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High-Accuracy Relative Event Locations using a Combined Multiplet Analysis and the Double-Difference Inversion

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Summary

In this work we apply multiplet analysis together with the double difference method (DD) to improve the accuracy of relative locations between microseismic events. We first identify multiplet groups, or groups of events that have similar waveforms and source mechanisms, by crosscorrelating all events with each other. Next we apply the double-difference algorithm. This is a relative location method that tries to minimize the residuals between observed and calculated travel-time differences for pairs of microseismic events at each station, done by iteratively adjusting the differences between all pairs of events in each multiplet group. Both techniques are applied to a microseismic data set from the mining industry. Results of DD are shown for one major multiplet group containing 29 events, revealing a clearer linear feature with a NE-SW strike after relocation.

Introduction

The objective of basic microseismic monitoring is to map out the locations where microseismic events occur as well as their magnitudes. However, absolute locations of events can be affected by a poor source-receiver configuration, errors in time picks and on the velocity model used, which is usually 1-D and cannot exactly represent the true velocities of the Earth (Pavlis, 1992). For that reason, we investigate a data set of triggered microseismic events from the mining industry by combining (i) multiplet analysis, which uses crosscorrelation methods to detect groups of events originated in the same source region, i.e., a multiplet group, and (ii) the double-difference method (DD), which is intended to reduce the effect of unknown velocity heterogeneities along the source-receiver ray paths specially when dealing with dense microseismic clusters, so that events can be more accurately located relative to one another.

Theory and Method

Multiplet Analysis

In this work we use a technique to identify microseismic doublets (Arrowsmith and Eisner, 2006). The main assumption is that events originated in the same source region will be highly correlated. For that reason, we crosscorrelate all events with each other, while defining a doublet as two microseismic events that are highly correlated, i.e., their waveforms show high similarity and a multiplet as more than two highly correlated microseismic events (see Figure 1).

After calculating crosscorrelation coefficients for all event pairs, we generate an *NxN* crosscorrelation coefficient upper triangular matrix, where *N* is the number of events (Figure 2). Then, we chose a minimum crosscorrelation level and also a maximum inter-event distance as criteria to define if two events are considered doublet. We allow the events to be grouped in a chain-like fashion, so they can belong to the same multiplet group even if there is limited mutual similarity among all event pairs. In Figure 3 we can notice a dense cluster of points at separation distances less than 50 m, when compared with event pairs having greater separation distances. For this data set, an inter-event distance of 50 m represents a decay of the crosscorrelation coefficients. Consequently, a crosscorrelation coefficient threshold of 0.8 and a separation distance threshold of 50 m are defined for doublet detection.

Double-Difference Method

Once the multiplet groups are detected, we apply the double-difference method (DD), which is a relative relocation method that seeks to reduce the effects of errors due to unanticipated velocity heterogeneities in the structure (Waldhauser and Ellsworth, 2000). The main assumption in the DD method is that ray paths between two events will be very similar if their hypocentral separation is small compared to the source-receiver distances; therefore, the relative travel-time difference at a common station will be due to the spatial offset between both events. In other words, the effects of most velocity heterogeneities will cancel out, such that only knowledge of the velocities in the source region is required.

For two events *i* and *j*, recorded at a station *k*:

$$(t_k^i - t_k^j)^{obs} - \left(t_k^i - t_k^j\right)^{cal} = \frac{\partial t_k^i}{\partial x}\Delta x^i + \frac{\partial t_k^i}{\partial y}\Delta y^i + \frac{\partial t_k^i}{\partial z}\Delta z^i + \Delta t^i - \frac{\partial t_k^j}{\partial x}\Delta x^j - \frac{\partial t_k^j}{\partial y}\Delta y^j - \frac{\partial t_k^j}{\partial z}\Delta z^j - \Delta t^j \,. \qquad (1)$$

Where $(t_k^i - t_k^j)^{obs} - \left(t_k^i - t_k^j\right)^{cal}$ is double-difference residual, $\left(\frac{\partial t_k^i}{\partial x}, \frac{\partial t_k^i}{\partial y}, \frac{\partial t_k^i}{\partial z}, 1\right)$ and $\left(\frac{\partial t_k^j}{\partial x}, \frac{\partial t_k^j}{\partial y}, \frac{\partial t_k^j}{\partial z}, 1\right)$ the respective partial derivatives with respect to the model parameters and $(\Delta x^i, \Delta y^i, \Delta z^i, \Delta t^i, \Delta x^j, \Delta y^j, \Delta z^j, \Delta t^j)$ are the eight unknown changes in the hypocentral parameters or perturbations we need to determine to better fit the data. For all event pairs and all stations, a system of linear equations is set. Here, for events closed together, e.g., within a multiplet group, the square of the crosscorrelation coefficient is used to weight each event pair, so that more importance is given to highly correlated events. Figures 4 and 5 show the results after DD is applied in one multiplet group.

Examples

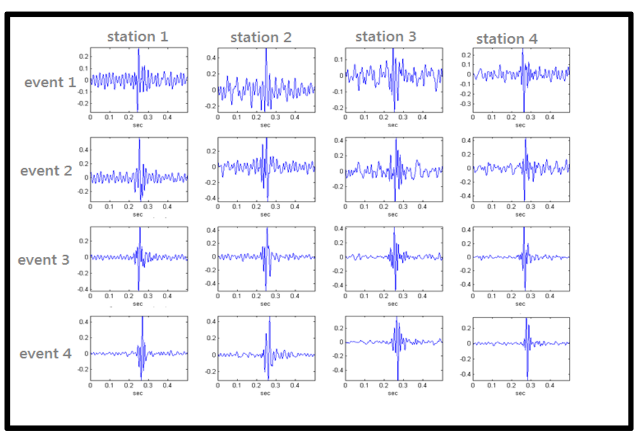

Figure 1: Four events belonging to the same multiplet group recorded at four stations. Only the horizontal component is displayed. Note the strong similarity in their waveforms.

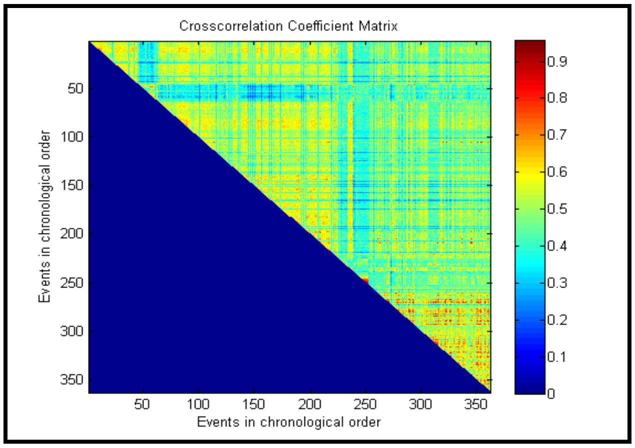

Figure 2: Crosscorrelation coefficient upper triangular matrix for all microseismic events. Each cell gives the crosscorrelation coefficient between any pair of events. A cell is blue for crosscorrelation coefficient of zero and red for crosscorrelation coefficient of one.

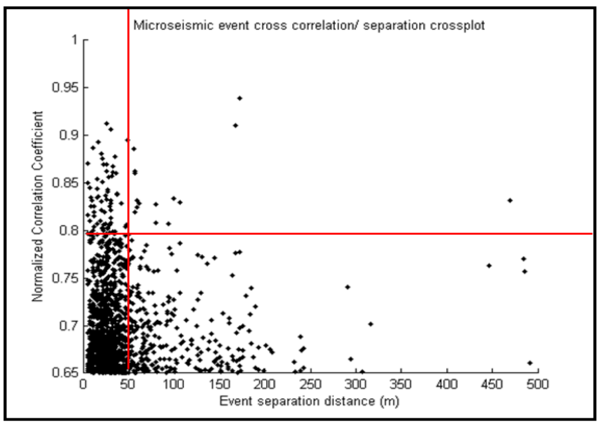

Figure 3: Normalized crosscorrelation coefficient versus event separation distance for all event pairs. Using this plot, a minimum crosscorrelation level and a maximum separation distance were chosen for multiplet detection.

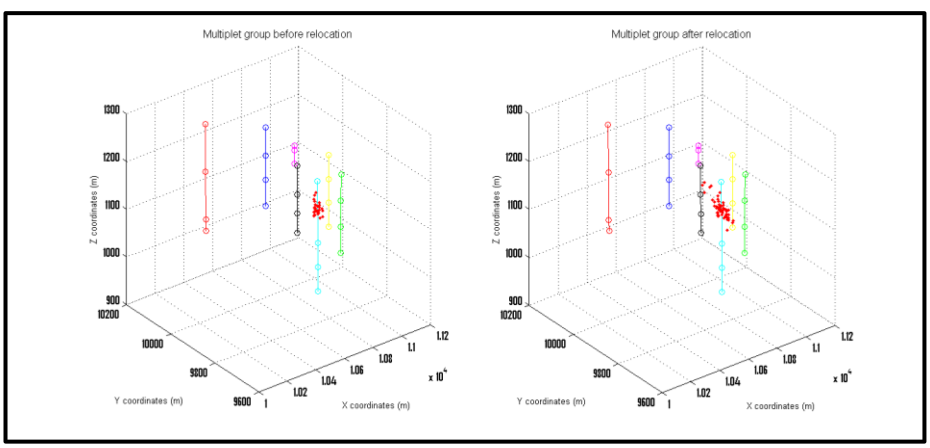

Figure 4: 3-D view of multiplet group containing 29 events before (left) and after (right) relocation using DD. Events: Red points. Receivers: Colored open circles.

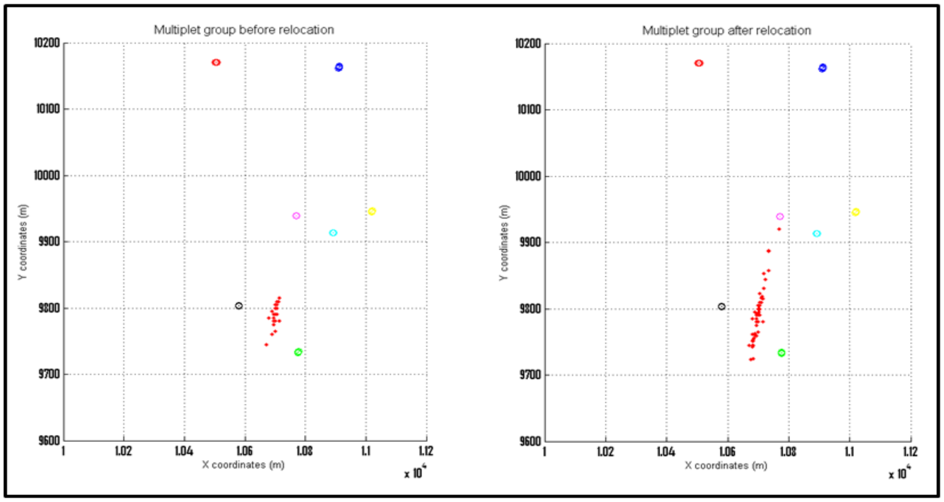

Figure 5: Map view of multiplet group containing 29 events before (left) and after (right) relocation. After relocation, a clearer linear feature, striking NE-SW is obtained. Events: Red points. Receivers: Colored open circles.

Conclusions

In this work we applied multiplet analysis and the double-difference method to triggered microseismic events recorded in a monitoring installation from the mining industry. Using crosscorrelation methods, multiplet analysis allows detecting and grouping events originated at similar source regions and source mechanisms. The main benefit when applying both techniques is that allows reducing the effect of velocity heterogeneities, which is useful since the velocity structure is usually complex and unknown. After applying them on a data set, both techniques applied together reveal a linear feature which may be related to a fracture or fault that might not be easily identified using absolute location algorithms.

Another advantage is that this method can be used as quality control. Plotting crosscorrelation coefficients versus inter-event distances for all event pairs provides indication of errors in locations, since highly correlated events with large separations distances suggest errors in time picks and/or velocity model (Kocon and van der Baan, 2011).

Acknowledgements

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References

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