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Estimating Magnitude of Microseismic Events with Unknown Focal Mechanism

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SUMMARY

See attached document.

Extended Abstract

This theoretical study discusses the possible bias in magnitude caused by the improper knowledge of an event focal mechanism. In such situation, common practice recommends using average radiation coefficients for the computation of seismic moment and magnitude (e.g. *Boore and Boatwright, 1984*). Based on simulations of microseismic radiation for a set of focal mechanisms, and for typical monitoring network configurations, we show here that such bias exists and can reach up to 0.5 magnitude unit. In addition, we show that its spatial distribution strongly depends on the considered focal mechanism. Note however that this bias can be significantly attenuated either by deploying large-aperture monitoring arrays, or by estimating the magnitude from both P and S arrivals.

The spatial pattern of errors in magnitude depends strongly on both the monitoring network geometry and the source focal mechanism, see figures below. This example provides theoretical errors in magnitude due to the use of an average radiation coefficient at every receiver, instead of their actual values (governed by the radiation pattern). All events are located in a 3D grid located just below the monitoring network (black triangles). Figure 1 displays the impact of the source focal mechanism on the error in magnitude for events located within this grid. It is very striking how areas of magnitude underestimation (blue areas) and of overestimation (red areas) change abruptly from one source mechanism to the other. As a consequence, the spatial bias in magnitude can hardly be anticipated if the focal mechanism is unknown.

Figure 1: Spatial error in magnitude for two different focal mechanisms. Hypothetical event locations are distributed within a 3-D grid below the monitoring network (black triangles). Blue dots stand for magnitude underestimation and red dots for magnitude overestimation. On each graph all events have the same focal mechanism: Strike 0°, Dip 90° and Rake 0° for the left panel, Strike 45°, Dip 60° and Rake -90° for the right panel. Insets at the top left hand corner of each panel display the S radiation patterns for each mechanism.

Conversely, the configuration of the monitoring network does not significantly alter the (spatial) pattern of errors in magnitude, but rather affects amplitude of errors. In this respect, Figure 2 presents errors in magnitude for two large-aperture networks monitoring events having all a similar mechanism. Both networks have a larger aperture than the single downhole array of receivers presented in Figure 1. It is striking how extreme errors in magnitude are significantly reduced by such large aperture networks. Especially, for events located below/within the network imprint.

Figure2: Same as Figure 1 for two different monitoring network configurations and a similar focal mechanism. The left diagram presents errors when events are recorded from a planar (surface) network of individual stations. The right diagram presents errors when events are recorded simultaneously on three downhole arrays of receivers. Patterns are quite similar, and both present significantly reduced errors for events located below the network imprint.

We investigated how the shape of earthquake-size distributions depends upon the location of a single monitoring array. Especially, we observe a spurious tail of small magnitude events in earthquake-size distributions for specific array locations in respect to microseismic locations. Nevertheless, slope of distributions (i.e. b -value) seems to be rather preserved, typically modified by less than 10% of its original value. For all array locations, distributions of the minimum estimated magnitude and of the completeness threshold for such a population of events are clearly more influenced by the geometrical spreading than by the radiation pattern. On the contrary, spatial variations of the maximum estimated magnitude are dominated by its focal mechanism, and B -values present a more complex spatial pattern, as arising from a more equilibrated combination of geometrical spreading and focal mechanism influences.

The bias presented here for magnitude estimates also similarly exists for any other source parameter obtained from the amplitude or from the spectrum of body-waves (e.g. seismic moment, stress drop ...). Thus, when monitoring hydraulic fracturing operations using a single vertical array of receivers, the monitoring setup influence should be considered before delivering any source parameters estimate.

We also present a more realistic hydraulic fracturing case-study by studying a population of events located during a fluid injection experiment in the Cotton Valley gas field, Texas (e.g. Rutledge et al., 2004). In this situation, monitoring could be performed only using a single array of receivers. We show that error can reach extreme values obtained in our theoretical study. We then discuss how correctly the distribution of magnitudes is retrieved for each of the treatment operations performed in this location.

References

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