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Abstracts

Oral presentations

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

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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 now nearing completion. As of August 2013, 280 of the 321 globally distributed stations of the International Monitoring System (IMS) have been installed, and 14 stations are currently under construction. 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 will provide results that will be used to assess the readiness of the OSI component of the CTBT verification regime.
The presentation will provide an overall assessment of the current 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.

On the Road to IFE14, Jordan

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CTBTO/PTS/OSI Division is preparing an Integrated Field Exercise at the end of the year 2014 in Jordan. This will be the second time to test the current preparedness to conduct a comprehensive on site inspection including almost all the approved OSI techniques.

This presentation follows the milestones on the road to the IFE14 and combines together the resent Build up Exercises and other training activities.

NNSN activities

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The Norwegian National Seismic Network, operated by the University of Bergen (UiB) and NORSAR. The talk will give an overview of the current status and future plans. The NNSN is still undergoing an upgrade towards more broadband seismometers. It is planned to add one station per year, and results from a recent installation will be shown. The talk will also introduce the upcoming NEONOR2 project, which will have 26 seismic stations installed in Northen Norway. With other deployments in the region, there will be a significant amount of data available for research. To conclude, the presentation will show results from the Storfjorden earthquake sequence active since 2008.

The importance of measuring small earthquakes and how it is achieved

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When designing a seismological network, the sensitivity or detectability is a crucial issue. The ability to record very small earthquakes is the most efficient mechanism to retrieve information on ongoing processes in the crust. Large earthquakes are destructive and a concern for the security of citizens in any earthquake prone country. But earthquakes are also informative. They give information about the stress situation in the crust and are the only direct information carrier from the deeper crust. When using not only the polarity information but also the spectral energy in the body waves enormous amounts of information can be retrieved even when only a few stations record the event. As our main focus is to understand the crustal processes, leading sometimes to large earthquakes, we need as much information as possible from the crust itself. Lowering the detection limit from ML = 2.5 to M L = 0.5 will increase the number of recorded earthquakes by a factor of 100. This also means that the time needed to record a given amount of data is decreased by the same factor. In addition, better data is obtained when the distance from the source to the recording stations is shorter. From 1993 to 2012 SIL has recorded approximately 68,900 event in the TFZ. 35,300 are above magnitude 1 and 4,860 are above magnitude 2. Magnitude of completeness is a little difficult to assess, but perhaps a little higher than 1. Earthquakes are providing information on the way the radiated waves are generated due to the source conditions. The stress situation in the crust is reflected in this radiation pattern. To give an example of seismological network design a description of the SIL system in Iceland and the Swedish National Seismic Network is given below.

The data acquisition system used in Iceland and Sweden is the SIL system, which was developed within the SIL project, a joint Nordic project for earthquake prediction research in Iceland, 1988 through 1992 (Stefánsson et al 1993, Böðvarsson et al 1996, 1999). The main achievement of the SIL-project was to establish an automatic earthquake data acquisition and evaluation system, the SIL-system. As detailed plans were made for the SIL project, the importance of microearthquakes for understanding the ongoing deformation processes within the crust were recognized.

Traditionally, such very small events were regarded as unimportant because even when added together they reflect only a very minor part of the total deformation on a fault, the few large events being responsible for almost all of the motion. However, every microearthquake carries information about the state of stress and ongoing movements within the volume, and as there are on average about a million microearthquakes (>M=0) for every magnitude 6 earthquake, by recording and analysing the small events much more information would be available. It was realised that the recording of earthquakes down to magnitude ML=0 and below, and retrieval of source information from these events, would require a new seismic network design, because the data flow would be far too large to be dealt with manually (Stefánsson et al 1986, Böðvarsson 1987). The rapid evolution in computer and communication technology and the introduction of nexpensive but powerful personal computers allowed for such a design of the SIL network (Böðvarsson et al 1996, 1999). The Icelandic network has now recorded and analysed several hundred thousand earthquakes.

At the time of the design of the SIL system, a very significant cost of running a large seismic network was that of communication between the stations and the central computer. In the SIL concept, these costs were kept within manageable limits by performing sophisticated analysis of the ground motion data locally at each individual station, and only communicating with the central computer when a possible event has been detected. Normally, a continuous data stream is not delivered to the central computer, and only data segments identified as possible earthquakes are transferred. As internet connections became more widely available, the cost of data transfer decreased and became less of a problem. However, the intelligent distributed character of the SIL system makes it both effective and robust, and downloading and archiving all incoming data is not necessary for monitoring of local seismicity.

Incoming data is stored temporarily on a ring buffer (a continuous file) at the station computer. In most cases, three weeks of data are stored. This means that the system is robust with regard to technical problems with the central computer or with communication. The station computer continously monitors the incoming data stream in order to detect possible earthquakes. The primary detector uses a simple comparison of the power in adjacent time windows. The bursts of energy so detected may correspond to an earthquake, or may be caused by some local disturbance close to the seismometer (e.g. an animal walking past). In order to detect earthquakes down to or below ML=0 it is important to have large gain in the system so that true ground motion (not instrumental noise) is recorded in frequencies up to ca 20 Hz. A careful matching between the seismometer and the digitizer is of major importance. Each detected transient is processed in the same manner as one
would process a true seismic phase, and the results are stored in a compact structure, called a phase log. Each phase log entry is only 128 bytes long and is therefore inexpensive to transmit to the center. The detection thresholds can therefore be set very low, ensuring large amount of phase
detections for the multi-station analysis at the center. This allows smaller earthquakes to be detected without the inevitable large number of false alarms making the system unworkable. The phase logs produced are retained locally, and regularly transmitted to the center. Each phase log includes onset time, duration, reference to previous and following phases, type of phase (P or S), signal and noise averages, maximum amplitude, azimuth and coherency (Roberts et al 1989) and spectral parameters
including DC-level and corner frequency.

After receiving phase logs from the network stations, the central computer assesses these to determine which transients may be from an earthquake. This is achieved by looking at the time, azimuth and amplitude consistency of detections from the different stations, followed by a preliminary estimation of the epicentre of the source and the consistency of this position with the signal arrival times at the different stations. If the phase logs are consistent with a real earthquake, an appropriate time segment of data is downloaded from the stations. The time series data is then analysed to provide detailed information about the source characteristics, including source location, depth and spatial orientation, slip, stress drop and moment magnitude. All of these operations are completely automatic. The estimation of focal mechanism and source parameters are based on results of the spectral analysis of short data segments containing the direct P and S wave arrivals. The spectral estimation is done at the site stations, using windows around the automatic time picks, and repeated at the center after manual refinement of arrival time readings. The low frequency amplitude of each phase is determined by fitting a three parameter model to the observed spectra (Boatwright 1978, Slunga 1981, Rögnvaldsson & Slunga 1993). To estimate the fault plane solution for the earthquake a systematic search over strike, dip and rake is performed. For each combination of the three source angles, the misfit between observed and predicted spectral amplitudes is calculated. In addition to the single best fitting solution, all solutions that fit the observed polarities and have amplitude misfit less than a predefined threshold value are taken as acceptable (Slunga 1981). Automatic locations in Iceland are published immediately on the web pages of the Icelandic Meteorological Office (www.vedur.is).

The final stage of intial analysis, leading to the discrimination of explosions and other noise sources from natural earthquakes, is carried out semi-automatically, the final stage including examination of the data by an operator. The intelligence in the system means that only a relatively small number of non-earthquakes pass this far through the system, so the operator work-load is small. In Sweden, information about all detected events is published on Uppsala University's web page (www.snsn.se)
when this procedure is complete.

The waveform recorded from an earthquake at any particular station is strongly influenced by the wave propagation characteristics of the material between the source and receiver. Therefore, events occuring at different times but in almost the same location tend to have very similar waveforms, because they have followed almost exactly the same path from source to reciever. By cross-correlating the recorded data from such close-lying events we can very accurately estimate the difference in distance to the station of the two events. By doing this for several different stations which have recorded both events, it is possible to very accurately estimate the location of the events relative to each other. This relative accuracy can be very high, e.g. +/- 5m even if the event is tens of kilometers from the closest recording station, and is very much higher than the accuracy of the absolute location of the events. In these cases, the fault orientation can be estimated with high resolution.

Automatic Correlation of Incoming Signals (ACIS)

To minimize labor cost when operating a large seismological network automatization of the earthquake analysis procedure is of large importance. Based on the positive results of the correlation techniques used in the relative location algorithm, a new approach can be taken regarding the automatic operation of the network. Experience shows that a substantial fraction of the events occurring within a given area belongs to a few clusters or families of earthquakes, characterized by highly similar waveforms. The cross correlation of seismograms at individual stations can be used to identify such clusters of similar events. We are currently working on a method using cross correlation of neighboring events to automatically determine the onsets of P and S phases with accuracy comparable to or better than achieved in the interactive analysis. The aim is to reduce the need for manual inspection of seismograms from local and regional earthquakes and to improve the quality of the readings in the microearthquake database.

The objective is to create a geographically indexed database (GID) where different classes of earthquakes will be stored. The area to be covered by the database is divided into equidimensional cells, 2 x 2 km laterally but of unconstrained depth. When creating the GID, each event within a given cell is correlated with all other earthquakes in the cell. The results of the correlation are used to group the earthquakes into classes. A few events of each class are stored in the GID.

As new earthquakes are recorded by the network, the system automatically looks for similar waveforms in the GID. The initial location estimate of the event is used when accessing the GID. The selection of waveform windows to be compared to data in the GID is done based on the automatically determined arrival times for stations that detected the phase. At other close stations that did not detect the phase, theoretical arrival times are estimated by ray-tracing through a layered velocity model.

The new phase is correlated with all phases of the same type (P or S) in the GID, recorded at the same station and originating within the same cell or a neighboring cell. The cross-correlation function (CCF) is resampled before determining the time lag, the correlation coefficient and the sign of the CCF at the peak. The lag gives the absolute arrival time of the phase, assuming the reference pick was "correct``. If the polarity of the reference phase is known, the sign of the CCF gives the polarity of the new phase. The normalized correlation coefficient gives a measure of the similarity of the new phase to the reference phase. By resampling the CCF the accuracy of the pick is practically only limited by the timing accuracy of the network clocks. For the timing in the SIL system this is better than 1~ms. The precise arrival time readings can also be used for determining accurate relative locations of similar earthquakes.

When all recorded phases for the new event have been compared to all relevant phases in the GID, a voting procedure is used to determine whether the event is similar to sufficiently many phases in the database to warrant skipping interactive analysis. If enough phases have been picked by correlation with existing phases, the picks are written to a file similar to those created in the interactive time picking procedure and the event is relocated using the correlation picks. Otherwise the new event is analyzed interactively by the network operators. Figure 1 gives a schematic overview of data flow in the proposed correlation analysis system.

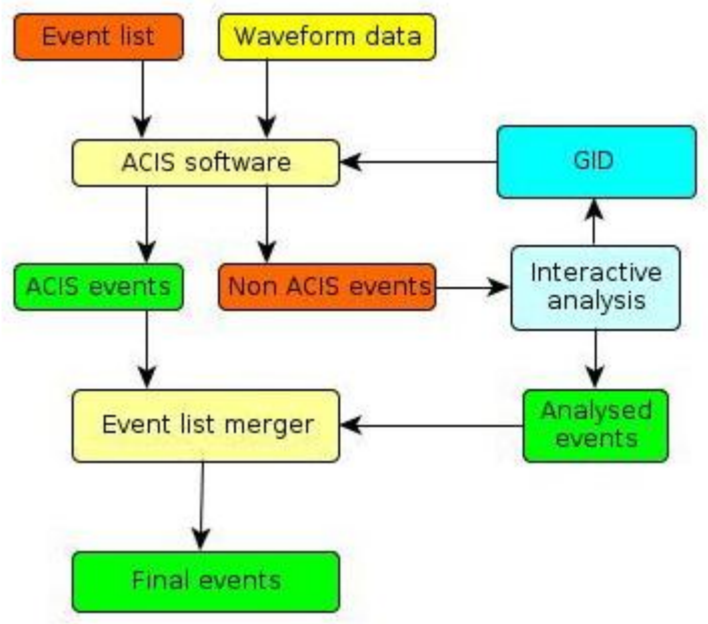

Fig 1. A simplified flowchart of the automatic cross-correlation procedure. ACIS stands for Automatic Correlation of Incoming Signals and GID stands for Geographically Indexed Database.

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ISC location procedures: Recent developments

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The new location algorithm developed for the International Seismological Centre (ISC) has been operational since January 2011. By providing improved hypocentre and magnitude estimates, the ISC locator has increased the efficiency and productivity of the ISC review process to generate the reviewed ISC bulletin. The second release of the ISC locator represents major improvements in speed and facilitates multicore processing. To support the validation of travel-time predictions from 3D velocity models, the ISC has developed a version of the ISC locator that accommodates local and regional travel-time predictions provided by the Regional Seismic Travel Time (RSTT) software package developed by the US DoE National Laboratories. The ISC locator can be downloaded from the ISC website.

On the classification of regional seismic events

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Abstract

Classification of seismic events is an essential practice of seismic observatories. It is of particular importance in low-seismicity areas with extensive mining activity, such as Fennoscandia, where several large underground mines, along with numerous open pit mines operate on a daily basis. In these locations, natural seismicity and mining-related events overlap in magnitude, space and time. Explosions from military exercises at sea further complicate seismic monitoring. If discrimination between man-made and natural seismic events is incomplete, regional earthquake catalogues become contaminated by man-made blasts. Thus, seismic investigations relying upon such data will give erroneous estimates of the rate of seismicity and, consequently, the seismic hazard.

The Institute of Seismology at the University of Helsinki (ISUH) maintains an open-access earthquake catalogue for Fennoscandia. The catalogue is a compilation of earthquake reports from cooperating seismological agencies. Here, we present the guidelines used by the ISUH for classifying and preprocessing the catalogue data. The analysis includes inspection of spectrograms, signal frequency content, first motion polarities, radiation pattern effects and relative amplitudes of different seismic phases. In addition, a database of known blasting sites, and diurnal and weekly distribution plots are useful tools for event classification.

An application of coda envelopes for estimation of stable event magnitudes in southern Norway

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NORSAR

In seismology, many applications require accurate and reliable magnitude estimates. Previous studies have shown that coda amplitude measurements have significantly less variability than measurements of direct wave amplitudes, and it has been demonstrated in several papers that stable estimates of source moment spectra can be derived from regional coda envelopes observed at only 1-3 stations.

The objective of this study is to test the coda based method at regional distances on broadband and short period
stations located in Norway. Initially, we address the NORSAR array, which when calibrated, could permit re-estimation of event magnitudes based on coda derived moment source spectra for a very large number of events, dating as far back as 1970. We have selected for calibration about thirty events located in the western part of southern Norway having magnitudes in the range 1.7 to 4.7. Our methodology consists of the following calibration steps: coda start time calibration, coda shape calibration, distance normalization, site-response correction using the smaller events as Green's functions, and conversion of the non-dimensional spectra to absolute source spectra using independent moments for the argest events.

Automatic classification of seismic events within a regional seismograph network

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Abstract

An automated method for seismic event classification within a sparse regional seismograph network is presented. Our main objective is to construct a tool that identifies and eliminates artificial seismic events and noise detections from fully automatic detection logs with a high level of confidence. The tool helps to reduce work-load in manual seismic analysis by leaving only the probable earthquakes for a detailed manual analysis. Our method is based on a supervised pattern recognition technique, Support Vector Machine (SVM), trained to distinguish local earthquakes from man-made or spurious seismic events. The classification rules utilize spectral information extracted from the total duration of seismic signals.

In this study we calculated SVM models for 19 permanent seismic stations in Finland. The number of positive (earthquake) and negative (non-earthquake) training examples was station-specific and varied between 11-268 and 223-1017, respectively.

In order to find the best voting rules for combining the results from different stations, a test data base comprising 1190 fully automatic seismic event determinations was used. The test period covered 85 days from November 2012 to February 2013. According to the manual analysis 1163 (98 %) of those events were explosions or noise and 27 (2 %) earthquakes. The events were classified with the SVM method. With the best voting rules 1084 (93 %) of the non-earthquakes and all the earthquakes were correctly identified.

Finally, the network processing rules were applied to an evaluation period covering 188 days from February 2013 to August 2013. The evaluation data comprised 2342 fully automatic event detections, of which 2293 (98 %) were manually identified as explosions or noise and 49 (2 %) as earthquakes. With the SVM method 2181 (95 %) of the non-earthquakes and all the earthquakes were correctly identified. The result implies that most of the events can be identified automatically.

Microseismic monitoring R&D at NORSAR

Anders Dahle, NORSAR

The presentation will give a brief review of NORSARs activities within microseismic monitoring examplified with glimpses from research projects, applications and current development.

Temperature and melt regime underneath the Knipovich Rigde – Seismic evidence for along-axis variations of lithospheric thickness

Andrea Demuth

Low magma budgets and uneven melt distributions along ridge axis are characteristic for ultraslow spreading mid-oceanic ridges. How segments of focused melt are established is not yet understood. A proposed theory is, that melt migration occurs along the base of the lithosphere and rises in areas of thin lithosphere. Thereby, upwelling ductile magma creates a localized hotter mantle area. However, geophysical evidence supporting this and other models is lacking.

In 2009 during the Polarstern expedition ARK – XXIV/3 a network of broadband ocean bottom seismometers was deployed for 10 days between 75°50' N and 76°50' N along the ultraslow spreading Knipovich Ridge. In this time period over 900 local earthquakes were recorded. The local velocity model, provided by seismic refraction data in this region, was used to localize these microearthquakes with Hyposat. After the identification of highly reliable events, the tectonic structures became visible.

A seismic gap in the uppermost mantle underneath the Logachev Seamount stood out. Since earthquakes reflect the released energy of a sudden stress drop caused by brittle failure, the absence of this failure suggest a higher temperature in this area. The lack of crustal and upper mantle seismicity in a clearly defined area beneath the seamount may thus yield a first convincing evidence for the existence of mantle upwelling cells underneath a magmatic center.

Teleseismic Tomography Across the Trans-European Suture Zone

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Abstract

The presented study is a part of the PASSEQ 2006-2008 project. The PASSEQ 2006-2008 project aims to study the lithosphere and asthenosphere around the Trans-European Suture Zone (TESZ) – the transition between the old Proterozoic lithosphere in Northern and Eastern Europe and the younger Phanerozoic lithosphere in Central and Western Europe. Nearly 200 temporary short-period and broadband seismic stations were installed along 1200 km long and 400 km wide area from Germany throughout Czech Republic and Poland to Lithuania, and provided continuous recordings from May 2006 to June 2008. The PASSEQ project is linked to the TOR project, which was realized during 1996 – 1997 and was focused on the northwestern part of the TESZ between Sweden and Denmark – Germany. From the PASSEQ data we manually picked 8308 arrivals of teleseismic P-waves and compiled the data set. The non-linear teleseismic tomography algorithm TELINV with the best quality data, i.e. 6008 P-wave arrivals, was used to obtain model of seismic P-wave velocity variations in the upper mantle beneath and around the TESZ. The results of inversion show variations of P-wave velocities of ± 6.5 % comparing to IASP91 velocity model. The higher velocities to the east of the TESZ correspond to the old East European Craton and the lower velocities to the west of the TESZ correspond to the younger Western European Platform. The deepest litosphere-asthenospere boundary (LAB) in the target area is under the Baltic Shield (Lithuania) where it goes down to about of 300 km deep, while the shallowest LAB is to the west of the TESZ under the Variscides where it goes down to about 120 km deep. The results show LAB dipping northeast direction at an angle of about 30 degrees in the northern part of the TESZ, and going to the south the LAB is shallower most probably due to younger tectonic settings.

A few Icelandic volcanoes; Correlation analysis of seismic and infrasound data

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Volcanic far-field seismic tremor recorded at 7-20 km from the Eyjafjallajökull 2010 summit eruption is investigated. Over a two months period, two very different eruptions occurred separated by 9 km and two days; an effusive flank eruption and later a highly explosive summit eruption. We observed high amplitude seismic tremor during the explosive eruption while the flank eruption produced very low amplitude tremor. Infrasound data was collected for a few days during the summit eruption, with 4-element triangular geometry array which was installed 8 km south of the erupting summit crater. The infrasound data shows repeating pressure pulses from the volcanic explosions, with the highest pulses reaching 105 Pa, which is in the higher limit compared to similar studies of other erupting volcanoes. We find the infrasound waveform data to correlate temporally (0.55-0.6) with the seismic eruption tremor data which is characterized by repeating low frequency events. A high correlation in amplitude (0.8) of individual events is also found between these datasets. The analysis reveals a time lag of 15-20 seconds, where seismic low frequency events are seen prior to the infrasound events. This is consistent with co-located seismic tremor and infrasound sources at the eruptive crater, and a surface wave velocity of 1350-1500 m/s. Single station three component analyses (undertaken for several stations) of the seismic low frequency events further confirms that they contain Rayleigh wave energy.
Since the eruption the infrasound array has been moved to a new permanent location, Gunnarsholt, 50 km northwest of the volcano. In the upcoming FP7 project FUTUREVOLC, focussed on establishing a volcano supersite in Iceland, three additional infrasound arrays will be installed near active volcanoes, by ARISE-partner University of Florence. With, on average, two volcanic eruptions in Iceland per decade a wealth of additional infrasound data is expected in future eruptions. These will greatly enrich the geophysical and meteorological observations and research on volcano early warning, performed by the Icelandic Meteorological Office in FUTUREVOLC.
The glacier overlain Katla volcano in South Iceland, is one of the most active and hazardous volcanoes in Europe. Katla eruptions result in hazardous glacial floods and intense tephra fall. On average there are eruptions every 50 years but the volcano is long overdue and we are now witnessing the longest quiescence period ever recorded.

Because of the hazard the volcano poses, it is under constant surveillance and gets a good share of the seismic stations from the SIL network (Iceland National Network). Every year the seismic network records thousands of seismic events at Katla with magnitudes seldom exceeding M3. The bulk of the seismicity is however not due to volcano tectonics but seems to be caused mainly by shallow processes involving glacial deformation.

Katla's ice filled caldera forms a glacier plateau of several hundred meter thick ice. The 9x14 km oval caldera is surrounded by higher rims off which the glacier in some places gently and in others abruptly falls down tens and up to hundred meters. The glacier surface is marked with a dozen depressions or cauldrons which manifest geothermal activity below, probably coinciding with circular faults around the caldera. Our current understanding is that there are several glacial processes which cause seismicity; such as dry calving, where steep glaciers fall off cliffs and movements of glacier ice as the cauldrons deform due to changes also in geothermal activity at the glacier/bedrock boundary. These glacial events share a common feature of containing low frequency (2-4 hz) and long coda. Because of their shallow origin, surface waves are prominent.

In our analysis we use waveforms from all of Katla's seismic events between years 2003-2013, with the criteria M>1 and minimum 4 p-wave picks. We correlate the waveforms of these events with each other and group them into families of highly similar events. Looking at the occurrence of these families we find that individual families are usually clustered in time over several months, and sometimes families may reappear even up to several years later. Can the repeating glacial seismic events be used to monitor stress changes within the underlying volcano? Using families including many events and covering long periods (10-20 months) we compare the coda of individual events within a family. This is repeated for all the surrounding stations. The analysis, coda wave interferometry (cwi) is a correlation method that builds on the fact that changes in the stress in the edifice lead to changes in seismic velocities. The coda waves are is highly sensitive to small stress changes. By using a repeating source, implying we have the same source mechanism and the same path, we can track temporal stress changes in the medium between the source and the receiver.

Preliminary results suggest that by using the coda wave interferometry technique we observe annual velocity changes around the volcano of ca. 0.7%. We find that seismic velocities increase from January through July and decrease in August to December. These changes can be explained by pore-water pressure changes and/or loading and de-loading of the overlain glacier. We do not find immediate precursors for an impending eruption, however we now have a better understanding of the background seismicity.

The 2012 and 2013 earthquake sequences in North Iceland: Is the Tjörnes Fracture Zone ready for the next major earthquake?

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The Tjörnes Fracture Zone (TFZ) is an offshore right lateral transform zone, compensating the offset between the Kolbeinsey ridge and the Northern Volcanic Zone in North Iceland. Its seismically most active features are the Húsavík Flatey fault (HFF), a WNW-ESE trending right lateral strike-slip fault, and the Grímsey Oblique Rift, with several N-S grabens and left-lateral bookshelf faults. On average 23 major earthquakes (M>6.5) occur per century, most recently in 1872 on the HFF, 1910 probably SE or E of Grímsey and 1964 on the western extension of the HFF.

In September and October 2012, two earthquake sequences occurred in the transition zone between the western HFF and the Kolbeinsey ridge, the so called Eyjafjarðaráll graben. Strongest events were of magnitude MW 5.3 and MW 5.6 on 21. October. Both main shocks showed normal faulting focal mechanisms and were located on known faults along the graben. During the subsequent aftershock series, activity migrated ESE-wards and triggered strike-slip events on the HFF.

Another major earthquake sequence started in the end of March 2013 east of Grímsey island, culminating in a MW 5.6 mainshock on 2. April. The event had a left lateral strike-slip mechanism and was located on one of the known N-S faults. Equivalent to the fall 2012 sequence, activity on adjacent faults was triggered.

Recent GPS measurements reveal that the stress load on the HFF since the 1872 earthquake is sufficient for a MW 6.5-7 earthquake (Metzger et. al., 2011). Further, studies of the microseismicity on the HFF suggest a retreat of the stress shadow induced by the Krafla intrusions in 1975-1984.

In this presentation, we summarize the earthquake activity in the TFZ during the past decades, focusing on the 2012 and 2013 sequences. Recent developments will be discussed in context with latest results of geodetic and seismological studies in the area. Further, we will give an overview on the short-and longterm response of monitoring / research institutions and the Icelandic Civil Defense.

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Revisiting the current activity on the endglacial faults in Sweden

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As the ice retreated at the end of the Weichselian glaciation, a number of very large earthquakes, M7-8, occurred in northern Fennoscandia. Recent studies indicate that these events were triggered by the glacial isostatic adjustment process, but driven by plate tectonics. Poor knowledge of the deep geometry of the faults and of the ambient stress field, however complicates the mechanical analysis.
The expansion of the modern Swedish seismic network (SNSN) into the north in 2004 revealed that these faults are currently active with microearthquakes. A temporary deployment of seismic stations on the 150 km long Pärvie fault was undertaken between 2007-2010. Running stations in remote locations in the mountains at 68 degree north was challenging, with power generated by wind mills and solar panels.
A new temporary six station network was installed around the Burträsk fault, south of Skellefteå, in late 2012. The Burträsk fault is currently the most active area in Sweden and the first three months with the temporary network shows an activity rate of 2-3 earthquakes per day.
In this talk I will revisit the results from the Pärvie fault and show initial data from the Burträsk network.

New magnitude scales and focal mechanisms of medium-small earthquakes for areas around Shanxi Rift, North China

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The Shanxi rift system is a seismically highly active area in North China. The densification of regional and local recording networks in recent years has greatly improved the potential for research on seismology and seismotectonics at a regional scale. In this study, we developed a new locally calibrated M_L scale from 2633 observations, 83 events on 56 stations recorded by the Shanxi Seismic Network (SSN) during the period of 2008-2012. We performed moment tensor inversion for 17 larger events, determined the spectrum based M_w and derived the relationship between the M_w and M_L for this region. With this study, we also determined a total of 83 focal mechanism solutions based on moment tensor inversion for larger events and P-wave polarities and amplitude ratios for smaller events in our data set. These results enhance our understanding of the regional seismicity and allow further insight into the regional seismotectonics and seismic hazard.

Seismicity and seismotectonics of Myanmar: importance of the the Sagaing Fault System

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The current seismicity of Myanmar is driven by a broad deformation zone associated with the Eastern boundary of the Indian Plate. The subduction system in the Andaman Sea is gradually transformed into the centrally localized Sagain Fault System, whereas in Western Myanmar and towards the border with Bangladesh and India, subduction system continues and is expressed by sporadic earthquake activity along a series of N-S oriented low-angle thrust faults at shallow depths, with deep seismicity associated with the subducting slab.

The main transcurrent motion is however, associated with the Sagaing Fault (SF) extending more than 1,000 km across entire Myanmar in N-S direction and forms the boundary between the Indian Plate in the West and the Burma and Sunda microplates in the East and Southeast. It is a typical continental dextral strike-slip fault with a slip-rate of 18 mm/year and is comparable to other well-known faults such as the San Andreas Fault (SAF) in California, U.S., North Anatolian Fault (NAF) in Turkey and the Great Sumatra Fault (GSF) in Indonesia. Historically and within the instrumental period, the Sagaing Fault has produced a number of large earthquakes some of which has caused significant damage. Since 1918, there has been six M>7 earthquakes between 1930 and 1956 with 610 casualties. These are May 1930 (M=7.4), December 1930 (M=7.5), January 1931 (M=7.7), September 1946 (two earthquakes with M=7.5 and M=7.8), and July 1956 (M=7.0) earthquakes. The most recent significant earthquakes occurred in January 1991 (M=6.9) and November 2012 (M=6.8). The coseismic rupture and associated deformation along the Sagaing Fault, which failed during the latest earthquake on the 11th of November 2012 at Shwebo, is investigated in a separate study (Watkinson et al., 2013). The location of these earthquakes and their surface ruptures leave two significant gaps, one in central Myanmar and the other in the southern section in the Andaman Sea. According to Hurukawa and Maung (2011), the largest one of these, the central segment is capable of generating a large earthquake (M~7.8-7.9) with max rupture length of 260 km. The location of the capital city of Myanmar, Nay Pyi Taw falls into this segment causing an important exposure to a possible future earthquake risk. Current efforts by the Myanmar Earthquake Committee on assessing the seismic hazard in the country revealed the need for establishing a long-term science program focused on understanding the true earthquake potential of the Sagaing Fault through geological, geophysical, seismological, and paleoseismological studies.

Seismotectonic and seismic network in Myanmar

Yin Myo Min Htwe

(to be distributed in the Conference)

NordQuake – status and future activities

P. Voss
Geological Survey of Denmark and Greenland – GEUS

The Nordic Earthquake Researcher Network – NordQuake, was established in 2011 with founding from NordForsk, an organisation under the Nordic Council of Ministers that provides funding for Nordic research cooperation as well as advice and input on Nordic research policy (http://www.nordforsk.org/).
A status of the NordQuake activities is given, including the Researcher Network meetings in 2011 and 2012 and the Researcher Training courses in 2012 and 2013. Furthermore, the activities of the research groups that have been supported is presented.
The 2013 training course was undertaken in June hosted by the Geological Survey of Denmark and Greenland – GEUS. Outcome of the course is presented.
The status of NordQuake is given and a draft for the plan of future meetings and training courses is presented. http://nordquake.net

Earthquake rupture details by the back projection method using data from the Swedish National Seismic Network (SNSN)

Hossein Shomali, Reynir Böðvarsson, Björn Lund, Peter Schmidt and Roland Roberts

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The initial portion of P-waves trains at teleseismic distances (30°–90°) contain valuable information about the source characteristics of moderate to large earthquakes. Rapid and robust images of the source rupture including the initiation of rupture and propagation of the earthquake rupture front can be obtained by back projecting high-quality teleseismic P-wave trains recorded by large arrays. Such results are interesting in relation to the issuing of warnings and assessments immediately after the occurrence the events. The analysis can provide detailed knowledge on the earthquake rupture propagation from the high-frequency radiated seismic energy in the P-wave trains. We apply the method to 66 three-component broadband (CMG-3TD) seismic stations of the Swedish National Seismic Network (SNSN) operated by Uppsala University since 1998. The SNSN array covers an area about 450 km by 1450 km with the high concentration of stations along the Baltic Coast. Well-correlated and uniform recorded waveforms of moderate to large earthquakes at teleseismic distances provide a high quality dataset with insignificant site effects suitable for back-projection application. It is especially significant that SNSN stations record clear signals even at relatively high frequencies. We present an application of the method to a number of large earthquakes including the April 11, 2012, Mw 8.7 northern Sumatra earthquake - one of the largest intraplate strike-slip earthquakes ever recorded. The high-frequency (0.2-1.0 Hz) data reveal the extent and magnitude of the fault slip and the progression of slip along the fault.

Source study of the Jan Mayen fracture zone strike-slip earthquakes

Quetzalcoatl Rodriguez-Perez and Lars Ottemöller, UiB

Abstract:

We analyzed source characteristics of five moderate-size strike-slip events (5.8 < Mw 6.7) in the Jan Mayen fracture zone from 1988 to 2012. Within this study, we determined the finite-fault slip distributions using teleseismic data. We also characterized heterogeneous slip models by determining source parameters on the asperities and on the background area, such as number of asperities, combined asperity area, stress drop on asperities, aspect ratio, and average stress drop. Sensitivity tests were carried out to estimate the variability of slip patterns and source parameters by changing fault dimensions, subfault size and the number of stations. We observed robust slip solutions and reliable source parameter estimations. The results may be useful in understanding the earthquake physics of the strike-slip events in Jan Mayen fracture zone.

Probabilistic seismic hazard assessment for Kyrgyzstan, Tajikistan and eastern Uzbekistan, Central Asia

By
Louise Wedderkop Bjerrum and Conrad Lindholm

Central Asia is a region of large crustal compression due to the collision of the Eurasian and Indian plates which has an estimated convergence of 50 mm/yr, of which 22 mm/yr of the crustal shortening is estimated to be accommodated by the Pamir and Tien Shan mountain belts. This deformation has resulted in many Mw≥7 earthquakes throughout the region recorded historically as well as instrumentally. Therefore, the seismic hazard in this region is of particular interest. Previous hazard studies have focused either on earthquake data or geological information and seismic hazard assessments have until now not considered models combining the two types of information. In this study we consider the existing fault model and the earthquake catalogs available for the region and combine these different types of data in a probabilistic hazard assessment, using a logic tree approach in order to quantify the seismic hazard in the region. We quantify the hazard in terms of peak ground acceleration (PGA) and spectral acceleration (SA) for different periods, all shown on maps for a return period of 475 years (10 % probability of exceedance within 50 years). The largest expected ground motions are found in southern Tien Shan with PGA in the range of 5 6 m/s2. Furthermore, we extract the expected ground motions for the capitals in the region and find for Bishkek and Dushanbe maximum expected spectral acceleration at bedrock level of 8 8.6 m/s2 for a period of 0.2 s. When considering the soil conditions beneath the two cities, the SA is expected to amplify to 9-9.5 m/s2. The expected maximum ground motion for Tashkent are 4.8 m/s2 and 5.5 m/s2 for bedrock and soft soil conditions, respectively, for a return period of 475 years.

Abstracts

Poster presentations

Earthquake activity in Finland and the Russian North in December 1758: rare reports and their interpretation

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Abstract
This investigation focuses on two historical earthquakes that occurred in the border region between Finland and Russian North in December 1758. They were close together in time and their magnitudes are among the largest observed in the region. We thoroughly searched for contemporary Russian and Scandinavian documentation on earthquake activity in several libraries in Moscow, Helsinki, Stockholm and Copenhagen. We found two primary reports, one from the Russian North and the other from Finland. The context and content of the reports indicate that they are independent and related to the dates of December 17 and December 31, 1758. The first occurrence was reportedly observed in Kandalaksha, Knyazhnaya Guba, Kovda, Chernaya reka and krest Vzista, and the second in Inari, Utsjoki, and Karasjok. We compiled macroseismic maps for both earthquakes and sets of possible parametric solutions that fit the sparse information available. We identified two types of uncertainty in epicenter and magnitude determination: one that stems from the ambiguity of intensity assessment at localities and the other from the spatial distribution of the data points.

Earthquake monitoring in Greenland: Achievements and improvements

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

Abstract
Results from the earthquake monitoring in Greenland during the last five decades are presented, and these results show; a large increase of the number of detected earthquakes, an improved detection threshold, new areas of high seismicity, several earthquake clusters and seismicity below the ice cap. Despite the improved monitoring, detection of local events is still performed manually, by analyzing all of the real time data. With a station separation of around 400km many earthquakes are only detected on one or two stations which make automatic detection very difficult. But improved instrumentation has enabled the use of single station location technique. Results from and challenges using this method are presented. The development of the seismic monitoring have gone from having only three seismic stations placed in Greenland in the 1960'ties, till today where there are18 permanent stations placed in Greenland. All equipped with broadband sensors, of which 13 has Internet connection and transmit 100sps data in real time, and 5 used the Iridium satellite system and transmit 1sps data with a delay. The resent major improvement of the seismic monitoring is performed by the Greenland ice sheet monitoring network (GLISN, http://glisn.info).

Preliminary estimates of dynamic characteristics of ground at BAVSEN stations by method of spectral ratios

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The dynamic characteristics of the ground are important in the construction in earthquake-prone areas and in areas with unconsolidated ground. In the East Baltic region is dominated by the weak, unconsolidated soils, which lie on a hard Devonian deposits. The crystalline basement is located in average at a depth of 1 km. The dynamic characteristics of the ground were estimated from the spectral relations Nakamura (H/V). Nakamura explains of amplification factor of peak values of H/V through of multiply refracted vertical SH waves, while other researchers explain with predominance of *Rayleigh* waves (Nakamura, 1989). Were used to records of microseismic from *BAVSEN* (*Baltic Virtual Seismic Network*). Stations are located in different geological conditions - on the East European Platform (SLIT, PBUR, PABE, VSU, MTSE) and the Svecofennian crystalline basement (MEF, RAF). *jSesame* program was used for estimation of spectral ratios (SR). SR (H/V) of microtremor was estimated by every daily for one week, to 30-minute recording intervals, every 8 hours in the frequency range of from 0.05 to 41.7 Hz.

Greatest interest SR (H/V) represent for the characteristic frequencies (0.2 - 10 Hz) of buildings. SR (H/V) has a quiet character at stations in Svecofennian area (MEF and RAF). SR (H/V) does not exceed 1.2 to 1.5 for stations MEF and RAF in this frequency range.

SR (H/V) is more for stations in the East European Platform. For MTSE SR $(H/V)_{max1}$ = 5.0 at a frequency of 10.0 Hz and SR $(H/V)_{max2}$ = 4.4 at a frequency of 7.3 Hz. For PABE SR $(H/V)_{max1}$ = 5.5 at a frequency of 0.75 Hz and SR $(H/V)_{max2}$ = 5.1 at a frequency of 0.45 Hz. For PBUR SR $(H/V)_{max}$ = 3.25 at a frequency of 0.55 Hz. For SUW SR $(H/V)_{max}$ = 4.4 at a frequency of 0.35 Hz. For VSU SR $(H/V)_{max}$ = 2.3 at a frequency of 2.3 Hz. For the SLIT SR $(H/V)_{max}$ = 3.15 at a frequency of 1.36 Hz.

Vulnerability index Kg (Nakamura, 2000) was estimated for *BAVSEN* stations. Found that vulnerability index Kg_{EEP} at the stations located on the East European Platform was significantly higher than Kg_{SCB} at the stations on the Svecofennian crystalline basement. Thus, Nakamura method of spectral ratios H/V and vulnerability index Kg may be used for estimation of adverse dynamic characteristics of ground in geological conditions of the East European platform and specifically in the East Baltic region.

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A fossil subduction zone in the East Greenland Caledonides revealed by a Receiver Function analysis

Christian Schiffer, Bo Holm Jacobsen, Niels Balling and Søren Bom Nielsen

Subsequent to their formation the East Greenland and Scandinavian Caledonides formed a major coherent mountain range. The understanding of the European Caledonides therefore naturally involves also the East Greenland Caledonides. The present-day topography and crustal and upper mantle structure in East Greenland were influenced by an extensive geological evolution involving several geodynamical processes, including closure of the Iapetus Ocean with continent-continent collision, subsequent gravitational collapse, extension and rifting. The passive margin development associated with the opening of the North Atlantic was furthermore spiced up by the pronounced localized anomalous volcanism around Iceland. Erosion shaped the today's distinct geological structure and landscape, culminating in the Quaternary glaciations.

The focus of this presentation is on the deep crustal and upper mantle evidence for the processes before and under the Caledonian orogeny.

We performed a Receiver Function analysis of data from 11 seismological broadband stations forming the Ella-Ø-array. This array, maintained by Aarhus University, covered an approximately 270 km long profile, spanning the East Greenland Caledonides from the Greenland Ice Sheet to the coast at about 73 °N for a period of two years (2009-2011).

The data reveal a clear eastward dipping lineament through the mantle lithosphere underneath the study area. The geophysical character as well as synthetic modelling is consistent with a 6-12 km thick, subducted slab of high velocity, eclogitized oceanic crust. We interpret this structure as a remnant of an early subduction and collisional event which pre-dates the main Scandian phase of orogeny with the collision of

Baltica and Laurentia. This is a key evidence for the unravelling of the complexity of the closure of the Iapetus Ocean and the formation of the Caledonides.