Assessment of geodynamic predictions with surface-wave tomography in the Pacific upper mantle accounting for full 3D resolution and robust uncertainties

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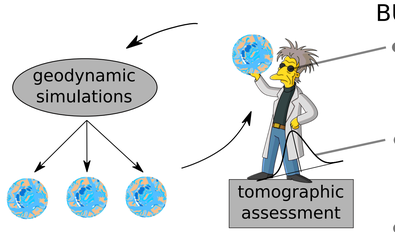
Motivations

We use seismic tomography to assess input parameters in geodynamic simulations.

Geodynamics predict mantle structure based on plausible physics.

Unknown physical parameters

CMB Temperature
Primordial layer
Viscosity = f(T)
Basal buoyancy
...



BUT:

- Tomographic **3D resolution**;
  - Lateral
  - Vertical
- Tomographic **uncertainties**;
  - Measurement
  - Theoretical
- Tomography maps **velocities**.

Method

Geodynamic simulation

- Use TERRA[(a)] to predict mantle temperature & composition (with plate velocities as boundary condition).

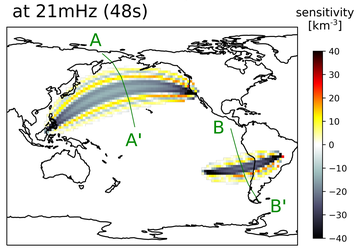
SOLA tomography

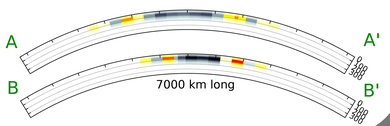
- Use SOLA[(b)] to map Vs, and control and produce resolution & uncertainty;
- Finite-frequency[(c)] for 3D;
- Multitaper measurement[(d)] for measurement errors;
- Synthetic studies for theoretical errors.

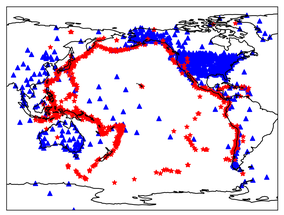
SOLA in a nutshell

$$\delta\phi_l(\omega) = \iiint_{\oplus} K_l(\omega;\boldsymbol{x})\delta \ln V_{SV}(\boldsymbol{x}) d^3\boldsymbol{x}$$

Examples sensitivity kernels at 21mHz (48s)







- 312 sources[(e)], 1228 stations[(f)]
- 6-21mHz (48-167s) every 1mHz
- 47700 data in final dataset

Assessment workflow

Example set of input physical parameters

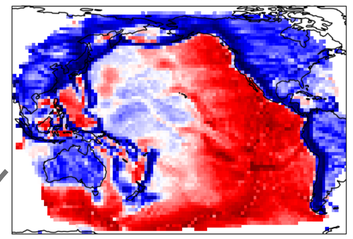
Thermo-chemical with Melting
Time scaling factor 2
Viscosity = f(Temperature)
CMB Temperature 4000
Core Cooling
Muller 2022 Plate Model
Murnaghan equation of state

Predictions

Temperature
Composition
Density

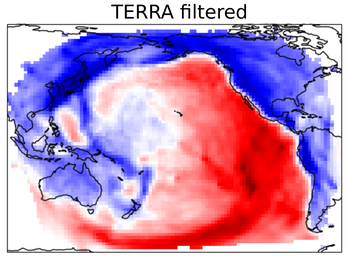
Convert with mineral physics

TERRA



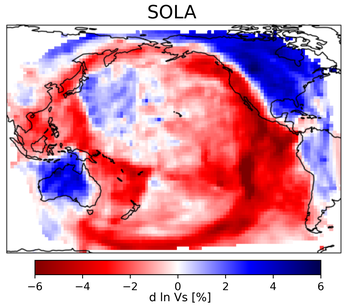
Filter with tomographic resolution

TERRA filtered

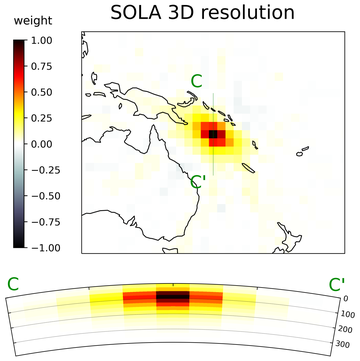


Compare to tomographic observations accounting for uncertainty

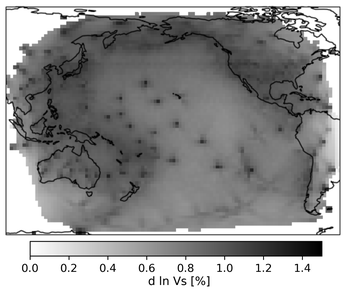
SOLA



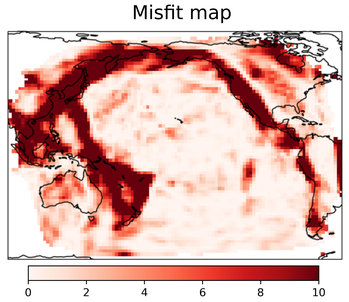
SOLA 3D resolution



SOLA uncertainty



Misfit map

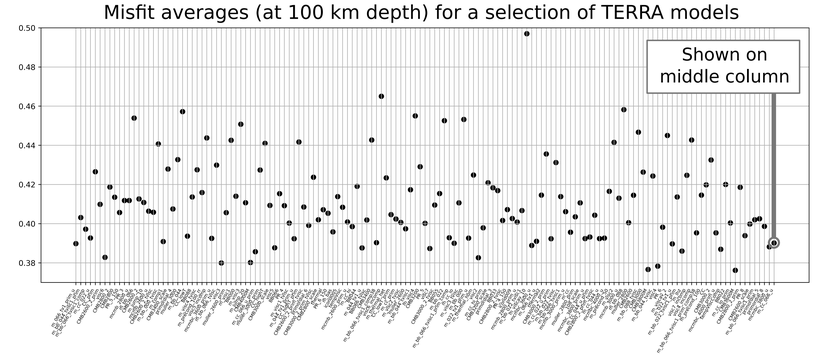


$$\text{Misfit} = \frac{[\text{SOLA - TERRA}]^2}{\text{SOLA uncertainty}^2}$$

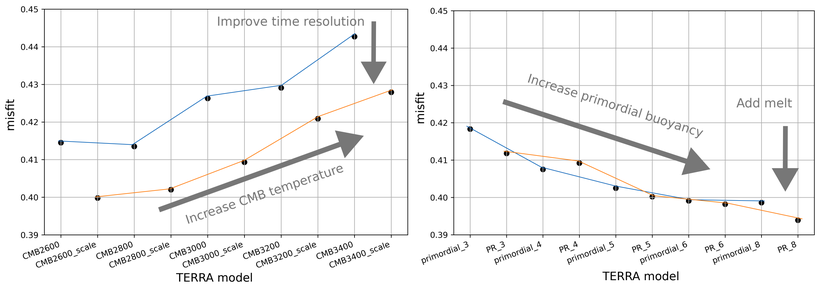
Maps at 112 km depth

Results

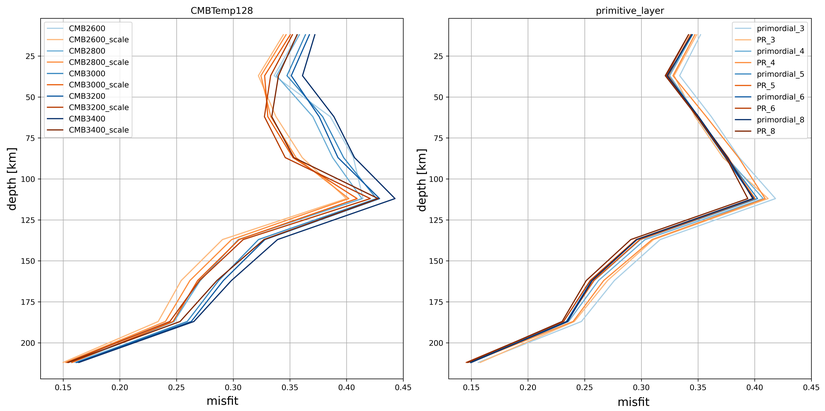
Misfit averages (at 100 km depth) for a selection of TERRA models



Misfit averages (at 100 km depth) for two selections of TERRA models



Misfit averages versus depth for two selections of TERRA models



Preliminary findings

- High misfit in back-arc regions;
- Lower CMB temperature, higher primordial buoyancy or better time resolution improve the fit;
- Misfit decreases at depth due to lack of resolution.

(a) TERRA codes from, e.g. Baumgardner, 1985; Davies et al., 2013.
(b) SOLA tomography theory and codes from Zaroli, 2016.
(c) Finite-frequency theory and codes from Zhou et al. 2008.
(d) Reference seismograms computed using MINEOS.
(e) Source solutions from GCMT.
(f) Station meta-data and waveforms from IRIS.

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