What is DAS? Fiber Optic Seismology in Theory and Practice

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10.05.2022

During the last decade, the field of fiber-optic seismology emerged and became increasingly popular for a wide range of geophysical applications, ranging from earthquake detection over volcanology to groundwater monitoring.
Distributed Acoustic Sensing (DAS) is a method to measure strain (or its temporal derivative) along a fiber-optic cable with unprecedented spatial (<1m) and temporal (kHz) resolution, over distances of up to over 100 km, with a single instrument. This generates a vast amount of data, with single datasets reaching 10s of TBs.
In this talk, first the measurement technology of DAS will be briefly introduced and compared to existing seismic instrumentation.
After establishing the foundation and measurement properties of such systems, we will discuss data properties and processing steps that can take advantage of the regularly sampled data (in space), such as data manipulation in the frequency-wavenumber domain.
The last part will give an overview on recent geophysical applications of DAS, with a focus on cryoseismology and alpine mass movements.

Insight to the DAS thechnology and its applications

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09.05.2022

2D elastic FD modelling of multi-component vibroseis data acquired at a salt pillar

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24.05.2022

The progress in salt and potash mining has been increased rapidly in the past decades. However, the occurrence of gas and saline solutions on-site poses an economic and safety risk for subsurface mining activities. In this context the German Research Centre for Geosciences in Potsdam (GFZ) with other contributors carried out high-resolution explorations of cavernous structures within the salt formations. I performed 2D elastic finite-difference modelling of a 20 m × 20 m big salt pillar. The multi-component receivers are installed around the salt pillar. A high-frequency magnetostrictive vibrator source is used to excite a sweep signal from 100 Hz to 12 000 Hz; the shot positions surround the pillar. The preprocessing of the observed data prior to the FD modelling consists of receiver rotation, spreading transformation and time-windowing of the first arrival P-wave. In order to fully satisfy the free surface boundary condition in FD modelling, the vacuum formalism (VF) approach is utilized where the boundary conditions are treated implicitly. Zero-phase Klauder wavelet extracted from the observed data is used as a source wavelet to forward simulate the respective wavefields based on realistic P-wave velocities obtained through a traveltime tomography by GFZ. From this traveltime tomography model, the S-wave velocity model is extracted by employing the typical vp/vs ratio in the salt, whereas the density model is obtained by interpolating density values from geochemical boreholes in the salt pillar. A synthetic modelling shows a good agreement of the first arrivals of modelled and observed data, especially for body waves. Surface waves present modeling difficulties and their exact behavior could not be explained conclusively. Therefore, time windowing is implemented to only display the direct P- and S-waves and cut off all other phases. An improved data fit can be obtained with source-time-function inversion. Future studies should investigate the results to perform the entire full-waveform inversion (FWI) and take advantage of the other observed data which are obtained after inserting various fluids into the salt pillar to see the influence of these fluids on the salt deposits.

A comparison of Machine Learning-based Methods for the Supervised Multi-class Classification of Volcano-seismic Signals at Santiaguito

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31.05.2022

The classification of volcano-seismic signals is a key task in volcano observatories worldwide. Historically, however, automatic classification routines have typically encountered difficulties when applied to such environments. The evolving nature of an active volcanoes subsurface affects the attenuation structure, resulting in non-stationary timeseries containing signals of varying frequency content, amplitude and duration. In addition, dense seismic networks around volcanoes are recording exponentially more data, rendering traditional visual-manual classification obsolete.
Lately, machine learning routines have emerged as promising set of methods to exploit the data contained in the latest seismic catalogues, proven to perform classification to a standard similar to a human expert, with unparalleled efficiency.
We compare a range of machine learning methods for supervised classification of volcano-seismic signals, trained on data from Santiaguito Volcano over the period 2018-2020. The training dataset is compiled from manually labelled signals and contains 4 class types: explosions, volcano-tectonic earthquakes, tremors and noise. Spectrograms of the timeseries are used as the training inputs. With over 1000 examples for each signal type, a large dataset is available for training the algorithm.
The results from this work will help to set up a routine for the automatic classification of seismic signals recorded at Santiaguito. Such tools to aid the workflow of analysts are crucial for volcanic hazard mitigation. Furthermore, the results provide insight into the general performance of deep learning-based classification routines when applied to volcanic settings.

Adjoint-state traveltime tomography: A new modality of seismic imaging

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Full waveform inversion has a theoretical advantage over traveltime tomography in resolving velocity variations with dimensions smaller than the dominant wavelength. In reality, this may not be (always) true, mainly due to the lack of an accurate initial model (including material properties and source mechanisms) and the high demand for computational resources. To use only reliable data in seismic inversions, we step back to common-source double difference traveltime data via cross-correlation measurement; however, it is still computationally prohibitive to model high-frequency data (>1 Hz in a regional scale), limiting the resolution of seismic images. We further simplify the mathematical-physical model for seismic wave modelling by using isotropic eikonal equation and anisotropic eikonal equations to model seismic wave propagation in various media. The associated inverse problems are solved by the efficient adjoint method. This gives a new modality of seismic imaging, named as adjoint-state traveltime tomography. In this talk, I will show how absolute traveltime data and differential traveltime data are used to reliably constrain velocity heterogeneity, seismic anisotropy and subsurface topography with the adjoint-state traveltime tomography method. The advantages of adjoint-state traveltime tomography over conventional ray-based traveltime tomography techniques and their differences will also be discussed. Adjoint-state traveltime tomography has the potential to become a routine seismic tomography technique.

What can neural networks tell us about earthquake rupture predictability? Using machine learning for real-time magnitude estimation

Jannes Münchmeyer

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21.06.2022

The ruptures underlying very large earthquakes can last from several seconds up to minutes. To which extent the final magnitude of an earthquake can be determined while its rupture is still ongoing is an open question. Evidence has been brought forward for both early predictability and full stochasticity. The answer to this question defines the fundamental limitations of earthquake early warning and is thereby integral for mitigating seismic hazard.

One appealing option to study rupture predictability is building real-time magnitude assessment systems. However, until recently such systems lacked either accuracy or timeliness to use them for studying rupture predictability. In this talk, we present a novel deep learning model for real-time magnitude estimation. We conduct an intensive study of this model to highlight its advantages and limitations. Finally, using this model, we study the question of rupture predictability of very large events.

Geophysics in practice - An insight to UXO detection

Mark Wienoebst

GPI alumni, now working in industry

28.06.2022

In Germany there is still an excessive amount of unexploded ordnance (UXO) hidden in the subsurface. Prior to digging at construction sites it is obligatory to survey the area with regard to UXO. This includes the analysis of aerial images taken by the Allied forces and – if necessary –geophysical measurements (geomagnetics, TDEM, GPR) performed at the suspected area. This talk gives an overview of the typical process from the initial suspicion to the disposal with a main focus on the geophysical measurements including real data examples.

Tailoring geophysical inversion for education and research with the open-source toolbox pyGIMLi

Thomas Günther

LIAG

05.07.2022

Inversion of geophysical data is of crucial importance for understanding states and processes in the subsurface, particularly if different methods are involved. However, very often, specialized (sometimes black-box) software hinders both method combination and the understanding in geophysical education and reproducible research. We present the open-source toolbox pyGIMLi (Geophysical Inversion and Modelling Library in Python), not as inversion program, but as a versatile toolbox that can be particularly used for data fusion purposes. We demonstrate how the subsurface can be specifically controlled, by incorporating structural constraints (e.g. from seismics) and prior data (e.g. from boreholes). Furthermore, we show different kinds of coupling, by using structural, petrophysical or temporal joint inversion. The software is thus particularly suited for teaching purposes, but also as a basis to reproduce publication results according to the FAIR standards.

Seismic signals from wind farms - Observations and modelling

Fabian Limberger

Industry
12.07.2022

Being mechanically coupled to the earth, wind turbines generate ground vibrations, which can have adverse effects on the capability of seismic stations to detect and analyse earthquakes; nevertheless, the distances at which these signals modulate seismic records are disputed between the operators of wind farms and seismic stations. We analyse the seismic signals of a small wind farm consisting of three linearly arranged wind turbines. The wave propagation is recorded along two profiles of about 4 km length, oriented parallel and perpendicular to the wind farm axis. One of the goals is the prediction of the wind turbine emissions at distance. Based on our observations and models we show that the wind farm geometry, interferences of the wavefields from the multiple wind turbines, and the local topography can have complex effects on the wave propagation. However, we are developing methods to better understand the emission of the signals produced by wind turbines and to handle the prediction of these signals.

Effects of seismic anisotropy and attenuation on first arrival waveforms recorded at the Asse nuclear waste repository

Sonia-Adelina Șortan

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19.7.2022

Two talks: Automatic Analysis of the Maule, Chile, Aftershock Sequence using AI Techniques & Advancing earthquake event detection pipelines through machine learning approaches.

Ankitha Pezhery & Jack Woollam

GPI - KIT

26.07.2022

Seismic phase picking and subsequent event association are inevitable steps of a seismic processing workflow for unravelling the characteristics and structure of Earth's subsurface with the help of earthquake data. With the increasing deployment of denser seismic networks rendering enormous volumes of frequent seismic data, manual phase picking and automated approaches are falling behind, but the field of seismology is taken by storm at the possibility of using AI techniques to develop efficient phase picking and event association algorithms. In addition to working with data from latest large N array seismic networks, such novel techniques help us to reinvestigate notable highly active seismic sequences already recorded. This study is an attempt to better understand the aftershock sequence of 2010 Maule, Chile earthquake of Mw = 8.8, one of the largest subduction zone earthquakes that was monitored by a dense seismic network, by adopting latest machine learning developments in seismic processing piplelines. We applied a deep neural network based phase picker, PhaseNet and subsequently Hyperbolic Event Extractor (HEX) as an event association algorithm on Maule dataset. To demonstrate if the event associator can keep pace with the vast amounts of picks detected by the phase picker and to tweak associator's configuration parameters, we developed a synthetic generator routine which was tested for homogeneous and 1D velocity models of this region. We hope that this synthetic data generator along with the results of this study will prove fruitful to better understanding the relative benefits of such novel seismic event detection routines over traditional approaches.

High-resolution earthquake locations are one of the most fundamental components in imaging subduction zone interfaces. The accurate association of seismic events in these regions is vital to understanding the physical processes associated with the largest earthquakes on record. The last decade has seen the continued increases in the scale of both onshore and offshore seismic deployments, aiming to better capture the variety of seismic processes occurring throughout these dynamic environments. Typical approaches for earthquake detection typically involve combinations of traditional automated methods (e.g STA/LTA picking) and manual refinement by a human expert. The trade-off in performance and accuracy afforded by this hybrid approach can result in under-exploited catalogs, when compared to a human expert exhaustively identifying and associating all arrivals manually. In recent years, Machine Learning (ML) methods have shown significant improvement in the task of automatically detecting seismic events. ML methods now potentially operate at a similar standard to a human expert, whilst running orders of magnitude more efficiently than comparable techniques. Here, we show the advances made when applying these latest machine learning-based algorithms to process continuous seismic data across seismic networks in practice.