A unified representation of quasi-dynamic deformation processes

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The last three decades have witnessed an explosion of studies on fault processes, from kinematic modeling of geodetic data, to dynamic modeling of fault rheology. These studies were made possible by fundamental solutions that describe the stress and displacements caused by slip on a fault (e.g., Okada, 1985, 1992). In contrast, direct imaging of the kinematics of off-fault deformation is still impractical, and the dynamic modeling of viscoelastic relaxation or poroelastic rebound still relies on computationally intensive numerical methods (e.g., Barbot & Fialko, 2010). As a result, much less has been learned on the mechanics of deformation at plate boundaries away from faults. Here, we describe a novel approach that allows us to resolve distributed processes in kinematic inversions of geodetic data and to incorporate off-fault processes in numerical models of earthquake cycles. We quantify analytically the displacement and stress incurred by distributed inelastic strain in finite shear zones (Barbot, Moore & Lambert, submitted, 2016). We use these elementary solutions to simultaneously invert for slip on faults and distributed strain in the surrounding rocks. We apply this new technique to study postseismic relaxation in various tectonic contexts. For example, using a decade of geodetic data following the 2010 Mw 7.6 Chi-Chi, Taiwan earthquake we constrain the temperature in the lower crust. Exploiting the stress perturbation of the 2010 Mw 8.6 Wharton Basin earthquake, we place bounds on the width of the oceanic asthenosphere. Our formulation also allows the dynamic simulation of earthquake cycles with distributed deformation using the integral method, an approach potentially many orders of magnitude faster than classic finite-element techniques. We simulate earthquakes cycles within the lithosphere-asthenosphere system using rate-and-state friction and the power-law flow of olivine (Lambert & Barbot, submitted, 2016), revealing the prevalence of viscoelastic flow in the early stage of postseismic relaxation. We show models of earthquake cycles in poroelastic media, highlighting variations of the water table at time scales from days to decades. Our approach will be instrumental to building comprehensive physical models of stress evolution at plate boundaries.