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Mantle Convection Models Constrained by Seismic Tomography

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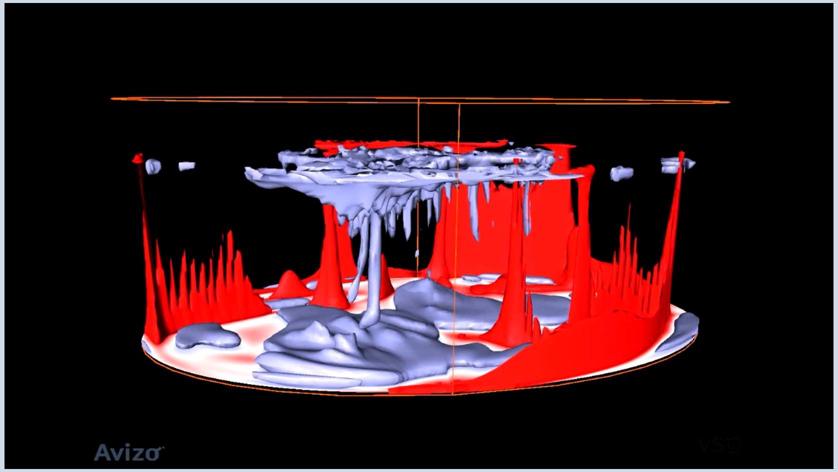
Overview

- Convection
  - Contains abundant physics and chemistry
  - Produces very small scale structure (limited by resolution)
  - Results are only as relevant as constraints, of which many are uncertain or unknown
  - A unique solution that is applicable to the Earth is very hard to find within the large model space
- Global Tomography
  - Image of the large scale lateral heterogeneity in the mantle that is consistent across many models which use different techniques and data
  - Can predict the longest wavelength features of geophysical observables (e.g. surface horizontal divergence and the geoid)
  - Poor small scale resolution (limited by data)

The Convection Model

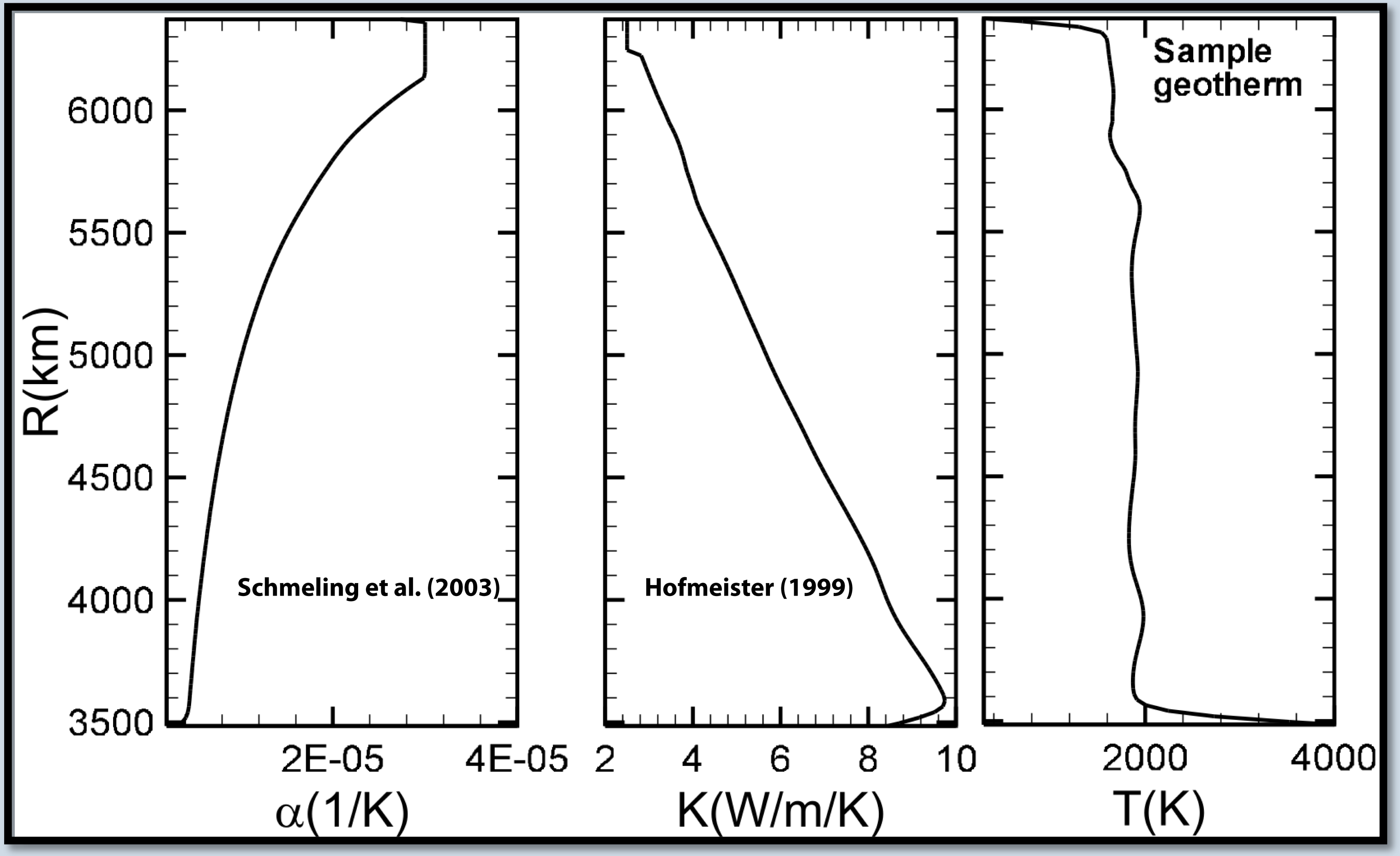
- Control Volume Method
- Approximations
  - Infinite Prandtl Number
  - Anelastically compressible
- Two internal phase transitions
  - 440km Olivine-Spinel
  - 660km Spinel-Perovskite
  - No post Perovskite in this presentation



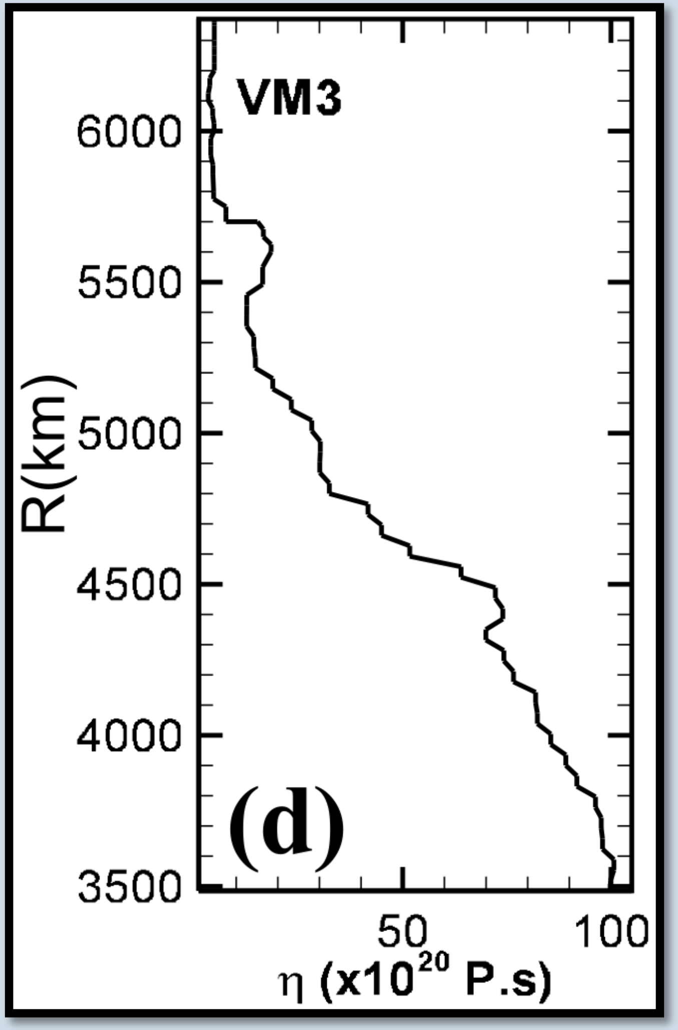
Reference

Shahnas & Peltier (2010) JGR vol. 115
Layered convection and the impacts of the perovskite-postperovskite phase transition on mantle dynamics under isochemical conditions.

P-T Dependent Physical Properties



The Convection Model



Radial viscosity profile

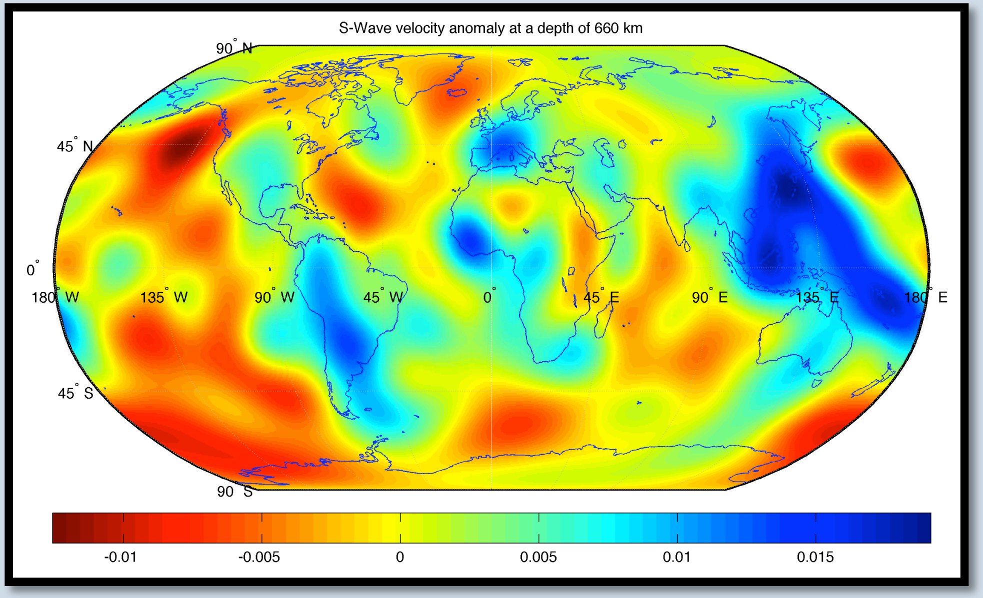
VM3 – Peltier (1998)

Code is capable of including lateral viscosity variations

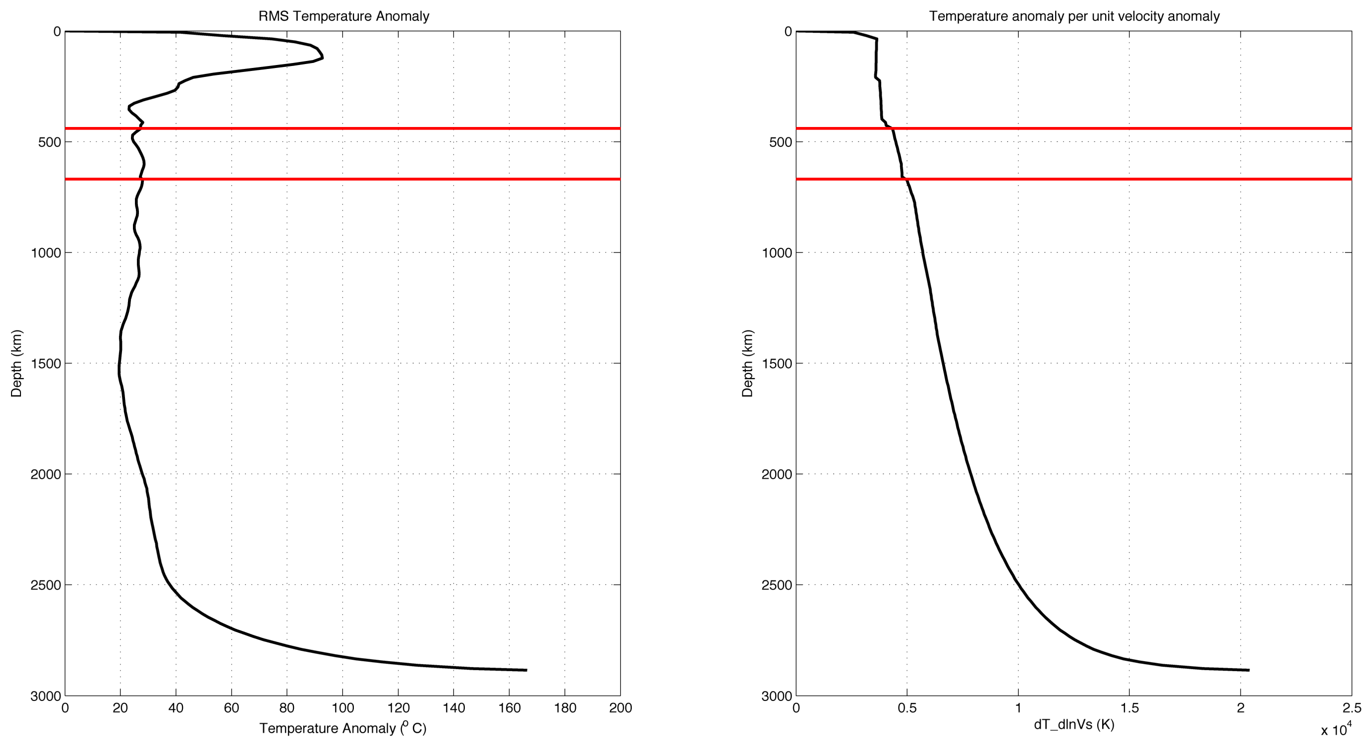
This is not exercised in this talk

The Tomography Model

- S20RTS model by Ritsema et al. (2004)
- 20 spherical harmonic degrees (degree and order 40 model is available)
- 21 depth nodes interpolated using cubic splines
- Data used
  - Phase velocities
  - Normal mode splitting functions
  - Body wave travel times

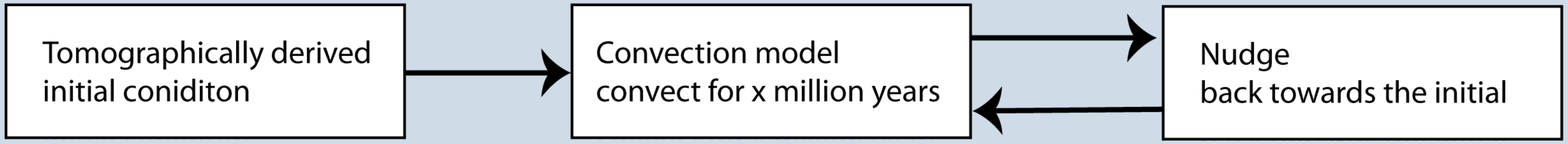


Mapping dVs to drho

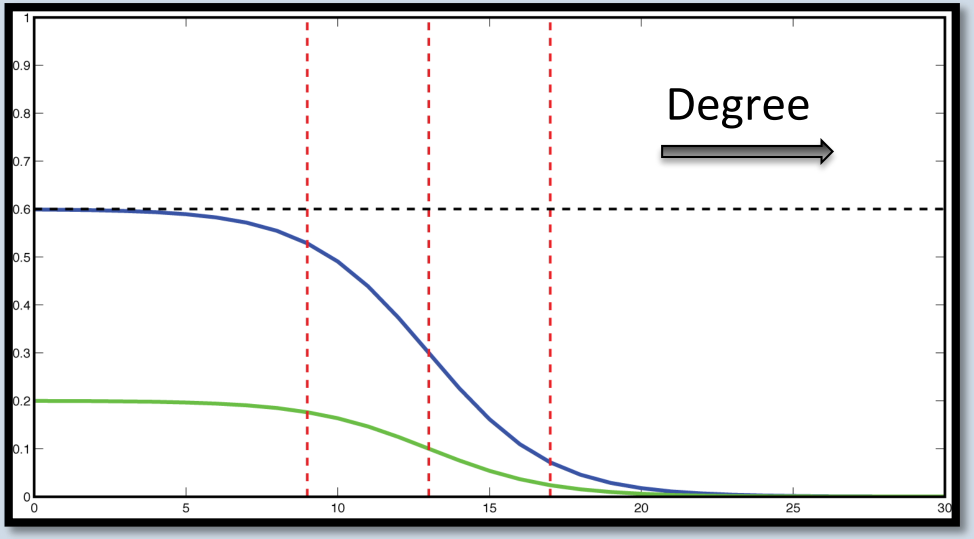


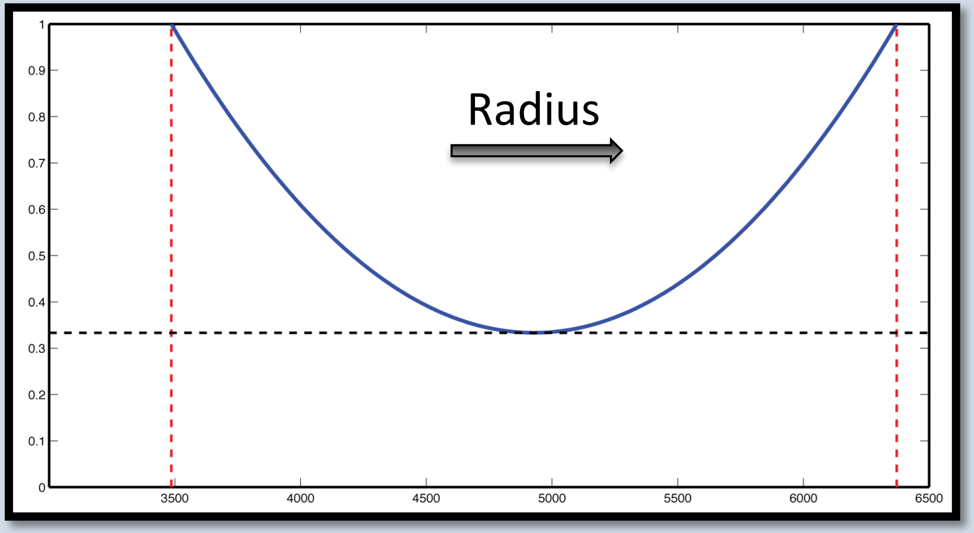
$$\rho = \bar{\rho}\left[1 - \alpha(T - T_r) + \frac{1}{K_T}(P - P_r)\right] + \Delta\rho_i(\Gamma_i - \Gamma_{ri})$$

The Nudging Methodology

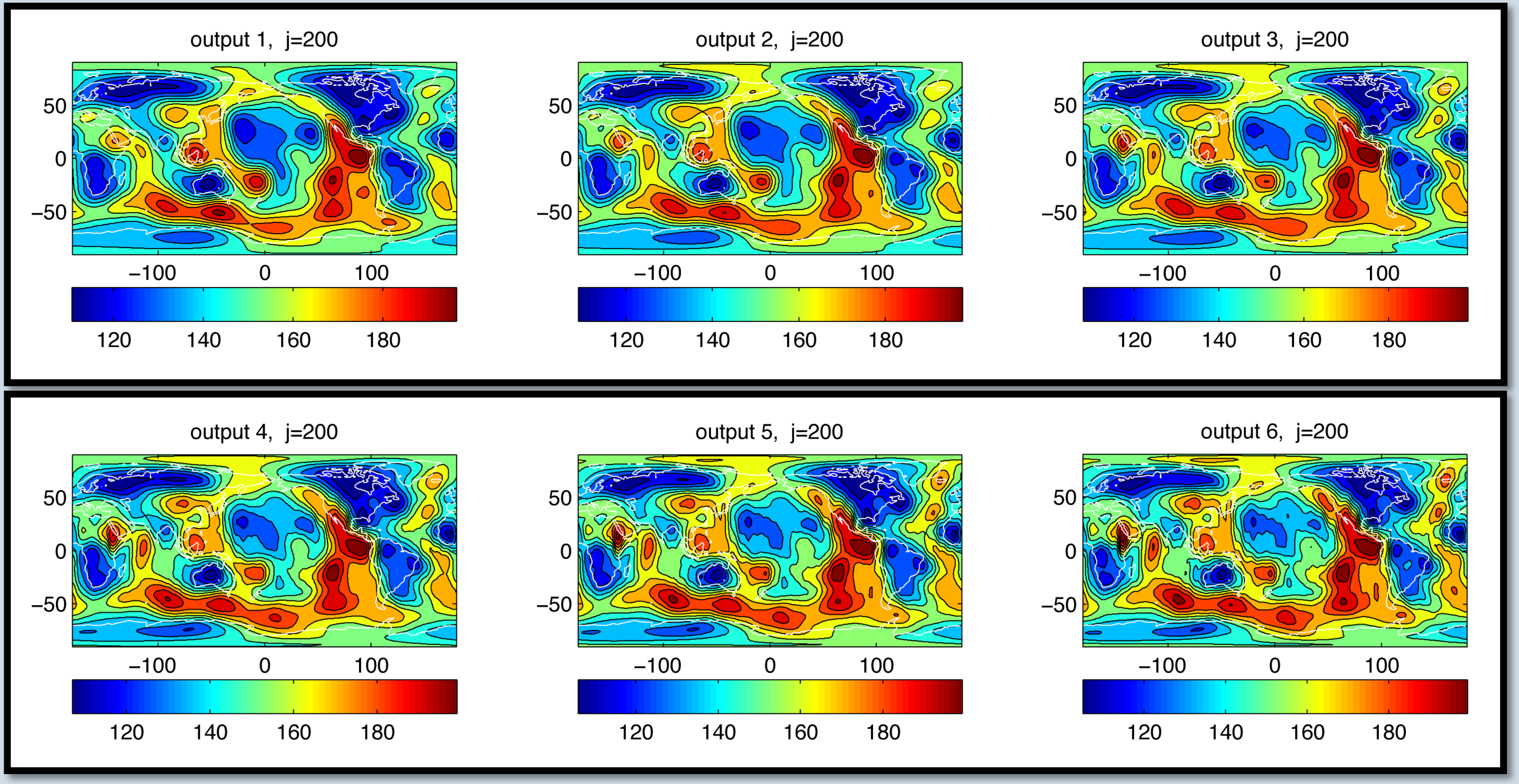


$$T^{\text{nudged}}_{l,m}(r) = T^{t}_{l,m}(r) + \kappa_l(r)\left[T^{\text{tomo}}_{l,m}(r) - T^{t}_{l,m}(r)\right]$$





Preliminary Results
Near Surface Temperature Field (<100km)



Durbin et al. (2011)

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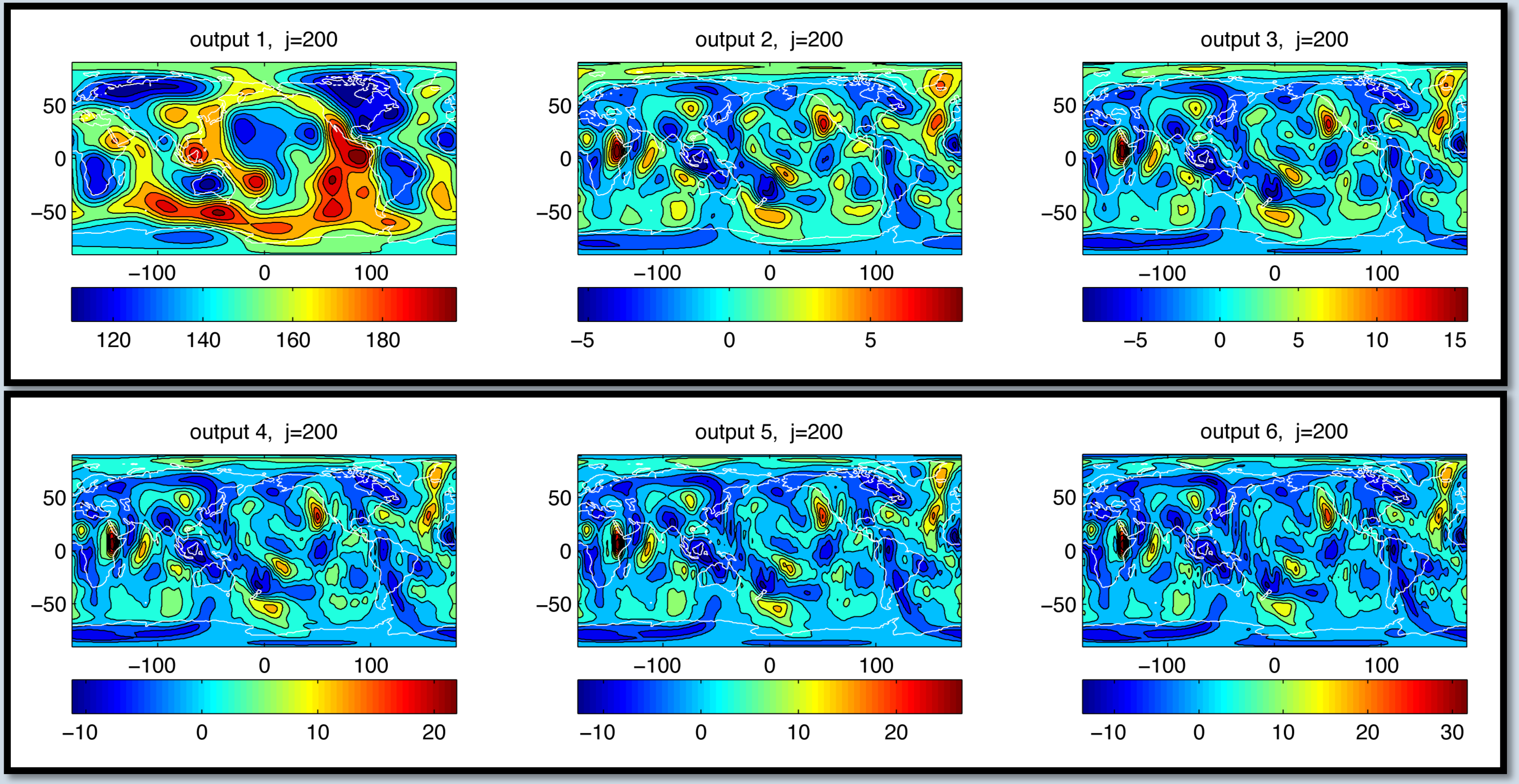
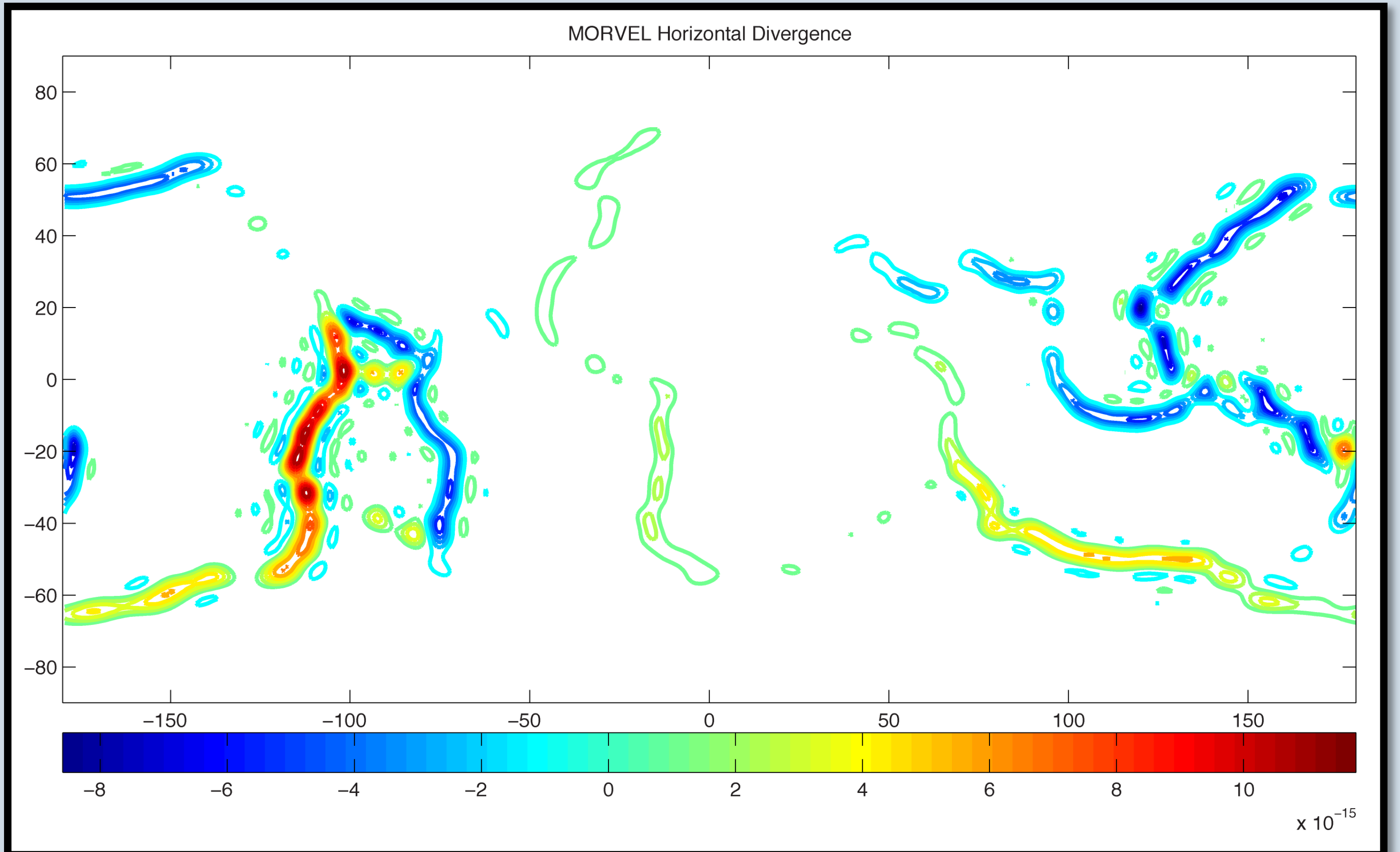


MORVEL
Horizontal Surface Divergence



Preliminary Results
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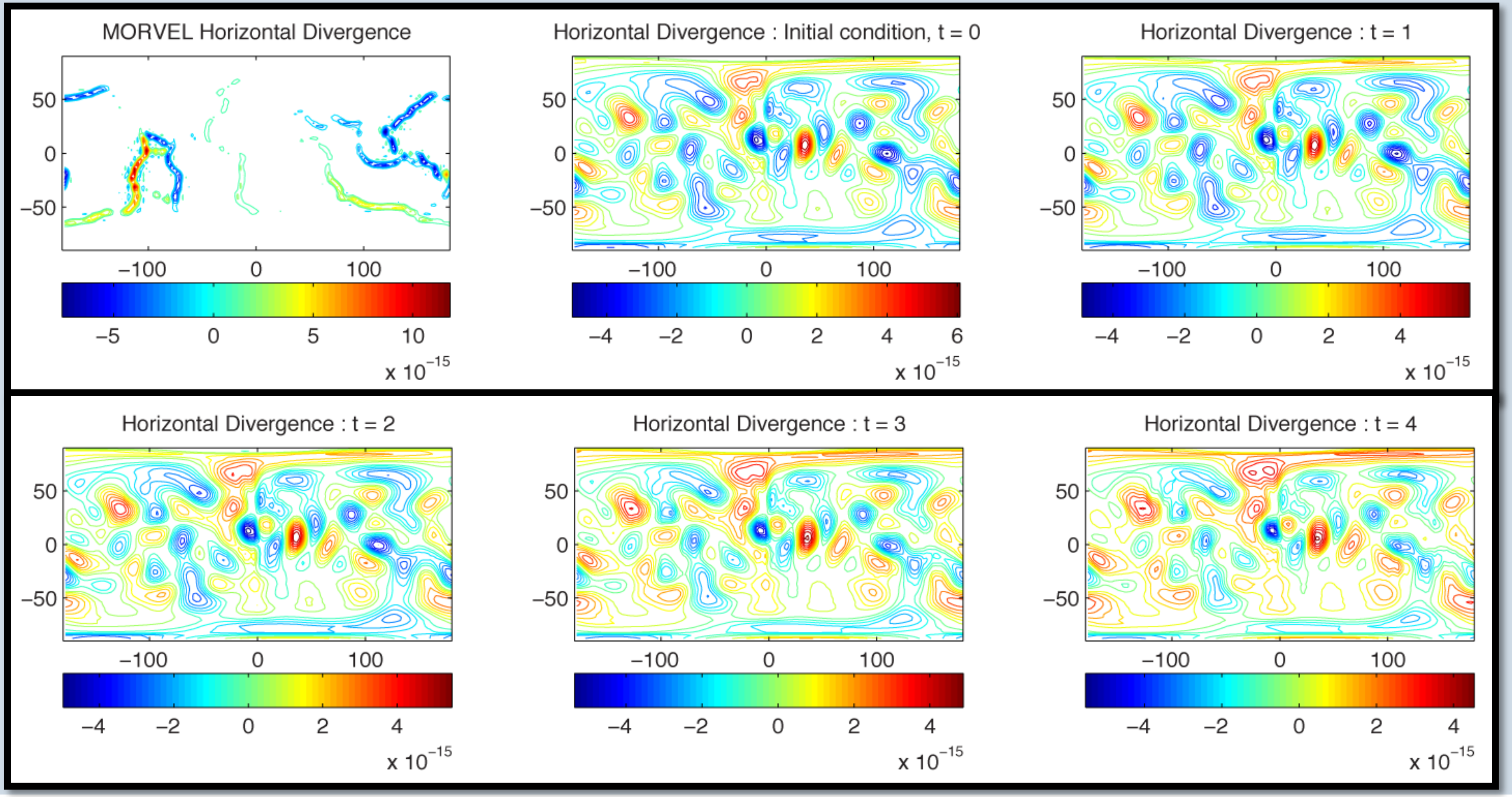
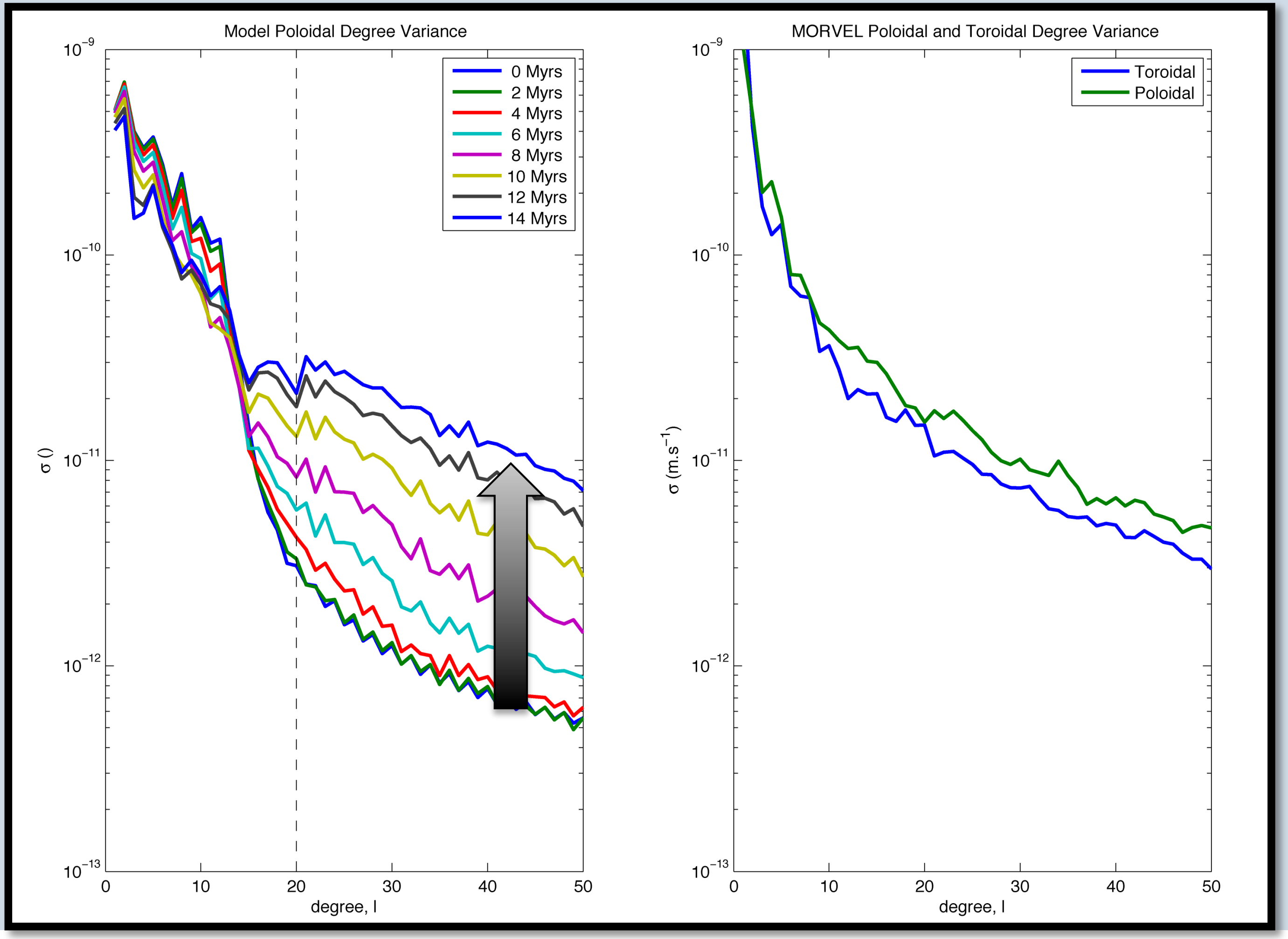
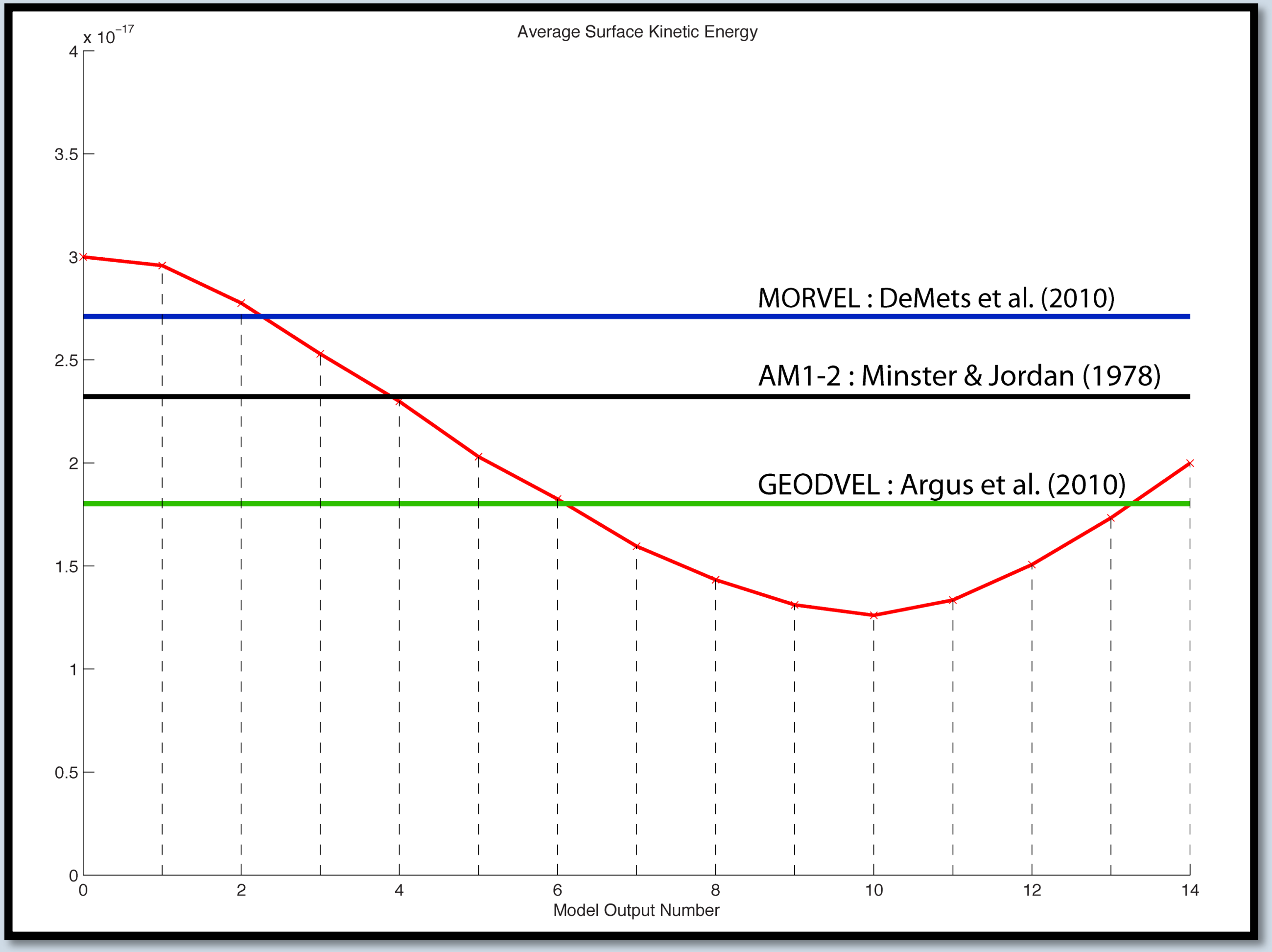


Preliminary Results
Poloidal Degree Variance



Preliminary Results
Surface Kinetic Energy



Conclusions

- Begun to develop methodology to use the structure imaged by seismic tomography to constrain models of mantle convection
- This produces a data assimilation model that generates mantle structure that is consistent with both the large scale images of tomography and the physics and chemistry contained within the convection model
- Basic implementations of such models
  - predict the pattern of surface horizontal divergence quite well
  - match the surface kinetic energy in current models of the motion of Earth's tectonic plates

Future Work

- Improve the scaling from seismic velocity to temperature and chemical heterogeneity
- Direct incorporation of lateral heterogeneity of bulk properties (viscosity, iron spin transition, chemical heterogeneity etc.)
- Constrain surface motions using models of plate motion
- Use newer, more detailed tomographic models containing more spherical harmonic degrees
- Compare the small scale structure produced by the convection model in subduction zones and mid-ocean ridges with high-resolution, local tomographic results