The influence of seismic anisotropy on microseismic moment tensors and their radiation patterns

N. Boitz and S.A. Shapiro
Freie Universität Berlin
boitz@geophysik.fu-berlin.de

Summary

Radiation patterns of earthquakes contain important information on tectonic strain responsible for seismic events. However, elastic anisotropy may significantly impact these patterns. Especially for microseismic events induced during hydraulic fracturing in shales this effect needs to be considered.
Therefore, we study systematically the influence of anisotropy on the radiation patterns of microseismic events, accounting for both, source- and anisotropy on the propagation path. We exemplary show the effects of different anisotropic media on the radiation pattern of a normal faulting source and observe significant deviations from the isotropic case.
Therefore, we propose an alternative visualization of source mechanisms by plotting beachballs proportional to their potency tensors and call this the potency tensor isotropic equivalent (PTI). In this way we visualize the tectonic deformation in the source, independently of the rock anisotropy.
Finally, we apply this theoretical findings to one of our microseismic datasets from a hydraulic fracturing treatment in a shale. We show, that the inverted moment tensors generally have high non-double components. However, their PTI is nearly pure double couple. In this case, the non-double components are an artifact of the anisotropic medium. We conclude that we should rather interpret the potency tensor, or the potency tensor isotropic equivalent, than the moment tensor.

Method - Radiation patterns in anisotropic media

The kinematic source process of an earthquake can be expressed as a double couple source (described by the normal of the fault plane **n** and the slip-vector **s**) and possibly additional volumetric parts (Equation 1).
By multiplying it with the elasticity tensor **C** we obtain the moment tensor **M** (Equation 2) which may be influenced by elastic anisotropy (source anisotropy).
The displacement, which is typically shown in the form of beachballs, is given by Equation 3 [4]. Due to the deviation between polarization and propagation direction of a quasi P-wave we create propagation anisotropy.

$$p_{ij}^{full} = \frac{1}{2}\left(n_i s_j + n_j s_i\right) + p_0\delta_{ij} \quad (1)$$

$$M_{ij} = C_{ijkl}\, p_{kl}\, A \quad (2)$$

$$u_k(\mathbf{x}_R, \mathbf{x}_S) = G_{kij}\frac{dM_{ij}}{dt} = \frac{\hat{g}_k^R(\hat{g}_i^S\hat{p}_j^S + \hat{g}_j^S\hat{p}_i^S)}{8\pi c_S^2 R(x_R, x_S)\sqrt{\rho_R\rho_S V_R V_S}}\frac{M_{ij}}{T_r} \quad (3)$$

Theoretical modeling

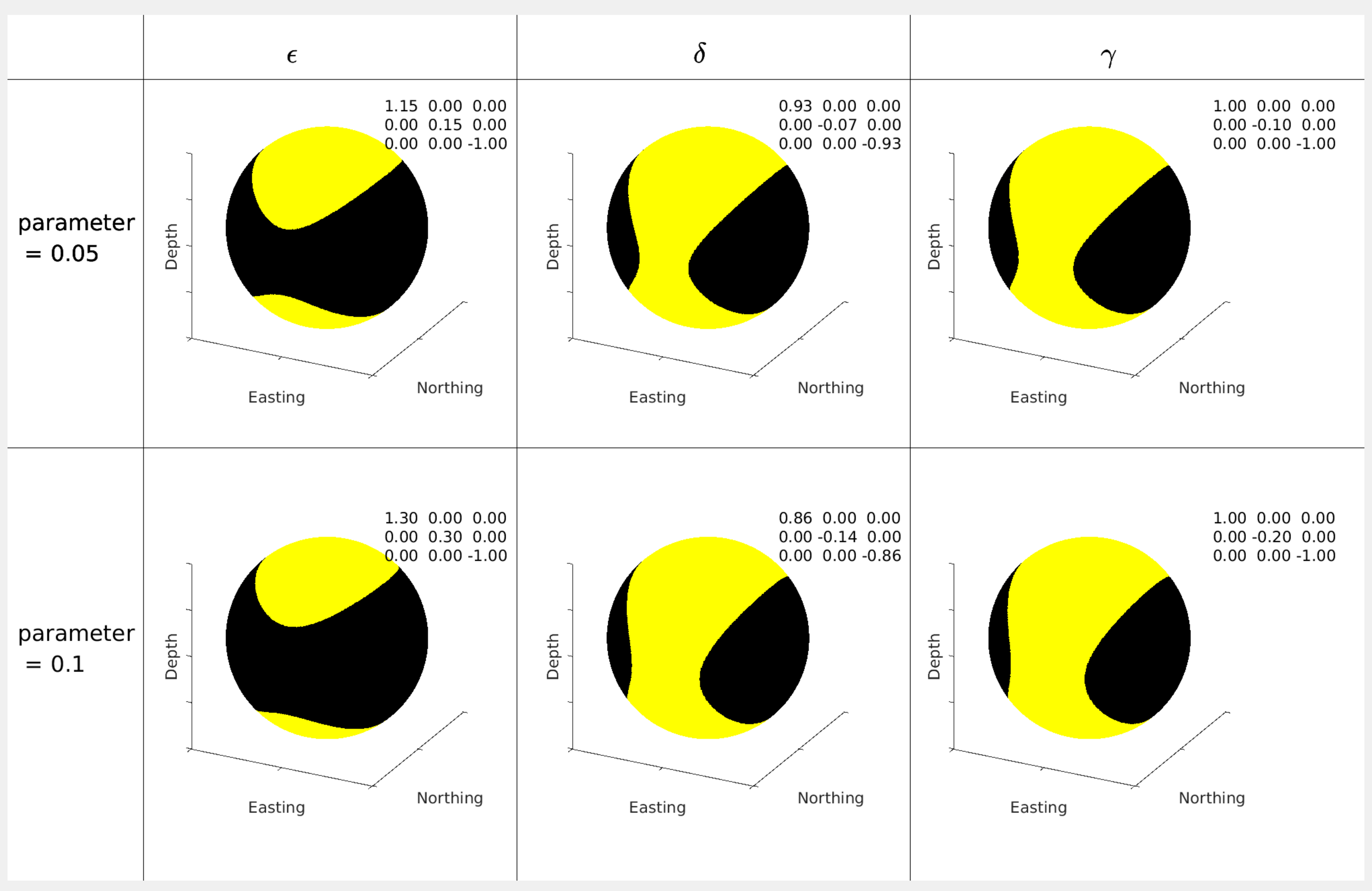
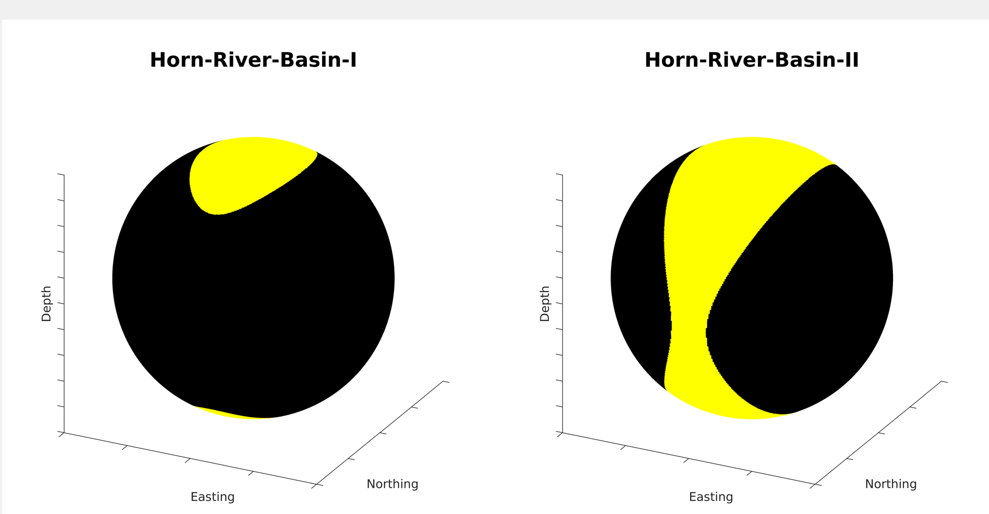


Figure 1: Individual influence of the three Thomsen paramters ϵ, δ and γ on the radiation pattern of a normal faulting source. For each column we vary one of the three parameters and set the other two to zero. Note also the influence on the corresponding moment tensors above each radiation pattern.



Vp_0	Vs_0	ϵ	δ	γ
3305	1550	0.437	0.069	0.684

Vp_0	Vs_0	ϵ	δ	γ
4050	2485	0.266	0.231	0.235

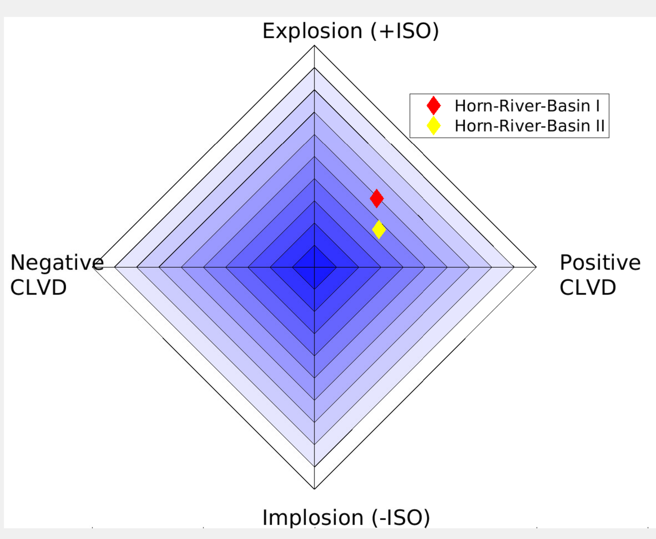


Figure 2: Radiation pattern for a normal faulting source geometry in the the two media defined below. Due to the strong anisotropy, both radiation pattern show significant volumetric and compensated linear vector dipole (CLVD) components. [3]

Removing the influence of anisotropy - the potency tensor isotropic equivalent (PTI)

The moment tensor is influenced by the anisotropy described by the elasticity tensor **C**. To remove this influence we decompose the elasticity into the isotropic and anisotropic parts (Equation 4). We express the moment tensor using these components (Equation 5) and finally ignore all volumetric (1st term) and anisotropic parts (3rd term). We obtain the potency tensor isotropic equivalent (PTI), a rescaled version of the potency tensor [1].

$$\mathbf{C} = \mathbf{C}^{ni} + \mathbf{C}^{\Delta aniso} = \lambda^{ni}\delta_{ij}\delta_{kl} + \mu^{ni}(\delta_{ik}\delta_{jl} + \delta_{il}\delta_{jk}) + \mathbf{C}^{\Delta aniso} \quad (4)$$

$$M_{ij} = \lambda^{ni}\delta_{ij}p_{kk}A + 2\mu^{ni}p_{ij}A + \mathbf{C}^{\Delta aniso}p_{kl}\cdot A \quad (5)$$

$$M_{ij}^{PTI} = 2\mu p_{ij}A \quad (6)$$

Figure 3: Left: Radiation pattern containing all effects of anisotropy, middle: Radiation pattern only showing the source effect, right: Radiation pattern as it would look in isotropic media (PTI)

Real data example - Hydraulic fracturing Horn-River Basin

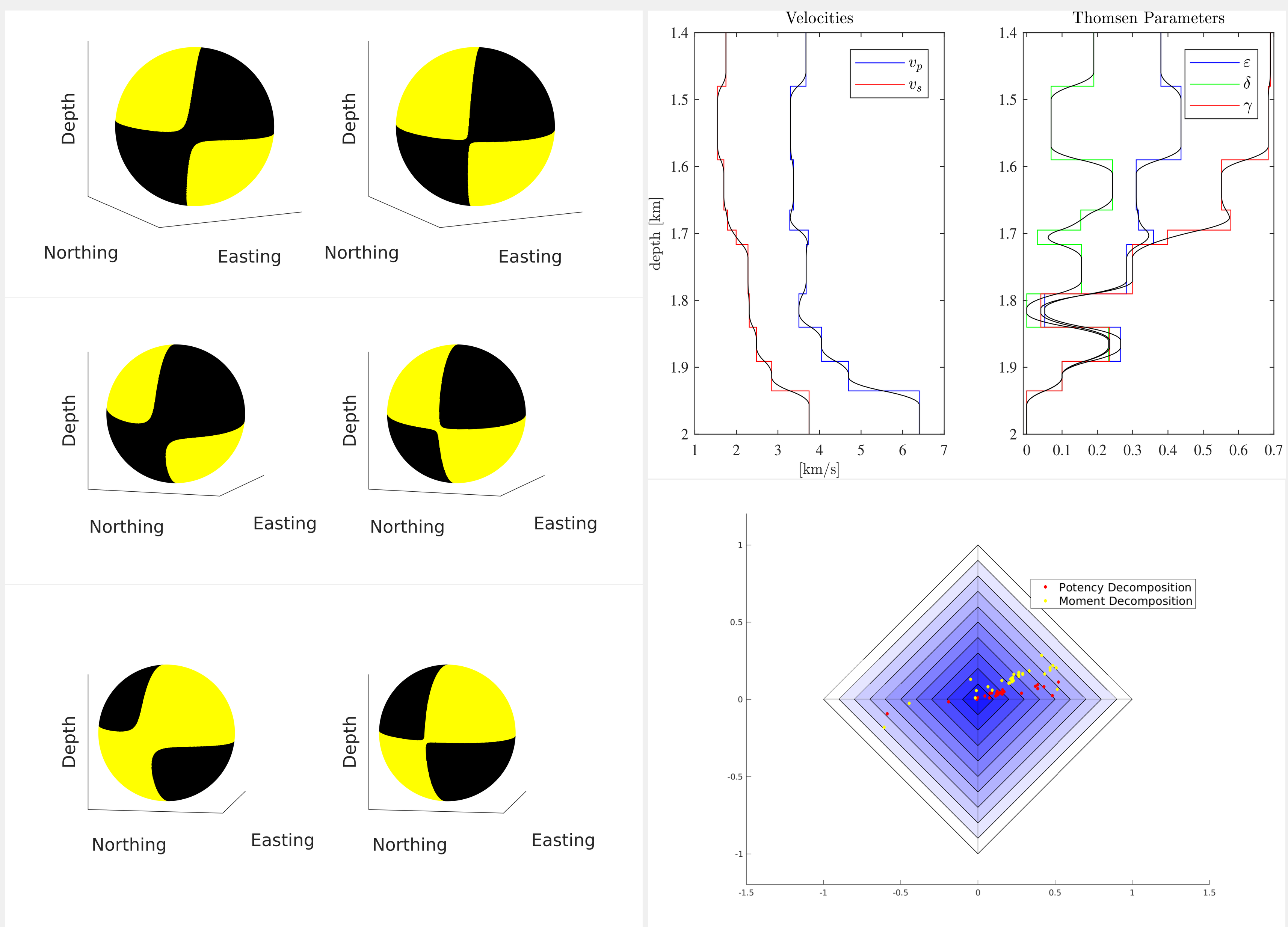


Figure 4: Left: Pairwise radiation patterns of the moment tensor (left) and the PTI (right) for events from the three layers between 1750m and 1850m depth. The moment tensors show significant non double couple components caused by the seismic anisotropy in the source region, whereas the PTI (cleaned up from anisotropy) shows for all three mechanisms very similar dip-slip mechanisms ([2]). Right: Used velocity model and Vavrycuk diamond for all 40 inverted events. The potency tensors show significantly less non double-couple components than the moment tensors.

Acknowledgements

We thank the sponsors of the *PHASE* consortium for supporting the research presented on this poster.

References

[1] Nepomuk Boitz, Anton Reshetnikov, and Serge Shapiro. Visualizing effects of anisotropy on seismic moments and their potency-tensor isotropic equivalent. *Geophysics*, 83:C85–97, 2018.

[2] Nepomuk Boitz and Serge Shapiro. Non double-couple components of seismic moments caused by seismic anisotropy. In *80th EAGE Conference and Exhibition*, 2018.

[3] Václav Vavryčuk. Moment tensor decomposition revisited. *Journal of Seismology*, 19:231–252, 2015.

[4] Xin Yu, Scott Leaney, Jim Rutledge, and Chris Chapman. Multievent moment-tensor inversion for ill-conditioned geometries. *Geophysics*, 81:KS11–KS24, 2016.