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# Kilometer-wide volumetric deformation of the shallow crust associated with strike-slip continental earthquakes and its relation with coseismic shallow slip deficits

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Surface deformation associated with continental earthquakes separates into a localized component occurring on faults, and distributed deformation affecting the surrounding medium, referred to as off-fault deformation (OFD). This OFD includes both displacement discrete on secondary faults and cracks, and more diffuse deformation affecting the bulk volume of the crust. Although the deformation occurring on faults and cracks can be observed and measured in the field, diffuse deformation is more challenging to detect because it generates kilometer-scale continuous gradients of displacement without any visible disruption of the ground surface. Consequently, surface displacements measured in the field generally underestimate the total surface displacement of the earthquakes. Moreover, results from inversions of geodetic and/or seismic data suggest that, for many earthquakes, the amount of coseismic slip occurring at depth (3-7 km) is larger than what occurs in the shallower part (<3 km). This is referred to as the shallow slip deficit (SSD). So far, because diffuse deformation is not explicitly considered in earthquake displacement budgets, and because the origin of the SSD remains debated, it is difficult to directly compare directly surface observations with modeling results. In this study, we use a set of complementary geodetic data (InSAR, GPS, high-resolution optical data) to jointly invert for the coseismic slip of the 2019 Ridgecrest earthquake sequence in Southern California ($M_w$6.4 and 7.1). To reproduce the rupture complexity observed in the high-resolution optical data, we use a complex fault model with increased resolution in the uppermost crust. We pay special attention that our preferred model fits both with the fault slip distribution observed at the surface in the high-resolution optical imagery data, and regional-scale displacement data from InSAR and GPS. In our best model, we estimate a 30% SSD in the upper 3 km. This value of 30% matches the amount of diffuse deformation we measured around the ruptures at the surface directly on the high-resolution optical data. From these observations, we propose that SSD is entirely balanced by the volumetric diffuse deformation, and more generally, that diffuse surface deformation is proportional to SSD. Finally, based on a compilation of published data, we show that SSD and diffuse deformation are both inversely proportional to the earthquake magnitude. Indeed, for large magnitude earthquakes, SSD and diffuse deformation are close to 0%. Conversely, for earthquakes that do not break the surface, diffuse deformation might be close to 100%. However, in this latter case, it still needs to be determined whether the diffuse deformation is only elastic, or

not.