Fault geometry and coseismic slip for the Balochistan Earthquake (2013, Mw7.7, Pakistan) inferred from SAR and optical data

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Abstract

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The 2013 Mw 7.7 Balochistan earthquake occurred in the complex tectonic setting of the triple junction between Arabia, Eurasia and India tectonic plates. The earthquake ruptured a 200-km-long curved section of the Hoshab fault. Coseismic motion was dominated by left-lateral slip with a minor reverse component.
By combining optical satellite data from Landsat 8 and SPOT-5, as well as radar satellite data from TerraSAR-X and RADARSAT-2, we derived the full 3D coseismic displacement field at the surface. We used this dataset to estimate the slip distribution of the earthquake, paying special attention to the relationship between slip and fault geometry. Following a statistical analysis of the coseismic surface trace, the fault is discretized into 15 segments (azimuth and length). To find the fault geometry, i.e. the dip and down-dip width for these 15 segments, we performed a non-linear elastic inversion of the geodetic dataset using Okada's equations, considering each segment as a single dislocation. We then used this first order modeling to set the geometry and linearly invert for slip and rake at depth with discretized segments.

Results show fault segments with a dip varying from 54 to 89◦ to the north-west. Steeper dips are inferred at each termination, whereas the fault seems to flatten in its middle part. Rake values range from 0 to 28◦, in good agreement with strike-slip motion with minor reverse component. The strike slip component peaks at 12.7 m near the epicenter, decays slowly southward, before terminating abruptly, forming a continuous patch confined between the surface and 8 km depth. The dip slip component is distributed on several patches that seem to get more shallow near the southern termination of the rupture where the amplitude peaks at 5.7 m. Slip seems to propagate very little north of the hypocenter.

Our joint model uses near-fault (radar and optical correlation) as well as far-field (InSAR) data and shows no shallow slip deficit. On the contrary, we infer for nearly all fault segments an increase of slip toward the surface. In line with recent studies (Vallage et al. 2015, Xu et al. 2016, Marchandon et al. 2018), we therefore argue that this earthquake falls in the category where shallow slip deficit vanishes when near-field data is included in the dataset, raising questions on the robustness of previous claims of shallow slip deficit for earthquakes where such observations are not available.
Furthermore the signature of a geometrical complexity is visible throughout all this study. This push-up (complexity C2 from Vallage et al. 2015) is indeed well observed in the rupture map and was systematically used as an intersegment by our multi-segment fit algorithm. It is also spatially concordant with the minimum dip we found for the Hoshab fault. The complexity matches a local minimum in the slip curves and marks the location where strike slip amplitude starts to decrease while the dip slip amplitude increases. These features thus suggest a significant role in both the earthquake kinematics and fault geometry.