Towards a robust characterization of mantle flow

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1 – Why study the mantle?

The mantle is a thick layer of rock extending from the bottom of the crust to the core-mantle boundary, at a depth of 2891 km. The mantle:

- Transfers the heat from core to surface → regulation of Earth's internal temperature
- Drives plate tectonics → control on the location of earthquakes and volcanoes
- Interacts with the fluid outer core → influence on the magnetic field

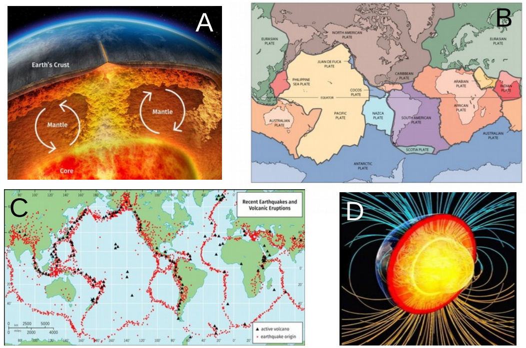

Figure 1.

Mantle convection transports the heat across the Earth (A) and drives plate tectonics (B). Earthquakes and volcanoes are mainly distributed along tectonic plate margins (C). The lowermost mantle interacts with the outer core, responsible for the Earth's magnetic field (D)

2 – Seismic tomography

Seismic tomography exploits the waves produced by the earthquakes to create models - called tomography models - which represent the perturbations in seismic wave velocity

Seismic wave velocity depends on the physical properties of the rocks, such as composition, density, temperature, elastic parameters

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Insights into the internal structure of the Earth
BUT
there are discrepancies among the different tomography models!

Still lots of debate topics!

Mantle flow can provide invaluable constraints on the Earth's physical properties

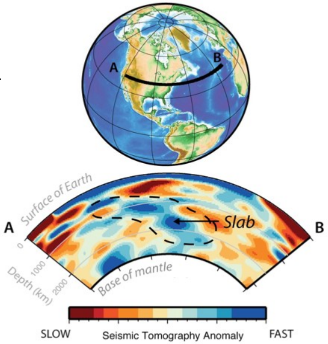
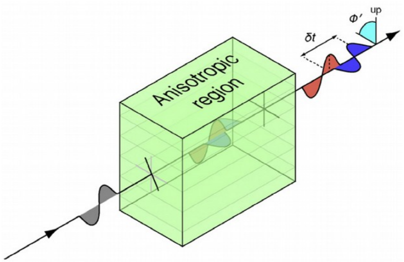


Figure 2.

Example of tomographic image. In a simplified interpretation, slow anomalies (red) are related to hot material and fast anomalies (blue) to cold material

3 – Seismic anisotropy and mantle flow



Seismic anisotropy - the dependence of wave velocity upon direction - is caused by alignment of intrinsically anisotropic minerals due to large-scale deformation caused by mantle convection

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Key to infer trajectories of mantle flow!

Figure 3.

When travelling in an anisotropic medium, seismic waves split into two waves that travel with different velocities, causing a delay time *(δt)* between them

4 – Motivation and aims of my project

A robust physical interpretation of tomographic images requires the model to have unbiased amplitudes and to be accompanied by uncertainties. Commonly-used techniques, such as damped least-square inversions, cause amplitudes to be biased and uncertainties are usually not computed

MY AIM:

- Build a new anisotropic tomography model using a newly developed method – called the SOLA method – to overcome the issues mentioned above
- Focus on seismic anisotropy to interpret the results in terms of mantle flow, mechanical and chemical properties

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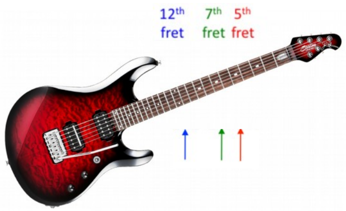
5 – Standing waves of the Earth

Standing waves will constitute the database of my model. After very large earthquakes, the Earth starts oscillating like a ringing bell for weeks. These oscillations are called standing waves and each one possesses a particular frequency – called resonance frequency - like the notes played by a musical instrument



A

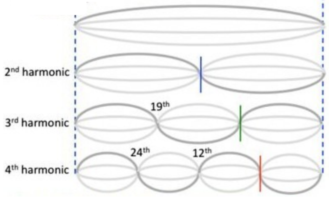
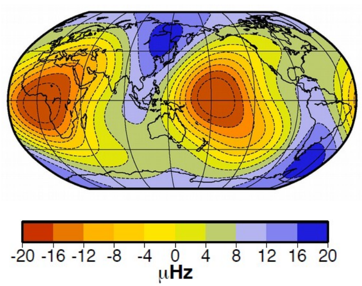


Figure 5A.

Each standing wave resonates with a particular frequency, just as the strings of a guitar oscillate at particular frequencies to generate specific notes

B



The presence of heterogeneities inside the Earth causes standing waves to oscillate at a frequency slightly different than the resonance frequency. This effect is called splitting. Splitting can be measured and used as input data to build a tomography model of velocity perturbations

Figure 5B.

Splitting function maps show the variation away from the degenerate frequency due to heterogeneities inside the Earth

Standing waves observations are not affected by uneven data coverage and are sensitive to multiple parameters!

6 – The SOLA method

The model will be built using the SOLA *(Subtractive Optimally Localized Averages)* method. The advantages with respect to other methods (e.g. DLS – *Damped Least Square*) are:

- Amplitudes constrained to be unbiased
- Computationally efficient and versatile
- Less influenced by poor data illumination
- Uncertainties always computed

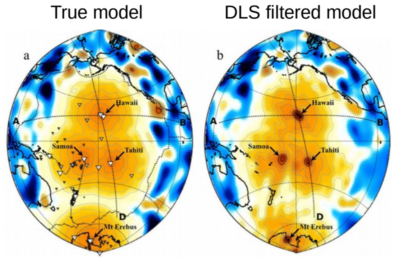


Figure 6.

Illustration of the local bias effect using DLS method

7 – Interpreting seismic velocities

Once a map of seismic velocity anomalies is created, I will interpret the result in terms of mantle flow and eventually physical properties (density, temperature, composition, etc.) with the help of other Earth Sciences subjects, such as geodynamics and mineral physics

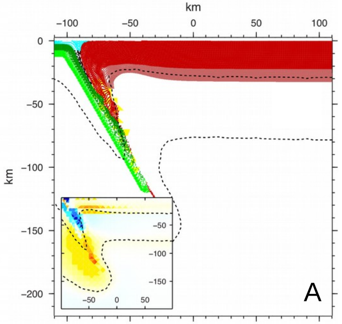
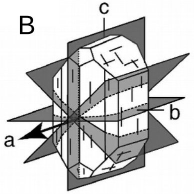


Figure 7.

Example of results obtained from geodynamic modelling (A) and mineral physics (B)



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2.https://blogs.egu.eu/geolog/2017/09/14/mapping-ancient-oceans/
3. Nowacki et al., 2011
5. Courtesy of Michel van Camp, Royal Obs. Of Belgium
6. Zaroli et al., 2017
7. Marotta et al., 2020; Satsukawa and Michibayashi, 2009