UserGuide

SplitLab Pro

by

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Preface

Thank you for using SplitLab. We tried to make it as self-explanatory as possible. However, we feel that a few additional words need to be said. We assume the reader has a basic knowledge of MatLab. Some aspects of data processing, e.g. filtering, resampling, etc., are addressed in this User Guide. We however recommend the reader to update his/her knowledge. Where appropriate we try to suggest further reading (the MatLab Help is usually our first choice). If you think you found something helpful, please share it with us, so we can add this to our list, which will eventually help others. Furthermore, if you change/add/remove a feature, please also contact us. We will discuss your recommendations for implementation, so other can make use of your work.

SplitLab is intended and tested for teleseismic shear-wave splitting measurements. This implies the assumption of near-vertical arrival of the S-phase to be analysed. This is generally not the case in regional experiments, where shallow earthquakes result in sometimes near-horizontal wave arrivals. Please refer to Booth and Crampin (1984), Savage (1999) and Vecsey et al. (2008) for more background. SplitLab assumes the fast axis to be oriented horizontally. Please ensure that this assumption holds true in your case. Possible situations include preferred crystal orientation due to mantle flow or vertical cracks.

Finally, we enjoy receiving your feedback. Please send us PostCards from the region you live, or at least a digital photo. It would be great if you could send us a copy (PDF) of any paper/report/thesis where you used SplitLab. A postcard may also speed up any support request...

Thanks

Andreas Wüstefeld, Bristol, December 2009

splitlab@gmx.net

SplitLab should run on every computer system (MS Windows, MAC, Linux, SUN) with **Matlab7.0** or higher and the **Signal Processing** toolbox. The mapping toolbox is NOT longer required, but a few additional functions and fancier display is available when the Mapping toolbox is installed.

Citation:

Wüstefeld, A., & Barruol, G (2009), The SplitLab UserGuide, http://gm.univ-montp2.fr/splitting

1 License

SplitLab is PostCard ware! If you like it, please send a Postcard of the place you live to:

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Or, simply send an email with a nice photo (your town, institute, famous landmark, pet,…) to splitlab@gmx.net.

A selection of the best Postcards will be places on the SplitLab homepage. SplitLab is free software; you can redistribute it and/or modify it under the terms of the GNU General Public License as published by the Free Software Foundation; either version 2 of the License, or (at your option) any later version.

SplitLab is distributed in the hope that it will be useful, but WITHOUT ANY WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE. See the GNU General Public License for more details.

2 Bug report & Suggestions

If you think you found a bug, don't hesitate and write an email to splitlab@gmx.net. Emails send to other addresses (work, private) are likely to be ignored. Please include the project file and the 3 SAC files in your email. This simplifies the search for the bug. Please also copy and paste the complete error message in the email, i.e. everything that Matlab outputs in red...

DO NOT SEND EMAILS LARGER THAN 2MB UNLESS REQUESTED

In general, any comments are welcome, especially positive ones :-)

Please report wishes for additional features or any changes in the source codes to splitlab@gmx.net. This helps every user and allows for the maximum functionality for every user.

In any case, having sent a PostCard may speed up replying....

2.1 An Example email which is likely to be answered quickly

```
Hi

     My name is Quint S. Henschel and during my Master thesis at
University of Cap Canaveral I'm working with Prof Rita Book on
shear-wave splitting on Mars. SplitLab is of great help. We have an
array of 20 broad band stations installed during a field campaign
last year.

However I now run into troubles when loading some SAC files. Please
find the error message from Matlab at the end of this mail. I also
attached 3 seismograms and the corresponding .PJT file.

I've sent you a postcards and hope you like it


With kind regards

Quint S. Henschel


%%START ERROR %%%%%%%%%%%%%%%%%%%%

??? Error using ==> rsacsun
Current rsac byte order: "B". File: "C:\SKS_data\2001.09.29-
02.40.07.SAGA.E.SAC" may be of opposite byte-order.

Error in ==> getFileAndEQseconds at 22
 sac = rsacsun([config.datadir filesep F(k,:)]);

Error in ==> SL_assignFilesAuto at 63
[FIsec,          FIyyyy,          EQsec,          Omarker]          =
getFileAndEQseconds(ff,eqin,config.offset);
%% END ERROR %%%%%%%%%%%%%%%%%%%%
```

2.2 An Example which is likely to be answered slowly

```
Dear Dr Andreas

     I downloaded SplitLab. I have problems. I need urgently to know
why my SAC files are not in the database. How do I change the
filename of my SAC files so I can use them in Splitlab.


Kindly reply at the earliest.

Tess Tickle & Shirley Knot
```

3 Installation

No installation is required anymore for Splitlab1.2.x or later. Simply unpack the Splitlab.X.X.zip file to a directory of your choice, add the splitlab folder to your path, including the subfolders Tools, ShearWaveSplitting, matTaup and SacLab.

For the technically interested: The JavaClassPath, used by matTaup is now loaded dynamically you start Splitlab in a new MatLab session.

Perhaps Troubleshooting helps case of problems

4 Running SplitLab

In the Matlab environment, type in the command line "`>> splitlab`". It opens the "*Configure SplitLab*" window that will allow you to prepare your project, i.e. your data selection, your data request, and to build your seismic database that will allow you to manage easily data and results in the processes of shear wave splitting measurements.

What is a SplitLab project? A project can be defined as a set of seismic data associated to a set of events derived from a given selection. Any given project concerns a single station since the selection of data is performed from station-events epicentral distances. A project is generally related to a directory where data are stored. A given project may concern only part of seismic data in the directory and alternatively, several projects may coexist in a given directory where data are stored: a first project may be focused on SKS splitting measurements, a second on P-wave analyses, etc.

In order to have the project OK and operational, one has to follow the six steps presented on the left-hand side of the "configure" window:

General

→ Station

→ Event

→ Request

→ Phases

→ Find Files

→ SplitOptions

→ViewSeismograms.

5 New in Version 1.2 or later

- Introduced P-wave arrival pick (left mouse-button click). Stored in the two element vector `eq.Ppick` The S-Window is selected by the right mouse button.
- Shift-click (left or right) chooses the Zoom window. Press `BackSpace` to Zoom-Out.
- The S-pick time is now stored in the two element vector `eq.Spick`
- Allow the number of poles of a filter to be selected. This is accessible via the filter dialog, if you press "f" in the SeismoViewer. Value stored as third element of `eq.filter`
- New "Zoom" and "Pan" behaviour of the SeismoViewer using the keyboard:

→	Pan right
←	Pan left
↑	Zoom in (relative to pointer)
↓	Zoom out (relative to pointer)
PageUp	Previous Event
PageDn	Next Event
l	(lower case "L") lock the y-axis to maximum value of all seismograms
s	Spectrum viewer of p-window selection
p	get polarisation of a window, using ransac algorithm. This is aimed at rotating into ray-frame. This algorithm first get the azimuth and then the inclination.
shift-p	Same a above, but this algorithm gets the azimuth and the inclination simultaneously (see Jurkewicz,1988).

See here for a complete list of keyboard shortcuts

- If you are using MatLab 7.4 or later, you can use your MouseScrollWheel for zooming
- The values of the polarisation are stored in `eq(n).Ppol`, where `n` is the event number. `Ppol` is a vector of format:

  `[PpolBackazimuth, PpolBackazimuthErr, PpolInclination, PpolInclinationError ]`
- Now all time markers of the SAC files (A, F, T0-9) are read and displayed
- Removed bug in delay time error calculation for test-delay times other than 4sec
- Double click on event in the Database Viewer will open it in the SeismoViewer
- Increased the default resolution of .JPG images to 300dpi (instead of 72dpi)
- New Configuration Panel for Splitting Options. See below for more details

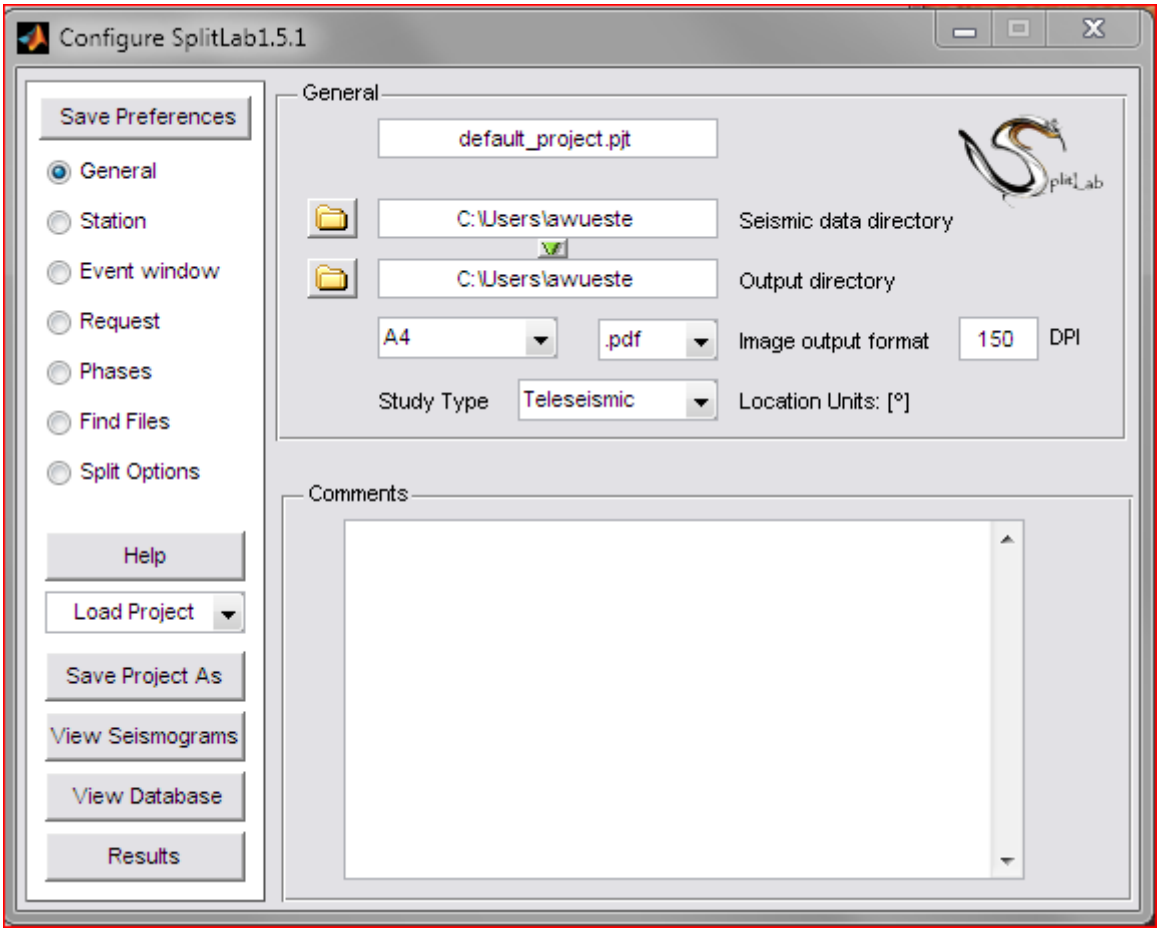
- Filter presets of the SeismoViewer can be from within the Configuration window.
- Additional to standard band-pass filter, since version 1.2.x SplitLab allows also high- and low-pass and even a band-reject filter. Default filter is a bandpass. For a highpass use “inf” as upper frequency limit. A low pass has “0” as lower limit.
- Options for resampling frequencies are now (in Hz):

  `'raw','4000','1000','250','100','50','20','10','other'`

  You can manually add other frequencies, but be aware that upsampling does not add information or accuracy. Be aware of too large sampling rates as that might exceed the memory capacity of your computer
- Option to change the resolution of the grid search used in splitting measurement. This may significantly speed up processing.
- New Batch Splitting Option: several windows are automatically selected around your S-Window and then split sequentially. Also, you can batch-process over selected filters.
- Improved Spectrogram Viewer
- In the PhaseViewer, if you click on a Ray-Path, it is high-lighted and the phase name is displayed
- New display options in the WorldViewer
- The Rotation Correlation, or Cross-Correlation method, now uses either “fixed” or “estimated” initial polarisation (before, it was fixed to backazimuth)
- Improved display of DiagnosticViewer, including Day-Night-shading
- Null Detection is now Numeric value between -1 (GoodNull) and +1(Good). 0 represents Poor measurements. See Wüstefeld et al. (2009) for more details.
- Improved Two-Layer-modelling of splitting results. Removed bug causing 180degree mix-up
- The result-viewer no longer displays the stereo plots, due to compatibility without Mapping toolbox.
- Progress indicator for the splitting process in the status bar of the SeismoViewer
- many more small things and code clean-up...

6 Configuring your SplitLab Project

6.1 The "General" panel



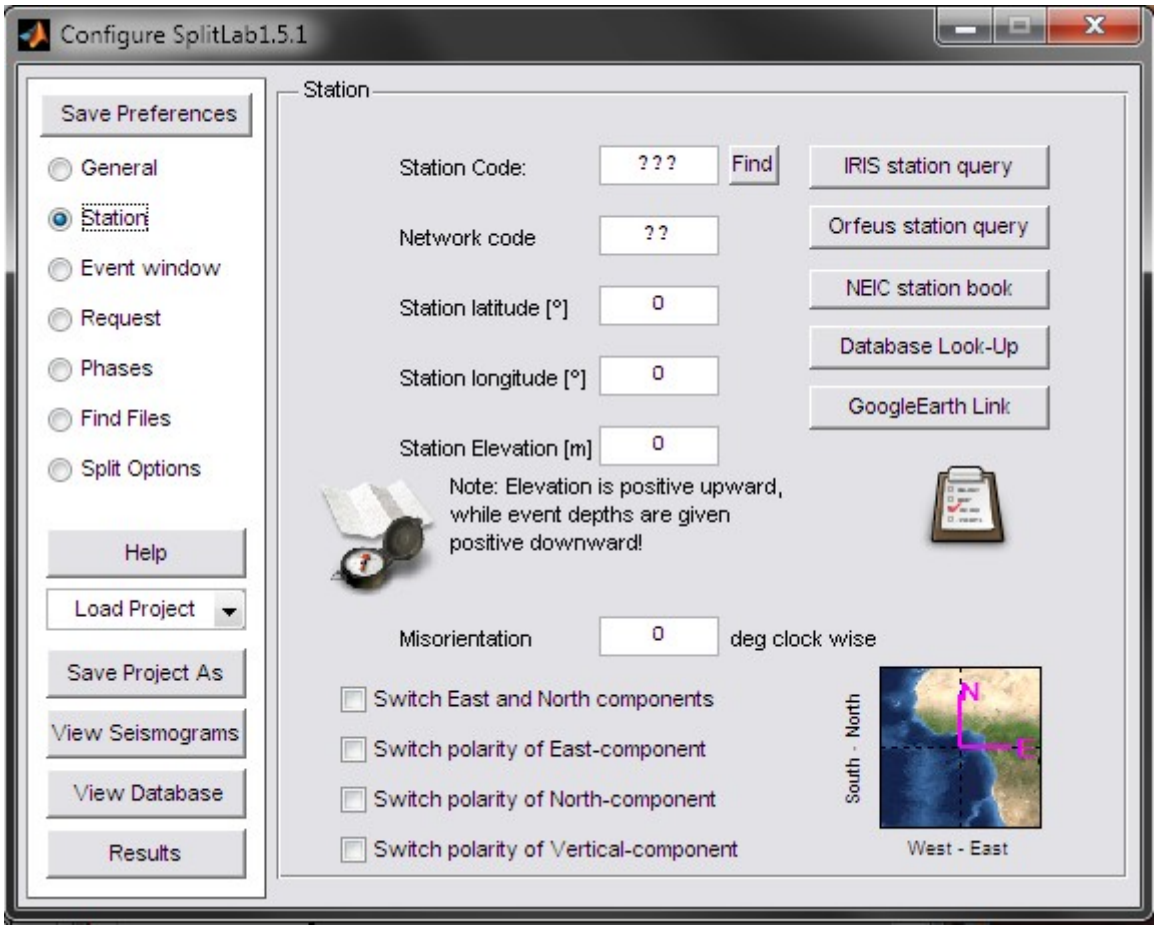
The upper window allows you to define your project name and the directories where the data are and where the output data will be stored. This allows the user to have the data ready in a directory and to store the results in another place, without affecting the data directory. The DPI field defines the resolution of bitmap images (jpg, png, etc...). A drop-down menu allows you to select the type of study you intend to do:

- Teleseismic
- Regional
- Reservoirs

This affects certain rotations (on a Sphere or Cartesian?), units (degree/km, or meter?) and calculations (great circle or direct line). Go into the code and search for occurrences of "`config.studytype`" to find out more...

The lower part of the window allows you to store various comments related to this project.

6.2 The “Station” Window



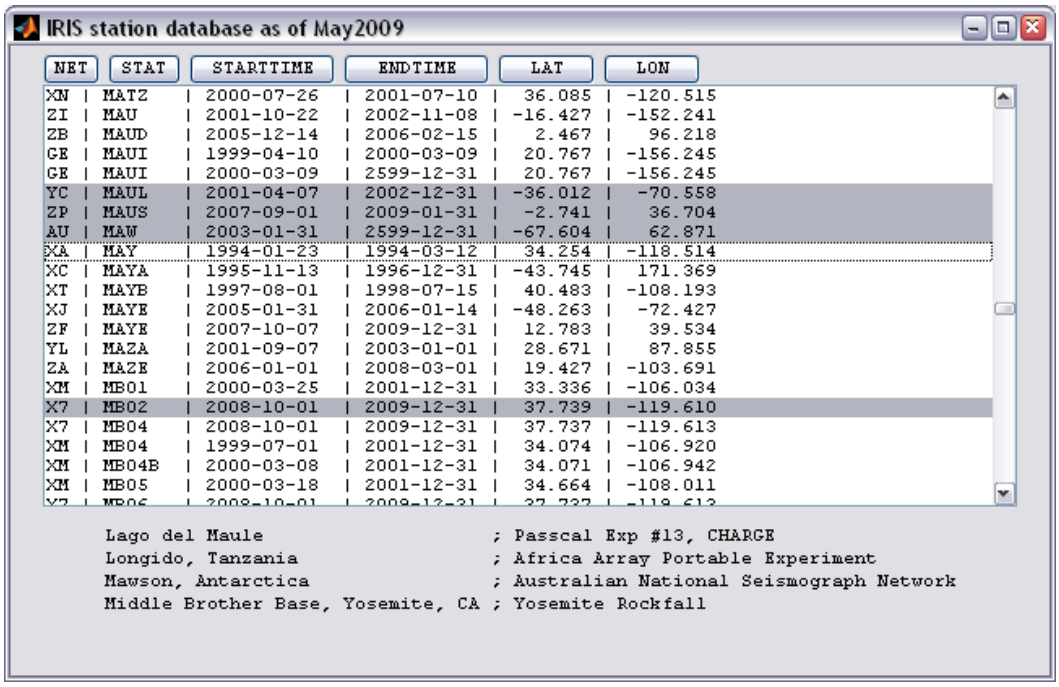
This window summarizes the information related to the station. The station latitude and longitude are absolutely necessary since they are used to select the event from the epicentral distance and to calculate the various phases travel times. Station Elevation is not required. Note, that this is an elevation, i.e. positive upward, while event depths are given positive downward.

In global or regional studies it is most appropriate to give the information in degrees (lat / long). If you are studying a small local area, you may want to use meter units. Please note, that in the latter case, your earthquake catalogue must be in meters as well (see later in this document).

If the station has a known *misorientation*, that rotation can be input in this window. This allow the user to work on true N, E and Z components and therefore, on the true radial and transverse components. Note that this operation is performed in Matlab and does thus not affect in any case your raw data.

Problems of component signs or polarities may be corrected in this window and may be combined together with the component misorientation value.

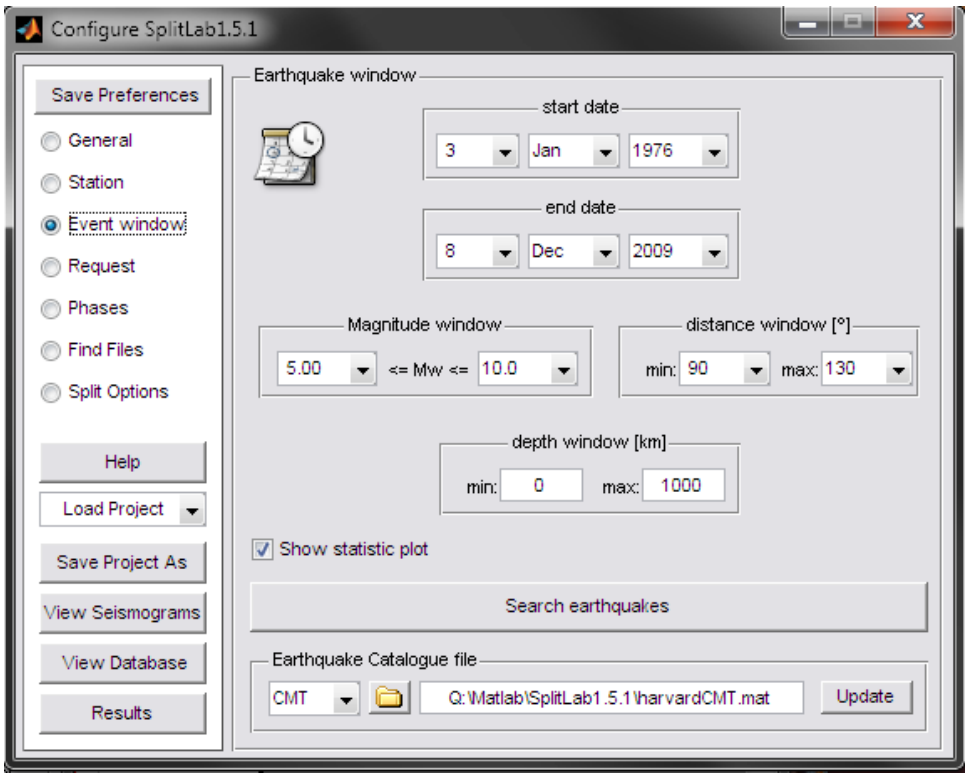
Note that Splitlab assumes a sensor setup generally used in broadband seismology, with components define a right-handed coordinate system: East-North-Up. Regional and reservoir studies may use the Aki-Richards definition of North-East-Down, in which case you may need to switch the **vertical** component.



Several buttons of the right of the window provide direct Internet access to station query tools (such as IRIS) or to station books (such as NEIC). This may be useful when preparing a request, to look for instance for a stations in a given area or running during a given period. We also have included a snapshot of the IRIS Station Catalogue, which can be accessed via the according button. Selecting a station will automatically import the station data to the SplitLab project

If you know the station code, you can type it in the appropriate box and click the “find” button to select station information.

6.3 The "Event" window:



This window allows to prepare your event selection within the earthquake catalogue file. This file contains the actual earthquake information (hypo time, location, magnitude, etc.) but is independent of the actual files you may be using. The database serves as basis for associating the event information to the seismogram traces, which usually do not contain much event information.

SplitLab provides earthquake catalogues covering the period 1976 to 2008 and it may be necessary for the user to keep the local CMT or the NEIC files updated in order to search through an updated event catalogue. The "*update*" button provides a way to automatically update the CMT files (in the case of the Harvard CMT format) or the information necessary to request to NEIC the data in the right format (in the case of the NEIC data format selection). Note that the NEIC catalogue does not allow the calculation of the phase energy. Supported formats are NEIC and Harvard CMT.

You can also provide a TXT file (in NEIC format) as described below, if you have your own event locations from a regional or reservoir study. This is slower, as the textfile has to be converted to matlab form, but should not be noticeable for small catalogues (<2000 events).

If you need your own catalogue (e.g. from local studies) this is possible also. We recommend that you prepare your event data in NEIC "spread sheet" format (header line is required)

```
 Year,Month,Day,Time(hhmmss.mm)UTC,Latitude,Longitude,Magnitude,Depth
2004,01,01,000308.95,-24.58,-179.97,4.7,488
2004,01,01,002517.32, 45.13,   7.38,2.6, 12
2004,01,01,003201.30, 37.76,  21.07,3.4,  5
2004,01,01,003652.09, 19.38, -64.45,4.1, 25
2004,01,01,004031.10, 39.02,  26.77,2.8, 14
2004,01,01,004452.37, 50.22,-177.64,2.6, 33
2004,01,01,005107.20,-31.85, -69.77,2.9,138
```

If you now select NEIC as catalogue format and press the update button, you can select the option "Use local file". This asks you for the file to load and reads the data. Save your new, personal catalogue as something like "myCatalogue.mat"

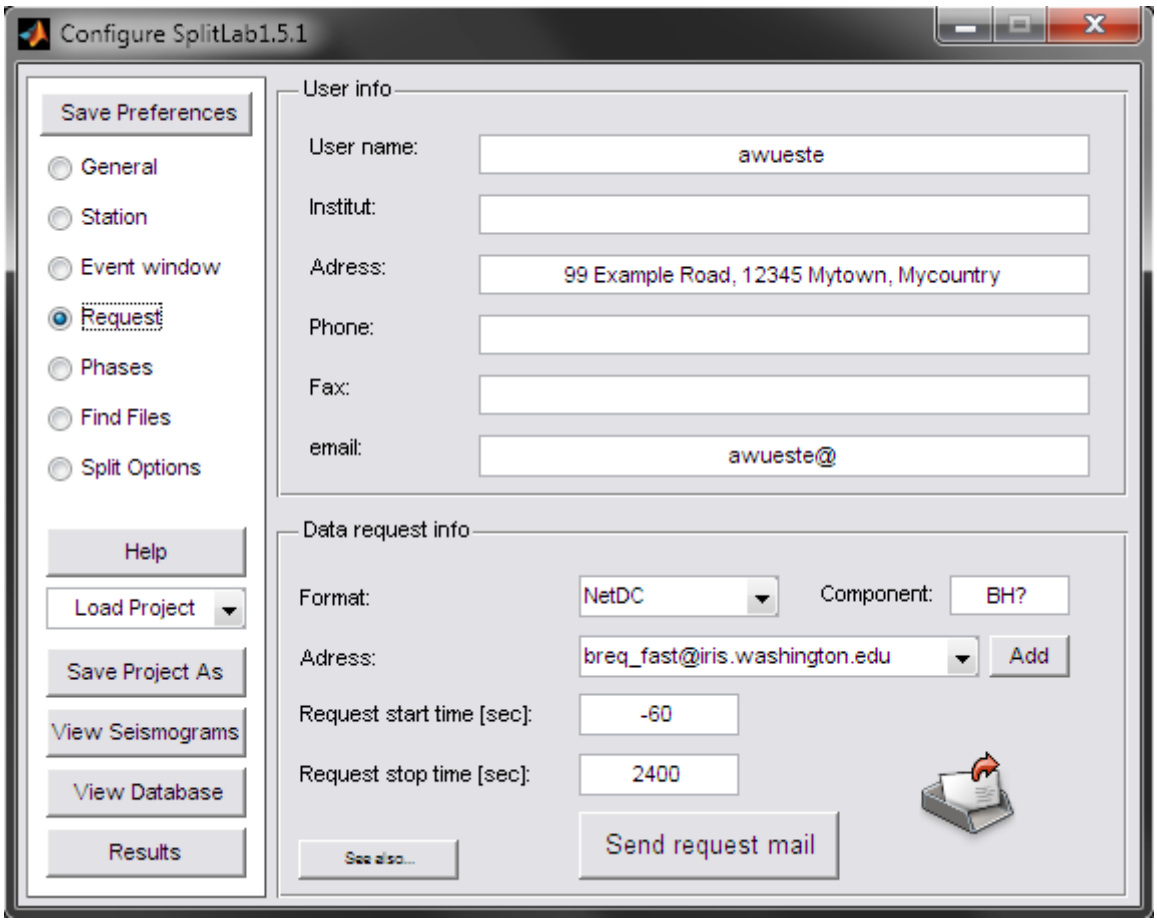
Click on the "Search" button when the parameters are OK. It results (if selected) in the "statistic plot" that displays:

- the event location on a map preserving the true backazimuths,
- the histogram of the backazimuthal distribution, for 360º in green and for 180º in gray
- a rose diagram presenting the same backazimuthal distribution.

6.4 The "Request" window:

The information that you enter here will allow preparing, formatting and sending the request to your selected request site. In the case where you already have the data ready (for instance after a temporary deployment or coming back on old data that you already worked on), you do not have to worry about this window. If you do not have the data, and if you wish to request them, you have to give all the necessary information:

- In the upper part of the window, you have to provide the information generally requested by the automatic request systems: your name, your institute, your address. Your email is absolutely necessary since you will be contacted by mail on the status of your request, and on the availability of the data.
- In the lower part of the window, you have to choose between the various request types (NetDC, BreqFast, AutoDRM or ASCII table) and to the request server where the request will be sent to. You have to define the component you desire, the "start time" relative to the event time (0 corresponds to event time) and the length of the seismogram in seconds (Figure 1a). There is no way is the present version of SplitLab to prepare request relative to a phase, such as a starting time 60 seconds before a P-wave arrival… Perhaps in a future version…



Click "Send request mail" button and wait for delivery, few minutes, few hours or few days depending on the size of the request and on the activity of the servers. Multiple short requests (less than 200 events) are supposedly handled faster than one big.

The Request Start and End times define the approximate times of the seismogram relative to the hypocentre time (see Figure 1 for more detail). Also a websearch on NetDC or breq_fast request can be instructive...

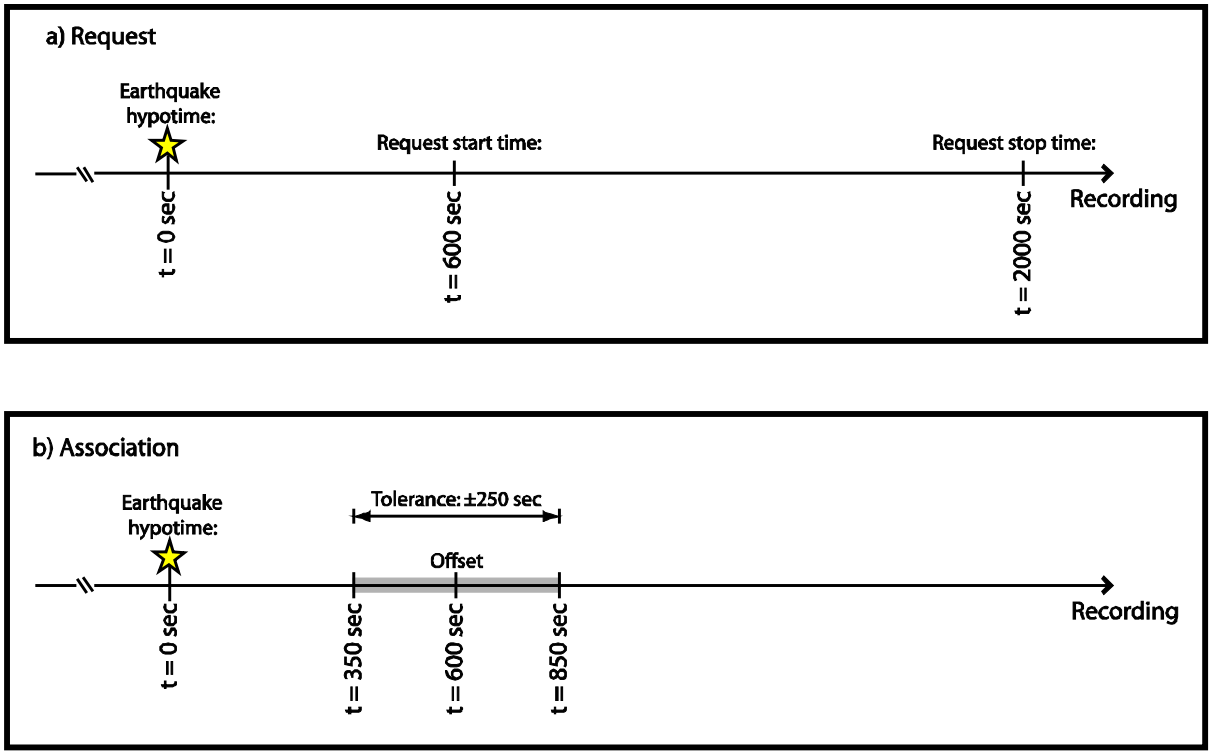
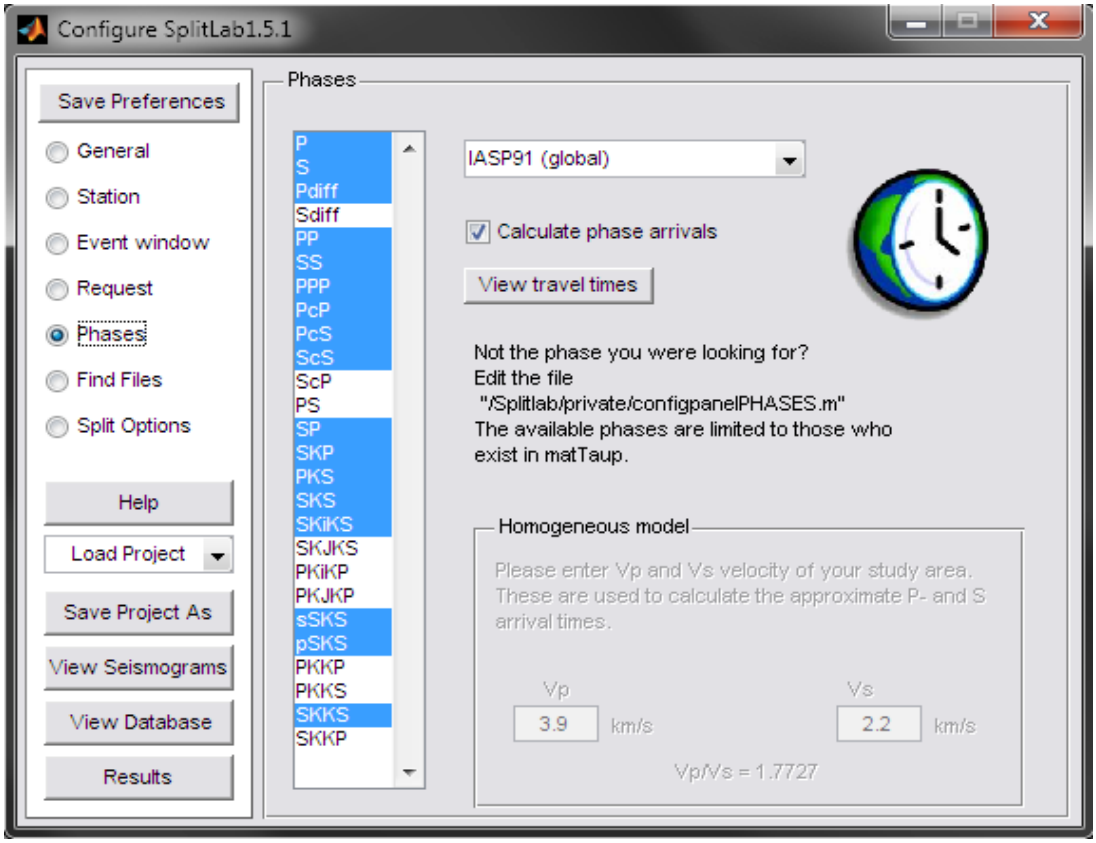


Figure 1: (a) Definition of request start and stop time and (b) their correspondence to the file-search offset and tolerance. Note, that if you are using the "Extract from SAC header" option (and if your O-marker in the SAC file header is set correctly) this O-marker offset is considered as reference time. You should therefore in this case set the manual offset to zero. You first request your files, then in file association, you define the offset from hypocentre time, around which the files should be searched.

6.5 The "Phases" window:



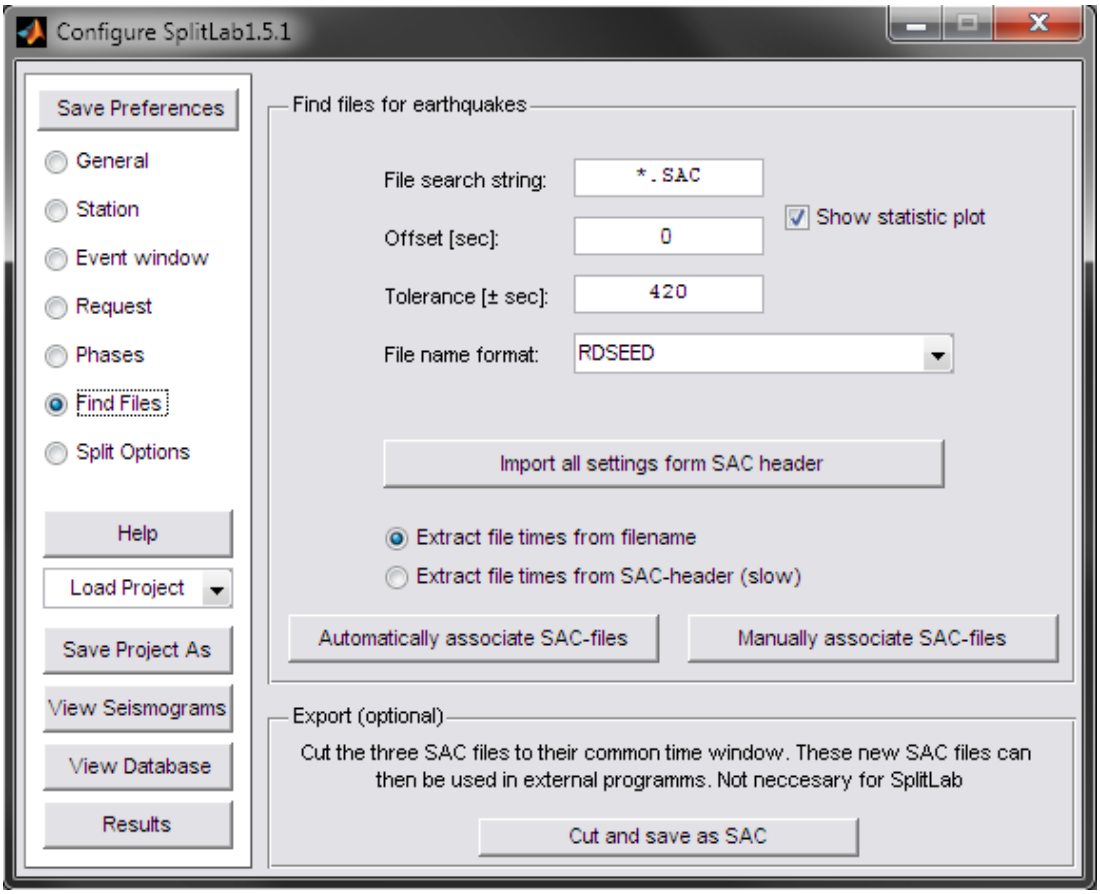
This window allows you to select the phases for which you wish to see the arrival times on your seismograms. These theoretical arrival times are calculated by using the PREM or the IASPEI91 Earth models. The "view travel time" button allows you to see the travel time of the selected phases as a function of the epicentral distance the travel paths through the Earth

New to Pro version is the travel time calculation for a homogeneous model. Choices are:

- PREM / IASP91/AK135/Jeffrey-Bullen/Herrin/SP6: Calculate phase arrivals using a standard earth model using matTaup. This is to be your choice in teleseismic studies, i.e. epicentral distance >1° or 100km. In local studies, when using direct waves, this generally won't give you any usable results. This is not what TauP was designed for
- Homogeneous model: This provides a basic homogeneous half-space model for travel time calculation. You enter v_p and v_s and SplitLab calculates theoretic arrivals for the P and S waves. However be aware that this may be a very crude simplification of the geology in your study area. Obviously, this only works on P- and S-wave arrivals.
- If you have any idea of how to improve this please contact splitlab@gmx.net, especially if you know a way of using rayinv or rayGUI in Matlab. The CREWES travel time calculator may be included in a future version.

Note that the Travel times are now calculated during reading of the seismogram, not during database creation in "FindFile Panel" (see below). This allows for dynamically switching phases on and off.

6.6 The "Find Files" window



Once you received or converted your files into SAC format, you need to assign them to the actual events from the catalogue. This is necessary, because otherwise certain information (source-receiver azimuth, magnitude, event location, etc.) might not be available. We thus have to compare the catalogue with the list of files.

In order to do so you need to supply a search string. Wildcards * and ? are supported, but especially the ? may react unexpected (on Windows). Be as specific as possible, perhaps include station name and/or year.

The association is based on comparison of event times from catalogue and time gathered from the file. Select tolerance and offset accordin to Figure 1. The file time can be either from the header information of each SAC file (make sure all time headers are set correctly...) or from file name (e.g. 1993.286.12.54.12.sac.e). At present SplitLab supports the following filename formats.

- RDSEED (see homepage)
- SEISAN (see homepage)
- YYYY.MM.DD-hh.mm.ss.stn.sac.e,
- YYYY.JJJ.hh.mm.ss.stn.sac.e.
- *.e; *.n; *.z

See “Create your own Format” for more information. Choose the filename format corresponding to your data. This is absolutely necessary to identify the seismogram components. If you select

*.e; *.n; *.z

the last letter of the filename is used to determine the component of each file and the file start times are extracted for the SAC header. Allowed component descriptors are e,n,z or E,N,Z

It is your responsibility to find the best file-search-string that may help the program to go through the whole set of data in the directory where your data are. Both the * as the ? wildcard is possible. However, on MS Windows, ending search strings on .? may have unexpected results as the dot may not be considered in that case (apparently an old heritage “feature”. Also Windows and some Macintosh are not case sensitive. Make your search string as precise as possible. Be aware that files other than the expected seismic data may complicate the task. For instance, the presence of *.sac.r or *.sac.t for radial or transverse component of SAC files will not allow a right linking of events and seismograms. The safest way to make this step successful is to have the directory full of only the sac.e, n and z components.

- The "offset" is the time duration between the event time and the starting time of your seismograms. Ideally, this offset should be identical to the "request start time" defined in the previous window but the data management centre may have sent you data beginning later than requested. The offset value represents this difference (Figure 1b).
  However, if you are using the “Extract from SAC header” option (and if your O-marker in the SAC file header is set correctly) the offset is considered as reference time. You should therefore in this case set the manual offset to zero.

- The "Tolerance" value in seconds will define the time window within which the program will try to associate a seismic file to an event file, by using either its name or the information contained in the header. It is up to the user to find the best compromise: a value too small will let orphans and a value too large will bring confusion since several files could be associated to a seismic event (Figure 1b).

If the name of the sac-file is (roughly) the beginning time of the seismogram, then use the "extract time from filenames" button else use the "extract times from SAC headers". This second way is slower since it has to physically open each file to read the header in order to find the begin time that will be used to connect to a given seismic event.

In the best case, the event-to-seismogram link will be created automatically by pushing the "Automatically associate SAC files" button. Otherwise, you can do this association manually via the "Manually associate SAC file" button. Anyway, at the end of the automatic association, the system may provide a list of orphan events and of seismic files that it did not succeeded to link together. This will happen when a wide event selection has been done and will be associated to a rather short existing seismic database. In that case, numerous events will not be associated to seismic files, but that is normal. Orphans may also happen when two or more events occur in a short time window, smaller than the "tolerance window". In that case the user may terminate manually the association. At the end of this linking process, the seismic "Database" is ready for use. Do not forget to save it ("Save Project" button). This database can then be viewed by using the "View Database" button that provides the list

of the events together with the global map. This database will be the starting point of the following processes such as the shear wave splitting measurements.

The button “Import all settings” is intended as a shortcut, if you are sure that the SAC files are in the right format (i.e. all headers for event and station, azimuth, distance, time, etc.) are set correctly. This feature is experimental and I strongly discourage from its usage. No support is provided. Please go to the source code to find out more! However if you have suggestions and/or improvements, they are welcome.

The "Cut and save as SAC" can be used when the e, n and z components start and end at different times and therefore have different names. This button will cut the beginning of the triplet at the latest start time and the ending time at the earliest ending time of the triplet. The triplets are then saved under new names. This provides a way to export data with coherent lengths and names for other purposes than splitting measurements (Figure 2).

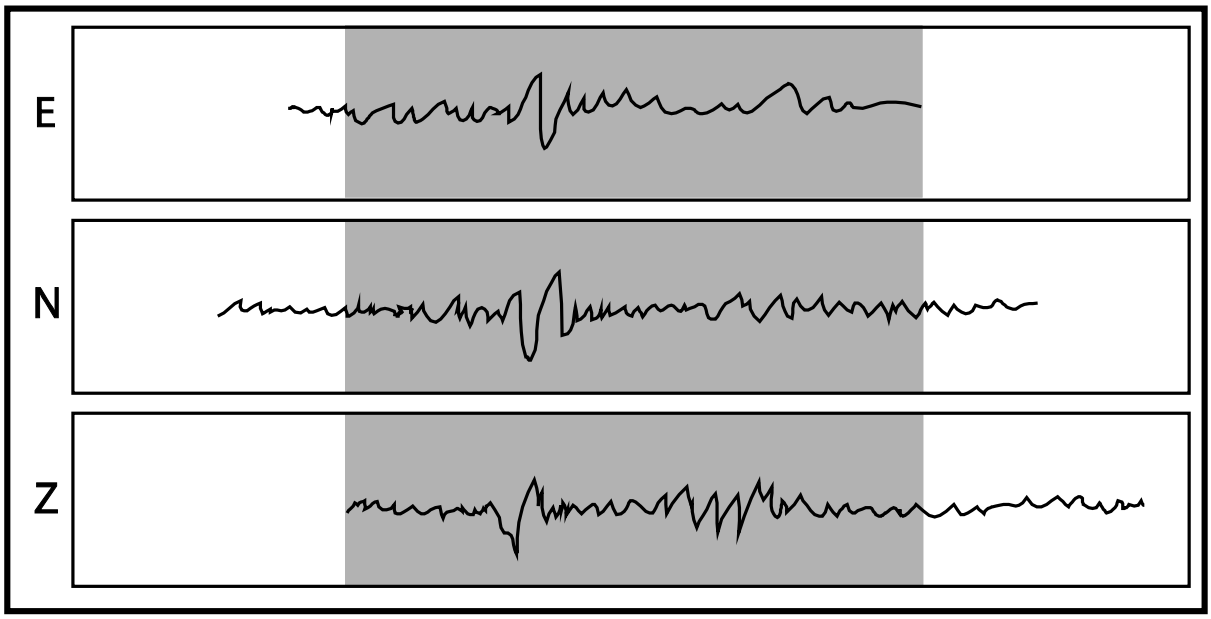
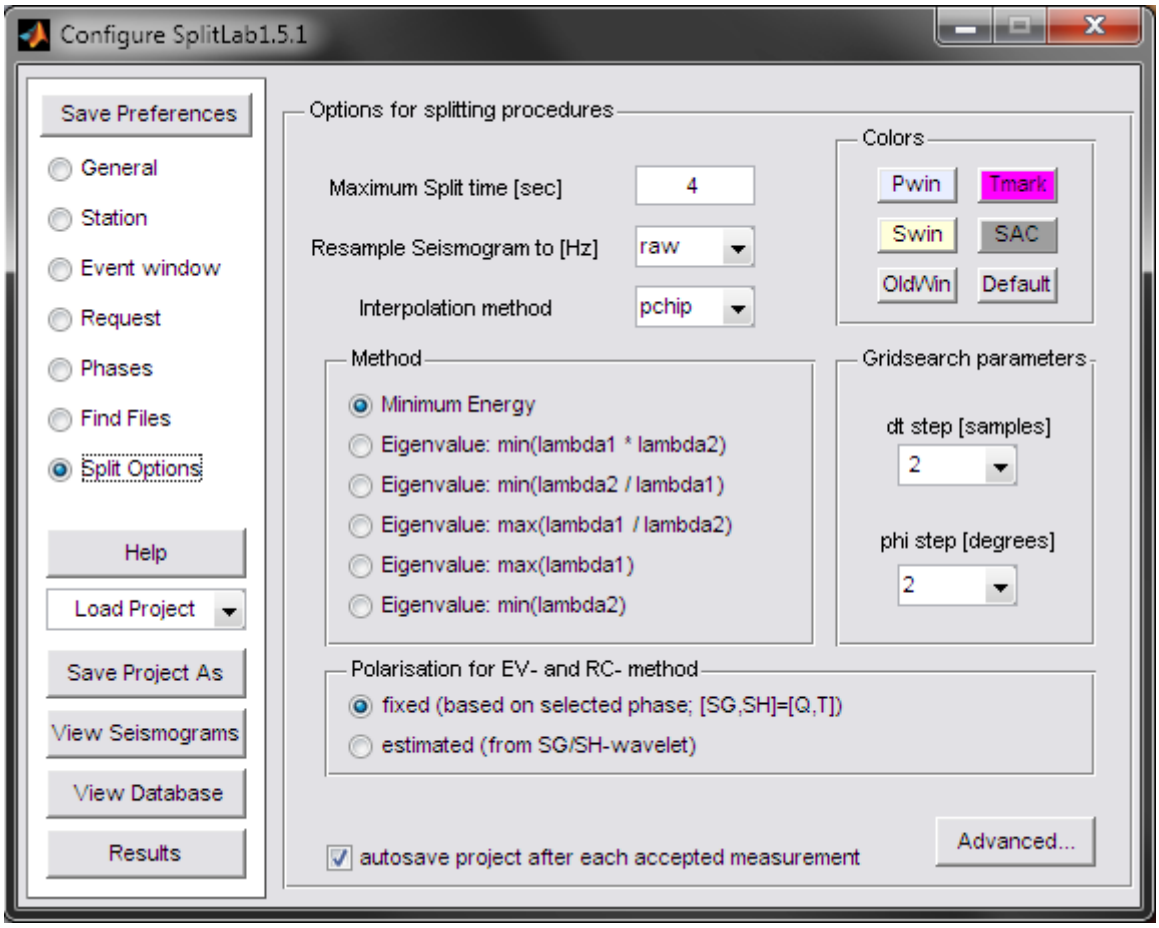


Figure 2 : The “Cut and save” button searches for the three SAC file components (East, North, Z) for their maximum common time window (here marked as gray area). Each seismogram is then cut to this time window and written to new SAC files.

6.7 The “Split Option” window



As of Version 1.5 the configuration of the Shear wave splitting procedure has been moved from the SeismoViewer (see below) to the main configuration Window.

- The maximum split time should be self-explanatory. Don’t make it too long, though, as the transverse signal may be over-corrected. Your selection window must also be larger than the maximum split time
- Resample the seismogram two a new sample frequency (up-sample or down-sample). Be careful. This can require huge amount of memory if you upsample to much. ‘raw’ means that no interpolation is performed.
- Interpolation method defines how interpolation is performed options are
  - Nearest neighbour
  - Linear
  - Spline
  - Piecewise Cubic Hermite Interpolating Polynomial (PCHIP)

  See the Matlab documentation on `pchip` for more information on the various interpolation methods.
- In the Grid Search Parameters panel you can specify the resolution of the grid search algorithm. Smaller values stand for higher resolution, but longer calculation time.

- The Methods panel allows switching between the several methods described in the Silver & Chan (1991) paper. Please read that carefully and choose the one most appropriate for your purpose. The chosen method is the one displayed in the lower panel of the diagnostic plot. If you choose an *Eigenvalue-method*, the *Minimum Energy* result is calculated regardless. This result may however be meaningless, depending on the type of experiment you perform, because it assumes the initial polarisation parallel to backazimuth. Again, please refer to the Silver & Chan paper. If you choose the Minimum Energy method, an Eigenvalue result is calculate based on the minimum of $\lambda_1 * \lambda_2$.

- Polarisation for EV and RC method: If your incoming polarisation is known, i.e. corresponds to the backazimuth (you are using core refracted (*KS) or core-reflected (*cS) waves), than you can use the "fixed" (or geometrical) option. Otherwise it is recommended to determine the polarisation from the the S-wavelet you selected in the SeismoViewer. In the latter case, the Q-component must be renamed $S_{Sagital}$ and the T-compoent is the $S_{horizontal}$

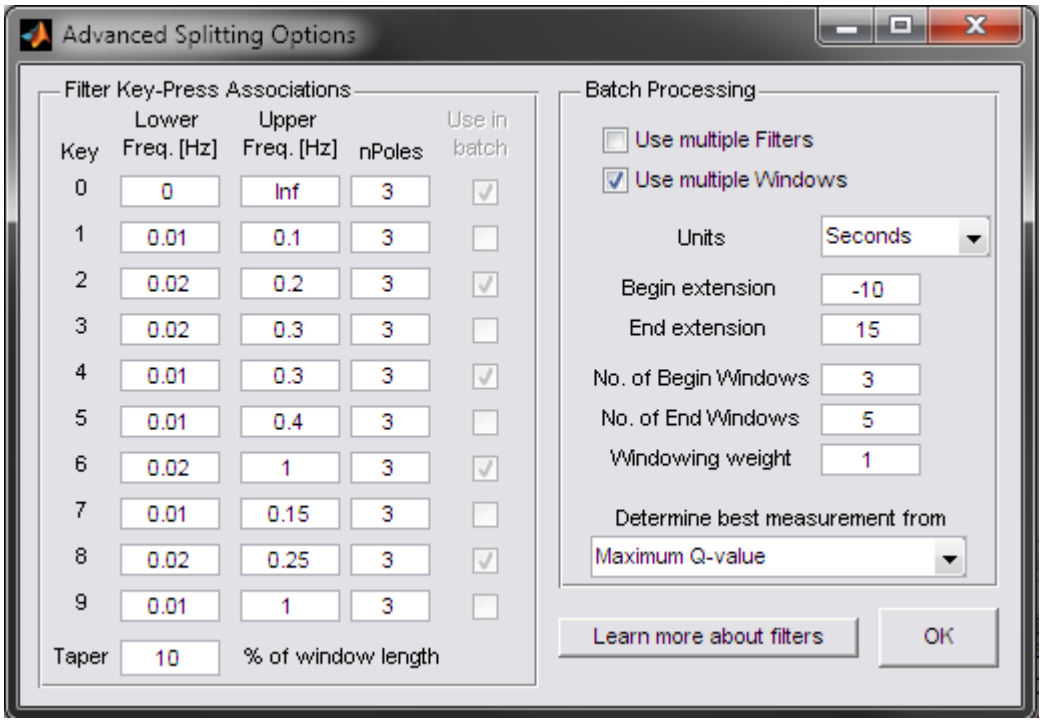
  The geometrical backazimuth is always defined as the azimuth (clockwise from north) from the station looking towards the epicentre. However, geometrical inclination has two different definitions: If your travel time model is PREM or IASP91, it is reasonable to assume you are working on global data. The inclination is derived from the ray path, according to the phase you selected in the PhaseSelector at the lower left corner of the SeismoViewer. If your travel time model is "Homogeneous Model" the straight line vector is calculated between hypocentre and station and the inclination is derived from that.

- Autosave project after each measurement: if you accept a measurement in the diagnostic viewer, the whole project is saved at the same time. For large projects (>1000 events) this may take some time. If you switch of the autosave, it is your responsibility to save your project using the "Save As" button in the Configuration Window. But don't forget to do so every now and then…

- The "Colors" panel allows you to set the colours of the several features in the SeismoViewer. Click on each button to change the corresponding colours (if you don't like the defaults...)

- The step size panels allows to chose resolution of your splitting. The grid search for best removal is done in the corresponding step sizes for samples (dt) and degrees. This strongly affects the speed of your calculation.

6.7.1 The Advanced… button



Even more options are available trough the Advanced Button. As you can imagine, the Filter Key-Press Panel sets the filter parameter whenever you press any of the number keys 0 to 9. The Number of Poles define, broadly spoken, the sharpness of the filter. Be aware that too high number of poles may cause "ringing" effects of the filter. Read the Matlab help on filtering or the provided PDF file to find out more.

You can define several possible filter types:

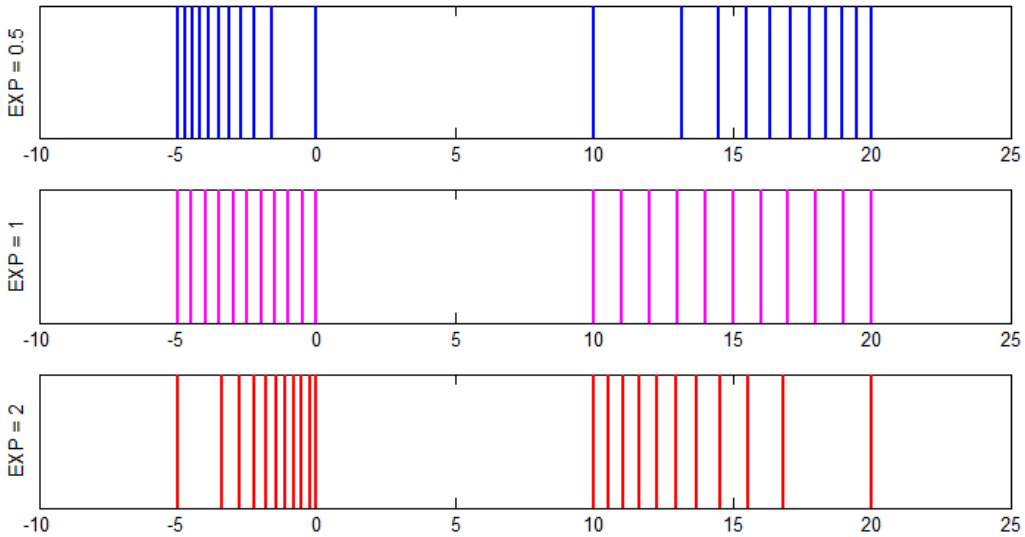
Type	Lower Frequency	Upper Frequency
Band Pass	> 0	> Lower Frequency
High Pass	> 0	= Inf
Low Pass	= 0	> 0
Band Reject	< Upper Frequency	< 0

For example, a 50Hz band reject would have for example an Upper Frequency of -40 and a Lower Frequency of -60Hz.

A taper mutes the beginning and end of signal, which is important to reduce edge effects on spectral analysis and filters. SplitLab uses a cosine (i.e. tuckey) taper. The zone of influence is defined by the taperlength. See Matlab help on tuckeywin for more help.

6.7.2 The Scenic Hike

- Batch processing: The splitting measurement can vary depending on the actual window you select. Batch processing allows you to automatically browse a few windows around your initial selection (Teanby et al. 2004). This is done by extending the window. You can select:
  - Units determines how the extended window is defined, based on the values in "Begin" "End Extension". "Seconds" means those two values are in seconds relative to the S-pick, percent means those are in percent of the total S-pick length. Alternatively, you can use the P-pick window to manually select the extended window.
  - Begin extension: define by how many seconds the splitting window should be extended at maximum extension, relative to start of S-Window. Note that you need to input negative values to be before the selection.
  - End extension: define by how many seconds the splitting window should be extended at maximum extension, relative to the end of S-Window.
  - No of Begin / End Windows: Defines in how many sub-windows the extension should be divided. Note that a value of 1 considers only the corresponding original S-Pick.
  - Window exponent: Defines how the windows are divided, which can be regarded as a weighting of the original window. A window exponent of 1 means equally (linearly) spaced sub-windows. This can be best explained by a figure:



Each line represents a window pick, in this case only for the "Begin window". The original S-pick is at 0 sec, and the Begin Extension is selected to be -5 sec. The original end of the S-window is at 10 seconds, and the selected End Extension is 10 seconds. 11 Begin and End Windows should be processed. In the first (blue) case the windows are spaced closer (EXP < 1) towards the end of the extension windows, the magenta example shows equally spaced (EXP = 1) windows, and last (red) case more windows are processed closer to the original window (EXP >1).

You can also add Filters to your scenic hike of looking around your selected base window.

Then, the selected filters are used to find the "best" measurement. The definition of "best" can be controversial, but SplitLab provides several attempts:

You can base the quality on the difference between two independent spitting methods (Wuestefeld and Bokelmann, 2007). The Quality is a numerical value between +1 (good) 0(poor) and -1(Null). See Wuestefeld et al, Geophysical Prospecting, in Press 2010. This is used in the Q-value methods. Maximum only finds highest correspondences, which may be poor (e.g. around 0). Maximum absolute allows for Nulls to be found as well (-0.95 is better than +0.8). Weighting means that the overall quality of the result includes all measurements (See Wuestefeld et al, Geophysical Prospecting, in Press 2010):

$$Q = \frac{1}{3}\sum Q_i / N + \frac{2}{3}\sum Q_{best}$$

If you select Stack Error Surfaces, all error surfaces will be summed-up. The resulting mean error-surface will be used to determine fast axis and delay time. Note that only individual measurements with a positive Quality (see automatic Null detection) are considered in the mean error surface.

Be aware that this stacking is different of that proposed by various authors (e.g. Wolfe and Silver, 1996; Restivo and Helffrich, 1999). For more discussion on that read my PhD thesis, Chapter 4.5, available on the SplitLab Homepage.

Finally you can select a cluster analysis of all events. See Teanby et al. (2004) for more information.

6.7.3 One note on stacking:

Stacking of error surfaces is used by some authors (e.g. Wolfe & Silver; Restivo & Helffrich; Bastow et al.) to improve the splitting quality for noisy stations. This method make certain assumptions and is thus requires user interaction. This means you have to write your script to do the stacking and decide which data to use with which weighting.

SplitLab provides however means to save the error-surface in the database. Only set the "hidden" option in the config variable to "true" by typing in the command line:

```
>> config.saveErrorSurface = 1;
```

and save the project file. The Error surface data are then stored in matlab matrix format in the variable

```
eq(num).results(n).ErrorSurface
```

Note that each error-surface consists of a large matrix and for big projects can result in huge SplitLab projects.

Please let me know of your experience with this option....

6.8 The “Save Preferences” button

The current configuration is saved as default Project entries for future sessions of SplitLab

6.9 The “?” button

It provides some help and information that may be useful for the user

6.10 The "Load Project" button

Allows loading a project that has been already saved. A selection of the last projects is available.

6.11 The "Save Project As" button

Allows saving a project. It is important to save a project after having successfully finished the association between the seismograms and the events ("Find Files" operation).

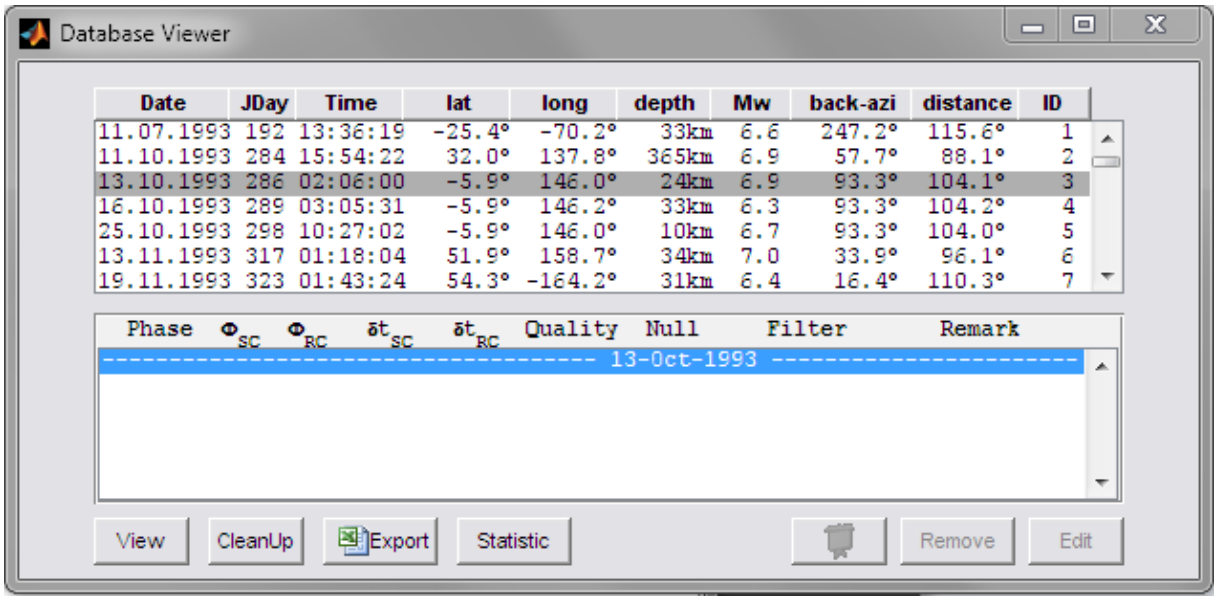
6.12 The "View Seismograms" button

Starts the Seismogram Viewer at the beginning of the database for a newly created database. If you loaded the project, the last used database entry will be displayed.

6.13 The "View Database" button

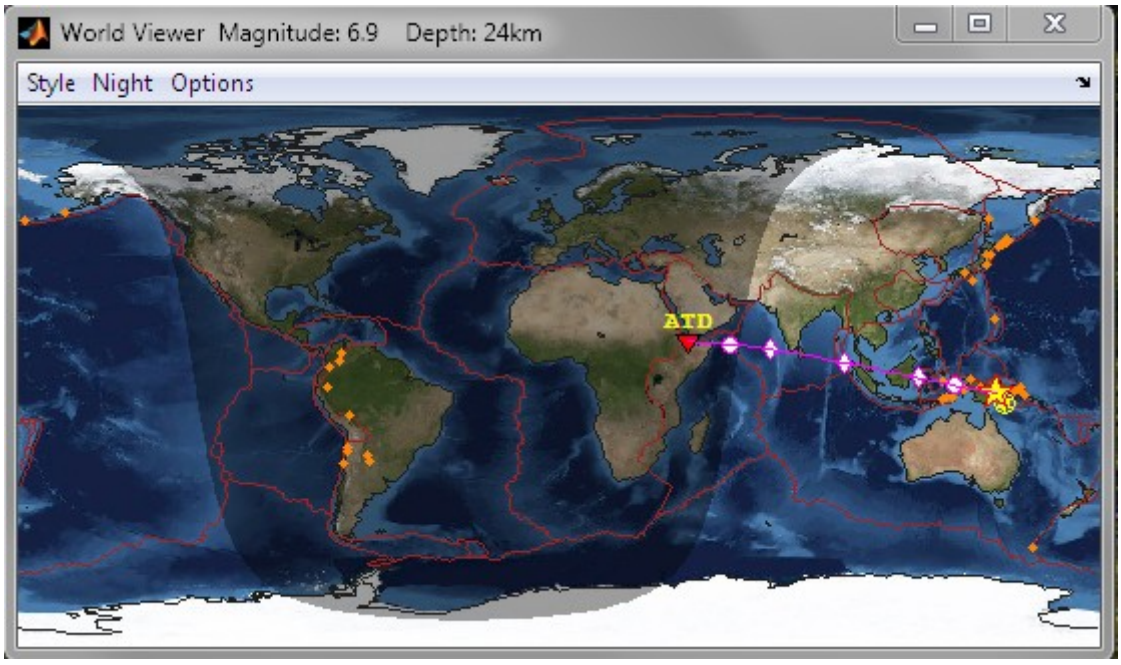
It provides a way to select and visualize each of the seismogram from the database. The Database is defined as the set of seismograms that have been successfully linked to the selected events. In other words, the database is closely related to a project and a given data selection and might not contain all the SAC files the data directory.

7 The "Database Viewer" window



This window lists the events present in the database and the "WorldViewer" geographically presents the events form the database. By clicking on one or several events from the list, you can visualize them as stars on the map. The user can zoom in and out on the map. The events are sorted by date as default but you can choose your sorting criteria by clicking at the top of the column, the event distance, depth or magnitude may be useful in the process of shear wave splitting measurements.

The WorldViewer displays the earthquakes in the database. The selected earthquakes from the DatabaseViewer are marked as stars. Also, the Great Circle path between station and Event is displayed. If switched-on in the figure's menu, the day-night situation and the position of the sun at time of the first earthquake is displayed. This may be referred to as the "Esoteric Mode"… Unfortunately, calculating the position of the moon is a bit more complex…



Apropos moon: The “Style” menu allows choosing between various background images, including Moon and Mars. Thus far, no usable seismograms for both are available (the Apollo mission put out seismometers; however these seismograms contain hardly any distinguishable S-Phases). If you ever come across some useful data, I would be keen on collaboration….

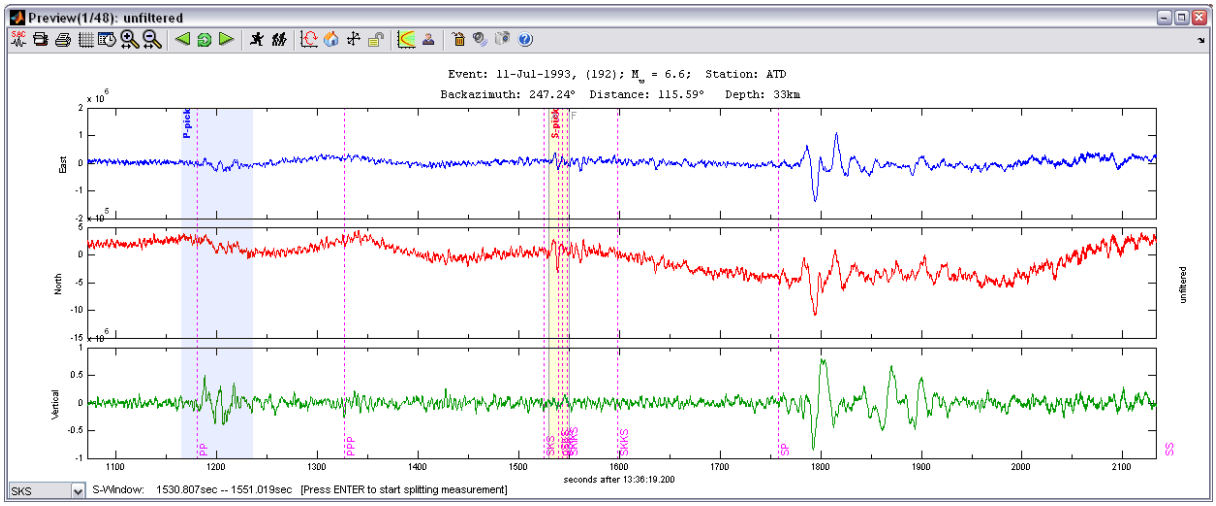
In Reservoir and Regional Mode the World viewer will show a 3D scene of the event locations and you can zoom and rotate around your database.

The lower part of the DatabaseViewer displays the shear-wave splitting result(s) that have been saved for a given event. It also presents some button:

- The button "view" allows opening the "SeismoViewer" to see the 3 components of the selected seismogram.
- The "Cleanup" button allows removing from the database the events on which no splitting measurements are made. After such an operation, it may be a good idea to save the project under a new name (button "Save Project As"), in order to keep the possibility to come back on data that did not provide splitting measurements.
- The "Export" button allows to save the table as an Excel file. This is only available on Windows, due to limitations in portability of Excel. However, you can also export as a Comma-Separated-Value file, a text file which can be used in other programs.
- The "statistics" button displays:
    - the event location on a map preserving the true backazimuths,
    - the histogram of the backazimuthal distribution,
    - a rose diagram presenting the same backazimuthal distribution.
- The "Presentation" button allows visualizing the graphical results of a splitting measurement. Indeed, when the user saves a result, a copy of the graph is also saved in the output directory.
- The "Remove" button allows the user to remove the result of a splitting measurement from the list.
- The "Edit" button allows visualizing the numerical values associated to the splitting measurements obtained on a seismic event.

8 The "SeismoViewer" window

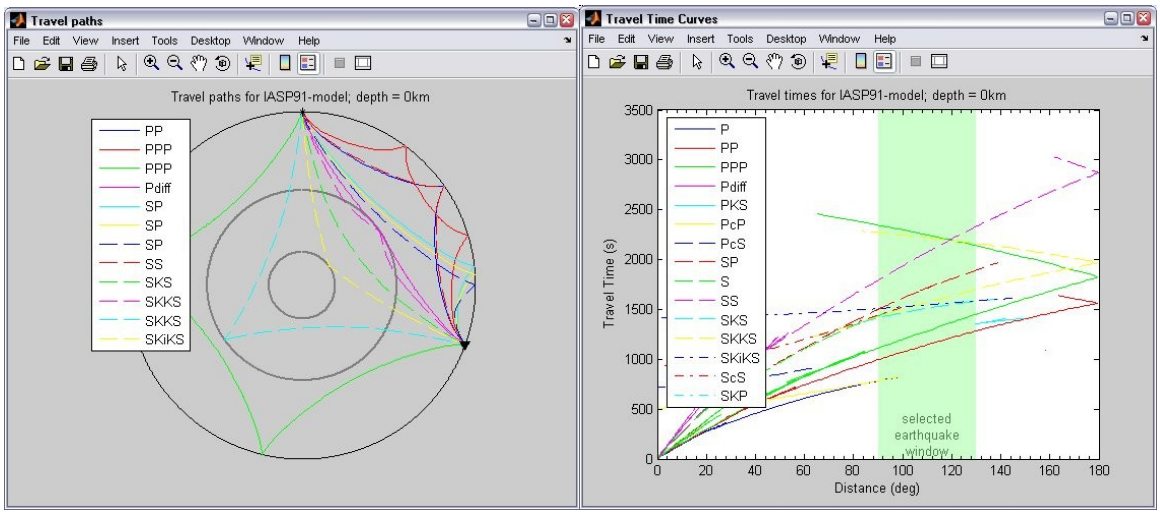
By clicking on the "View Seismogram" button in the main "Configuration" window, one accesses to the "SeismoViewer" window, which displays the 3 components of the selected event, together with the predicted arrival times (selected in the “Phases” panel). The user can select a P-Window (in blue) with a left-mousbutton-click-and-drag, and an S-Window (in yellow) with a right-mousbutton-click-and-drag. Middle-mousebutton or Shift-click will Zoom-In to the selected time-range



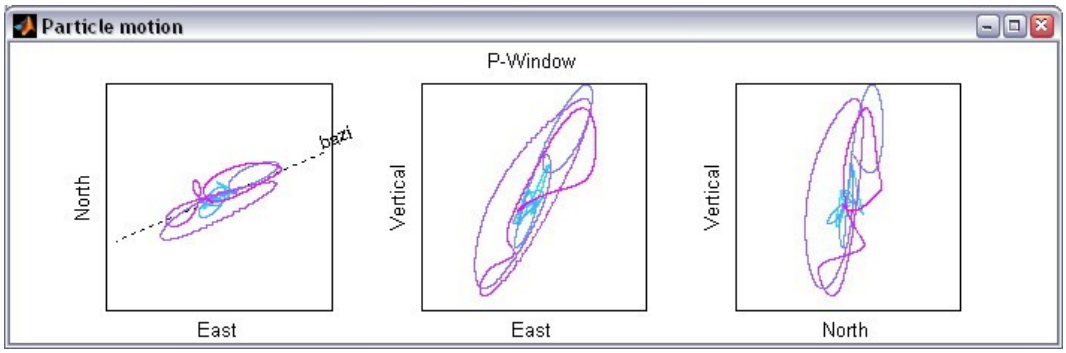
The data can be easily filtered through a set of prepared filters accessible through the keyboard. Further functions directly accessible through key-pressing are described below. The basic operations are accessible by a set of buttons aligned at the top of the window:

Figure 3 : the SeismoViewer button bar offers manifold options…

- The "SAC" button save the seismograms visible at the screen as SAC files (“SAC screenshot”). Note that only the length of the currently displayed window is exported.
- The "Database" button allows to select a seismic event through the database
- The "Print" button allows to print the window
- The "Grid" button puts and removes grids on the seismogram. By default, each seismogram is vertically scaled to the maximum value of the component.
- The "Time table" button allows plotting the arrival times and the travel paths of one of several seismic phases selected by the user for the current event.



- The "Zoom In" button allows to zoom into a time window defined by the user by dragging the mouse along the seismogram.
- The "Zoom Out" button removes the zoom.
- The "Left Green Arrow" allows visualizing the previous seismic event of the database.
- The “Green Loop” allows to reload the current seismogram
- The "Right Green Arrow" allows visualizing the next seismic event in the database.
- The “Sprinter” button performs a splitting measurement on the selected S-window
- The “Hikers” button starts multi-window batch processing as described in Chapter 6.7, under Advanced Splitting Options
- The "Particle Motion" button presents the particle motion diagram of the selected time window. Note that the colormap is different for P- and S-window

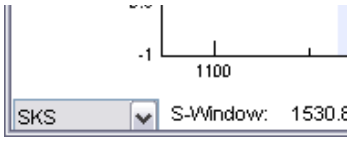


- The "Home" button allows to zoom directly onto a selected seismic phase, that is selected on the rolling menu at the bottom left of the window. It can be accessed also by typing on the "home" key (for the PC) or on the "esc" key for the Macintosh.
- The "System" button allows switching between the E-N-Z reference frame to the L-T-Q reference frame.
- The "Lock" button allows to present the 3 component at the same vertical scale

- The “Spectrogram” button accesses the SpectrogramViewer (see below)
- The "Trash" button removes the current event from the database.
- The "Speaker" button plays the selected P-window as sounds.
- The "Camera" button saves the actual seismogram as a graphic file.
- The "?" button provides database information on the current event…

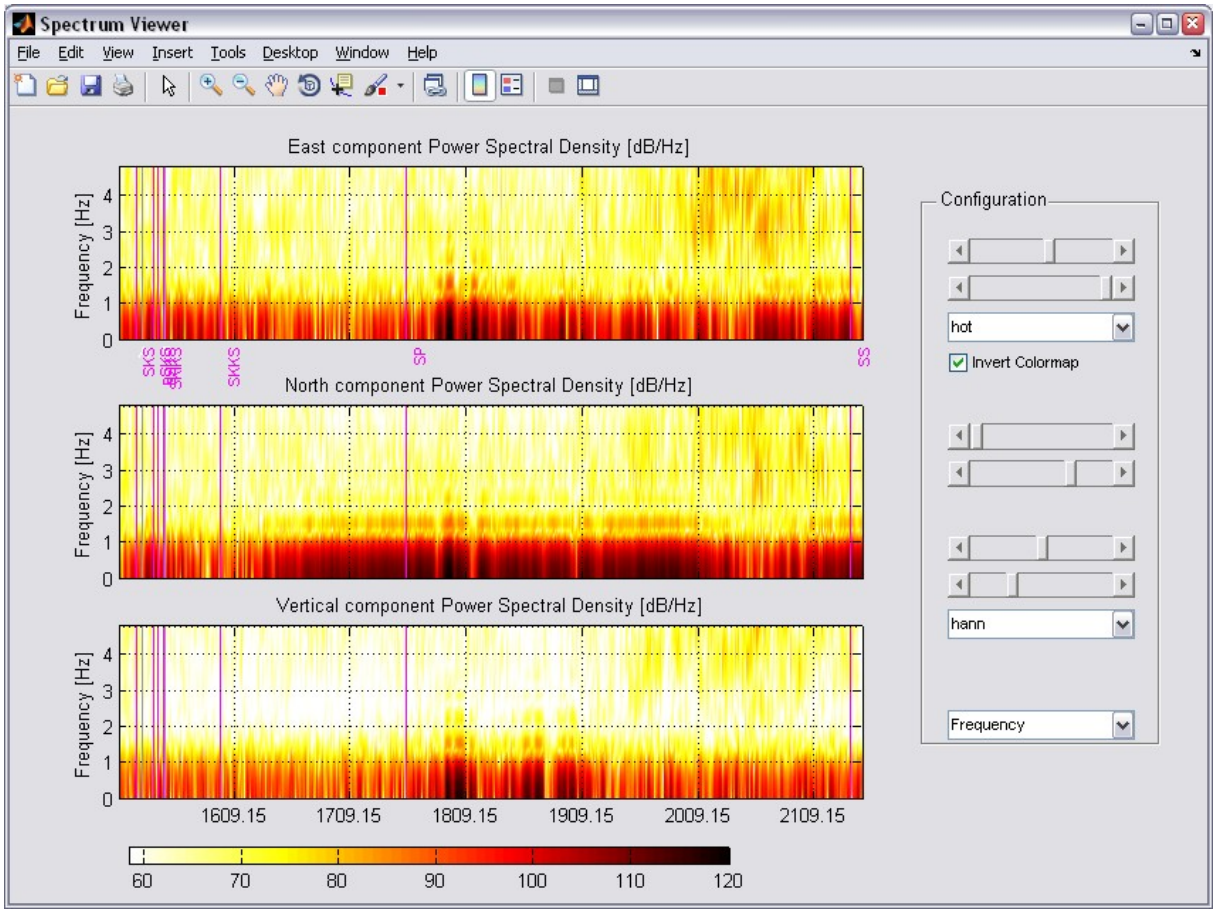
8.1 Performing shear wave splitting measurements

- In the "Database Viewer", select your seismic event and click on the "View" button; It is loaded in the "SeismoViewer" window
- Select the phase-of-interest. The Phase selector can be found in the lower left corner of the SeismoViewer.



- Visualize your event in both the geographic and ray reference frame, use different kinds of filters and zooming options to evaluate the quality of the data and to locate the core shear phase on which you wish to make your measurement.
- Press Enter or click on the “Sprinter” button to start splitting measurement. Shift-Enter or clicking the “Hiker” button will start Multi-window batch processing.

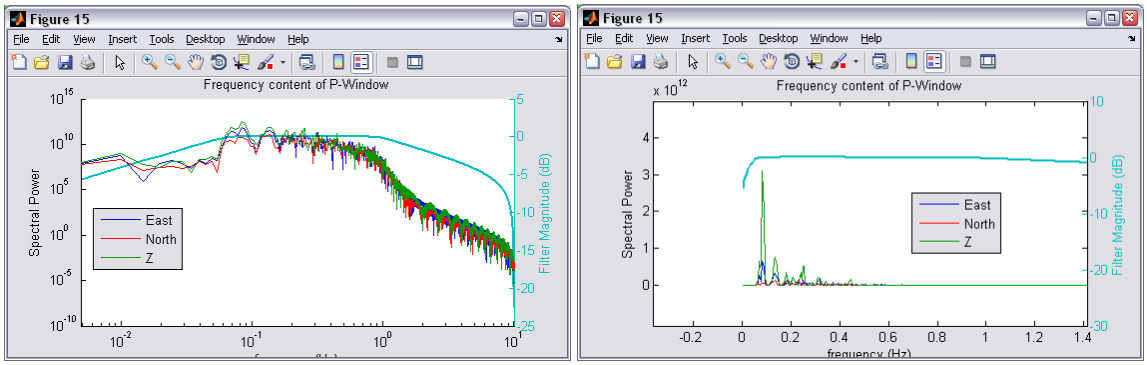
8.2 SpectrogramViewer



The SpectrogramViewer allows to determine the frequency contents of the P-Window varying with time. The colour represents the power of a particular frequency at a given time. This may help identifying relevant phases. The configuration panel offers several options:

- The first two sliders determine the extend (upper and lower limit) of the color scale
- The Menu below allows selection of a color map
- You may also invert the colour map
- The next pair of sliders determine the frequency limits of the plots. Note that their scale is logarithmic to allow finer tuning for low frequencies
- The third pair of sliders determine spectrogram calculation parameters: 1) number of FFT-points to use (default, central position means optimum based on sampling rate) and 2) overlap of the sliding windows (default is 25%). See MatLab documentation of `spectrogram`
- The menu below chooses the form of the sliding window
- Finally, you can choose between “Frequency” or “Period” display of the Y-axis

8.3 Spectrum Viewer

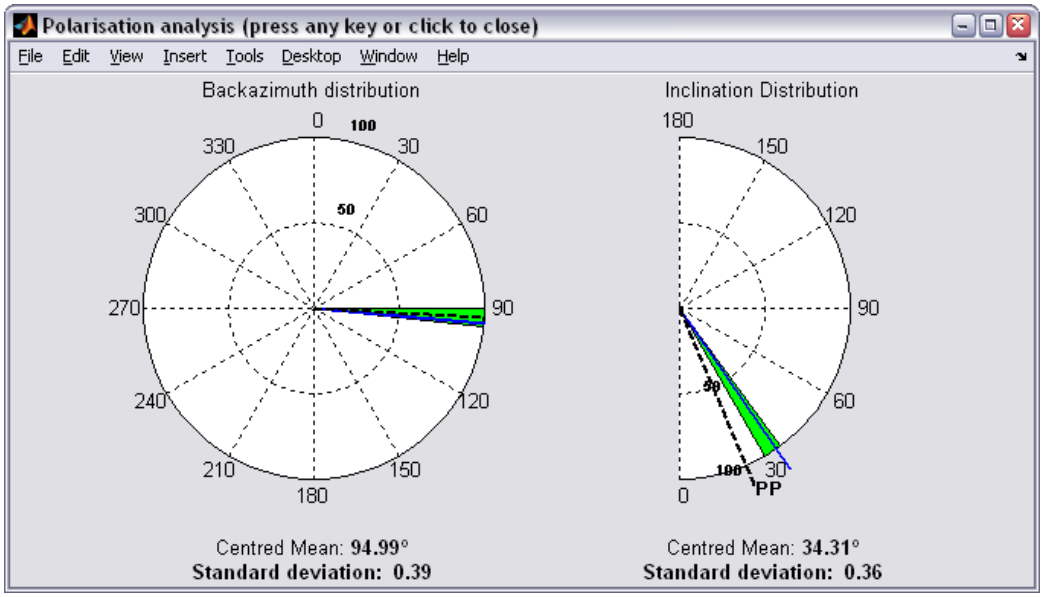


If you select a P-window and press the "s" key on you keyboard, a plot of the overall, not time dependant, spectral power of the three components will be displayed. This gives you a hint whether you have chosen an appropriate filter or time window length. The filter magnitude as a function of frequency is also displayed. For further information see the Matlab documentation on `fft` and `freqz`. Pressing "s" will result in a logarithmic display of frequencies, pressing "Shift-s" in a linear display, which may sometimes be more appropriate. You can use the arrow-keys to move in the figure, shift-arrow will cause directional zooming, and PageUp and PageDown general Zoom. Zoom is relative to mouse pointer.

8.4 P-polarisation analysis

New in SplitLab Pro is also the P-polarisation analysis. This is to determine the (back-)azimuth and inclination of an event in the case of

- a misoriented station
- a microseismic or local study, where initial polarisation does not coincide with backazimuth



We provide two possible polarisation algorithms, both performing a principal-component analysis (PCA; see for example Jurkevics, 1988). To stabilise the result, multiple Monte-Carlo simulations are run on the P-window, each considering only a certain subset of samples (50 - 95%). This is repeated

various times and each time the Backazimuth and inclination is determined. Outliers are determined using the RANSAC algorithm (Matlab implementation from the Mathworks Central FileExchange). This method allows a stable result and also can estimate the error, as the width of the 95% standard deviation from the outlier-free mean value. One method (Teanby) first determines the backazimuth from the horizontal components and then the inclination from this “radial” component and the vertical component. The second method (Jurkewicz) performs a full 3D PCA simultaneously.

Obviously, the PCAs work best for events which result in P-energy on all components: For example steeply incident waves will have only a poorly constrained azimuth. By selecting “P-pol$_{bazi}$” you can force SplitLab to use the geometrically determined azimuth (receiver-source backazimuth)

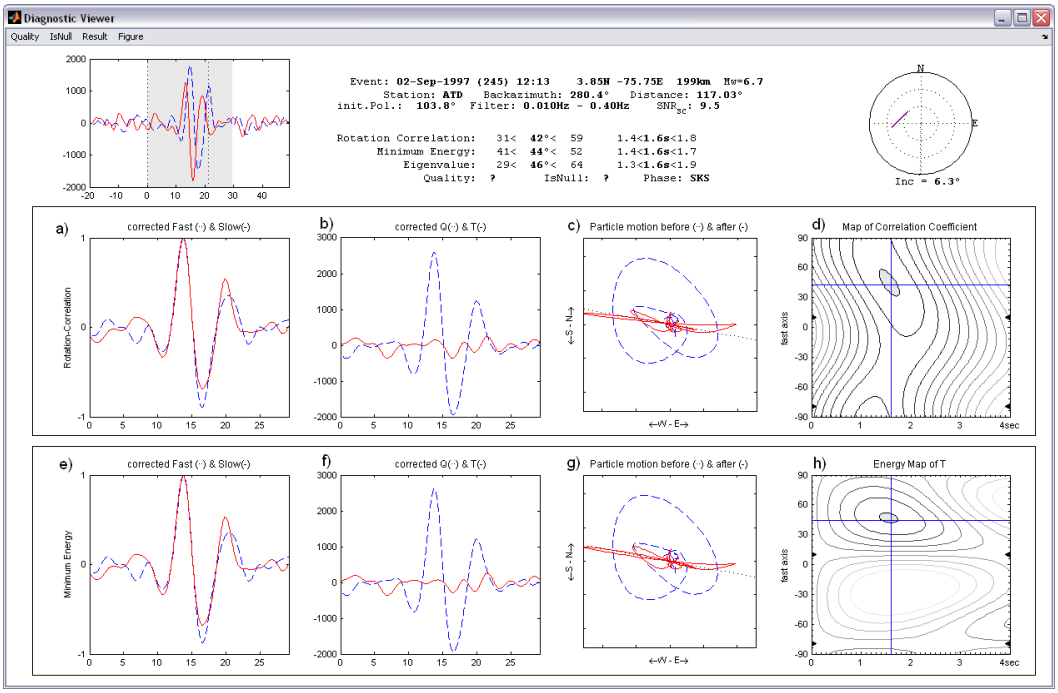
8.5 How to start Splitting measurement

Select the S-window (left-click and drag) on which you want to make the splitting measurement. The active time window will appear in gray whereas the old selection, if any, appears in yellow.

Press the "ENTER" key to start the measurement. When the measurement is finished, the "Diagnostic Viewer" window appears, which summarizes the results obtained by the different methods:

9 The DiagnosticViewer

At the top of the window is presented the radial (in blue solid) and transverse (in red dashed) components at the same vertical scale, filtered in an extended section of the previously chosen window without any correction.



- The upper horizontal panel presents a set of diagrams obtained by using the rotation-correlation method. From left to right:
- The fast (blue solid) and slow (red dashed) split components corrected from the delay time. This diagram allows checking the correlation of the waveforms.
- The radial (blue) and transverse (red) components corrected from the anisotropy. This allows to see if the signal on the transverse component has been well removed after correction for the best phi and dt pair.
- The particle motion diagram, before (in blue) and after (in red) the anisotropy correction. In case of a good measurement, the elliptical particle motion is well linearized after the anisotropy (phi and dt) correction.
- The map of the correlation coefficients showing the quality of the correlation between the fast and slow split waves for phi varying from -90 to 90° and for dt varying from 0 to 4 s (or any other maximum delay time chosen in the SeismoViewer options Menu). Note that the program calculates the correlation for steps of 1° in phi and each sample.

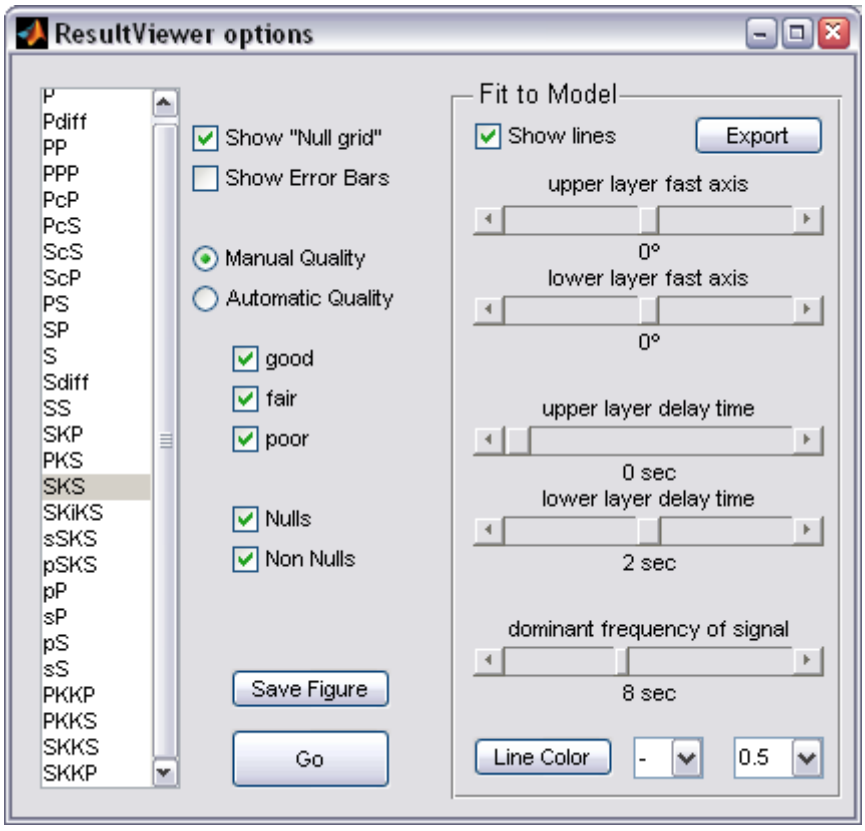
The lower horizontal panel presents a set of diagrams obtained by using the minimum energy (or Silver and Chan) method. (Note: If you selected any EigenValue based method, which will be displayed instead of Minimum Energy). From left to right:

- The fast and slow split component corrected for the best delay time.
- The radial and transverse component corrected from the anisotropy.
- The particle motion diagram, before (in blue) and after (in red) the anisotropy correction.
- The map of the Energy on Transverse components or of Eigenvalue (as chosen in the Option Menu of the SeismoViewer). Here, the grid-search parameters are 2º in phi and 2 samples in time. For a 20 Hz acquisition (delta of 0.05 s between two samples), the time steps will be of 2x0.05=0.1s.

The results are summarized in the upper part of the window, as numerical values and the error bars for the different methods and as a polar diagram on which the fast direction is plotted with the actual backazimuth and inclination.

If you do not like the measurement, go in the "Results" menu and choose "Discard" to reprocess another time window, another phase or to test another filter. If you wish to keep this measurement, you have to choose a quality in the "Quality" menu, to indicate whether it is a null or not in the "IsNull" menu and to save it in the "Save" menu. Note that the quality and null information are just comments and have no role in the subsequent process. In that case, the figure is saved in the format selected in the "configuration" panel and the numerical results are also summarized in the "Database Viewer", linked to the right event. The “Result Viewer” window

9.1 The “ResultsOptions”



The “ResultViewer Options” window allows selecting which part of the result database you want to see. This is mainly designed for teleseismic studies. You may need to write your own tool (and then share it) for regional or reservoir studies...

In the “Phases” panel select the phases of which you want to see the results

Select if you want the “Manual Quality” of the “Automatic Quality”. The former uses the Quality assigned to each measurement in the “Diagnostic plot” The latter determines the quality of each measurement based on the difference between the RC and SC results. See Wüstefeld & Bokelmann, (BSSA 2007) for details

- Select the Qualities you want to see: good, fair, poor
- Select if you want to see the Nulls or non-Nulls (or both)
- Select “Show Error bars” if you want to include the error limits of each measurement
- Select “Show Null grid” to display grid-lines in the fast axes plots. The solid grid-lines indicate where backazimuth and fast-axes coincide. The dashed grid-lines indicate a 45° difference between backazimuth and fast axes.

The “Fit to Model” panel allows calculating the theoretical backazimuthal variation of the fast axes and delaying times (Savage & Silver, 1994). Set the delay time slider of second layer to “0” to see the lines for a single layer model. Note that the “Export” button only works if the results window is drawn (press “Go” first). This saves the theoretic two-layer lines to a file.

9.2 The “Backazimuth distribution”

The results corresponding to the selected options are displayed for each technique (RC, SC, EV). The fast axis estimates make up the first row, the delay time estimates the second row.

In the third row of the result plot, stereoplots of the non-Null results are displayed. The lengths of the markers scale with the delay time, the centre of the lines correspond to backazimuth and the inclination of the wave at surface.

10 Trouble Shooting

10.1 Installation problems

(see also at http://www.gm.univ-montp2.fr/splitting/install.html)

In case of problems please check:

The file classpath.txt You can view the file by typing in Matlab: edit(which('classpath.txt'))

This file contains the path to JAVA classes in Matlab.

At the end of the file should be the proper path to the file "matTaup.jar" located by default in SplitlabX.X.X/mattaup/matTaup.jar

After editing classpath.txt you have to restart Matlab. You can also add it dynamically to your javaclasspath. Please see the Matlab Documentation.

The Matlab search path should contain the following folders:

`SplitlabX.X.X/`

`SplitlabX.X.X/Tools`

`SplitlabX.X.X/ShearWaveSplitting`

The path to the SacLab Utility

`SplitlabX.X.X/SacLab`

The path pointing to matTaup (usually at the end of the path)

`SplitlabX.X.X/mattaup`

For editing the path use the command: `>> pathtool` or edit/create your local `startup.m` file. See the Matlab documentation for startup options

10.2 Create your own filename format

The association of a SAC seismogram to an event in the Database is done in tow steps:

The finding of appropriate file start times corresponding (within a tolerance and eventually an offset) to the hypocentral time (Figure 1). This is done in the Matlab function in `/Tools/getFileAndEQseconds.m`

The ordering of three matching files by component: East, North, Vertical. This ensures that in the database variable eq.seisfile of your project the first entry corresponds always to the East component, the second entry to the North component and the third to te Vertical. This is done in the Matlab function in `/Tools/sort_components.m`

Two variables of your project configuration determine your choices:

`config.FileNameConvention` is a string corresponding to your selection in the File-Format Menu (eg 'RDSEED')

`config.UseHeaderTimes` is a logical value: "1" means you wish to use SAC header times, and "0" means you would like to use the filename to determine the start time of the file.

Knowing all this, adding a new Filename format should now be straightforward:

```
>> edit XXX/Tools/getFileAndEQseconds.m
```

- go to the line which states

  ```
  switch config.FileNameConvention
  ```

- after this line add a new case statement:

  ```
  case 'MyFormat'
  ```

  state the position of year, julian_day, hour, minute and second in the filename. If not all these information are given, make sure you set the search-tolerance and search offset appropriately! Please use the existing formats as templates to your format. If your format uses day and month instead of julian_day, you have to use the "`dayofyear`" function, as in the 'YYYY.MM.DD-hh.mm.ss.stn.sac.e' format.

  The given values have to be transformed to seconds after Jan, 1st of the corresponding year. Add something like the following:

  ```
  FIsec  =  FISS + FIMM*60 + FIHH*3600 + (FIddd)*86400;
  ```

  Note, that this approach omits any event lose to "midnight, new year".

- Save /Tools/getFileAndEQseconds.m
- Type

  ```
  >> edit /Tools/sort_components.m
  ```

- go to the line which states

  ```
  switch config.FileNameConvention
  ```

- after this line add a new case statement:

  ```
  case 'MyFormat'
  ```

  Define then a variable `pos` whose value corresponds to the position of the Letter in the filename which determine the Component name. For expample, if the Component corresponds to the 18th letter, use: `pos = 18;` Please use the existing formats as templates.

- Save /Tools/sort_components.m
- Finally add your format to the file format menu

  ```
  >> edit XXX/private/configpanelFINDFILE.m
  ```

- find the line where the menu entries of the uicontrol are defined:

  ```
  str = {'RDSEED' 'SEISAN', 'YYYY.JJJ.hh.mm.ss.stn.sac.e'
  'YYYY.MM.DD-hh.mm.ss.stn.sac.e'};
  ```

- add your format to this cell array:

  ```
  str = {'RDSEED' 'SEISAN', 'YYYY.JJJ.hh.mm.ss.stn.sac.e'
  'YYYY.MM.DD-hh.mm.ss.stn.sac.e' 'MyFormat'};
  ```

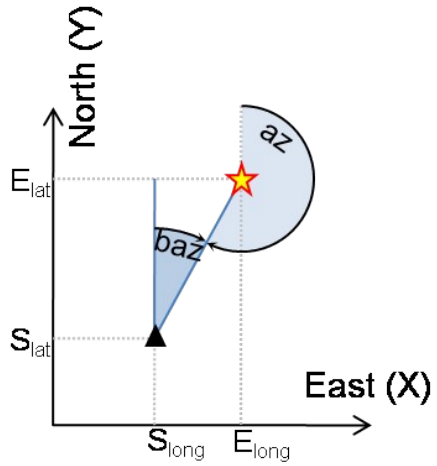
  All entries should be in a single line! Furthermore, this entry name should be exactly the same as used before since it determines the value of the variable `config.FileNameConvention`

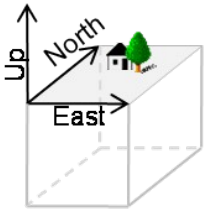
- save XXX/private/configpanelFINDFILE.m
- restart SplitLab

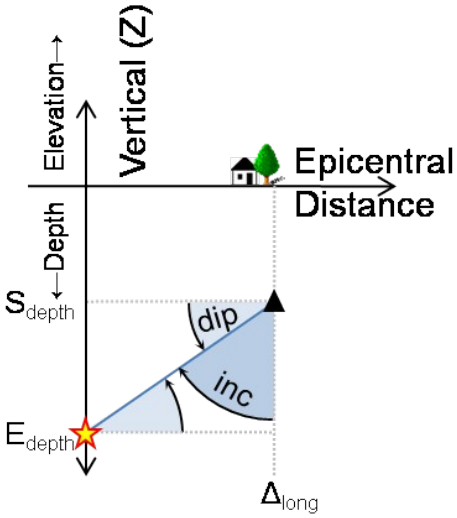
10.3 Preferences problems

During installation, SplitLab preferences are added to the Matlab environment (See the prefdir documentation for further details on preferences). The SplitLab Preferences contain the fields CONFIGURATION (default SplitLab project configuration), ASSOCIATIONS (figure export file types and, on non-PCs, the system command line to open the file type) and HISTORY (recently used SplitLab Projects). These preferences are only valid for the user, who installed SplitLab. However, if a new user runs SplitLab, new default preferences are automatically created for that user. In multi-user case be sure that all users have permission to the SplitLab, SacLab and matTaup path and the paths are set correctly for each user.

11 The SplitLab coordinate systems

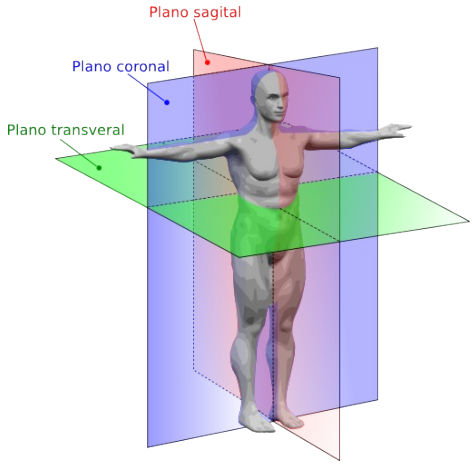


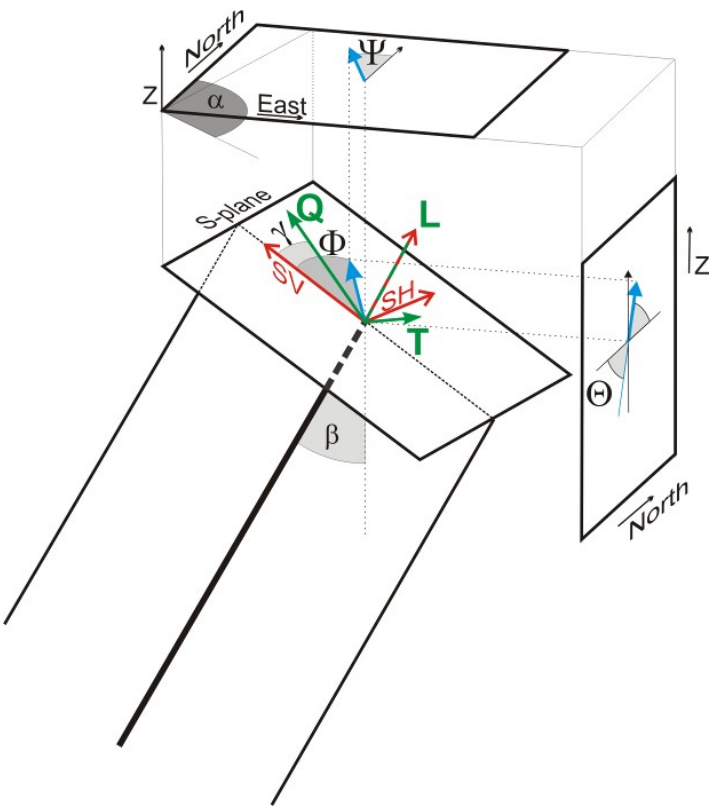




$baz = \text{atan2}((E_{long}–S_{long}), (E_{lat}–S_{lat}))$
$az = 180 + az$

$E_{elev} = - E_{depth}$; $S_{depth} =- S_{elev}$
$\Delta = sqrt((E_{long}–S_{long})^2 + (E_{lat}–S_{lat})^2)$
$inc = atan(\Delta / (E_{depth}–S_{depth}))$
$dip = 90 - inc$





modified after Vecsey et al. 2008

α = azimuth
α' = backazimuth
β = inclination (from down direction)
γ = angle between initial polarisation and backazimuth (counting ccw in S-plane relative to SV; [-90…90]
Φ = fast direction relative to backazimuth in S-plane [-90…90]
Ψ = strike of fast orientation vector [-90…90]
Θ = dip of fast plane [0…90]

Z = vertical component (positive up)
E = East Component
N = North Component
Forming right handed coordinate system **E-N-Z**

L = Ray component (positive from event to station)
SH = horizontal component of S-Wave
SV = vertical component of S-wave (pointing from station to event)
Forming right-handed coordinate system **SH-SV-L**
Note: strictly, SV is the component in the sagital plane, perpendicular to both SH and L. This is only SV for horizontally [sic!] incident waves. You may want to call it SG instead…

Q = component along S-polarisation; in S-plane, pointing from station towards event
T = component perpendicular to S-polarisation; in S-plane
Forming right-handed coordinate system **L-T-Q**

Rotation:

Counter-clockwise rotation matrix (mathematically positive)

$$R(\varphi) = \begin{bmatrix} \cos\varphi & -\sin\varphi \\ \sin\varphi & \cos\varphi \end{bmatrix}$$

therefore

$$M_Z = \overbrace{\begin{bmatrix} \cos\alpha' & -\sin\alpha' & 0 \\ \sin\alpha' & \cos\alpha' & 0 \\ 0 & 0 & 1 \end{bmatrix}}^{rotation\_about\_Z}$$

$$M_H = \overbrace{\begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\beta & -\sin\beta \\ 0 & \sin\beta & \cos\beta \end{bmatrix}}^{rotation\_about\_SH}$$

$$\Rightarrow$$

$$M = M_Z * M_H$$

$$= \begin{bmatrix} \cos\alpha' & -\sin\alpha' & 0 \\ \sin\alpha'\cos\beta & \cos\alpha'\cos\beta & -\sin\beta \\ \sin\alpha'\sin\beta & \cos\alpha'\sin\beta & \cos\beta \end{bmatrix}$$

First, a ccw rotation about Z by backazimuth to give

E=SH & N = Radial (both are horizontal)

Then ccw rotation about SH by inclination to give L-SH-SV

$$\begin{bmatrix} SH \\ SV \\ L \end{bmatrix} = M * \begin{bmatrix} E \\ N \\ Z \end{bmatrix}$$

Q is the orientation of initial S-wave polarisation, as derived from corrected EV method. In Splitlab, the inversions of all techniques (XC, SC, EV) are done relative to SV-SH coordinates.

To rotate from SH-SV to T-Q coordinates we need a counter-clockwise rotation by γ

$$\begin{bmatrix} T \\ Q \end{bmatrix} = \begin{bmatrix} \cos\gamma & -\sin\gamma \\ \sin\gamma & \cos\gamma \end{bmatrix} \begin{bmatrix} SH \\ SV \end{bmatrix}$$

12 Keyboard Shortcuts

0-9	Filter seismograms, frequencies as selected in Advanced Split-Options Panel
+	Add 3% to lower filter frequency
-	Substract 3% from lower filter frequency
*	Add 3% to upper filter frequency
/	Substract 3% from upper filter frequency
f	Open filter dialog box
p / P	Perform polarisation analysis
s / S	Plot the spectrum of the current P-wave window
a	advanced splitting options
l (letter "*el*")	lock the y-axis to maximum value of all seismograms
Enter	Start Splitting Measurement
Shift-Enter	Start Batch-mode splitting
Delete	Remove current event from database (not the SAC files...)
Space	Rotate between ENZ and QTL system
Backspace	Reset zoom
RightArrow	Scroll right
LeftArrow	Scroll left
UpArrow	Zoom In (relative to mouse position)
DownArrow	Zoom Out (relative to mouse position)
Home/Escape	Zoom to phase
PageUp	Previous Event
PageDown	Next Event

Suggested Reading:

Boness, N. L. & Zoback, M. D. (2006), 'A multiscale study of the mechanisms controlling shear velocity anisotropy in the San Andreas Fault Observatory at Depth', *Geophysics* 71, F131.

Brechner, S.; Klinge, K.; Krüger, F. & Plenefisch, T. (1998), 'Backazimuthal Variations of Splitting Parameters of Teleseismic SKS Phases Observed at the Broadband Stations in Germany', *Pure Appl. Geophys.* 151, 305-331.

Carter, A. J. & Kendall, J.-M. (2006), 'Attenuation anisotropy and the relative frequency content of split shear waves', *Geophys. J. Int.* 165(3), 865-874.

Chapman, M. (2003), 'Frequency-dependent anisotropy due to meso-scale fractures in the presence of equant porosity', *Geophys. Pros.* 51(5), 369--379.

Chapman, M. (2003), 'Frequency-dependent anisotropy due to meso-scale fractures in the presence of equant porosity', *Geophysical Prospecting* 51(5), 369--379.

Chevrot, S. (2000), 'Multichannel analysis of shear wave splitting', *J. Geophys. Res.* 105(B9), 21579-21590.

Chevrot, S.; Favier, N. & Komatitsch, D. (2004), 'Shear wave splitting in three-dimensional anisotropic media', *Geophys. J. Int.* 159(2), 711-720.

Crampin, S. (1984), 'Effective anisotropic elastic constants for wave propagation through cracked solids', *Geophysical Journal of the Royal Astronomical Society* 76, 135--145.

Crampin, S. & Peacock, S. (2008), 'A review of the current understanding of seismic shear-wave splitting in the Earth's crust and common fallacies in interpretation', *Wave Motion* 45, 675-722.

Evans, M. S.; Kendall, J.-M. & Willemann, R. J. (2006), 'Automated SKS splitting and upper-mantle anisotropy beneath Canadian seismic stations', *Geophys. J. Int.* 165(3), 931-942.

Gao, S.; Davis, P. M.; Liu, H.; Slack, P. D.; Rigor, A. W.; Zorin, Y. A.; Mordvinova, V. V.; Kozhevnikov, V. M. & Logatchev, N. A. (1997), 'SKS splitting beneath continental rift zones', *J. Geophys. Res.* 102(B10), 2281-22798.

Gerst, A. & Savage, M. K. (2004), 'Seismic Anisotropy Beneath Ruapehu Volcano: A Possible Eruption Forecasting Tool', *Science* 306(5701), 1543-1547.

Grechka, V. & Kachanov, M. (2006), 'Effective elasticity of fractured rocks: A snapshot of the work in progress', *Geophysics* 71, W45.

Heintz, M. & Kennett, B. L. N. (2006), 'The apparently isotropic Australian upper mantle', *Geophys. Res. Let.* 33, L15319.

Helffrich, G. (2006), 'Heterogeneity in the mantle--its creation, evolution and destruction', *Tectonophysics* 416(1-4), 23-31.

Hess, H. H. (1964), 'Seismic Anisotropy of the Uppermost Mantle under Oceans', *Nature* 203, 629-631.

Jordan, T. H. (1978), 'Composition and development of the continental tectosphere', *Nature* 274, 544-548.

Kendall, J.; Stuart, G.; Ebinger, C.; Bastow, I. & Keir, D. (2005), 'Magma-assisted rifting in Ethiopia', *Nature* 433, 146-148.

Kendall, J.-M.; Pilidou, S.; Keir, D.; Bastow, I. D.; Stuart, G. W. & Ayele, A. (2006), *The Afar Volcanic Province within the East African Rift System.*, chapter Mantle upwellings, melt migration and the rifting of Africa: insights from seismic anisotropy, pp. 55-72.

Kneller, E. A.; van Keken, P. E.; Katayama, I. & Karato, S. (2007), 'Stress, strain, and B-type olivine fabric in the fore-arc mantle: Sensitivity tests using high-resolution steady-state subduction zone models', *J. Geophys. Res.* 112(B4), B04406.

Liu, E.; Chapman, M.; Zhang, Z. & Queen, J. H. (2006), 'Frequency-dependent anisotropy: Effects of multiple fracture sets on shear-wave polarizations', *Wave Motion* 44(1), 44--57.

Liu, E.; Maultzsch, S.; Chapman, M.; Li, X.; Queen, J. & Zhang, Z. (2003), 'Frequency-dependent seismic anisotropy and its implication for estimating fracture size in low porosity reservoirs', *The Leading Edge* 22(7), 662--665.

Long, M. D. & van der Hilst, R. D. (2005), 'Estimating Shear-Wave Splitting Parameters from Broadband Recordings in Japan: A Comparison of Three Methods', *Bull. Seism. Soc. Am* 95(4), 1346-1358.

Mainprice, D.; Barruol, G. & ben Ismaıl, W.Union, A. G., ed. (2000), *The seismic anisotropy of the earth's mantle : From single crystal to polycrystal*, Vol. 117, AGU.

Maultzsch, S.; Chapman, M.; Liu, E. & Li, X. (2003), 'Modelling frequency-dependent seismic anisotropy in fluid-saturated rock with aligned fractures: implication of fracture size estimation from anisotropic measurements', *Geophys. Pros.* 51(5), 381--392.

Morgan, W. (1971), 'Convection plumes in the lower mantle', *Nature* 132, 42-43.

Plomerová, J.; Sileny, J. & Babuska, V. (1996), 'Joint interpretation of upper-mantle anisotropy based on teleseismic P-travel time delays and inversion of shear-wave splitting parameters', *Phys. Earth Planet. Inter.* 95(293-309), 293-309.

Restivo, A. & Helffrich, G. (1999), 'Teleseismic shear wave splitting measurements in noisy environments', *Geophys. J. Int.* 137(3), 821-830.

Rial, J. A.; Elkibbi, M. & Yang, M. (2005), 'Shear-wave splitting as a tool for the characterization of geothermal fractured reservoirs: lessons learned', *Geothermics* 34(3), 365--385.

Savage, M. K. (1999), 'Seismic anisotropy and mantle deformation: what have we learned from shear wave splitting', *Reviews of Geophysics* 37, 69-106.

Shearer, Peter, M. (1999), *Introduction to seismology*, Cambridge Univ. Press.

Sileny, J. & Plomerova, J. (1996), 'Inversion of shear-wave splitting parameters to retrieve three-dimensional orientation of anisotropy in continental lithosphere', *Phys. Earth Planet. Inter.* 95, 277-292.

Silver, P. G. (1996), 'Seismic Anisotropy Beneath the Continents: Probing the Depths of Geology', *Annu. Rev. Earth Planet. Sci* 24, 385-432.

Silver, P. G. & Chan, W. W. (1991), 'Shear Wave Splitting and Subcontinental Mantle Deformation', *J. Geophys. Res.* 96(B10), 16429-16454.

Silver, P. G. & Savage, M. (1994), 'The interpretation of shear-wave splitting parameters in the presence of two anisotropic layers', *Geophys. J. Int.* 119, 949-963.

Teanby, N.; Kendall, J. M. & van der Baan, M. (2003), 'Automation of shear-wave splitting measurements using cluster analysis', *Bull. Seism. Soc. Am* 94, 453-463.

Thomsen, L. (1995), 'Elastic anisotropy due to aligned cracks in porous rock1', *Geophys. Pros.* 43(6), 805-829.

Thomsen, L. (1986), 'Weak elastic anisotropy', *Geophysics* 10, 1954-1966.

Upper, D. (1974), 'The unsuccessful self-treatment of a case of “writer's block”', *J. Appl. Behav. Ana.* 7(3), 497.

Vecsey, L.; Plomerová, J. & Babuska, V. (2008), 'Shear-wave splitting measurements -- Problems and solutions', *Tectonophysics* 462(1-4), 178 - 196.

Vecsey, L.; Plomerová, J.; Kozlovskaya, E. & Babu ska, V. (2007), 'Shear wave splitting as a diagnostic of variable anisotropic structure of the upper mantle beneath central Fennoscandia', *Tectonophysics* 438, 57-77.

Wolfe, C. J. & Silver, P. G. (1998), 'Seismic anisotropy of oceanic upper mantle: Shear wave splitting methodologies and observations', *J. Geophys. Res.* B1, 749-771.