version 10.0 (2013-06-11)

Changes since version 10.0:

The main change is the SeisanExplorer has been more intgrated with SEISAN and can be used with many new functions. Other changes are:

- New program to make automatic spectra and amplitudes, AUTOMAG, also used in EEV, based on AUTOSIG.
- New program: RDSEED2SEISAN - use it to get SEED metadata into SEISAN
- Program DELS to deelte par of S-file, like all S-readings. Als option form EEV
- MULPLT can use arrows to scale amplitudes
- Options in EEV to plot Ml as a functions of distance and seismic moment as a function of arrival time
- New and improved CLUSTER program
- new program ASSO for events association, also use magnitude as a criteria, mainly for seismic hazard
- R command in EEV can now be used to rename event type (L, R or D) and to change event ID e.g. LE or LP (use LB for blank)
- All programs using the REA data base carnb now work back to year 0000
- MULPLT changes: new parameter in MULPLT.DEF to fix the filter, set a center station for muplt_area option, set output format for Out option
- New options in EEV-MULPLT to deal with archives, particularly the use of wild cards. In S-file there is no longer a differenciation between, SCP and BUD, both are now called ARC and the archive type is given in SEISAN.DEF
- filenr.lis file now up to 99999 files
- New sample program sample_resp_correction

E.9 SEISAN version 9.1 (2013)

Changes since version 9.1:

- Chad Tabant's seed read and write routines are now used in all programs.
- Dregers moment tensor inversion integrated with SEISAN.
- Compilation has been simplified with the integration of DISLIN and Libmsed into the seisan distribution.
- New option in SPEC(no plot, used for batch).
- New conversion program HINOR, Hypoinverse archive format to NORDIC.
- Several programs in SEISAN reads Guralp gcf format.

- Several programs in SEISAN read Helberger format (used for MT inversion).
- MULPLT can now, for the first time, write out any processed signal seen on the screen (option `OutW`).
- Filter routiens gave been reorgnized giving more options (see MULPLT section on filters).
- MULPLT can overlay channels.
- MULPLT can select many channels in multitrace mode by left and right button mouse click.
- MULPLT can plot files in a file of files via EEV, LIST option.
- MULPLT can select only to plot stations for plotting in a given distance from a point, usually the epicenter.
- SELECT has a new option for selecting data for CODAQ.
- GMAP new option: automatic plotting of epicenters in Google Earth, see page 188.
- GMAP: Error ellipses are implemented.
- CODAQ output results in at station-evetn midpoints
- CODAQ_area: new program to sort CODAQ out put in areal bins.
- JSEISAN has been removed.
- SeisanExplorer, a new graphical interface to replace EEV and JSEISAN, distributed separately.

E.10 SEISAN version 9.0.1 (2011)

Changes since version 9.0.1:

- Fixed some minor bugs in version 9.0.
- New options and changes in EEV: IFP: Input munually fault plane solution, INPUTFPS: input complete fault plane solution line, COML: Input geographical location line, COMF: Input felt event comments, U: Update event (was UPDATE, UP: Update event list (was U), M: Input model indicator on header line.
- program FOC now also makes rose diagrams.

E.11 SEISAN version 9.0 (2011)

Changes since version 9.0:

- New compiler and graphics system for Windows: This is the largest change. Windows now uses Gfortran and gcc and the graphics library is DISLIN. This has stabilized the graphics on Windows end enabled to use the same compiler on most platforms. However, the gfortran on Windows has created new problem in some programs most of which probably has been solved.
- SEISAN can now extract and plot data from a BUD and a SEISCOMP archive, read more at page 12.
- EEV has several new options: CM: Copy many files, DD: Duplicate header, FH: HASH fault plane solution, FP: FPFIT fault plane solution, FO: Plot all fault plane solutions, IFP: Input munually fault plane solution, INPUTFPS: input complete fault plane solution line, COML: Input geographical location line, COMF: Input felt event comments.
- FOC: A program to plot and analyze fault plane solutions.

- FPFIT: FPFIT fault plane solution program with SEISAN driver program FPFIT_SEISAN.
- HASH_SEISAN: HASH fault plane solution program.
- THIS PROGRAM IS NO LONGER PART OF SEISAN (2018): GETPDE - A new program that grap the PDE from the USGS web page and add the events in a database.
- SEIS2VIEWER - A new program for plotting earthquakes on a map, command smap, see page 197.
- EPIMAP: Can now plot fault plane solutions.
- MULPLT: Has a three component option facilitating working with three component data.
- AVQ: new program to average Q-relations.
- MAG2: new program to invert amplitudes for ML scale.
- Individual size of graphics windows for different programs can now be set in COLOR.DEF.
- The following programs do not work with Gfortran: HYPINV, HYP_ISC, NORHYP, ARCSEI

E.12 SEISAN version 8.3 (2010-06-05)

Changes since version 8.3:

- Manual now written in Latex, html version is available
- Unix setup files were remamed to SEISAN.csh and SEISAN.bash to make them visible
- MULPLT: Plot hour and minute on time axis, show shortcut keys on menu, select picked traces from trace selection, new keyboard shortcuts when reading amplitudes, also shortcut keys for the first 10 traces in trace selection (these changes were put in by Wayne Crawford)
- Two events are now included in the SEISAN software, so that one can plot data after unpacking SEISAN, both events are found by typing `eev 199606 TEST` (Note : in unix one must first source the `COM/.SEISAN` file)
- PINV, new program for estimation of fault plane solution using polarities, see page 329
- 64 bit, have only been tested on Linux
- SEISAN can now use SAC PAZ response as created with rdseed
- code now compiles with gfortran
- AUTOREG has new option for moving waveform file to WAV, see page 224.
- EEV accept SEED orientation codes : A,B,C,1,2,3,U,V,W,S and Z,N,E
- MULPLT orientation code 1 and 2 are read as N and E, respectively. 1 and 2 are used if orientation is different from N and E. (This still requires a more general solution)
- ASCSEI, A bug in in the reading of the input file was found and fixed, the first sample was lost if data was not PSN data.
- ISCNOR : A bug in the reading of surface wave amplitudes was fould and fixed.
- The problem with extracting time windows on the last page in MULPLT continous mode has been fixed, page 130.
- EEV copies the name and path of the current s-file to a file named `eev.cur.sfile`, when the system command `'o'` is used.

- Plot STATION?.HYP and SEISAN polygon files with Google Earth using GMAP, see page 188.
- The Herrmann modeling programs finally work under Windows.
- FOCMEC: Use of amplitudes has been improved and bugs fixed in amplitude section.
- New broadband body wave and surface wave magntudes have been implemented.
- New conversions programs: AHSEI, DIMASSEI, DATABASE2MSEED
- Noise spectra from continuouis data, CONNOI and EVANOI.
- Magnitude implementation has been adjusted to the new IASPEI standard, see table below.

Codes for reporting amplitude readings				
Magnitude	Old SEISAN	ISC	Old IASPEI	NEW IASPEI
Local	AMP AMPL	AML	IAML	IAML
mb		AMB	IAmb	IAmb
mB	AMP AMB AMpb AMb AMPB		IAmB	IVmB_BB
Ms	AMP	AMS	IAMS20	IAMs_20
MS			IAMSBB	IVMs_BB

E.13 SEISAN version 8.2.1 (2008-10-10)

Changes since version 8.2.1:

- Improved handling of continous data bases, particularly with SEED data
- New and expanded training document
- Several bug fixes reported after version 8.2
- Mistakes in manual reported after releases of version 8.2
- More examples of making response files
- Improved filtering in MULPLT by introducing tapering

E.14 SEISAN version 8.2 (2008)

Changes since version 8.2:

- Improved SEED reading and writeing (still not perfect, sometimes problem with Steim2)
- SEED channel naming convention now used
- SAC reading and writing also under windows
- New conversion programs
- Improved WAVETOOL
- SEISEI use all formats for input and SEISAN and MiniSEED for output
- Store waveform data in memory for faster plotting (see MULPLT section, page 125)
- Array processing of teleseismic P- arrival on regional network using plane wave approach, PFIT
- Plot of arrival times using EEV
- Epicenter plotting using GoogleMap or GoogleEarth (program GMAP)

- Spectral analysis also of teleseismic events
- Particle motion plot in MULPLT
- In MULPLT from continuous plot with one channel, it is possible to extract out time windows in a data file, page 130.
- SEISAN has been tested on Vista and there are problems with some graphic programs like LSQ.
- EDRNOR, conversion program for USGS parametric data
- GSERESP2SEED, prorgam to create dataless SEED volumes from GSE response files, using GSE2SEED
- QLg program has new features to test effect of noise and source perturbation
- Instructions on how to use SEISAN under Cygwin have been added

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