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The coseismic deformation and fault slip distribution of the Mw9.0 Tohoku-Oki earthquake estimated from GPS and InSAR

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The magnitude Mw9.0 Tohoku-Oki earthquake occurred on 11 March 2011 off the Pacific coast of Tohoku district in eastern Japan. It is the largest earthquake in the recent history of Japan and the fourth largest earthquake to occur in the world since 1900. Utilizing different geophysical datasets, e.g. teleseismic, strong motion, geodetic observations and tsunami datasets, several coseismic slip distribution models have already be published. However, while InSAR is another important data source, it has mostly been excluded in studies of the fault slip distribution of this earthquake. In addition, the earthquake provides an excellent opportunity to study fault-slip resolution obtained by different measurement methods, as the Japanese islands are extensively instrumented with both seismic and GPS instruments.

In this study, we map the coseismic deformation of the Tohoku-Oki earthquake with InSAR by using data from three descending Envisat tracks and six ascending ALOS tracks that cover most of northeastern Japan. Due to the inaccurate satellite-orbit information, the coseismic interferograms contain phase ramps, which have resulted in inconsistency between the deformation maps released by different research groups. We removed these ramps in the InSAR data by using a 2-D quadratic phase model based on GPS measurements provided by the ARIA team at JPL and Caltech. The average RMS between the InSAR and GPS measurements decreased from 17.8 cm to 7.7 cm after the orbital ramp correction, indicating significant improvements to the InSAR data by this procedure. The calibrated coseismic deformation InSAR measurements show a maximum line of sight (LOS) displacement of up to 3.7 m in the ascending ALOS data and 2.4 m in the descending Envisat data.

Using onland and offshore GPS data, as well as the InSAR data, we generated 5 solutions based on 5 different combinations of the data: (a) GPS data, (b) InSAR data without GPS calibrations, (c) GPS-calibrated InSAR data, (d) GPS and InSAR data, and (e) GPS and InSAR data, but without offshore GPS data. Based on comparisons between the resulting 5 fault-slip models, we find that the GPS-only model (based on dataset (a)) is almost identical to the joint model (dataset (d)), regarding slip magnitude, pattern, and rake. This means that little is gained by including the InSAR observations in the fault slip modeling in this case. However, we also find that the main pattern of fault slip can be determined by the InSAR observations alone, by simultaneously estimating long wavelength orbital and atmosphere delay errors in the data. Our final preferred solution includes both reverse faulting and strike slip. The maximum reverse and strike slip values are 36.0 m and 6.0 m, respectively, at a depth of 6 km northeast of the epicenter. The total geodetic moment is 3.6×1022 Nm (Mw 9.01), similar to seismological estimates.

Keywords: Tohoku-Oki earthquake; coseismic deformation; InSAR; orbital ramps correction; Slip distribution