Extracting robust splitting measurements from the splitting intensity method

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Summary

Reliable measurements of the splitting intensity (SI) are needed to constrain seismic anisotropy. The splitting intensity method, which was first proposed by Chevrot (2000) is supposedly more robust and gives reliable estimates of the splitting parameters Δt and Φ. We found however, that the Chevrot-method is biased towards zero in the presence of noise. This leads to an underestimation of the delay time and the extent and strength of the anisotropic anomaly.

Bias in the Chevrot method

The error lies in the initial assumption that noise is only present on the transverse component:

$$T = -\frac{1}{2} s \otimes r + N$$

Considering noise on both components, the biased splitting intensity becomes:

$$s^* = -2 \frac{\int T(t) \cdot R_0'(t) dt}{\int R_0'(t)^2 dt + (n-1)\sigma^2}$$

Synthetic tests confirm the bias towards noise:
With increasing noise level σ, splitting intensity values deviate to smaller values.

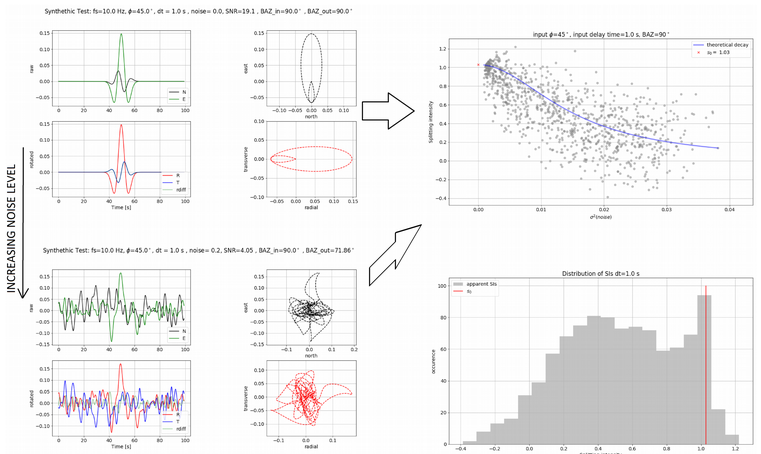

Fig.1: Synthetic waveforms were used to calculate the splitting intensities. The top left subfigure shows the noise-free synthetic waveforms, which were rotated into their radial and transversal components. Repeating this for various noise conditions reveals a bias towards zero.

Conclusion

The bias can be corrected with estimated noise and signal energies in the records. The scattering will then be centered around the expected value. However, scattering also increases for low SNR ratios, due to the added uncertainty in the approximation.

Noise on horizontal components causes a **bias** towards zero in the splitting intensity method.

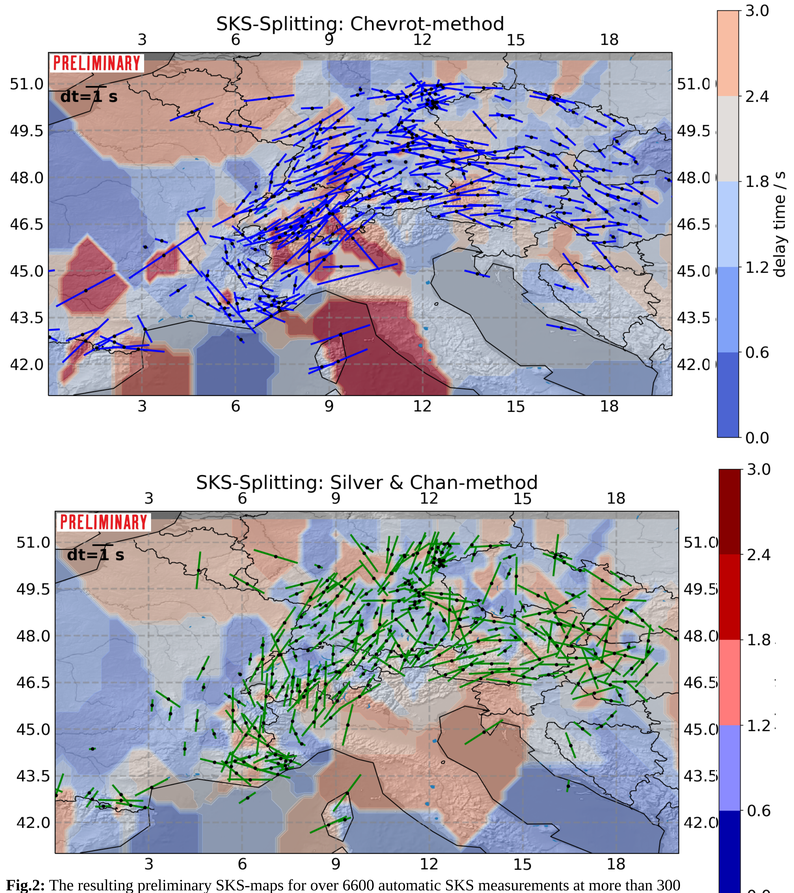

Fig.2: The resulting preliminary SKS-maps for over 6600 automatic SKS measurements at more than 300 AlpArray stations after correcting the noise bias in the Chevrot method. Similar but less robust results were generated with the transverse minimization technique (Silver & Chan) and are shown for comparison below.

How to obtain reliable splitting measurements?

Correcting the bias with an estimate of energy of noise and signal:

$$s = s^* \left(1 + \frac{E_{Noise}}{E_{Signal}}\right)$$

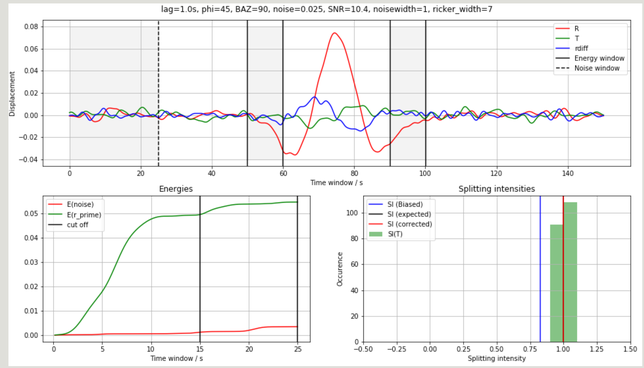

Fig.3: Exemplary procedure for the synthetic bias correction. Noise and Energy is estimated over a sufficiently wide time window. SIs are calculated for different time windows and estimated from the maximum of the distribution.

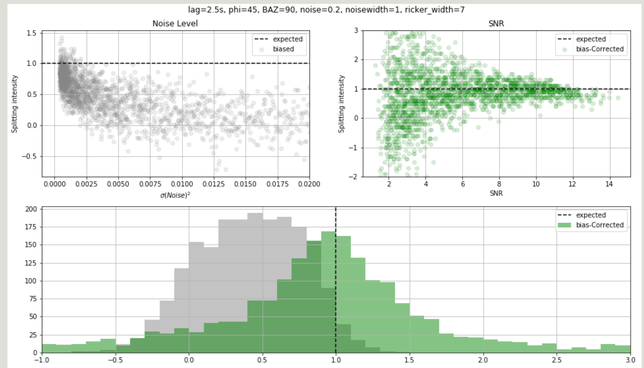

Fig.4: Splitting intensity measurements for various noise levels before and after the energy correction. The bottom histogram shows, that the values are correctly centered around their expected value.

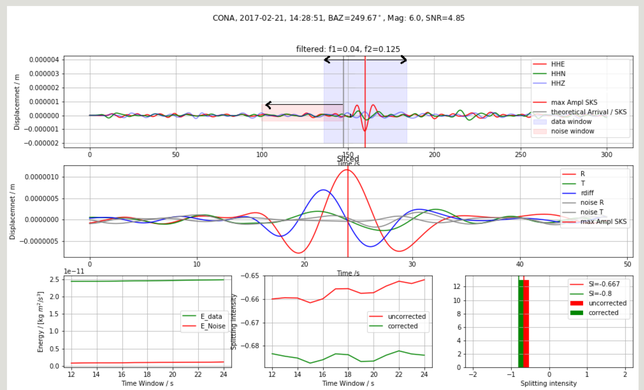

Fig.5: Exemplary SKS measurement for a magnitude 6 event at station CONA is used to estimate the splitting intensity. The correction shifts the initially lower values further away from zero.