Role of boundary conditions and mechanical models for the SCEC Community Rheology Model

Thorsten Becker
University of Southern California, Los Angeles

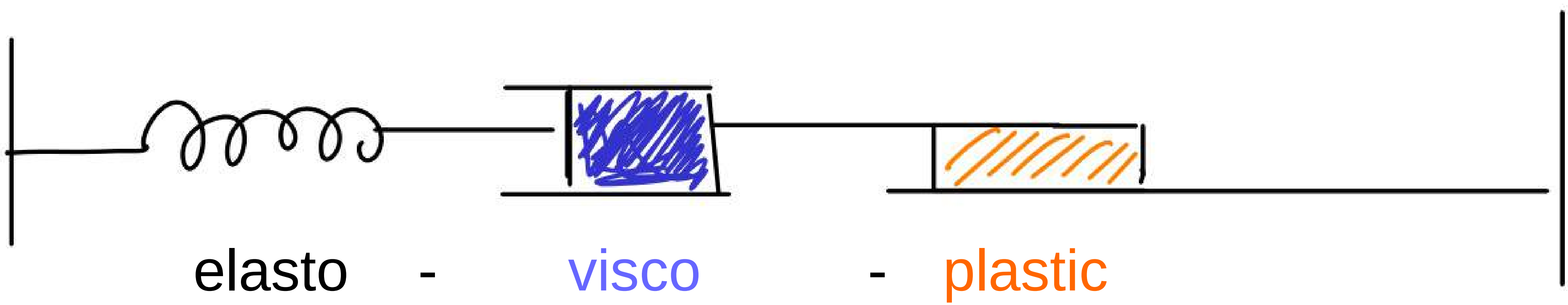
SCEC CRM workshop
September 12, 2015

constitutive relationship

$$\tau = f\left(\epsilon, \dot{\epsilon}, T, p, f_{H_2O}, \varphi, \ldots\right)$$

Example rheology for the lithosphere

$$\dot{\epsilon} = \frac{\dot{\tau}_{el}}{2\mu} + \frac{\tau_{vis}}{2\eta} + \dot{\epsilon}_{pl}$$



$$\dot{\epsilon} = \frac{\dot{\tau}_{el}}{2\mu} + \frac{\tau_{vis}}{2\eta} + \dot{\epsilon}_{pl}$$

$$\epsilon = \frac{1}{2\mu} \int_{t}^{t+\delta t} \dot{\tau}_{el} \, dt + \frac{1}{2\eta} \tau_{vis} \delta t + \dot{\epsilon}_{pl} \delta t$$

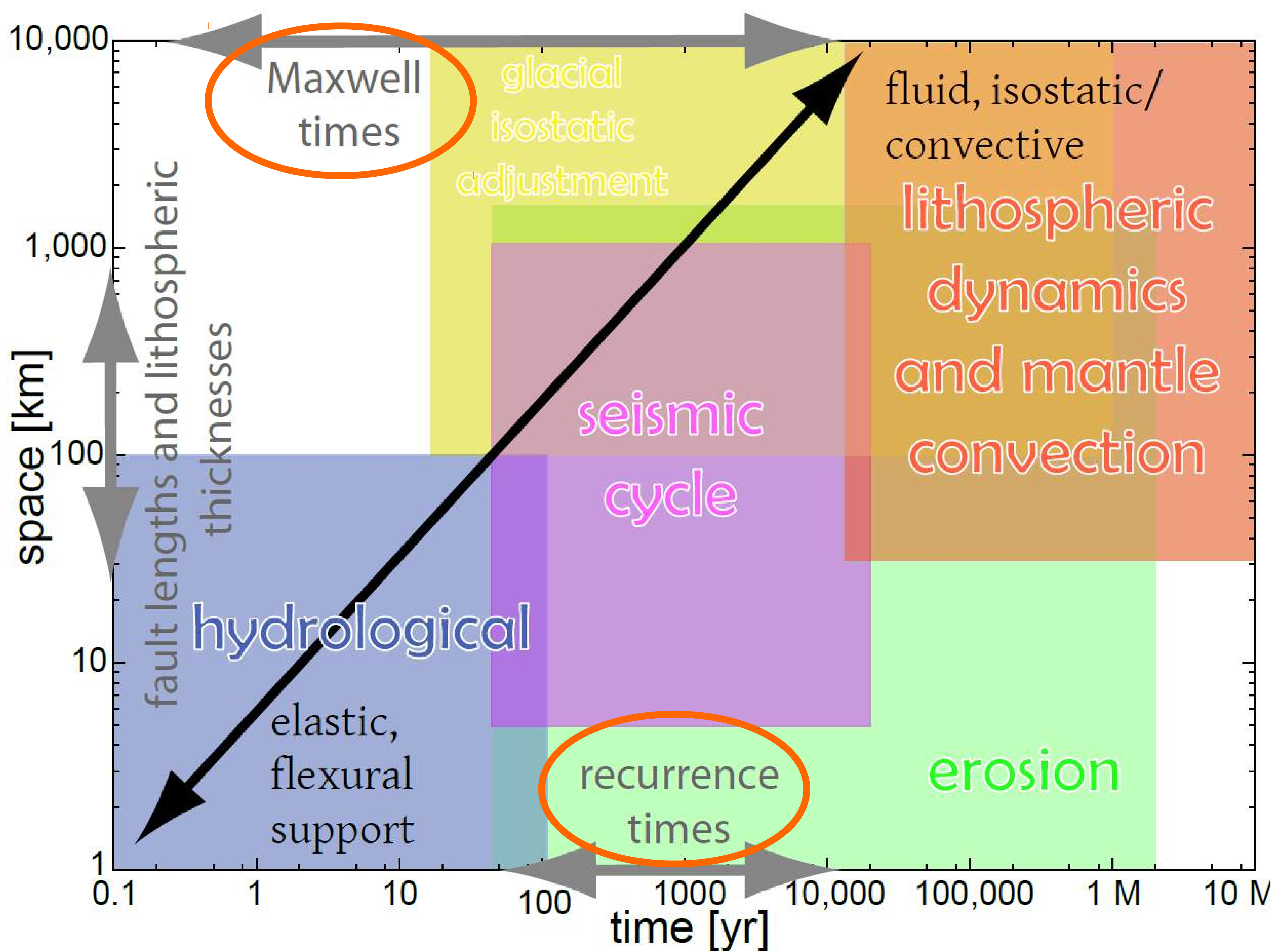
short time-scales

$$\delta T \sim T_{cycle}$$

$$\epsilon = \frac{1}{2\mu} \int_{t}^{t+\Delta t} \dot{\tau}_{el} \, dt + \frac{1}{2\eta} \int_{t}^{t+\Delta t} \tau_{vis} \, dt + \int_{t}^{t+\Delta t} \dot{\epsilon}_{pl} \, dt$$

long time-scales

$$\Delta T \gg T_{cycle}$$



Maxwell times
glacial isostatic adjustment
fluid, isostatic/ convective
lithospheric dynamics and mantle convection
seismic cycle
hydrological
elastic, flexural support
recurrence times
erosion
fault lengths and lithospheric thicknesses
space [km]
time [yr]
10,000
1,000
100
10
1
0.1
1
10
100
1000
10,000
100,000
1 M
10 M

homogenization is loading, time and length scale dependent

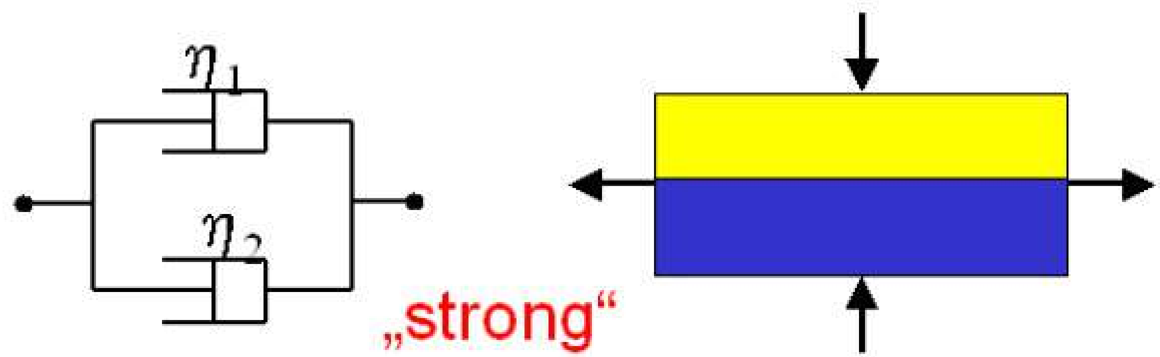
$$\tau = \langle f_i(\ldots, c_i, \ldots) \rangle_{complicated}$$

Simple viscous flow of two materials example:

Arithmetic mean

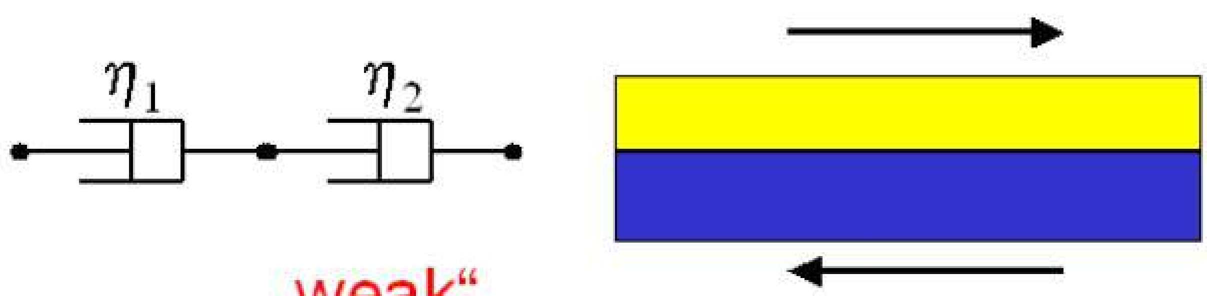
$$\eta_{ave} = c_1\eta_1 + c_2\eta_2$$

c_1, c_2 = weights



Harmonic mean

$$\frac{1}{\eta_{ave}} = \frac{c_1}{\eta_1} + \frac{c_2}{\eta_2}$$



→ power-law leads to apparent anisotropy

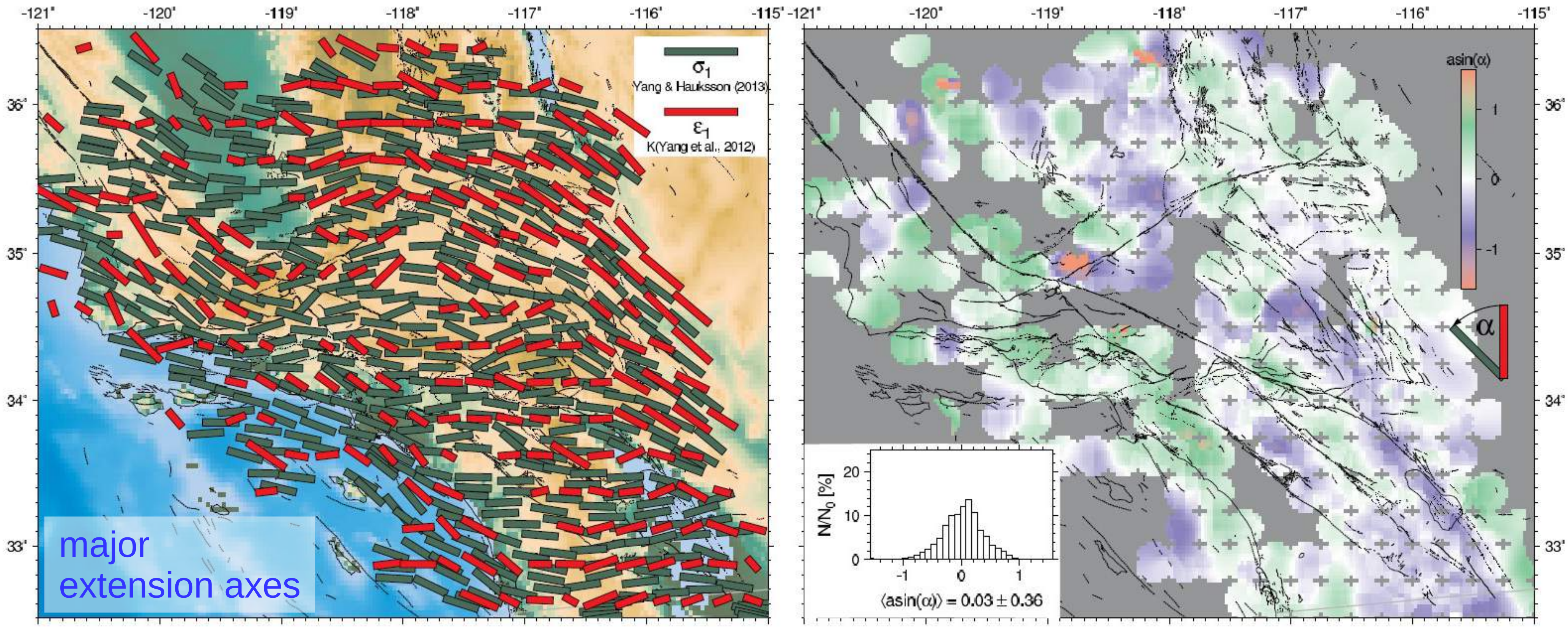
sketch from Schmeling et al. (2008)

Stress and strain-rates informed from earthquakes

upper crust

$\delta t < T_{cycle}$

Michael (1984) stress (*Yang and Hauksson*, 2013) *vrs. Kostrov* (1974) strain based on *Yang et al.* (2012)



→ elastic anisotropy? (via anisotropic fault distribution?)

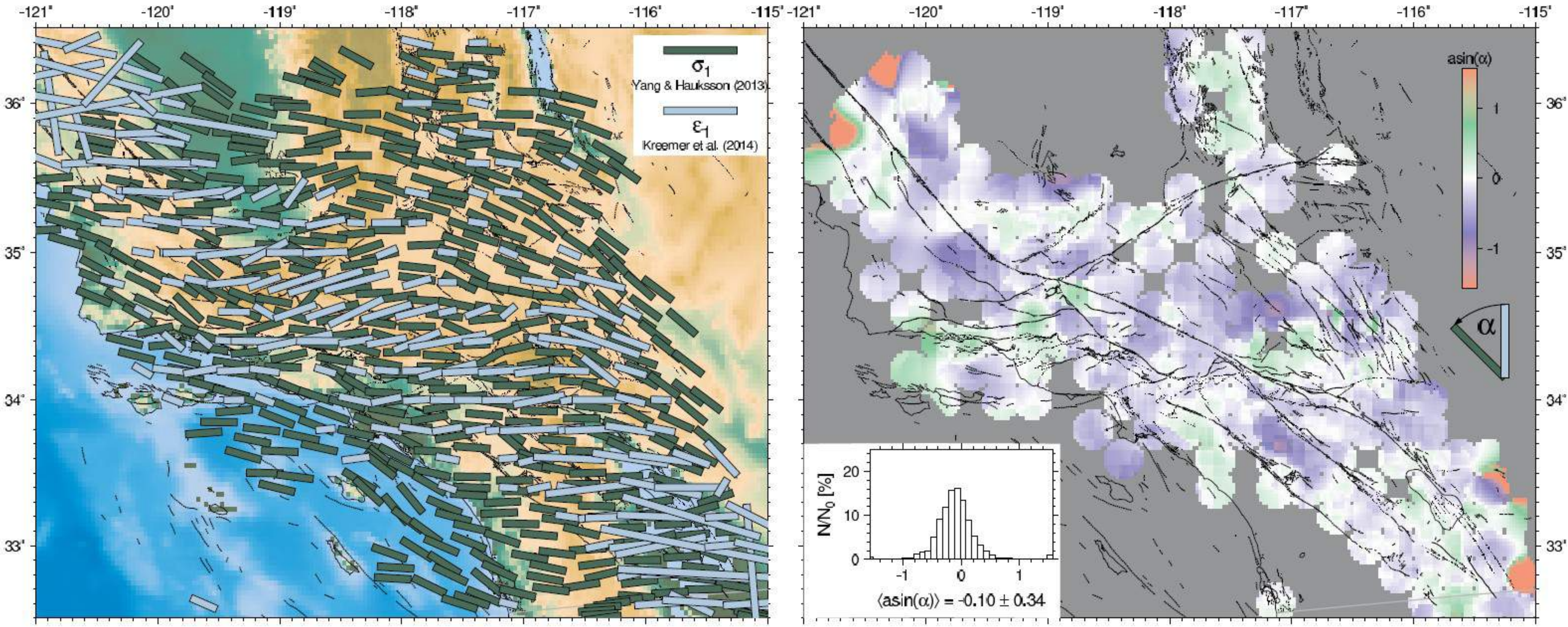
$$\tau_{ij} = C_{ijkl}\,\epsilon_{kl}$$

Stress from seismicity vs. strain-rates from GPS

upper crust

$\Delta t \sim T_{cycle}$

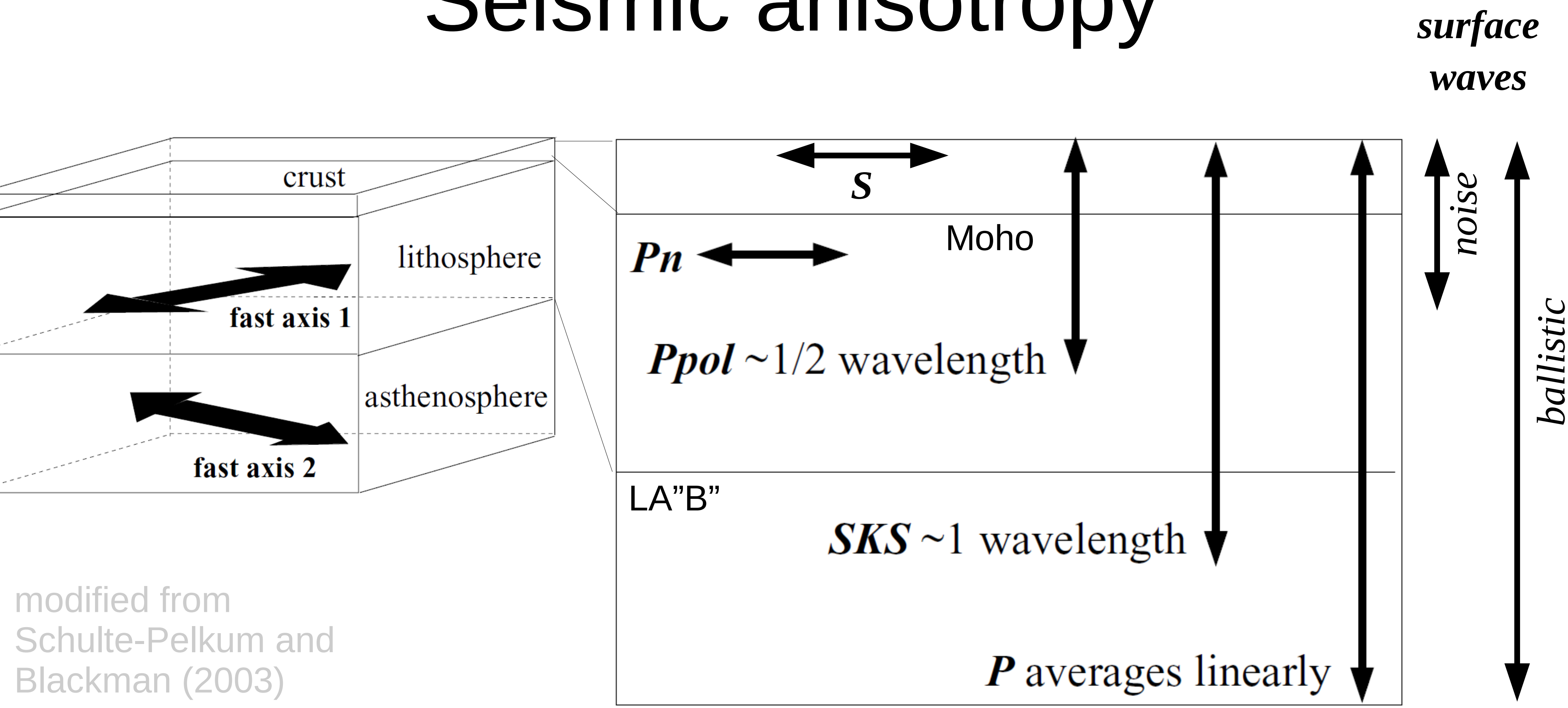
Michael (1984) stress (*Yang and Hauksson*, 2013) *vrs.* geodetic strain-rates (*Kreemer et al.*, 2014)



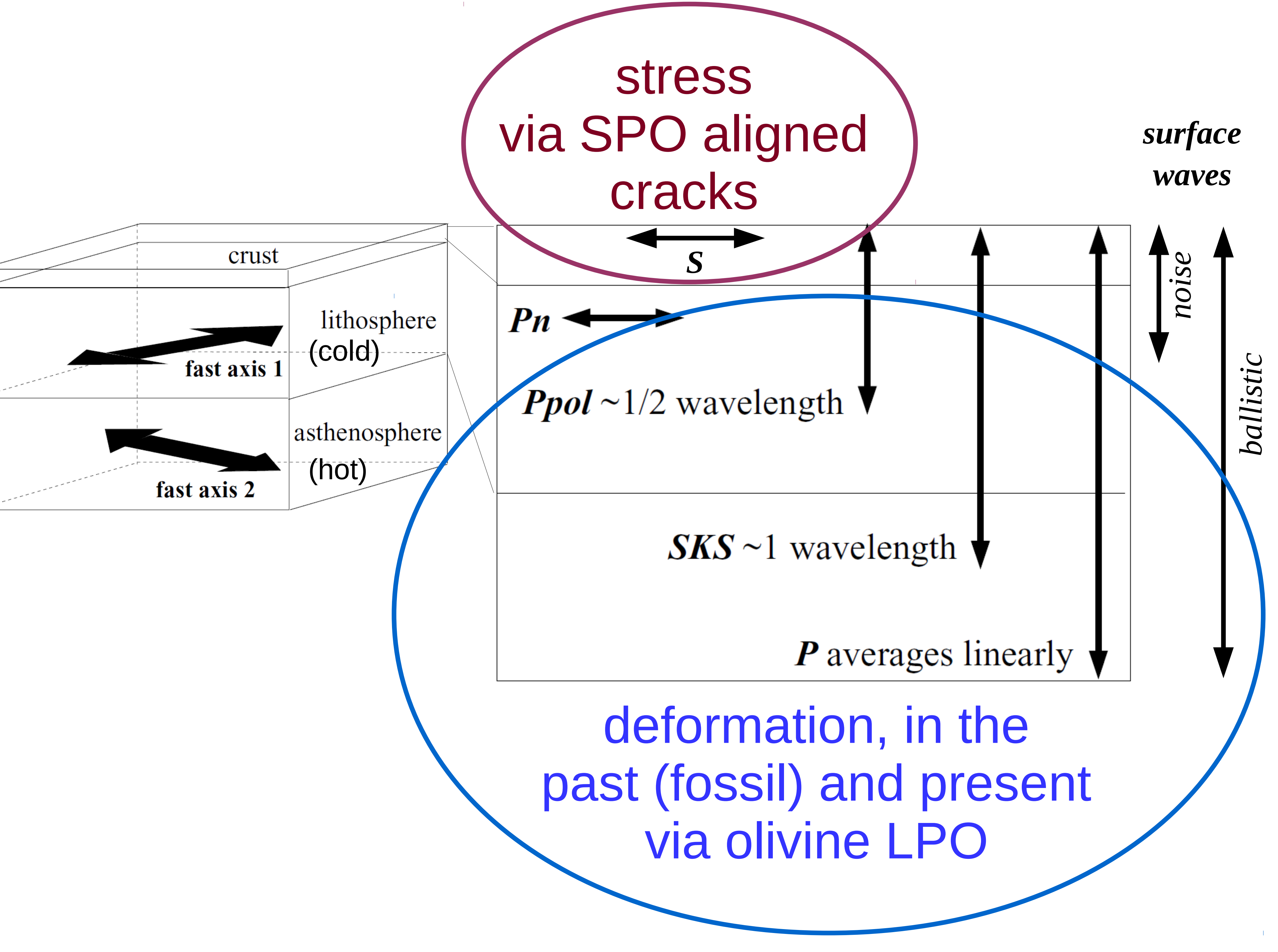
→ variations of alignment throughout the seismic cycle?

$$\epsilon = \frac{1}{2\mu} \int_{t}^{t+\Delta t} \dot{\tau}_{el}\, dt$$

Seismic anisotropy



modified from Schulte-Pelkum and Blackman (2003)


stress
via SPO aligned
cracks
surface
waves
crust
S
lithosphere
(cold)
Pn
fast axis 1
noise
Ppol ~1/2 wavelength
asthenosphere
(hot)
fast axis 2
ballistic
SKS ~1 wavelength
P averages linearly
deformation, in the
past (fossil) and present
via olivine LPO

GPS vs. crust and *SKS* anisotropy

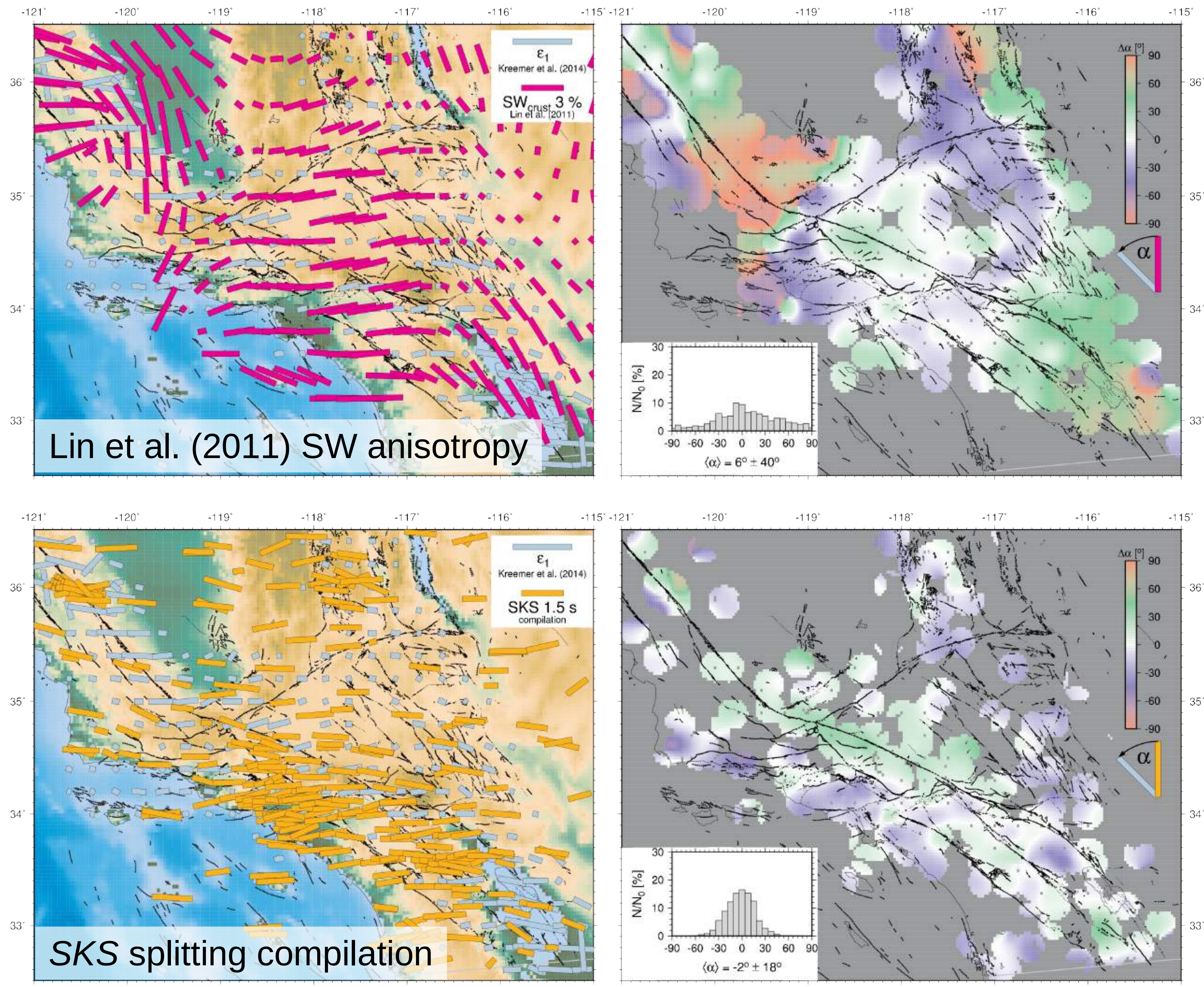
$\Delta t > T_{cycle}$

mid crust

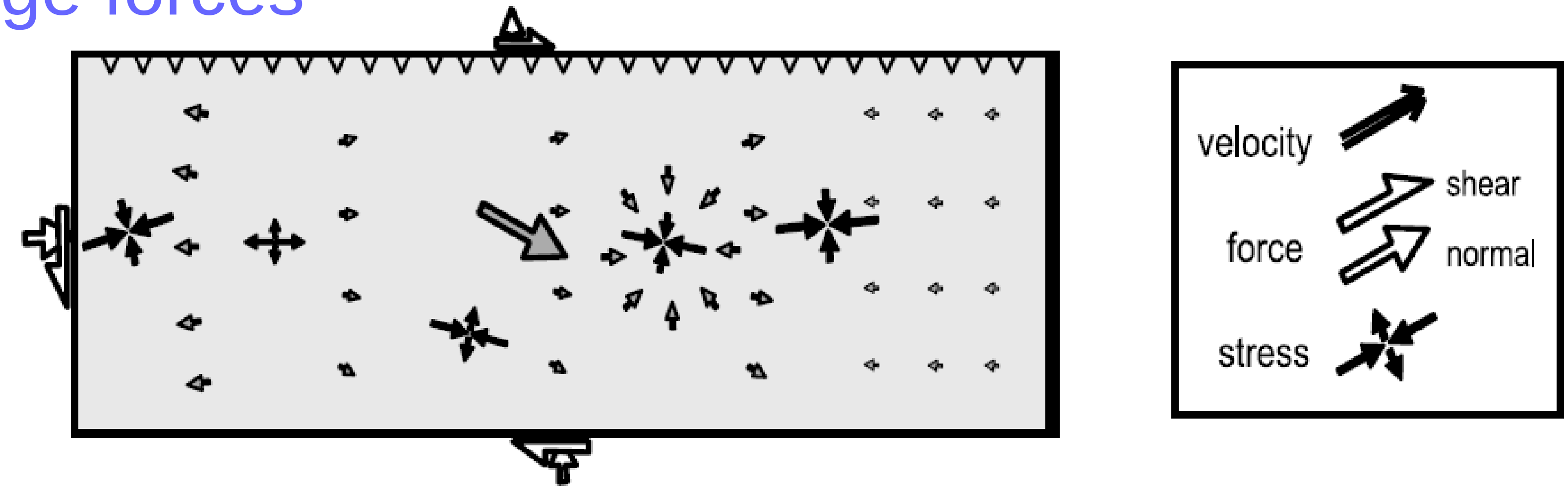
SPO, LPO?

upper mantle

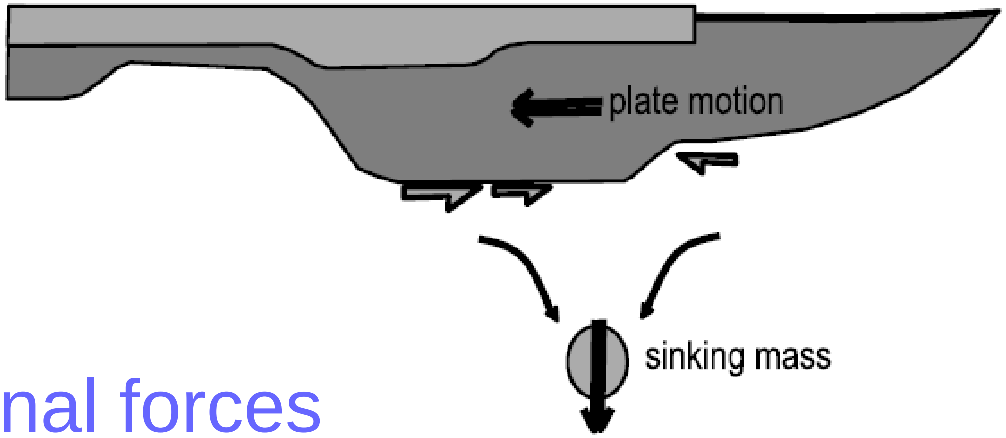
olinve LPO



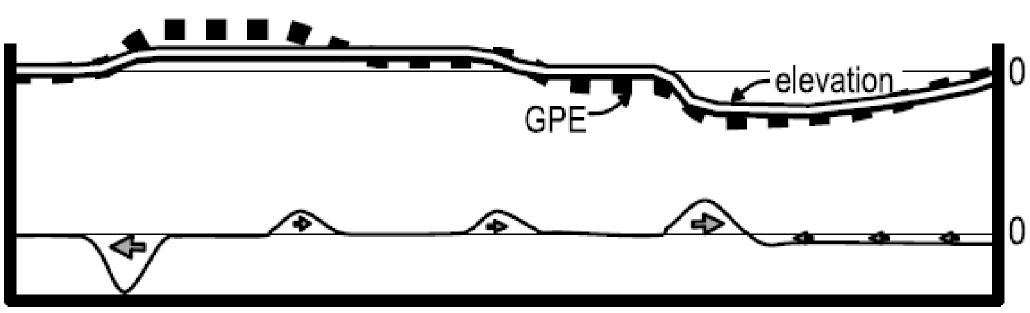
Edge forces



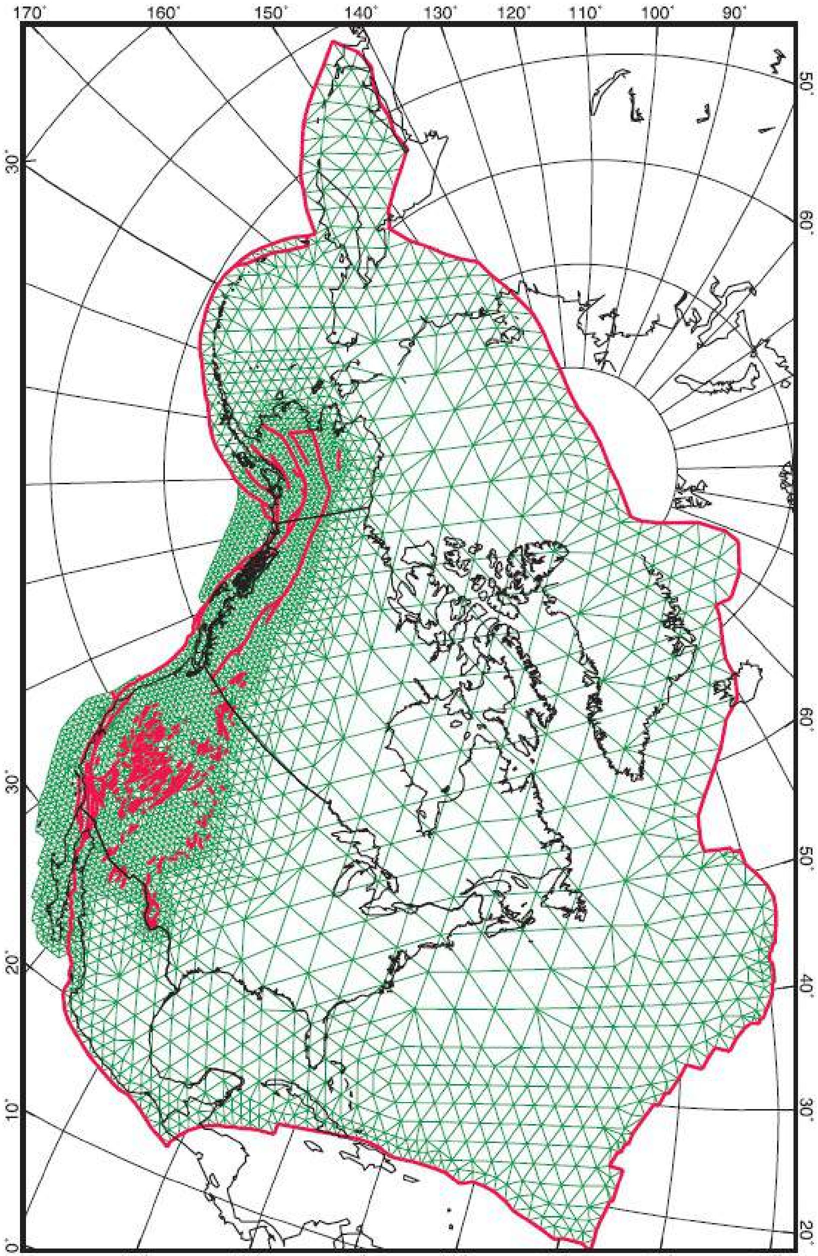
Basal forces



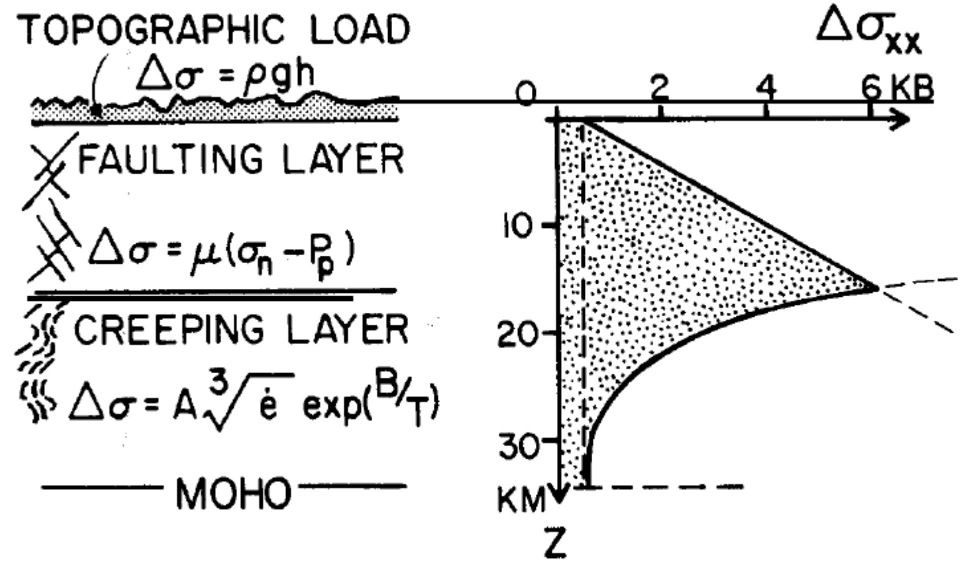
Internal forces



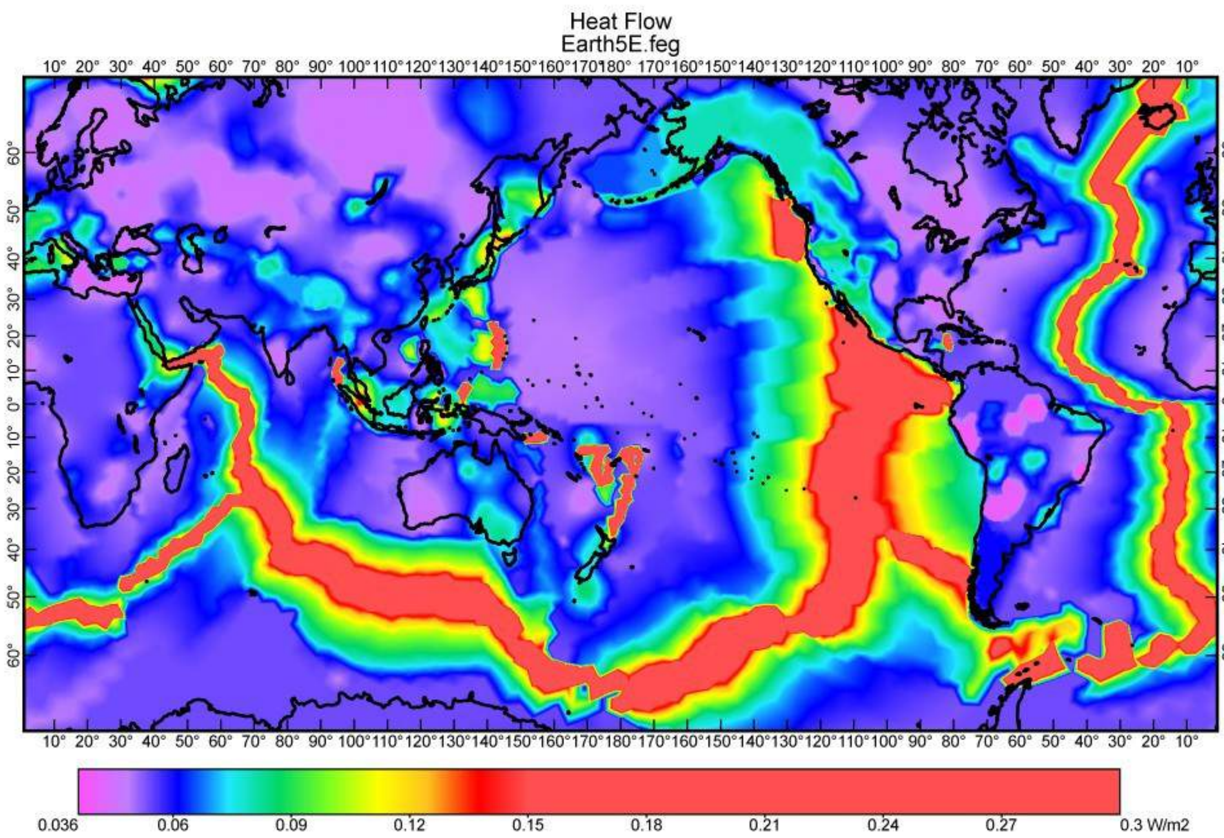
Humphreys and Coblentz (2010)



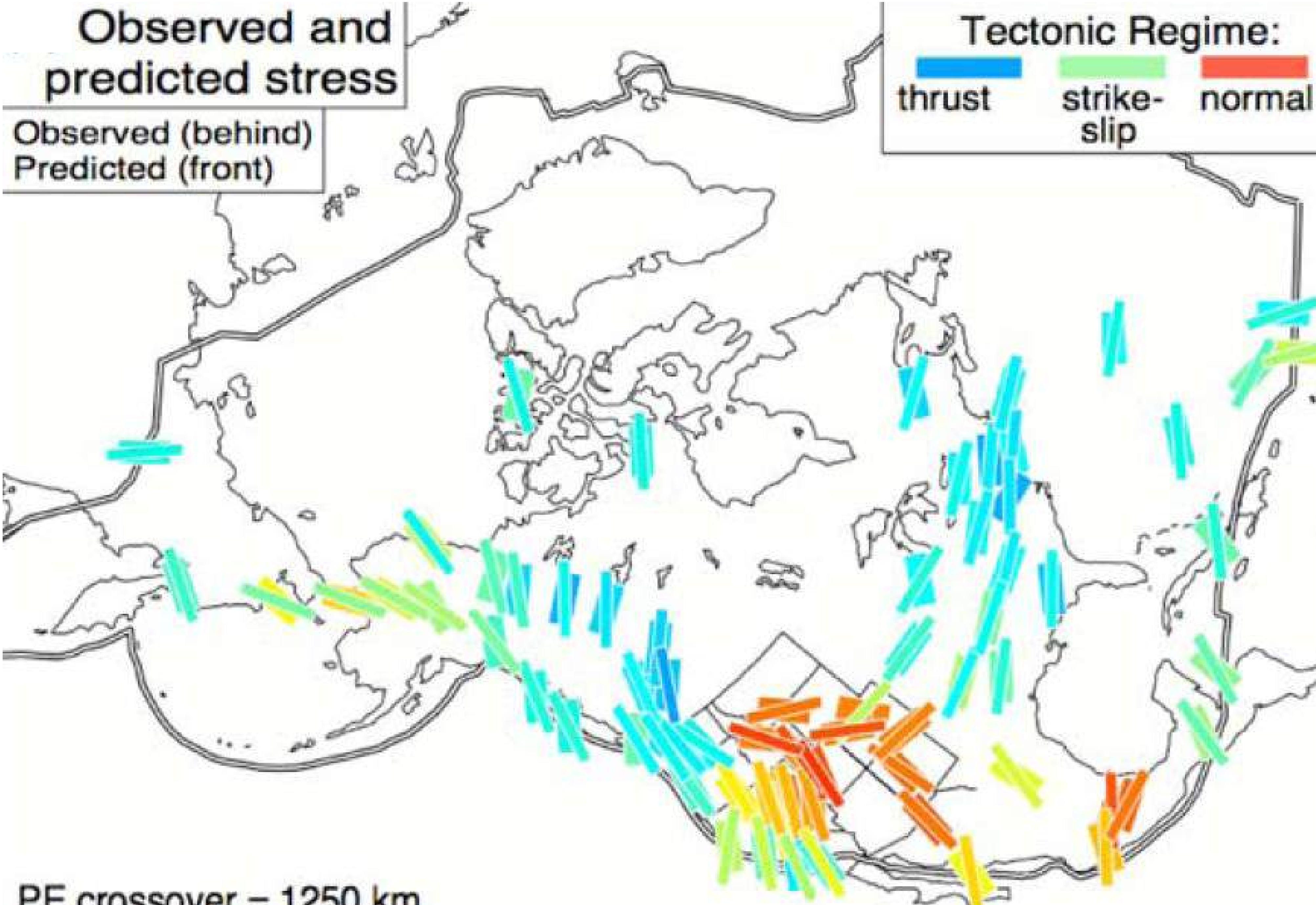
Liu and Bird (2002)



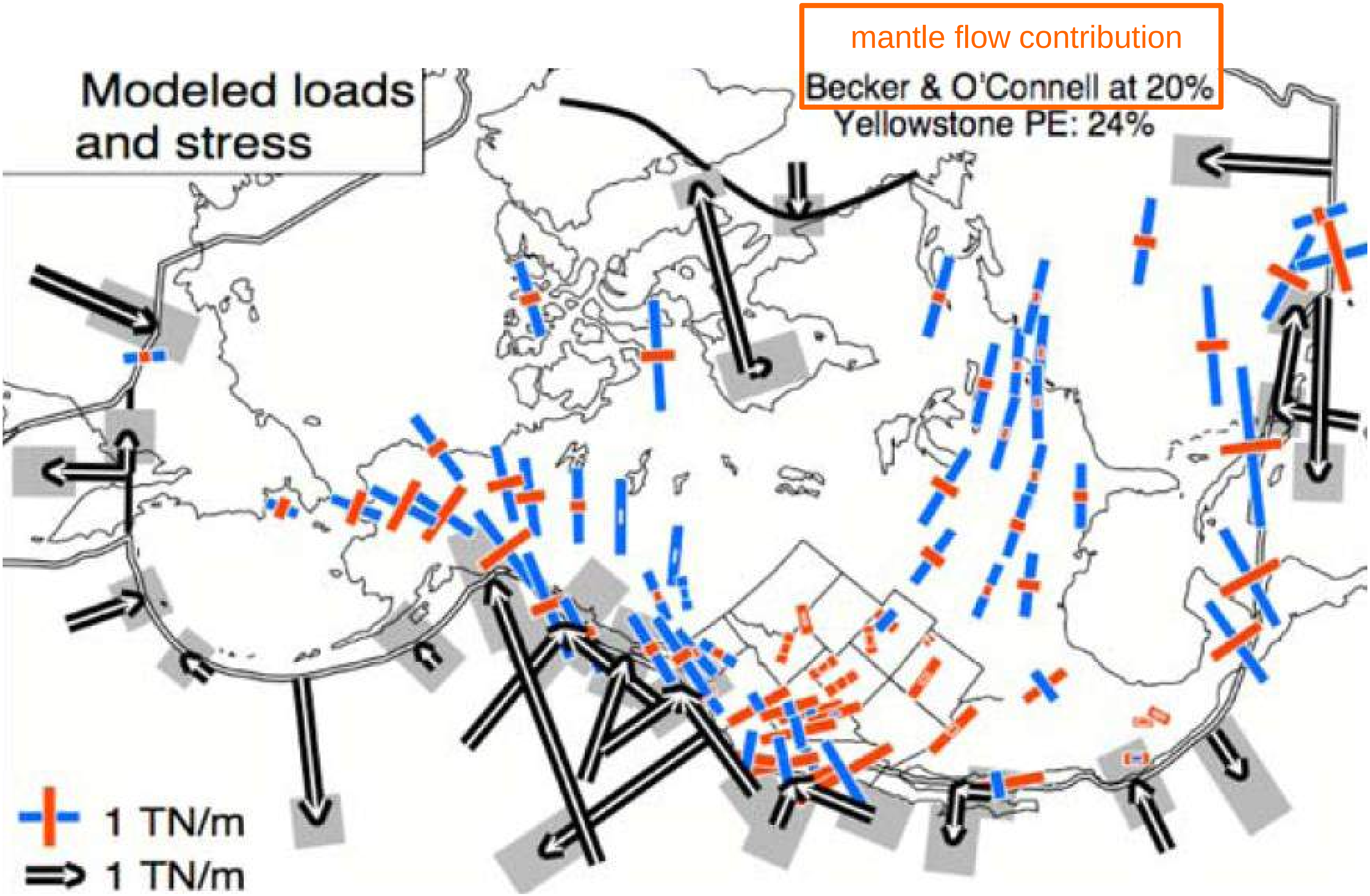
Bird and Piper (1980)



Liu and Bird (2002)



Humphreys and Coblentz (2010)



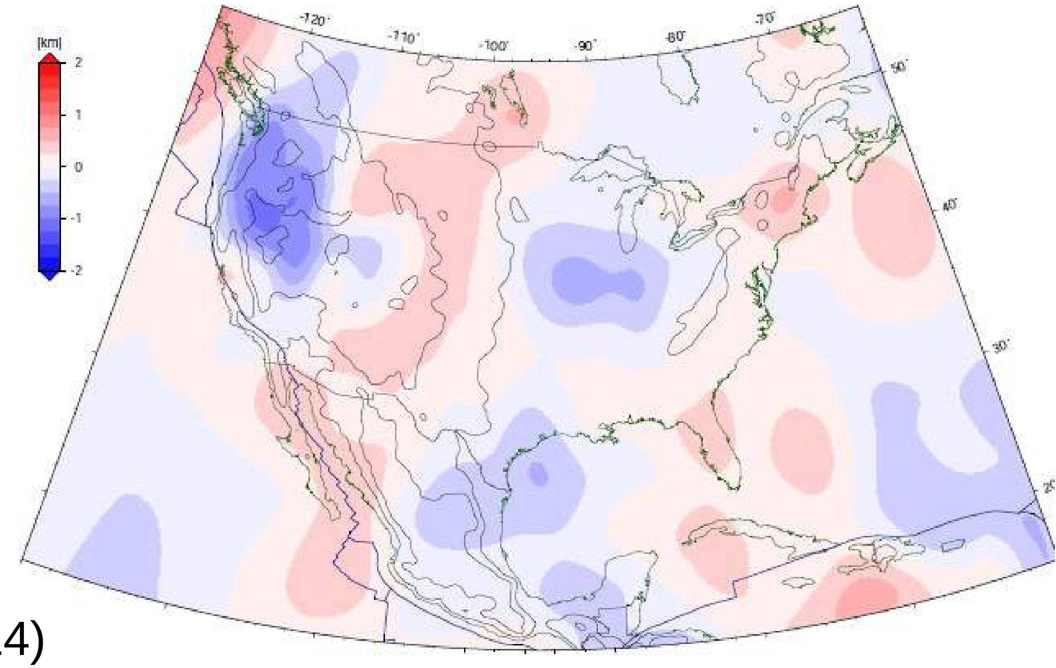
GPE sets the scale

Humphreys and Coblentz (2010)

Inferring the basal contribution

- infer lithospheric mantle density anomalies from tomography (hard)
- Infer deeper mantle density anomalies from tomography (easier)

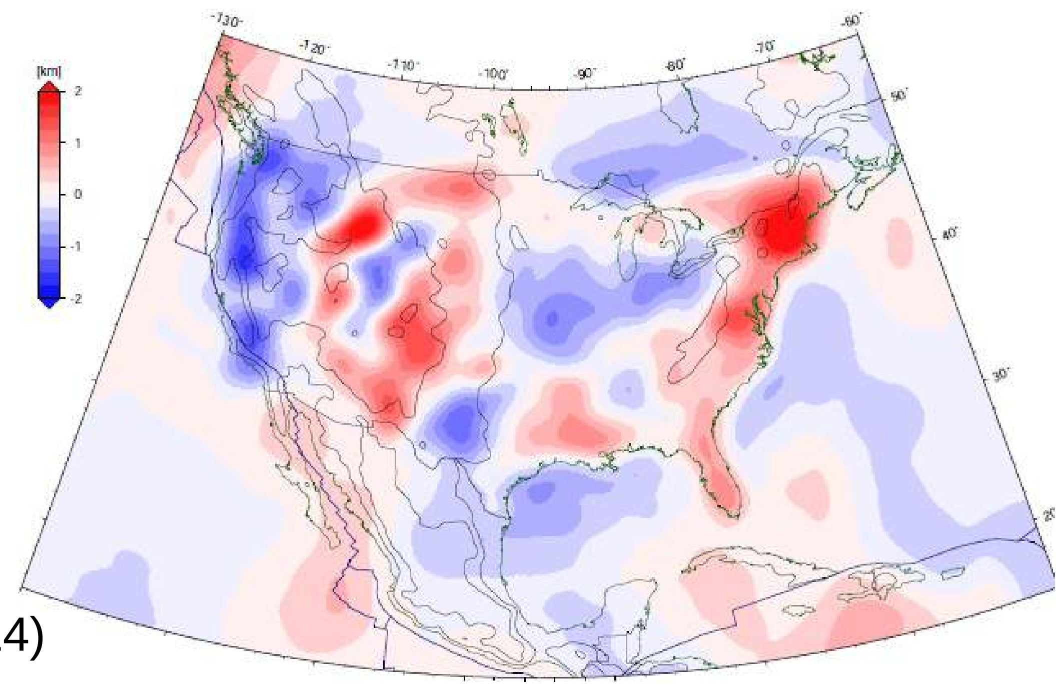
old seismic tomography

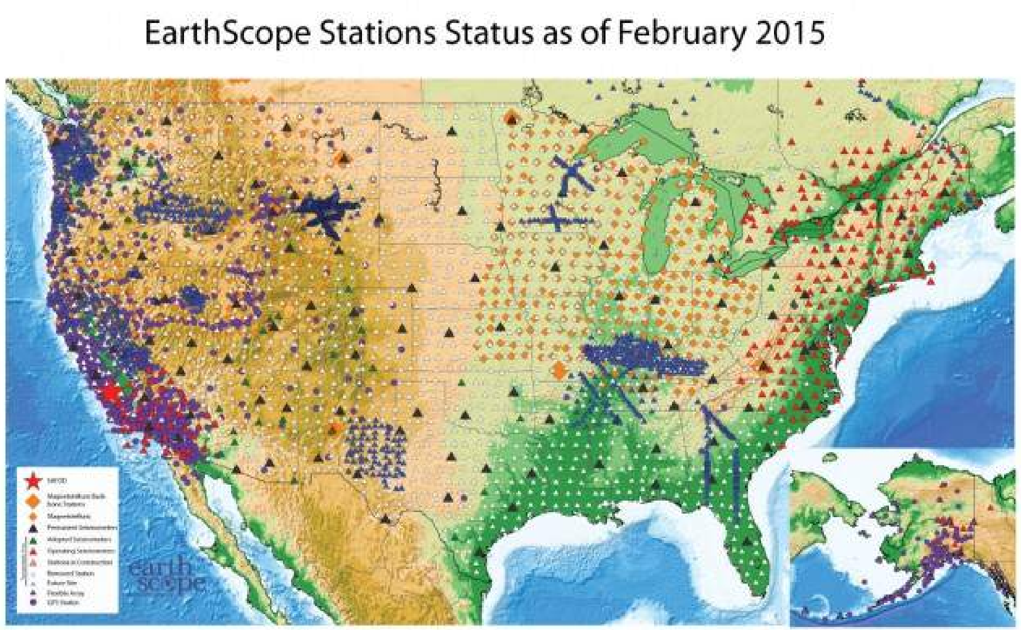


Auer et al. (2014)

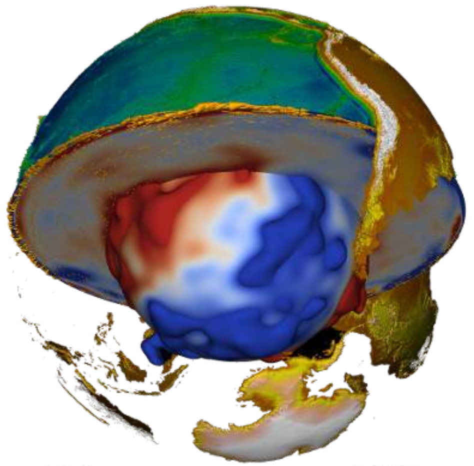
$L > 12$

new seismic tomography

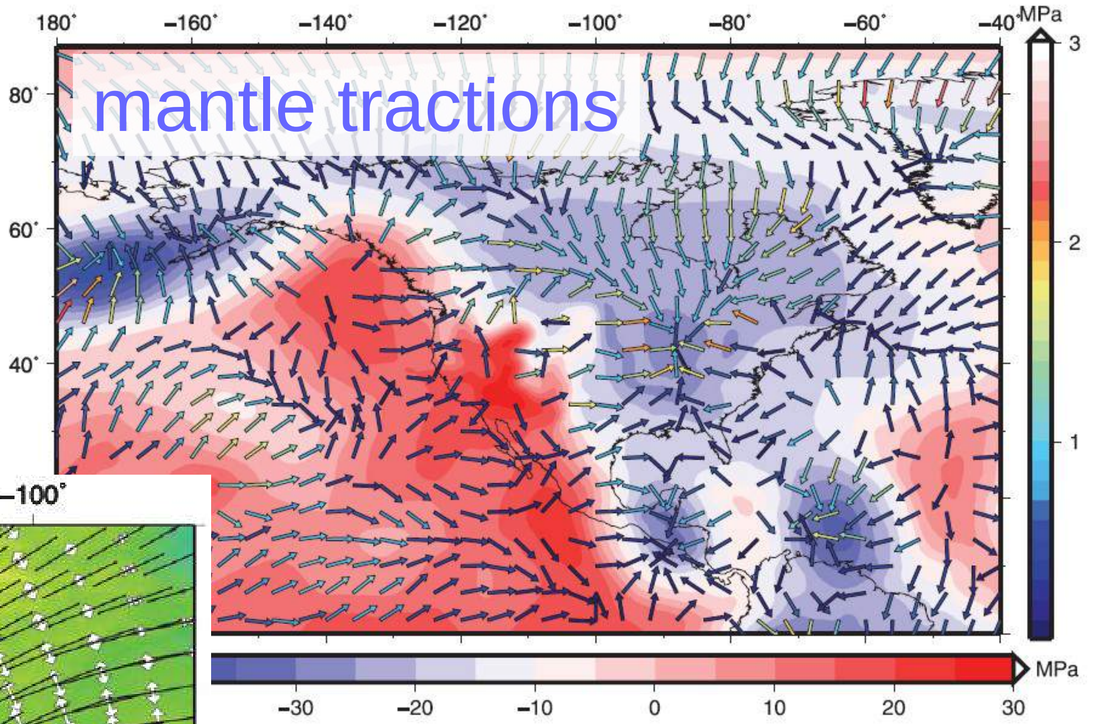


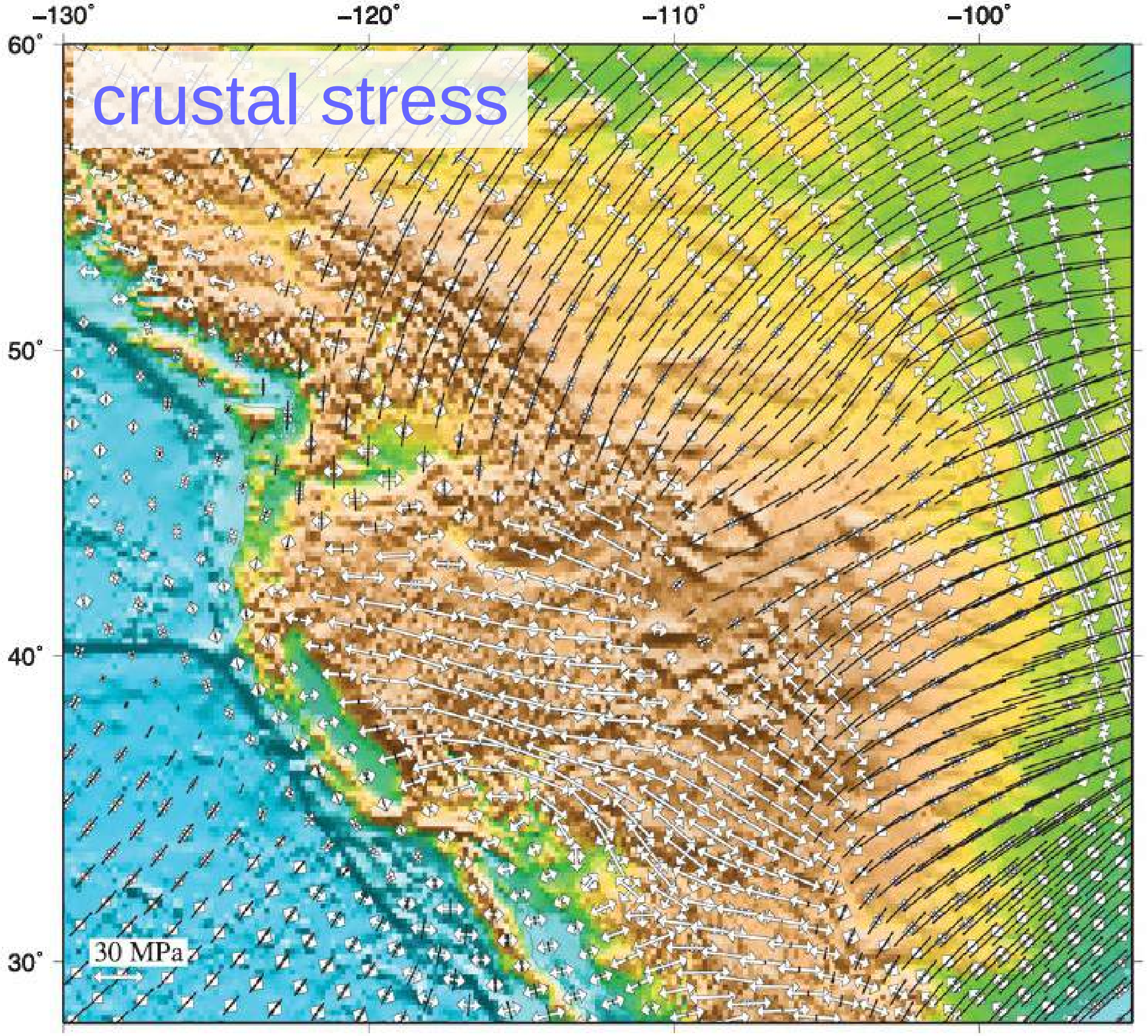


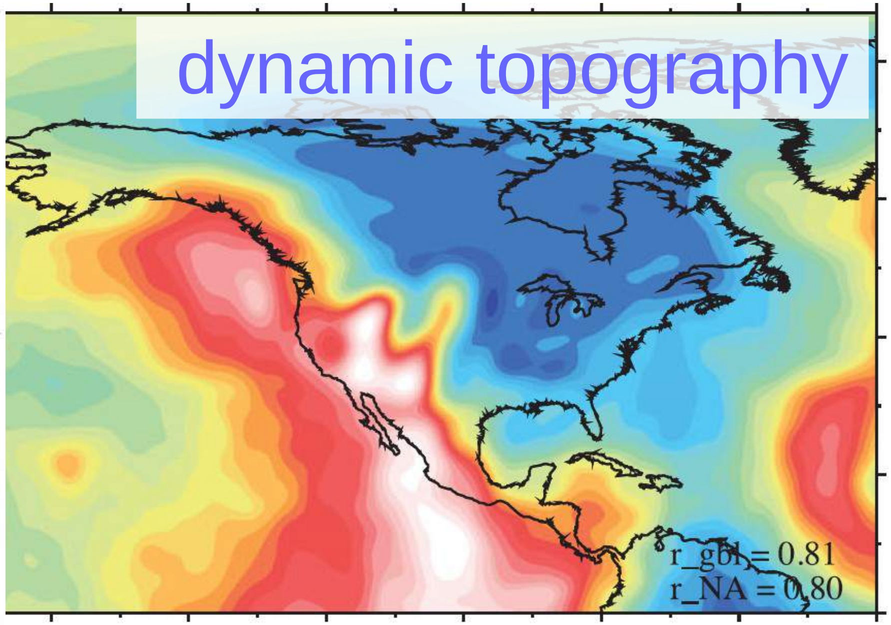
Schmandt and Liu (2014)



global convection model (with viscous anisotropy) and ~20 km resolution

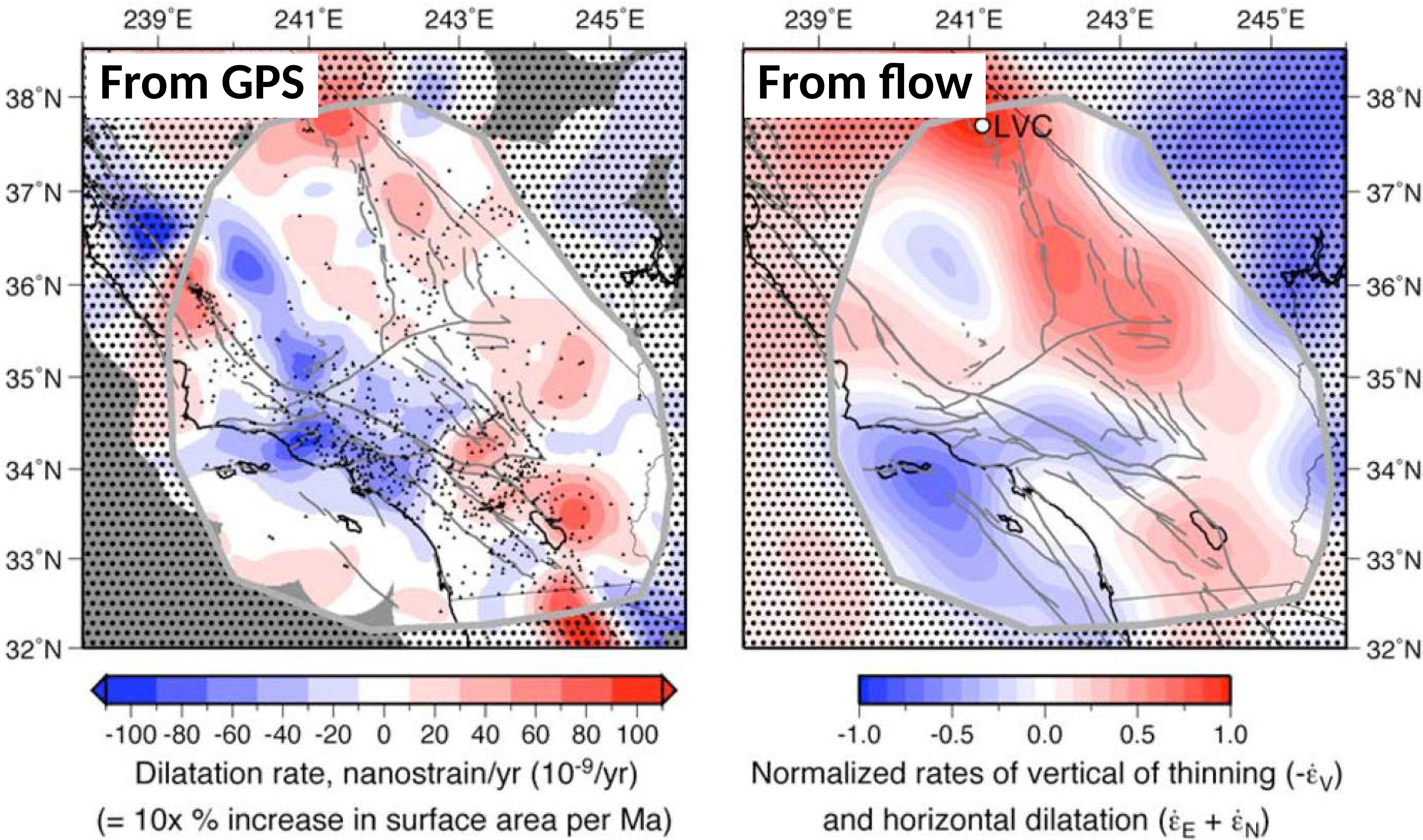






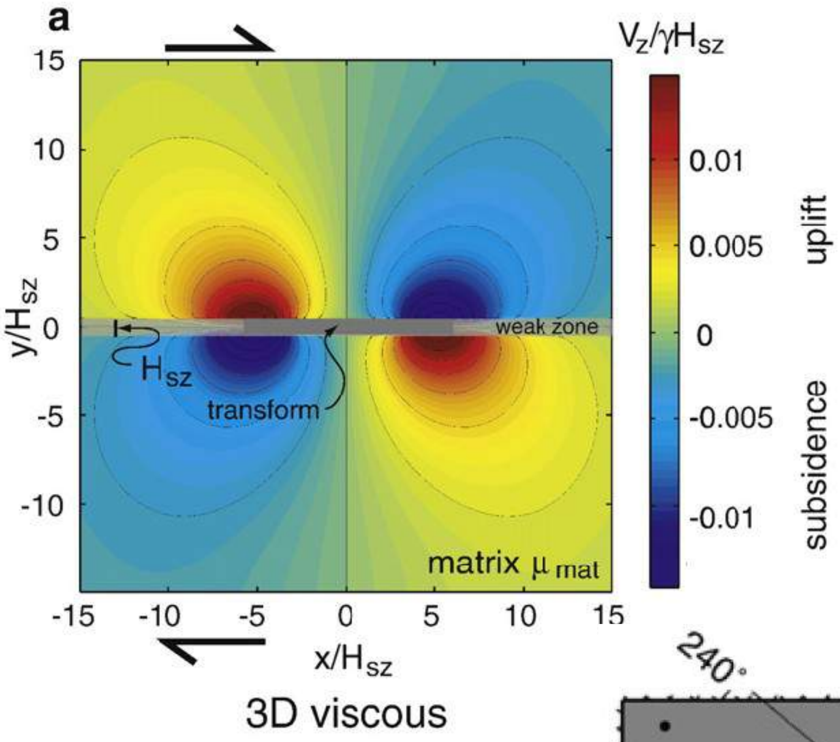
Ghosh et al. (2013)

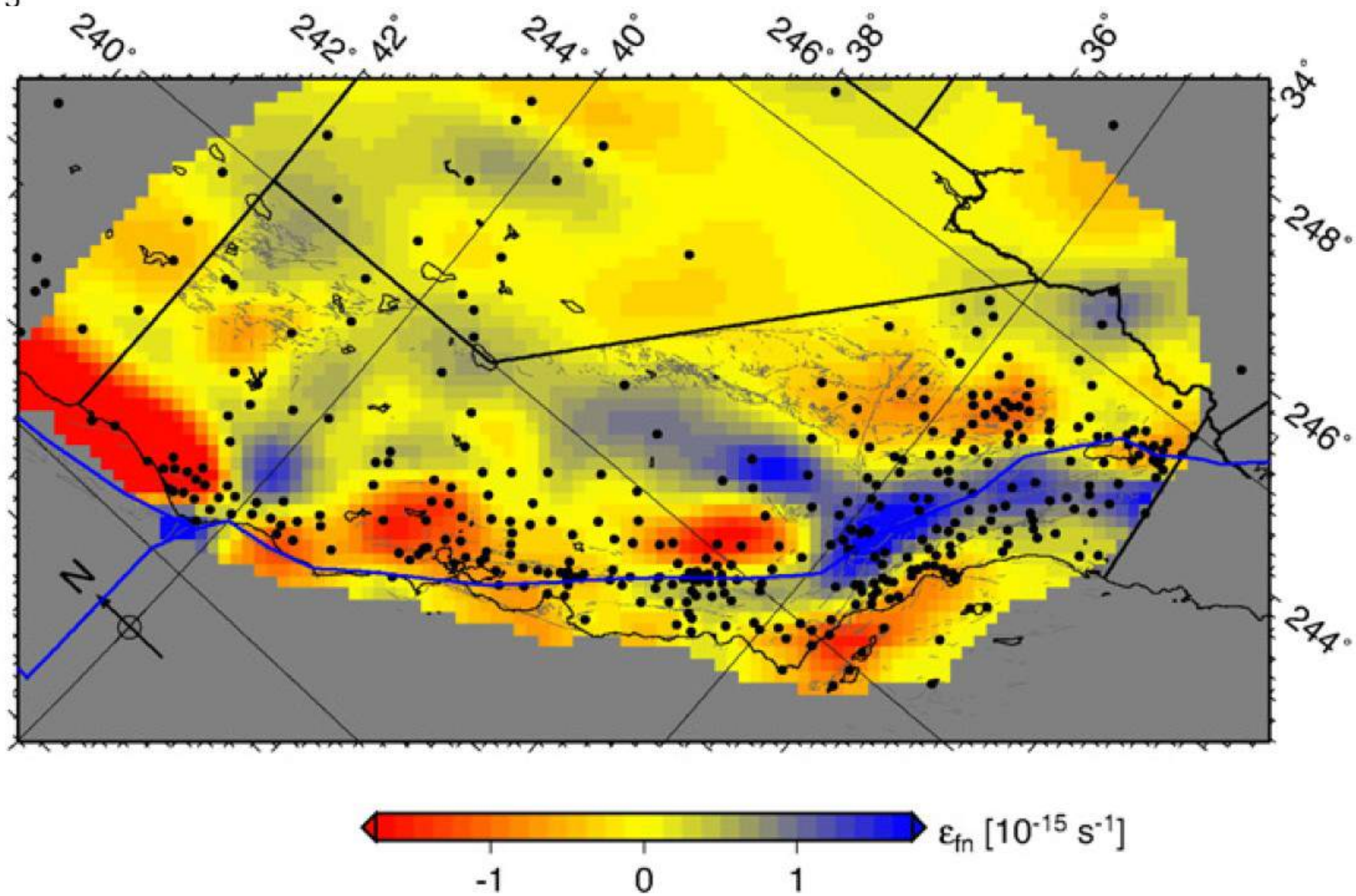
Small scale convection effects?



Fay et al. (2008)

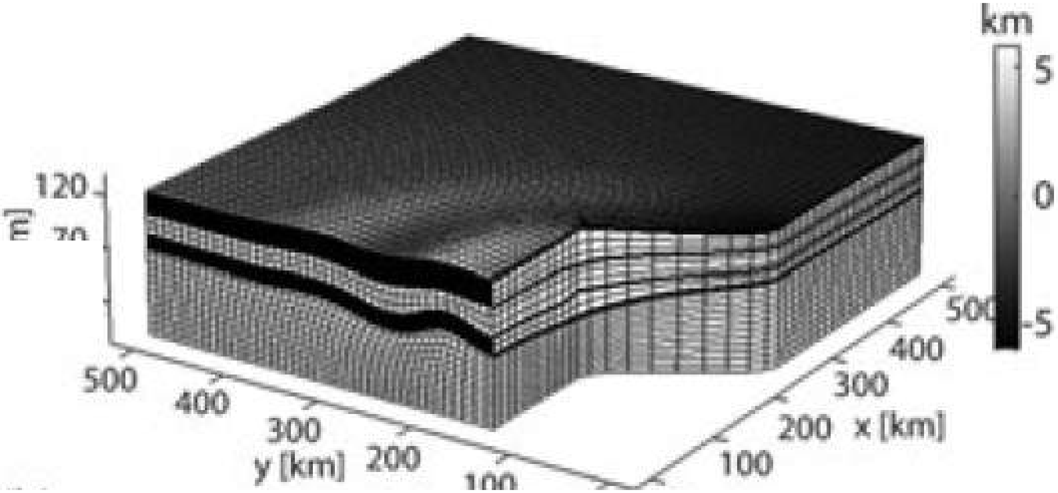
Non-uniqueness (or chicken and egg problem)

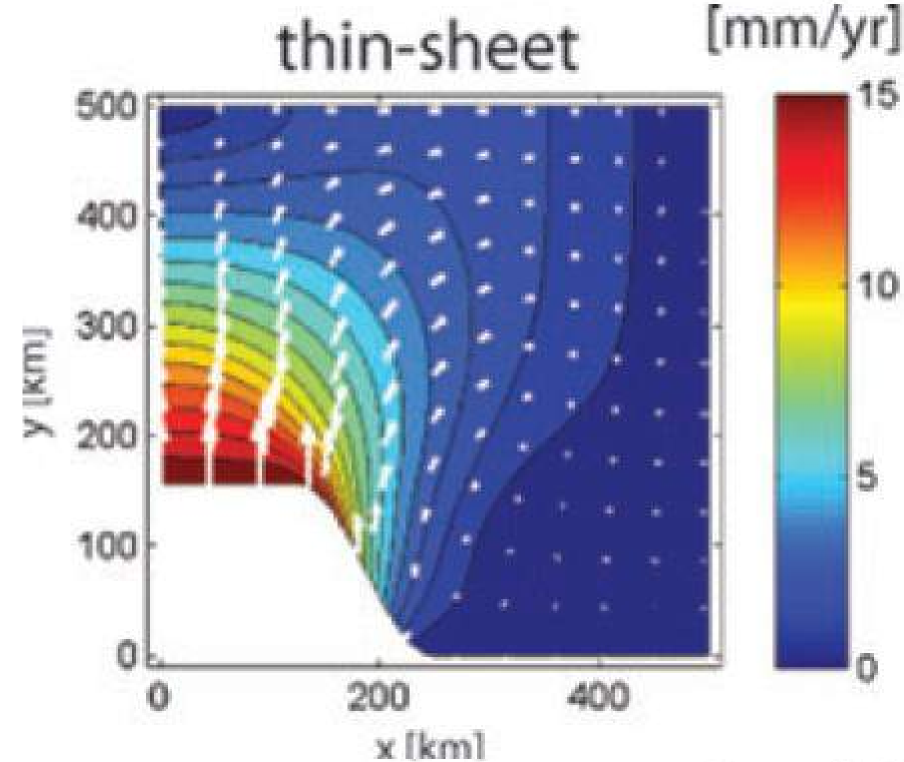


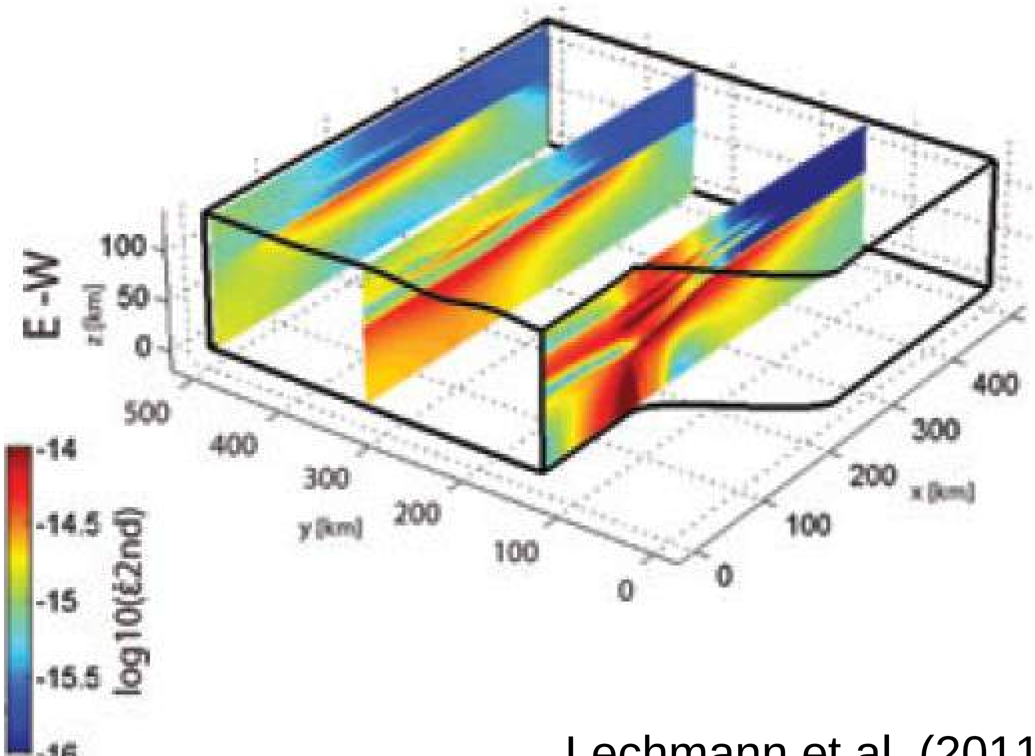


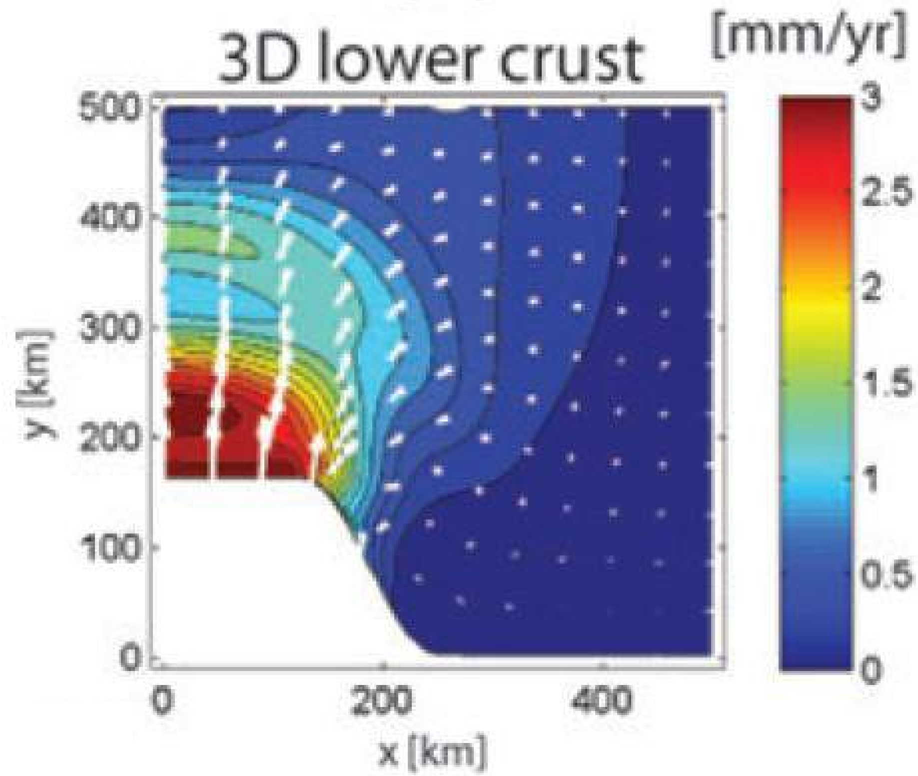
Platt et al. (2008)

Full 3D lithospheric models









Lechmann et al. (2011)

Deformation models can provide *average* stress bounds

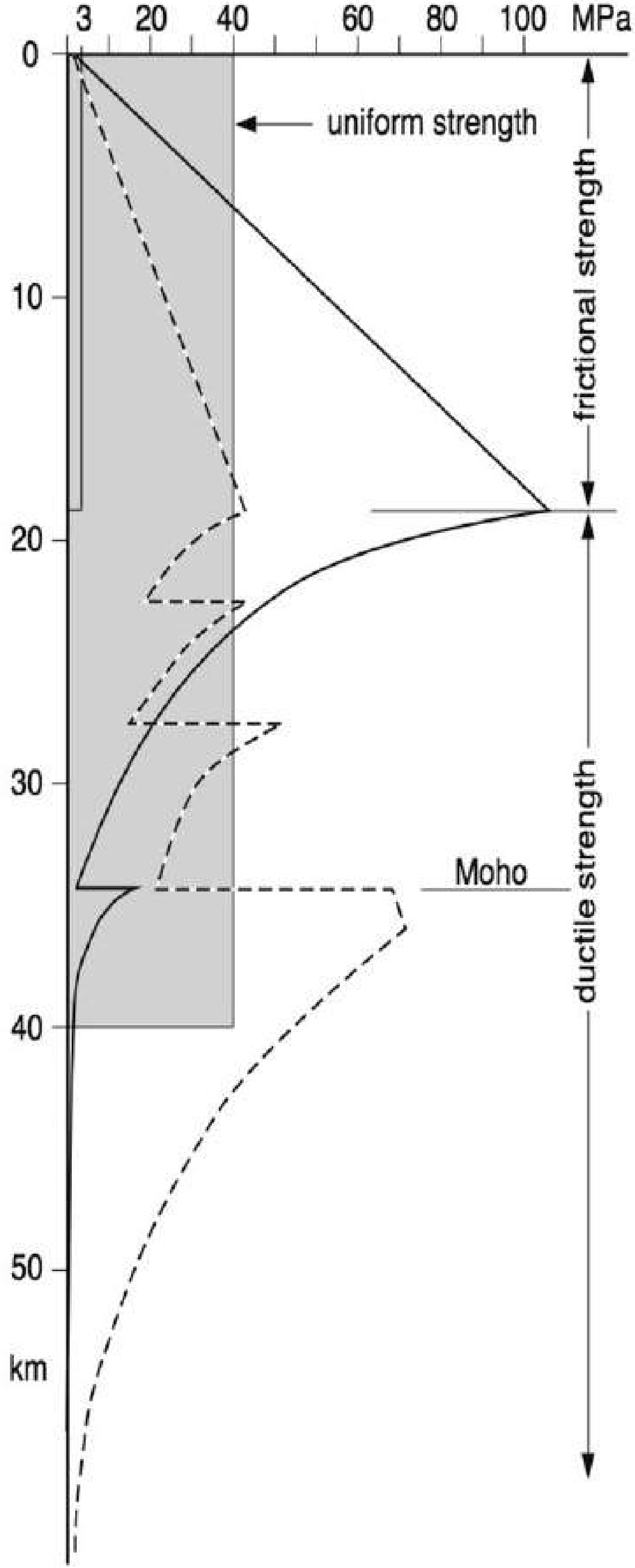
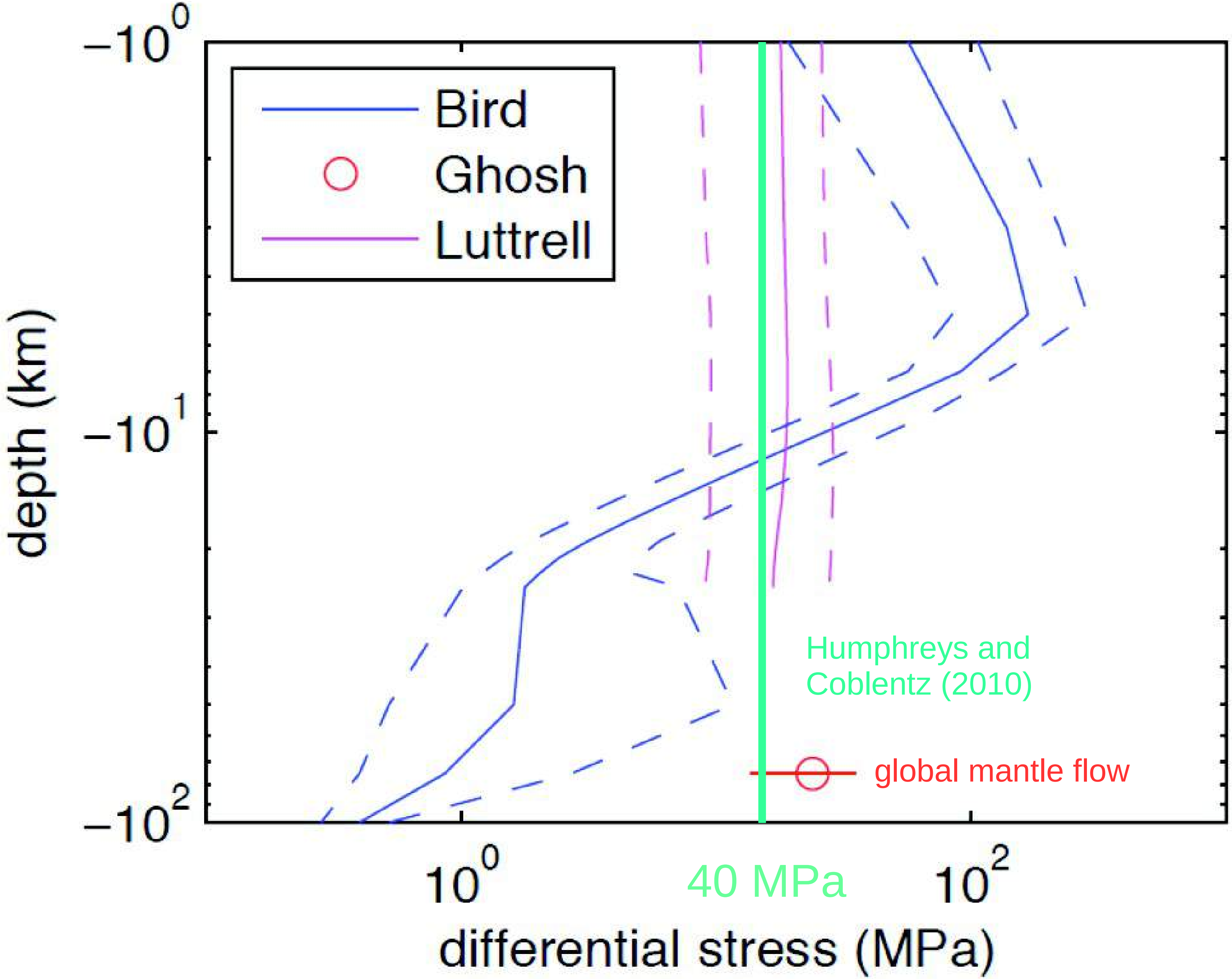


Figure 6. Three representative strength profiles with depth-integrated strength equaling 1.6 TN/m, similar to the resolved shear load on the San Andreas plate margin. Regardless of strength profile, midcrustal shear stress is far below the ~300 MPa expected at 18 km depth from rock mechanics experiments (assuming a friction coefficient of 0.6) and far greater than a typical earthquake stress drop of ~3 MPa.

Humphreys and Coblentz (2010)



modified from Hardebeck et al. (2013)


40 MPa