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Abstracts for oral and poster presentations

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Kwabena Atobra: Physics based machine learning for characterizing induced seismicity in enhanced geothermal systems (EGS)

Institute of Seismology, University of Helsinki

This project involves using a combination of numerical models and machine learning techniques to understand the properties and stress state of a geothermal reservoir using data obtained from a field scale hydraulic stimulation experiment. Induced seismicity patterns are simulated for a hydraulically stimulated reservoir using a 3D viscoelastic damage rheology model (DRM) to produce a forward model. A machine learning based inversion is then be carried out to determine the posterior distribution of unknown reservoir and material properties using Likelihood-free inference methods (such as ABC and BOFLI) conditional on the observed induced seismicity patterns obtained from the hydraulic stimulation experiment. The project is focused on data from the Otaniemi geothermal reservoir in Finland, however the workflow and techniques are applicable to other EGS projects and test sites.

Gunnar Eggertsson, Björn Lund, Peter Schmidt, Michael Roth and Hossein Shomali:
Automatic Seismic Event Classification in Sweden

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At SNSN, currently all major seismic events occurring in Sweden are subject to routine manual analysis. An important aspect of such analysis is the distinction between different source types. Historically, analysts at SNSN have distinguished between three different types of seismic events in Sweden; industrial blasts, natural earthquakes and mining-induced events. Since May 2020, the mining-induced events have been further distinguished into two separate types. We have developed station-specific classification models, based on Artificial Neural Networks, with the aim of automatically filtering spurious events from actual events and assigning correct source type to actual events. The models are already in use at SNSN, both as a revision tool to identify potential classification mistakes made during manual analysis, and as a tool for directly assigning preliminary source type to automatically detected events. Initial results show a high degree of accuracy and suggest that the method is suitable for automatic source type classification of seismic events in Sweden.

Ludovic Fülöp[1], Niina Junno[2], Kati Oinonen[2], Päivi Mäntyniemi[2]: A new seismic source zone model for Finland

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A new seismic hazard model, for the whole territory of Finland, is being developed in the Seismic-Risk project. The hazard results obtained will be used as baseline for estimating the additional effect of induced seismicity from deploying deep geothermal wells. At the same time, the calculations are carried over to risk estimation.

The model draws on recently completed hazard modeling projects for the nuclear industry, like Korja and Kosonen (2015), Mäntyniemi et al. (2021) and Fülöp et al. (2022), with respect to data collection and modeling technique.

The model is particular in that it focuses on hazards from lower magnitude earthquakes, down to the minimum magnitude of Mw2. In traditional hazard calculations, the minimum magnitude is usually chosen to be higher, in the range of Mw4. As highlighted by Boomer and Crowley (2017), this choice is ultimately related to seismic risk and the risk target of the calculation. In traditional hazard calculations, the safety target is primarily collapse-prevention of ordinary buildings. This safety target is associated (e.g. in the Eurocode 8) with probability of exceedance of 10% in 50 years, which is the usual design life of an ordinary building. In the Seismic Risk project, the focus is on risks posed by disruption of functionality and societal disturbance.

In this work we focus on the seismic source zones used in the model, their basic properties and techniques utilized to establish activity rates. The base model consists of 25 zones, synthesized from the initial delineation work carried out in a workshop between on the 8th and 9th of February 2021. The workshop resulted in four zoning proposals, which were harmonized later to the model presented here. Additional adjustments considered discussions with Norwegian and Swedish researchers, as well as ideas from the European Seismic Hazard model 2020. In five cases the basic zones can be used individually, or combined in larger units of related seismicity – e.g. in case of the post-glacial faults or the Kuusamo -Kandalaksha zones.

The earthquake catalogue used in the project has been cleaned to contain only natural earthquakes. For calculations, time- and space- clusters of earthquakes have been removed, apart from the largest event. Finally, the different magnitude types have been homogenized. As the analysis was progressing, meso- and macro scale zoning divisions were developed to derive seismicity parameters, when the basic zones lack appropriate data (i.e. central and eastern regions of Finland).

This investigation has received funding from the SEISMIC RISK project of the Academy of Finland (decision no. 337913, 338075 and 339670).

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Ryan Gallacher, Tom Garth and Dmitry Storchack: **Seismic Station Polarity Reversal Detection Using Parametric Data from the ISC Bulletin**

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A comparison of the goodness of fit of reported first motion picked polarities from the International Seismological Centre (ISC) Bulletin versus reported earthquake mechanism solutions can be used to detect systematic phase reversals at seismic stations. The goodness of fit is determined by calculating the probability distribution of a set of Bernoulli trials from perturbed combinations of hypocenter locations and velocity models. The station polarity information is reported showing average polarity over time and the number of observations per month. Specifically plots show a 90 day rolling average of polarity with data gaps of greater than 90 days being highlighted for users. Additionally individual polarity measurements are shown alongside a confidence value obtained from a measure of the distance from the likely nodal plane for that earthquake. It is intended to eventually make these plots available through the ISC website, allowing data users and seismic network operators to be made aware of stations requiring attention. Future work includes using the predictions of reversed polarities from this method to correct reported polarities used in other ISC products such as the first motion derived focal mechanisms, ISC-FM.

Federica Ghione[1,2], Steffen Mæland[3], Abdelghani Meslem[1,4] and Volker Oye[1,2]: Machine learning for building stock classification: a case study for Oslo, Norway

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To evaluate potential human and economic losses in a seismic risk assessment, it is important to define an exposure model by defining building materials and characteristics. The common approach to develop an exposure model is to have a first overview of the area with Google Earth and to perform extensive fieldwork in representative areas of the city. This procedure is time and cost consuming, and it is also subject to personal interpretation. To mitigate these costs, a Convolutional Neural Network (CNN) is used to automatically identify the different building typologies in the city of Oslo, Norway, based on facade images taken from in-situ fieldwork and Google Street View.

The present article attempts to categorize Oslo's building stock in five main building typologies: timber (T), unreinforced masonry (MUR), reinforced concrete (CR), composite (steel reinforced concrete) (SRC) and steel (S). This method shows good results for timber buildings with 91% accuracy score, but only 41% for steel reinforced concrete buildings. These variations can be explained by differences in the number of labelled images for each typology, comprising the training data, and differences in complexity between typologies.

This work is the first tentative to identify Norwegian building typologies: based on experts judgement, the five types observed in Oslo can be applicable at national level. In addition, this study shows that CNNs can significantly contribute in terms of developing a cost-effective exposure model.

P. Haapanala, T. Oksanen, K. Komminaho, A. Juntunen, P. Linblom, P. Seipäjärvi, G. Hillers, I. Kukkonen, and FLEX-EPOS consortium members: The Finnish Seismic Instrument Pool (FLEX-EPOS SIP)

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The Institute of Seismology at the University of Helsinki is hosting and coordinating the Finnish Seismic Instrument Pool (SIP) in collaboration with other Finnish universities and research organizations. The SIP includes about 50 broadband and 1200 short period seismic instruments that facilitate controlled source experiments, and earthquake and passive seismology research. The greatly expanded observational capability of the SIP will contribute to science by providing massive new seismic datasets, observations, and results, and strengthen and extend the role of Finland in the European EPOS framework.

This pool is part of a Flexible instrument network for enhanced geophysical observations and multi-disciplinary research (FLEX-EPOS) project under the FIN-EPOS umbrella funded by the Academy of Finland. The pool instruments are owned by the University of Helsinki, the Geological Survey of Finland, the University of Turku, Aalto University, and the University of Oulu. In addition to the SIP owners, VTT Technical Research Centre of Finland and the Finnish National Land Survey of Finland/Geospatial Research Institute FGI are part of the FLEX-EPOS consortium. The consortium members are encouraged to use the instruments in international collaboration projects, but the main applicant to the Pool needs to be affiliated with one of the FLEX-EPOS partners.

The University of Helsinki coordinates the practicalities of the buildup phase (2021–2024) and the operation of the pool in collaboration and under the guidance of the owners of the SIP instruments and the FLEX-EPOS Steering Group. In this poster, we give an overview to the FLEX-EPOS project in general and to the objectives and basic details of the SIP.

More information about the FLEX-EPOS project and the SIP (instrumentation, how to apply, fees, liabilities, Principles of Operation etc) can be found at https://wiki.helsinki.fi/display/FLEX/Flex-epos+Home. This work is related to an accompanying abstract by Haapanala et al. 2022 (this volume) that introduces Solid Earth Science RI collaboration in Finland including FIN-EPOS research infrastructure (poster presentation + oral presentation by A. Korja).

The FIN-EPOS and FLEX-EPOS are funded by Academy of Finland (Funding Decisions no. 328984, 328776, 328778, 328779, 328780, 328781, 328782, 328784 and 328786).

P. Haapanala, A. Korja and FIN-EPOS, FLEX-EPOS, Nordic EPOS partners: **Solid Earth Science RI collaboration in Finland**

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EPOS, the European Plate Observing System (https://www.epos-eu.org/epos-eric), facilitates the use of European solid Earth data, data products, and facilities. EPOS hosts a multi-disciplinary open data portal for Solid Earth science datasets https://www.epos-eu.org/dataportal.

Finland's participation in EPOS is coordinated by a FIN-EPOS research infrastructure consortium (https://www2.helsinki.fi/en/infrastructures/fin-epos/european-plate-observing-system-epos). FIN-EPOS partners operate geophysical observatories and laboratories and plan together the long-term national solid Earth science strategies. The permanent seismic, geodetic and magnetic observatory networks are distributed around Finland, whereas the geophysical, geodynamic and rock physical laboratories are located in Helsinki, Espoo, Kuopio, Rovaniemi, Oulu and Pyhäsalmi (Calliolab).

One of the progressing projects under the FIN-EPOS umbrella is a Flexible instrument network for enhanced geophysical observations and multi-disciplinary research (FLEX-EPOS) -project. Its objective is to create a national geophysical instrument pool and multi-disciplinary geophysical superstations. Abstract and poster by Oksanen et al. 2022 (this volume) will introduce Seismic Instrument Pool that is part of FLEX-EPOS project (https://wiki.helsinki.fi/display/FLEX/Flex-epos+Home).

Finland also takes part in Nordic capacity building and knowledge exchange related to EPOS. University of Helsinki is coordinating Nordic EPOS - A FAIR Nordic EPOS data HUB -project funded through NordForsk's Nordic Research Infrastructure Hubs (2020–2022). The project supports active Nordic collaboration by organizing workshops, trainings and events on EPOS data usage, FAIR data principles, and on harmonizing data management. The arranged activities are aimed for students, researchers, and technical staff working in Nordic countries in the field of Solid Earth sciences. By developing and sharing expertise and tools designed to integrate Nordic RI data and further enhancing their accessibility and usefulness to the Nordic research community we are addressing global challenges in Norden with Nordic data. For more information see https://www.helsinki.fi/en/infrastructures/nordic-epos.

We will introduce the European Solid Earth Science research infrastructure EPOS via outreach videos (https://www.epos-eu.org/communication/outreach-materials?category_id[]=6) and national FIN-EPOS and Nordic EPOS collaboration related to it via a poster presentation. Visit FIN-EPOS, FLEX-EPOS and Nordic EPOS websites for more information.

FIN-EPOS receives FIRI funding from Academy of Finland (Funding Decisions No. 328984). The Nordic EPOS is funded through the NordForsk's call for Nordic Research Infrastructure (RI) Hubs for 2020–2023 (project No. 97318)

Benedikt Halldorsson[1,2], Milad Kowsari[1] and Farnaz Bayat[1]: Overview of the ESHM20 results for Iceland and comparison with previous estimates

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The new revised European Seismic Hazard Model (ESHM20) has recently been published and its results differ dramatically from previous harmonized European efforts of probabilistic seismic hazard assessment (PSHA) for Iceland. The two main reasons are that the European efforts benefitted greatly from: 1) An intense and independent research effort in recent years in Iceland that has laid a robust and physically consistent foundation for all the three fundamental elements that PSHA is based on: the earthquake source specifications, their seismic activity, and the attenuation of ground motion peak amplitudes. 2) Improved communication with local experts. As a result, the ESHM20 estimates are greatly improved from the ESHM13 efforts (the SHARE project) and exhibit hazard values that are more consistent with the Icelandic National Annex to Eurocode 8 than the ESHM13. In this study we showcase the new provisional earthquake source zonation of Iceland, with special focus on the two large transform zones of the country, show the consistency of new finite-fault system models of the transform zones with the historical catalogues, and showcase the hazard results. We emphasize the differences in hazard values between estimates, and focus on areas that still need improvement. In general, the new seismic hazard model for Iceland is based on a major development compared to previous models, and lays the foundation for physics-based PSHA in the transform zones of Iceland.

<u>Benedikt Halldorsson</u>[1,2], Sahar Rahpeyma[1], Atefe Darzi[1], Kristín S. Vogfjörð[2]: **The estimation of new geology-based frequency-dependent site amplification functions for Iceland**

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The prevalence of bedrock site condition in Iceland as the ideal and robust building foundation on has inadvertently caused low emphasis on the quantitative estimation of site factors, a standard element in aseismic building design considerations. Site factors, ideally are estimated from frequency-dependent site amplification functions for the site, or for a specific site class, usually correlated with surficial geology or geophysical parameters of the subsurface from site studies. Such amplification functions are key inputs for seismic ground motion estimation, either as a continuous function in the stochastic simulation method, or for parameter prediction using empirical ground motion models (attenuation relationships) and then usually in the form of a discrete proxy of e.g., Vs30. In the past, either site effects have been considered insignificant on rock, with the scarcity of soft soil or sand recordings precluding the estimation of their site amplification. However, recent localized site effect studies in Iceland have showed that surficial lava rock has a different and unique site response compared to bedrock. This has prompted a more region-wide analysis of Icelandic strong-motions recorded on the regional network. Through the use of Bayesian hierarchical modeling with one of the newly proposed Bayesian hybrid and empirical ground motion models as a backbone, we have quantitatively estimated $\delta S2S$, the "station effect", over the range of frequencies of engineering interest at Icelandic strong-motion recording stations. The station effects show a remarkable consistency with 1) theoretically predicted frequency dependent amplification functions, and 2) surficial geology in Iceland. On this basis, we have proposed new and distinct frequency-dependent seismic wave amplification functions for four key geological units in Iceland, complete with uncertainty measures. The new amplification functions have been incorporated in one of the recently proposed Bayesian hybrid empirical ground motion model for PSHA in Iceland. They now enable the preparation of shakemaps that quantitatively account for regional geological effects, their confirmation by extending the analysis to include the National seismic network stations, and eventually prompt a revision of PSHA as previous efforts have excluded site effects.

Taavi Heikkilä, Tuija Luhta and Toni Veikkolainen: **NorDB version 2 – a comprehensive tool for handling seismic metadata**

Institute of Seismology, University of Helsinki, Finland

Seismic data has little use without good methods of storing and accessing the processed metadata of the seismic events the data represents. For this purpose, Institute of Seismology has developed an in-house database system NorDB.

The database system NorDB has been in use in the Institute since 2020. The system is used, with accompanying in-house graphical analysis software NorLyst, as the basis of the manual seismic analysis work carried out in the Institute. The analysis use includes integrations to automatic detection data flow. NorDB is used in the institute also by itself for handling separate campaign related metadata sets.

In 2022, a new major version 2 of the NorDB was taken into use in the Institute. The current version provides tools for inserting and exporting seismic metadata in multiple formats (Nordic, CSS, QuakeML), enriching the data (by adding tags, tensor solution info, etc.) and making searches with multiple available parameters. As a new feature, the database can also be used for storing information on the seismic networks.

In the current form, the NorDB database system provides a practical way of storing and handling both small separate seismic metadata sets as well as large sets even with complete network information. With accompanying analysis software NorLyst the database system can be used as the basis of a whole analysis and research workflow.

Jennifer Hällsten and Tuija Luhta: Åland network

Institute of Seismology, University of Helsinki, Finland

The Institute of Seismology, University of Helsinki, has installed a temporary research network on Åland in August 2022. The network consists of three on-line broad-band stations and nine geophone stations. The network will be operational at least one year, although our ambition is to make part of the stations permanent.

The aims of the network are better detection and analyses capability of seismic events happening on or near Åland. Data of the network will also be used for structural studies of the area. The main motivation for the network are the four earthquakes that occurred in summer 2021 near Mariehamn - the biggest with ML 1.8. These were typical, shallow rapakivi earthquakes. Åland is the second largest rapakivi occurrence in Finland. The largest one, Wyborg rapakivi batholith, is well known for its characteristic seismicity. With the data from the network, the object is to find out if Åland rapakivi batholith hosts a similar kind of seismic activity as its larger counterpart.

The project is supported by the Nordenskiöld-samfundet.

Niranjan Joshi, Björn Lund and Roland Roberts: Probabilistic seismic hazard assessment of Sweden

Uppsala University, Sweden

We provide an overview of the ongoing probabilistic seismic hazard assessment of Sweden. The hazard assessment is carried out using the OpenQuake engine and uses the same parameters as those used in the 2020 European Seismic Hazard Model (ESHM20), such as the ground motion prediction equations and the source zonation scheme. Furthermore, we use the most recent data recorded by the Swedish seismic network, up to 2020, to produce this hazard map. We discuss the methods used to obtain the recurrence parameters and compare our results to the ESHM20 results.

Ríkey Júlíusdóttir[1], Kristín Vogfjörd[1], Bryndís Brandsdóttir[2], Guðmundur Valsson[3], Dalia Prizginiene[3], Ásdís Benediktsdóttir[4], Lovísa Ásbjörnsdóttir[5], Þorbjörg Ágústsdóttir[4], Kjartan Akil Jónsson[1], Matthías Pétursson[1], Hanna Blanck[1], Hildur M. Fridriksdóttir[1], Magnús T. Gudmundsson[2], Kristján Jónasson[5] and the entire EPOS-Iceland team: **Earth science data from Iceland in FAIR access**

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[4] Iceland GeoSurvey (ÍSOR)
[5] Icelandic Institute of Natural History

EPOS-Iceland (epos-iceland.is) is one of six projects selected for the first Icelandic *Roadmap for research infrastructure*, funded by the Icelandic Infrastructure fund at the Icelandic Centre for Research (RANNÍS). The project is a joint national effort striving to provide FAIR (Findable, Accessible, Interoperable, Re-usable) open access to multi-disciplinary geoscience data with associated metadata from Iceland. The collaboration is led by the Icelandic Meteorological Office with participation of the Institute of Earth Sciences of the University of Iceland, the National Land Survey of Iceland, the Icelandic Institute of Natural History, and Iceland GeoSurvey (ÍSOR) and is thus far the largest collaboration between these partners. This effort provides a substantial boost to Iceland's long-term participation in the European Plate Observing System - European Research Infrastructure Consortium (EPOS-ERIC).

The overarching aim of EPOS-Iceland is to provide access to hitherto inaccessible data and products, e.g. various volcanic data like ash-, gas- and radar measurements from volcanic plumes, volcanic activity reports and guidelines, along with data from the national seismic (SIL) and GNSS (ISGPS) networks, rock samples, geological maps, and collections of photographs and web-camera images from the main eruptions of the last several decades. Special effort is placed on constructing and providing state-of-the-art e-infrastructure for data services directly linked to the Volcano Observations Thematic Core Service (VO-TCS) of EPOS ERIC to build up societal resiliency to volcanic hazards. Furthermore, the facilitated access to important, quality checked, and standardized geoscience data can provide greater opportunities for research and education.

The EPOS Iceland collaboration is therefore extremely important in the long-term and is of significant importance in terms of the advancement of knowledge, innovation and further utilization of research. EPOS Iceland is the most extensive development of data services for earth science undertaken in Iceland.

N. Junno[1], L. Fülöp[2], K. Oinonen[1], P. Mäntyniemi[1], A. Korja[1] and SEISMIC RISK working group: **SEISMIC RISK – Mitigation of induced seismic risk in urban environment**

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Deep geothermal energy has huge potential as environmental friendly district heat source in urban cities. A drawback is that geothermal systems can induce earthquakes that pose a previously non-existing seismic risk to the surroundings. A new project *SEISMIC RISK – Mitigation of induced seismic risk in urban environments* (https://www2.helsinki.fi/en/projects/seismic-risk) focuses on, how to evaluate, mitigate and communicate seismic hazard and risk in an urban environment in Finland. The key to risk management is in how well the process is understood and governed. To better understand the level of risk to urban societies, interdisciplinary data sets modelled around Otaniemi, Finland.

SEISMIC RISK is an interdisciplinary project, where several expert groups collaborate closely to fully exploit their expertise. The project's scientific results: seismic hazard maps, ground-motion prediction equations, 3D tomographic and geological models of the capital area, surveys and interviews on the planning and regulating processes, are used to assess induced seismic risk. The risk is mitigated by evaluating soil and bedrock properties for urban planning and construction; outlining tremor and noise sensitive areas; and serving as expert in groups drafting guidelines and legislation for construction of critical infrastructure.

As part of the project, a seismic hazard map is prepared for the national needs. A hazard map is the prerequisite for the analysis of seismic risk. A Nordic workshop has been organized to determine seismic source area (SSAs) models in spring 2021. In this presentation, we present the SSA models.

SEISMIC RISK project is funded through the Academy of Finland's call for new research projects on crisis preparedness and security of supply for 2020-2023 (decision numbers 337913, 338075, 339670).

Maren Kjos Karlsen and Mathilde B. Sørensen: New national seismic hazard model for Norway

University of Bergen, Norway

A new national probabilistic seismic hazard assessment (PSHA) for Norway is currently under development at the University of Bergen. The goal is to develop a widely applicable PSHA model using state of the art methods and data, and which is consistent with hazards models in neighboring countries.

In this presentation, we will present how the input earthquake catalog has been compiled and quality controlled. We also present a preliminary zonation model that can be discussed during the meeting. Finally, we will present the planned further steps of the analysis.

Balasubramaniam V R, Vikalp Kumar and Divyalakshmi K S: Seismic Hazarad Analysis of a mined out areas

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Kolar Gold Fields (KGF) in the south-eastern part of Karnataka, India is one of the deepest and most well-known mines that were in operation since 1880. As the mining got deeper during the active mining days, there have been several rockburst leading to extensive seismic monitoring investigations. The mines have experienced more than 10,000 significant seismic events since 1957 and in the first decade of this century, there have been more than 2000 events. There has been a regular decline in events since 2005. However sporadic incidences of ground sinking, cracks in the buildings, etc. had raised apprehensions about the safety and stability of the mining area. It was suspected that the shallow events could be the prime impacting factor because of the energy of the seismic waves and the ground motion. This led to an expert committee recommending seismic monitoring for the assessment of seismic hazards in the mining area.

Accordingly, seismic monitoring involving a five-station seismic network with triaxial geophones was carried out in May 2017. The monitoring zone was divided into three major zones viz, the Nundydroog Mines, Champion Reefs Mines, and the Mysore Mines. The seismic monitoring located as many as 40 seismic events till May 2018. Most of the seismic events were found to be low magnitude (-0.82 to 1.05) and low energy events in the depth range of 130-2000m, with occasional high magnitude events associated with significant stress drop. However, the associated peak ground motion parameters were found to be far lower than the permissible levels and as such none of these events resulted in physical damage to any of the properties in the mining area except perception of vibration due to the very few events >0 magnitude in the shallow levels (<500m). A couple of deeper events had sent perceptible vibrations but with again no destructive consequences. Thus, based on the overall strength of the seismic events, their depth, stress levels, and the ground motion parameters, this work has indexed monitored mining area from least to potentially hazardous scale of Zl-Z5 (Zl very low; Z5 very high). It is found that the majority of the mining area i.e. 70% falls under the Z2 (low hazard) category, with 15% area under Z3 (moderate hazard), and around 2% in Z4 {high hazard). This work gives the details of the work done till the generation of a map of the hazard index in the old mining area, despite various constraints in data acquisition to visualization of seismic events in the underground mines. The seismic monitoring from the surface brings out the prevailing hazard level and estimation of seismic hazards due to the seismic events in the area of the old mine during the monitoring period. Such a technique is applicable for the estimation of seismic hazards in mining areas with similar problems in mined-out areas in any country.

Andreas Köhler, Celso Alvizuri, Ben Dando, Anna Maria Dichiarante, Bettina Goertz-Allmann, Kamran Iranpour, Annie Jerkins, Tormod Kvaerna, Volker Oye, Berit Paulsen and Johannes Schweitzer: **NORSAR's analysis of the Nord Stream pipeline explosions**

Two clear seismic events were observed on 26th September 2022 associated with the reported leaks from the Nord Stream 1 (NE of Bornholm) and Nord Stream 2 pipelines (SE of Bornholm). Arrivals of both events were detected at NORSAR's arrays (NORES, NOA) and associated together with automatic phase readings from the Finnish FINES array, and for the second event, NORSAR's ARCES array in Troms and Finnmark. Both events exhibit reverberation signatures typical of underwater explosions close to the seafloor, consistent with ca. 75 m water depth. The first event was registered with a local magnitude of 1.8 at 2 am, followed by a stronger event with magnitude 2.3 at 7 pm local time. We estimate a yield of ca. 240 kg TNT equivalent for the first, and ca. 880 kg TNT equivalent for the second, larger explosion. The latter is most likely overestimated due to interference of multiple events. Additional signal analysis with data kindly provided by the Swedish National Seismic Network enabled a third, and possibly fourth explosion to be identified, coincident with the signal of the second explosion. Cepstrum and auto-correlation analysis of the second event reveal a third event about 7 seconds after the main amplitude of the P onset, with indications of a possible fourth event at 8 seconds delay. In contrast, for the first event no additional events could be identified from cepstrum or auto-correlation analysis, which increases confidence that these additional arrivals are not caused by interaction with geological structures. On the NORES origin beam, we also observe an arrival 7 s after the Pn phase, before the theoretical Pg. However, this travel time coincides with the PnPn phase which is known to be observed at such distances and has a similar moveout as the Pn. We also estimated preliminary full moment tensors for the main events using seismic waveform data and analised them on a source-type diagram. The results show positive isotropic parameters consistent with explosion-type mechanisms.

Pasi Lindblom: The Finnish National Seismic Network (FNSN) 1924-2022

Institute of Seismology, University of Helsinki

An overview of building up the seismic station network in Finland starting from the year 1924.

Tuija Luhta, Kari Komminaho, Kati Oinonen, Jari Kortström, Tommi Vuorinen, Pirita Seipäjärvi and Timo Tiira: **Complementing monitoring networks with SmartSolos**

Institute of Seismology University of Helsinki

Institute of Seismology University of Helsinki purchased 50 SmartSolo IGU-16 3-component 5Hz geophones and a 16 Slots All-In-One portable data harvester, battery charger and device tester late in 2019. Since then, the devices have been used in numerous projects including monitoring as well as other research projects. Durations of projects have varied from weeks to years. With external batteries, we have managed to measure continuously over six months without changing the devices. Data quality of SmartSolo geophones has proven to been adequate for seismic monitoring purposes, thus these devices are a practical and affordable way to complement on-line monitoring networks for more specific studies of local seismicity or structure.

B. Lund, the SNSN and others: The 26 September 2022 blasts in the southern Baltic

A brief presentation of the data and analysis of the 26 September 2022 blasts in the southern Baltic.

Harald Nedrebø: Nordic FAIRness Data Survey presentation by EPOS UiB

EPOS UiB will present an analysis of the FAIRness Survey prepared by Nordic-FAIR-DM-WG in Q4-2021 and that was executed in Q1-2022. The survey was collecting the current status of how the FAIR principles (Findability, Accessibility, Interoperability, and Re-useability) related to Solid Earth data are applied in Nordic countries in 2022.

Nordic EPOS partners have been participating from Iceland, Denmark, Finland, Norway, Sweden, Lithuania and Estonia in a 10-minute online survey on FAIRness.

Thematic domains present in the survey are geological information and modelling, volcano observations, geomagnetic observations, GNSS Data and Product and Seismology. Tsunami, Geo-Energy Test Beds for Low Carbon Energy, Multi-Scale Laboratories, Anthropogenic Hazards, Satellite Data and Near-Fault Observatories are not present in this survey.

The analysis of the FAIRness survey consists of a gap analysis for datasets and products, metadata and services. The results of data and datasets reveal that most participants agree or partly agree that language, licenses, indexing, search ability and identification of data are good. Regarding metadata there are many answers that are “I don’t know” regarding the same topics, indicating either that the questionnaire is unclear or that the participants might not know the metadata status. For service for access most participants has a research infrastructure that provides data and agrees that it has an open, free and implementable protocol. Few participants has a protocol that allow for authentication and authorization.

Jan Michalek, Päivi Haapanala, Nil Eryilmaz, Harald Nedrebø: Nordic FAIRness Data Survey

We present analysis of the FAIRness Survey prepared by "A Nordic FAIR and Data Management Working Group" (Nordic-FAIR-DM-WG) within the framework of the **Nordic-EPOS - A FAIR Nordic EPOS Data Hub Project** supported by the NordForsk Program of the Nordic Ministries. The survey was designed in Q4-2021 and executed in Q1-2022. The survey was collecting status of how the FAIR principles (Findability, Accessibility, Interoperability, and Re-useability) related to Solid Earth data are applied in the Nordic countries. Nordic EPOS partners from Iceland, Denmark, Finland, Norway, Sweden, together with Lithuania and Estonia have been participating in an online survey on FAIRness. The gap analysis considers status of datasets and products, metadata, and services.

Jan Michalek[1], Daniela Mercurio[2] : Update on EPOS ERIC developments

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The European Plate Observing System (EPOS) addresses the problem of homogeneous access to heterogeneous digital assets in geoscience of the European tectonic plate. Such access opens new research opportunities. Previous attempts have been limited in scope and required much human intervention. EPOS adopts an advanced Information and Communication Technologies (ICT) architecture driven by a catalog of rich metadata. The architecture of the EPOS system together with challenges and solutions adopted are presented. The EPOS ICS Data Portal is introducing a new way for cross-disciplinary research. The multidisciplinary research is raising new requirements both to students and teachers. The EPOS portal can be used either to explore the available datasets or to facilitate the research itself. It can be very instructive in teaching as well by demonstrating scientific use cases.

EPOS ERIC had been established in 2018 as the European Research Infrastructure Consortium for building a pan-European infrastructure and accessing solid Earth science data. The sustainability phase of the EPOS (EPOS-SP – EU Horison2020 – InfraDev Programme – Project no. 871121; 2020-2022) is focusing on finding solutions for long-term sustainability of EPOS developments.

The presentation is providing update on recent developments of EPOS ERIC and showing the achievements of the EPOS community with focus on the EPOS Data Portal which is providing information about available datasets.

Tora Haugen Myklebust[1,2] and Henk Keers[1]: Elastic isotropic modeling and full waveform inversion for regional seismology

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Inversion of regional seismological data is routinely done using travel time tomography, earthquake (re)location and moment tensor inversion. Going beyond this, exploiting amplitudes and whole waveforms, in the inversion has also been done in some cases. For example, the Generalized Radon Transform, which is based on approximation of the full waveform inversion Hessian, has been applied successfully on seismological array data. However, more general elastic isotropic full waveform inversion is not trivial. Challenges include the computation of waveforms, which needs to be efficient and accurate, inverting the Hessian and mitigation of crosstalk. In addition to this, accurate estimation of the source parameters is important. In this abstract we focus on the former problems. We present an efficient elastic ray-Born modeling technique that models the complete elastic-isotropic wave field. This modeling technique is then used to do both multi-parameter imaging and full waveform inversion. Both the modeling and imaging/full waveform inversion are done in the frequency domain. The imaging is done by taking the diagonal of the Hessian. The Hessian for the full waveform inversion is too large to be stored and the full waveform inversion is therefore performed using L-BFGS, which stores and inverts the Hessian using limited memory. When inverting for multiple parameters, P-velocity, S-velocity and density, cross-talk becomes an issue and we discuss how this can, at least partly, be mitigated. The implementation is done in both 2D and 3D. We present a 2D numerical example for a strongly heterogeneous elastic isotropic model and present both elastic isotropic imaging and full waveform inversion results. The model is based on exploration scale rather than regional scale. However, with some modification it should be possible to apply this to regional (array) data.

Päivi Mäntyniemi[1], Ludovic Fülöp[2], Gabriel Toro[3] and Olli Okko[4]: A Bayesian prior distribution of the maximum credible magnitude, M_{max}, for Fennoscandia

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[3]Lettis Consultants International, USA
[4]Radiation and Nuclear Safety Authority (STUK), Finland

The size of large future earthquakes has a direct bearing on understanding of long-term seismic hazard in a given region. However, to determine which value would characterize the full seismogenic potential of the tectonic situation of the target region without the inclusion of unrealistically large earthquakes is complicated. In low-seismicity regions, where seismic design is not required in the general building code, the issue of assessing the maximum possible magnitude (Mmax) arises particularly in probabilistic seismic hazard analysis (PSHA) for critical infrastructure. It is typically used as the upper bound of earthquake magnitude for the doubly truncated version of the Gutenberg-Richter magnitude-frequency equation in the representation of seismicity. The required value for Mmax appears as a technical parameter that facilitates the hazard computation, but has simultaneously fundamental implications to the seismogenic potential of the target region.

The aim of this work is to establish a prior distribution of the Bayesian approach for the determination of Mmax for Finland and adjacent areas in northern Europe. The Bayesian methodology to establish the Mmax is intuitively appealing, because it makes use of evidence of earthquake occurrence in analog regions worldwide. Earthquake magnitudes are sampled in space to compensate for the brevity of seismicity records available, in accordance with the ergodic principle. The slowly accumulating evidence of fault activation within unbroken ancient cratons is incorporated into the rigorous calculation and provides insight into maximum magnitudes to be considered in Fennoscandia.

We follow the original methodology described in the benchmark Electric Power Research Institute (EPRI) investigation by Johnston et al. (1994), who developed Mmax prior distributions based on earthquakes in continental interiors for the purpose of assessing the Mmax for Central and Eastern U.S. (CEUS). Emphasis is on the prior distribution: the posterior will be nearly identical to it, because the likelihood function based on earthquake data from Fennoscandia will be nearly flat in the region where the prior distribution is non-zero. The CEUS is a very large and complex stable continental region, in which large-magnitude historic earthquakes have occurred, while our target region is far more compact, covers some of the most ancient crust on Earth, and has exhibited low seismicity levels during historic times.

Reference

Johnston, A.C., Coppersmith, K.J., Kanter, L.R., Cornell, C.A., 1994. The earthquakes of stable continental regions. Electric Power Research Institute Report TR-102261-V1 + Appendices A–E

Acknowledgement

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Minttu Pekkala[1], Tuija Luhta[1], Kari Komminaho[1] and Christian Schiffer[2]: The Scandinavian Arctic Continental Experiment (SCARCE) – Installation and scientific goals

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SCARCE (The Scandinavian Arctic Continental Experiment), a network of 16 broad-band stations and 17 geophones was installed in Finnish Lappland and Finnmark in Norway in the late summer of 2022. The project is a collaboration between University of Helsinki and University of Uppsala. A field trip for deploying the seismic stations took place from the 20th of September to 2nd of October 2022. The aims are to monitor local seismicity and study lithospheric structure. The post glacial faults and other intraplate seismicity are challenging to study with the existing, more sparsely distributed seismic networks of the area. The data will also be used to study the structure of the crust and upper mantle. Specifically, collisional structures and crustal thickness may reveal information about the relationship between Timanian, Caledonian and older terranes and structures and can add to the understanding of the region's geological history. The first data will be collected after one year, and the remaining data after two years, when the stations will be retrieved.

Annukka Rintamäki: Full moment tensor solutions of the induced seismicity in the Otaniemi enhanced geothermal system

Institute of Seismology, University of Helsinki

An pilot enhanced geothermal system (EGS) was developed at record depth of ~6 km in Otaniemi, Espoo, southern Finland. This depth was required in the cool Precambrian Fennoscandian shield to reach the required temperature of 120 °C. Two EGS stimulations were performed at Otaniemi in 2018 and 2020 to create a fracture network between two geothermal wells and to increase permeability. Records of the seismicity induced by stimulations provide a unique opportunity to study the stress and fracture interactions in deep crystalline bedrock in an area of relative seismic quiescence and persistent glacial isostatic uplift. The environment of outcropping competent bedrock and the absence of a sedimentary rock layers supports the good data quality, which enables the application of various analysis techniques to the small magnitude seismicity.

In this work, the seismic source mechanisms of the induced events are analysed by full moment tensor (FMT) inversion using waveform fitting. The advantage of waveform fitting is that more information of the seismic signal can be utilized compared to first motion polarities or scalar amplitude values, but the analysis is sensitive to noise. Small scale crustal variations, seismic noise and site effects introduce features in the waveform data, that cannot be modelled by FMT and Green's functions based on 1D velocity models. This can complicate the analysis of small earthquakes and of the typically small non-double-couple components of the FMT that are, however, important for reservoir characterization. Here we are able to select high-SNR waveforms and apply correction coefficients for time delays and amplitude scaling between observed and synthetic waveforms, which yields good quality results for events with magnitudes as small as $M_W0.5$.

We present FMT solutions of ~260 induced events from the 2018 and 2020 EGS stimulations in Otaniemi. The dominant reverse mechanisms and focal plane orientations are in agreement with ambient stress field and the S_{Hmax} orientation. The event source types average to a double-couple solution. Moreover, the source type distribution can be attributed to random variation around the mean, indicating that the dominant source mechanism type is close to a pure double couple without significant opening components. The seismic source mechanism analysis indicates that the dominant fracture process of the Otaniemi induced events was shear failure induced by pore pressure increase and that fracture propagation was driven by tectonic stresses. Reported stress magnitudes and pumping pressures support these observations.

M. Roth, B. Lund, M. Schieschke, B. Oskooi, P. Schmidt, G. Eggertsson, H. Shomali, K. Berglund: **The Swedish National Seismic Network - News and Status 2022**

The Swedish National Seismic network is operating currently 66 permanent and 13 temporary broadband stations.

Station UMAU (Umeå) had a failure in autum 2021 and was taken out of operation. We decided to close down the site permanently, because of drainage problems and the planned construction of a wind farm in close vicinity. We have scouted a suitable site some 15 km northwest of UMAU, where we are going to establish a new station BLMU.

We also deinstalled station UDD (Uddeholm) in September 2022. This station was one of the earliest stations of the SNSN (analogue from 1969-1998, digitial from 1999 - 2022), but the ambient noise conditions -especially arising from a close by road- worsened to a degree that the station became useless for local and regional monitoring. As replacement for UDD, we are using a broadband station of the Hagfors array (operated by FOI), which is about 7 km to the northeast of UDD.

On the data processing side we further adapted our 4 automatic systems (MSIL, SeisComp, Earthworm, and Migration Stack). Since the beginning of 2022 we generate a near-realtime automatic 'Common' bulletin that contains events located independently by SeisComp as well as by Earthworm. We also implemented an automatic classification schema for events in the Common and the automatic SIL bulletins. We intend to skip the manual processing of clear explosion events (except for felt events or events of special interest). This will greatly decrease the workload of our analysts (historically more than 93% of events analyzed at the SNSN are blasts/explosions) and allows to focus on earthquakes.

<u>Amir Sadeghi-Bagherabadi</u>, Vuan , A., Aoudia , A., Parolai , S., the AlpArray and AlpArray SWATH D working group: High-Resolution Crustal S-wave Velocity Model and Moho Geometry Beneath the Southeastern Alps: New Insights From the SWATH-D Experiment

Institute of Seismology, University of Helsinki

We compiled a dataset of continuous recordings from the temporary and permanent seismic networks to compute the high-resolution 3D S-wave velocity model of the Southeastern Alps, the western part of the external Dinarides, and the Friuli and Venetian plains through ambient noise tomography. Part of the dataset is recorded by the SWATH-D temporary network and permanent networks in Italy, Austria, Slovenia and Croatia between October 2017 and July 2018. We computed 4050 vertical component cross-correlations to obtain the empirical Rayleigh wave Green's functions. The dataset is complemented by adopting 1804 high-quality correlograms from other studies. The fast-marching method for 2D surface wave tomography is applied to the phase velocity dispersion curves in the 2–30 s period band. The resulting local dispersion curves are inverted for 1D S-wave velocity profiles using the non-perturbational and perturbational inversion methods. We assembled the 1D S-wave velocity profiles into a pseudo-3D S-wave velocity model from the surface down to 60 km depth. A range of iso-velocities, representing the crystalline basement depth and the crustal thickness, are determined. We found the average depth over the 2.8–3.0 and 4.1–4.3 km/s iso-velocity ranges to be reasonable representations of the crystalline basement and Moho depths, respectively. The basement depth map shows that the shallower crystalline basement beneath the Schio-Vicenza fault highlights the boundary between the deeper Venetian and Friuli plains to the east and the Po-plain to the west. The estimated Moho depth map displays a thickened crust along the boundary between the Friuli plain and the external Dinarides. It also reveals a N-S narrow corridor of crustal thinning to the east of the junction of Giudicarie and Periadriatic lines, which was not reported by other seismic imaging studies. This corridor of shallower Moho is located beneath the surface outcrop of the Permian magmatic rocks and seems to be connected to the continuation of the Permian magmatism to the deep-seated crust. We compared the shallow crustal velocities and the hypocentral location of the earthquakes in the Southern foothills of the Alps. It revealed that the seismicity mainly occurs in the S-wave velocity range between ~3.1 and ~3.6 km/s.

Jari Kortström, Pasi Lindblom and Pirita Seipäjärvi: Latest updates and maintenance of IMS station PS17 FINES array

Institute of Seismology, University of Helsinki

FINES is a small aperture array consisting of 16 sites in three concentric rings. The soil in the station area is dominated by precambrian gneiss outcrops, and the terrain varies between 133 and 176 meters above the sea level.

Electricity and the intra-site communication are distributed from CRF to the sites with overhead cables. Each site uses twisted pair cable line from the CRF and telecommunication is based on DSL modems. The most common reason for data outages of the station is damages on the overhead cables and malfunctions of DSL modems. Telecommunication cables have been broken many times, thus the quality of cable lines has been affected.

Recently we have paid attention to preventive maintenance of intra-site telecommunication. New DSL modems were installed in 2021 with new Moxa models utilising G.SHDSL technique, reaching significantly faster data transfer speed compared to old modems.

In 2022, we started major maintenance to the telecommunication lines. Multi pair cables from CRF (FIA1) to FIA2 and FIA3 were completely renewed starting from the equipment rack. The renewal of cables continues and next step is to replace single pair cable lines to the sites where we see low data connection quality between the DSL modems.

Hossein Shomali, Michael Roth, Gunnar Eggertsson, Peter Schmidt and Björn Lund: The SNSN automatic bulletin

University of Uppsala, Sweden

Historically the Swedish National Seismological Network (SNSN) have on a regular basis only made manually analyzed earthquakes publicly available, typically at a delay of one to two weeks. Today at SNSN, two automatic near real time systems are run for detection of seismic events within Sweden and its close neighborhood, seiscomp and earthworm.

Utilizing all SNSN stations as well as stations from seismic networks in surrounding countries, both system detect all "large enough to be felt" events within Sweden but also produces spurious events. As the two systems differ in algorithms used for phase detection as well as event association, the spurious events formed by the two systems may differ, hence selecting the intersection of the automatic catalogs of the two systems spurious events not common to both will be eliminated. This forms the basis of the SNSN automatic bulletin which is planned to be made publicly available during fall/winter 2022/23. The bulletin is further augmented by a machine learning algorithm for event type classification. This poster will present the details behind the creation of the bulletin and compare its performance to the manual analysis of events within the Swedish borders.

Hanna Silvennoinen and Janne Narkilahti: Northern Finland seismological network in 2022 Sodankylä geophysical observatory, University of Oulu, Finland

Sodankylä geophysical observatory, University of Oulu, Finland

Northern Finland seismological network is a network of permanent seismic broadband stations operated by Sodankylä geophysical observatory, University of Oulu. The current network consists of nine seismic stations, of which four are connected to the international data centres offering open access real-time data. The first permanent seismic station in Sodankylä geophysical observatory started in 1956. There has been a seismic station operational in Sodankylä area nearly continuously, though the station has had to move a couple of times. It's currently operating under station code SGF. It was followed by two more station on subsequent years near Oulu (OUL) and Kuusamo (MSF). These original three stations were modernizated 2005-2007 with replacing the old short-period instruments with state of the art very broadband seismometers and modern data acquisition system. As a part of the modernization project, the fourth station was established. These four stations form the Northern Finland seismological network operating under the network code FN in the Federation of Digital Seismograph Networks. The continuous and real-time data from the stations is freely distributed and archived by GeoForschungsZentrum Potsdam (GFZ) in addition to the archive held at the observatory. Between 2013-2017 five new stations were installed in Oulanka (OLKF), Kolari (KLF), Ranua (RANF), Raja-Jooseppi (RAJF) and Kaamanen (KMNF). Of these stations, RNF, RAJF, and KMNF were found during an Academy of Finland funded co-project with Institute of Seismology as a part of the EPOS effort of these institutes. The stations at OLKF, RAJF, and KMNF have been installed in boreholes equipped with so-called posthole seismometers standing freely at the bottom of the borehole while KLF and RANF are more “traditional” setups. The installation in a borehole offers several benefits, for example, the stable temperature throughout the year and attenuation of certain types of seismic noise. On the other hand, this type of installation offers new challenges and SGO staff has been testing new solutions and materials for the installation, as well as insulation, power supply, and other practical details on all the five new sites.

Heidi Soosalu[1], Michael Roth[2], Michael Schieschke[2], Peter H. Voss[3], Thomas Funck[3] and Jari Kortström[4]: Nordic Seismology Hardware Knowledge Sharing

[1]GSE, Geological Survey of Estonia
[2]SNSN, Uppsala University
[3]GEUS, Geological Survey of Denmark and Greenland,
[4]FNSN, University of Helsinki

Seismological institutions in the Nordic countries use a variety of sensors, digitizers and communication equipment in their station networks. In order to improve dissemination of knowledge on instruments used for Nordic seismological monitoring, we established a list of equipment and contact information of persons with in-depth experience with the hardware (the author list of this poster). All authors have expressed willingness to assist and share information with Nordic colleagues on the listed instrumentation. We intend to maintain the list as a living document with the aim to extend it and to invite more colleagues with hardware expertise to join.

Heidi Soosalu[1,2], Marja Uski[3], Kari Komminaho[3] and Anu Veski[1]: **Geological interpretation of recent Estonian earthquakes**

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Estonia is a low-seismicity area, where instrumental observations span just the latest decades. Accordingly, little research has so far been carried out upon Estonian earthquakes. Few fault lineations of the Precambrian crystalline basement in Estonia can be observed directly, because of the overlying 100–600 m thick sequence of sedimentary bedrock. Mostly the faults can be sketched on the basis of geophysical measurements, with the aid of a few drill cores.

During recent years, the 3-station permanent seismic network of Estonia has been supplemented with seven temporary stations as a joint Finnish-Estonian endeavour. The extended network has collected a seismic dataset that allows quantitative analysis. Four local earthquakes, detected in 2016–2018 and with magnitudes 1.2–2.0 have been tentatively geologically interpreted. Their focal parameters were determined, and their mechanisms examined in the regional stress field context. The results were compared with the magnitude-4.5 Osmussaar earthquake from 1976, the largest known Estonian event. The analysis indicates that all five earthquakes can be associated with predominantly left-lateral strike-slip movement taking place on NNW-SSE subvertical faults. This interpretation is in harmony with the general stress field of northern Europe, which is dominated by plate movement.

Mathilde B. Sørensen[1], Torbjørn Haga[2] and Atle Nesje[1]**: Earthquake-induced landslides in Norway**

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Norway is located in an intraplate setting with low to moderate seismicity. The mountainous landscape leads to a high level of landside activity throughout the country. Earthquake-induced landslides (EQIL) are common in seismically active areas, but there are only few studies of EQIL in intraplate regions. We systematically analyse all earthquakes in Norway with magnitudes ≥ 4.5 in the time period 1800-2021. For each event we search for reports of EQIL in the available macroseismic data and in the Norwegian landslide database. We furthermore consider precipitation data from the Norwegian Climate Service Centre to evaluate the role of precipitation in the triggering of the identified potential EQIL. Through this approach we identify 21 EQIL that have been triggered by 8 earthquakes in the magnitude range 4.5 – 5.9. The events are widely distributed in northern and southern Norway. The landslide distance limits and landslide areas are much larger than those found in empirical studies on global datasets, and in agreement with data from other intraplate regions. For half of the events, it seems that triggering was due to a joint effect of precipitation and earthquake ground shaking. Our observations confirm that intraplate earthquake have potential to trigger EQIL over large distances, most likely due to the low ground motion attenuation in such regions. Slope susceptibility seems to be another important factor in the triggering. Our conclusions demonstrate the importance of considering EQIL potential in earthquake risk management in intraplate regions.

Steffen Uhlmann: Managing logistically challenging broadband monitoring projects on high latitudes using latest generation seismic instrumentation

IGM GmbH / Nanometrics Inc., Germany

Mastering remote VBB monitoring projects has always been a challenge requiring prohibitively expensive and extensive logistics, rough environmental conditions, harsh power requirements and absence of status monitoring.

We describe the capabilities and possibilities for realizing challenging projects using latest generation seismic instrumentation such as the polar rated Pegasus Digitizer and the Trillium Horizon 360, cutting down logistics, installation and maintenance costs while still providing lowest noise high fidelity seismic that can be fielded today.

Toni Veikkolainen, Kati Oinonen, Tommi Vuorinen, Jari Kortström, Päivi Mäntyniemi, Pasi Lindblom, Tuija Luhta, Jennifer Hällsten and Timo Tiira: Monitoring urban seismicity with the HelsinkiNet network

Institute of Seismology, University of Helsinki, Finland

The City of Helsinki reached out to the Institute of Seismology (ISUH) in 2019 to build a network of three seismic stations in Helsinki, Finland. The resulting HelsinkiNet network could register seismic events in its test phase in late 2019, before the full operation in 2020. The network originally consisted of three stations in Kuninkaantammi (KUNI), Lauttasaari (LAUT), and Vuosaari (VUOS), located on the outskirts of the city to reduce azimuthal gaps associated with events within the city boundaries. In early 2021, an additional station was installed in Ruskeasuo (RSUO) to monitor a medium-depth heat well currently under construction. All stations have a direct contact to the prevailing Svecofennian bedrock but, for easy maintenance, none of them have been installed in drillholes. In near future, the institute will extend the network with another station in Seurasaari, western Helsinki.

The main goal of HelsinkiNet is to improve the seismic event detection accuracy in the Helsinki metropolitan area. The induced seismicity, especially the events associated with stimulations of the St1 Deep heat project in Otaniemi, Espoo, played a key role when the project was initiated. The strongest induced earthquakes were around magnitude 2 and were widely felt by residents, not only in Espoo but especially in western Helsinki. The increasing demand for high-rise and underground construction, and the location of several societally critical facilities in the Helsinki region also calls for better knowledge of the possible adverse effects of urban seismicity.

During the operation of HelsinkiNet, the most prominent induced seismic events so far occurred in the Otaniemi-Laajalahti area in April-May 2020 with magnitude 1.2. HelsinkiNet stations also detected two induced earthquakes in Koskelo, western Espoo in November-December 2020. The stronger one was of magnitude 1.1. The network has registered natural earthquakes in the sea area of Kirkkonummi, and in Hakunila, Vantaa in 2020-2021, with magnitudes 1.0, 0.8, and 0.7, respectively. Macroseismic reports could be associated with the events in Hakunila, one event in Koskelo, and several events in Otaniemi-Laajalahti. A few events with magnitudes no more than 1.0 observed in the Otaniemi-Laajalahti area in December 2021 showed that human activity can alter the stress field of the bedrock, leading to induced seismicity even if no drilling, or pumping of water into the bedrock takes place simultaneously. In September 2022, the network detected two small natural earthquakes, both with magnitude 0.2, in central Espoo, outside the St1 stimulation area.

A most exotic event was observed in September 2021 when citizens reported in the social media about hearing an unusual loud noise. While investigating the seismic data from the network and some temporarily deployed stations of the FLEX-EPOS project, a seismic signal was found. Research cooperation with the Ursa Astronomical Association reached the conclusion that the reason behind the observation was not a bolide from the space, but a detonation of an improvised explosive device in low atmosphere in northern Pasila, Helsinki.

Apart from the event detector of the Finnish National Seismic Network (FNSN), HelsinkiNet has its own tailored event detector that registers signals within a 30-km distance from downtown Helsinki. The network also uses data from other permanent and temporary seismic stations in the Uusimaa province of Southern Finland, and stations of the Estonian National Seismic Network. Although the maintenance of HelsinkiNet is based on bilateral agreements renewed annually, the design of the network supports long lasting operation.

Kristín Vogfjörd: SIL seismic network and data management and quality control

Icelandic Meteorological Office, Iceland

Abstract

Peter H. Voss[1] and Michael Roth[2]: Nordic EPOS Research Infrastructure Management - Plans and Recommendations

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We present the status of the Nordic EPOS report on Research Infrastructure Management - Plans and Recommendations.

The report is the outcome of a discussion conducted during session on “Efficient RI management and services, including EPOS services” at the joint Joint Nordic EPOS Meeting and 52nd Nordic Seismology Seminar, where different approached on RI management were presented and a request for a joint presentation on the topic was formed.

The report includes examples and suggestion on how to manage a research infrastructure, from a seismological point of view. But we hope that is also can serve as an inspiration to RI managers from other fields.

Seismological RI most often consist of data acquisition system (seismometers) distributed in an area where the seismic activity needs to be monitored or geological structures studied. The RI also include a central datacentre at where the data is collected, processed, analysed and shared.

The report does not include guidelines on resource management, such as staff training etc. It also does not give guidelines on the selection of sites for seismological monitoring, only on aspects that could have an effect on the data acquisition system failures.

Peter H. Voss, Trine Dahl-Jensen, Tine B. Larsen & Nicolai Rinds: **Cryo-generated seismic events in Greenland**

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We here present the status of GEUS' web service that provides parametric data from cryo-generated seismic events in Greenland, detected, processed and analysed at the Geological Survey of Denmark and Greenland – GEUS. The web service consists of two web listings, one with a simple CSV listing of time and location and one including all the parametric data of the cryo-generated events, e.g. location uncertainties and arrival times and amplitudes of the seismic waves at the seismic stations. Here we outline the background for seismic monitoring of sources related to the dynamics of the cryosphere, the observation of glacial earthquakes, and the initiation of the ongoing GLISN project. We describe the process of extracting the parametric data from the seismic recordings in Greenland for the database that is linked to the web service. We describe how to access and use the web service. The nature of seismic signals from the cryo-generated events, provided by the web service, are often tremor signals with unclear or multiple P- and S- phases, the uncertainty of the location of the events is therefore also addressed. A previous version of the parametric data was presented at the 2022 ESC/3ecees meeting (see https://3ecees.ro/wp-content/uploads/2022/08/Proceedings_3ECEES_2022.pdf#page=4268).

Peter H. Voss[1], Trine Dahl-Jensen[1], Tine B. Larsen[1], Marie Keiding[1], Elin Skurtveit[2] & the SHARP Team*: The SHARP Storage project

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The SHARP Storage project (Stress history and reservoir pressure for improved quantification of CO2 storage containment risks) was launched in late 2021 with the overall aim to increase accuracy of subsurface CO2 storage containment risk management througt the improvement and integration of subsurface stress models, rock mechanical failure and seismicity observations. SHARP is collaboration between 16 research institutions and companies and is supported under the ACT3 call. ACT is an ERA NET Cofund, which is a tool established by the European Commission under the Horizon 2020 programme for research and innovation. In this presentation we will give an overview of the SHARP Storage project and introduce the ongoing seismological activities in the project. This include e.g. building a new earthquake catalogue for the North Sea area and design improved seismic monitoring schemes for CO2 storage sites. More information on the SHARP Storage project is found at https://sharp-storage-act.eu/.

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Tommi Vuorinen: Detection of Induced Seismicity With a Dense Surface Network: Otaniemi Case

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The Otaniemi Enhanced Geothermal System in Espoo, Finland, was a pilot project by the company ST1. The project was aimed to generate up to 40 MW of district heating using water circulation between two wells drilled down to ~6 km depth in a cool and (presumably) competent Proterozoic bedrock. In order to create the necessary water reservoir and the flow connection, the site was hydraulically stimulated twice – the primary stimulation in June-July of 2018 and a smaller counter-stimulation in May 2020 – inducing thousands of microearthquakes.

To monitor the incuded seismicity, Institute of Seismology (ISUH) installed temporary dense surface networks consisting of ~100 geophone stations (mostly DSS Cubes with 4.5 Hz 3-channel geophones), which complemented the station networks operated by ISUH and ST1. This wealth of data (~8 to 10 TB) has been – and is being – used for detecting, locating and analyzing the induced earthquakes.

In this talk, the application of a template matching routine for the collected datasets is presented. The use of different detection methods, and the unique challenges brought by the urban environment are also briefly discussed.

C. Weidle[1], T. Meier[1], A. Omlin[2], K. Obst[3]: Seismic monitoring in Northern Germany

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Northern Germany is a weak seismicity region with low level of exposure to seismic hazard. Accordingly, seismic hazard assessment has been pursued with low priority in the past. Rather poor observational conditions in the North German Basin are also a limiting factor for seismic monitoring. In a multi-institutional collaboration, we have been able to increase the number of permanent broadband stations in the North German Federal States of Schleswig-Holstein and Mecklenburg-Vorpommern from previously four in the year 2013 to currently fifteen. All data of the network are freely available through the EIDA node at the Federal Institute for Geosciences and Natural Resources (BGR) in Hannover.

Three small-scale seismic arrays, around Bad Segeberg north of Hamburg, on Heligoland in the North Sea, and on Rügen in the Baltic Sea, are complementary local seismic networks for improved monitoring of offshore areas and targeted investigations. Data from these seismic arrays can also be used to investigate properties of oceanic microseism in epicontinental seas. The array on Rügen has only been established in late 2021 and expands the GEOFON station RGN with seven additional broadband seismometers to an array of 5 km aperture.

In addition to the development and operation of the seismic network, regular data analysis has been established at Kiel University. Analysis routines are based around a Seiscomp system for continuous, automated data collection and processing. Continuous array analysis and a network waveform amplitude detector provide additional, redundant detection capabilities. Recent events near the island of Bornholm provide an opportunity to evaluate and improve our routine monitoring scheme.