49. Sitzung der AG Seismologie in Freiburg im Breisgau

26. - 28. September 2023

Abstracts

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 Deutschen Regionalnetzes (GRSN):
  - neue Standorte GR.KBON und GR.SCHI
  - Gorleben-Netz erneuert
- Integration permanenter Länder- und Universitätsnetze in EIDA
  - Aktuell neben GR Netze BQ (Bensberg), HS (Hessen), KQ (Kiel), RN (Bochum), SX (Sachsen), TH (Thüringen)
  - neu hinzukommend LE (Erdbebendienst Südwest)
- Stand beim Aufbau des GQ-Netzes
- Seismologisches Datenzentrum der BGR:
  - Aufbau einer neuen Ereignisdatenbank auf Basis von Seiscomp
  - Beginn eines Neuaufbaus der IT des Datenzentrums, Nutzung von Software-Containern

Geophysikalischer Gerätepool (GIPP) – Statusbericht 2023

Christian Haberland, GFZ Potsdam

Der "Geophysikalische Gerätepool" (“Geophysical Instrument Pool Potsdam”, GIPP) am Deutschen GeoForschungsZentrum Potsdam (GFZ) stellt seismische und magnetotellurische Geräte und Sensoren für temporäre Feldexperimente zur Verfügung. Die Nutzung ist Forschungsgruppen von Universitäten, dem GFZ und anderen Forschungseinrichtungen (national und international) möglich. Seit der Inbetriebnahme 1993 hat der GIPP über 470 geowissenschaftliche Projekte mit Geräten unterstützt (jedes Jahr ca. 20 bis 40). Am GIPP werden auch die Landstationen des „Deutschen Pools für amphibische Seismologie“ (DEPAS) betreut. Die Gerätebereitstellung läuft über ein transparentes Antrags- und Evaluierungsverfahren (www.gfz-potsdam.de/gipp). Die Anträge werden durch einen extern besetzten Lenkungsausschuss evaluiert.

Heute besteht der seismologische Teil des GIPP aus ~150 EarthData EDR-210 Rekordern, >1000 Omnirecs/DIGOS Cube Rekordern, ~250 Nanometrics Trillium Compact Seismometern, >100 größeren Breitbandsensoren und einer Vielzahl von Geophonen nebst notwendigem Zubehör. Er ist damit der größte geophysikalische Gerätepool Europas. Die Geräte sind gut nachgefragt und es kommt regelmäßig zu Überbuchungen. Viele der Geräte können auch für aktive seismische Experimente verwendet werden. Ebenso betreiben wir ein Datenrepositorium zur Archivierung der gesammelten Daten und entwickeln Hard- und Software.

In letzter Zeit wurden (passive) seismologischen Experimenten mit vielen Registrierstationen (sog. LARGE-N Experimente) populär. Der GIPP hält für solche Experimente 310+ Geräte bereit und stattet (und stattete) in diesem Zusammenhang Experimente in der Eifel, Albanien, Irland, Deutschland, Spanien und Italien aus. Die Mehrzahl der GIPP-unterstützen seismologischen Netze besteht aus weniger als 50 Stationen.

Der GIPP arbeitet in den letzten Jahren an Datenmanagementprojekten, insbesondere im Rahmen von EPOS und ORFEUS. Derzeit sind wir aktiv bei der Vernetzung europäischer Gerätepools im Rahmen von ORFEUS.

In der Präsentation werden der momentane Stand, aktuelle Hardware Entwicklungen, Aspekte der Datenarchivierung sowie zukünftige Vorhaben vorgestellt. Die Abgabefrist zur Einreichung neuer Anträge ist der 10.10.2023.

Recent developments at GEOFON

Angelo Strollo

Operation of ocean-bottom seismometers in ice-covered areas

Mechita C. Schmidt-Aursch, Vera Schlindwein and Henning Kirk

Alfred-Wegener-Institut, Helmholtz-Zentrum für Polar- und Meeresforschung, Bremerhaven

Broadband ocean-bottom seismometers (OBS) are a valuable tool for marine or amphibian seismological experiments. The number of available OBS is rapidly increasing and many attempts are made to improve the instruments. Long-term measurements of OBS become more and more common leading to numerous new data sets around the world. The only exception are the polar regions. Expeditions in these remote areas need a complex and expensive logistics and particularly a vessel with ice-breaking capability.

The deployment of OBS in ice-covered areas is not very complex. A small opening in the sea ice is sufficient enough to lower the OBS to the water surface and disconnect them there. In contrast, the retrieval of the instruments at the end of the measurement is much more challenging. The OBS are drifting in the water column during their way down to the sea floor and up again, so the exact positions on the sea floor and and at the surface are not known. There is a high risk that an OBS emerges right below an ice floe. Hence, most polar OBS experiments so far have been conducted in areas with only intermittend ice coverage where ice-free areas in the summer allow a safe OBS recovery.

Many interesting geological targets are unfortunately located in areas with perennial sea ice converage like the ultra-slow spreading Gakkel Ridge in the central Arctic Ocean. Therefore, we modified some standard OBS for operations in these regions. The instruments were additionally equipped with an ultra-short baseline acoustic positioning system to track their ways through the water column. Some trials were done with different types of head buoys to allow the recovery of the OBS in case they stuck under an ice floe.

A first prototype was tested during a short experiment in July 2014 at the Aurora vent field, which is located at the western Gakkel Ridge near the transition to the Lena Trough. The first long-term measurement of four instruments was performed at the eastern Gakkel Ridge from September 2018 to September 2019. After the successful recovery of these units in favourable ice conditions, a second long-term deployment of eight OBS around the Aurora vent field was started in August 2022. The ice conditions during the recovery in July 2023 were very difficult, nevertheless all instruments could be retrieved.

Abstract für AG Seismologie 2023

Autor: Steffen Uhlmann, IGM GmbH

Art: Vortrag

Titel: Going posthole - Benefits and drawbacks of subsurface seismic installations.

Abstract:

The growing densification and expansion of seismic networks in urban areas, coupled with the increasing intrusion of noise sources into previously quiet rural areas, necessitates the deployment of a greater number of subsurface stations to meet site noise requirements. This presentation aims to compare the effectiveness of surface and borehole seismometer deployments in terms of average noise levels and average signal-to-noise ratios. We will outline the typical characteristics of both surface and subsurface installations and discuss their implications for seismic monitoring in various scenarios. The objective is to provide a comprehensive guide for achieving cost-effective and convenient deployments, thereby enhancing the efficiency and accuracy of seismic monitoring in diverse environments.

Aktuelle Fortschritte und Entwicklungen in SeisComP

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Tagung: AG Seismologie, 2023 in Freiburg

Zusammenfassung

Die öffentliche Version von SeisComP ist ein umfangreiches, quelloffenes Softwarepaket, das sich als internationaler Standard für die Überwachung lokaler, regionaler und globaler seismischer Aktivitäten in der Forschung, den öffentlichen Diensten und der Industrie etabliert hat. Das Paket umfasst Module für die automatische und interaktive Datenakquise, Archivierung, Verteilung sowie die Verarbeitung von Wellenformen und abgeleiteten Parametern in Echt- und Nicht-Echtzeit.

SeisComP bietet benutzerfreundliche, moderne grafische Oberflächen, Kommandozeilen-Tools und eine gut dokumentierte Python-API. Diese Funktionen ermöglichen ein hohes Maß an Professionalität und Flexibilität sowohl in der Routineanalyse als auch in spezialisierten Anwendungen.

Erstmals im Jahr 2006 als SeisComP3 vom GFZ Potsdam vorgestellt, wird SeisComP heute hauptsächlich von der Gempa GmbH entwickelt und gewartet. Dabei werden sowohl eigene Forschungs- und Entwicklungsarbeiten als auch Beiträge aus der wissenschaftlichen Gemeinschaft berücksichtigt. Unter anderem tragen das GFZ Potsdam und die ETH Zürich ebenfalls Programmcode bei.

Dieser Beitrag präsentiert wesentliche Weiterentwicklungen in SeisComP, insbesondere seit dem Übergang von SeisComP3 zu SeisComP im Jahr 2020. Zu den Hauptentwicklungen zählen die Überarbeitung des Messaging-Systems, die erweiterte Python-Unterstützung, die Einführung neuer Open-Source- und Closed-Source-Module, Verbesserungen bei der interaktiven Datenbearbeitung und der Katalogisierung von Ereignissen sowie die Integration neuer Lokalisierungsprogramme, neue Magnitudentypen sowie die Regionalisierung von Magnituden.

Nachhaltige Sicherung und Digitalisierung von analogen seismischen Daten in Deutschland.

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Die Bedeutung der Erhaltung analoger seismischer Daten wurde in den letzten Jahren in der seismologischen Gemeinschaft voll und ganz anerkannt. Weltweit gibt es mehrere Gruppen, die Strategien zur Bewahrung und Digitalisierung dieser Daten entwickeln und laufende Projekte durchführen. Allerdings fehlte in Deutschland bisher ein solches Projekt, obwohl dessen Bedeutung oft angesprochen wurde.

Die BGR hat in diesem Jahr eine Pilotstudie angekündigt, die die Möglichkeiten zur Digitalisierung von seismischen Aufzeichnungen in Deutschland abschätzen soll. Diese Studie wird von einer kleinen Arbeitsgruppe von Forschern der Universität Potsdam und der Universität Hamburg durchgeführt, die über umfassende Expertise in der Arbeit mit analogen seismischen Daten verfügen.

In Deutschland gibt es mindestens 12 Institutionen, die seismische Aufzeichnungen in analoger Form und entsprechende Metadaten in ihren Archiven gespeichert haben. Wir haben die Vertreter dieser Institutionen kontaktiert und ihre Unterstützung für das Projekt zur Sicherung der analogen seismischen Daten erhalten. Im Rahmen dieses Projekts werden alle offenen Archive besichtigt und deren Inhalt sorgfältig dokumentiert. Als Ergebnis planen wir die Erstellung eines Katalogs aller in Deutschland vorhandenen analogen seismischen Datenarchive mit detaillierter Beschreibung ihrer Inhalte. Bis jetzt haben wir schon 6 Archive besichtigt und werden die bisher gesammelten Informationen über den Inhalt dieser Archive hier präsentieren.

Darüber hinaus wird der technische Aufwand für die Digitalisierung dieser analogen seismischen Aufzeichnungen und der Metadaten abgeschätzt. Dies umfasst das Scannen und Digitalisieren der Papierseismogramme in eine digitale Zeitreihe, sowie das Scannen von Papierbulletins und Stationsbüchern. Anschließend wird die Schätzung des durchschnittlichen Zeitbedarfs für dieses Verfahren und der dafür erforderlichen Techniken untersucht. Außerdem soll analysiert werden, welche Scanmöglichkeiten notwendig sind und wie diese am effizientesten genutzt werden können.

Weiterhin sollte die für die Digitalisierung am besten geeignete Software unter den vorhandenen Angeboten vorgeschlagen werden. Um den Arbeitsaufwand für das kontinuierliche Scannen und Digitalisieren seismischer Aufzeichnungen abzuschätzen, wird ein Testlauf über einen bestimmten Zeitraum durchgeführt. Für diesen Test werden die Papierseismogramme von maximal 3 seismischen Stationen über einen Zeitraum zwischen 1 und 3 Monaten (abhängig von der Arbeitsbelastung) kontinuierlich gesammelt. Entsprechende Metadateninformationen werden erfasst. Diese Daten werden gescannt und digitalisiert. Ein bestimmtes Ereignis wird ausgewählt, um die Methoden zur Bestimmung der Parameter einer Erdbebenquelle (z. B. Lage des Epizentrums, Magnitude und Bestimmung des Herdmechanismus) auf der Grundlage dieser digitalisierten analogen Daten zu testen.

Am Ende des Projekts erwarten wir, ein langfristiges Konzept zur Erhaltung und Digitalisierung aller in Deutschland verfügbaren analogen seismischen Aufzeichnungen und entsprechenden Metadaten vorzulegen.

No more wiggles from Mars – results from the final year of the InSight mission

Brigitte Knapmeyer-Endrun[*] (brigitte.knapmeyer-endrun@dlr.de) and the InSight Science Team

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Due to loss of power, the InSight lander on Mars stopped working on December, 20, 2022, after almost continuously recording seismic data for 4 years (2 Martian years), twice the baseline mission duration. The data recorded during the extended mission resulted in many discoveries, which will be summarized in this presentation. The recordings of the final Martian year of InSight set a number of records, including the largest marsquake S1222a (M_L=4.7) recorded in May 2022, the most distant marsquake (Δ=146°), and a meteorite impact leaving a crater of 150 m diameter on Christmas eve 2021. Together with a second impact, this event generated the first clearly observed surface waves (R1) on Mars, which showed little dispersion, pointing to a nearly constant crustal velocity. This is in contrast to the layered crustal velocity structure beneath the landing site, indicating that this structure might only be of local extent. S1222a produced not only short-arc Rayleigh waves, but also Love waves, a higher mode, and multi-orbit Rayleigh waves up to R7. Analysis of this rich data set found seismic anisotropy within the uppermost 30 km of the crust, provided an independent crustal thickness estimate, and the global average crustal S-wave velocity. As the great circle path through S1222a and the InSight location also covers the southern highlands, the difference in density across the Martian dichotomy could be constrained to be less than 200 kg/m^3, indicating that the dichotomy does not coincide with a major change in crustal composition, but rather a large difference in crustal thickness. Additionally, H/V analysis of the Rayleigh waves helped to refine the velocity structure below the lander (see presentation by S. Carrasco), for which independent new information was also provided by the combined analysis of body wave travel times and surface wave dispersion of close impacts at 50 to 250 km distance form the lander. Analysis of the high-frequency coda decay of S1222a and additional events indicates that scattering is the dominant attenuation mechanism on Mars and that the crust as a whole is the origin of the strong scattering. Finally, the two most distant events provided the first observation of core-transiting phases (SKS) on Mars.

Preparing for the DLR/ESA LUNA analogue facility – urban seismology in a planetary context

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The Moon has become the focus of renewed interest in space science and exploration, by both national space agencies and commercial players. Geophysics, including seismology, will play a key role, as evidenced by geophysical payloads already in operation on the Moon (e.g. the Lunar Penetrating Radar on China's Yutu-2 rover and the Instrument for Lunar Seismic Activity on India's Chandrayaan-3 lander), scheduled for flight, for example within the next 3 years in the US CLPS program (e.g. Lunar Magnetotelluric Sounder, LISTER Heat Flow Probe, and the Farside Seismic Suite), or under development in mission studies, e.g. for active seismics and DAS.

A large-scale testbed facility is required for the development, demonstration and validation of new lunar instrumentation and operational concepts, and to provide training and testing for astronauts, scientists and companies in a controlled, standardized environment. The LUNA analogue facility currently under construction at DLR Cologne will provide this kind of environment. The main hall of the LUNA facility, 700 square meters in size, will be covered by 60 cm of EAC-1 mare regolith simulant. A 140 square meters section is designated as deep floor area (DFA), with regolith depth increasing up to 3 m along 25° and 40° slopes. This provides an explorable underground structure suitable for seismic profiling, ground penetrating radar, geoelectrics and geomagnetics, and sufficient depth for drilling and deployment of heat flow probes. Support by the facility will include expertise in geophysical measurements, data analysis and flight operations, an end-to-end operational environment including a control center with standard uplink and downlink technology, and training of astronauts in co-operation with robotic units to operate the equipment in lunar surface suits, under gravity offloading and simulated lunar illumination conditions.

To support future seismic experiments, a permanent broad-band station (DL.LUNA) will be installed on the concrete floor of the hall, below the regolith. In preparation, we carried out various test measurements to characterize both the subsurface and the local noise conditions. As expected for a location on an urban research campus with large-scale infrastructure (wind tunnels, thrust chambers, centrifuges…) and in the direct vicinity of an airport, the recordings are dominated by man-made noise during workdays, specifically caused by machines, traffic, and planes. Properties of the corresponding signals are investigated in detail. At periods below 1 s, though, a test installation within an office building provided good quality data. A seismic refraction line as well as two sets of array measurements were used to investigate the subsurface structure. Results are consistent with information on local geology, which consists of approximately 250 m of sediments above the bedrock, with a thin soil cover above roughly 12 m of sand and gravel on top of clay. Array measurements at the building site will be repeated after the building is finished and after the regolith is emplaced to monitor for changes in background noise and the resolvability of the subsurface.

Constraints for the Martian crustal structure from Rayleigh waves ellipticity of large seismic events

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Abstract

For the first time, we measured the ellipticity of direct Rayleigh waves at intermediate periods (15–35 s) on Mars using the recordings of three large seismic Martian events, including S1222a, the largest event recorded by the InSight mission. These measurements, together with P-to-s receiver functions and P-wave reflection times, were utilized for performing a joint inversion of the local crustal structure at the InSight landing site. Our inversion results are compatible with previously reported intra-crustal discontinuities around 10 and 20 km depths, whereas the preferred models show a strong discontinuity at ~37 km, which is interpreted as the crust-mantle interface. Additionally, we support the presence of a shallow low-velocity layer of 2–3 km thickness. Compared to nearby regions, lower seismic wave velocities are derived for the crust, suggesting a higher porosity or alteration of the whole local crust.

The 14. Nov. 2017 meteor over Germany using seismological records to estimate the meteor's trajectory

Eickhoff, Dario; Föst, Jan-Phillip; Ostermeier, Runa; Koushesh Mohsen; Ritter, Joachim

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Abstract:

A meteor's trajectory in the Earth's atmosphere carries information about its origin within or beyond the solar system. Knowledge about meteoroid origins helps to achieve a better estimation of the meteoroid flux which the Earth is subjected to. The traditional visual methods work best at nighttime hours, leaving daytime hours poorly monitored. Closing this temporal observational gap is a challenge in meteor monitoring, but it can be partially achieved by using seismological observations to verify nighttime meteors and to record and detect new meteor occurrences in the daytime hours. The increasing number of seismic stations also helps closing spatial observational gaps of the traditional meteor monitoring methods. To estimate the feasibility of using seismological data to study meteor trajectories a visually well detected meteor over Germany is studied.

On November 14th 2017 around 16:47:00 UTC a meteor flew over Germany and the Czech Republic. The meteor's shock wave was measured by in total 228 seismometer stations in Germany and surrounding countries. Additionally, the DEEP-TEE seismic network of KIT, located in the Eifel in Germany, also recorded the shock wave of the meteor. Using the recorded seismic data at 42 stations we estimate the meteor's trajectory and velocity. The shape of the first arrival times and synthetic wave modelling indicates a Mach Cone in the atmosphere (see also talk by Föst et al.). The location and distribution of seismic stations is favourable and a reconstruction of the trajectory with high accuracy is possible. The meteor's trajectory is found to be ca. 285 km long and the meteor had a velocity of ca. 36 km/s. The meteor's incident and azimuth angle are calculated as 13.9 ° and 93.3 °, respectively. Constraining the meteor's velocity still proves to be difficult and should be improved in future seismological meteor studies.

Finite difference modelling of meteor-induced acoustic and seismic signals: Findings of coupled Surface waves

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Meteor trajectory determination plays a pivotal role in modern astronomical research, enabling scientists to gain valuable insights into the origin and composition of meteors, their parent bodies, and their impact potential on Earth. When meteors enter Earth's atmosphere, they generate acoustic waves (Mach Cone, explosions) which then induce seismic waves by coupling into the Earth's body. This research aims to understand the behaviour and characteristics of meteor-induced seismic signals by simulating their propagation through the atmosphere and Earth's subsurface using finite difference numerical methods (WAVE-toolbox). The simulations consider various meteor properties such as velocity, and entry angle to understand the resulting signatures in seismic recordings.
The acquired knowledge can aid in discriminating meteors from other seismic events and distinguishing between different signal sources like the super-sonic shock or induced surface waves. In this way, wave propagation modelling can contribute to the detection and monitoring of meteor falls. The ability to differentiate between the arriving wave types has practical applications by improving meteor trajectory determination with the assistance of seismic monitoring networks. The usage of dense seismic networks to estimate a meteor trajectory allows one to benefit from a good spatial observational coverage. This makes it also feasible to describe meteor falls during daylight hours in contrast to optical observation techniques.

Sigward Funke, Institut für Erdsystemwissenschaft und Fernerkundung, Universität Leipzig

Überschallfront über Ostthüringen/Westsachsen 23. Juni 2023

Am 23. Juni 2023 wurde in der Umgebung von Altenburg und Zwickau an mehreren Orten ein Knall beobachtet, der sich als Schallfront eines Überschallflugzeugs erwies.

Dank der Lage in der Erdbebenzone zwischen Nordwest-Böhmen und Halle-Leipzig ist dieses Gebiet seismologisch vergleichsweise dicht instrumentiert. An über 20 Stationen verschiedener Messnetze konnte der Durchgang der Schallfront beobachtet werden. Die flächenhafte Darstellung der daraus ermittelten Einsatzzeiten illustriert den raum-zeitlichen Verlauf der Schallfront, die Verteilung der Amplituden lässt eine aufsteigende Flugbahn vermuten. Es ensteht der Eindruck, dass der Überschallflug in geringerer Höhe bei Altenburg begann und mit zunehmender Höhe nach Süden führte.

Lars Ceranna, Stefanie Donner, Peter Gaebler, Nicolai Gestermann, Gernot Hartmann, Patrick Hupe, Christoph Pilger, Thomas Plenefisch, Klaus Stammler, Andreas Steinberg
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Seismologische Auswertung der Ereignisse im Zusammenhang mit den Leckagen an den Gas-Pipelines NordStream-1 und -2 vom 26.09.2022

Am 26.09.2022 wurden seismische Ereignisse in der Ostsee nahe der dänischen Insel Bornholm detektiert und lokalisiert, die zeitlich und räumlich mit Leckagen an den Gas-Pipelines NordStream-1 und -2 in Verbindung gebracht werden können. Für die seismologischen Untersuchungen wurden die Daten der folgenden Stationsnetzwerke verwendet: Swedish National Seismic Network, Danish Seismological Network, GEOFON Seismic Network, Polish Seismological Network, German Regional Seismological Network und assoziierter Stationen sowie vier Arrays des CTBT-Messnetzes (FINES, ARCES, NOA, HFS). Das erste Ereignis mit einer Lokalmagnitude M_L 2.6 fand um 00:03 UTC 37 km ost-südöstlich von Bornholm statt. Die bestimmte Lage und die Herdzeit des Ereignisses sind konsistent mit den Daten der Druckabnahme auf einer der NordStream-2-Leitungen, gemessen an der Anlandestation auf deutscher Seite in Lubmin. Eine weitere Ereignisfolge ereignete sich etwa 17 Stunden später um 17:03 UTC rund 60 km nordöstlich von Bornholm mit einer maximalen M_L 3.0. Sie bestand aus drei dicht aufeinanderfolgenden, aber trennbaren, Einzelereignissen. Dies führte zu einem komplexen registrierten Wellenfeld aus sich überlagernden seismischen Wellenzügen. Die Epizentren der drei einzelnen Ereignisse, konnten durch Relativlokalisierung den Lokationen der Leckagen an den Leitungen von Nordstream-1 und -2 zugeordnet werden.

Anhand von Vergleichsereignissen in der Region, die sowohl tektonische Beben als auch Sprengungen umfassen, kann der Explosionscharakter der untersuchten Ereignisse nachgewiesen werden. Dabei unterscheiden sich diese Ereignisse in ihrem Frequenzgehalt jedoch von (Munitions-)Sprengungen in der Ostsee. Modellierungen zeigen, dass die gemessenen seismischen Signale hinreichend durch einen instantanen Gasentlass am Meeresboden ähnlich einer *Airgun* beschrieben werden können. Synthetische Seismogramme für eine solche Quelle und ein für das Untersuchungsgebiet angepasstes Untergrundmodell weisen große Übereinstimmungen mit den gemessenen Signalen auf. Anhand der freigesetzten Energie und der Charakteristik der registrierten Wellenformen kann der dominierende Anteil des impulsiven Gasentlasses aus den geborstenen Gasleitungen als Signalquelle erklärt werden.

Infraschall-Signale im Zusammenhang mit der Zerstörung der NordStream Pipelines wurden an zwei Stationen (I26DE im Bayerischen Wald und IKUDE bei Kühlungsborn) in Deutschland registriert. Insbesondere nach der Ereignisfolge um 17:03 UTC wurden deutliche Signale registriert, deren Charakteristik auf ein explosives Ereignis mit nachfolgendem Gasaustritt an der Oberfläche hindeutet. Dieser Gasaustritt wurde an I26DE über einen Zeitraum von mehr als neun Stunden gemessen. Daher wird auf Basis der Infraschall-Analysen die Ereignisfolge in diesem Zeitraum als stärker gegenüber dem Einzelereignis um 00:03 UTC eingeschätzt.

How seismometers tilt in response to atmospheric pressure variations: the case of the Hunga Tonga Lamb wave.

Rudolf Widmer-Schnidrig(1,3) Walter Zürn(3) and Thomas Forbriger(2,3)

(1) Geodätisches Institut, Universität Stuttgart
(2) Geophysikalisches Institut, KIT Karlsruhe
(3) Black Forest Observatory (BFO), Wolfach

The Hunga-Tonga eruption (15.1.2022) excited Lamb waves in the atmosphere that circled the globe multiple times and were recorded by barometers and broad-band seismometers of the Global Seismic Network (GSN). The dominant period was 45 minutes and the amplitude for the direct wave was typically 2-3 hPa.

Based on our previous work we expect that the response of horizontal component seismometers at these long periods is dominated by tilts due to two distinct physical mechanisms: (A) tilt due to the local deformation of the vault in which the accelerometer is installed: eg. warping of the vault floor in response to an atmospheric pressure change. We call this the local deformation tilt, LDT. (B) a regional tilt due to a lateral pressure gradient along the surface. We call this the travelling wave tilt, TWT.

While LDT is in phase with the locally recorded atmospheric pressure change the TWT is 90 degrees out of phase. Thus LDT is proportional to the pressure, while TWT is proportional to its Hilbert transform. These two signals are linearly independent and in a regression where scaled versions of the two signals are sought to match the horizontal accelerograms one can separate the contributions of the two tilt mechanisms. In a second step the estimated TWT scale factors for the two horizontal components can be vectorially added and the resulting vector should align with the back-azimuth to Hunga Tonga.

We have inspected all the GSN recordings of the Hunga-Tonga Lamb wave and only retained 21 stations with clean baro- and seismograms. We find that for any 3-component sensor the tilt due to vault deformation points in a fixed, sensor specific direction independent of the Lamb wave propagation direction. Furthermore we find that LDT is larger than TWT at 80% of retained GSN stations. While accelerations can be well modeled in most cases, pressure gradient induced ground tilts point towards Hunga-Tonga for only 7 stations.

Currently we lack any model which would allow us to explain the observed TWT tilt directions for the remaining 14 stations as we do not think that Lamb wave front deformations due to atmospheric wind or temperature variations can account for the observed tilt misalignments.

On DAS-recorded strain amplitude

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Distributed Acoustic Sensing (DAS) has become very popular for recording seismic waves in recent years as it provides dense spatial sampling along an optical fiber with only one single interrogator needed for hundreds of channels. Fibers can be several tens of kilometers long and in some applications so-called dark-fibers can be used, which were deployed for telecommunication purposes, but currently not in use. This greatly reduces the necessary effort for field deployment.

The DAS fiber is strained by ground deformation and a laser interferometer in the interrogator samples the varying differential distance of light scatterers in the fiber. In this way the fiber acts as a strainmeter. The ability to record waveforms with useful phase information has been demonstrated in numerous studies. Validation of the sensitivity factor with respect to strain is commonly done by application of fiber stretching-devices in laboratory environment. The lack of in-situ calibration with respect to actual rock strain leaves room for unknown amplitude loss caused by imperfect coupling of the cable jacket to the rock and the loss through several layers of coating of the fiber in the cable.

We use DAS-recordings together with recordings of the colocated invar-wire strainmeter array at BFO and an STS-2 broad-band seismometer to investigate the coupling of DAS fibers in situ. The read-out from the fiber is done with a Febus A1-R DAS interrogator. Two types of optical fiber cables are installed in parallel providing signals from two fibers in each cable. One is a conventional telecommunication cable, where fibers are embedded in a gel-type substance to avoid damage potentially caused by straining the cable jacket. The other is a dedicated (so-called 'tight-buffered') DAS cable in which the fibers are more rigidly coupled to the cable jacket. We compare recordings from a section where the cables are simply unreeled and lay unprotected on the floor with recordings from a section, where sandbags are densely put on the cables to improve mechanical coupling.

We use signals from the Mw 7.7 and Mw 7.6 earthquakes that took place on the East Anatolian Fault on February 6th 2023. A proper comparison of signals from all three instruments is possible in the frequency-band between 50 mHz and 0.2 Hz. At lower frequencies the DAS signal-to-noise ratio is insufficient. At higher frequencies the invar-wire strainmeters show a parasitic response to vertical ground motion. The seismometer signal is used to estimate strain for an incoming plane wave, based on the ray parameter. The latter varies along the recording but is sufficiently well known and can be validated against the strainmeter recording. With the seismometer signal we extend the amplitude comparison up to a few Hertz.

We find that the DAS fibers do not pick up the full strain amplitude. Amplitude loss depends on the type of cable. The tight-buffered and the telecommunication cable pick up about 1/2 and 1/4 of the amplitude, respectively. Surprisingly the application of sandbags has little effect. Both sections show similar discrepancy in amplitude. The signal loss apparently is not due to the imperfect coupling of the cable jacket to the rock, but due to reduced internal coupling of the fiber to the cable.

Grounding Zone of the Ekstroem Ice Shelf – Geophysical characterization with GPS, Seismology and Magnetotelluric

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Antarctica's ice shelves are a highly critical component for the interlinkage between ice sheet and ocean. Their shape and evolution play an important role for the strength of ice mass loss, e.g. by amplification or weakening of the buttressing effect. Ocean tides are the most important direct forces acting on the ice shelves, inducing vertical and horizontal motion and deformation. In our study we investigate the effect of ocean tides on the Ekström Ice Shelf using seismological, geodetic and magnetotelluric methods. The northward flow of the ice is mainly modulated by the tidal constituents at the ter-diurnal and quarter-diurnal bands, whereas the dominant vertical tides have a diurnal and semi-diurnal periodicity and amplitudes up to ten times larger than the ter- and quarter-diurnal tides. The causes of the higher frequency tidal modulations are still poorly understood. The area of the largest effect of the higher frequency tides is assumed to be the grounding zone of the ice streams feeding the ice shelf.

Here we present first results of geophysical experiments at the grounding zone of the Ekström Ice Shelf conducted in the field seasons 2021/2022 and 2022/2023. In 2021/2022 we setup GNSS and seismic stations to record vertical and horizontal motion of the ice as well as seismic events in order to gain insights into ice dynamics and ground properties. In season 2022/2023 GNSS and seismic station were dismantled, and the experiments were complemented by magnetotelluric measurements to image the sub-ice ocean-land transition and the crustal structure beneath the ice stream.

Rapid and high-resolution damage proxy maps from space observations combined with building data from volunteer mapping

Henriette Sudhaus & Danijel Schorlemmer

After large damaging earthquakes, fast and well-informed help efforts can save lives. The key information are the location and extent of damage and losses, in particular for disasters that affect large areas. Space-borne imaging methods, together with building-wise exposure data, can enable rapid damage assessments, delivering damage proxy maps for an entire affected region within hours.

Space-borne damage proxy maps are generated e.g. from repeated synthetic aperture radar (SAR) imaging of the ground before and after an event to detect changes in the radar backscatter. Such changes are expressed in a drop of interferometric (InSAR) coherence. Dense human infrastructure, like building agglomerations, shows long-term stable backscatter characteristics and high coherence compared to many natural surfaces. Therefore, a sudden drop in coherence between pre- and post-earthquake images can be attributed to damage on the ground. However, without further information a detected damage tells little about the involved severity concerning human lives. Also, less dense settlement structures like villages may not show as long-term coherent areas and may not be included in damage maps even if strongly affected.

Based on InSAR damage proxy maps from the 2023 Turkey Syria earthquakes, we present an approach to combine InSAR damage maps with information from exposure models, which are based on open building data. This combination can improve guiding rescue efforts by highlighting approximated damage with exposure models, e.g. through an estimation of where how many people are affected. Also, the building data help revealing blind spots in space-borne damage proxy maps, which are method-related, and should not go unnoticed.

Oral presentation

Title: Chronicle of Processes Leading to the 2018 Eruption at Mt. Etna As Inferred by Seismic Ambient Noise Along With Geophysical and Geochemical Observables

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Abstract

This work analyzes temporal variations of seismic velocities at Mt. Etna from August 2018 to February 2019. During this time period, a strong flank eruption accompanied by intense seismicity and ground deformation took place along a fracture that opened on 24 December 2018 at the base of the New South-East summit crater. Furthermore, two moderate earthquakes—the 6 October 2018 M_L 4.7 and 26 December 2018 M_L 4.8—associated with the volcanic activity were recorded. In this study, we computed cross-correlation functions (CCFs) between windows of seismic ambient noise to identify seismic velocity variations within the volcano edifice. We calculated daily CCFs at 16 stations for 120 interstation pairs using the vertical component in the 1.0–1.5 Hz frequency band. We observe that dv/v starts to decrease rapidly from the beginning of October 2018 and reaches approximately −0.45% in the pre-eruption period. The spatio-temporal distribution of seismic velocities shows that the reduction of *dv/v* mostly occurs in the vicinity of the summit and close to the flank area and is interpreted to be affected by magmatic intrusion at 0–3 km depth. To infer the source mechanism of this eruption, we compared these observations with volcano-tectonic earthquakes, volcanic tremor, volcanic degassing, gravity, and ground deformation data. Our study suggests that a relationship between magma intrusion and associated crack opening is responsible for the decrease of *dv/v*.

Shallow melt storage and carbonatite eruptions: Seismo-acoustic tremor at Oldoinyo Lengai volcano, Tanzania

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Oldoinyo Lengai volcano is a strato-volcano in the eastern part of the East African Rift system and as such, a curious end member of a young magmatic segment: it is the only volcano worldwide that currently erupts carbonatitic lava. Known to alternate between large explosive (ash) and smaller effusive eruptions, we analyze volcanic tremor from Oldoinyo Lengai during a renewed phase of eruptive but non-explosive activity which began in late 2018.

From March 2019 onwards, we recorded one year of data at a co-located seismic and infrasound station about 200 m below the summit as part of the SEISVOL deployment (Seismic and Infrasound Networks to Study the Volcano Oldoinyo Lengai). We show the very first observations of seismo-acoustic tremor at this peculiar volcano which is highly variable throughout the one year of data. We characterize the tremor by analyzing its seismic amplitude, duration, recurrence, dominant seismic frequency and harmonics. Frequency gliding occurs frequently and over short (minutes to hours) to long time scales (hours to days). Seismic and acoustic wavefields correlate well for stronger eruptive sequences but are only partially coherent which suggests that high-frequency seismic tremor (up to 25 Hz) may be caused by the low viscosity of the carbonatitic melt and not by ground-coupled airwaves. In addition, the comparison between seismic-acoustic and satellite InfraRed thermal data allows us to infer different volcanic activity styles which partially alternate throughout the year: varying styles of extrusive activity, in particular spattering, degassing, activity from a lava pond, intrusive activity, and the construction of hornitos. Our study provides important insights into the eruption dynamics of this peculiar volcano which suggests shallow melt storage within the crater floor.

Abstract - AG Seismologie 2023

Authors:
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Title: 3D P- & S-wave velocity model for the Alpine mountain chain from AI enhanced local earthquake tomography

In this study we present a 3D P & S-wave Local Earthquake Tomography of the European Alpine mountain chain based on seismic data from a total of more than 1100 broadband stations of the AlpArray Seismic Network and other permanent and temporary stations.
Accompanying the recent rapid advances in day-to-day AI applications, various deep-neural-network seismic picking algorithms have been developed during the last 5 years. We assess the performance of the most commonly used AI pickers with "SeisBench - A toolbox for machine learning in seismology" and find PhaseNet to be the most accurate on our data set.
When dealing with automatic onset picks the task of identifying erroneous arrivals becomes even more crucial. Therefore, we developed a purely data-driven pre-inversion pick selection method applicable to P- and S-phases which consistently detects outliers and discards later arriving phases in the crustal triplication zone. When applied to a subset of 384 events compiled for a 1D study of the area this yields 16,351 Pg-, 23,068 Pn-, 10,967 Sg- & 2,221 Sn-phases.
For the 3D tomography we expand the catalog to 3078 events within a magnitude range of $1.5 < Ml < 5.5$ with 93,237 Pg- and 40,358 Sg-observations.
Based on these direct Pg & Sg arrival times we relocate the seismicity while simultaneously inverting for the upper crustal velocity structure and station corrections using the SIMUL2000 tomography algorithm. This model is used as input for the subsequent inversion run where we fix the hypocentres and add Pn- & Sn-phases to gain resolution in the lower crust and upper mantle.
Moho maps based of receiver function studies generally are in good agreement with velocity isolines of our final model. Foreland basins and the orogenic root of the mountain belt are forming the most prominent low velocity anomalies which is in accordance with previous P-wave travel time tomography and ambient noise studies.

Non-linear inversion of a multi-layer intrinsic and scattering S-wave attenuation model in a sedimentary basin (Insheim, Germany)

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Using Monte Carlo simulations, we can numerically solve the acoustic radiative transfer theory for seismic S-waves and estimate the seismic attenuation of the subsurface using an improved method called QEST. It is designed to estimate the frequency- and depth-dependent intrinsic and scattering attenuation as well as the spectral source energy of the earthquakes and the site amplification of the stations by non-linear envelope inversion. Energy particles are propagated along rays in a multi-layer 1-D model. For the simulation of the anisotropic scattering process, we assume a von Kármán type random medium that overlays the deterministic layered model. We analyzed data of fluid-induced earthquakes of a geothermal reservoir located in Insheim, Germany in the frequency range of 6.0 to 67.9 Hz. The results of the inversion highlight higher absorption in the near-surface sedimentary basin than in the crystalline basement. In addition, the inversion suggests that the assumption of isotropic scattering may be oversimplified and leads to an underestimation of scattering attenuation. The average exponent of the high-frequency fall-off of the Insheim earthquake source spectra is 4.2, which is significantly higher than the exponent of 2.0 in the standard omega-square model. So the omega-square model is not applicable to these earthquakes.

The impact of isolated noise sources on correlation wavefields

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Seismic interferometry gives rise to a correlation wavefield that is closely related to the Green's function under the condition of uniformly distributed noise sources. Asymmetric correlation wavefields result from the violation of this condition and are commonly observed in field data. In the presence of an additional isolated noise source a second contribution to the correlation wavefield is introduced that emerges from the isolated source location at negative lapse time. The two wavefield contributions interfere, resulting in biased surface wave dispersion measurements.

Isolated noise sources that act continuously, such as wind turbines or ocean microseisms, further have significant impact on the coda of the correlation wavefield. The coda can be dominated by direct waves propagating from the isolated noise source, not by multiply scattered waves originating from the master station. This fundamentally challenges the current understanding of how velocity changes detected in the coda can be measured and interpreted.

Application of a denoising autoencoder to three months of continuous data from networks TH and SX

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Different studies show that denoising autoencoders can effectively suppress seismic noise and are able to improve the signal-to-noise ratio of seismic events or even to detect new events that were previously covered by noise. However, in these studies, the autoencoder was only tested on certain selected events. Here, we applied the denoising autoencoder to three month of continuous data from the networks TH and SX to test how many new events can be detected in the denoised data. Therefore, we trained a separate denoising autoencoder model for each seismological station of the networks. Each model was trained with high signal-to-noise ratio events from the Stanford earthquake data set and noise from the seismological station. Afterwards, the continuous data can be denoised using these different models.

EQTransformer was then applied to the raw and denoised data from each station to detect seismic events and pick phases. In a second step, GaMMA was used for earthquake phase association. We detected 402 events in the raw data and 2110 events in the denoised data. Unfortunately, many of the denoised detections need to be visually checked by an analyst afterwards, because EQTransformer has picked too many phases which can be associated by GaMMA to a false event. To get idea about the false detections in the denoised data set, an analyst manually picked seismic phases of a few days using PyLOT (Python picking and Localisation Tool).

Aftershock forecasts based on incomplete records of early aftershocks: Example of the 2023 SE Türkiye earthquake sequence

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The Epidemic-Type Aftershock Sequence (ETAS) model is the state-of-the-art approach for modeling short-term earthquake clustering and is therefore preferable for short-term aftershock forecasting. However, due to the large variability of different earthquake sequences, the model parameters must be adjusted to the local seismicity for accurate forecasting. Such an adjustment based on the first aftershocks is hampered by the incompleteness of earthquake catalogs in the aftermath of a mainshock, which can be explained by a blind period of the seismic networks after each earthquake, during which smaller events with lower magnitudes cannot be detected. Assuming a constant blind time, direct relationships can be established between the actual seismicity rate and magnitude distributions and those that can be detected, based only on this additional parameter. The ETAS-Incomplete (ETASI) model uses these relationships to jointly estimate the true ETAS parameters and the catalog incompleteness. In this study, we apply the ETASI model to the SE Türkiye earthquake sequence, consisting of a doublet of M7.7 and M7.6 earthquakes that occurred within less than half a day of each other on February 6, 2023. We show that the ETASI model is able to explain the catalog incompleteness and to fit the observed earthquake numbers and magnitudes very well. A forecasting experiment shows that the daily number of detectable m>=2 can be well predicted based on very limited and incomplete information from early aftershocks. However, the maximum magnitude (*Mmax*) of the next day's aftershocks would have been overestimated, probably due to the highly variable *b* value within the sequence. Instead, using the regional *b* value estimated for 2000-2022 would have predicted the observed *Mmax* values well.

Oral presentation

Title: The 2023 Southeast Türkiye Seismic Sequence: Rupture of a Complex Fault Network

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Abstract

On 6 February 2023, southeastern Türkiye experienced two Mw 7.7 and 7.6 earthquakes. The earthquake sequence caused widespread damage and tens of thousands of casualties in Türkiye and Syria. We analyze mainshocks and aftershocks, combining complementary source characterization techniques, relying on local, regional, and teleseismic data. Backprojection analysis and finite source inversion for the mainshocks resolve coseismic slip, rupture length, and propagation mode along the main faults, whereas centroid moment tensor inversion for 221 aftershocks resolves details of the fault network. The first mainshock nucleated on a splay fault and activated the neighboring East Anatolian fault zone (EAFZ). It ruptured bilaterally along ∼500 km first toward northeast and later to south-southwest on multiple, previously partly dormant fault segments. The second mainshock ruptured the east–west-oriented Sürgü-Misis fault zone (SMFZ), reaching a slip of 7 m. The analysis of aftershocks with heterogeneous moment tensors retrospectively reconstructs rupture details. Along the main strand of the EAFZ, they map the geometry of different segments in unprecedented detail, whereas along the SMFZ they illuminate the geometry and behavior of large structures for the first time. Our work sheds light on multiple aspects of rupture evolution and provides new insights into the devastating earthquake sequence.

Investigating continental collision/subduction processes in Albania with a Large-N deployment: The ANTICS project

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When in November 2019 a strong earthquake (Mw 6.4) hit the eastern Adriatic coast, partly destroying the port town of Durrës, the world was reminded that Albania is one of the most earthquake prone countries in Europe. Deformation in Albania is driven by the counterclockwise rotation of the Adriatic microplate against the western Balkans that causes convergence at a rate from 2 to 4 mm/year along the southeastern Adriatic coast. The deformation front is seismically highly active, manifested not only by this most recent event, but also by one of the largest instrumentally recorded earthquakes in Europe (1979 M7.1 Montenegro event) slightly further north and several further disastrous historic earthquakes. However, the structural control of these large earthquakes has not been investigated in detail due to a lack of high resolution geophysical/seismic data. The AlbaNian Tectonics of Continental Subduction - ANTICS - experiment is now addressing this issue.

In October 2022 we installed 350 short period and 50 broadband three-component stations in central Albania in an area approximately 130 km x 130 km, reaching from the coast to Lake Ohrid. Interstation-spacing was approximately 7 km and we serviced the stations in May 2023. Data recovery was about 80% due to the adverse weather conditions with heavy rain and snow in the winter months. All data have now been archived and we used AI and Ml techniques for automatic phase picking (SeisBench, Woollam et al., 2022) and event association (HEX, Woollam et al., 2022). So far, we could detect about 6000 earthquakes in the first 7 months of the deployment. We also used ambient noise correlations to derive empirical Greens' functions which already illuminate the upper crust in great detail. We will show preliminary results for the obtained seismicity distribution and seismic velocity model.

Megathrust structure at seismogenic depths illuminated by high-resolution earthquake locations

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While the plate interface is often conceptualized as a single plane along which earthquakes and slow slip occur, we know this to be a simplified view of reality. Fossil subduction zones and geophysical imaging have shown that the seismogenic plate interface is a deformed, 100m-1km thick tabular region. However, an outstanding question remains: is seismic slip localized on a single fault within this region, or is it distributed over several active faults, and if so, how does this impact seismogenesis. We use high-resolution earthquake locations to shed light on these questions.
On March 27th 2022, a Mw 5.8 subduction earthquake occurred in the North of Ecuador, near the town of Esmeraldas. Here, we take advantage of the dense temporary seismic network deployed during the HIPER2 marine campaign to analyze this seismic sequence. We use artificial intelligence and machine learning to pick and detect over 1700 earthquakes (Mw 0-3), which we then locate using a double difference algorithm with cross-correlation times and a 3D velocity model.
We obtain an exceptionally detailed image of the seismicity in the region. Focal mechanisms and relative event locations confirm that most earthquakes occur at the plate interface. An interface topography of about 600 m and a thickness of about 400 m can be determined, comparable to plate interface thicknesses observed in exhumed subduction zones. Using a cross-correlation threshold of 0.75, we extract families of similar earthquakes, whose geometry we investigate using the 3-point method. We find that they generally occur on subparallel, sometimes superposed planes with a thickness of 0-40 m, like the thickness of individual fault zones within subduction shear zones. This geometrical complexity appears to impact the aftershock expansion, itself likely controlled by afterslip. Thus, we show the importance of considering the 3D structure of the plate interface when modeling slip on the megathrust.

New Seismotectonic Insights into Active Faults in northern Switzerland and the Hegau-Bodensee Graben

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This study presents a seismotectonic analysis of active faults in northern Switzerland and its border region to southern Germany. The focus of this presentation is a study of the Miocene-aged Hegau-Bodensee Graben, a major tectonic element in the northern foreland of the European Central Alps. The graben is characterized by comparatively low strain rates and low-to-moderate seismicity. Our study of the Hegau-Bodensee Graben builds on the seismological analysis of earthquakes recorded by a recently densified seismometer network. The derived high-precision absolute and relative hypocenter relocations allow to identify seismogenic structures in the pre-Mesozoic basement, which we relate to bounding faults on either side of the NW-SE striking graben. A cluster of seismicity on the SW side of the graben is associated with the previously mapped Neuhausen Fault. In contrast, the seismogenic, SW-dipping bounding faults on the opposite side of the graben, between the extinct Hegau volcanic field and the Bodanrück peninsula of Lake Constance, cannot be associated with any known fault. A set of 51 focal mechanisms allows for a high-resolution analysis of kinematics and stress regime of the graben. Our results show that the bounding faults of the graben are optimally oriented to be reactivated in transtensional mode in the present-day stress field. Slip rates across the Neuhausen and Randen Faults estimated from geodetic data are likely < 0.1 mm/yr. In comparison with historical seismicity over the past 600 years and geomorphic field observations, geodetic rates of 0.1 mm/yr appear overestimated. Nevertheless, historical seismicity suggests that slip rates have the potential to generate M_W 5.0 earthquakes within this slowly deforming, transtensional fault zone in the foreland of the Alpine collision zone on timescales of several hundred years.

Abstract Zeckra – AG Seismologie 2023 – Freiburg

Standortcharakterisierung der Permanentstationen im belgischen, seismologischen Netzwerk (BE) mithilfe von SmartSolo 3-Kanal Geophonen.

Martin Zeckra[1,2], Koen Van Noten[2], Thomas Lecocq[2], Raphael De Plaen[2] and Giovanni Rapagnani[2], (1) – Erdbebenstation Bensberg, Universität zu Köln (2) – Königliches Observatorium von Belgien, Brüssel, Belgien.

Zusammenfassung:

Die geologischen Standortbedingungen in Belgien stehen in einem starken Nord-Süd Kontrast, welcher einen großen Einfluss auf die seismologischen Aufzeichnungsbedingungen ausübt. Während der flämische Teil durch ein nach Norden hin abfallendes Sedimentbecken charakterisiert ist, wird der südliche Teil durch das anstehende Grundgebirge mit scharfem Relief dominiert. Die Intraplattenseismizität konzentriert sich dabei hauptsächlich auf das südlichen Staatsgebiet. Zeitgleich mit der Erneuerung von Teilen des nationalen seismologischen Stationsnetzes hin zu Breitbandinstrumenten und Öffnung des Datenstroms zum ORFEUS EIDA Knoten, wurde im Zuge des belgischen Beitrags zur EPOS Initiative die Standortcharakterisierung von diesen Stationen durchgeführt. Durch die Verlinkung dieser Stationen zu bestimmten stratigraphischen Untergrundbedingungen als Archetypen, konnten die gewonnenen Erkenntnisse auf weitere Stationen mit vergleichbarer Geologie ausgeweitet werden, wodurch eine Datenbank für Standortfaktoren der 125 aktuellen und ehemaligen seismologischen Stationen auf dem belgischen Staatsgebiet erstellt werden konnte.

Für die Standortcharakterisierung wurden passive Noisemessungen mithilfe von SmartSolo IGU-16HR 3C Sensoren durchgeführt und mittels Arraymethoden ausgewertet, um ein Verständnis der elastischen Parameter des flachen Untergrundes zu modellieren. Diese leichten, autonomen Geophonsensoren wurden erst vor wenigen Jahren auf den Markt gebracht, sodass wir zeitgleich verschiedene Grundlagentests durchführten, um die Fähigkeiten, Verlässlichkeit und Grenzen dieser Sensoren für den seismologischen Einsatz zu untersuchen. Darin wurde deutlich, dass diese Geräte auch weit unterhalb ihrer natürlichen Eckfrequenz noch wissenschaftlich verwertbare Daten generieren. Im Kontext der Standortcharakterisierung wurde zusätzlich ersichtlich, dass die effizientere Installation von vielen solcher Nodalsensoren die aufwendige Installation hochempfindlicher Instrumente in Anbetracht der notwendigen Personen und Arbeitszeit aussticht, während die resultierenden Daten ein deutlich breiteres Informationsspektrum abdecken.

An Interactive Approach to Earthquake Location for Research and Teaching

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Earthquake location is a basic task in the routine works of every seismologist, and a wide selection of tools is available. The workflow is often similar: After choosing a velocity model and picking phase onsets – be it manually or automatically – a solution is generated by non-linear inversion. Like a black box, the algorithm presents a solution to the analyst. While this is fine for day-to-day work, more information on the influence of single picks, velocity model and v_P/v_S ratio can only be achieved by assigning station weights and repeated operations of the 'black box'. This is, obviously, a very tedious and counter-intuitive approach for location improvements.

We introduce an alternative method where each step of the location process can be controlled and verified manually. Showing a selection of screen recordings, we present a software tool where the effect of each change in input parameters is visualized in real-time to study the process of event location in detail. This approach is very helpful in all cases where each input has to be weighed carefully:

- *Short campaigns*, where no local velocity model could be established yet.
- *Troubleshooting*, where non-linear inversion provides unreasonable results.
- *Forensic seismology*, where single, exceptional events must be located.

Additionally, the interactive and visual approach is ideal to teach the next generation of seismologists the influence of picking strategy, depth constraint, and velocity model on the solution – especially when used with their own data collected during a field course. Experience has shown that students can locate earthquakes after just one hour of software introduction.

Abstract

Mikroseismische Überwachung der kerntechnischen Anlage Asse II

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Das ehemalige Kali- und Steinsalzbergwerk Asse II bei Wolfenbüttel in Niedersachsen wurde seit 1965 für die Durchführung von Forschungs-und Entwicklungsarbeiten zur Endlagerung radioaktiver Abfälle in Salzformationen genutzt. Im Rahmen dieser Arbeiten sind von 1967 bis 1978 schwach- und mittelradioaktive Abfälle eingelagert worden.

Das Ziel der aktuellen Arbeiten ist die endgültige und sichere Stilllegung des Bergwerks nach Rückholung des eingelagerten Inventars. Die Stilllegung der Schachtanlage Asse II wird insbesondere nach Atom- und Bergrecht durchgeführt. Die Schachtanlage Asse II ist eine kerntechnische Anlage.

Die Überwachung der mikroseismischen Aktivität im Grubengebäude und in der Umgebung des Grubengebäudes ist ein wesentlicher Bestandteil des geowissenschaftlichen Kontroll- und Überwachungsprogramms der Schachtanlage Asse II. Wesentliche Ziele der mikroseismischen Überwachung sind das frühzeitige Erkennen möglicher arbeitssicherheitlich relevanter Bruchvorgänge im Grubengebäude sowie die indirekte Beobachtung des nicht zugänglichen grubennahen Deckgebirges, um eine gebirgsmechanische Gesamtbewertung des Grubengebäudes und seiner Umgebung zu ermöglichen.

Das mikroseismische Netz besteht aus einer übertägig angeschlossenen 3-Komponenten-Station sowie bis zu 28 untertägigen 3-Komponenten-Stationen. Mittelfristig ist geplant, das untertägige Netzwerk zu modernisieren und mit einem von den untertägigen Einrichtungen unabhängigen Stationsnetzwerk an der Oberfläche zu ergänzen.

Neben der Vorstellung des Stationsnetzwerkes präsentieren wir hier eine Zusammenfassung der Messergebnisse aus dem Jahr 2022.

Das Erdbeben am 10. Februar 1871 im Nördlichen Oberrheingraben – makroseismische Auswertung des Hauptbebens und der Nachbeben

Uwe Braumann (St. Peter), Diethelm Kaiser (BGR Hannover)

Am 10. Februar 1871 ereignete sich ein Schadenerdbeben bei Lorsch im nördlichen Oberrheingraben. Obwohl dieses Erdbeben schon mehrfach untersucht wurde, unterscheiden sich seine Parameter in aktuellen Publikationen und Erdbebenkatalogen erheblich voneinander. So liegen die Epizentren in den Katalogen EMEC (Grünthal & Wahlström 2012) und FCAT-17 (Manchuel et al. 2018) um 57 km auseinander. Die publizierten Herdtiefen liegen zwischen 5 und 18 km, die Epizentralintensitäten zwischen 5 und 7. Die Nachbeben wurden bislang kaum untersucht. Aus diesen Gründen wurde eine umfassende Neubewertung dieser Erdbebenserie durchgeführt.

Zunächst wurden alle auffindbaren Berichte zusammengetragen. Der überwiegende Teil der Primär- und Sekundärquellen liegt heute online vor, jedoch mussten auch Archive in Deutschland und Frankreich besucht und Texte im Original oder auf Mikrofilm eingesehen werden. Den weitaus größten Anteil an den Primärquellen stellen Berichte in zeitgenössischen Zeitungen. 85 Zeitungen im Zeitraum bis Ende März 1871 wurden ausgewertet, die insgesamt 535 Berichte zu den Erdbeben enthielten. Dazu kommen noch Tagebuchaufzeichnungen, amtliche Berichte und Chroniken. Die Sekundärliteratur ist umfangreich. Bereits in den ersten Monaten nach dem Hauptbeben wurde eine große Zahl von Artikeln von sehr unterschiedlicher Qualität veröffentlicht, die jedoch viele Fehler enthalten, die später von den Bearbeitern von Erdbebenkatalogen übernommen wurden und sich z. T. noch in aktuellen Erdbebenkatalogen wiederfinden. Jeder Bericht wurde für die Intensitätsbestimmung hinsichtlich seiner Qualität von gut bis mangelhaft bewertet und einem Beobachtungsort und, anhand der Uhrzeit, einem Erdbeben zugeordnet.

Für jeden Beobachtungsort wurde zunächst die kleinste und größte Intensität nach EMS-98 festgelegt, die anhand der makroseismischen Wahrnehmungen möglich ist bzw. wäre, anschließend die Intensität, die die Beobachtungen am besten zusammenfasst (best estimate). Jedem Intensitätsdatenpunkt (IDP) wurde zusätzlich eine Qualität von A (sehr gut) bis E (sehr schlecht) nach der Vorgehensweise in Brüstle et al. (2020) zugewiesen.

Das Hauptbeben am 10. Februar 1871 um 05:32 Uhr wurde in 283 Orten beobachtet. Für 154 Orte konnten Intensitäten festgelegt werden. Für die überwiegende Zahl der IDP lagen nur knappe Beobachtungen oder dürftige Einzelbeobachtungen (IDP-Qualität D und E) vor. In 9 Orten wurden Schäden der Intensität 7 beobachtet, häufig herabgestürzte Schornsteine und Risse in Häusern und Kirchen bis Schadensgrad 3.

Die Auswertung der Nachbeben wurde durch ungenaue Zeitangaben erschwert. Besonders für die schwächeren Nachbeben lagen oft nur wenige, zudem äußerst knappe Berichte vor. Das stärkste Nachbeben am 12. Februar 1871 um 10:24 Uhr erreichte die Intensität 6. Bis Ende März 1871 wurden 55 Nachbeben identifiziert, von denen bislang nur 11 in Erdbebenkatalogen gelistet waren. 16 Erdbeben wurden als „Fake" identifiziert.

Brüstle, W., Braumann, U., Hock, S. & Rodler, F.-A. (2020): Best practice of macroseismic intensity assessment applied to the earthquake catalogue of southwestern Germany. DOI:10.23689/fidgeo-3864

Grünthal, G. & Wahlström, R. (2012): The European-Mediterranean Earthquake Catalogue (EMEC) for the last millennium. Journal of Seismology, 16, 3: S. 535-570. DOI:10.1007/s10950-012-9302-y

Manchuel, K., Traversa, P., Baumont, D., Cara, M., Nayman, E. & Durouchoux, C. (2018): The French seismic CATalogue (FCAT-17). Bulletin of Earthquake Engineering, 16, 6: S. 2227-2251. DOI:10.1007/s10518-017-0236-1

Poster abstracts

(alphabetisch geordnet)

Preliminary results on background seismicity from a large seismic experiment in Albania

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Located over the active continental collision of the Adriatic micro-plate with Eurasia, Albania presents a high-rate of seismicity and one the largest earthquake hazard per capita within Europe. Recently, in 2019, a Mw=6.4 earthquake struck the strategically vital port of Durrës, only 30 km away from the capital Tirana, causing major damage and killing 51 people. Despite this, the background seismicity and velocity structure of the country remain poorly constrained, mostly due to the lack of extensive modern instrumentation.
As part of the ANTICS project (AlbaniaN TectonIcs of Continental Subduction), a joint effort between research institutions of Albania and Germany, in September 2022 we deployed 390 seismic stations with an inter-station spacing of 6 km, fully covering the southern half of the country. Here we present the first seismicity results from the analysis of continuous waveforms collected between September 2022 and May 2023. We use AI-based methods for the automatic phase picking (SeisBench, Woollam et al., 2022) and event association (HEX, Woollam et al., 2022), and relocate the whole catalogue using a recently obtained 1-D local velocity model for the area. Our preliminary results show nearly 6000 events with local magnitudes varying between 0 and 4.9. The seismicity seems to be clustered around local earthquake sequences, the largest of them occurring nearby the town of Klos, 30 km northeast of Tirana. The 2019 epicentral area seems to be seismically quiet during the 8-month observation period. The next steps include the consolidation of the catalogue and the addition of new data to be collected in the next months. Our ultimate goal is to illuminate the seismic image of the country by means of the identification of active seismic sources and velocity structure using local earthquakes.

Abstract AG Seismology conference :

Seismic imaging of the Northern Ecuadorian seismogenic zone that hosted the 2016 M7.8 Pedernales earthquake

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In the last decades, a multitude of different rupture behaviors and slip modes have been uncovered, ranging from large earthquakes to aseismic slip events (slow earthquakes, afterslips) and non-volcanic tremors, among others. Studies carried out in Japan, Costa Rica and New Zealand on the basis of offshore campaigns and IODP drilling have revealed that fluids, lithology and structure play a major role in these slip modes.

In 2016, a magnitude 7.8 earthquake occurred beneath the Ecuadorian margin (Pedernales), known for having generated the mega-earthquake of Mw 8.8 in 1906, the 7th largest global earthquake ever recorded. Furthermore, in the same area, the Ecuadorian seismological/geodetic network has recorded aseismic slip, such as slow earthquakes and post-seismic slow slip. Together with the relatively small forearc and shallow megathrust fault found along the Ecuadorian margin makes it an exceptional natural laboratory to study earthquake processes.

In 2022, a marine campaign named HIPER2 acquired seismic dataset by deploying 45 OBS along 2D lines and 3D grid, on the rupture zone of the Pedernales earthquake. By combining this new active seismic data with existing passive seismological data the aim of the HIPER initiative is to image, in 3D, the structure and estimate the content of fluids around and along the subduction fault. This will enable us to investigate the role of structure and/or fluids on subduction zone processes in a region where mega-earthquakes and slow earthquakes initiate and propagate. Here we will focus on the first results of tomographic inversion of 2D seismic profiles, giving a first insight on 3D structures.

Application of Denoising Autoencoder for continuous and real-time analysis of seismological data

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Over the last years, the seismic noise generated by wind turbines and its influence on the continuous record and processing of seismological data came into focus. Seismological data of stations located next to a wind turbine site can be disturbed by the generated noise. Unfortunately, those noise signals appear in a similar frequency band as the event data, that are continuously analysed. Therefore, an appropriate filter function is needed to separate noise from data.

We use the Denoising Autoencoder (Heuel et al, 2022*) to filter data from different seismological networks and integrate the denoised data in the workflow of our analysis routines in SeisComP (gempa GmbH, 2008**). Good results are achieved in filtering data from undesired noise by wind turbines with this method. Also, noise from other sources is suppressed.

Waveform data from the SeisComP buffer are used as input for our denoising process. Our developed python routine allows to filter data nearly in real-time. Therefore, denoised data can be imported to the processing in SeisComP using the mseedscan module.

We use the SeisComP pipeline concept to process and analyse denoised data in a separate workflow. Automatic localisations are assigned as single origins to an event. Thus, we can compare the results from a localisation with denoised data to those results from unmodified data.

Using denoised data in the processing, we get numerous picks from the SeisComP autopick routine due to disturbing signals presumably from the site environment. The disturbing signals cause undesired picks and inaccurate event localisations, so sophisticated processing and parameter settings will be required.

An enhanced model training of the Denoising Autoencoder for the individual stations might help to better suppress the undesired noise. Thereby, we pursue to develop an automated retraining integrated in our workflow.

*Heuel, J. & Friederich, W. Suppression of wind turbine noise from seismological data using nonlinear thresholding and denoising autoencoder Journal of Seismology, 2022

**Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences and gempa GmbH (2008). The SeisComP seismological software package. GFZ Data Services. doi:10.5880/GFZ.2.4.2020.003

Determination of Minimum 1-D Seismic Velocity Models with an inapt Event Distribution and the Usage of *a priori* Information

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The determination of seismic velocity models (*vp*, *vs*) is important to describe the elastic structure of the Earth at depth and to locate earthquake hypocenters. A popular used code to determine 1-D *vp* and *vs* models from arrival times of P- and S-waves is VELEST what we apply in our study case (Kissling; https://seg.ethz.ch/software/velest.html). In an ideal case there is a homogeneous station and event distribution with many near-horizontal wave paths to well resolve the seismic velocity in the different layers at depth.

We analyze a dataset which is far from being ideal: Our recordings from the East Eifel Volcanic Field (EEVF) originate from upper crustal tectonic earthquakes which preferably occur along few NW-SE lineaments which mostly provide sharp P- and S-wave onsets. In addition, we record very weak (*ML* < 2) events which are deep (ca. 10-45 km) and of low-frequency (2-8 Hz) (Hensch et al., GJI, 2019). The seismic recordings of these DLF events contain very weak P-wave arrivals, if any at all, and emergent S-wave arrivals. The main goal of our study is to well locate these DLF events, because they are thought to be related with magmatic processes and thus they may play a role in the hazard estimation for the EEVF. The DLF events occur within a narrow (<10 km) steep zone and their recorded ray paths are all subvertical. Hence the resolution of seismic velocities is very low in horizonal layers. Another difficulty is the known velocity structure: a published seismic refraction P-wave velocity model contains low-velocity layers which are quite thin (Mechie et al., Plateau Uplift, Springer, 1983) and which are hard (or even impossible) to resolve with our earthquake data and ray paths. In order to circumvent these problems, we include as much *a priori* information as possible from the seismic refraction model. In addition, we determine depth-dependent *vp*/*vs* values with the Wadati method and use these values as additional constraints. We outline different inversion attempts and their results, especially their impact on the hypocenter locations which are our ultimate goal.

Automatic characterization of seismic signals emitted from wind turbines with hierarchical waveform clustering

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Wind turbine (WT) emissions significantly affect the sensitivity and resolution of sensitive measurement instruments. Looking at the signals and their spectrograms, distinct signals corresponding to the eigenmodes of the WTs tower and blades, as well as the multiples of the blade passing frequency can be observed. Consequently, characterizing measured ground motion recordings becomes the initial step to address this issue.

It should be noted that the observed ground motion patterns are influenced not only by the WT's rotation rate, but also by factors such as meteorological conditions. With extensive measurements taken at diverse locations, including stations within the WTs vicinity or near roads, as well as variations in distance from the wind farm Tegelberg in the eastern Swabian Alb, we have a remarkable dataset. However, manually evaluating the entire dataset or identifying unknown patterns would be impractical. To overcome these challenges, we employ a hierarchical waveform analysis, an unsupervised machine learning approach, for a comprehensive signal characterization.

We expect to enhance the grouping of seismic WT emissions, identify patterns associated with the WTs and their operation, and establish links between signal patterns and meteorological effects or other signals like traffic. By achieving these goals, we aim to provide a new way to identify ground motion patters, even in cases where essential data such as rotation rate or wind speed are unavailable.

Ground motion measurements on a wind turbine foundation to analyze frequency dependent source characteristics

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Wind turbine (WT) emissions have been studied extensively in the seismological community to investigate the amplitude decay of specific signals at frequencies related to the WTs eigenmodes. For low frequencies (<5 Hz) mainly geometrical spreading contributes to the amplitude decay. Furthermore, the excitation of Rayleigh and Love waves with a wind direction and frequency dependent emission pattern is discussed.

Within the Inter-Wind project we conducted measurements in the vicinity of two wind farms on the eastern Swabian Alb to study the amplitude decay as well as directional dependencies. A ring measurement in distances of 150 m around a WT was carried out with eight recording instruments. The analysis of time windows with differing wind speeds and wind directions has not shown any clear patterns regarding horizontal component ground motion amplitudes related to the wind direction. The horizontal oscillation direction of the instrument on the WT foundation is consistently oriented in the same constant direction independent on wind direction though.

To better understand how surface waves are excited by the movement of the WT foundation we conducted an additional measurement at one of the WTs for approximately two hours with high wind speeds and a constant wind direction. For this purpose we used six broad band seismometers which were distributed symmetrically on the foundation outside the WT tower. In narrow frequency bands centered at the eigenmodes (1.2 Hz and 3.6 Hz) we observe a beating pattern on all components. Signals are inversely polarized on the vertical component of measurement sites located opposite to each other. Using these measured data we can visualize the 3-D motion of the foundation which might give further indications on how to predict the emitted wavefield of a WT in the future.

Synthetic rotational seismograms in Pyrocko

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With the recent advancements in portable sensors for rotational seismic ground motions, the need for rapidly and easily available analysis tools increases. A crucial task is the generation of synthetic data.
We present an extension of the "Pyrocko-GF" Greens function (GF) framework (“Fomosto”) to derive rotational seismic ground motions from translational data allowing to generate synthetic seismograms of both translational and rotational motions within the same, familiar framework. The rotational GFs are derived from an existing translational data store using finite differences, exploiting the fact that rotational motions mathematically result from spatial derivatives of translational motions. The rotations from finite-differences correspond perfectly to analytically computed ones. The new rotational GF store also integrates with the software package "Grond" which allows to include rotational seismic data in the inversion for seismic moment tensors using a Bayesian bootstrap approach.
We show first comparisons between the synthetic and recorded data from the Vogtland region and synthetic tests of the inversion for the moment tensors.

Analysis of earthquake sequences in the region of the Albstadt Shear Zone, southwest Germany – a new model of the rupture processes

Mader, Sarah[1], Ritter, Joachim R. R.[1], Brüstle, Andrea[2] and the AlpArray Working Group

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The Albstadt Shear Zone (ASZ), on the Swabian Alb, a mountain range in Southwest Germany, is one of the seismically most hazardous areas in Germany. Although the approximately NNE-SSW striking sinistral strike-slip fault zone is characterized by continuous microseismic activity no surficial expression is visible. This is in contrast to the NW-SE striking Hohenzollern Graben (HZG), a shallow graben structure with a depth down to app. 2-3 km and an inverted relief at the Earth's surface, which crosses the ASZ between Albstadt and Burladingen. Up to today, the HZG is interpreted as aseismic, because observed seismicity is located significantly below the graben structure.

In October 2018 and September 2019, the state earthquake service of Baden-Württemberg (LED) observed two low-magnitude swarm-like earthquake sequences with hundreds of events near the ASZ. During this time period nine temporary seismic stations of the AlpArray and the StressTransfer projects were recording in the ASZ region. In combination with permanent seismic stations of the LED and other agencies this dense local network gives the unique opportunity to identify further potential low-magnitude earthquakes and for detailed seismo-tectonic studies of the ASZ area. Therefore, we apply a template matching routine to analyze the earthquake sequences of October 2018 and September 2019 and search for additional sequences in the years 2018 to 2020. Finally, relative event locations and the determination of fault plane solutions allow us to image a cluster of several active fault structures.

In total, we identified six earthquake sequences (>10 events), of which the three biggest (> 100 events) can be separated in one fore- and aftershock sequence and two earthquake swarms (October 2018 and September 2019). This is new, as swarms were so far not observed in the area of the ASZ. The detected earthquake sequences images three different fault types: We observe the well-known NNE-SSW striking sinistral strike-slip ASZ at depths of 5-10 km. Beneath the HZG in 11-15 km depth we identify a NW-SE striking dextral strike-slip fault zone. Despite of the same orientation as the HZG, the depth difference between the NW-SE striking fault zone and the shallow HZG exclude a direct connection. At the interception of the ASZ and the NW-SE striking fault zone NNW-SSE striking sinistral strike-slip and normal faulting events are observed and indicate a heterogeneous deformation zone with complex faulting zone.

AdriaArray – a passive seismic experiment to study plate deformation in the central Mediterranean: status in September 2023

Petr Kolínský (Czech Academy of Sciences, Prague), Thomas Meier (CAU Kiel) and the AdriaArray Seismology Group

The densely populated area around the Adriatic Sea is prone to strong multi-geohazards including earthquakes, tsunamis, landslides, flooding and volcanic activity as the Adriatic Plate is presently consumed in a tectonically active belt spanning from Sicily, over the Apennines to the Alps, the Dinarides and Hellenides. The Adriatic Plate and its active margins, which regularly generate earthquakes up to magnitude 7, represent a natural laboratory to study geodynamic causes of geohazards. To identify drivers of associated plate deformation, the plate configuration including slabs and plate boundaries, properties of active fault systems and of the acting stress field have to be determined. AdriaArray, a dense plate-scale regional array deployed in the central Mediterranean, will provide data necessary for passive seismic imaging of the crustal and upper mantle structure and for the analysis of seismic activity. AdriaArray consists of 995 broad-band stations (corner period: 30 s and larger) and 446 broad-band temporary stations from 24 mobile pools. Currently, 390 of the planned temporary stations, corresponding to 87 %, have already been installed. The average station spacing amounts to about 50 km. For the first time, a homogeneous coverage by broad-band stations in an area from the Massif Central in the west to the Carpathians in the east, from the Alps in the north to Sicily and the Kefalonia Fault Zone in the south will be achieved. The backbone network - operated between 2022 and 2025 - is complemented by several locally densified and LargeN networks for example in the western Carpathians, Croatia, in the Vrancea region, and Albania. Recorded data is archived at 8 EIDA nodes mostly by transmission of real-time data streams. Regular data quality checks ensure high data availability and data quality. AdriaArray, the largest passive seismic experiment that has been performed in Europe so far, is based on intense cooperation between local network operators, mobile pool operators, field teams, ORFEUS, EPOS and interested research groups. Altogether, more than 60 institutions are participating in the AdriaArray experiment and are forming the AdriaArray Seismology Group founded in 2022. Currently, Collaborative Research Groups are established to coordinate the data analysis.

Determination of the trajectory of the 15th of March 2015 meteor over Southern Germany and Switzerland

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Meteors are an interesting and often spectacular phenomena in the atmosphere. The common way to determine their trajectories is the use of all-sky cameras using visual observations. However, acoustic waves are also generated during a meteor fall. These waves can be observed at seismic stations. Signals from the meteor event on 15th March 2015 over Switzerland and Southern Germany are recorded by 29 seismic stations in this region which are used for the further analysis. We analyse what kind of physical effect is responsible for the observed signals: an acoustic point source caused e.g., by the fragmentation of the meteor, or an acoustic line source generated by a Mach cone. For this task, a map with signal-arrival times is collected to unravel the physical causes of the signals. The localization under the assumption of a point source is done with the help of the inversion program VELEST and a standard model representing the acoustic wave velocity in the atmosphere. This result has large residuals and RMS errors and therefore is not reasonable. In the other case of a line source with a Mach cone, the determination of the trajectory is more successful with the use of the graphical method of Pujol et al. (Bull. Seis. Soc. Am., 2005). However, the results strongly depend on the spatial configuration of the seismic stations. Furthermore, the influence of the temperature and the humidity in the atmosphere are estimated by using data from vertical meteorological soundings.

Shakemap of the Sierentz earthquake (2022/09/10, Mw 3.9) based on French, German and Swiss data. Challenge of integrating cross-border macroseismic data.

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Shakemap™ computes shaking severity maps for a given event, considering source properties, attenuation laws, instrumental and macroseismic data. It provides a better understanding of the regional shaking and can reveal potential inconsistencies between the various data.

We present the shakemap of the Sierentz earthquake (2022/09/10), Mw 3.9 (after Delouis B., Geoazur, Nice), that was felt in France, Germany and Switzerland. We included the macroseismic data collected by the three observatories (BCSF-Rénass, LGRB and ETHZ respectively). The challenge is that each country collects and processes the macroseismic data differently. Our goal is to understand the optimal way to use them for a coherent cross-border shakemap.

We first use the municipal internet macroseismic intensities derived from testimonies for the three countries. We can see that a slight jump in intensity appears at the borders. In an attempt to reduce the uncertainty over the data, we selected only intensities based on at least ten testimonies, using the number of testimonies as a proxy of quality. This decreases the variation between countries.

In France, we also collected macroseismic data through authorities surveys providing statistical impacts following the EMS98 which enables us to obtain higher-quality intensity estimates. This kind of data doesn't exist in Germany and Switzerland, therefore we kept the previous internet intensities for them. The poster will present the various results for open discussion.

Induced seismicity during mine flooding in the Ruhr area – using geomechanical-numerical modeling of stress distribution to interpret seismicity distribution

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The Ruhr area is characterized by centuries of intense coal mining. After the closure of the last mines, their controlled flooding began. The FloodRisk project investigates ground uplift, stress changes due to pore pressure changes and the reactivation potential of faults to explain induced seismicity. We have a special focus on monitoring Haus Aden drainage catchment in the eastern Ruhr area and are investigating in detail the relationship between mine water level rise, tectonic stress, and induced seismicity.
As part of the FloodRisk project, the Ruhr-University Bochum has installed a network of up to 30 short-period seismic stations in the region of the former "Bergwerk Ost", which has the highest seismicity in the Ruhr area during active mining. The stations cover an area of about 160 km^2 with a station spacing between 0.5 and 3.5 km. They enable continuous monitoring of seismicity. Since the start of flooding in 2019, over 2200 induced events have been localised, showing spatial and temporal clustering.
A prerequisite for the interpretation of seismicity is a localization of the events that is as detailed as possible. Localization of events could be improved significantly using relative localization techniques. This detailed localization of earthquakes enabled the investigation of the spatial and temporal development of earthquake clusters due to the rise of the mine water level.
The resulting pattern of seismicity has been compared with known underground structures, like faults, mined out areas and mine galleries that now serve as the main underground waterways. The comparison between structures and seismicity distribution indicates that most of the events occur about 300 m below the main pillars between the longwall mining panels in the already flooded deepest mine level.
Based on the geometry of the pillars, shafts and longwall panels, a generic FE numerical model was developed for section of the Heinrich Robert Mine. The stress data for the model calibration are based on a compilation of the regional stress state in the eastern Ruhr area. For this purpose, hydraulic fracture tests carried out in the mines to minimize rock outbursts, were re-evaluated and compared with stress orientations from independent sources such as boreholes fractures and earthquake source mechanisms.
The modeling results indicate increased vertical stresses within and below the pillars as a result of stress arching. As the horizontal stress changes below the mining levels are small this results in increasing differential stress that can lead to the observed events below the mining level as mine water level rises.

Transfrontier macroseismic studies of the Upper Rhine Graben: Two recent earthquakes near Sierentz, France, in 2022 & 2023

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The geographical setting of the Upper Rhine Graben (URG) is a trinational region where the impact of near-border earthquakes easily affects two or three countries. The border region of France and Baden-Württemberg (Germany) along the southern URG spans about 160 km. Hence, the BCSF-RéNaSS (French Central Seismological Bureau and National Seismic Monitoring Network) and the LED (Landeserdbebendienst Baden-Württemberg) startet a regular exchange of reported observations and their macroseismic evalutation for felt local earthquakes.

In October 2022 and June 2023 two significant earthquakes took place near Sierentz, Dep. Haut-Rhin in France, with local magnitudes of 4.8 and 3.1, respectively. Although BCSF-RéNaSS and LED both make use of the EMS-98 macroseismic scale, questionnaires, survey protocols, and analyses of the reported data are quite not identical. Here, we present a comparative summary of the methods used to collect and analyse macroseismic data on both sides of the river Rhine border.

Global Secondary Microseism Observation Map from a Large N ANTICS Deployment

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The AlbaNian Tectonics of Continental Subduction - ANTICS - focuses on the underlying processes of continental subduction in Albania, one of the most earthquake-prone countries in Europe. As part of ANTICS, we installed 350 short-period and 50 broadband seismometers in a Large N deployment in Albania covering an area of app. 130 x 130 km^2 with interstation spacings ~7 km. Due to the Large N deployment and the compact nature of the network, we captured the daily global secondary microseism via ambient noise cross-correlation beamforming (CCBF) and backprojection (BP) in the slowness-backazimuth domain. We calculated stable ambient noise CC with 400 s lag and 18 substacks per day. In the secondary microseism frequency band, 0.1-1 Hz, we detect clear and vigorous high apparent velocity P phase (> 10 km/s) arrivals in daily stacks (DS) and stacks over the full deployment period (FS). The daily stacks demonstrate clear temporal amplitude changes in station-pair-distance and symmetry changes of causal and acausal branches, indicating the active evolution of ambient noise source location and strength. We further calculate the CCBF in the frequency domain for DS and FS. From the FS-CCBF, one stable and strongest energy patch emerged with back-azimuth (BAZ) 280°-330° and slowness around 8-10 s/deg. A further two energy patches appeared in BAZ 90°-135° with slowness 4-6 s/deg and along 0° BAZ with slowness 5-7.5 s/deg. We back-projected the strongest energy patch based on the IASP91 model assuming propagation as direct P wave. The back-projection results reveal that the strongest energy comes from the North Atlantic covering a broad arc-shape area (from northeast coast of the US to the west coast of the UK, and from the south of Greenland and Iceland down to 45°N). The two other energy patches with much higher apparent velocity originate in the south Indian Ocean and the north Pacific near the Aleutian Islands. The daily changes are also traced by our DS-CCBF and BP approach. Our results are consistent with existing wave height maps and have a higher resolution than the surface wave-based Ambient Noise Source maps (SANS). Our study provides a simple method to estimate the daily and even hourly oceanic wave height location map based on a single array, which is a relatively “cheaper” and more flexible approach than the conventional daily BF methods.