

Source rupture process of the 2016 Kumamoto earthquake derived from strong motion data

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A series of earthquakes in Kumamoto and Oita Prefectures from April 14, 2016, which are collectively called the 2016 Kumamoto earthquake, caused destructive damages by their strong ground motions. In this study, we estimate the source processes of two major events using strong motion data; One occurred at 21:26 on April 14 with Mj 6.5 (which we will call "the M6.5 event") and the other occurred at 1:25 on April 16 with Mj 7.3 (which we will call "the M7.3 event").

The multi-time-window linear waveform inversion method (Olson and Apsel 1982; Hartzell and Heaton 1983) is used in this study. For the fault plane model of the M6.5 event, we assume a 22 km x 12 km rectangle with a strike of 212 degree and a dip of 89 degree referring to the F-net moment tensor solution. For the fault plane model of the M7.3 event, we assume a 56 km x 24 km rectangle with a strike of 226 degree referring on the F-net moment tensor solution. The dip angle is set to 65 degree based on the hypocenter distribution of aftershocks after the M7.3 event and the surface-rupture distribution, and the static coseismic displacements inferred by InSAR and GNSS. These fault planes are discretized with 2 km x 2 km subfaults. The rupture starting point of each event is set to the hypocenters determined by Yano et al. (2016) with the double-difference method. The slip time history of each subfault is represented by 5 time windows of 0.8 s for the M6.5 event and 13 time windows for the M 7.3event. The triggering velocity of first time window is set to 2.4 km/s for the M6.5 event and 2.8 km/s for the M7.3 event to minimize the data-fit residual.

We use three components of velocity waveforms at the 16 stations of K-NET and KiK-net, F-net of NIED for the M6.5 event and the 27 stations for the M7.3 event. The waveforms for the analysis of the M6.5 event are band-pass filtered between 0.1 and 1.0 Hz, resampled to 10 Hz, and windowed from 1 s before S-wave arrival for 7-10 s. The waveforms for the analysis of the M7.3 event are band-pass filtered between 0.05 and 1.0 Hz, resampled to 5 Hz, and windowed from 1 s before S-wave arrival for 30 s.

Green's functions are calculated with the discrete wavenumber method (Bouchon 1981) and the reflection/transmission matrix method (Kennett and Kerry 1979) assuming a 1-D velocity structure model. The structure model is obtained for each station from the 3-D structure model (Fujiwara et al. 2009). Logging information is also used for the KiK-net station. To consider the rupture propagation effect, 25 point-sources are uniformly distributed over each subfault in the calculation of Green's functions.

Two orthogonal slips of each time window at each subfault is derived by minimizing the difference between the observed and synthetic waveforms using the non-negative least-squares scheme (Lawson and Hanson 1974). The slip angle is allowed to vary within ± 45 around the F-net rake angle (-164 degree for the M6.5 event and -142 degree for the M7.3 event). In addition, the spatiotemporal slip smoothing constraint (Sekiguchi et al. 2000) is imposed in the inversion and its weight is determined based on ABIC (Akaike 1980).

In the estimated source model of the M 6.5event, the seismic moment and maximum slip are 1.8×10^{19} Nm (Mw 6.1) and 0.7 m, respectively. Two large slip areas are found in the region around the rupture staring point and the shallow region north-northeast of the rupture starting point.

In the estimated source model of the M7.3 event, the seismic moment and maximum slip are 5.3×10^{19} Nm (Mw 7.1) and 4.6m, respectively. The large slips are found from 10km to 30km northeast of the rupture starting point. The rupture mainly propagated to the northeast, developed into the large

moment release between 5 s and 15 s, and almost ceased after 20 s. The slip distribution in the shallow part is consistent the observed surface-rupture distribution. In addition, the large slip area does not overlap with the active aftershock area after the M7.3 event.

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