Influence of Dynamic Topography on Sea Level and its Rate of Change

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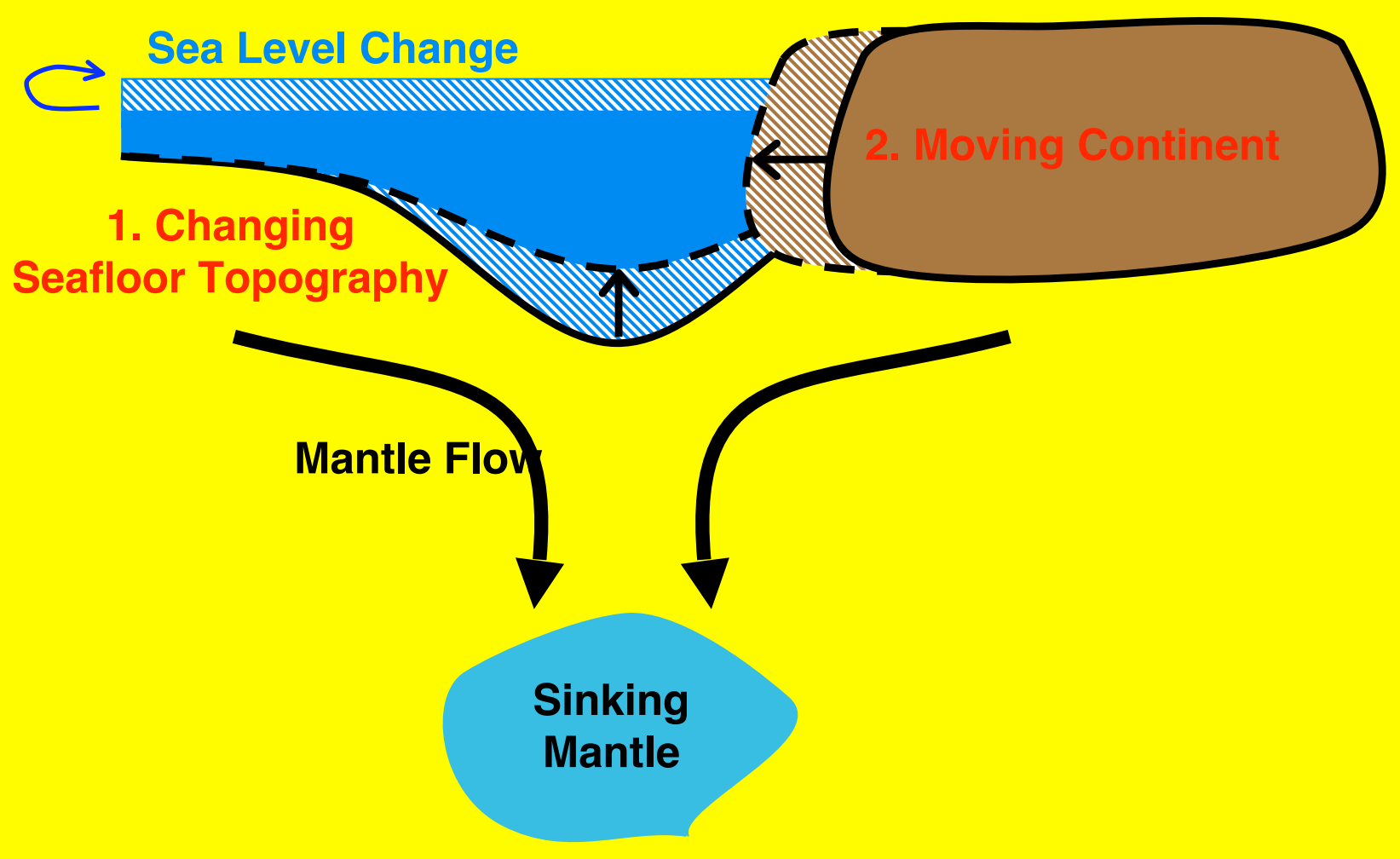
INTRODUCTION

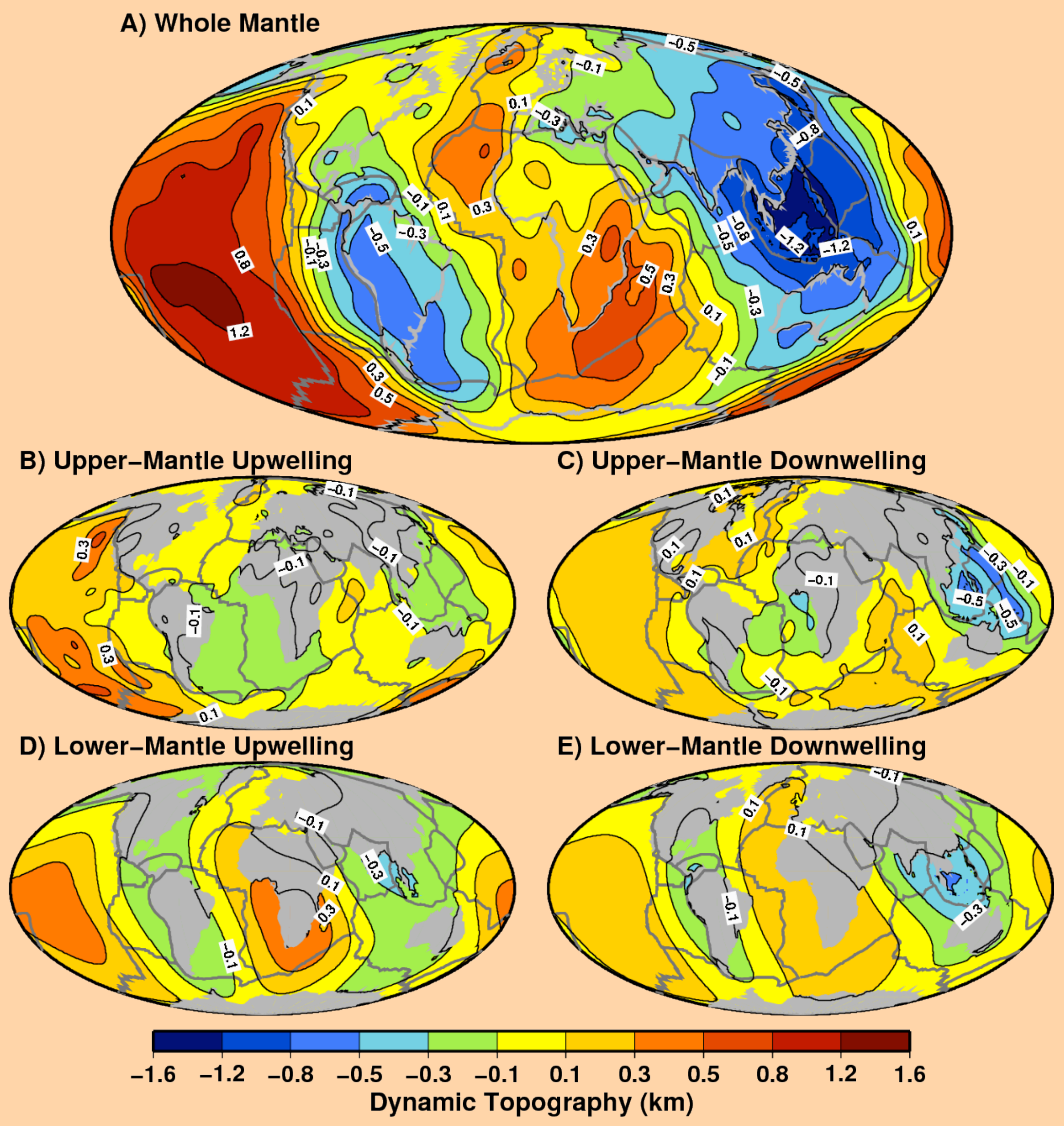
Convection of the mantle interior produces dynamic deflection of the Earth's surface with amplitudes of up to ±1.5 km. Is this "dynamic topography" occurs within the ocean basins, it changes the ocean basin volume and thus will offset sea level. This dynamic offset of sea level may change with time if either:

(1) Dynamic topography changes with time
(2) Continents move over the dynamic topography

We estimate the rate of sea level change due to both processes here using a time-dependent model of present-day mantle flow.



DYNAMIC TOPOGRAPHY AND THE SEA LEVEL OFFSET



We calculate dynamic topography *h* using:

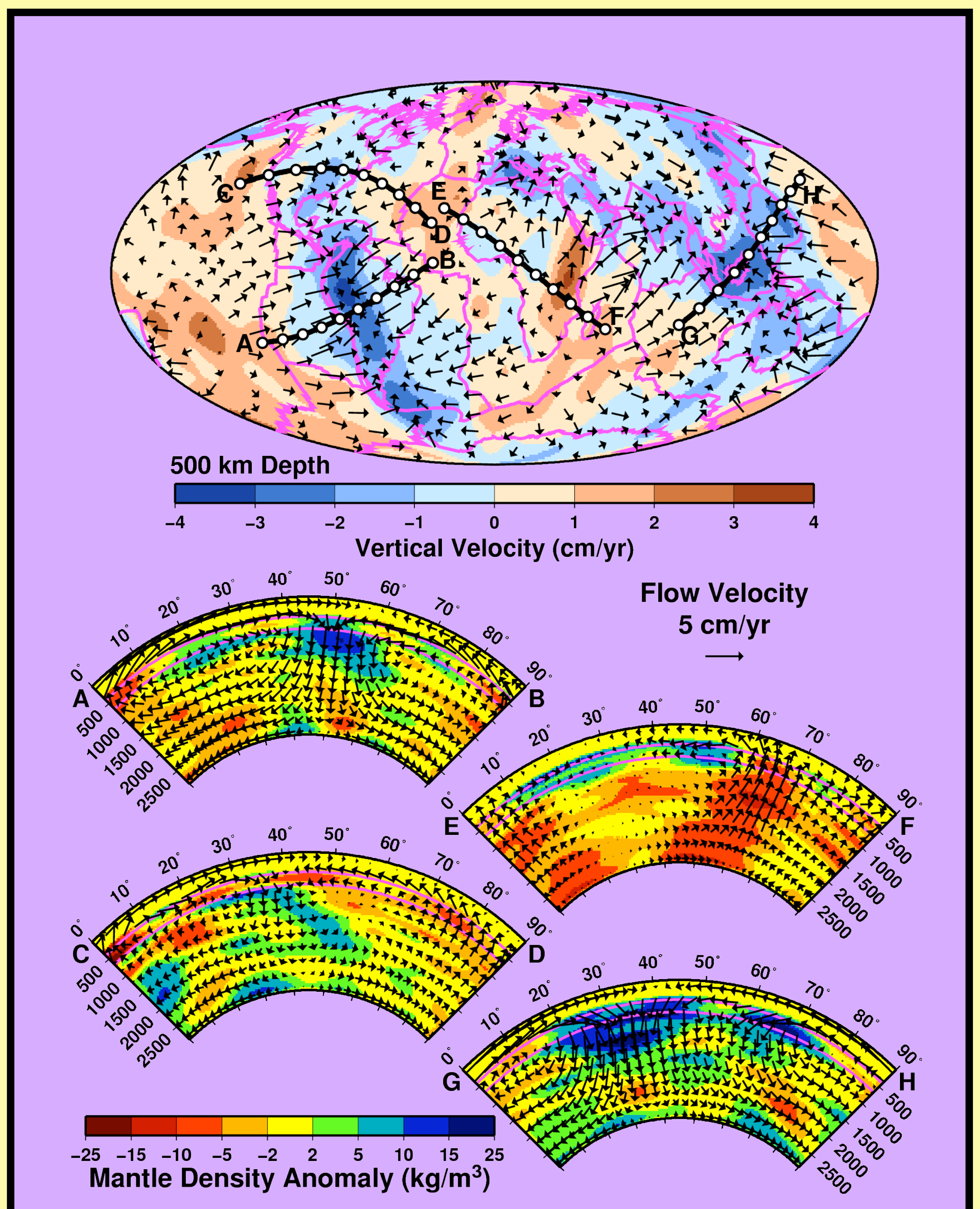
$$h = \sigma_{zz} / \Delta\rho g$$

where *g* = gravity, $\Delta\rho$ = surface density contrast, and σ_{zz} is the radial traction that mantle flow exerts on the free-slip surface. We calculate σ_{zz} from global flow models, and include perturbations associated with self-gravitation effects as described by *Zhong et al.* [2008] and now implemented in CitcomS. We measure dynamic topography relative to the degree-1 component of the geoid.

The average dynamic deflection of the surface is zero. However, continents preferentially mask negative dynamic topography because slabs tend to sink beneath continents. As a result, continents are depressed an average of 295 m while the seafloor is uplifted an average of 132 m. Because of isostatic compensation, eustatic sea level is thus positively offset by 92 m compared to an earth without internal density heterogeneity.

The relative contributions to the sea level offset are:

+23 m	Upper Mantle Upwelling
+22 m	Upper Mantle Downwelling
+25 m	Lower Mantle Upwelling
+23 m	Lower Mantle Downwelling
+92 m	**Whole Mantle Flow**



GLOBAL MANTLE FLOW MODELS

We use the CIG-supported finite element code *CitComS* [*Zhong et al.,* 2000; *Tan et al.,* 2006] to solve for global mantle flow. Dynamic topography can be determined from an instantaneous flow calculation; determining its rate of change requires solution of the energy equation to constrain advection of density heterogeneity by the flow field.

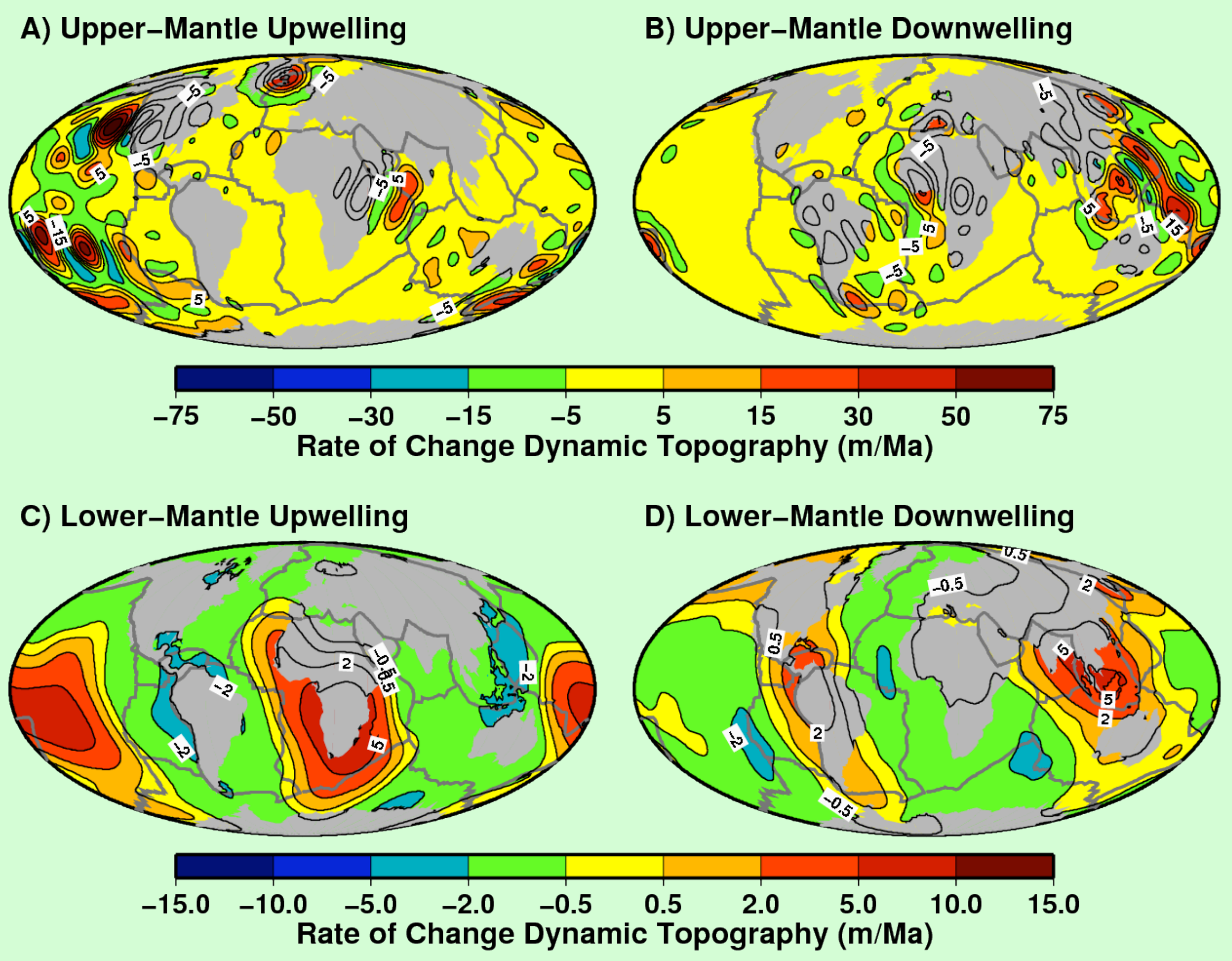
Model Setup and Initial Conditions

We assign mantle density heterogeneity inferred from seismic tomography (S20RTSb, *Ritemsa et al.,* 2004) using a conversion factor of 0.15 g cm^{-3} km^{-1} s. We use a free-slip boundary condition on the top and bottom boundaries. We use 105 km horizontal resolution and 25 to 100 km vertical resolution in the upper and lower mantles, respectively. The flow calculations are similar to those used by Conrad et al. [2007] to predict seismic anisotropy.

Viscosity Structure:

We use a layered mantle viscosity structure where the lower lower mantle, asthenosphere, and lithosphere have viscosities 50, 0.1, and 30 times the upper mantle viscosity.

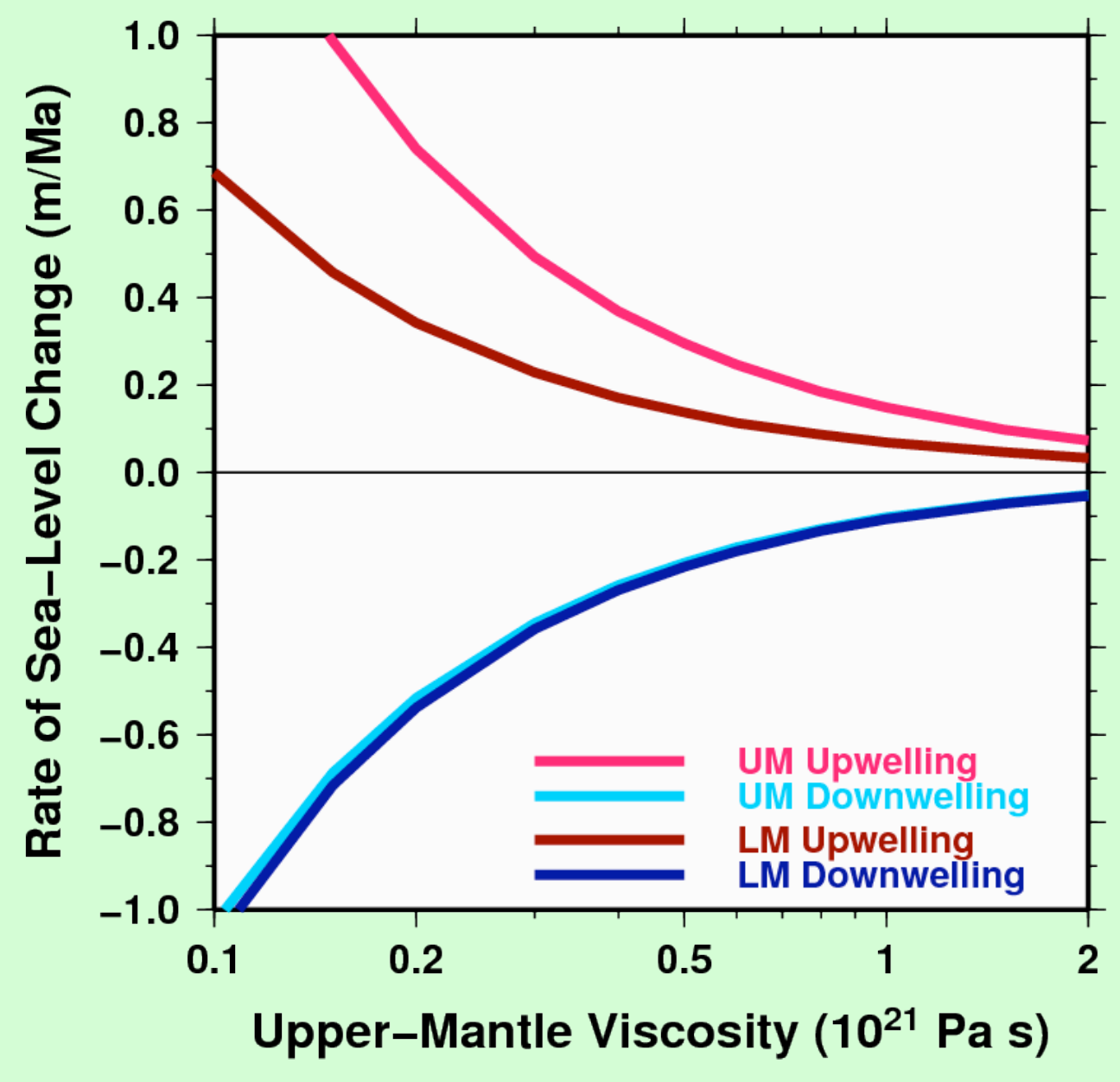
TIME-DERIVATIVE OF DYNAMIC TOPOGRAPHY



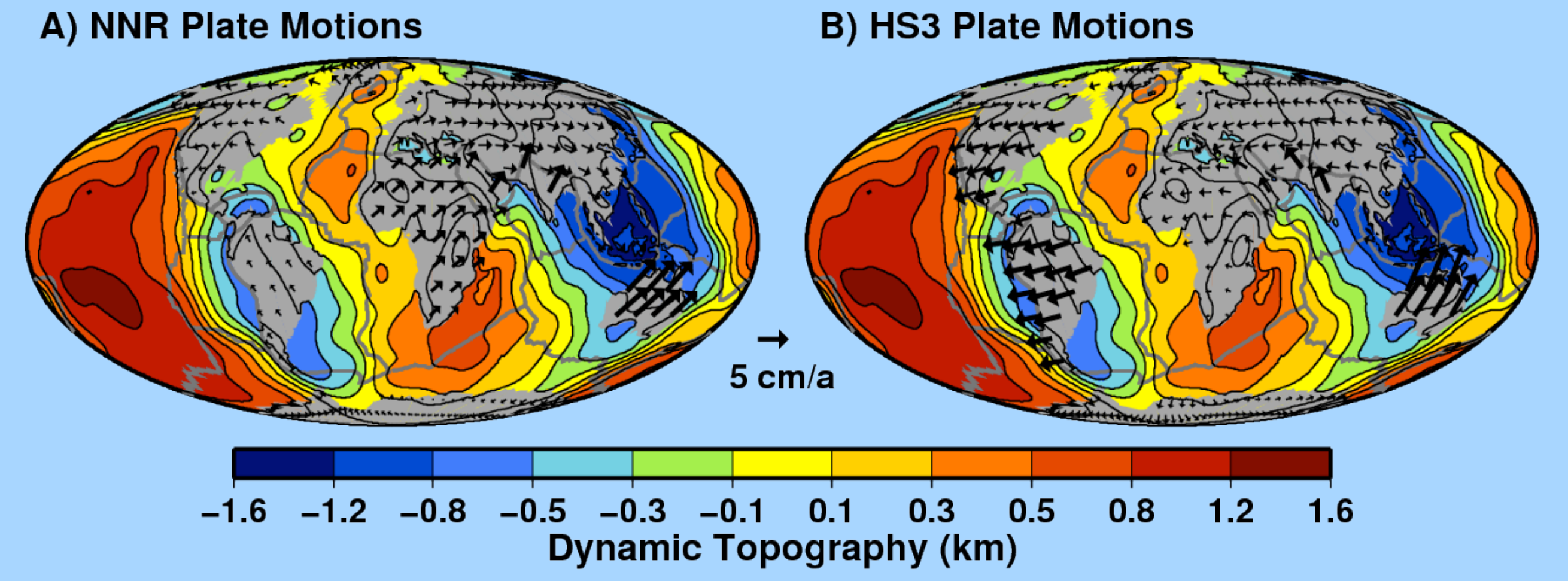
We calculate sea level change caused by the time-dependent deflection of the seafloor by comparing the sea level offset for the present-day to the sea level offset that is produced after mantle density heterogeneities have been advected forward in time by the mantle flow field. Because of the different viscosities of the upper and lower mantles, we solve for the contribution of each separately and advect the flow forward in time by 1.0 and 2.0 Myr, respectively. We find growing dynamic topography above both active upwellings and active downwellings. Above upwellings, growing topography occurs because negative density heterogeneity moves closer to the surface, where it can induce more uplift. Above downwellings, growing topography is caused by a decreasing negative topography associated with movement of positive density heterogeneity downward away from the surface.

The apparent uplift above downwelling is probably not physically meaningful as our models do not account for constant replenishment of slab material by subduction. This should not be a problem for topography above upwellings.

The rate of sea level change associated with each mantle contribution (see figure on right) is inversely proportional to the absolute mantle viscosity (expressed here as η_{um}).



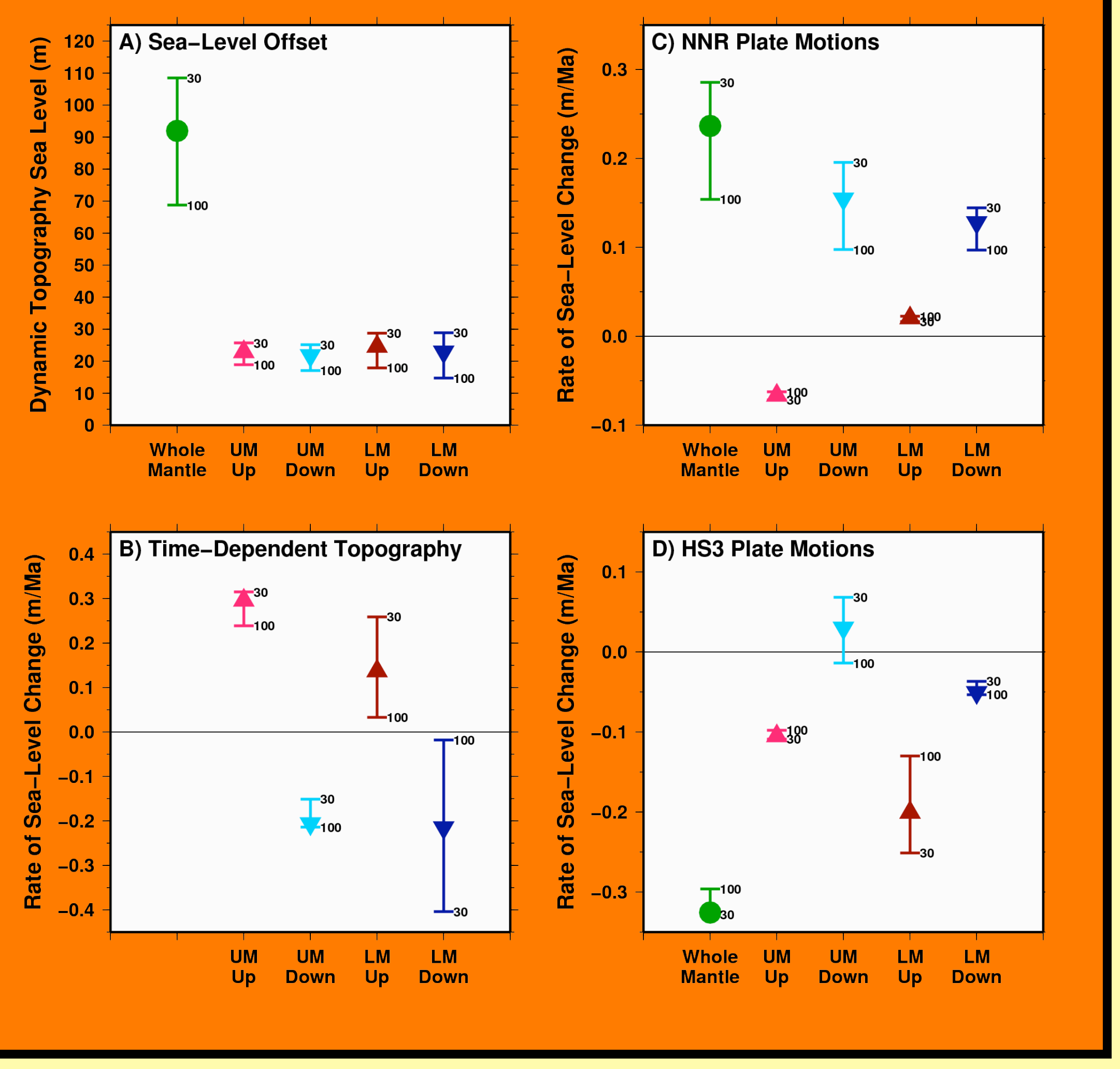
CONTINENTAL MOTION OVER DYNAMIC TOPOGRAPHY



To determine how continental motion over the present-day dynamic topography field affects sea level, we compare the sea level offset for the present-day (92 m) to the offset after moving the continents forward in time by 5 Myr. We impose plate motions in both the No-Net-Rotation (NNR, *DeMets et al*. [1994]) and the HS3 (*Gripp & Gordon* [2002], which includes nearly 5 cm/yr or westward net rotation) reference frames. We find that the NNR frame produces 0.24 m/Myr of sea level rise while the HS3 frame produces 0.33 m/Myr of sea level drop. The difference is primarily caused by the motion of Asia relative to the depressed topography near southeast Asia.

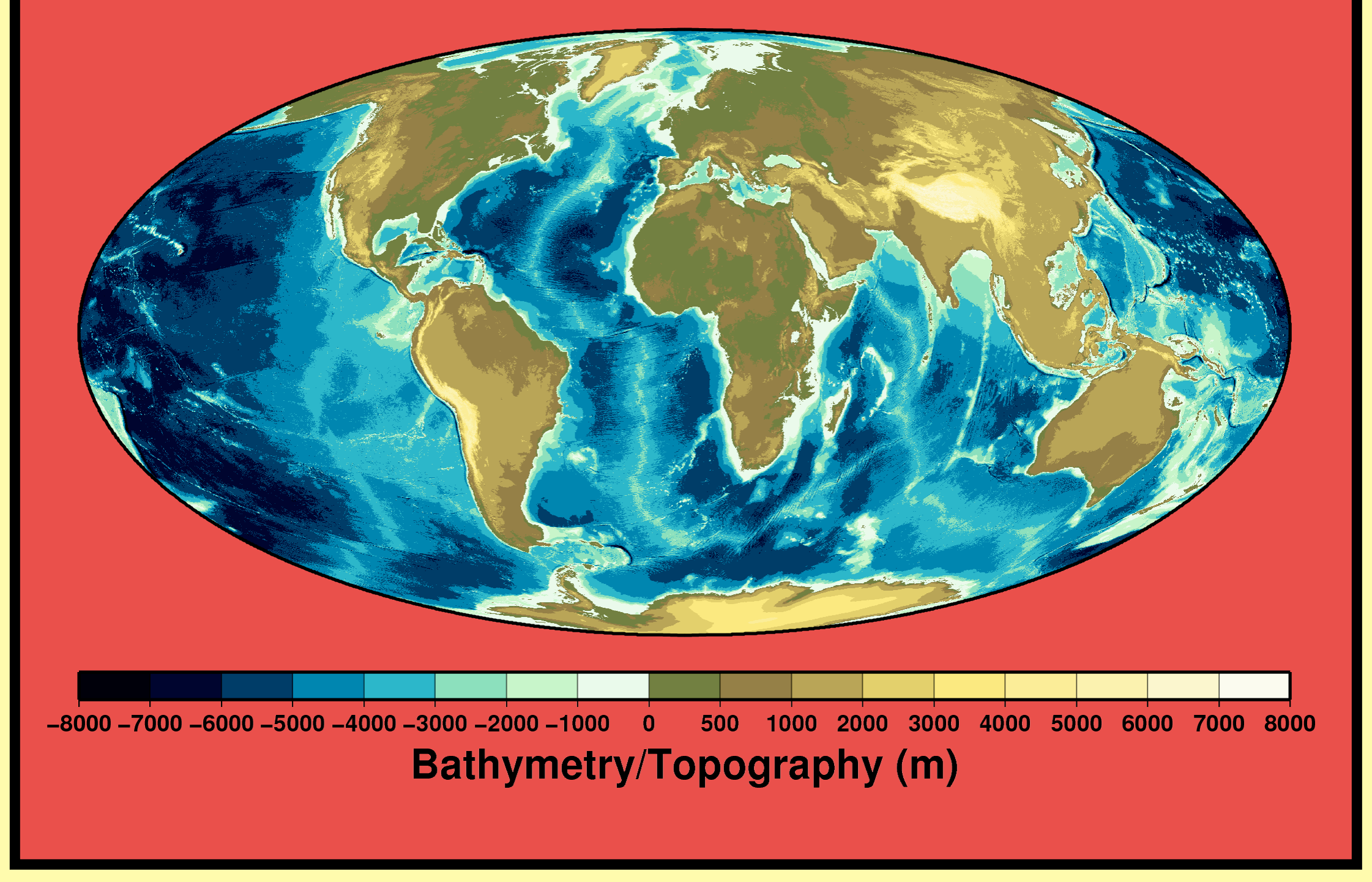
SUMMARY: DYNAMIC SEA LEVEL OFFSET AND AND ITS RATE OF CHANGE

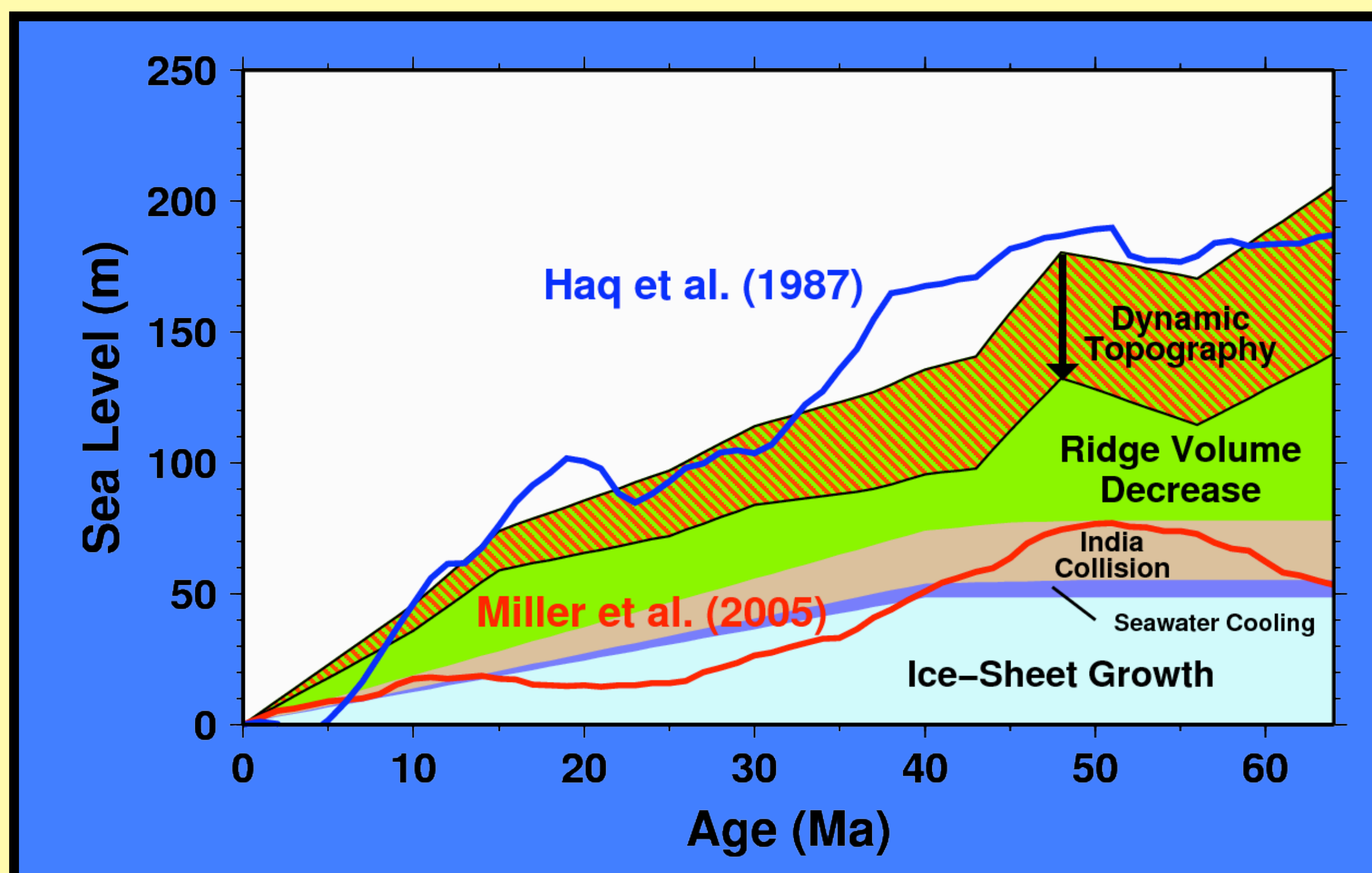
We estimate the contributions to the sea level offset and it rate of change for a range for values of the lower mantle viscosity, which is the quantity that produces the largest variations in amplitudes within geophysically-reasonable limits. Taken together, these results suggest that dynamic topography is currently producing sea level rise, with a rate up to about 1 m/Myr.



A WORLD WITHOUT MANTLE DYNAMICS

By removing dynamic deflections of Earth's topography and geoid from the Earth's present-day topography and sea surface, and by dropping sea level 92 m, we create an image of how the Earth would look in the absence of a dynamic interior.





We compare our estimate of up to 1 m/Myr of sea level rise caused by dynamic topography (orange hatches) with estimates of Cenozoic sea level drop caused by decreasing ridge volume (green [*Xu et al.,* 2006)], ocean area increase due to the India-Asia collision (brown [*Harrison*, 1990]), and climatic cooling causing seawater cooling and ice sheet growth (blues [Harrison, 1990]), and to two estimates ofr Cenozoic sea level change (blue and red lines).

CONCLUSIONS

1. **For the present-day, dynamic topography positively offsets sea level by about 92±20 m.**
2. **Upwelling mantle flow is currently amplifying the sea level offset at a rate of up to 1 m/Myr (depending on mantle viscosity).**
3. **The downwelling contribution to sea level change is poorly constrained.**
4. **Continental motion over the present-day dynamic topography produces ±0.3 m/Myr of sea level change, depending on mantle reference frame.**
5. **If sustained during the Cenozoic, the dynamic topography contribution to sea level change (up to 1 m/Myr of rise) is comparable in magnitude, but opposite in sign, to contributions from other sources.**
6. **During a complete Wilson cycle, we speculate that sea level should fall during supercontinent stability and rise during periods of dispersal.**

References are available upon request. Also see:

Conrad, C.P., and L. Husson, Influence of dynamic topography on sea level and its rate of change, *Lithosphere, in press*, 2009.