Abstract-Sammlung

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Bericht über technische Arbeiten am Erdbebendienst des Bundes der BGR

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Überblick über die Tätigkeiten im technischen Bereich des Erdbebendienstes des Bundes der BGR mit folgenden Themen:

- Betrieb des GRSN, neue Standorte
- Datenzentrum, Qualitätsprüfungen auf Datenströmen mit öffentlich zugänglicher Ergebnisdarstellung
- Integration weiterer Länder- und Universitätsnetze am EIDA Knoten der BGR

AG Seismologie 2021

Development of the earthquake activity at Laacher See Volcano since 2019

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The occurrence of Deep Low-Frequency earthquakes (DLF) in four distinct clusters underneath Laacher See Volcano (LSV) in the East Eifel Volcanic Field (EEVF) since 2013 has attracted broad interest of the scientific community beyond seismology. The discovery led to further densifications of the permanent seismic monitoring network and additional temporary deployments of seismometers as well as other interdisciplinary research efforts.

This presentation gives an overview on the development of seismic activity around LSV and in the EEVF since the GJI-publication of Hensch et al. (2019). Three major developments have been observed since:

1) DLF activity has been lower compared to previous years and was limited to the mantle clusters, especially to a cluster at 30-35 km depth. However, while only a few DLF pulses were detected in 2019 and 2020, already six pulses of activity were observed since spring 2021.

2) Shallow high-frequency earthquake swarm activity in two clusters at Glees (NW of LSV) gradually faded out in 2018. A third comparable cluster was sporadically active at Galenberg (further to the NW) in 2019 and early 2020.

3) Activity along the Ochtendung Fault Zone (OFZ) is persistent, but lower compared to previous years. The last felt earthquake occurred in January 2021.

Summarising, following two years (2017 and 2018) of high activity in the DLF clusters, the two Glees clusters and along the OFZ, the overall seismicity around LSV and in the EEVF shows slight signs of decrease during the past three years. However, the overall short monitoring time since 2013 does not yet allow to determine clear trends in the occurrence of seismicity.

In addition to the monitoring results, recent and future work concentrates on trigger mechanisms and source processes of the DLFs and swarm events. In this context, data examples of tornillo-like DLFs will be shown, which are proposed to either be caused by fluid resonance or non-laminar fluid flow. Further work on the development and application of DLF detection routines will be presented by Koushesh et al. in the accompanying presentation.

Five Years Magmatic-origin Seismic Activity at the Laacher See Volcano, Germany, Determined by an Automated Detection Algorithm

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Previous studies on the East Eifel Volcanic Field (EEVF) in Germany suggested a mantle plume system and the existence of magma chambers beneath the Laacher See Volcano (LSV). There**,** the last big eruption occurred only 12.9 thousand years ago. Monitoring the seismicity in the EEVF became an important task since the detection of two Deep Low Frequency (DLF) microseismic events (ML = 0.9 and 0.7) in the upper mantle in depths of 40 km and 43 km, in September 2013. To investigate the microseismic activity in the region more closely, a dense recording network, called DEEP-TEE, has been installed since July 2014 by KIT and the Seismological Service in Mainz. In this regard and as the two accompanying presentations, an overview on the development of seismic activity around LSV and in the EEVF since beginning of 2019 will be presented by Hensch et al., and the latest updates regarding 1-D velocity model and the corresponding station corrections for the EEVF will be presented by Föst et al..

A new robust seismic event detector was developed to cope with the difficulties in detection of weak (ML<1) diverse DLF/LF events hidden in high to moderate seismic background noise. This detector applies a 6-dimensional search in the seismic dataset using its frequency-dependent energy content and coincidence at neighbouring sites. This technique enabled us to detect many different types of seismic signals which propagate through the ground and air and which are finally recorded bythe network.

We applied the detector to the almost 5 years seismic dataset (from 31 July 2014 to 31 Dec. 2018 and from 1 July 2020 to 31 Dec. 2020). Several DLF events were found, however, discrimination with quarry blasts is still a problem due to similar waveforms. Statistical analysis of the detector outputs considering 2 years of the dataset shows the ratio of the number of the quarry blasts to the tectonic/magmatic-origin events in the region is higher than 8 during the day time (07:15 - 15:15 UTC) with sharp peaks in number of events between 09:00 and 10:15 UTC. Hence, for the rest of the analysis of the detector outputs, we focused only on the night time recordings from 15:15 to 07:15 (16 hours records per day) and postponed studying the day time seismic activities to the future works.

The detected DLF/LF events are manually inspected and picked. Then the locations are determined by the VELEST program to map the seismically active plumbing system in the lithosphere. The hypocenters of the DLF show a vertical distribution from the lithosphere-asthenosphere boundary (ca. 45 km depth) up to the upper crust. The most active zone is between 18 km and 27 km depth indicating a magmatic pool in the lower crust. Our results suggest a model of active magma rise (intrusion) through the whole lithosphere beneath the LSV.

Determination of Improved Hypocentres and 1-D Seismic Velocity Models in the East Eifel Volcanic Field.

Föst, J.-P.1, Bühler, J.1, Koushesh, M.1, Mader, S.1, Ritter, J.1, Hensch, M.2 and Schmidt, B.3

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The observation of deep low-frequency microearthquakes in the upper mantle and lower crust of the East Eifel Volcanic Field (EEVF) has motivated the Deep Eifel Earthquake Project – Tiefe Eifel Erdbeben (DEEP-TEE). As a part of DEEP-TEE we densified the seismic network in the area since 2014. This dataset should improve the understanding of the magmatic processes beneath the EEVF. Basic requirements are precise regional P and S wave velocity models for the EEVF to enhance the quality of the hypocentre locations. For this purpose, we compile a new dataset based on local earthquake waveforms of the state earthquake services of Rhineland-Palatinate, Hesse and Nord Rhine-Westphalia as well as the BGR. We analysed 1675 events between 2010 and 2021 using the permanent recording stations and the 26 mobile stations from KIT KABBA (2014-2021) and GFZ GIPP (2014-2016). The outputs are new minimum 1-D seismic *vp* and *vs* velocity models and corresponding station delay times for earthquake relocation based on VELEST. Compared to previous studies, the extended dataset allows to sort out phase picks with low quality to minimize location errors. To sample the model space, we use different velocity starting model for the inversion process, also to investigate the uncertainty ranges. The final minimum 1-D models will be chosen from the simplest layering with minimized RMS-values. These *vp* and *vs* models are then used to better determine the magmatic channel outlined by deep low-frequency events.

Deriving Structural Phase Velocity Fields with AlpArray and Neighboring European Networks

M. Tesch, T. Meier, AlpArray Working Group

The modern-day coverage and availability of broad-band stations in the greater Alpine area offered by AlpArray, Swath-D and the European seismological networks allows for spatially imaging of seismic wave-fields in unprecedented detail. We leverage this dense distribution of more than 1500 individual stations to derive spatial phase and amplitude fields of teleseismic fundamental mode surface waves on an event-by-event basis. Correlation with synthetic single-mode reference wave-forms is employed to isolate the fundamental mode signal and to suppress noise, higher modes, coda waves, adjacent events etc.

We present examples of large-scale fundamental mode surface wave-fields computed with our method, highlighting in particular the importance of the dynamic perturbations to the eikonal phase velocity. As surface wave's amplitudes carry significant information in regard to the deformation of the wave-front, it is essential to consider them for correcting disturbances induced by heterogeneities along the path of propagation when assessing structural information.

Template matching applied to the September 2019 earthquake swarm of the Albstadt Shear Zone, SW Germany

Mader, S., Brüstle, A., Ritter, J. and the AlpArray Working Group

The Swabian Alb near the town of Albstadt, SW Germany, is one of the seismically most active regions in Central Europe. Since the beginning of the twentieth century continuous seismic activity is observed. At least three earthquakes with magnitudes greater than 5 occurred, causing major damages on the buildings in the closer vicinity. Despite of the size of these earthquakes no rupture structures are visible on the Earth's surface. Earthquake locations are concentrated along a N-S striking zone, the so-called Albstadt Shear Zone (ASZ), at focal depths of about 1 km to 18 km. The central part of this seismogenic zone has a lateral extension of approximately 20 km to 30 km and is characterized by dominantly sinistral strike-slip focal mechanisms.

The State Earthquake Service of Baden-Württemberg (LED) operates a dense seismic network of 6 high-gain and 9 strong-motion stations in the area of the ASZ. In 2015 and in 2018, 9 temporary high-gain stations were deployed around the ASZ within the framework of AlpArray Project and StressTransfer Network. This densified seismic network gives a unique opportunity to detect and locate the seismically active structures of the ASZ in more details (Mader et al., Solid Earth, 2021).

In order to find microseismic events, a template matching algorithm is applied to a comprehensive dataset obtained from permanent and temporary recording stations. Here we focus on an earthquake swarm in September 2019. Results are compared with the existing earthquake catalog of the LED and statistics of the outcomes are presented.

Lithospheric Structure of the Eastern Mediterranean Sea: Inferences from Stochastic Surface Wave Inversion Constrained by Wide Angle Refraction Measurements

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Abstract

The tectonic plate under the eastern Mediterranean Sea shows a remarkable variability as it comprises Earth's oldest oceanic lithosphere as well as the transition towards continental lithosphere beneath the Levant Basin. Its thickness and other properties offer essential information on the lithospheric evolution but have been difficult to determine seismically due to the high heterogeneity of the region and its complex crustal structure. Here, we combine a large, new surface wave dataset with published wide-angle data in order to determine lithospheric properties in the eastern Mediterranean. Our stochastic inversions of broad-band, phase-velocity dispersion measurements resolve the crust-mantle structural trade-offs and yield robust, 1-D shear-wave velocity models down to 300 km depth beneath the Ionian and Levant Basins. The thickness of the crust beneath the two locations is 16.4 ± 3 km and 22.3 ± 2 km, respectively. The Poisson's ratio (σ) of 0.32 and Vp/Vs of 1.93 in the crystalline crust confirm the presence of serpentinized oceanic crust beneath the Ionian Basin. Beneath the Levant Basin, low crustal Vp/Vs (∼ 1.7) and Poisson's (∼ 0.24) ratios indicate continental crust. Beneath the Ionian Basin, the lithosphere is about 180 km thick. By contrast, thin, 75 km thick lithosphere is found beneath the Levant Basin. S-velocity tomography based on surface wave data also shows thick, spatially variable oceanic mantle lithosphere beneath the eastern Mediterranean. Thickness of the oceanic lithosphere increases eastwards from the Triassic Ionian towards the Permo-Carboniferous lithosphere in the Central Eastern Mediterranean. These results demonstrate that oceanic lithosphere can thicken by cooling substantially beyond the limits suggested by the plate cooling model. Beneath the eastern Herodotus oceanic Basin, lithospheric thickness is decreasing to about 180 km. Thin continental lithosphere and shallow asthenosphere are present beneath the Dead Sea Fault, demonstrating that the localization of the lithospheric deformation and crustal seismicity along the fault correlates spatially with the thinning of the underlying continental lithosphere.

Clustering in Microseismic Basin Systems: Hints of Local Deformation

Criado-Sutti Emilio J.M.[1,2], Krüger Frank[1], Zeckra Martin[1], Montero-López Carolina[2], Elías Leonardo[2].

The Lerma Valley, located in the Salta province of northwestern Argentina, is an intermontane basin of the Eastern Cordillera filled by Neogene-quaternary lacustrine and alluvial-fluvial sediments. It is placed in an intraplate region of the Central Andean foreland system. This region has undergone several destructive earthquakes with historical and modern records, starting from 1692 (M>7) Nuestra Señora de Esteco up to 2010 (Mw 6.2) Salta events.

Regarding tectonics, this area presents a basement-involved, thick-skinned shortening deformation, which means that seismicity would be concentrated near the mountain ranges where the stress transfer is the most effective.

A seismological field-based study has been carried out within the basin, in order to identify the event distribution and related tectonically active structures. A twelve-station seismic network ran for thirteen months. The event locations are in concordance with the expected thick skin deformation behavior. The overall low number disperses inside the valley and fall into two clusters on the western flank; one composed of 6 and other of 8 events.

This work aims to interpret and correlate the solutions obtained from the newly recorded data set with previous geological basin models. In addition, we plan a cluster correlation with the 2010 Salta earthquake (Mw 6.2).

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Titel: Volcanic plumbing and seismicity in the developing magmatic Natron rift, Tanzania

Autoren: Miriam Christina Reiss[1], James D. Muirhead[2], Amani S. Laizer[3], Frederik Link[1], Emmanuel O. Kazimoto[3], Cynthia J. Ebinger[4], Georg Rümpker[1]

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The break-up of strong, cold lithosphere in continental rifts is facilitated by the interplay of faulting, magmatism and fluids. Here we constrain the architecture of the complex plumbing system of Earth's only active carbonatite volcano Oldoinyo Lengai and its impact on rift processes in the Natron basin (East African Rift System).

We report seismicity and fault plane solutions from a 10-month temporary seismic network spanning Oldoinyo Lengai, Naibor Soito volcanic field and Gelai volcano. We locate ~6800 earthquakes with M_L -0.85 to 3.6, which are related to previous and ongoing magmatic and volcanic activity in the region, as well as regional tectonic extension. We observe seismicity down to ~17 km depth north and south of Oldoinyo Lengai and shallow seismicity (3 - 10 km) beneath Gelai, including two swarms. The deepest seismicity (~down to 20 km) occurs above a previously imaged magma body below Naibor Soito. Focal mechanisms vary spatially. T-axis trends reveal dominantly WNW-ESE extension near Gelai, while strike-slip mechanisms and a radial trend in P-axes are observed in the vicinity of Oldoinyo Lengai.

These seismicity patterns and focal mechanisms reveal a detailed image of a complex volcanic plumbing system which supports potential lateral and vertical connections between shallow- and deep-seated magmas. Local variations in state of stress results from the interplay of regional tectonic forces, edifice loading and pressurized magmas, where fluid and melt transport to the surface is facilitated by intrusion of dikes and sills. Our results indicate that the southern Natron basin is a segmented rift system where strain transfers from a border fault to a developing magmatic rift segment

Title: **Performance Test of a Rotational Sensor on Etna volcano, Italy**

Authors: **Eva P.S. Eibl, Martina Rosskopf, Frank Krüger, Mariangela Sciotto, Giuseppe Di Grazia, Gilda Currenti, Philippe Jousset, Michael Weber**

Etna volcano in Italy is one of the most active volcanoes in Europe. We recorded the volcanic activity including degassing and a strombolian eruption using a seismometer and rotational sensor in August to September 2019. We test the newly developed rotational sensor in the field in comparison to a seismometer and seismic-network-based locations using the INGV network. A single rotational sensor co-located with a seismometer can be used to identify specific seismic wave types, to estimate the back azimuth of an earthquake and to estimate the local seismic phase velocities.

We present our event catalogs for VLP, LP and VT events. We find that VLP, LP and tremor are dominated by SH-/ Love waves while VT events are dominated by SV-/ Rayleigh waves. We derive back azimuths and phase velocities in the range of 500 to 1000m/s which are consistent with observations by INGV and conclude that our rotational sensor performed reliably in the field.

Remote Seismology: Understanding seismo-volcanic unrests at remote locations on Earth

Simone Cesca, Torsten Dahm, GFZ Potsdam

Seismology can contribute to discover rare processes in the Earth interior, even when they take place at remote locations. The detection and characterization of seismic signals, and the modeling of their sources, can help to identify and image such processes. However, these seismological analysis are challenging at remote locations, where the seismic monitoring is often very poor. Relying on specific techniques and on the combination of different datasets help to tackle these problems. In particular, combining seismological and geodetic data as well as observations at different distances, e.g. single local stations and sparse regional recordings, allow to detect, track, classify and characterize earthquake sources accompanying the failure of active faults or triggered by magmatic intrusions. We discuss recent seismological and geodetic analysis of seismo-volcanic unrest episodes in the Indian Ocean and Antarctic regions. We show how, by mapping the spatiotemporal evolution of seismicity and its properties, we are able to reconstruct the path of magma intrusions from mantle to seafloor.

Fluid migrations and volcanic earthquakes from depolarized ambient noise

Luca de Siena, Univ. Mainz

Ambient noise polarizes inside fault zones, yet the spatial and temporal resolution of polarized noise on gas-bearing fluids migrating through stressed volcanic systems is unknown. At Campi Flegrei caldera (Southern Italy), high polarization marks a transfer structure connecting the deforming centre of the caldera to open hydrothermal vents and extensional caldera-bounding faults during periods of low seismic release. Fluids pressurize the Campi Flegrei hydrothermal system, migrate, and increase stress before earthquakes. The loss of polarization (depolarization) of the transfer and extensional structures maps pressurized fluids, detecting fluid migrations after seismic sequences. After recent intense seismicity (December 2019-April 2020), the transfer structure appears sealed while fluids stored in the east caldera have moved further east. Depolarized noise has the potential to monitor fluid migrations and earthquakes at stressed volcanoes quasi-instantaneously and with minimum processing.

Seismic signals of crater-rim instability at Oldoinyo Lengai volcano, Tanzania

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Abstract

Oldoinyo Lengai volcano in the North Tanzanian Divergence is one of the few highly active volcanoes in Africa. Its eruptive cycle is characterized by effusions of carbonatite lava and severe explosions. The most recent of these occurred in 2007 and left a circular crater nearly 400 wide and approximately 100 m deep. The crater is currently being filled with new lava which solidifies and has formed several characteristic hornitos. In 2019, we set up a temporary seismic network of 10 short-period stations, equipped with 4.5 Hz geophones, surrounding the crater area at altitudes between about 1990 and 2885 m to monitor the eruptive activity of the volcano. Seven of the stations were recovered in February 2020. The retrieval of the remaining stations was delayed due travel restrictions caused by the pandemic. However, in Sept. 2021, two of the missing stations were returned from the volcano. Due to the limited battery capacity, recordings were restricted to a period of about five weeks between 14/09 and 23/10/2019. A preliminary analysis of the data from 7 stations shows tremor activity and more than 80 distinct recordings of high-frequency seismic signals in the immediate vicinity of the network. However, the recordings lack clear S-wave arrivals, and the station configuration is unfavorable for the application of classical localization techniques based on iterative inversion. We, therefore, apply a grid-search approach based on a Bayesian formulation which also accounts for the topography and shape of the volcanic edifice. The results show two linearly arranged groups of hypocenters that “cut” through the crater rim and are separated by an azimuth of about 110 degrees. We argue that the events are caused by a near-vertically sliding segment of the crater wall which has become gravitationally unstable, possibly due to magmatic undermining. The interpretation may be supported by surface observations of opening cracks at the outer base of the crater rim. Seismic data from the additional 2 stations will be included to better constrain the locations of the observed seismic activity within the crater area.

Challenges and perspectives for lowering the horizontal component long-period detection level

Thomas Forbriger, Walter Zürn, and Rudolf Widmer-Schnidrig

Mass fluctuations in the atmosphere produce a permanent background noise level in normal mode data (period band from about two minutes to one hour) and such limit the signal-to-noise ratio. The mechanisms coupling this atmospheric signal into the vertical component data are quite well understood and mitigation procedures exist. The situation is more difficult for horizontal component data, where horizontal gradients of pressure loading and local elastic structure near the sensor play a significant role. In the current presentation we present results obtained from the analysis of horizontal component data. We demonstrate that in the majority of 109 analyzed cases 80 percent and more of the signal energy of the disturbance could be removed by application of a correction based on two coupling mechanisms. The one mechanism, which we call 'local deformation tilt' (LDT), is due to local heterogeneity and the other, which we call 'traveling wave tilt' (TWT) is due to horizontal gradients of surface loading. Both effects can be well separated in recorded data.
Horizontal component and strain data is essential to observe toroidal free oscillations of the globe. Spectral analysis of these toroidal modes can put integral constraints on the viscoelastic properties of the Earth's mantle, such complementing the analysis of body wave amplitude decay. These properties, commonly expressed by the Q parameter of viscoelastic material, are desired to constrain models of mantle convection.
Tilting of the ground due to loading by the variable atmosphere is known to corrupt very long-period horizontal seismic records (below 10 mHz) even at the quietest stations. At BFO (Black Forest Observatory, SW-Germany) the opportunity arose to study these disturbances on a variety of state-of-the-art broadband sensors operated simultaneously. A series of time windows with clear atmospherically caused effects was selected and attempts were made to model these 'signals' in a deterministic way. This was done by least squares fitting the locally recorded barometric pressure and its Hilbert transform simultaneously to the ground accelerations in a bandpass between 3600s and 100s period. Variance reductions of up to 97 percent were obtained. We show our results by combining the 'specific pressure induced accelerations' for the two horizontal components of the same sensor as vectors on a horizontal plane, one for direct pressure (LDT) and one for its Hilbert transform (TWT). It turned out that at BFO the direct pressure effects (LDT) are large, strongly position dependent, and largely independent of atmospheric events for instruments installed on piers, while three posthole sensors are only slightly affected. The infamous 'cavity effects' are invoked to be responsible for these large effects on the pier sensors.
On the other hand, in the majority of cases all sensors showed very similar magnitudes and directions for the vectors obtained for the regression with the Hilbert transform (TWT), but highly variable especially in direction from event to event. Therefore this direction most certainly has to do with the gradient of the pressure field moving over the station which causes a larger scale deformation of the crust. The observations are very consistent with these two fundamental mechanisms of how fluctuations of atmospheric surface pressure causes tilt noise. The results provide a sound basis for further improvements of the models for these mechanisms. The methods used here can already help to reduce atmospherically induced noise in long period horizontal seismic records.

Incorporating complex Earth structure in Matched Field Processing

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Matched Field Processing (MFP) is a source localisation approach. It is essentially Beamforming in the spatial domain, where potential source locations are sampled instead of the slowness domain. This approach can account for curved wavefronts and other wave propagation effects. The MFP algorithm is straight-forward: For a given potential source location, a synthetic wave field is computed and matched against the recorded wave field, i.e., the seismograms. This match is evaluated and compared against other potential source locations.

In seismological applications of MFP so far, the synthetic wave field has been expressed through simple analytical Green's functions for individual arrivals. This approach has been demonstrated successfully on local and regional scale, but can struggle with complex structure, realistic sources, and the presence of multiple phases in the wave field.

We propose to replace the analytically express synthetic wave fields by wave fields computed numerically for Earth structure to address these shortcomings. Here, we present the advantages and disadvantages of this approach and demonstrate its applicability on a real data example.

Automatic Picking of Teleseismic P- and S-Phases using an Autoregressive Prediction Approach

Stampa, J., Eckel, F., Kallinich, N., Meier, T.
and the AlpArray Working Group

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Abstract

In the recent decade, the amount of available seismological broadband data has increased steeply. Picking later arriving phases such as S-phases is difficult, and there are few manual picks available for these phases. Data sets of manual picks can also be problematic, since phase arrival picks are sensitive to the parameters of the filtering, which are often unknown, and the individual picking behavior of the analysts. However, accurate arrival times, especially for these phases, could be used to greatly improve the accuracy of velocity models obtained from seismic tomography. This necessitates the adoption of automatic techniques for determining teleseismic phase arrival times consistently over a large data set.

In this work, a robust automatic picking algorithm based on autoregressive prediction is examined with regards to its accuracy. For this, a series of tests were carried out, using synthetic waveforms as well as real data in conjunction with manual picks obtained from the reviewed ISC-catalog.

Picking errors are estimated by comparing the automatic picks with manual picks, automatic picks at the neighboring stations as well as statistical methods. The quality evaluations suggest potential of using these automatically determined phase arrival times for a travel time tomography.

Precursory processes leading to the nucleation of moderate magnitude earthquakes: Observations from the Istanbul-Marmara region, NW Turkey

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Laboratory experiments and some field observations show that seismic and aseismic slip can occur concurrently, and loading by aseismic slip may promote the occurrence of seismic events. In the eastern Sea of Marmara region of the North Anatolian fault zone (NAFZ), the GONAF borehole observatory (Bohnhoff et al., Sci. Drill., 2017) is fully operating since 2015, providing the means to monitor earthquake nucleation and crustal deformation over the entire frequency band in direct vicinity of the Istanbul metropolitan region. In this study, we summarize our main observations regarding the precursory phase of three M+4 earthquakes in the Marmara region that have been investigated in detail with higher resolution seismicity catalogs. First, we report on the observation of more than 18 small foreshocks preceding a M_W 4.2 earthquake, which was recorded in 2016 in the Armutlu peninsula close to Istanbul (Malin et al., Sci. Rep., 2018). Waveform cross-correlation analysis of events from the foreshock sequence revealed progressive localization towards the epicenter of the M_W 4.2 event. Analyzing long-term continuous waveform recordings from the borehole seismic network, we also study the spatiotemporal evolution of seismicity during a sequence of moderate (including a M_W 4.7 and a M_W 5.8) earthquakes in September 2019 (Durand et al., Seism. Res. Lett., 2020). These were the largest regional events since 1999 and occurred offshore at the transition between a creeping and a locked segment in the central Sea of Marmara. We find sequences of foreshocks preceding the two largest events, exhibiting two different behaviors: a long-term activation of seismicity along the entire fault segment and a short-term concentration foreshock activity around the epicenters of the large events. While the mainshocks often display seismic precursors, evidence for slow slip preceding larger events is scarce. Available strainmeter data indicates two slow slip events following the occurrence of two M4+ earthquakes in the region in 2016 and 2018 and lasting for at least 30 days or more (Martínez-Garzón et al., EPSL, 2019; Seism. Res. Letters, 2021). Currently, we analyze the precursory process of a M_W 4.6 event at the Armutlu Peninsula.

The results suggest that the sequence could have initiated after a large local storm which resulted in a local sea level change of about 0.8 m. Lastly, applying a nearest-neighbor approach to the Marmara Sea seismicity catalog for a 10 year time period, allowed us to identify the heterogeneous distribution of foreshocks along different NAFZ fault segments in the Marmara Sea (Martínez-Garzón et al., Tectonophys., 2019). The occurrence of foreshocks is likely linked to hydro-thermal activity (i.e. on the Armutlu Peninsula) and possibly to fault creep as on the Western High segment. Still, further studies combining seismological and geodetic data are needed to determine whether slip transients could actually have started before the M+4 earthquakes, how systematic these patterns are in terms of driving earthquake nucleation in this region, and what are the implications for local earthquake forecasting.

InSAR observations of superficial small-scale slip features activated during deeper set earthquakes

Henriette Sudhaus

The short revisit times of the Sentinel-1 SAR images result in excellent interferometric phase coherence and high-quality maps of details in the surface displacements. In earthquake modeling we usually concentrate on the dominant features of the displacement pattern. Full-resolution processing of current mission SAR data to InSAR displacement maps is computationally comparatively expensive in calculation and uses a large amount of disk space. For the analysis of the predominant pattern such resolution is not needed in most cases. However, it seems, that in their full resolution these data contain valuable information we tend to overlook. I observe shallow activation of faults that do not exceed a few millimeters of slip and seem to be not directly connected to fault slip at depth. Rather, they appear to be secondary features on both hanging wall and footwall of the main rupture within the generally smooth, moderate-gradient co-seismically deformed area. Still these features seem to follow surface traces of actual faults with imprints in the morphology and they can extend for kilometers.

Because the direction of slip motion is hard to judge based on the satellite line-of-sight only, I present the combination of coseismic ascending and descending SAR acquisition, which are characterized by their down-east and down-west look directions, respectively, from which I calculate projections to achieve east-west and nearly vertical surface displacement components. A further step is the calculation of spatial displacement gradients to better outline the offsets and measure the sense of motion.

Anmeldung für einen Kurzvortrag (7 Minuten + 3 Minuten Diskussion)

Titel: Characterisation of Local Microseism in the Baltic Sea

Autor: Sell, M., Weidle, C., Meier, T.

Abstract:

Seismological records of 32 Stations around the Baltic Sea and 2 stations on the coast of Norway from 2019-01-01 until 2020-12-31 were analysed. Spectrograms were calculated to visualize the variability of the microseism in the secondary microseism band (SMB, 0.1 Hz – 0.4 Hz) and the local microseism band (LMB 0.4 Hz – 0.8 Hz). From the spectrograms, the median frequency dependent microseism amplitudes were determined for horizontal- and vertical component, respectively. Parts of the spectrograms of the Z component and of the H/V-ratio were compared with the wave period at Arkona with the aim of identifying local primary and local secondary microseism. Additionally, time series of microseism amplitudes in the SMB and LMB were calculated. RMS values of the time series indicate large lateral differences in the local microseism signal around the Baltic Sea. Stations at the German coast and the Baltic States show in general large H/V-ratios (in most cases >2 (SMB) and >1.5 (LMB) compared to the stations in Finland, Sweden, Denmark and Norway (in most cases <1 (SMB) and <1.2 (LMB). To identify potential source regions of Rayleigh and Love microseism, these time series were correlated with models of wave periods in the Baltic Sea and parts of the North Atlantic, the North Sea for summer 2020. The resulting maps show a strong correlation for nearly all stations in the North Sea in the SMB and locally high values in the Baltic Sea in the LMB with minor influences of the Norths Sea and the North Atlantic in most cases.

Seismic noise characterization and reduction for gravitational wave detection

Jana Klinge, Jan Walda, Celine Hadziioannou, Dirk Gajewski

The composition of the ambient seismic noise wave field – in absence of any earthquakes – is particularly relevant for the construction of the Einstein Telescope (ET). As the proposed underground infrastructure to host a gravitational-wave observatory of third generation, ET aims to achieve a significantly enhanced sensitivity in comparison to preceding generations. Interfering signals, such as different seismic noise sources, affect the measurements of the ET detector and thus influence the sensitivity. Consequently, one of the targets is to remove them as efficient as possible. The goal of this project is to develop an offline, post-processing Newtonian noise (NN) removal system, which does not require real time interaction with the actual gravitational-wave detector. Thereby, the approach is two-fold and focuses, on the one hand, on the measurement and characterization of seismic noise and, on the other hand, on the development of Machine Learning algorithms based on different network structures for noise prediction and removal. One of the currently used methods to predict and remove NN is based on Wiener optimum filters assuming that NN is non-deterministic and described by the auto-correlation function. Some noise sources, such as ocean microseism, are deterministic and neglecting phase information insufficiently characterizes the shape and time dependence of the noise signal. To overcome this loss, we pursue an idea not exposed to this assumption. The initial way of work follows, thereby, the use of an autoencoder network as a noise-removal feed-forward system. Future directions will also include the comparison of performance with optimum Wiener filters as well as the inclusion of novel rotational seismometer measurements.

Analysis of earthquake swarm dynamics using a 3D seismic array at the ICDP Eger Rift site in Landwüst (Vogtland, German-Czech border region)

K. Hannemann[1,2] , M. Ohrnberger[1] , N. Rein[1,2] , D. Domigall[1] , M. Isken[3] , M. Korn[2] , F. Krüger[1] , T. Dahm[1, 3]

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The ICDP project “Drilling the Eger Rift” focuses on the German-Czech border region (Vogtland/ West Bohemia) which is known for its earthquake swarms. These swarms consist of small magnitude earthquakes (Ml<4) which are supposed to be related to the migration of mantle fluids within the crust. Within the project, we aim to improve the seismological observations of these events and related processes, especially for the high frequency content above 50 Hz. For this purpose, a seismic 3D array was recently installed in Landwüst (Vogtland) about 10 km West of the main earthquake swarm activity area in Novy Kostel (CZ). This 3D array consists of a surface geophone array with an aperture of 400 m and a borehole chain with geophones up to a depth of 400 m. The seismic traces are recorded with sampling rates between 400 Hz and 1000 Hz to ensure a high temporal resolution of the high frequency content of the swarm quakes. After the completion of the installation in November/ December 2020, several earthquake swarms have been recorded at the 3D array.

In this study, we present first results for the analysis of the earthquake swarms using the 3D array. Besides a classical 2D frequency-wavenumber-analysis (fk-analysis) at an surface array, the combination with a borehole chain offers the possibility to estimate the full 3D slowness vector of an incoming wave front. Based on the obtained results with the 3D array, we analyse the temporal evolution of the earthquake swarms and investigate the implications for the spatial event distribution based on the parameters estimated using the 3D array such as backazimuth and incidence angle. Analysing the spatio-temporal behaviour of the small magnitude earthquakes will give indications for the dynamics of the underlying processes and their relation to fluid migration within the crust.

Wind turbine signatures from long distances at the Gräfenberg Array

K. Stammler, L. Ceranna, BGR

Since 2012 many wind turbines have been installed on the Frankonian Jura and a number of them also in the vicinity of stations of the Gräfenberg array (GRF), consisting of 13 broadband stations within an area of about 50x100 km. These turbines take a significant effect on the noise level at many of the GRF station sites. The array as a whole suffers from a deterioration of its sensitivity to teleseismic events of more than 0.1 magnitude units at wind speeds above 3.5 m/s (in 10m height). At individual station sites the noise signatures at frequencies above 2 Hz can be attributed to close-by wind turbines observing an approximate power decay law with increasing distance to the recording site. At a frequency of about 1.1 Hz, however, at most stations the strongest influence is visible, but the relation between measured PSD amplitudes and turbine distances does not support a simple decay law when taking into account only the closest wind turbine locations. This suggests that for this frequency turbines at larger distances play a role. This investigation tries to model the propagation of the turbine induced noise and to explain the observed PSD values at the GRF stations.

Ritter, J., Gaßner, L., Forbriger, T., Rietbrock, A., Karlsruher Institut für Technologie, Geophysikalisches Institut

Untersuchungen des KIT zur Emission und Immission von seismischen Wellen durch Windenergieanlagen

Windenergieanlagen (WEA) können seismische Wellen emittieren. Entsprechend können an anderen Orten (ungewünschte) Immissionen auftreten. Hierzu ist das Geophysikalische Institut des KIT in verschiedene Projekte eingebunden, über ein Überblick gegeben wird:

WINSENT: Am WINSENT Testfeld bei Stötten / Schwäbische Alb, sollen an Testwindrädern verschiedene Komponenten experimentell untersucht werden: Artenschutz, Wind- und Wettergeschehen, technische Aspekte. U.a. werden 3 Breitband-Seismometer in ca. 5 m Tiefe dauerhaft eingebaut.

Inter-Wind: An drei Windkraftstandorten werden mögliche Einflüsse auf Anwohner untersucht: Infraschall, Bodenerschütterungen, psychologische Effekte.

BFO: Am Standort des Observatoriums BFO sind Immissionen von WEA ein dauerhaftes Forschungsthema.

Beratung: Firmen und Behörden.

Ausbildung: Planung einer DFG-Graduiertenschule in Süddeutschland.

Das Projekt MISS - Minderung der Störwirkung von Windenergieanlagen auf seismologische Stationen

Rüter, H., HabourDom

Das im Mai 2021 zu Ende gegangen Projekt MISS war ein vom Land NRW und der EU finanziertes Projekt im Rahmen der Leitmarkwettbewerbe. Vorrangiges Ziel des Projektes war es, den Konflikt zwischen Windenergieanlagen und seismologischen Stationen zu entschärfen, bzw. Grundlagen hierzu zu schaffen. Es wurde und wird dabei davon ausgegangen, dass bei gegenseitiger Rücksichtnahme ein friedliches Nebeneinander möglich ist. Da sowohl der Betrieb seismologischer Stationen als auch der Ausbau Erneuerbarer Energien in einem starken öffentlichen Interesse ist, hat die Beschäftigung mit diesem Thema großes öffentliches Interesse gefunden. Erste Auswirkungen der Projektergebnisse werden schon in der Genehmigungspraxis umgesetzt.

Joachim Ritter, Karlsruher Institut für Technologie, Geophysikalisches Institut

Abschätzung der Störwirkung von Windenergieanlagen auf ein seismologisches Netzwerk und der zugehörigen Schutzradien

Windenergieanlagen (WEA) können seismische Wellen emittieren und dadurch den Rauschpegel von seismologischen Messstationen erhöhen. Um die notwendigen Messanforderungen an ein seismologisches Messnetz zu gewährleisten, wurde eine Methodik entwickelt, die auf einfache Weise die Störwirkung abschätzt. Hierfür mussten einige Vereinfachungen der Eingangsparameter festgelegt werden, damit sie durch Nicht-Seismologen angewandt werden kann: a) die Anlagen werden nur durch ihre Leistung kategorisiert, b) der Untergrund wird in nur zwei Arten, verfestigt und unverfestigt, unterteilt, c) für die Messstationen werden Schwellenwerte in dB (power spectral density) nach Anforderung der Nutzer definiert. Diese Methodik basiert auf wenigen verfügbaren Messdaten von WEA-Emissionen und soll zukünftig durch eine verbesserte Datenlage modifiziert werden.

Gaßner, L., Ritter, J., Karlsruher Institut für Technologie, Geophysikalisches Institut

Seismic measurements in the vicinity of two wind farms on the Swabian Alb

Within the project Inter-Wind we conduct seismic measurements to support psychological questionnaires, combined with acoustic measurements and meteorological data at wind farms on the Swabian Alb. The aim of the project is to understand reasons for residents' suffering from wind turbine (WT) immissions. Measurements are conducted in the municipalities, in the forests surrounding the wind farms, and within WT towers. We study seismic signals in the vicinity of two wind farms on the Swabian Alb consisting of three (wind farm Tegelberg) and sixteen (wind farm Lauterstein) wind turbines of the same type. In the town of Kuchen near the wind farm Tegelberg ongoing complaints from residents are registered while at wind farm Lauterstein only few residents with strong symptoms from WT immissions were found. Our seismic measurements show which signals are generated by the WTs and give indications to other noise and vibration sources present close to the disturbed residents. No signals connected to WT operation are registered which surpass the threshold of human perceptibility.

This study is supported by the Federal Ministry for Economic Affairs and Energy based on a resolution of the German Bundestag (03EE2023D)

Bereich: AK Wind
Vortragslänge: 7 min
Vortragender: Fabian Limberger

Seismic signals from wind turbines – An analytical modeling approach and effects of local topography

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As part of the project KWISS we developed an analytical modeling approach to approximate the surface wave field emitted by a wind farm by also including effects of phase differences between source signals of multiple wind turbines. With good agreement, we compared modeled and observed distance dependent amplitude decays at frequencies between 1 Hz and 8 Hz. The developed approach allows to estimate the expected spatial seismic radiation for different signal frequencies of arbitrary wind farm layouts. Limitations can arise e.g. in the case of complex topography, which is not included in the developed approach.

To study the effect of the topography on the seismic wave propagation, we performed first tests using 2D numerical simulations including digital elevation profiles. Based on preliminary results, we find that the topography affects the expected signal amplitude at a remote seismometer significantly if the topography between the wind turbine and the seismometer is pronounced. We are planning to extend the study by performing 3D numerical simulations with complete digital elevation models. The aim is to identify the key factors that are related to the topographic effects.

The project KWISS is funded by the Federal Ministry for Economic Affairs and Energy and ESWE Innovations- und Klimaschutzfonds.

Bereich: AK Wind
Vortragslänge: 7 min
Vortragender: Michael Lindenfeld

Seismic signals from wind turbines – Spectral characteristics and frequency-dependent amplitude decay

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One of the tasks within the KWISS project is the analysis of the spectral characteristics and the amplitude decay of seismic signals emitted by a wind farm in Uettingen/Bavaria. For that purpose, we deployed 19 seismic stations along a profile of about 9 km length and continuously recorded the wave field propagation for a period of about 1 year. From these long-term observations we calculated average PSD spectra in which we identified seven characteristic energy peaks in the frequency band between 1 Hz and 10 Hz. The decay of these energy peaks with increasing distance from the wind farm can be described by a power law and exhibits an almost perfect linear frequency dependence of its exponent b.

In spring 2021, we removed some stations at the far end of the profile and re-installed the instruments along a second profile whose azimuth is running roughly perpendicular to the first profile. This enables us to record the wave propagation simultaneously in two different directions and to detect possible radiation patterns which are predicted by analytical estimates due to the geometrical layout of the wind farm.

Here, we present the first preliminary results of the new setup for an observation period of two months. For both profiles, the calculated average PSD spectra show the same spectral peaks as seen before in the long-term results. However, the measured amplitude decay of the second profile seems to deviate significantly from the observation along the first profile. We discuss the differences and suggest possible reasons for this observation.

The project KWISS is funded by the Federal Ministry for Economic Affairs and Energy and ESWE Innovations- und Klimaschutzfonds.