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Crustal Deformation in the San-in Shear Zone Before and After the 2011 Tohoku-oki Earthquake Inferred from a Dense GNSS Network

〇Angela MENESES-GUTIERREZ, Takuya NISHIMURA

1. Introduction

The San-in Shear Zone (SSZ) is a ~N80ºE right-lateral shear zone in southwest Japan with a 30-50 km width, where active seismicity and high strain rates have been observed. In the past century several large (M_j 6~7) earthquakes occurred within the SSZ in 1943, 1983, 2000, and 2016, showing that the SSZ is seismotectonically active. Recent seismic events, excluding the 1943 earthquake, exhibit left-lateral motion on NNW-SSE oriented faults, despite the general right-lateral motion observed on the SSZ. Nishimura and Takada (2017) suggested conjugated Riedel shears within the shear zone. However, it is not clear the extend of the shear zone in the lower crust or how the overall E-W trending right lateral slip is accommodated by the active faults within it.

Meneses-Gutierrez and Sagiya (2016) studied geodetic strain rate distributions in the Niigata-Kobe Tectonic Zone (NKTZ) before and after the 2011 M_w9.0 Tohoku-oki earthquake and found persistent localized contraction (4~10 x 10^{-8}/yr) in northern NKTZ, demonstrating significance of inelastic processes, in the form of aseismic fault slip, in crustal deformation of inland Japan.

Steady aseismic crustal faulting might be persistent in other inland active faults in Japan, where aseismic faulting or localized shear loads the upper crustal faults through time. Under this framework, we analyze GNSS data in the SSZ before and after the 2011 Tohoku-oki earthquake in order to characterize the source of deformation within the area.

2. Data and methodology

We analyzed daily coordinates from continuous GNSS stations in southwest Japan. The network includes GEONET stations and original stations in the SSZ operated by Kyoto University since 2014 near the source regions the 2000 and the 2016 earthquakes. Precise daily coordinates for the GNSS sites are calculated with the GNSS-Inferred Positioning System and Orbit Analysis Simulation Software (GIPSY-OASIS), version 6.2 using the Precise Point Positioning processing strategy with ambiguity resolution (Zumberge et al., 1997; Bertiger et al., 2010).

We evaluated crustal deformation in the SSZ in the preseismic and postseismic periods of the 2011 Tohoku-oki earthquake. We considered three time periods: one before the earthquake, spanning from 1 April 2005 to 31 December 2009, and two after the earthquake, 1 July 2011 to 31 March 2015 and 1 April 2014 to 1 April 2018. Horizontal displacement rates are calculated for all stations using a linear regression for each time period with respect to site 0344 (35.09ºN, 134.59ºE). During the analyzed periods two major earthquakes affected the crustal deformation in the area: the 2016 Kumamoto earthquakes (M_w 7.0) and the 2016 Central Tottori earthquake (M_w 6.2). Coseismic and postseismic corrections were applied for the perturbed stations. To constrain the width of the shear zone, the latest postseismic period is modeled assuming parallel vertical dislocations below 13 km depth (Omuralieva et al., 2012).

Based on the horizontal displacements rate, we calculated horizontal strain rate distributions at a regular grid every 0.05º using the Shen et al.'s (1996) method with a distance decay constant of 20 km, considering the spatial distribution of the GNSS sites. We focus on deformation on the N80ºE direction, along the SSZ strike. Following Meneses-Gutierrez and Sagiya (2016), we decomposed the strain rate distributions into long and short wavelength components. We employed a moving average filter to extract the long wavelength deformation. The short wavelength component corresponds to the residual value between the observed strain rate and the long wavelength pattern for each time period. We tested various filtering radius to extract the long-wavelength component from the strain rate data, and found no significant differences. We then, selected 50 km as the filtering radius (Figure 1).

Additionally, in order to evaluate stress rate in the SSZ, we analyzed background seismicity changes before and after the Tohoku-oki earthquake using time Epidemic Type Aftershock Sequence (ETAS) model (Ogata, 1988; Okutani and Ide, 2011; Nishikawa and Ide, 2015).

3. Results and Discussion

Shear strain rate distributions in SSZ evidence right lateral motion both in the preseismic and postseismic period of the 2011 Tohoku-oki earthquake. Long wavelengths indicate right-lateral motion before and after the Tohoku-oki earthquake. However, increase on the magnitude of the deformation is observed after the event, representing the postseismic deformation of the 2011 Tohoku-oki earthquake. On the other hand, short-wavelength components evidence persistency of localized deformation in the SSZ before and after the earthquake (Figure 1). Shear localization is reveled in the SSZ, in agreement with previous studies. On the other hand, background seismicity rate did not change significantly before and after the earthquake. Change of stress rates before and after the 2011 Tohoku-oki earthquake is smaller than the background stress rates in the area.

Optimized models using horizontal displacement in the latest postseismic period along two profiles, revealed different widths of the shear zone (i.e., 60 km and 21.5 km) for Western and Central-Eastern Tottori, respectively. They suggest that ductile flow in the lower crust is distributed in a channel beneath the SSZ. However, models with a single vertical fault in the middle of the shear zone are also within the confidence interval. GNSS data alone cannot constrain the width of the shear zone in the lower crust.

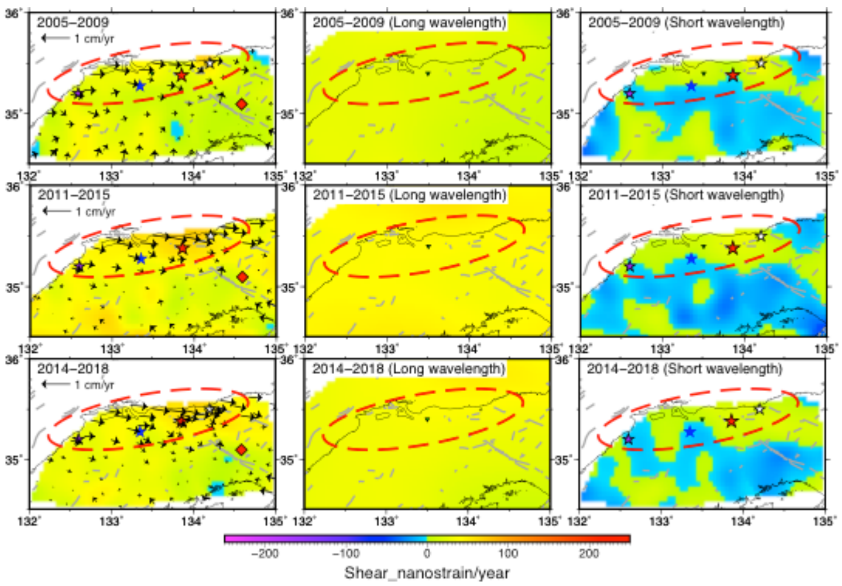

Figure 1. Wavelength decomposition of the geodetic shear strain rate on the N80ºE direction before and after the Tohoku-oki earthquake around the SSZ (enclosed area by red line). Positive values indicate right lateral motion, while negative values indicate left lateral motion. Horizontal displacement rates for each period with respect to station 0344 (red diamond) are also shown. Stars denote recent large earthquakes in the area.