Nodal-plane-independent objective functions for stress tensor inversion from seismic focal mechanisms

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Seismic focal mechanisms are the most popular sources to investigate the earth's crustal stress field through the stress tensor inversion techniques. The unknown parameters to be determined in this inverse problem are the principal stress orientations and a ratio between principal stress magnitudes, which are equivalently expressed as a reduced stress tensor with four degrees of freedom. A focal mechanism datum has two nodal planes, only one of which is the real fault plane. There has been a problem that the choice between nodal planes is required prior to the inversion analysis. If one tries to compare all possible combinations of choices for N focal mechanisms, 2^N cases have to be tested, which costs an enormous amount of computing resources and time even when the number of data N is not so large.

Recently, a proficient solution to this problem has been provided by Angelier (2002). He proposed a nodal-plane-independent objective function called SSSC (slip shear stress component) to be maximized in the inversion. The SSSC always has the same value against trial stress solutions between two nodal planes. However, it should be noted that Angelier's method has an essential difference from conventional stress tensor inversion methods. The SSSC has its theoretical basis in the Tresca criterion of faulting, not in the Wallace-Bott criterion (Wallace, 1951; Bott,1959). The Tresca criterion says that the fault plane is oriented at 45 degrees to the maximum and minimum principal stress axes. Meanwhile, the Wallace-Bott criterion makes no assumption on the fault orientation, and observed slip directions are assumed to be parallel to shear stresses on fault planes. The former can be applied to newly created faults in intact rocks, and the latter has an advantage in dealing with slippages on preexisting weak surfaces such as foliations and older faults.

We propose another objective function free of the choice between nodal planes, which enables an inversion analysis based on the Wallace-Bott criterion for seismic focal mechanisms. The new technique is devised by utilizing the parameter space for stress tensor inversion (Sato and Yamaji, 2006), where points on five-dimensional unit sphere have one-to-one correspondence with reduced stress tensors. The objective functions not only of us but also of Angelier (2002) are expressed in the parameter space, and the reason why the two objective functions are independent from nodal planes can be geometrically grasped. We compared the Wallace-Bott-based objective function with the Tresca-based SSSC from a theoretical viewpoint and show some numerical experiments with simulated data to see differences in reduced stress tensors determined by two criteria. When the fault planes were diversely oriented, our objective function was found to work better than SSSC in constraining stress tensor.