Stress Inversion and Mechanism Tomography

The crustal stress states can partly be estimated from the analysis of seismic data, including cluster analysis and stress inversion methods. In cluster analysis method, the directions of the maximum and minimum principal stress axes are determined by averaging the directions of the P and T axes of seismic events, respectively [e.g., Isacks and Molnar, 1971; Zoback and Zoback, 1980]. In the stress inversion approach, the average stress patterns of pre-partitioned blocks are determined from the fault slip data of seismic events with the least squares method (e.g., Gephart and Forsyth 1984; Hardebeck and Michael 2006; Michael 1987). Later, methods, a new inversion method (Terakawa and Matsu'Ura 2010) was developed to estimate the 3D pattern of tectonic stress from the CMT data of seismic events by using Akaike's Bayesian information criterion (ABIC) [Akaike, 1980], which is a criterion for objective model selection based on the entropy maximization principle [Akaike, 1977].

The assumptions of stress inversion are (1) that seismic slip occurs in the direction of the resolved shear traction acting on preexisting faults (Wallace, 1951; Bott, 1959), (2) that the fault strength is controlled by the Coulomb failure criterion with suggested friction coefficient (the standard friction coefficient of 0.6 (Byerlee, 1978) is often used). By further suggest that seismic slip on favorably oriented faults relative to the prevailing regional stress pattern occurs under hydrostatic fluid pressure, porepressure required for activation of unfavorably oriented faults can be estimated (Terakawa et al. 2013; Terakawa et al. 2010).

In GeoTaos, inversion of stress pattern and estimation of overpressure are based on the SATI codes of Hardebeck and Michael (2006) and the approach of Terakawa (201), respectively.

Suggested readings:

Hardebeck, J. L., and A. J. Michael (2006), Damped regional‐scale stress inversions: Methodology and examples for southern California and the Coalinga aftershock sequence, Journal of Geophysical Research: Solid Earth, 111(B11).

Terakawa, T., A. Zoporowski, B. Galvan, and S. A. Miller (2010), High-pressure fluid at hypocentral depths in the L'Aquila region inferred from earthquake focal mechanisms, Geology, 38(11), 995-998, doi:10.1130/g31457.1.

The slip vector ***d*** on a fault plan is given by

$$d = Gm \tag{1}$$

where, m is a vector of stress tensor component:

$$m = \begin{pmatrix} \sigma_{11} \\ \sigma_{12} \\ \sigma_{13} \\ \sigma_{22} \\ \sigma_{23} \end{pmatrix} \tag{2}$$

Since fault slip cannot constrain the isotropic part of the stress tensor, $\sigma_{33} = -(\sigma_{11}+\sigma_{22})$ is assummed. The matrix G is derived from the fault normal vector and given by(Hardebeck and Michael 2006)

$$G = \begin{pmatrix} n_{11} - n_{11}{}^3 + n_{11}n_{13}{}^2 & n_{12} - 2n_{11}{}^2 n_{12} & n_{13} - 2n_{11}{}^2 n_{13} & n_{11}n_{13}{}^2 - n_{11}n_{12}{}^2 & -2n_{11}n_{12}n_{13} \\ n_{12}n_{13}{}^2 - n_{12}n_{11}{}^2 & n_{11} - 2n_{12}{}^2 n_{11} & -2n_{11}n_{12}n_{13} & n_{12} - n_{12}{}^3 + n_{12}n_{13}{}^2 & n_{13} - 2n_{12}{}^2 n_{13} \\ n_{13}{}^3 - n_{13}n_{11}{}^2 - n_{13} & -2n_{11}n_{12}n_{13} & n_{11} - 2n_{13}{}^2 n_{11} & n_{13}{}^3 - n_{13}n_{12}{}^2 - n_{13} & n_{12} - 2n_{13}{}^2 n_{12} \end{pmatrix}$$

(3)

To estimate m, slip data on at leat 2 faults of different orentaion are required. For slip data on multi faults, the least square inversion solution is given by

$$m = G^T d \left(G^T G \right)^{-1} \quad \mathbf{(4)}$$

This standard method was expanded to invert for a regional, possibly varying stress field. Mean stress in spatial and/or temporal boxes are solved by damped inversion method, which minimizes the weighted sum of the data misfit and the model length (see Hardebeck and Michael, 2016 for detail).

Gephart JW, Forsyth DW (1984) An improved method for determining the regional stress tensor using earthquake focal mechanism data: application to the San Fernando earthquake sequence. Journal of Geophysical Research: Solid Earth 89 (B11):9305-9320

Hardebeck JL, Michael AJ (2006) Damped regional‐scale stress inversions: Methodology and examples for southern California and the Coalinga aftershock sequence. Journal of Geophysical Research: Solid Earth 111 (B11)

Michael AJ (1987) Use of focal mechanisms to determine stress: A control study. Journal of Geophysical Research 92 (B1):357 doi:10.1029/JB092iB01p00357

Terakawa T, Hashimoto C, Matsu'ura M (2013) Changes in seismic activity following the 2011 Tohoku-oki earthquake: Effects of pore fluid pressure. Earth and Planetary Science Letters 365:17-24 doi:10.1016/j.epsl.2013.01.017

Terakawa T, Matsu'Ura M (2010) The 3‐D tectonic stress fields in and around Japan inverted from centroid moment tensor data of seismic events. Tectonics 29 (6)

Terakawa T, Zoporowski A, Galvan B, Miller SA (2010) High-pressure fluid at hypocentral depths in the L'Aquila region inferred from earthquake focal mechanisms. Geology 38 (11):995-998 doi:10.1130/g31457.1