StackSplit - UserGuide

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Contents

1 Requirements

StackSplit should run on every computer system on which the original SplitLab[1] package runs. Thus, *MATLAB 7.0* or higher, the *Mapping toolbox* and for full functionality the *Signal Processing toolbox* are required. If *MATLAB 2014b* or higher is running on your system or no license for the *Mapping toolbox* is available, I recommend to use the updated SplitLab version of Rob Porritt[2]. However, StackSplit was designed to work with both versions (with and without the *Mapping toolbox*) and the installer checks which of both is stored on your system.
For further information on SplitLab see the corresponding UserGuide that is included in the download package.

1.1 License

StackSplit 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 3 of the License, or (at your option) any later version.
StackSplit 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[3] for more details.

1.2 Bugs/errors

If any problems occur while installing/running StackSplit (especially due to MATLAB version issues) or you found a potential bug, please feel free to write an email to michael.grund@kit.edu. Please indicate the corresponding function that generates the error and/or copy the whole error message output of MATLAB into your email. If StackSplit will not fulfil your expectations, don't hesitate to send an email with comments and suggestions for improvements etc.

[1] available from http://splitting.gm.univ-montp2.fr/
[2] available from https://robporritt.wordpress.com/
[3] https://www.gnu.org/licenses/gpl-3.0.de.html

1.3 Miscellaneous

For updates of the StackSplit package, please have a look (from time to time) on the corresponding GitHub account (https://github.com/michaelgrund/stacksplit) or MATLAB exchange server (https://de.mathworks.com/matlabcentral/fileexchange/62402).

If you make use of StackSplit please acknowledge the following contributing papers:

Software overall

- Grund, M. (2017), StackSplit - a plugin for multi-event shear wave splitting analyses in SplitLab, Comput. Geosci. 105, 43-5, https://doi.org/10.1016/j.cageo.2017.04.015.
- Wüstefeld, A., Bokelmann, G., Zaroli, C., Barruol, G., 2008. Split-Lab: A shear-wave splitting environment in Matlab. Comput. Geosci. 34, 515528.

Methods (depending on your selections)

- Roy, C., Winter, A., Ritter, J. R. R., Schweitzer, J., 2017. On the improvement of SKS splitting measurements by the simultaneous inversion of multiple waveforms (SIMW). Geophys. J. Int. 208(3), 1508-1523, https://doi.org/10.1093/gji/ggw470.
- Wüstefeld, A., 2007. Methods and applications of shear wave splitting: The East European Craton. Ph.D. thesis, Univ. de Montpellier, France, http://splitting.gm.univ-montp2.fr/.
- Restivo, A., Helffrich, G., 1999. Teleseismic shear wave splitting measurements in noisy environments. Geophys. J. Int. 137, 821830.
- Wolfe, C. J., Silver, P. G., 1998. Seismic anisotropy of oceanic upper mantle: Shear wave splitting methodologies and observations. J. Geophys. Res. 103 (B1), 749771.
- Silver, P., Chan, W., 1991. Shear wave splitting and subcontinental mantle deformation. J. Geophys. Res 96, 1642916454.
- Bowman, J., Ando, M., 1987. Shear-wave splitting in the upper-mantle wedge above the Tonga subduction zone. Geophys. J. Roy. Astron. Soc. 88, 2541.

2 Installation

1. After unzipping the downloaded StackSplit package, please copy the whole StackSplit folder into SplitLabs main folder where the file ***install_splitlab.m*** is located.

   To find the path to this folder you can use the command:

   ```
   folderSL=fileparts(which('install_SplitLab.m'))
   ```

2. Please add the following folder to to your MATLAB search path:

   ```
   SplitlabX.X.X/StackSplit
   ```

   For editing the path use the command **pathtool**

3. Change to the StackSplit folder in the SplitLab main directory:

   ```
   cd([folderSL '/StackSplit'])
   ```

4. Inside MATLABs command window type:

   ```
   install_StackSplit
   ```

5. Restart MATLAB

3 Running StackSplit

Since StackSplit expects several struct fields from different modified SplitLab functions, the plugin is only applicable if you create a new project after installation. For old projects, analyzed before installing StackSplit, it's not possible to perform the different stacking procedures! Sorry!
Once you installed the StackSplit package, run SplitLab as before via **splitlab** in the command window. On the left side panel now a new push button ***Stacking*** is available at the lowermost position (Fig. 1). If no saved results of single event measurements are available for the current project, of course also no stacking is possible at this point.
Before stacking single measurement results, you have to analyse your event waveforms in SplitLab as before:

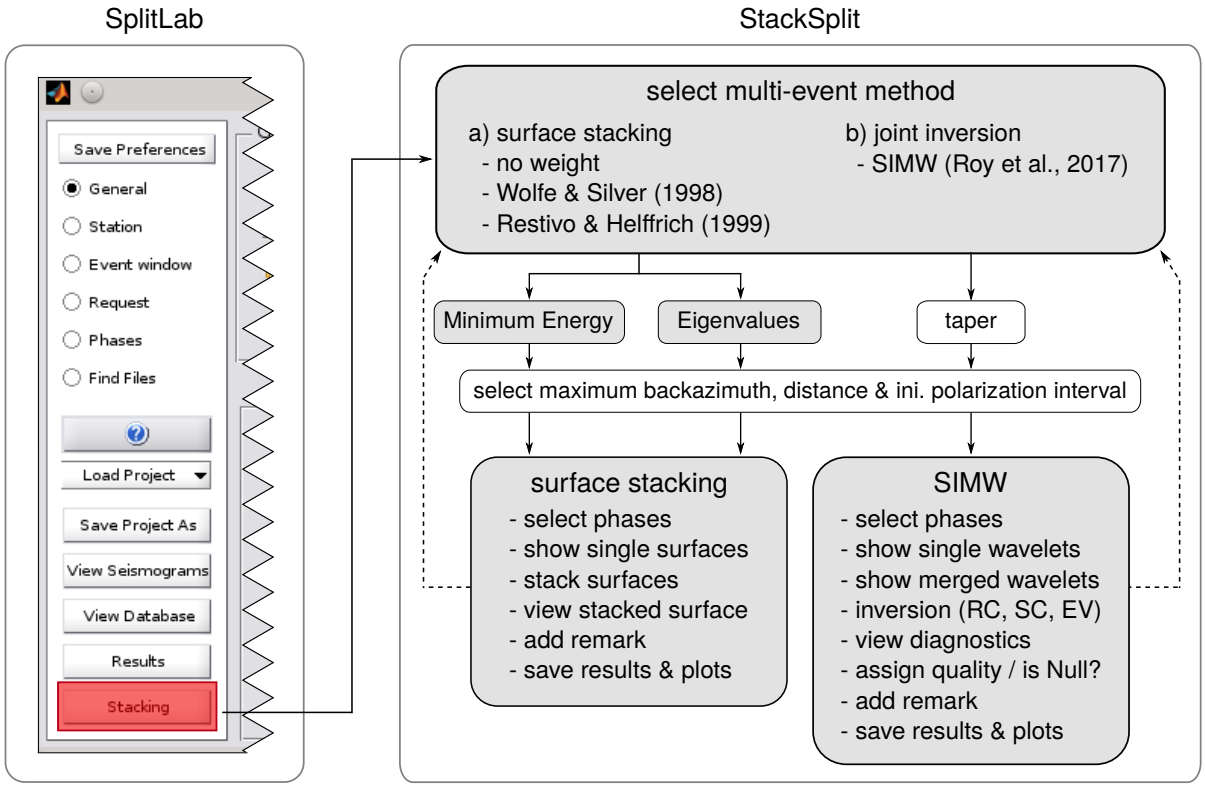

Figure 1: StackSplit workflow with main features/processing steps. Boxes colored in gray are essential, white ones indicate optional settings.

1. click button ***View Seismograms***
2. Select a time window around a specific phase
3. press the enter key to start the inversion
4. check the diagnostics
5. discard the result or save it

If you now save a result, several new struct fields are created for the current event. For example the currently shown error maps, the cut waveforms on all components, the degrees of freedom etc. For each single station project they are all saved in a mat-file named ***STANAME_eqresults.mat***. At this point, thanks to Rob Porritt for initialising this variable in his updated SplitLab version. To check your single results like before you can browse through the wellknown options of SplitLab. Additionally, now you can select the ***Stacking*** button in the main panel. If more than one single event measurement was saved before, a new graphical user interface (GUI) will open (Fig. 2).

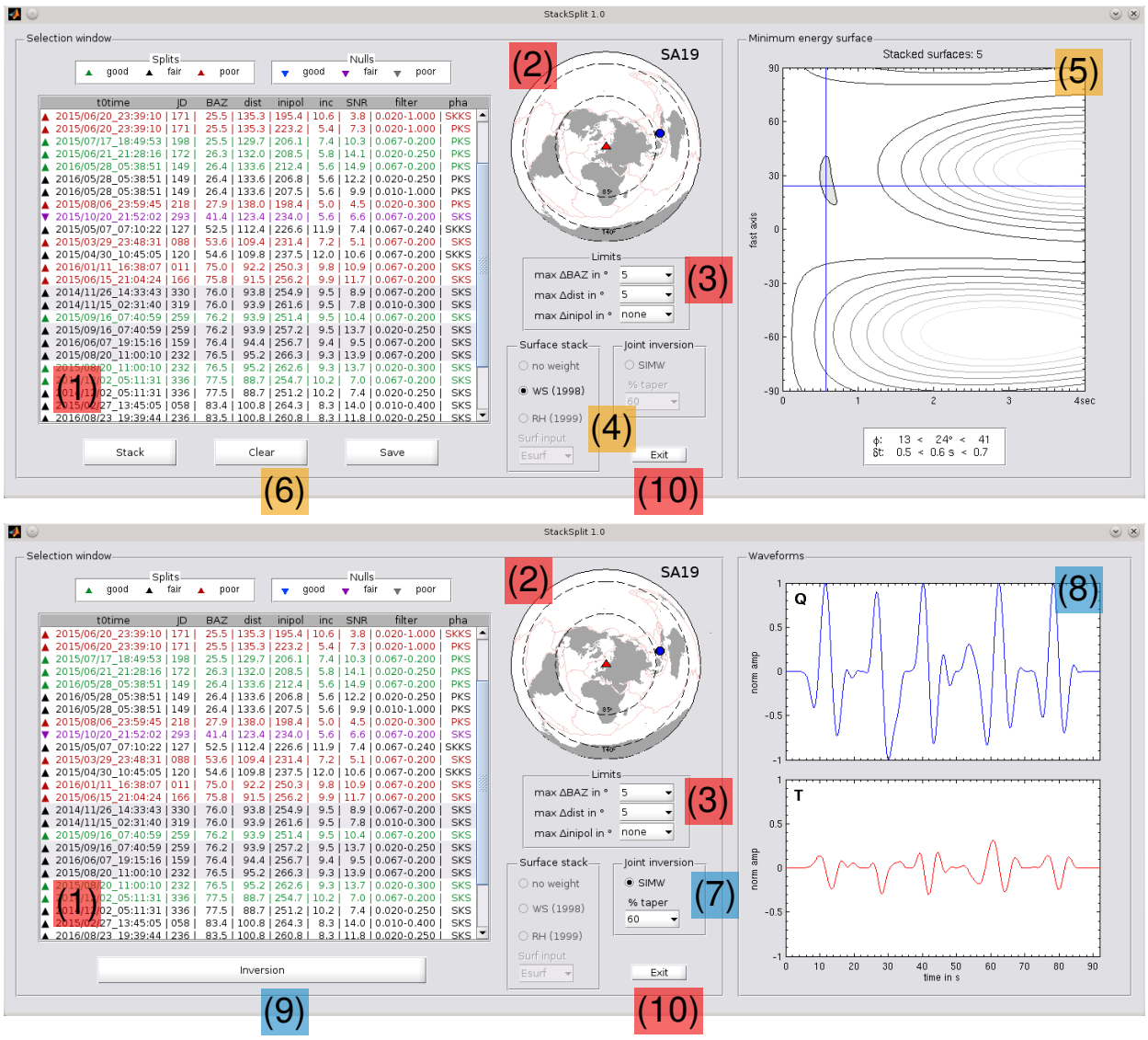

Figure 2: Graphical user interface of StackSplit for two different approaches. Top panel shows an example of five stacked minimum energy surfaces using the WS method. Bottom panel shows the concatenated waveforms for the same five events when SIMW is selected. Numbers highlighted with colors correspond to the module descriptions in section 4. Orange indicates modules that are available if a stacking method (no weight, WS or RH) is selected, blue ones belong to SIMW. The red ones are available for all both approaches (surface stacking and SIMW)

Additional remark

After running StackSplit the first time, please check if the single listbox entries are aligned below their corresponding headlines, otherwise please open file ***SS_basic_settings.m*** and adjust the fontsize of the listbox entries in the upper part of the function to fit a correct version.

4 Applying StackSplit

From the StackSplit main window you can manage your whole multi-event processing (see also workflow in Fig. 1). The possible options and structures in this window are briefly described in the following (please note also the references to Fig. 2):

4.1 The listbox (1)

Lists all available single event measurements for the current station project. If you did more than one measurement for an event (e.g. SKS, SKKS, PKS...) all of these are displayed in this list. Additionally you maybe analysed the same phase with different filters and saved the results. Then this result also appears in the list. From left to right the information in the list are: event source time based on your selected earthquake catalog, Julian day (JD) of the event's appearance, the backazimuth (BAZ) of the event, epicentral distance, initial polarization, incidence angle of the corresponding phase, SNR, used filter, phase name. Quality and Null/non-Null are indicated in color (see the two legends on top of the listbox). By default the list is sorted by increasing BAZ. If you want to change this, go into function ***SS_read_SLresults.m*** and modify the settings in the top row after the license and terms of use section.

4.2 The world map (2)

Displays the currently selected entries from the listbox (blue dots ●) and the latest station you are working on (red triangles ▲). If no *Mapping toolbox* is available on your system, please use the updated SplitLab version of Rob Porritt (see section 1). In this way automatically a simplified worldmap is displayed at this position instead of the epidistance map.

4.3 The "Limits" panel (3)

Define limitations (optionally) for the stacking/inversion, depending on the BAZ, epicentral distance and initial polarization (all in °) of the used events, especially when a backazimuthal dependency of the splitting parameters was observed for the single event measurements or direct S waves without knowledge about the polarization are used.

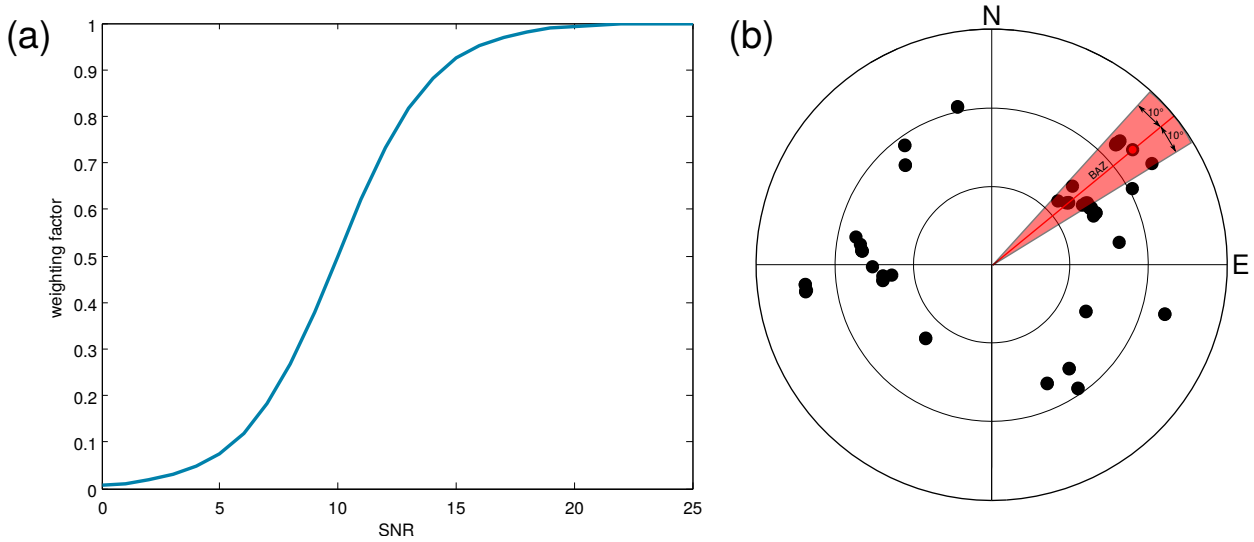

Figure 3: Sketch to demonstrate the implemented RH procedure. (a) Weighting function that assigns a weigthing factor between 0 and 1 to the corresponding error surface depending on the SNR of the event. (b) Each single error surface is scaled to a factor of $1/N$, with its great-circle direction defining a wedge of $\pm$ 10° in which N observations fall (see Restivo & Helffrich, 1999). The red dot enclosed by the thick black line represents the current used measurement, the black dots the remaining single measurements. The parameters for both, weighting and normalization, can be adjusted in function ***SS_calc_RH.m***

.

4.4 The "Surface stack" panel (4)

In this panel you can select three different approaches that are all based on stacking the individual error surfaces of the single event measurements (for details, see references in section 1.3).

1. **no weight** (as proposed e.g. by Wüstefeld, 2007), "raw surfaces" without weighting or normalization will be stacked

2. **WS** (approach by Wolfe & Silver, 1998), each surface is normalized on its minimum value before stacking

3. **RH** (approach by Restivo & Hellfrich, 1999), modified WS version with surfaces weighted depending on the singal-to-noise ratio (SNR) and normalized by backazimuthal coverage before stacking (see Fig. 3)

The default setting after starting StackSplit the first time for a project is "no weight". Additionally the user can choose between two different types of surface inputs by adjusting the ***Surf input*** pop up window, the minimum energy surfaces or the eigenvalue (EV) surfaces.

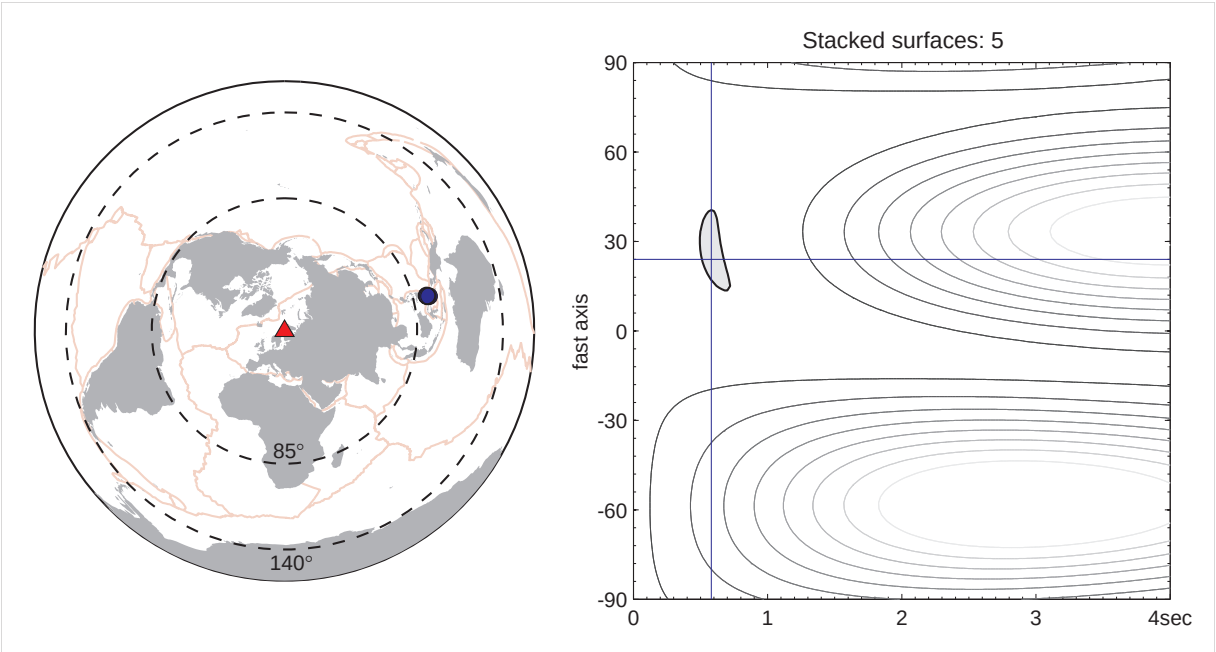

Figure 4: Exemplary diagnostic plot for the surface stacking approach with five used single minimum energy (SC) surfaces. The 95 % confidence region is enclosed by the thick black line.

For the latter one the input depends on the previously selected eigenvalue-based option in SplitLab (maximizing λ_1 or λ_1/λ_2, minimizing λ_2 or $\lambda_1\lambda_2$).

4.5 The "Surface" window (5)

By clicking a list entry using any of the three surface stacking approaches, the corresponding minimum energy or EV map of the single event measurement is displayed together with the corresponding result that was calculated by SplitLab for the SC or EV method. If more than one entry is selected (hold **`Ctrl`** + select entries), only the map of the first one is displayed and the ***Stack*** button becomes active.

4.6 The "Stack"/"Clear"/"Save" buttons (6)

If several entries are selected, pressing the ***Stack*** button results in displaying the new calculated stacked error surface together with the result values for the splitting parameters ϕ

and δt in the bottom. On top also the number of the stacked surfaces is displayed and the ***Clear*** and ***Save*** buttons become active. The user can select one of both buttons or directly select again a new list entry which discards the current result without saving. By choosing the ***Save*** button, the user optionally can give a remark to the current result to note additional information about the multi-event measurement. Results are saved in textfiles (similar to the single results from SplitLab as well as in a format usable in GMT) and in a mat-file for further analysis in other programs/functions. In GMT the resulting files can be used as follows:

```
...
datfile=splitresultsSTACK_OUTPUTNAME_4GMT.dat
psxy $datfile -R -J -SJ -W0.25p,blue -Gred -O -K >> $ps
...
```

with `datfile` representing the output file of StackSplit.

Futhermore, a diagnostic plot is saved for each measurement (see example in Fig. 4).

If you select list box entries of more than one phase (or filter) per event, a warning box will appear and asks for continuing or dicarding the current calculation. Please note that if any difference between e.g. SKS and SKKS appears stacking would potentially bias the overall result!

4.7 The "Joint inversion" panel (7)

Apply the SIMW approach (Roy et al., 2017) in which the waveforms of the selected events first are concatenated in the time domain. Then the merged waveform is inverted simultaneously using the three different methods that are implemented in SplitLab (RC, SC and EV). Optionally a taper can be applied on each of the wavelets by adjusting the ***% taper*** pop up window. Please note that SIMW only should be applied to events with similar hypocentral parameters (similar BAZ, distance etc.).

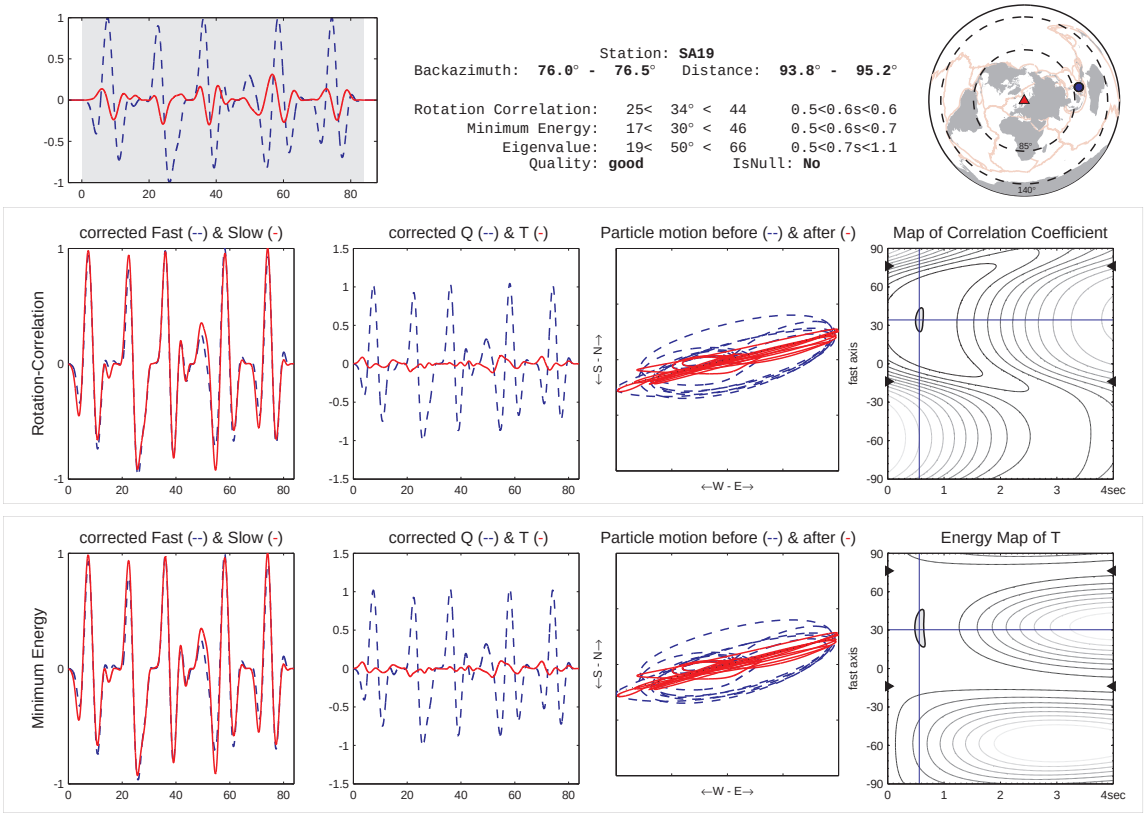

Figure 5: SIMW diagnostic plot for five exemplary SKS phase records from earthquakes that occured in the Pacific region between fall 2014 and fall 2016. Displayed are the standard SplitLab panels, except the worldmap in the upper right corner that displays all the used events. The header gives additional information about the measurement and the input data.

4.8 The "Waveforms" window (8)

By clicking a single list entry using SIMW, the corresponding waveforms of the Q and T components used for the single event measurement in SplitLab are displayed. If more than one entry is selected (hold **`Ctrl`** + select entries), the concatenated (normalized) waveforms for Q and T are displayed and the ***Inversion*** button becomes active

4.9 The "Inversion" button (9)

By clicking the ***Inversion*** button, the SIMW calculation will start and a new window opens (similar to the diagnostic plots from SplitLab) where the SIMW results are displayed depending on the method settings adjusted for the single event measurements (RC, SC and EV).

Equivalent to the single event measurements the user can save the results and assign again

a quality ranking. The results are saved in separate textfiles, similar to the stacked surface results (standard and in GMT format, for details see above). Additionally, the results are stored in the same mat-file like the surface stacking measurements. Diagnostic plots are saved in the preselected results folder (see example in Fig. 5). After closing the diagnostic plot, the user can make a new measurement using SIMW or change to another method.

4.10 The "Exit" button (10)

Exit and close StackSplit window

5 Uninstall StackSplit

If you are not happy with StackSplit, you can remove the whole package and recover your original SplitLab version as before the installation. For this purpose, only type the following command (no matter in which folder you currently are) in the MATLAB command window:

```
uninstall_StackSplit
```