Deformation at Continental Thrust Faults Before, During and After Major Earthquakes

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Much of our understanding of the earthquake deformation cycle is derived from observations at major strike-slip faults. By contrast, relatively few long-term geodetic data sets exist at continental thrust faults, and it remains unclear whether ideas developed at strike-slip faults are applicable to other fault systems. Here, we use geodetic observations from convergent zones in Nepal and Pakistan where major earthquakes have occurred in the geodetic era. We investigate the geometries and frictional properties of the thrust systems.

We first examine the Himalayan frontal thrust system, where a major earthquake occurred in 2015 (M7.8 Gorkha, Nepal). Despite extensive study, the geometry of the fault system remains controversial. Here, we use interseismic, coseismic and postseismic geodetic data to investigate the proposed down-dip geometries. We find that kinematic modelling of geodetic data alone cannot easily distinguish between the previously proposed geometries. We therefore develop a mechanical joint coseismic-postseismic slip inversion which simultaneously solves for the distribution of coseismic slip and rate-strengthening friction parameters. A synthetic test shows that we can recover coseismic slip and frictional parameters well using a Bayesian inversion. We run this inversion using the proposed geometries and find that they are all capable of explaining the majority of geodetic data. We find different frictional properties down-dip of the coseismic slip patch to up-dip, and confirm that the up-dip portion of the thrust remains locked.

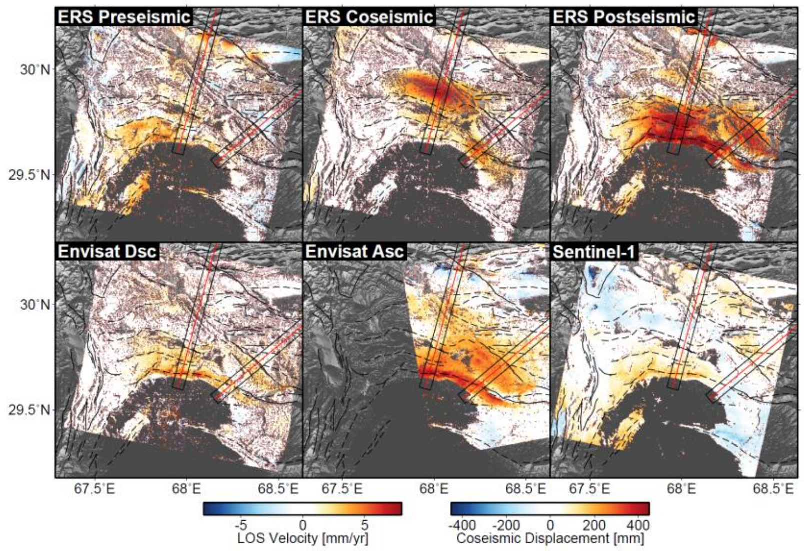

Figure 1: Deformation occurring before, during and after a M7.1 earthquake double in Pakistan in 1997, observed with InSAR from ERS-1, ERS-2, Envisat, Sentinel-1A and Sentinel-1B.

We also show results from the Sibi area of the Sulaiman fold-and-thrust belt in Pakistan, where an earthquake doublet occurred in 1997. Here we combine deformation data spanning 25 years from ERS-1, ERS-2, Envisat, Sentinel-1A and Sentinel-1B to give a long-term geodetic history for the area, including interseismic deformation measured before the earthquake, coseismic deformation, and postseismic deformation (Figure 1). We find that afterslip dominates the post-seismic deformation and that this slip occurs both up-dip and down-dip of the coseismic rupture. We investigate the relationship between short-term deformation and topography and use the data to constrain the frictional properties of the fault system. We discuss the implications of our results for earthquake hazard and the long-term evolution of topography in the continents.