Icelandic Meteorological Office

Institute of Earth Sciences, University of Iceland

42nd Nordic Seismology Seminar

Organizing Committee:

Bergthóra S. Thorbjarnardóttir
Bryndís Brandsdóttir
Kristján Ágústsson
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Sigþrúður Ármannsdóttir
Steinunn S. Jakobsdóttir

Programme

List of participants

Abstracts

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WEDNESDAY, OCTOBER 5

08:30 Registration

09:00 Opening address
Steinunn S Jakobsdóttir

09:05 Session I: Seismic Event Studies
Chairman: Peter Voss

09:05 The March 11, 2011 (M_w=9.1) Japan earthquake: What happened and what next?
Mohammad Raeesi and Kuvvet Atakan

09:30 The mega-thrust earthquake of March 11, 2011, Japan: a complex fault rupture process aloong the plate interface in a mature subduction zone
Kuvvet Atakan and Mohammad Raeesi

09:55 The May 29th 2008 earthquake aftershock sequence within the South Iceland Seismic Zone: Automated microseismic event detection and location by continuous spatial mapping
Bryndís Brandsdóttir, Matthew Parsons, Robert S. White, Ólafut Guðmundsson, Julian Drew and Bergþóra S. Þorbjarnaradóttir

10:20 – 10:50 Coffee break

10:50 Session I continued: Seismic Event Studies

10:50 Seismic monitoring in Latvia using the Baltic virtual network. Results for 2008-2011.
Valerijs Nikulins

11:15 Earthquake scenarios: A practical way to deal with the uncertainties of historical earthquake data
R. E. Tatevossian, P. Mäntyniemi, T. N. Tatevossian

11:40 Earthquake swarms in the West Bohemia/Vogtland region
Hana Čermáková, Michalek J., Bouskova A., Fischer T., Horalek J.

12:05 – 13:30 Lunch break

13:30 Session II: Crustal and lithospheric structure and tomography
Chairman: Martin Hensch

13:30 Crustal and upper mantle shear wave velocity structure of Southern Norway: Results from surface wave analysis of ambient seismic noise and earthquake data
Andreas Köhler, Valerie Maupin, Christian Weidle

13:55 Reflection seismic method in mining environments: Re-processing of Kevitsa 2D Reflection Seismic Data
Emilia Koivista, Pekka Heikkinen and Alireza Malehmir

14:20 Moment tensor inversion in very heterogeneous media: the Pyhäsalmi mine, Finland
D. Kühn, V. Vavryčuk, H. N. Gharti, V. Oye

14:45 Poster session

15:15-15:35 Coffee break

15:35 Session III: Seismic hazard and earthquake engineering/CTBTO and ISC related studies
Chairman: Pasi Lindblom

15:35 Seismic vulnerability curves for low-rise buildings
Bjarni Bessason, Jón Örvar Bjarnason, Ari Guðmundsson and Júlíus Sólnes

16:00 Implications of considering finite fault rupture properties in seismic hazard and risk assessment
Mathilde B. Sørensen and Dominik H. Lang

16:25 Recent Developments at the International Seismological Centre (ISC)
Dmitry A. Storchak

THURSDAY, OCTOBER 6

08:30 – 19:00 Field trip to Snæfellsnes Peninsula

After the field trip, IMO and IES invite participants to a buffet dinner at Sjávarbarinn in Reykjavík

FRIDAY, OCTOBER 7

09:00 Session IV: Monitoring and forecasting/predicting earthquakes and volcanic eruptions
Chairman: Reynir Böðvarsson

09:00 Detecting active volcanic areas using coda Q, a comparative study between the Azores Islands, Jan Mayen and Norway
Dina Silveira and Jans Havskov

09:25 Unrest in Icelandic volcanoes: Magmatic or hydrothermal activity?
Kristín S. Vogfjörð and Gunnar Sigurðsson

09:50 Intrusive activity beneath Eyjafjallajökull heralding the 2010 flank and summit eruptions: An analysis of earthquake and geodetic data
Martin Hensch, Bryndís Brandsdóttir, Thóra Árnadóttir, Jon Tarasewicz

10:15 – 10:35 Coffee break

10:35 Session IV continued: Monitoring and forecasting/predicting earthquakes and volcanic eruptions

10:35 Eyjafjallajökull 2009-2010: Magma movements tracked with relocated earthquakes and GPS measurements
Sigurlaug Hjaltadóttir, Sigrún Hreinsdóttir, Kristín S. Vogfjörð, Freysteinn Sigmundsson, Þóra Árnadóttir, Ragnar Slunga

11:00 Seismic activity in the Katla volcanoe
Gunnar B. Guðmundsson, Matthew J. Roberts, Steinunn S. Jakobsdóttir and the IMO geophysical monitoring group

11:25 Grímsvötn eruption 21 – 28 May 2011
Steinunn S. Jakobsdóttir, Gunnar B. Guðmundsson, Matthew J. Roberts, Þórður Arason and the IMO geophysical monitoring group

11:50-14:00 Lunch break/EPOS meeting

14:00 Session V: Seismic Networks and Instruments
Chairman: Kuvvet Atakan

14:00 WEBNET – local seismic network in the West Bohemia, Czech Republic
Jan Michalek, Alena Bouskova, Hana Cermakova, Josef Horalek

14:25 Swedish National Seismic Network (SSNN)
Reynir Böðvarsson, Hossein Shomali and Björn Lund

14:50 Recent developments of seismology in Lithuania
Andrius Pacesa

15:15 – 15:35 Coffee break

15:35 Session V continued: Seismic Networks and Instruments

15:35 Informal information about Finnish National Seismic Network and relevant issues
Pasi Lindblom

16:00 Analysis of glacial earthquakes from Greenland recorded by the POLENET/LAPNET temporary array during IPY 2007-2009
Elena Kozlovskaya and POLENET/LAPNET Working Group

16:25 The Nordic Earthquake Researcher Network – NordQuake
Peter H. Voss

16:50 NordQuake meeting

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ABSTRACTS OF TALKS

The March 11, 2011 (Mw=9.1) Japan earthquake: What happened and what next?

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What is commonly known as a great earthquake is in fact the last stage of an earthquake cycle. Preparatory processes which precede great earthquakes generate large-scale phenomena; however, such phenomena should be viewed in a right domain to be interpretable. Almost all such phenomena take place out of asperity areas. Asperities are the patches in rupture area that release major parts of the stored earthquake energy. The March 11, 2011 Tohoku earthquake and its asperities will be discussed in the domain of Trench Parallel Bouguer Anomaly (TPBA). The leading processes and especially role of the major foreshock of March 9, 2011 (Mw=7.5) will be discussed. Correlation of TPBA-derived asperities with the asperities obtained through inversion of tele-seismic body-waveforms will be demonstrated. Stress transfer and current activity with respect to the location of TPBA-derived asperities will be used to discuss the characters of the likely future tsunami-generating earthquake in the neighboring area.

The mega-thrust earthquake of March 11, 2011, Tohoku, Japan: a complex fault rupture process along the plate interface in a mature subduction zone

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The fault rupture process during the Tohoku earthquake of March 11, 2011 (M_W=9.0), has been a subject of debate for many authors. Existing slip distributions all agree on the location of the shallow asperity which caused presumably the largest slip during the earthquake. This is claimed to be associated with the low-frequent part of the seismic energy which fit reasonably well with the extensive GPS data as well as the tsunami wave. However, there is a continuing discussion on whether the co-seismic slip extended down-dip rupturing also the smaller asperities at depths close to the termination of the contact zone.

The location of the shallow large asperity in our slip inversion fits well to the large shallow slip as obtained by other authors, which continues down-dip to intermediate depths through a neck-like structure. Additionally, we see clearly the role played by the foreshock on the 9th of March, where a smaller asperity at intermediate depths ruptured causing static stress increase in the hypocentral area of the mainshock. This was probably the triggering mechanism for the March 11 mega-thrust event. Apart from this, we do not observe any significant slip at intermediate depths. This is also confirmed by both the distribution of the aftershocks, as well as the location of the previous large earthquakes (7+) in this region.

Resolving the variations observed in slip inversions as obtained by different authors, requires an independent data set. In this regard, gravimetric data being independent from the seismological data provide important clues on the location of the most significant asperities along the subduction-interface where there is presumably strong coupling. The trench parallel gravity and topography anomalies have previously been used for mapping the location of asperities. Recently, we have applied trench parallel Bouguer anomaly (TPBA), to enhance that picture, delineating the location of strongly coupled areas more precisely. Using this methodology we find that there is a perfect match between the positive TPBA and the location of the shallow up-dip asperity as obtained by several authors. The smaller down-dip asperities seem to be associated by high-frequency energy, which is documented through the analyses of extensive strong motion data recorded in Japan. The importance of the TPBA should be investigated further because it provides independent evidence on the location of the asperities along the subduction zones prior to the occurrence of the mega-thrust events and hence will enable us to better estimate the likelihood and the extent of these infrequent but disastrous earthquakes. Furthermore mapping of asperities along subduction zones provide also significant constraints on the initial fault rupture models of the scenario earthquakes used in ground motion simulations.

The May 29th 2008 earthquake aftershock sequence within the South Iceland Seismic Zone: Automated microseismic event detection and location by continuous spatial mapping.

Bryndís Brandsdóttir(1), Matthew Parsons(2), Robert S. White(2), Ólafur Guðmundsson(3,4), Julian Drew(2) and Bergþóra S. Þorbjarnardóttir(5)

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On May 29th 2008, two Mw 6 earthquakes struck the western part of the South Iceland Seismic Zone. The first event was followed within seconds by a similar size event on a second fault 5 km further west. Earthquakes, detected by a temporary network of 11 seismometers and three permanent SIL-network stations were located using an automated Coalescence Microseismic Mapping technique. The epicenters delineate two major and several smaller N-S faults as well as an E-W zone of activity stretching further west into the Reykjanes Peninsula Rift Zone. Fault plane solutions show right lateral strike slip mechanisms along the two major N-S faults and suggest both smaller N-S right-lateral strike slip faults further west as well as an E-W zone of left lateral strike slip fault. The aftershocks deepen from 3-5 km in the north to 8-9 km in the south, suggesting thatthe main faults dip southwards. A brief increase in aftershock seismicity is most likely caused by short-term static stress buildup on adjacent faults. The faulting is interpreted to be driven by the local stress due to transform motion between two parallel segments of the divergent plate boundary crossing Iceland.

Seismic monitoring in Latvia using the Baltic virtual network. Results for 2008 - 2011 year

Valerijs Nikulins

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Is presented a brief review of seismic monitoring in Latvia. Seismic monitoring is based on the use of seismic stations that participate in an international network *GEOFON* with center at the *GFZ Potsdam*. Seismic station Slitere (*SLIT*) is part of the *GEOFON* network. It is located at northwestern Latvia. A data from other stations in the Baltic region and Scandinavia is using for the hypocentral location of regional seismic sources. Thus, a so-called Baltic virtual seismic network *BAVSEN* is used.

1771 seismic events were recorded by the Baltic virtual seismic network *BAVSEN* from January 2008 up to September 2011 in the Baltic region (φ = 53.9°N - 59.7°N; λ = 19.4°E - 29.6°E) and their parameters were determined. The main seismic sources in the Baltic region are explosions in the industrial quarries, in mines (Estonia), as well as a offshore explosions in the Baltic Sea.

There are three main problems of seismic monitoring in the Baltic region: the detection of signal from the noise background, the localization of the hypocenter of the seismic event and identification of the nature of the seismic event.

BAVSEN stations have signal/noise ratio (*SNR*) different characteristics. Therefore, data from different stations of *BAVSEN* network more frequent or rarer is using for the location of hypocenters of seismic events. Seismic station Slitere unfortunately is not in very good conditions.

The velocity models *iasp91*, *Fennoscandian*, *ISHU* and *baltic07* are using for the location of hypocenters of regional seismic events. The *baltic07* model was created on base of results from *DSS Sovetsk-Riga-Kohtla-Jarve* (1986) and *Eurobridge* (1995-1997). This model is more successfully applicable to the location of seismic events in Latvia. This is confirmed by several examples of location of calibrated seismic events.

A huge amount of man-made sources in the Baltic region complicates the identification of tectonic earthquakes. A spectral ratio *P/S* is used for identification of tectonic earthquakes. However, this parameter is not always allows to unambiguously identify the origin of seismic events.

Earthquake scenarios: A practical way to deal with the uncertainties of historical earthquake data

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The present study investigates the uncertainties of historical earthquake data. In particular, the largest uncertainties are examined. They are usually associated with the historical macroseismic data preceding systematic collection of earthquake observations. The study focuses on low-seismicity regions, where the available earthquake data may be quite sparse.

The solutions listed for historical earthquakes in parametric catalogues are usually accompanied by some error limits. However, they may follow from judgments that are not clear and may have only a formal character. We propose to use so-called earthquake scenarios to improve the transparency of decision-making involved in evaluating historical earthquakes. The concept is defined as any past earthquake (natural phenomenon), its occurrence (when and where) and possible consequences (how large the size). Different scenarios can be modeled on the basis of the macroseismic information available, and a probability value can be attached to each of them. Thus, an earthquake scenario means that uncertainties associated with historical earthquake data become discrete instead of continuous. Moreover, seismo-tectonic knowledge can be incorporated into earthquake scenarios. The proposed ideas are illustrated using examples from the Fennoscandian shield, including the earthquakes of 1542 and 1765.

Earthquake swarms in the West Bohemia/Vogtland region

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The West Bohemia/Vogtland region is a typical area of intraplate seismicity where mainly earthquake swarms occur. The most intensive instrumentally recorded swarms occurred in 2000, 2008 and 2011. The last mentioned swarm started at the end of August 2011 and lasted for about three weeks. It is not completely over yet because there are still events with Ml>0.5. This swarm has slightly different behavior from those in 2000 and 2008 when the seismic activity appeared nearly on the same two parts of the fault. Between those parts almost no events were found and it was this gap which was activated during recent activity. The swarms in 2000 and 2008 lasted for four and about two months, respectively. In case of ongoing swarm the same energy was released during just two weeks compared with the previous ones.

Crustal and upper mantle shear wave velocity structure of Southern Norway: Results from surface wave analysis of ambient seismic noise and earthquake data

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This work is part of the TopoScandiaDeep project whose objective is to study the possible relation of the anomalously high topography of the Scandes mountains with lithospheric structure and processes. One major component of the project is the analysis of seismological data recorded at a temporary passive seismic array in Southern Norway and parts of Western Sweden. As part of this analysis we integrate measurements of surface wave phase velocities to invert for crust and shallow upper mantle structures.

Surface waves generated from earthquakes at regional and teleseismic distances are analyzed at periods from 18 to 200s using a novel multiscale wavefield interpolation method and f-k analysis. Such waves are mostly sensitive to upper mantle seismic velocities but also crustal structure, primarily crustal thickness. Surface waves at shorter periods are more difficult to observe in earthquake generated wavefields due to higher attenuation and scattering, but can be obtained from analysis of ambient seismic noise. We are able to measure reliable Rayleigh and Love wave phase velocities for periods between 3 and 25s from noise cross-correlation functions. By combining observations from noise and teleseismic events, we obtain phase velocity maps of southern Norway for Rayleigh and Love waves continuously in the period range 3 and 70 s. This bandwidth of observations allows us to invert for shear wave velocities entirely independently of external data input.

The average model of the S-wave velocity variation with depth under southern Norway shows that the lithosphere in the area has the characteristics usually found under continental platforms and not, as we would have expected, those found under cratonic areas. On the Swedish site of the study region, however, higher upper mantle velocity are found which are expected for the Baltic shield area. We are able to resolve lateral phase velocity variations at shorter periods in the order of 3%. These anomalies can be explained by variation of the crustal structure (e.g. Caledonian nappes, Oslo Graben) and Moho depth. We also observe discrepancy between Love and Rayleigh waves velocities in parts of the studied region which can be explained by radial anisotropy in the crust and upper mantle.

Reflection seismic method in mining environments: Re-processing of Kevitsa 2D Reflection Seismic Data

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In December 2007, 2D reflection seismic survey was conducted at the Kevitsa Ni-Cu-PGE deposit in northern Finland as a part of the HIRE project (High Resolution Reflection Seismics in Ore Exploration 2007-2010; Kukkonen et al., 2009) run by the Geological Survey of Finland, and with SFUE *Spetsgeofizika/*Vniigeofizika, Moscow, Russia as the seismic contractor. Initial processing of the 2D data was done by *Spetsgeofizika*, and the initial images revealed a complex reflectivity structure of the Kevitsa Intrusion, which hosts the Kevitsa Ni-Cu-PGE deposit, and its surroundings. However, it was noted that a more detailed work had potential to improve the images, in particular new processing with specific emphasis on the problems related to the crooked-line survey geometry.

The positive preliminary results from the 2D seismic survey led Kevitsa Mining Oy/First Quantum Minerals Ltd to initiate 3D reflection seismic survey that was carried out in 2010. In preparation for the Kevitsa 3D survey, the 2D lines were re-processed with the hope to improve the initial images. However, this re-processing work did not take full advantage of the frequency content of the data, and thus the resolution of the final images was left wanting. Also, as is the case with the initial processing work by *Spetsgeofizika*, the velocities used in the previous re-processing work, for both stacking and migration of the data, are too low.

Improvement of these aspects, among other adjustments to the processing sequence, resulted in clearly enhanced seismic sections presented herein, in particular for the shallowest 0.5 seconds. The new images reveal aspects not visible in the earlier versions, and can be used to pinpoint a wider structural context of the Kevitsa deposit. A simplified cross-dip analysis was conducted to further assess the reflector geometries, and revealed reflectors with clear cross-dip components, along with some peculiar diffraction packages. The cross-dip analysis provides additional information that can potentially be used to further improve the 2D seismic sections, and in interpretation of the data. Further analysis is required to confirm the origin of the diffraction packages.

The new re-processing of the Kevitsa 2D seismic lines was done in parallel, and in co-operation, with Uppsala University working on the Kevitsa 3D seismic data (Malehmir et al., 2011).

Acknowledgements: Kevitsa Mining Oy/First Quantum Minerals Ltd

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Moment tensor inversion in very heterogeneous media: the Pyhäsalmi mine, Finland

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Microseismic monitoring in mines is a well-established tool to minimise risk for personnel and to optimise production (e.g. Mendecki, 1997). The estimation of full moment tensors of microearthquakes may provide valuable information on presence and geometry of faults as well as on stress fields and their changes. Nevertheless, the accurate determination of source mechanisms in mines is extremely difficult. The structural model is not only very complex, comprising host rock, ore body and voids on various scales (e.g. excavations, access tunnels and stopes), but it changes also with time. In addition, earthquake sources are complex, frequently having large non-double couple components.

The Pyhäsalmi ore mine in central Finland is one of the deepest mines of its kind in Western Europe extending to a depth of 1.4 km (Puustjärvi, 1999). The seismic network in the Pyhäsalmi mine consists of 6 three-component and 12 one-component stations and has been operated in a continuous mode since January 2003. The most seismically active regions are connected to an ore pass as well as to the current production areas.

For moment tensor inversion, we first apply the code by Manthei (2005). Observed P-wave first-motion amplitudes are inverted for all six independent components of the moment tensor using Green's functions of the homogeneous full space. Some events, however, have a very heterogeneous distribution of polarities on their focal sphere which even cannot be explained by a non-double couple solution. We suspect that this behaviour is a result of complex travel paths and scattering. In order to improve the accuracy of the calculated moment tensors, we employ a waveform inversion using a 3-D velocity model. Green's functions are computed using the finite difference code E3D (Larsen and Schulz, 1995). The inversion is performed in the frequency domain using a generalised linear inversion scheme. The correctness of the code was verified on synthetic data. The retrieved moment tensor contains significant non-double couple components. Comparing the moment tensors obtained using amplitude and waveform inversion, we see visible differences in the double couple as well as non-double couple parts.

Larsen, S., and Schultz, C.A. [1995] ELAS3D: 2D/3D elastic finite difference wave propagation code. Technical Report No. UCRL-MA-121792, 19 pp.
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Seismic vulnerability curves for low-rise buildings

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Detailed information about all buildings in Iceland is registered in the official property database, Registers Iceland. It contains among other things data about usage, date of construction, number of stories, building material, GPS-coordinates, reconstruction insurance value. Insurance against natural disasters is mandatory for all buildings in Iceland. It is managed by the Iceland Catastrophe Insurance, an official institution. Whenever a destructive earthquake occurs, the extent of damage of all houses is investigated and reported by trained technicians. The damage data is classified into a number of subcategories, both with respect to structural and non-structural damage. Based on the thus compiled damage database, the repair and replacement cost for every affected building is evaluated. The Earthquake Engineering Research Institute of the University of Iceland operates a strong motion network in Iceland which has been gradually expanded since its implementation in 1985. Ground motion data from number of significant earthquakes have already been recorded by the network, including valuable information from three strong earthquakes, i.e. the two South Iceland Earthquakes of June 2000 (both of size M_w=6.5), and the one in May 2008 (M_w=6.3). The data have been useful to evaluate an area-specific attenuation model for Iceland.

A 6.3 magnitude earthquake occurred in May 2008 in the Ölfus region in South Iceland. A great deal of damage occurred but fortunately there was no loss of life. The recorded maximum peak ground acceleration (PGA) was 0.88g in Hveragerði, one of the small towns in the area. The detailed and complete information in the property database, the damage reported along with recorded strong motion data and the area-specific attenuation model, has provided an opportunity to create probabilistic vulnerability functions for the building stock in the affected region. Vulnerability functions were evaluated for five building classes, i.e. two categories of reinforced concrete shear-wall buildings, built before and after 1980, two categories of timber buildings, before and after 1980, and finally one category of pumice buildings. These building classes cover the majority of all houses in the region. In fact the presented vulnerability functions are based on 4746 buildings which were hit by the 2008 Ölfus earthquake. Of these 2382 were damaged, and 21 thereof suffered total loss. None of the "totally damaged buildings" collapsed, but the damage was so severe that repair was considered impractical. The reported damage data show that the damage of new low-rise timber houses and new low-rise reinforced shear wall concrete houses (both built after 1980) is quite similar for all earthquake intensity levels. The study also showed that they have an inherent and satisfactory earthquake resistance capacity. As an example, for the highest earthquake action intensity, i.e. when PGA is in the range 0.34–0.65g, it can be expected that over 90% of these buildings will only suffer light damage, that is have a repair cost which is less than 10% of reconstruction cost. Furthermore if only structural damage is considered (non-structural damage excluded), the figure is less than 1.5%. This is the main explanation why no deaths and hardly no injuries occurred in the South Iceland earthquakes 2000 and 2008. Inventory damage (cabinets, bookshelves, furniture etc.) was and continues to be more of a threat to the residents than the buildings themselves (for more details see [1]).

[1] *Bjarni Bessason, Jón Örvar Bjarnason, Ari Guðmundsson, Júlíus Sólnes & Scott Steadman, 2011. Probabilistic earthquake damage curves for low-rise buildings based on field data, Earthquake Spectra (In Press).*

Implications of considering finite fault rupture properties in seismic hazard and risk assessment

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Tools for scenario-based seismic hazard and risk assessment are well documented and are generally used for predicting or reproducing the consequences of earthquakes. Traditionally, such evaluations were based on simplistic earthquake models combining a finite fault plane with one or more ground motion prediction equations (GMPE). However, more sophisticated tools exist for the simulation of earthquake ground motion, considering the effects of slip distribution, rupture propagation and other aspects of rupture dynamics. Whereas these methods are well tested and widely used in seismic hazard assessment, their influence on earthquake damage and loss estimates is not well known. In the current study the effects of implementing stochastic finite fault ground motion simulations in seismic hazard and risk assessment are evaluated, both in terms of ground motion estimates and corresponding structural damage and losses. The investigations are applied to the city of Dehradun, located in the Indian Himalayas, for which a detailed building stock database and vulnerability model is available. Ground motion simulations are first calibrated against the 1991 M_w 6.8 Uttarkashi earthquake, which was recorded at a number of strong motion stations nearby. Afterwards, a number of relocations of the event are considered in order to investigate the difference between ground motions and losses estimated using the simplified GMPE-based approach and those estimated through simulations at varying distance and azimuth to the source. Furthermore, magnitude dependencies of these differences are studied. Results indicate that there are large differences between ground motion and risk estimates derived by the two methods especially in the direction of rupture propagation, which persist also at several fault lengths distance. The same observation is made, but to a much smaller extent, when the rupture propagates away from the site of interest. It is therefore strongly recommended to always consider rupture directivity and orientation to the test bed when providing ground motion estimates for seismic damage and loss assessment studies. In cases where these parameters are not well constrained, a range of scenarios with varying rupture directivity should be considered, thereby allowing for a more thorough estimation of the range of possible ground motions and losses.

Recent Developments at the International Seismological Centre (ISC)

Dmitry Storchak, James Harris, István Bondár, Domenico Di Giacomo, Ben Dando

The ISC is a non-governmental non-profit making organization, charged with production of the Bulletin – the definitive summary of the global seismicity based on reports from 126 institutions worldwide. Jointly with the World Data Center for Seismology (Denver), the ISC runs the International Seismographic Station Registry. The ISC provides a number of additional services including the depository of the IASPEI Reference Event list (GT), EHB and ISS data.

A substantial development programme ensures that the ISC data remain an important source for geophysical research.

We recently modernized the ISC event location procedures that now take into account the wealth of all seismic arrivals predicted by ak135, account for correlated model error structure and provide more accurate and robust hypocentre and network magnitude estimates with uncertainties.

We are working towards re-building the entire ISC Bulletin (1960-2010) by re-computing the hypocenters and magnitudes with the new location algorithm using ak135 velocity model, identifying and filling gaps in the data, correcting known errors and introducing bulletins from temporary deployments.

The ISC leads compilation of the GEM Instrumental Seismic Catalogue (1900-2009) where consistent hypocentre parameters and magnitudes will be provided for large earthquakes using a considerable amount of newly obtained data.

The ISC is also running the CTBTO-Link where the ISC Bulletin data are provided to the monitoring community as a reference and a historical perspective into current recordings by the IMS network.

Detecting active volcanic areas using coda Q, a comparative study between the Azores Islands, Jan Mayen and Norway

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Coda Q was determined in different areas of the Azores Islands and compared to coda Q of Jan Mayen and Norway. The main purpose of the study was to detect regional difference within the Azores Islands and use other areas for reference. Considering that coda Q results vary significantly with the parameters used, all results have been processed in an identical manner using local earthquakes. Both the Azores Islands and Jan Mayen are located on or near the Midatlantic ridge, however the Azores Islands has a much larger volcanic area than Jan Mayen and is more active.

Within the Azores Islands, there was surprisingly little variation in coda Q except for the island of San Miguel which showed considerably lower coda Q the any other of the Azores areas. This is surprising considering that all the islands have similar active volcanoes. San Miguel has two large volcanic complexes, Fogo and Congro, which in the last 100 years has shown a high level of local seismicity and in the last 10 years has given rise to extremely high level of local swarm activity in the 1-10 km depth range, so much so that there has been fears of a new large eruption.

Coda Q of the Azores, without using data near Fogo and Congro, is very similar to coda Q of Jan Mayen indicating similar tectonics and considerably lower than Norway coda Q indicating that the coda Q method is sensitive to large difference in tectonics. Considering this, it is concluded that the Fogo – Congro area of San Miguel presents an abnormal low Q area, which might indicate the location the largest body of active volcanic material within the Azores.

Unrest in Icelandic volcanoes: Magmatic or hydrothermal activity?

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At most Icelandic volcanoes signs of unrest are revealed by seismic activity. High precision locations of this seismicity recorded by the national seismic network and supported by observations of crustal deformation on the national continuous GPS network, have enabled tracking of magmatic intrusions into active volcanoes and volcanic areas in Iceland's Eastern Volcanic Zone. The presentation will show seismic signs of unrest at Katla volcano and at volcanoes under western Vatnajökull ice cap.

At Katla volcano a few periods of increased seismicity have occurred over the last decades. During the last two decades, most of the located seismicity is at the surface on the volcano's western flank and is likely associated with movements of the overlying glacier. In common with many calderas most of the recorded seismicity inside the caldera is related to geothermal activity. This is revealed through predominantly shallow earthquakes, whose locations largely correlate with ice cauldron locations on the glacier surface; the cauldrons being manifestations of geothermal activity in the underlying caldera. Since July 2011, shallow seismicity has increased within Katla‘s caldera and several of the ice cauldrons drained in a sudden glacial outburst flood (jökulhlaup) in July. Some of this shallow seismicity correlates with locations of the drained cauldrons. In association with the floods, harmonic tremor signals were also observed on the seismic network. Their characteristics resemble previous subglacial floods from the Katla caldera and suggest a non-magmatic source of the tremor.

Since 2005 seismicity has been increasing at several volcanoes and volcanic areas under the Vatnajökull ice cap. These include: Grímsvötn, Bárdarbunga, Kistufell, Loki ridge, Kverkfjöll and Esjufjöll. And, although less constrained, persistent seismicity is recorded at Öræfajökull volcano. This suggests that the whole region under western Vatnajökull is experiencing magmatic intrusions. The earthquake relocations indicate: That most of the pre-eruptive seismic activity at Grímsvötn was concentrated at shallow depth under the southern caldera rim; that the seismicity at Bárdarbunga is confined outside the caldera, extending from the caldera rim, north along the fissure swarm to Kistufell; and that the activity at Loki ridge is concentrated in five separate and tight clusters, two of which coincide with the locations of the Skaftárkatlar cauldrons. Of the agitated areas in Vatnajökull, two have already released material: A powerful volcanic eruption occurred at the southern caldera rim of Grímsvötn in May 2011 and three of the seismic areas on Loki ridge drained in jökulhlaups in July 2011; the two Skaftárkatlar cauldrons and the westernmost seismic area on Loki ridge, just east of Hamarinn. Seismic tremor signals from these episodes will be presented and their characteristics compared to those from previous floods and eruptions.

Intrusive activity beneath Eyjafjallajökull heralding the 2010 flank and summit eruptions: An analysis of earthquake and geodetic data

Martin Hensch, Bryndis Brandsdottir, Thora Arnadottir, Jon Tarasewicz

The Eyjafjallajökull stratovolcano is located at the western border of the Eastern Volcanic Zone (EVZ) in South Iceland, west of Mýrdalsjökull (Katla). The EVZ is propagating southwestwards into older oceanic crust. Since the settlement in Iceland, three eruptions have been documented in Eyjafjallajökull before 2010, in 920, 1612 and 1821-1823.

Following three major episodes of persistent microearthquake activity in the 1990s, seismicity picked up again in spring 2009 under the northeastern flank of Eyjafjallajökull. The activity increased throughout the year and culminated in an intense earthquake swarm in February-March 2010. Simultaneous inflation observed by GPS and InSAR data confirmed magmatic accumulation within the volcano and heralded the subsequent eruptions.

In early March, permanent seismic and continuous GPS networks around the volcano were augmented by aditional stations. Data from these networks greatly enhanced the spatial coverage of the inflation signal and hypocentral earthquake locations. Earthquake locations have revealed more than one accumultion zone at shallow (3-5 km) depth beneath the northeastern flank of the volcano, eventually feeding the March 20^{th} Fimmvörduháls eruption at the eastern margin of Eyjafjallajökull. Another seismic cluster beneath the central part of the volcano was recorded prior to the April 14^{th} summit eruption. Focal mechanisms derived from P-wave polarity analysis and moment tensor inversion indicate E-W striking reverse faulting for the February-March earthquake swarm, same as for a recent intrusion event in 1994, and normal faulting events beneath the summit crater prior to the second eruption.

The GPS data analysis reveals a temporally and spatially complex intrusion rather than pressure changes in a single magma chamber. First modelling on the geodetic data suggests two preeruptive sill intrusions between December 2009 and March 2010 beneath the main earthquake clusters at 4-6 km depth and eastward ascent of a dike prior to the first eruption onset on 20^{th} of March. The analysis of seismic and geodetic data will enable us to further constrain accumulation zones and ascent velocity of the intruding magma prior to the Fimmvörduháls and Eyjafjallajökull eruptions.

Eyjafjallajökull 2009-2010: Magma movements tracked with relocated earthquakes and GPS measurements

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Eyjafjallajökull volcano, S-Iceland, awoke, after 187 years of dormancy on March 20th 2010 when a small, basaltic, fissure eruption began on the eastern flank, outside the volcano's ice-cap. This three-week-long, effusive eruption was followed by a six-week-long explosive eruption of trachy-andesite that began on April 14th in the ice-filled summit crater and caused local flooding and widespread air-traffic disruption. This eruptive phase was preceded by a 18-year-long period of intermittent swarm activity and crustal uplift, indicating magma intruding into the upper crust and the lower crust. Here we show how relocated earthquakes and GPS-measurements can be used to infer magma movements beneath Eyjafjallajökull before and during the 2010 eruptions.

The seismicity indicates that the recent unrest period began at 20-25 km depth, near the crust-mantle boundary in March 2009 and was followed by small intrusive activity into the upper crust the following summer. The intrusion also caused a subtle southward movement of a near cGPS-station on the southern flank. Seismicity, picked up again in December 2009 and early January 2010 a cGPS station on the south flank of the volcano started moving away from the volcano, suggesting inflation.

Deformation observed at cGPS stations in January and February suggests formation of intrusions under the southeastern flank of the volcano. Similarly, the seismic pattern indicates the formation of intrusions beneath the south-eastern flank between February 20th and March 3rd. Also, time series from more distant cGPS stations show a small but distinct change around the 20th of February, with sites moving in toward the volcano, suggesting deep pressure changes.

From March 4th seismic activity migrated eastwards and intensified and observed rapid deformation is interpreted as northward and upward migration of the intrusion. When the effusive flank eruption started deformation almost ceased and the volcano remained at an inflated state. However, when the summit eruption began, rapid deformation toward the summit of the volcano and subsidence observed both with GPS and InSAR measurements indicate contraction of a shallow source at 3-4 km depth below the summit. A seismic gap in the magma pathway towards the summit, definded by relocated earthquakes, is also observed at 3-5 km depth just south-south-east of the summit. Deep seismic activity (near the crust-mantle boundary) in early May is interpreted as signs of new deep magma input from the mantle, before the effect of the new material reached the surface and caused increased ash production again.

Seismic activity in the Katla volcano and jökulhlaups

Gunnar B. Guðmundsson, Matthew J. Roberts, Steinunn S. Jakobsdóttir & IMO geophysical monitoring group.

Katla volcano is situated below the Mýrdalsjökull ice cap at the southern coast of Iceland. It is defined by an ice-filled caldera, occupying an area of about 100 km^2. Since the settlement of Iceland in the ninth century, Katla volcano has erupted 20 times; each eruption has produced a variety of volcanic hazards, the primary threat being glacial floods, jökulhlaups, which have caused repeated damage to farmland east of the ice cap. The last confirmed eruption in the Katla volcano took place in 1918. It has been suggested that a small eruptions took place in 1955 and again this summer (2011) in connection with a jökulhlaup from ice-cauldrons within the Katla caldera.

The monitoring capabilities of Katla volcano have been improved in the recent years and five additional seismic stations were installed around the volcano in cooperation with British Geological Survey near the end of year 2011.

During last decades most of the seismic activity has been very shallow and concentrated at the western flank of the volcano, near Goðabunga. Earthquakes beneath Goðabunga are seasonal in character with most earthquakes occurring in the autumn. The earthquake activity usually terminates near the end of the year. Exceptions from this behavior have occurred in 1966-1967, 1976-1977 and 2001-2004. During these periods, seismicity did not cease but rather continued with almost the same intensity throughout the year. However, the period of greatest seismic activity in Goðabunga is consistently October. One likely reason for this seismic pattern is changes in bedrock stress due to the effects of ice-volume variation. Other reasons like crypto-dome and ice-quakes have also been postulated.
The seismic activity within the Katla caldera is usually highest in July. On 9 July this year a jökulhlaup emerged from ice-couldrons in the southeast part of the caldera and destroyed the bridge over Múlakvísl river southeast of the volcano. During and after this episode the seismic activity within the caldera increased considerably and has been high since. A persistent very shallow microseismic activity has occurred south of the caldera and earthquakes have also occurred at about 6 km depth west of the caldera rim. Here we will mainly focus on recent seismic activity within the Katla caldera and its connection with jökulhlaup.

Grímsvötn eruption 21 – 28 May 2011

Steinunn S. Jakobsdóttir, Matthew J. Roberts, Gunnar B. Guðmundsson, Þórður Arason and IMO geophysical monitoring group.

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Grímsvötn is one of the most active volcanoes in Iceland, situated above the Iceland Hot Spot beneath Vatnajökull ice-cap. It has erupted about 60 times during the last eight centuries. A volcanic eruption started in Grímsvötn at approximately 1900h on 21 May 2011. The eruption was expected as the magma chamber inside the Grímsvötn caldera had inflated, giving approximately the same deformation as before the Grímsvötn eruption in 2004. There were even some speculations in October 2010 if an ongoing glacial flood, jökulhlaup, from Grímsvötn at that time would trigger an eruption, but that did not happen.

The onset of the eruption in 2011 was somewhat different from the one in 2004. Firstly, there was a decrease in seismicity the weeks before the eruption in 2011, while there was a considerable increase in seismicity before the one in 2004. Similarly, the 2011 eruption was preceded by only 80 minutes of intense seismicity.

Also the plume height during the first hours was much higher than in the 2004 eruption, reaching up to 20 kilometers intermittently. Very intensive lightning activity was observed during the first day. A large portion of the ash fell out from the lowermost ~5 kilometers of the plume and a considerable part spread out in about 10-12 kilometers height, while the uppermost part of the plume was light colored.

The eruption went on for seven days, the last explosions occurring around 0700h on 28 May.
The magma chamber is already inflating again, but as usual there are almost no earthquakes observed in Grímsvötn in the first months after the eruption.

WEBNET - local seismic network in the West Bohemia, Czech Republic

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The West Bohemia (WB) is a region in the Central Europe with an exeptional seismicity regime characterized by repeated occurence of earthquake swarms - specific type of seismic activity during which the deformation energy is released subsequently in a huge number of weak earthquakes that are clustered in space and time. Such activity is typical mainly for volcanic areas. Earthquake swarms without active volcanism are less common and occur mainly in the areas of enhanced crustal fluid activity. The typical swarm activity here lasts from several hours to few months. Maximum magnitudes are below ML=4.0. For example the ML<3.8 swarm in Oct 2008 tooks about one month and included over 20.000 of events. The swarms are occuring in the same place for more than 100 years and increased activity in 1985/86 led to deployment of the seismic monitoring system.

The WB area is continuously monitored since 1990 by WEBNET seismic network which nowadays consists of 13 permanent stations and similar amount of temporary stations. All stations are recording 3-components with 250 Hz sampling frequency and data from almost all permanent stations are transfered to data center in real time via seedlink. Data from the network are used not only for locating earthquakes but also for earthquake source studies which should help to understand the driving processes. The network is maintained by the Institute of Geophysics and Institute of Rock Structure and Mechanics, Academy of Sciences of the Czech Republic.

http://www.ig.cas.cz/en/structure/observatories/west-bohemia-seismic-network-webnet/

The evolution, basic characteristics, data processing and its progress as well as the historical seismicity of the area is presented here.

Swedish National Seismic Network (SNSN) - present status and ongoing developments

Reynir Bödvarsson*, Hossein Shomali and Björn Lund

The Swedish National Seismic Network (SNSN) now consist of 63 broad-band high-gain seismological stations. All stations are transmitting waveform data to Uppsala in real-time. Data from ten stations are now transmitted via Internet to Orfeus and ew have bilateral data exchange with Denmark, Finland and Norway. Until now, the network has mainly been used to locate local earthquakes and evaluation of their source parameters but now we also locate and estimate magnitudes of regional and global earthquakes. In this talk we will give an overview of the present status of the network.

Recent developments of seismology in Lithuania

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Seismological monitoring of Lithuania and adjacent territories are performed using data of Seismic Monitoring System (SMS) of Ignalina NPP which was installed in 1999. From the beginning of operating of SMS some flaws in SMS were noticed. Project of modernization of SMS was provoked by the two earthquakes of average-magnitude in the Kaliningrad District (Russia) in 2004. The system upgrade started in spring, 2007 and ended in summer, 2008. The SMS became more stable and started providing data of higher quality.

Only very few local tectonic events were registered during last decade of seismological monitoring by the SMS. A few tenths of local events were associated with explosions in quarries or explosions carried out during mine-clearing operations in the Baltic Sea. Number of registered teleseismic and regional events increased significantly after the SMS was upgraded in 2008.

A project “Passive seismic monitoring of the territory of Lithuania” was started in LGS at the very end of 2005 and finished at the end of 2009 within the framework of the international Passive Seismic Experiment in Trans-European Suture Zone (PASSEQ). PASSEQ was a prominent international research project with more than 10 countries involved and ~150 seismic stations deployed in Germany, Czech Republic, Poland and Lithuania. The major aim of the project was to investigate the deep structure of the lithosphere of the Central Europe and Precambrian East European Craton utilizing records of teleseismic events. 26 temporary seismic stations were deployed on territory of Lithuania and provided unique possibility to monitor and register weak local seismic events.

First of all the search of local seismic events presented in Helsinki catalogue were carried out using set of data from “Lithuanian” stations. Later continuous data registered at night time, i.e., from 9 p.m. till 3 a.m., when human activity was minimal were analyzed. All events of day time could be associated with quarry blasts or explosions of mine-clearing operations in the Baltic Sea. A few seismic events having possibly tectonic origin have been found analyzing continuous data of night time. However, poor quality of data prevented from clear identification of origin of these events.

After two earthquakes stroke Kaliningrad area in 2004 more public attention was drawn to seismic investigations in Lithuania. Ministry of Environment mediated attracting financial funds of European Union and a project “Strengthening of the institutional capacities of the geological monitoring in Lithuania” was initiated in LGS. One part of the project was dedicated to install two new brad band stations. Quite a lot of efforts were applied selecting appropriate sites of seismic stations and arranging various bureaucratic formalities. One vault of seismic station PBER was almost finished in September 2011. The new seismic stations are planed to be associated with GEOPHONE network.

Informal information about Finnish National Seismic Network and relevant issues

Pasi Lindblom

Institute of Seismology, University of Helsinki

There might be an ongoing plan to develop some present systems, to upgrade a national seismic network or to have some new plans to be carried out in the future. Where to discuss these issues with friends if not during the Nordic Meetings?

This year 2011 we have started two new stations, we do have a temporary infrasound array and also we do have plans. This presentation is a mixed salad and tries to give some hints on these issues in an informal way.

Analysis of glacial earthquakes from Greenland recorded by the POLENET/LAPNET temporary array during IPY 2007-2009

E. Kozlovskaya and POLENET/LAPNET Working Group

Monitoring of glacial earthquakes from Greenland was one of the major targets of the POLENET/LAPNET passive seismic experiment in northern Fennoscandia (northern parts of Finland, Sweden, Norway and Russian Karelia) during the IPY 2007-2009. The POLENET/LAPNET array, with the average spacing between stations of 70 km, recorded high-frequency continuous data (sampling rate from 50 to 100 sps) of 37 temporary stations, which were in operation during the time frame from 01.05.2008 to 31.09.2009, and of 21 stations of selected permanent networks in the Fennoscandia. Analysis of the POLENET/LAPNET data have shown that the array, located at regional distances from Greenland, recorded more such events than it has been recorded by the Global Seismographic Network (GSN) during the same observation period. Recordings of glacial earthquakes obtained by the array contain the long-period energy only. In many cases the events were recorded in groups within the time interval of up to 1 hour. For some of the events it was possible to recognize not only the long-period surface wave, but also the first arrival of a long-period P-wave. The waveforms of glacial seismic events recorded by the POLENET/LAPNET array can be subdivided into two major groups. The first group corresponds to classical glacial seismic events detected from the GSN data and reported in previous studies (Ekström et al, 2003, Ekström et al., 2006, Nettles and Ekström, 2010). The second group of waveforms is different from both long-period waveforms of glacial earthquakes recorded at teleseismic distances and from short-period glacial rumblings recorded at local distances. These long-period waveforms correspond to events which can be called ?glacial tremors? or ?long-period glacial rumblings?. The events were located using standard array technique. We found out that significant number of events originated from the northwestern Greenland, where recent investigation (Chen et al., 2011) showed rapid increase of ice loss rate from northwestern glaciers.
In order to explain specific features of the observed waveforms, we performed a forward modelling of propagation of waves from sources in Greenland using the spectral-element method (SEM) (c.f. Komatitsch et al. (2002), Tromp et al., 2008). We tested different source mechanisms and source time functions and compared synthetic seismograms to the waveforms recorded at different POLENET/LAPNET stations. Our results suggest that diversity of the observed waveforms can be explained by diversity of their sources. Namely, the waveforms of events from the first group correspond to single source with long duration, while specific features of waveforms of glacial tremors can be explained by interference of signals from multiple events shifted in time.

The Nordic Earthquake Researcher Network – NordQuake

P.H. Voss

Geological Survey of Denmark and Greenland – GEUS

Earthquake monitoring is today performed in all of the Nordic and Baltic countries. The technical development in earthquake monitoring has over recent years evolved to a system of real time data transmission through the Internet. These data are a key component in both earthquake research and in research training at many Nordic and Baltic universities and research institutions. Through the Nordic Earthquake Researcher Network – NordQuake, the quality of the earthquake research and research training in the Nordic and Baltic countries, will be strengthen and increased.

Cooperation, networking and joint use of research infrastructure is necessary to consolidate and develop the competence and experience that exist within the Nordic and Baltic countries. Earthquakes risk is relevant in the Nordic and Baltic countries to infrastructure such as nuclear power plants, hydrocarbon industry and nuclear waste storage. Understanding of earthquake risk overseas is also of great importance to the public and industry in the Nordic region, which has been expressed by the resent devastating earthquakes in e.g. Sumatra 2004, Haiti 2010 and Japan 2011. Earthquake risk is a key topic for NordQuake.

Furthermore, recent earthquakes such as Kaliningrad in SEP 2004 and Sweden in DEC 2008, clearly illustrate that earthquakes are not bounded by national borders and that the public does and will benefit tremendously, by a joint use of the Nordic infrastructure in this field. The Kaliningrad earthquakes were a remarkable manifestation of seismicity in an area whose seismological record is devoid of any seismicity throughout centuries. The largest earthquake was felt in all the countries surrounding the Baltic.

This network of Nordic researchers will provide a link between the researchers in Nordic and Baltic counties and the EPOS project on plate observing systems founded by the European Commission, and constitute a forum for earthquake research topic in relation the Comprehensive Nuclear-Test-Ban Treaty, a UN treaty ratified by all the countries in the Nordic region.

Earthquake engineering is an increasing business field in the Nordic and Baltic countries, NordQuake will provide information on industry with job opportunities to students in the network.

For all involved scientists this network of Nordic researchers goal is to widen their perspective in the earthquake research field, to introduce them to new scientific problems and to give them the tools and the network to solve these.

Physical approach in earthquake prediction research, and how it can be applied for useful warnings ahead of earthquakes

Ragnar Stefánsson

Council of Europe proposed in the early 80ties to perform multinational, multidisciplinary prediction research in some test areas of “Europe“. Among these areas was the South Iceland Lowland (SIL), where earthquakes of up to magnitude 7 have repeatedly caused catastrophes through historic times. The Nordic Countries took this challenge and planned earthquake prediction research in this area, called the SIL project. In light of the criticism on previous methods, often solely based on observations and statistics of phenomena, without really understanding what caused the phenomena, it was decided to go the long way, i.e. to concentrate on studying the physical processes leading up to large earthquakes.

Following guidelines were established for the SIL project, which started in 1988.

1) The fundamental requisite to predict earthquakes is to understand the physics of the processes leading to them.
2) The best way to study these processes is to retrieve information carried from depth by very small earthquakes (down to magnitude zero), expected to occur almost continuously near the plate boundary.
3) This task which could involve monitoring thousands of earthquakes per day, would require the development of new methods for automatic acquisition and automatic analysis of immense information carried by the small earthquakes.

The basis laid by the SIL project was followed up by multinational EC projects.

The main finding of 20 years of earthquake prediction research projects in the study area are:

1) Earthquakes occur at sides where they have previously occurred. They leave seismically observable scars in the crust for at least 100 years.
2) In a low-permeability crust, and in response to strain, fluids migrate upward to modify crustal conditions in ways that may gradually favor nucleation of large earthquakes.
3) Crustal processes, near and below faults of earthquakes that occurred hundreds of years ago, can be observed even decades before the sudden onset of a new large earthquake there.
4) No two earthquakes nor their preparatory processes can be assumed to be the same. We learn about an impending earthquake by observing preparatory processes at the fault, to develop constitutive relationship in real time , and then to extrapolate it into near space and n ear future.
5) Useful warnings can be issued along the way, from the time we discover the fault activity stating the location, and right up to the time of rupture.

These results put on the agenda the build-up of an earth-watch system, which continuously evaluates and models the fault process in light of the emerging physical understanding, and provides information which help to provide risk mitigating measures.

The book Advances in Earthquake Prediction, Research and Risk Mitigation, by R. Stefansson (2011) and an article in the August issue of the BSSA by Stefansson, M. Bonafede and G. Gudmundsson (2011) contain a good overview of these findings.

ABSTRACTS OF POSTERS

Volcano Anatomy

Ásdís Benediktsdóttir, Freysteinn Sigmundsson, Þóra Árnadóttir, Ólafur Guðmundsson, Sigrún Hreinsdóttir, Rikke Pedersen, Sigurlaug Hjaltadóttir, Kristín Vogfjörð, Martin Hensch, Ari Tryggvason and other members of the Volcano Anatomy group.

Volcanic eruptions present challenges for societies, but their effects can be mitigated by scientific research. In order to advance our understanding of volcanoes in general an interdisciplinary interpretation of data has to be carried out. That is the aim of a new project entitled "Volcano Anatomy", supported the by the Icelandic Research Fund, involving a large group of collaborators in Europe and USA. The aim of the volcano anatomy project is to jointly interpret seismic, geodetic and geochemical data from some of Iceland's most hazardous volcanoes, including Eyjafjallajökull, Katla, Hekla and Grímsvötn. While benefiting from the interdisciplinary cooperation from the standpoint of science we also hope to advance methods for rapid evaluation of observations that can be used in an early warning system for volcanic eruptions in Iceland.

Over the course of next three years we will use state-of-the-art techniques to attempt to reveal the "anatomy" of volcanoes. Mapping the volcano's 3-D structure, magma accumulation and intrusive activity will be some of the aspects addressed. Seismic methods will be used to constrain three dimensional velocity structure of volcanoes. The aim is to use local-earthquake tomography and ambient-seismic-noise tomography for this purpose. Results from seismic studies can be a crucial and a very useful input to the finite element modeling of the deformation field around the volcano. We will use the results from the seismic tomography to construct 3D finite element rheological models of the volcanoes. In particular, we will investigate how rheology may affect magma migration from depth, and address the apparent lack of inflation prior to the summit eruption in Eyjafjallajökull in 2010.

Overall, the Volcano Anatomy project will integrate results from geodetic observations and results obtained from seismic data, considering as well geochemical aspects, in order to better understand the ongoing complex processes within the volcanoes.

Secondary phases and irregularities in seismograms of local earthquakes in West Bohemia and Iceland

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West Bohemia/Vogtland earthquake swarm region is output of its secular geological trend, which is impressed by complex tectonic structure. Cheb basin, situated in the centre of seismically active region, originated in intersection of two main fault systems, Eger rift trending to NE and Mariánské Lázně fault zone trending to NW. More, N-S and E-W trending faults are indicated, where the main swarm area in the vicinity of Nový Kostel correspond to N-S trending fault plane. Numerous mineral springs and CO_2 vents are located at the intersection of these faults. Two Quaternary volcanoes, Komorní Hůrka and Železná Hůrka, are located in the seismoactive region.
Seismicity of West Bohemian area is monitored by 13 permanent and 10 temporal seismic stations of local WEBNET network, covering an area of about 900 km^2. Sampling frequency 250 Hz enables detailed analyses of seismograms. In addition to regular P and S phases, the seismograms display pronounced P-and S- reflected, refracted and split S waves. Some irregularities in seismic wave propagation (azimuthal dependences of P- and S-wave velocities, wave backazimuth deviations) were described. These phenomena pointed to complex geological structure and tectonics of the region.
We try to identify some similar reflections and/or irregularities in data from local Icelandic stations and compare it with WB data. First results are presented.

Using microearthquakes to track repeated magma intrusions beneath the Eyjafjallajökull stratovolcano, Iceland

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We have located microearthquakes caused by magma migration during the April–May 2010 eruption of Eyjafjallajökull stratovolcano in South Iceland using a Coalescence Microseismic Mapping technique, refined by manual picking and double-difference relative relocation. The microearthquakes extend from the upper mantle at ~30 km depth to the summit crater, on a sub-linear trend inclined ~5–10° from vertical. Spatial and temporal clustering of >5,000 events under the eastern flank of the volcano illuminates several northeast–southwest striking sub-vertical dikes at 2–6 km b.s.l., emplaced before the March 2010 Fimmvörðuháls flank eruption. The clusters at 20–30 km depth in May were directly beneath these earlier shallow intrusions, possibly indicating a common deep upwelling source for both eruptions. All microearthquakes display characteristics of brittle fracture, with several subsets of events exhibiting closely similar waveforms within clusters. This suggests similar, repetitive source processes. The deeper earthquake clusters may be caused by fracturing solidified magma plugs that form constrictions in an otherwise aseismic melt conduit. Or they may occur at exit points from melt pockets, in which case they indicate positions of magma storage at depth. The deep seismicity starts three weeks after the onset of the summit eruption, after which the largest clusters occur at progressively greater depths. This temporal pattern may result from pressure release at shallow levels in the magmatic plumbing system progressively feeding down to mobilize deeper melt pockets, or from a change in flow conditions in the conduit causing a transition from aseismic to seismogenic magma migration.

Detected and classified seismic events due to calving activity reveal seasonal variations of glacier dynamics at Kronebreen, Svalbard

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We detect and cluster waveforms of seismic signals recorded close to the calving front of Kronebreen, Svalbard, to identify glacier-induced seismic events and to investigate their relation to calving processes. Single-channel geophone data recorded over several months in 2009 and 2010 are combined with eleven days of direct visual observations of the glacier front. We apply a processing scheme which combines classical seismic event detection using a sensitive trigger algorithm and unsupervised clustering of all detected signals based on their waveform characteristics by means of Self-Organizing Maps (SOMs). We are able to distinguish between false alarms, instrumental artifacts, and three classes of signals which are, with different degrees of uncertainty, emitted by calving activity. About 10% of the directly observed calving events close to the geophone (< 1 km) can be correlated with seismic detections. By extrapolating the interpretation of seismic event classes beyond the time period of visual observations, the temporal distribution of glacier-related events shows an increase in event rate in autumn, particularly for the class which is clearly related to iceberg calving. Using the seismic event distribution in this class as a proxy for the calving rate and measurements of glacier velocity and glacier front position, we discuss the relationship between glacier dynamics and calving processes. On the seasonal time-scale, the well-marked glacier acceleration in spring is not accompanied by an increase in calving activity. With a slowdown in glacier velocity in autumn, however, a remarkable increase in calving activity is observed. The calving rate seems thus to behave rather independently from the actual glacier speed, suggesting a complex and indirect dynamical link between the two quantities.

Seismotectonic and seismic hazard maps of Lithuania – recent implication of intracratonic seismicity

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Lithuania, situated in the western part of the East European Craton, is regarded as an intracratonic area of low seismicity. Several dozens of earthquakes of intensity up to VII (MSK-64) were recorded since 1616 implying the possible occurrence of stronger earthquakes. The northern part of in the Baltic region is seismically more active than the southern, but the Kaliningrad earthquakes of 2004 showed the necessity to re-assess the seismicity of the region. The identification of seismogenic faults in the Baltic region is rather complicated due to the small scale of tectonic structures and significant errors of location of seismic events and even faults. Still, recently the seismic hazard and seismotectonic maps of Lithuania were compiled implying the highest seismic hazard of 32,6 cm/s^2 PGA in eastern and 25-30 cm/s^2 in northern Lithuania. The majority of the territory is described by PGAs of 10-20 cm/s^2.

Historical earthquakes in the Gulf of Bothnia area

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The Gulf of Bothnia has long been recognized as one area of enhanced seismicity in the Fennoscandian shield. The available seismicity record spans about three centuries. Modern instrumental observations define the background seismicity consisting of numerous micro-earthquakes, while the longer non-instrumental catalogue may be helpful in the search for rare events. Rare events mean, in particular, large earthquakes that occur far more seldom than small ones.

This study analyzes historical earthquakes in the Gulf of Bothnia area using the macroseismic method. The area is quite challenging for macroseismology, because it is crossed by sea and, for more than two centuries, also by a state border. Micro-earthquakes are not felt over very long distances, so an earthquake felt both on the eastern and western coast is noteworthy. This is a handy rule of thumb for detecting a rare event in terms of earthquake size. However, the accuracy of the historical observations is not adequate to pin down onshore and offshore events. The threshold magnitude for an earthquake to be felt on both coasts also depends on the site, because the width of the Gulf of Bothnia varies between about 80 and 350 km.

New macroseismic maps are presented for a selection of earthquakes felt on both coasts of the Gulf of Bothnia. They occurred on 27 November 1757, 14 July 1765, 28 July 1888 (*), 26 May 1907, 31 December 1908, and 9 March 1909. Many previously unknown reports of these earthquakes were brought to light, when scanning the contemporary press.

(*) published in Mäntyniemi P (2005) A tale of two earthquakes in the Gulf of Bothnia, Northern Europe in the 1880s. Geophysica 41: 73-91. Available at www.geophysica.fi

Detection of Earthquakes at the Geological Survey of Denmark and Greenland - GEUS

Rasmussen, H.P. and P.H. Voss

Geological Survey of Denmark and Greenland – GEUS

In this presentation we describe the processing and parameters that is the basics for the earthquake bulletin provided by the Geological Survey of Denmark and Greenland - GEUS.
The processing is separated in two steps:
In step one the continuous data stream is manually reviewed, in 24 hours windows, where earthquake signals are observed and selected for further analysis. The data review is based on the signals of the vertical component, using different band pass filters adjusted to the selected stations. The advantages of this method are that only a very small number of false events are selected, earthquakes that are only registered on one station are found and that it include QC. The disadvantage of this method is that it is more time consuming than automatic detection. After the manual review data is extracted from all stations in the network and associated to the observed event.
In step two the selected earthquake signals are analyses using standard procedures. For the teleseismic earthquakes arrival time of significant body waves are picked and the amplitude of the P-phase and the surface wave are measured and a location is attempted. For local earthquakes the arrival time of the P- and S-phase is picked and the amplitude of the Sg/Lg-wave is measured and the earthquake is located. In some cases the back-azimuth is determined used for single station location.
The earthquakes from the last seven days, are daily at 15UTC, extracted from the database, and after a filtering e-mailed to the ISC and other datacenters. Likewise is all phase reading e-mailed, on a weekly basis.

Seismology at the Department of Earth Science, University of Bergen

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In this poster we provide an overview of the research activities within seismology at the Dept. of Earth Science, University of Bergen. Activities include running the Norwegian National Seismic Network, studies of Norwegian seismicity, seismic and tsunami hazard assessment, seismotectonic studies and earthquake source studies.