Mechanisms of postseismic deformation following the 2010 M=7.2 El Mayor-Cucapah earthquake

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Outline

The "conveyor belt" model of plate tectonics, in which steady flow in the Earth's asthenosphere carries plates along through basal tractions, has been shown to be unrealistic. Nevertheless, it remains possible that the lithosphere and asthenosphere are mechanically coupled in some way and that viscous flow in the asthenosphere contributes to lithospheric deformation. Two key questions are 1) whether this coupling exists and 2) if so, whether the asthenosphere flows quickly enough to play a role in the loading of earthquake faults in the interseismic period, affecting seismic hazard.

One way to answer these questions is to study the spatiotemporal evolution of surface deformation following large earthquakes. The stress changes imparted by a large earthquake to the surrounding medium trigger a number of postseismic processes that may include viscous flow in the lower crust and upper mantle, afterslip on the deep extension of the coseismic rupture, and poroelastic rebound in the crust. Each process produces deformation at the surface, and so one can study the evolution of surface deformation following an earthquake in the hopes of determining which processes caused the deformation, thereby gaining insight into the nature of deformation at depth.

Due to the sparsity of information about the depth of the asthenosphere, previous studies of postseismic deformation have generally been unable to determine whether surface deformation specifically required viscous flow in the asthenosphere (as opposed to, for example, in the mantle lithosphere). The depth to the lithosphere-asthenosphere boundary in southern California has recently been constrained using receiver functions and has been observed to be uncommonly shallow (<50 km) in the Salton Trough region due to the onset of continental rifting there. The 2010 M=7.2 El Mayor-Cucapah earthquake, the largest event in the Salton Trough in over a century, occurred directly above this shallow asthenosphere. If the lithosphere and asthenosphere are coupled and the asthenosphere can flow quickly enough to affect interseismic deformation, the postseismic deformation following this earthquake should contain a particularly strong signal of deep flow. On the other hand, if coupling at the lithosphere-asthenosphere boundary is negligible and/or the effective viscosity of the asthenosphere is too high, postseismic deformation here should be entirely explainable by shallower mechanisms.

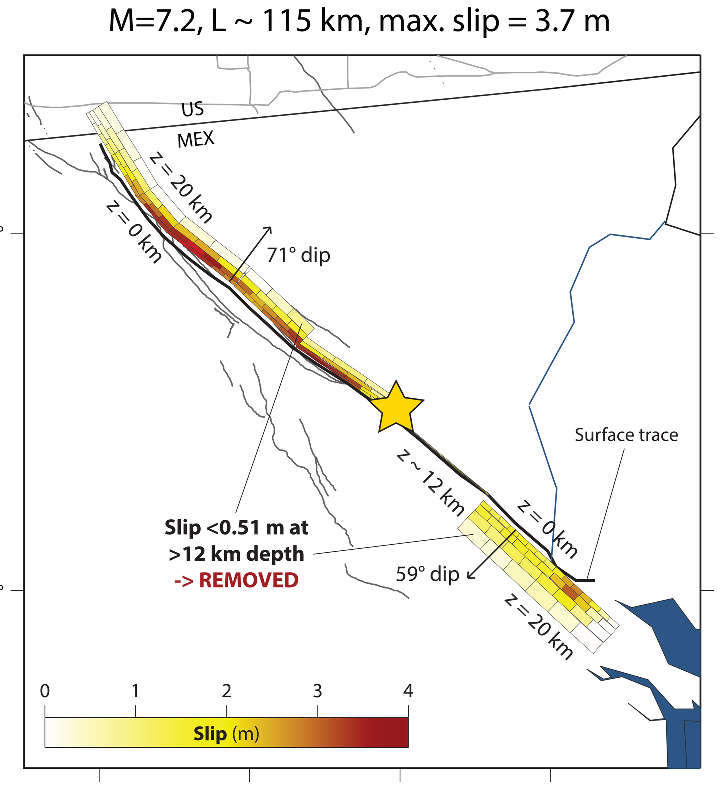
Using the Fialko et al [2010] slip model for the mainshock and the deformation modeling software RELAX, we calculate the expected postseismic surface deformation resulting from coupled afterslip and viscous flow in a variety of hypothetical geometries, then compare these forward models to continuous GPS data. Preliminary findings suggest that viscous flow in the shallow Salton Trough asthenosphere is required to explain a pattern of systematic uplift observed at GPS stations in the Imperial Valley in the first year after the earthquake.

Ingredients

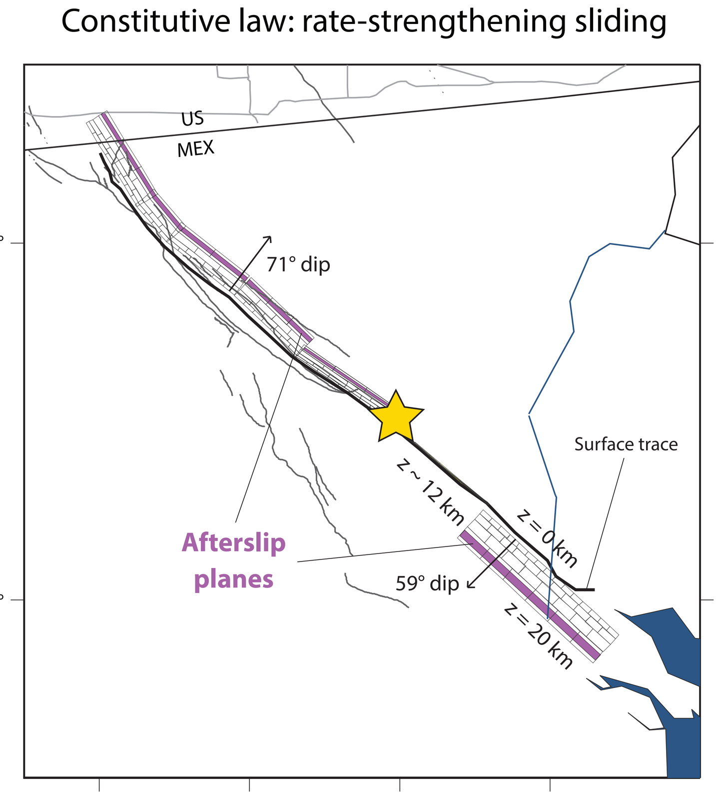
- RELAX deformation modeling software

- Plug in coseismic slip model, calculate elastic stress changes in generalized viscoelastic halfspace
- Simulate postseismic deformation mechanisms (afterslip, viscoelastic relaxation, poroelastic rebound) triggered by the instantaneous state of stress at each timestep
- All mechanisms are represented as equivalent body forces and surface tractions -> they also feed back on the instantaneous state of stress
  -> can simulate full dynamic coupling between mechanisms

Coseismic slip model [Fialko et al 2010]
Inverted from GPS, InSAR, optical displacements
M=7.2, L ~ 115 km, max. slip = 3.7 m

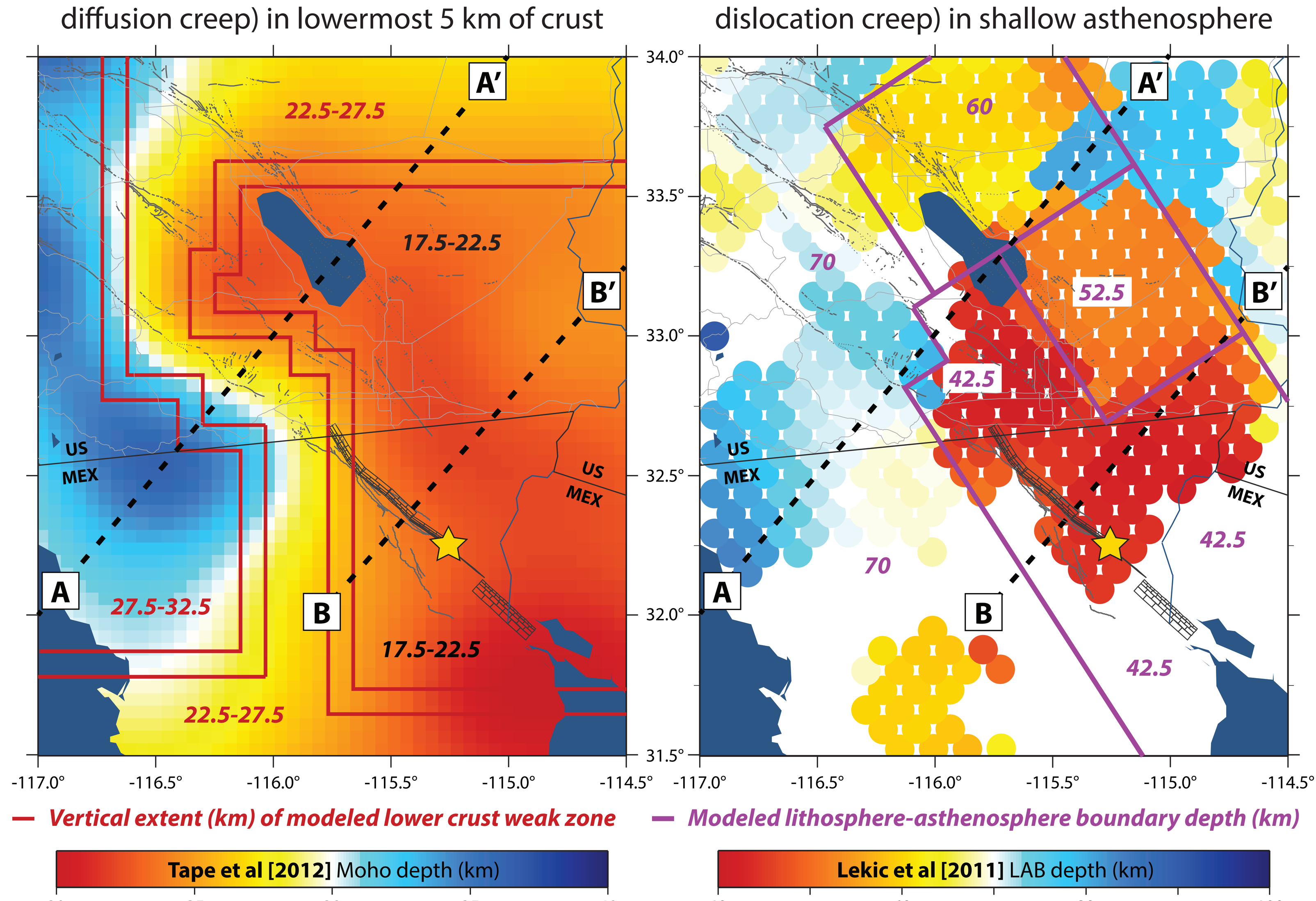


Afterslip at 14-18 km depth
Triggered by coseismic shear stress changes
Constitutive law: rate-strengthening sliding

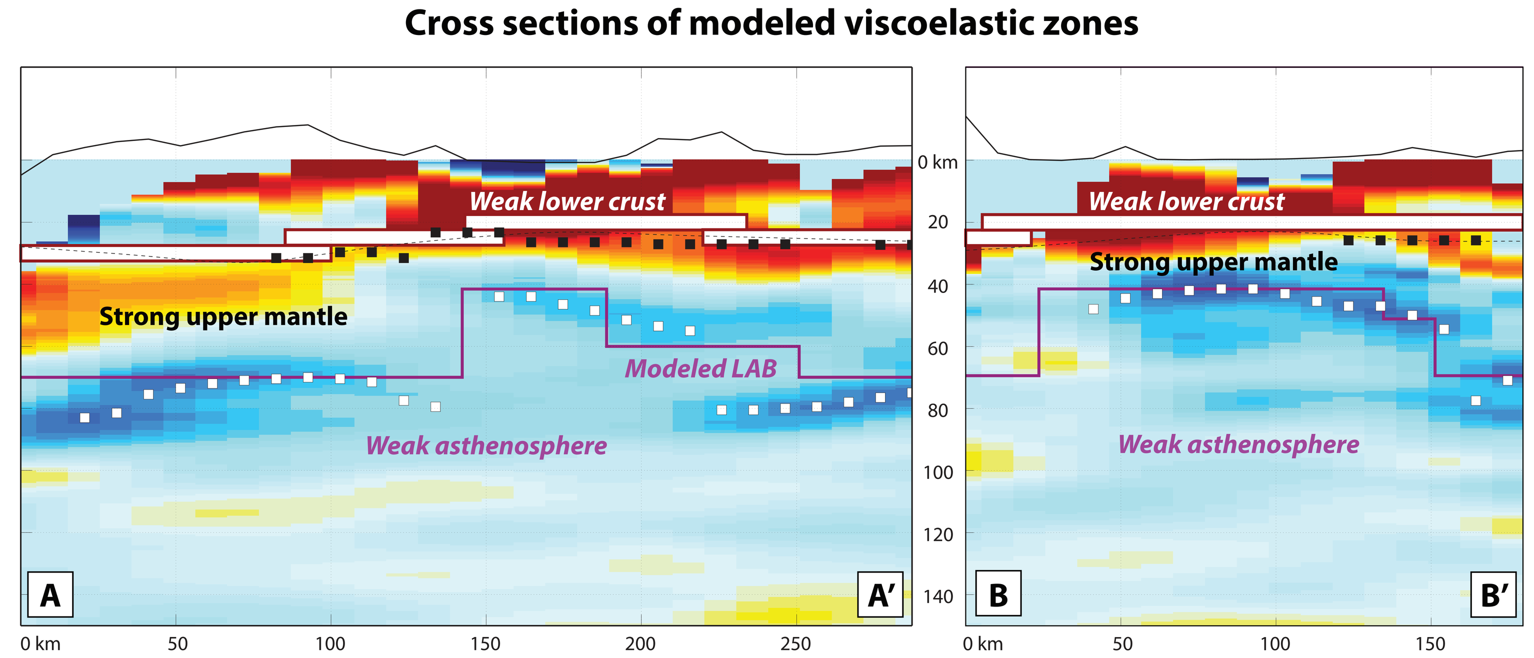


Viscoelastic zone (elastic stress change -> diffusion creep) in lowermost 5 km of crust

Viscoelastic zone (coupled diffusion creep and dislocation creep) in shallow asthenosphere



Cross sections of modeled viscoelastic zones

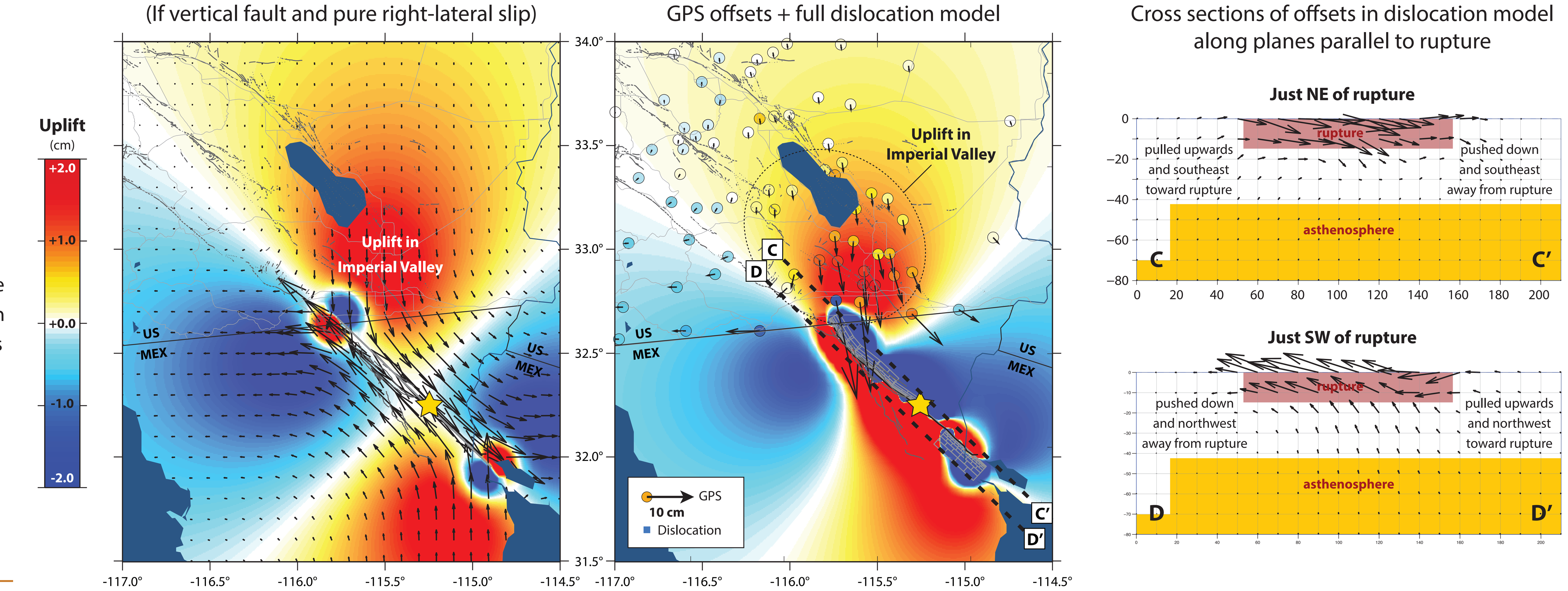


Deformation during the mainshock

(If vertical fault and pure right-lateral slip)

GPS offsets + full dislocation model

Cross sections of offsets in dislocation model along planes parallel to rupture

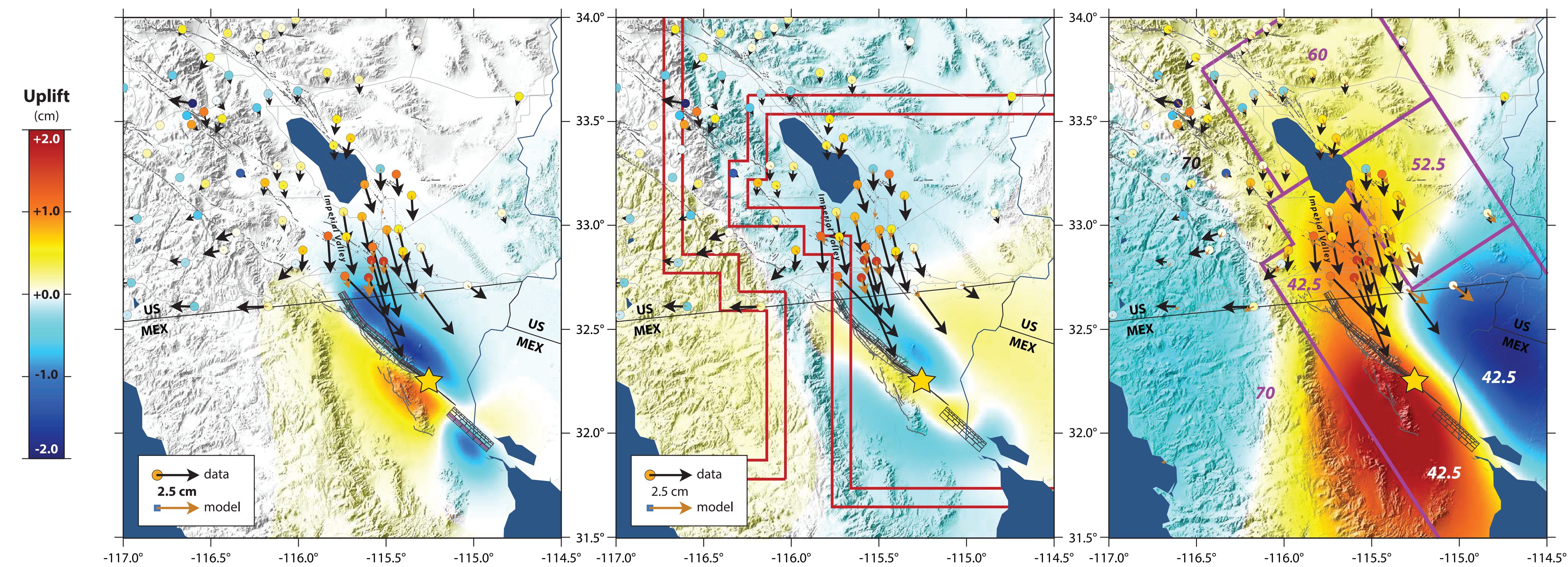


Deformation patterns of individual postseismic mechanisms

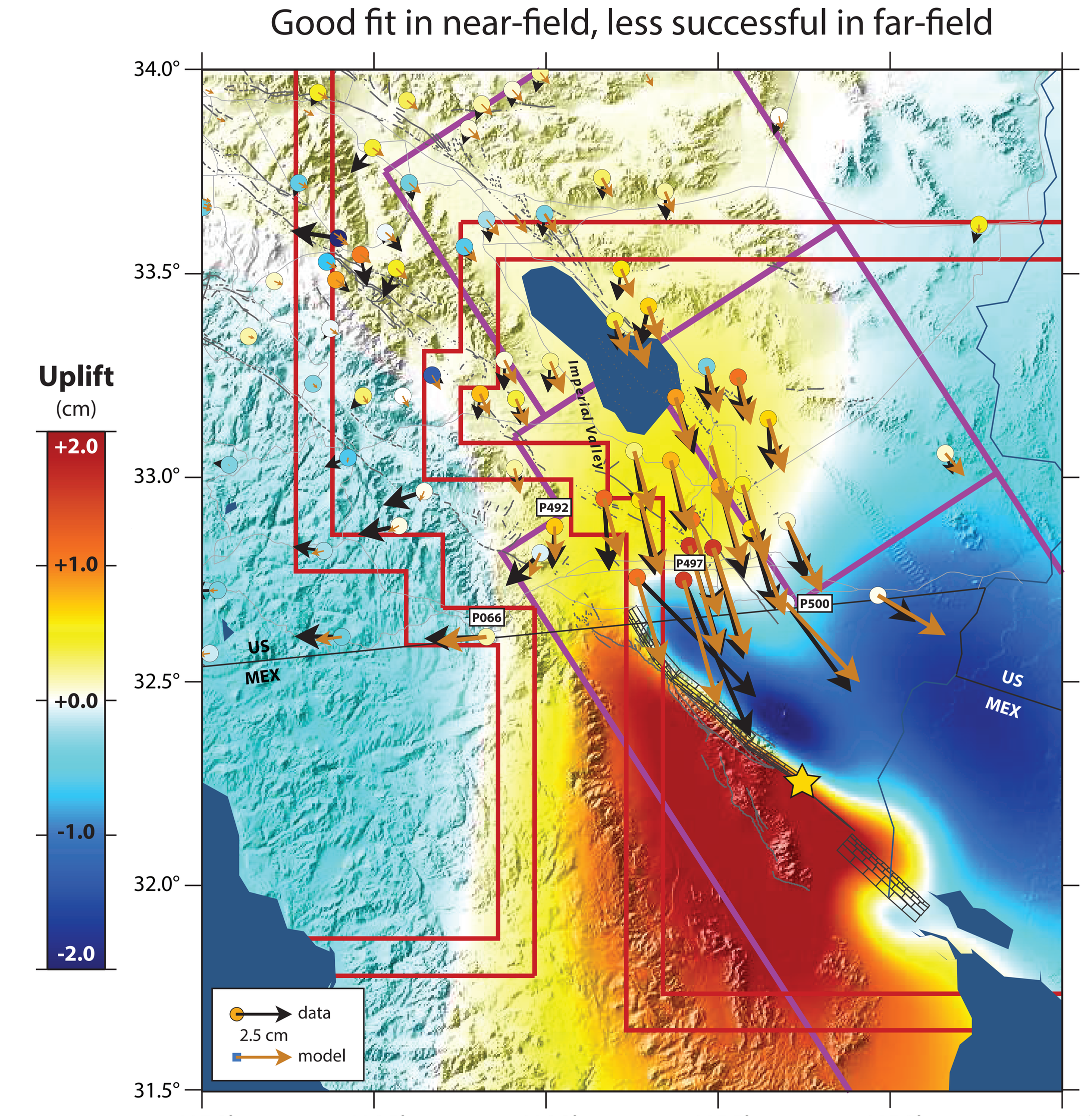
Afterslip: stations in Imperial Vy. move due south (SSE in data) and subside (uplifted in data)

Viscous flow in lower crust: Imperial Vy. stations move SSE but subside

Viscous flow in asthenosphere: Only mechanism that produces uplift in Imperial Vy.



Coupled model: afterslip and both viscous flow regimes
Good fit in near-field, less successful in far-field



Real and synthetic timeseries at near-field GPS stations