Focal Mechanism of Composite Microseismic Events

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Objectives

It is often difficult to obtain a reliable single-event source mechanism with a sparse surface array, mainly due to the typically low S/N and poor azimuthal coverage. For areas with frequently repeating earthquake swarms, aftershock sequences or microseismic clusters, under a sparse surface monitoring array, a common focal mechanism can be resolved by using the P-wave polarities or S/P amplitude ratios of the multiple events with the assumption that the all the events within the cluster have the similar or identical source mechanism (Got et al., 1994; Sato, et al., 2004; Godano et al., 2014; Lee et al., 2014).

The objective of this study is to propose an inversion procedure using polarities of P-wave first motion together with Sh/P amplitude ratios to estimate the focal mechanism of composite microseismic events recorded by a sparse surface network and investigate the effects of various factors (e.g. geometrical spreading, absorption, transmission and inverted polarities) on the focal mechanism inversion results.

Methodology

It has been shown that, for the source mechanisms of induced seismicity and microseismicity, non-double-couple (non-DC) components tend to be larger than that of the natural earthquakes (Šílený et al., 2009; Zhang et al., 2016). Nevertheless, the double-couple (DC) component, in general, is the dominant component (Kamei, et al., 2015). Under the assumption that composite microseismic events have identical focal mechanisms, we use an objective function defined as

$$\phi = \alpha \sum_{k=1}^{M} [log_{10}|R_k^{theo}| - log_{10}|R_k^{obs}|]^2 + (1-\alpha) \sum_{k=1}^{N} (P_k^{theo} - P_k^{obs})^2/4 \qquad (1)$$

where M is the number of stations for which the Sh/P amplitude ratio can be calculated; N is the number of stations with clear polarity of P-wave first motion; $|R_k^{theo}|$ and $|R_k^{obs}|$ are the modeled and observed Sh/P amplitude ratios in the absolute sense at the kth station; P_k^{theo} and P_k^{obs} are the modeled and observed polarities of P-wave first motion at the kth station, which have values +1, -1 and 0 representing the positive, negative and null polarities respectively; α is a weighting factor for the fitting error of Sh/P amplitude ratio.

The focal mechanism of composite events is obtained by an exhaustive search algorithm over all the possible strike, dip, rake angles with a sampling of $2°$. The focal mechanism with the least error between the observed and modeled polarities as well as the amplitude ratios is then taken as the final focal mechanism of composite microseismic events.

Data Example

The dataset used in this study is from the Marcellus Surface Microseismic Experiment (MSME) which was conducted by the Microseismic Industry Consortium to record continuous ground motion data during and after multistage fracturing treatments in Marcellus Shale formation of West Virginia and Pennsylvania, USA. Under the sparse monitoring array, only 13 events with moment magnitude ranging from 0 to 1 were identified visually with sufficiently high S/N.

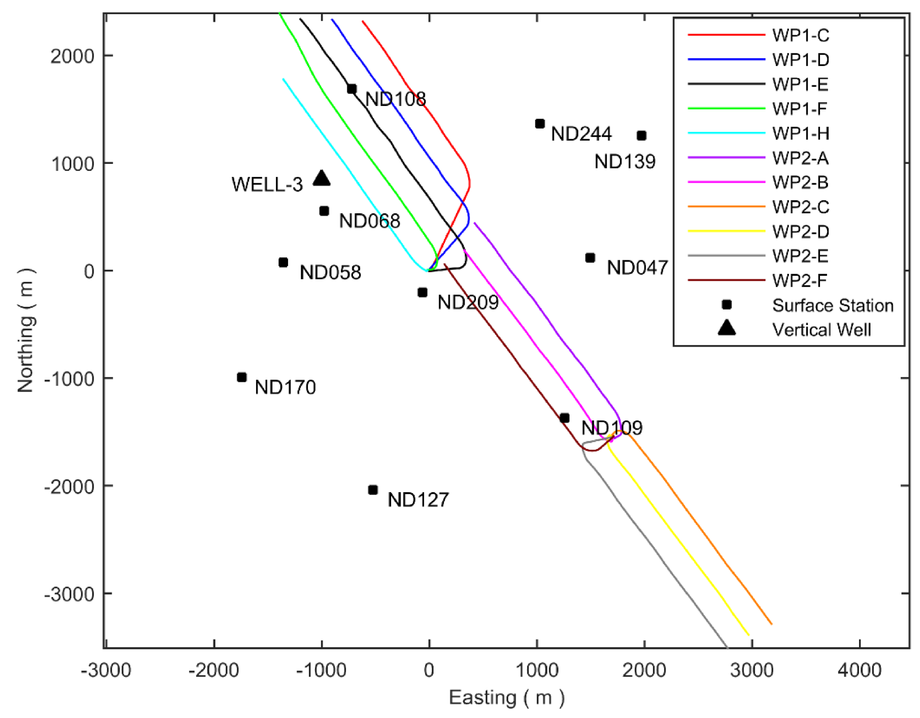

Figure 1: Map view of the layout of the treatment wells and surface seismometers.

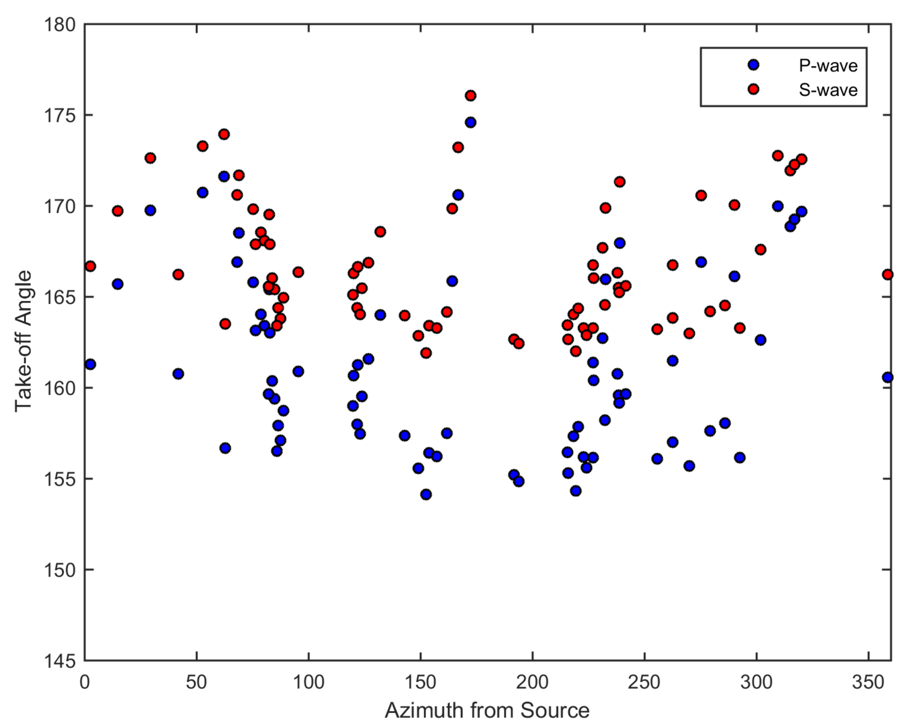

Figure 2: Distribution of the take-off angle and azimuth from the source for the 13 composite microseismic events.

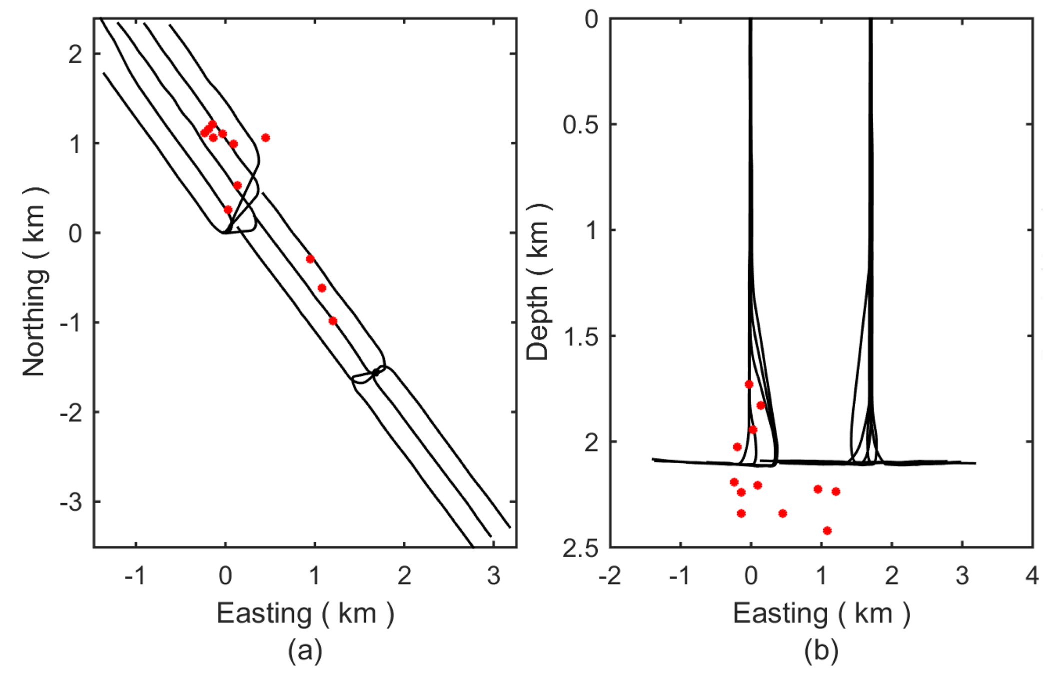

Figure 3: (a) Map view and (b) side views of the locations for the 13 composite microseismic events.

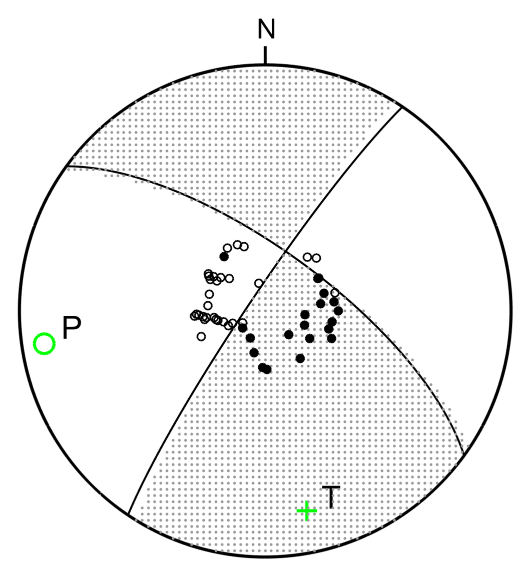

Figure 4: Inverted focal mechanism of the 13 composite microseismic events, which exhibits a good agreement with a previous study by Ellison (2014).

Data Example

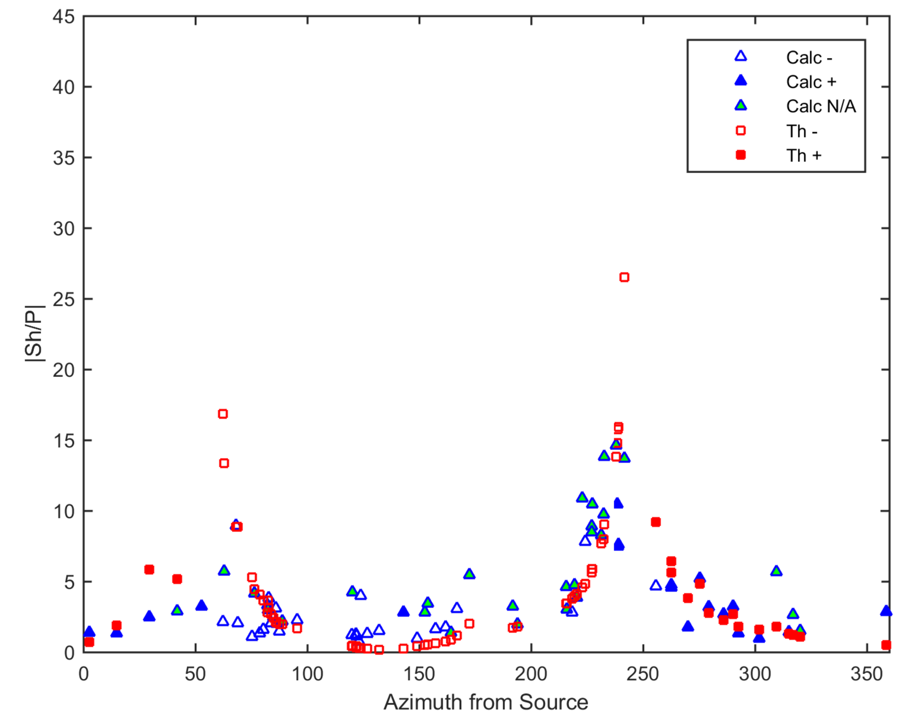

Figure 5: $|Sh/P|$ fitting results between the observed and theoretical values.

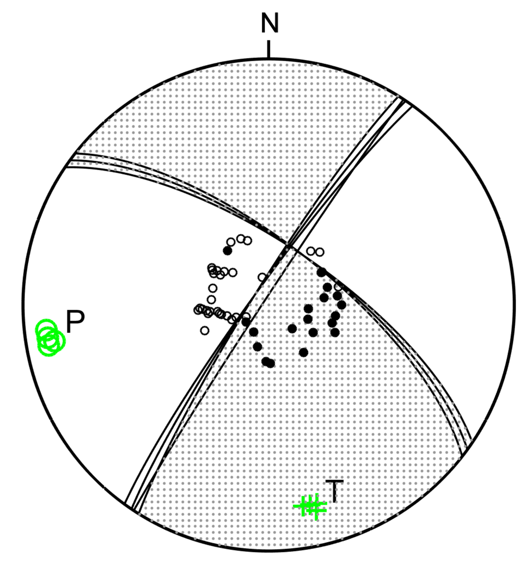

Figure 6: Result of Jackknife test. One event from the 13 events is removed each time, and an inversion is performed using the remaining 12 events. .

Synthetic Experiment

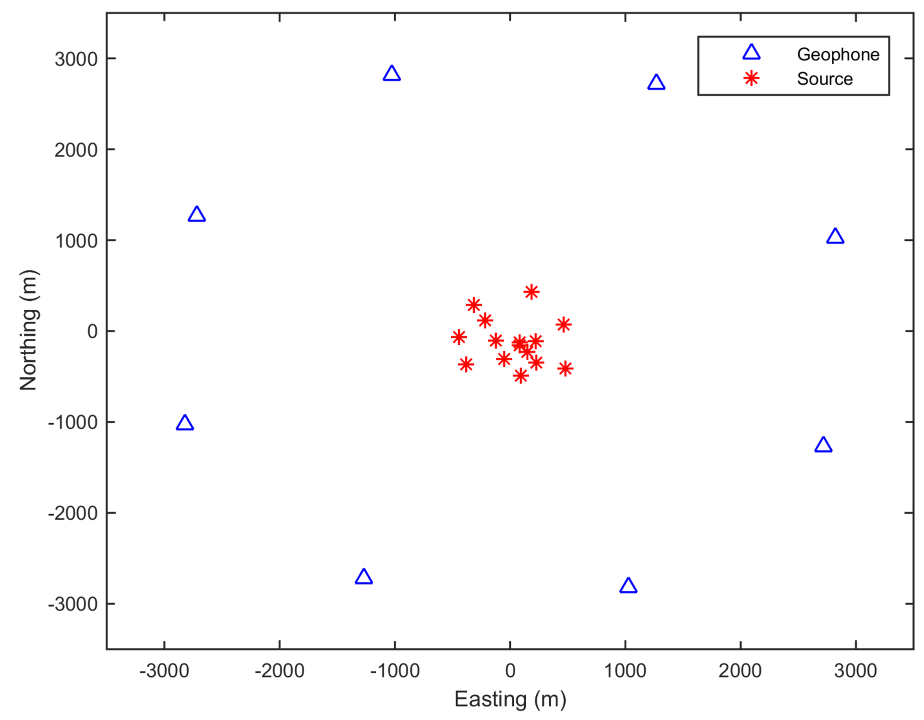

Figure 7: Locations of the microseismic sources and stations in the synthetic experiment.

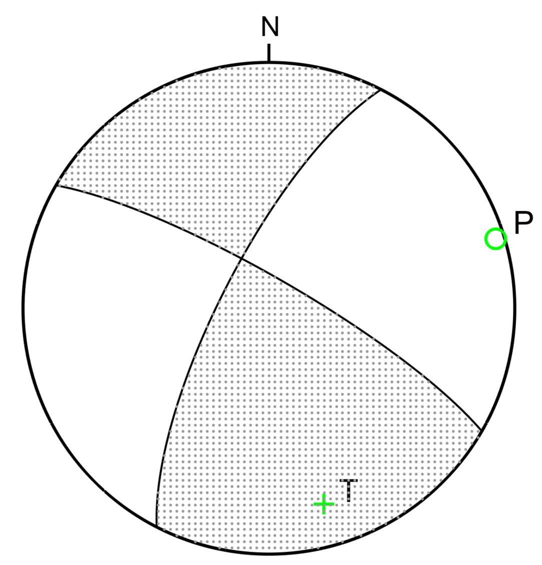

Figure 8: True focal mechanism of the sources.

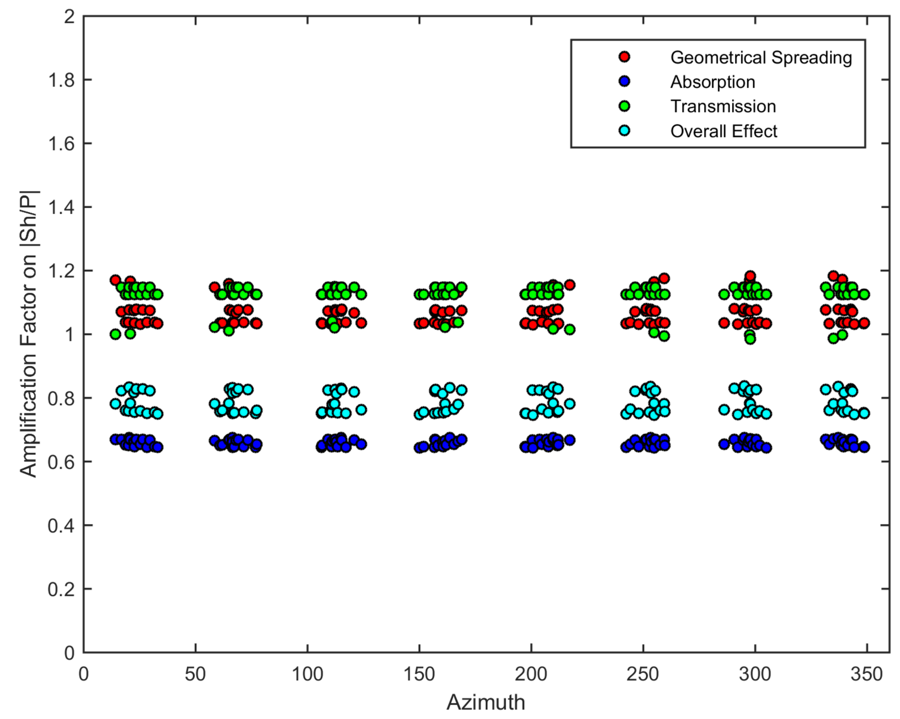

Figure 9: Amplification factors due to geometrical spreading, absorption and transmission on $|Sh/P|$.

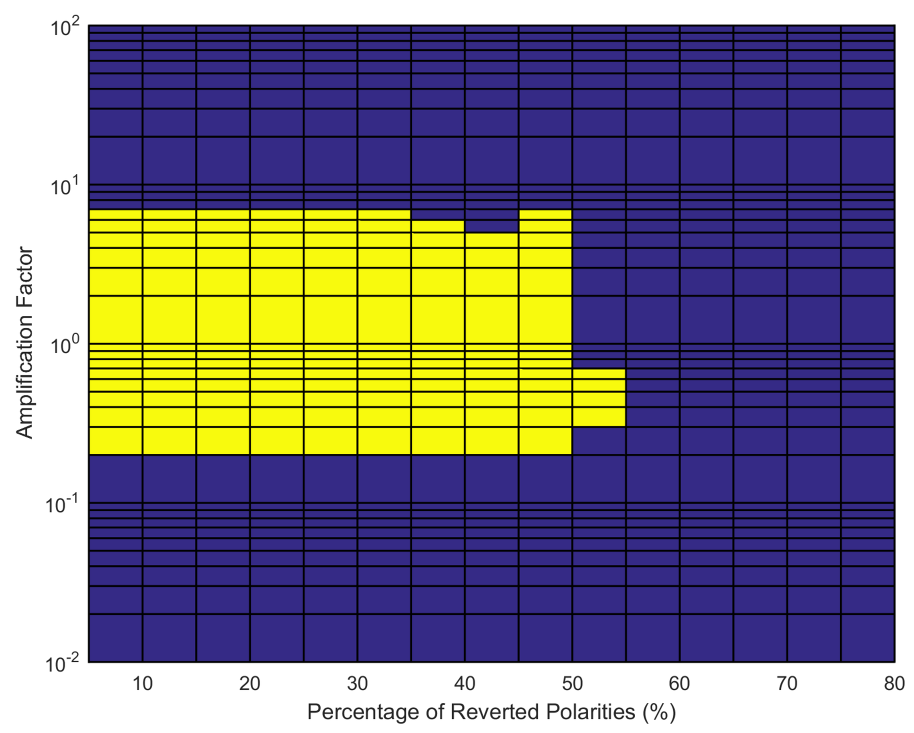

Figure 10: Impact of incorrectly picked polarities and amplification of the $|Sh/P|$ on the inverted focal mechanisms. Yellow region has errors of strike, dip and rake angles that are $\leq 4°$, and blue represents the area with errors $> 4°$.

Conclusion

- We propose an inversion approach to estimate focal solutions for composite microseismic events by using both P-wave polarities and Sh/P amplitude ratios, which can overcome the limitation of small azimuth coverage caused by sparse surface arrays.
- We obtain an estimated composite focal mechanism for 13 composite microseismic events in Marcellus Shale formation of West Virginia and Pennsylvania, USA, which is a northwest or northeast trending strike-slip accompanied by a minor thrust-faulting component. This solution shows good agreement with a previous study by Ellison (2014) for the focal mechanisms of microseimic events in the same study area.
- A synthetic experiment indicates that reliable focal mechanisms can be obtained if both the amplification factor on amplitude ratios is within the range of 0.2 - 7, and $> 50\%$ of polarities are picked correctly.

Acknowledgement

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