Non-double-couple component of fluid-related earthquakes

Kazutoshi Imanishi and Takahiko Uchide
Geological Survey of Japan, AIST
imani@ni.aist.go.jp

It has been reported that non-double-couple (non-DC) components in the seismic source are contained for earthquakes involving a fluid, such as earthquakes occurring in a volcanic region or induced earthquakes associated with deep well injection in oil, gas and geothermal fields (e.g., Martínez-Garzón et al., 2017). To gain further understanding of fluid-driven earthquakes, we need to estimate moment tensor solutions of many microearthquakes with high precision. However, it is generally limited to relatively large earthquakes that the non-DC component can be estimated with enough accuracy, because of our poor knowledge of the underground structure, which may lead to large artificial non-DC components. Dahm (1996) develop a relative moment tensor inversion (RMTI) method for earthquake source clusters, in which relative body-wave amplitudes for two earthquakes recorded at a common station are used to eliminate the effect of propagation paths. If the moment tensor of one of those earthquakes is known a priori, the other moment tensors can be determined without a computation of Green's function. A difficulty in this method is that errors in the moment tensor of reference events may lead to biased solutions for other events.

Here we propose a method that iteratively applies the RMTI to source clusters improving each moment tensor as well as their relative accuracy. This method successfully solves the aforementioned problem of RMTI, while taking advantage of RMTI that the moment tensors can be determined without a computation of Green's function. The procedure is summarized as follows:

(1) Sample co-located multiple earthquakes with source mechanisms, as initial solutions, determined by an ordinary method.
(2) Apply the RMTI to estimate the moment tensor of each event relative to those of the other events.
(3) Repeat the step 2 for the modified moment tensors until the reduction of total residual converges.

In order to confirm whether the method can resolve non-DC components, we conducted numerical tests on synthetic data. Amplitudes were computed assuming non-DC sources, amplifying by factor between 0.2 and 4 as site effects, and adding 10% random noise. As initial solutions in the step 1, we gave DC sources with arbitrary strike, dip and rake angle. In a test with eight sources at 12 stations, for example, all solutions were successively improved by iteration. Non-DC components were successfully resolved, although we gave DC sources as initial solutions. We applied the method to microearthquakes in Kakkonda geothermal field in Japan, revealing that most of earthquakes predominate in shear components, but they also have a small non-DC component due to fault opening as well as fault compaction with sufficient accuracy.