Stress concentration from upper mantle heterogeneity in the Central and Eastern United States

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Why this study?

Far from the plate boundaries with negligible strain rates, sources of stress for earthquake generation at the intraplate seismic zones remain enigmatic.

Proposed models for CEUS:

- Crustal/upper mantle zone of weakness [1]
- Reactivation of shear zone from a major fault[3]

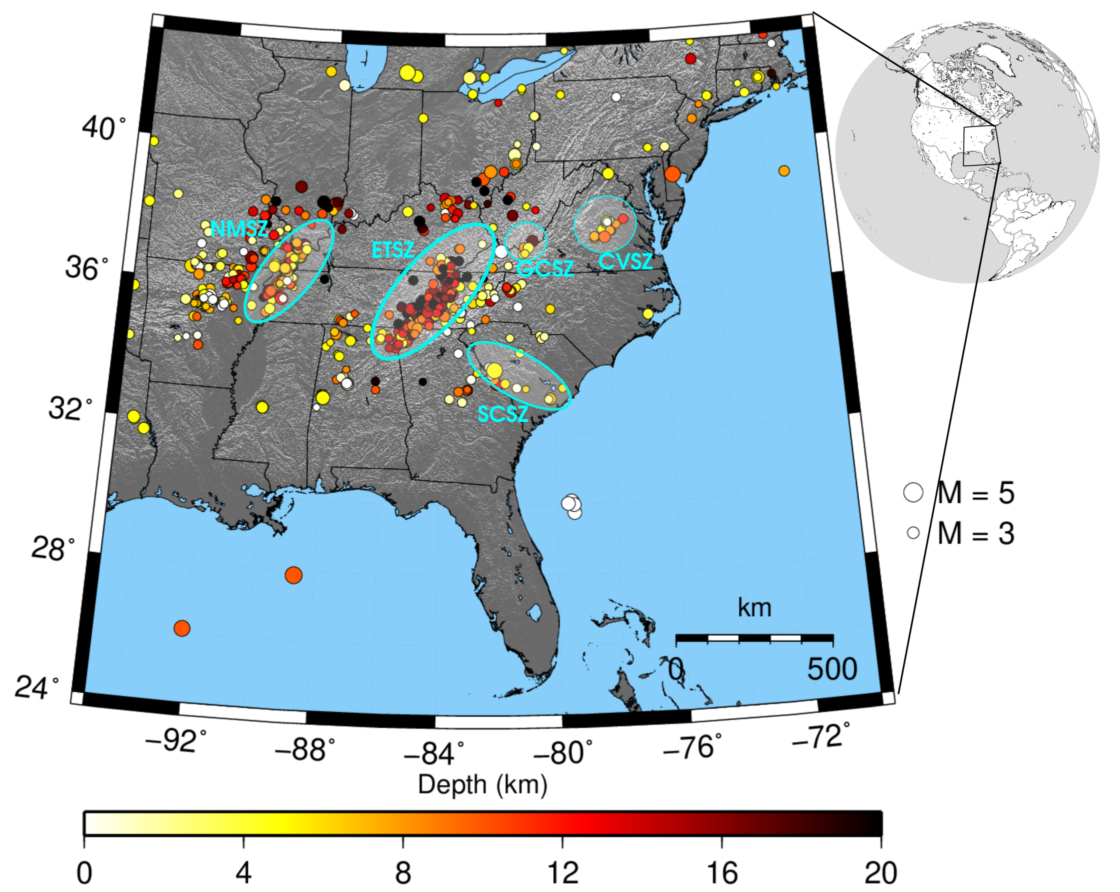

Figure 1: Earthquake epicenters (> Mw2.5) in the CEUS from Nov., 2011 to Nov., 2018.

Recent observations

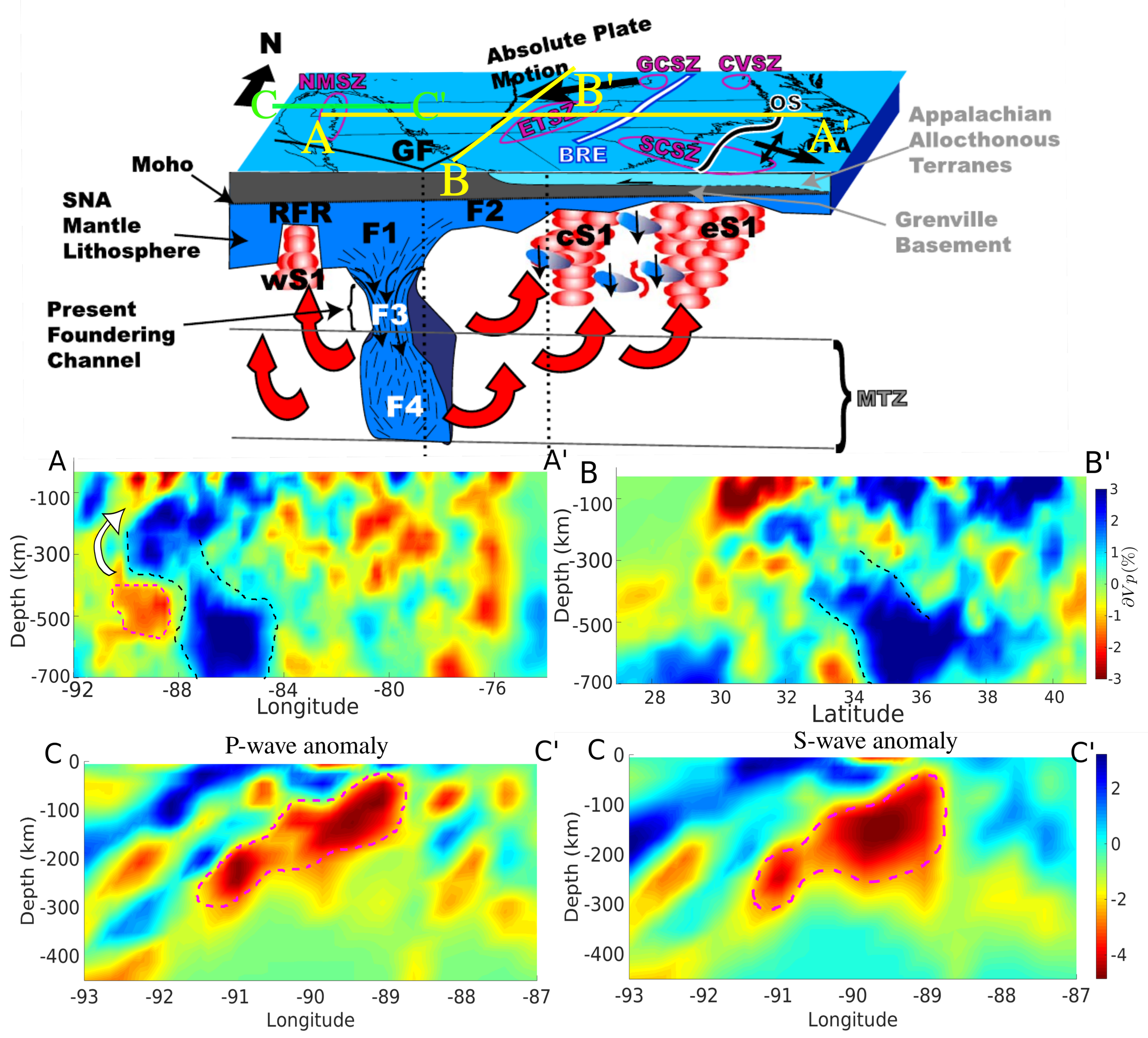

Figure 2: Tomography results by *Biryol et al., [2016]*[4] and *Nyamwandha et al, [2016]* where high and low velocity patterns are interpreted as lithospheric drip and asthenospheric upwellings, in the respective studies.

Temperature calculation

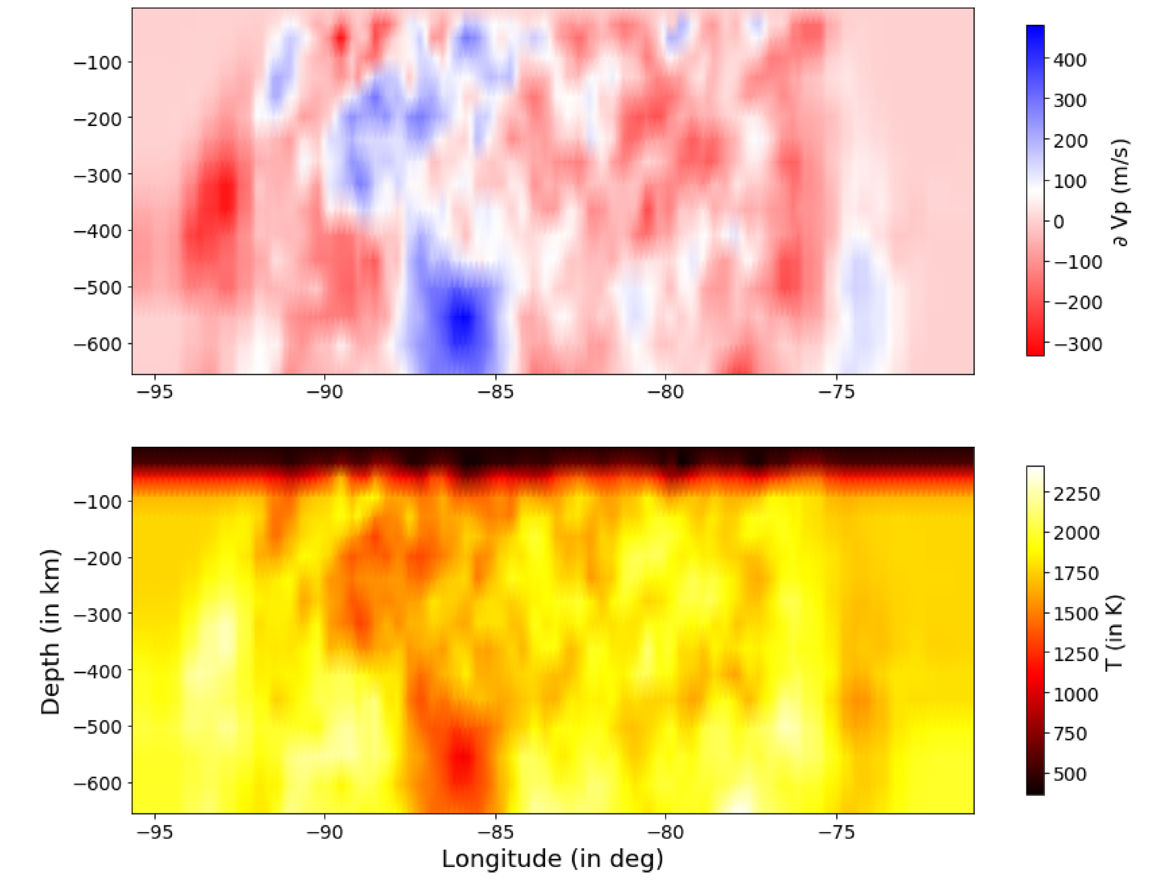

Figure 3: Temperatures calculated based on the tomography results taking into effects of pressure, anharmonicity, anaelasticity and phase transition following the approach by *Cammarano et al., [2003]*

Model setup

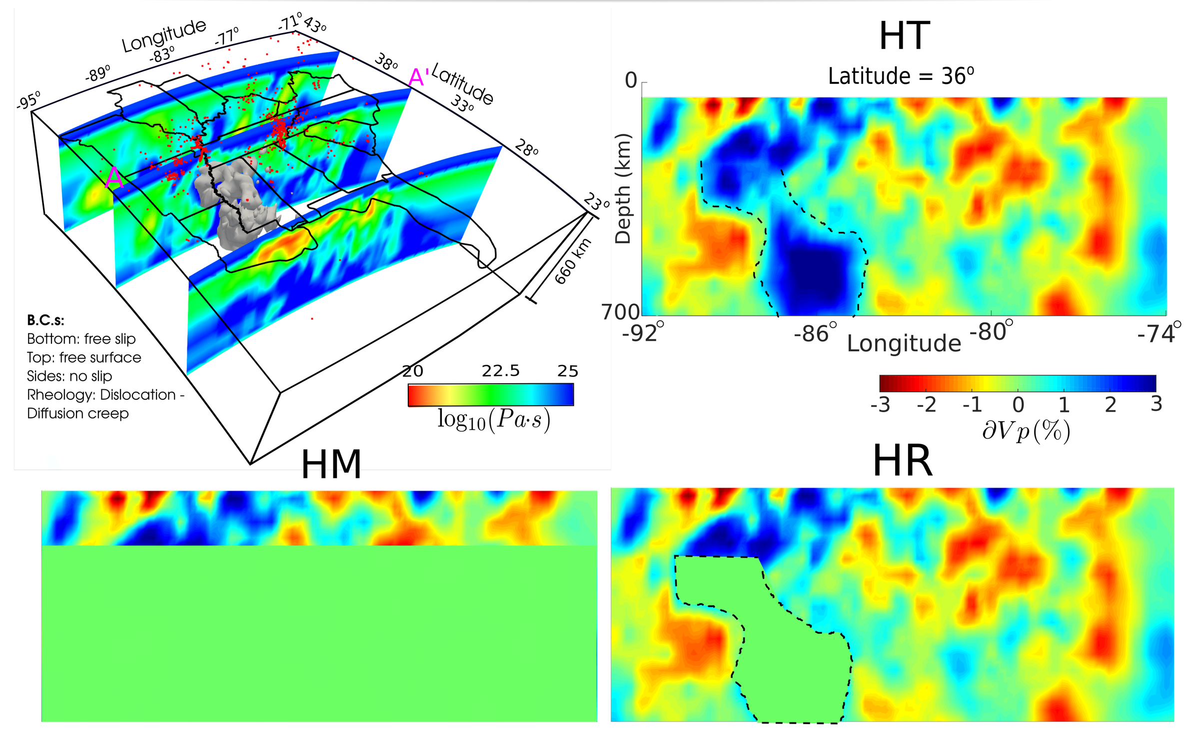

Figure 4: Viscosity distribution computed based on the temperatures in ASPECT. Different model setups used in this study: HT (heterogeneous), HM (homogeneous) and HR (homogeneous root)

Viscosities are computed in ASPECT[6] based on the temperatures, T, as the average of dislocation and diffusion creep:

$$\eta = 0.5 \dot{\varepsilon}^{\frac{1-n}{n}} A^{-1/n} d^{m/n} \exp\left(\frac{E+PV}{nRT}\right)$$

Stress field generated from mantle heterogeneity

We calculate stresses from isolated upper mantle heterogeneity (> 200 km) and lithospheric root in HT−HM and HT−HR, respectively.

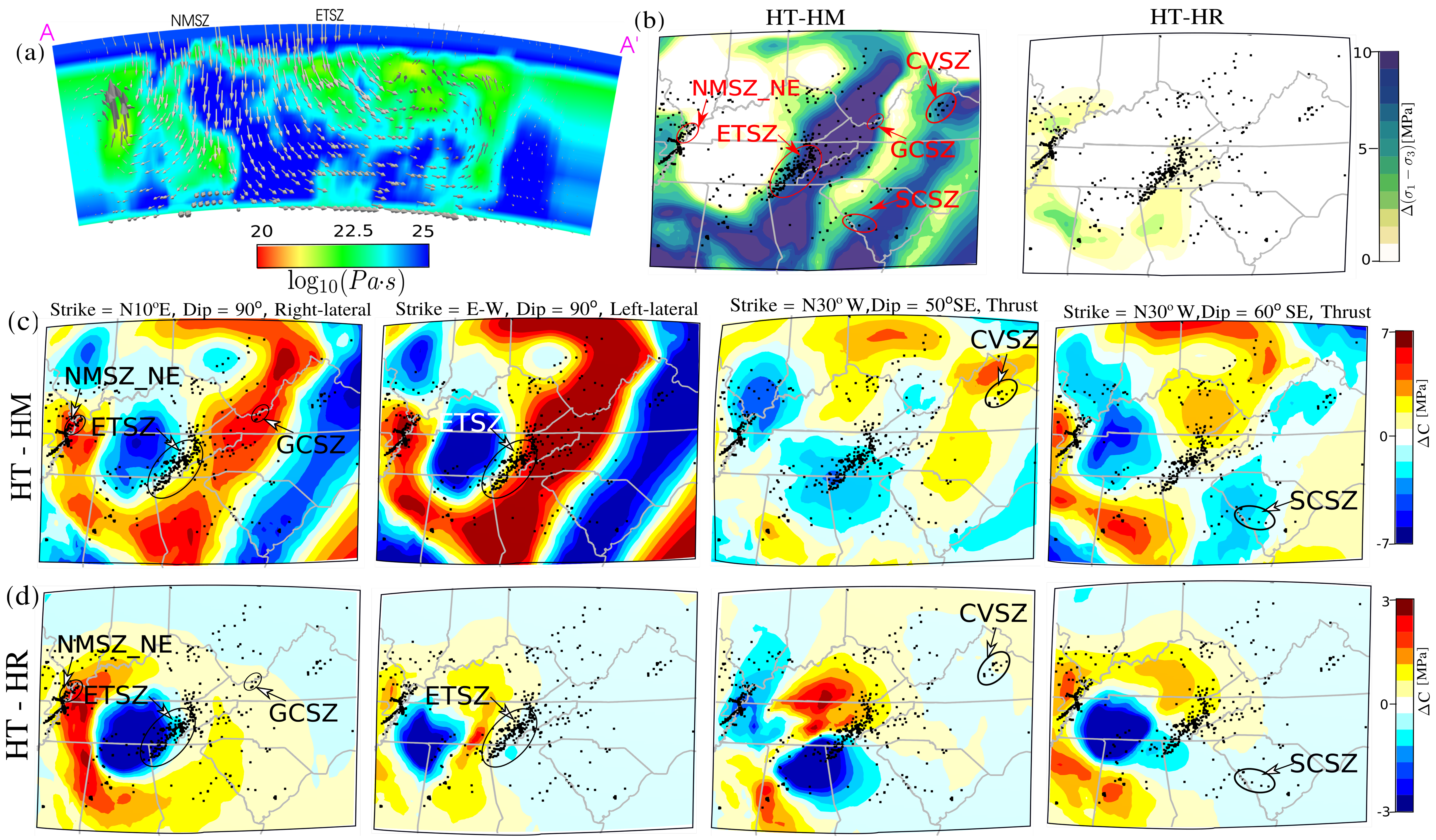

Figure 5: (a) Instantaneous flow generated in the model due to the root indicated by the isosurface of Temperature 1500K.(b) Differential stress, $\sigma_1 - \sigma_3$, change for HT−HM and HT−HR.(c) Coulomb stress change, ΔC, for HT−HR at different fault orientations obtained by other observation studies.(d) Same as (c) but for Coulomb stress change of HT with HR.

Interpretations

- Instantaneous mantle flow in Fig. 5(a) indicates significant downward flow beneath the ETSZ and the NMSZ, which might suggest that the present-day mantle flow beneath the NMSZ is not upwards as suggested by *Biryol et al., [2016]*[4].
- To simultaneously explain the high and similar-magnitude negative Vp and Vs anomaly west of NMSZ, Opx contents up to 40% along with high temperatures are invoked.
- The increase in the differential stress at ETSZ, NMSZ, SCSZ, CVSZ, and GCSZ has a limited area of influence when only effects of root are considered (Fig. 5(b)). This suggests that in the absence of the surrounding low-velocities, the root has a wide length of its convection cell which is reflected as small negative differential stress change.
- Positive Coulomb stress in all seismic zones except SCSZ for HT−HM (Fig. 5(c)) implying that upper mantle heterogeneity increases the tendency for preexisting faults to slip in those zones. However, Coulomb stress change due to the presence of root only does not show any obvious correlation with the seismicity.

Proposed Origin of Anomalies

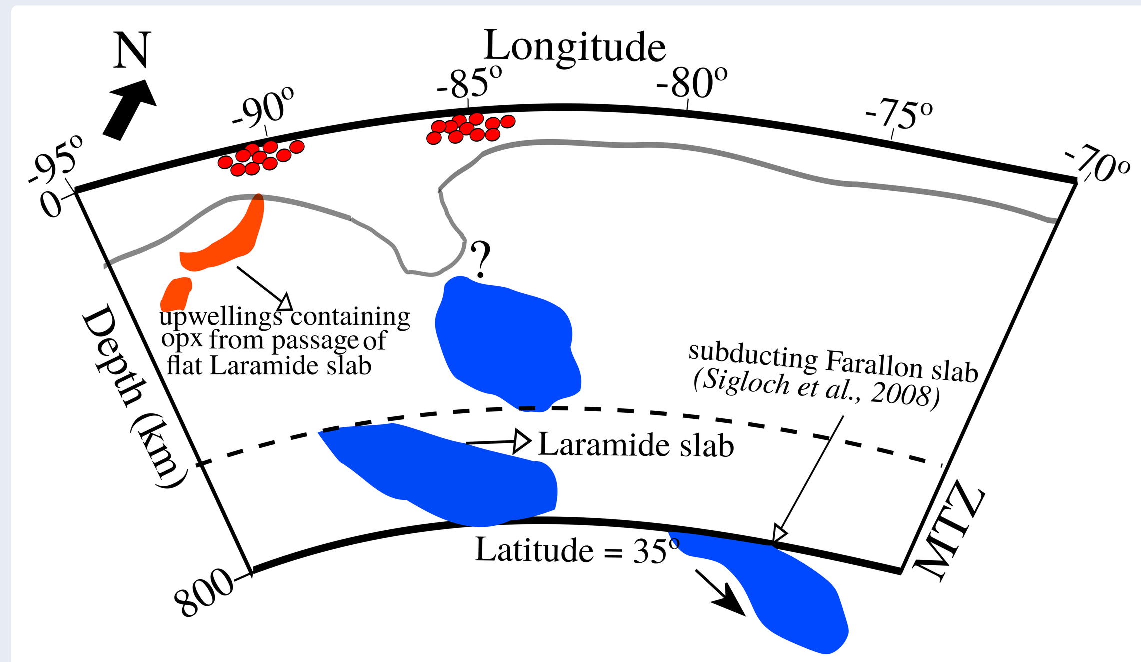

Figure 6: Cartoon representation of our model. Lithosphere is marked by grey line and the changes in lithospheric thickness acts as stress concentrators generating earthquakes. The low-velocity anomalies (red) may be from Opx enrichment above the flat Laramide slab. The high-velocity anomalies might be indicative of fragments of Farallon slab subduction based on the compilation of other tomography studies in this region.

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References

[1] Powell, Christine A., et al. "A seismotectonic model for the 300-kilometer-long eastern Tennessee seismic zone." Science 264.5159 (1994): 686-688.

[2] Biryol, C. Berk, et al. "Relationship between observed upper mantle structures and recent tectonic activity across the southeastern United States." Journal of Geophysical Research: Solid Earth 121.5 (2016): 3393-3414.

[3] Cammarano, Fabio, et al. "Inferring upper-mantle temperatures from seismic velocities." Physics of the Earth and Planetary Interiors 138.3-4 (2003): 197-222.

[4] Bangerth, W.; Dannberg, J.; Gassmoeller, R.; Heister, T. (2018), ASPECT v2.0.0 [software], doi: 10.5281/zenodo.1244587, url: https://doi.org/10.5281/zenodo.1244587