49th Nordic Seismology Seminar
3rd Nordic EPOS Meeting

Program
Abstracts

October 9, 2006 — mb 4.0 ~ 0.5 kT
May 25, 2009 — mb 4.5 ~ 1-3 kT
February 12, 2013 — mb 5.0 ~ 10 kT
January 6, 2016 — mb 4.8 ~ 5 kT
September 9, 2016 — mb 5.1 ~ 10 - 15 kT
September 3, 2017 — mb 6.1 ~ 200 - 300 kT

NORSAR seismic array, Hedmark, Norway

Time (seconds)
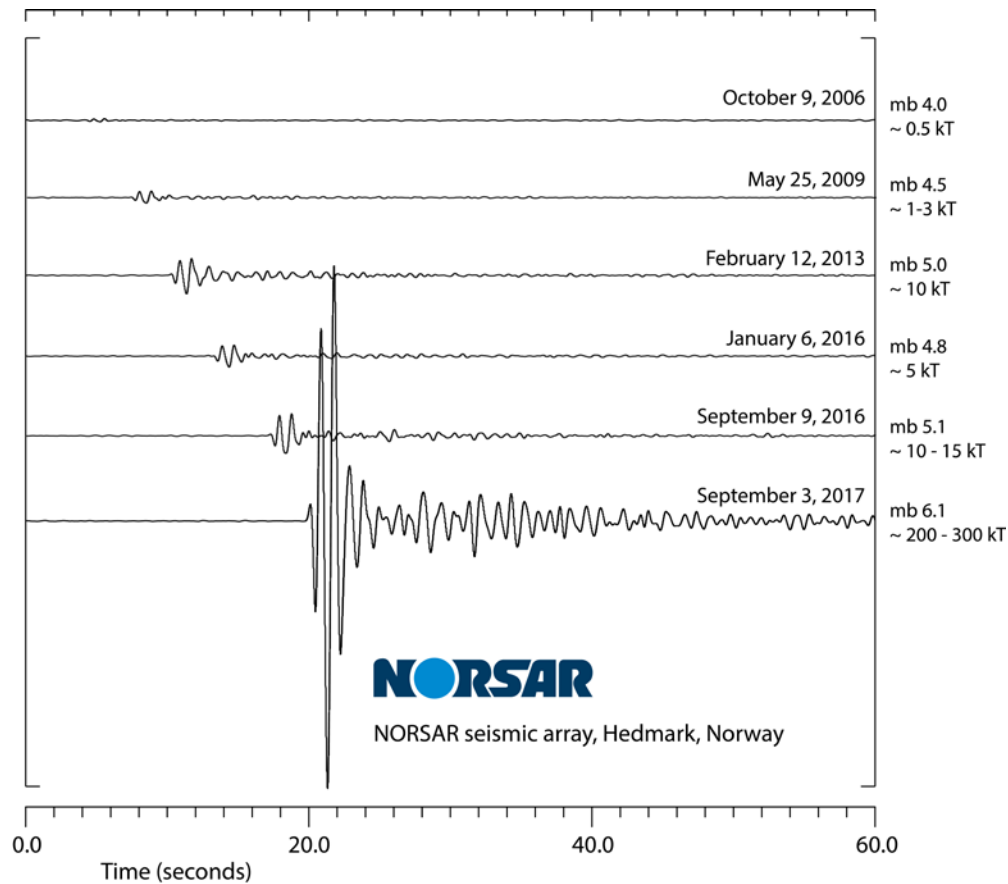
24-27 September 2018
NORSAR, Kjeller, Norway

49th Nordic Seismology Seminar

24-26 September 2018
NORSAR, Kjeller

Program

Monday, 24 September 2018

- 11:30 – 12:15 Registration at NORSAR's premises at Kjeller

- 12:15 – 13:00 Lunch

- 13:00 – 14:45 Opening Session

  Chair: Tormod Kværna

  - Opening address by Arve E. Mjelva, Deputy Director of NORSAR

  - Mathilde B. Sørensen

    - **What do we know about large historical earthquakes in Norway?**

  - Conrad Lindholm

    - **A model for the Scandinavian Postglacial faults**

  - Peter Schmidt and Björn Lund

    - **Fault stability in Fennoscandia during the Weichselian glaciation**

  - Päivi Mäntyniemi, Mathilde B. Sørensen, Tatiana N. Tatevossian, Ruben E. Tatevossian and Björn Lund

    - **The Lurøy, Norway earthquake of 31 August 1819: A reappraisal of the data east of Norway**

- 14:45 – 16:00 Poster session and coffee break

  - Nicolai Rinds and Peter H. Voss

    - **The operations manual to produce the earthquake bulletin for Denmark and Greenland – a work in progress (poster)**

  - Peter H. Voss, M. B. Sørensen, Zeinab Jeddi and the INTAROS Team

    - **The status of the seismological component of INTAROS project (poster)**

  - Pietari Koskenniemi, Jari Kortström, Marja Uski and Tommi Vuorinen

    - **Real-time seismic monitoring of a hydraulic fracture stimulation (poster)**

Tuesday, 25 September 2018

- 09:00 – 10:30 Morning Session 1

  Chair: Mathilde B. Sørensen

  - Myrto Pirli, Sebastian Hainzl, Johannes Schweitzer, Andreas Köhler and Torsten Dahm
    - **Localised thickness variations and ephemeral grounding of the Fimbul Ice Shelf, East Antarctica, from tidally modulated cryoseismicity**
  - Andreas Köhler, Giusi Buscaino, Pierre Marie Lefeuvre, Valerie Maupin, Christopher Nuth, Michal Petlicki, Johannes Schweitzer and Christian Weidle
    - **Seismic monitoring of glaciers and permafrost: What micro-seismicity and ambient noise can tell us about cryospheric processes in Svalbard**
  - Johannes Schweitzer, Andreas Köhler and Christian Weidle
    - **Regional seismicity observed with two temporary seismic arrays in Kongsfjorden, Svalbard**
  - Steven J. Gibbons
    - **Improved location estimates for seismicity along the northern North Atlantic Ridge**
- 10:30 – 10:50 Coffee break

- 10:50 – 12:15 Morning Session 2

  Chair: Peter H. Voss

    o Svein Mykkeltveit

        ▪ **Current status of implementation of the verification regime for the Comprehensive Nuclear-Test-Ban Treaty (CTBT)**

    o Tormod Kværna, Steven J. Gibbons and Svein Mykkeltveit

        ▪ **The large nuclear test in North Korea on 3 September 2017 and its aftershocks**

    o Kostas Lentas, Dimitry Storchak and James Harris

        ▪ **New additions in the ISC Bulletin: ISC focal mechanism solutions**

    o Björn Lund, Peter Schmidt, Hossein Shomali, Michael Roth and the SNSN team

        ▪ **Current status and developments at the Swedish National Seismic Network**

- 12:15 – 13:00 Lunch

- 13:00 – 14:15 Afternoon Session 1

  Chair: Päivi Mäntyniemi

    o Peter H. Voss

        ▪ **Recent national and international activities at the seismological service at GEUS**

    o Jon Magnus Christensen

        ▪ **NORSAR Stations Operations**

    o Zeinab Jeddi, Mathilde B. Sørensen, Peter H.Voss and the INTAROS Team

        ▪ **Seismological monitoring in the Arctic: A brief introduction to INTAROS**

- 14:15 – 14:50 Poster session and coffee break

    o Ilmo Salmenperä, Tommi Vuorinen and Riina Aapasuo

        ▪ **NorDB - Database solution for maintaining seismic metadata (poster)**

    o Z. Hossein Shomali, Björn Lund, Peter Schmidt and the SNSN team

        ▪ **Monitoring the instrument response of The Swedish National Seismic Network (SNSN) (poster)**

- 14:50 – 16:20 Afternoon Session 2

  Chair: Björn Lund

  - o Tommi Vuorinen, Riina Aapasuo, Ilmo Salmenperä and Päivi Mäntyniemi

    - **EVOGY – Evolving the Fennoscandian GMPEs: From Seismometers to Ground Motion Estimates**

  - o Won-Young Kim and Lars Ottemöller

    - **Regional Body-Wave Magnitude Scale mb(Pn/Sn) for Earthquakes in the North Atlantic Region**

  - o Norunn Tjåland and Lars Ottemöller

    - **Evaluation of Seismicity in the Northern North Sea**

  - o Annie Elisabeth Jerkins, Steven Gibbons, Tormod Kværna and Johannes Schweitzer

    - **Location and Depth Estimation of the North Sea Earthquake of 30 June 2017**

- 19:00 Conference dinner hosted by NORSAR, Scandic Hotel, Lillestrøm

Wednesday, 26 September 2018

- 10:00 – 12:00 Morning Session

  Chair: Johannes Schweitzer

  - Jens Havskov, Mathilde B. Sørensen, Dina Vales, Mehmet Özyazıcıoğlu, Gerardo Sánchez and Bin Li
    - **Coda Q in different tectonic areas, influence of processing parameters**
  - Laure Duboeuf, Volker Oye, Inga Berre and Eirik Keilegavlen
    - **Induced seismicity in a geothermal reservoir: a case study in the Reykjanes peninsula in Iceland**
  - Yuriy Vinogradov and Elena Kremenetskaya
    - **The analysis of infrasound and seismic signals caused by helicopter crash in Svalbard on 26 October 2017**
  - Sven Peter Näsholm, Erik Mårten Blixt, Steven J. Gibbons, Felix B. Stettner and Tormod Kværna
    - **Interpreting explosive acoustic arrivals at the ARCES seismic array in the context of atmospheric cross-winds**
- 12:00 – 12:15 Closing remarks by organizers and invitation by next year's host
- 12:15 – 13:00 Lunch

3rd Nordic EPOS Meeting

26-27 September 2018
NORSAR, Kjeller

Program

Wednesday, 26 September 2018

- 12:15 – 13:00 Lunch
- 13:00 – 14:30 Opening Session

  Chair: Svein Mykkeltveit
    - Kuvvet Atakan and the EPOS Consortium
        - **European Plate Observing System (EPOS): Establishing a Sustainable Research Infrastructure in Solid Earth Science**
    - Aleksi Aalto
        - **Finland in the European Plate Observing System - Looking forward to the next decade**
    - Tor Langeland, Ove Daae Lampe and Gro Fonnes
        - **EPOS-N E-infrastructure development – the Norwegian National Web Portal**
    - Jan Michalek, Christian Rønnevik, Terje Utheim, Øyvind Natvik, Lars Ottemöller, Ulf Baadshaug, Jon Magnus Christensen
        - **Building UIB-NORSAR EIDA node - integration of Norwegian seismic data into EPOS**
- 14:30 – 14:50 Coffee break

- 14:50 – 16:10 Afternoon session
    - Svein Mykkeltveit
        - **Status for the new seismic array on Bjørnøya, to be established as part of EPOS-Norway**
    - Jan Michalek, Kuvvet Atakan, Xiaoliang Wang, Christian Ronnevik, Tor Langeland, Ulf Baadshaug, Jon Magnus Christensen, Halfdan Pascal Kierulf, Bjørn-Ove Grøtan
        - **EPOS-Norway – Integration of Norwegian geoscientific data into a common e-Infrastucture (poster)**
    - Xiaoliang Wang
        - **GRanularity DataBase (GRDB) in EPOS (poster)**

Thursday, 27 September 2018

Chair: Kuvvet Atakan
- 09:00 – 10:30 Discussion among all EPOS participants
- 10:30 – 10:50 Coffee break
- 10:50 – 12:15 Discussion among all EPOS participants
- 12:15 – 13:00 Lunch

49th Nordic Seismology seminar
24-26 September 2018
NORSAR, Kjeller

Abstracts

What do we know about large historical earthquakes in Norway?

Mathilde B. Sørensen, Dept. of Earth Science, University of Bergen, Norway

Norway is known as a country of low to moderate seismicity. The largest historical event (outside the cinema) on the Norwegian mainland was the M5.8 Lurøy event in 1918. In total, we have information on 11 events with magnitude 5 or higher throughout history. Despite this lack of large events, felt earthquakes are rather frequent, on average 10-15 earthquakes are felt in Norway each year. Seismologists in Bergen have collected detailed information on these felt events for more than a century, and an extensive dataset of macroseismic information is now available at University of Bergen. In this presentation, I will give an overview of the available data, with focus on some of the larger earthquakes and their impact. I will further describe an ongoing effort to make this dataset available online, and I will present examples of some of the work we are doing with the dataset. Such a historical earthquake dataset is crucial in constraining seismicity rates, one of the most important input parameters in any seismic hazard assessment.

A model for the Scandinavian Postglacial faults

Conrad Lindholm, NORSAR

Abstract: The Postglacial faults in northern Scandinavia were first recognized in the 1980's and we have today a fair understanding of their size and uniqueness in a global perspective. Huge earthquakes must have ruptured and left fault scarps of several meters. Norway has only one major fault: the Stuoragurra fault in Finnmark. A description of the Stuoragurra fault will be presented together with a model for why the ruptures took place in that particular region.

Fault stability in Fennoscandia during the Weichselian glaciation

Peter Schmidt and Björn Lund, Uppsala university

The Nordic countries are located on the Eurasian plate interior and as a consequence the seismic risk at present day in is considered low. Throughout historic times only a handful of earthquakes greater than M5 have been documented in the region and none above M6. Despite this, the northern parts of Norway, Sweden and Finland bears marks of larger events in form of fault scarps of up to 150 km in length and with offsets of up to 20 meters, estimated to have hosted single event earthquakes of magnitude 6-8. Dating has not yet been undertaken at all sites but where such studies have been performed, the timing of the events range from about 9,000 to 10,500 years before present, largely coinciding with the last stages of the Weichselian glacial cycle. Commonly known as end-glacial or post-glacial faults (PGF), today some of these remain highly active, most notably the Pärvie, Burträsk and Stuoragurra faults, where numerous earthquakes up to M3 are detected every year. Here we show the results from glacial isostatic adjustment (GIA) modelling of the Weichselian ice-sheet focusing on the evolution of stress and fault stability at seismogenic depths. We model the GIA process using finite element analysis and compare the stresses arising from three different reconstructions of the Weichselian ice-sheet: The observationally driven ICE5G and ANU models and the UMISM model based on thermo-mechanical modelling. We set up earthmodels with elastic parameters from the PREM model and mantle viscosities and elastic thicknesses fine-tuned to best match present day uplift rates in Fennoscandia. We run models with both uniform well as laterally varying elastic thickness. While the ice induced vertical stresses largely are proportional to the local thickness of the ice-sheet, the horizontal stresses are strongly influenced by the bending of the lithosphere as it flexes under the load of the ice. As the deglaciation of the icesheet occurs over significantly shorter time scales than the relaxation time of the mantle beneath Fennoscandia, induced fault destabilizing shear-stresses will persist longer in the crust than induced fault-stabilizing vertical stresses. The glacially induced stresses are however not solely large enough to have generated the observed displacements on the PGF's and we need to consider the background stress field. Unfortunately, the state of stress in Fennoscandia is not well known at seismogenic depths. We therefore generate synthetic regional fields for both reverse and strike-slip stress state. We find that the stress state is of great importance to the fault stability. Coulomb failure analysis under the assumption of a reverse background stress state yields increased fault stability during the build-up of the ice-sheet and reduced during and after the deglaciation in good agreement with the timing of the dated events. If instead the background stress state is strike-slip, the analysis yields increasing fault stability throughout the glacial cycle if the glacially induced pore pressure head is less than 50% of the local weight of the ice column. If the pore pressure is even greater reduced fault stability may occur during the buildup phase of the ice-sheet. This however is in disagreement with the observed timing of the end-glacial faults in Fennoscandia. The inferred geometry of the Weichselian ice-sheet with center over the bay of Bothnia results in the greatest induced stress perturbations in the northern parts of Fennoscandia explaining the geographical distribution of confirmed end-glacial faults in this region of the lack thereof in the southern regions. Taking into consideration the thickening of the lithosphere to the east we find that the fault instability is slightly suppressed in central Sweden whilst increased to the north. faults in Fennoscandia.

The Lurøy, Norway earthquake of 31 August 1819: A reappraisal of the data east of Norway

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Mathilde B. Sørensen, Department of Earth Science, University of Bergen, Norway
Tatiana N. Tatevossian, Institute of Physics of the Earth RAS, Russia
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Björn Lund, Department of Earth Sciences, Uppsala University, Sweden

The earthquake of 31 August 1819 has been located near Lurøy (66.5°N and 14.5°E), on the coast of Nordland, Norway. Ambraseys (1985) and Muir Wood (1988) have prepared the previous macroseismic maps. The magnitude has been estimated at 5.8M_S, which makes it the largest onshore/nearshore earthquake in the historical seismicity record of Fennoscandia. The maximum intensity value has been estimated at 8 MMI in the territory of Norway. This investigation focuses on the eastern area of perceptibility that is important for defining its extent.

Ambraseys (1985) and Muir Wood (1988) used the contemporary press in Sweden, Finland and Russia. Here, archives and libraries have been visited to uncover previously disregarded documents and to confirm old data points. However, Swedish and Russian newspaper reports were also found.

There were four types of revisions to the intensity data points (IDPs) on the basis of the uncovered documentation: 1) the new reports referred to previously unknown places and created new IDPs, 2) no report of any kind could be found for an existing IDP, which resulted in its removal, 3) the intensity assessment could be confirmed/revised for a given place on the basis of the original documentation and 4) one previously accepted and later omitted place was brought back on the map. There are four entirely new IDPs, two were removed and more extensive documentation was found on four previously known places (Stockholm, Umeå, Tornio, Kola). Thus, rather a significant portion of the IDPs in the eastern area of perceptibility was subjected to revision.

References

Ambraseys NN (1985) The seismicity of western Scandinavia. Earthquake Eng Struct D 13:361-399
Muir Wood R (1988) The Scandinavian earthquakes of 22 December 1759 and 31 August 1819. Disasters 12:223-236

The operations manual to produce the earthquake bulletin for Denmark and Greenland – a work in progress

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To produce earthquake bulletins from seismological recordings is a complex task that involves the execution of multiple functions. The seismologist in charge or the earthquake bulletin production must understand the purpose of each function and the limitation of it. An operations manual describes the used functions and gives guidelines on which order the functions are applied and on ways to solve problems with each function, in order to produce the bulletin. At GEUS we found that a lot of the information involved in the production of our earthquake bulletin was not documented, either because it was only a single person that undertook the function or since it was a function everybody knew. We have therefore initiated the work to write an operational manual for the production of our earthquake bulletin. The focus on documentation the operation was in the past on describing the instrument type and location used in the network, station history and contact information. Documentation on data processing was only available in software manuals or in seismological literature, documentation on in-house software was nonexistent and training of new staff was shoulder-to-shoulder based. Our first steps in creating our operations manual has been 'a who does what' description and to initiate systematic descriptions on functions, with checklists. We try to apply Kanban philosophy whenever possible; in the case of data loss, this e.g. means that different pull signals are send with respect to the different data sources. Our aim for the operations manual is, that the functions applied during the earthquake bulletin production becomes independent of the seismologists present.

The status of the seismological component of INTAROS project

P.H.Voss[1], M. B. Sørensen[2], Z. Jeddi[2], the INTAROS Team
1) Geological Survey of Denmark and Greenland
2) University of Bergen, Norway

By 1 December 2016 the five-year INTAROS project was launched with Horizon 2020 funding from the European Commission. The overall objective of INTAROS is to develop an integrated Arctic Observation System (iAOS) by extending, improving and unifying existing systems in the different regions of the Arctic. INTAROS will have a strong multidisciplinary focus, with tools for integration of data from atmosphere, ocean, cryosphere and terrestrial sciences, provided by institutions in Europe, North America and Asia. Here we present the status of the ongoing work to map the data completeness of the earthquake monitoring in the Arctic region. The work includes estimated earthquake magnitude detection threshold for different time intervals and modelling of ways to improve detection threshold. This seismological component of INTAROS is based on existing earthquake catalogues for the Arctic, and it provides knowledge on which areas that are poorly monitored. This knowledge is key for the next seismological component of INTAROS to perform a yearlong deployment of broadband OBS'es in the Arctic using ROV technology. The aim using OBS'es is to show how to fill the earthquake/seismic monitoring gap in the Arctic region. Furthermore, as part of an initiative that is focused on community-based science, simple geophones has been installed in Greenland and in Svalbard. We will give an overall presentation of INTAROS and outline the status of the seismological contributions.

Real-time seismic monitoring of a hydraulic fracture stimulation

Pietari Koskenniemi, Jari Kortström, Marja Uski and <u>*Tommi Vuorinen*</u>
Institute of Seismology, Department of Geosciences and Geography, University of Helsinki

The Finnish power company St1 Deep Heat (SDH) has initiated an Enhanced Geothermal System (EGS) project in the city of Espoo, southern Finland. EGS-type power plant exploits bedrock heat by injecting water into a deep borehole and after heated by geothermal heat pumping it to heat exchanger through another borehole. Water circulation between the boreholes is opened by hydraulic fracturing, i.e. by pumping fluids into the borehole under pressures high enough to fracture the rock.
Hydraulic fracture stimulation of the first 6.4km deep borehole was performed in June-July 2018. To control increased seismic risk associated with the operation, SDH implemented a three level (green, amber, red) seismic traffic light system (TLS): if earthquake magnitude and/or peak ground velocities exceeded the low limit for amber, risk mitigation actions were applied. The city of Espoo mandated the Institute of Seismology, University of Helsinki (ISUH) to monitor the induced seismicity levels and the TLS exceedances. Preliminary results of the induced seismicity analyses at ISUH are presented in the following.

Localised thickness variations and ephemeral grounding of the Fimbul Ice Shelf, East Antarctica, from tidally modulated cryoseismicity

Authors:
Myrto Pirli[1], Sebastian Hainzl[2], Johannes Schweitzer[3,4], Andreas Köhler[5] and Torsten Dahm[2,6]

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[4] *CEED, University of Oslo*
[5] *Department of Geosciences, University of Oslo*
[6] *Institute of Earth and Environmental Sciences, University of Potsdam*

A dataset of cryogenic seismic events that covers nearly two decades of continuous seismic recordings has been acquired for the Fimbul Ice Shelf, in Dronning Maud Land, East Antarctica. The activity, which commences abruptly during the austral summer 2011, is located near the calving front of the ice shelf, in a region of shallow bathymetry.

Highly repetitive events, recorded at the broadband stations TROLL and SNAA, at near-regional distances, display remarkably periodic patterns of recurrence rates and magnitudes, correlating with the cycles of the ocean tide. More specifically and in contrast to the common unpredictability of earthquake magnitudes, deterministic trends are evident within single semi-diurnal tidal cycles, while strong correlations are also observed with spring tides and tide height. The quasi-periodic occurrence of the seismicity is accompanied by the landward migration of the highly constrained event-sources during rising tide.

A simple, mechanical model that assumes stick-slip motion on a patch of grounded ice-shelf, forced by variations in ocean-tide height and ice flow, can explain most of the observations.

The results provide new insights into the general process of frictional triggering of earthquakes, while constituting independent evidence of subtle variations in ice-shelf thickness and ephemeral ice-shelf grounding.

Seismic monitoring of glaciers and permafrost: What micro-seismicity and ambient noise can tell us about cryospheric processes in Svalbard

Authors:
Andreas Köhler[1], Giusi Buscaino[3], Pierre Marie Lefeuvre[1], Valerie Maupin[1], Christopher Nuth[1], Michal Petlicki[5], Johannes Schweitzer[1,2], Christian Weidle[4]
1:University of Oslo, 2:NORSAR, 3:IAMC-CNR, Sicily, Italy, 4: University of Kiel, Germany, 5: Center for Scientific Studies, Valdivia, Chile

Cryo-seismology has become a popular tool to study and better understand glacier dynamics on different spatial scales. For example, we have previously used seismic records of regional glacier seismicity from the past two decades to study glacier surges and to quantify iceberg calving at tidewater glaciers in Svalbard. Here, we present results from a temporary seismic field experiment in 2016 in the Kongsfjord region, NW Svalbard, including analysis of glacier seismicity as well as ambient seismic noise.

We analyzed data between April and August 2016 from a 4.5 Hz geophone in a shallow glacier borehole on Holtedalfonna, an ice field which drains into Kongsfjord through Kronebreen, one of the fastest glaciers in Svalbard. Seismic events were detected using a STA/LTA trigger and master event cross-correlation. Polarization analysis allowed to determine source backazimuth of icequakes and comparison with synthetic waveforms to estimate distance, depth, and possible source mechanisms. We found repeating events of different classes, mostly of shallow origin and presumably related to crevasse opening and cracking. Correlation with glacier velocity (i.e., fast flow episodes), meteorological conditions (rain events and positive temperatures), and solar radiation suggests a close relation with glacier dynamics. For seismic modeling we used a sub-surface velocity model of the glacier inverted from ambient seismic noise using the Horizontal-to-Vertical Spectral Ratio (HVSR) method and the diffuse wavefield theory. Furthermore, ambient seismic noise correlates with positive temperatures, suggesting the presence of melt-water tremors.

Time-lapse monitoring of the sub-surface with ambient seismic noise is promising and powerful technique in environmental seismology. We used data of two temporary seismic arrays deployed between April and August 2016 close to Ny Ålesund and the permanent GSN station KBS to assess the reliability of the HVSR method for monitoring seasonal permafrost active layer variability covering frozen and thawed soil conditions. Complex HVSR variability is observed between 1 and 50 Hz. While strong variations can be related to changing noise conditions, mainly wind and degrading instrument coupling, a seasonal trend is observed at some stations that has most likely a sub-surface structural cause. A HVSR peak emerges close to the Nyquist frequency in beginning of June which is then gradually gliding down to frequencies of about 15-25 Hz in the end of August. We were able to reproduce this variability by HVSR forward-modeling using a set of structural models that simulate different stages of active layer thawing. However, as a general recommendation, we suggest a careful analysis of temporal variations since HVSR seasonality is not always and not necessarily related to changes in the sub-surface. In addition, we investigate if effects of changing noise sources on HVSRs can be avoided by utilizing a directional, narrow-band repeating seismic tremor which is observed at station KBS during the past decade.

Regional Seismicity observed with two temporary seismic arrays in Kongsfjorden, Svalbard

Authors:
Johannes Schweitzer[1,2], Andreas Köhler[3] and Christian Weidle[4]

[1] *NORSAR*
[2] *CEED, University of Oslo*
[3] *Department of Geosciences, University of Oslo*
[4] *Kiel University (CAU)*

The goal of the CalvingSEIS project is to produce high temporal resolution, continuous calving records for the glaciers in Kongsfjord, Svalbard, and in particular for the Kronebreen glacier laboratory. Through innovative, multi-disciplinary monitoring techniques combining fields of seismology and bioacoustics, individual calving events were detected and located autonomously, and methods to quantify calving ice volumes directly from the seismic and acoustic signals have been developed.
One element of the seismic monitoring was the installation of a temporary, 8-element seismic array (BRA) west of Ny-Ålesund in Kongsfjord, Svalbard, between 10 April and 4 September 2016. The 3C sensors of the array consisted of 4.5 Hz geophones and Data CUBE recorders of the German pool of mobile stations (GIPP). A second temporary, 3-element array (KRBS) was running with same equipment close to the calving front of the glacier (24 August – 3 September 2016).
These seismic arrays not only recorded calving events at the glaciers around Kongsfjord, but also regional seismicity from e.g., the Knipovich Ridge, which at its shortest distance is situated only about 100 km away from Ny-Ålesund.
In this study, the capabilities of these geophone arrays to monitor the regional seismicity will be investigated by comparing their records with NORSAR's automatic and analyst reviewed bulletins.

Improved location estimates for seismicity along the northern North Atlantic Ridge

Steven J. Gibbons, NORSAR

Accurate location estimation for earthquakes along mid-oceanic ridges is essential to better understanding the relationship between seismic activity and tectonic mechanisms. Locating oceanic earthquakes is difficult due the lack of stations at local distances. In particular, location estimates for lower magnitude seismic events may be significantly biased due to limited numbers of high quality recordings and poor station coverage. We have applied two independent procedures on different sets of events along the mid-Atlantic ridge between Iceland and north of Svalbard in order to obtain an improved overview of the distribution of seismicity in this region over the last three decades. In the first procedure, a double-difference algorithm was applied to cross-correlation measurements on Rayleigh waves generated by larger magnitude events. In the second procedure, a Bayesian multiple event location algorithm was performed on body-wave arrival time measurements both at regional and teleseismic distances. Both procedures result in a greatly reduced spread in hypocenter estimates, and visualizing the resulting distributions of seismicity together on a high-resolution sea-bed map indicates far better alignment of events and a better correspondence between hypocenter estimates and tectonic features. The two independent event location procedures show a far more consistent pattern of seismicity than is apparent from existing event catalogs and regions of significant seismic activity and regions of sparse seismic activity are far better separated. The improved location estimates will allow for improved calibration of seismic traveltimes.

Current status of implementation of the verification regime for the Comprehensive Nuclear-Test-Ban Treaty (CTBT)

Svein Mykkeltveit, NORSAR

The CTBT, which bans nuclear weapon test explosions and any other nuclear explosions, was adopted by the United Nations and opened for signature in 1996. The build-up of the CTBT verification regime, funded and organized by the Preparatory Commission for the CTBT Organization and its secretariat based in Vienna, Austria, is nearing completion. As of September 2018, 293 of the 321 globally distributed stations of the International Monitoring System (IMS) have been installed. Almost all of the stations installed are providing data to the International Data Center (IDC), which produces an analyst reviewed bulletin containing on average 100 events per day, based on processing of seismic, infrasound and hydroacoustic data. The IDC also issues daily reports on the results of analysis of spectra from radionuclide monitoring stations. The arrangements for on-site inspections (OSI) to clarify concerns related to 'suspicious events' detected by the IMS/IDC system, have also reached a mature stage. A large OSI field exercise in Jordan in late 2014 provided results that are being used to further develop the OSI component of the CTBT verification regime through implementation during 2016-2019 of an action plan for the OSI regime.

The presentation will provide an overall assessment of the status of implementation of the CTBT verification regime. The emphasis will be on current work and challenges to complete the verification regime in a timely manner, as well as on technical and other factors affecting progress of remaining work. The role of Working Group B, which is the forum for Member States to exercise its policy and oversight functions for verification related tasks, will be underlined. In addition, NORSAR's assignments for the Ministry of Foreign Affairs will be described.

The large nuclear test in North Korea on 3 September 2017 and its aftershocks

Tormod Kværna, Steven J. Gibbons and Svein Mykkeltveit, NORSAR

On 3 September 2017 the Democratic People's Republic of North Korea conducted a very large underground nuclear test, having an estimated body-wave magnitude of 6.1. This was the 6th underground nuclear explosion in a series of tests which started in 2006. The 3 September 2017 event was an order of magnitude larger than any of the previous explosions, and its large size indicates a nuclear fusion device.

In this presentation we address the following topics related to the North Korean underground nuclear tests:
- Observations - seismograms
- NORSAR's alert system for detection of events near the North Korean test site
- Estimates of location, magnitudes and yields
- Detection and analysis of aftershocks

New additions in the ISC Bulletin: ISC focal mechanism solutions

K. Lentas, D. Storchak & J. Harris
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The Bulletin of the International Seismological Centre (ISC) is the most comprehensive source of seismological parametric data, which is mainly hypocentre solutions and their associated seismic phase arrivals. Every new data year added in the Bulletin consists of tens of thousands of seismic events spread worldwide and a few millions of seismic phases which are routinely being reviewed by the ISC analysts. The main outcome of this work is a set of ISC relocated seismic events combining seismic phase arrivals made available to the ISC that may have been provided by more than one seismological agency for the same event. Occasionally, other kind of information such as phase polarities and source mechanisms are also being collected, and being added in the ISC Bulletin, without further review by the ISC analysts. However, this data is either not provided by all reporting agencies in a routine way, or in some cases the data is provided for strong earthquakes only, which yields a gap on earthquake source mechanism availability for moderate magnitude (e.g., mb ~4.5) earthquakes in the ISC Bulletin.

The ISC has now made part of its routine operations the determination of focal mechanisms based on first motion polarities from the ISC Bulletin (mb ISC $\geq$ 4.5) combined with automatic picks of available waveforms for the seismic stations that do not report phase polarities, aiming to provide a complementary source of earthquake mechanism solutions and fill in gaps of earthquakes with no previously associated mechanism solutions. The first set of ISC computed mechanisms was added in the ISC Bulletin for the data month April 2015, and since then focal mechanisms are being calculated for every data month reviewed by the ISC analysts and being added in the Bulletin. In addition, ISC focal mechanism solutions from previous years (2011-2014) will be made available very soon, whilst ISC earthquake mechanisms based solely on reported first motion polarities are already added in the ISC Bulletin for the time period covering the earthquakes in the International Seismological Summary (ISS) for the time period 1938 – 1963, as well as the first part of the ISC rebuild project (1964 – 1979).

The focal mechanism computations are carried out by a modified version of the HASH technique, that allows the calculation of takeoff angles from local to teleseismic epicentral distances (up to 90°), using the ak135 velocity model for teleseismic distances and CRUST2.0/5.1 for local and near regional distances, respectively. The whole process is fully automated, meaning that from the data selection to pick validation and mechanism solution acceptance no interaction with an operator is required, whilst a number of validation tests check the correctness of auto picks and final mechanism solutions. Currently, an attempt to enhance the quality of the automatic picks by optimizing the performance of the automatic picker is under way, with preliminary results showing that the picker has become more selective (less prone to false triggering) resulting in lower misfit values in the obtained mechanisms.

Current status and developments at the Swedish National Seismic Network

Björn Lund, Peter Schmidt, Hossein Shomali, Michael Roth and the SNSN team

The Swedish National Seismic Network (SNSN) has grown to 68 permanent stations and number 69 is in the making. In this presentation we will review the current state of SNSN, focusing on instruments, site equipment, communication and data retrieval. We present an updated seismicity map of Sweden and work in progress on 3D velocity models and focal mechanisms. The SNSN also run projects such as microseismic monitoring for (future) geothermal energy and for the (future) Swedish nuclear waste repository as well as seismic risk related projects. We will present results and experiences from these projects and discuss implications for SNSN and Swedish seismology.

Recent national and international activities at the seismological service at GEUS

Peter H. Voss
Geological Survey of Denmark and Greenland – GEUS

In this presentation, the activities at the seismological service at GEUS on a national and international level are presented. With respect to the operation of the seismological service at GEUS, the main change during the recent year is the addition of a new staff member to primary handle the screening for, and analyzing of seismic events in the incoming data from Denmark and Greenland. On the infrastructure side, increasing noise level at the Bornholm station BSD led to a site survey and a test installation at a new location is now conducted. The borehole instrument at southern Jutland station SSRD is installed and sending data, next step at this station is to determine the metadata, especially the rotation of the sensor. Another metadata challenged have been observed at the EGRIP station on the Greenland Icecap, since the station has moved more than 100 m since 2016. The seismological group at GEUS is taking part in several projects, three for the EC, one test of the DanSeis infra structure and a landslide screening project in Greenland. The EC projects are the INTAROS project (presented by poster), the SECURe project and HIKE project. SECURe has a focus on "Subsurface Evaluation of Carbon capture and storage and Unconventional Risk", in connection to SECURe GEUS is installing a seismic monitoring network at the natural gas storage facility in Denmark. The HIKE project (Hazard and Impact Knowledge for Europe), has its focus on induced hazards and impacts that are related to the exploitation of subsurface resources and capacities, GEUS main activity is on earthquake location techniques. DanSeis the Danish national research infrastructure "that provides access to cutting edge seismic research equipment to scientists from research institutions in Denmark and worldwide" (https://danseis.dk), has undertaken a large test of the equipment and training of staff. Challenges found during the test are presented.

NORSAR Stations Operations

Jon Magnus Christensen, NORSAR

NORSAR is the Norwegian National Data Centre (NDC) and currently operates six stations in the International Monitoring System. This includes two primary seismic arrays (PS27, PS28), one auxiliary seismic array (AS72), one auxiliary single seismic station (AS73), one infrasound station (IS37) and one radionuclide station (RN49). In addition to several other installations. In total NORSAR operates more than 100 instrumentation sites and approximately 150 seismometers and infrasound sensors in the field. All NORSAR instrumentation is sending real-time, continuous data totaling about 280 channels.

This presentation will give an overview of NORSARs field installations and station operations. Including newly installed temporary and semi-permanent installations.

Seismological monitoring in the Arctic: A brief introduction to INTAROS

Z. Jeddi[1], M. B. Sørensen[1], P.H. Voss[2] and the INTAROS Team
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2) *Geological Survey of Denmark and Greenland*

The Arctic is experiencing the rapid changes in the climate system worldwide. Accordingly, several natural disasters, e.g. landslides or earthquakes among others, are likely to increase together with the expected changes in the climatic conditions in the Arctic.

To study the temporal variations of the Arctic seismicity and assess the seismic hazard in the area, a unified earthquake catalogue is required. Many datasets are currently available through national and international monitoring networks, however there has been little effort to integrate interdisciplinary data and make it available to the scientific community. Eu-funded INTAROS project (Integrated Arctic Observation System) is expected to assess the strengths and weaknesses of the existing observing systems, and contribute with innovative solutions to fill some of the critical gaps in the in situ observing network. The seismological session of the INTAROS is focused on creating a baseline earthquake database, and in this regard a catalogue of seismological monitoring capabilities was developed for the Arctic region between 1965 – 2015, together with new focal mechanism calculations for larger events.

To improve the existing catalogue and fill part of the large observational gap in the offshore regions of the arctic (mainly due to the harsh weather conditions), Ocean Bottom Seismometers (OBS) were deployed in the Fram Strait near the Northern Mid-Atlantic Ridge during summer 2018 and will sit on the sea floor for one year. The improvement of the monitoring coverage will provide a new dataset which will enable us to lower the earthquake detection threshold in the study area.

NorDB - Database solution for maintaining seismic metadata

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Institute of Seismology, University of Helsinki (ISUH) is responsible for maintaining the Finnish seismological network (HE). ISUH is also responsible for collecting and storing large quantities of raw seismological waveform data, as well as metadata describing the said data. Overhead for manually maintaining the relevant metadata information is considerable and prone to errors, which leads to avoidable work-hours. There are many existing database systems designed to combat this problem, but most of them are outdated, poorly maintained and documented or, crucially, do not ft in to our analysis workflow. For the past year we have been developing or own database system for storing event and station data and metadata. Currently the system can be divided into three parts: PostgreSQL database for storing the information, Python API for accessing the database operations and StationTool PyQT5 application for maintaining the database effortlessly. The database system has already been used in various ISUH projects, such as Evolving Fennoscandian GMPE (EVOGY).

Monitoring the instrument response of The Swedish National Seismic Network (SNSN)

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The modern Swedish National Seismic Network (SNSN), in operation since 1998, consists of 68 new, permanent, digital, broadband seismological stations distributed from Skåne in the south to Lappland in the north of Sweden. Average station spacing is in order of 70 km and magnitude completeness is close to "ML=0.5" within the network. High gain seismometers (20,000 Vs/m) are deployed to ensure monitoring of true ground motion at higher frequencies to be able to detect even a motion of 0.01 mm over a fault area with a radius of about 50 m through the corresponding small shaking. Such measurements require accurate maintenance of the seismic stations and monitoring instrument response and possibly its temporal-changes. This work investigates the instrument responses of approximately 70 SNSN sensors using signals from teleseismic events and also seismic ambient noise over a period of 10 years. The teleseismic P-waves approach the network almost near vertically, i.e. they become less sensitive to local structures beneath the seismic stations, thus the amplitude of ground motion at close-by stations should be comparable to each other within the passband of different sensor types and after instrument response corrections. Temporal changes in sensor/digitizer types were also investigated using background seismic ambient noise. In this study we show examples of how the two techniques are used to identify faulty responses associated with particular instruments, and how this can be used for monitoring of response information.

EVOGY – Evolving the Fennoscandian GMPEs:From Seismometers to Ground Motion Estimates

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EVOGY (Evolving the Fennoscandian GMPEs) is a collaborative project between the Institute of Seismology, University of Helsinki (ISUH) and VTT Technical Research Centre of Finland Ltd. (VTT). It is part of the SAFIR program (Finnish research programme on nuclear power plant safety), and its purpose is to bring the Fennoscandian GMPEs up-to-date in order to give regulators and other interested parties effective tools to estimate seismic hazard in Fennoscandia. This will be accomplished by producing a new ground motion prediction equation (GMPE) which will embody recent developments in the field and will include all available ground- motion data in Fennoscandia.

As part of EVOGY, and for other commitments such as EPOS, ISUH is developing a ground-motion data framework, which will include waveform and event data and metadata from permanent and temporary seismic stations and tools for accessing the stored data. While the framework is still under construction, it is already in use in EVOGY for producing the necessary ground-motion data for the new GMPE. When completed, it will also be integrated into the ISUH workflow enabling end-users to access event data, waveforms, ground-motion data and, ultimately, calculated and estimated ground-motion parameters through a fast and user-friendly interface.

Regional Body-Wave Magnitude Scale mb(Pn/Sn) for Earthquakes in the North Atlantic Region

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The mid-ocean ridge system is one of the most prominent features on the surface of the Earth, and it plays a key role in creating new oceanic crust. Hence, characterizing the earthquakes that occur along the mid-ocean ridge is important in understanding ongoing tectonic process. The magnitude is a key parameter to assign relative size of the earthquakes. However, until this study, no reliable magnitude scale was available to be used for small earthquakes along the mid-ocean ridges. The magnitude scale used for mainland Norway is based on Lg-wave amplitude measurements and does not work for the oceanic crust in the North Atlantic region. We obtained a robust magnitude scale for earthquakes along the northern mid-Atlantic ridges by using Pn and Sn waves that propagated through oceanic crust and uppermost mantle, then are recorded at seismic stations on land in the Northern Atlantic region. The new magnitude scales are called mb(Pn) for Pn and mb(Sn) for Sn measurements, respectively. Attenuation parameters in the magnitude scales were computed for earthquakes that are included in the global CMT catalogue by tying the new magnitudes to M_W. We inverted for station and event specific correction terms and found that the earthquakes that occurred along the spreading ridges of the mid-Atlantic Ridges showed strong long-period waves but poor high-frequency signals, which required about +0.1 magnitude units of compensation, whereas earthquakes that occurred along fracture zones and transform faults showed relatively strong high-frequency waves that lead to a negative adjustment of −0.2 magnitude units. The mb(Pn) and mb(Sn) magnitude calculations have been incorporated into the Norwegian National Seismic Network processing system and have been applied retrospectively to earthquakes in the catalogue. On average, the new magnitudes are almost 1.5 magnitude units larger than previously calculated M_L values. The new catalogue magnitudes are used to compute b-values for the different segments of the mid-Atlantic ridge.

Evaluation of Seismicity in the Northern North Sea

Norunn Tjåland and Lars Ottemöller, University of Bergen

The northern North Sea is one of the regions in Norway of relatively high seismicity, and over the years, several larger earthquakes have been registered in this area. In the time period between January 1990 and July 2018, a total of 3263 earthquakes in the magnitude range ML 0.1 to ML 4.2, have been recorded by available seismic stations. With the available data from the Norwegian National Seismic Network (NNSN) database, we have reviewed the earthquake focal mechanisms solutions that exists for this region. Within this study, we also present estimates of earthquake locations errors, as well as the results of applying the double-difference relocation algorithm.

Location and Depth Estimation of the North Sea Earthquake 30 June 2017

Annie Elisabeth Jerkins, Steven Gibbons, Tormod Kværna and Johannes Schweitzer, NORSAR

30 June 2017 a magnitude 4.5 mb earthquake occurred in the Viking Graben of the North Sea. When recorded, the event was the largest in the area for several decades. This is an area with several offshore platforms related to oil and gas production, and an accurate location and depth estimate of this event is therefore important for risk assessment. However, applying standard location procedures to P- and S-phase arrival times observed at station network surrounding the North Sea leaves the event depth rather unconstrained, and we are seeking alternatives for constraining the location and depth estimate.

Different from most other events in the North Sea, this relatively large event has been recorded by stations at both regional and teleseismic distances, with depth phases observed at several of the far field stations. Depth phases like pP and sP are phases which are reflected at the surface from below in the source region, and the difference in arrival time between the first arriving P and the depth phase can be used to better constrain the depth of the event.

We located the event using different methods: The HYPOSAT algorithm, a grid search algorithm using the LLNL-3D velocity model and a grid search using the global ak135 1D velocity model. For calculation of more accurate pP and sP travel times, the HYPOSAT algorithm was extended to accommodate the use of local velocity models for the source region, combined with global models (as ak135).

In the HYPOSAT algorithm we included P, S and depth phases (at various distances and azimuths) and tested three different local and regional 1D velocity models. The local model most representative for the source region included local low velocity sedimentary layers. This resulted in a depth estimate of approximately 8 km. Secondly, the event was located using a standard grid search with the LLNL-3D velocity model. For this location only P and depth phases at teleseismic distances were included. However, this also resulted in a depth of approximately 8 km. A new grid search was done using the ak135 velocity model with the same phases as for the previous grid search. This gave a depth of 15 km. The grid search using the LLNL 3D velocity model gave a 20% lower residual than for the ak135 1D velocity model.

Thus, from this study it is concluded that depth estimation is challenging. The estimation strongly depends on choice of method, velocity models and phases used for the location. However, we reckon that the HYPOSAT algorithm which includes a local model provides the best solution, since this estimation includes the velocity model that best represents the source region.

Coda Q in different tectonic areas, influence of processing parameters.

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Published results of coda Q show a large variation in values. These variations have often been claimed to be related to different tectonics, while they might just be related to using different assumptions in the processing, leading to different input parameters for the analysis. In this study, the effect of using different processing parameters is investigated and significant differences, particularly at low frequencies, are observed. We find a new set of optimal parameters which we recommend using in future studies. Using a short lapse time of 30 s and optimal parameters, data from both similar and very different tectonic regions are used to calculate coda Q using the same program and the same parameters. The regions considered are Eastern Anatolia, the Azores, Jan Mayen, North-western and central Argentina, the Shanxi Rift System in China and South-western Norway. We obtain the following relations:

Eastern Anatolia	$Q=88 \; f^{0.66}$
Azores	$Q=86 \; f^{0.70}$
Jan Mayen	$Q=90 \; f^{0.72}$
North-western and central Argentina	$Q=89 \; f^{0.94}$
Shanxi Rift System	$Q=99 \; f^{0.89}$
South-western Norway	$Q=124 \; f^{0.91}$

The results show that coda Q is very similar for regions of similar tectonics and significantly different for regions with different tectonics. Using alternative, more common parameters gives different Q but the regional differences remain, so which parameters to use to get 'correct' coda Q values is still uncertain. However, coda Q can clearly distinguish different tectonic areas provided identical processing parameters are used, even if they are not optimal.

Induced seismicity in a geothermal reservoir: a case study in the Reykjanes peninsula in Iceland

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Induced seismicity related to subsurface processes at geothermal power plants is an active field of research where we contribute with a case study from the Reykjanes peninsula. We present our first results from the analyses of microseismic events that in one case are induced by fluid injections and in the other case occur due to natural, tectonic stress build up.

In this study, we try to relate microseismic event clouds to a fracture network by detailed characterization and clustering of individual microseismic events. These results will guide us in further testing and improving methods for:

a) numerical modelling of fluid flow in fractured media
b) interaction of fluid flow with fracture initiation/propagation and heat transfer
c) risk and hazard mitigation estimates related to induced seismicity

The Reykjanes geothermal field is located on the South-West of Iceland, on the Reykjanes Peninsula. A dense sensor network, composed of 38 three-component geophones, short period and broadband, has recorded both natural and induced seismicity from April 2014 until August 2015. Parts of this deployment is related to a previous study (EU project IMAGE), which had a different focus. Our study, however, is interested in microseismic events and fracture network modeling. We selected three different weeks of seismicity occurring in 2015 for further, more detailed analysis.

During these three weeks, 876 earthquakes were detected using an STA/LTA triggering method. Most of these events were characterized by a low frequency content of about 2 to 20 Hz. The locations of about 500 events have an uncertainty of less than 1.5 km, which allow us to separate earthquakes occurring on the Reykjanes Ridge from those located on the Reykjanes Peninsula. The first events are assumed to be natural seismicity, whereas the later ones are suspected to be induced earthquakes due to the geothermal activity known at these locations. Hence, we consider the 344 possibly induced events for further detailed analysis.

As some seismic events show waveform similarities, they have been cross-correlated. Clusters of similar events with a minimum cross-correlation coefficient greater than 0.5 (for both P- and S-waves) have been created. They were used to perform a relative location, using the double-difference method. 210 events are relocated, which is 61 % of the total catalogue. We hereafter focused on the analysis of only one week.

Most of these relocated microseismic events, which are closer to each other and shallower than their absolute locations indicate, seems to occur in the geothermal field. On the other hand, non-relocated seismic events appear to be outside of it and should present alignment along known geological fractures. A comparison with the occurrence times shows a general trend that seismic events migrated towards the surface over time. This observation is also made in other geothermal fields and could be linked to the rise of fluids.

A spectral analysis, based on the Brune (1970) model, leads to a magnitude range spanning from -0.4 to 1.6. Because of the chosen sampling rate and the corresponding cut-off frequency of the sensors, the corner frequency is not well constrained even if the plateau, which is directly linked to the moment magnitude, is well estimated. Most of the biggest events are not included in cluster families and are also the deepest events. Consequently, it seems that seismic events present two different behaviors, which is dependent on whether they are or are not part of a cluster.

The analysis of infrasound and seismic signals caused by helicopter crash in Svalbard on 26 October 2017

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On 26 October 2017 at 13:08 hours a Russian helicopter *MI-8AMT* with 8 persons on board crashed into the sea near the home base close to the Russian settlement Barentsburg on Svalbard. It was the planned flight from Pyramiden to Barentsburg. The crew was last in contact with the air traffic services at Longyearbyen at 13:06 hours. At this time the helicopter was in 8 km from homebase. The helicopter never arrived Barentsburg and it was reported missing.

An extensive air, sea and land search operation was launched immediately after helicopter went missing. The helicopter was found at 209 meters depth approximately 2 km off the coastline northeast of the helicopter base only the 29 October.

Since October 2010 the Geophysical Survey, Kola Branch, Russian Academy of Sciences has continually monitored the seismic and infrasound signals on the Spitsbergen archipelago by the seismo-infrasound station "Barentsburg". Station is located on the northern outskirts of the town of Barentsburg (coordinates $78.094°$ N and $14.208°$ E) and consist of 3-component broadband seismic sensor *Guralp-3ESP* and three infrasonic microphones distributed on the surface on distance 150 meters each other at the vertices of an isosceles triangle. Such an arrangement of acoustic sensors makes it possible to determine the azimuth of the source and the speed of approach of the front of the infrasonic wave by the time difference of arrival of a coherent signal at each microphone. The seismo-infrasound station was registered seismic and infrasonic signals caused by accident. The data obtained made it possible to accurately determine the time and place of the accident. An interpretation of the obtained data is discussed in this report.

Interpreting explosive acoustic arrivals at the ARCES seismic array in the context of atmospheric cross-winds*:*

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The cross-wind effect on infrasound propagation has been studied on the seismic array ARCES, Norway, utilizing 30 years of data from explosions at the Hukkakero military blast-site in Finland. Around 99% of the seismically identified explosions at Hukkakero (around 600 in total) are detected as seismo-acoustic signatures around 10 minutes after the arrival of the seismic
P- and S-waves, indicating a good ducting through the stratosphere between the two sites. Despite these observations, ray-tracing of infrasound through model atmospheres typically predict ARCES to be in the shadow zone for these explosions.

The total cross-wind effect, throughout the whole propagation path, has instead been estimated along a simplified ray-path model. The observed back azimuth deviation of the infrasound arrivals is then analyzed in light of the estimated cross-wind effects predicted from the atmospheric models and we make statistical estimates of these effects.

We discuss our ambition to invert for the average stratospheric cross-winds and to generate atmospheric dynamics datasets valuable to the atmospheric modelling and numerical weather prediction research communities.

**3rd Nordic EPOS meeting
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Abstracts

European Plate Observing System (EPOS): Establishing a Sustainable Research Infrastructure in Solid Earth Science

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The *European Plate Observing System* (EPOS) aims to create a pan-European infrastructure for solid Earth science to support a safe and sustainable society (Horison2020 – InfraDev Programme – Project no. 676564). The main vision of the European Plate Observing System (EPOS) is to address the three basic challenges in Earth Science: (i) unravelling the Earth's deformational processes which are part of the Earth system evolution in time, (ii) understanding geo-hazards and their implications to society, and (iii) contributing to the safe and sustainable use of geo-resources. The mission of EPOS is to monitor and understand the dynamic and complex Earth system by relying on new e-science opportunities and integrating diverse and advanced Research Infrastructures for solid Earth science.

A large number of Data, Data products, Software and Services (DDSS) are already implemented provided by the 10 Thematic Core Services (TCS) covering the entire spectrum of Solid Earth Science. Integration of these elements with the Integrated Core Services - Central Hub (ICS-C) has started already with a pilot implementation in 2017 which is being constantly improved to meet the user requirements. The ICS-C will go into operational phase in October 2019 and is hosted jointly by the three Geological Surveys of UK (BGS), France (BRGM) and Denmark (GEUS). In addition to the standard data and data products, such as seismological, geodetic, geomagnetic and geological data, there are a number of non-standard data and data products that will be integrated. The implemented services are now being validated by an external group of experts. The validation process started with an internal verification through Technical Readiness Assessment (TRA) is now followed by the external validation by an international expert panel. The resulting services will go into pre-operational phase and will be tested extensively before entering into operation in the end of 2019. In parallel with the technical implementation of EPOS ICS-C, there has been considerable effort put in legal, governance and financial aspects of the EPOS services. All 10 Thematic Core Services (TCS) have developed their internal consortia and have identified the related service providers that are legal bodies committed to provide these services through contractual relations with EPOS. In order to provide a sustainable organizational structure for EPOS the official EPOS-ERIC (EPOS – European Research Infrastructure Consortium: A legal body under the jurisdiction of the European Parliament) is now established and will be launched on the 7th of November 2018 in Rome, Italy by the European Commission. Italy was selected after a competitive call and INGV in Rome will be the hosting institution for EPOS-ERIC.

Finland in the European Plate Observing System - Looking forward to the next decade

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As the European Plate Observing System (EPOS) is approaching its next phase, the first round of national infrastructure initiatives of the Finnish EPOS consortium FIN-EPOS is approaching end-of-life. Since 2015, FIN-EPOS has initiated nine projects funded by the Academy of Finland, a major scientific funding organization in Finland.

The projects have increased the performance of the national solid Earth research infrastructure, results of which will carry to the future. Various scientific outputs have also already made it out of the pipeline. The projects have involved collaboration with various EPOS Thematic Core Services and their key players. As a result, FIN-EPOS has been evaluated as an advanced research infrastructure in the national infrastructure roadmap.

EPOS-N E-infrastructure development – the Norwegian National Web Portal

Tor Langeland, Ove Daae Lampe and Gro Fonnes. NORCE – CMR

The aim of the Norwegian EPOS e-infrastructure is to integrate data from the seismological and geodetic networks, as well as the data from the geological and geophysical data repositories. In this abstract, we present ongoing work on development of the Norwegian web portal for accessing the data.

The Norwegian web portal is implemented by adapting Enlighten-web, a server-client program developed by CMR in several projects, among them EPOS-Norway. Enlighten-web facilitates interactive visual analysis of large multidimensional data sets and supports interactive mapping of millions of points.

The Enlighten-web client runs inside a web browser. The user can create layouts consisting of one or more plots or views. Supported plot types are table views, scatter plots, line plots and map views. For the map views, we apply CESIUM. Multiple scatter plots can be mapped on top of these map views.

An important element in the Enlighten-web functionality is brushing and linking, which is useful for exploring complex data sets to discover correlations and interesting properties hidden in the data. Brushing refers to interactively selecting a subset of the data using the mouse e.g. to dynamically alter a bounding box. Linking involves two or more views on the same data sets, showing different attributes. The views are linked to each other, so that highlighting a subset in one view automatically leads to the corresponding subsets being highlighted in the linked views.

If the updates in the linked plots are close to real-time while brushing, the user can perceive complex trends in the data by seeing how the selections in the linked plots vary depending on changes in the brushed subset. This interactivity, especially for large data sets, requires GPU acceleration of the graphics rendering. In Enlighten-web, this is realized by using WebGL.

To realize the EPOS-N Web Portal, we extend Enlighten-web to handle metadata about data. Metadata can e.g. specify data sources, ownership, license information and how the data can be accessed. Enlighten-web can then use this information to access remote data. The brushing and linking concept will be extended to brushing and linking in metadata for data discovery and access. The intention is that the user can link several different plot types for filtering all EPOS-N datasets based on her requirements. E.g. map plots can be used for filtering on location, and time plots for filtering on time ranges. We also introduce bar charts for filtering of the metadata on textual categories.

The root metadata for the Web portal will be the EPOS-Norway DDSS Master Table, which was established at an early stage in the EPOS-N project. We are now working on a detailed mapping of how the different DDSS elements shall be included in the portal. Relevant web services include FDSNWS for seismological data, GLASS for GNSS and OGC services for geological and geophysical data (e.g. WMS – Web Map Services).

Building UIB-NORSAR EIDA node - integration of Norwegian seismic data into EPOS

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The European Plate Observing System (EPOS) is a European project about building a pan-European infrastructure for accessing solid Earth science data. Implementation phase of the EPOS project (EPOS-IP – EU Horison2020 – InfraDev Programme – Project no. 676564) started in 2015. The EPOS-Norway project (EPOS-N; RCN-Infrastructure Programme - Project no. 245763) is a Norwegian project funded by National Research Council and is closely linked to the EPOS-IP project. The aims of EPOS-N project are divided into four work packages where one of them is about integrating Norwegian geoscientific data into an e-infrastructure. The other three work packages are: management of the project, improving the geoscientific monitoring in the Arctic and establishing Solid Earth Science Forum to communicate the progress within the geoscientific community and also providing feedback to the development group of the e-infrastructure. Within the WP2 of EPOS-N project, University of Bergen (UIB) and NORSAR are building a new UIB-NORSAR node of European Integrated Data Archive (EIDA) for providing seismological data via webservices. Currently there are 9 primary EIDA nodes located in various countries in Europe (NL, DE, FR, IT, CH, RO, TR and GR) but none of them is placed in the Nordic countries. Seismic networks from Nordic countries are of course contributing to the EIDA system but the data flows through existing EIDA nodes like GFZ (DE) or ORFEUS (NL). In addition, some data goes to IRIS (USA) as well. Building a new EIDA node will contribute to better data quality handling and will also provide data from stations which are not in the EIDA system yet. EIDA system is used for seismic waveform distribution within the EPOS initiatives. Therefore, it is natural to follow the same procedure in Norway. The UIB-NORSAR node will provide access to data from 114 existing permanent seismic stations and also to data from stations deployed within the EPOS-N (up to 28). Data from temporary deployments in Norway will be also available through this node. EIDA is dealing with seismic waveforms and stations only. But EPOS-N is aiming to provide parametric data about earthquakes via webservices as well. The standard format for provision of earthquake parametric data within EPOS is QuakeML. However, UIB is storing parametric files in the Nordic format which is internationally recognized but still needs to be converted to QuakeML. UIB is working on a conversion tool to allow smooth conversion between those formats in both ways.

Status of the new seismic array on Bjørnøya, to be established as part of EPOS-Norway

Svein Mykkeltveit, NORSAR

NORSAR is, through its participation in the EPOS-Norway project, preparing for the installation of a new seismic array station on Bjørnøya (Bear Island), which is located in the Barents Sea half way between mainland Norway and Spitsbergen. Seismic stations on Bjørnøya close a large gap for monitoring seismic events on the western Barents Sea shelf, the Mohn's Ridge and the Knipovich Ridge, as well as the main Barents Sea region to the east of Bjørnøya. A temporary seismic array was deployed on Bjørnøya during the summer of 2008. The temporary array showed significantly improved event detection capability in comparison with that of the permanent three-component station, located on the northern tip of the island. A number of additional earthquakes could be detected and located in the surrounding region. A seismic array on Bjørnøya will be essential for a number of research areas.

The original plan for a nine-element array within the nature reserve at Bjørnøya was rejected by the authorities, due to environmental restrictions that apply to the nature reserve. An application for the necessary permissions to install a smaller, 6-element array within the area hosting the meteorological station on Bjørnøya (which is outside the nature reserve) was submitted in the spring of 2018, and approval for this array was granted in late August 2018. The planning for the installation phase is now progressing and the array will be installed on Bjørnøya in 2019.

EPOS-Norway – Integration of Norwegian geoscientific data into a common e-Infrastucture

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The European Plate Observing System (EPOS) is a European project about building a pan-European infrastructure for accessing solid Earth science data. Implementation phase of the EPOS project (EPOS-IP – EU Horison2020 – InfraDev Programme – Project no. 676564) started in 2015. The EPOS-Norway project (EPOS-N; RCN-Infrastructure Programme - Project no. 245763) is a Norwegian project funded by National Research Council and is closely linked to the EPOS-IP project. The aims of EPOS-N project are divided into four work packages where one of them is about integrating Norwegian geoscientific data into an e-infrastructure. The other three work packages are: management of the project, improving the geoscientific monitoring in the Arctic and establishing Solid Earth Science Forum to communicate the progress within the geoscientific community and also providing feedback to the development group of the e-infrastructure. Among the six EPOS-N project partners, four institutions are actively participating and providing data in the EPOS-N project – University of Bergen (UIB), Norwegian Mapping Authority (NMA), Geological Survey of Norway (NGU) and NORSAR. The data which are about to be integrated are divided into categories according to the thematic fields – seismology, geodesy, geological maps and geophysical data. Before the data will be integrated into the e-infrastructure their formats need to follow the international standards which were already developed by the communities of geoscientists around the world. Also, description of the data, i.e. metadata, needs to follow structure developed in EPOS-IP. For now, there are 33 Data, Data Products, Software and Services (DDSS) described in EPOS-N list.

We present the Norwegian approach of integration of the geoscientific data into the e-infrastructure, closely following the EPOS-IP project development. The sixth partner in the project - Christian Michelsen Research (CMR) is specialized in visualizations of data and developing of a web-based graphical user interface (GUI) allowing the users to visualize and analyze cross discipline data. Expert users can launch the visualization software through a web-based programming interface (Jupyter Notebook) for processing of the data. The seismological waveform data (provided by UiB and NORSAR) will be available through an EIDA system, seismological data products (receiver functions, earthquake catalogues, macroseismic observations) as individual datasets or through a web service, GNSS data (provided by NMA) possibly through the GLASS framework (web service) and geological and geophysical (magnetic, gravity anomaly) maps (provided by NGU) as WMS web services. Integration of some specific geophysical data is still under discussion, such as georeferenced cross-sections which are of interest especially for visualization with other geoscientific data. There are several challenges in the project to be handled. Our aim is not only to find the appropriate technical solution which will allow continuing the development in the future but also to build it in a way providing seamless integration of various data types/sources (including useful tools) and allowing the scientists to work with them in a single environment through the web interface.

GRanularity DataBase (GRDB) in EPOS

Xiaoliang Wang at University of Bergen

GRanularity DataBase is conducted within the framework of the European Plate Observing System (EPOS) Implementation Phase Project (EPOS-IP – EU-Horison2020, InfraDev, Project.no. 676564) and linked to the national integration of Norwegian data to the National EPOS project, EPOS-Norway (EPOS-N – RCN Infrastructure Programme Project No. 245763).

In EPOS , many Thematic Core Services (TCS) shall provide various services and data while hundreds of people and organizations will participate the development of EPOS. It will be complicate to organize information such as which TCS provides what data or service, who and which organization is related to a certain data or service. In order to systematically manage such information in an efficient way, we develop a web application, called GRanularity DataBase (GRDB). An example page is shown in Figure 1. With the web application, users from TCSs can view and update their information.
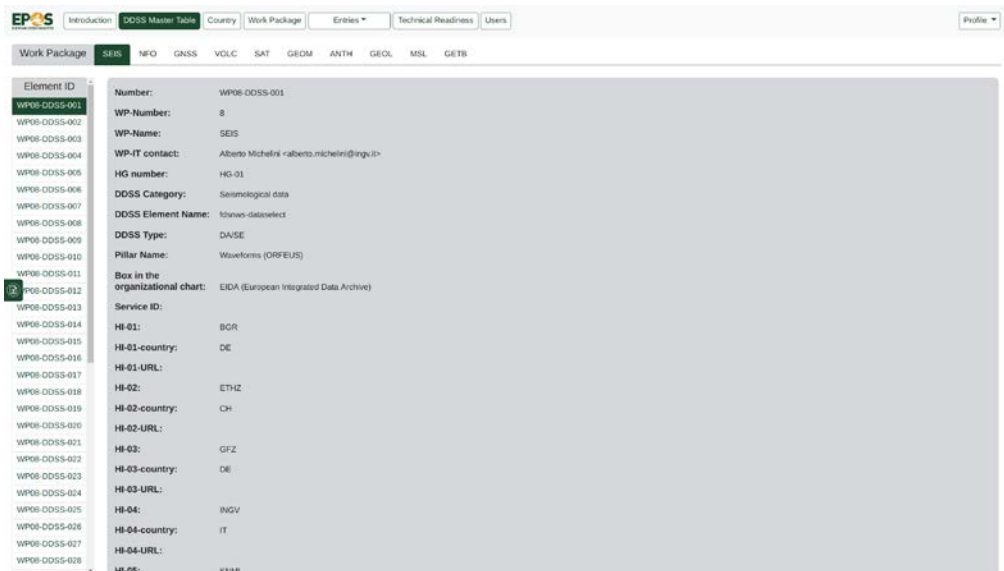

Figure 1: GRanularity DataBase (GRDB)

The application gives an overview about the detailed information of a data, data product, software and services (DDSS) element. In addition, users can also view and/or update information about entities such as Country, Work Package, DDSS Element, Institution, Person, Consortium and Service Providers by clicking corresponding buttons on the top of the front page. Each entity contains a list of items. On the page of each entity, the following functions are optionally available:

  * view the related information of the items
  * update the information of an item
  * add more items
  * load and update the information of items from an Excel file
  * view the statistics of the entity

It should be noticed that, the web application is designed to be used by some authorized users in each TCS to manager their information respectively, therefore, to ensure the information security.