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Simulation of 3D Global Wave Propagation Through Geodynamic Models

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Project Description

Abstract

This 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 velocity models independently from seismological studies. In this way one can test the effects of varying parameters of the mantle convection models (MCM) on the seismic wave field. In order to obtain the seismic velocities from the temperature field of the geodynamical simulations we follow a mineral physics (MP) approach. Assuming a certain mantle composition (e.g. pyrolite) we compute the stable phases for each depth (i.e. pressure) and temperature by system Gibbs free energy minimization. Through the same equations of state that model the Gibbs free energy of phases, we compute elastic moduli and density. For this we built a mineral physics database based on calorimetric experiments (enthalphy and entropy of formation, heat capacity) and EOS parameters.

Motivation

- Tomography only provides "a snapshot" → geometry
- Different tomographic studies use different datasets and different techniques for the inversion → differences in models (geometry, amplitude of perturbations, resolution and parameterization)
- Inversions for P-/S-wave speed and density lead to different geometries and to date cannot be explained uniquely

Therefore

- Creation of physically consistent velocity models independent of seismological observations → Model Planet
- Possibility of testing the effect of various geodynamical parameters on the seismic wave field
- Better understanding of the forward problem of seismology
- Exploration of different processing methods and configurations beyond current observational capabilities

Approach

Mantle Circulation Model (temperature field) ↘ Mineral Physics Model (elastic moduli, density) ↙

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 MCM not yet feasible (current resolution of MCM leads to overestimated temperature variations)

Solution

- Averaging each 3D MCM_MP will give a theoretical 1D reference model that serves as a kind of "artificial PREM"
- This will provide the opportunity to constrain the global characteristics of global wave fields

Important seismological parameters are:

- amplitude ratios (3D/1D average) → focusing/defocusing
- 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-assimilation 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 10^8
- Viscosity increases from upper to lower mantle by a factor of 40
- 85% internal heating by radioactive decay
- 15% of heat coming from CMB
- Model is parameterized in spherical harmonics (degree > 120) for 65 radial levels

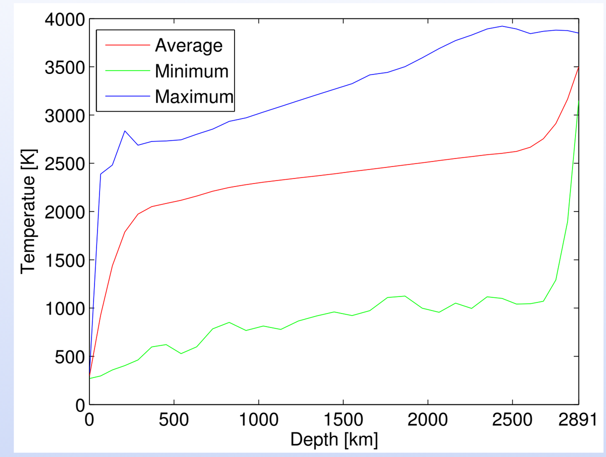


Figure 2. Radial temperature profile of the geodynamic mantle convection simulation together with the minimum and maximum temperature for each depth.

Mineral Physics Model Conversion of Temperatures to Seismic Velocities

- Pyrolitic composition (38.3% SiO_2, 49.33% MgO, 6.27% FeO, 3.3% CaO, 2.22% Al_2O_3)
- Computation of stable phases by minimizing Gibbs free energy of the system using equation of state parameters and calorimetric data
- Density and elastic moduli obtained by appropriate equations of state (for each phase) and Voigt-Reuss-Hill averaging for the mixture applied to temperatures and pressures from the geodynamical model

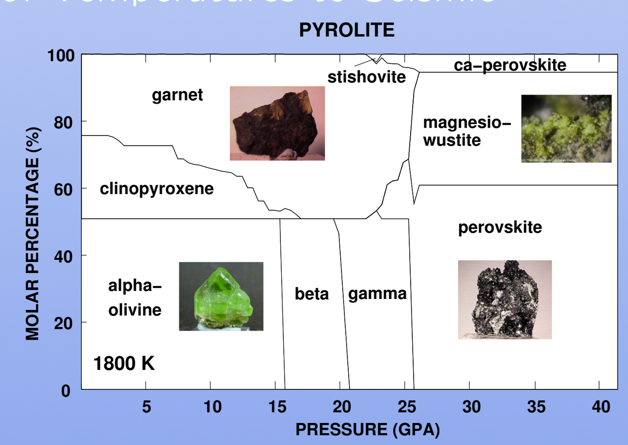


Figure 3. Molar fractions of the stable phases at 1800K for a pyrolitic composition from Gibbs free energy minimization.

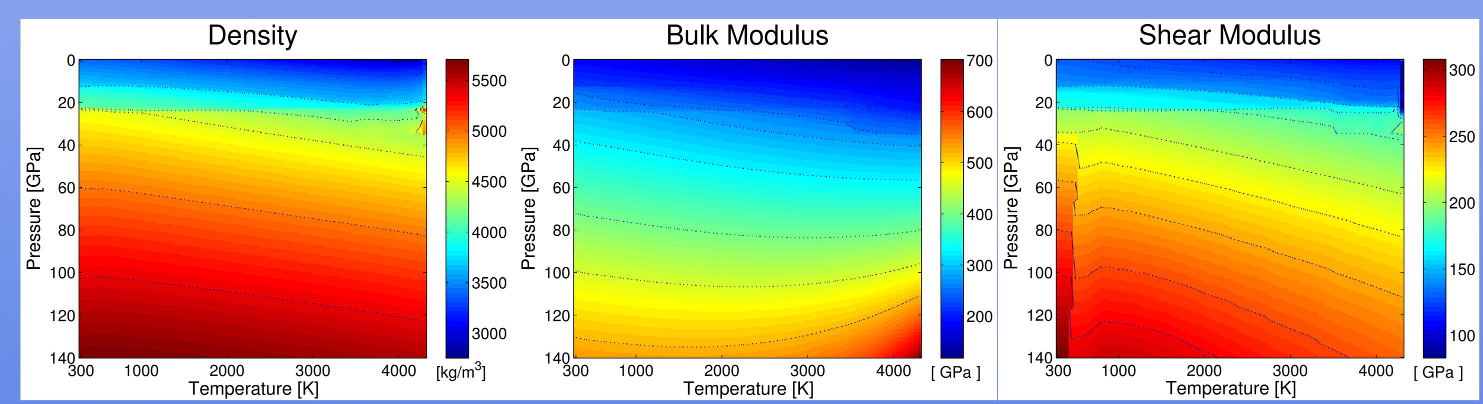


Figure 4. Elastic properties and density for a pyrolitic mantle for a large range of P and T conditions obtained by applying appropriate EOS for the stable phases.

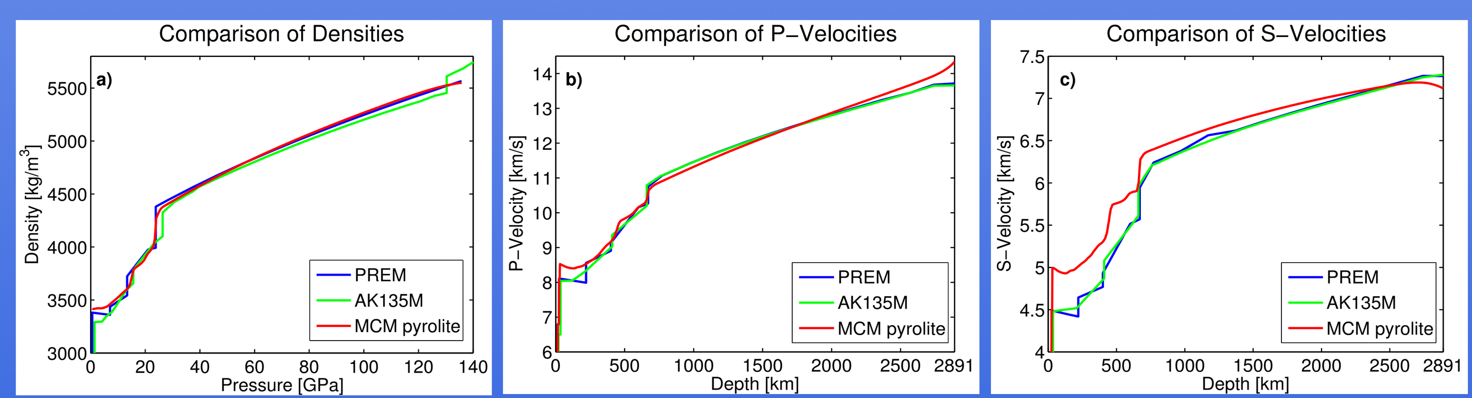
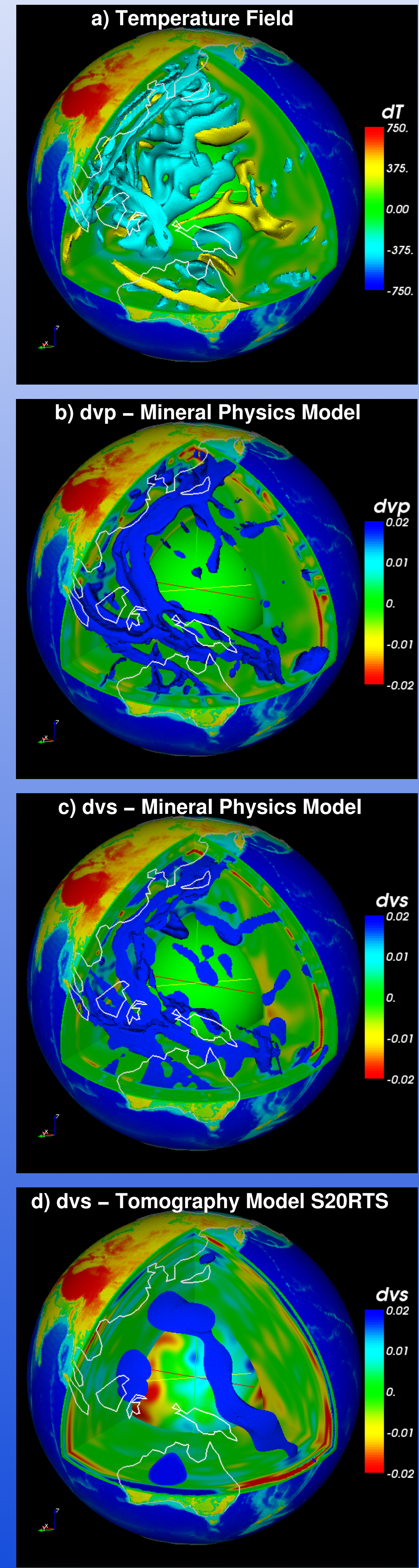


Figure 6. Radial 1D profiles of the converted (T→Vs/Vp) mantle convection model from radially averaging the 3D seismic velocities. In addition profiles of PREM and AK135M are shown for comparison.

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

Figure 1. Compilation of Earth models used in this study.
a) Temperature field from mantle circulation model. Isosurfaces for -350K and +350K are displayed b) and c) Velocity models (dvp and dvs, respectively) derived from a) using mineral physics modelling. d) Tomography model S20RTS (dvs) for comparison to c). Isosurfaces for +1.75% are shown for the velocity models.



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References **Komatitsch, D., Tromp, J.**, *Spectral element simulations of global seismic wave propagation, Part I: Validation*, Geophys. J. Int., 149, 390-412, 2002a; **ditto** *Part II: 3-D models, oceans,rotation and gravity*, Geophys. J. Int., 150, 303-318, 2002b; **Bunge, H.-P., Richards, M.A., and Baumgardner, J.R.**, *Mantle circulation models with sequential data-assimilation: Inferring present-day mantle structure from plate motion histories*, Phil. Trans. Roy. Soc. A , 360 (1800), 2545-2567, 2002; **Ritsema, J.,Van Heijst, H.J.**, *Seismic imaging of structural heterogeneity in Earth's mantle*, Science Progress, 83, 243-259, 2000; **Sigloch, K., Nolet, G.**, *Measuring finite-frequency amplitudes and travel times of teleseismic P waves*, Poster presented at EarthScope National Meeting, March 29-31, 2005;

Simulations and First Results

First Step: 4 Simulations

- Mantle Convection Model: Pyrolite - 1D average (spher. harmonics degree 20)
- Seismological Models: S20RTS - PREM

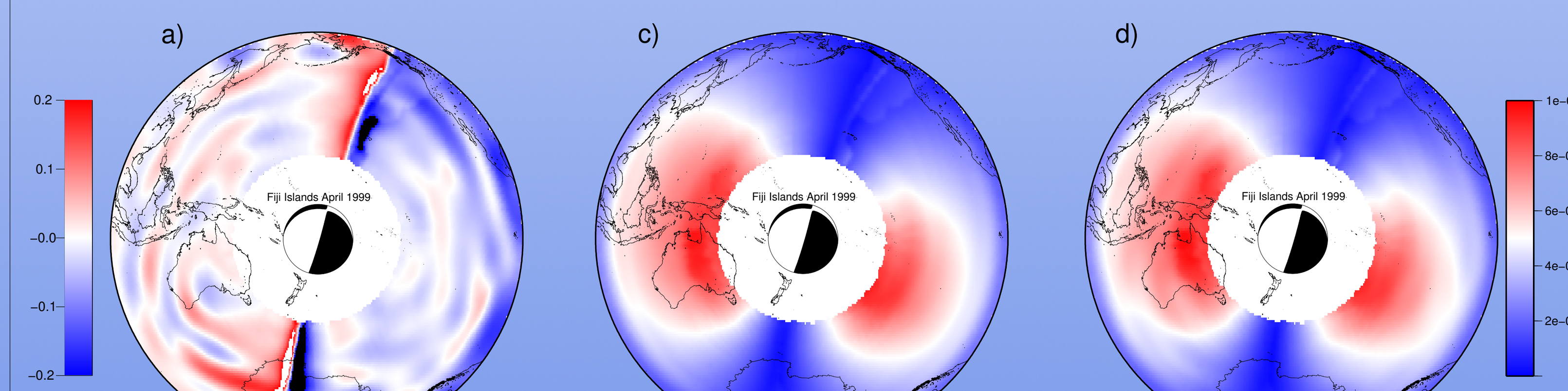
Setup and input parameters:

- Event: Fiji Islands M6.4, April 13 1999, depth 164 km (intermediate moment, allows comparison to P-amplitude study on real data, Tibuleac et al. 2003)
- Stations: all GSN (Global Seismographic Network) stations and a uniformly spaced grid of 42250 stations all over Earth's surface, 6 components (3 rotational and 3 translational) → 133 Gb of data per simulation
- Resolution allows accurate seismograms down to 20s period
- Simple model to allow study of pure mantle effects (spherical, no topography, no ocean loading, no 3D crustal model, no self-gravitation and no rotation)

Processing

First Test - How are P-wave amplitude ratios (3D/1D) related to mantle structure?

- Z-component of Stations between 35° and 88° epicentral distance
- Apply lowpass-filter (corner period 20s) and pick first arrival
- Cut window around P-arrival (from 30s before and 15s after pick; same window for 1D and 3D models)
- Cross-correlation and ellimination of time shift between 3D and 1D reference
- Computation of RMS amplitude ratio for shifted traces (Sigloch & Nolet 2005, Earthscope Meeting)



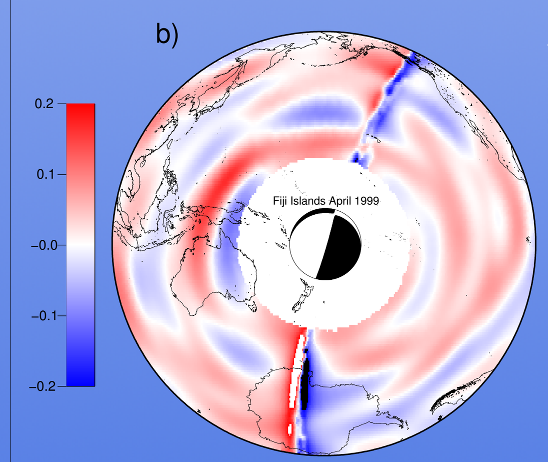
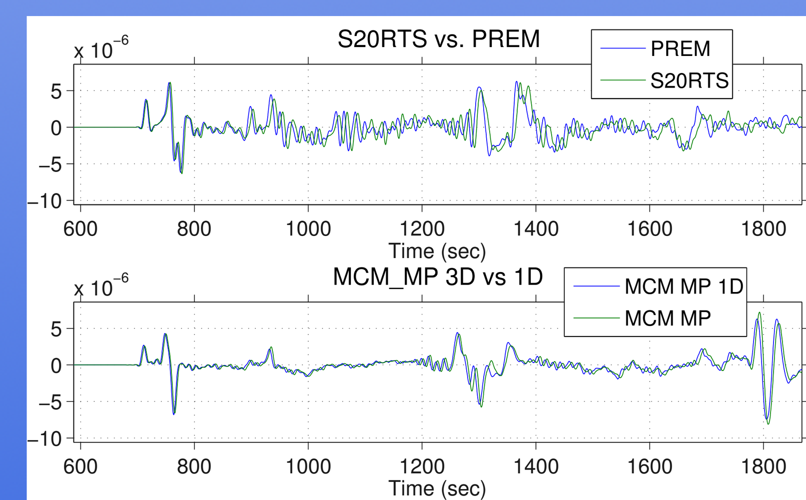


Figure 7. RMS amplitude ratios of the 3D models used in this study relative to their 1D model. a) MCM_MP 3D/1D. b) S20RTS/PREM. Values exceeding +/–0.2 are plotted in black and white to allow for a linear colorscale. c) and d) show absolute RMS amplitudes for MCM_MP 1D and 3D.

Figure 8. Seismogram example of the Fiji Islands Region event simulated in this study. The upper part shows the Z–component of displacement at Pinon Flat Observatory obtained with the tomography model S20RTS and PREM The lower parts shows the seismograms for our model.



Outlook

Interpretation is just at the beginnig! Main task is to find relation between pattern of amplitude ratios and structure in models. Further analysis and simulations are planned:

- Different location of earthquake keeping the same CMT solution (e.g. outside subduction zone)
- Different CMT solution at same location (e.g. explosion, 90° rotation of strike)
- Apply same processing to earthquakes where more stations are on continents
- Compute amplitude ratios for varying frequency bands
- Additionally check traveltime differences
- Build new model using dvp and dvs perturbations of MCM MP applied to PREM
- Change heterogeneity length scale in MCM MP by varying the degree of the spherical harmonics expansion
- Improve mantle circulation models: higher resolution soon possible due to new supercomputing facilities, additionally include mineral physics modelling
- Increase resolution of wave propagation simulation → higher frequencies