Do Moment Tensors Flip During Hydraulic Fractures?

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Abstract

Surface and near-surface monitoring of microseismicity faces large challenges because of the generally low signal-to-noise environments. While the technology to image arrivals as brightspots, colloquially to use the “power of stack”, to overcome this hurdle has proven the value of surface microseismic in general, the techniques to further characterize these events may not necessarily be as easily overcome by multichannel signal enhancement. Moment tensor inversion, for example, classically requires the identification of waveform first motions on individual sensors: should this first motion be obscured by noise, but a later phase be above noise and opposite in sign, a moment tensor will show up as the mirror image of what it should be. To overcome this potential pitfall, mechanisms are inverted from their maximum amplitudes and we assume that if it is highly clamped in the background stress regime, we flip it by applying a negative sign to all components. In this work, we formally spell out the assumption that we use, and test the hypothesis that events are not showing large scale reversals within a dataset by identifying events with confident first motions and comparing the ensemble of mechanisms obtained from our more automated workflow.

Introduction

Moment tensors for microseismicity are frequently used to tie observations to the geomechanics of completions, as they inform on the fracture sets that are being stimulated and the dynamic (perturbed) stress state. These quantities, being a bridge from the microseismic data to the geomechanics, can be critical for extracting value out of microseismic acquisitions. However, the automation of moment tensor data is not without challenge - the one we focus on in this study is the ability to resolve the first motion on the seismic traces and how they may be reversed from the maximum amplitudes that are much more easily determined. As such, maximum amplitude moment tensors may be reversed in sign from reality, and convey incorrect interpretations on the stress state.

A hydraulic fracture completion was monitored with a combination of near-surface borehole-deployed geophone arrays and an array of “superstations” on the surface. All of the detected 17000 events (complete to M_w−1.2) were inverted for their moment tensors and a quality score was assigned to each inversion to determine the high-confidence (>95%) dataset. More aspects of these data are discussed in Baig et al., (2021) and Witten et al. (2021). Mechanisms incongruent with the background stress are explicitly flipped and the resulting dataset is shown in **Figure 1**. We wish to understand the impact of this assumption with comparison to the subset of mechanisms where first motions can be unambiguously assigned. The highest magnitude events are examined from the dataset to compare the mechanisms obtained from clear first motions to the automatically inverted and then flipped dataset.

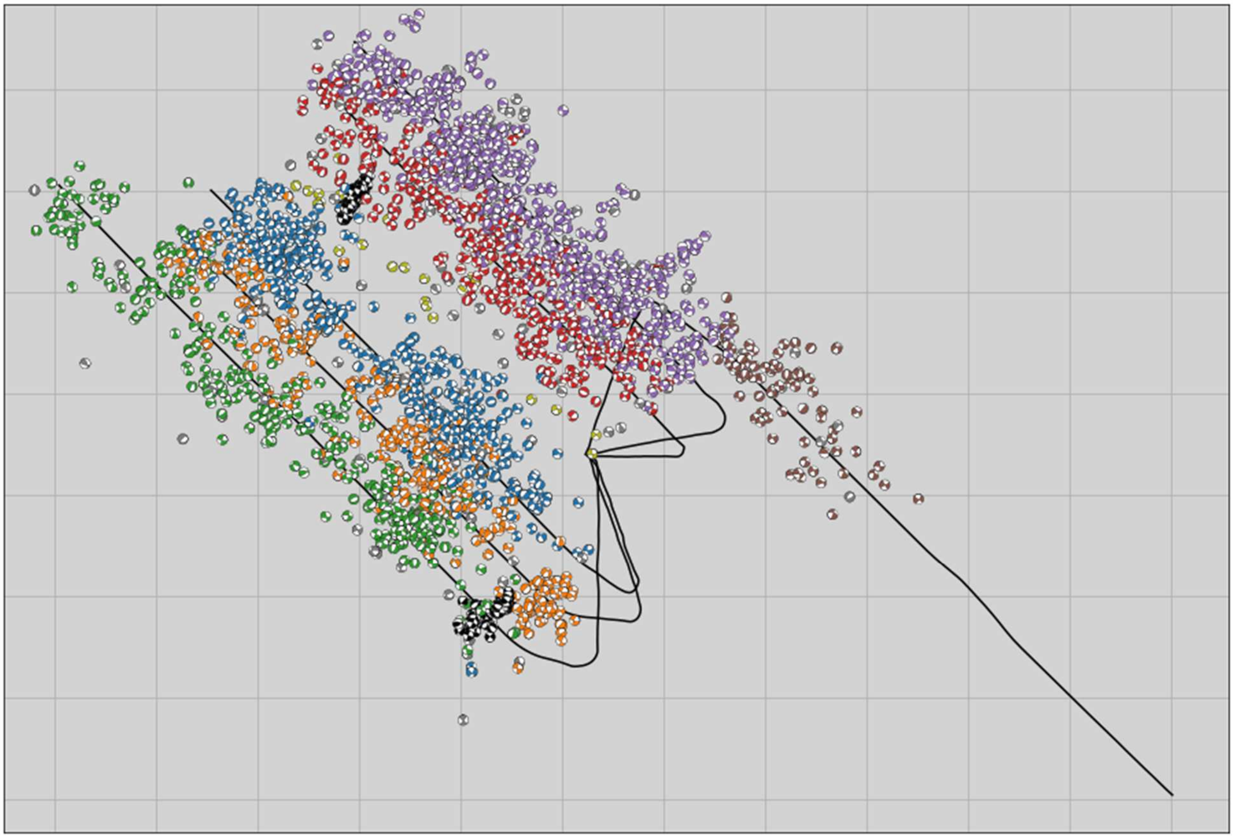

Figure 1. Moment tensors colored by treatment well or (black) where they are associated with an induced cluster. The grid spacing is 250m.

Comparison of Inversions

When we invert the mechanisms from unambiguous first motions, we observe large-scale agreement with the solutions inverted automatically from strongest amplitudes and flipped to be congruent with our notion of the background stress. Furthermore, by applying our quality scoring to the first-motion dataset, we observe that these mechanisms are better fit than the automatic solutions. **Figure 2** shows a summary of this unambiguously inverted first motion dataset, events we were still able to invert events above Mw-0.8. These mechanisms are compared to the high-confidence mechanisms obtained from the more automated workflow described in Baig et al. (2019) in **Figure 3**.

Disagreements do exist on subdominant mechanisms, generally not as well-aligned with the background stress regime, complicating the decision to flip. The hypothesis that complete rotations of the stress regime is not supported. Furthermore, mechanisms that on the surface imply such rotation are likely misaligned between the picked phase and the first motion, and clear first motions suggest no such flip.

Discussion

Assuming a stress state to invert for moment tensors which then informs on the stress state sounds like the very definition of circular reasoning. However, we are suggesting something slightly more subtle: the stress state should be dominantly one regime, but we use that information to only resolve the sign of that mechanism: for example, is a given mechanism normal or thrust? Effectively, we assume that the microseismicity around the hydraulic fracture is responding to perturbations in the stress regime that do not represent a complete overturning of it. With that caveat, we resolve stress fields nuanced in space and time during the hydraulic fracture rapidly without the arduous task of first motion picking, although this can still be used for validation.

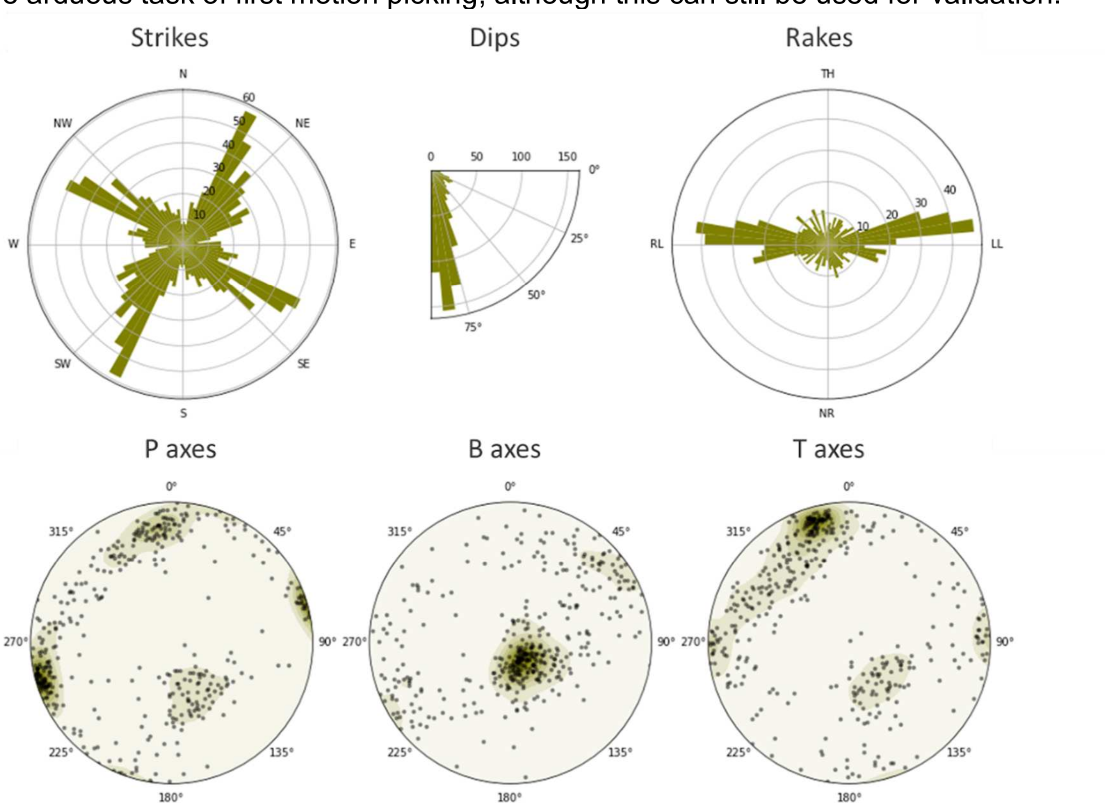

Figure 2 The distribution of high-confidence (R>0.7, condition number <5) moment tensors obtained from picking unambiguous first motions above Mw-0.8. The top row are rosette plots and the bottom row are lower-hemisphere plots of strain axes

Acknowledgements

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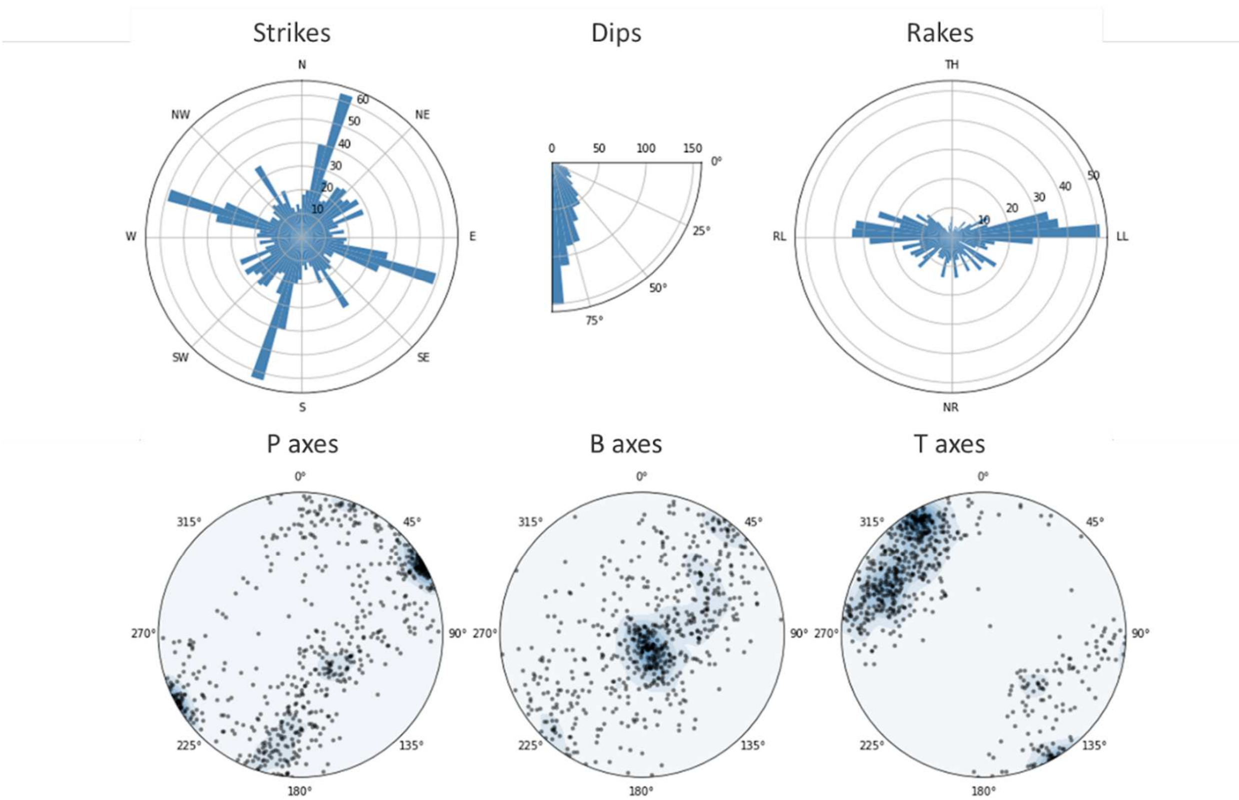

Figure 3 Same as figure 2, but for the high-confidence mechanisms (probability different from noise past 95%) from the dataset automatically inverted and selectively reversed in sign following

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