

Topic	User Manual for HYPOSAT 6 and HYPOMOD 2
Author	Johannes Schweitzer, NORSAR, P.O.Box 53, N-2027 Kjeller E-mail: <a href="mailto:johannes.schweitzer@norsar.no">johannes.schweitzer@norsar.no</a>
Version	June 2018; DOI: 10.2312/GFZ.NMSOP-3_PD_11.1

## Table of Contents

1	Introduction.....	1
2	Getting Started .....	2
3	The File hyposat-parameter .....	4
4	The File hyposat-in .....	29
5	The File hyposat-out .....	32
6	The Program HYPOMOD and the File hypomod-out.....	35
7	References.....	37

---

## 1 Introduction

**HYPOSAT** is a program package developed to locate seismic sources. It utilizes observed onset time, backazimuth (*i.e.*, station-to-event azimuth) and ray-parameter measurements. Seismic phases considered are those included in IASP91-type tables, and in addition reflections from the Conrad or Mohorovičić discontinuities, if local/regional seismic velocity models are used. The program follows the phase name convention as recommended by IASPEI on its General Assembly in Sapporo in July 2003 (*e.g.*, IS 2.1 in NMSOP; Storchak *et al.*, 2003; 2011; Bormann *et al.*, 2013). Additionally, all possible travel-time differences between different onsets at individual stations are estimated and can be included in the location process (*e.g.*, PcP-P as an additional constraint for the source depth). If amplitude and period measurements for P onsets or surface waves are available, individual station and network magnitudes can also be estimated. More details about the general features of the program can be found in Schweitzer (1997, 2001, 2006) and Schweitzer & Kennett (2007). The file *hyposat\_history*, which is part of the program package, contains a listing of the program versions and changes.

The travel-time tables for the global spherical Earth models are based on the tau-spline algorithm (Bulland & Chapman, 1983) as distributed with the IASP91 tables. When implemented, this software had been modified that all tables are platform independent ASCII files. In addition to the original software, diffracted PKPbc and double surface reflections

(e.g., PPP or S'S'S') were included. However, for double surface reflections, at this moment no ellipticity corrections or corrections for the different crustal structures at the reflection points are possible.

The data files containing global spherical Earth models (e.g., *iasp91\_A.tbl* and *iasp91\_A.hed*) and the ellipticity corrections (*elcordir.tbl*) must be all in the same directory. The files containing the attenuation corrections for magnitude estimations (*MB\_G-R.DAT*, *MB\_V-C.DAT* and *MB\_M-R.DAT*) and the list of European seismo-tectonic units (*REG\_L3.DAT*) must also reside in this directory. The path to this directory must be set by the environment variable **HYPOSAT\_DATA**. In **HYPOSAT 6** the now obsolete global 5° x 5° crustal model Crust 5.1 (Mooney *et al.*, 1998) was exchanged with the global 1° x 1° model Crust 1.0 of Laske *et al.* (2013).

The program needs two input files in ASCII format. One file contains the general parameters to steer the inversion process (*hyposat-parameter*) and the other file contains the observed data for the event to be localized (*hyposat-in*). Contents and structure of these files will be explained in the following sections.

The program **HYPOMOD** uses the same input files as **HYPOSAT**, but it calculates all the residuals for a given hypocenter, the observations and a set of parameters without any inversion.

The newest versions of the programs (including source code, this manual, the PDF version of Schweitzer (1997), data files containing travel-time models and station parameters, and several examples) are available in two compressed files (*hyposat.version.tar.gz* and *hyposat.version.zip*) for free download from NORSAR's anonymous ftp-address *ftp.norsar.no* under the directory */pub/outgoing/johannes/hyposat*. The address when using your web-browser is: <ftp://ftp.norsar.no/pub/outgoing/johannes/hyposat>. Questions related to program updates and maintenance should be directed to the author.

The software was developed and tested for the Fortran compiler gfortran on both 32- and 64-bit LINUX PCs. The software can also be compiled in a SUN (Solaris) environment, but this will no longer be supported or tested. If you have a Fortran and a C compiler on your WINDOWS PC, the attached LINUX scripts need some adaptations, respectively. The software was also tested with Intel's IFORT Fortran compiler in a WINDOWS 10 environment.

All older versions of the software package are no longer supported and obsolete.

## 2 Getting Started

This section describes how some simple examples for **HYPOSAT** can be started and executed. The simplest way to learn to use the program is to start from one of the following examples and modify input data and parameters to fit your needs. The meaning and format of the input is described in the following sections.

Installation of **HYPOSAT** or **HYPOMOD** on a LINUX machine:

1) Make a directory for **HYPOSAT**, copy the compressed file containing the *hyposat-software package* and run:

```
gunzip hyposat.version.tar.gz
```

```
tar -xvf hyposat.version.tar
```

or

```
unzip hyposat.version.zip
```

depending on the module you have downloaded.

Then you will have a directory containing the following files and subdirectories:

```
bin/    data/    examples/  man/  README  src/
```

The file *README* contains a complete list of all files following with the installed **hyposat-software package** and an explanation of these files.

- 2) If you need to recompile the software, this can be done in the *src/* subdirectory by executing the C-shell script:

```
make_hyposat
```

This will install both **HYPOSAT** and **HYPOMOD** on your computer in the *./bin* subdirectory and in addition in the directory defined as by the **DEST** environment variable, which can be changed in *make\_hyposat*.

- 3) Executing **HYPOSAT**:

Change to the subdirectory *examples/*.

Here you will find input-file examples for four different cases: an event observed with a network of stations (*.net*), a single array (*.single\_array*), a set of local and regional stations (*.regional*), and a teleseismically observed event (*.tele*). **HYPOSAT** runs with two principal input files. To check your installation, try *e.g.*, the following:

```
cp hyposat-in.net hyposat-in
cp hyposat-parameter.net hyposat-parameter
setenv HYPOSAT_DATA $path/hyposat/data
```

(where *\$path* is the actual path to your directory for **HYPOSAT**)

and execute:

```
../bin/hyposat
```

You will then get two output files *hyposat-out* and *hyposat-isf*, which should be identical to the files *hyposat-out.net* and *hyposat-isf.net* distributed with the **hyposat-software package**. You can then also check the other examples or execute some of the provided C-shell scripts. The example files contain only a subset of all possible parameter settings and data input. In the following chapters, possible settings and input data are described in detail.

### 3 The File *hyposat-parameter*

The file *hyposat-parameter* contains the inversion-steering parameters. The file must reside either in the actual directory where the program is executed or in the directory as defined by the environment variable **HYPOSAT\_PARA**. If the parameter file has another name than *hyposat-parameter*, this name including its whole path name must be defined by the environment variable **HYPOSAT\_PARA**.

The order in which all parameters are set is arbitrary. The parameters (bold-faced) must be written in the file in upper case letters! The settings themselves must follow after the 37th character of each line (*i.e.*, two characters after the mandatory colon). Whenever a line does not comply with this rule, it will be ignored (*e.g.*, blank lines or comment lines starting with a '\*', ...). This file is read only once at the beginning of a location run. Each line can be repeated several times within the file with another setting. In this case, the last set value is used for the location process. For file names, the full path name can be given.

Several of the parameters are only applicable in special cases and without any effect in many other cases. They contribute to the flexibility of the program for different applications, but the user should check carefully, what is at the end really needed for each actual case and what can just be ignored or not set. See also the examples in *examples/*.

**HYPOSAT** and **HYPOMOD** can read (and write) data either from files formatted in its own format or in the International Seismic Format (ISF) as defined by the Commission of Seismological Observation and Interpretation of IASPEI. This format is compatible with the format used by the International Monitoring System (IMS) of the CTBTO for its bulletins. Some of the parameter settings in the *hyposat-parameter* file are only related to i/o of ISF formatted files.

In the following all allowed parameters are explained in detail:

```
----- start of an example for a hyposat-parameter file -----
---

*      hyposat-parameter file for HYPOSAT 6.
*
* Any blank line or lines starting with a '*' are ignored.
*
* All default values are set by the program at start.
*

*
* Event source solution author: a free character string with
* maximum 10 characters
*
AUTHOR OF SOLUTION                               : HYPOSAT
```

```

*
**** SEISMIC VELOCITY MODEL RELATED PARAMETERS
*   (TRAVEL-TIME TABLES)
*
*
* GLOBAL MODEL: Type of the reference spherical velocity model
* used to calculate all travel-time related theoretical data.
* This package contains the following models:
*
*   ak135_A      AK135 model (Kennett et al., 1995)
*   iasp91_A     IASP91 model (Kennett, 1991; Kennett &
*                 Engdahl, 1991)
*   iasp91a_A    IASP91, with a corrected core model
*   jb_A         Jeffreys-Bullen model (Jeffreys & Bullen,
*                 1940 and later)
*   prem_A       PREM model (Dziewonski & Anderson, 1981)
*   sp6_A        SP6 model (Morelli & Dziewonski, 1993)
*
* Some additional, regional spherical Earth models with
* different crusts and uppermost mantle layers were also
* implemented in the HYPOSAT software package:
*
*   barey_A      BAREY, regional model for the European Arctic
*                 (Schweitzer & Kennett, 2007)
*   barez_A      BAREZ, regional model for the European Arctic
*                 (Schweitzer & Kennett, 2007)
*   barents16_A  BARENTS16, regional model for the western
*                 Barents Sea (Pirli & Schweitzer, 2017)
*   bergen_A     University of Bergen's velocity model for
*                 Norway (Havskov & Bungum, 1987)
*   fescan_A     NORSAR's Fennoscandia model (Mykkeltveit &
*                 Ringdal, 1981)
*
* The directory, where these travel-time tables reside, must
* be specified with HYPOSAT_DATA before the program can start.
* The travel-time tables are based on the libtau-software
* package (Buland & Chapman, 1983), and distributed as
* IASP91-software.
*
* All global travel-time models using the libtau-software were
* recalculated for the HYPOSAT package, stored in ASCII format
* and got the suffix '_A' in their table names.
*
* The default global model is 'ak135_A'
*
GLOBAL MODEL                                : ak135_A
*
* Alternative spherical Earth models can be used for specific
* paths:

```

```

*
* GLOBAL MODEL 2: Here one can give the name of any other
* second global model to be used for specific ray paths as
* indicated in the data input file hyposat-in.
*
GLOBAL MODEL 2                               : ak135_A

*
* GLOBAL MODEL 3: Here one can give the name of any other
* third global model to be used for specific ray paths as
* indicated in the data input file.
*
GLOBAL MODEL 3                               : ak135_A

*
* GLOBAL MODEL 4: Here one can give the name of any other
* fourth global model to be used for specific ray paths as
* indicated in the data input file.
*
GLOBAL MODEL 4                               : ak135_A

*
* That HYPOSAT can apply crustal corrections, the seismic
* velocities in the crust must be known for the chosen
* dominant global model (set with GLOBAL MODEL). The crustal
* structures of all libtau-type models are collected in a file
* called std_crusts.dat and marked with a unique code. This
* file must reside in the same directory as defined by
* HYPOSAT DATA. std_crusts.dat is included in the directory
* data/. The different codes are:
*
*   E1      Jeffreys-Bullen (global standard model)
*   E2      PREM      (global standard model)
*   E3      IASP91     (global standard model)
*   E4      IASP91a    (global standard model, with corrected
*                      core)
*   E5      SP6        (global standard model)
*   E6      AK135      (global standard model)
*   E7      FESCAN     (regional standard model)
*   E8      BAREY      (regional standard model)
*   E8      BAREZ      (regional standard model)
*   EA      BARENTS16  (regional standard model)
*   EB      BERGEN     (regional standard model)
*   The default value is 'E6' (for AK135)
*
GLOBAL CRUSTAL MODEL CODE                     : E6

*
* In the case of an ISF-formatted input file, no alternative
* spherical Earth models can be defined. Instead, an
* epicentral distance in [deg] can be defined, from which

```

\* distance on **GLOBAL MODEL 2** should be used. As epicentral  
 \* distance the value from the ISF-formatted input file is  
 \* used.

\*

\* The default value is '999.' = no 2nd model usage with ISF  
 \* input.

\*

**ISF\_2ND MODEL DISTANCE** : 999.

\*

\* **HYPOSAT** can combine global velocity models with an  
 \* epicentral distance dependent **LOCAL OR REGIONAL MODEL**.  
 \* Travel times will be calculated for the following seismic  
 \* phases (as far as they can be observed with respect to  
 \* distance and source depth): Pg, Pb, Pn, P, pPg, pPb, pPn,  
 \* pP, PbP (*i.e.*, in this program the upper side reflection  
 \* from the 'Conrad'), PmP, PgPg, PbPb, PnPn, PP, and the  
 \* converted phases sPg, sPb, sPn, sP, SbP and SmP. The same  
 \* set of phases is also calculated for S-type phases,  
 \* respectively.

\*

\* If the file is not in the run-directory or the directory  
 \* defined by **HYPOSAT\_DATA**, one must give the full file name  
 \* including its path.

\*

\* Set to '\_' if no local model is used.

\*

**LOCAL OR REGIONAL MODEL** : \_

\* Local/regional travel-time models are either used around the  
 \* source and/or to calculate travel-time corrections for  
 \* reflection points of phases at the Earth's surface or for  
 \* crustal differences between the dominant global model and  
 \* the actual structure at the stations (velocities &  
 \* elevation). The input is the name of the file containing the  
 \* model parameters. The velocity model must contain the  
 \* following information:

\*

\* In the first line maxdis = maximum distance in [deg] for  
 \* which this model shall be used. It is followed by lines with  
 \* depth in [km], the P-phase velocity Vp in [km/s], and the S-  
 \* phase velocity Vs in [km/s]. The model may contain layers  
 \* with a constant velocity or with velocity gradients. First  
 \* order discontinuities must be specified with two lines for  
 \* the same depth. Additionally, the Conrad- and the  
 \* Mohorovičić-discontinuities must be marked as shown in the  
 \* following example. Otherwise, all calculated phases would be  
 \* called Pg (or Sg, respectively). The maximum number of  
 \* layers is set to 100.

\*

```

---example for a file containing a regional velocity-----
10.          | maxdis in free format
    0.000      5.400      3.100      | depth, vp, vs in format (3F10.3)
    10.000     5.800     3.200
    20.000     5.800     3.200CONR    | + mark for the 'Conrad'
    20.000     6.500     3.600        | in format (3F10.3,A4)
    30.000     6.800     3.900MOHO    | + mark for the 'Moho'
    30.000     8.100     4.500
    77.500     8.050     4.400
    120.000    8.100     4.500
-----end of example-----

```

```

*
* When using the local/regional model for calculating
* local/regional travel-time tables and their partial
* derivatives, one can define the seismic phase types to be
* considered by a 4-digit number code: The position of a digit
* defines the phase type for which the value of the digit
* defines the action for this phase:
*
* dxxx      the digit (d) at this place is the flag for
*            surface reflections (e.g., pP or sS)
* xdx       the digit (d) at this place is the flag for
*            surface multiples (e.g., PP or SS)
* xxdx      the digit (d) at this place is the flag for
*            reflections at the Conrad- or the Mohorovičić-
*            discontinuity (e.g., PbP or SmS). Note that here
*            the name 'PbP' is used to indicate reflection
*            from the Conrad discontinuity, is not a regular
*            phase name as recommended by IASPEI (e.g.,
*            NMSOP-2, IS 2.1).
* xxxd      the digit (d) at this place is the flag for
*            converted phases (e.g., sP or PmS)
* d          itself can have the following values:
* d = 1      only P-type onsets will be calculated
* d = 2      only S-type onsets will be calculated
* d = 3      both phase types (P and S) will be calculated
* e.g., 1320 means:
*            the phases pP, PP, SS, SbS and SmS will be
*            calculated, but no conversions.
* 0000 or simply 0 means:
*            only the direct P- and/or S-onsets, but none of
*            the reflected and/or converted phases will be
*            calculated.
*
* The default value is set to '3333' and for any value below
* 0, the program will ignore the local/regional model set by
* LOCAL OR REGIONAL MODEL.
*
PHASE INDEX FOR LOCAL MODEL          : 3333

```

```

*
* The following settings are steering the usage of the 1x1

```



```

* degree crustal model CRUST 1.0 of Laske et al. (2013)
* together with the other local/regional velocity models.
*
* <= 0      no usage of CRUST 1.0 or LOCAL OR REGIONAL MODEL
*           (default)
* = 1       only the local/regional model is used as defined
*           in LOCAL OR REGIONAL MODEL.
* = 2       CRUST 1.0 only used for calculating travel-time
*           corrections at stations and for surface
*           reflections (e.g., PnP, sS, P'P',...).
* = 3       CRUST 1.0 is used to calculate travel times to
*           stations with a maximum distance of 1.5 degrees
*           from the source.
* = 4       combines options (3) and (4).
*
CRUST 1.0      (0/1/2/3/4)          : 0

*
* If set, the applied local/regional model around the source
* is listed at the end of the output file hyposat-out.
*
OUTPUT OF REGIONAL MODEL    (DEF 0) : 0

*
* Set VERY LOCAL GEOMETRY if all the stations are within an
* epicentral distance of less than about 50 km and a
* LOCAL OR REGIONAL MODEL is given.
*
* If VERY LOCAL GEOMETRY is set, the ray-tracing algorithm is
* adjusted for denser ray coverage to calculate the travel
* times for the different local/regional phases and no
* ellipticity corrections for the travel times are applied.
*
VERY LOCAL GEOMETRY    (DEF 0) 0/1 : 0

*
* The program can use different types of surface waves, for
* which mean group velocities can be set as e.g.:
*
RG GROUP-VELOCITY    (DEF 2.5  km/s) : 2.5
LG GROUP-VELOCITY    (DEF 3.5  km/s) : 3.5

LQ GROUP-VELOCITY    (DEF 4.4  km/s) : 4.4

LR GROUP-VELOCITY    (DEF 3.95 km/s) : 3.95

*
* Infrasound onsets and T-phases can also be included. Onset
* times of these phases are not well defined, but mean group
* velocities can be used to identify such onsets.
*

```

```
*
* Infrasound mean group velocity
*
IS PHASE GROUP-VEL (DEF 0.33 km/s) : 0.33

*
* T-phase mean group velocity
*
T PHASE GROUP-VEL (DEF 1.4 km/s) : 1.45

*
* The model uncertainty can be defined as the mean uncertainty
* of the travel-time table.
*
* The default value is no model uncertainty ('0').
*
INCLUDING MODEL UNCERTAINTY (0/1) : 0

*
* The uncertainties can be given separately for P and S phases
* in [s], but are assumed to be distance independent and equal
* for all phases of the same type (P or S).
*
* The uncertainties will be used to calculate ray parameter
* and distance dependent uncertainties for the different
* observations, which will be added to the calculated standard
* deviations of the source parameters after the last
* iteration.
*
* The default values are set to 0.01 s for both P and S
* phases.
*
MEAN P-WAVE MODEL UNCERTAINTY [s] : 0.01
MEAN S-WAVE MODEL UNCERTAINTY [s] : 0.01

*
**** STATION RELATED PARAMETERS
*

*
* Definition of the file containing the station coordinates.
* Two formats are supported: CSS3.0 and PDE. The file format
* is detected automatically. To get the location results
* faster, the usage of a file containing only the actually
* used stations is recommended.
*
* The default file name is 'stations.dat'
*
STATION FILE : ./stations.dat
```

```

*
* Defines if station corrections (elevation, crust) will be
* applied. By default, this is switched on '1'.
*
STATION CORRECTIONS      (DEF 1) 0/1 : 1

*
* Global velocities in [km/s] for elevation corrections can be
* set here:
* All values below 0.001 and above 99. km/s are ignored and
* the AK135 values are used as default.
*
* If S-VELOCITY TO CORRECT ELEVATION is set to 0. and
* P-VELOCITY TO CORRECT ELEVATION is defined earlier, the
* S-VELOCITY TO CORRECT ELEVATION is calculated by
* P-VELOCITY TO CORRECT ELEVATION divided by sqrt(3.).
*
*P-VELOCITY TO CORRECT ELEVATION      : 99.1           > AK135
*S-VELOCITY TO CORRECT ELEVATION      : 99.1           > AK135
*P-VELOCITY TO CORRECT ELEVATION      : 5.56           JB
*S-VELOCITY TO CORRECT ELEVATION      : 3.37           JB
*
P-VELOCITY TO CORRECT ELEVATION      : 5.80           AK135
S-VELOCITY TO CORRECT ELEVATION      : 3.46           AK135

*
* Fixed station corrections or local velocities at stations
* can be added in a file and will be used to correct for
* elevation or timing errors. Corrections are separate for P
* and S waves. This value can also be used to correct for a
* known velocity anomaly below a station. The input is format
* free. If such information is not available, leave it blank.
* If a station is not in this list, the default values as
* defined by the input parameters
* P-VELOCITY TO CORRECT ELEVATION and
* S-VELOCITY TO CORRECT ELEVATION are used
*
STATION CORRECTION FILE              : _

--example for an ASCII file containing station corrections ---
*
* This is a file containing values to calculate corrections
* for the listed stations only
*
* All lines starting with a star '*' are ignored.
*
* Minimum input:
*
* Station name and local P and S velocities to calculate
* elevation effect

```

```

*
*      vp  vs
*GERES 5.2 3.2
*
* Optional input (e.g., to correct for results from
* tomographic studies or clock errors):
*
* Static corrections for P and S body waves
*
*      vp  vs  dtp  dts
*GERES 5.2 3.2 0.0 0.0
*
* Additonal static corrections for surface waves
*
*      vp  vs  dtp  dts  dtsurface
*GERES 5.2 3.2 0.0 0.0 0.0
*
GERES 5.2 3.2 0.0 0.0 0.0 | in free format

```

----- end of example-----

```

*
* If the station corrections in the STATION CORRECTION FILE
* file are only valid for the 1st onsets of the P or S phase
* (as e.g., if calculated with velest), this switch must be
* set to '1'.
*

```

```

* By default, the station corrections are used for all onsets
* from the particular station.
*

```

```

STATION CORR ONLY 1ST PHASE (0/1) : 0

```

```

*
* In the case of a very local geometry, stations may be
* located below the surface (e.g., in mines). Then one must
* set this switch to '1'.
*

```

```

* The default value is '0'.
*

```

```

LOCAL STATION BELOW SURFACE (0/1) : 0

```

```

*
* Maximun and minimum epicentral distance of stations to be
* considered during the inversion. Both distances are by
* default in [deg]. But if the inversion output is set to [km]
* with OUTPUT IN KM (see below), both MIN EPI DIST OF STAT and
* MAX EPI DIST OF STAT are also in [km].
*

```

```

MIN EPI DIST OF STAT (DEF 0 deg) : 0.
MAX EPI DIST OF STAT (DEF 180 deg) : 180.

```

```

*
**** SOURCE RELATED PARAMETERS
*
*
* The program has different ways to calculate a preliminary
* epicenter and source time. This can be steered with
* different parameters. In any case, any value given directly
* as initial value, will overwrite all estimated values.
*
* The following parameters are defining an initial solution
* including its uncertainties:
*
* Source time:
*
* To set an initial source time the allowed formats are:
*   Epochal time (= seconds since 01/01/1970 00:00:00)
*   allowed is any number larger than -2840140800.0
*   (= default = 1 January 1880)
*
* or (seconds can be omitted):
*   yyyy-doy:hh.mi.ss.sss      (doy = Day of year)
* or
*   yyyy-mm-dd:hh.mi.ss.sss
*
* Any time earlier than the default value will be ignored.
*
* STARTING SOURCE TIME : 1970-001:00.00.00.000
* or
* STARTING SOURCE TIME : 1970-01-01:00.00.00.000
* or
* STARTING SOURCE TIME (EPOCHAL TIME): 0.
* STARTING TIME ERROR [s] : 10.0
*
*
* If no STARTING SOURCE TIME is set, an initial source time
* will be estimated from the travel-time differences between
* direct S-type and direct P-type observations by using
* Wadati's approach (Wadati, 1933). For this, the program
* calculates mean Vp/Vs ratios for each phase type and
* estimates a source time, respectively. The phase types
* (Pg & Sg, Pb & Sb, Pn & Sn, P & S) are identified with help
* of the global model AK135. The initial source time is then
* the mean value of all estimated source times. In the case of
* only one S-P observation, the Vp/Vs ratio is set to  $1.72 = \sqrt{3}$ .
* If no S-P time observation is available, the source
* time is set to the earliest observed onset time.
*
* The Wadati approach can be steered by the length of the

```

```

* allowed S-type - P-type travel-time differences.
*
MIN DT FOR WADATI      (DEF 0. s) : 0.
MAX DT FOR WADATI      (DEF 150. s) : 150.

*
* Depth:
*
*
* Set source depth, the default depth is 0. +/- 20. km
*
STARTING SOURCE DEPTH      [km] : 0.
STARTING DEPTH ERROR      [km] : 20.

*
* The allowed depth range can be set. At this moment, the
* program does not allow any sources with negative depth (=
* models with topography above the sea level, see also
* DEPTH ALLOWED ABOVE 0).
*
MINIMUM DEPTH              (DEF 0. km) : 0.
MAXIMUM DEPTH              (DEF 800. km) : 800.

*
* Flags steering the depth determination during inversion
*
* f (or F) = fixed depths at STARTING SOURCE DEPTH
* d (or D) = a new depth is determined from the beginning
*             for each inversion step.
* b (or B) = both, the inversion starts with a fixed depth
*             and when an epicenter is found, the inversion
*             continues with inverting also for the depth.
* By default this flag is set to 'F'.
*
DEPTH FLAG                  (f,b,d,F,B,D) : F

*
* Epicenter:
*
*
* If backazimuth observations are available from several
* stations, these data are used to calculate an epicenter by
* calculating the possible crossing points of these different
* observations. A start epicenter including its uncertainties
* is then calculated as mean value of all crossing points and
* their spread.
*
* If possible and no backazimuth observations are available,
* the program tries a plane-wave fit through first P-wave
* onsets at all stations to get an azimuth direction to the

```

```
* epicenter. Then if possible, S - P travel-time differences
* are used to estimate an epicentral distance and a start
* epicenter is calculated.
*
* By default, this option is switched on '1'.
*
PLANE WAVE APPROX                (0/1) : 1
*
* Latitude:
*
* Allowed range -90 - +90 degrees; all other values are
* ignored.
*
STARTING SOURCE LATITUDE        [deg] : 999.
STARTING LATITUDE ERROR        [deg] : 10.
*
* Longitude:
*
* Allowed range -180 - +180 degrees; all other values are
* ignored.
*
STARTING SOURCE LONGITUDE      [deg] : 999.
STARTING LONGITUDE ERROR      [deg] : 20.
*
* The ISF solution (or only parts like epicenter and/or depth)
* can be used as start (and reference) solution.
*
* By default, both flags are switched off '0'.
*
ISF EPICENTER                  (0/1) : 0
ISF DEPTH                      (0/1) : 0
*
**** GENERAL INVERSION PROCESS STEERING PARAMETERS
*
*
* The maximum is set by default to 80 iterations
*
MAXIMUM # OF ITERATIONS                : 80
*
* The iterations stop when two consecutive solutions are
* separated less than the given accuracy in [km].
*
LOCATION ACCURACY                  (DEF 1. km) : 0.5
*
* Confidence level of modelled uncertainties in [%]
```

```
* probability. The default value is 68.3 % (i.e., +/- 1
* standard deviation)
*
CONFIDENCE LEVEL (68.3 - 99.99 %) : 95.

*
* In some cases, the inversion result is oscillating between
* two or more solutions. The following parameter defines how
* many iterations back we search for such oscillations. The
* maximum number allowed is 15; the default value is 4.
*
# TO SEARCH OSCILLATIONS : 4

*
* In the case that the mean residuum of all defining travel
* times is unequal 0., the source time can be corrected to
* compensate for this mean shift.
*
* By default, this option is switched on '1'.
*
MEAN T-T RES. CORREC (0/1) : 1

*
* The last iteration can constrain the solution by
* concentrating on the most trustable/important data. Five
* different cases are implemented:
*
* 0 = default, no final constraining
* 1 = final constraining of the solution by removing data
* with larger residuals
* 2 = final constraining by removing unimportant data as
* defined by the Information Density Matrix (see GMI
* theory)
* 3 = case 1 & 2
* 4 = case 1 with fixed max residuum (default 30 s)
* 5 = case 4 & 2
*
CONSTRAIN SOLUTION (0/1/2/3/4/5) : 4

*
* Additional parameter needed for the cases 2, 3, 5 of
* CONSTRAIN SOLUTION:
*
* All data with Information Density matrix diagonal-element
* entries smaller than this threshold are not used. The
* threshold is calculated as ratio between actual Information
* Density Matrix entry and the entry with the maximum value.
* The default is 0.005 = 0.5 % of the most important datum.
*
INF. DENSITY MATRIX THRESHOLD : 0.005
```



```

*
* Additional parameters needed for the cases 4 and 5 of
* CONSTRAIN SOLUTION:
*
MAXIMUM ALLOWED P RESIDUUM (DEF 30): 30.

MAXIMUM ALLOWED S RESIDUUM (DEF 30): 30.

*
* The MAXIMUM AZIMUTH ERROR allowed value: 90. deg
MAXIMUM AZIMUTH ERROR (DEF 45) : 45.

* The MAXIMUM SLOWNESS ERROR in [s/deg!] allowed value:
* 15. s/deg.
MAXIMUM SLOWNESS ERROR (DEF 5) : 5.

*
* The reading uncertainty of a seismic onset follows not a
* Gaussian distribution. HYPOSAT can use two different
* standard deviations (STD) for the onset time to weight
* travel-time data residuals, depending on the sign of the
* residuum (always observation - calculation). The first STD
* will then be used for positive and the second STD for
* negative residuals. For more details see Schweitzer (2006).
*
* 0 = default, no 2nd STD
* 1 = reading of 2nd STD from input file (see the
* hyposat-in description)
* 2 = 2nd STD is STD * DBLE SID. ERROR FACTOR
*
DOUBLE SIDED TIME ERROR (0/1/2) : 2
DBLE SID. ERROR FACTOR : 0.5

*
**** STEERING THE USAGE OF OBSERVATIONS
*
*
* Onset time observations and phase names:
*
*
* If an event location should be only based on P-type onsets
* one sets this here.
*
* By default, this is switched off '0'
*
P-TYPE ONSETS ONLY (0/1) : 0
*

```

\* The usage of phase names SG and LG is not always consistent.  
 \* Following the IASPEI recommendations for seismic phase  
 \* names, **HYPOSAT** assumes LG to be a surface wave with a given  
 \* group velocity (see **LG GROUP-VELOCITY**).

\* The following parameter settings can be used to homogenize  
 \* the input by automatically changing the phase names for all  
 \* SG or LG observations.

\* By default, both options are switched off '0'.  
 \* If both flags are set to '1', they will be both ignored.

**LG-PHASE TO SG** (0/1) : 0  
**SG-PHASE TO LG** (0/1) : 0

\*  
 \* If one wants to use both the travel times of SG-type onsets  
 \* as body-waves and LG onsets as surface waves, it can make  
 \* sense to separate these two phases by the epicentral  
 \* distance.

\* If the following distance in [km] has a value above zero,  
 \* this epicentral distance is used as separation between SG  
 \* and LG.

\* Then, all LG are renamed to SG if the epicentral distance is  
 \* shorter and all SG are renamed to LG if the epicentral  
 \* distance is equal or larger than this distance.

**SG--LG DISTANCE** (DEF -999. km) : -999.

\*  
 \* By default, **HYPOSAT** uses travel-time differences between  
 \* different onsets at the same station as additional  
 \* constraint. This can be switched off '0'

**FLAG USING TRAVEL-TIME DIFFERENCES** : 1

\*  
 \* **(Back)azimuth (BAZ) observations:**

\* The backazimuth (BAZ; azimuth from station to epicenter)  
 \* information is by default used as defining observation. This  
 \* can be switched off by '0'.

**AZIMUTH AS DEFINING** (0/1) : 1

\* This switch must be set if one wants to use the BAZ

\* observations only for the estimation of an initial solution  
 \* (from crossing BAZ observations) and not for the further  
 \* inversions.  
 \*

**AZIMUTH ONLY INIT SOL** (DEF 0) 0/1 : 0

\*  
 \* If one has many BAZ observations and wants to get a location  
 \* based only on these observations (e.g., several infrasound  
 \* array observations).  
 \*

**AZIMUTH ONLY** (DEF 0) 0/1 : 0

\*  
 \* Defines the maximum allowed travel-time residual for which  
 \* the BAZ is used as defining observation for body waves and  
 \* short-period, regional surface waves.  
 \*

\* The default value is 30 s.  
 \*

**MAX T RES FOR AZI OF B USE** [s] : 30.

\*  
 \* Defines the maximum allowed travel-time residual for which  
 \* the BAZ is used as defining observation for long-period  
 \* surface waves.  
 \*

\* The default value is 180 s.  
 \*

**MAX T RES FOR AZI OF L USE** [s] : 180.

\*  
 \* **Slowness observations:**  
 \*

\*  
 \* The slowness (ray parameter) of an observed onset is either  
 \* defined by its inverse, the apparent velocity in [km/s] or  
 \* as spherical ray parameter in [s/deg]. The program handles  
 \* both, but in one input file (see **hyposat-in**), only one type  
 \* of units can be used.  
 \*

\* By default, and if the input file is in ISF format, the unit  
 \* is set to [s/deg].  
 \*

**SLOWNESS [S/DEG]** (0 = APP. VEL) : 1

\*  
 \* If the slowness observations should not be used as defining,  
 \* one must set this switch to '0'.  
 \*

**SLOWNESS AS DEFINING** (DEF 1) 0/1 : 1

\*

\* Defines the maximum allowed travel-time residual for which  
 \* the slowness is used as defining observation for body waves.  
 \* The default value is set to 15 s.

\*

**MAX T RES FOR SLOWNESS USE** : 15.

\*

\* If the onset times of surface waves should be used as  
 \* defining observations, one must set this switch to '1'.

\*

**LP SURFACE WAVES (LQ/LR)** (DEF 0) : 0

\*

\* When using ISF-formatted files as data input, no  
 \* uncertainties (standard deviations) of the observations are  
 \* given. These values must be set.

\*

\* To define standard deviations of the observed parameters  
 \* based on the reported quality of the onset readings, see  
 \* the ISF/IMS documentation.

\*

\* For higher precision readings (input in milliseconds), the  
 \* values set here are reduced by 20%.

\*

\* For non-P-type onsets, the values given here are doubled.

\*

\* **ISF\_i** and **ISF\_e** are also used to define the quality of an  
 \* onset  
 \* based on the applied uncertainty of the reading during the  
 \* inversion process.

\*

\* Standard deviation for impulsive onset readings:

**ISF\_i** (DEF .1 s) : 0.1

\* Standard deviation for emergent onset readings:

**ISF\_e** (DEF .5 s) : 0.5

\* Standard deviation for other, non-defined onset readings:

**ISF\_o** (DEF 1. s) : 1.

\* Standard deviation for BAZ observations

**ISF\_az** (DEF 20. deg) : 20.

\* Standard deviation for ray parameter observations

**ISF\_slo** (DEF 1. s/deg) : 1.

```
*
* Other input data:
*
*
* If infrasound observations (IS) shall be used as defining
* this switch must be set to '1'.
*
IS-PHASE USAGE                (DEF 0) 0/1 : 0
*
* If the T-phase observations shall be used as defining
* this switch must be set to '1'.
*
T-PHASE USAGE                (DEF 0) 0/1 : 0
*
* General input settings:
*
*
* If the following flag is set, all observations are used
* during inversion according to the setting of TASDR (see
* detailed description in hyposat-in), independently of the
* size of the residual(s).
* By default, this option is switched off '0'.
*
FLAG USING INPUT FIXED        (0/1) : 0
*
* The program can check the input for more than one onset of
* the same phase at one station and reduce these onsets to one
* entry. This option is of particular interest whenever onset
* readings from several sources are merged together to one
* single input file. The reduction (after removing double
* entries) is done by calculating mean onset parameters and
* adding the spread of the different onset parameters (time,
* BAZ and slowness) to the reading uncertainty of this
* observation.
*
* Amplitude/period readings will not be changed.
*
* By default, this option is switched off '0'.
*
FLAG CHECKING MULTIPLE ONSETS (0/1): 0
*
* The maximum time difference between two observations to be
* merged into one new observation in [s].
*
MAX DT FOR MULTIPLE ONSETS (DEF 5.): 5.
```

```

*
**** MAGNITUDE CALCULATION PARAMETERS
*
*
* If the input file hyposat-in contains amplitude/period
* readings, station and network magnitudes can be estimated.
*
* By default, this option is switched off.
*
MAGNITUDE CALCULATION (DEF 0) (0/1): 0
*
* For all magnitude calculations corresponding attenuation
* relations must be provided.
*
* Body wave magnitude mb from first P-type onsets:
*   G-R   = Gutenberg-Richter
*   V-C   = Veith-Clawson
*   M-R   = Rezapour
*
P-ATTENUATION MODEL (G-R/V-C/M-R) : G-R
*
* Surface wave magnitude MS from LR observations:
*   IASPEI = Prague Formula from 1966
*   R-P    = Rezapour-Pearce formula
*
MS-ATTENUATION MODEL (IASPEI / R-P): R-P
*
* Local /regional magnitude ml from S and Lg onsets:
*
*           Model           file name
*           -----
*           Bath            - MLCORR.TABLE
*                           This period depending attenuation
*                           relation (Båth et al., 1976) is in
*                           original only defined for periods
*                           between 0.3 and 1.4 s. The program
*                           accepts period measurements values
*                           between 0.24 s (= 4.16 Hz) and
*                           1.68 s (= 0.595 Hz).
*
*           Richter        - MLCORR.TABLE.wa
*                           The original Wood-Anderson
*                           attenuation curve for California
*                           (Richter, 1935).
*

```

```

*           Richter      - MLCORR.TABLE.wa.nicolas
*                           A Wood-Anderson type curve for
*                           Europe modified from Nicolas et
*                           al., (1982)
*
* Note: 'Richter' ml assumes Wood-Anderson instrument
* simulated amplitude measurements in [mm] and the period
* information is not used.
*
ML-ATTENUATION MODEL                : Bath

*
* Setting the file name (see above), which contains the
* attenuation corrections for the chosen ML-ATTENUATION MODEL.
* The file must be either located in the run-directory, or the
* directory defined by HYPOSAT_DATA, or one has to give the
* full file name including the path information.
*
ML-CORRECTION FILE                : MLCORR.TABLE

*
**** I/O RELATED PARAMETERS
*
*
* Input:
*
* The default data-input file name is hyposat-in.
* Here another file name for the data-input file can be given.
* The default is also used when set to '_' or ' '.
*
INPUT FILE NAME                    : hyposat-in

*
* The hyposat-in format has slightly changed with the new
* HYPOSAT 6. If the input file still follows the old syntax,
* one has to set this flag. The default is '0' for using the
* new syntax.
*
HYPOSAT-IN OLD SYNTAX (DEF 0) 0/1 : 0

*
* Besides data input in HYPOSAT format, HYPOSAT can also read
* ISF (IMS) Bulletin formatted files as data input. The
* input-file name can be either hyposat-in or any other name
* as set with INPUT FILE NAME.
*
* By default, the input is in HYPOSAT format.
*
INPUT FORMAT ISF                  (DEF 0) 0/1 : 0

```

```

*
* Output:
*
*
* Program output is written by default in the file
* hyposat-out, which is also used when input is '_' or ' '.
* This name can be changed.
*
OUTPUT FILE NAME                                : hyposat-out
*
* With this flag any output to a file can be switched off. By
* default set to '1' and the output is written in the file
* defined by OUTPUT FILE NAME.
*
OUTPUT SWITCH                                (DEF 1) 0/1 : 1
*
* The epicentral distance of the observations can be
* calculated in [km] or [degree].
* See also MAX EPI DIST OF STAT and MIN EPI DIST OF STAT.
*
* If setting the flag OUTPUT IN KM, no ISF-formatted file can
* be written (OUTPUT FORMAT ISF is then automatically set to
* '0').
*
* The default output is epicentral distances in degrees '0'.
*
OUTPUT IN KM                                (0/1) : 0
*
* The program can calculate theoretical BAZ and slowness
* values for all observations and write these values in the
* hyposat-out file.
*
* If theoretical values are added to the output file, no
* residuals are calculated and these fields stay empty.
*
* These values are ignored in ISF formatted output.
*
*      0 = default, no output of theoretical values
*      1 = theoretical BAZ are given in output
*      2 = theoretical slowness values are given in output
*      3 = both (BAZ & slowness values) are given in output
*
OUTPUT OF THEO. BAZ+P      (0/1/2/3) : 0
*
* The program can calculate an epicentral error ellipse based

```



\* on the chosen **CONFIDENCE LEVEL** and the estimated hypocenter  
 \* or epicenter uncertainties.

\*

\* By default, this option is switched on '1'.

\*

**EPICENTER ERROR ELLIPSE** (0/1) : 1

\*

\* The primary and secondary azimuthal gaps can be calculated  
 \* for

\* = 0 all defining observations (default)

\* = 1 all observing stations

\*

\* In any case, observations are considered only from stations  
 \* in the allowed distance range (see **MAX EPI DIST OF STAT** and  
 \* **MIN EPI DIST OF STAT**)

\*

**AZIMUTHAL GAP FOR OBSERVATIONS** : 0

\*

\* **HYPOSAT** can also calculate for all identified body-wave  
 \* onsets the corresponding emergence angles at the seismic  
 \* source.

\* This flag is by default switched off.

\*

**FLAG EMERGENCE ANGLE OUTPUT (DEF 0):** 0

\*

\* **HYPOSAT** calculates two types of RMS values: one is the  
 \* traditional RMS of all residuals from defining travel-time  
 \* observations and the other is the RMS calculated from the  
 \* weighted residuals as done at the ISC. Both values are  
 \* listed in the *hyposat-out* file.

\*

\* In the case of an additional ISF-formatted output file (see  
 \* **OUTPUT FORMAT ISF**), the origin line contains only one place  
 \* to write an RMS value.

\* By default, the traditional RMS value is used. If the  
 \* following switch is set, the ISC-type RMS value is written.

\*

**ISC-TYPE ISF RMS** (0/1) : 0

\*

\* The final **HYPOSAT** solution can be compared with a reference  
 \* location, which can be set with the following parameters

\*

\* The default is that no reference location is used '0'.

\*

**REFERENCE EVENT** (0/1) : 0

**REFERENCE SOURCE LONGITUDE** [deg] : -999.

**REFERENCE SOURCE LATITUDE** [deg] : -999.

REFERENCE SOURCE DEPTH [km] : -999.

\*

\* In ISF-formatted files, the listed origins are identified with an author (source). Different authors are allowed but usually one location is identified as primary location.

\*

\* Here the author of the preferred reference location can be set. This location will then be used as reference location and as starting solution for the inversion process.

\*

\* If one wants to use the primary location, independently from the author, one has to give 'PRIME'.

\*

\* If the parameter is set to '\_', just the first origin in the input file is used.

\*

\* e.g.:

\*ISF REFERENCE LOCATION : NOA

\*ISF REFERENCE LOCATION : PRIME

\*ISF REFERENCE LOCATION : ISC

\*

ISF REFERENCE LOCATION : \_

\*

\* **HYPOSAT** can additionally write the location results in an ISF-formatted file. The file name is either *hyposat-isf* or any other name defined by **OUTPUT FILE NAME** with the additional extension *\_isf*.

\*

\* By default ('0'), no ISF-formatted output is written.

\*

OUTPUT FORMAT ISF (DEF 0) 0/1 : 0

\*

\* In ISF-formatted files, Event and Origin Identifications (Ids) can be defined.

\*

\* Event Id:

\* Any integer is allowed between 0 and 999999999. By default, it will be set to 0 (but then the number from an eventually used ISF-formatted input file is used).

\*

ISF EVENT ID : 0

\*

\* An ISF-formatted file can contain several event locations for the same event. The different locations can be separated by Origin Ids. The Origin Id can be any 8-character long string.

\* By default ('\_') **HYPOSAT** uses, if it exists, the Id from the

\* ISF-formated input file.

\*

**ISF ORIGIN ID** : \_

\*

\* Based on the location results and after eventually renaming  
 \* and/or merging onsets, the program can write a new file in  
 \* input format. The file name will be **hyposat-in.rev** or the  
 \* file name defined by **OUTPUT FILE NAME** with the extension  
 \* **\_rev**.

\*

\* By default, this option is switched off.

\*

**FLAG NEW INPUT FILE** (0/1) : 0

\*

\* **HYPOSAT** has different verbosity levels for output on the  
 \* screen during program execution. This level can be defined  
 \* here.

\*

\* If **OUTPUT LEVEL** > 10, the output level for the screen is  
 \* internally calculated and an extra output file  
 \* **hyposat\_gmi.out** is written with additional information about  
 \* the Generalized Matrix Inversion (GMI) results. Then, the  
 \* resolution, covariance, correlation, and the information-  
 \* density matrix will be written out. A definition of the  
 \* matrices can be found e.g., in the text books of  
 \* Menke (1989) or Aki & Richards (1980). The file  
 \* **hyposat\_gmi.out** always contains the named matrices for the  
 \* last inversion. **OUTPUT LEVEL** can be set to the following  
 \* values:

\*

<b>OUTPUT LEVEL</b>	Matrix Output	Output Level on Screen
* 0 - 10	None	0 - 10
* 11	Resolution Matrix	4
* 12	Covariance Matrix	4
* 13	Correlation Matrix	4
* 14	All Three Matrices	4
* 15	"	5
* 16	"	6
* 17	"	7
* 18	"	8
* 19	"	9
* 20	", plus diagonal elements of the Information-Density Matrix	4
* 21 - 29	"	as for levels 11 - 19
* 30	", plus whole Information- Density Matrix	4
* 31 - 39	"	as for levels 11 - 19

\*

\* As default value, the output (verbosity) level '4' is used.  
\*

**OUTPUT LEVEL** : 4

-----end of the *hyposat-parameter* file example-----

## 4 The File *hyposat-in*

**HYPOSAT** needs a file with all the data readings for a specific event: This file has by default the name *hyposat-in*, but another name can be defined in the parameter file *hyposat-parameter*. Be aware that the format of this file has slightly changed in **HYPOSAT 6**. If you have some older formatted files, this has to be indicated in *hyposat-parameter*. The data input file must have the following format:

1. line: any title for event identification of maximum 80 characters (used also in the output-file *hyposat-out*).
2. – (n+1)’th line with the n-observed onsets. This line must (!) be compatible with the following format (FORTRAN):

```
(a5,1x,a8,1x,i4,4(1x,i2),1x,f6.3,1x,f5.3,1x,f6.2,3(1x,f5.2),1x,a7,1x,f6.3,1x,f12.2,1x,f7.2,
1x,a8,1x,f5.2)
```

station name, phase name, year, month, day, hour, minute, second, standard deviation of the onset time, backazimuth, standard deviation of the backazimuth observation, either ray parameter [s/deg] or apparent velocity [km/s] (see **SLOWNESS [S/DEG]** in the file *hyposat-parameter*), standard deviation of the slowness observation in [s/deg] or [km/s], and a seven character long combination of controlling flags. These steering flags (**1234567**) control the usage of the different onset parameters during the inversion and have the following meanings and options:

Position **1** the time reading of this onset can be (**‘T’** or **‘t’**) or not (**‘\_’**) used for the inversion.

Position **2** the backazimuth reading of this onset can be (**‘A’** or **‘a’**) or not (**‘\_’**) used for the inversion.

Position **3** the slowness reading of this onset can be (**‘S’** or **‘s’**) or not (**‘\_’**) used for the inversion.

Position **4** the time reading of this onset can be (**‘D’** or **‘d’**) or not (**‘\_’**) used to calculate travel-time differences as input data for the inversion.

Position **5** the onset time reading of this onset will be (**‘R’** or **‘r’**) or not (**‘\_’**) corrected for the crustal structure below a reflection point at the Earth’s surface by calculating the travel-time difference for the ray path through the crust path in the used global model (as set with **GLOBAL MODEL** in *hyposat-parameter*) and in **CRUST 1.0**.

Position **6** the amplitude and period readings of this onset can be (**‘M’** or **‘m’**) or not used (**‘\_’**) used for magnitude calculations. (Remark: the *hyposat-in* files in older format do not have this flag).

Position **7** if set to **‘2’**, **‘3’**, or **‘4’**, other global, spherical Earth models (as set with **GLOBAL MODEL 2**, **GLOBAL MODEL 3**, or **GLOBAL MODEL 4** in file

*hyposat-parameter*) will be used to calculate the theoretical onset time, the ray parameter, and their partial derivatives for this onset. With any other character at this place the standard global Earth model (see **GLOBAL MODEL** in file *hyposat-parameter*) will be used.

If keeping positions 1 – 7 blank, the flag combination **TASDRM\_** will be used as default value.

Then follow as optional input parameters: the period of the observed onset, the amplitude of the signal in [nm], the signal-to-noise ratio (SNR), an eight-character long arrival id and finally the second standard deviation for the onset time reading (see also **DOUBLE SIDED TIME ERROR** in *hyposat-parameter*).

S-type onsets must always be listed after the corresponding P-type onsets – if not, the travel-time difference between these two onset types (S-P) cannot be used for calculating an initial solution for the source time with the Wadati approach and/or the distance from the corresponding station.

If the type of the P or S onset you have is unknown, you can choose the names **P1** or **S1** to tell the program that you know it is the first P-type or the first S-type onset at this station. Then the program chooses the right phase name depending on the epicentral distance of the observation and the travel-time table.

For each phase name not defined by the applied travel-time model(s), the program searches for the best fitting phase. However, the onset time and ray parameter of such a phase are not used in the inversion, but eventually the backazimuth information!

The values for backazimuth, slowness, period, and amplitude are optional. If backazimuth or slowness values are not available, these places can stay blank or they must be set to -999. or -1..

If an onset time, a backazimuth, or a slowness value is given without its standard deviation the following default values are used: onset time 2 s; backazimuth 30 deg (40 deg for LQ and LR); ray parameter 5 s/deg (any input of an apparent velocity in [km/s] will internally converted to [s/deg]).

The amplitude/period information is only used if both values are larger than 0.

All onsets with a station name starting with the a \* character and lines starting with a blank character are not used.

When using the correct format, an input file may look like the following example:

```
----- example for a hyposat-in file -----
NORTHERN MOLUCCA SEA, 1996 29 June, converted from pIDC's Reviewed Event Bulletin (REB)
*23456789 123456789 123456789 123456789 123456789 123456789 123456789 123456789 123456789 123456789
*aaaa aaaaaaaa iiii ii ii ii ii ff.fff f.fff fff.fff ff.fff ff.fff ff.fff aaaaaa ff.fff fffffffffff.fff ffff.fff aaaaaa ff.fff
WRA P 1996 06 29 00 41 44.700 0.300 331.50 20.00 11.10 1.00 T ASD_M_ 0.300 4.50 97.80 abcdef01 0.10
WRA S 1996 06 29 00 45 48.7 0.600 338.0 20.0 17.0 2.00 T ASD_M_ 0.900 2.00 8.10 abcdef02 0.20
QIS P1 1996 06 29 00 42 12.8 0.300 -999. 0.0 -999. 0.00 T_D_ 35.50 abcdef03 0.10
QIS PcP 1996 06 29 00 45 44.8 0.300 T_D_ abcdef04 0.10
ASAR P 1996 06 29 00 42 16.9 0.300 346.3 20.0 7.1 1.00 T ASD_M_ 0.500 3.40 35.10 abcdef05 0.10
ASAR PcP 1996 06 29 00 45 45.2 0.300 345.1 20.0 2.3 1.00 T ASD_M_ 0.500 2.20 11.50 abcdef06 0.10
ASAR S 1996 06 29 00 46 45.3 0.600 347.6 20.0 20.3 2.00 T ASD_M_ 0.800 3.90 6.10 abcdef07 0.20
WARB P 1996 06 29 00 42 31.2 0.300 339.4 30.0 8.2 2.00 T ASD_M_ 0.700 6.50 8.20 abcdef08 0.10
WARB PcP 1996 06 29 00 45 49.4 0.300 -999. 0.0 -999. 0.00 T_D_ abcdef09 0.10
MEEK P 1996 06 29 00 42 42.7 0.300 -999. 0.0 -999. 0.00 T_ 6.80 abcdef10 0.10
CMAR P 1996 06 29 00 43 09.0 0.300 109.7 30.0 7.8 2.00 T ASD_M_ 0.400 0.60 4.30 abcdef11 0.10
CMAR LR 1996 06 29 00 57 48.7 50.000 110.0 30.0 39.5 2.00 A_M_ 19.360 188.80 abcdef12 25.00
FORT P 1996 06 29 00 43 11.3 0.300 T_ 10.80 abcdef13 0.10
WOOL P 1996 06 29 00 43 15.6 0.300 7.9 30.0 9.9 2.00 T ASD_M_ 0.600 4.10 8.80 abcdef14 0.10
SHK P 1996 06 29 00 43 25.4 0.300 -999. 0.0 -999. 0.00 T_ abcdef15 0.10
STKA P 1996 06 29 00 43 46.8 0.300 323.2 20.0 9.0 1.00 T ASD_M_ 0.600 7.20 8.30 abcdef16 0.10
STKA PcP 1996 06 29 00 46 12.0 0.300 -999. 0.0 -999. 0.00 T_D_ abcdef17 0.10
KSAR P 1996 06 29 00 43 46.7 0.300 177.3 20.0 10.1 2.00 T ASD_M_ 0.700 1.70 7.20 abcdef18 0.10
KSAR LR 1996 06 29 01 04 25.0 50.000 160.0 20.0 46.0 2.00 A_M_ 19.860 40.10 abcdef19 25.00
MJAR P 1996 06 29 00 43 51.9 0.300 357.1 20.0 18.8 1.00 T ASD_M_ 0.550 2.00 abcdef20 0.10
PDY P 1996 06 29 00 46 47.0 0.300 111.2 30.0 6.6 2.00 T ASD_M_ 0.450 4.30 23.80 abcdef21 0.10
ZAL P 1996 06 29 00 47 09.0 0.300 -999. 0.0 -999. 0.00 T_ abcdef22 0.10
ABKT P 1996 06 29 00 48 09.5 0.300 -999. 0.0 -999. 0.00 T_ abcdef23 0.10
*
*NRI P 1996 06 29 00 48 08.7 0.300 195.9 30.0 3.9 2.00 T ASD_M_ 0.750 3.00 11.20 abcdef24 0.10
* Note, the following phase has an irregular phase name! Therefore, we cannot use its onset time
* or slowness for the inversion.
*
NRI x 1996 06 29 00 48 08.7 0.300 195.9 30.0 3.9 2.00 A_M_ 0.750 3.00 11.2 abcdef24 0.10
```

MAW	P	1996 06 29 00 49 01.1	0.300 -999.	0.0 -999.	0.00 T_____					abcdef25	0.10
KVAR	P	1996 06 29 00 49 17.2	0.300 -999.	0.0 -999.	0.00 T_____					abcdef26	0.10
NPO	P	1996 06 29 00 49 31.0	0.300 -999.	0.0 -999.	0.00 T_____					abcdef27	0.10
ARCES	P	1996 06 29 00 49 51.7	0.300 94.5	20.0 4.1	1.00 TAS_M_	0.550	0.80	10.50		abcdef28	0.10
SPITS	P	1996 06 29 00 49 55.9	0.300 116.6	30.0 3.5	2.00 TAS_M_	0.900	3.60	10.40		abcdef29	0.10
FINES	P	1996 06 29 00 50 00.0	0.300 111.2	20.0 5.9	1.00 TAS_M_	0.550	0.60	6.60		abcdef30	0.10
HFS	P	1996 06 29 00 50 28.7	0.300 311.3	30.0 1.5	2.00 TAS_M_	0.750	1.10	3.70		abcdef31	0.10
TXAR	PKPdf	1996 06 29 00 55 42.7	0.300 -999.	0.0 -999.	0.00 T_____					abcdef32	0.10
SCHQ	PKPdf	1996 06 29 00 55 41.2	0.300 -999.	0.0 -999.	0.00 T_____					abcdef33	0.10
DBIC	PKPdf	1996 06 29 00 55 57.1	0.300 -999.	0.0 -999.	0.00 T_____					abcdef34	0.10
PLCA	PKPdf	1996 06 29 00 56 09.1	0.300 311.9	30.0 6.4	2.00 TAS_M_	0.900	0.90	4.40		abcdef35	0.10
LPAZ	PKPdf	1996 06 29 00 56 44.7	0.300 -999.	0.0 -999.	0.00 T_____					abcdef36	0.10

----- end of the *hyposat-in* file example -----

## 5 The File *hyposat-out*

With the previous example for a *hyposat-parameter* and a *hyposat-in* file you will get the following output-file *hyposat-out*: This example was calculated on a LINUX system running Centos7, on other systems the results might be slightly different. Explanations are included in [ .... ]:

-----example for a *hyposat-out* file -----

```
HYPOSAT Version 6.0c

Event solution by HYPOSAT

NORTHERN MOLUCCA SEA, 1996 29 June, converted from pIDC's Reviewed Event Bulletin (REB)

Parameters of initial solution ( 1 standard deviation):

[ Not all backazimuth-observation pairs are used: if one station is more than 170 deg apart from the crossing point, this crossing point is skipped. ]
Mean epicenter calculated from 165 backazimuth observation pairs
Mean epicenter lat: 29.475 42.008 [deg]
Mean epicenter lon: 121.592 6.098 [deg]

[ type 1: S - P or S1 - P1 observation, type 2: Sg - Pg observation, type 3: Sn - Pn observation, type 4: Sb - Pb observation ]
S-P Travel-time difference type 1 with 2 observation(s)
to= 836008582.7 11.6 [s] Vp/Vs= 1.76 0.04
Mean source time: 836008582.700 11.636 [s]
Mean vp/vs: 1.758 0.035

Iterations : 9
Number of defining: 40
Main reference model : ak135_A
Second reference model : iasp91_A

The new source parameters:

Confidence level of given uncertainties: 68.27 %

Source time : 1996 06 29 00 36 42.467 0.090 [s]
or 836008602.467 0.090 [s]
or 1996-181:00:36.42.467 0.090 [s]

Epicenter lat: 1.3946 0.0172 [deg]
Epicenter lon: 126.3036 0.0352 [deg]
Source depth : 0.00 [km] Fixed

Epicenter error ellipse:
Major half axis: 8.03 [km] Minor half axis: 7.93 [km]
Azimuth: 113.1 [deg] Area: 200.11 [km**2]

Flinn-Engdahl Region ( 266 ): Northern Molucca Sea

Magnitudes: 4.4 (mb, G-R) 3.6 (Ms, R-P)

[ Stat - station name; Delta - epicentral distance in [deg] or [km]; Azi - azimuth from epicenter in [deg]; Phase - phase name from hyposat-in: [used]
- program chosen phase name (if not identical with Phase); Onset time - hours, minutes & seconds from hyposat in; Res - travel time residuum in [s];
Baz - backazimuth (from station to epicenter) in [deg]; Res - Baz residuum in [deg]; Rayp - ray parameter of onset in [s/deg]; ray parameter residuum
in [s/deg]; Used - usage of input data as defining; SNR - signal-to-noise ratio; Amplitude - signal amplitude in [nm]; Period - signal period in [s];
MAG - magnitude and magnitude type; Q - onset quality as defined by parameter settings in hyposat-parameter; Em-Ang - emergence angle of seismic onset
at the source in [deg]; ARID - the arrival identification from data input file]
Stat Delta Azi Phase [used] Onset time Res Baz Res Rayp Res Used SNR Amplitude Period MAG Q Em-Ang ARID

WRA 22.623 160.01 P 00 41 44.700 -0.455 331.50 -7.20 11.10 0.48 T S 97.80 4.50 0.300 4.44 mb e 33.64 abcdef01
WRA 22.623 160.01 S 00 45 48.700 -5.776 338.00 -0.70 17.00 -2.31 A 8.10 2.00 0.900 e 36.94 abcdef02
QIS 25.412 149.84 P1 P 00 42 12.800 0.780 T D 35.50 e 28.27 abcdef03
QIS 25.412 149.84 PcP 00 45 44.800 0.186 T D e 6.75 abcdef04
ASAR 25.984 163.93 P 00 42 16.900 -0.312 346.30 3.87 7.10 -1.96 TA D 35.10 3.40 0.500 4.24 mb e 28.19 abcdef05
ASAR 25.984 163.93 PcP 00 45 45.200 -0.694 345.10 2.67 2.30 0.00 T ASD 11.50 2.20 0.500 e 6.88 abcdef06
ASAR 25.984 163.93 S 00 46 45.300 -3.756 347.60 5.17 20.30 4.48 6.10 3.90 0.800 e 29.48 abcdef07
WARB 27.419 179.34 P 00 42 31.200 1.106 339.40 -19.86 8.20 -0.78 SD 8.20 6.50 0.700 4.51 mb e 27.92 abcdef08
WARB 27.419 179.34 PcP 00 45 49.400 0.218 T D e 7.20 abcdef09
MEEK 28.840 194.38 P 00 42 42.700 -0.102 T 6.80 e 27.63 abcdef10
CMAR 31.748 304.00 P 00 43 9.000 0.386 109.70 -9.47 7.80 -1.00 T S 4.30 0.60 0.400 3.88 mb e 27.31 abcdef11
[ The following LR onset was not used because its backazimuth residuum became too large. ]
CMAR 31.748 304.00 LR 00 57 48.700 26.323 110.00 -9.17 39.50 0.45 188.80 19.360 3.88 MS _ abcdef12
FORT 32.039 177.15 P 00 43 11.300 0.348 T 10.80 e 27.27 abcdef13
WOOL 32.587 187.38 P 00 43 15.600 -0.198 7.90 -0.71 9.90 1.14 TA 8.80 4.10 0.600 4.54 mb e 27.20 abcdef14
SHK 33.501 9.56 P 00 43 25.400 1.651 T e 27.05 abcdef15
KSAR 35.901 2.15 P 00 43 46.700 2.271 177.30 -5.40 10.10 1.53 7.20 1.70 0.700 4.00 mb e 26.57 abcdef18
KSAR 35.901 2.15 LR 01 04 25.000 260.898 160.00 -22.70 46.00 6.96 40.10 19.860 3.26 MS _ abcdef19
STKA 36.128 157.63 P 00 43 46.800 0.310 323.20 -10.24 9.00 0.44 T SD 8.30 7.20 0.600 4.67 mb e 26.52 abcdef16
STKA 36.128 157.63 PcP 00 46 12.000 -0.541 T D e 8.93 abcdef17
MJAR 36.668 16.15 P 00 43 51.900 0.816 357.10 156.90 18.80 10.27 T 2.00 0.550 4.09 mb e 26.41 abcdef20
PDY 59.037 351.99 P 00 46 47.000 2.949 111.20 -52.89 6.60 -0.34 S 23.80 4.30 0.450 4.78 mb e 21.22 abcdef21
ZAL 62.474 333.78 P 00 47 9.000 1.430 T e 20.42 abcdef22
ABKT 72.027 309.49 P 00 48 9.500 0.824 T e 18.23 abcdef23
[ The unknown phase x was associated as P and the corresponding residuals were calculated. ]
NRI 72.531 346.75 x P 00 48 8.700 -2.189 195.90 56.32 3.90 -2.06 11.20 3.00 0.750 4.50 mb e 18.11 abcdef24
MAW 81.431 200.28 P 00 49 1.100 0.070 T e 16.05 abcdef25
KVAR 84.428 313.85 P 00 49 17.200 -0.185 T e 15.33 abcdef26
NPO 87.382 25.36 P 00 49 31.000 -0.385 T e 14.60 abcdef27
ARCES 92.478 339.77 P 00 49 51.700 -3.475 94.50 15.10 4.10 -0.52 S 10.50 0.80 0.550 4.31 mb e 13.94 abcdef28
SPITS 92.672 348.81 P 00 49 55.900 -0.039 116.60 46.41 3.50 -1.12 T 10.40 3.60 0.900 4.77 mb e 13.93 abcdef29
FINES 93.674 331.72 P 00 50 0.000 -0.785 111.20 30.85 5.90 1.30 T 6.60 0.60 0.550 4.17 mb e 13.89 abcdef30
SFS 99.871 332.03 P 00 50 28.700 -0.197 311.30 -118.21 1.50 -2.95 T 3.70 1.10 0.750 4.58 mb e 13.41 abcdef31
SCHQ 122.925 9.01 PKPpdf 00 55 41.200 0.409 T e 5.74 abcdef33
TXAR 123.344 53.16 PKPpdf 00 55 42.700 0.209 T e 5.74 abcdef32
DBIC 130.601 279.95 PKPpdf 00 55 57.100 0.557 T e 5.68 abcdef34
PLCA 137.969 160.79 PKPpdf 00 56 9.100 -0.699 311.90 106.25 6.40 4.56 T 4.40 0.90 0.900 e 5.51 abcdef35
LPZ 159.475 136.94 PKPpdf 00 56 44.700 -0.522 T e 3.44 abcdef36

Defining travel-time differences:

Stat Delta Phases Observed Res
QIS 25.412 PcP - P 212.000 -0.594
```



```
ASAR 25.984 PcP - P      208.300 -0.382
WARB 27.419 PcP - P      198.200 -0.889
STKA 36.128 PcP - P      145.200 -0.851
```

Number of usable stations: 28

[ The azimuth range of the maximum gap without any observations is always given in clockwise direction. ]  
Maximum azimuthal gap of defining observations: 53.2 -> 136.9 [deg] = 83.8 [deg]

[ The azimuth range of the maximum possible secondary gap (see Bondár et al., 2004) without any observations is always given in clockwise direction. ]  
Maximum secondary azimuthal gap of defining observations: 25.4 -> 136.9 [deg] = 111.6 [deg]

[ RMS is defined as  $\sqrt{\frac{\sum Res^2}{N}}$ , MEAN-ERROR is defined as  $\frac{\sum Res}{N}$ , and MEAN is defined as  $\frac{\sum Res}{N}$ ; all with the listed residuals *Res* and the number of data *N*. ]

Residuals of defining data	RMS	MEAN-ERROR	MEAN
25 onset times	0.476	0.409	0.000 [s]
4 backazimuth values	2.400	1.985	1.282 [deg]
7 ray parameters	0.586	0.507	-0.244 [s/deg]
4 travel-time differences	0.709	0.679	-0.679 [s]

[ The weighted RMS is here defined as  $\sqrt{\frac{\sum Res^2 w}{N}}$  with the listed residuals *Res* and the data weights *w* used for the inversion (i.e., here the standard deviations of the data from **hyposat-in**) as used at the ISC. ]  
Weighted RMS of onset times (ISC type): 0.476 [s]

[ The weighted misfit is here defined for the L1-norm as  $\frac{\sum |Res|}{N}$  and for the L2-norm as  $\sqrt{\frac{\sum Res^2}{N}}$  with *N* the number of data. Input data also means data not used to locate the event. In this case, all backazimuth and ray parameter observations defined as usable by the switches in **hyposat-in** were also included. ]

Weighted misfit of input data	L1	L2
33 onset times	2.815	4.080
20 backazimuth values	1.351	2.281
17 ray parameters	1.474	2.734
4 travel-time differences	1.600	1.672
74 misfit over all	2.046	3.271

[ The following line is a repetition of the most important inversion results ]

T0	LAT	LOX	Z	VPVS	DLAT	DLOX	DZ	DT0	DVPVS	DEF	RMS
1996-06-29 00 36 42.467	1.395	126.304	0.00	1.76	0.0172	0.0352	Fixed	0.090	0.04	40	0.476

[ However, we have still a fixed depth. Let us now try to fit the data better with another depth (see **DEPTH FLAG** is set to b! )

```
Iterations      : 4
Number of defining: 48
Main reference model : akl35_A
Second reference model : iasp91_A
```

The new source parameters:

Confidence level of given uncertainties: 68.27 %

```
Source time : 1996 06 29 00 36 49.514 0.492 [s]
or           836008609.514 0.492 [s]
or           1996-181:00.36.49.514 0.492 [s]
```

```
Epicenter lat: 1.3237 0.0145 [deg]
Epicenter lon: 126.2875 0.0347 [deg]
Source depth : 47.15 4.37 [km]
```

[ The mean travel-time residuum was not zero. The source time is therefore corrected for this bias. ]  
Source time corrected for mean travel-time residual ( -0.035)

```
Source time : 1996 06 29 00 36 49.480 0.492 [s]
or           836008609.480 0.492 [s]
or           1996-181:00.36.49.480 0.492 [s]
```

[ Note the now much smaller error ellipse. ]

```
Epicenter error ellipse:
Major half axis: 5.16 [km] Minor half axis: 3.10 [km]
Azimuth: 71.5 [deg] Area: 50.27 [km**2]
```

Flinn-Engdahl Region ( 266 ): Northern Molucca Sea

Magnitudes: 4.4 (mb, G-R) 3.6 (Ms, R-P)

Stat	Delta	Azi	Phase	[used]	Onset time	Res	Baz	Res	Rayp	Res	Used	SNR	Amplitude	Period	MAG	Q	Em-Ang	ARID
WRA	22.562	159.91	P		00 41 44.700	-1.177	331.50	-7.09	11.10	0.52	SD	97.80	4.50	0.300	4.36	mb	e	50.23 abcdef01
WRA	22.562	159.91	S		00 45 48.700	-1.901	338.00	-0.59	17.00	0.65	TASD	8.10	2.00	0.900			e	41.40 abcdef02
QIS	25.359	149.74	P1	P	00 42 12.800	0.379					T D	35.50					e	41.16 abcdef03
QIS	25.359	149.74	PcP		00 45 44.800	0.505					T D						e	9.38 abcdef04
ASAR	25.921	163.86	P		00 42 16.900	-0.612	346.30	3.95	7.10	-1.95	TA D	35.10	3.40	0.500	4.19	mb	e	41.02 abcdef05
ASAR	25.921	163.86	PcP		00 45 45.200	-0.351	345.10	2.75	2.30	0.00	TASD	11.50	2.20	0.500			e	9.56 abcdef06
ASAR	25.921	163.86	S		00 46 45.300	0.613	347.60	5.25	20.30	4.50	T D	6.10	3.90	0.800			e	39.72 abcdef07
WARB	27.349	179.30	P		00 42 31.200	0.887	339.40	-19.83	8.20	-0.76	T SD	8.20	6.50	0.700	4.41	mb	e	40.54 abcdef08
WARB	27.349	179.30	PcP		00 45 49.400	0.578					T D						e	10.00 abcdef09
MEEK	28.768	194.38	P		00 42 42.700	-0.287					T	6.80					e	40.12 abcdef10
CMAR	31.774	304.11	P		00 43 9.000	-0.645	109.70	-9.60	7.80	-0.99	T S	4.30	0.60	0.400	3.78	mb	e	39.59 abcdef11
CMAR	31.774	304.11	LR		00 57 48.700	18.291	110.00	-9.30	39.50	0.45			188.80	19.360	3.88	MS	-	abcdef12
FORT	31.969	177.12	P		00 43 11.300	0.160						10.80					e	39.55 abcdef13
WOOL	32.515	187.37	P		00 43 15.600	-0.360	7.90	-0.70	9.90	1.14	TA	8.80	4.10	0.600	4.47	mb	e	39.42 abcdef14
SHK	33.573	9.56	P		00 43 25.400	0.245					T						e	39.12 abcdef15
KSAR	35.972	2.16	P		00 43 46.700	0.923	177.30	-5.42	10.10	1.55	T	7.20	1.70	0.700	4.03	mb	e	38.35 abcdef18
KSAR	35.972	2.16	LR		01 04 25.000	251.114	160.00	-22.72	46.00	6.96			40.10	19.860	3.26	MS	-	abcdef19
STKA	36.069	157.57	P		00 43 46.800	0.075	323.20	-10.17	9.00	0.45	T SD	8.30	7.20	0.600	4.72	mb	e	38.31 abcdef16
STKA	36.069	157.57	PcP		00 46 12.000	-0.213					T D						e	12.44 abcdef17
MIAR	36.740	16.15	P		00 43 51.900	-0.526	357.10	156.90	18.80	10.29	T		2.00	0.550	4.17	mb	e	38.09 abcdef20
[ This P onset has now a larger residuum than in the first run and is therefore no longer defining for the solution. ]																		
PDY	59.104	352.00	P		00 46 47.000	2.110	111.20	-52.92	6.60	-0.32	S	23.80	4.30	0.450	4.79	mb	e	30.09 abcdef21
ZAL	62.530	333.80	P		00 47 9.000	0.730											e	28.90 abcdef22
ABKT	72.059	309.51	P		00 48 9.500	0.424					T						e	25.68 abcdef23
NRI	72.595	346.76	x	P	00 48 8.700	-2.773	195.90	56.29	3.90	-2.04		11.20	3.00	0.750	4.36	mb	e	25.49 abcdef24
MAW	81.359	200.28	P		00 49 1.100	0.350					T						e	22.54 abcdef25
KVAR	84.465	313.86	P		00 49 17.200	-0.440					T						e	21.46 abcdef26
NPO	87.452	25.36	P		00 49 31.000	-0.759					T						e	20.35 abcdef27
ARCES	92.539	339.77	P		00 49 51.700	-3.764	94.50	15.06	4.10	-0.52	S	10.50	0.80	0.550	4.29	mb	e	19.52 abcdef28
SPITS	92.738	348.81	P		00 49 55.900	-0.352	116.60	46.38	3.50	-1.11	T	10.40	3.60	0.900	4.74	mb	e	19.51 abcdef29
FINES	93.729	331.71	P		00 50 0.000	-1.042	111.20	30.80	5.90	1.30		6.60	0.60	0.550	4.19	mb	e	19.44 abcdef30
HFS	99.925	332.02	P		00 50 28.700	-0.428	311.30	-118.26	1.50	-2.95	T	3.70	1.10	0.750	4.57	mb	e	18.77 abcdef31
SCHQ	122.997	9.01	PKPdf		00 55 41.200	0.490					T						e	7.98 abcdef33
TXAR	123.399	53.19	PKPdf		00 55 42.700	0.322					T						e	7.97 abcdef32
DBIC	130.597	279.89	PKPdf		00 55 57.100	0.784					T						e	7.88 abcdef34
PLCA	137.908	160.83	PKPdf		00 56 9.100	-0.364	311.90	106.30	6.40	4.56	T	4.40	0.90	0.900			e	7.65 abcdef35
LPZA	159.435	137.10	PKPdf		00 56 44.700	-0.227					T						e	4.78 abcdef36

Defining travel-time differences:

Stat	Delta	Phases	Observed	Res
WRA	22.562	S - P	244.000	-0.724
QIS	25.359	PcP - P	212.000	0.126

```

ASAR  25.921 PcP - P      208.300  0.262
ASAR  25.921 S - P      268.400  1.226
ASAR  25.921 S - PcP    60.100  0.964
WARB  27.349 PcP - P      198.200 -0.309
STKA  36.069 PcP - P      145.200 -0.288

```

Number of usable stations: 28

[ Here we get the number of all iterations e.g., also including an earlier solution for fixed depth. ]  
Total number of iterations: 22

Maximum azimuthal gap of defining observations: 53.2 -> 137.1 [deg] = 83.9 [deg]

Maximum secondary azimuthal gap of defining observations: 25.4 -> 137.1 [deg] = 111.7 [deg]

```

Residuals of defining data      RMS  MEAN-ERROR  MEAN
29 onset times      :    0.615    0.515    0.000 [s]
 4 backazimuth values :    2.447    1.996    1.351 [deg]
 8 ray parameters    :    0.593    0.526   -0.120 [s/deg]
 7 travel-time differences :    0.678    0.557    0.179 [s]

```

Weighted RMS of onset times (ISC type): 0.694 [s]

```

Weighted misfit of input data      L1      L2
33 onset times      :    2.199    3.128
20 backazimuth values :    1.351    2.282
17 ray parameters    :    1.429    2.726
 7 travel-time differences :    0.952    1.071
77 misfit over all      :    1.695    2.700

```

```

T0          LAT      LON      Z      VPVS  DLAT  DLON  DZ      DT0  DVPVS DEF  RMS
1996-06-29 00 36 49.480  1.324 126.288 47.15 1.76  0.0145 0.0347 4.37  0.492  0.04 48  0.615

```

-----end of the *hyposat-out* example file-----

## 6 The Program HYPOMOD and the File *hypomod-out*

For a given seismic hypocenter solution, the program **HYPOMOD** calculates the residuals for all observed data: the travel times, the backazimuths, and slowness values. With the example given here for a hypocenter inversion with **HYPOSAT**, one has only to modify slightly the *hyposat-parameter* file and then one can apply the program **HYPOMOD**. The modifications needed in *hyposat-parameter* are to set in for the starting source parameters the inversion results. Then, you will get an output-file called by default *hypomod-out*, which is also used if **OUTPUT FILE NAME** is set to *hyposat-out*. The file *hypomod-out* has in principle the same format as *hyposat-out*.

----- example for changes in the *hyposat-parameter* file -----

```
STARTING SOURCE LATITUDE [deg]      : 1.3237

STARTING SOURCE LONGITUDE [deg]     : 126.2875

STARTING SOURCE DEPTH [km]          : 47.15

STARTING SOURCE TIME (epochal time): 836008609.48
or
STARTING SOURCE TIME (DOY)          : 1996-181:00.36.49.48
or
STARTING SOURCE TIME (human format): 1996-06-29:00.36.49.48

*
* The following flag is used only with HYPOMOD.
* It allows to search for the best fitting phase name for an
onset.
*
* By default this option is switched off ('0').
FLAG FREE PHASE SEARCH           (0/1) : 0
*
```

----- end of example -----

Then execute the C-shell script *./run\_hypomod\_example* and you should get an output file *hypomod-out*, which should look like:

----- example for a *hypomod-out* file -----

```
HYPOMOD Version 2.0a

Event solution by HYPOSAT

NORTHERN MOLUCCA SEA, 1996 29 June, converted from PIDC's Reviewed Event Bulletin (REB)

Main reference model   : ak135_A
Second reference model : iasp91_A

The source parameters:

Source time   : 1996 06 29 00 36 49.480 [s]
or            836008609.480 [s]
or            1996-181:00.36.49.480 [s]

Epicenter lat:      1.3237 [deg]
Epicenter lon:     126.2875 [deg]
Source depth  :      47.15  [km]
```

Flinn-Engdahl Region ( 266 ): Northern Molucca Sea

Magnitudes: 4.4 (mb, G-R) 3.6 (Ms, R-P)

Stat	Delta	Azi	Phase	[used]	Onset time	Res	Baz	Res	Rayp	Res	Used	SNR	Amplitude	Period	MAG	Q	Em-Ang	ARID
WRA	22.562	159.91	P		00 41 44.700	-1.177	331.50	-7.09	11.10	0.52	TASD	97.80	4.50	0.300	4.36	mb	e	50.23 abcdef01
WRA	22.562	159.91	S		00 45 48.700	-1.901	338.00	-0.59	17.00	0.65	TASD	8.10	2.00	0.900			e	41.40 abcdef02
QIS	25.359	149.74	P1	P	00 42 12.800	0.379					T D	35.50					e	41.16 abcdef03
QIS	25.359	149.74	PcP		00 45 44.800	0.505					T D						e	9.38 abcdef04
ASAR	25.921	163.86	P		00 42 16.900	-0.613	346.30	3.95	7.10	-1.95	TASD	35.10	3.40	0.500	4.19	mb	e	41.02 abcdef05
ASAR	25.921	163.86	PcP		00 45 45.200	-0.351	345.10	2.75	2.30	0.00	TASD	11.50	2.20	0.500			e	9.56 abcdef06
ASAR	25.921	163.86	S		00 46 45.300	0.612	347.60	5.25	20.30	4.50	TASD	6.10	3.90	0.800			e	39.72 abcdef07
WARB	27.349	179.30	P		00 42 31.200	0.887	339.40	-19.83	8.20	-0.76	TASD	8.20	6.50	0.700	4.41	mb	e	40.54 abcdef08
WARB	27.349	179.30	PcP		00 45 49.400	0.577					T D						e	10.00 abcdef09
MEEK	28.768	194.38	P		00 42 42.700	-0.287					T	6.80					e	40.12 abcdef10
CMAR	31.774	304.11	P		00 43 9.000	-0.646	109.70	-9.60	7.80	-0.99	TAS	4.30	0.60	0.400	3.78	mb	e	39.59 abcdef11
CMAR	31.774	304.11	LR		00 57 48.700	18.291	110.00	-9.30	39.50	0.45	A		188.80	19.360	3.88	MS	—	abcdef12
FORT	31.969	177.12	P		00 43 11.300	0.160					T	10.80					e	39.55 abcdef13
WOOL	32.515	187.37	P		00 43 15.600	-0.361	7.90	-0.70	9.90	1.14	TAS	8.80	4.10	0.600	4.47	mb	e	39.42 abcdef14
SHK	33.573	9.56	P		00 43 25.400	0.244					T						e	39.12 abcdef15
KSAR	35.972	2.16	P		00 43 46.700	0.923	177.30	-5.42	10.10	1.55	TAS	7.20	1.70	0.700	4.03	mb	e	38.35 abcdef18
KSAR	35.972	2.16	LR		01 04 25.000	251.114	160.00	-22.72	46.00	6.96	A		40.10	19.860	3.26	MS	—	abcdef19
STKA	36.069	157.57	P		00 43 46.800	0.075	323.20	-10.17	9.00	0.45	TASD	8.30	7.20	0.600	4.72	mb	e	38.31 abcdef16
STKA	36.069	157.57	PcP		00 46 12.000	-0.214					T D						e	12.44 abcdef17
MJAR	36.740	16.15	P		00 43 51.900	-0.527	357.10	156.90	18.80	10.29	TAS		2.00	0.550	4.17	mb	e	38.09 abcdef20
PDY	59.104	352.00	P		00 46 47.000	2.109	111.20	-52.92	6.60	-0.32	TAS	23.80	4.30	0.450	4.79	mb	e	30.09 abcdef21
ZAL	62.530	333.80	P		00 47 9.000	0.730					T						e	28.90 abcdef22
ABKT	72.059	309.51	P		00 48 9.500	0.424					T						e	25.68 abcdef23
NRI	72.595	346.76	x	P	00 48 8.700	-2.773	195.90	56.29	3.90	-2.04	A	11.20	3.00	0.750	4.36	mb	e	25.49 abcdef24
MAW	81.359	200.28	P		00 49 1.100	0.349					T						e	22.54 abcdef25
KVAR	84.465	313.86	P		00 49 17.200	-0.441					T						e	21.46 abcdef26
NPO	87.452	25.36	P		00 49 31.000	-0.760					T						e	20.35 abcdef27
ARCES	92.539	339.77	P		00 49 51.700	-3.764	94.50	15.06	4.10	-0.52	TAS	10.50	0.80	0.550	4.29	mb	e	19.52 abcdef28
SPITS	92.738	348.81	P		00 49 55.900	-0.353	116.60	46.38	3.50	-1.11	TAS	10.40	3.60	0.900	4.74	mb	e	19.51 abcdef29
FINES	93.729	331.71	P		00 50 0.000	-1.043	111.20	30.80	5.90	1.30	TAS	6.60	0.60	0.550	4.19	mb	e	19.44 abcdef30
HFS	99.925	332.02	P		00 50 28.700	-0.429	311.30	-118.26	1.50	-2.95	TAS	3.70	1.10	0.750	4.57	mb	e	18.77 abcdef31
SCHQ	122.997	9.01	PKPdf		00 55 41.200	0.489					T						e	7.98 abcdef33
TXAR	123.399	53.19	PKPdf		00 55 42.700	0.321					T						e	7.97 abcdef32
DBIC	130.597	279.89	PKPdf		00 55 57.100	0.783					T						e	7.88 abcdef34
PLCA	137.908	160.83	PKPdf		00 56 9.100	-0.364	311.90	106.30	6.40	4.56	TAS	4.40	0.90	0.900			e	7.65 abcdef35
LPZ	159.435	137.10	PKPdf		00 56 44.700	-0.227					T						e	4.78 abcdef36

Defining travel-time differences:

Stat	Delta	Phases	Observed	Res
WRA	22.562	S - P	244.000	-0.724
QIS	25.359	PcP - P	212.000	0.126
ASAR	25.921	PcP - P	208.300	0.262
ASAR	25.921	S - P	268.400	1.225
ASAR	25.921	S - PcP	60.100	0.964
WARB	27.349	PcP - P	198.200	-0.309
STKA	36.069	PcP - P	145.200	-0.288

Number of usable stations: 28

Maximum azimuthal gap of defining observations: 53.2 -&gt; 137.1 [deg] = 83.9 [deg]

Maximum secondary azimuthal gap of defining observations: 137.1 -&gt; 25.4 [deg] = 111.7 [deg]

Residuals of defining data	RMS	MEAN-ERROR	MEAN
33 onset times	0.985	0.698	-0.118 [s]
20 backazimuth values	55.010	34.013	8.355 [deg]
17 ray parameters	3.152	1.974	0.963 [s/deg]
7 travel-time differences	0.678	0.557	0.179 [s]

Weighted RMS of onset times (ISC type): 1.015 [s]

Weighted misfit of input data	L1	L2
33 onset times	2.199	3.128
20 backazimuth values	1.351	2.282
17 ray parameters	1.429	2.726
7 travel-time differences	0.952	1.071
77 misfit over all	1.695	2.700

T0	LAT	LON	Z	VPVS	DLAT	DLON	DZ	DT0	DVPVS	DEF	RMS
1996-06-29 00 36 49.480	1.324	126.287	47.15	0.00	0.0000	0.0000	Fixed	0.000	0.00	77	0.985

-----end of the *hypmod-out file* example-----

**HYPOMOD** calculates residuals and the statistical parameters for this solution from all input data as defined in the *hypomod-in* file. Therefore, the statistical parameters as *e.g.*, mean residuals or RMS values are different from the ones calculated after the final inversion in **HYPOSAT** (please compare with the second solution in the file *hyposat-out.tele*), where weighting and data usage may be different.

## 7 References

- Aki, K. & Richards, P.G. (1980). Quantitative seismology. Freeman and Company, San Francisco.
- Bondár, I., Myers, S. C., Engdahl, E. R., and Bergman, E. A. (2004). Epicenter accuracy based on seismic network criteria. *Geophys. J. Intern.*, 156, 483–496; doi10.1111/j.1365-246X.2004.02070.x.
- Bormann, P., Storchak, D.A. & J. Schweitzer (2013). The IASPEI standard nomenclature of seismic phases. 20 pp., doi: 10.2312/GFZ.NMSOP-2\_IS\_2.1, in NMSOP-2.
- Buland, R. & Chapman, C.H. (1983), The Computation of Seismic Travel Times, *Bull. Seismol. Soc. Am.*, 73, 1271-1302.
- Båth, M., Kulháněk, O., Van Eck, T. & Wahlström, R. (1976). Engineering analysis of ground motion in Sweden. *Seism. Inst. University of Uppsala*, Report No. 5-76, 48 pp. + 11 Fig.
- Dziewonski, A.M. & Anderson, D.L. (1981). Preliminary reference Earth model. *Phys. Earth Planet. Inter.*, 25, 297-356.
- Gutenberg, B. & Richter, C.F. (1956 a). Magnitude and energy of earthquakes. *Annali Geofisica*, 9, 1-15.
- Gutenberg, B. & Richter, C.F. (1956 b). Earthquake magnitude, intensity, energy, and acceleration. *Bull. Seism. Soc. Amer.*, 46, 105-143.
- Havskov, J. & Bungum, H. (1987): Source parameters for earthquakes in the northern North Sea. *Norsk Geologisk Tidsskrift*, 67, 51-58.
- Jeffreys, H. & Bullen, K.E. (1940, 1948, 1958, 1967 & 1970). *Seismological Tables*. British Association for the Advancement of Science, Gray Milne Trust, London, 50 pp.
- Kennett, B.L.N. (editor) (1991). *IASPEI 1991 Seismological Tables*. Australian National University, Research School of Earth Sciences, 167 pp.
- Kennett, B.L.N. & Engdahl, E.R. (1991). Travel times for global earthquake location and phase identification. *Geophys. J. Int.*, 105, 429-466.
- Kennett, B.L.N. Engdahl, E.R., & Buland, R. (1995). Constraints on seismic velocities in the Earth from traveltimes. *Geophys. J. Int.*, 122, 108-124.
- Laske, G., Masters, G., Ma, Z. & Pasyanos, M. (2013). Update on CRUST1.0 - A 1-degree Global Model of Earth's Crust. *Geophys. Res. Abstracts*, 15, Abstract EGU2013-2658 & <https://igppweb.ucsd.edu/~gabi/crust1.html>.
- Menke, W. (1989). *Geophysical data analysis: discrete inverse theory*. 2<sup>nd</sup>, rev. edition, 12+289 pp., Academic Press, San Diego and London.
- Morelli, A. & Dziewonski, A.M. (1993). Body-wave traveltimes and a spherically symmetric P- and S-wave velocity model. *Geophys. J. Int.*, 112, 178-194.
- Mooney, W.D., Laske, G., & Masters, T.G. (1998). CRUST 5.1: a global crustal model at 5° x 5°. *J. Geophys. Res.* 103, 727-747.
- Mykkeltveit, S. & Ringdal, F. (1981). Phase Identification and Event Location at Regional Distance Using Small-Aperture Array Data. In *Identification of Seismic Sources - Earthquake or Underground Explosion* (eds. Husebye, E.S. & Mykkeltveit, S.), 467-481.
- Nicolas, M., Massinon, B. Mechler, P. & Bouchon, M. (1982). Attenuation of regional phases in western Europe. *Bull. Seism. Soc. Amer.*, 72, (6), 2089-2106.

- NMSOP: New Manual of Observatory Practice (2002). Edited by P. Bormann, ISBN 3-9808780-0-7.
- NMSOP-2: New Manual of Seismological Observatory Practice (NMSOP-2) 2<sup>nd</sup> (revised) edition (2012). Potsdam: Deutsches GeoForschungsZentrum GFZ, doi: 10.2312/GFZ.NMSOP-2 P. Edited by P. Bormann (2012).
- Pirli, M. & Schweitzer, J. (2017). BARENTS16: A 1-D velocity model for the western Barents Sea. *J. Seism.*, 22, (1), 69-81, doi: 10.1007/s10950-017-9692-y.
- Rezapour, M. (2003). Empirical global depth-distance correction terms for mb determination based on seismic moment. *Bull. Seism. Soc. Amer.*, 93, 172-189.
- Rezapour, M. & Pearce, R.G. (1998). Bias in surface-wave magnitude  $M_s$  due to inadequate distance corrections. *Bull. Seism. Soc. Amer.*, 88, 43-61.
- Richter, C. (1935). An instrumental earthquake magnitude scale. *Bull. Seism. Soc. Amer.*, 25, (1), 1-32.
- Schweitzer, J. (1997). HYPOSAT – a new routine to locate seismic events. NORSAR Scientific Report, 1-97/98, 94-102.
- Schweitzer, J. (2001). HYPOSAT – an enhanced routine to locate seismic events. *Pure and Applied Geophysics*, 158, 277-289.
- Schweitzer, J. (2006). How can the ISC location procedures be improved? *Physics Earth Planetary Interiors*, 158, 19-26, 2006, doi: 10.1016/j.pepi.2006.03.017.
- Schweitzer, J. & Kennett, B.L.N. (2007). Comparison of location procedures – The Kara Sea event of 16 August 1997. *Bull. Seism. Soc. Amer.*, 97, (2), 389-400, doi: 10.1785/0120040017.
- Storchak, D.A., Schweitzer, J. & Bormann, P. (2003). The IASPEI standard seismic phase list. *Seismological Research Letters*, 74, 761-772, doi: 10.1785/gssrl.74.6.761.
- Storchak, D.A., Schweitzer, J. & Bormann, P. (2011). Seismic phase names: IASPEI standard. In: Gupta, H. K. (ed.) (2011): *Encyclopedia of Solid Earth Geophysics* (Encyclopedia of Earth Sciences Series), ISBN: 978-1-4020-8702-0, Springer, Dordrecht, xxxvii + 1539 pp., 1162-1173 (also available as Electronic publication ISBN 978-90-481-8702-7 and Print and electronic bundle ISBN 978-90-481-8732-4), doi: 10.1007/978-90-481-8702-7\_11.
- Veith, K.F., & Clawson, G.E. (1972). Magnitude from short-period P-wave data. *Bull. Seism. Soc. Amer.*, 62, 435-452.
- Wadati, K. (1933). On the travel time of earthquake waves. Part. II. *Geophys. Mag.* (Tokyo), 7, 101-111.