[S1-P01] Seismic Anisotropy in the Mantle Transition Zone from the SS Precursors

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Abstract

The mantle transition zone (MTZ), delineated by the 410 and 660 km discontinuities, plays an important role in mantle dynamics through changes in mantle material density and viscosity. Wadsleyite and ringwoodite are predicted by mineral physics to have up to 13% and 2% single-crystal anisotropy respectively, indicating that seismic anisotropy may exist where mantle flow aligns minerals within the MTZ. Here we use the SS precursors to study the topography change and azimuthal seismic anisotropy in the vicinity of MTZ discontinuities. An up-to-date SS precursor dataset consisting of 45,624 records was collected to investigate MTZ topography and anisotropy. We stacked the whole dataset into geographical caps to obtain the global topography of 410 and 660 km discontinuities. The MTZ is thickened by _˜15 km beneath subduction zones (e.g. Japan and South America) and also thinned by _˜15 km beneath mantle plume regions (e.g. Bowie and Iceland hotspots), which is consistent with thermal heterogeneity in the mid-mantle. We use the azimuthal coverage of SS precursors to study anisotropy in the MTZ, with the goal of detecting the azimuthal dependence of travel time and amplitude of SS precursors. Globally, we find that the MTZ has weak anisotropy, $<$ 1%, with regional regions up to 3% beneath hotspots and subduction zones. Furthermore, we observe trench-parallel fast direction for both S410S and S660S travel times and amplitudes, indicative of upper mantle anisotropy in subduction regions. We postulate the weak signature of anisotropy in the MTZ owes to recrystallization and the resetting of upper mantle fabrics as they are brought into the MTZ, weakening the signature of mantle flow in our body wave study.

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[S1-P02] Global detections of mid-mantle discontinuities: implications for structure and dynamics

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Abstract

Seismic velocity tomography models reveal that both up and downwelling mantle flow is commonly deflected and trapped in the mid-mantle. Only very few recently-subducted slabs sink unobstructed through the mid-mantle; upwelling plumes are similarly impeded. This deflection has been suggested to correspond to the presence of numerous seismic reflectors found at a range of mid-mantle depths (800 – 1350 km). However, there is no candidate mineral phase change at these depths to explain either the reflectors or deflections. Recent studies propose that the mid-mantle represents a significant transition in physical properties, such as a viscosity jump and/or a compositional change, to which the deflection may be ascribed. Yet, a lack of detailed seismic studies of the region means that any relationship between deflection of flow and seismic reflectors remains unconstrained.

Here, we perform comprehensive global scale interrogations of mid-mantle seismic reflectors, using precursors to SS [1] and to PP. Abundant reflectors are detected globally, with strongly varying seismic properties including depth, lateral size, and impedance. Regions with no reflectors are also detected globally. This diversity in reflector properties indicates widespread heterogeneity in the mid-mantle. We find that the reflectors may be grouped regionally into three categories based on the background seismic velocity (fast, slow, neutral); each group has highly different seismic signatures and reflector characteristics, indicating distinct domains in the mid-mantle. Our observations are interpreted in the context of global geodynamical models, to ascertain the correlation between seismic features and mantle flow processes, and ultimately inform regarding the regionally-diverse styles of mantle mixing.

1. Waszek, L., Schmerr, N., Ballmer, M. Global observations of mid-mantle reflectors with implications for mantle structure and dynamics. *Nat. Commun.*, 9(385), doi:10.1038/s41467-017-02709-4, 2018.

*Speaker

[S1-P03] Kinetics of the bridgmanite to post-perovskite transformation

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Abstract

Brigmanite, the dominant lower mantle mineral, transforms into post-perovskite at pressure and temperature conditions relevant for the Earth's D" layer. This transformation induces changes in mechanical and thermal properties which, in turn, affects the dynamics of the Earth's lowermost mantle. Fundamentals of this transformation, however, remain ill-understood. Here, we study the kinetics of the brigmanite to post-perovskite transition in (Mg,Fe)SiO3 and evaluate the associated thermodynamical parameters. We demonstrate that the transformation is fast on geological time scales for all reasonable geotherms and ùantle grain sizes. We also show that transformation kinetics can affects reflection coefficients for S waves which could be used as a probe for physical properties in D".

*Speaker

[S1-P04] Phase transformation microstructures and their effect on seismic signals from the Earth's mantle

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Abstract

Phase transformations in minerals induce physical boundaries in the Earth's interior and the analysis of seismic signals arising from these regions brings key information for our knowledge of the structure, composition, and dynamics of the planet. As such, combined knowledge of mineral physics and seismology can help advancing our understanding of the deep Earth.

Phase transformations induce changes in the material's structure, density, elastic properties, but also microstructure, i.e. the arrangement of mineral phases, grain sizes, grain orientations, and strains. In recent years, we developped a new technique (high pressure multigrain crystalloraphy HP-MGC) that allows characterizing hundreds of crystals in a polycrystalline material under going processes such as phase transformation.

Here, we will show how the technique is useful for understanding the effect of phase transformation on microstructures and the implications of this work for our interpretation of deep Earth processes.

*Speaker

[S1-P05] Investigating the seismic structure and visibility of dynamic plume models

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Abstract

Despite the fact that mantle plumes may play a major role in the transport of heat and mass through the Earth, their possible origin and thermochemical structure still fuels many debates. Here, geodynamic modelling and mineral physics data are combined to calculate the 3-D seismic structure of two different thermochemical plume models. We use these models to perform a full-waveform simulation, sending seismic waves through the plumes, in order to generate synthetic seismograms. We then analyse the seismograms with array methods to investigate potential seismic scattering from the plumes. Using velocity spectral analysis and slowness-backazimuth plots, we do not detect scattering. However at longer dominant periods (25 seconds) we see several out-of-plane arrivals that are consistent with an apparent bending of the wavefront around the plume conduit. At shorter periods (15 seconds) these arrivals are no longer visible. We also detect reflections off the dense chemical pile at the base of the mantle which serves as the plume source. Our results indicate that observation of plume-like structures in real data may be achieved by considering waves travelling in all directions and over a range of periods.

*Speaker

[S1-P06] Detecting structures in the mid mantle

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Abstract

Seismic signals from the deep Earth are affected by complexity in structures and composition of the mantle. The presence of structures and heterogeneities in the mid- and lower mantle has been reported before, but it is still matter of debate if these heterogeneities are related to microstructures induced by phase transformations, deformational processes or presence of subducting slabs or crustal material. In this study, we aim to investigate the heterogeneities in the mid mantle using array methods, enhancing the signal-to-noise ratio by summing the coherent signals from the array stations. This enables us to study seismic phases that are not visible in seismograms of single stations with amplitudes that are lower compared to those of the direct arrivals. In particular, we look for reflected waves from structures in the mid mantle that arrive out of the great circle plane particularly from the subduction beneath India and the Himalayas. For this purpose we search for seismic waves arriving at an array with a back azimuth (the direction of the great circle path connecting source and array) differing from the theoretical back azimuth of the earthquake. The dataset consists of events located in Indonesia and recorded at the Münster-Morocco array stations, between 2010 and 2013. To ensure sufficient seismic energy for the out-of-plane arrivals, we only consider events with magnitude Mw $>$ 5.6. By applying seismic array techniques, we measure the slowness, backazimuth and traveltime of the out-of-plane arrivals. These information are used to backtrace the wave to its scattering location and to map seismic heterogeneities. Amplitudes, polarities and frequency dependence of the seismic waves are used to further investigate the seismic structures. This leads to high resolution images that help to understand mantle structures and to relate the signals to microstructures and processes associated with phase transitions in deep subducting slabs.

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[S1-P07] Investigating PKP path deviations - influence of mantle structures

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Abstract

We investigate the role of the heterogeneous lowermost mantle in deviating the seismic waves that are commonly used for core imaging and inner core anisotropy. For inner core imaging, we usually assume that waves travel on the great circle path and here we test this assumption. We select events with magnitude greater than 6.0 and a high signal to noise. We used the newly available data from the transportable US array to test the path deviations especially for the polar path South Sandwich to Alaska. We used 61 events for this path and between them we selected 7 event with depth deeper than 50 km. In addition to the US array data, the Kyrgyz network (KNET) has been running continuously since 1991 and provides another near polar path using events from South America recorded at KNET and we used this path to compare with the South Sandwich to Alaska path. We used 366 events for this path and between them we selected 85 event with depth deeper than 50 km. On these events we perform a slowness-backazimuth analysis of these waves that provides measures of backazimuth and slowness of an arriving wave. The slowness-backazimuth analysis is carried out for each phase and the deviations from the theoretical values in both slowness and backazimuth recorded. For all source- receiver combinations we map deviations in slowness and backazimuth and also in associated travel time. Subtracting these calculated travel time difference based on the path deviation, we will gain a better understanding of travel time differences from path deviations likely due to mantle structure and can estimate errors in determining the anisotropy of the inner core that are purely based on travel time differences.

*Speaker

[S1-P08] Using SP and PS precursor waves to detect upper mantle discontinuities

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Abstract

We investigate the usability of converted phases, such as SP and PS, and their precursors, which reflect off the underside of upper mantle seismic discontinuities. In contrast to PP and SS waves, converted phases do not reflect midway between source and receiver but about three quarters for SP and one quarter for PS on the great circle path and therefore might lead to a better data coverage, especially of oceanic regions where usually few receivers can be deployed. As the SP and PS phase arrive at about the same travel time and with similar slowness values, the standard array seismological processing methods do not provide usable results. The two phases can be distinguished using their polarization, therefore we developed a polarization filter. Here we show that the polarization filter successfully makes such a separation possible and that precursor signals of SP and PS can be detected in vespagrams. For this study, we analysed events with Mw $>$ 5.7 and ranging between 80 and 140 deg epicentral distance from all azimuthal directions recorded at the Transportable Array. Even though the depth and distance ranges for which precursor signals can be detected are very limited for this method, the study resulted in 52 events showing SP precursor signals reflected off the 410 km and/or 660 km discontinuities. For this final dataset, differential travel times between the main phase and the precursor signals were measured and converted into depth values to map the topography of the 410 km and 660 km discontinuities.

*Speaker

[S1-P09] Lowermost mantle thermo-chemical structure beneath the western Pacific inferred from seismic attenuation and shear-wave speed anomalies

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Abstract

The seismic structure of the Earth's deep mantle is dominated by two large low shear-wave velocity provinces (LLSVPs) located beneath Africa and the Pacific. While these structures have been observed by many studies and data sets, their nature, purely thermal or thermo-chemical, is still debated. Shear-wave velocity structure alone is unable to resolve the trade-off between temperature and composition, and discriminating between purely thermal and thermo-chemical hypotheses requires constraints independent from this structure. Seismic shear-wave attenuation, measured by the quality factor QS, strongly depends on temperature and may thus bring key information on temperature, resolving in turn the trade-off between temperature and composition. Here, we first invert seismic waveform data jointly for radial models of shear-wave velocity anomalies (dln VS), and QS at two different locations beneath the Pacific, and from a depth of 2000 km down to the core-mantle boundary (CMB). At the Northern Pacific (NP), VS and QS remain close to the PREM values, representing the horizontal average mantle, throughout the investigated depth-range, with dln VS _˜ -0.1% and QS _˜ 300 (compared to QPREM = 312). At the Western Pacific location (WP), both VS and QS are substantially lower than PREM. Importantly, dln VS and QS sharply decrease in the lowermost 500 km, from -0.6 % and 255 at 2500 km, to -2.5% and 215 close to the CMB, respectively. We then show that WP models, sampling the western tip of the Pacific LLSVP and the Caroline plume, cannot be explained by thermal anomalies alone, but require excess in iron of _˜ 3.5 % from the CMB up to 2600 km, and _˜ 0.4 % at shallower depths. By contrast, NP models may have a purely thermal origin. Our results strongly support the hypothesis that LLSVPs are thermo-chemical structure enriched in iron by a few percent, compared to average mantle composition. We further suggest that the slight enrichment in iron we infer at WP in the depth range 2000-2500 km is related to the entrainment of small amounts of the Pacific LLSVP material by the Caroline plume.

*Speaker

[S1-P10] Electrical Conductivity Studies of the Mantle

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Abstract

Electrical conductivity varies over 5 orders of magnitude in Earth's mantle, from 10ˆ{-4} S/m or less in the cooler parts of the lithospheric mantle to nearly 10 S/m in the lower mantle and in regions of melting in the upper mantle. These changes are driven not only by temperature and melting, but also by phase changes, volatile/water content, and deformation/rheology.

Electrical conductivity studies start with collection of data using magnetic satellites, magnetic observatories, and magnetotelluric field campaigns. These data are then converted from time series into frequency-dependent electromagnetic responses by a variety of processing methods. Finally, the electromagnetic responses are inverted for conductivity structure, in one, two, and three dimensions, using sophisticated modeling and inversion algorithms.

If all this is done correctly, we obtain electrical conductivities that are representative of the mantle, but to covert conductivities into physical properties we need laboratory measurements of the electrical properties of mantle materials under temperatures, pressures, and volatile contents representative of mantle conditions. These measurements are challenging in themselves, and there is not always agreement between laboratories studying the same properties. Further ambiguity can exist because similar conductivities can result from dissimilar mechanisms. For example, partial melting and hydrogen dissolved in sub-solidus minerals can both elevate mantle conductivities.

Various examples and data sets will be presented to illustrate these issues. Lab-based conductivity calculations will involve the use of the new version of SIGMELTS, which is a free web-application (available at sigmelts.ucsd.edu) that helps interpret field electrical data using laboratory studies, and thus, understand the structure of the interior of our planet.

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[S1-P11] Waveform inversion for localized 3-D shear velocity structure in D beneath the western Pacific using Thai Seismic Array (TSAR) data

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Abstract

Global tomographic models of shear velocity have shown two large-scale low shear velocity provinces (LLSVPs) in D beneath the Pacific and Africa. It is controversial whether these LLSVPs are due to thermal effects, chemical effects, or a combination. Previous seismological studies based on travel-time analysis or forward modeling inferred a sharp side velocity boundary of the Pacific LLSVP beneath the western Pacific and suggested that the LLSVP is chemically distinct, although there were differences in the inferred boundary locations (Takeuchi+ 2008; He+ 2006). To better understand the origin of LLSVPs, it is essential to infer the detailed 3-D velocity structure in D beneath the western Pacific. We recently deployed a seismic array in Thailand (Thai Seismic Array-TSAR). We assemble waveforms recorded by TSAR as well as other networks such as TM, AU, MM, and MY, allowing us to sample a wider region than previous studies. We conduct waveform inversion of this dataset for the detailed 3-D shear velocity structure in D beneath the western Pacific. The inferred model shows a low velocity anomaly immediately above the core-mantle boundary (CMB) and high velocity anomalies extending vertically from 400 to 50 km above the CMB. The size of the inferred low velocity anomaly suggests a thermal plume rather than a chemical anomaly. The location of the high velocity anomaly in Dis consistent with the Izanagi plate subduction boundary 180 Ma (Mathew+ 2016). This suggests that a cold paleo-slab makes the western edge of the Pacific LLSVP seismologically sharp. Hence, we conclude that the Pacific LLSVP and its sharp boundary can be explained mainly by thermal effects.

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[S1-P12] Azimuthal anisotropy in the mantle from normal mode spectra

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Abstract

Azimuthal anisotropy of seismic waves has been widely observed in the lithospheric mantle and is generally attributed to the mantle's response to plate tectonic movements. The observation of azimuthal anisotropy elsewhere in the mantle could therefore serve as an indicator of azimuth- dependent deformation or flow. Particular regions of interest are the mantle transition zone and the D"-layer, as the behaviour of slabs and mantle material in these regions is much debated. For example, Yuan & Beghein (2013) used fundamental and overtone Rayleigh-wave phase velocity maps to resolve the global directions of azimuthal anisotropy up to 1000 km depth in the mantle. They found a distribution of anisotropic directions and amplitudes that changes significantly in signature at the depths of the phase transitions in the transition zone. Azimuthal anisotropy was found at the same large depths using love wave overtones (Trampert & van Heijst, 2002; Yuan & Beghein, 2014).

Surface waves and whole Earth oscillations induced by large earthquakes are sensitive to some of the same elastic parameters describing azimuthal anisotropy, so that the results from studies using either of the two data types may be compared. However, the sensitivity of surface waves decays rapidly with depth, while normal modes do have the ability to resolve structures throughout the entire mantle. The coupling of normal modes can occur due to presence of azimuthal anisotropy, leaving a signature in the resulting frequency spectra. Normal mode coupling can be seen as the exchange of energy between normal modes caused by deviations from a spherically symmetric, non-rotating and isotropic Earth. The many possible forms of this normal mode coupling are described by mathematical coupling rules, which may be incorporated in a model for forward calculating synthetic normal mode spectra.

We chose to start our study of mantle azimuthal anisotropy by analyzing the sensitivity of coupled fundamental normal modes to the elastic parameters describing azimuthal anisotropy. In our model, the anisotropy was confined to the upper 670 km of the mantle, and values for the elastic parameters were taken from the results of the model space search performed by Beghein et al. (2008). The effects are clearly visible in the normal mode spectra.

It is not a straightforward task to distinguish the signal of azimuthal anisotropy in the normal mode data, as mode coupling may be the result of a number of factors. For example the Coriolis force as a result of the Earth's rotation, which is on the same time scale as the

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periods of low-frequency normal modes, may also couple the fundamental modes we used in this study so far. However, the coupling due to the Coriolis force is negligible or even zero for equatorial paths, as the Coriolis force is zero at the equator. Here, we show that this is clearly visible in synthetic normal mode spectra, indicating that it is best to look for the signal of azimuthal anisotropy in the data of equatorial paths (e.g. Hu et al., 2009).

Our next step will be to implement the surface wave models of azimuthal anisotropy from Yuan & Beghein (2013) and Yuan & Beghein (2014) and use them to study the influence of azimuthal anisotropy on synthetic normal mode spectra.

[S1-P13] Towards toroidal mode sensitivity to mantle anisotropy and attenuation

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Abstract

Large earthquakes excite whole Earth oscillations, i.e. the normal modes of the Earth. These modes are long period, standing waves along Earth's surface and radius. The study of these modes is fundamental to seismology, as they provide strong constraints on the velocity, density and attenuation structure of the Earth's mantle. Unlike other kinds of seismic data, normal mode observations represent broad averages of the Earth's compositional properties and do not suffer from sparse data coverage due to uneven source and receiver distribution (Woodhouse & Deuss, 2007).
Based on their characteristics normal modes can be divided in toroidal modes, governed by horizontal surface motion, and spheroidal modes, involving a combination of horizontal and vertical surface motion. We are specifically interested in toroidal modes, which involve horizontal SH-motion at the Earth's surface and are similar to Love waves.

Toroidal modes haven't been measured for 20 years, since Resovsky & Ritzwoller (1998) and Tromp & Zanzerkia (1995). Compared to spheroidal mode measurements toroidal mode measurements were poorly constrained by only a limited number of seismic horizontal component records. More recent studies by Deuss et al. (2013) only used vertical components to measure spheroidal modes.

Here, we will expand the study bey Deuss et al. (2013) by adding horizontal component data for all new large earthquakes from the last 20 years. By adding new horizontal data recordings, we are able to refine and extent the few toroidal mode measurements.This enables us to compare horizontal and vertical data recordings for toroidal modes and look for cross-coupling (i.e. resonance or exchange of energy) between fundamental toroidal and spheroidal modes.Due to cross-coupling, toroidal mode energy may become visible on the vertical component recording instead of only on the horizontal components.
Cross-coupling between fundamental spheroidal and toroidal modes due to rotation of the Earth has been well documented in previous studies, and we will investigate the occurrence of additional cross-coupling due to anisotropy and attenuation. Toroidal-spheroidal mode cross-coupling may provide important information of the azimuthal anisotropic structure of Earth's mantle (Beghein et al., 2008), and also lead to a better determination of attenuation.

*Speaker

[S1-P14] Constraining 1D attenuation using new measurements of Radial Modes

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Abstract

Robust estimates of the Earth's temperature, composition and partial melt are hard to obtain from seismic tomography models based only on wave velocities. Seismic attenuation, or loss of the waves' energy, will add crucial information and allow us to answer elemental questions regarding the existence of water and melt within the mantle. However, generating mantle attenuation models is not an easy task, as scattering and focusing effects need to be included in order to distinguish between intrinsic attenuation (transformation of energy to heat) and scattering (redistribution of energy). Here we use normal modes, and exploit that scattering and focussing can be easily included using cross-coupling (or resonance) between free oscillations, without the need for approximations.

Radial modes describe the radial expansion and contraction of the whole Earth. These modes are long period and low attenuating, and can be described by only two parameters: centre frequency and attenuation. Previous studies have only used one deep earthquake ($>$ 500 km), and sometimes only one station, for the measurement of these modes (He & Tromp, 1996; Durek & Ekstrom, 1995; Widmer et al., 1991; Riedesel et al., 1980). This approach relied on the assumption that radial modes do not cross-couple to other modes, and that their surface pattern does not vary geographically.

Here we report measurements for radial modes using multiple events. We find that, for radial modes, there is a consistent amplitude difference between shallow and deep events. Shallow events present amplitudes up to 15 times higher than the ones predicted by 1D synthetics, preventing us from making consistent attenuation measurements. This difference cannot be explained by an inversion using a self-coupling approach. We will show that radial modes are strongly cross-coupled to nearby modes due to ellipticity and inner core anisotropy. Including cross-coupling improves the amplitude fit between radial modes and synthetics, and will provide us with improved estimates of the centre frequency and attenuation of radial modes.

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[S1-P15] Towards a 3D mantle model using full spectrum tomography

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Abstract

One of the most common features of global tomographic images is large regions in the lowermost mantle beneath Africa and the Pacific Ocean where shear wave velocities are lower than average. The reason for low velocities in these so-called LLSVPs remains a subject of debate until this day. Proposed hypotheses include compositional heterogeneity and an increase in temperature. It cannot be resolved by only looking at velocity anomalies. We need additional information, such as density and intrinsic attenuation. Unfortunately, it is difficult to constrain density and attenuation in the lower mantle, because of resolution issues and trade-offs (Kuo and Romanowicz, 2002). We will attempt to create 3D density and attenuation models using full spectrum inversion of normal modes, building on previous work by Li, Giardini and Woodhouse (1991).
Normal modes (or free oscillations) are low frequency standing waves along the surface and radius of the Earth. The advantage of normal modes over body waves is that scattering (i.e. exchange of energy between modes) is implicit in the full coupling approach, which might help in constraining 3D density and attenuation. Deuss and Woodhouse (2001) have demonstrated the importance of wide-band cross-coupling for taking all the energy into account. Here, we will apply wide-band coupling to perform full spectrum tomography.

To get an idea of the size of the sensitivity of each free oscillation to density, attenuation, S- and P-wave velocity, we first calculated the relative shift in singlet frequencies and Q-factors when one of these parameters is added as perturbation on top of PREM. The size of the frequency shift for density variations in the lower mantle is comparable to that for attenuation, when both are scaled to S-wave variations. Sensitivity to attenuation is therefore expected to be small.
Then we made initial tests for full spectrum tomography. We will use the data from Deuss et al. (2013) which contains normal mode spectra for mantle modes between 0 and 10 mHz for 91 events with Mw $\geq$ 7.4. These spectra will be inverted directly, without the intermediate step of measuring splitting functions. Our first inversion will be for S-wave velocity only, with scaled density and P-wave velocity, and few depth- and spherical harmonic parameters. Gradually, more complexity and sophistication will be added to the model parameterization.

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[S1-P16] Obtaining the 3D density structure of the Earth using direct inversion of normal mode spectra

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Abstract

Observations of free oscillations provide important constraints on the heterogeneous structure of the Earth. This inference problem is traditionally addressed by measuring and interpreting splitting functions. These can be seen as secondary data extracted from low frequency seismograms. Their measurement necessitates the calculation of synthetic seismograms, but current implementations rely on approximations referred to as self- or group-coupling, which have been shown to be insufficiently accurate. To avoid such difficulties, we instead consider a one-step inversion going directly from observed spectra to Earth structure based on large-scale group coupling calculations.

We have implemented and investigated such a direct spectral inversion method based on large-scale group coupling. As is well known, lateral density variations have a relatively weak effect on low frequency spectra, and so it is not clear how well this parameter can be recovered independently of other effects. We first used synthetic data to test our inversion method and help to select suitable regularization parameters. Inversions performed with real data returns models of S-wave velocity in good agreement with previous studies. Variations in P-wave velocity and, in particular, density, are, however, significantly less well constrained, with the results depending quite strongly on the starting model for the inversion. This could be due in part to issues with data noise and/or a lack of sufficient data coverage. It also needs to be investigated if full coupling, computationally much more demanding, can improve the resolution of density.

*Speaker

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[S1-P17] A study of the topography of the mantle seismic discontinuities beneath the Alaskan subduction zone using receiver functions

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Abstract

The mantle transition zone is the region between the globally observed major seismic velocity discontinuities around depths of 410 and 660 km. The transition zone delineates the upper from the lower mantle, and its characteristics both effect and reflect the style of mantle convection. Also, subducting slabs and rising plumes may leave an imprint on the transition zone discontinuities. Thus, by studying the mantle transition zone, we will be able to constrain the dynamics of the Earth's mantle.
In this study, P to S converted waves, or receiver functions, are used to investigate these seismic mantle discontinuities beneath the Alaskan subduction zone. Receiver functions are sensitive to the local Earth structure underneath a seismic station by representing the response to the incoming compressional (P) wave, and can therefore be used to study discontinuities at different depths. In the Alaskan subduction zone, the Pacific plate subducts underneath the North American plate. Different models do not agree on the depth extent of the subducting slab, and better imaging of the Earth structure underneath Alaska is required. I used roughly 20,000 high quality radial receiver functions to make a common conversion point stack. Regional velocity anomalies are accounted for by a regional tomographic velocity model and a crustal model.

I observed an uplifted 410 discontinuity and a thicker mantle transition zone underneath central Alaska, at the location that corresponds to the location of the subducting slab in the velocity model. Little variation is seen in the topography of the 660 discontinuity. These observations indicate that the slab has clearly penetrated through the top of the mantle transition zone, but that there is no clear slab signature on the transition zone bottom. This could imply that the slab has not reached the bottom of the mantle transition zone, but since this part of the slab is likely to consist of young and thin lithosphere, it could also have reached the 660 without the receiver functions being able to image it.
In the southwestern part of the slab, P410s arrivals have very small amplitudes or no significant arrival at all. This could be caused by water in the subducting slab, or by too much topography on the 410 discontinuity. In the southeast of Alaska, deeper than average discontinuity depths are observed, combined with a thinner mantle transition zone. This area corresponds to the location of a slab window, and thinning of the mantle transition zone may be caused by hot mantle upwellings.

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[S1-P18] A new method examines physical properties in southern Canada – temperature and composition

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Abstract

Geophysical observations indicate a significant lateral variation in mantle properties between Cordillera and North American Craton in southwestern Canada. Compared to the Craton, the Cordillera has lower seismic velocity, higher surface heat flow, lower electrical resistivity, and lower effective elastic thickness. This suggests a hot, thin lithosphere for the Cordillera and cold, thick lithosphere for the Craton. Previous studies have argued that the thin Cordilleran lithosphere is maintained by vigorous convection of a low viscosity, hydrated mantle, whereas Cratonic lithosphere is dry and resistant to thinning. We use two independent data sets, seismic shear-wave (Vs) tomography (Models NA07 and SL2013NA) and magnetotelluric (MT) observations, to examine temperature, composition and water content at 70-250 km depth. The Vs analysis requires a few assumptions, including mantle composition (via Perple_X), grain size, and attenuation. The effects of attenuation become significant at temperatures higher than 1000 ◦C. The MT analysis is based on empirical models of the electrical resistivity of hydrous olivine as a function of temperature and water content. The joint Vs-MT analysis suggests that the Cordillera mantle has an average temperature of 1200-1300 ◦C. In contrast, the Craton mantle is 800-1300 ◦C. Even if there are no significant variations of water content, the temperature versus depth provides the information of the upper mantle. Cordillera temperatures are consistent with previous studies from the shear wave, heat flow observations, and xenoliths. The boundary between Cordillera and Craton is delineated by a high lateral gradient in Vs and electrical resistivity, suggesting a sharp contrast in temperature and water content.

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[S1-P19] Seismic scatterers in the mid-lower mantle near subduction zones

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Abstract

We investigate the distribution of S-to-P scatterers in the lower mantle beneath subduction zones, where seismicity extends down to the bottom of the upper mantle and where downwelling mantle flows probably dominate. We find many strong S-to-P scatterers shallower than 1000 km, at all of the subduction zones around Pacific; Peru to Bolivia, Tonga-Fiji, Vanuatu, Bismarck, Indonesia, Philippine-Mindanao,Mariana, Izu-Bonin, Japan Sea, Kuril, and Okhotsk. Prominent shallow lower mantle scatterers are found also beneath southern Spain where the deepest seismicity occurs indicating the subduction of an oceanic lithosphere. Anomalous later phases in the P coda usually arrive along off-great circle paths, and with positive and nearly zero slowness relative to direct P. Most of them thus cannot be S-to-P conversion at a globally horizontal discontinuity, but are more adequately interpreted as a scatterer. The delay times of the S-to-P waves after P waves vary from 20 s to greater than 100 s, and the number of observations markedly drops above about 50 s. The number of S-to-P scatterers decreases below about 1000 km, although there are certain numbers of deeper S-to-P scatterers. S-to-P scatterers deeper than 2000 km are not observed. Many of the scatterers are fairy pronounced, characterized with an amplitude comparable to the anomalous phase arriving earlier and probably representing the "S660P" wave. This indicates that the elasticity jumps at the scatterer are as larger as the post-spinel transformation.

*Speaker

[S1-P20] Hydrolytic Weakening in Olivine: Peierls-Nabarro Investigations

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Abstract

The Earth's upper mantle potentially contains significant amounts of water and thus the effect of water on the rheology of upper mantle minerals (hydrolytic weakening) is a key constraint in upper mantle dynamics. Previous investigations have shown that small amounts of water (_~100 ppm) can both significantly weaken olivine and change its texture. Some dispute remains about the extent and nature of these effects and the exact mechanism of hydrolytic weakening is unknown.
To examine this problem we use Peierls-Nabarro calculations to model the major slip systems of olivine in both dry and hydrated forms. We find that the primary effect of water on olivine is to increase the number of vacancies rather than to lubricate their slip. As has been seen experimentally hydrous olivine has different primary slip systems than dry olivine and different responses to pressure. We speculate on the effect of temperature based on previous work on hydrated vacancies and speculate that there should not be significant temperature effects on hydrolytic weakening.

*Speaker

[S1-P21] Constraints on water content in the mantle transition zone near subducted slabs from anisotropy tomography and mineral physics data

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Abstract

We examine the patterns of radial anisotropy in global tomography images of the mantle transition zone near subducted slabs in the western Pacific. Fast SV velocity anomalies are observed in this region, which are compatible with anisotropy due to lattice-preferred orientation in wadsleyite. Using mineral physics reports of the dependency of the strength of radial anisotropy on water content in wadsleyite, we estimate the water content in the transition zone near subducted slabs from the tomography images. We find that fast SV anisotropy anomalies over _˜1.5 % observed beneath most subduction zones in the western Pacific imply a low water content (smaller than _˜3,000 ppm H/SI), notably beneath the Tonga-Kermadec, the Philippine and the Sumatra trenches.

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[S1-P22] Exploring detailed feature of transition zone seismic discontinuities beneath US continent with receiver function amplitudes

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Abstract

Transition zone seismic discontinuities (TZSDs) at depths of about 410 and 660 km are associated with mineral phase transformations. A comprehensive understanding of the discontinuity properties, such as topography, shear velocity jump and density jump, and the transition width, is essential for exploring the nature of the transition zone. While numerous studies have investigated TZSDs with diverse datasets, none has simultaneously obtained robust observations of these properties.

Joint analysis of forward scattering waves (or converted waves, Pds) and backward scattering waves (or top-side reflections, PpPds) recorded by dense seismic arrays allows us to independently constrain shear velocity and density jump across the discontinuities and explore the detailed feature of TZSDs. We collect USArray seismic data for M≥6.0 earthquakes in the distance range of 60-95 degrees, and calculate receiver functions up to 350 s after P arrival. Stack of receiver functions in different distance bins shows robust detection of forward and backward scattering waves in various frequency bands. Timing of the forward/backward scattering waves are migrated to obtain the topography of the 410 and 660. Frequency-dependent (0.1 Hz – 0.5 Hz) amplitudes of Pds conversions and PpPds top-side reflections from transition zone discontinuities are analyzed to estimate the shear velocity and density jump, as well as the transition width and velocity/density gradient near the 410 and 660 beneath the US continent.

In general, as expected theoretically, the amplitude of Pds conversions decreases with increasing epicentral distance, while the amplitude of PpPds reflection increases with increasing epicentral distance. However, the amplitude oscillates with varying distance possibly due to effect of topography and interferences from other mantle waves. At high frequency (0.5 Hz), the amplitudes of forward and backward scattering waves from the 410 are about 1% and 0.5%, respectively, while at longer period (10 s), the amplitudes increase to about 2% and 1.5%. In the frequency band of 0.1-0.5 Hz, the amplitude ratio A410/A660 for forward and backward scattering waves is in the range of 0.6-0.8 for the whole US, slightly higher than the predicted value of 0.5-0.7 from reference IASP91 model. To examine the impact of long-term subduction on the thermochemical state of the transition zone, we will compare features of TZSDs in the tectonically active western US and stable eastern US, while contrasting them against the result previously obtained in the Chinese continent and Korea.

*Speaker

[S1-P23] Seismic imaging of mantle convection

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Abstract

I will present two recent tomographic models, SEISGLOB1 and SEISGLOB2, which bring new constraints on mantle dynamics. SEISGLOB1 is based on the joint inversion of new Rayleigh phase velocity measurements, and of recent splitting and cross-coupling normal mode data; while SEISGLOB2 contains in addition body wave travel times. On one hand, SEISGLOB1 reveals that the new normal mode data require a more complex velocity structure at the base of the mantle than that expected from a dominant spherical harmonic degree 2, as well as stronger odd degrees. On the other hand, SEISGLOB2 enables us to confirm the existence of a global change in the shear velocity spectrum at around 1000 km depth thanks to an increased resolution in the mid-mantle. These two observations provide key constraints on mantle dynamics. Indeed, changing the large-scale pattern of the Large Low Shear Velocity Provinces can have great impacts on the mantle and outer core convection, and, a global change at around 1000 km depth has great implications for material exchanges between the upper and lower mantle.

*Speaker

[S1-P24] Inversion of P-to-S converted waves for mantle thermal and compositional structure: methodology and application

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Abstract

P-to-S waves converted at the 410- and 660-km discontinuities have been widely used to map variations in velocity gradients associated with the mantle transition zone (TZ). These gradients reflect phase transitions of major mantle minerals providing valuable insight on mantle thermo-chemical state. We here present a methodology to invert P-to-S receiver function (RF) waveforms directly for mantle temperature and composition. This is achieved by interfacing the geophysical inversion with self-consistent mineral phase equilibria calculations from which rock mineralogy and its elastic properties are predicted as a function of pressure, temperature, and bulk composition for two end-member mantle compositional models: the equilibrated Equilibrium Assemblage (EA) and the disequilibrated Mechanical Mixture (MM) models. This approach anchors temperatures, composition, seismic properties, and discontinuities that are in mineral physics data, while permitting the simultaneous use of geophysical inverse methods to optimize models of seismic properties to match RF waveforms. Resultant TZ topography and volumetric seismic velocities are independent of tomographic models usually required for correcting for upper mantle structure.

We first analyzed the dependency of RFs on thermal and compositional variations.
The former significantly influence arrival times, whereas the latter affect the amplitude of waves converted at the discontinuities bounding the TZ. Second, we tested the robustness of the inversion strategy by performing a set of synthetic inversions in which crustal structure was assumed both fixed and variable. This indicates that unaccounted-for crustal structure strongly affects the retrieval of mantle properties, calling for a two-step strategy to simultaneously recover both crustal and mantle parameters. Finally, and as a proof of concept, the methodology was applied to data from two cratonic stations: Siberian and East European craton. The MM model leads to more harzburgite-enriched compositions, whereas the EA model results in higher transition zone temperature estimates (_˜60 ◦C).

*Speaker