Influence of mantle structures on deviations of PKP waves

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Abstract

The seismological exploration of the Earth's inner core has revealed some structural complexities such as seismic anisotropy and hemispherical separation. Investigating at least two different ray paths, a polar and an equatorial one, is one of the commonly used methods to probe the inner core's properties. Former studies show clear deviations in travel times from the predicted values for PKP waves that are going through the inner core.

In this study we use data from an equatorial paths with events from Indonesia recorded in Morocco and a nearly polar one with earthquakes in New Zealand recorded in England. The two waves used in our study, PKPdf and PKPab, both propagate through the mantle and the outer core but the df branch propagates through the inner core and therefore we would expect to observe stronger deviations for this path. In order to characterize and analyse the residuals between the observed values and the ones predicted by ak135 we use vespagrams and slowness backazimuth analysis. Furthermore we produce synthetic seismograms to compare it with the real data and eliminate possible picking errors.

The results of this study show negative slowness deviations in the equatorial path (ray angle from 60°- 80°) for PKPdf and PKPab waves that propagate through the quasi eastern hemisphere (43° E - 177° E) and positive slowness deviations of the two waves for the quasi-polar path (ray angle 35°- 52°) in the same hemisphere. In general the backazimuth deviations show a reverse pattern compared to slowness.

Observations of the same trend of the residuals for the PKPdf and PKPab waves would lead us to the assumption that the deviations are not caused by the inner core but rather by mantle structures. To confirm this synthetic data with additional layers at the CMB like ULVZ will be tested. Furthermore we will pick the travel times of the real and the synthetic data to compare the residuals with the results of earlier studies.

The benefits of rotational motion: 1D versus 3D structure

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Waveform inversion for seismic point (moment tensor) is a standard procedure. However, especially in the local and regional distances a lack of appropriate velocity models, the sparsity of station networks, or a low signal-to-noise ratio combined with more complex waveforms hamper the successful retrieval of reliable source solutions.
We assess the potential of rotational ground motion recordings to increase the resolution power and reduce non-uniquenesses for seismic point source solutions. Based on synthetic waveform data, we perform a Bayesian (i.e. probabilistic) inversion. Thus, we avoid the subjective selection of the most reliable solution according the lowest misfit or other constructed criterion. In addition, we obtain unbiased measures of resolution and possible trade-offs.
Here, we especially test the influence of the velocity model on the inversion including rotational ground motion, focusing on the question: With respect to the resolution of the moment tensor parameters and computational effort, what is the better strategy: invert only 3C data with a good 3D velocity model, use 6C data and a 1D velocity model, or go for both, 6C data and a 3D structural model?

Scattering in the lowermost mantle beneath the Caribbean

Vanessa Hiemer, Christine Thomas

The D” region is characterized by a variety of structures at many different scales, ranging from scatterers and ultra-low velocity zones with up to 10’s of km-sizes to the large-low shear velocity provinces beneath the Atlantic and Pacific. Another prominent structure is the D” reflector that has been found in many regions.

The focus of this study is on the lowermost mantle where scattering of the PKP phase occurs and arrives as precursors to PKPdf. Here the area of interest is the region of and around the Caribbean Sea. To investigate the structure in the lowermost mantle below this region, events in Central and South America from 1991 to 2017 are used with a magnitude of 6 and greater in a depth below 100 km. The corresponding data are taken from stations in a distance of about 120 to 145°, as for example the Kyrgyz Seismic Telemetry Network (KN).

The scattered and diffracted waves in the seismograms are studied in different frequencies to look for changes in amplitude ratios of precursors to PKPdf with regard to frequency, direction and distances. We find that precursors to PKPdf show a dependency of amplitude with frequency and epicentral distance. In addition the arrival time of precursors shows a frequency and distance dependency, as well. We also test directional dependencies of scattering to test whether scattering could be anisotropic.

Abstract

Investigating the subsurface structure using wind turbine noise

Jana Klinge, Stéphanie Durand, Christine Thomas

Over the last 15 years, the development of wind energy has shown considerable acceleration in Germany as a way to face excessive energy consumption in Europe using sustainable resources. As a result, many wind turbines have been built and many of them next to seismological stations. While a wind turbine is operating, it generates acoustic signals, which can have an influence on the local noise level. In this study we show that wind turbines generate acoustic seismic noise at precise frequencies and we test whether it can be used to image the subsurface. To that aim, we analysed the ambient noise recorded by the 13 stations of the Graefenberg array (Bavaria) in a frequency range up to 10 Hz. We used two years, 2007 and 2017, between which the number of wind turbines has significantly increased around the array.
To demonstrate the effect of wind turbines on the data, a spectral analysis was applied. The data show increased power spectral density amplitudes in specific frequency bands, which are correlated to wind speed. The comparison of years 2007 and 2017 shows, that the results are correlated with the number of wind turbine around the stations. Then, in order to test if subsurface structures can be imaged using the noise generated by wind turbines, we extracted the group and phase velocity dispersion curves at various frequencies for years 2007 and 2017. We are now generalizing this analysis to a new array of 10 stations located in Northern Germany.

Rupture processes of major earthquakes in Borohoro Shan region (China).

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Earthquakes in the Tien Shan region (Central Asia) have caused several natural catastrophes in the past. Estimation of seismic hazard in this region requires identification of faults with potential risk for destructive earthquakes. Comprehensive analysis of earthquakes including investigation of historic and prehistoric events is essential for better understanding of rupture processes.

Here we present the results of a project aiming to identify the active faults in the region of Xinjiang (particularly Borohoro Shan) in western China. During this research work we study history/prehistory of major earthquakes which have occurred within Borohoro Shan region. Two largest instrumentally recorded earthquakes occurred in 1906, Manas earthquake and in 1944, Xinyuan earthquake. Determination of precise source parameters of these events is of crucial importance for characterization of fault processes in the region.

Within our study the source parameters of two major earthquakes in Borohoro Shan region were determined. The epicenters of the earthquakes were relocated, their magnitudes were re-estimated and the focal mechanisms were determined.

The Manas earthquake occurred at 18:21:10.6 on December 22, 1906 in Northern Tien Shan. Epicenter of the earthquake was relocated to 43.96°N (±0.5) and 84.93°E(±0.3). Three types of magnitudes: broad-band body wave magnitude m_B=7.4±0.3, surface waves magnitude M_S= 7.9±0.2 and moment magnitude M_W7.7 ±0.2 were determined. The minimum misfit, corresponding the best fitting focal mechanism was observed for the combination strike/dip/rake: 96°/46°/70°. Based on overall tectonic regime of the region, we expect south dipping fault plane.

Detailed analysis of seismic records of the 1944 Xinyuan event has shown that the earthquake was in fact a double event, as the catalogs reported earlier. The first earthquake 1944a occurred at 22:03:43.3 and the second event 1944b at 22:12:59.3 on March 9, 1944. We relocated both earthquake epicenters to: 1944a - 43.66°N and 84.34°E; 1944b - 43.48°N and 84.163°E. This places the epicenters ∼25 km apart in Northern Xinjiang region. Our recalculated respective magnitudes for the earthquakes are: m_B6.4 and M_S6.5 for the 1944a; and m_B7.1 and M_S7.2 for the 1944b. Amplitude ratios comparison has shown that the earthquakes have the same (or at least similar) type of focal mechanism with minimum misfit for the combination of strike/dip/rake: 240°/60°/130°.

These results will help to estimate the chances of large earthquakes occurrence, and better understand relationship between rupture length, amount of slip and potential for large earthquakes to occur due to complex rupture across multiple short faults. The outcome of this study is of great importance for seismic hazard estimation in the region.

Exploring small-scale heterogeneities in the lowermost mantle using PKP precursors

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Small-scale heterogeneities in the lower mantle can scatter seismic energy that can be observed as precursor to PKP phases. Global observations indicate that these scattering heterogeneities could be on the scale of ~10 km with ~0.1% velocity variations in the deep mantle. Scattering could result from seismic heterogeneities (e.g., remnants of ancient subducted slabs, melt pockets or ultra-low velocity zones) and/or CMB topography. However, the primary source of these small-scale heterogeneities and relationships with seismic structures remain elusive.

Here we investigate regional variations in precursor amplitude to aid the interpretation of the source of scattering. For one specific path, we collect PKP precursor waveforms from earthquakes in South America which are recorded by seismic arrays in Australia. By analysing the slowness and scatterer location, we obtain the spatial distribution of these scatterers in the lowermost mantle east of Pacific LLSVP. We further constrain the geometry and velocity variations of these strong seismic anomalies using waveform modelling. Our results show that these seismic scatterers could be interpreted as localized, patchy ULVZs with P-wave velocity reductions of ~3-10% and thickness of several tens of kilometers. To extend the coverage of precursor observations, we now examine a global data set of PKP precursors in individual seismograms and array data, to better constrain scatterer locations, scattering magnitudes and sources of scattering. We find strong variations of scattering amplitudes in many different paths. This helps to determine the relationship between regional variations in scattering amplitudes and timing of precursors with seismic structures in the mantle.

The Stress Transfer Project within 4D-MB and AlpArray

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In the last century four earthquakes with *Ml* > 5 occurred in the northern Alpine foreland in SW Germany. Although a lot of faults exist, due to the deformation of the Alps, only a few details of the seismically active faults are known. The aims of the Stress Transfer Project are to map and to identify the active faults by means of neotectonics and seismicity and to determine the stress field. The focus is on three regions of outstanding seismicity: Albstadt Shear Zone, Molasse Basin around Bad Saulgau and southern Upper Rhine Graben. Our current work is focused on the installation of 15 seismic stations and on picking phases on AlpArray stations. The seismic events are then relocated using also the picking times of the earthquake service of Baden-Württemberg.

Poster:

Systematische Untersuchungen an einem Windpark zur Bewertung des seismischen Rauschniveaus induziert durch Windenergieanlagen

Tobias Neuffer und Simon Kremers

Im Rahmen eines vom „Ministerium für Klimaschutz, Umwelt, Landwirtschaft, Natur- und Verbraucher des Landes NRW“ beauftragten Untersuchungsprojektes über Einwirkungen durch den Betrieb von Windenergieanlagen (WEA) auf seismologische Einrichtungen sind insgesamt 6-wöchige Messungen an 5 verschiedenen Windparks in NRW durchgeführt worden. Zur Vermessung und Beurteilung des induzierten Grundrauschens durch die Windparks sind jeweils 5 bzw. 10 mobile seismologische Stationen in logarithmischen Abständen zwischen 1 – 10 km zu den WEA im freien Feld und möglichst isoliert von anderen Rauschquellen errichtet worden. Betriebsdaten der untersuchten WEA sind von den Herstellerfirmen über den gesamten Messzeitraum in 1 bzw. 10-minütiger Auflösung zur Verfügung gestellt worden, was eine Korrelation zwischen den Rauschbedingungen und den Betriebszuständen der WEA ermöglicht. Spektrale Leistungsdichtekurven (PSD) aus den kontinuierlichen Wellenformen, die das frequenzabhängige Rauschniveau für einen bestimmten Zeitraum beschreiben, wurden für den Frequenzbereich unterhalb von 10 Hz berechnet. Durch die verlustfreie Datenaufzeichnung und den hochauflösenden Betriebsdaten können diskrete Peaks und deren Stärke im Rauschspektrum eindeutig dem Betrieb verschiedener WEA zugeordnet werden. Zusätzlich geplante Abschaltzeiten der Windparks liefern genaue Resultate über die Eigenfrequenzen und Harmonischen der WEA Türme, die in den Untergrund eingeleitet werden. Die stärksten Vibrationen, die an den seismologischen Stationen zu messen sind, sind auf die Turmeigenschwingungen, die durch die Rotation der Rotorblätter angeregt werden, zurückzuführen und im Frequenzbereich zwischen 3 – 4 Hz zu finden. Ein Zuschaltversuch wurde durchgeführt, wobei die WEA eines Windparks sukzessive in 10-Minuten Abständen in Betrieb genommen werden. Hieraus lässt sich erkennen, dass ein Anstieg des Rauschniveaus zwischen 3 – 8 Hz mit dem Faktor $\sqrt{n}$ (mit n = Anzahl der WEA) an nahegelegenen Messstationen beschrieben werden kann.

Discriminating between causes for D" anisotropy using reflections and splitting measurements for a single path

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Knowledge of deep mantle deformation is based on seismic anisotropy, the variation of seismic wave speed and polarization with direction. Measuring this directional dependency requires azimuthal seismic coverage at D" depth – the bottoming few hundred kilometers of the mantle - which is often a limit in retrieving the style of anisotropy. Shear wave splitting is the standard technique for probing mantle anisotropy and recently, reflections from the D" region have been used to infer azimuthal anisotropy. Here we combine observations and modelling of D" reflections with shear wave splitting along a given ray path direction in order to constrain a scenario of anisotropy and mineralogy of the lower mantle. From our modelling, a clear distinction between different anisotropic media is possible by using both types of observations together but only one directional path. We focus on the lowermost mantle beneath the central Atlantic Ocean by using south-central American earthquakes recorded in Morocco. We find complex azimuthal and distance variation for both polarities of D" reflections and shear wave splitting parameters, which rules out a simple style of anisotropy – such a vertical transverse isotropy – for the region. Our preferred model consists of a phase transition from a randomly-oriented bridgmanite to lattice-preferred orientation fabric in post-perovskite, developed in a sub-horizontal plane sheared along a roughly SE-NW deformation direction.

Detecting structures in the mid mantle

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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 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. This information is used to backtrace the wave to its scattering location and to map seismic heterogeneities. We find out-of-plane reflections from structures beneath Africa showing agreement with the low-velocity structure connecting the Core-Mantle Boundary with the East African Rift system.

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 Earth.

Seismic evidence for mid-mantle reflectors beneath the North Atlantic

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The presence and nature of mid-mantle reflectors have significant implications for the dynamics of the mantle. Some regional studies reported the existence of reflectors from 700 to 2000 km depth in the mantle. The evidences of such reflectors have been found beneath subducted areas as well as regions of upwelling. However, the global existence of any mid-mantle reflector is still under debate.

In this study we search for any mid-mantle reflector beneath the North Atlantic and surrounding regions by using precursor arrivals to PP seismic waves that reflect off such a reflector. Numerous source receiver combinations have been used in order to collect a large dataset of reflection points beneath the investigation area. We analysed over 1500 seismograms from $M_W \geq 5.8$ events using array seismic methods to enhance the signal to noise ratio. The measured time lag between PP arrivals and their corresponding precursors on robust stacks are used to measure the depth of any mid mantle reflector. Slowness-backazimuth analyses have been applied to avoid the erroneous picking of any scattered or out-of-plane reflection as precursor signal. Our results reveal the existence of mid-mantle reflectors beneath the North Atlantic in the range depth of ~800 to 1800 km. To confirm our observations we will search for any reflector in the mid-mantle, using precursors to the seismic phase SS as well. Synthetic seismograms will be calculated in order to check the reliability of the observed signals.

DEPAS – Deutscher Geräte-Pool für Amphibische Seismologie

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Der "**De**utsche Geräte-**P**ool für **a**mphibische **S**eismologie (DEPAS)" ist ein im Jahre 2005 gegründeter Pool breitbandiger Seismometer für Langzeiteinsätze an Land und auf dem Meeresboden. Er besteht zur Zeit aus 95 Landstationen, welche vom Helmholtz-Zentrum Potsdam - Deutsches GeoForschungsZentrum (GFZ) betrieben werden, sowie aus 80 Ozeanboden-Seismometern (OBS), welche technisch und organisatorisch vom Alfred-Wegener-Institut, Helmholtz-Zentrum für Polar- und Meeresforschung, Bremerhaven (AWI) betreut werden.

In diesem Beitrag wird der marine Teil des DEPAS-Pools vorgestellt, die Ozeanboden-Seismometer (OBS). Es werden unter anderem die Geräte-Technik und das Antragsverfahren erläutert. In den kommenden Jahren sollen die OBS durch den Austausch von Seismometern und Datenloggern technisch auf den neuesten Stand gebracht werden. Das Eigenrauschen der Seismometer bei langen Perioden und der Stromverbrauch des Gesamtsystems können damit erheblich reduziert werden. Eine aktuelle Eigenentwicklung befasst sich mit einer speziellen technischen Erweiterung der OBS für Einsätze in eisbedeckten Regionen.

“Bewertung der Anwendung eines AR-Pickers auf einen globalen Datensatz”

Johannes Stampa, Christian-Albrechts-Universität zu Kiel

abstract

Es wird ein AR-AIC-Picker erweitert, und auf einen globalen Datensatz, mit über 5000 Stationen und Aufnahmen aus einem Zeitraum von 1990 bis 2014, angewandt. Das Ergebnis sind etwa 1.5 Millionen bestimme P-Wellen-Ersteinsätze und etwas weniger als 0.8 Millionen bestimmte S-Wellen-Phasenankünfte. Für Picks der höchsten Qualitätsklasse (42.5% der P-Picks, 38.4% der S-Picks) werden die mittleren Fehler zu 0.37 s (P), respektive 1.79 s (S), abgeschätzt. Es wird ausserdem dargelegt, dass diese Fehler zufällig und auf Null zentriert verteilt sind, und deshalb kaum in die Berechnung einer Tomographie propagieren.

HELGA – Helgoland Array

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Helgoland ist die einzige deutsche Hochseeinsel, 50km vor der Küste in der Nordsee gelegen und seit über einem Jahrhundert Standort für seismologische Observationen. Seit 1956 betreibt die CAU Kiel in der James-Krüss-Schule eine Erdbebenwarte, welche seit 2001 digital an das GEOFON Netzwerk angeschlossen ist. Die seismischen Daten der Station HLG sind erwartungsgemäß sehr stark von meteorologischen und ozeanografischen Einflüssen geprägt. Dazu zählen zuvorderst Variationen in der primären, sekundären, nicht zuletzt aber auch lokalen Meeresmikroseismik, welche im Frequenzbereich zwischen 0.3 Hz und 1Hz stark ausgeprägt ist.

Um Quellregionen und die physikalischen Anregungsmechanismen der Meeresmikroseismik näher untersuchen zu können, haben wir im Sommer 2017 ein temporäres Multi-Parameter-Array auf Helgoland installiert. Dazu gehören neben dem permanenten Seismometer fünf weitere Breitbandseismometer, insgesamt drei Mikrobarometer und zwei Tiltmeter.

Fragestellungen, welche mit dem derzeit operierenden Array adressiert werden können, umfassen Untersuchungen zur räumlichen und zeitlichen Quellverteilung der Meeresmikroseismik, wobei besonders die Beobachtung von Lovewellen im Frequenzbereich der Meeresmikroseismik bisher nicht schlüssig verstanden ist. Darüberhinaus bietet der Datensatz Möglichkeiten zur lokalen Strukturuntersuchung der Kruste und des oberen Mantels in der Nordsee oder zur Detektion von schwach seismischen Ereignissen welche in Zusammenhang mit der Salztektonik stehen könnten.

Title: Structural analysis of the Oman using P- Receiver functions

Authors: Lars Wiesenberg[1], Frank Krüger[2], Christian Weidle[1], Thomas Meier[1]

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The Oman ophiolite is one of the best preserved and studied ophiolites, where oceanic lithosphere was obducted on top of a continent. The obduction process occurred around 94-97 million years ago. It covers an area of about 700 x 140 km with a thickness of up to 12 km. Due to Major uplift processes around 30 to 40 million years ago continental crustal rocks were put locally on top of the ophiolite again. Here, we want to use P- Receiver functions to map at first the Moho and deeper discontinuities like the 410 and 660 km. Afterwards we want to get some ideas on the thickness of the ophiolite. Therefore we use the data of 58 seismic stations (40 temporary, 18 permanent), which we operated for passive seismic registration from October 2013 to February 2016.
The results are promising. We can observe differences in the travel time for the Moho which are comparable to e.g. Crust 1.0 in this area showing that the Moho depth is decreasing eastwards. Deeper discontinuities like 410 and 660 km can be observed at lower frequencies as well. Their travel time variations are acting slightly like the changes in the P-T conditions caused by e.g. the Makran Subduction zone northeastern of our array. Looking at higher frequencies we can observe indications for discontinuities at small travel times at some stations which might be due to the ophiolite. But this needs more detailed work. Synthetic tests need to be done to check how a receiver function for a model with a low velocity zone looks like.

Using PP and SS precursors to analyze phase transition variations in the upper mantle at tectonic areas of the Caribbean plate

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We investigate the subduction history of the Caribbean plate by mapping upper mantle discontinuities at 410 and 660 km depth beneath the Caribbean Sea and surrounding areas. We use PP and SS waves and their precursors, which reflect off the underside of the discontinuities and midway between source and receiver on the great circle path, to derive the topography of the two discontinuities. Our final data set consists of 81 data points from 14 events with $M_w \geq 5.9$ and a signal-to-noise ratio of $SNR \geq 1.5$. We densely cover the investigation area, also by using crossing paths of earthquakes from the Mid Atlantic Ridge and South America recorded in North America and earthquakes from the East Pacific Rise recorded in Europe. As PP and SS precursors have low amplitudes, we use standard array seismological methods to process the data and detect the weak phases. The vespagram method enhances coherent signals in the data and reduces incoherent noise. To identify waves traveling along the great circle path, slowness backazimuth diagrams are calculated. The measured differential travel times between the PP and SS waves and their precursors are corrected for tomographic features and converted into depth values to map regional variations of phase transitions at 410 and 660 km depth. Those corrected discontinuity depths can be interpreted in terms of mineralogy and mantle dynamics as distinct tectonic features of the Caribbean plate and surrounding areas. Our results show a mostly elevated 410 km discontinuity beneath Columbia and a slightly deepened discontinuity beneath the eastern Caribbean Sea and southern Mexico. The 660 km discontinuity shows a general elevated trend in the entire investigation area.