Mantle flow models with core-mantle boundary constraints support evidence for chemical heterogeneities in the lowermost mantle

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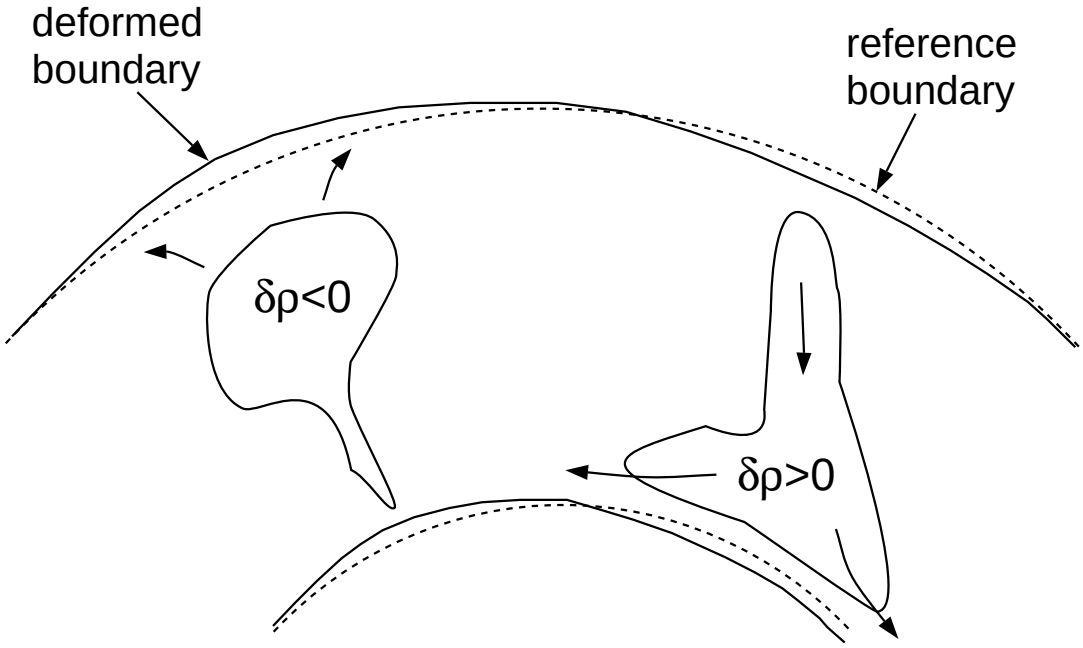
Overview

- Mantle flow models based on s-wave tomography models and constrained by geoid, global heat flux, postglacial rebound tends to over-predict CMB excess ellipticity and long-wavelength r.m.s. CMB topography

- Bulk sound and shear wave anomalies decorrelate in the lowermost mantle.

In an effort to obtain a better fit to core-mantle boundary constraints, we construct a flow model that is based on both s-wave and bulk sound tomography models, and contains a distinct chemical layer at the base of the mantle

Computation of mantle flow field, boundary deformations and geoid



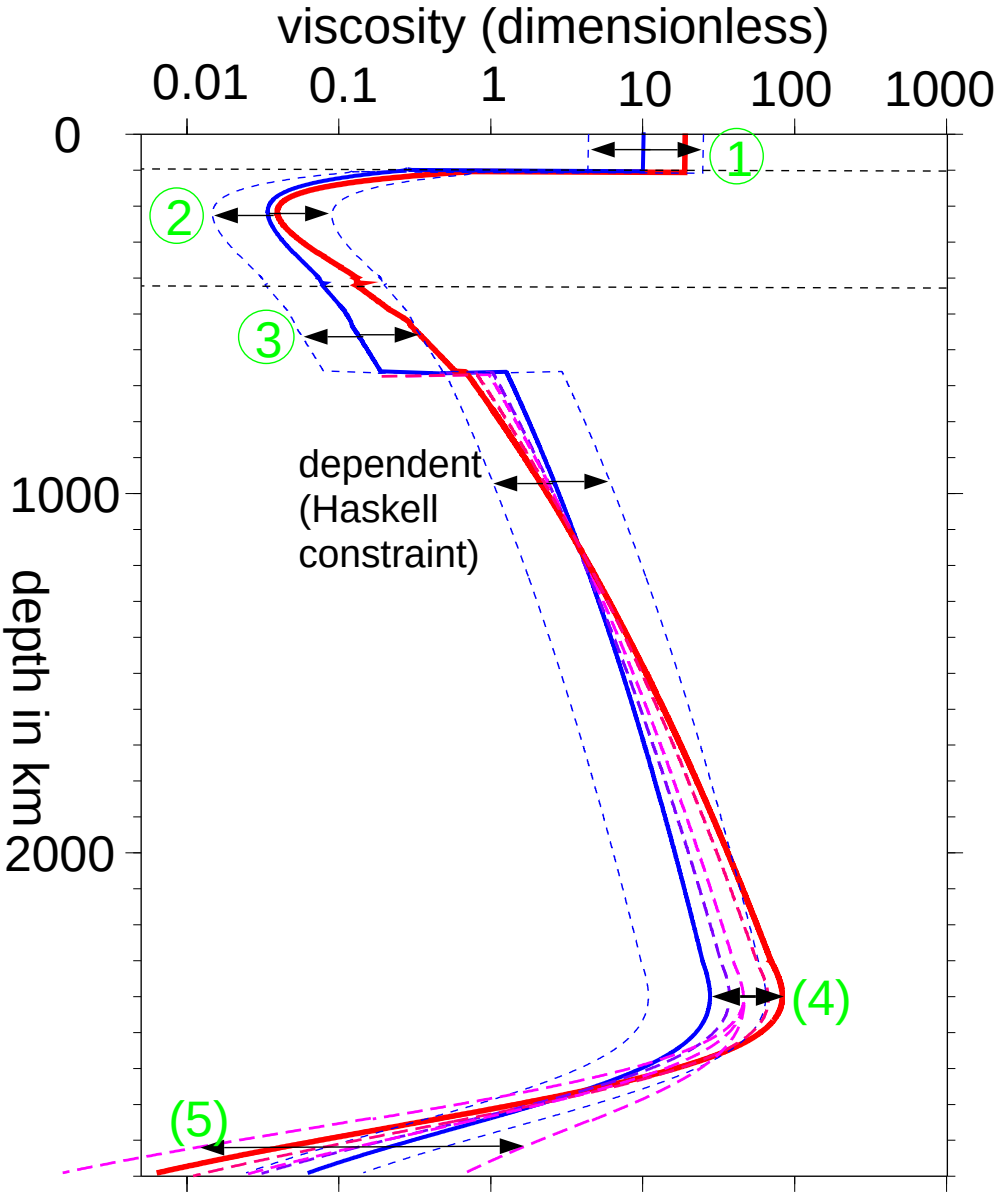
- Density anomalies (inferred from tomography models) drive flow, computed with spectral method (Hager and O'Connell, 1981)

- Flow deforms boundaries

- Density anomalies and deformed boundaries contribute to geoid anomalies (Richards and Hager, 1984)

Viscosity structure; free model parameters

- assume viscous rheology, radial viscosity variations only
- relative viscosity variations in each layer (upper mantle, transition zone, lower mantle) based on Calderwood (1999)



Optimizing the model

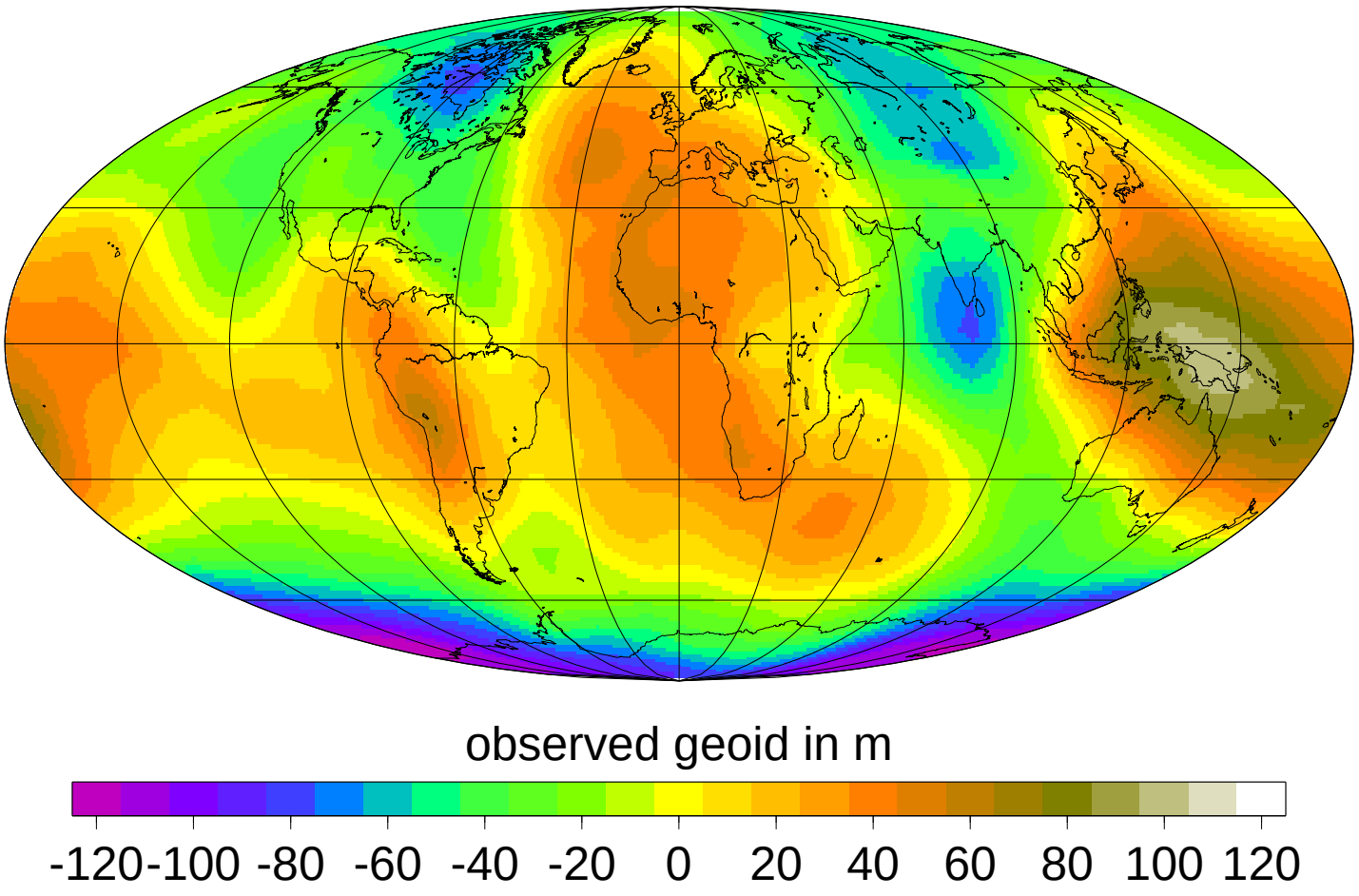
Try to minimize MF = MF(1) + ... + MF(n), where MF(i) describe "misfit" to various observations

1. Geoid

Use variance reduction

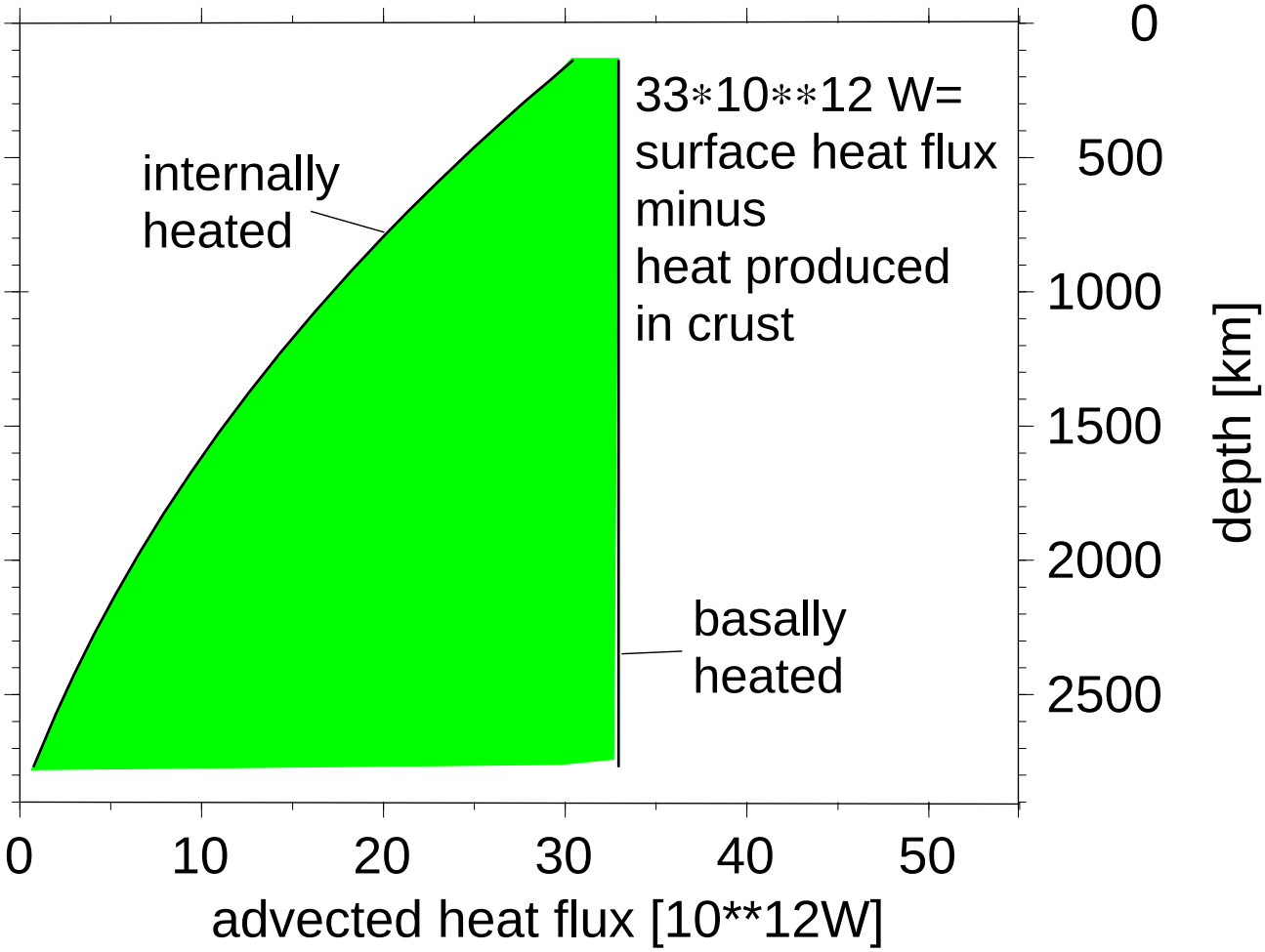
$$VR = \left(1 - \frac{\text{Var(Predicted - Observed)}}{\text{Var(Observed)}}\right)$$

to describe fit; MF(1)= - VR)



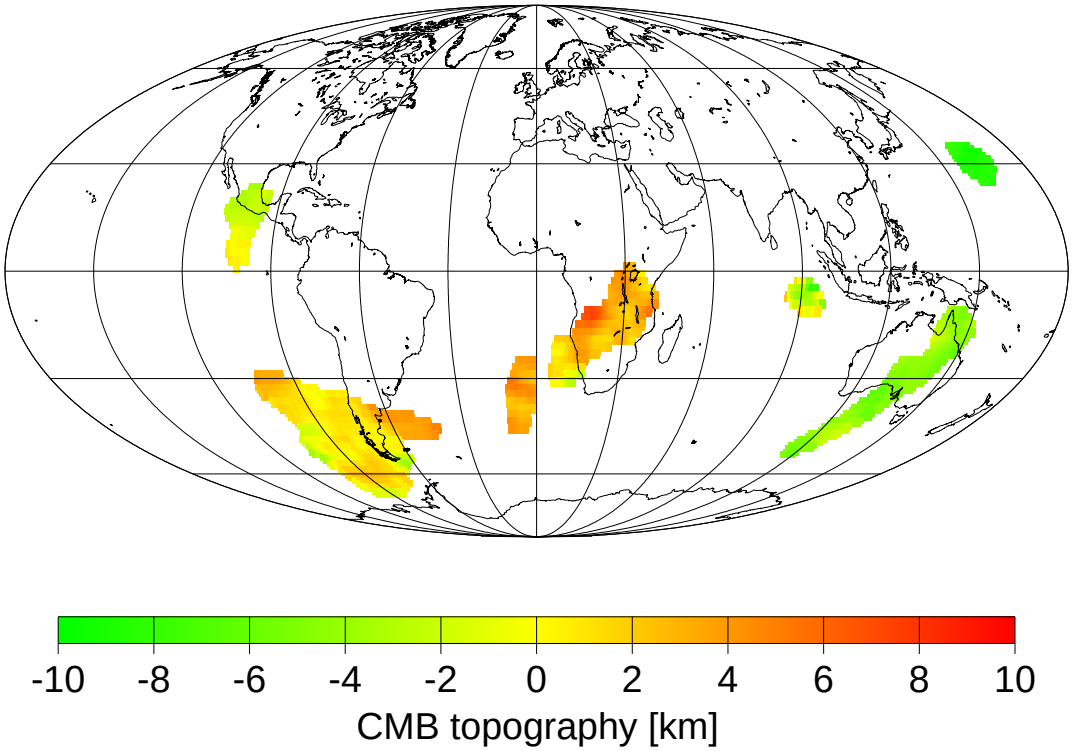
2. Heat flux profile

Computed based on density anomaly, flow, thermal expansivity and heat capacity. MF(2)>0, if part of the computed curve is not in green area



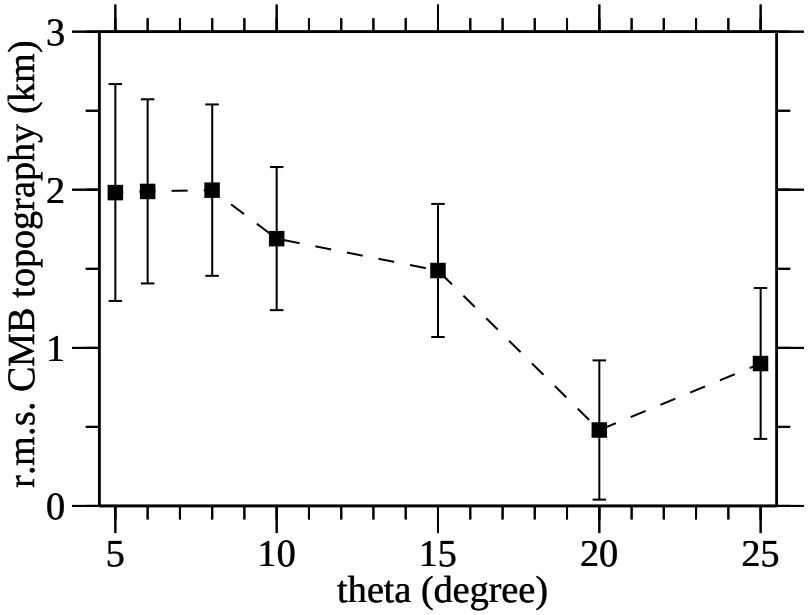
3. CMB constraints

A. Topography point constraints



from R. Garcia (pers. comm.)

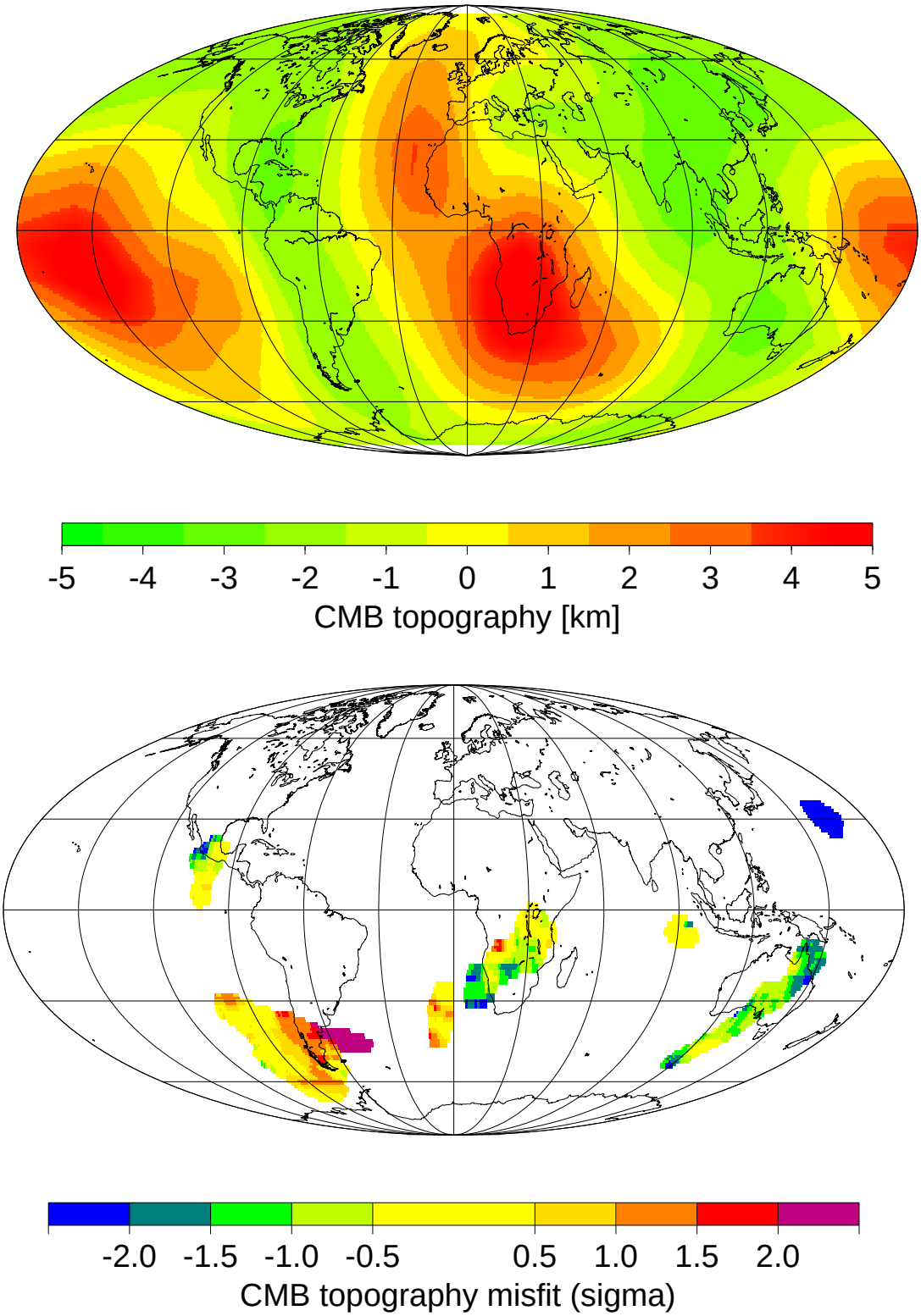
B. r.m.s. topography (Garcia and Souriau, 2000)



C. excess ellipticity

490 ± 110 m peak-to-valley (from geodetic constraints).

CMB predictions - no chemical layering



r.m.s. topography 2147 m

excess ellipticity 2237 m peak-to-valley

Interpretation of seismic velocity variations in terms of a chemical layer at the base of the mantle

$$\begin{aligned}\frac{\delta v_s}{v_s} &= \frac{1}{\alpha_{s,th}}\frac{\delta\rho}{\rho}_{th} + k_s\delta h \\ \frac{\delta v_c}{v_c} &= \frac{1}{\alpha_{c,th}}\frac{\delta\rho}{\rho}_{th} + k_c\delta h\end{aligned}$$

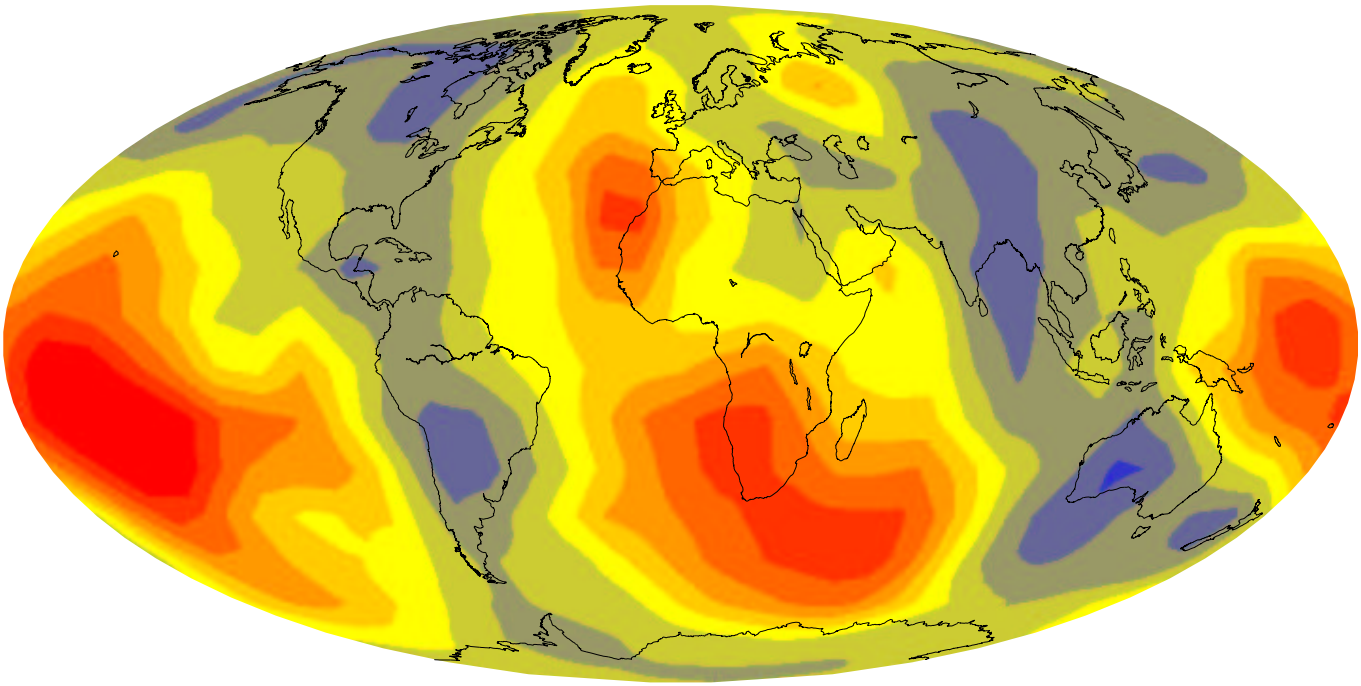
δv_s and δv_c are vertical averages below 2600 km (bottom two layers)

$$\begin{aligned}\delta h &= \left(\frac{\delta v_c}{v_c} - \frac{\alpha_{s,th}}{\alpha_{c,th}}\frac{\delta v_s}{v_s}\right)\left(k_c - k_s\frac{\alpha_{s,th}}{\alpha_{c,th}}\right)^{-1} \\ \frac{\delta\rho}{\rho}_{th} &= \frac{\delta v_s}{v_s}\cdot\alpha_{s,th} - k_1\cdot\alpha_{s,th}\cdot\left(\frac{\delta v_c}{v_c} - \frac{\alpha_{s,th}}{\alpha_{c,th}}\frac{\delta v_s}{v_s}\right)\end{aligned}$$

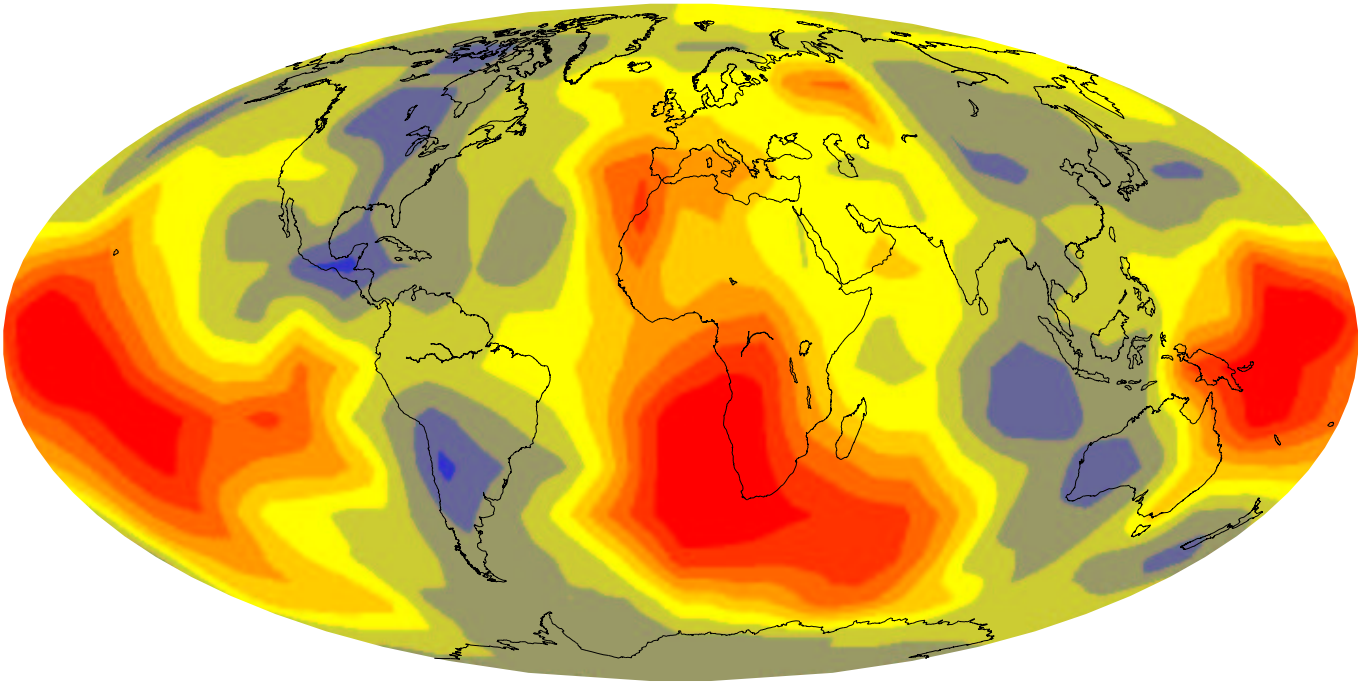
$k_1 := k_s\cdot\left(k_c - k_s\frac{\alpha_{s,th}}{\alpha_{c,th}}\right)^{-1}$ is additional free parameter. Optimum value $k_1 = 0.56$

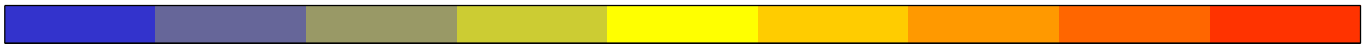
Deflection of lowermost mantle chemical boundary inferred from v_s and v_c (Masters et al., 2000)

From flow model



Directly from tomography model

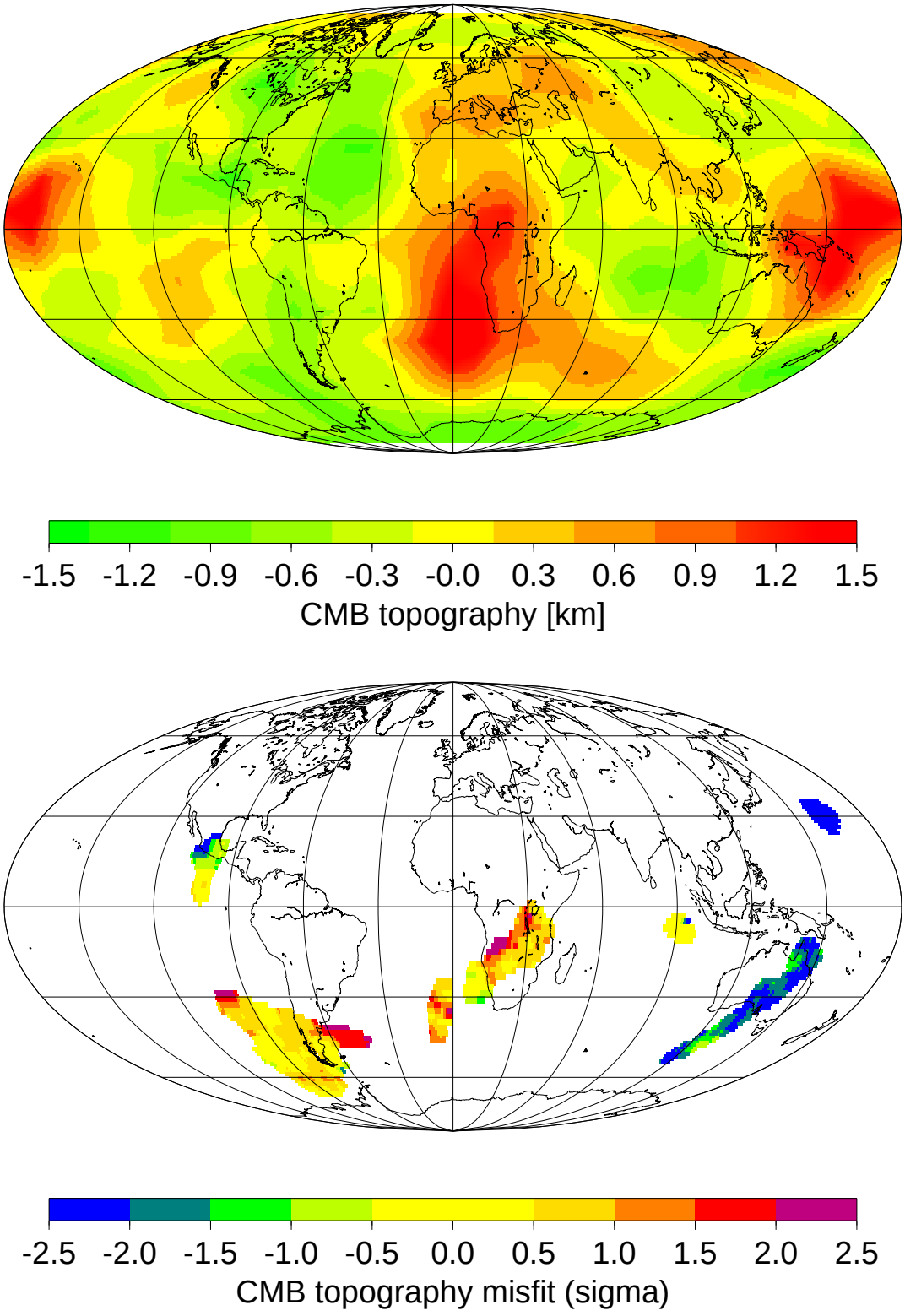




down boundary elevation up

Correlation coefficient = 0.90

CMB predictions - chemical layering at 0.59 r_E

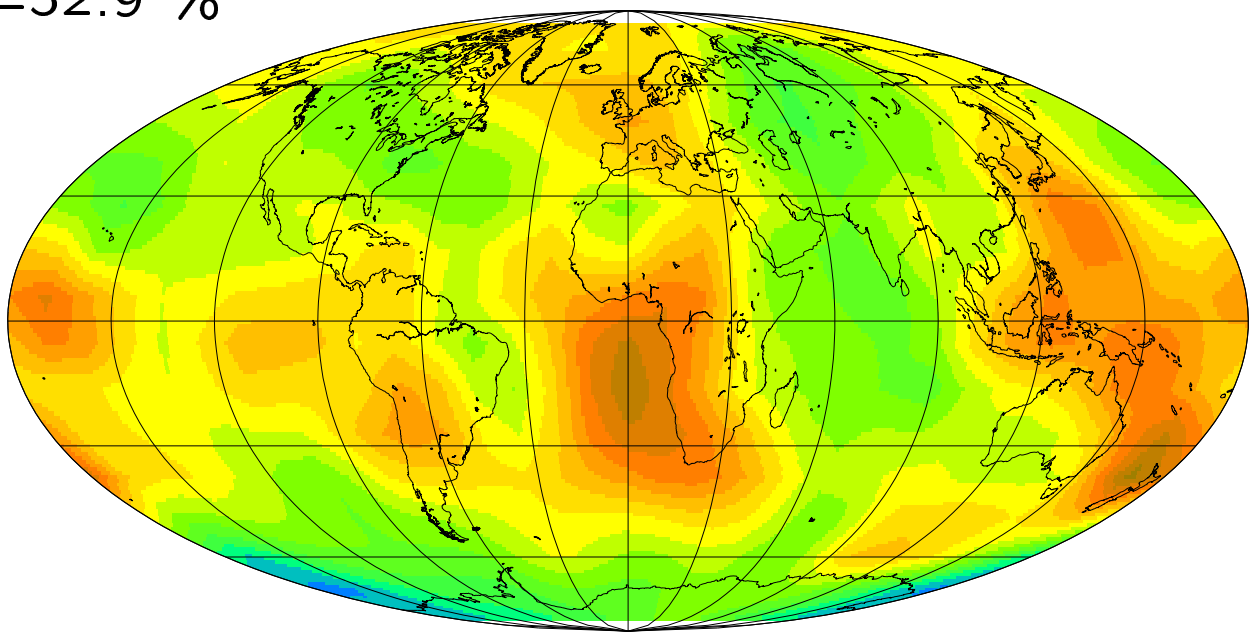


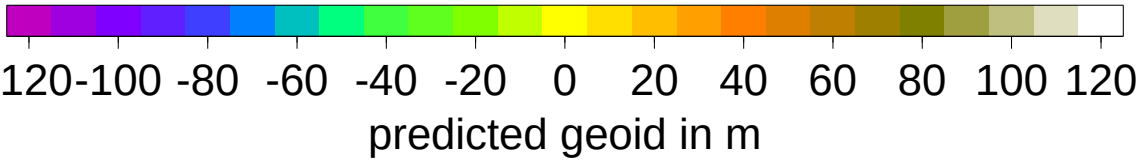
r.m.s. topography 576 m

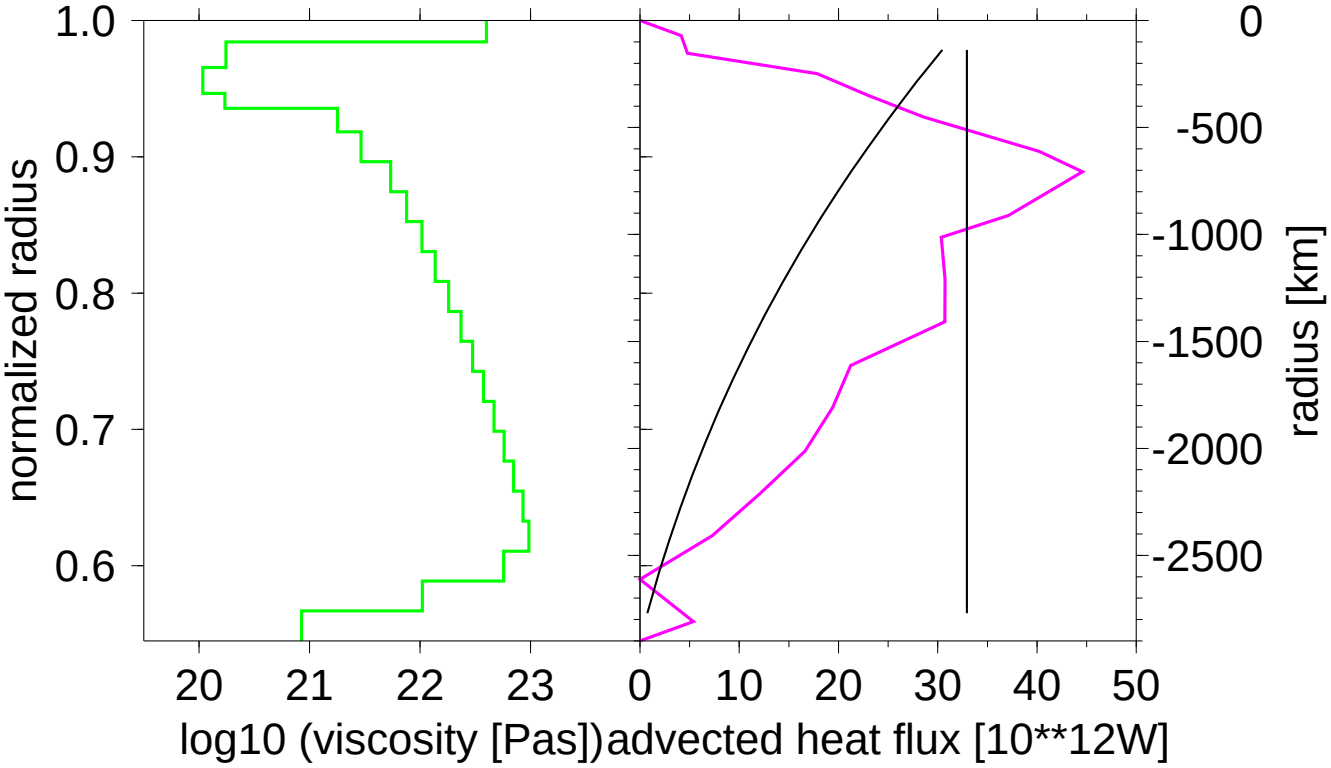
excess ellipticity 507 m peak-to-valley

Geoid and heat flux predictions - layering at 0.59 r_E

VR=52.9 %







Summary

- Mantle flow model derived from s-wave tomography in accordance with geoid, global heat flux, postglacial rebound – strong increase of viscosity with depth required, *but . . .*

- . . . These models tend to over-predict CMB excess ellipticity and long-wavelength r.m.s. CMB topography – *Therefore . . .*
- . . . we consider both s-wave and bulk sound velocity anomalies, and assume that decorrelation between bulk sound and shear wave anomalies in the lowermost mantle is due a chemically distinct layer of variable thickness at the base of the mantle.
- Thickness variations directly inferred from the tomography model are highly correlated with thickness variations computed with the flow model (correlation coefficients about 0.9).
- We are now able to reasonably fit CMB excess ellipticity and long-wavelength r.m.s. CMB topography as well, *but . . .*
- CMB topography point constraints are still not well fit. Also, in contrast to observations, modeled r.m.s. CMB topography does not significantly increase if shorter wavelengths are considered.
- Both may indicate that the input density model is less accurate at shorter wavelength