# On the consistency of seismological models of the core-mantle boundary

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## Abstract

Seismological models of the mantle are routinely developed using a range of techniques applied to different data types. For quite some time, it has been recognised that on long wavelengths models of shear-wave velocity variations show a large degree of consistency. More recently, the same has been suggested for models that describe compressional-wave velocity variations. However, controversy remains regarding models of lower mantle density variations, which provide important constraints on the nature of mantle structures, e.g. whether they are caused by thermal variations or whether additional chemical heterogeneity is required. The imaging of density structure is difficult due to a small effect on seismic observables and a strong trade-off with core-mantle boundary (CMB) topography. In addition, no consistent model of CMB topography variations exists with current models differing both in amplitude and pattern. Here, I review models of lower mantle density structure and core-mantle boundary topography from the literature, with the aim to identify which structures are consistent and what we can already learn from these models. In addition, I discuss ways in which differences between existing models may be resolved in future.

# DI21A-0012: On the consistency of seismological models of the core-mantle boundary

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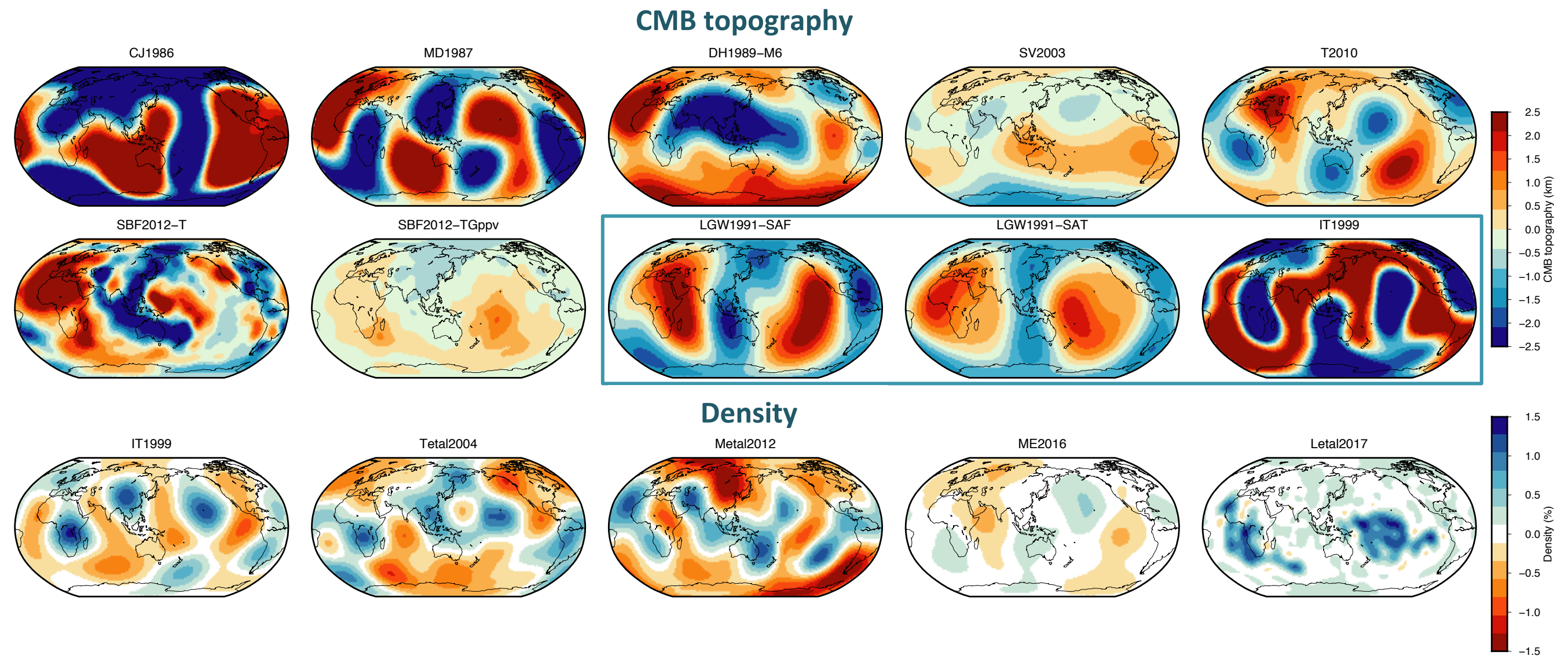
**Seismological models of the mantle are routinely developed using a range of techniques applied to different data types. While models of S- and P-wave velocity show a large degree of consistency, controversy remains regarding models of lower mantle density and core-mantle boundary (CMB) topography, which are vital for determining the nature of mantle structures.**

**Existing models of CMB topography and lower mantle density are reviewed, with a focus on seismological models. Average models and vote maps are presented, which aid in finding model consistencies. A discussion on what these may teach us about lower mantle structure and dynamics is included.**

### *Data and methodology*

1) Take existing models of mantle density and CMB topography
2) Expand consistently in spherical harmonics, cut at degree *l* = 6
3) Calculate power spectra, correlation and correlation matrices
4) Compute average models, vote maps and combined models
5) Compare to predictions from geodynamic simulations



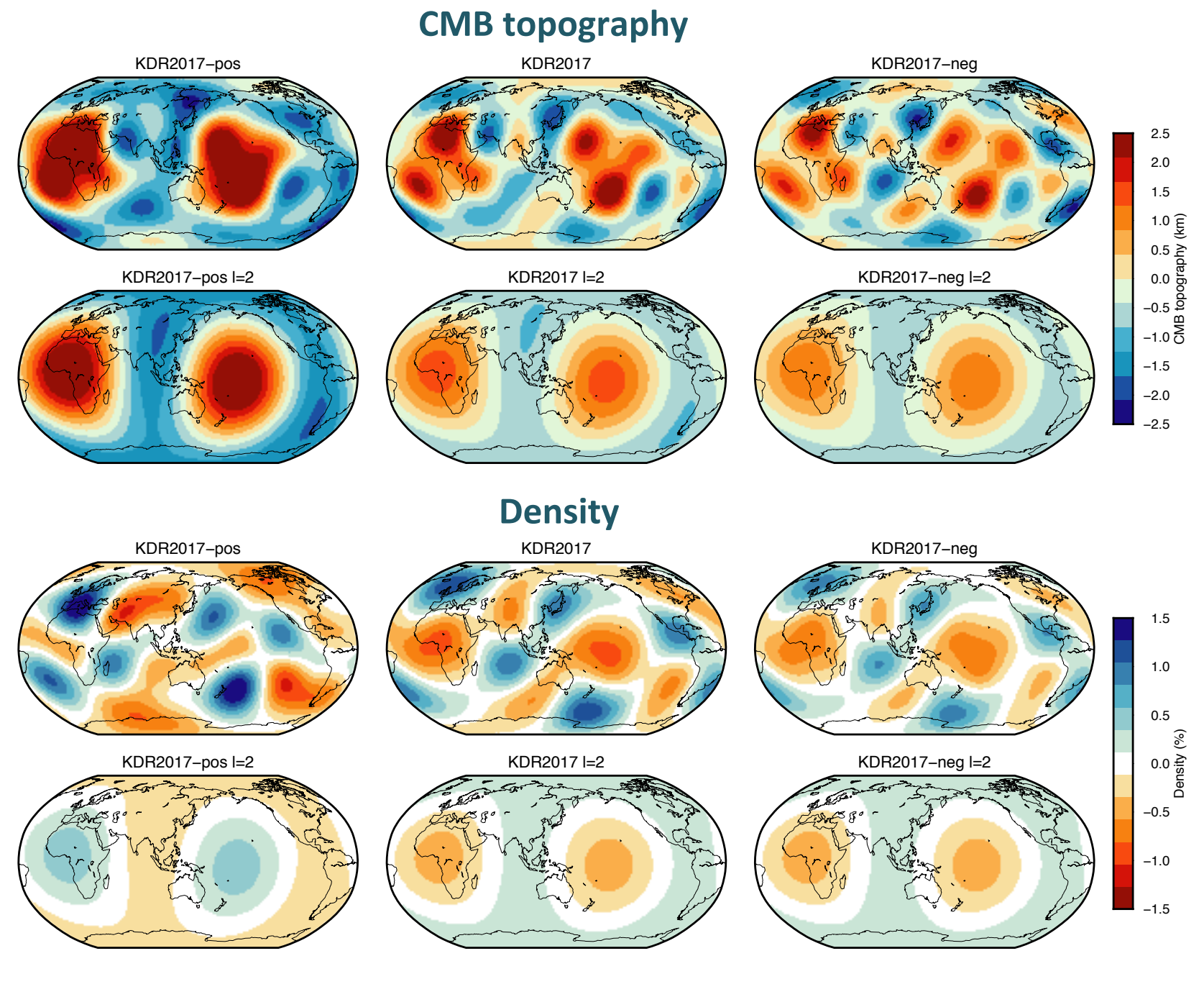


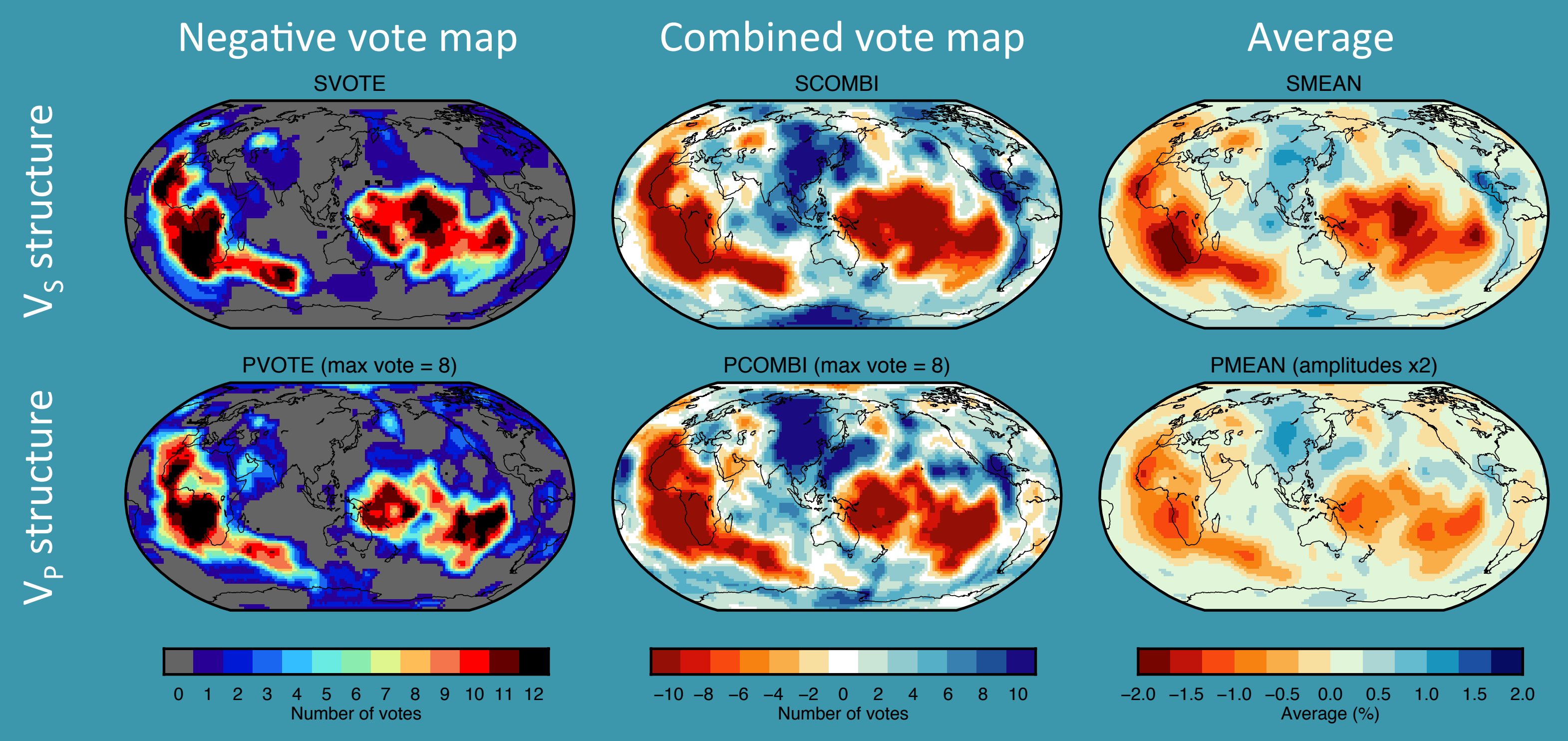
***Fig 1 (top).*** *Existing models of CMB topography ($h_{CMB}$) and lower mantle density (ρ) taken from the literature. Note that the maximum degree varies between models.*

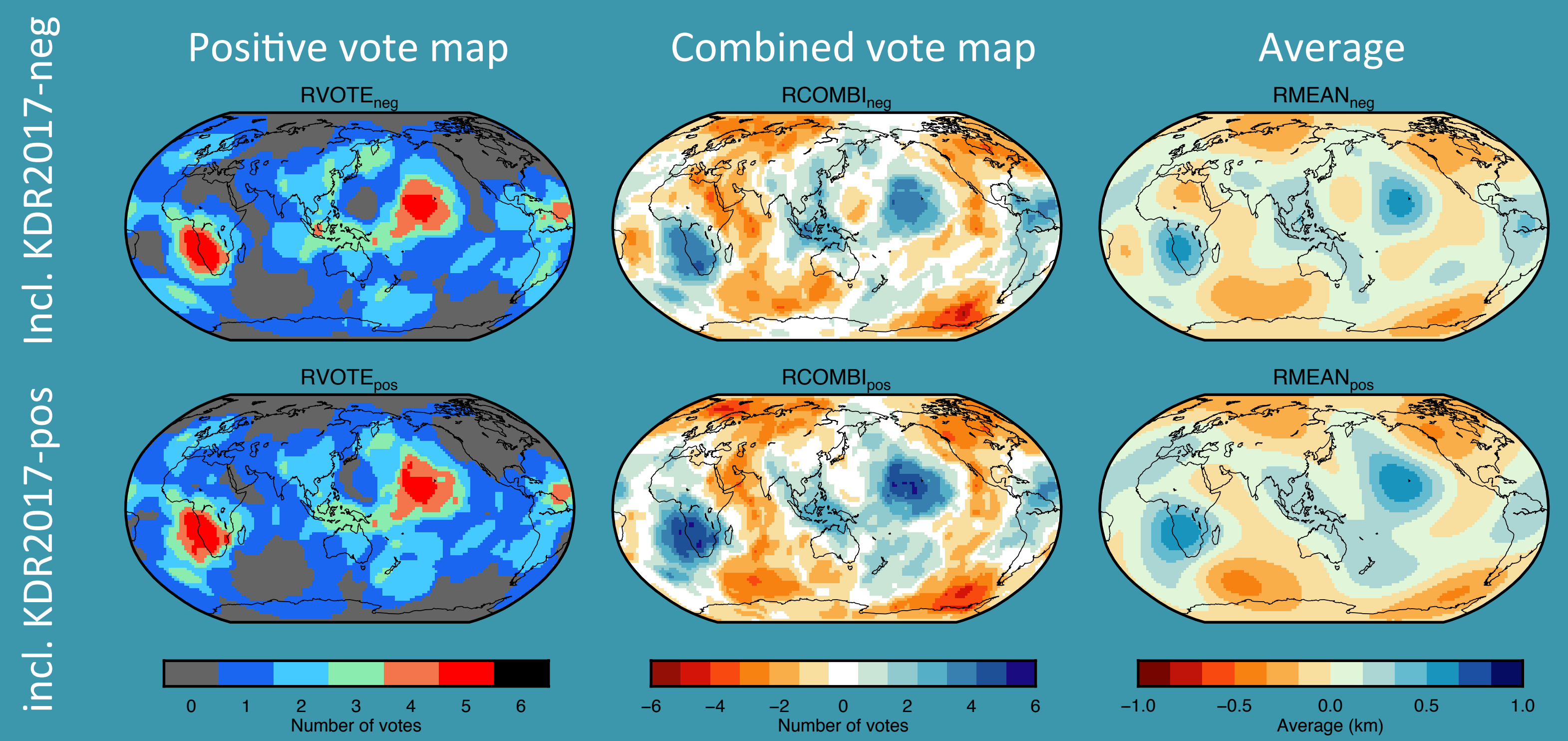
***Fig. 2 (left)****. Models from KDR2017 (Koelemeijer et al., 2017) who found two model classes with opposite relationship between density and CMB topography.*

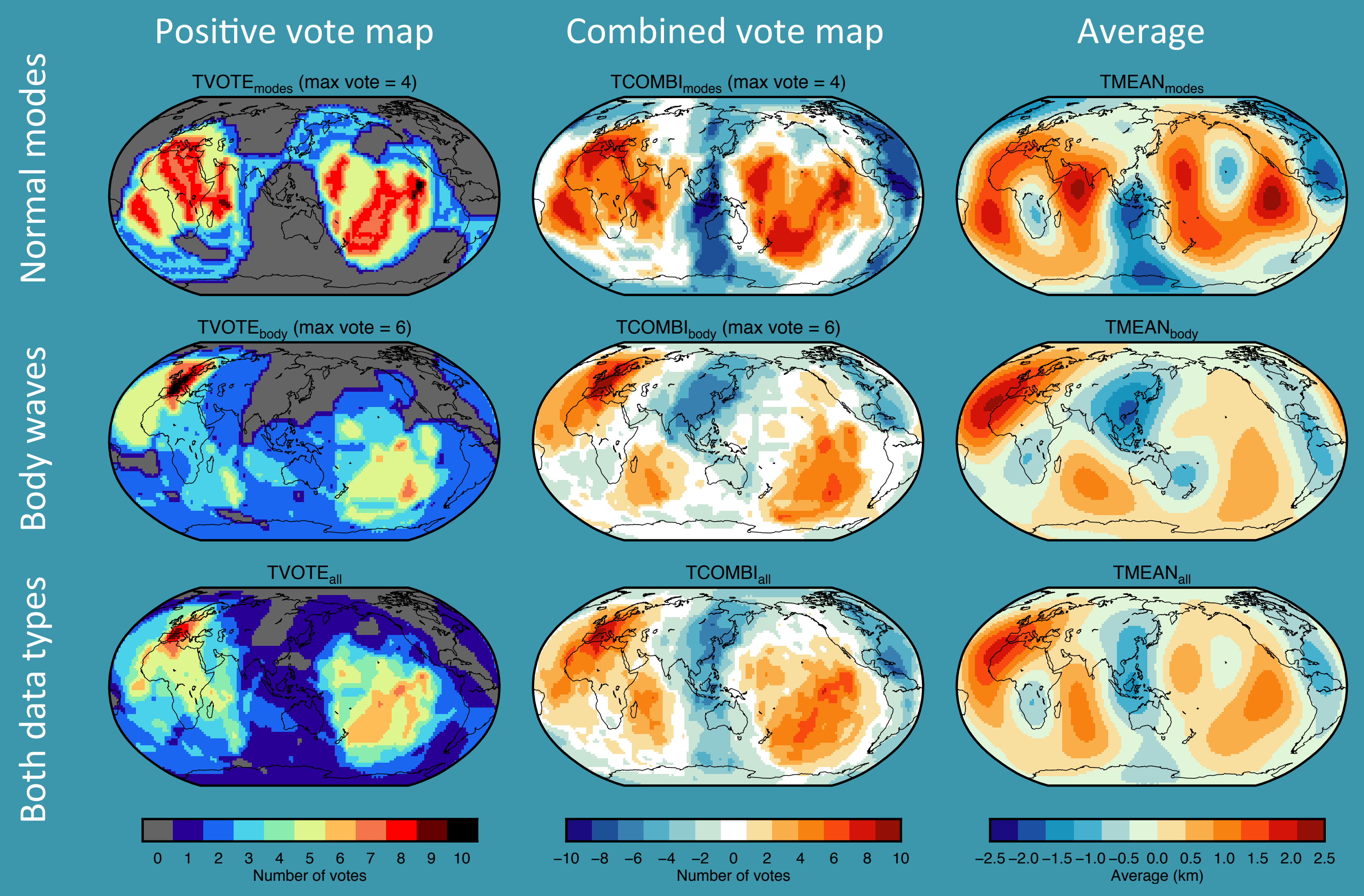
Both model classes show a good fit to normal mode data, but:

- KDR2017-pos is characterised by dense LLVPs and large topography amplitudes
- KDR2017-neg is characterised by light LLVPs and small topography amplitudes
- KDR2017 is the model with the best overall fit to the mode data.

# The seismological landscape of the CMB







## SEISMIC VELOCITY

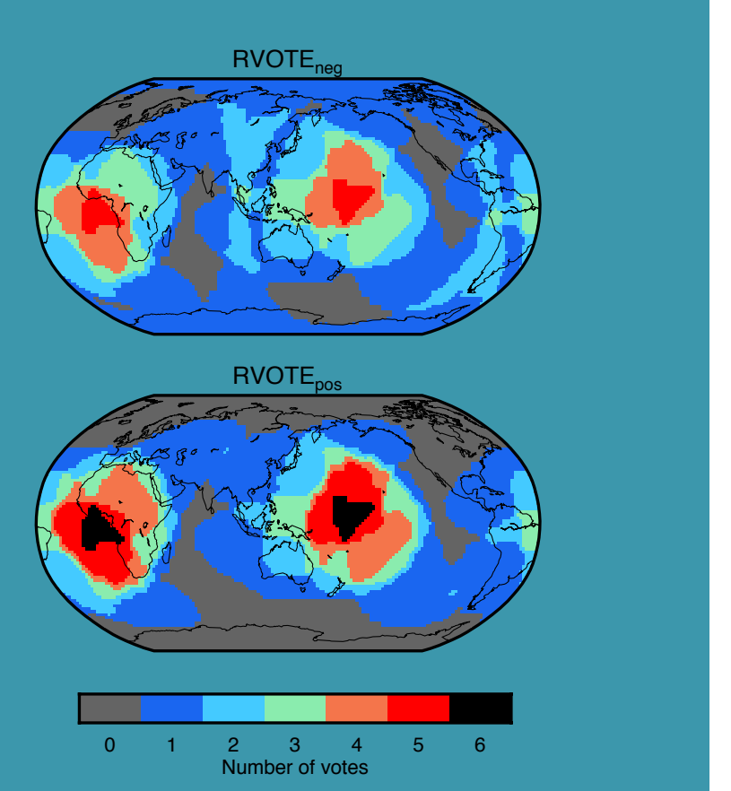
Both $V_S$ and $V_P$ show strong consistency across recently developed (since 2010) models of lower mantle structure, with LLSVPs imaged consistently for structure up to l=12.

## DENSITY

Most density models consistently image two areas of dense anomalies beneath South Africa and the North Pacific, though their exact location and relationship to seismic velocity differs.

CMB topography strongly influences the retrieved density structure (model KDR2017-pos vs KDR2017-neg), which helps to resolve differences between recent studies based on Stoneley modes and tidal data, particularly for *l*=2 only.

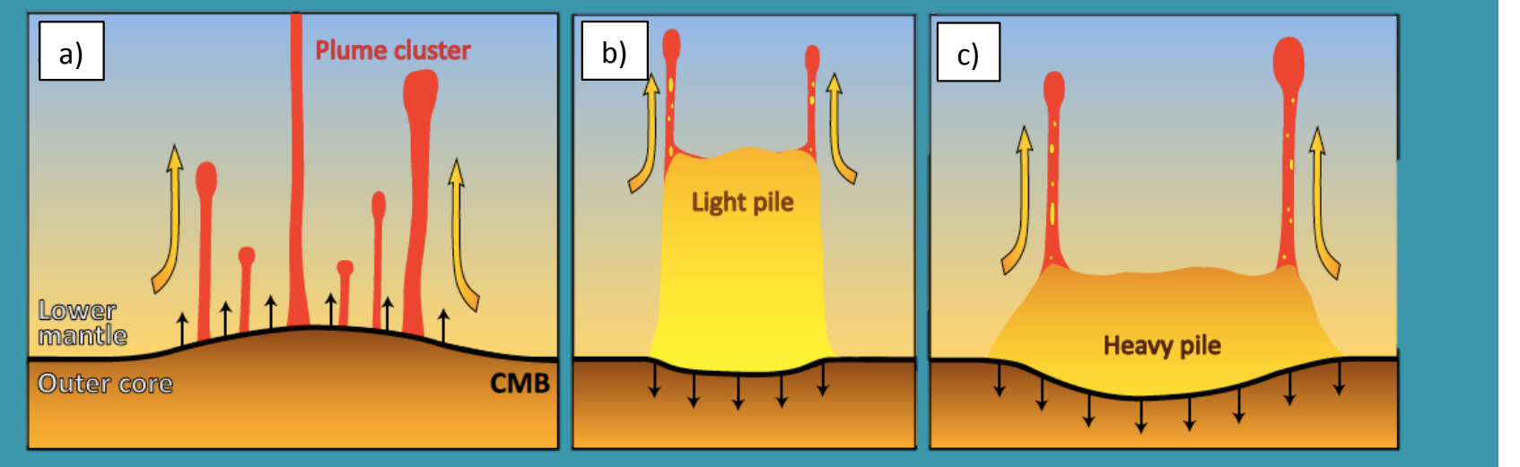
Positive vote map *l*=2



## CMB TOPOGRAPHY

Average models and vote maps do not agree, indicating that particular models dominate results. A disparity (evident as low overall vote) also exists between models based on body-wave and normal-mode data, which show consistently elevated topography in the South Pacific and Central Africa.

As existing models feature elevated topography below the LLSVPs, strongly thermochemical models (heavy piles) may be ruled out.



## FUTURE

- To achieve similar consistency for density and CMB topography as is observed for $V_S$ and $V_P$, studies have to combine multiple data sets to break existing trade-offs.
- Important considerations in these studies should be the choice of theoretical approximation and parameterisation.
- Efforts to develop CMB topography models consistent with body-wave and normal-mode data should be intensified.
- This will aid in narrowing down possible explanations for the LLVPs and provide more insights into mantle dynamics.

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**Analysis**: This work is submitted as: **Koelemeijer, P.** Towards consistent seismological models of the core-mantle boundary landscape. *AGU monograph "Mantle upwellings and their surface expressions", ed. Cottaar et al.* Average models are computed similarly to Becker & Boschi (G-cubed, 2002), while vote maps are computed following Shephard et al. (Scientific Reports, 2017). Geodynamic model predictions are taken from DRT2018 (Deschamps et al., GJI, 2018) and DL2019 (Deschamps & Li, JGR, 2019). Figures have been produced using the Generic Mapping Tools (GMT) version 5 software (Wessel et al., 2013). Please ask for references of individual models included for the average models and vote maps.

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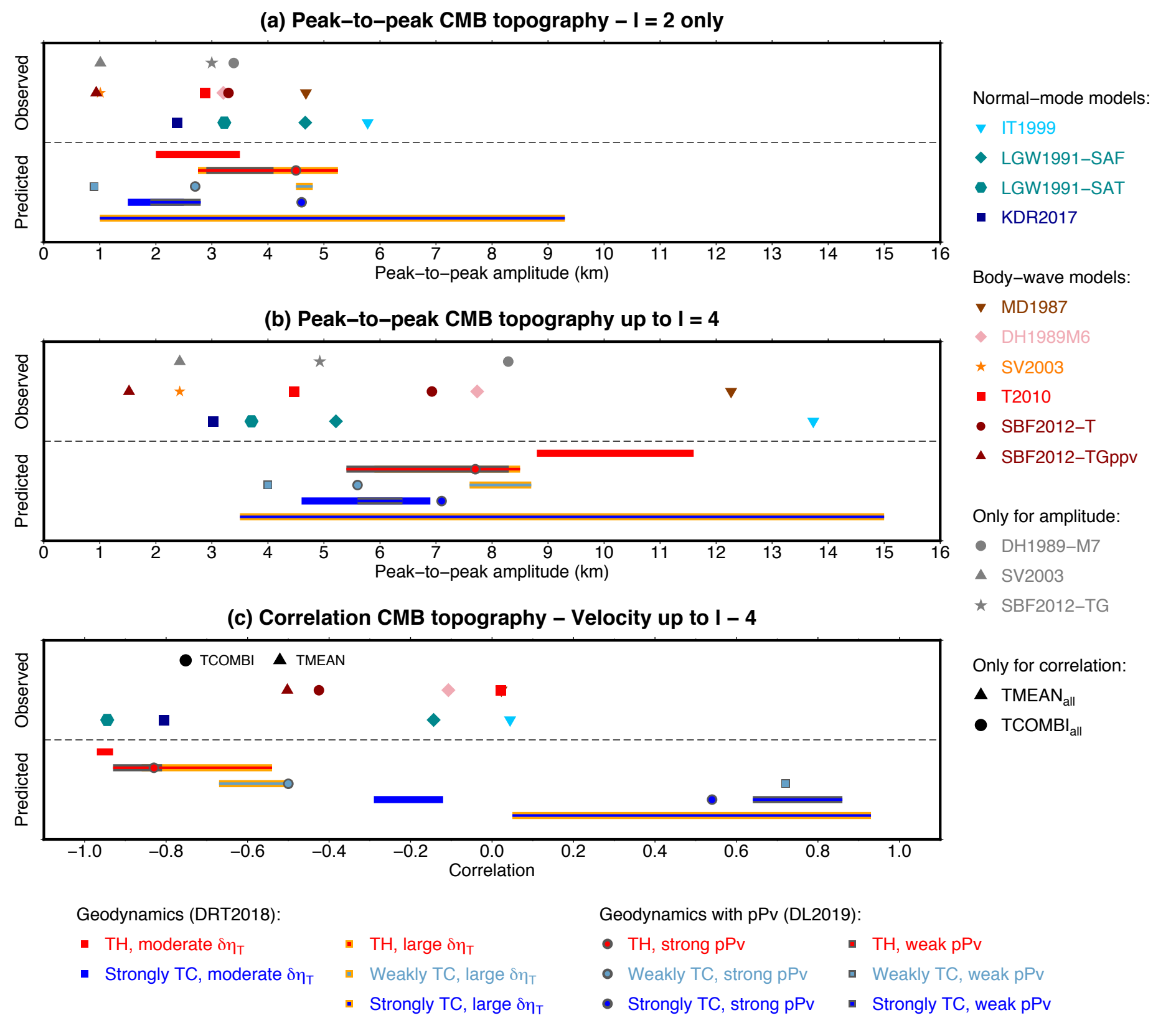


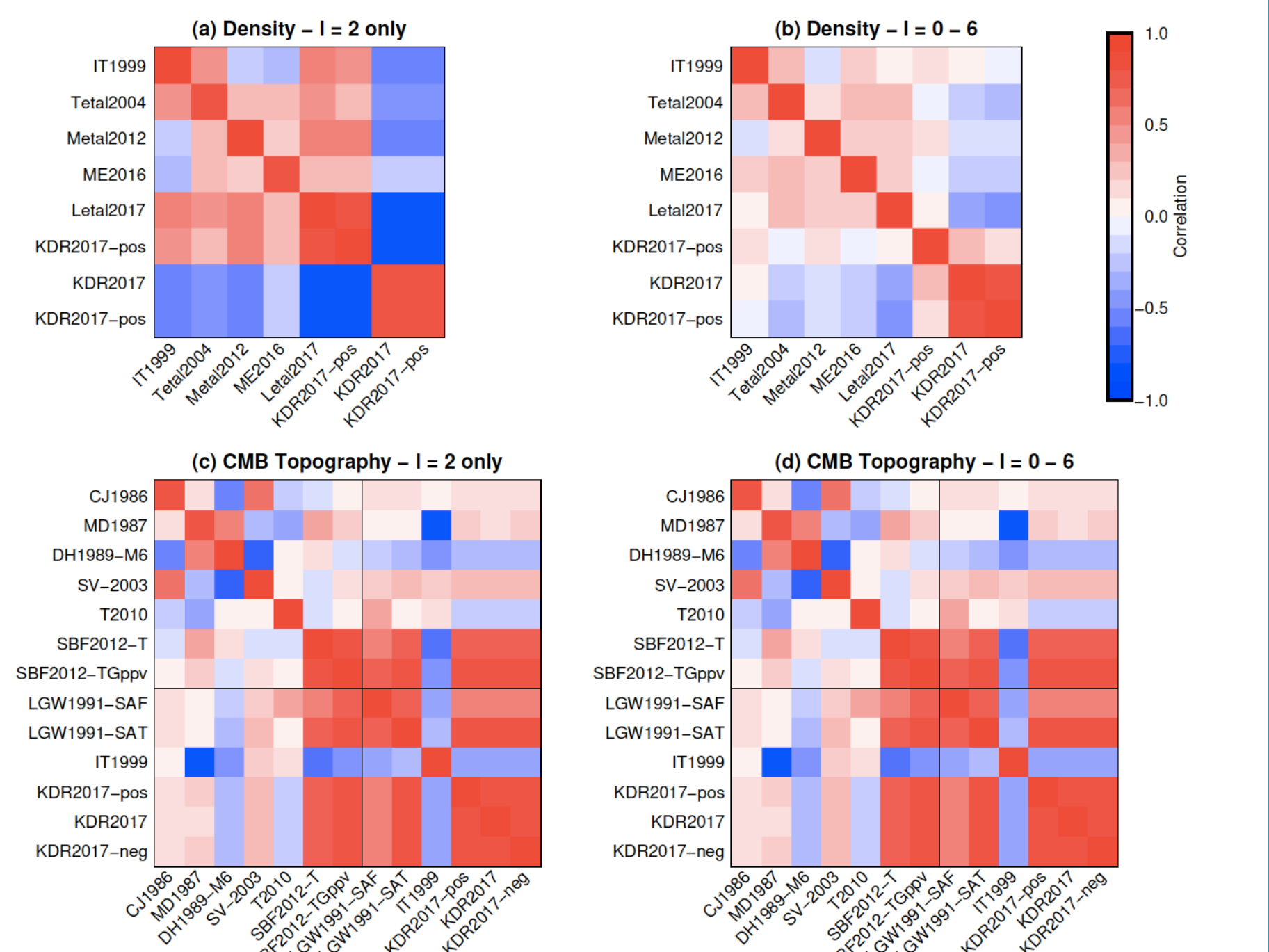
***Fig 6 (left).*** *Comparison between seismic constraints and geodynamic predictions, showing (a–b) l=2 and l=4 peak-to-peak CMB topography amplitudes and (c) correlation of CMB topography with velocity.*

- For *l*=2 (a), several geodynamic scenarios can reproduce seismological amplitudes.
- For *l*=4 (b), most seismological models, particularly normal-mode ones, have smaller amplitudes than predicted.
- The CMB topography – Vs correlation varies (c), but most consistent models of Fig. 5 have a correlation lower than -0.4, which would rule out strongly thermochemical models.

***Fig 5 (right).*** *Correlation matrices for (a-b) lowermost mantle density and (c-d) CMB topography for structure (a,c) at l=2 and (b,d) up to l=6. Thin black lines in (c-d) separate out body-wave and normal-mode models.*

- For *l*=2 (a), there is a strong agreement between density models, except KDR2017 and KDR2017-neg.
- Note that Letal2017 and KDR2017-pos show a correlation of 0.96.

- Body-wave CMB topography models do not show much consistency (c-d).
- Normal-mode models correlate well with each other (correlation larger than 0.60), except for IT1999.



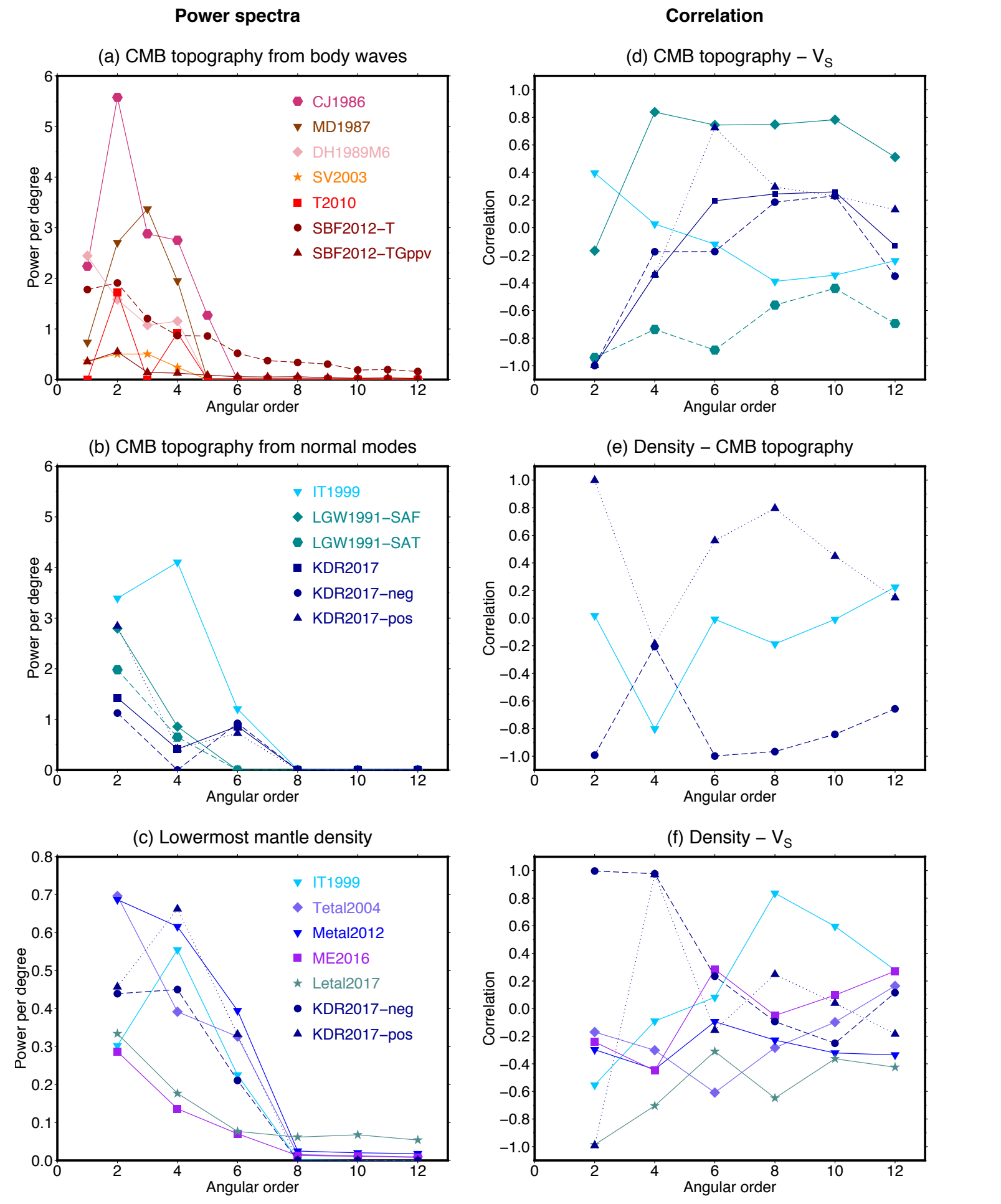


***Fig 4 (left).*** *Properties of CMB topography and density models, showing (a–c) power spectra of individual models and (d–f) the correlation between different model properties, which is only computed when both properties are provided in a consistent manner.*

- CMB topography models derived from body waves have larger amplitudes the older the model (a).
- The IT2001 CMB topography model has larger power in *l*=4 than other models (b).
- For density, amplitudes vary significantly, with small power in *l*=4 for ME2016 and Letal2017 (c).
- The CMB topography – Vs correlation is negative for *l*=2 except for IT1999 (d).
- Only few models provide CMB topography and density structure in a consistent way, with the two KDR2017 models showing a clear opposite relationship for *l*=2 (e).
- All existing density models negatively correlate with Vs at *l*=2 & *l*=4, except for KDR2017-neg (f).

***Fig 3 (right).*** *Overview of normal mode measurements through time, showing (a) number of modes measured, (b) their integrated sensitivity to lower mantle structure, and total sensitivity to different parameters (Vs, Vp, ρ and $h_{CMB}$) for modes (c-f) measured up to 1999 or (g-j) measured up to 2013.*

- Early measurements are primarily sensitive to Vs, thus providing good constraints on Vs structure (a-b, c).
- Current data sets also contain sufficient Vp sensitivity (a-b, h).
- However, sensitivity to density and CMB topography remains much smaller making it harder to constrain (a-b, i-j).