Towards Inverting Seismic Waveform Data for Temperature and Composition in the Earth's Upper Mantle

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paper number: DI41A-**1255**

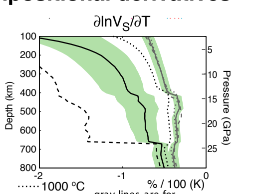
Objective

Propose a seismic waveform inversion by incorporating mineral physics data in an early stage of the process to directly map lateral variations in temperature and composition. Our approach aims to exploit the different effect that variations in temperature and composition have on seismic waveforms (phase and amplitude) and it will be based on the existing formalism for global elastic and anelastic tomography (Gung and Romanowicz, 2003).
Here, first steps towards such procedure are presented. We discuss the effects due to the uncertainties in the mineral physics parameters and the importance of a physical reference as background model for the seismic inversion. A preliminary - low resolution - global thermal model for the upper mantle is shown. Inferences on average 3-D structure are drawn.

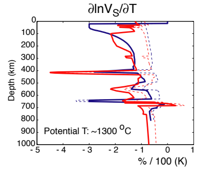
Temperature and compositional derivatives

- Temperature-dependent anelasticity affects seismic velocity interpretation in the upper mantle by:

1. increasing sensitivity
2. increasing uncertainties
3. introducing non linearity: i.e., conversion of same ΔV into ΔT changes in hot and cold regions AND importance to have a physical reference as background velocity model.



Cammarano et al., 2003

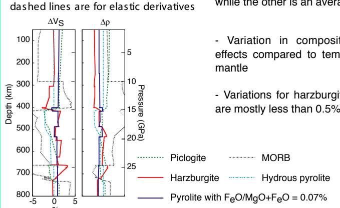


PREF 1 (Cammarano et al., 2005)
Pyrolite with a thermodynamically consistent EOS (Stixrude)
dashed lines are for elastic derivatives

- Phase transitions add complexity to the shape of temperature derivatives

- Differences in the upper mantle between the two models are due to diffferent Q model: radial part of QR19 (Romanowicz, 1995) for red model, Q5 (Cammarano et al., 2003) for PREF.

- Differences between purely elastic derivatives reflect uncertainties in mineral physics parameters (note however that PREF 1 is a best fit mineralogical model to global seismic data, while the other is an average pyrolite)



relative to pyrolite Mg# 89 Cammarano et al., 2003

- Variation in composition have secondary effects compared to temperature in the upper mantle

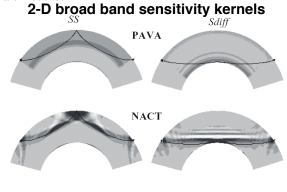
- Variations for harzburgite - depleted mantle - are mostly less than 0.5%

Seismic data and method

- Long period waveform data are inverted in the framework of **Non-linear Asymptotic Coupling Theory** (NACT - Li and Romanowicz, 1995), a normal-mode based approach which consider coupling between modes along and across dispersion branches.

- Considering across mode branches (i.e, NACT) instead than the classical Path AVerage Approximation (PAVA, Woodhouse and Dziewonski, 1984) is important when higher order modes are modelled.

2-D broad band sensitivity kernels

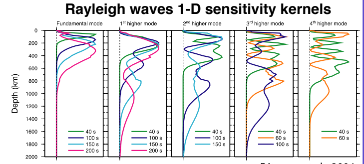


- The dataset is composed by 39829 of fundamental and 59831 of higher order surface waveforms (minor and major arc) for teleseismic events (15° < Δ < 165°) with M_W > 6. We consider period down to 60 s.

- Both spheroidal and toroidal modes, characterized by different depth resolution, are used for the inversion.

Rayleigh waves 1-D sensitivity kernels

- Including higher order modes plus an appropriate weighting scheme (Li and Romanowicz , 1995) improve the resolution in the deeper part of the upper mantle.



Ritsema et al., 2004

Seismic waveform inversion for temperature

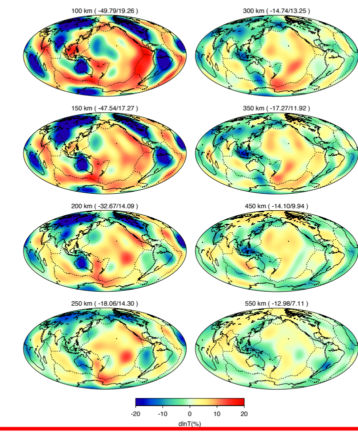
- We invert the seismic data for both temperature and ξ (V_{SH}^2/V_{SV}^2).

There is a general agreement between existing seismic V_S models at large scale (degree 12). Hence, we decide to start with this resolution first.

As starting model we use the 3-D anisotropic model SAW24AN16 (Panning and Romanowicz, submitted), reparametrized in spherical splines at ~ degree 12, but we substitute the reference model (i.e. PREM) with a physical reference model (PREF 1, Cammarano et al., 2005).

Two different ways have been followed:
1. Inversion in velocity => thermal interpretation, i.e. the isotropic part of the model is translated into temperatures.
2. Directly inversion in temperature, by using the 3-D starting thermal model and a reference thermal profile for the mantle (60 My old ocean geotherm in the lithosphere plus mantle adiabat below)

The 1st approach is not affected by the non-linearities arising in the T inversion. However, a direct temperature inversion is required in the view of the future work where compositional partial derivatives will be added.

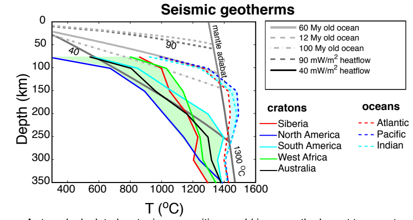


- Lateral temperature variations, although dependent on the background models are fairly constrained.

- Absolute temperatures are enough well constrained in the shallow upper mantle, but deviations of starting model from the average (see below) hamper a purely thermal interpretation in the transition zone.

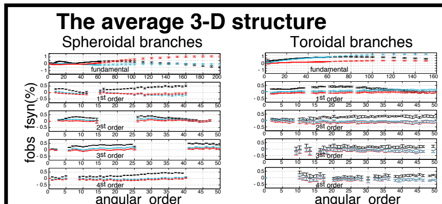
- Effects of mineral physics unertainties on the inversion and on the 1-D starting model have been so far investigated by running a similar inversion by using a different Q model.

Seismic geotherms

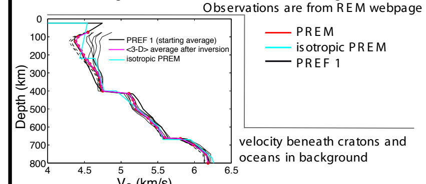


- A strongly depleted cratonic composition would increase the lowest temperature of ~200 °C

The average 3-D structure



Observations are from REM webpage



velocity beneath cratons and oceans in background

- The physical reference model we use for the inversion is one of the PREF models (Cammarano et al., 2005). The model was fitting satisfactorily P and S travel times and fundamental modes (specially at angular order > 60 ~ surface wave range)

- Fit to higher order modes, sensitive to the UM structure, and fundamental at l~10 are worse than PREM

- Inverted average structure requires a slower transition zone (hydrous minerals?) (and faster V_S just above 400km) than the starting model and shifts towards PREM (which is confirmed to be, seismically, a very good model). Further tests on alternative EOS for dry pyrolite are required before to reject definitively pyrolite as average compositional model

- Change in gradient around 220 is required by the seismic data, but there is no need for a discontinuity.

What next

- **Assess effects of the uncertainties in the mineral physics parameters**: run inversions by using different physical reference models . Consistent partial derivatives and background model will be used for each inversion.

- **Account for non-linearities in the inversion directly for temperature:** use spatially varied temperature kernels between different tectonic regions (e.g., cratons, oceans) after 1st iteration of the inversion

- **Implement compositional derivatives:** use a self-consistent EOS to define accurate compositional derivatives, expressed in terms of basalt depletion, and incorporate into a combined inversion for temperature and composition.

We are grateful to Federica Marone for the help given with the seismic codes.

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December 2005