Challenges to Inferring the Mechanisms and Nature of Postseismic Processes Following Strike-Slip Earthquakes

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Main Objective of Postseismic Studies

- Sort out the relative contributions of viscoelastic relaxation, afterslip, and poroelastic rebound
- Understand the constitutive relations that controls each mechanism

Main Challenges

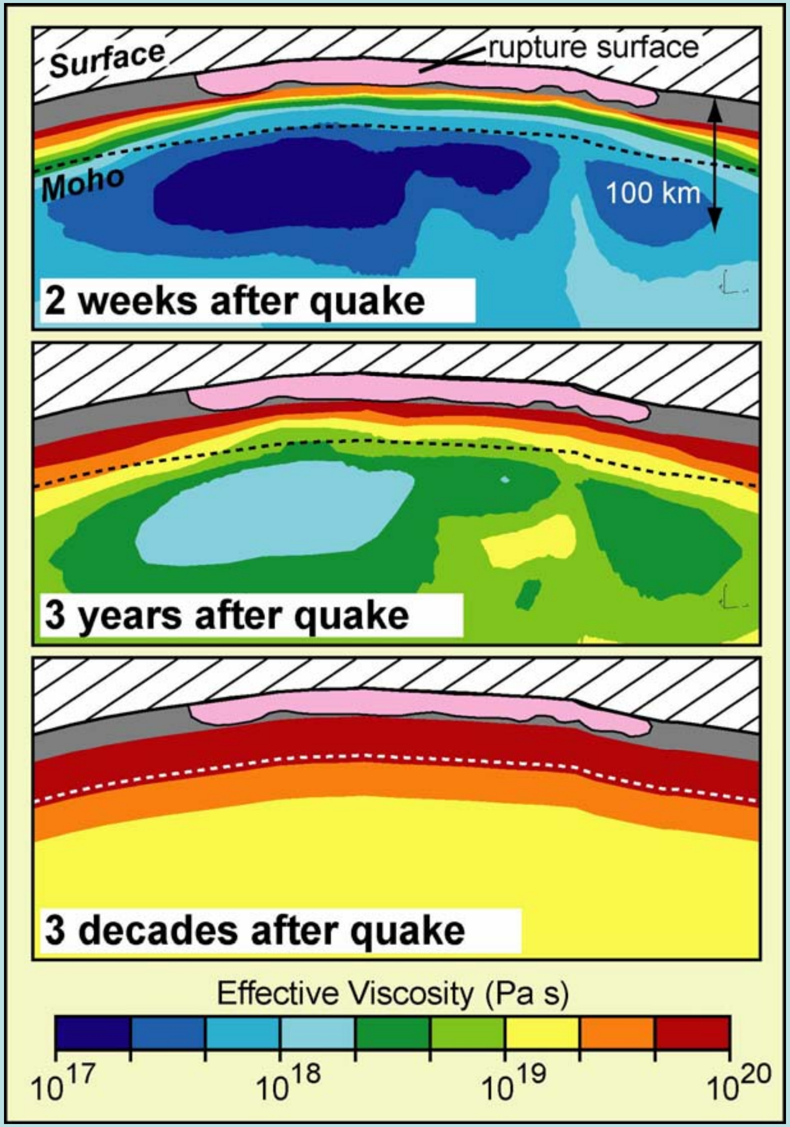
- Inferring power-law flow
- Isolating transient displacements
- Developing finite element meshes of sufficient complexity to calculate interseismic stresses and test candidate rheologies
- Inferring coseismic slip based on a layered Earth
- Sort out mechanism contributions
- Simulating stress-driven afterslip in shallow regions

The Importance of Power-law Rheology

$$\eta = \frac{\sigma^{(1-n)} e^{(Q/RT)}}{2A}$$

Laboratory flow laws suggest n = 3-4 in the lower crust and upper mantle

- The viscosity of the lower crust and upper mantle will vary spatially and temporally following transient loads.
- Viscosity will vary due to different loading events.
- Effective viscosities inferred from postseismic or glacial unloading events have limited utility.
- Power-law rheology could explain short-term weakness and long-term strength.

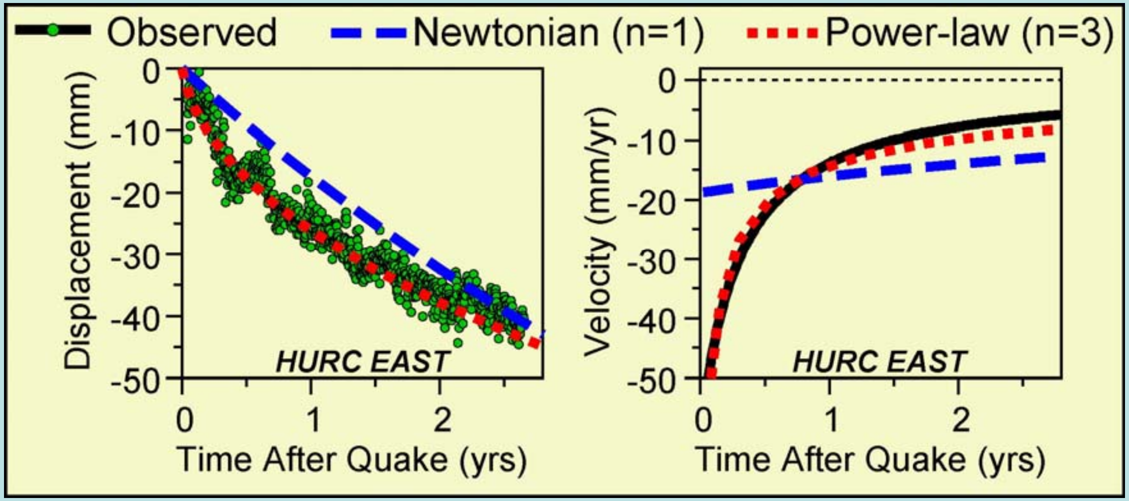


Inferred viscosity structure following the 2002 M7.9 Denali, Alaska quake.

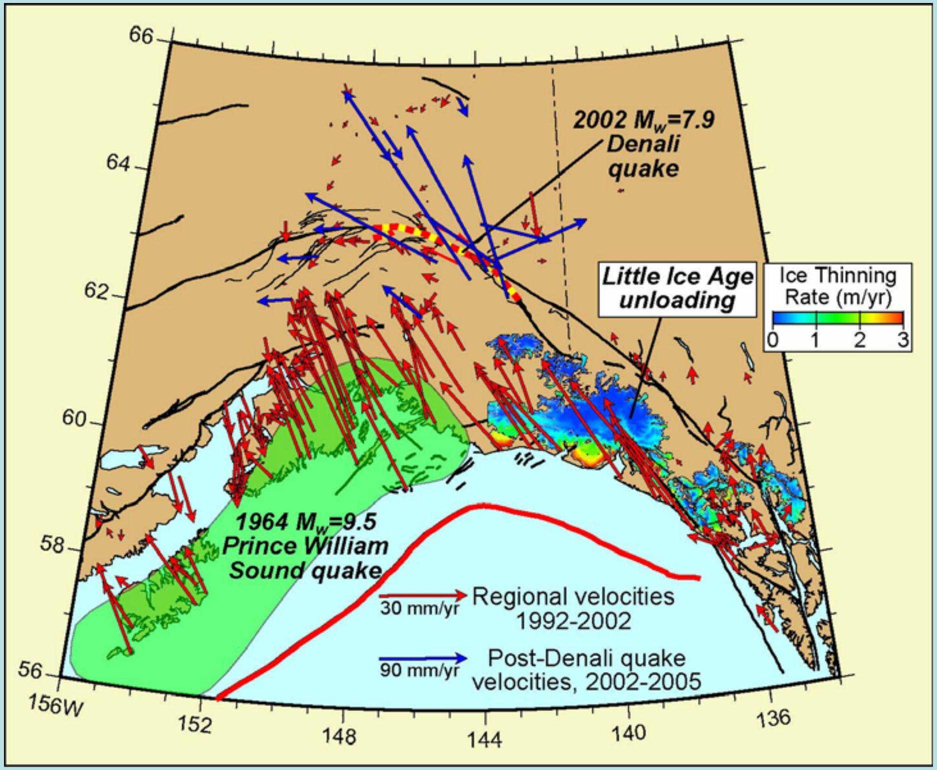
Two Ways to Infer Power-law Rheology

$$\eta = \frac{\sigma^{(1-n)} e^{(Q/RT)}}{2A}$$

Use time-series displacements and velocities from one event.

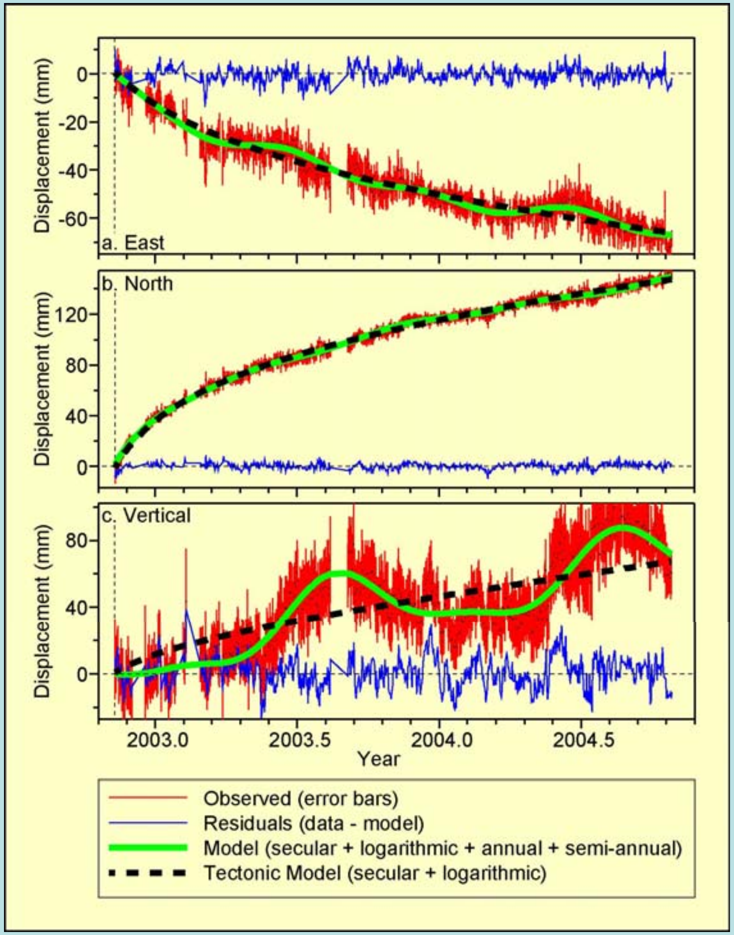


Use cumulative displacements from different magnitude events (Mojave events not ideal because there were of similar magnitude).



Data Acquisition

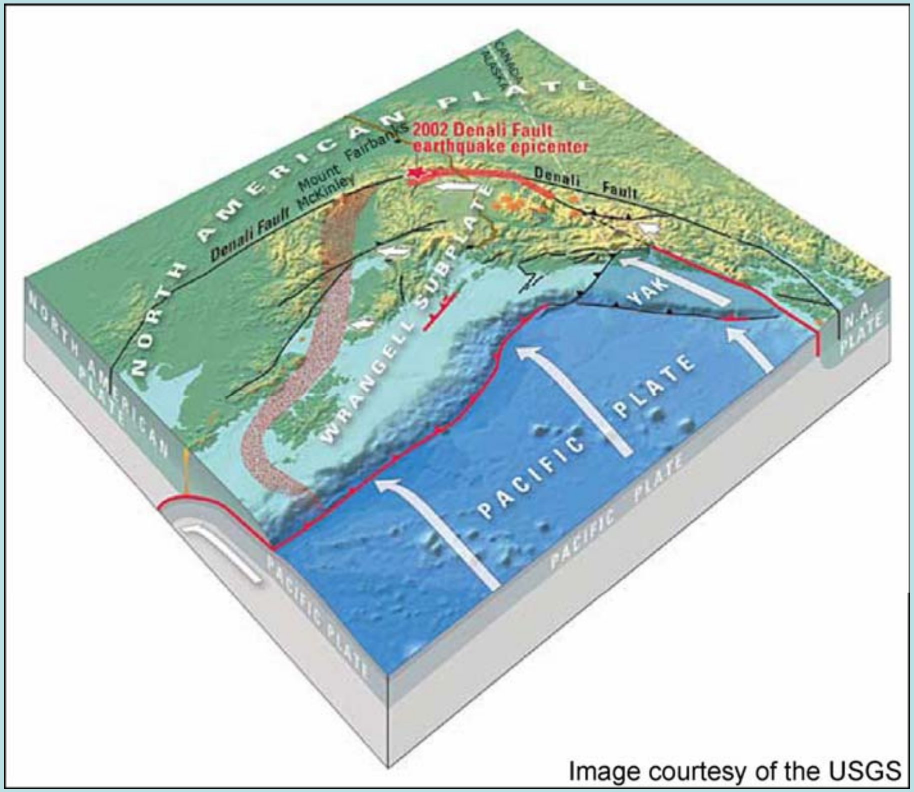
First challenge: Separate out tectonic from non-tectonic contributions (continuous GPS is best).



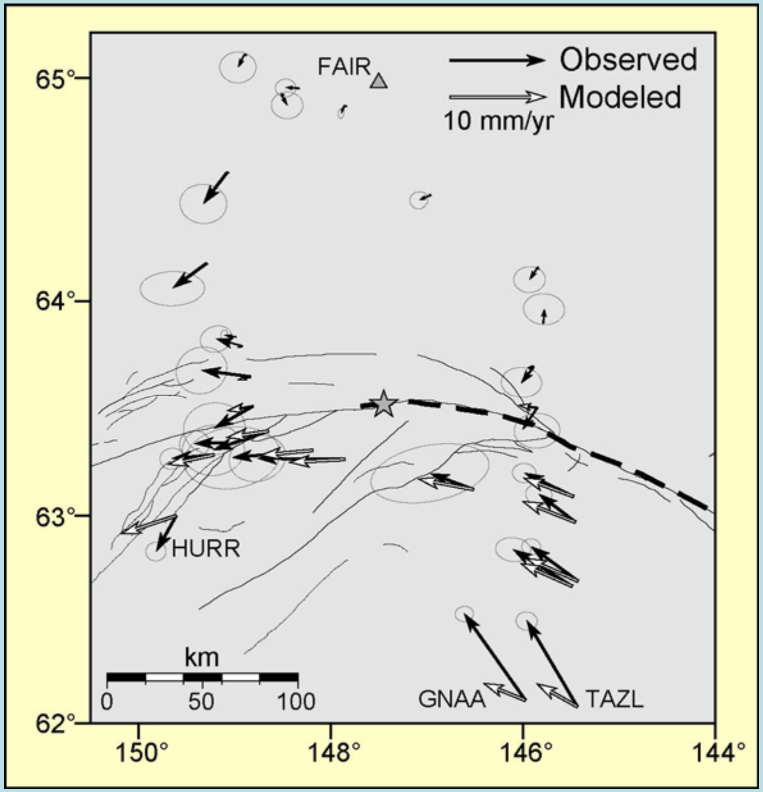
Time-series data from a continuous GPS station following the Denali quake

Data Acquisition

Second Challenge: Separate out transient from steady-state contributions.



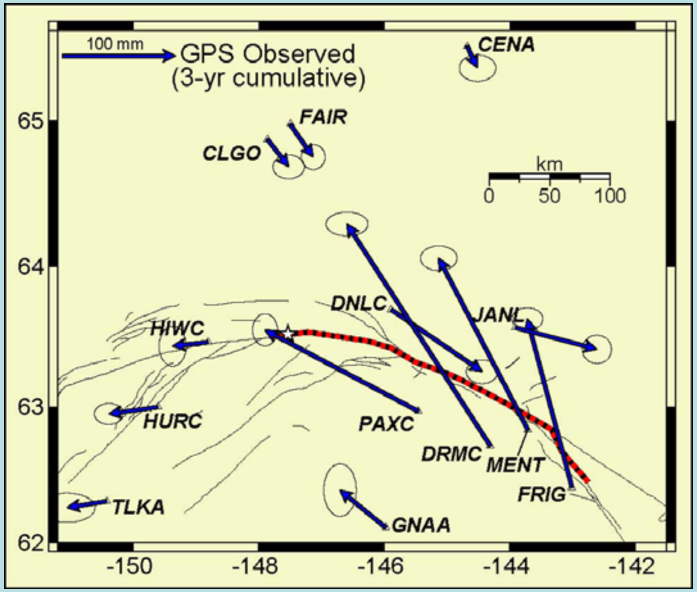
Regional tectonics

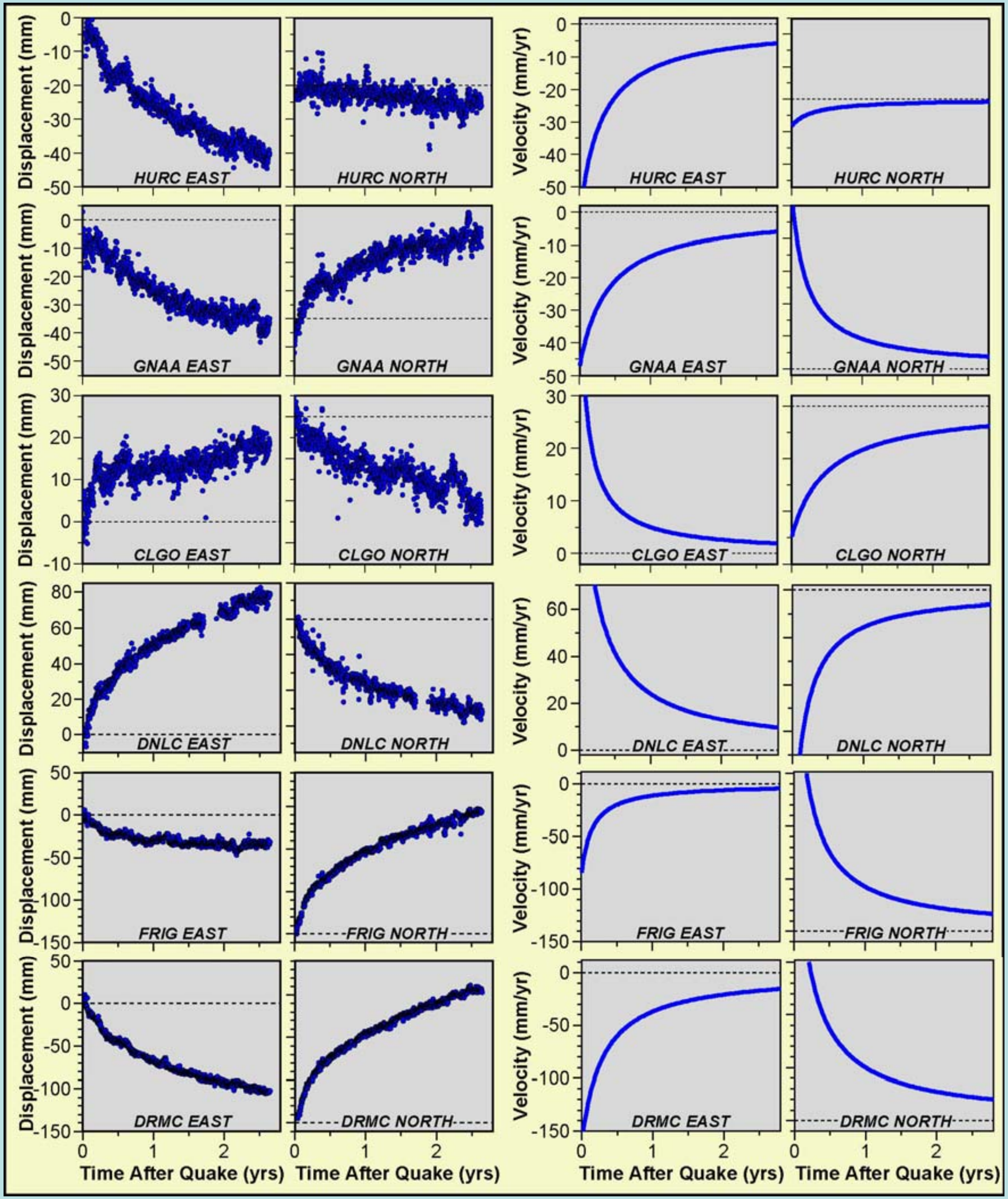


Modeled vs observed prequake velocities

Data Acquisition

Cumulative displacements following the Denali quake.





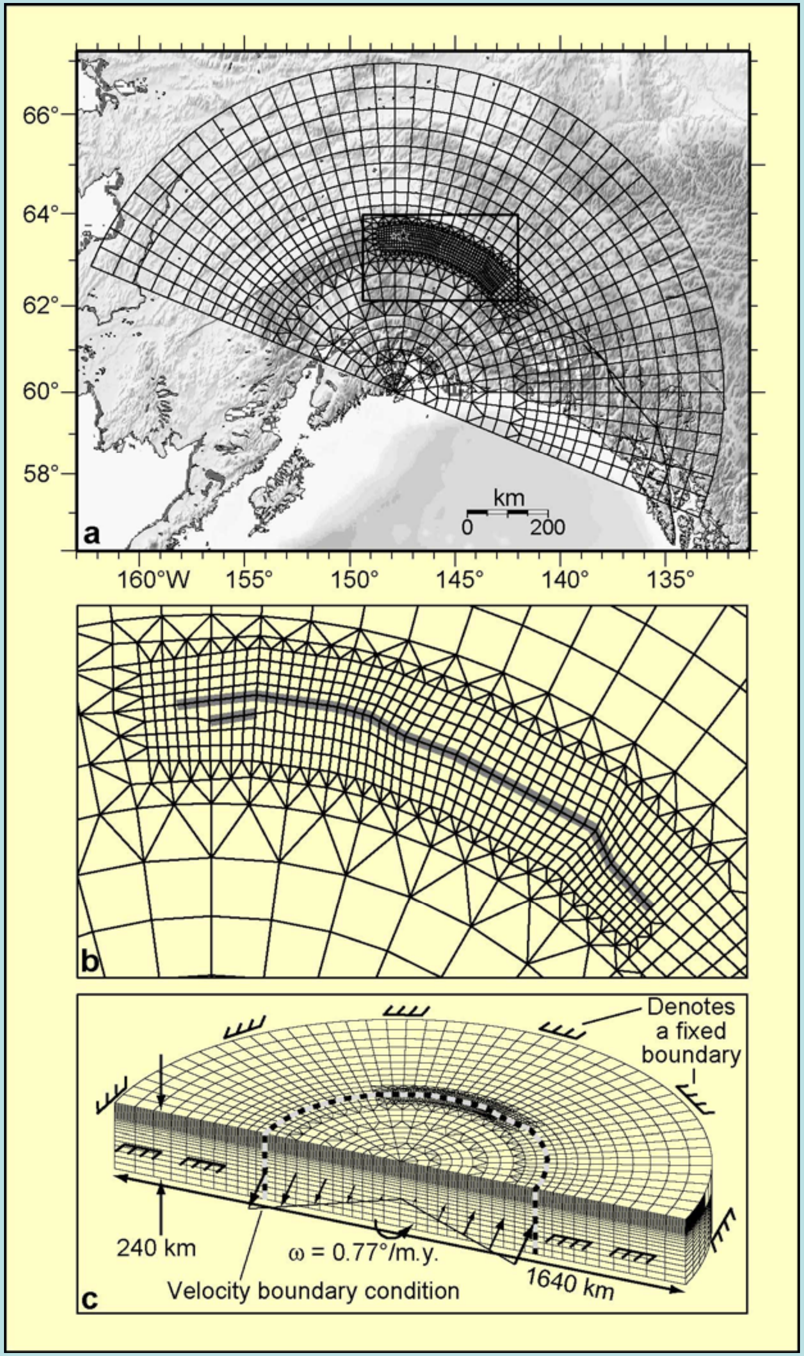
Transient time-series displacements and velocities following the 2002 Denali quake.

Finite Element Models

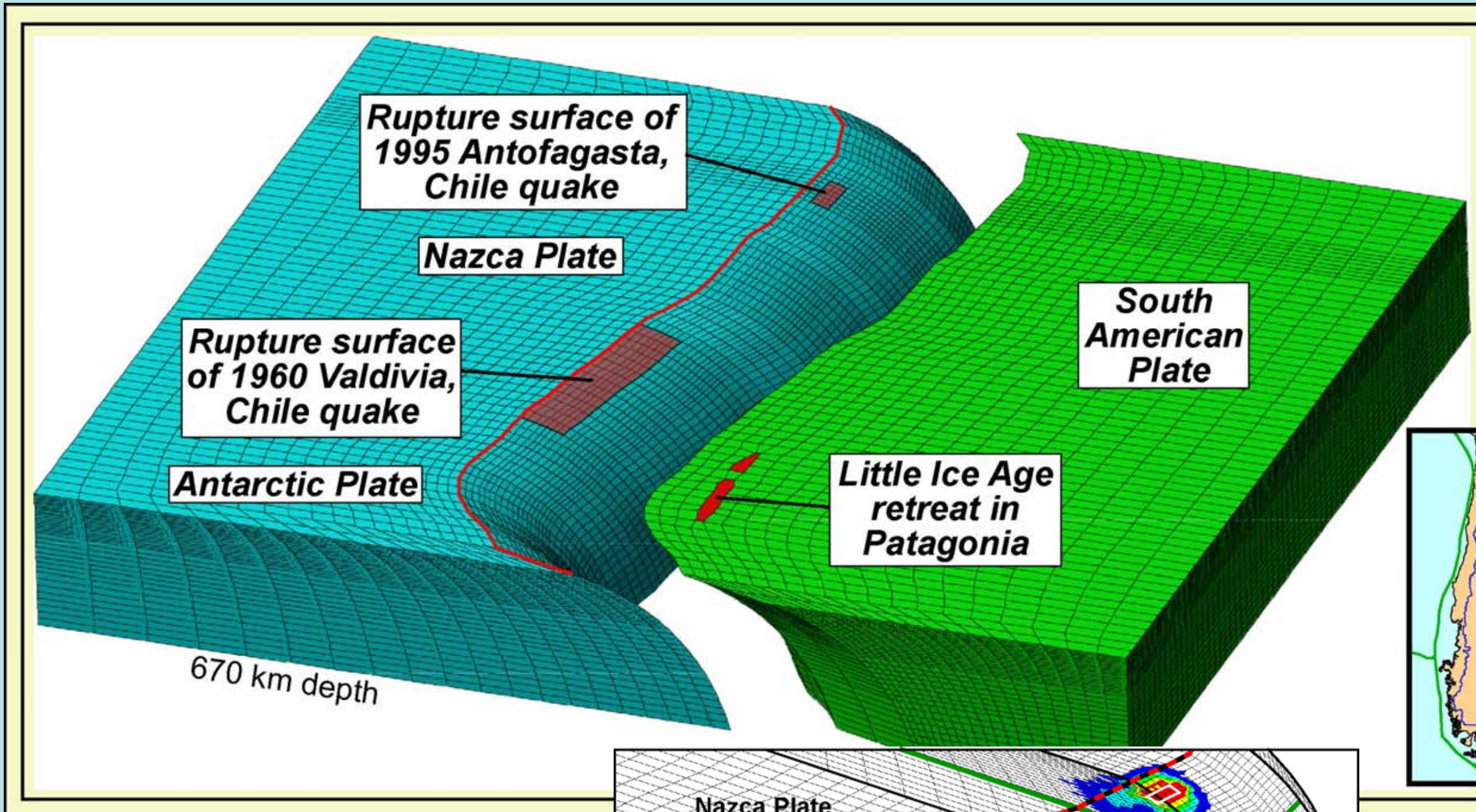
- Mesh geometry needs to enable simulation of the rupture and the regional tectonics
- Brick elements are best for depth-dependent rheologies and to view mesh interior.

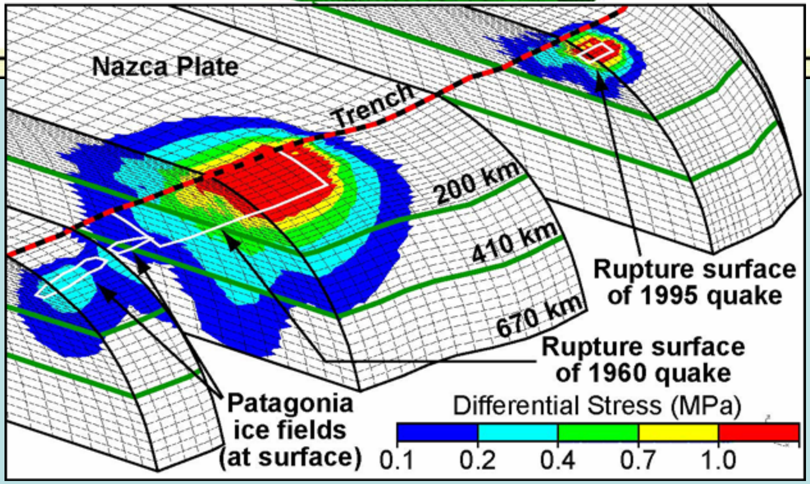
2002 Denali Mesh

- Captures rupture surface in detail
- Capture long-term block rotation
- Ignores subduction zone

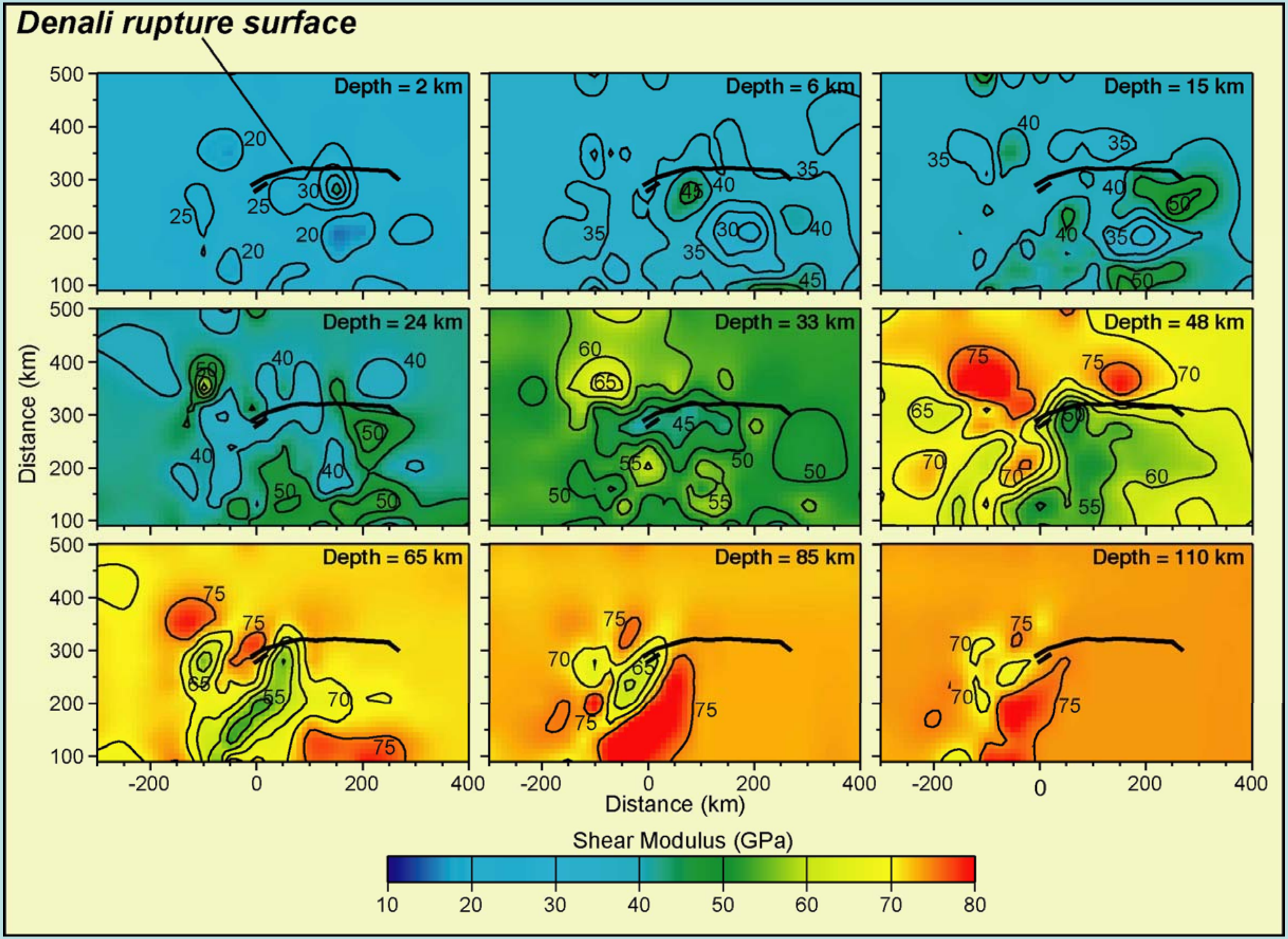


Mesh of the Chilean Margin

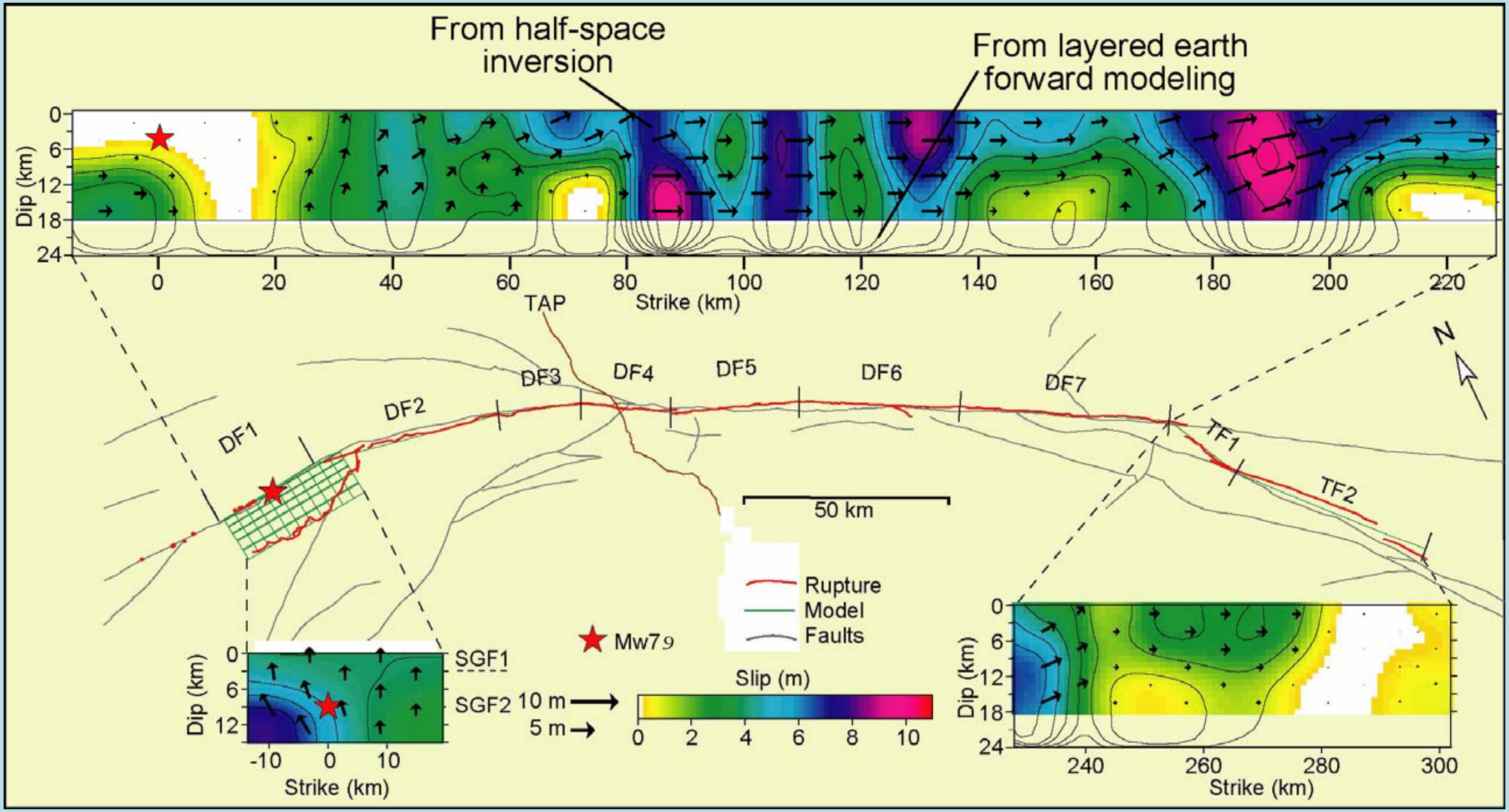




Shear Modulus Increases With Depth



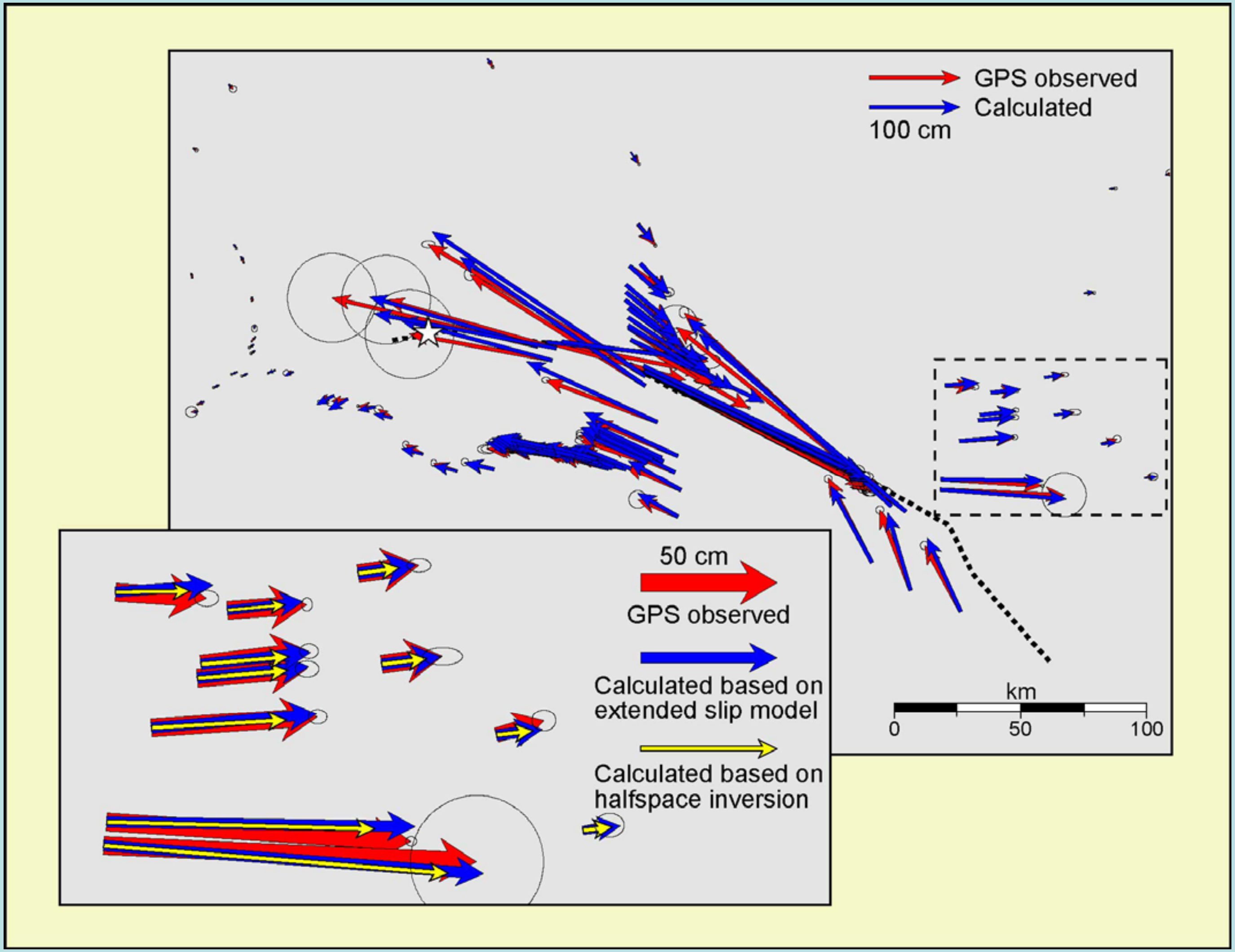
Assuming a half-space instead of a layered Earth inversion of GPS data has a significant influence on the inferred slip distribution



Half-space inversions:

- Underpredict seismic moment
- Underpredict coseismic slip at depth
- Underpredict coseismic stress changes in the lower crust

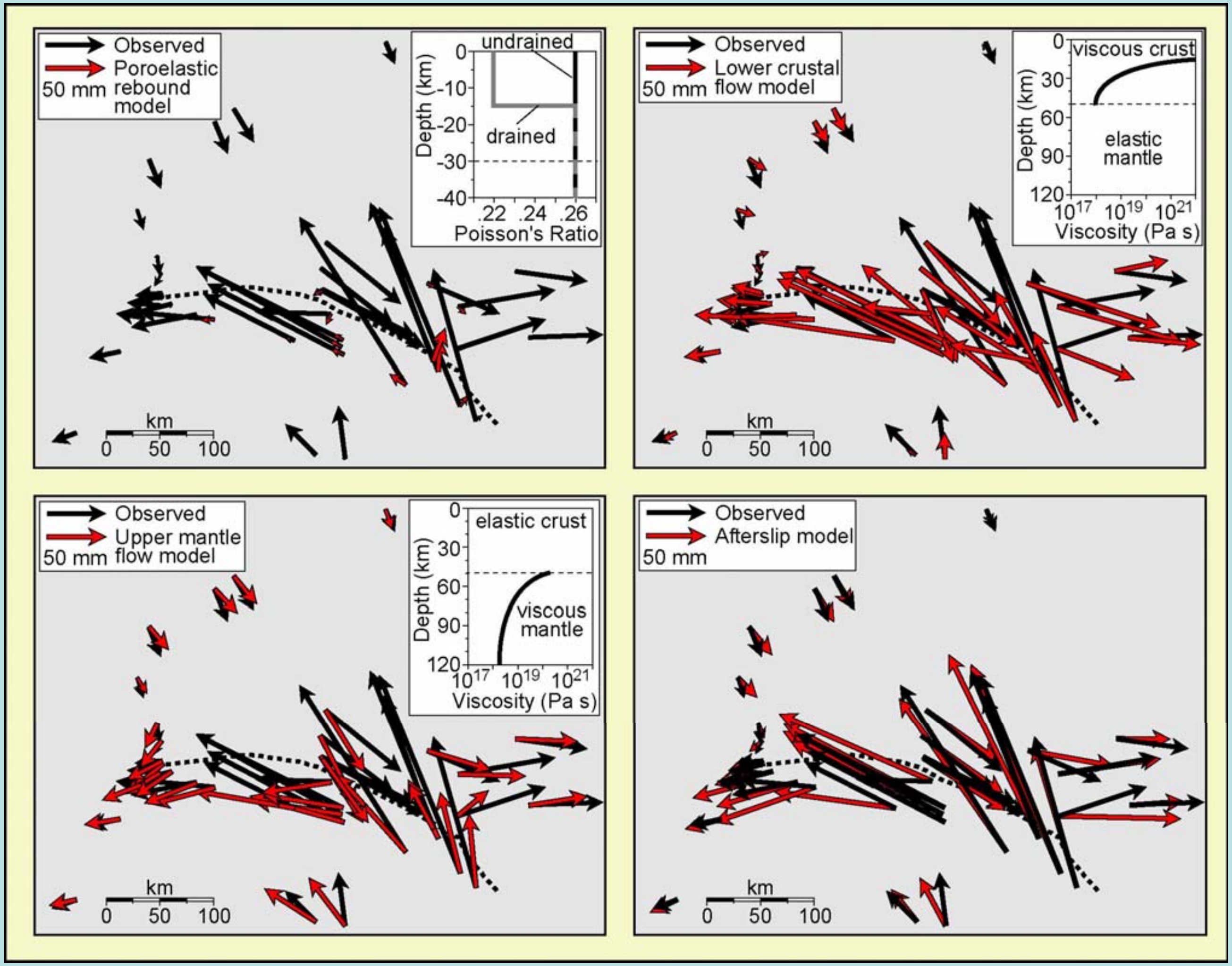
Consequences of assuming a half-space elastic model of a layered Earth



Additional reference: Hearn, E. H. and R. Bürgmann, The effect of elastic layering on inversions of GPS data for coseismic slip and resulting stress changes: Strike-slip earthquakes, *Bull. Seismol. Soc. Am.*, 95, 1637-1653, 2005.

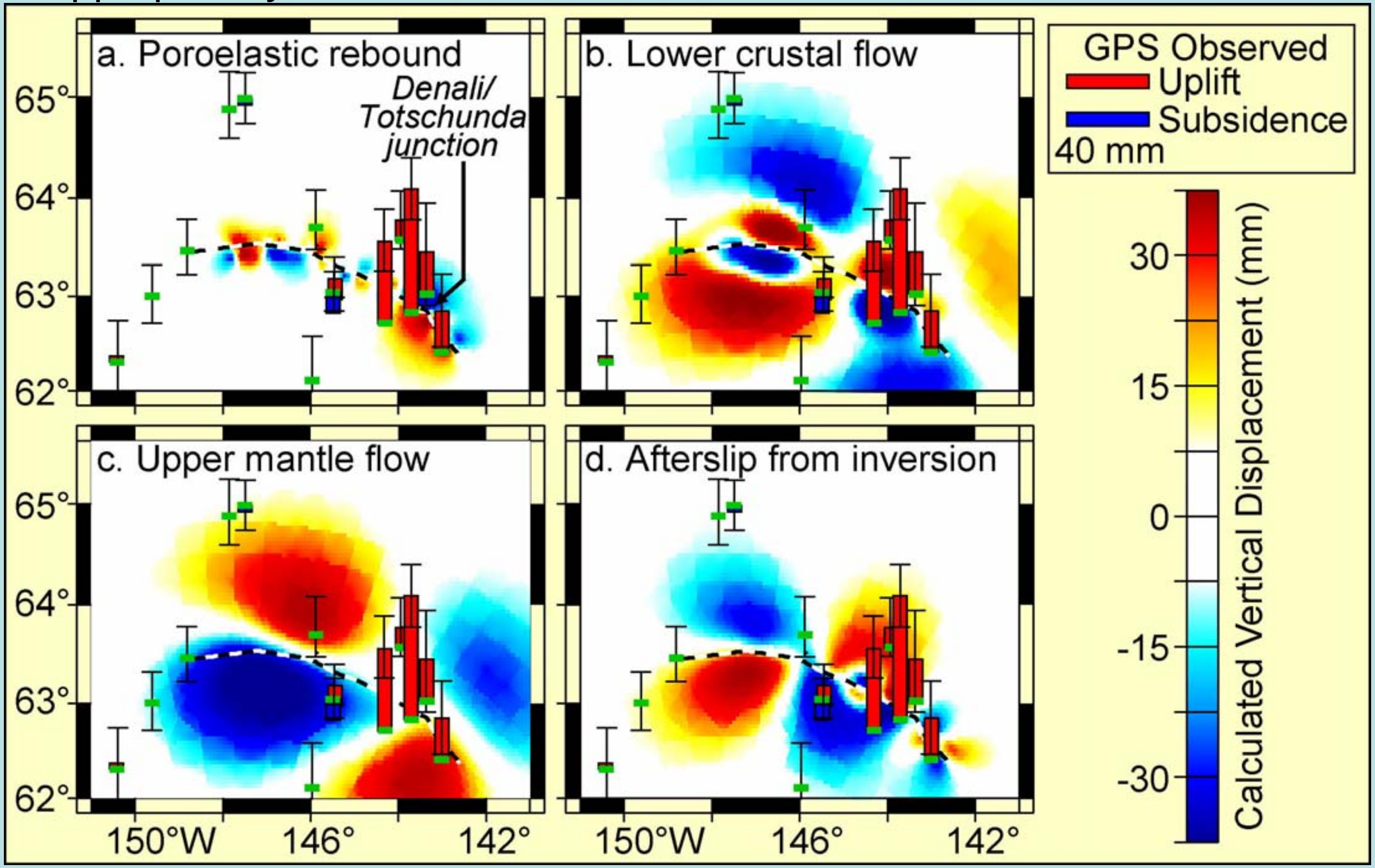
Sorting out viscoelastic flow, afterslip, and poroelastic contributions to postseismic deformation

General problem: All mechanisms can lead to similar postseismic lateral surface displacements.



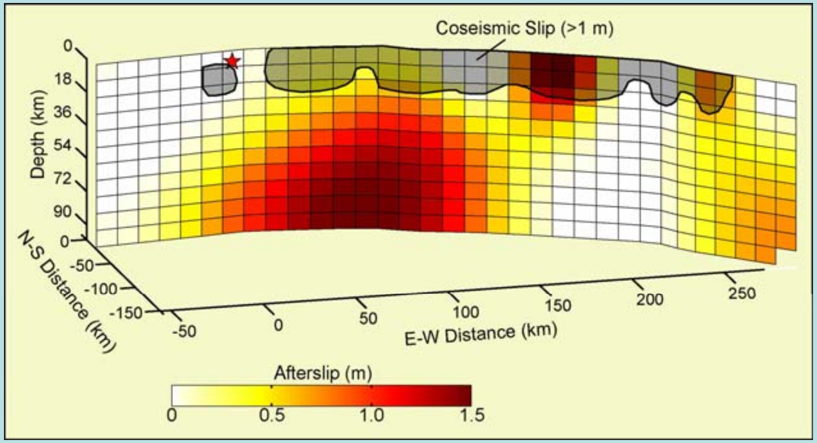
Sorting out viscoelastic flow, afterslip, and poroelastic contributions to postseismic deformation

- Best approach: Use postseismic vertical displacements (very sensitive to depth of flow) in conjunction with lateral displacements.
- Unfortunately, vertical constraints are not always available or appropriately located.

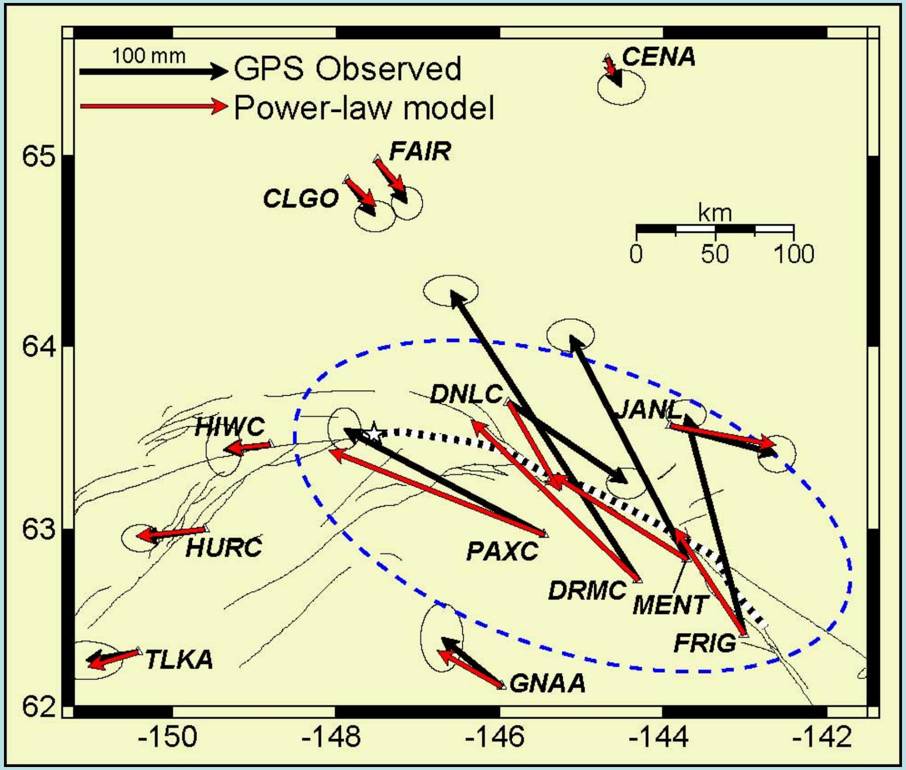


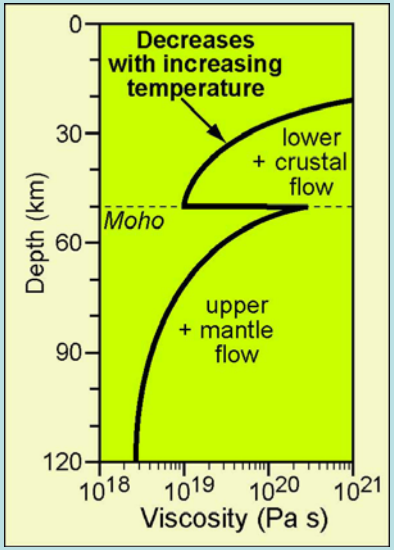
GPS observed vertical post-Denali displacements compared with those calculated from several postseismic mechanisms.

Next approach: Utilize geophysical data that suggest that deep (>60 km) flow is not likely to be afterslip, thus far-field displacements (driven by deep flow) are likely induced by viscoelastic flow in the mantle (70-80% in this case).



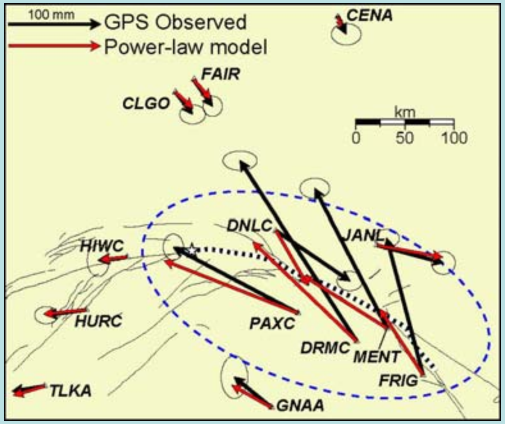
Afterslip from GPS inversion.

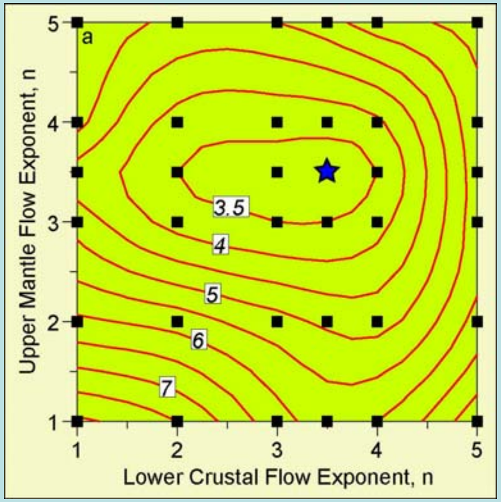


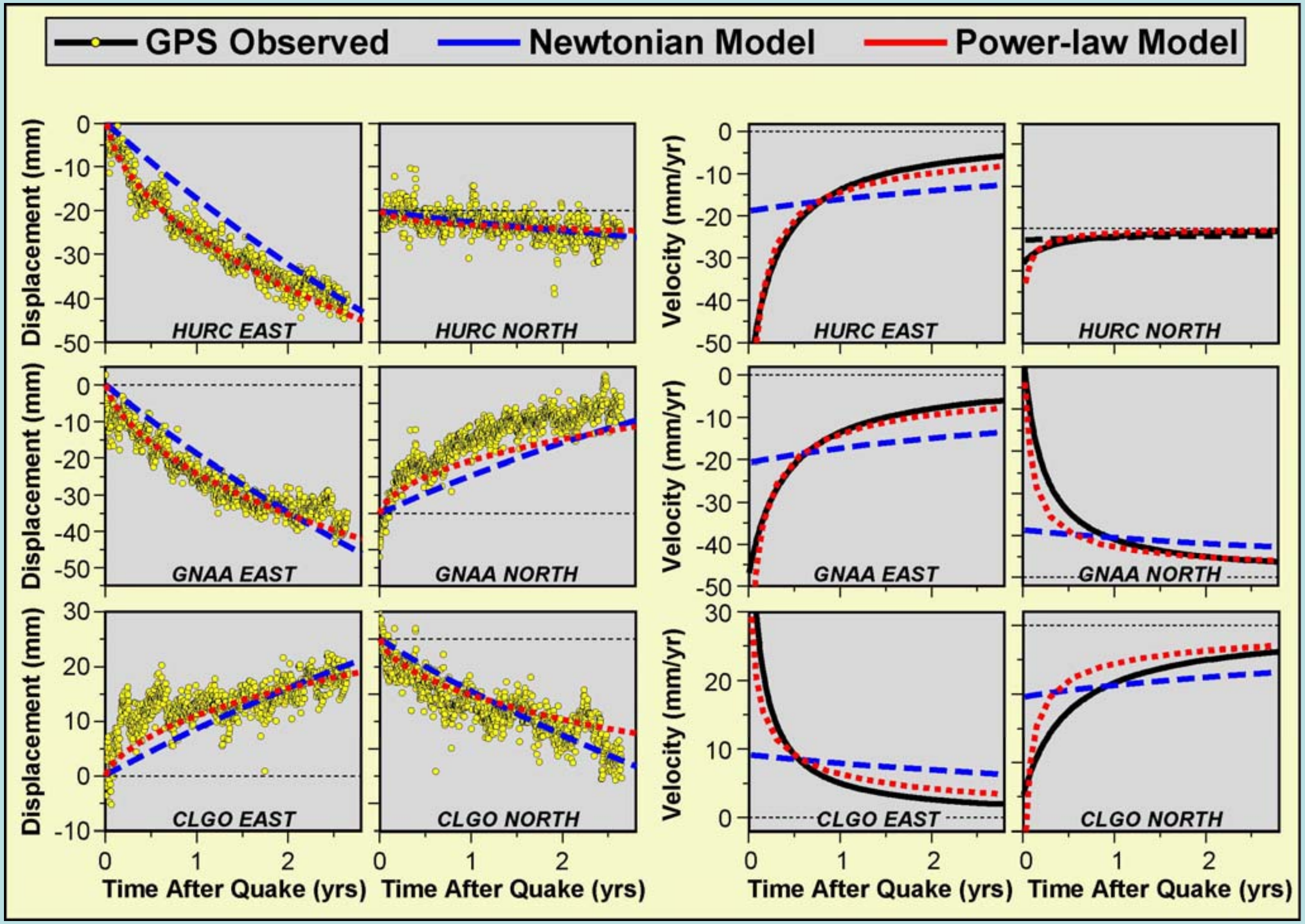


Inferred Newtonian rheology to explain far-field observations.

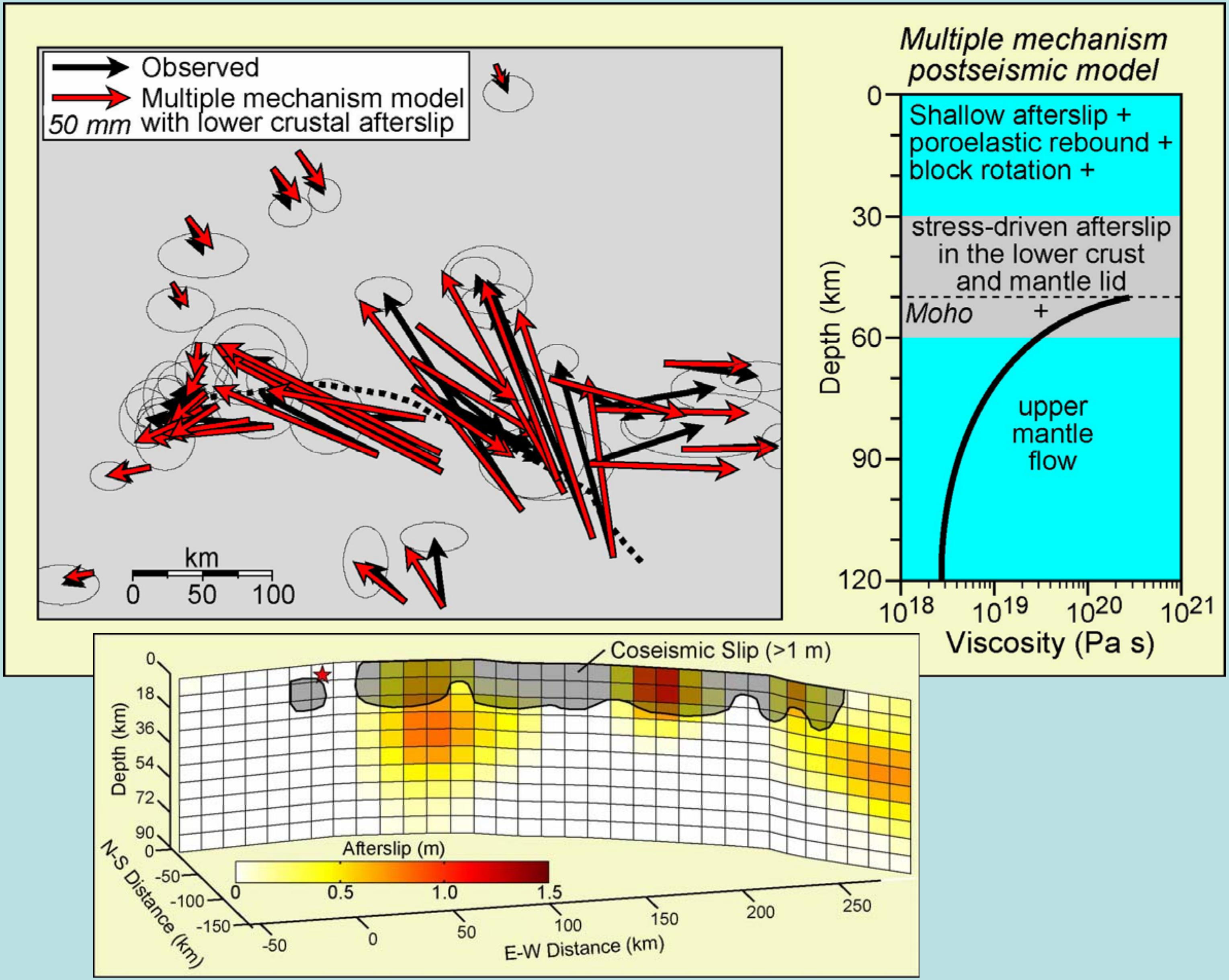
Far-field Time-Series Best Fit by Power-law Flow in the Upper Mantle



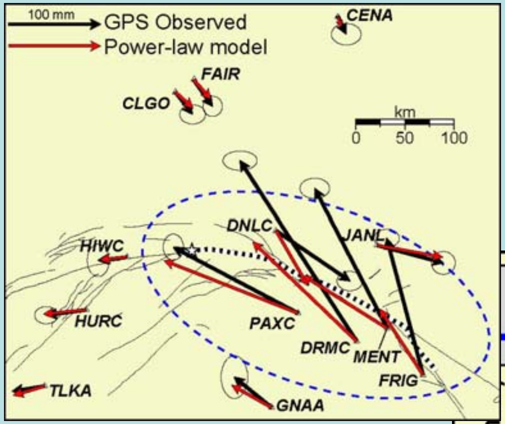


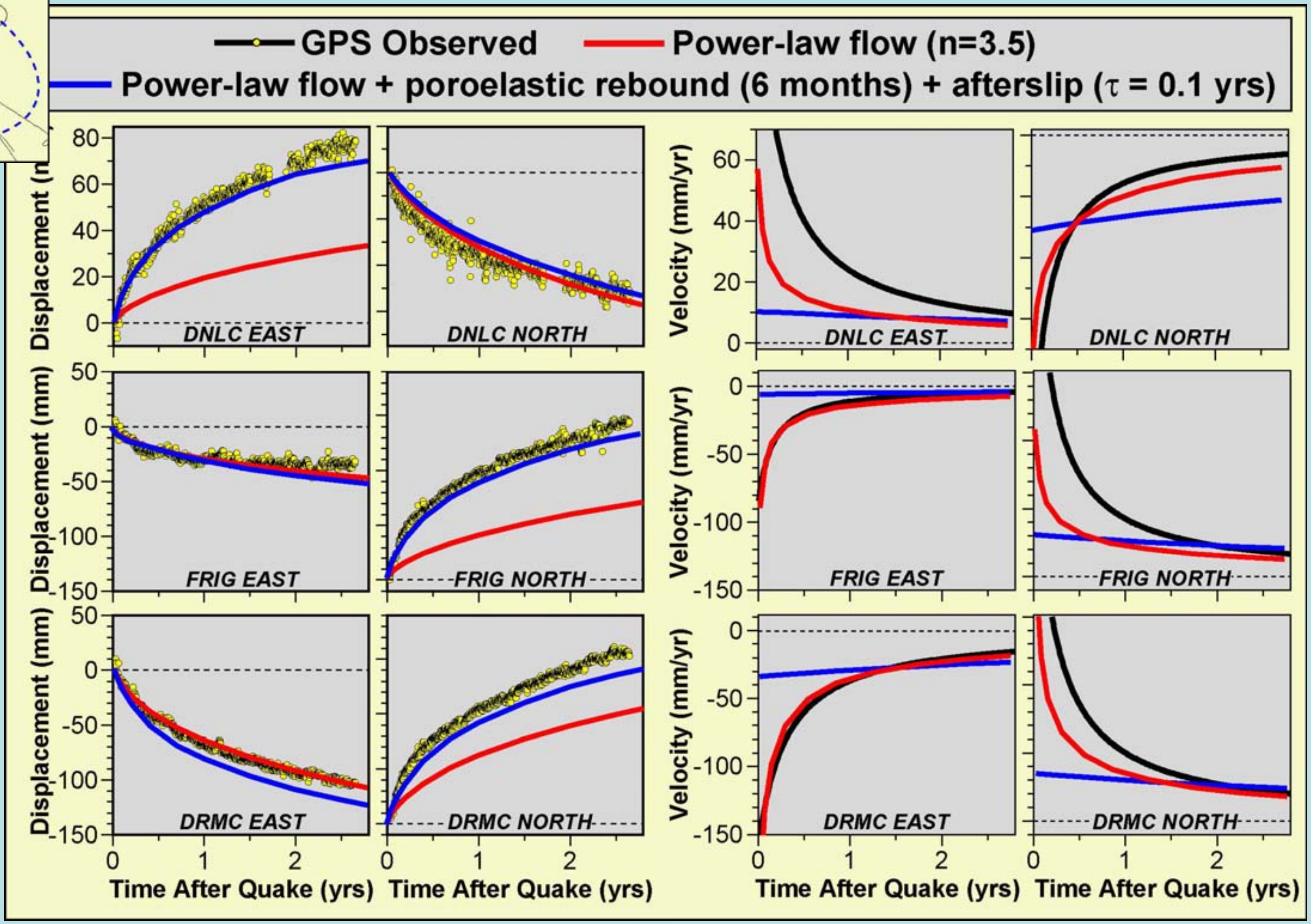


Inferred Multiple Mechanism Model to Explain Far- and Near-Field Displacements



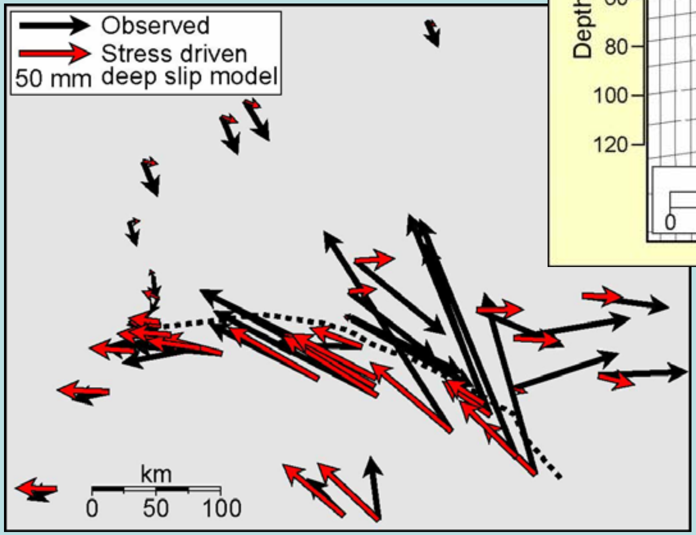
Near-field Time-Series Best Fit by Power-law Flow in the Upper Mantle Plus Afterslip and Poroelastic Rebound

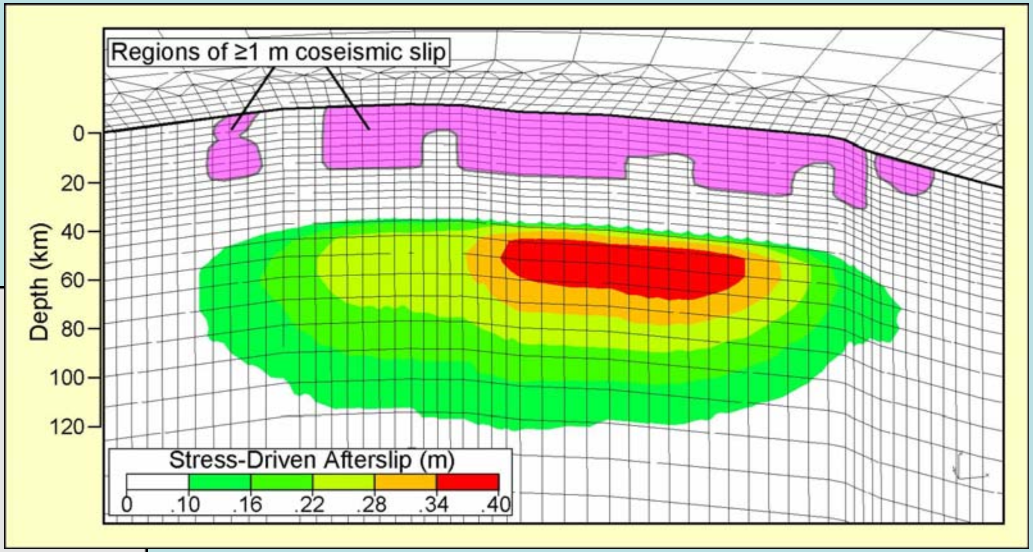




Challenges in Modeling Stress Driven Afterslip

- Need a good frictional element
- Difficult with a finite element formulation to model stress driven afterslip within the coseismic slip zone.
- Requires an accurate representation of deep coseismic slip
- Knowledge of prequake stress levels is important in the shallow, stronger area - though this is very difficult to constrain.





Model of stress driven deep afterslip

Resist The Temptation To Over-Simplify

- Power-law flow
- Prequake tectonics
- Layered earth
- Temperature dependence
- Multi-mechanism models
- Stress-driven afterslip

Uplift Patterns Cannot Readily Help to Differentiate Newtonian from Power-law Flow