GNSS data assimilation for the Bungo channel Long-term SSEs using Ensemble Kalman Filter (EnKF)

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Long-term Slow Slip Events (L-SSEs) in the Bungo channel, southwest Japan occur in the down-dip side of the seismogenic zones on the megathrust plate interface. Although L-SSEs release accumulated strain in the L-SSE zones, they can increase strain in the up-dip seismogenic locked zones. Therefore, better understanding of the temporal evolution of L-SSEs is very important for earthquake hazard assessment. Hirahara, and Nishikiori (JpGU, 2018) developed a method for estimating slip evolution and frictional properties on L-SSE area in the Bungo channel, by applying a data assimilation method EnKF (Ensemble Kalman Filter), which has been developed in meteorology and oceanology, to the synthetic GNSS data. Although they used the surface velocity data as GNSS data, the actual data which we can observe at GNSS station is the surface displacement data, not surface velocity data. In order to apply EnKF to the actual GNSS observational data, we conducted two numerical experiments, as follows.

i)We used the surface velocity data converted from the synthetic surface displacement data as observational data.

ii) We used the surface displacement data, not the surface velocity data as observational data.

We used the same model settings in above two numerical experiments as Hirahara and Nishikiori (2018) did. Firstly, we set a plane fault in homogeneous isotropic elastic body, whose angle of dip is 15 degrees. The frictional force on the plane fault follows a Rate and State Friction (RSF) law with an aging law [Dieterich,1979; Ruina,1983]. We set a velocity weakening (A-B<0) circular patch, whose radius R is 35 km, in the velocity strengthen (A-B>0) fault plane. We reproduced the observed L-SSEs in the Bungo Channel, using the frictional parameters in such a way that R is smaller than the critical nucleation size R_c [Rubin and Ampuero (2005), Chen and Lapusta (2009)]. Secondly, we considered the effect the seismogenic locked zones in the up-dip side of the L-SSEs zone. We set a locked zone at the up-dip of the L-SSE fault, whose back-slip rate is 6.0 cm/yr.

As the common analysis settings, we selected several pairs of frictional parameters in a wide range of parameter space which reproduce L-SSEs for the initial ensemble members of frictional parameters. We made the daily synthetic GNSS surface displacement data for 93 GEONET stations around the Bungo channel by calculating the surface displacements using true synthetic frictional parameters and adding random Gaussian noise. We set the assimilation interval to 10 days.

In experiment i), we calculated 31 day moving averages of the synthetic GNSS displacement data, and we obtained the surface velocities at GNSS stations from the derivatives of a 150-day cubic spline function fitting the moving averaged surface displacements. Then we applied EnKF to the obtained surface velocities and we successfully estimated slip evolution and frictional parameters. This result suggests this method for converting the surface displacement data into the surface velocity data at GNSS stations might be applicable.

In experiment ii), we applied EnKF to the synthetic GNSS displacement data directly. When we conducted experiment ii), we changed some analysis settings for stabilizing the assimilation. Firstly, when the slip velocity at the center of fault plane is low, we added larger random noise to the innovations artificially. Secondly, when the slip velocity at the center of fault plane is high, we reduced the assimilation interval to 1 day and introduced additive inflation to prevent the prediction errors from being too small. As a result, we also successfully estimated slip evolution and frictional parameters using the surface displacements, although the experiment sometime fails depending on the start timing of the analysis. Therefore, this method has not been fully stabilized yet, and we need to improve it for robust estimation.

Finally, we applied EnKF to the real GNSS data before the 2011 Tohoku-oki earthquake in the same settings as experiment i) and ii) respectively. We corrected offsets of major earthquakes and antenna changes in the GNSS data. However, both experiments stopped during the assimilation due to negative slip velocities. It manifests an importance of correction of GNSS data including removing annual and semiannual components for a stable assimilation of real GNSS data. Furthermore, we need to consider the realistic model settings including the geometry of the subducting Philippine Sea plate interface and distribution of both L-SSE and locked zones.

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