A stress-constrained geodetic inversion method for spatiotemporal slip of a slow slip event with earthquake swarm

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Geodetic inversions have been performed by using GNSS data and/or tiltmeter data in order to estimate spatio-temporal fault slip distributions. They have been applied for slow slip events (SSEs), which are episodic fault slip lasting for days to years (e.g., Ozawa et al., 2001; Hirose et al., 2014). Although their slip distributions are important information in terms of inferring strain budget and frictional characteristics on a subduction plate interface, inhomogeneous station coverage generally yields spatially non-uniform slip resolution, and in a worse case, a slip distribution can not be recovered.
It is known that an SSE which accompanies an earthquake swarm around the SSE slip area, such as the Boso Peninsula SSEs (e.g., Hirose et al., 2014). Some researchers hypothesize that these earthquakes are triggered by a stress change caused by the accompanying SSE (e.g., Segall et al., 2006). Based on this assumption, it is possible that a conventional geodetic inversion which impose a constraint on the stress change that promotes earthquake activities may improve the resolution of the slip distribution.
Here we develop an inversion method based on the Network Inversion Filter technique (Segall and Matthews, 1997), incorporating a constraint on a positive change in Coulomb failure stress (Delta-CFS) at the accompanied earthquakes. In addition, we apply this new method to synthetic data in order to check the effectiveness of the method and the characteristics of the inverted slip distributions.
We model a horizontal square fault with its area of 80 x 80 km^2 at 15 km depth in a half-space. This fault is divided into 64 square subfaults with each dimension of 10 x 10 km^2. We define the four subfaults at the center of the modeled fault as "slip patch" where slip lasts for five days and evolves to 50 cm. 49 GNSS stations are located on grid points on the surface with 20 km spacing. Theoretical surface displacement time-series at each GNSS station are calculated based on Okada's (1992) formulation. Pseudo observation data are generated by adding Gaussian noise with its standard deviation of 1 mm in horizontal components and 3 mm in vertical components, respectively, to the calculated displacements. These data are inverted with or without the Delta-CFS constraint, and both of the estimated slip distributions are compared. We test two GNSS station distributions: (a) all of the 49 stations are included; (b) reduced 28 stations which cover only a half area of the fault. The triggered earthquake hypocenters are located at the center of each subfault around the assumed slip patch where Delta-CFS is calculated. The same focal mechanism of these earthquakes is assumed as that of the SSE for the stress calculation.
In case (a), because the station coverage is sufficient to reproduce the given slip distribution, the difference between the inversion results with and without the Delta-CFS constraint is small. In case (b), where the observation condition is worse than (a), the inversion result with the Delta-CFS constraint has larger slip (closer to the assumed slip amount) on the slip patch and smaller smearing on the surrounding subfaults than that without the Delta-CFS constraint.
These show that there is a case in which the reproduction of a slip distribution is better with earthquake information than without it. That is, it is possible to improve the reproducibility of a slip distribution of an SSE with this new inversion method if an earthquake catalog for the accompanying earthquake activity can be used when insufficient geodetic data are available.

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