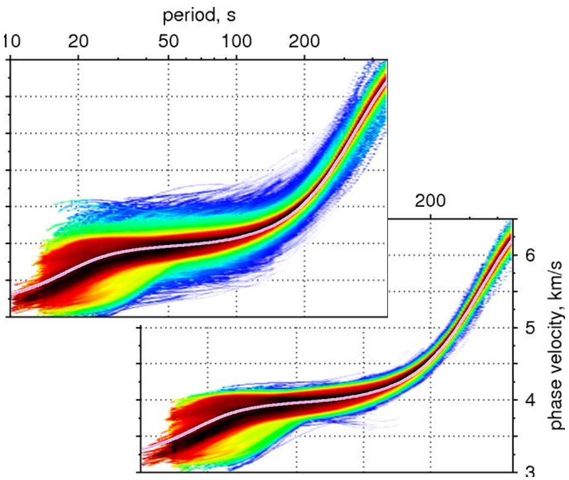
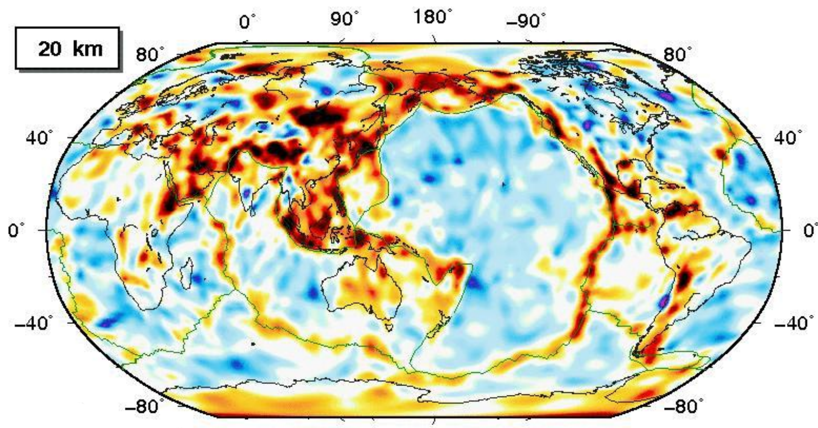
Seismic tomography meets millions of waveforms: Exploiting data redundancy to control errors and increase resolution





Sergei Lebedev and Andrew Schaeffer

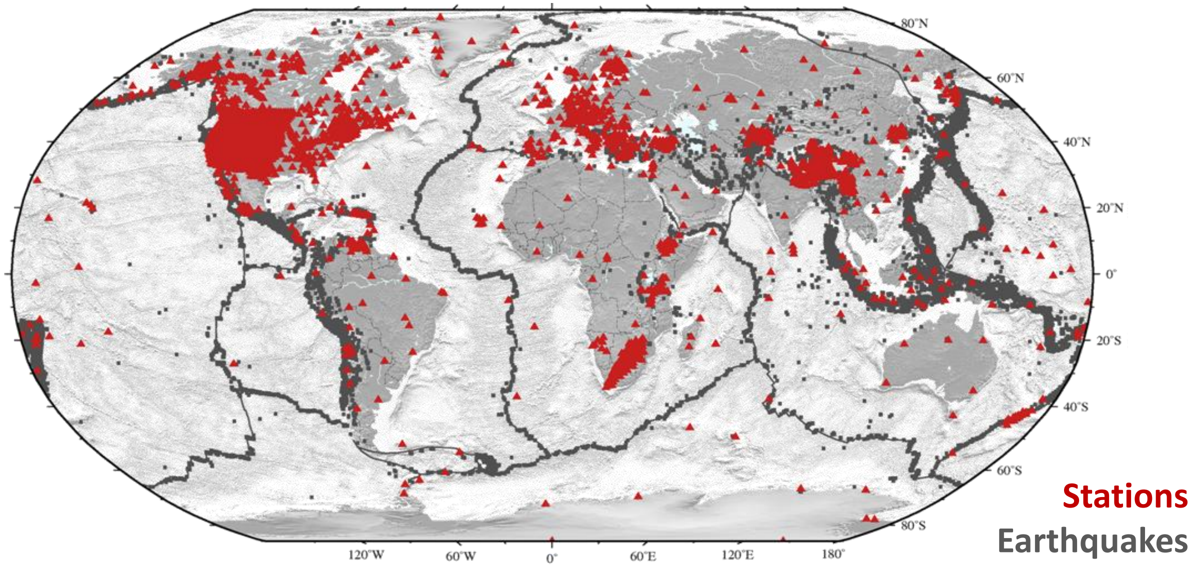
Dublin Institute for Advanced Studies

DATA

- rapid recent growth in global broadband data coverage
- new generation of upper-mantle models
- millions of broadband waveforms available for use in tomography

TOMOGRAPHY OF THE CRUST AND UPPER MANTLE

- waveform inversion
- inversion of multi-mode phase and group velocities



Errors and Uncertainties

- errors in data and modelling limit the resolution of the imaging
- source-parameter errors
- station timing and response correction errors
- errors in wave-propagation and sensitivity modelling
- unresolved strong crustal heterogeneity

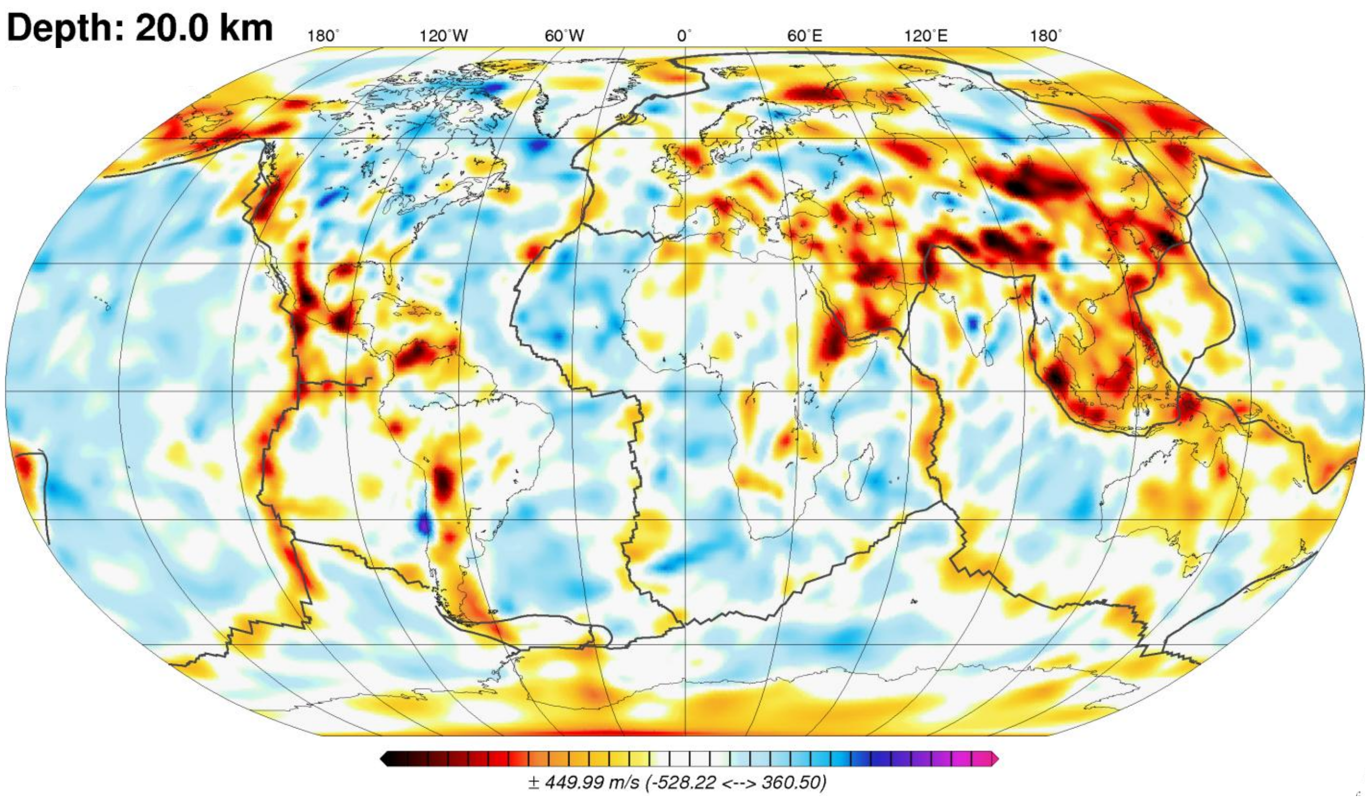
MAKING THE MODEL *SL2013SV*

- **The dataset: >1 million multimode seismogram fits** (750K Rayleigh; 250K Love)
- **Automated Multimode Inversion of surface, S, multiple S waves** (Lebedev et al. 2005)
  - waveform fitting in time-frequency windows with nearly exact fit within each
  - windows are selected, case-by-case, so that the WKBJ approximation within them is most likely to hold
- **3D reference model** (modified CRUST2 + 1D mantle)
- **perturbations in both the crust and mantle are solved for** (resolving the crust is more accurate than crustal corrections)
- **model parameters include V_{SV}, azimuthal anisotropy, V_P**
- **beyond ray theory:** approximate sensitivity kernels; a mode's phase and its derivatives computed by integration over the kernels

TREATMENT OF ERRORS:
SELECT THE MOST MUTUALLY CONSISTENT DATA

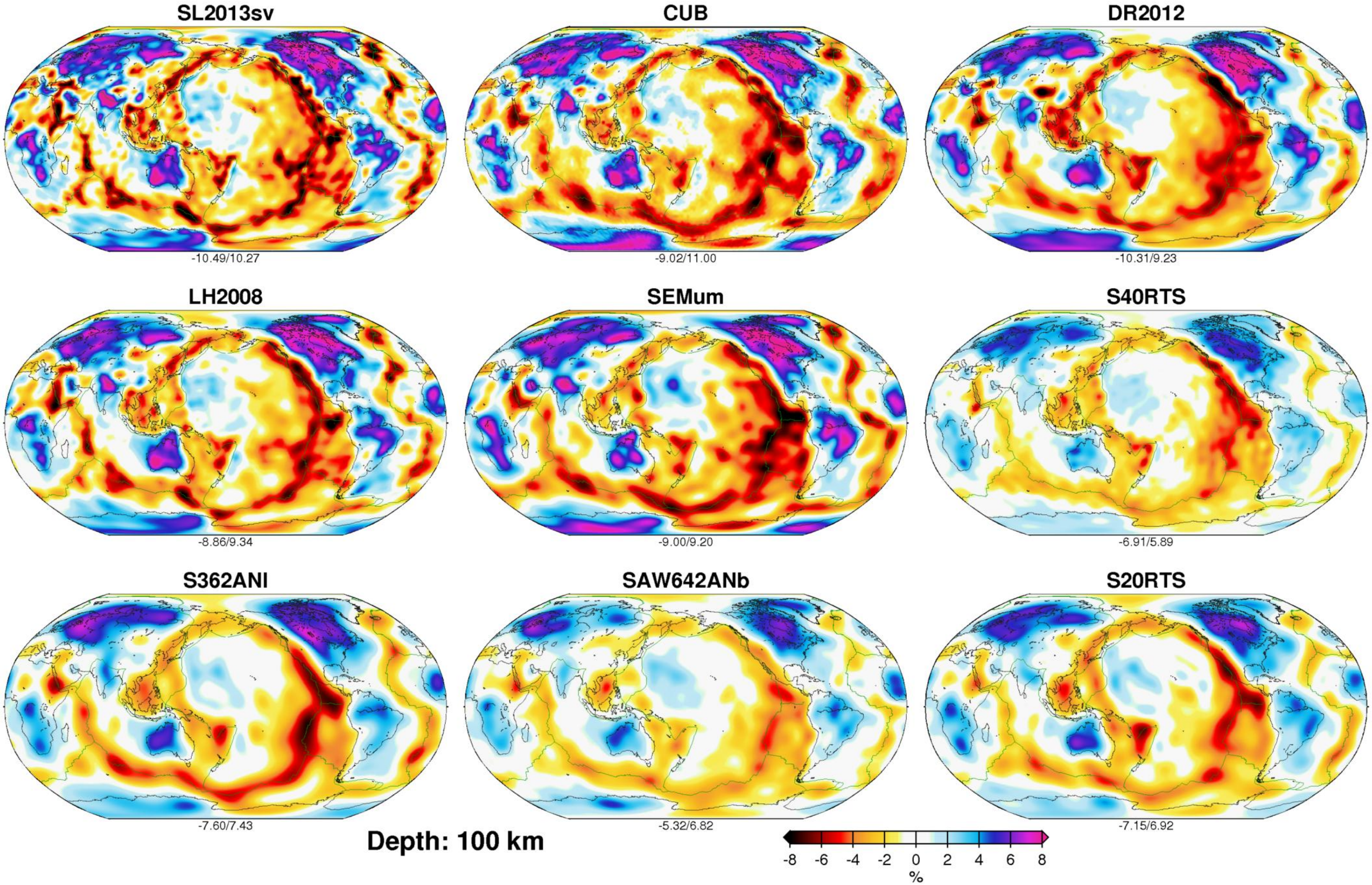
- **“outlier analysis”** (Lebedev & van der Hilst 2008; Schaeffer and Lebedev 2013):
  - compute a tomographic model
  - check which data is fit the worst by the model; remove them
  - compute an updated tomographic model; repeat
- **750K → 510K seismograms**

Crustal structure resolved by surface-wave data

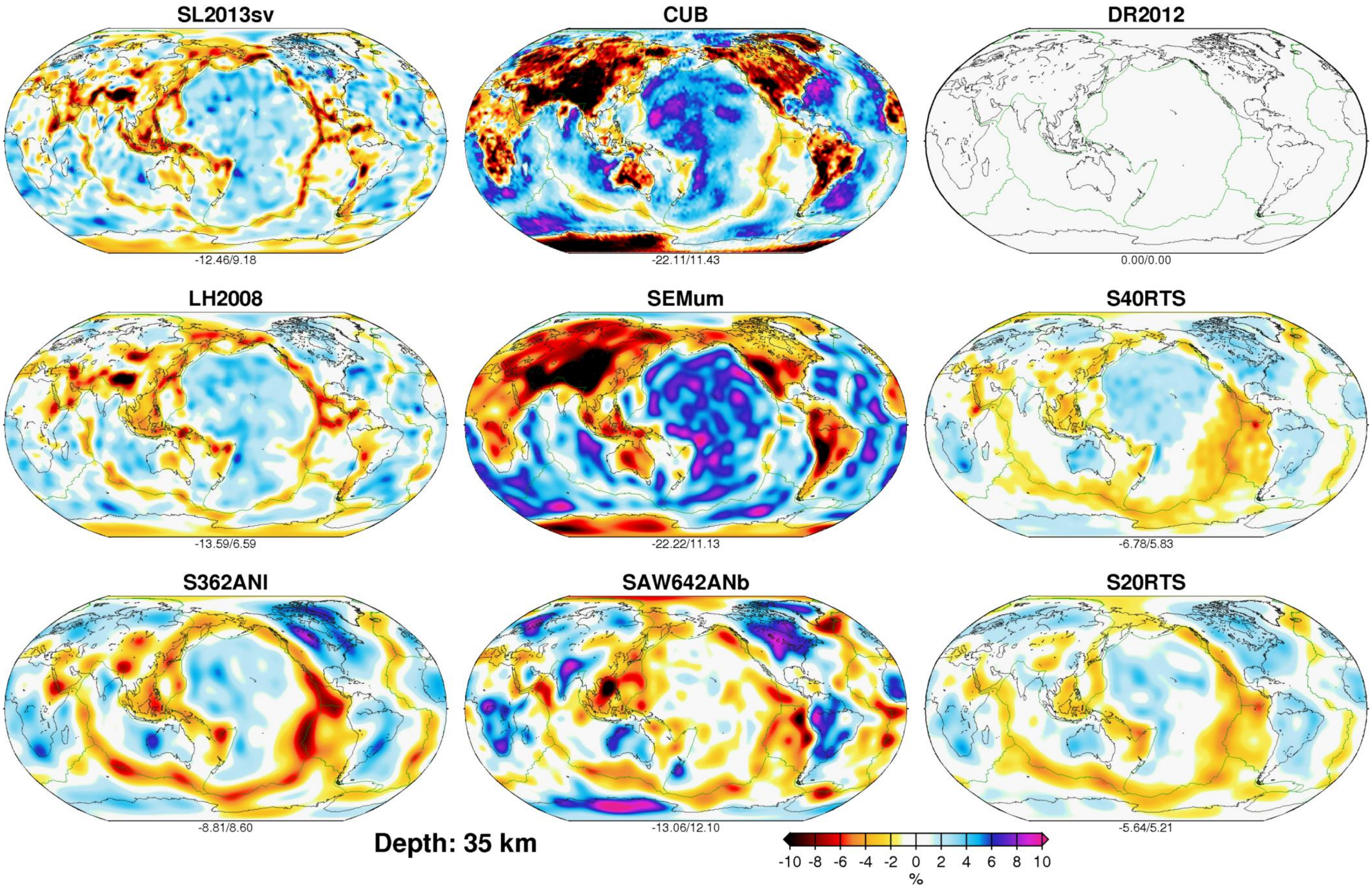


- Anomalies in the crust with respect to (modified) CRUST2.0; in the mantle – with respect to the global average
- In parts of continental crust – very large changes from CRUST2.0
- Close match of major anomalies with tectonic boundaries and known structure

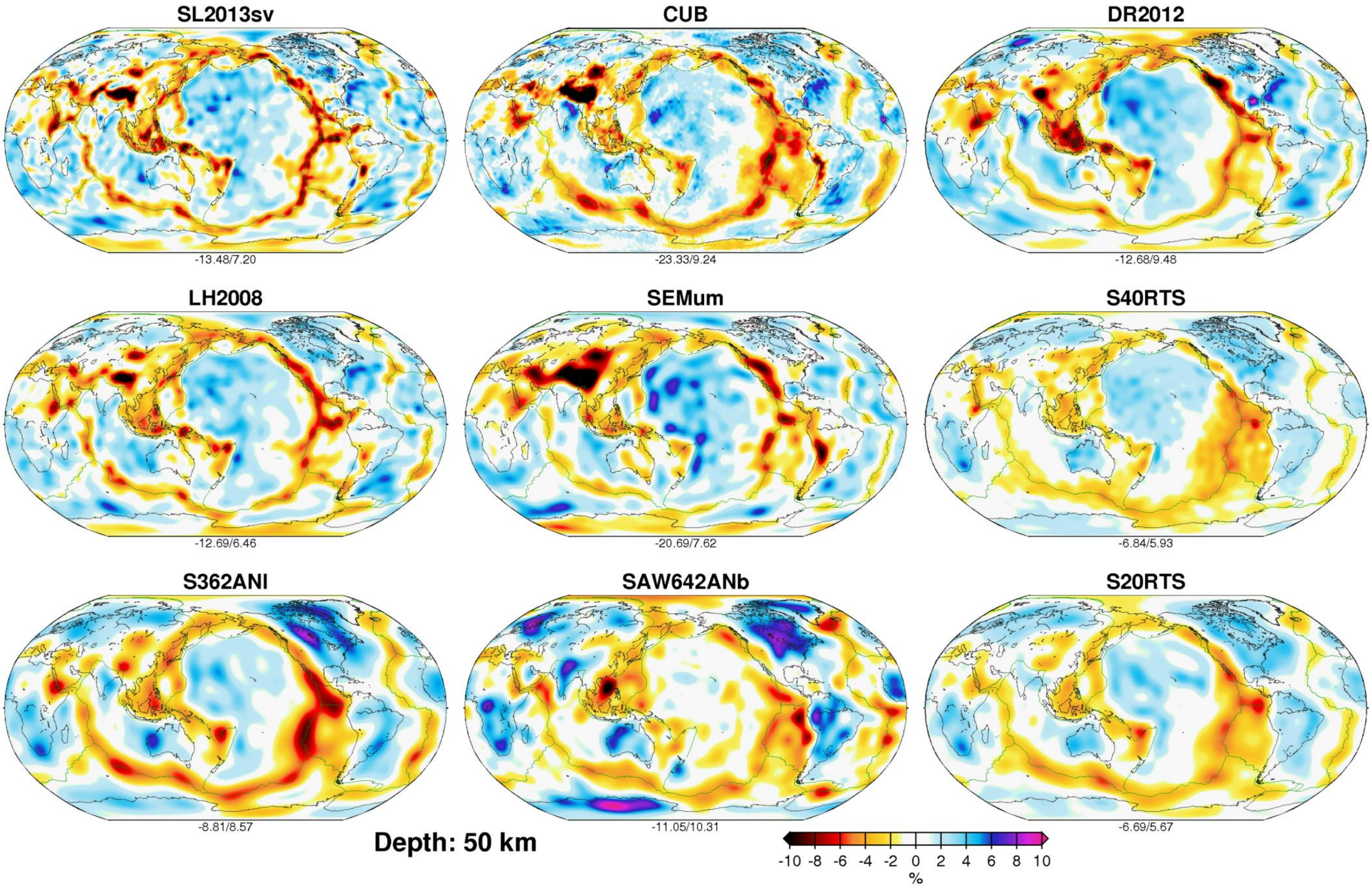
Schaeffer & Lebedev, GJI 2013



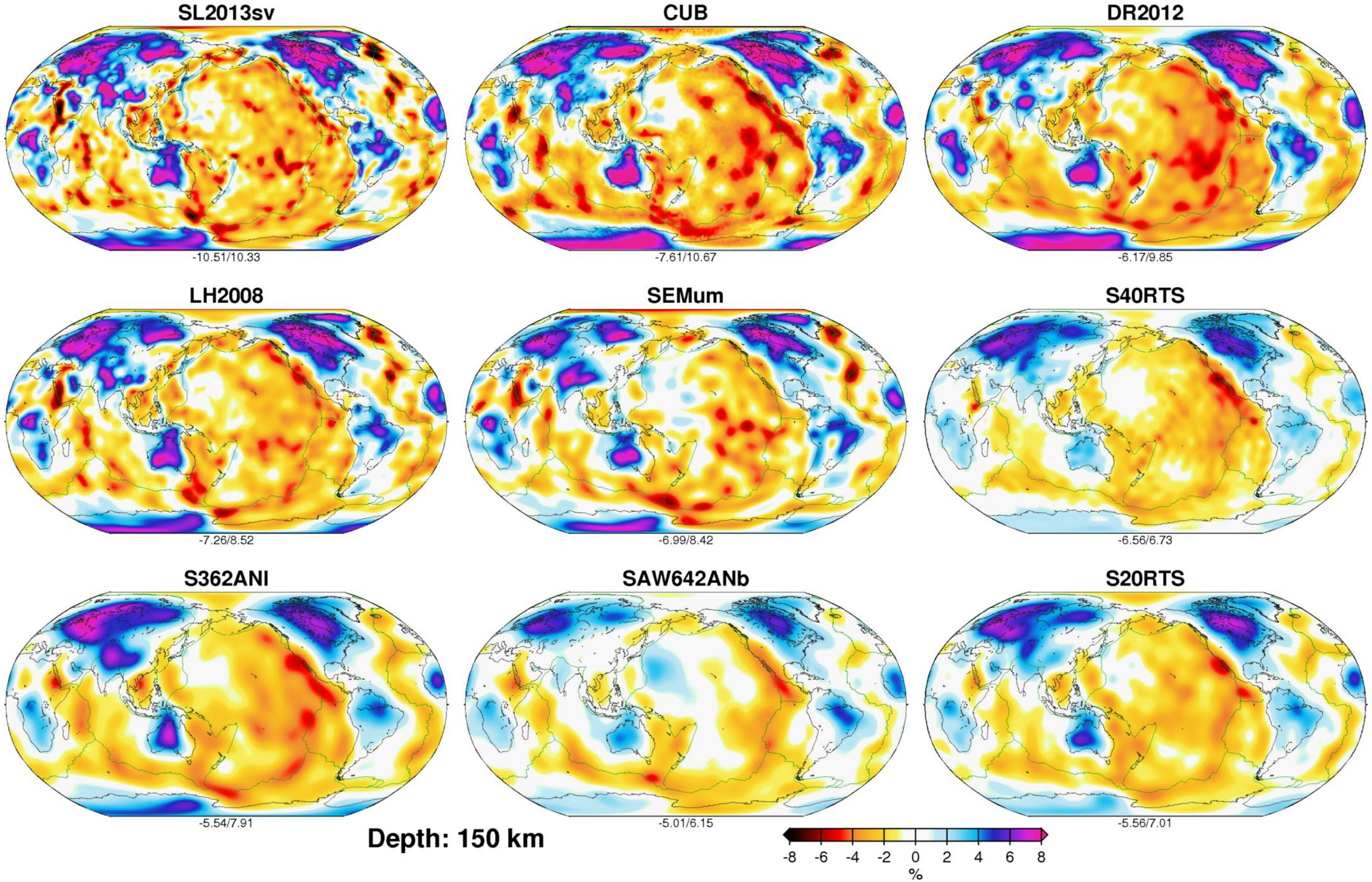
Schaeffer & Lebedev, submitted, 2013



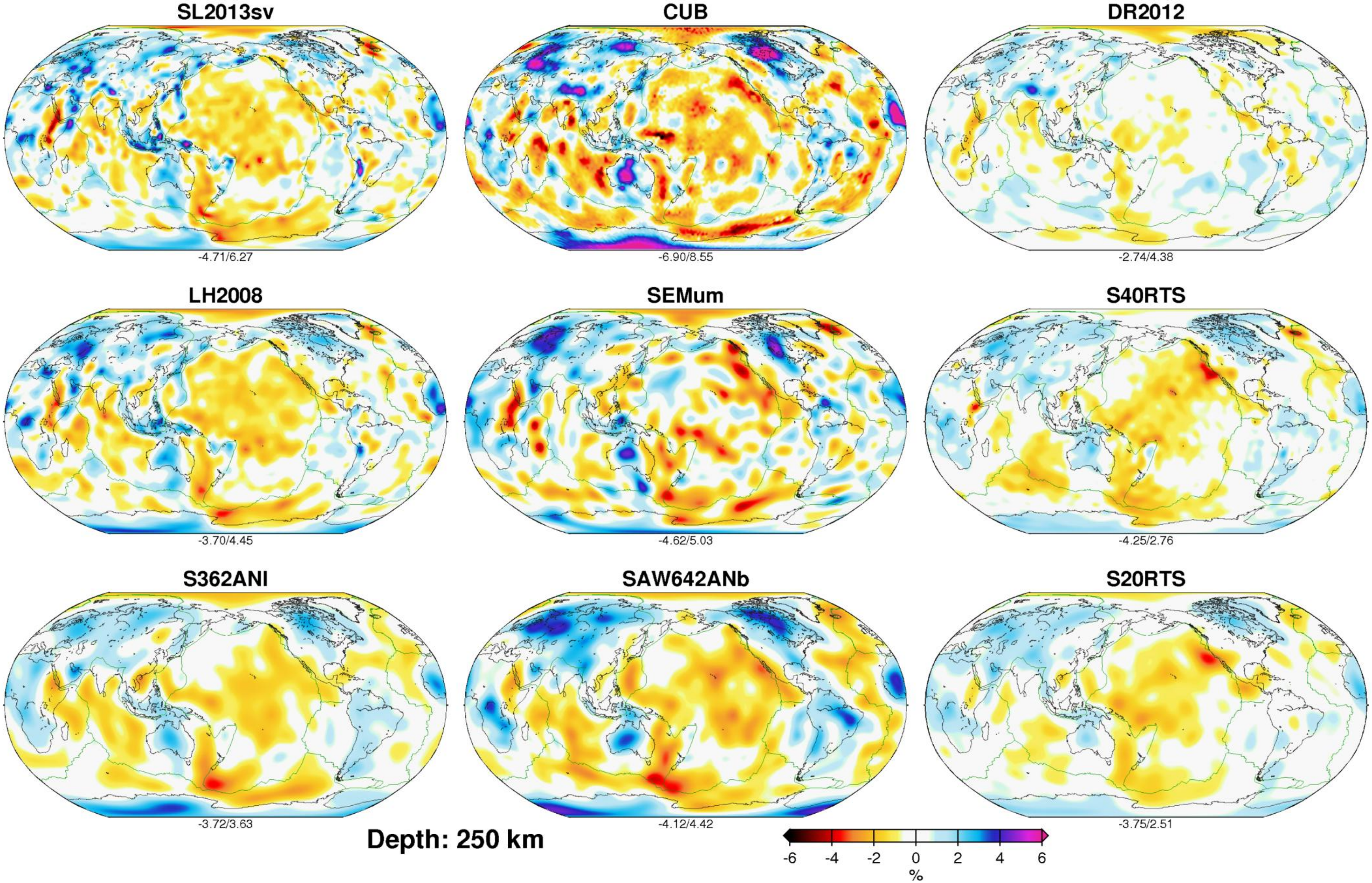
Schaeffer & Lebedev, submitted, 2013



Schaeffer & Lebedev, submitted, 2013

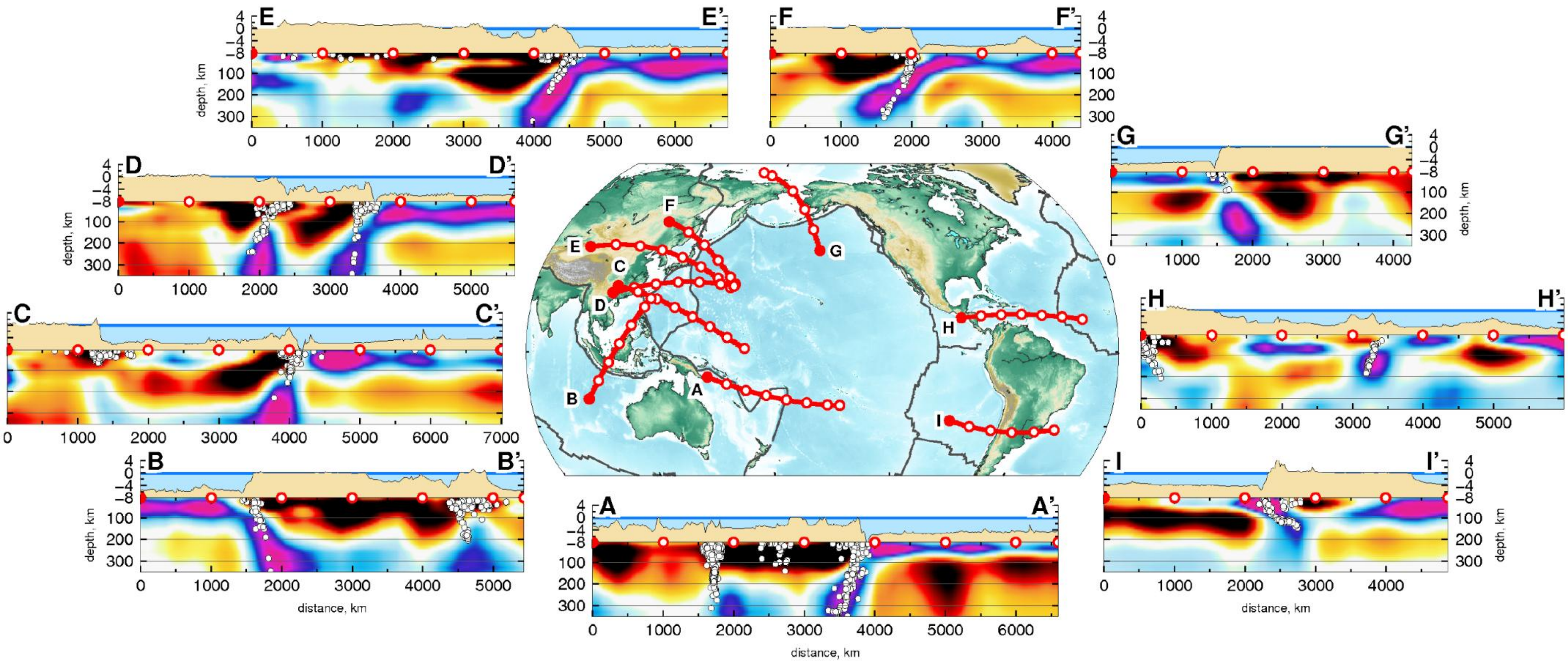


Schaeffer & Lebedev, submitted, 2013



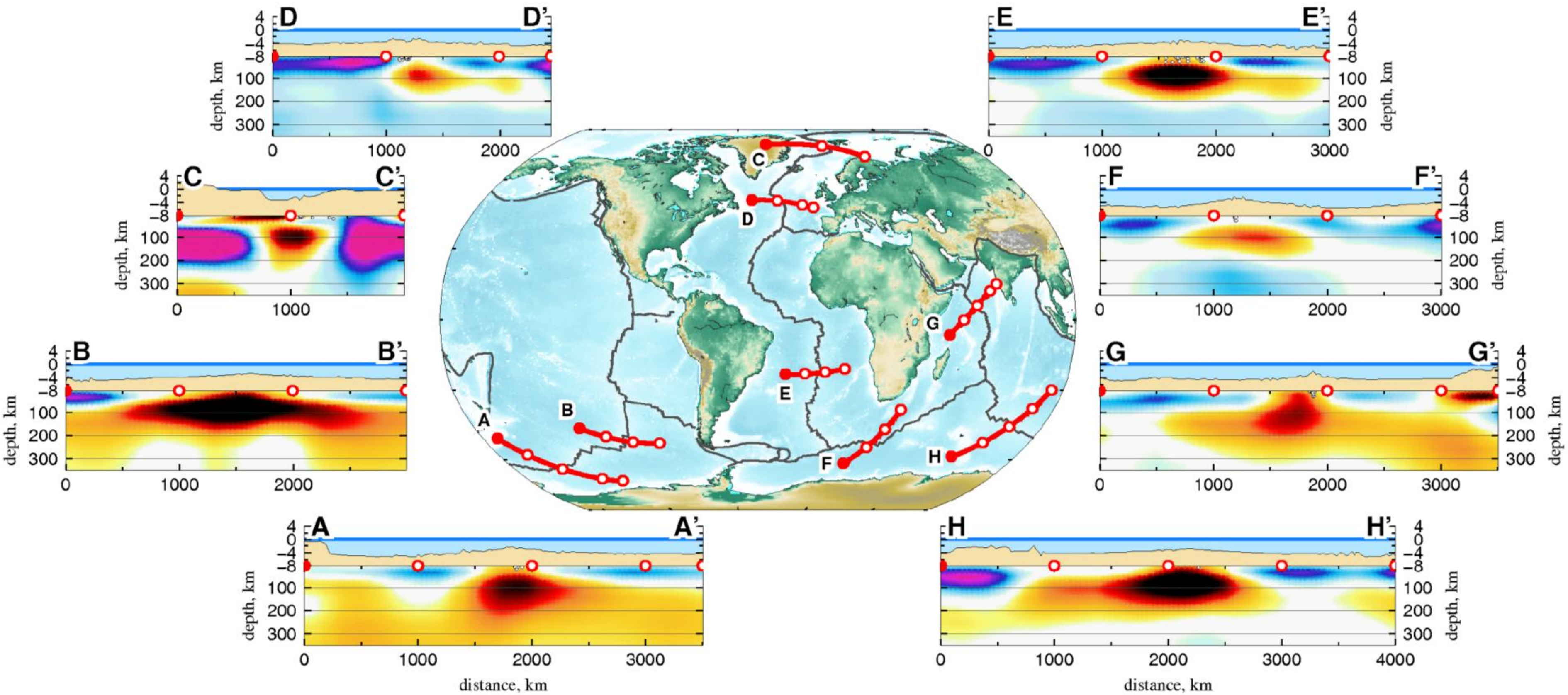
Schaeffer & Lebedev, submitted, 2013

Subduction zones



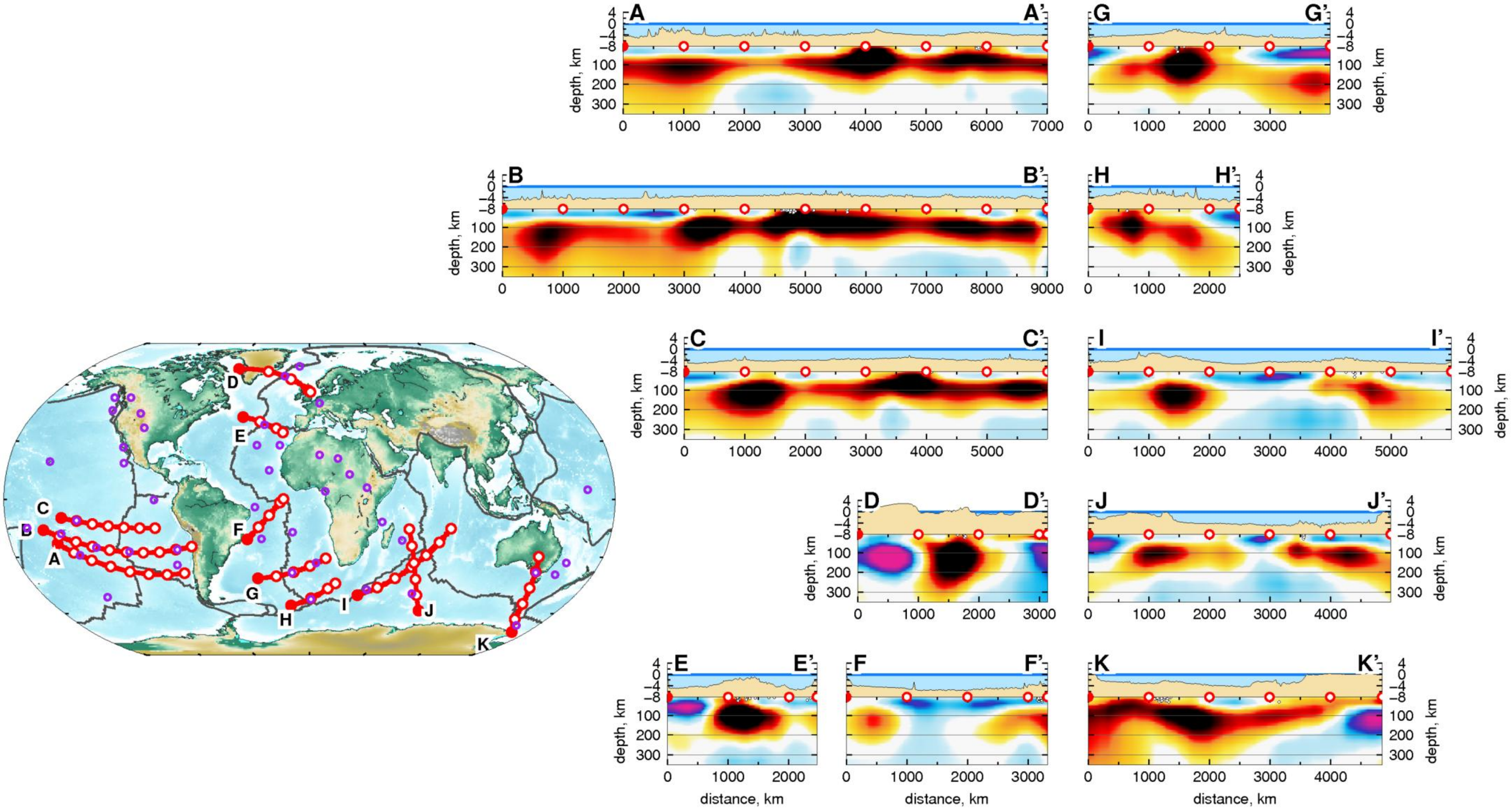
Schaeffer & Lebedev, submitted, 2013

Mid-ocean ridges



Schaeffer & Lebedev, submitted, 2013

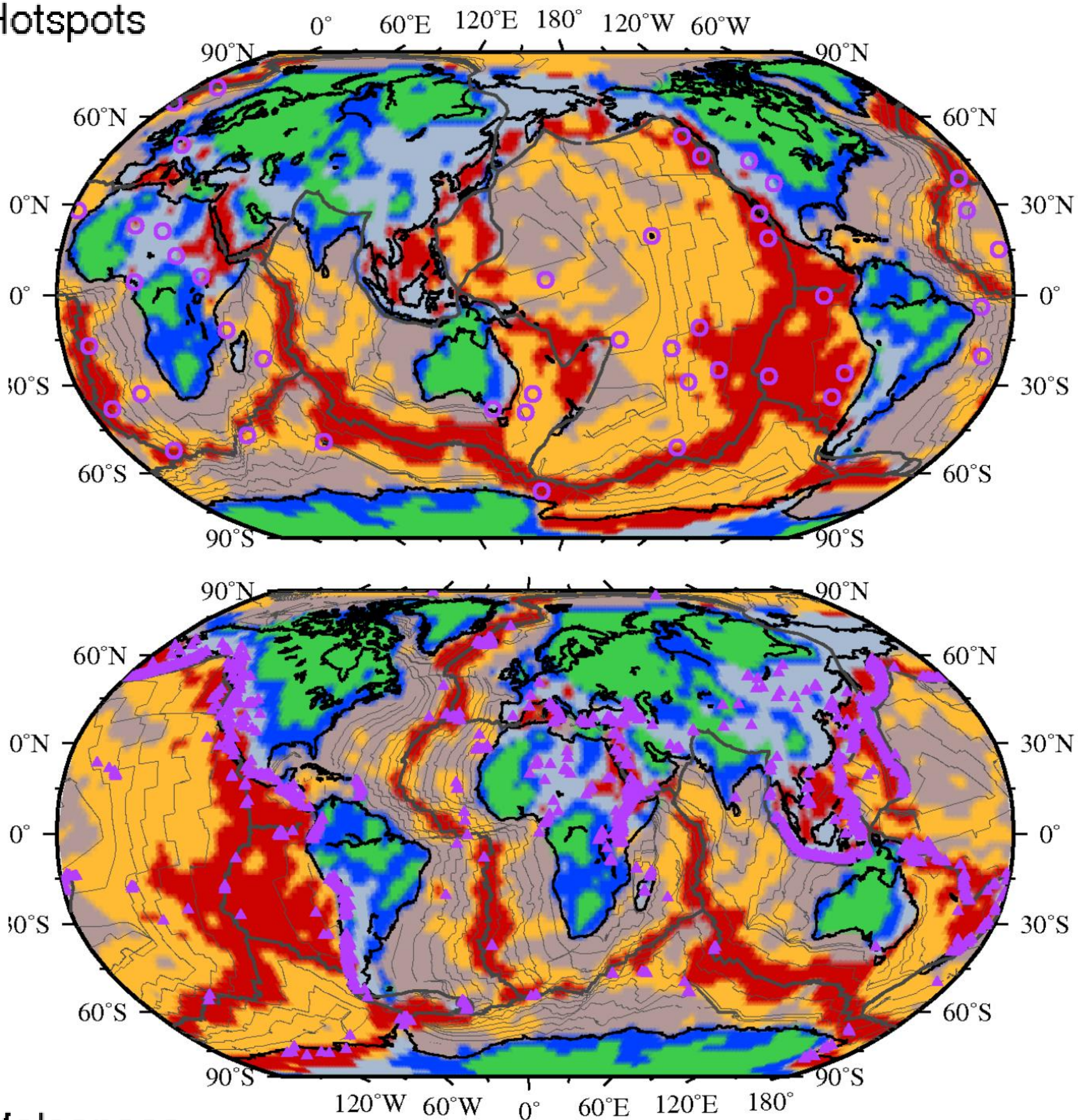
Ridges + hotspots



Schaeffer & Lebedev, submitted, 2013

Lithospheric Regionalisation

○ Hotspots



▲ Volcanoes

Oceans

- Oldest Oceanic
- Oceanic
- Ridges & Backarcs

Continents

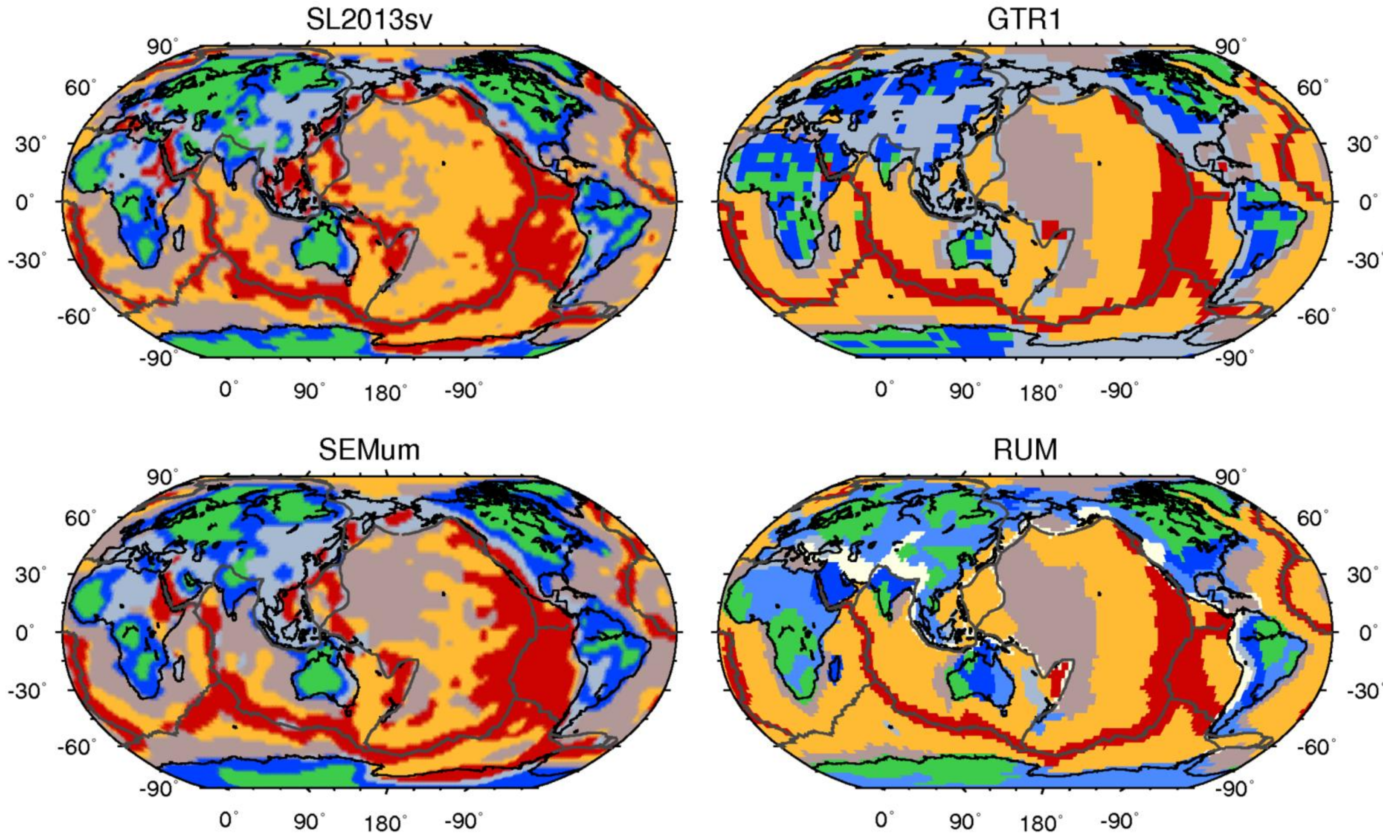
- Phanerozoic
- Stable non-cratonic
- Cratons

Schaeffer & Lebedev, submitted, 2013

Lithospheric Regionalisation

Oceans

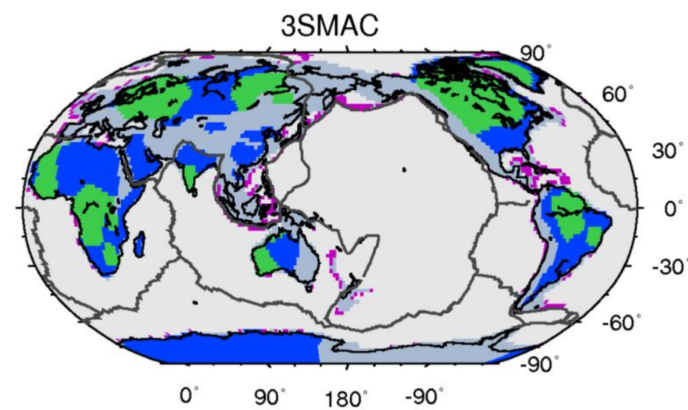
- Oldest Oceanic
- Oceanic
- Ridges & Backarcs



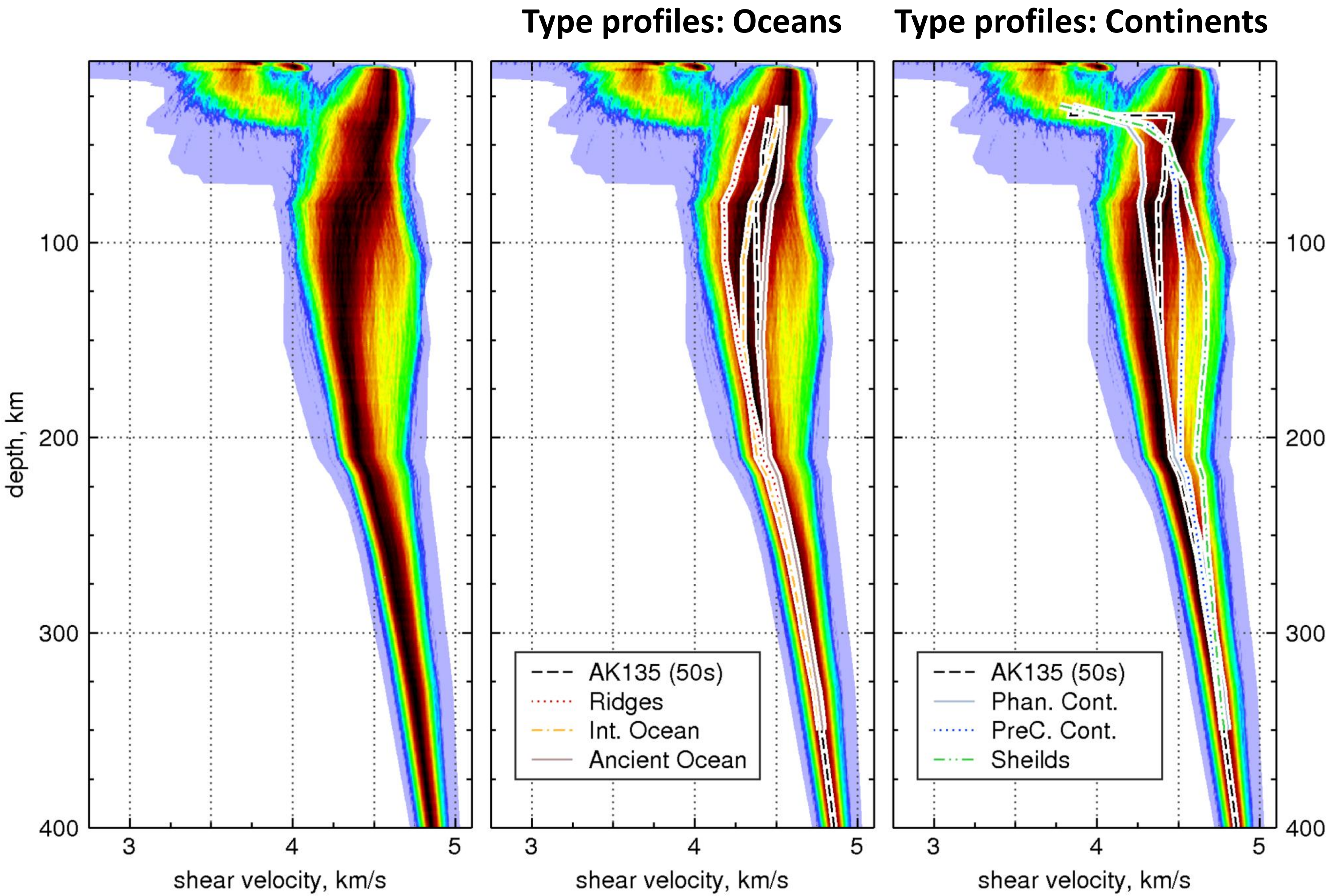
Continents

- Phanerozoic
- Stable non-cratonic
- Cratons

- RUM "Tectonic Continents"
- RUM "Intermediate Continents"
- 3SMAC "Back-Arcs & Shallow Slab Framgents"

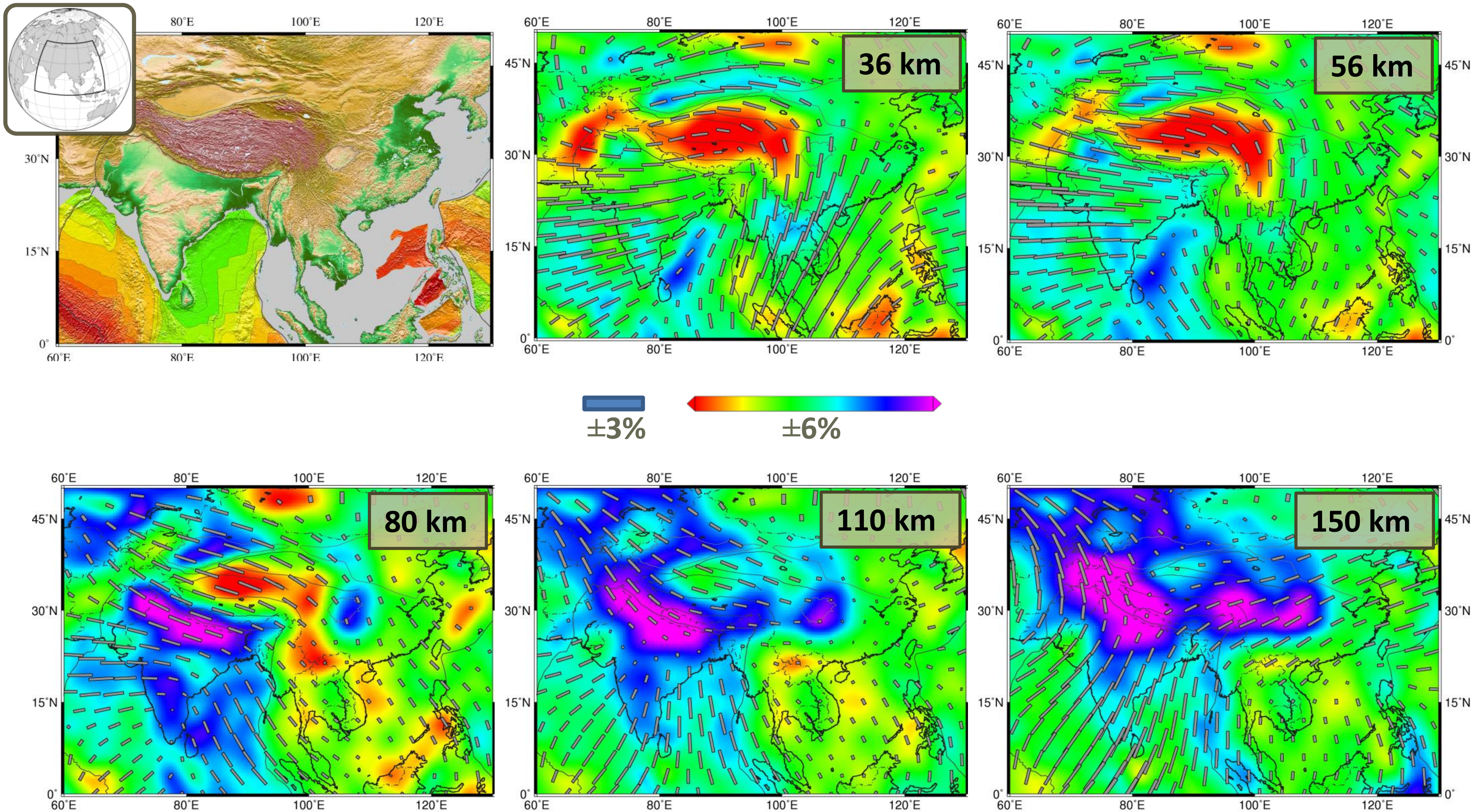


Global stack of *Vs* profiles

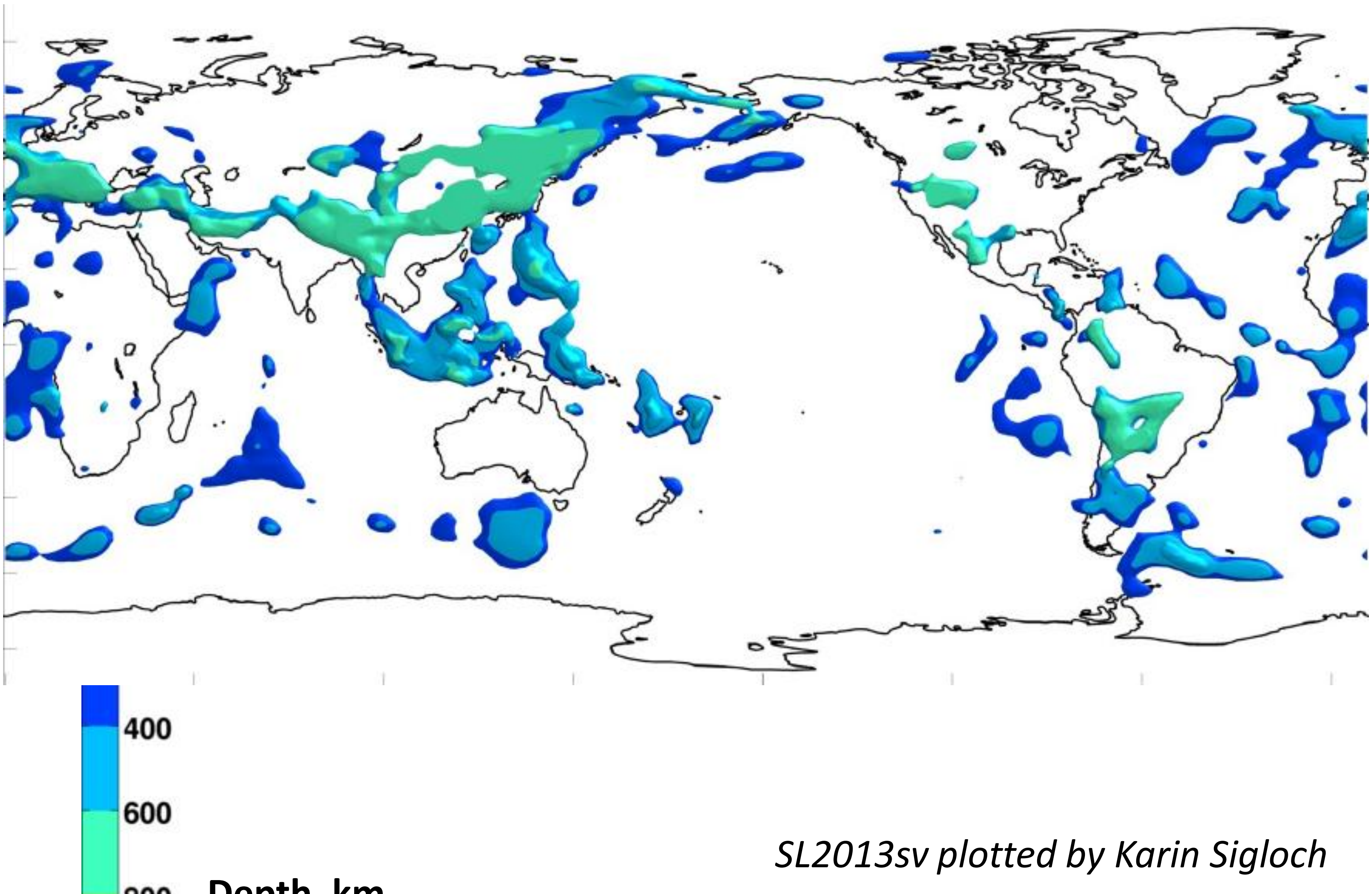


Schaeffer & Lebedev, submitted, 2013

Anisotropic Structure beneath Tibet and India



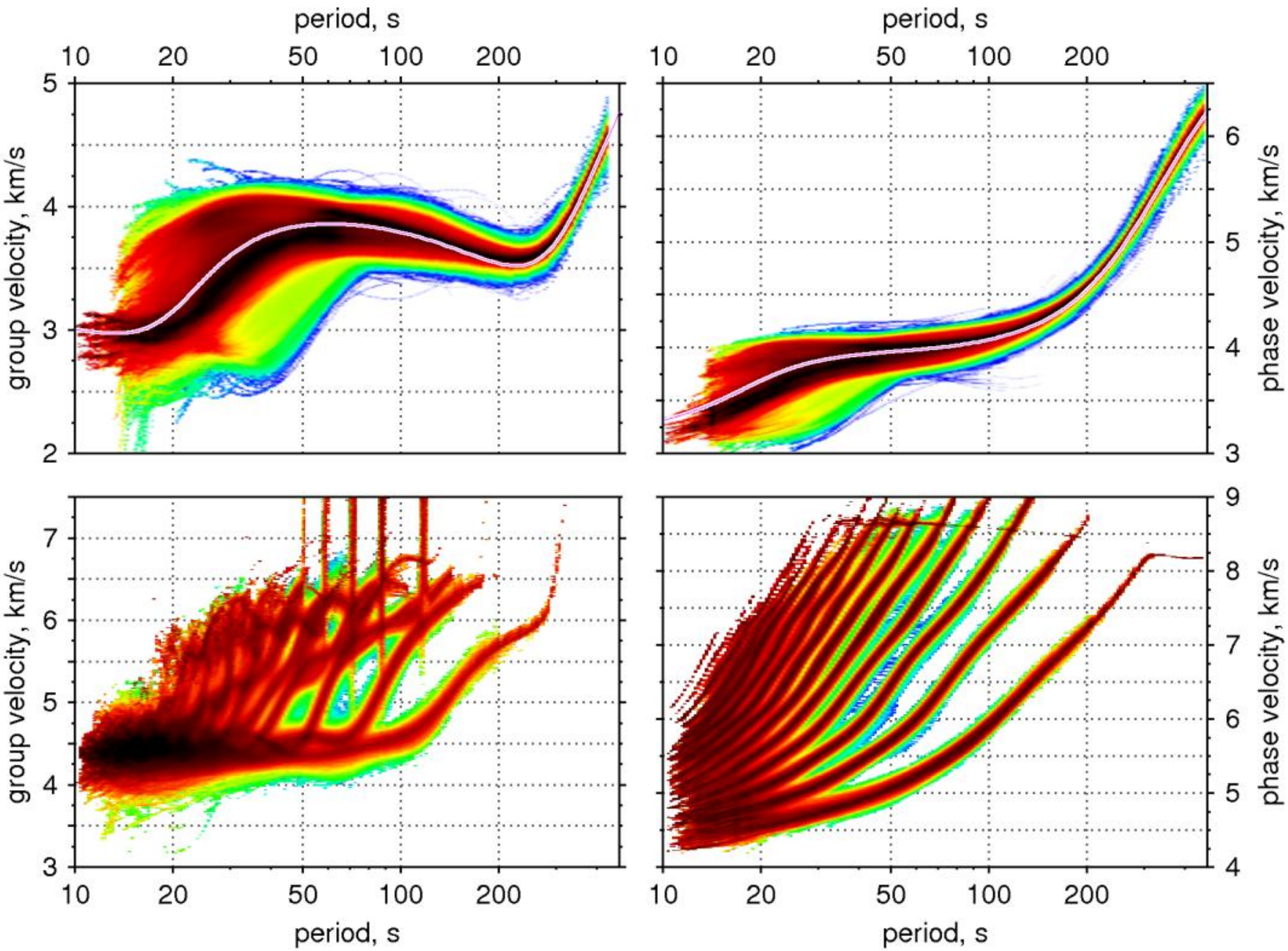
Transition zone: subducted lithosphere



SL2013sv plotted by Karin Sigloch

Dispersion diagram of Rayleigh waves on the Earth

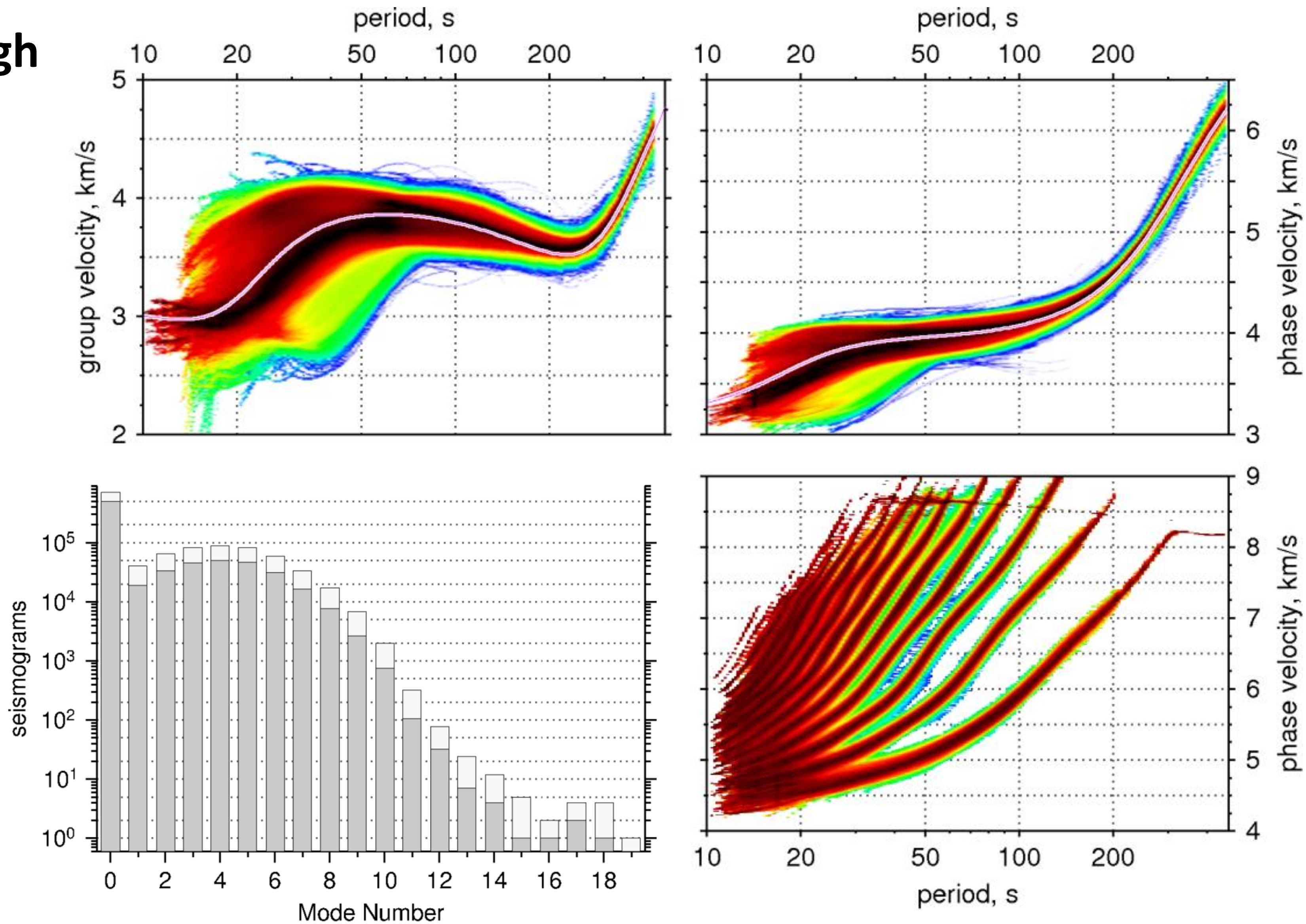
Rayleigh waves
(SL2013sv)



Dispersion diagram of Rayleigh waves on the Earth

Rayleigh waves

(SL2013sv)

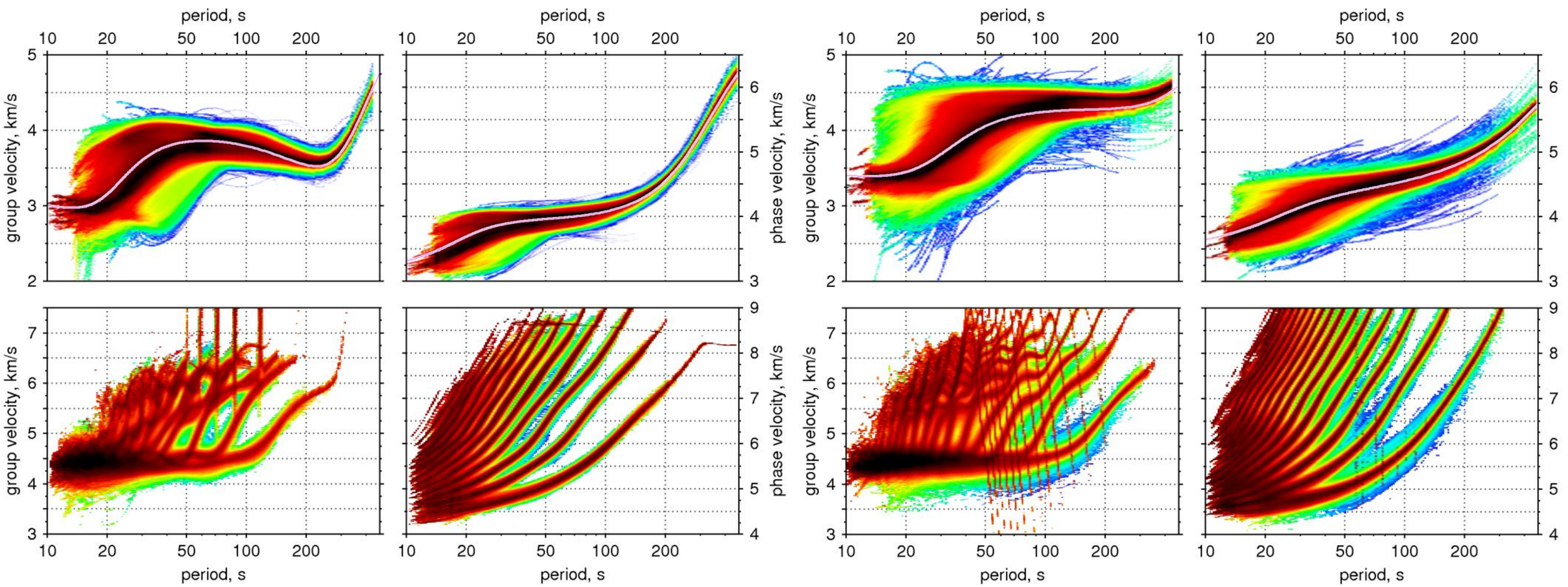


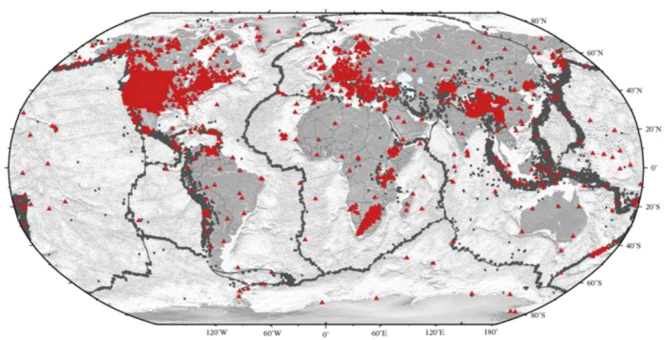
Dispersion diagrams of Rayleigh and Love waves

Rayleigh waves

(SL2013sv)

Love waves





Fundamental and higher-mode phase velocities measured from >1 million seismograms

CONCLUSIONS

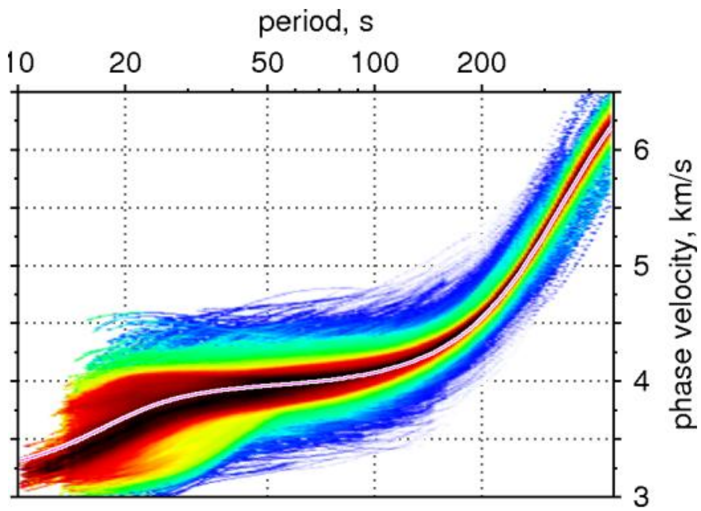
- **errors can reduce the resolution of the imaging**

  - source parameter errors

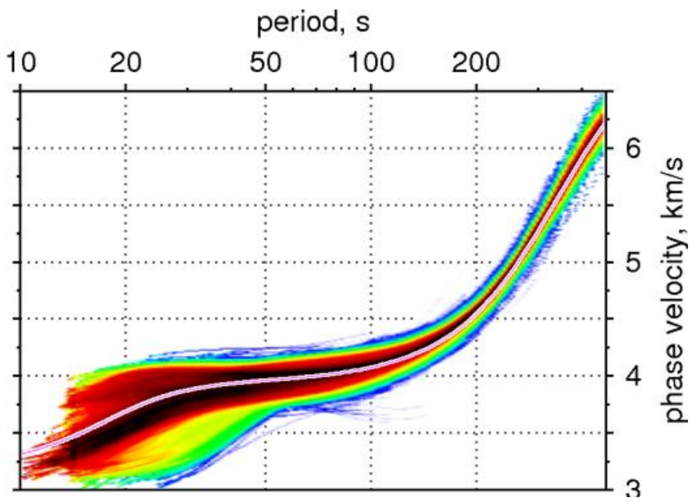
  - timing and response correction errors

  - errors in wave-propagation and sensitivity modelling

- **selection of most mutually consistent data works**



Whole dataset (750K)



Selected dataset (510K)

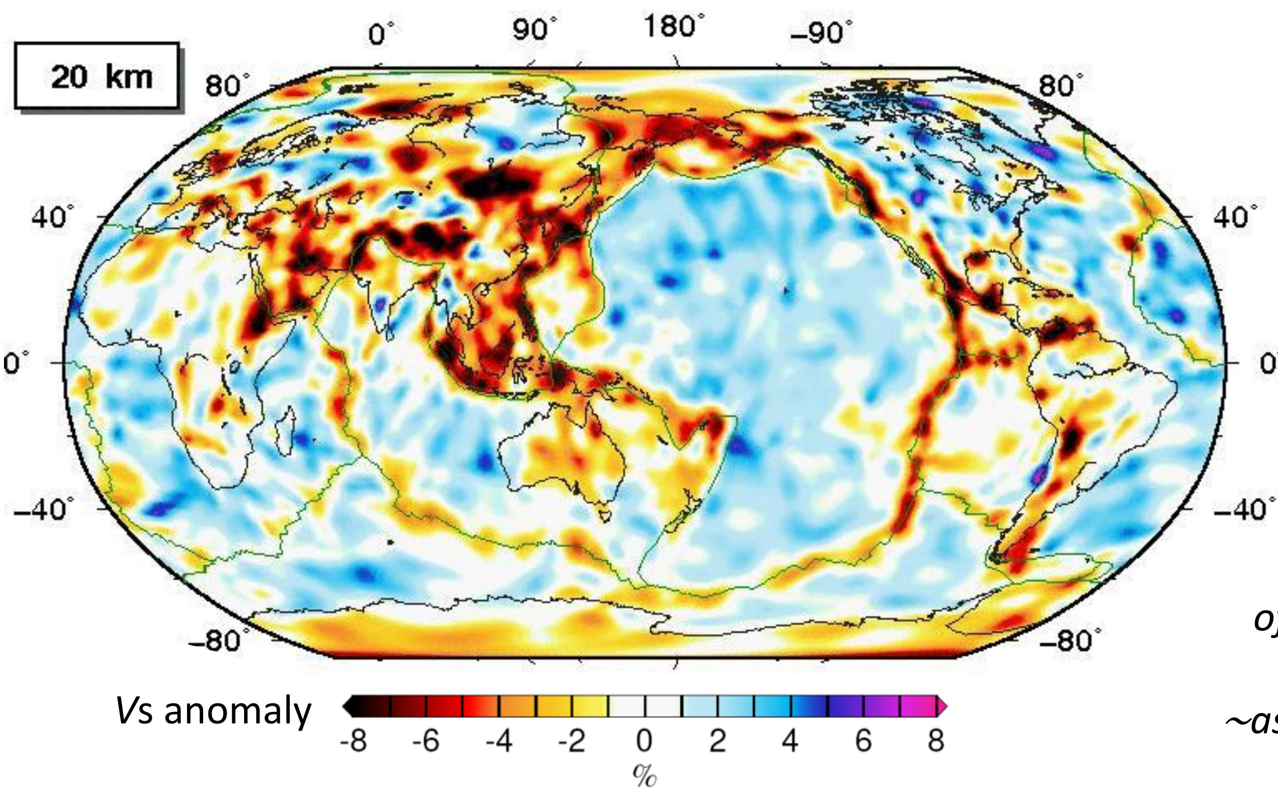
Model SL2013sv

- regional-scale tectonic structure imaged globally, in the crust and upper mantle

The depth of tectonics

- old oceans' mantle is colder than younger oceans' mantle down to ~200 km depth
- geotherms of young and intermediate continents and oceans converge at 200-250 km
- mantle beneath cratons stands out (is colder) down to 250-280 km depth

(*Schaeffer & Lebedev,* submitted, 2013)



SL2013sv,
the movie,
and the comparison
of global models poster:
http://www.dias.ie/
~aschaeff/SL2013sv.html.