Supplementary material for:

Geological, tomographic, kinematic and geodynamic constraints on the dynamics of sinking slabs

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Qualitative approach to picking slabs

The correlation of surface geological features indicative of subduction with sub-surface seismic tomography anomalies is a difficult process. To constrain the location of slabs, we used an iterative process as follows. We start by defining a slab to be one standard deviation away in the positive direction from any tomography model's median velocity perturbation. This provides us with a quantitative set of positive seismic velocity anomalies, indicative of a subducted slab. We then reconstruct paleo-subduction zones, using age ranges derived from assuming approximate sinking speeds, and correlate voluminous subduction zones with locations of slabs in tomography. Now we use our forward geodynamic models to also infer the location of slab material, and correlate this with slabs in tomography. Where all parcels intersect we may deduce that it is the approximate location of a slab (Figure S1, S2, S3). We perform each step in a 3D environment to constrain the lateral and radial location of a slab (Figure S4). We use 2D cross-sections for all available depth slices to constrain the maximum and minimum location of the slab. Disagreement of slab material location between tomography, geodynamic models, and kinematic models, may imply incorrect assumed sinking rate, poor absolute and relative plate motion constraints, slabs not sinking vertical, and poor resolution tomography, or a combination of these.

To provide subduction volume constraints on apparent slab locations we utilise plate convergence velocities along with an estimate for lithospheric thickness. Convergence velocity is derived from the relative motion of an overriding and subducting plate at each time step in the plate model. Oceanic lithosphere thickness is derived from the paleo-reconstruction model along with sampling age grids with a $1^\circ \times 1^\circ$ resolution (Müller et al., 2008). Using a Half-Space Cooling model truncated at 95 km (after Chapter 4.2 Schubert et al., 2001) the thickness of the lithosphere, z, is determined as

$$z = erf^{-1}\left(\frac{T_l - T_o}{T_m - T_o}\right) 2\sqrt{\kappa}\sqrt{age}, \tag{1}$$

where, erf^{-1} is the inverse of the error function, $T_l = 1300^\circ$C and is the isotherm of the lithosphere, $T_o = 0^\circ$ and is the surface temperature, $T_m = 1600^\circ$C and is the temperature of the mantle, $\kappa = 8 \times 10^{-8}$m/s and is the thermal diffusivity constant, and *age* is the age of the lithosphere sampled from the age grids. We calculate the volume of slab material as the convergence rate times the lithospheric thickness times each subduction segment length (from the resolution of the plate model). This provides a kinematic estimate on the amount of material that is entering the mantle at any given time. Correlation of kinematically estimated slab material and seismic tomography helps to constrain the evolution of a slab (Figure S1, S2, S3).

Supplementary figures

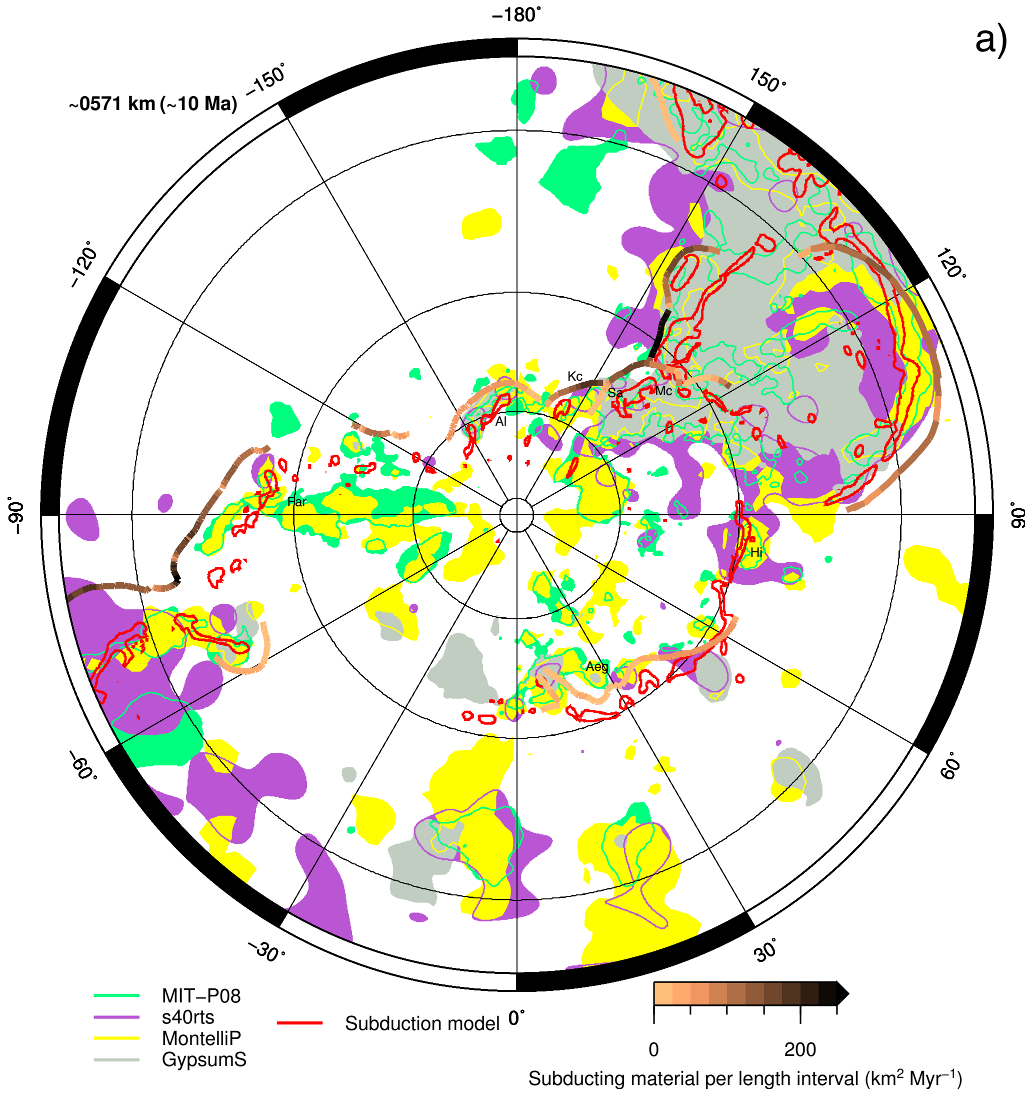

Figure S 1 cont.

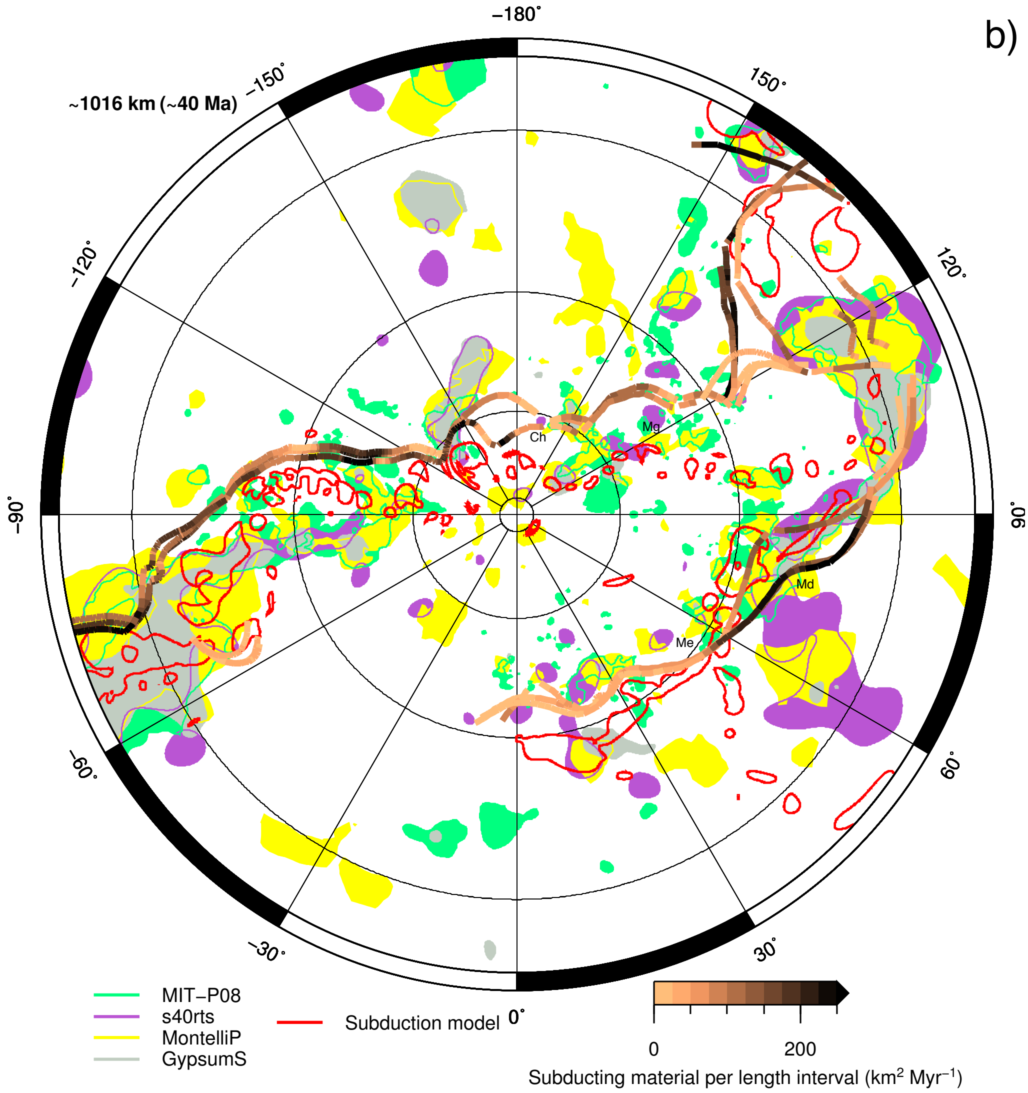

Figure S 1 cont.

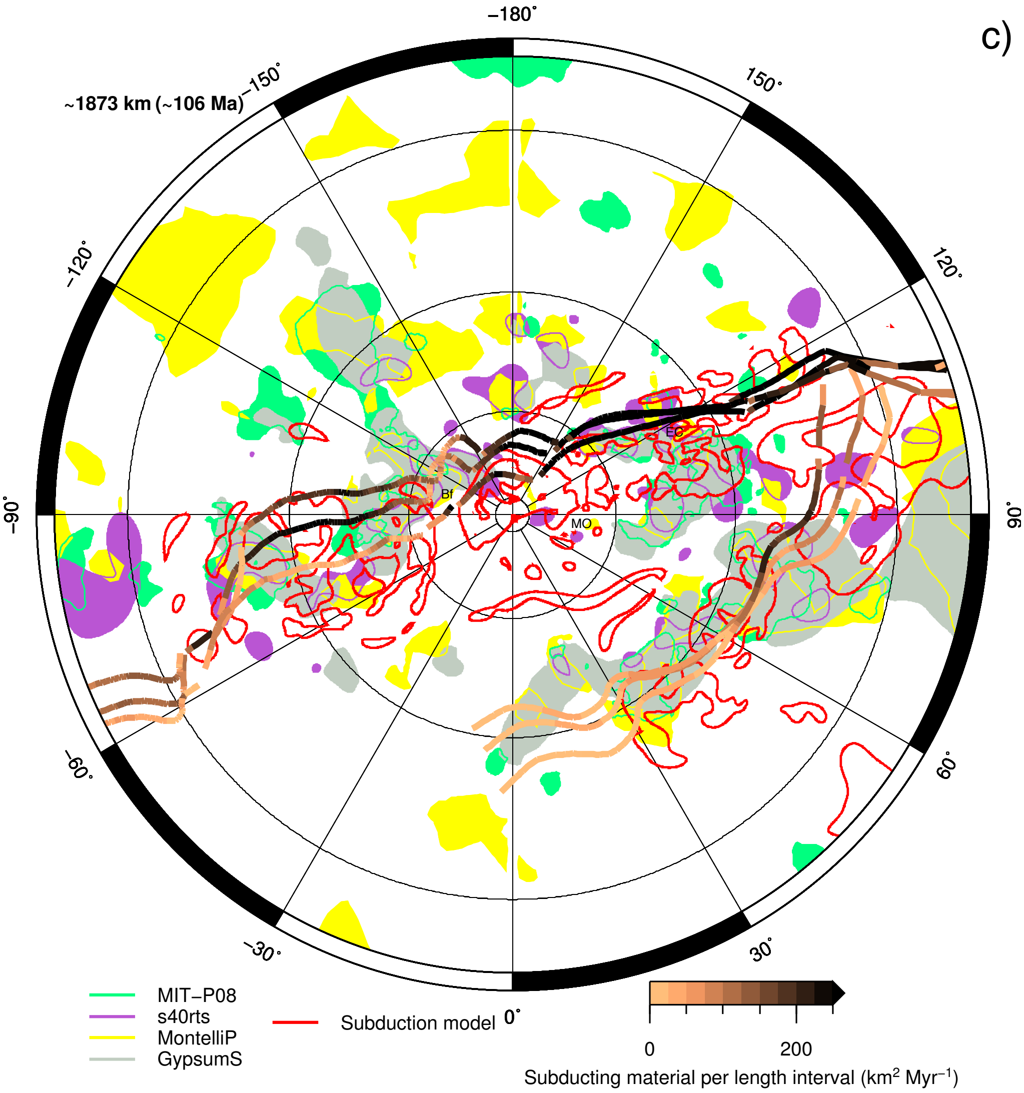

Figure S 1 cont.

Figure S 1: Horizontal depth slice comparing tomography models, Subduction reference frame kinematic information, and the Subduction reference frame model geodynamic output. The stereographic projection is centred on the North Pole, with gridlines every 30°. Depth in a) is 571 km for the geodynamic model and each tomography model slice corresponding to the closest depth available. Depth in b) is 1016 km for the geodynamic model and each tomography model slice corresponding to the closest depth available. Depth in c) is 1873 km for the geodynamic model and each tomography model slice corresponding to the closest depth available. Approximate slab location interpretations are represented by the text, Aeg (Aegean Tethys), Al (Aleutian), Bf (Beaufort), Ch (Chukchi), EC (East China), Far (Farallon), Hi (Himalayas), Kc (Kamchatka), Mc (Manchuria), Md (Maldives), Me (Mesopotamia), MO (Mongol-Okhotsk), Mg (Mongolian), and Sa (Sakhalin). The colors of each tomography model are shown in the legend, and represent the locations of statistically significant positive velocity perturbations. These values are +0.6% for GyPSum-S, +0.2% for MITP-08, +0.6% for s40rts, and +0.3% for Montelli-P. The -200 K temperature contour of the geodynamic model is overlain for comparison. The subducting material volume corresponds to kinematic reconstructions using the Subduction reference frame at a) 11 Ma, b) 48 Ma, 40 Ma, and 35 Ma, c) 134 Ma, 106 Ma, and 89 Ma. Here, the equivalent ages are derived from assuming a sinking rate of 52 mm/yr in the upper mantle, and 13±3 mm/yr in the lower mantle. Multiple times are used to provide an indication for the error in slab surface location in space and time.

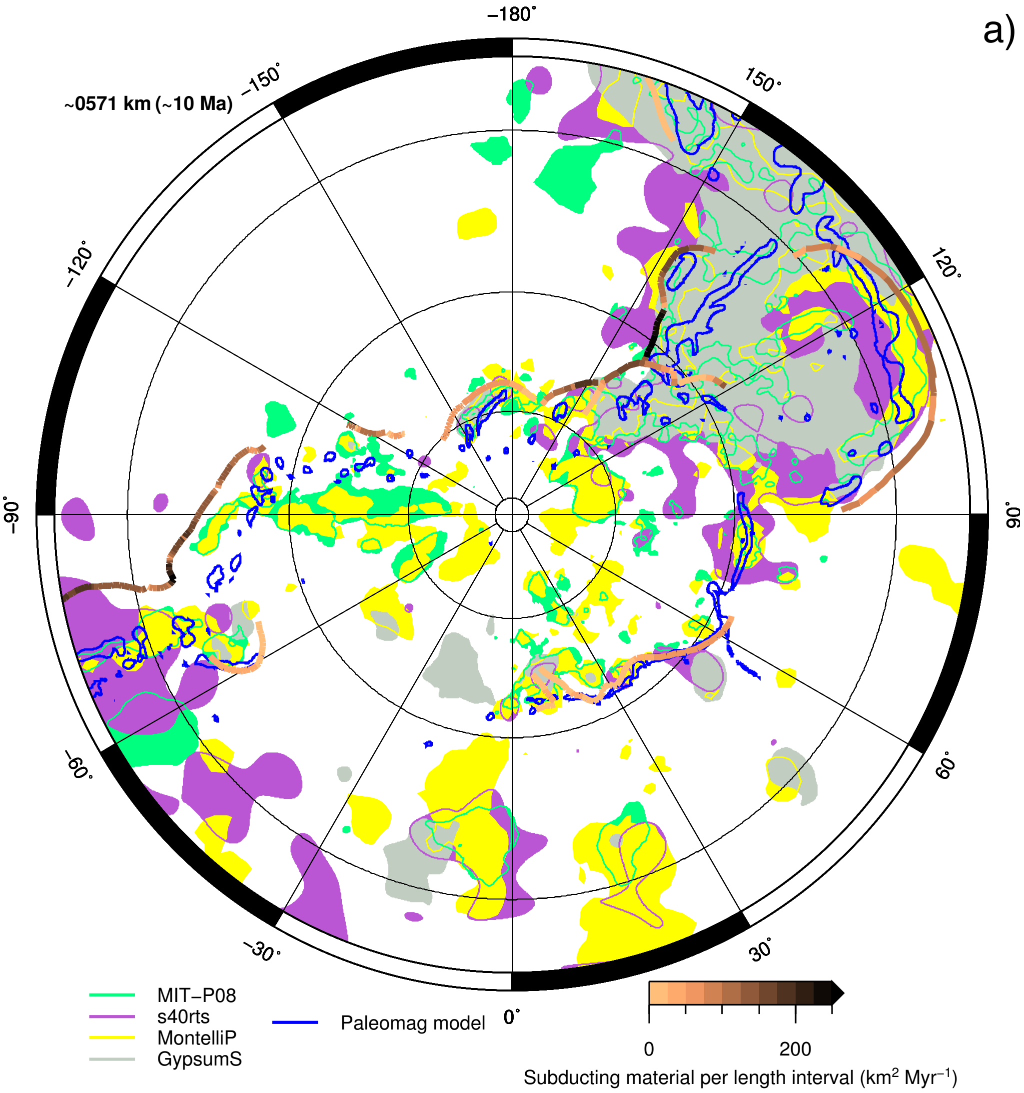

Figure S 2 cont.

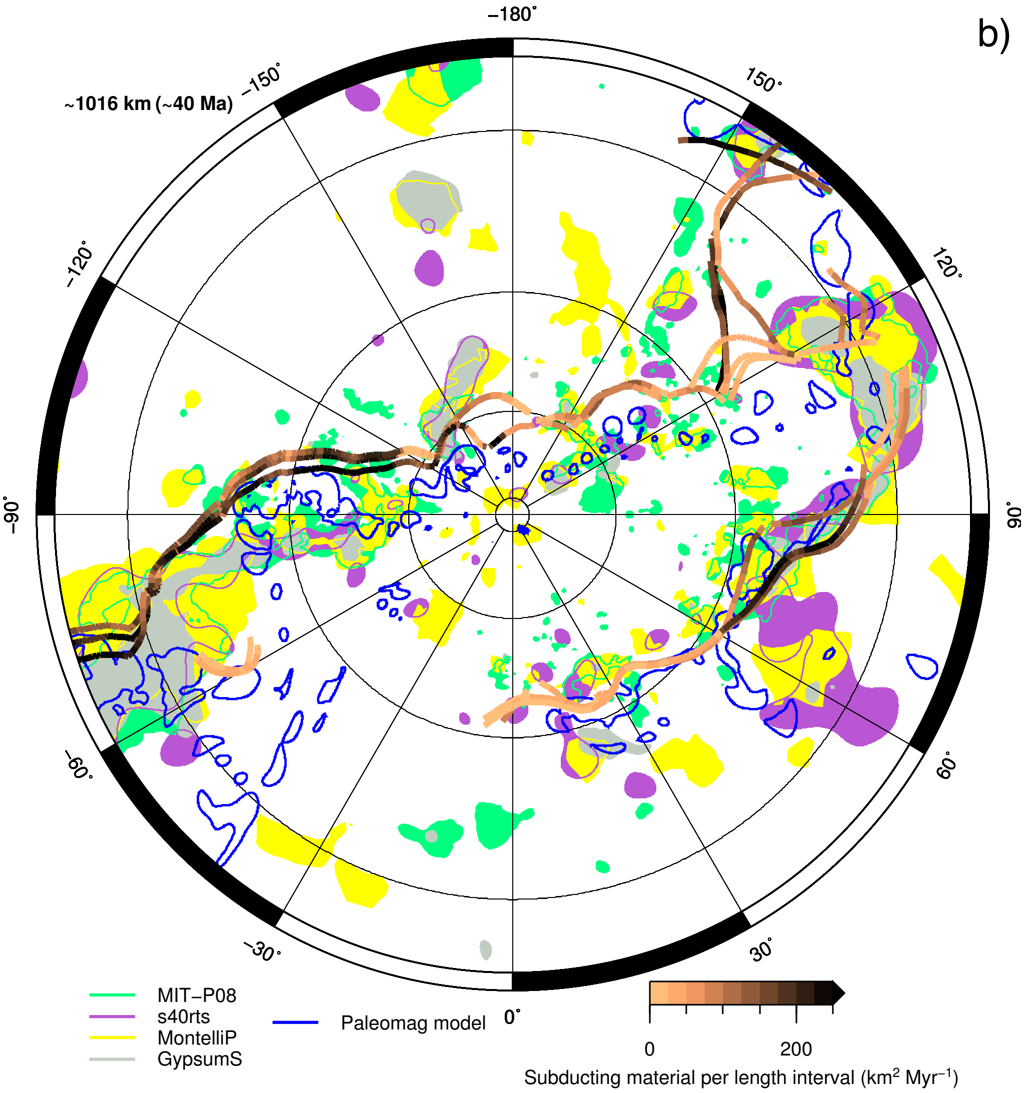

Figure S 2 cont.

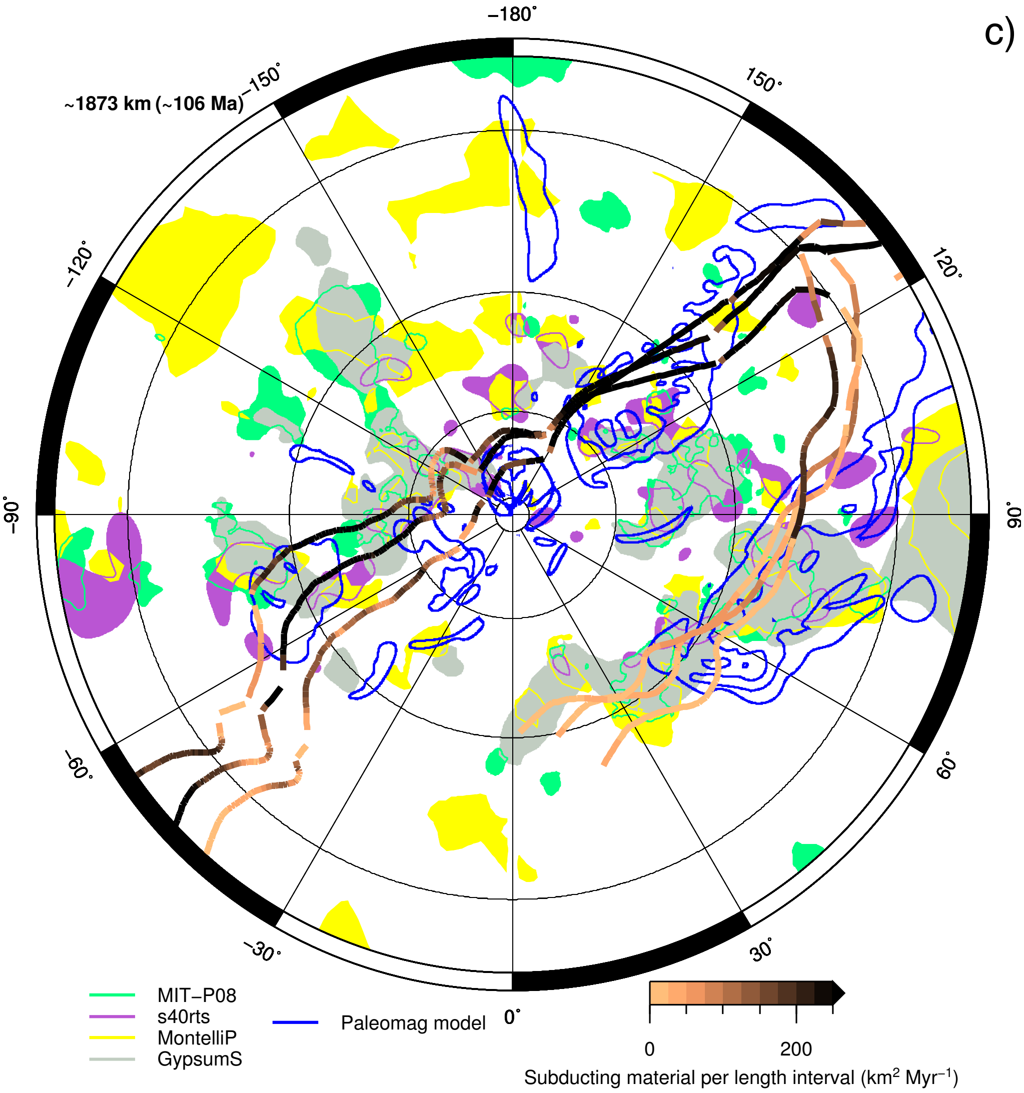

Figure S 2: Same as Figure S1 but with the Hybrid Paleomagnetic reference frame and geodynamic model output.

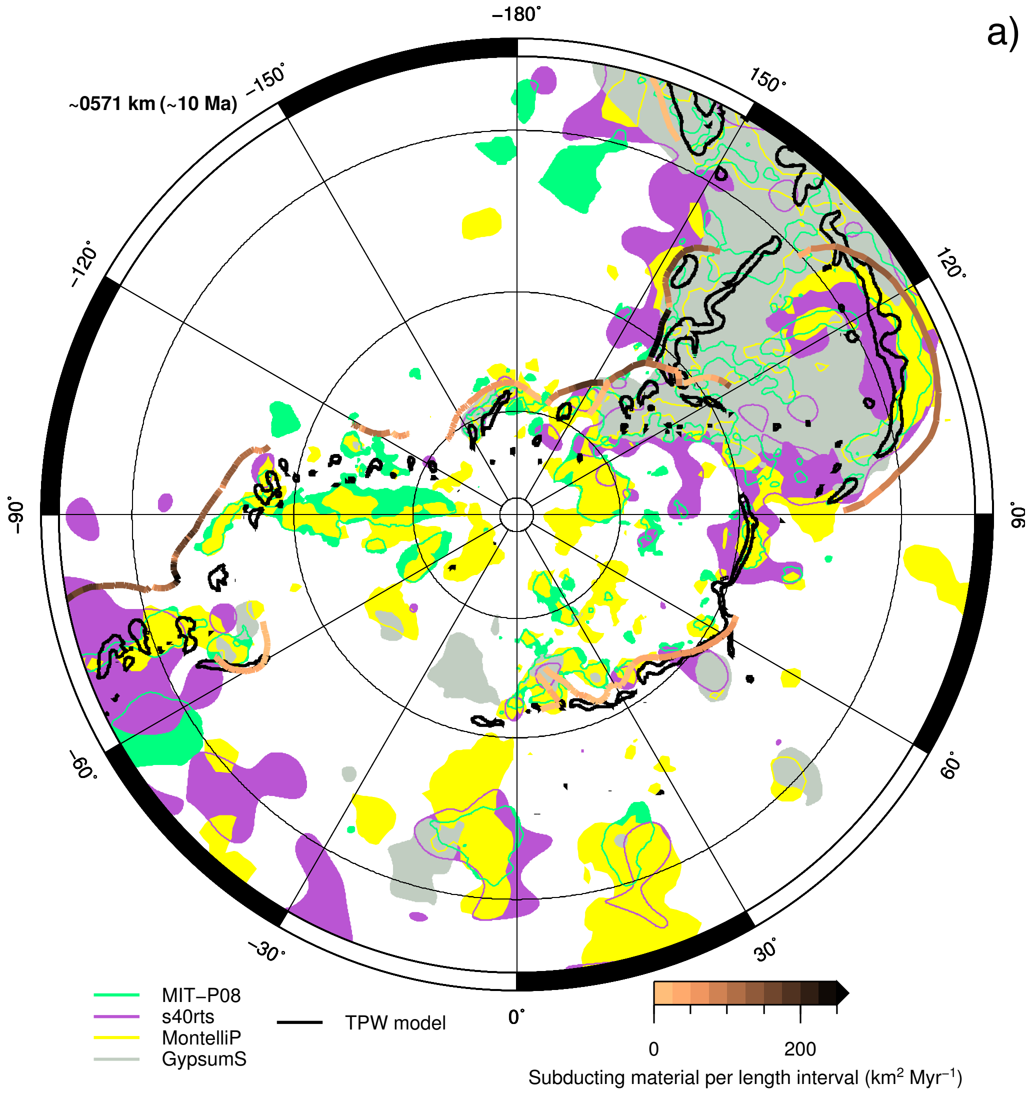

Figure S 3 cont.

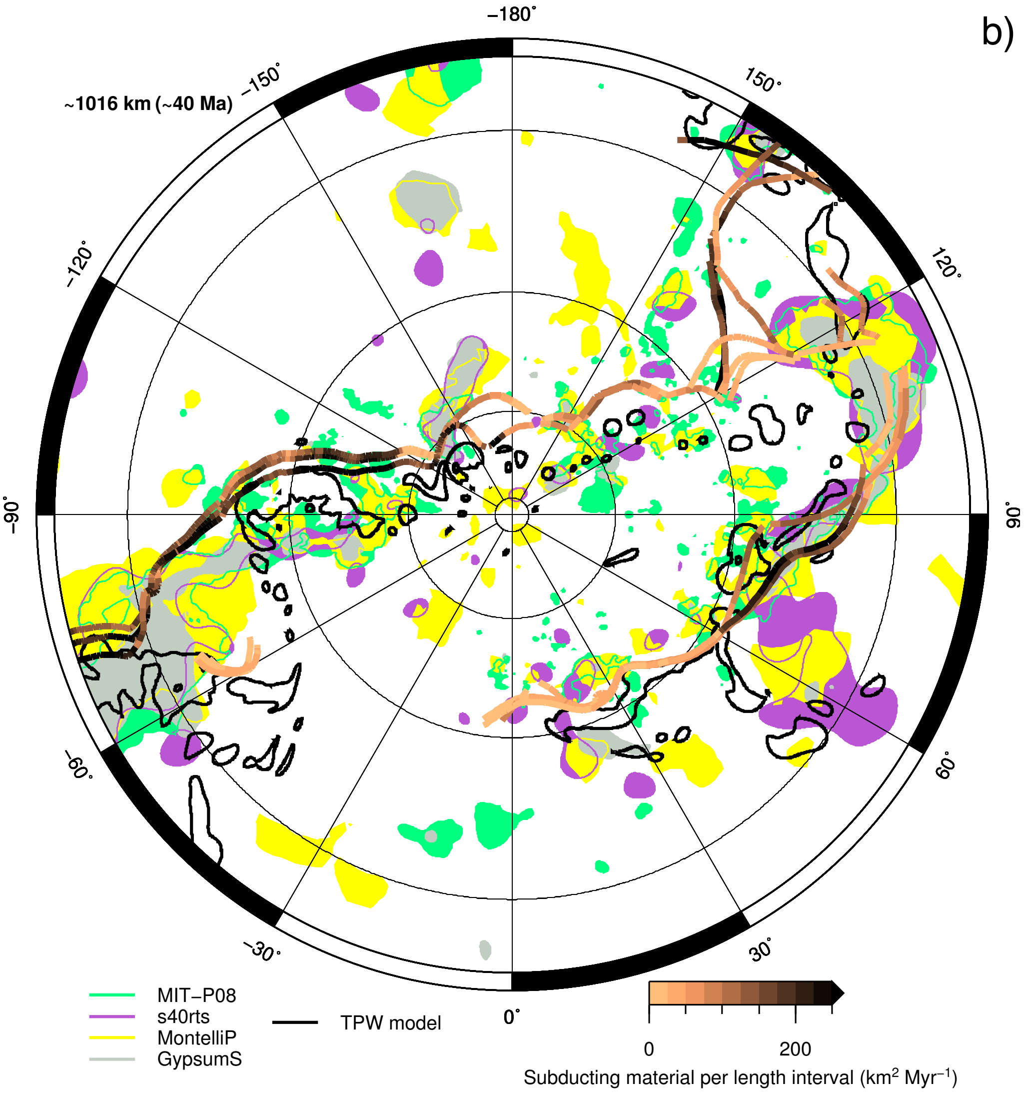

Figure S 3 cont.

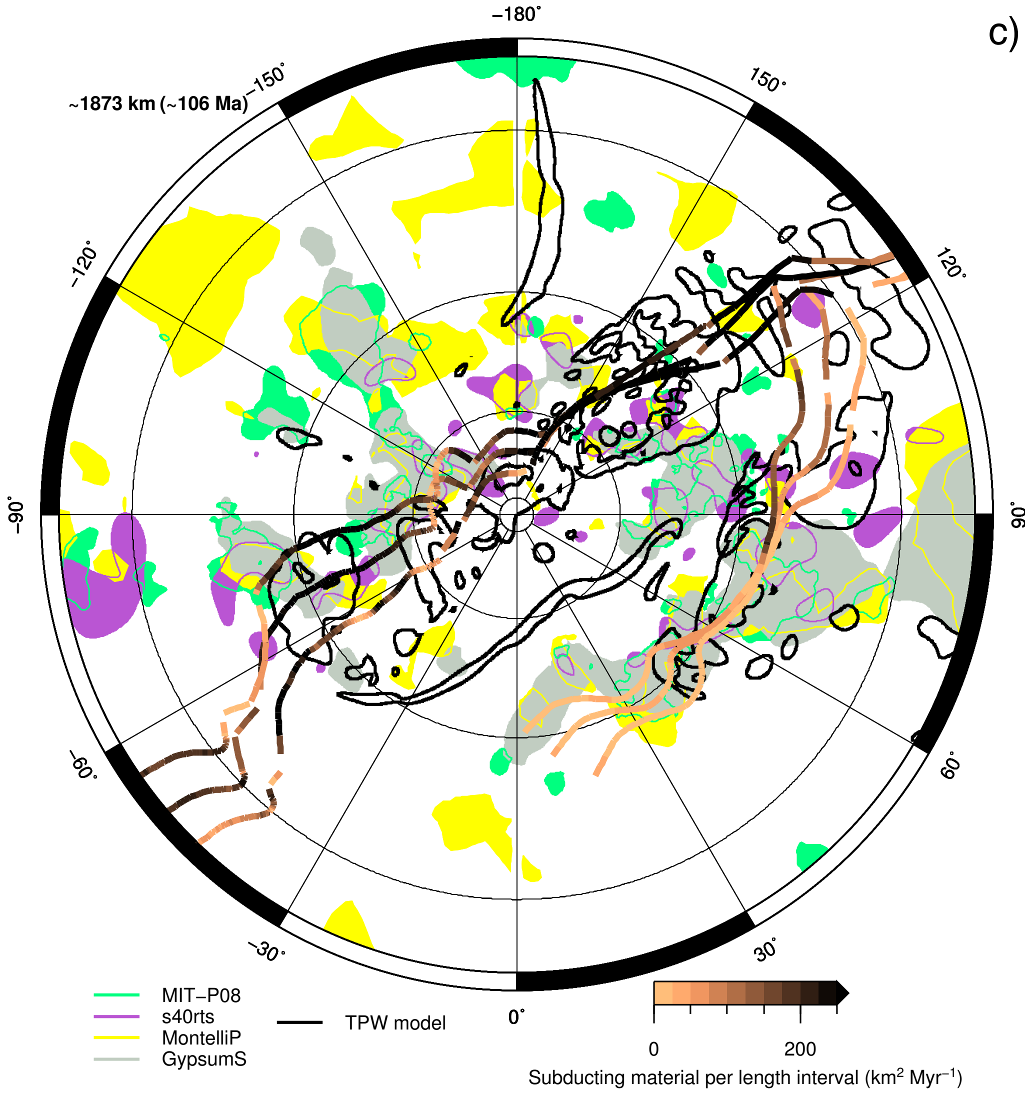

Figure S 3: Same as Figure S1 but with the Hybrid TPW Paleomagnetic reference frame and geodynamic model output.

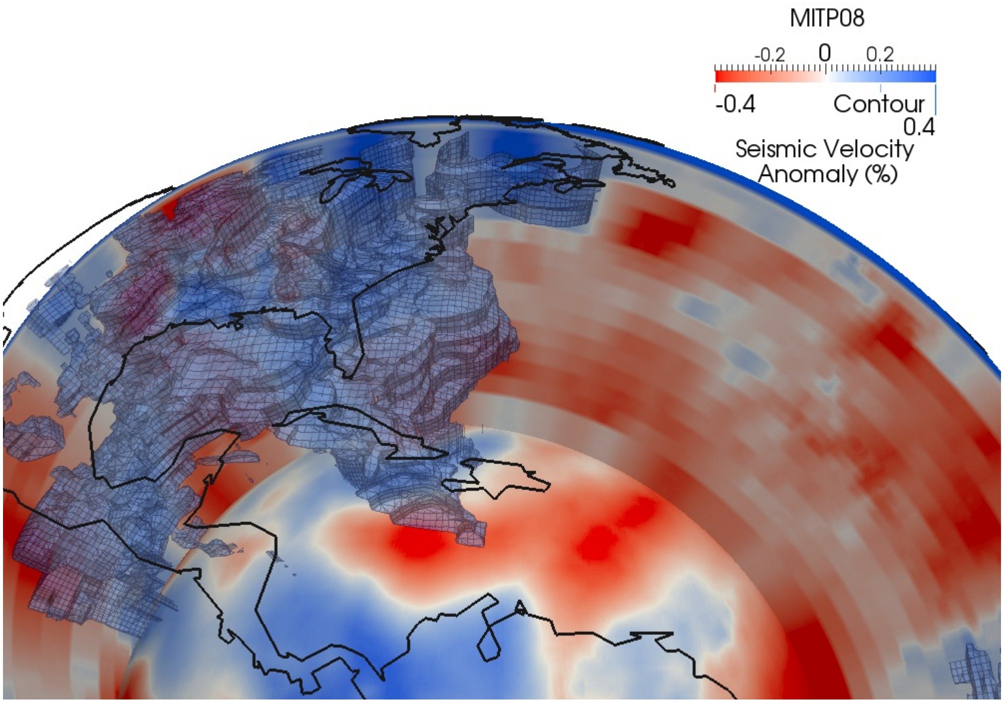

Figure S 4: Snapshot of 3D tomography model (MIT-P08). The image shows the Farallon slab extending from 25°N in the foreground terminating at a vertical cross-section at 60° N. The lowermost depth slice forms the base of the image reflecting the mantle structure at the CMB. The continents are overlain for context. Colors shown in the legend are the seismic velocity perturbation, blue is positive, fast, slab material, and red is negative, slow material. The image highlights the complex nature of assigning a particular depth for any particular slab. Similar results are found for all slabs discussed.

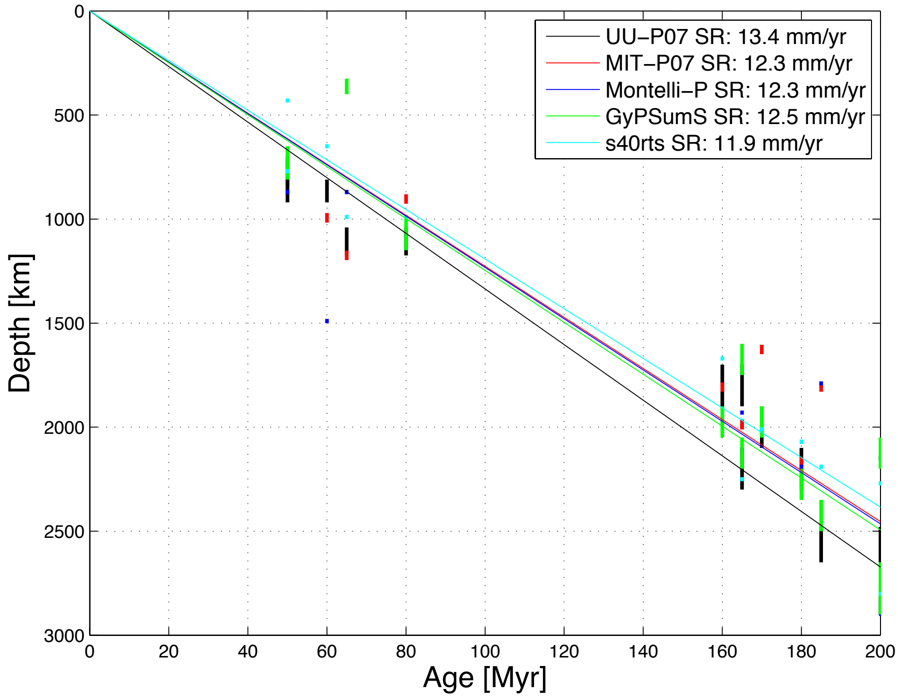

Figure S 5: Age-depth plot for each of the tomography models. Each model is colored as in the legend, and is accompanied by the corresponding sinking rate. The thick bars show the locations of the slab tops and bases (Table 2, 3, 4). The length of the bar corresponds to the maximum and minimum depth for each inferred point.

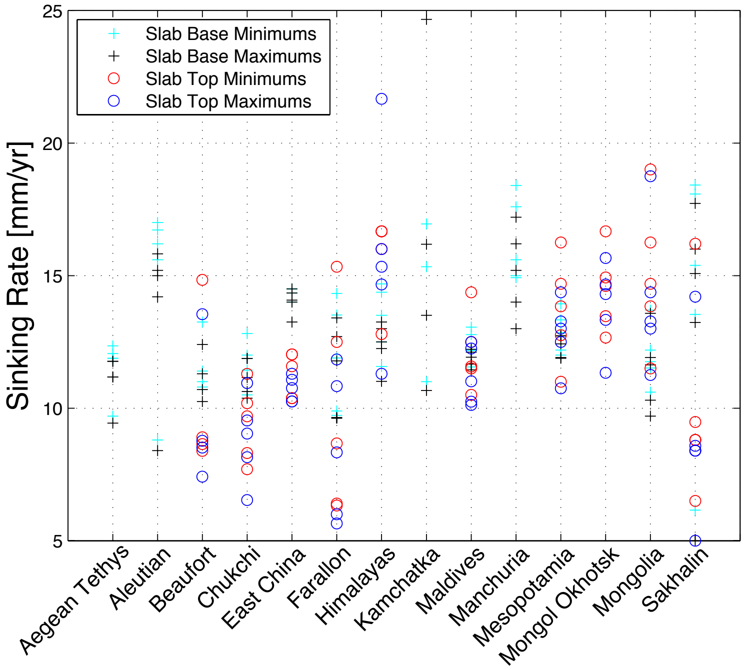

Figure S 6: Regional sinking rates for the slabs appearing in each tomography model used in this study (Table 2, 3, 4). Crosses correspond to slab bases and circles correspond to slab tops. Aqua and red are minimum values for each model, whilst black and blue are maximum values for each model.

References

Müller, R., Sdrolias, M., Gaina, C., Roest, W., 2008. Age, spreading rates, and spreading asymmetry of the world's ocean crust. Geochemistry, Geophysics, Geosystems 9, Q04006.

Schubert, G., Turcotte, D.L., Olson, P., 2001. Mantle Convection in the Earth and Planets. Cambridge University Press.