Simulation of 3D Global Wave Propagation Through Geodynamic Models

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Project Description

Abstract

The project aims at a better understanding of the forward problem of global 3D wave propagation. We use the spectral element program "SPECFEM3D" (Komatitsch and Tromp, 2002a,b) with varying input models of seismic velocities derived from mantle convection simulations (Bunge et al., 2002). The purpose of this approach is to obtain seismic velocities independently from seismological studies. In this way one can test the effects of varying parameters of the mantle convection models (MC) on the seismic wave field. In order to obtain the seismic velocities from the geodynamical field we simulate a mineral physics (MP) approach. Assuming a certain mantle composition we calculate the stable phases for such depth (i.e. pressure) and temperature by system Gibbs free energy minimization. Through the same equations of state that model the Gibbs free energy we model the pressure-dependent elastic moduli, density and viscosity. The purpose of this approach is to obtain seismic velocities from global 3D circulation models with sequential data-assimilation: Inferring present-day mantle composition from past plate motions of Bunge et al. (2002). This will provide the opportunity to constrain the mantle models. This approach is to obtain seismic velocities from regional 3D circulation models with sequential data-assimilation: Inferring present-day mantle composition from past plate motions of Bunge et al. (2002).

Motivation

This project provides a "microscope" into mantle processes. Different seismological studies use different datasets and different techniques for the inversion – differences in models (geodynamic, mineral physics modeling), different parameters (temperature, elastic moduli, density) and density of data can be explained uniquely.

Therefore

Creation of physically consistent velocity models independent of seismological observations.

Better understanding of the forward problem of seismology.

Exploration of different processing methods and configurations beyond current observational capabilities.

Approach

Mantle Circulation Model (MC)

Mineral Physics Model (MP)

Velocity Model (MCM MP, physically consistent)

Global 3D Wave Propagation (SPECFEM3D)

Processing

What to look for in the synthetic data?

Direct comparison between tomography models and realistic mantle models at realistic current resolution of MCM leads to underestimated temperature variations.

Solution

Averaging each 3D MCM/MP will give a theoretical 1D reference model. This model serves as a basis for "artificial" PREM.

We will proceed to estimate the global characteristics of global wave fields.

Important seismological parameters are:

- amplitude ratios (3D/1D average) -- focusing/diffusing
- frequency content/spectral ratios
- envelope (energy)
- spatial and temporal distribution of these features

Models

Geodynamic Model

- Present day temperature field from mantle convection simulations based on sequential data-assemble of past plate motions of Bunge et al. 2002.
- Whole mantle, spherical geometry.
- Over 10 million finite elements -- ca. 60km horizontal grid spacing.
- Rayleigh number based on internal heating of order 10^6.
- Viscosity increases from upper to lower mantle by a factor of 40.
- 350K internal heating by radioactive decay.
- 15% of heat coming from CMB.

Mineral Physics Model

- Pyrolitic composition (38.3% SiO_2, 40.3% MgO, 6.7% H_2O, 3.7% CaO, 3.2% FeO, 2.5% Al_2O_3).
- Computation of stable phases for minimizing Gibbs free energy of the system using equation of state parameters and caloric data.
- Density and elastic moduli obtained by appropriate equations of state (for each phase) and Vughe-Reuss-Hill averaging for the mixture evolved to temperatures and pressures from the geodynamic model.
- Model is parameterized in spherical harmonics (degree = 126) for 65 radial levels.

Conversion of Temperatures to Seismic Velocities

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Tomography Model S20RTS (CalTech)

- Shear velocity model derived from Rayleigh wave dispersion, body wave travel time and normal mode splitting data.
- Parameterized in spherical harmonics up to order and degree 20 and 21, vertical spline functions.

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Acknowledgements

This work is supported by the "Bundesforschung Promotionsprogramm" and a Sonderforschungsbereich SFB 574, "Dynamik der Erdkruste", and a Bavarian State Ministry grant "Mein Engagement für Wissenschaft". We thank the following institutions for financial support: "Earth" Program of the European Community, BMBF Priority Program "Earth and Life Interactions" (Earth-Environment Interaction, Earth-Environment Interactions: Impact of the Geosphere). This work is supported by the "Bundesforschung Promotionsprogramm" and a Sonderforschungsbereich SFB 574, "Dynamik der Erdkruste", and a Bavarian State Ministry grant "Mein Engagement für Wissenschaft". We thank the following institutions for financial support: "Earth" Program of the European Community, BMBF Priority Program "Earth and Life Interactions" (Earth-Environment Interaction, Earth-Environment Interactions: Impact of the Geosphere).

References