Joint Nordic EPOS Meeting and 52nd Nordic Seismology Seminar

18-21 October 2021

PROGRAM

Monday 18 Oct. 09:00-16:30 CEST (07:00–14:30 UTC)

Session 1 EPOS training activities

09:00–12:00 EPOS data portal (arranged by EPOS-ERIC/UiB)

13:00–14:30 Earthquake Hazard and risk (arraged by TCS-SEIS/EFEHR group)

15:00–16:30 Anthropogenic hazard in the Nordic region (arranged by TCS-AH/IG-PAS)

Tuesday 19 October 08:00–13:30 UTC (10:00-15:30 CEST)

NOTE: time slots given in UTC (CEST)

08:00 – 10:45 (CEST 10:00-12:45) Session 2. Efficient RI management and services, including EPOS services

Chair: Peter Voss

08:00–08:05 Welcome Address: Kristín S. Vogfjörð

08:05–08:20 Annakaisa Korja, et al.: Nordic EPOS: Strengthening Nordic collaboration

08:20–08:35 Jan Michalek: Nordic FAIR and Data Management Working Group

08:35–08:50 Peter Voss: RI management and services at the seismological service for the Kingdom of Denmark.

08:50–09:05 Peter Schmidt, Zaher Hossein Shomali, Michael Roth, Björn Lund: Nordic EPOS related activities at SNSN. Automatic and reviewed regional bulletins.

09:05-09:10 5 min. break/stand up and stretch!

09:10–09:25 Kati J. Oinonen, M. Uski: Future challenges of the FENCAT catalog.

09:25–09:40 Ilmo Kukkonen et al.: Updates from FIN-EPOS: Seismic Instrument Pool.

09:40–09:55 Kristín S. Vogfjörð and EPOS Iceland team: EPOS Iceland: Construction and management of RI to provide FAIR access to Geoscience data.

09:55–10:10 Ryan Gallacher, Dmitry Storchak and James Harris: An update on the CTBTO Link to the ISC Database.

10:10-10:45 Discussion session

10:45–11:15 Break (CEST 12:45-13:15)

11:15 – 13:55 (CEST 13:15-15:55) Session 3. European earthquake hazard model and its modification for the Nordic region

Chair: Björn Lund

11:15–11:30 Laurentiu Danciu: The 2020 Update of the European Seismic Hazard Model: insights for Iceland and Finno-Scandia Region

11:30–11:45 Helen Crowley: European Seismic Risk Model (ESRM20)

11:45–12:00 Björn Lund: On seismic hazard assessment in Sweden

12:00–12:15 Ludovic Fülöp, Päivi Mäntyniemi, Niina Junno, Kati Oinonen and Annakaisa Korja (WG1 of the Seismic-Risk project): Seismic source zone refinements of the Seismic-Risk project in Finland.

12:15–12:30 Benedikt Halldorsson, Farnaz Bayat, Milad Kowsari, Claudia Abril: New 3D fault system models of the two transform zones of Iceland for physics-based seismic hazard assessment

12:30-12:45 Short break (CEST 14:30-14:45)

12:45–13:00 Farnaz Bayat, Benedikt Halldorsson, Milad Kowsari: On the calibration of the first 3D transform fault system model of the South Iceland Seismic Zone and Reykjanes Peninsula Oblique Rift

13:00–13:15 Milad Kowsari and Benedikt Halldorsson: Sensitivity of the Seismic Hazard Maps to the Selected Ground Motion Models: A Case Study of North Iceland

Poster

13:15–13:25 Niranjan Roshi: Probabilistic seismic hazard assessment of Sweden

13:25-13:55 **Discussion** on the status of the earthquake hazard model in the Nordic region

Wednesday 20 October 08:00–14:30 UTC (10:00-16:30 CEST)

08:00 – 09:10 (CEST 10:00-11:10) Session 4. General seismology session

Chair: Sigríður Kristjánsdóttir

08:00–08:05 Welcome day 2

08:05–08:20 Michael Roth, Björn Lund, SNSN Team, Uppsala University: The Swedish National Seismic Network - Status 2021.

08:20–08:35 Heidi Elisabet Soosalu: Future plans for the Estonian seismic network.

08:35–08:50 Valerijs Nikulins: State and problems of seismological monitoring in Latvia. Prospects and ways of solving problems.

08:50–09:05 Sigríður Kristjánsdóttir: The HIKE project: Towards better earthquake locations.

Posters:

09:05–09:15 Akash Kharita, Peter Voss, Trine Dahl-Jensen, Michael West: Discrimination of icequakes and tectonic earthquakes using unsupervised Machine Learning.

09:15-09:30 Short break (CEST 11:15-11:30)

09:30 – 11:15 (CEST 11:30-13:15) Session 5. Seismic and volcanic events and activity in Iceland

Chair: Benedikt Halldórsson

09:30–09:45 Atefe Darzi, Benedikt Halldorsson, Birgir Hrafnkelsson, Hossein Ebrahimian, Fatemeh Jalayer, Kristín S. Vogfjörð: Improving short-term seismicity forecasting following strong earthquakes in the South Iceland Seismic Zone

09:45–10:00 Tom Winder, Robert S. White, Bryndís Brandsdóttir: Investigating shallow seismic swarms between Askja and Herðubreið with QuakeMigrate: a new, open-source Python package for automatic earthquake detection and location

10:00–10:15 Hanna Blanck, Dirk Rössler, Bernd Weber, Benedikt Halldórsson: On the capability of the new Grindavik seismic and strong motion array on inferring volcano-tectonic processes.

10:15–10:30 Egill Árni Guðnason: Iceland Geosurvey's seismic monitoring of exploited geothermal areas.

10:30–10:45 Päivi Mäntyniemi, M.B. Sørensen and R.E. Tatevossian: Investigation of earthquake environmental effects in Fennoscandia.

10:45-11:15 General Discussions

11:15 Invitation to next Nordic Seismology meeting (53rd)

11:20 Closing Remarks: Sigurlaug Hjaltadóttir/Kristín S. Vogfjörð

11:25 End of meeting (CEST 13:25)

List of participants

Hanna Blanck	IMO and Univ. of Iceland
Tine B. Larsen	GEUS Dk
Kuvvet Atakan	Universitetet i Bergen (UiB)
Grzegorz Lizurek	IGF Poland
Federica Ghione	NORSAR
Gunnar Eggertsson	SNSN/Uppsala Universitet
Tom Winder	University of Cambridge
Sigríður Kristjánsdóttir	ÍSOR (Iceland Geosurvey)
Dmitry Storchak	International Seismological Centre (ISC)
Ryan Gallacher	International Seismological Centre (ISC)

Kristín S. Vogfjörð	Icelandic Met. Office (IMO)
Sigurlaug Hjaltadóttir	IMO
Akash Kharita	Indian Institute of Technology Roorkee
Nicolai Rinds	GEUS Dk
Ríkey Júlíusdóttir	IMO
Bergrún Arna Óladóttir	IMO
Thomas Funck	GEUS Dk
Hildur María Friðriksd.	IMO
Peter Voss	GEUS Dk
Peter Schmidt	Uppsala Universitet
Zaher Hossein Shomali	Uppsala Universitet
Christian Rönnevik	Universitetet i Bergen (UiB)
Sara Kverme	Universitetet i Bergen (UiB)
Heidi Elisabet Soosalu	Geological Survey of Estonia
Björn Lund	Uppsala Universitet
Päivi Mäntyniemi	Institute of Seismology, Univ. of Helsinki
Kati J. Oinonen	Institute of Seismology, Univ. of Helsinki
Michael Roth	Uppsala Universitet
Niranjan Joshi	Uppsala Universitet
Ludovic Fülöp	VTT Technical Research Centre of Finland
Päivi Haapanala	Institute of Seismology, Univ. of Helsinki
Annakaisa Korja	Institute of Seismology, Univ. of Helsinki
Jan Michalek	Universitetet i Bergen (UiB)
Valerijs Nikulins	Latvian Environm., Geology and Meteorology Center
Toni Veikkolainen	Institute of Seismology, Univ. of Helsinki
Katriina Arhe	Institute of Seismology, Univ. of Helsinki
Benedikt Halldórsson	IMO/Univ. of Iceland
Farnaz Bayat	University of Iceland
Milad Kowsari	University of Iceland
Atefe Darzi	University of Iceland
Laurentiu Danciu	ETH Zurich, CH
Helen Crowley	EUCENTRE, PAVIA, ITALY
Lars Ottemöller	Universitetet i Bergen (UiB)
Egill Árni Guðnason	ÍSOR (Iceland Geosurvey)
Jennifer Hällsten	Institute of Seismology, Univ. of Helsinki
Andrius Pacesa	Lithuanian Geological Survey
Tuija O. Luhta	Institute of Seismology, University of Helsinki
Þorbjörg Ágústsdóttir	ÍSOR (Iceland Geosurvey)
Kristján Ágústsson	ÍSOR (Iceland Geosurvey)

Gunnar B. Guðmundsson	IMO
Hanna Silvennoinen	University of Oulu
Niina M. Junno	Institute of Seismology, University of Helsinki
Joana C. Esteves Martins	Advisory Group for Economic Affairs and Climate, Utrecht
Ilmo Kukkonen	University of Helsinki
Jouni Nevalainen	University of Oulu
Anna Maria Dichiarante	NORSAR
Outi Kaisko	Rock Mechanics Consulting Finland Oy
Marianne Malm	AFRY, Vantaa
Lauri Rinne	AFRY, Vantaa
Marja Uski	Institute of Seismology, University of Helsinki

NORDIC EPOS: Strengthening Nordic collaboration

A. Korja[1], K. Atakan[2], P.H. Voss[3], M. Roth[4], K. Vogfjord[5], E. Kozlovskaya[6], E.I. Tanskanen[7], P. Haapanala[1], and Nordic EPOS Working Groups*

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[2]University of Bergen, [3]Geological Survey of Denmark and Greenland (GEUS), [4]Uppsala University, [5]Icelandic Meteorological Office (IMO), [6]Oulu Mining School, University of Oulu, [7]Sodankylä Geophysical Observatory, University of Oulu
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Nordic EPOS - A FAIR Nordic EPOS Data Hub – is a consortium of Nordic geophysical institutions, universities and surveys financed by NordForsk. Nordic EPOS enhances and stimulates the active Nordic interactions related to EPOS and solid Earth research in general. It promotes common Nordic interests in EPOS, builds data services beneficial for the Nordic community. Nordic EPOS offers joint workshops and trainings on FAIR data collection, usage and management, monitoring of seismicity and induced seismicity, ash and gas eruptions, and geomagnetic hazards. It also disseminates related tutorials, demos, and actual and virtual training sessions. Together we can address global challenges in Norden with Nordic data.

Keywords: EPOS (European Plate Observing System), Nordic countries, collaboration, FAIR (Findable, Accessible, Interoperable and Re-usable), data

1. Overview

The European Plate Observing System, EPOS, brings together Earth scientists, national research infrastructures (RIs), information and communication technology experts, decision makers, and public to develop new concepts and tools for accurate and sustainable solutions for today's and future's societal questions concerning geo-hazards and those geodynamic phenomena relevant to the environment and human welfare. EPOS is a multidisciplinary, distributed ESFRI landmark RI that facilitates the integrated use of data, data products, and facilities from the solid Earth science community in Europe.

Nordic EPOS builts on the long-standing Nordic tradition of sharing geo-related data and experiences on processing and analyzing of such a data. Nordic EPOS enhances and stimulate the ongoing active Nordic interactions related to solid Earth RIs in general and EPOS in particular. 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.

Nordic EPOS - A FAIR Nordic EPOS Data Hub- is a project funded through NordForsk's Nordic Research Infrastructure Hubs (2020–2022). It is a consortium of geophysical institutions from Nordic universities and surveys that are members of the national EPOS consortia. Namely, the six partners are University of Helsinki (UH; Finland), Geological Survey of Denmark and

*__Nordic EPOS working group:__ Barsotti S., Dahl-Jensen T., Funck T., Hillers G., Indrøy H.K.S., Keiding M., Kukkonen I., Larsen T.B., Lund B., Michalek J., Oladottir B., Pfeffer M.A., Rinds N., Rønnevik C., Tellefsen K., Vuorinen T., Junno N. etc.

Greenland (GEUS; Denmark and Greenland), Icelandic Meteorological Office (IMO; Iceland), University of Bergen (UiB; Norway), University of Oulu (UOULU; Finland), and Uppsala University (UU; Sweden). Partner organizations operate National Research Infrastructures (NRI) that deliver data to EPOS Thematic Core Services (TCS) and/or are partners in TCS consortiums.

2. Nordic EPOS Objectives

One of the main objectives of the FAIR Nordic EPOS Data Hub is to increase awareness of the FAIR principles in the geoscientific community by offering trainings on EPOS data and metadata standards to RI and research personnel specially in Nordic countries. Trained personnel can proceed in opening new EPOS related data sets and they can help other scientists and students in applying the standards to their experimental data sets for publication in international journals. In addition, the hub aims to increase expertise of the geoscientific community in using multi-disciplinary scientific data set of EPOS in cross-disciplinary research of the Arctic and in the supplying mineral and energy resources of Fennoscandia. Similarly the data sets will be open to other groups studying e.g. the Arctic, global change, natural hazards and urbanization. For comprehensive list of objectives, see Figure 1 where the mission and goals of the hub are illustrated.

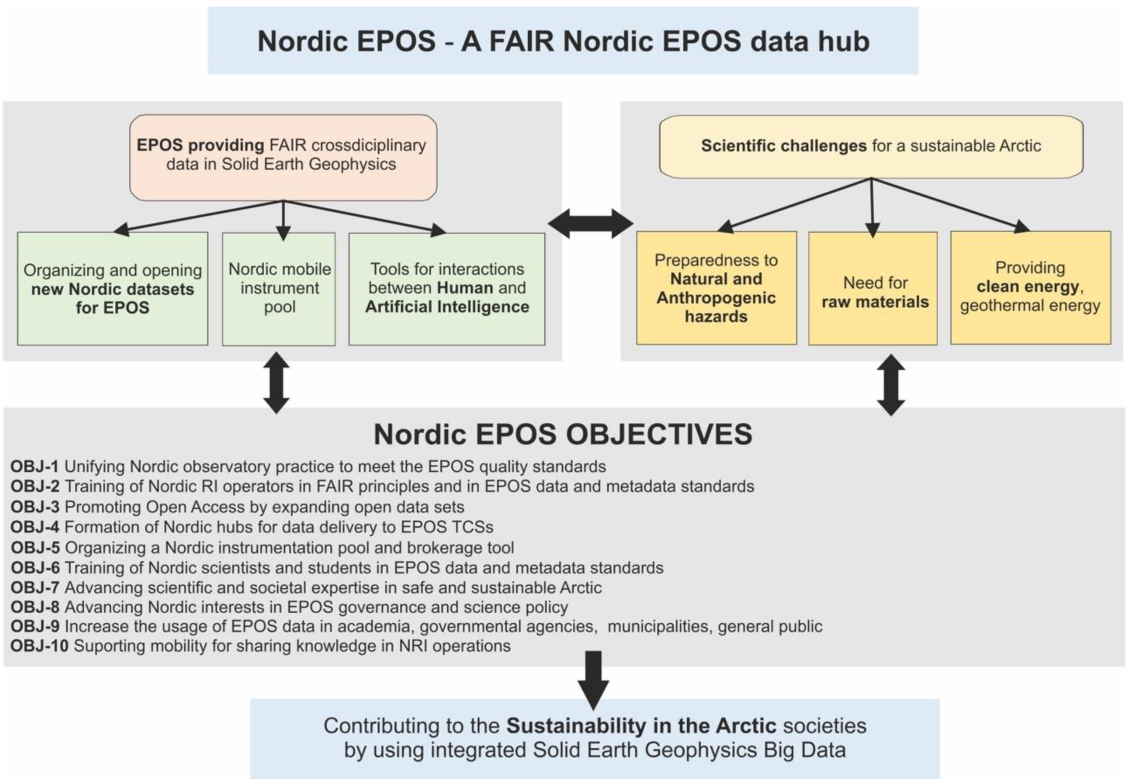

Figure 1. *Mission and goals of Nordic EPOS.*

3. Nordic EPOS objectives and activities

The hub aims to advance the usage of multi-disciplinary solid Earth data sets on scientific and societal problem solving, increase the amount of open, shared homogenized data sets, and increase the scientific expertise in creating sustainable societies in Nordic countries and especially in the Arctic region. In addition to developing services better suited for Nordic interest for EPOS, it will also try to bring forward Nordic research interest, such as research of Arctic areas in TCS and EPOS-ERIC governance and scientific boards.

To reach the objectives, the hub is organized into tasks and activities. The main task are:

- Training in usage of EPOS-RI data and services
- Nordic data integration and FAIRness (Findable, Accessible, Interoperable and Reusable)
- Nordic station management of seismological networks
- Induced seismicity, safe society
- Ash and gas monitoring
- Geomagnetic hazards
- Communication and dissemination

Activities within the tasks are e.g. workshops, tutorials, demonstrations and training sessions (virtual and on-site) communication and dissemination of EPOS data and metadata at local, national and international workshops, meetings, and conferences. Many of the task are addressing several objectives of the hub and each of the main partners is responsible for several activities in one or several tasks.

In seismology, NORDIC-EPOS is particularly active in standardizing observatory practices and databases, especially in following EPOS metadata standards, in increasing expertise in seismic hazard assessment for intraplate regions, in preparing a seismic hazard map for the Nordic countries and in expert capacity building in monitoring of induced seismicity in urban areas.

For comprehensive list of upcoming events, see the Nordic EPOS webpages (https://www.helsinki.fi/en/infrastructures/nordic-epos). In addition, the activities are advertised via EPOS (https://www.epos-eu.org) and national RI websites and communicated and disseminated in public lectures, seminars, and short articles in expert journals. Most activities take place at or back-to-back with local, national and international conferences, meetings, workshops and seminar series.

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

Nordic FAIR and Data Management Working Group

Jan Michalek, Department of Earth Science, University of Bergen ,Norway

Nordic FAIR and Data Management Working Group has been established in 2020 within the Nordic EPOS project with aim to harmonize and share best practices on Data Management Plan (DMP) and implementation of FAIR principles within Nordic countries.
Short presentation of the topics discussed within this group and outcomes will be given.

Updates from FIN-EPOS: Seismic Instrument Pool

I. Kukkonen[1], E. Koivisto[1], G. Hillers[1], J. Näränen[2], S. Heinonen[3], E. Kozlovskaya[4], E. Tanskanen[5], T. Fordell[6], J. Leveinen[7], P. Skyttä[8], M. Poutanen[2], S. Mertanen[3], A. Viljanen[9], A. Pursula[10], N. Junno[1], P. Haapanala[1], A. Korja[1], and FLEX-EPOS and FIN-EPOS working groups

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FIN-EPOS is the Finnish national node of the European Plate Observing System (EPOS) and it is listed in the national research infrastructure roadmap. Process is ongoing in Finland to join the EPOS ERIC as a member. Under the FIN-EPOS umbrella a *Flexible instrument network for enhanced geophysical observations and multi-disciplinary research (FLEX-EPOS*) -project funded by the Academy of Finland is ongoing. A sub-component of the project is a Seismic Instrument Pool that provides seismic instruments for seismological (both controlled source and earthquake seismology) experiments for the FLEX-EPOS consortium parties.

Keywords: EPOS (European Plate Observing System), Research Infrastructure, national node, observatory network, Seismic Instrument Pool

1. Overview

The European Plate Observing System EPOS (https://www.epos-eu.org) is a long-term plan for the integration of existing national and trans-national research infrastructures (RIs) for solid Earth science in Europe. It is a multidisciplinary, distributed ESFRI (European Strategy Forum on Research Infrastructures) landmark RI that facilitates the integrated use of data, data products, and facilities from the solid Earth science community in Europe.

In Finland, the national initiative of EPOS called FIN-EPOS is part of the national research infrastructure roadmap for 2021–2024. FIN-EPOS is a joint community of universities (University of Helsinki (UH), University of Oulu (UOULU) and Aalto University) and research institutions (National Land Survey (NLS, FGI), Finnish Meteorological Institute (FMI), Geological Survey of Finland (GTK), VTT Technical Research Center for Finland Ltd, CSC-IT Centre for Science Ltd). The partners own and operate Earth science observatories, laboratories and data centers in Finland. Partners own their (meta)data and deliver it to EPOS Thematic Core Services (TCS) through national nodes, international data centers or global scientific programs, where they are members.

FIN-EPOS is coordinated by the Institute of Seismology, University of Helsinki. FIN-EPOS has a council that is responsible for defining a long-term national solid Earth sciences RI plan, for monitoring of the data delivery to EPOS TCSs, and for establishing transnational access. The council is also responsible for enhancing Finnish participation at European level initiatives related to EPOS, increasing the user base of EPOS data and the number of scientific partners in

FIN-EPOS. In Finland, a national governmental process to join EPOS ERIC as a member is proceeding.

FIN-EPOS is working together with the Nordic counter parts. University of Helsinki, namely the FIN-EPOS director, is leading a NordForsk funded Nordic EPOS consortium that organizes workshops and meetings on EPOS data usage, FAIR (Findable, Accessible, Interoperable and Reusable) data principles, and on harmonizing data management for students, researchers and technical staff of the Ris (see abstract: *Nordic EPOS: Strengthening Nordic Collaboration*).

2. FLEX-EPOS project

The FIN-EPOS station network has been renewed, e.g., within projects financed by Academy of Finland. During the past few years, FIN-EPOS has been upgrading the Finnish National Seismological Network (FNSN), and the geodetic and magnetic networks and laboratories, and initiated national collaboration with other ESFRI environmental RIs in establishing geophysical and environmental superstations. The development of superstations is based on existing permanent national seismic network and GNSS (Global Navigation Satellite System) stations that are under the FinnRef network; these stations are essential for future geophysical research.

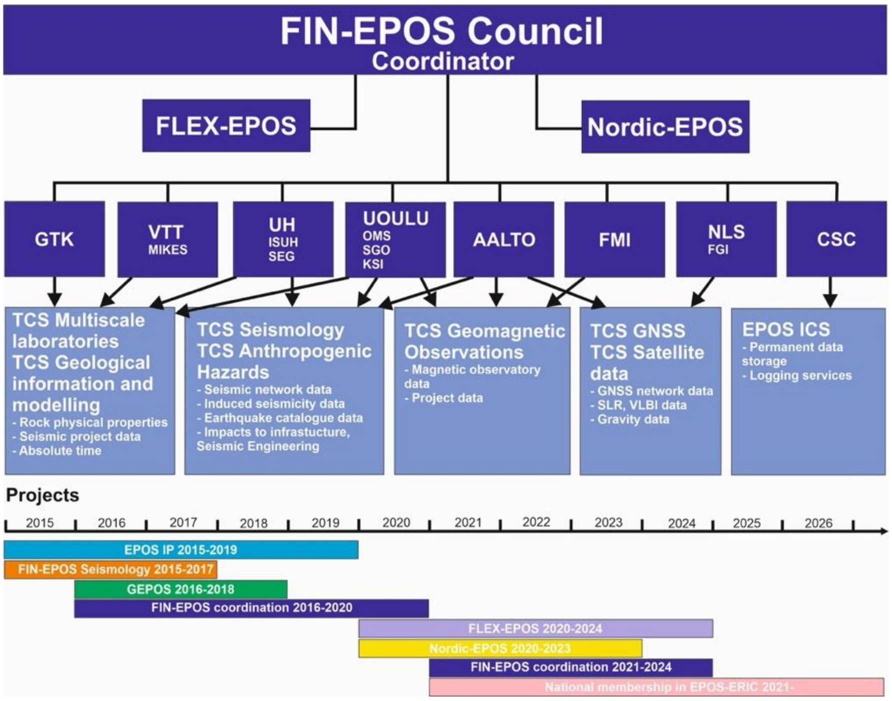

Figure 1. FIN-EPOS organization, projects and data transfer to EPOS TCSs (i.e., national and international data centers).

One of the progressing projects under the national FIN-EPOS umbrella is a FLEX-EPOS RI project. The objective of FLEX-EPOS is to create a national research infrastructure of geophysical instruments and multi-disciplinary geophysical superstations to be further utilized in separately funded research projects aiming at solving fundamental scientific questions in seismology, geomagnetism and geodesy.

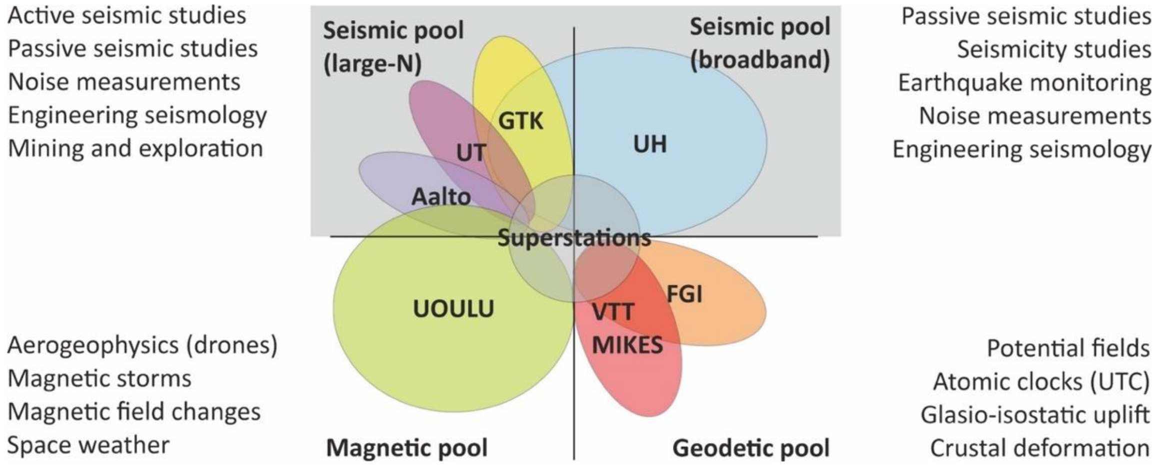

Figure 2. *Schematic representation of the FLEX-EPOS instrument pools.*

Within the FLEX-EPOS project, a Seismic Instrument Pool (SIP) is created, maintained, and operated in a national co-operation with four universities (UH, UOULU, University of Turku (UT), and Aalto) and a research institution (GTK). In addition, other two research institutions are part of the FLEX-EPOS consortium (VTT, FGI). The SIP provides seismic instruments for seismological (both controlled source and earthquake seismology) experiments of the FLEX-EPOS consortium parties. FLEX-EPOS consortium parties may use the instruments in national or international collaboration projects, but the main applicant to the SIP is always a consortium party. The greatly expanded observational capability of FLEX-EPOS SIP will contribute to science by providing massive new seismic datasets, observations and results, and strengthen and extend the role of Finland in the EPOS.

The FLEX-EPOS SIP Coordinator (UH) coordinates the practicalities of the buildup and operation of the pool in collaboration and under the guidance of the owners of the instruments and the FLEX-EPOS Steering Group. A Principles of Operation document is created for practical purposes to aid the application procedures and operations of the FLEX-EPOS SIP. The principles have been drafted using the Terms of Use[1] of the Geophysical Instrument Pool Potsdam (GIPP) of the Helmholtz-Zentrum Potsdam, Deutsches GeoForschungsZentrum (GFZ) as a reference.

Website of the Finnish national node of EPOS, FIN-EPOS: https://www2.helsinki.fi/en/infrastructures/fin-epos. More information on FLEX-EPOS and the SIP (instrumentation, how to apply, fees, liabilities, Principles of Operation etc): https://wiki.helsinki.fi/display/FLEX/Flex-epos+Home .

[1] https://www.gfz-potsdam.de/fileadmin/gfz/sec22/pdf_doc/GIPP/rules_GIPP_10_2019.pdf

Acknowledgements
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)

Title:
RI management and services at the seismological service for the Kingdom of Denmark

Presented by:
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Øster Voldgade 10
1350 Copenhagen K
Denmark

Type:
talk

Abstract:
This presentation will give an overview on how research infrastructure (RI) management and services are organized and planned at the seismological service at the Geological Survey of Denmark and Greenland (GEUS). Furthermore, insight to the Danish pools of mobile seismological equipment is given.
The main task of the seismological service is to monitor and detect earthquakes and other seismic events, including nuclear explosions, in the Kingdom of Denmark. To fulfil this task data from seismological monitoring conducted in Denmark, the Faroe Islands and Greenland, is collected, processed and analysed by seismologist at GEUS. The infrastructure used for the monitoring is managed by many different institutions specially in Greenland, where the Greenland Ice Sheet Monitoring Network project (GLISN) (see http://glisn.info/) a joint international effort to improve our understanding of Ice Sheets dynamics have installed many stations. For each station the equipment, power and communication management conducted by the institution operating the station. Several stations in Greenland are operated by two or more institutions, GEUS is involved in the coordination of most of the stations. The data collected at the permanent stations is made available for research in near real time via a seedlink webservice, mainly from GEUS, IRIS and GEOFON. Data are archived and made available by partly IRIS and partly GEOFON, through the fdsnws-dataselect webservices and EIDA (http://www.orfeus-eu.org/data/eida/).
A joint pool of mobile instruments (land sensors and OBS) is made available by the DanSeis consortium (see https://danseis.dk/), the instruments is managed jointly by Copenhagen and Aarhus University, data is available at the DanSeis ftp server after a quarantine period, normally 2 yrs. In addition to DanSeis Copenhagen University, Aarhus University and GEUS host a small number of mobile land stations. A major part of the data collected using these are hosted at the seismic waveform data archive at GEOFON and made available through EIDA ond/or the fdsnws-dataselect webservice, after a quarantine period. Aarhus University also host equipment for active source seismology (see https://geo.medarbejdere.au.dk/faciliteter/booking-af-instrumenter-og-udstyr)
The parametric data produced at GEUS by manual analysing the data produced at monitoring stations, is collected in NORDIC format and made available via e-mails or websites services. The e-mails are sent one daily to recipients requesting the e-mail. The parametric data is made available as catalogues of earthquakes for Denmark and Greenland and cryo-generated in Greenland. Additionally, GEUS provide a daily updated website service with the bulletin, showing source parameters and phase reading (http://seis.geus.net/seismic_service.html).

Nordic EPOS related activities at SNSN. Automatic and reviewed regional bulletins

Peter Schmidt, Zaher Hossein Shomali, Michael Roth, Björn Lund, SNSN, Dept. of Geophysics, Uppsala University

Abstract:
The Swedish National Seismic Network (SNSN) runs 4 different automatic systems for regional seismic event detection: SeisComp (SC), EarthWorm (EW), an in-house system based on Migration and Stacking (MS), and the (multi) South Iceland Lowland (mSIL) system. While mSIL serves as the primary base for the reviewed catalogue, the MS system serves as an auxiliary source for the manual analysis. Both of these systems run as delayed systems with emphasis on sensitivity rather than speed of detection, resulting in a magnitude of completeness of approximately 0.5 in the final catalogue. Reviewed parameter data for events large enough to be detected by neighboring networks are currently made available to EPOS via the institute webpage (www.snsn.se/data), in the Nordic format. Efforts are ongoing to also offer the data in quakeML format, which is expected to be in place during the fall of 2021. The SC and EW systems are run in (near) real-time employing, in addition to SNSN's 68 seismic stations, data streams from approximately 100 stations in neighboring countries. Individually, both SC and EW are sensitive enough to detect most events large enough to be felt, while the combination of the two have shown to significantly reduce the number of spurious events. This forms the basis of a near real-time catalogue currently under development at SNSN and expected to be publicly available on our webpage before the end of the year. Further development of filtering procedures and event classification schemes are planned in order to confidently identify automatic events that are likely to be natural earthquakes, which will be forwarded to EMSC. At present, continuous data from 10 of SNSN's stations are available via the European Integrated Data Archive (EIDA) initiative of ORFEUS. From January 2022 Sweden will become a member of EPOS at which point additional data will be made available to EPOS.

Future challenges of the Fencat catalog

K. Oinonen & M. Uski

Institute of Seismology, University of Helsinki, Finland

Institute of Seismology, University of Helsinki applies three steps procedure in seismic data analysis. The first step is daily analysis, where events picked by automatic detection program are checked (excluding explosions from known mines at known blasting time) and earthquakes and other interesting events manually analyzed. The next step is monthly bulletin, where data from co-operating agencies in Estonia, Sweden and Norway are combined with Finnish data. This step will improve the hypocenter accuracy, especially for events located close to or outside the national borders. After data quality checks the bulletin is submitted to ISC. Lastly, an annual earthquake bulletin and catalog (FENCAT) is compiled by merging all earthquakes reported by co-operating agencies into a joint dataset. This step includes e.g. thorough cross-checking of event reports to detect and remove misidentified events from the data.

These three types of seismic bulletins as well as FENCAT catalog are available in our website: https://www2.helsinki.fi/en/institute-of-seismology/bulletins

In this presentation, we will take a closer look at the FENCAT catalog, tell you about its ongoing updates and open a discussion on how other users would like to develop it.

An update on the CTBTO Link to the ISC Database

Authors: Ryan Gallacher, Dmitry Storchak, James Harris

The CTBTO Link to the database of the International Seismological Centre (ISC) is a service provided on behalf and by arrangement with IDC/CTBTO. The Link was originally part funded by NORSAR, Geological Survey of Denmark and Greenland (GEUS), Swedish National Defence Research Establishment (FOI) and the University of Helsinki. The Link enables PTS and National Data Centres (NDC) with dedicated access to long-term definitive global datasets maintained by ISC using specially designed graphical interfaces, database queries and non-IMS waveform requests. This service gives access to the ISC Bulletins of natural seismicity of the Earth, mining induced events, nuclear and chemical explosions; the ISC-EHB dataset; the IASPEI Reference Event list (GT) and the ISC Event Bibliography.

The searches are tailored to the needs of the monitoring community and divided into four categories: Area based spatio-temporal search (based on ISC Bulletin), REB based spatio-temporal search, GT event based search and the IMS station based search (historical reporting patterns of stations close to IMS sites).

We have recently made several improvements to the usability of the Link in addition to enabling waveform downloads from the IRIS and ORFEUS data centres. These features will be discussed in addition to recent complimentary improvements/additions to ISC products including an electronic archive of printed station/network bulletins and a community dataset repository.

The 2020 Update of the European Seismic Hazard Model: insights for Iceland and Finno-Scandia Region

Laurentiu Danciu (ETH Zurich, CH):

Abstract: This contribution will provide an overview of the 2020 European Seismic Hazard Model, with focus of the key input datasets (earthquake catalogue, active faults), model components (i.e. seismogenic source models, ground motion models) and outcomes for the Northern Europe.

European Seismic Risk Model (ESRM20)

Helen Crowley, EUCENTRE, PAVIA, ITALY

Abstract: This presentation will present the European Seismic Risk Model 2020 (ESRM20), which has been computed with open data and open source software and is now being released to the wider scientific community. Particular focus is given to the European site response, exposure and vulnerability models, and the calculation of various risk metrics at the European scale.

On seismic hazard assessment in Sweden

Björn Lund, Departm. of Geophysics, Uppsala University

Sweden is one of few countries in Europe without building codes for earthquake resistant structures. Consequently, there is not a national seismic hazard map and construction companies do not concern themselves with seismic hazard. Even sensitive infrastructure, such as nuclear power plants, are not required to do modern seismic hazard assessment. In this talk I will review the status of seismic hazard assessment in Sweden, and present some ongoing projects.

Seismic source zone refinements of the SEISMIC RISK project in Finland

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Seismic sources need to be designed for probabilistic seismic hazard analysis (PSHA). In low-seismicity regions, it is widespread practice to design seismic source areas (SSAs) as proxies to un-identified seismogenic structures. SSAs typically assume the shapes of polygons and are defined based on geologic, geophysical and seismotectonic criteria. A challenge in this process may be that no obvious connection can be discerned between the geologic setting and observed seismicity.

The ongoing SEISMIC RISK – Mitigation of induced seismic risk in urban environments – (https://www2.helsinki.fi/en/projects/seismic-risk) project is conducted as cooperation between the Institute of Seismology of the University of Helsinki, VTT Technical Research Centre and the Geological Survey of Finland. The project focuses on how to evaluate, mitigate and communicate seismic hazard and risk associated with deep geothermal power plants in urban environments in Finland. One of the project aims is to create a national seismic hazard map that can be used for risk assessment of potential geothermal power plants planned in the country.

We present results from an attempt to delineate new SSAs and refine preexisting ones in the PSHA part of the project. The Finnish territory exhibits an overall low level of natural seismicity with areas of enhanced seismic activity and seismic quiescence, thus the design criteria tend to vary spatially. The sketches of the proposed zoning were drawn up in dialog between Finnish, Swedish, Norwegian, Russian and Estonian experts in early 2021. The outcome is generally aligned with, but also refines for the Nordic countries, the map of the European Seismic Hazard Model (ESHM2020).

Acknowledgement
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New 3D fault system models of the two transform zones of Iceland for physics-based seismic hazard assessment

Benedikt Halldorsson[1,2], Farnaz Bayat[1], Milad Kowsari[1], & Claudia Abril[2]

The rate of plate motion in Iceland drives the seismic activity of the two large transform zones in Iceland, the South Iceland Seismic Zone (SISZ) in the southwest and the Tjörnes Fracture Zone (TFZ) in the north. The SISZ is well known for its „bookshelf" style of faulting on an array of strike-slip faults oriented near perpendicular to the long axis of the zone. Recently, this faulting system has been shown to be continuous from the SISZ and all along the Reykjanes Peninsula Oblique Rift zone (RPOR). Moreover, the bookshelf faulting is thought to dominate the long-term release of tectonic strain over the entire SISZ-RPOR transform zone. The larger TFZ is more complex, characterized primarily by two features, the Grímsey Lineament and Grímsey Oblique Rift zones vs. the Húsavík-Flatey Fault Zone (HFFZ). The former can be described as a mirror image of the SISZ-RPOR bookshelf system while the HFFZ is a unique feature, a long strike-slip fault zone striking parallel to the vector of plate motions.

We have constructed new physics-based 3D fault models of the strike-slip fault systems of the SISZ-RPOR and TFZ, respectively. The models have been calibrated on the basis of first-principles to the rate of plate motions in Iceland and account for the systematic spatial variation of the seismogenic potential of the zones, modeled by distinct subzones. The fault systems are completely specified in terms of their fault locations, fault dimensions, maximum expected magnitudes and the long-term slip-rate on each fault. The sensitivity of the fault systems to their key parameters have also been evaluated and their total long-term seismic moment rates are completely consistent with other estimates in the literature based on various earthquake catalogues for the transform zones. Moreover, we have constructed simple seismic area source models of each subzone and calibrated them to the average slip-rates of each sub-zone of the 3D models. The sub-zones can thus also be completely specified by their maximum magnitudes and zone-specific magnitude-frequency relationships (MRF, i.e., Gutenberg-Richter). The total MFRs for the SISZ-RPOR are in complete agreement with the earthquake catalogue and incorporate uncertainty measures. The same comparison for the subzones of the TFZ is underway.

The new 3D fault system models now enable the first comprehensive and physics-based revision of probabilistic seismic hazard assessment (PSHA) in the transform zones of Iceland, that can take advantage of advanced earthquake rupture modeling techniques. A consistent PSHA using standard engineering approach can also simply be obtained via the equivalent seismic area source MRFs. By evaluating the MRFs for the remaining seismic and volcanic areas of Iceland using the ICEL-NMAR catalogue, we have presented a simplified but complete and hybrid area source zone model for Iceland for PSHA applications. This model is the foundation of the latest European seismic hazard model (ESM20) efforts of PSHA in Iceland.

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On the calibration of the first 3D transform fault system model of the South Iceland Seismic Zone and Reykjanes Peninsula Oblique Rift

Farnaz Bayat[1], Milad Kowsari[1] and Benedikt Halldorsson[1,2]

Abstract

Geohazards, volcanic and seismic activity, are pronounced in Iceland due to its location on the Mid-Atlantic Ridge. The strongest earthquakes in Iceland occur primarily in two transform zones, the Tjornes fracture zone in the North, and the South Iceland seismic zone (SISZ) and Reykjanes Peninsula oblique rift (RPOR) in the South. The left-lateral transcurrent motion across the SISZ-RPOR is accommodated by “bookshelf faulting” on an array of NS near-vertical dextral strike-slip faults oriented near perpendicular to the vector of plate motions. In this study, we have developed new 3D physics-based bookshelf fault system models for the SISZ-RPOR. The models have been calibrated to the steady-state relative velocity of plate extension in southwest Iceland and are constrained by the geometry of the fault system and its spatially variable seismogenic potential. We model this spatial variability by through distinct subzones of faulting and allow for both deterministic and random fault locations across the SISZ-RPOR. The fault system models are fully specified in terms of fault locations, fault dimensions, expected maximum magnitudes, long-term slip rates, and moment rates on individual faults. The long-term cumulative rate of seismic moment predicted by the new fault system models are fully consistent with those calculated from the various long-term earthquake catalogues for the region. The slip-rate along the zone is shown to vary systematically and increasing towards the west. This allows us to designate average slip-rates for each subzone and calibrate zone-specific magnitude-frequency relationships (i.e., Gutenberg-Richter). In other words, we present seismic area source zones of different maximum magnitudes and distinct a and b-values that are equivalent to the activity of the 3D physics-based fault system model of this study. The cumulative seismicity rate of the area source zones is in complete agreement with the earthquake catalogues, including the new ICEL-NMAR. The findings presented here form the basis for physics-based probabilistic seismic hazard assessment of the bookshelf fault system in Soutwest Iceland.

Keywords: bookshelf fault system; slip rate; finite-fault model; physics-based probabilistic seismic hazard assessment; RPOR; SISZ

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Sensitivity of the Seismic Hazard Maps to the Selected Ground Motion Models: A Case Study of North Iceland

Milad Kowsari[1] and Benedikt Halldorsson[1,2]

Abstract

The Tjörnes Fracture Zone (TFZ) in north-eastern Iceland, is one of the most active seismic zones in northwestern Europe. In this region, most of the earthquakes take place on two separate structures, the Grímsey Oblique Rift (GOR) to the north and the Húsavík–Flatey Fault zone (HFFZ) to the south. The HFFZ is the largest transform fault in Iceland that is located in the close vicinity of Húsavík, the second largest town in North Iceland. Therefore, this region is prone to severe earthquake damage and a careful evaluation of the earthquake hazard is vital. However, previous seismic hazard studies for this region have relied on a single ground motion model (GMM) and incorporated uncertainties in a limited way. In this study, we perform a probabilistic seismic hazard analysis (PSHA) based on the previous site-specific hazard studies for North Iceland, specifically regarding delineation of seismic sources and seismicity parameters. We apply multiple GMMs that have been proposed and used for PSHA in Iceland in the past. We show that the variability in the hazard estimates is quite large, which is a direct result of the inconsistency in the GMMs used in previous studies. In contrast, we re-evaluated the variability of PSHA for North Iceland based on new empirical Bayesian GMMs that not only satisfy all the conditions required for use in PSHA, but also fully capture the characteristics of the existing Icelandic ground motion dataset and in addition contain elements that account for the saturation of near-fault peak ground motions at large magnitudes. The results show that the confidence in the PSHA values is significantly increased using the new models vs. the older ones. The confidence of the PSHA values is quantified through the coefficient of variation. The confidence is shown to be largest over distance ranges where data is most abundant. On the other hand, the confidence decreases considerably at near-fault and far-field distances, primarily because of lack of data for those distances. The findings highlight the importance of using appropriate GMMs for PSHA in Iceland and the need for a revision of the PSHA using not only the new GMMs, but also physics-based seismic source models.

Keywords: Tjörnes fracture zone, PSHA, Bayesian GMMs, Physics-based seismic source models

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Probabilistic seismic hazard assessment of Sweden

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Sweden finds itself in a region with low-seismicity and sees very few damaging earthquakes. In terms of geology, most of the country lies on Precambrian crystalline rocks which are part of the 1 billion year old Fennoscandian shield. The seismicity in Sweden, on the other hand, is primarily driven by plate tectonics through the continental-scale ridge-push from the mid-Atlantic ridge, which is located a fair distance away towards the west. The post-glacial isostatic rebound is another driver of seismicity in Sweden and has been attributed to the genesis of the post-glacial faults that caused large earthquakes (~M8.0). The modern-day seismicity in Sweden, however, is relatively benign, with only four M4+ events in last 20 years, and is mostly observed in the south-west around Lake Vänern, along the north-east coast near Skellefteå, and in the Norrbotten region. Seismicity is also limited by the span of instrumental observations. The seismic catalogs, however, have been more complete in the recent years with the magnitude completeness being about M0.5 for earthquakes between 2000 and 2020. In this study, we have decided to focus on the recent seismicity (2000-present) and have excluded older and paleoseismic observations. We will present the challenges we faced when performing the PSHA study of Sweden and show how we demarcate the seismic source areas and the effects of choosing different ground motion models. We present the results for peak ground acceleration (PGA) values, in the form of a hazard map.

The Swedish National Seismic Network - Status 2021

Michael Roth, Björn Lund, SNSN Team, Uppsala University

The Swedish National Seismic network is operating currently 68 permanent broadband stations. During the last 2 years we were conducting major upgrades, and we improved the data availability significantly. End of 2020 all station computers were replaced by newer ones or upgraded to an up-to-date Linux OS. Data processing (detection, phase picking, amplitude measurements, etc) - performed at the station computers in the framework of the original SIL processing system, was migrated to the SNSN data centre in Uppsala. These measures solved the issue of data gaps at the station computers. In 2021 we focussed solving communication problems between the stations and our data centre. We replaced more than half of our cell network routers, which had the tendency to get stuck in reboot loops, replaced radiao antennas, changed network providers where necessary and even identified and helped to solve a problem in the core system of a network service provider. On top of the operation and maintenance of the permanent network, we completed the civil works for a temporary small-scale (150x100km) regional network, installed 7 out of the 13 sites and hopefully we will have the network fully operational at the end of the year.

Future plans for the Estonian seismic network

Heidi Soosalu, Geological Survey of Estonia

Seismic monitoring is performed in Estonia as a subprogramme of the state environmental monitoring programme under the governance of the Ministry of the Environment. This duty is defined in the environmental legislation. In this context, seismic observations are often considered to be of little practical importance. Recognition of other useful applications of seismic data and understanding of their significance are still awaiting their time in Estonia. Accordingly, until today it has been a challenge to find national financing for seismic monitoring in order to bring it to a level appropriate for a modern European country.

International co-operation, especially with the Helsinki University Institute of Seismology and GFZ, the German Research Centre for Geosciences in Potsdam, has been of great importance for Estonia with its meagre resources – three permanent stations and manpower of one person. Arrangements with these partners have effectively facilitated high-quality routine seismic analysis of Estonian events.

Convincing experience of the significance of a more extensive national network has been gained from 2015 on, in co-operation with Helsinki by deploying and running up to eight temporary seismic stations around Estonia, equipped with instrumentation on loan from the Institute of Seismology. A data set from 3 + 7 stations spanning a few years proves that the detectability and location accuracy of Estonian events have improved considerably. Taking particularly into account that the majority of the local seismic events – both natural and man-made – tend to be small in size (magnitudes < 2), it is of vital importance to have a tight enough network for fulfilling current expectations regarding data production.

The Geological Survey of Estonia has started taking action to modernise the national network by a step-wise process of buying and installing sets of equipment, using both its own finances and other resources. With the experience from the sites of the temporary network, the plan is to increase the number of permanent Estonian stations to up to at least ten during the next couple of years.

State and problems of seismological monitoring in Latvia. Prospects and ways of solving problems.

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Despite the low level of seismic activity in Latvia, it is expedient to conduct seismological monitoring. This is due to the following factors: 1) the intensity of earthquakes (historic and modern) shaking reached 6 - 7 points, and the maximum magnitude - 5.2 (Kaliningrad, 2004); 2) unfavourable ground conditions (sedimentary cover with a thickness of about 1 km and its upper part - Quaternary deposits) can contribute to the intensification of fluctuations; 3) some infrastructure facilities (Incukalns underground gas sdtorage), agglomerations (Riga, Liepaja et al.), hydroelectric (Plavinu HPP) and nuclear power plants are located in areas with signs of geodynamic activity.

Seismic hazard assessments in 2007 showed that with a 10% probability within 50 years, shaking will exceed 10 - 13 cm/sec^2 in some regions of Latvia (Sigulda, Riga, Cesis, Aizkraukle, Olaine et al.). This level of shaking refers to the surface of bedrock, represented mainly by the Devonian. Taking into account the possibility of additional amplification of oscillations due to resonance phenomena, the level of oscillations on the surface can increase. This is probably why the intensity of some historical (1616, 1821, 1857) and modern (1976, 2004) earthquakes reaches 6 - 7 points. Local seismic-geological conditions play a significant role here. In particular, this was shown by the tremors from the 2004 Kaliningrad earthquakes.

Studies of regional seismicity began in 1994. However, full-fledged seismological studies have become possible since 2006, when the *Slitere* station was installed in Latvia, which was included in the international GEOFON network with its center in the GFZ Potsdam.

The station is equipped with typical seismological equipment used in the GEOFON network. Participation in the GEOFON network made it possible to receive data from other stations in the Baltic region and thereby create the Baltic Virtual Seismic Network. The area of responsibility of Latvian seismological monitoring covers the Eastern Baltic region (EBR) (φ = 53.9°N - 59.7°N; λ = 19.4°E - 29.6°E).

Most of the seismic events localized using the BAVSEN network are associated with artificial sources that are associated with industrial quarries and the Baltic Sea. These are industrial explosions for the extraction of oil shale, dolomite, gypsum and limestone. In the Baltic Sea, the explosions are associated with the destruction of sea mines left after the war. The BAVSEN network annually registers 300 - 400 regional seismic events. For example, in 2020, 310 regional seismic events were recorded within the FBG. Magnitude range changing from 1.2 to 2.8. Most of the seismic events take place during business hours (from 9 am to 5 pm local time).

After the Kaliningrad earthquakes in 2004, tectonic earthquakes in the EBR occurred mainly in Estonia (northern and western Estonia, Lake *Võrtsjärv* region). According to macroseismic data, one seismic event (November 22, 2010) was felt in some places of Riga and its environs. It was associated with a tectonic earthquake confined to the zone formed by the subparallel tectonic faults *Olaine-Incukalns* and *Bergi*. The stations of the seismic network BAVSEN did not register it. Distances between stations reach 150 - 250 km.

One seismic event in Lithuania on June 12, 2015 occurred in the area of geothermal resources and oil wells development and was identified as an induced earthquake.

Signs of geodynamic activity have been found for the *Olaine-Incukalns* fault, the largest tectonic fault in Latvia. It crosses the territory of Latvia, including the territory of Riga, from southwest to northeast. In the southwest, anomalous velocities of movement of the opposite sides of the *Cirulisi* fault were found, which adjoins the *Olaine-Incukalns* fault. A radon anomaly was found on the northeastern edge of the *Olaine-Incukalns* fault. In the central part, as already mentioned, tremors were felt in 2010.

Hydroelectric power plants are other objects requiring increased attention, including seismic monitoring. The area of *Plavinas* reservoir and hydroelectric power station deserves special attention. In fact, the dam of the hydroelectric power station is located inside a graben-like structure formed by the *Piebalga* and *Aizkraukles* faults. In the area of the dam, unfavorable processes are noted associated with deformations and the removal of finely dispersed soil by water flows.

The main problems of seismological monitoring are associated with a rare seismic network in the East Baltic region (Estonia, Latvia, Lithuania, Kaliningrad region of Russia), poor seismic-geological conditions. The first factor limits the magnitude threshold of recorded seismic events. The second factor complicates the wavefield, especially the arrivals of the first P-waves. This is due to wave interference at the boundaries of the sedimentary cover.

It is proposed to expand the seismic network of Latvia with a uniform coverage of the territory. Taking into account its peculiar configuration, it is proposed to create 6 more stations. In areas of intense anthropogenic noise (Riga), it is proposed to organize borehole observations to reduce man-made noise.

Methods of recognition of tectonic earthquakes in conditions of a thick sedimentary cover overlapping the crystalline basement are of great importance. Unfortunately, so far none of the tested methods (spectral and amplitude ratios of P and S-waves, spectral-time analysis) has demonstrated efficiency. In this direction, the search for effective methods for recognizing the genesis of seismic events will continue. One of the options is the creation of a *National Data Center* (through the CTBTO) and access to the nearest infrasound stations (IS37, IS43, IS26). Infrasound stations can greatly facilitate the identification of explosions.

In the area of the *Plavinas* water reservoir and HPP, it was proposed to create a local system of seismological observations as an addition to the existing complex of hydrogeological, deformation, geodetic measurements.

The results of seismological observations are accumulated in the BAVSEN (SEISAN software) database. Seismological monitoring reports are published on the LEGMC website https://videscentrs.lvgmc.lv/lapas/seismologiskais-monitorings

HIKE: Towards better earthquake locations

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1. GEUS, 2. ÍSOR, 3. TNO

The HIKE project (Hazard and Impact Knowledge for Europe) is a large GeoERA funded project which aims to create a platform for sharing information and knowledge to support induced hazard and risk assessment in the participating countries. The platform is in the form of 1) a database of faults and tectonic features in the participating countries, 2) a knowledge share point which provides access to a guided search regarding the risks and hazards of human subsurface activities, and 3) a semantic network. An important part of the project was to bring institutions with different levels of expertise and methods together to harmonize the approach to assessing hazard and risk. A team of seismologists from GEUS, TNO, and ISOR was tasked with exploring how we can improve earthquake locations, which are of course crucial for estimating and monitoring the activity of seismic faults. We studied three different seismically active areas, a hydro-carbon field in the North Sea, a decommissioned gas field just off the shore of the Netherlands, and a high temperature geothermal field in Iceland. We located earthquakes using the NonLinLoc software by Lomax et al. (2000). The software is a non-linear, probabilistic program which can offers to option to use both 1D and 3D velocity models. NonLinLoc is a powerful location program but it has its disadvantages, and we show examples of both its strengths and its limitations. One of the outcomes of our task is a guide for taking your first steps in NonLinLoc.

Improving short-term forecasting following a damaging earthquake in South Iceland Seismic Zone

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The Epidemic-Type Aftershock Sequence (ETAS) model is one of the top ranked seismicity models describing the occurrence of earthquakes in space and time. For this reason, the ETAS family models are widely used for short-term aftershock forecasting in operational earthquake forecasting systems throughout the world (e.g., United States, Japan, New Zealand, and Italy). However, ETAS model parameters estimation has always been challenging due to the complexity of the likelihood function. Therefore, most previous studies of the ETAS model have relied on point estimates of the model parameters. In this study, to take parameter estimation uncertainty into account, we use a fully simulation-based forecasting framework by leveraging the Bayesian inference technique to assess the uncertainties incorporated into the well-established spatio-temporal ETAS model parameters through the posterior joint probability distributions. Subsequently, we use Markov Chain Monte Carlo simulation to draw samples from the posteriors. Finally, we generate plausible earthquake sequences for the prescribed forecasting time interval across the defined aftershock zone.

We stress that, to our knowledge, the existing ETAS model for southwest-Iceland is not capable of providing efficient forecasting and thus has not found practical operational use so far. To explore the potential of the Bayesian spatio-temporal ETAS model, we used the adaptive prior estimation method employing the conventional ETAS model parameters proposed by Eberhard (2014) for south Iceland as initial values. In this regard, we conducted a retrospective forecasting experiment on the June 2000 earthquake sequence that followed the $M_\mathrm{w}6.4$ and $M_\mathrm{w}6.5$ mainshocks the aftershock sequence of which scattered over the South Iceland Seismic Zone (SISZ) and Reykjanes Peninsula Oblique Rift (RPOR) in Southwest Iceland. The results stress the importance of reliable and informative set of ETAS priors in order to attain reliable forecasts immediately after a strong earthquake. Then, by more data being available for the inference due to an ongoing sequence, well-determined posterior distributions for ETAS model parameters are quickly attained, and thus acceptable forecasted seismicity has been delivered. Moreover, the areas with increased seismicity forecasted across SISZ and RPOR regions were in great agreement with the geographical location of the actual aftershocks that occurred during the various forecasting intervals, thus indicating a strong spatial forecasting skill of the model. Robust seismicity forecasting framework used in this study has the potential of improving short-term forecasts in southwestern Iceland, even in early aftershock period and may potentially be implemented in a regional operational aftershock forecasting system.

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On the capability of the new Grindavik seismic and strong motion array on inferring volcano-tectonic processes

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Abstract

Dike intrusions are often accompanied by numerous small earthquakes that sometimes occur in quick succession over short intervals. While regional seismic networks perform reliably when detecting individual earthquakes, detection may become incomplete in such cases when the inter-event time is greatly reduced. One approach to enhance the network performance is its densification but this is expensive and time intensive in inaccessible areas such as rural Iceland. A cost-effective addition to regional networks are small-aperture arrays which can be quickly deployed at practically feasible locations, and that way monitor seismic activity while being unaffected by many other limitations.

When the most recent seismic sequence started in the Reykjanes Peninsula Oblique Rift zone in February 2021, efforts immediately commensed to prepare and install an urban seismic and strong-motion array in cost- and time-efficient manner. The result was a new array in the nearby town of Grindavik was deployed on 11 and 12 March. The array consists of five RS4D instruments that each contains three accelerometric sensors and one vertical geophone. The units became a part of the TURNkey network that recently has been deployed in Iceland. The array immediately started to monitor the seismic sequence that was caused by a dike intrusion that eventually culminated in a volcanic fissure eruption eight days after the array installment. Since the deployment, array data processing methods have been applied continuously on the real-time seismic data using SeisComP by Gempa. For that we applied the modules LAMBDA and AUTOLAMBDA of the SeisComP system to obtain back azimuth and slowness pairs of incoming waves.

In addition, extensive sensitivity analyses have been carried out to investigate the reliability of the results of the analyses. Comparing the array detections to the earthquake catalogue from the regional network shows that the magnitude of completeness of the array is about M_L 2 but in favourable conditions, earthquakes of magnitudes as small as M_L 0.6 are detected reliably. The back azimuths are on average 2°-4° degrees smaller and the slownesses 0.015 s/km higher when compared to the hypocentral locations reported by the regional network. This discrepancy is most likely caused by the local geology underneath the array which is higly fractured with prominent NS and SW-NE strike directions, respectively. Nevertheless, the relative changes in back-azimuth and slowness are shown to provide considerable detailed view of the volcano-tectonic seismicity that greatly exceeds the resolution of the regional network earthquake locations. Thus, with the considerable advantages such as low-cost and fast deployment in urban areas, small aperture arrays appear to be a robust and valuable addition to local and regional networks for the monitoring of imminent seismic and volcanic events, and in particular the rapid microearthquake occurrence, possibly associated with magma movements.

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Iceland GeoSurvey's seismic monitoring of exploited geothermal fields in Iceland

Egill Árni Guðnason, Sigríður Kristjánsdóttir, Þorbjörg Ágústsdóttir, Rögnvaldur Líndal Magnússon, Karl Gunnarsson, Gylfi Páll Hersir, Friðgeir Pétursson (Kristján Ágústsson and Ólafur G. Flóvenz).

Abstract

Geothermal areas in Iceland, specifically the high-temperature ones, are located in tectonically active areas that naturally experience seismicity. Iceland has successfully exploited the bountiful energy of some of the geothermal areas, both for electrical power production and space heating. Iceland GeoSurvey (ÍSOR) currently monitors six exploited geothermal areas with permanent seismic stations for three Icelandic energy companies: Landsvirkjun Power (LV), Reykjavík Energy (ON) and Norðurorka (NO). Previously, ÍSOR also operated a seismic network for HS Orka, and has in the past run various temporary networks for the Icelandic energy companies. The geothermal areas currently monitored are Krafla (LV), Þeistareykir (LV), Námafjall (LV), Hellisheiði (ON), Nesjavellir (ON) and Eyjafjörður (NO). Additionally, ÍSOR takes part in multiple European collaboration projects in geothermal areas with the respective energy companies, as well as independent research institutions. The seismic stations of the different networks are all online, streaming data in real-time to ÍSOR, and subsequently, automatic locations of earthquakes are available to the respective energy company. The online seismic stations are a combination of stations owned by the energy companies, ÍSOR stations operated for the energy companies, stations from the national seismic network of the Icelandic Meteorological Office and research stations. The seismic networks comprise 1s, 5s and 120s instruments. In addition, ÍSOR's collaborators run research networks of seismic stations on the Reykjanes Peninsula, comprising 30s and 120s instruments.

At ÍSOR, the SeisComP software by Gempa is used for automatic detection and location of earthquakes, and day to day monitoring of the geothermal areas where the majority of events are manually refined. In general, increased but variable seismic rate is observed in production and injection areas. However, it can be challenging to distinguish between natural and induced seismicity. The mapping of seismic activity can give valuable information about the fracture permeability of the geothermal fields. For a more detailed analysis, earthquakes are relatively relocated, earthquake source mechanisms calculated, and new 1D velocity models constructed. The development of ÍSOR's seismic data analysis mostly takes place within the European collaboration projects, where for example new SeisComP modules are tested and implemented, new data processing techniques explored, and beneficial relationships between scientists are established. ÍSOR strives towards interdisciplinary interpretation of the seismic data with existing geophysical and geological data sets.

Investigation of earthquake environmental effects in Fennoscandia

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The Fennoscandian Peninsula in northern Europe is an intraplate domain where instrumental data must be extended back in time to improve knowledge of earthquake consequences. We opted to search for hitherto disregarded earthquake environmental earthquake effects (EEEs) for the important earthquakes of 1626, 1759, 1819, and 1904, and analyze their geographical distribution. We mainly investigated EEEs using contemporary newspaper accounts.

The compiled data sets are most probably incomplete, but testify to such EEEs as rockfalls and turbulent waters. In 1759, turbulent waters were reported from distances up to approximately 380 km. In 1904, they caused trouble to sailors on many lakes. Numerous rockfalls and landslides were reported in 1819 and 1904. In the 1904 rockfalls, boulders fell onto a roadway and into a river, causing flooding that reached rye crops.

We assessed the EEEs for 27 localities of interest using the Environmental Seismic Intensity scale ESI-07. A challenge in using slope failures for intensity assignment is that the triggering of landslides is highly dependent on the level of water saturation in the slope prior to the earthquake. This precipitation effect poses an extra uncertainty in the assignment of ESI-07, which is especially pronounced in areas of high precipitation, such as western Norway. EEEs are also affected by temperature: the winter earthquake of 1759 cracked ice on many lakes.

The overall agreement between ESI-07 values and EMS-98 intensities is good, but many assigned ESI-07 intensities remain uncertain due to the character of the textual information and brevity of the documentation. However, the ESI-07 scale also has practical importance for regions with infrequent EEEs. For a full understanding of seismic risk, EEEs must be incorporated in the analyses also in Fennoscandia.

Reference

Mäntyniemi P, Sørensen MB, Tatevossian RE (2021) Testing the Environmental Seismic Intensity scale on data derived from the earthquakes of 1626, 1759, 1819, and 1904 in Fennoscandia, northern Europe. Geosciences 11, 14. https://doi.org/10.3390/geosciences11010014

Investigating shallow seismic swarms between Askja and Herðubreið with QuakeMigrate: a new, open-source Python package for automatic earthquake detection and location

Tom Winder[1], Robert S. White[1] & Bryndís Brandsdóttir[2]

Abstract

Intense swarms of microearthquakes have been detected in the rift zone of Central Iceland since the 1970s, but the cause of their swarm-like nature remains enigmatic. We use the QuakeMigrate earthquake detection and location software[3] to produce a highly complete catalogue of microseismicity from 2007-2020, using data from a dense local seismic network.

Detecting and locating microearthquakes from continuous waveform records is the fundamental step in microseismic processing. Dense local networks and arrays have introduced the possibility to detect large numbers of far weaker events, but when viewed on seismic records from individual stations their waveforms are often obscured by noise. Furthermore, areas of interest for microseismic monitoring often feature extremely high event rates, highlighting the limitations of traditional techniques based on phase picking and association. QuakeMigrate is a new modular, open-source Python package providing a framework to efficiently and robustly detect and locate microseismicity. The user inputs continuous seismic data, a velocity model or pre-calculated look-up table and list of station locations. Instead of reducing the raw waveforms to discrete time picks, they are transformed (by amplitude, frequency and/or polarisation analysis) to continuous functions representing the probability of a particular phase arrival through time. These 'onset functions' from stations across the network are then migrated according to a travel-time look-up table and stacked to perform a grid-search for coherent sources of energy in the subsurface. This enables detection of earthquakes at close to or below the signal-to-noise ratio at individual stations, and implicitly associates phase arrivals even at very small inter-event times.

In this study automatic hypocentre locations are further refined by waveform cross-correlation and relative relocation, and combined with tightly constrained focal mechanisms obtained by manual analysis of a subset of events. The resulting high-resolution earthquake catalogue reveals a network of conjugate strike-slip faults, oriented to accommodate plate-boundary extension. Seismicity within individual swarms displays a systematic migration of hypocentres at velocities of ~ 1 km/day. Analysis of swarms within this fault network triggered by the 2014 Bárðarbunga-Holuhraun dike intrusion provides further constraint on the amplitude of the stress cycle. These exceptionally high-resolution observations provide an opportunity to probe the rheology of these faults, and the processes controlling their swarm-like behaviour.

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2: Institute of Earth Sciences, University of Iceland, Reykjavík, Iceland

3: https://github.com/QuakeMigrate/QuakeMigrate Tom Winder, Conor Bacon, Jonathan D. Smith, Thomas S. Hudson, Julian Drew, & Robert S. White. (2021, January 15). QuakeMigrate v1.0.0 (Version v1.0.0). Zenodo. http://doi.org/10.5281/zenodo.4442749

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Probabilistic seismic hazard assessment of Sweden

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[1]Department of Geosciences, Uppsala University, Sweden

Summary

Sweden is a low seismicity region and as such has neither a national seismic hazard map nor seismic building codes. In this project we develop a seismic hazard map for Sweden, using data accumulated in the last 20 years. We use relatively large seismic source areas, distance and adaptive smoothing of seismicity, two recently developed GMPEs appropriate for the region plus five older GMPEs. The fixed distance smoothing seems to focus the hazard in places with dense seismicity, e.g. the Pärvie fault. The adaptive smoothing seems to spread the hazard out into lower density regions. The PGA values are between 0.025-0.03g(poe=0.1), with the ESHM20 craton GMPE estimating the highest mean PGA(0.03g) around the Burträsk fault. 0.024g is the lowest mean PGA estimated for it by the cluster GMPEs.

METHODS AND MATERIALS

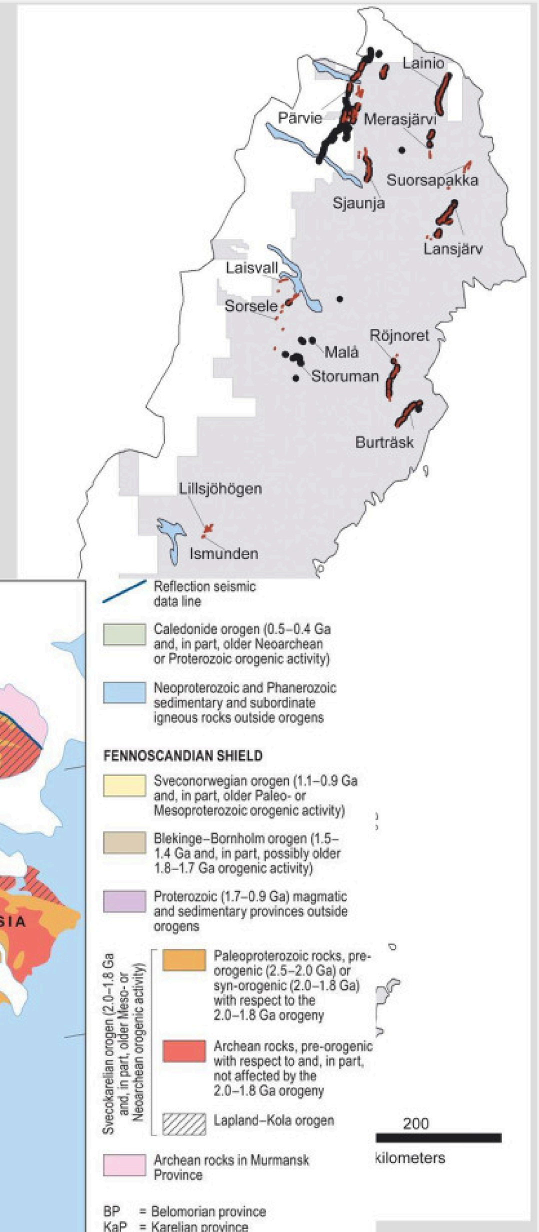
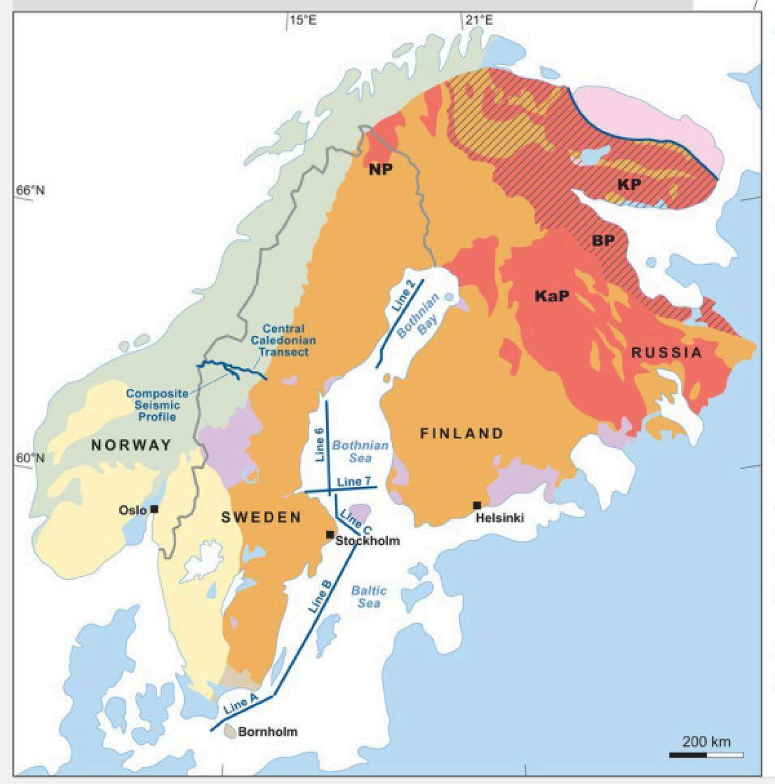
In this study we estimate the b-value using Aki's MLE method[4] and smooth the seismicity using the inbuilt function in OpenQuake, and adaptively using the nearest neighbour distance[5].
We then calculate the hazard using the Fülöp GMPE[6], the experimental ESHM20[7] craton GMPE and a suite of 5 equally weighted GMPEs(Campbell2003, Toroetal2002, AkkarBOmmer2010, CauzziFaccioli2008 and chiouYoungs2008)[8]

Seismicity

Sweden lies in a low-seismicity region with very few damaging earthquakes. Most of the country lies on Precambrian crystalline rocks which are part of the billion-year-old Fennoscandian shield.
The modern-day seismicity is quite benign, with only four M4+ events in last 20 years and is mostly observed in the south-west around Lake Vänern, along the north-east coast near Skellefteå, and in the Norrbotten region[1],which is home to the post-glacial faults that caused large earthquakes 10,000 years ago. The rest of the country is relatively inactive. Seismicity is also limited by the span of instrumental observations, oldest of which have been recorded back in 1375. The catalogues are more complete in the recent years, and we have decided to focus on the recent seismicity (2000-present) in this study. In the future we aim to incorporate all the historical data, which includes events such as the 1759 M5.6 event in Kattegatt, and the 1904 M5.4 event at Kosteröarna, which are the largest events in the catalogue's history.

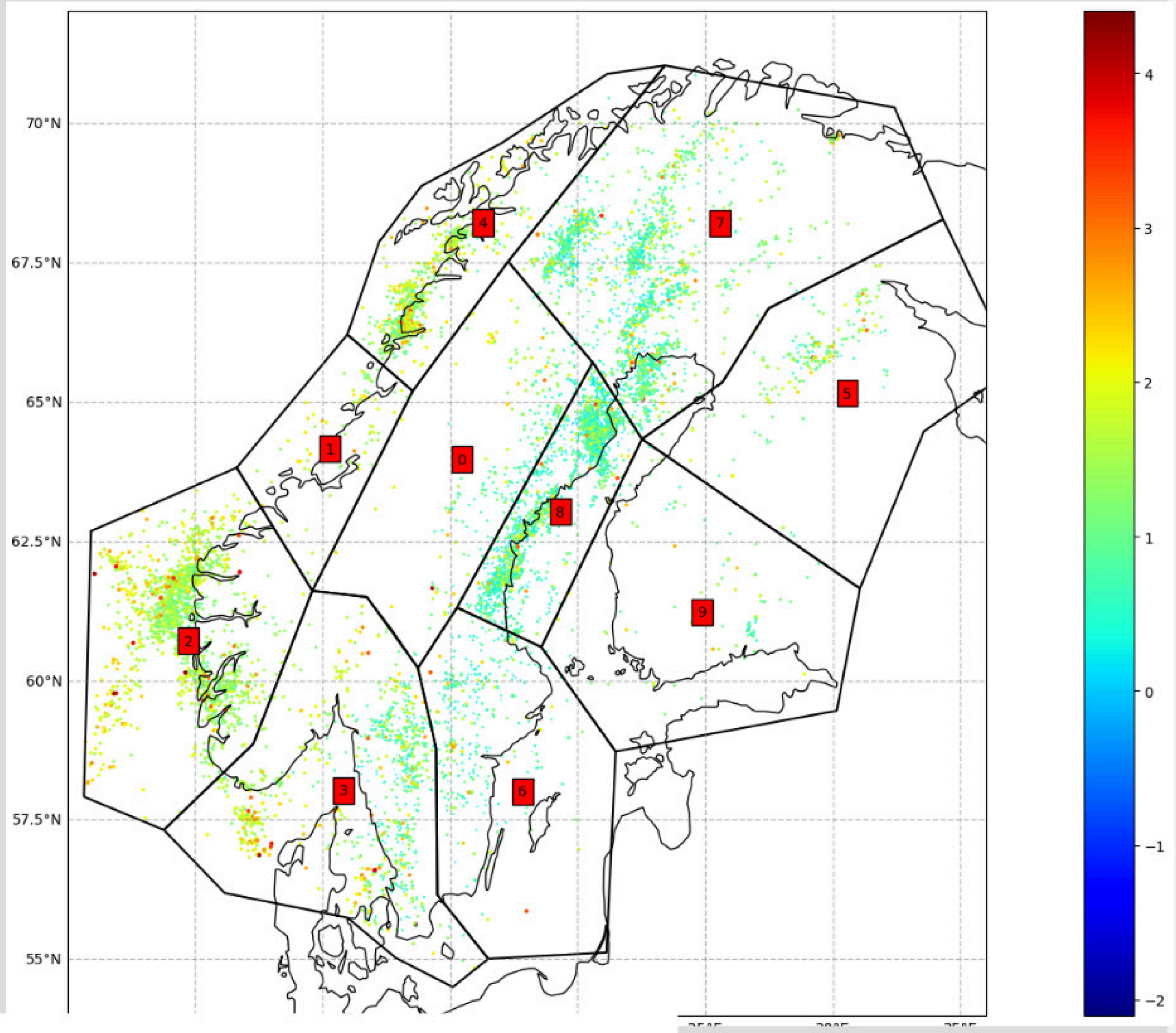
Geological setting of Sweden[2]

Figure 1.
Locations of the mapped postglacial faults in Sweden[3]

Seismicity and zonation map

Figure 2.
We try to keep the zones as broad as possible and try to align them with the underlying geology and seismicity. Colorbar shows the magnitude



Smoothing algorithms

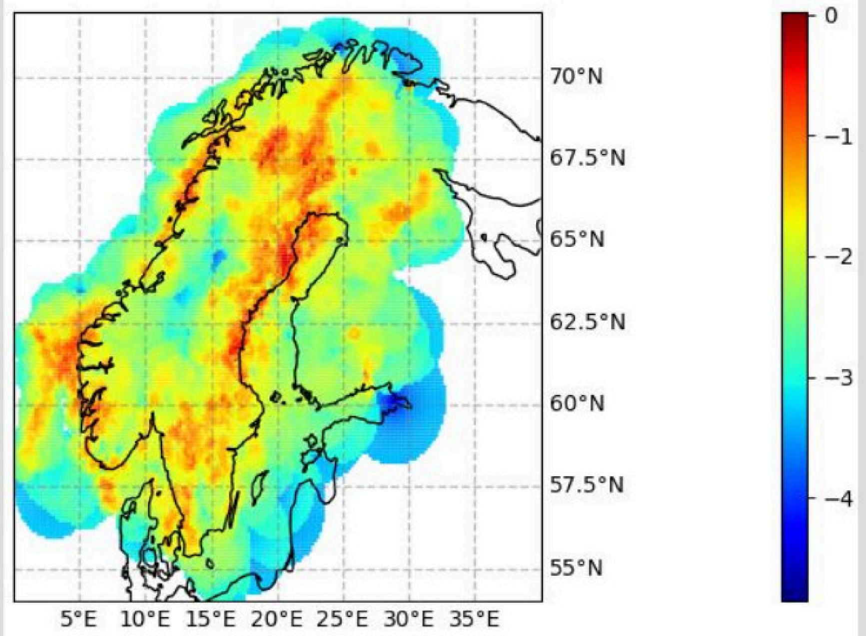


Figure 3.
Log of activity rates per grid cell, as seen for Adaptively smoothed Seismicity (NN6)

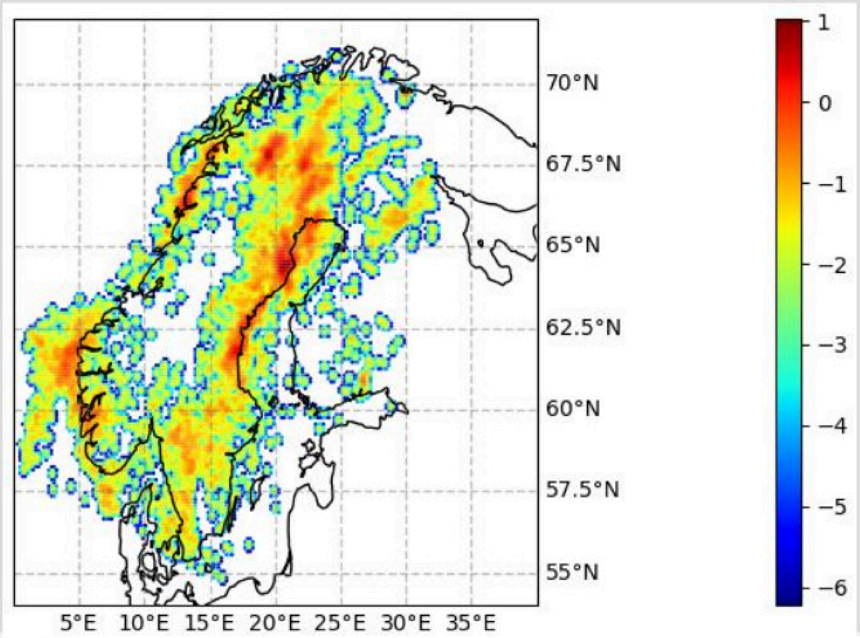
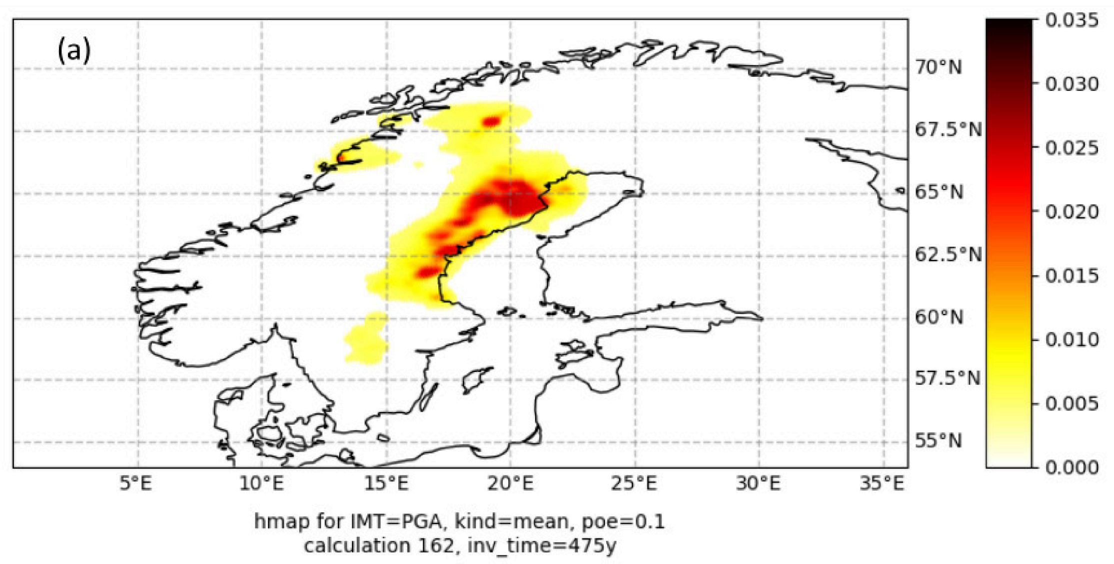


Figure 4. Log of activity rates per grid cell, as seen for Smoothing using a fixed distance (5km)



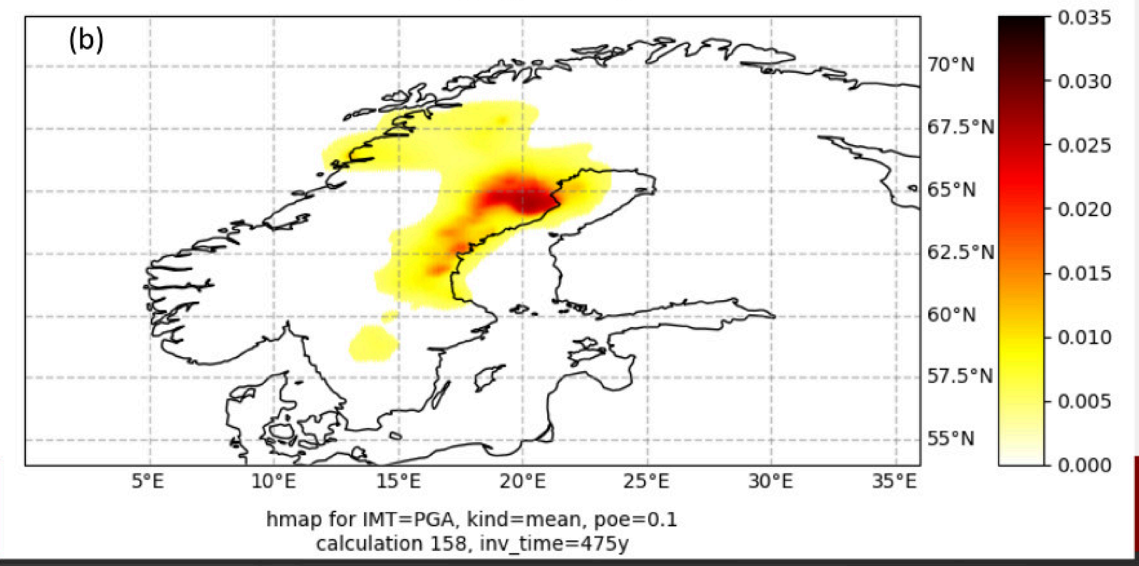
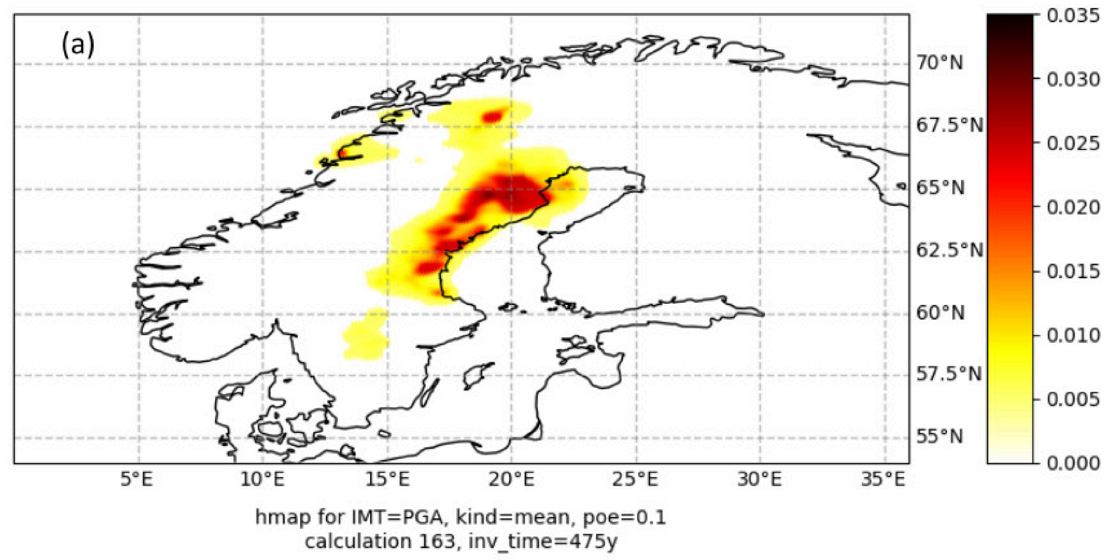


Figure 5. Hazard map based on the Fülöp GMPE and smoothed Seismicity using (a)fixed distance 5km(b) Adaptive smoothing (NN6)



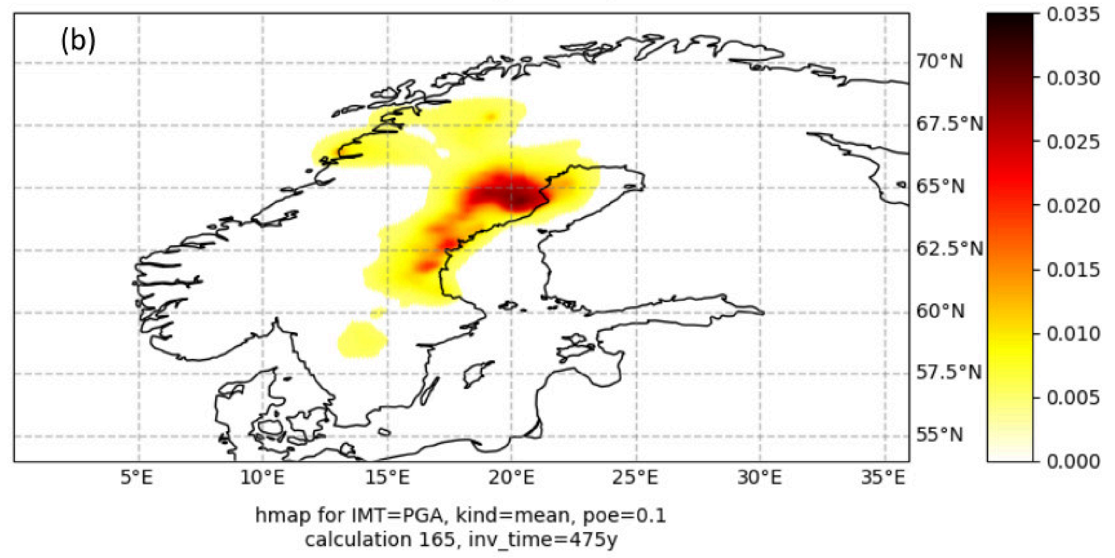
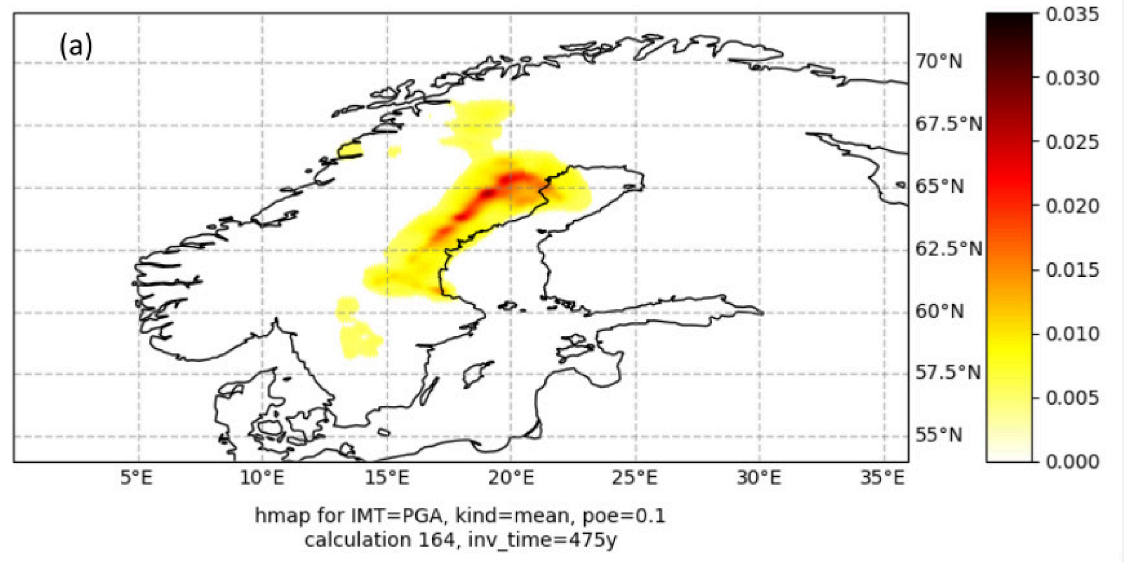


Figure 6. Hazard map based on the ESHM20 craton GMPE and smoothed Seismicity using (a)fixed distance of 5km(b) Adaptive smoothing (NN6)



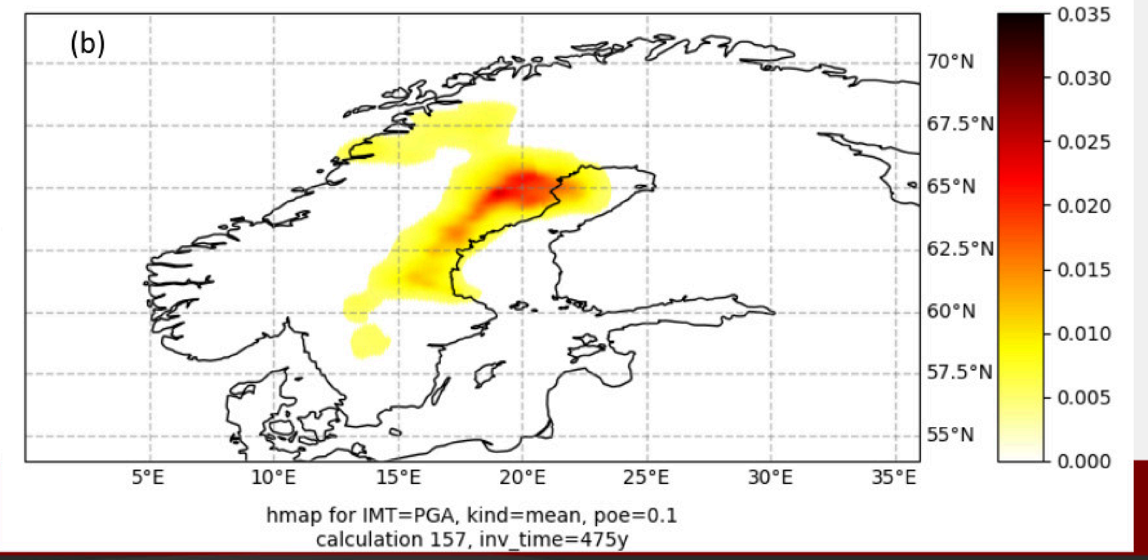


Figure 7. Hazard map based on a suite of GMPEs and smoothed Seismicity using (a)fixed distance 5km(b) Adaptive smoothing (NN6)

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3. Mikko et al, 2015
4. Aki M.,1965
5. Helmstetter et.al, 2007
6. Fülöp et al., 2020
7. Weatherill et.al, 2020
8. Bykova et.al, 2016

Discrimination of Icequakes and Tectonic Earthquakes using Unsupervised Machine Learning

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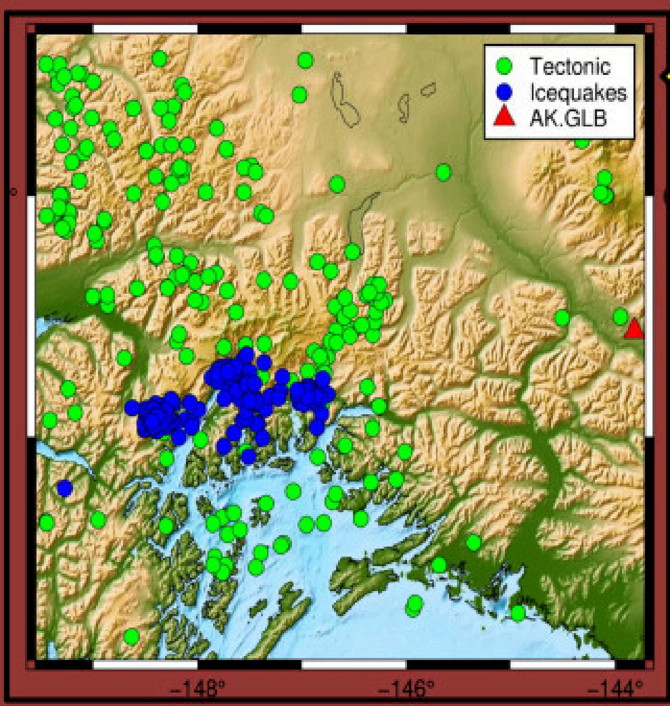
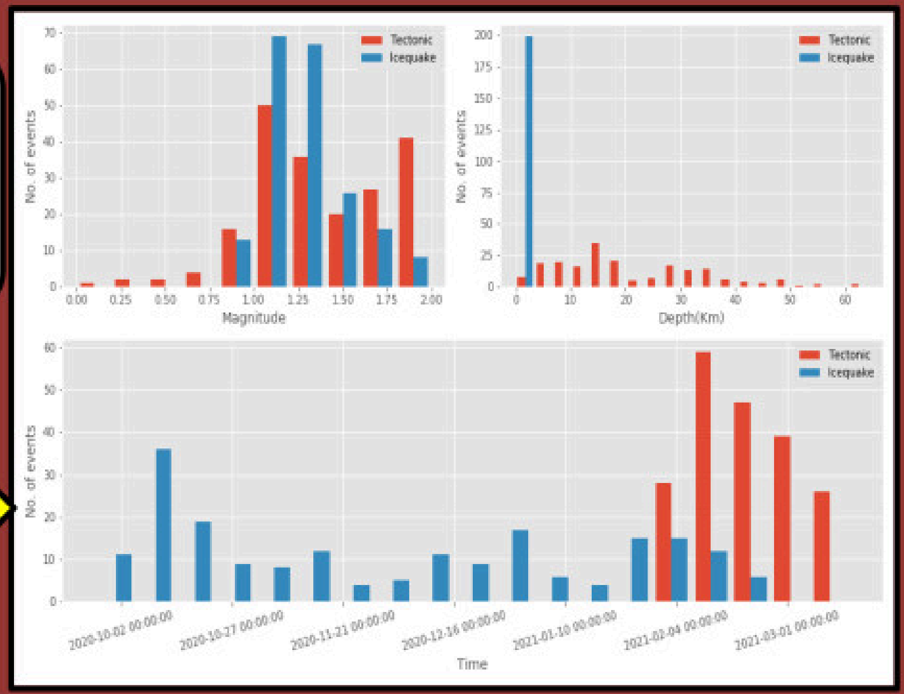
1. Indian Institute of Technology Roorkee India 2. Geological Survey of Greenland and Denmark
3. Alaska Earthquake Centre, University of Alaska Fairbanks

1. Background

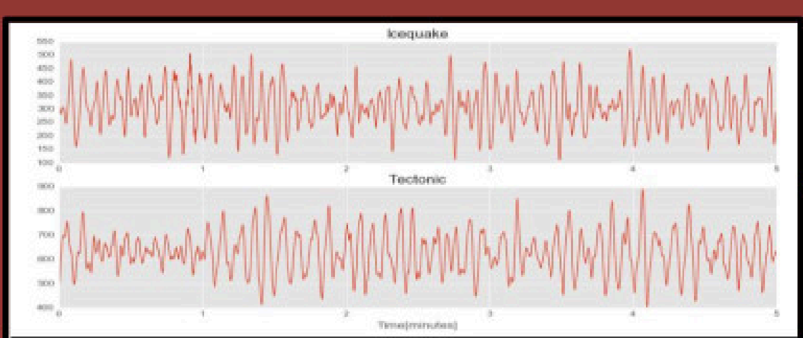


- We took 200 icequakes and tectonic earthquakes near columbia glacier in Valdez, South-eastern Alaska.
- The icequakes are distinct from tectonic earthquakes in the sense that P and S phase are clearly identified in the case of tectonic earthuakes

- Nonetheless, If the magnitude of these events are very small and they overlap in terms of location and timing, it is challenging for analysts to distinguish icequakes from tectonic earthquakes
- We experimented on this data to build an unsupervised machine learning model
- The model uses Principal Component Analysis [PCA] and Gaussian Mixture Models [GMM]

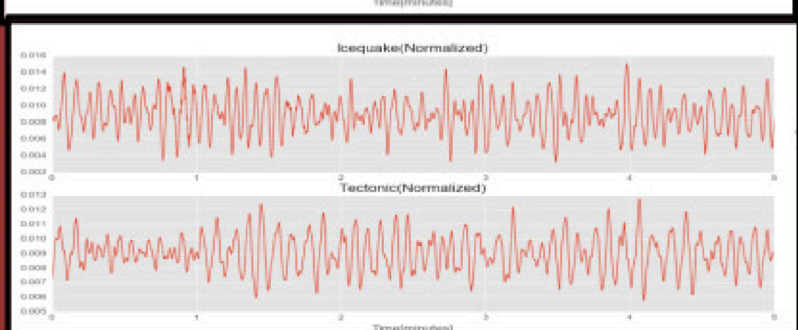


2. Model and stepwise illustrations



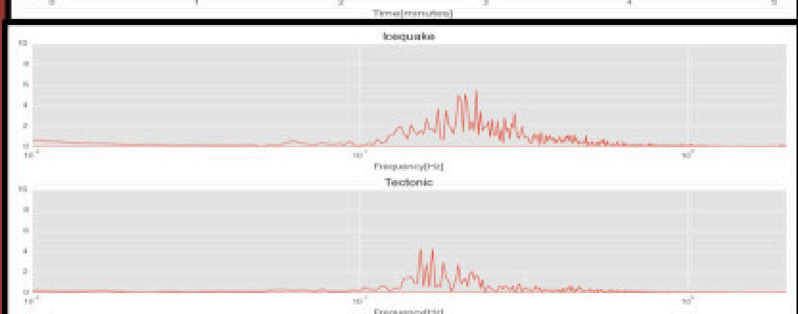
Input Z component seismograms, 2.5 minutes in duration from the origin of event. X_i is the trace corresponding to i^{th} event, n is the total no. of events and n_s is the no. of samples in the trace-

$X_1(t,n_s), X_2(t,n_s), X_3(t,n_s), \ldots X_n(t,n_s)$



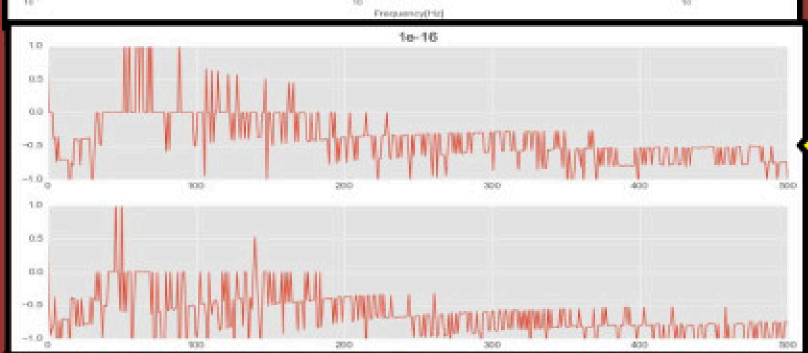
Convert each individual series to frequency domain by applying fast fourier transform. F_i refers to the Fourier spectrum of the i^{th} series.

$F_1(f,n_s), F_2(f,n_s), F_3(f,n_s), \ldots F_n(f,n_s)$



Take absolute values of each series and amplify each series by taking 10^{-16} power.

$abs(F_1(f,n_s))^{1e-16}, abs(F_2(f,n_s))^{1e-16}, abs(F_3(f,n_s))^{1e-16}, \ldots abs(F_n(f,n_s))^{1e-16}$

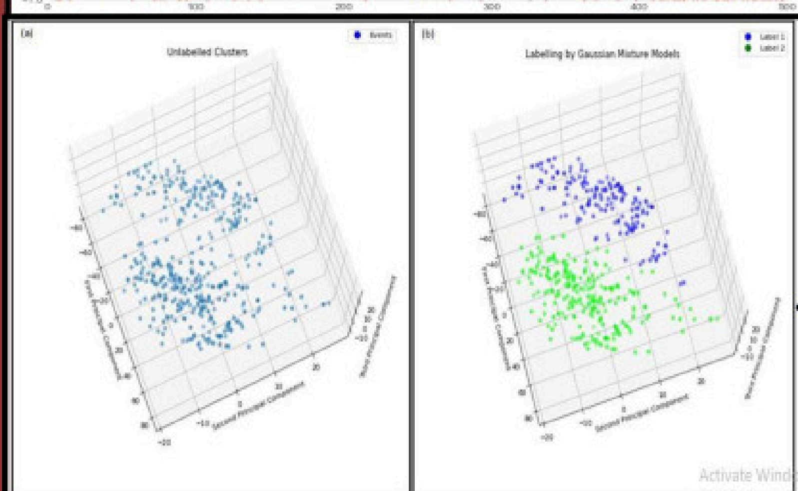


Standardizing each series by removing the mean and scaling to unit variance before putting applying PCA

$S_1(f,n_s), S_2(f,n_s), S_3(f,n_s), \ldots S_n(f,n_s)$

Applying PCA to reduce each input series to 3 dimensions.

$K_1(f,3), K_2(f,3), K_3(f,3), \ldots K_n(f,3)$

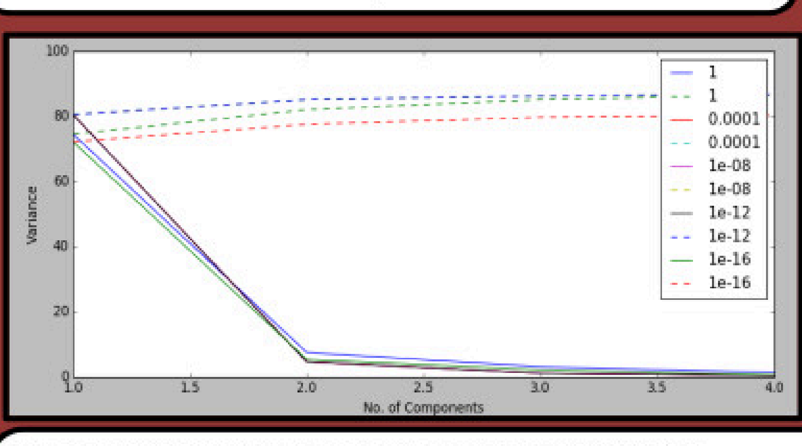


Label each series using Gaussian Mixture Models clustering. The output will look something like this where 0 and 1 are labels-

0,0,1,0,1,0,0 0

We will also get probabilities of each event belonging to each clusters.

- We reduced to only three components because the variance was not changing significantly with addition of more components. And it is easier to visualize each event on a 3D plot.



We found that our model gave the accuracy of 72 % when compared with the preliminary catalog provided by GEUS. However the difference mainly occurred at Disko Island. We further analyzed the events at Disko island and found them to be tectonic events as suggested by our Model.

3. Application to Glacial and Tectonic events in Greenland

- We applied our model to discriminate the tectonic and glacial events near Jacobshavn glacier in Greenland.
- The events were recorded in the year 2017
- The events overlapped in terms of magnitude, time and space.