3-D Dynamic Rupture Simulations of the 2016 Kumamoto, Japan, Earthquake

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Using 3-D dynamic rupture simulations, we investigated the 2016 M7.3 Kumamoto, Japan, earthquake to illuminate why and how the rupture of the main shock propagated successfully, assuming a complicated fault geometry estimated on the basis of the distributions of the aftershocks. The M7.3 main shock occurred along the Futagawa and Hinagu faults. A few days before, three M6-class foreshocks occurred. Their hypocenters were located along the Hinagu and Futagawa faults, and their focal mechanisms were similar to those of the main shock; therefore, an extensive stress shadow may have been generated on the fault plane of the main shock. First, we estimated the geometry of the fault planes of the three foreshocks as well as that of the main shock based on the temporal evolution of the relocated aftershock hypocenters. We then evaluated the static stress changes on the main shock fault plane that were due to the occurrence of the three foreshocks, assuming elliptical cracks with constant stress drops on the estimated fault planes. The obtained static stress change distribution indicated that the hypocenter of the main shock was located in the region with a positive Coulomb failure stress change (ΔCFS), while the ΔCFS in the shallow region above the hypocenter was negative. Therefore, these foreshocks could encourage the initiation of the main shock rupture and could hinder the propagation of the rupture toward the shallow region. Finally, we conducted 3-D dynamic rupture simulations of the main shock using the initial stress distribution, which was the sum of the static stress changes caused by these foreshocks and the regional stress field. Assuming a slip-weakening law with uniform friction parameters, we conducted 3-D dynamic rupture simulations by varying the friction parameters and the values of the principal stresses. We obtained feasible parameter ranges that could reproduce the characteristic features of the main shock rupture revealed by seismic waveform analyses. We also demonstrated that the free surface encouraged the slip evolution of the main shock.

