Observability of lower mantle structures in Earth's free oscillation data

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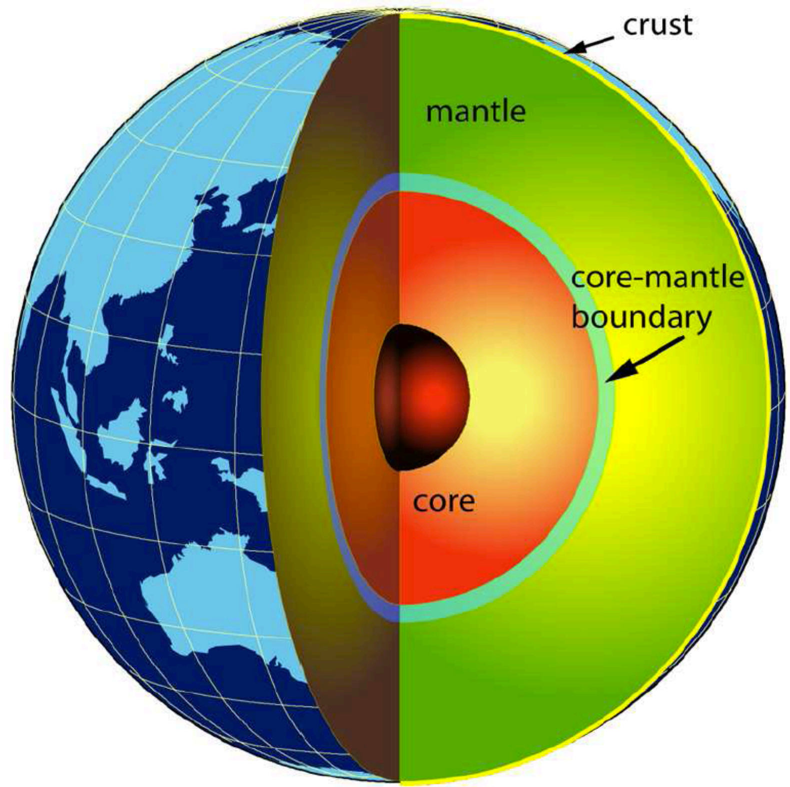
The D'' region

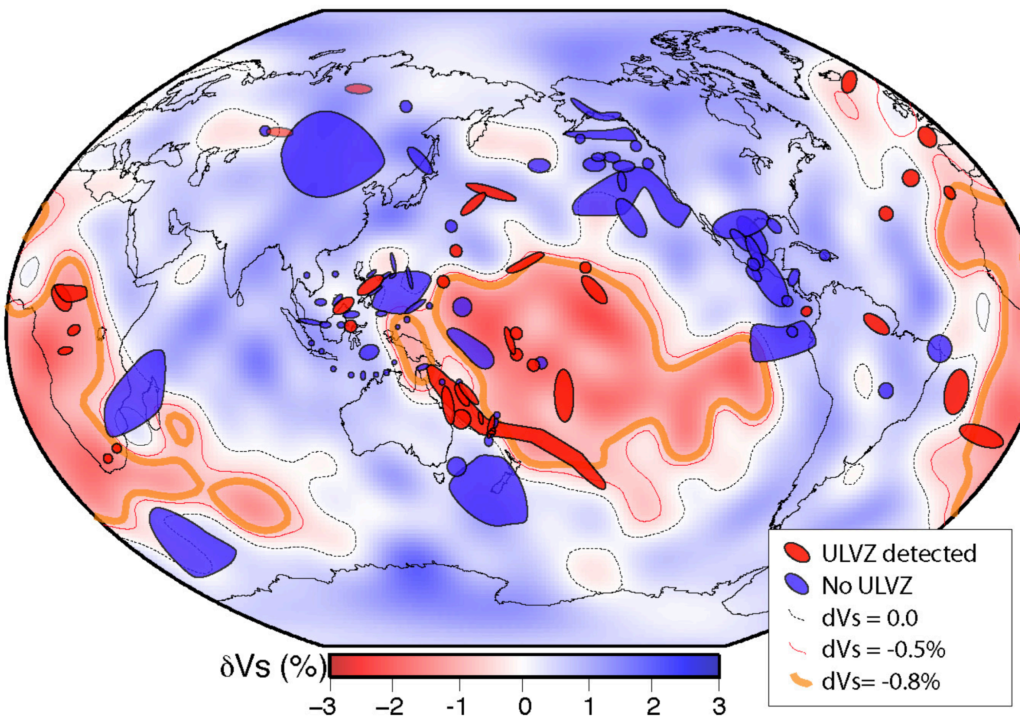
- Largest compositional and thermal interface
- Thermal boundary layer
- Origin of mantle plumes and slab graveyard?
- Constraints on boundary conditions for convection
- Evolution of the core and inner core growth



Ed Garnero, http://garnero.asu.edu

LLSVPs

- dlnVs reductions of ~3 %
- Large scale degree 2 structure visible in tomography
- Possible chemical origin?



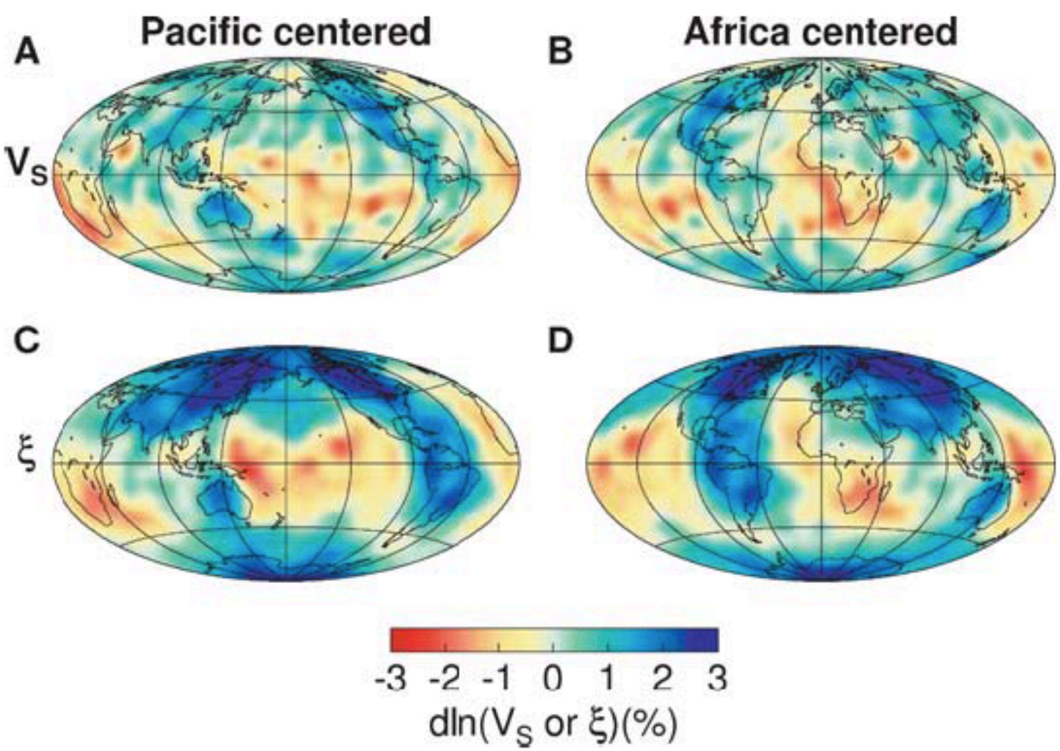
ULVZs

- Extreme reductions up to 30 %
- Small scale structures observed with body waves
- Possible relation with LLSVPs
- Partial melt and/or chemical origin?
- Observable by modes?

McNamara et al., EPSL, 2010

D’’ anisotropy

2800 km

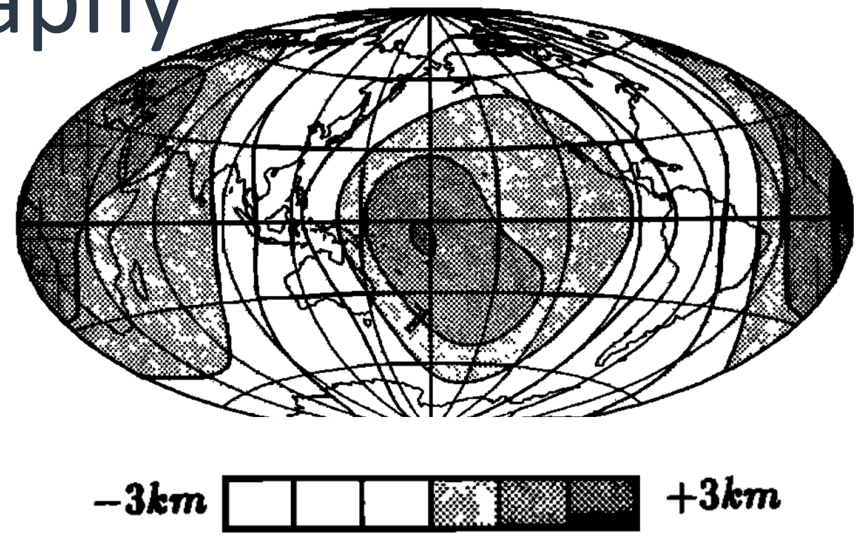


Panning & Romanowizc, GJI, 2006

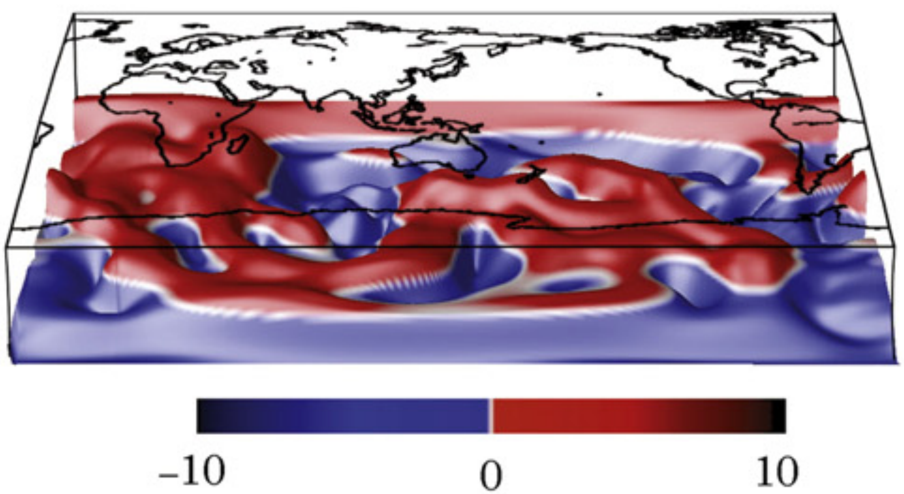
- Radial anisotropy required to match normal mode data
- Lateral varying anisotropy from S-wave splitting
- Explained by
  - deformation induced aligned crystals
  - flow aligned melt inclusions
  - pPv phase

Dynamic CMB topography

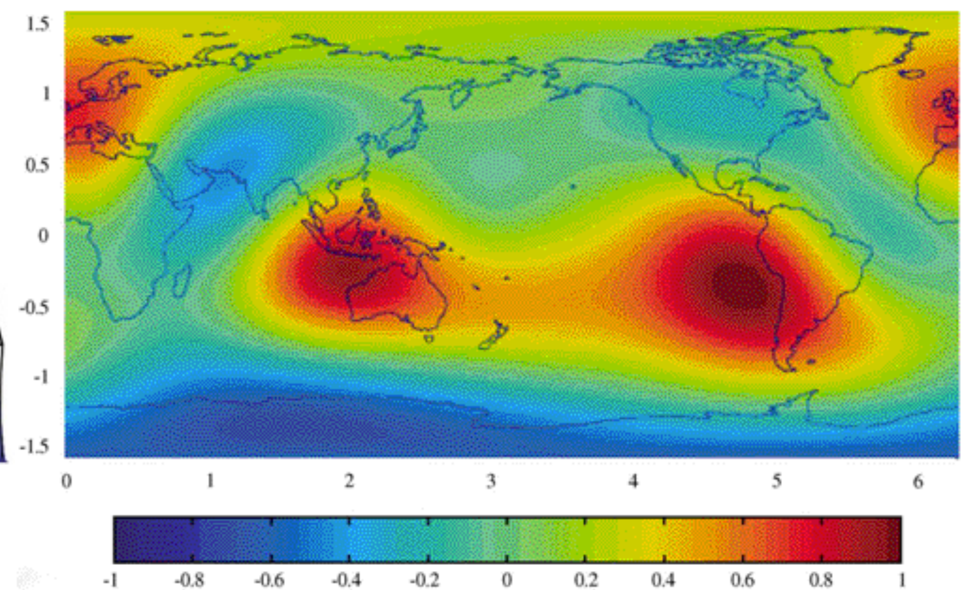
- Topography induced by convection
- Long wavelength <10 km
  short wavelength <300 m
- Models from variety of disciplines differ in pattern and amplitude



Li et al., 1991, JGR



Lassak et al., EPSL, 2010



Sze & Van Der Hilst, 2003, PEPI

Normal mode splitting functions

- Standing waves with discrete frequencies, denoted as ${}_nS_l$
- $2l+1$ singlets for a degenerate Earth – split by rotation, ellipticity and heterogeneous structure

- Describe splitting of normal modes by c_{st}:

$$c_{st} = \int_0^a \delta m_{st}(r) K_s(r) + \sum_d \delta h_{st}^d H_s^d$$

- Linearly related to Earth's structure by sensitivity kernels
- Splitting function map (similar to phase velocity map)

$$c(\theta, \phi) = \sum_{s=0}^{2l} \sum_{t=-s}^{s} c_{st} Y_s^t(\theta, \phi)$$

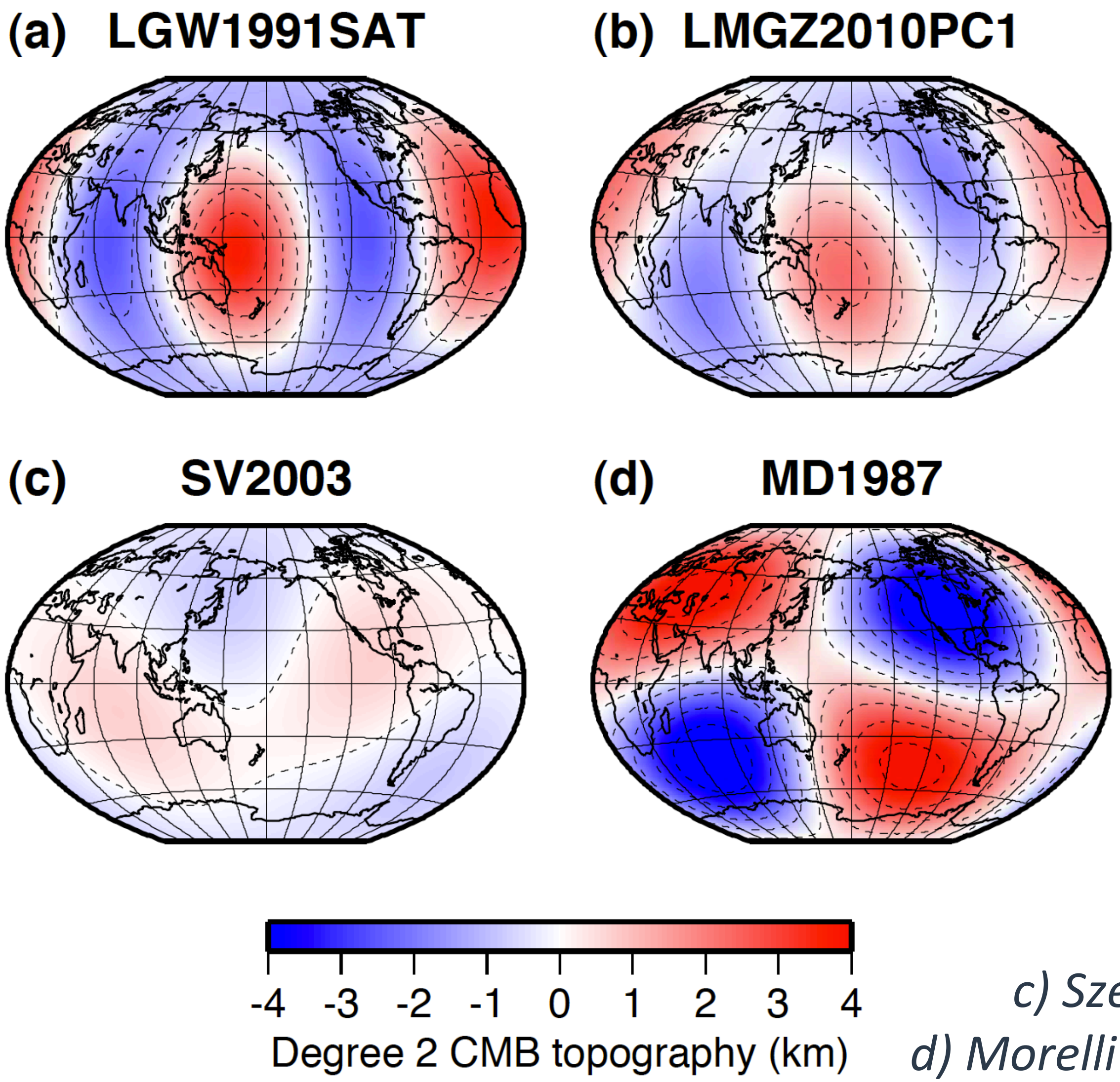
Observability

- General trends in data are well reproduced by global mantle models
- Hence, only consider splitting due to extra structure
- Calculate observability using predictions and data uncertainty:

$$O_s = \frac{1}{2s+1} \sum_{t=-s}^{s} \frac{\left| c_{st}^{A} - c_{st}^{B} \right|}{\sigma_{st}^{data}}$$

- Values larger than 1 are significant
- For selection of modes with large sensitivity to D''

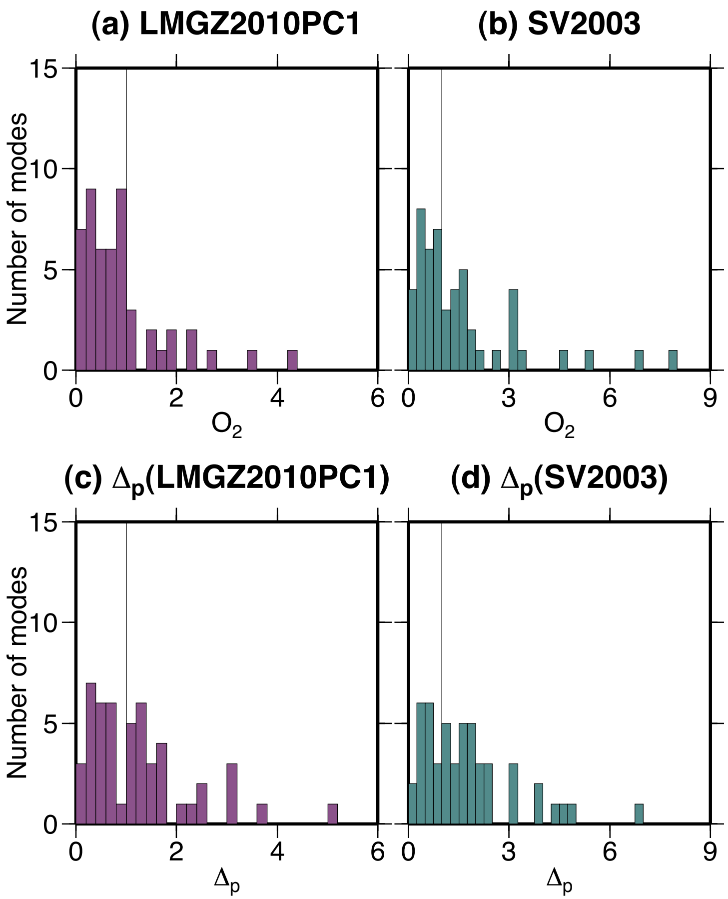
CMB topography input



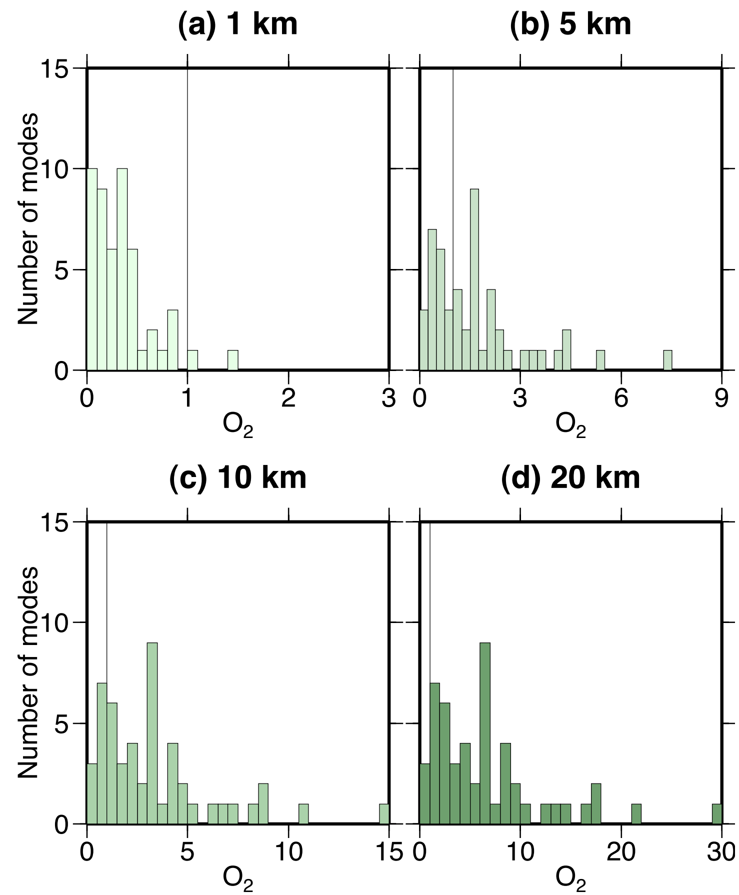
- Models taken from different disciplines
- Peak-to-peak amplitude is also varied

a) Li et al., JGR, 1991
b) Lassak et al., EPSL, 2010
c) Sze & Van Der Hilst, PEPI, 2003
d) Morelli & Dziewonski, Nature, 1987

Pattern



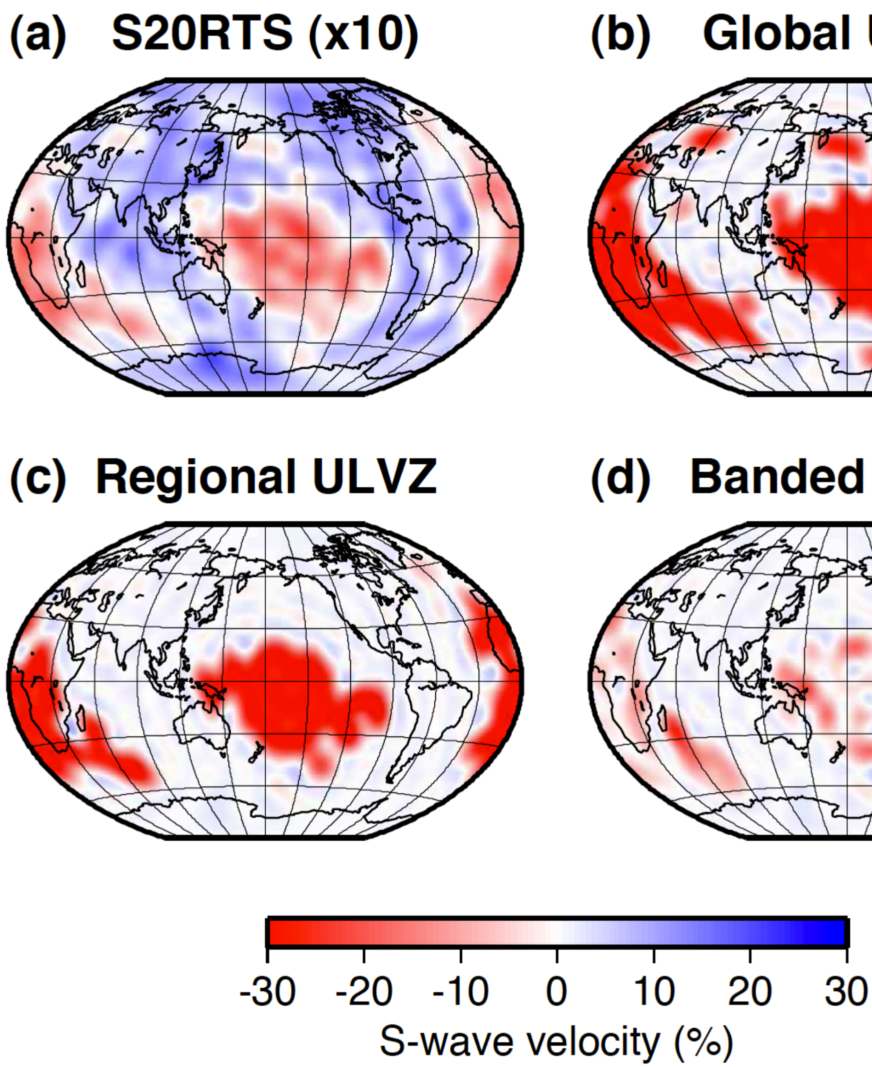
Amplitude



Koelemeijer et al., GJI, 2012

- Observability of patterns in the limit of the data
- Topography smaller than 5 km is not observable

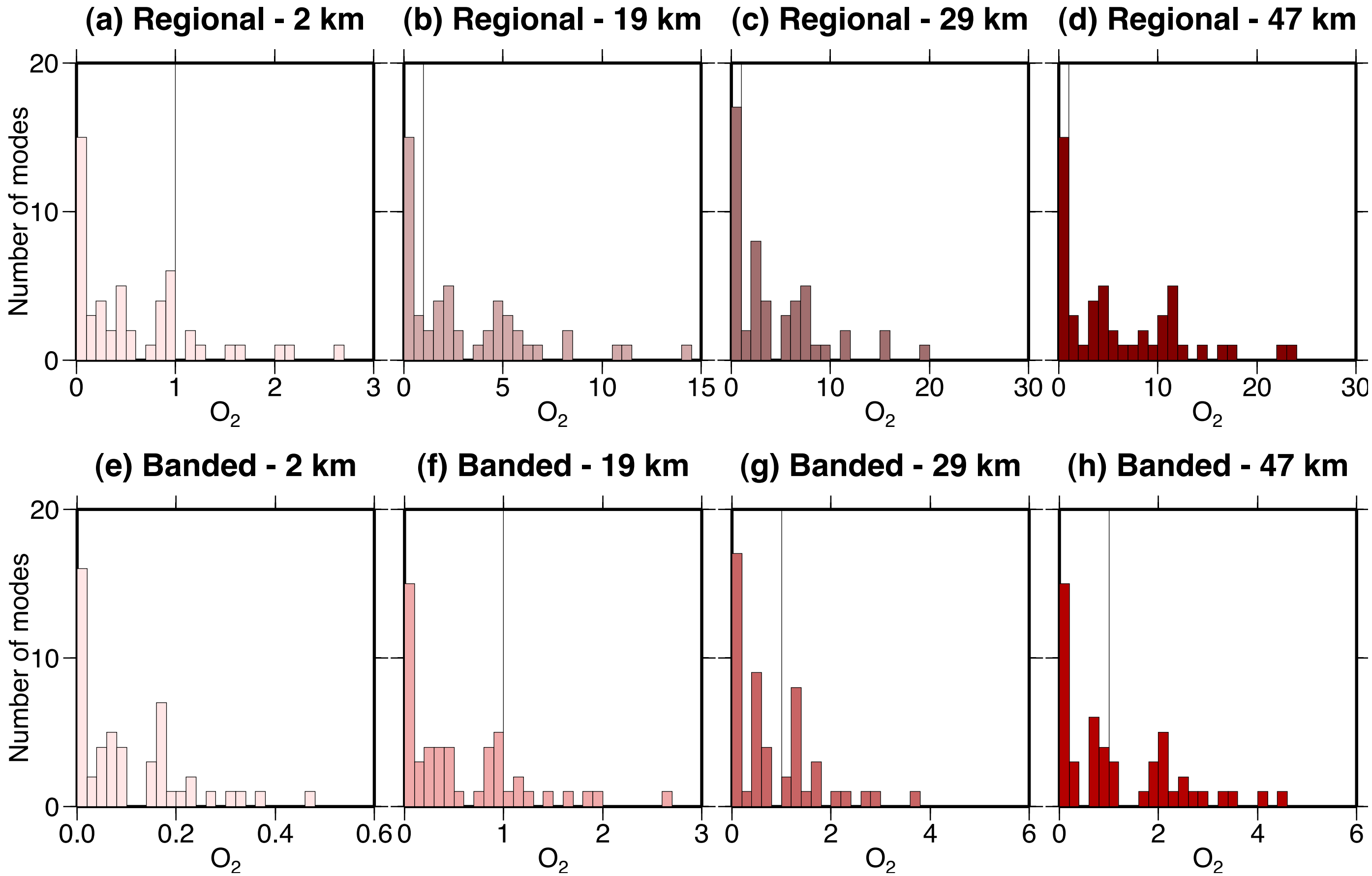
ULVZ input



- Use variations in S20RTS for parameterization
- Banded ULVZs synthesized are consistent with the edges of LLSVPs

Regional

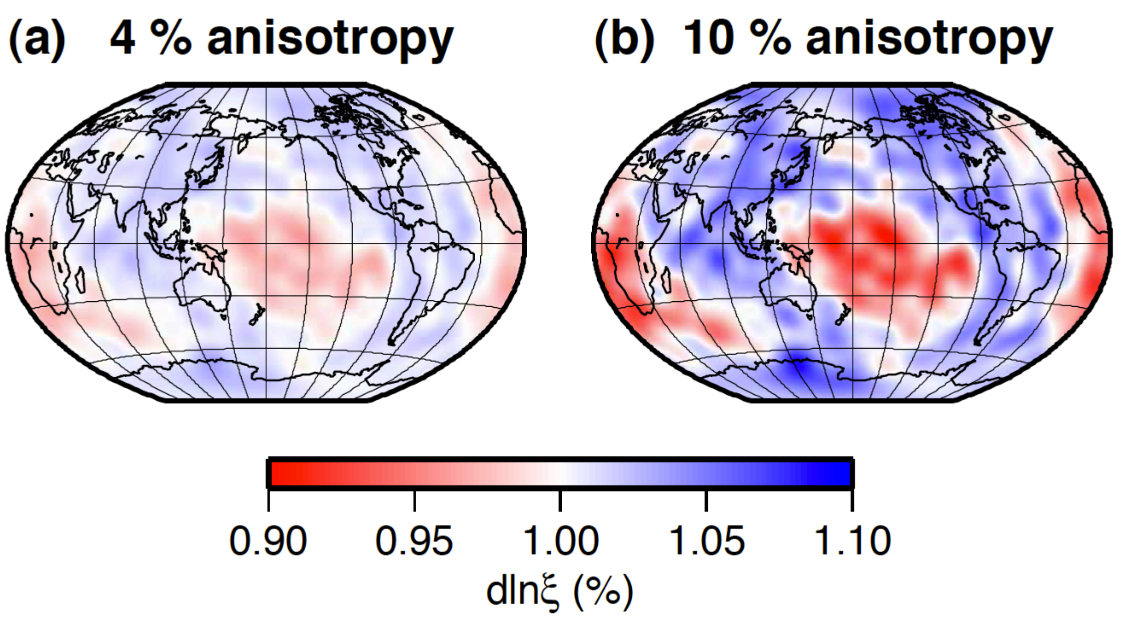
Banded

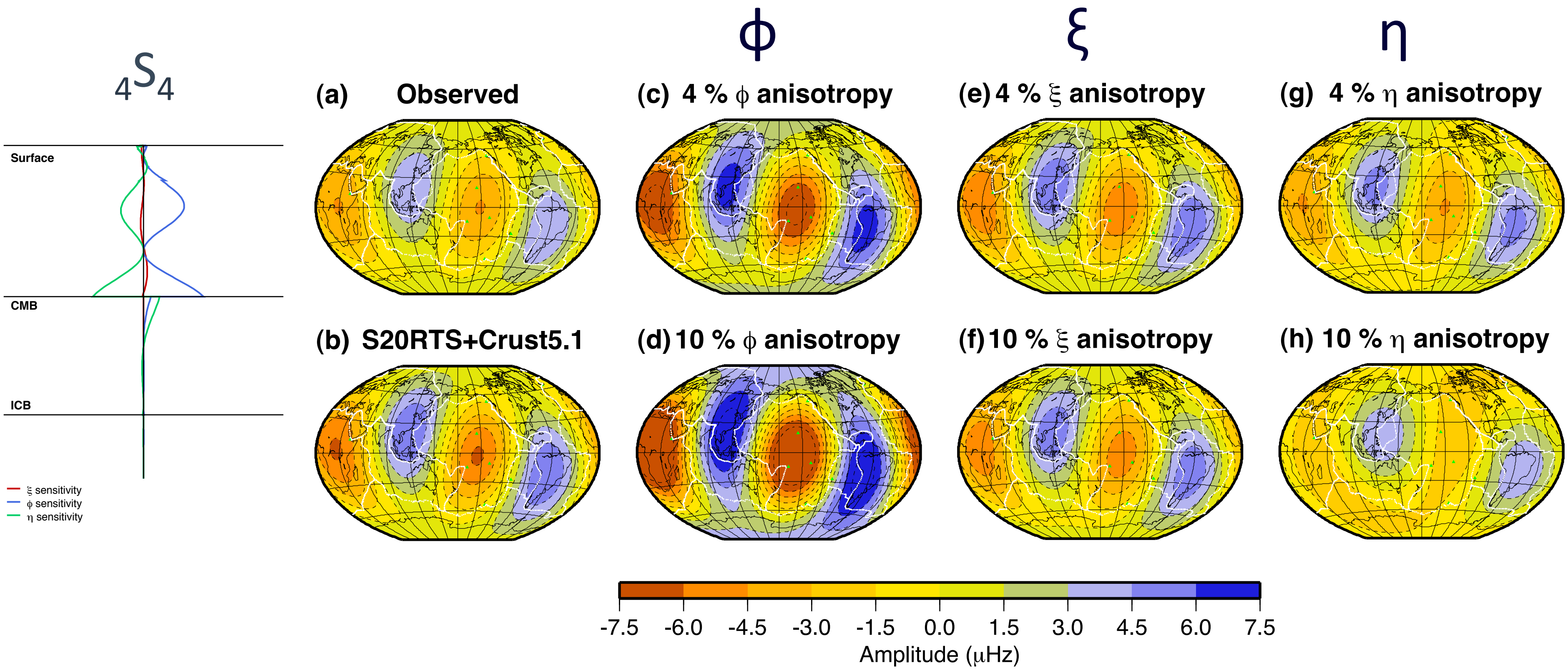


- Regional ULVZs larger than 19 km are observable
- For banded ULVZs the thickness needs to be larger than 29 km

Anisotropy input

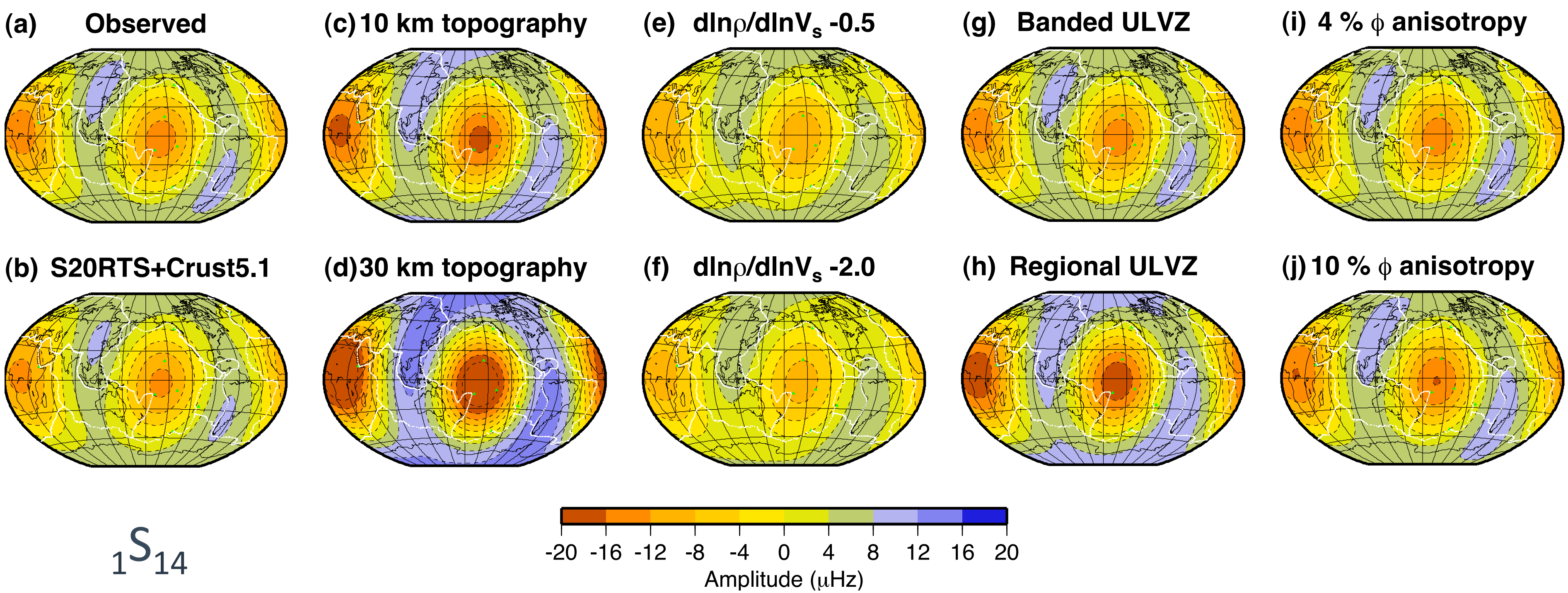
- Relate to S20RTS variations
- Parameterize in Love parameters ϕ=C/A, ξ=N/L and η
- $0.9 < \phi, \xi, \eta < 1.1$ for ξ: > 1 parallel to CMB
  < 1 perpendicular to CMB



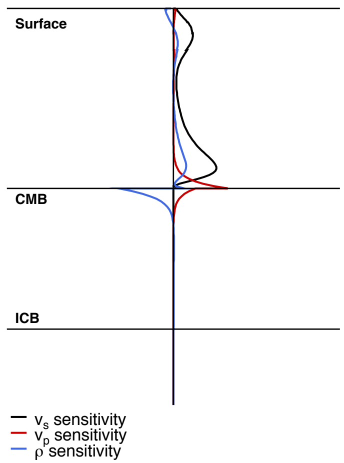


- Small variations due to ξ except for fundamentals
- Modes mainly sensitive to ϕ and η
- However, large trade-offs exist between the two

Trade-offs between structures



$_1S_{14}$



- CMB topography and ULVZs large effect
- dlnρ/dlnVs scaling effect cannot even out large topography
- Observability anisotropy dependent on mode

Higher degree observability

	Topography		ULVZs		Scaling	Anisotropy		
	T_p	T_a	U_r	U_b	S	A_ϕ	A_ξ	A_η
O_2	x	x	x	x	x	x	x	x
O_4	x	x	x	x	x	x	-	x
O_6	x	x	x	-	x	x	-	x
O_8	-	-	-	-	-	-	-	-

Koelemeijer et al., GJI, 2012

- Most structures observable up to degree 6
- Banded ULVZs only up to degree 4 and S-wave anisotropy only up to degree 2
- However, observability dependent on available data

Conclusions

Normal modes are sensitive to small scale D'' structures

- CMB topography smaller than 5 km cannot be resolved
- Effect of different patterns close to limit of the data
- To be visible, regional ULVZs should be thicker than 19 km and banded ULVZs thicker than 29 km
- S-wave anisotropy is difficult to resolve, P-wave and anisotropy in η easier, but show a strong trade-off
- Trade-offs between all structures depend on the mode
- Observability generally large enough up to degree 6


Thank you for you attention