Geophysical Research Abstracts
Vol. 13, EGU2011-4710, 2011
EGU General Assembly 2011
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Signature of depth-dependent crustal viscosity in post-seismic deformation

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Real-time surface deformation detected by satellite-based geodetic observations (GPS and/or InSAR) can provide precise constraints on the mechanism of stress relaxation following an earthquake. Among several post-seismic deformation mechanisms, visco-elastic relaxation may be the dominant component for long periods and long wavelengths. However, quantitative modelling of this mechanism is essential to understand the constraints imposed by observed surface deformation patterns. Several transient rheological models have been proposed to explain observed post-seismic deformation which appears to require greater viscosities as deformation progresses (e.g., Freed and Bürgmann, Nature, 30, 548, 2004; Ryder et al., GJI, 169, 1009, 2007; Hearn et al., JGR, 114, B08405, 2009). Alternatively, the variation of viscosity with depth may be important in explaining observed post-seismic displacement rates (e.g., Riva and Govers, GJI, 174, 614, 2009). In this study, we examine the effects of depth-dependent viscosity in the crust on post-seismic surface displacements. We solve for the linear Maxwell visco-elastic response following an applied internal fault displacement in a rectangular block, using a parallelized 3-D finite element code, oregano_ve. Beneath the faulted elastic layer we assume a viscosity profile which decreases exponentially with depth. Slip on a strike-slip fault is implemented using the split node method (Melosh and Raefsky, BSSA, 71,1391,1981). We compare the post-seismic surface displacement histories at different points on the surface. Compared to a model with uniform viscosity, the apparent rates of relaxation of the depth-dependent viscosity model initially imply smaller viscosities at points that are more distant from the fault, but at a given measurement point the apparent viscosity increases with time. The model behaviour described in this study demonstrates why both spatial and temporal variation of displacements are important in constraining the sub-surface viscosity variation in the lithosphere. We attempt to use the InSAR dataset of Ryder et al. (GJI,2007), obtained following the 1997 Manyi (Tibet) earthquake, to constrain crustal viscosity structure beneath this region, and to discuss whether or not mechanisms other than linear visco-elastic creep are required to explain observed post-seismic displacement patterns.