A New Methodology for the Estimation of Crustal Stress from the Comparison of Coseismic Shear Strain Energy Change with Aftershock Activity

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To know the stress state in the Earth's crust is one of the most essential problems not only in seismology but also in crustal dynamics. We propose a new methodology for estimating the magnitude of background tectonic stress from the comparison of coseismic change in shear strain energy with aftershock activity.

Given a spatial pattern of background tectonic stress orientation $\bar{S}'_{ij}$ and the coseismic change in deviatoric stress $\Delta\sigma'_{\mathrm{ij}}$ due to an earthquake, we can evaluate the coseismic change in shear strain energy density Δe_s as follows [Matsu'ura et al., 2018, 10th ACES Workshop]:

$$\Delta e_s(\mathbf{x}) = \frac{1}{2\mu}\left[\gamma \bar{S}'_{ij}(\boldsymbol{x})\Delta\sigma'_{\mathrm{ij}}(\boldsymbol{x}) + \frac{1}{2}\Delta\sigma'_{\mathrm{ij}}(\boldsymbol{x})\Delta\sigma'_{\mathrm{ij}}(\boldsymbol{x})\right]. \quad (1)$$

Here, μ is the rigidity of the Earth's crust, and the scale factor γ is an unknown parameter (MPa) to be determined from the observed aftershock activity. The first term on the right-hand side of Eq. (1) is positive (negative) in the stress accumulation (release) region, while the second term is positive everywhere. Then, the spatial pattern of Δe_s strongly depends on the magnitude of background tectonic stress, namely the scale factor γ. Saito et al. [2018, JGR] evaluated the first term due to interplate slip deficit and found that the background seismicity is high where the shear strain energy increases.

By using Eq. (1), we evaluated the change in shear strain energy density caused by the 2016 Kumamoto earthquake for various values of γ (Figure 1). In this evaluation, we used the results of CMT data inversion by Terakawa & Matsu'ra [2010, Tectonics] as the spatial pattern of background tectonic stress orientation $\bar{S}'_{ij}$. We calculated the deviatoric stress change $\Delta\sigma'_{\mathrm{ij}}$ from the coseismic slip distribution estimated from GNSS displacement data.

Now, we can compare the spatial pattern of Δe_s with aftershock activity to find the optimum value of γ. It should be noted that the activation of aftershocks is caused by not only (1) the increase of shear strain energy due to coseismic stress accumulation but also (2) the decrease of fault strength due to pore fluid pressure increase [e.g., Terakawa et al., 2013, EPSL]. Therefore, we need to consider the focal mechanisms of aftershocks to distinguish aftershock activations due to (1) and (2).

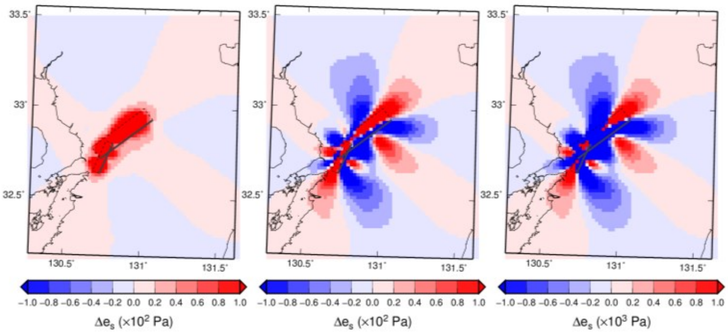

Figure 1. Shear strain energy changes at 10 km in depth. Left: γ=1MPa, Center: γ=10MPa, Right: γ=100MPa.