Statistical biases in microseismicity parameters

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Summary

Microseismic event analysis has become a useful tool to monitor hydraulic fracturing experiments. The most common setup includes a single observation well. This type of setup can lead to inaccuracies on event detection, location and magnitude computation. We analyze simulated catalogs of events that represent usual hydraulic fracturing experiments. The first results show that the detection threshold due to the distance from the observation well does not influence the shape of event clusters. The shape of clouds of events is thus controlled by the environment. The b-value that quantifies the magnitude distribution is slightly modified by the detection threshold (or any magnitude threshold) but always within the errorbar. Hence analyses based on that parameter to distinguish between fluid and tectonic induced microseismic events seem to be robust. But further tests with different setups are necessary to draw definite conclusions.

Introduction

The monitoring of microseismic events is more and more used to evaluate the success of hydraulic fracturing in oil, gas and geothermal reservoirs. This monitoring allows to follow almost in real-time the development of the fracture network. Care should be taken when interpreting the attributes from microseismic events (Cipolla et al., 2011). Indeed not all microseismic events are recorded because of energy attenuation during propagation. Aseismic deformation also takes place during fluid injection. And often only one observation well is used to monitor the events, which leads to inaccurate position and loss of recording for microseismic events happening far from that well. Maxwell (2012) suggested to focus on quality over quantity by using only the highest magnitude events to interpret fracturing. So the questions are: how much information is lost? How can we quantify that loss? Should we favour quality over quantity?

One easy way to find out about information loss is to use modeling. In simulations all events are known and a detection threshold can always be used to mimic the loss in recording of microseismic events due to distance to the observation well. Quantification can be achieved by using geostatistics and computing the variations in the associated statistical parameters (Grob and van der Baan, 2011). The question of quality over quantity can then be tested by thresholding the event magnitude and calculating the change in the statistical parameters. We show here some simple simulations which try to answer some of the questions cited above.

Simulations

We create a catalog of three thousand events from a random spatial distribution of points inside an elliptical shape (as this shape is usually seen in hydraulic fracturing experiments). The magnitude associated with each point is taken from a known Gutenberg-Richter relationship (Gutenberg and Richter, 1944) and attributed randomly to each point. Clouds of events are setup similarly to hydraulic fracturing stages. Figure 1 shows an example of catalogs representing five stages. The black triangle represents a single observation well. Circles representing the events are proportional to their magnitude.

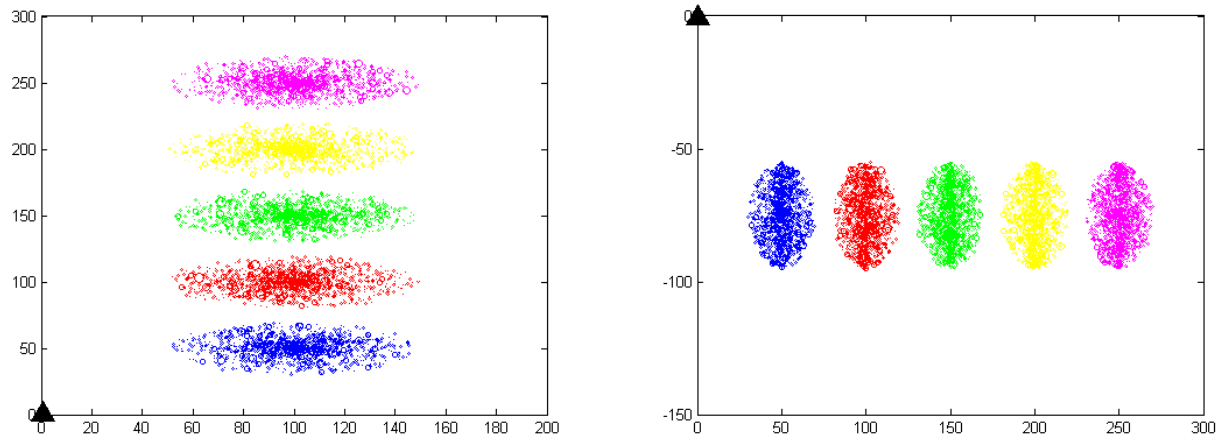

Figure 1: Map (left) and depth (right) views of the clouds of events for one simulation (for better visualization, this example is done with 1500 events). Each color represents one stage. The black triangle represents the observation well. The size of the circles is proportional to the magnitude.

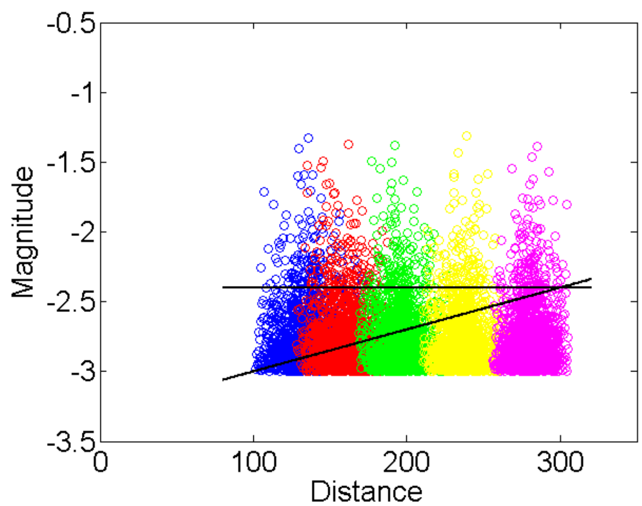

Figure 2: Magnitude versus distance from the observation well plot. Each circle is an event. The colors correspond to the stages in Figure 1. The oblique black line represents the detection threshold like for real microseismic data. The horizontal line shows the magnitude threshold applied.

The theoretical b parameter chosen for the magnitude distribution is 1.8. The magnitude range is chosen to be between -3 and -1 to avoid empty bin in the distribution. After computing the catalog, the b-value is found to equal 1.78 ± 0.02. The D-value which quantifies the spatial distribution of events (Grassberger and Procaccia, 1983) is computed after creating the catalog. The shape of the ellipses is chosen in that case so that D would be close to 3. The D value computed when analyzing the spatial distribution of the simulated events is on average 2.66 ± 0.03.

A detection threshold is then applied to represent the lack of events seen in the magnitude-distance plots for real microseismic events. This threshold is shown as the oblique black line in Figure 2. All events below that line are no longer considered in the analysis. Finally a magnitude threshold at -2.4 (Figure 2) is applied to take into account only the best quality events like in Maxwell (2012).

Results

After thresholding the catalog according to the detection line (see Figure 2), two thousand events are left for the cloud in blue while only 320 events are left for the furthest cloud from the observation well in purple. The shape of the clouds did not change and the D-value is still around 2.66, but the uncertainty on D for the furthest cloud increases to 0.07. The b-value falls to 1.76 ± 0.04 for the cloud in blue to 1.75 ± 0.05 for the furthest cloud. The higher uncertainty might be due to a shorter range of magnitude after threshold that increases the magnitude of completeness. The numbers are still quite similar to the original b value. The number of events decrease to 250 for each cloud when thresholding according to magnitude -2.4. The number of events is the same for each cloud as the same magnitude distribution was applied for all of them. The b-value decreases very slightly to 1.75 ± 0.05 for every cloud. The elliptical shape is still visible (Figure 3) and the D parameter is still around 2.66 although there can be quite some variations between the clouds but these changes are not linked to the distance from the observation well.

This analysis suggests that the asymmetrical shape of events found in some of the hydraulic fracturing experiments is caused by the environment and not by a detection problem. The D value can be used to quantify the shape of a cloud of events. The b-value is usually used to distinguish clusters of events due to fluid injection from those due to tectonic movements. Indeed high b-values are in general linked to fluid induced events whereas a b-value around 1 shows a tectonic cause for the events. The change in b after detection threshold is not highly significant even if the uncertainty doubles to lead to the wrong interpretation. So it seems statistical analyses of microseismic events are quite robust methods to help for interpretation of hydraulic fracturing development.

Conclusions

We simulated catalogs of events representing successive stages of hydraulic fracturing experiments with a single observation well. The catalogs were cut according to the thresholds used for real events analysis. The results show that the shape of the event cloud does not vary after thresholding. The statistical parameter b from the Gutenberg-Richter distribution does not change significantly either. Analyzing microseismicity based on b and D parameters seems quite a robust and useful technique. But further tests on other parameters (number of events, location of the observation well…) are required to definitely draw some conclusions.

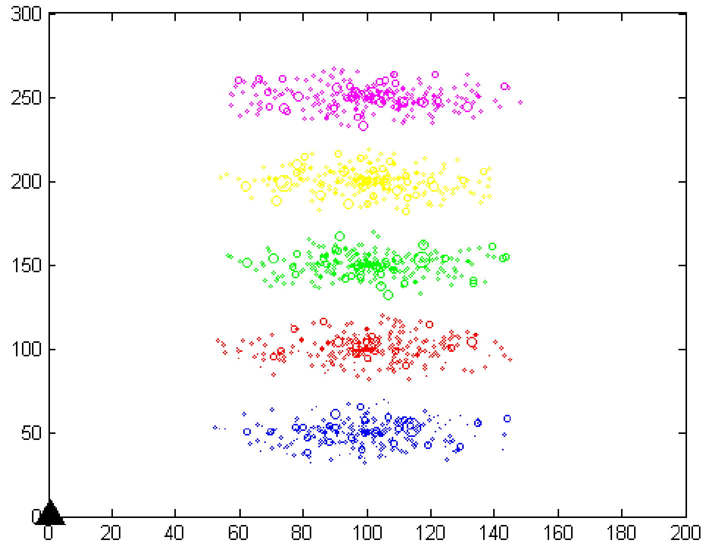

Figure 3: Map (left) and depth (right) views of the clouds of events for one simulation after magnitude thresholding. Each color represents one stage, same as in Figure 1. The black triangle represents the observation well. The size of the circles is proportional to the magnitude.

Acknowledgements

The authors thank the Microseismic Industry Consortium for funding.

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