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A Power-law Rheology Model for the Postseismic Deformation of the 2010 Maule Earthquake, Chile

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The postseismic surface deformation associated with the 2010 Mw 8.8 Maule earthquake in Chile was recorded in great detail. The high data quality of the continuous GPS (cGPS) observations of the Maule case has facilitated a number of studies that have improved our understanding on the relaxation processes that control the induced differential stresses in the lower crust and upper mantle due to the main shock, i.e. frictional afterslip in the fault plane and viscous flow in the upper mantle. However, the processes that relax the differential stresses in the lower crust, as well as the influence of the rheological parameters, are still not well understood. Recently, Peña et al. (2019) used a 2D geomechanical-numerical model combining afterslip, relocking, and temperature-dependent power-law rheology together with six years of postseismic cGPS observations to show that most of the viscous relaxation occurs in the lower crust, below the volcanic arc, due to dislocation creep processes. In this study, we extend this 2D model approach to a 3D geomechanical-numerical model using the same cGPS data set to investigate (1) the principal differences based on the model dimension, (2) the whole spatial cumulative observed patterns, and (3) the implications of power-law rheology on afterslip magnitude and location.

Our results show that a 2D model approach overestimates the surface deformation in comparison to a cross-section at the same region obtained from the 3D model because of Poisson effects. As a result, besides stress relaxation in the lower crust, relaxation in the mantle wedge is also required to explain the overall deformation patterns. The transient creep localized both in the lower crust and mantle wedge resembles the linear viscosity heterogeneity structure or deep afterslip needed by previous studies to explain the postseismic surface patterns, in particular, the uplift in the volcanic arc. The different patterns observed along strike in the near field are mainly controlled by afterslip processes; however, the amount of afterslip required in our approach is considerably smaller compared to studies that used an inversion approach and a linear viscoelastic upper mantle. Interestingly, the main patterns in the far field north and south of the rupture zone are also reproduced by our 3D model approach. There, an increase of deformation in the sense of the interseismic contraction is shown. This may explain the acceleration observed by cGPS data away from the rupture zone. Thus, by using power-law rheology without including complex rheological discontinuities our model results constrain both the quantity and location of postseismic deformation in the near and far field.