The 54th Nordic Seismology Seminar

Herdla, Bergen, 12-14 June, 2023

Program

Monday

12:00-13:00 Lunch

Session 1 Networks and instrumentation

13:00-13:10 Welcome and practical information

13:10-13:30 Michael Roth: The Swedish National Seismic Network - Status 2023

13:30-13:50 Björn Lund: SNSN: demands and opportunities in these times of change

13:50-14:10 Heidi Soosalu: Estonian input in instrumental seismology

14:10-14:30 Pasi Lindblom: New Challenges of the Millennium for the Finnish National Network

14:30 Check-in as rooms become available

Refreshments

~~15:00~~ **14:55** **Departure excursion** – short walk to the boat.

~~15:15~~ **15:10** **Departure** with boat from Biologen, Herdla to Blomøyna
Short walk to the visitor center

15:40 Guided tour at Northern Lights visitor center for CO_2 transport and storage.

17:30 Possible departure with boat to Biologen, Herdla – Alternative 1*

18:15 Guaranteed departure with boat to Biologen, Herdla – Alternative 2*

*The boat is in regular passenger transport between islands. If one trip is cancelled due to no travelers, departure will be at 17:30

19:00 Dinner

Tuesday

Session 2 Seismicity, structure, data processing

09:00-09:20 Kathrin Lieser: The extended ISC-EHB Bulletin: 1964 – 2020

09:20-09:40 Peter Voss: The SHARP Storage project, WP2: New earthquake bulletin for the North Sea

09:40-10:00 Hasbi Ash Shiddiqi: Building a high-quality earthquake catalog for the North Sea: preliminary results

10:00-10:20 Helene Meling Stemland: Experiences from two passive seismic surveys in front of a Svalbard glacier

10:20-10:40 Break

Session 3 Networks and instrumentation

10:40-11:00 Tormod Kværna: A web-based tool for near real-time estimation of network detection capability

11:00-11:20 Steffen Uhlmann: Going posthole - Benefits and drawbacks of subsurface seismic installations

11:20-11:40 Mathilde B. Sørensen: The High Arctic Ocean Observation system – HiAOOS

11:40-12:00 Jon Magnus Christensen: NORSAR Stations – Current status and future plans

12:00-13:00 Lunch

13:00-14:00 Walk

Session 4 Seismicity, structure, data processing

14:00-14:20 Annie Jerkins: Location of the 21 March 2022 Tampen Spur Mw 5.1 Earthquake, North Sea

14:20-14:40 Jens Havskov: Measuring near surface attenuation kappa from the displacement spectrum of small earthquakes: a case study from intraplate Norway

14:40-15:00 Felix Halpaap: Closing the Gap Between Local and Regional Observations of Segmented Ocean Plate Boundaries With a New 25-Year Earthquake Catalog of the European Arctic Seas

15:00-15:20 Stéphane Rondenay: GLImER/PyGLImER - A suite of automated tools for receiver function analysis, everywhere, all at once

15:20-15:30 Break

15:30-15:50 Przemyslaw Domel: Local seismicity in the obliquely spreading setting of Fram Strait constrained from ocean bottom seismometers: Implications for fluid flow and methane seepage

15:50-16:10 Tommi Vourinen: An overview on four years of induced seismicity in the Otaniemi EGS

16:10-16:30 Peter Schmidt: Automatic event detection and potential intersection catalogs in Sweden

16:30 Poster session with short presentation of the posters (2 min each)

Refreshments

19:00 Dinner

Wednesday

Session 5

09:00-09:20 Jan Michalek: UIB-NORSAR EIDA node - new data, new services

09:20-09:40 Harald Nedrebø: Nordic perspective of EPOS Data Portal

09:40-10:00 Annakaisa Korja: A FAIR Nordic EPOS Data Hub 2020-2023 round up

10:00-10:20 Nordic EPOS and the way forward - Discussion

10:20-10:40 Break

10:40-11:00 Lars Ottemöller: Intraplate earthquake swarms: Nature and causes

11:00-11:20 Toni Veikkolainen: SOFIC - a seismic profile along the southern coast of Finland

11:20-11:40 Discussion and closing remarks.

Check-out

12:00-13:00 Lunch

Bus departure from Herdla to Bergen

12:36 – 13:50 Bus #499 to Kleppestø and then #484 (or boat) to Bergen

14:34 – 15:51 Bus #499 to Ravnanger terminal and then #495 to Bergen

https://reise.skyss.no/planner

ORAL PRESENTATIONS

The Swedish National Seismic Network - Status 2023

Michael Roth, Björn Lund, Peter Schmidt, Hossein Shomali, Gunnar Eggertsson, Michael Schieschke, Behzad Oskooi, Karin Berglund, Ruth Beckel

In recent years the Swedish National Seismic Network (SNSN) made an increased effort to modernize station and communication equipment, and thereby has significantly improved continuous real-time data availability and data quality. Currently, the SNSN is operating 67 permanent broadband seismic stations evenly distributed in the South, along the Eastern shore and the North of Sweden. In addition, a temporary network of 13 station was deployed in 2021 for a 3-years period to monitor small earthquakes associated with postglacial faults at the Western coast of the Gulf of Bothnia. Within the last 23 years SNSN has recorded and analyzed about 199000 seismic events out of which only 12960 (~6.5%) were classified as natural events. Automatic event processing and event type classification are of the essence in order to cope with the amount of data and to decrease the workload of the analysts. SNSN is running four different and independent automatic processing routines in parallel. One purpose is to detect and locate seismic events in real-time at magnitudes as low as possible. The other purpose is to utilize intersection bulletins to screen out spurious events. SNSN has recently also implemented an automatic Neural Network event type classification in order to support the analysts. SNSN plans to skip the manual analysis of all clear explosions and mining induced events, that were independently detected and located both with the SeisComp as well as with the Earthworm systems - except they are of special interest. We intend to include the reliable automatic solutions, inclusive associated automatic phase readings, clearly marked as automatic solutions, into the SNSN bulletin. We will give an update on the current status of the SNSN infrastructure, the data processing flow, data products and future plans.

SNSN: demands and opportunities in these times of change

Björn Lund and the SNSN team

The times they are a-changing, and with that comes new demands and opportunities for a contry-wide monitoring operation as a seismic network. In this talk I will show some examples of how seismic analysis can contribute to national security and law-and-order, discuss opportunities for seismic network operations and raise the issue of how security and information exchange is sometimes at odds with each other.

Estonian input in instrumental seismology

Heidi Soosalu
Geological Survey of Estonia, heidi.soosalu@egt.ee
Department of Geology, Tallinn University of Technology

Global instrumental seismology was initiated at the end of the 19th century. A few countries were in the forefront of development of seismic equipment: Italy, Japan, Great Britain, Germany, and Russia. The success of Russian seismology during the early decades of the 20th century is tightly connected with Estonia.

One of the “fathers of modern seismology” was the Russian physicist, prince Boris Galitzin. In 1893, he spent a semester teaching at the University of Tartu, Estonian Johan Wilip being his student. In 1896, Galitzin invited Wilip to St. Petersburg as his assistant. Hugo Masing, an Estonian constructor of precision mechanical instrumentation followed suit. Together they produced equipment for physical measurements. Galitzin devised and experimented new technical solutions. Masing compiled drawings, built prototypes, and worked out means of mass production. Wilip assisted in experimenting, specializing in seismology.

The invention by Galitzin in 1902, an electromagnetic seismometer was a major improvement in comparison with existing mechanical earthquake recording systems. Vertical and horizontal Galitzin seismographs equipped 18 observatories in the Russian empire, Europe, and China.

Untimely death of Galitzin in 1916 ended the fruitful co-operation between the trio. Turbulent political situation in Russia deteriorated chances for pursuing seismology. In 1920, Wilip and Masing moved to Tartu in newly independent Estonia. They continued manufacturing the Galitzin seismographs and developed new solutions to overcome weaknesses of the original instruments. By 1925 this led to production of the next generation: the Galitzin-Wilip seismographs. The most important improvement was temperature compensation of the vertical seismometer for getting rid of drift.

Galitzin-Wilip seismographs gained fame and spread in 23 observatories around the globe. The first country to acquire them was Denmark. The Danes desired best available instruments for deployment in Greenland. They experimented with various equipment, and these “Russian pendulums” turned out to excel in teleseismic observing. Seismograms of the Greenland Scoresbysund station had a crucial role in Inge Lehmann’s discovery of Earth’s inner core.

Cornelius G. Dahm studied the 1931 magnitude-7.8 New Zealand earthquake using recordings of 113 seismic stations around the globe. From the seismographs of European Galitzin-type sensors he deduced that in fact three subsequent earthquakes had taken place. He particularly praised the precision of recordings of Wilip’s own seismic station in Tartu.

Again, tumultuous events in Europe cut the flourishing production of seismic equipment. The Tartu seismic station operated until the onset of the World War II in 1939 when they run out of photographic seismogram paper from Holland. The workshop of Masing was hit by a Russian bomb in 1943. During the 1950s, construction of Galitzin-Wilip seismographs was resumed in Germany. During the 1960s, the Galitzin-Wilip seismographs or their newer analogies were operating at more than 50 seismic stations, and still at seven stations in the 1970s.

New Challenges of the Millennium for the Finnish National Network

Matti Tarvainen, Pasi Lindblom and Seppo Nurminen

Seismograph stations in Finland have met and will head for big changes and configurations in 1999 and next year.
The certification of the IMS primary station PS17 (FINESS) began in January, and as the final upgradings will be done, the status of the station changes.

The on-line stations are transformed gradually into dial-up stations. This new upgrading means installations of PC mother board based (LINUX) data loggers at some stations. During this autumn stations VAF, NUR, KAF and KJN have been equipped with these new instruments. Also GS-13 seismometers at VAF were replaced by a GURALP broad-band 3-component unit.

This presentation will show the status of the Finnish national network as it is now, and also some plans in the future will be unveiled.

The extended ISC-EHB Bulletin: 1964 – 2020

Kathrin Lieser[1], Burak Sakarya[1], E.R. Engdahl[2], James Harris[1], Domenico Di Giacomo[1] and Dmitry A. Storchak[1] and the ISC team

1) International Seismological Centre (ISC), Thatcham, UK 2) University of Colorado, Boulder, USA

The ISC-EHB dataset is a groomed subset of the ISC Bulletin with only well constrained teleseismic events. It is a valuable tool for global and regional seismicity studies, as well as for tomographic studies. The original EHB dataset covering data years 1960 to 2008 was developed with procedures described by Engdahl et al. (1998) and has been widely used in the past in various types of earth science studies. In this talk we describe the refined criteria and procedures for the construction of the ISC-EHB dataset defined in Weston et al. (2018). e.g., event selection, data processing and earthquake relocation with a special focus on depth. In the past decade there has been a consistent decline in the number of depth phase picks reported to the ISC. Depth phases are crucial for the ISC-EHB dataset as they directly influence the quality of the depth constraint. In order to address this issue, we have been routinely picking depth phases from data month April 2016 for earthquakes across the globe with mb

NEIC≥4.8 recorded at 28°-72° distance range. This has allowed to constrain free depths of about 4000 earthquakes in the ISC Bulletin that were fixed to default depths before. The ISC-EHB is updated annually in line with the completion of analysis of the data year in the Reviewed ISC Bulletin and was just extended by data year 2020. Here, we illustrate some of its features in regions of e.g., flat subduction, slab segmentation and complex subduction. The ISCEHB Bulletin is freely available from the ISC website (http://www.isc.ac.uk/isc-ehb), where seismicity maps and cross sections along all subduction zones are shown.

The SHARP Storage project, WP2: New earthquake bulletin for the North Sea

Evgeniia Martuganova[1], Tom Kettlety[2], Johannes Schweitzer[3], Annie Jerkins[3], Daniela Kühn[3], Peter Voss[4], Trine Dahl-Jensen[4], Brian Baptie[5] and Cornelis Weemstra[1]

[1]Delft University of Technology; [2]University of Oxford; [3]NORSAR; [4]GEUS; [5]BGS

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 through the improvement and integration of subsurface stress models, rock mechanical failure and seismicity observations. As part of the SHARP Storage project's work package 2, an extensive unique earthquake bulletin for the North Sea is compiled using seismicity data from all relevant data centres. The bulletin is stored using the IASPEI Seismic Format (ISF). Preliminary processing included duplicate removal and explosion identification. In total, 15 230 events were recorded between 1382 and 2022, of which 3 223 were identified as likely or potential explosions. We here present the current status of this earthquake bulletin. More information on the SHARP Storage project can be found at https://sharp-storage-act.eu/ .

Building a high-quality earthquake catalog for the North Sea: preliminary results

Hasbi Ash Shiddiqi, Lars Ottemöller, Felix Halpaap
University of Bergen

The North Sea is one of the most seismically active regions in Norway. Accurate earthquake location is needed to assess the region's seismic hazard, especially in relation to oil and gas

facilities and CO2 storage. Hypocenter locations, usually derived using stations in mainland Norway and the British Isles, have relatively large uncertainties due to large azimuthal gaps and lack of nearby observations. This study was carried out as part of the HNET Phase 3 project. We present preliminary results of our effort to develop a high-quality earthquake catalog and assess location uncertainties. We apply a machine learning algorithm to detect and pick earthquakes from seven years of continuous waveforms (2016-2022), including one year of OBS data that were collected as part of HNET. We are able to detect 50% additional events, mostly smaller than ML 1, than the Norwegian National Seismic Network. The increase in event numbers is due to both a more sensitive detection algorithm and additional stations. The new catalog reduces the magnitude of completeness from Mc 1.5 to Mc 1.1. We find that using the improved catalog the b-value changes from 1.0 to 0.94 for the seven years. The new catalog is relocated using a Hierarchical Bayesian algorithm and will be interpreted in relation to the tectonics.

Acknowledgement: We are grateful for useful review and discussion with all partners of the HNET project in Phase3 (Equinor ASA, Shell, TotalEnergies, NORSAR, University of Bergen, Northern Lights, CGG and GASSNOVA).

Experiences from two passive seismic surveys in front of a Svalbard glacier

Helene Meling Stemland, University of Bergen

Widespread glacier loss is observed in the Arctic region due to rising surface temperatures. Since there are many natural sound sources in the glacial environment, seismic monitoring in front of glaciers can be used to monitor glacier dynamics, such as their calving rate. Acquiring such data is challenging due to the remote location of many glaciers, heavy equipment, and frozen ground. Further, analysis of seismic icequake events is challenging due to their complex source functions.

In this talk, I will describe the details of two seismic experiments we have conducted in front of a partly marine-terminating glacier on Svalbard. We placed seismic receivers on land and at the seabed in front of Nordenskiöldbreen and passively monitored the glacier for up to five weeks. We recorded seismic signals attributed to calving, fracturing/crevassing, and tectonic earthquakes. Here, I will talk about the challenges involved in the seismic campaigns, lessons learnt, and share some of the preliminary analysis of the data.

A web-based tool for near real-time estimation of network detection capability

Tormod Kværna, Mathias Johansen, Håkan Bolin (all NORSAR)

The instantaneous detection capability of a seismic network can be estimated from the amplitudes of observed data at the different stations, provided that representative amplitude-distance curves are available for the seismic phases considered. On the global scale, an extended version of the Veith-Clawson amplitude-distance curve can be applied to short-period P-wave amplitudes observed in the distance range 0°-180°.

The seismic network of the International Monitoring System (IMS) forms the backbone of the verification regime of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO). Consequently, the performance of the network needs to be documented. A key parameter in this respect is the event detection threshold which can vary significantly with time during situations such as high station noise levels, large earthquakes, or outages of key stations. NORSAR has in cooperation with the CTBTO staff developed a web-based tool for enhanced analysis and presentation of detectability maps based on the Threshold Monitoring methodology. Key elements of the application are:

- Display of absolute and relative thresholds maps for time intervals selected by the user.
- Options for setting of colour scales, contour levels and magnitude scales.
- Analyses of detection thresholds for any user-selected geographical area.

We will in this presentation demonstrate the functionality of the tool and show examples of absolute and relative detection thresholds at global, regional, and local scales.

Going posthole - Benefits and drawbacks of subsurface seismic installations.

Steffen Uhlmann, IGM GmbH / Nanometrics Inc.

In this talk, we show the results of a comparison study between surface, posthole and borehole seismometer deployments; aiming to provide a guide to achieve cost-effective and convenient deployments. We present typical noise characteristics of surface and subsurface installation and discuss the implications for seismic monitoring in different scenarios.

The High Arctic Ocean Observation system – HiAOOS

Mathilde B. Sørensen, UiB

The “High Arctic Ocean Observation system”-project (HiAOOS) was launched in January 2023 with funding from the Horizon Europe Research Infrastructures programme. HiAOOS will develop, implement, and validate several ocean observing technologies to improve data collection in the ice-covered Arctic Ocean. A network of multipurpose moorings will be deployed for two years in the deep Nansen and Amundsen Basins. UiB will develop methods for analyzing acoustic data to detect and locate earthquakes and other geohazard events and lead a work package on “Use cases and training”. In this presentation I will present the plans for the project, with focus on UiB’s planned acoustic seismology work.

ORSAR Stations – Current status and future plans

Jon Magnus Christensen

This presentation will give an overview of NORSARs field installations and station operations. Emphasis will be on newly installed stations and how we have set up the State-of-Health monitoring system as well as future projects.

Location of the 21 March 2022 Tampen Spur Mw 5.1 Earthquake, North Sea.

Annie Jerkins, Volker Oye, Tormod Kværna

On the 21 March 2022 a M_w 5.1 earthquake struck the Tampen spur region in the North Sea. The event was the largest recorded earthquake in the region for 33 years and was felt all over southern Norway and resulted in a temporary shut-down of the Snorre B oil platform. As the event occurred close to a high number of offshore installations, it is important to obtain a reliable location estimate.

What is so unique about this earthquake was that it was detected by one of the world’s most extensive permanent reservoir monitoring systems, stationed at the Snorre field, only a few kilometers from the epicenter. Additionally, the earthquake was observed with high signal-to-ratio at both regional and teleseismic distances. To pinpoint a location, we employ two different approaches utilizing different data sets and methods. Firstly, we estimate a location using data from the large Snorre array and a local velocity model in a grid search location algorithm. Secondly, we relocate the earthquake by combing local, regional and teleseismic data in a regular inversion scheme. Due to the earthquake’s magnitude teleseismic depth, phases are recorded globally with high azimuthal coverage. The time difference between the P and depth phase aided in refining the depth estimate. Both methods yield similar locations with a depth of 27 km, suggesting a well-constrained location of the earthquake.

Measuring near surface attenuation kappa from the displacement spectrum of small earthquakes: a case study from intraplate Norway

Jens Havskov (1), Lars Ottemöller (1) and Olga-Joan Ktenidou (2)

1: University of Bergen, Norway

2: National Observatory of Athens, Greece

This study has, for the first time, determined near surface attenuation κ for hard rock sites in Norway. In contrast to most κ studies we have used small events (Ml<1.5) at short distances (< 50 km) to determine κ from the displacement spectra and thus make no assumptions about the spectral decay for frequencies above the corner frequency. The average κ for the horizontal and vertical components are 32 and 27 ms respectively. These values are comparable to other studies, however studies using acceleration spectra generally have higher horizontal than vertical κ..

The Nordland area in northern Norway is the only area deviating significantly from the average value. This area is characterized by swarm like shallow seismicity, which seems to be related to fluid saturated fracture zones that may cause the higher κ of 46 ms.

Closing the Gap Between Local and Regional Observations of Segmented Ocean Plate Boundaries With a New 25-Year Earthquake Catalog of the European Arctic Seas

Felix Halpaap, Lars Ottemöller, Calum Chamberlain, Steven Gibbons

Oceanic ridges and transform faults comprise nearly 45% of the Earth's plate boundaries. Even though they have lower seismic moment release rates than convergent plate boundaries, these intricately segmented oceanic plate boundaries host a large part of Earth's seismicity. Analyzing how their segmentation is expressed through their seismic behavior has not been commonly possible due to limited observations compared to plate boundaries on land. Even with ocean bottom deployments, a challenge is that there is often no overlap between event catalogs produced routinely from regional networks (typically with M>3.5) or from short local deployments (M<3). To close this gap, we apply a sensitive earthquake detection pipeline to complement a regional catalog over 25 years through template matching. We focus on the 3000 km of oceanic plate boundaries and adjacent areas in the European Arctic (68° - 87°N, 20°W - 40°E). For our initial catalog of 35000 earthquakes, we merge data from local to global observations and consolidate phase picks, hypocenters, and probabilistic location errors with BayesLoc. The waveforms of a well-observed subset with 15500 events form the templates that we correlate against continuous seismograms recorded at up to 300 stations (incl. 8 arrays). We use optimized versions of the software packages RobustRAQN (preparation and quality control), EQcorrscan (template matching) and fmf2 (GPU vendor-agnostic correlation) on a GPU-powered cluster. We set strict thresholds for robust event detections based on correlations and picks at >6 sites and in 3 independent time windows. From >200M initial detections, we filtered out, picked, and relocated >700K earthquakes, revealing seismicity in the oceanic crust and on the Svalbard archipelago at an unprecedented scale (25 yrs, Mc<2.5, relative error <2 km). A preliminary analysis shows that earthquake swarms, aftershock sequences, persistent sites of seismic activity (including repeaters), and sites devoid of seismicity characterize a complex segmentation of the plate boundary. We relate the activity to the boundary's tectono-magmatic character which includes (ultra-)slow spreading ridges, volcanic centers, and transform segments.

GLImER/PyGLImER - A suite of automated tools for receiver function analysis, everywhere, all at once

Stéphane Rondenay, Lucas Sawade, Peter Makus, Felix Halpaap, Kathrin Spieker

This presentation provides an overview of a suite of automated tools developed over the past decade to compute teleseismic receiver functions and construct images of the subsurface from the crust down to the mantle transition zone. The workflow takes care of the entire process, from data selection and download to signal processing, decovolution, quality control and generation of the images. The latest incarnation the package, PyGLImER, is written in Python. It is publicly available through GitHub and can be run through a set of user-friendly Jupyter Notebooks. We will illustrate some of the functionalities of GLImER and PyGLImER through a series of targeted surveys.

Local seismicity in the obliquely spreading setting of Fram Strait constrained from ocean bottom seismometers: Implications for fluid flow and methane seepage

Przemyslaw Domel1, Vera Schlindwein2,3, Andreia Plaza-Faverola1, Stefan Bünz1

1-CAGE-Centre for Arctic Gas Hydrate, Environment and Climate, Department of Geosciences, UiT-The Arctic University of Norway, Tromsø, Norway
2-Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany
3-University of Bremen, Faculty of Geosciences, Bremen, Germany

The Fram Strait opening is associated with a complex stress regime that results from the oblique relation between two ultra-slow spreading mid-ocean ridges, the Molloy ridge (MR) and the Knipovich Ridge (KR), offset by the Molloy Transform Fault (MTF). Gas-charged thick sedimentary deposits developed over both oceanic and continental crust. Sedimentary faulting reveals recent stress transfer into the sub-surface. However, the mechanisms by which stress accommodates across the west Svalbard margin and its effect on fluid flow and seepage dynamics remain poorly understood. An analysis of earthquake occurrence and focal mechanisms can shed light on the present state of tectonic forces in the area, their origin and potential influence on nearby faults. Conventional studies using land instrumentation provide incomplete seismological records even for such comparatively land proximal settings, due to still large distances to the nearest permanent observatories and a poor azimuthal coverage. We deployed 10 ocean bottom seismometers (OBS) for 11 months between 2020-2021 about 10 km north of the northern termination of KR to investigate patterns of stress transfer off the ridge and the influence on the sedimentary system. OBSs are spaced by about 10 km around an area characterized by fault-related seepage and sedimentary slumps visible on the bathymetry. Using partially automated routines we detected local earthquakes and manually picked seismic phases. We tried several 1D velocity models based on the nearby refraction study and selected one with smallest RMS error and average error ellipse. We subsequently located events with HYPOSAT using OBS phases only and in combination with phase arrivals from nearby land stations. We compared the location accuracy, and due to lack of earthquakes inside the network, estimated the range of distances within with OBS locations are more reliable. We discuss the observed misalignment of events at Molloy Transform Fault (MTF), sporadic seismicity at sedimentary drift Vestnesa Ridge and persistent seismicity in the outside corner between Knipovich Ridge and MTF (also seen on decadal land observations). The inferred earthquake distribution in the region has implications for understanding fault-related gas transport and methane seepage at Arctic margins.

An overview on four years of induced seismicity in the Otaniemi EGS

Tommi Vuorinen[1], Valtteri Hopiavuori[1], Gregor Hillers[1], Kati Oinonen[1], Jennifer Hällsten[1], George Taylor[2], and Martin Gal[2]
[1]University of Helsinki, Institute of Seismology, Helsinki, Finland
(tommi.at.vuorinen@helsinki.fi)
[2]Institute of Mine Seismology, Kingston, Tasmania, Australia

The company ST1 Oy planned to construct an Enhanced Geothermal System (EGS) with two boreholes drilled down to ca. 6 km depth beneath the Aalto University campus in Otaniemi, Espoo. The company performed two stimulations, in 2018 and in 2020, with a goal of opening up a water reservoir and achieving water circulation between the boreholes. The stimulation periods, which induced thousands of earthquakes, and their immediate surroundings were monitored by both permanent and temporary seismic networks with over 100 stations located within a few tens of kilometers of the site. Between and after the stimulations, the site was and is still being monitored by a relatively dense, consisting in total of ca. 20 stations, regional surface station and company installed borehole station networks.

We provide a brief summary of the induced seismicity from the beginning of the primary stimulation in June 2018, through the shorter second stimulation in May 2020, all the way to the end of 2022. We discuss the various features of the induced seismicity discovered using an event catalogue spanning 3½ years created using a cross-correlation based event detection tool. Further, we present the seismogenic index and a statistically derived Mmax.

Automatic event detection and potential intersection catalogs in Sweden

Peter Schmidt and the SNSN team

At the Swedish National Seismological Network (SNSN), four automatic systems for regional seismic event detection are currently in operation: Seiscomp (SC), Earthworm (EW), Migration stack (MS), and SIL. In addition an intersection catalog (COMBULL), is produced by considering the events in SC and EW whose origins are within 5 seconds and 30 km central distance. While SIL forms the basis for the manual analysis at SNSN all four systems as well as COMBULL contribute with information during the manual analysis. The COMBULL will further during 2023 be made publicly available as a fast and reliable automatic catalog of seismic events in Sweden, augmented by automatic event classification by a newly developed artificial neural network. All automatic systems use different algorithms for phase detection and association and are tuned to different detection sensitivity. In general, the more sensitive one of the systems is to smaller events the more spurious detection's are also formed, increasing the workload of the manual analysis. Over the period COMBULL has been in production at SNSN it has shown to effectively filter out spurious events. SNSN is therefore considering the potential of other intersection catalogs between the automatic systems currently in use. Here we present the statistics of the automatic detection's systems in use and potential intersection catalogs that can be formed from them over a period of five months in 2022. We compare each automatic catalog to the manually analyzed, within the Swedish borders, and study the results in terms of matched events and un-matched events.

UIB-NORSAR EIDA node - new data, new services

Jan Michalek

The UIB-NORSAR EIDA node was established in 2019 for providing access to seismic waveform data from Norwegian territory and from networks deployed by UiB and NORSAR globally. The presentation will show statistics of data usage and update you on new EIDA services (being developed or already implemented) which might simplify your workflows and reporting.

Nordic perspective of EPOS Data Portal

Harald Nedrebø, Jan Michalek

The EPOS Data Portal (https://www.ics-c.epos-eu.org/) has been officially released publicly in April 2023. Which services and datasets are covering the Nordic area? What can be improved?

A FAIR Nordic EPOS Data Hub 2020-2023 round up

Annakaisa Korja[1], Päivi Haapanala[1], Nordic EPOS Council members[1-6] and Nordic EPOS Working groups[1-10].

[1]University of Helsinki, [2]Geological Survey of Denmark and Greenland, [3]Icelandic Meteorological Office, [4]University of Bergen, [5]University of Oulu, [6]Uppsala university, [7]Finnish Meteorological Institute, [8]Geological Survey of Estonia, [9]NORSAR, [10]Luleå University of Technology

Nordic EPOS - A FAIR Nordic EPOS Data Hub – collaboration project between 6 Nordic partners ended this April (31.4.2023). The project was funded through NordForsk's Nordic Research Infrastructure Hubs (2020–2022). University of Helsinki was coordinating the project aiming to enhance Nordic capacity building and knowledge exchange related to EPOS (European Plate Observing System). Other partners were: Geological Survey of Denmark and Greenland (GEUS), Icelandic Meteorological Office (IMO), University of Bergen (UiB), University of Oulu (UO), and Uppsala University (UU). All partner organizations operate National Research Infrastructures (NRI) that deliver data to EPOS Thematic Core Services (TCS) and/or are partners in TCS consortiums.

Nordic EPOS project supported active Nordic collaboration by organising workshops, trainings and events on EPOS data usage, FAIR (Findable, Accessible, Interoperable, Reusable) data principles, and on harmonising data management. The arranged activities were aimed for students, researchers, and technical staff working in Nordic countries in the field of Solid Earth sciences. Project outcomes are available on project website: www.helsinki.fi/nordic-epos.

In this presentation we will show the highlights of the project and reflecting on the project aims and outcomes. During the meeting, this presentation together with online Flinga whiteboard (edu.flinga.fi/s/EHB3F7Q) will serve as introduction to community discussion on the next steps for future Nordic collaboration.

Intraplate earthquake swarms: Nature and causes

Lars Ottemöller, Hasbi Ash Shiddiqi, Stephane Rondenay, Felix Halpaap (University of Bergen)

Earthquake swarms are observed in various tectonic environments such as plate boundaries and volcanoes, and are often associated with migration of fluids. However, they also occur in intraplate areas that are located away from plate boundaries and tectonically less active. This presentation will focus on earthquake swarm activity in three different intraplate regions: New Madrid (USA), Palghar (India) and Nordland (Norway). The examples will be used to demonstrate how seismic monitoring is used to detect and characterize seismic activity. The main physical cause for earthquakes is tectonic stress, but in these three cases fluids and hydrological load are considered to play a triggering role, evidence and models for this will be presented.

SOFIC - a seismic profile along the southern coast of Finland

Timo Tiira[1], Tomasz Janik[2], Toni Veikkolainen[1]* Kari Komminaho[1], Sakari Väkevä[3], and Aku Heinonen[4]

[1]*Institute of Seismology, Department of Geosciences and Geography, University of Helsinki, P.O. Box 68, 00014 Helsinki, Finland*
[2]*Institute of Geophysics, Polish Academy of Sciences, Księcia Janusza 64, 01-452 Warsaw, Poland*
[3]*Data and Information Centre, Finnish Environment Institute, Latokartanonkaari 11, 00790 Helsinki, Finland*
[4]*Geological Survey of Finland, P.O. Box 96, 02151 Espoo, Finland*
** gives the presentation*

The SOFIC – the South Finland Coastal Deep Seismic Sounding experiment was the latest one to continue the tradition of wide-angle reflection and refraction (WARR) profiles in Finland (Tiira et al., 2022). The project fully relied on data gathered from industrial and military blasts, thus making the experiment much less expensive compared to any with explosions produced fully for the project purposes. Similar experiments were carried out in 2012-2013 along KOKKY (Kokkola-Kymi) profile (Tiira et al., 2020) on a northwest-southeast-facing line spanning from Central Ostrobothnia to South Karelia, and along 450 km long profile HUKKA 2007 (Tiira et al., 2014) that crossed Paleoproterozoic and reactivated Archean terranes of Central Lapland. The geological environment of the 450 km long SOFIC profile can be divided in three parts: 1.7-1.9 Ga Southern Finland Subprovince of the Uusimaa Belt in the western 220 km, 1.62-1.65 Ga Wiborg Rapakivi Batholith in the eastern 170 km, and the geologically most diverse 1.75-1.95 Ga Saimaa Area in the far eastern 60 km.

The temporary recorders used in the SOFIC experiment consisted of 59 Data-Cube and 44 RefTek 125 (Texan) devices that were installed in Finland to the vicinity of the southern coast for summer 2015. Additional information was received from permanent stations of the national network. Due to data corruption, part of information from temporary recorders was lost. The spacing of stations with useful data was 6 km. The number of explosions recorded with adequate location and time constraints was 46. Out of them, 41 were from Finland and the rest from Russia. The least-squares algorithm of the SeisAn software, as well as satellite and aerial imagery were important for the initial estimation of shot locations. Origin times were initially estimated using the extrapolation of station arrival times to the past, using the standard three-layered one-dimensional model utilized in the routine analysis of the institute. Finally, ray-tracing modeling with the SEIS83 package (Červený and Pšenčík, 1984) was used to prepare a two-dimensional velocity model.

Results visible in Figure 1 show that along the SOFIC profile, P-wave velocities (Vp) of 5.9-6.2 km/s dominate at the depth range of 0-8 km in the west, 0-15 km in the middle, and 0-5 km in the east. Two deeper layers with Vp values of 6.3-6.6 km/s and 6.7-6.9 km/s are visible throughout SOFIC. In the middle, the lower of them reaches the greatest depth, 30 km. High velocity lower crust is visible at both ends in the profile, with Vp ~7.2 km/s in the west and Vp ~ 7.4 km/s in the east. Reflections indicated two upper mantle layers. The upper one had Vp ~ 8.2 km/s and a thickness of 7 km and was present in all but the westernmost 125 km of the profile. Another layer with Vp 8.3-8.4 km/s is visible along the entire profile. The Moho depth decreases from 52-54 km in the west, to 40-43 km in the east. Among the Finnish WARR profiles, it is unique as it shares the direction of the east-west trending extensional regime that led to the formation of rapakivi granites in southeastern Fennoscandia.

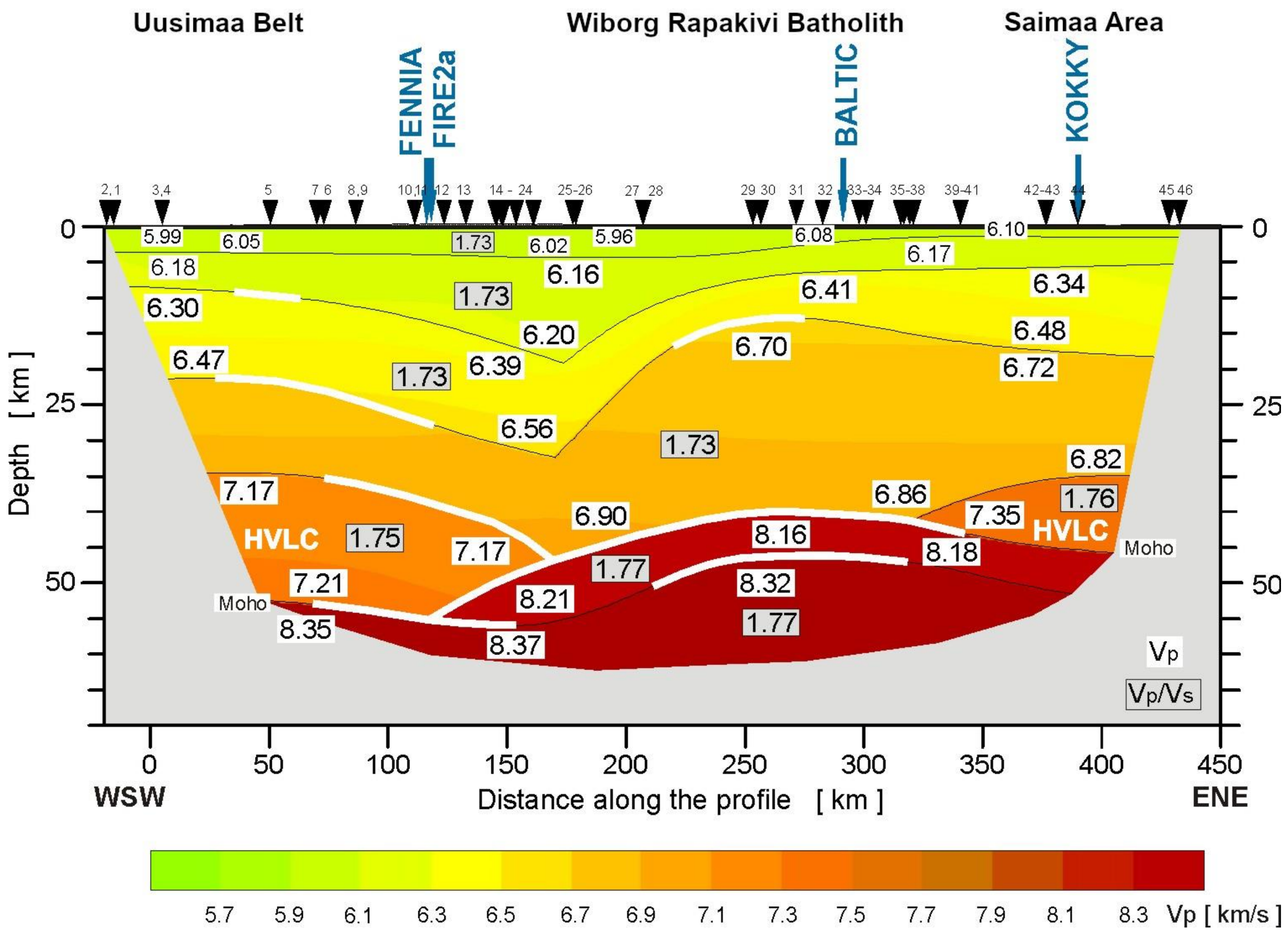

Figure 1. Final two-dimensional model of P-wave velocity along the SOFIC profile. The ratio of P- and S-wave velocities is also shown.

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POSTER PRESENTATIONS

Experiences in powering SmartSolos's with air-alkaline fence batteries in monitoring projects

Pirita Seipäjärvi, Tuija Luhta, Kari Komminaho, Jukka Keskinen Since 2019, Institute of

Seismology University of Helsinki has conducted several passive seismic measurement campaigns using SmartSolo IGU-16 3ch 5Hz geophones. In these projects, located in different parts of Finland, the devices have been measuring for a long time in harsh conditions, and often in locations that are difficult to reach. One of the most common issues with long-time measurements is securing sufficient power for the devices. The SmartSolo internal battery usually lasts around 2 weeks and is unsuitable for projects that aim to last up to 12 months. We have been experimenting with 9V 65 to 150Ah air-alkaline fence batteries to power SmartSolos during long field campaigns. In this poster we present our experiences. The fence batteries have proven to be cost efficient, reliable and easy to implement power solution for up to 12 months SmartSolo geophone measurements.

Open access data of seismic events for research purposes from the Institute of Seismology, University of Helsinki

Kati Oinonen, Jennifer Hällsten, Tommi Vuorinen & Toni Veikkolainen,
Institute of Seismology, University of Helsinki, Finland

Open access data of seismic events have different audiences and therefore it should be offered with different level of accessibility. For the general public, search tools with visualization by maps can be an easy way to explore the history of earthquakes in familiar neighborhoods or to inquire whether the experienced phenomenon was actually an earthquake. These services can be done with limited information on time, location, depth and magnitude of the event, which makes it more accessible for everyone regardless of background. An example of a search tool for the general public can be found on the Institute of Seismology, University of Helsinki (ISUH) website: https://www.seismo.helsinki.fi/EQs/query.php

For research purposes more information is usually needed, whether it is to evaluate the identification of the event or to compare the data with data from other agencies and services. At ISUH website there is a catalog of earthquakes which also includes some cryoseismic events, rock bursts and induced events, but identifies these with specified terms. There are also events that do not have reliable identification specified in the catalog. This information can be lost in services for the general public. Excluding these events from research produces a cleaner catalog. The catalog can be found here: https://www.seismo.helsinki.fi/bulletin/list/catalog/Scandia_updated.html

When combining catalogs from different Nordic countries earthquakes reported by several agencies are identified and the data are then integrated. However, there is always a chance that catalogs extending to neighboring areas have misidentified events that cannot be excluded just by combining earthquake catalogs. Therefore it is important to also combine catalogs with datasets that include explosion data. ISUH publishes monthly bulletins of all identified and located seismic events in Nordic format at https://www.seismo.helsinki.fi/bulletin/list/pdfbul.html

This bulletin data can also be found in the International Seismological Center's (ISC) bulletins.

Earthquake Catalogue of the Faroe Islands

Peter Voss[1], Finn Mørk[1], Tine B. Larsen[1], Trine Dahl-Jensen[1] & Nicolai Rinds[1]

[1]The Geological Survey of Denmark and Greenland – GEUS, Øster Voldgade 10, 1350 København K, Denmark, Contact: pv@geus.dk

On December 14th, 2022, the agreements delimiting the continental shelf beyond 200 M between Norway, Iceland and the Faroe Islands/the Kingdom of Denmark, was ratified. At GEUS we maintain the database of earthquakes recorded in Denmark, Greenland and the Faroe Islands. The new maritime boundaries extend the area of the Faroe Island by app. 27.000 km2, a review of the earthquake catalogue for the Faroe Islands has therefore been initiated. In this presentation we give the status of the catalogue review and provide an overview of the current and historic earthquake monitoring.

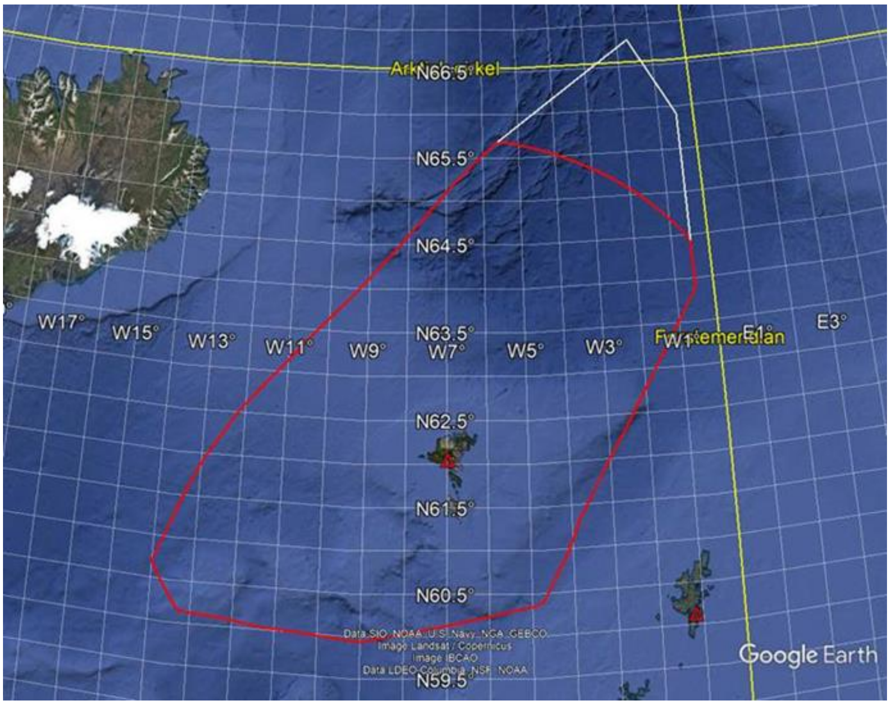

Figure: Map of the Faroe Islands, the white line shows the location of the new border. Red triangles are seismic stations.

REF: https://via.ritzau.dk/pressemeddelelse/de-maritime-graenseaftaler-nord-for-faeroerne-er-nu-tradt-i-kraft?publisherId=2012662&releaseId=13667373

Classification of Seismic Events in Sweden using Fully-Connected Neural Networks.

Gunnar Eggertsson, Björn Lund, Peter Schmidt, Michael Roth - Uppsala University

Distinguishing between different types of seismic events is a non-trivial task during automatic event analysis and thus typically requires manual revision. Analysts at the Swedish National Seismic Network (SNSN) use four different event types in the routine analysis: natural (tectonic) earthquakes, blasts (e.g. from mines, quarries and construction) and two different types of mining-induced events associated with large, underground mines. In order to aid manual event classification and to assign preliminary classification to automatic event definitions, we have implemented station-specific classification models, using fully-connected neural networks, which distinguish between the four event types. For each event, we band-pass filter the waveform data in twenty narrow frequency bands before dividing each component into four non-overlapping time windows, corresponding to the P-phase, P-coda, S-phase and S-coda. In each window we compute the root-mean-square amplitude and the resulting array of amplitudes is then used as the neural network inputs. We have also implemented a separate extension to the models, which distinguishes spurious phase associations from real seismic events in automatic event definitions. The most important features, on average, for the model predictions are computed from time windows associated with the P-phase and P-coda at intermediate to high frequencies (12-41 Hz) as well as S-phase and S-coda at low frequencies (1-3 Hz). Models trained on data recorded at specific stations have the capacity to be applied to data recorded on a different station and maintain high accuracy. The models are already in use at the SNSN, where they are used as a tool to assign preliminary type predictions to automatic event detections and to review manually analyzed events, identifying potential mistakes. The models will also be used to evaluate which events to subject to manual analysis in the future.