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DC moment tensor estimation based on P- and S-waveform stacking

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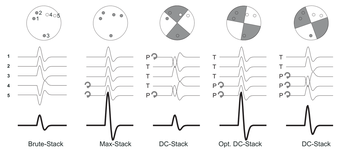
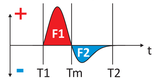
Method

Stacking of P- and S-waveforms



In most cases the stacking of P- and S-waveforms emitted from earthquakes does not result in an amplification of the amplitudes (**Brute Stack**). Maximum amplitudes of the stacked waveforms can instead be achieved by a consecutive rectification of all individual waveforms prior to stacking (**Max. Stack**). Waveforms can also be stacked after rectification according to the radiation pattern of a double-couple seismic source (**DC-Stack**). In the case of the orientation of the assumed DC-source correspondings to the actual focal mechanism, an optimum stacking result is achieved (**Opt. DC-Stack**). In this case the Opt. DC-Stack should converge to the Max. Stack.

Definition of polarity



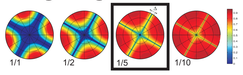
We consider the first two deflections of P- or S-waveforms and define the polarity by the function sign(**F1 - F2**). T1 is the arrival time of the waveform. We derive **T2 - T1** interactively from the length of the average first period of the waveforms and determine **Tm** automatically.

Objective function

The identification of the Opt. DC-Stack is carried out by maximization of the following objective function:

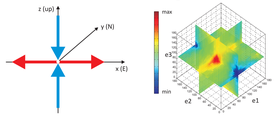
$$OF = (F1_{stack} - F2_{stack}) * Semblance_{stack}$$

Weighting



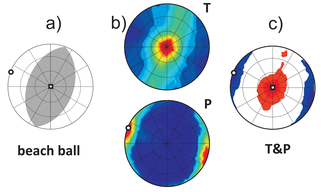
Waveforms are weighted according to their S/N ratio. When performing the DC-Stacks we additionally attenuate traces near the nodal planes of the trial DC-source according to the $1/5^{th}$ power of the radiated amplidutes.

Global search of Opt. DC-Stack



The global search for the Opt. DC-Stack starts with a normal fault directed toward east (T axis = X-axis, P axis = Z-axis). We calculate the objective function for the whole solution space by means of Euler rotations (e1, e2, e3) and detect the maximum.

Presentation



In addition to the traditional beach balls (a), we visualize the objective functions of the different DC-Stacks separately for the T- and P-axes in two stereographic projections (b), and in one single stereographic projection with T in red and P in blue (c).Representation (b) in particular offers a good inspection of the whole solution space.

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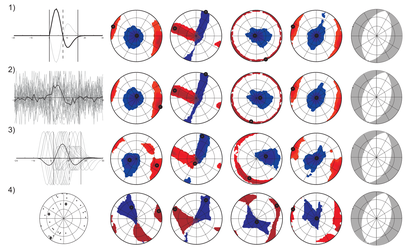
Tests with synthetic data

We performed tests with synthetic data in order to explore the sensitivity of our method against degraded data quality. We generated synthetic data of a normal fault focal mechanism (strike = 20°E, dip = 45°, rake / slip = -90°). The location of the hypocenter and the configuration of the seismic network (26 stations) are representative of the real data used in this study.



1) P- and S-wavelet; inversion for P-, SH-, SV-wavelets and combined solution (weighting P:SH:SV = 2:1:1); beachball; (1)represents ideal data

2) effect of a reduction of the S/N ratio to 0.5 on the inversion

3) effect of random picking errors of P- and S-arrivals (with a standard deviation of 0.25 s) on the inversion

4) effect of the reduction of the number of stations from 26 to 3 on the inversion; the configuration of the complete net and the remaining 3 stations are plotted on the left side. Note that only P&SH&SV was able to recover the focal mechanism.

The tests reveal our method to be as very resistant to degraded data quality. Picking errors of the P- and S-wave arrival times affects the solution most severely. We pick travel times on the trace envelopes in order to avoid subjective predetermination of the polarities.

Conclusion

Stacking of P- und S-waveforms after rectification of the polarities according to the radiation pattern of a DC-focal mechanism offers a nearly automatic derivation of the optimum focal solution. We achieved consistent results from data recorded by a local network and observatories for earthquakes with magnitudes of Ml = 2 and up. Accurate picking of the P- and S-wave arrivals, unbiased by subjective estimates of the polarities is an essential precondition for good results.

Current work concentrates among other things, on the following issues:

- Quantification of uniqueness and accuracy of the solution including parameters derived from waveforms and stacking
- Transformation of the particle motion at the seismic stations from the coordinate system R, T, Z into a ray coordinate system at the focal sphere (which includes consideration of the influence of free surface, slope, and near surface layering)
- Optimal weighting of the P-, SH-, and SV-solutions for a combined P&SH&SV solution
- Application to more real data

Acknowledgments

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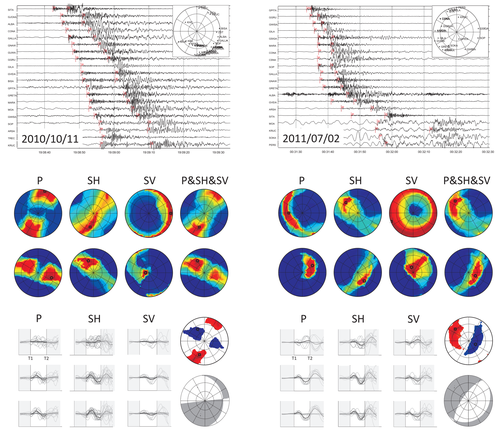
Application to real data

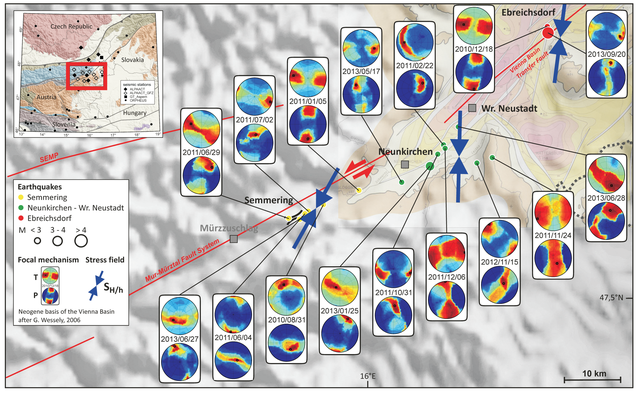


1) 2010/10/11: longitude 15.366° E, latitude 48.262° N; ML = 2.3; SE corner of the Bohemian Massif, not on map below; network configuration in upper right corner

2) 2011/07/02: longitude 15.848° E, latitude 47.644° N; ML = 2.2; Neunkirchen - Wr. Neustadt area, see on map below; network configuration in upper right corner

Solution spaces of T- and P-axes in separate stereographic projections for P-, SH-, SV-wavelets, and the combined solution P&SH&SV (weighting P:SH:SV = 2:1:1)

Brute Stacks, Max. Stacks, and Opt. DC-Stacks (top > down) for P-, SH-, and SV-wavelets; combined stereographic projections of T- and P-axes, beach balls



Individual focal mechanisms for the Semmering, Neunkirchen - Wr. Neustadt, and Ebreichsdorf areas (Mur-Mürz and Vienna basin transfer fault systems) derived from P-waveforms show considerable scatter and include strike-slip, normal fault and reversed fault mechanisms. The median magnitude of the evaluated earthquakes is ML = 2.5. The average principal horizontal compressional stresses in the different areas show very consistent reasonable directions relative to the strike of the main fault system.

Godfrid Wessely, 2006. Niederösterreich. Geologie der österreichischen Bundesländer. ISBN 3-85316-23-9