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Difference between CMT Data Inversion and Fault Slip Data Inversion

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The earthquake occurrence can be regarded as a stress release process in the crust. This means that the observed seismological data contain first-hand information about the stress state in the crust. In the 1980s several stress inversion methods have been proposed to estimate the crustal stress state from fault slip data (fault orientations and slip directions) of seismic events (e.g., Ellsworth & Zhonghuai 1980; Gephart & Forsyth 1984; Michael 1984; Michael 1987). In the conventional methods, on the basic assumption that seismic slip occurs in the direction of resolved shear stress on a preexisting fault (Wallace 1951; Bott 1959), the pattern of average deviatoric stress is determined for each partitioned block by minimizing the difference in direction between the predicted and observed slip vectors in the least-squares sense. However, as pointed out by Twiss & Unruh (1998), the conventional methods have an essential problem that the inversion of fault slip data provides direct constraints on the regional deformation rate but not the regional stress. In order to estimate the regional stress, we have to know the constitutive equation for a seismic flow (Kostrov 1974), which is not clear.

On the other hand, we developed the CMT data inversion method to estimate the stress fields related to earthquake generation (seismogenic stress fields) from the centroid moment tensors (CMT) of seismic events, following the Bayesian statistical inference algorithm developed by Yabuki & Matsu'ura (1992) (Terakawa & Matsu'ura, GJI, 2006 submitted). An essential difference between the present method and the conventional methods is that the present method uses CMT data directly but the conventional methods use fault slip data. The CMT data provide direct information about stress release at and around the hypocenter of a seismic event. The CMT solution is usually represented as the integral of 2-D moment tensor density over a rupture area, but by applying Gauss' divergence theorem this usual representation can be transformed into the integral of 3-D moment tensor density over a sufficiently large volume including the rupture area. Therefore, these two representations of CMT are mathematically equivalent with each other. Since dynamic rupture propagation, which radiates seismic waves, is controlled by energy flow into the rupture zone from the surrounding medium storing elastic strain energy (e.g., Aki & Richards 1980), the volume integral representation of CMT is more essential than the area integral representation. In other words, an earthquake is strongly influenced by the stress field outside its rupture extent. Actually, if the surrounding medium has no elastic strain energy to be released, any earthquake does not occur. In the present formulation of stress inversion, we used the latter representation of CMT, taking a weighting function for the volume integral to be a 3-D Gaussian-type distribution with its peak at the hypocenter and the variance proportional to the two-third power of the seismic moment. With the weighting functions, we can rationally relate the seismogenic stress field to observed CMT data, considering the hypocenters and magnitudes of seismic events. In the present method we need not partition the study area in advance. Instead, we represent the seismogenic stress field by the superposition of a finite number of basis functions to obtain parameterized observation equations and introduce prior smoothness constraints to construct a highly flexible stochastic model (Yabuki & Matsu'ura 1992). The use of such a flexible stochastic model and a Bayesian information criterion (ABIC) enables us to objectively extract the spatial pattern of seismogenic stress field from observed data. If we formulate the present method based on the usual representation of CMT, we must assume the smoothness of stress fields in some way. But then, the relation between the stress field and CMT data is ambiguous.