NORSAR

# The 39th Nordic Seismology Seminar

## Holmen Fjordhotell

**June 4-6, 2008**

**Oslo, Norway**

# 39th NORDIC SEISMOLOGY SEMINAR
# Holmen Fjordhotell, Oslo
# 4-6 June 2008

## Program

## Wednesday, 4 June 2008

10:30 – 11:30: Registration and Hotel check-in

**11:30 – 12:30: Lunch**

13:00 – 13:10: Opening address

**Session 1:** **Seismic Hazard & Seismicity Studies**
Session Chair: Frode Ringdal

13:10 – 13:30: **Kuvvet Atakan**, Lars Ottemöller, Mohammad Raeesi and Jens Havskov
Two recent earthquakes: linking long-term deformation with present day seismicity and hazard

13:30 – 13:50: **Louise W Bjerrum** and Kuvvet Atakan
Scenario based ground motion simulations using refined slip models for Izmir and Tuzla faults in Izmir, Turkey

13:50 – 14:10: **Dominik H. Lang**, Sergio Molina, Conrad Lindholm, and Vladimir Gutierrez
The seismic risk and loss assessment tool SELENA – Recent developments and applications

14:10 – 14:30: Mathilde B. Sørensen and **Kuvvet Atakan**
Continued earthquake hazard in Northern Sumatra

14:30 – 14:50: **Gunnar B. Guðmundsson**, Steinunn S. Jakobsdóttir, Matthew J. Roberts, Halldór Geirsson and Ragnar Slunga
Seismic activity near Mt. Upptyppingar, North Iceland. Likely a magma intruding deep in the crust

**14:50 – 15:20: Coffee break**

**Session 2:** **Seismicity Studies**
Session Chair: Heidi Soosalu

15:20 – 15:40: **Björn Lund**, E. Karlsson, P. Erlendsson, C. Juhlin, A. Dehghannejad, R. Bödvarsson, T. Kvaerna and M. Uski
The Pärvie project: Background and current status

15:40 – 16:00: Mathilde B. Sørensen, **Peter Voss**, Jens Havskov, Søren Gregersen and Kuvvet Atakan
Seismotectonics of Skagerrak

16:00 – 16:20: **Andrius Pačėsa**
Recent seismology related developments in Lithuania

16:20 – 16:40: **V. E. Asming**
Anomalies of recordings of strong Spitsbergen earthquakes

16:40 – 17:00: **Myrto Pirli**, Johannes Schweitzer, Berit Paulsen and Tormod Kværna
Preliminary analysis of the Storfjorden, Svalbard, 21st February 2008 earthquake and its aftershock sequence

**18:00** **Dinner**

## Thursday, 5 June 2008

**07.00 – 08.30** **Breakfast**

08:30 – 08:35: Administrative remarks

**Session 3:** **Seismic Networks & Seismicity Studies**
Session Chair: Ragnar Stefansson

08:35 – 08:55: **Reynir Bödvarsson**, Pálmi Erlendsson, Björn Lund, Hossein Shomali and Ari Tryggvason
Swedish National Seismic Network (SNSN) today and tomorrow

08:55 – 09:15: **Jens Havskov** and Jan Fyen
New Norwegian National Seismic Network

09:15 – 09:35: **Jari Kortström** and Marja Uski
Automatic Location of Regional Events with Sparse Seismic Network

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|---|---|
| 09.35 – 10.00: | **Dmitry Storchak** *(Invited)*<br>ISC: Interaction in Nordic Region & Further Development Plans |
| **10:00 – 10:20:** | **Coffee break** |
| **Session 4:**<br>Session Chair: | **Seismic Networks & Event Location**<br>Kuvvet Atakan |
| 10:20 – 10:40: | **Torild van Eck** and Remy Bossu *(Invited)*<br>ORFEUS, EMSC and NERIES: Coordinating European data exchange and Archiving |
| 10:40 – 11:00: | **B. Assinovskaya**, V. Karpinsky V., T. Manshina T., H. Goldfain H. and A. Popov<br>2006-2008 Ladoga instrumental seismic events |
| 11:40 – 11:20: | **M. Roth** and J. Fyen<br>Status of the NORSAR network |
| 11:20 – 11:40 | Short (5 min) presentations of Posters:<br><br>P. Wiejacz and **W. Debski**<br>Current Functioning of the Polish Seismological Network<br><br>**Marja Uski**, Timo Tiira, Marek Grad and Jukka Yliniemi<br>Crustal velocity models and Moho map for the Kainuu-Peräpohjola region in Finland<br><br>Valery Nikulin, **H. Soosalu**, M. Uski, A. Pacesa<br>Testing the location and discrimination capability of Nordic-Baltic virtual seismic network in the Baltic region<br><br>**Volker Oye** and W. Ellsworth<br>Monitoring Microearthquakes with the San Andreas Fault Observatory at Depth |
| **11:40 – 12:30:** | **Lunch** |
| **Session 5:**<br>Session Chair: | **CTBT & Seismic Networks**<br>Peter Voss |
| 13:00 – 13:20: | **Svein Mykkeltveit**<br>Status of implementation of the verification regime of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) |

13:20 – 13:40: **Pasi Lindblom**
Data and data quality Operators' responsibilities in producing good data

13:40 – 14:00: **Y.A. Vinogradov** and Z.A. Yevtyugina
The application of infrasound monitoring for registration of powerful explosions at long-distances.

14:00 – 14:20: **Ingvar Nedgård**
Monitoring seismic events in Iran reported in the SSEB-bulletin from the International Data Centre

14:20 – 14:40: **Cecilia During**, Per Andersson, Nils-Olov Bergkvist, Ingvar Nedgård, Leif Persson, Anders Ringbom, Torbjörn Ståhlsten and Peter Jansson
A New Information System for NDC Purposes

14:40 – 15:00: **Heidi Soosalu**, Marja Uski and Jari Kortström
Joint Finnish-Estonian Seismic Analysis of Quarry Blasts in NE Estonia

**15:00 – 15:20: Coffee break**

**Session 6: Microseismicity & Structural Investigations**
Session Chair: Pasi Lindblom

15:20 – 15:40: **Wojciech Debski**
Mining induced seismicity in Poland

15:40 – 16:00: **Antti Lakio** and Jouni Saari
Orientation of Triaxial Borehole Sensor

16:00 – 16:20: **Daniela Kühn**, Hom Nath Gharti, Volker Oye and Michael Roth
Automatic determination of focal mechanisms from P-wave first-motions applied to mining-induced seismicity

16:20 – 16:40: Christian Weidle and **Valerie Maupin**
An upper mantle S-wave velocity model for Northern Europe from surface wave group velocities

16:40 – 17:00: **Mohammad Raeesi,** Jens Havskov, and Kuvvet Atakan
The Mid Atlantic Ridge, a look through global travel-time tomography

**18:00 Dinner**

## Friday, 6 June 2008

**07.00 – 08.30** **Breakfast**

08:30 – 08:40: Administrative remarks

**Session 7:** **Seismicity Studies, Structural Investigations & Seismic Networks**
Session Chair: Björn Lund

08:40 – 09:00 **H. Bungum**, J. I. Faleide, F. Pettenati, J. Schweitzer and L. Sirovich
The M 5.4 October 23, 1904, Oslofjord earthquake: Reanalysis based on instrumental and macroseismic data

09:00 – 09:20: **Peter Voss**
Improvements to the processing of earthquake data recorded with the seismological network in Denmark and Greenland

09:20 – 09:40: **J. Schweitzer** and the IPY Project Consortium
The IPY Project "The Dynamic Continental Margin Between the Mid-Atlantic-Ridge System (Mohns Ridge, Knipovich Ridge) and the Bear Island Region"

09:40 – 10:00: Mohammad Raeesi and **Kuvvet Atakan**
A snapshot on the subduction zone processes along the Kurile-arc

**10:00 – 10:20: Coffee break**

**Session 8:** **Earthquake Prediction & Data Processing**
Session Chair: Johannes Schweitzer

10:20 – 10:50: **Ragnar Stefansson** *(Invited)*
Significant results of 20 years of earthquake prediction research projects of the Nordic countries and Europe, and export of the results to other parts of the world

10:50 – 11:10: **Hossein Shomali**, Reynir, Bödvarsson, Björn Lund and Ari Tryggvason
An Application of "energy-duration" method for fast-estimate of earthquake magnitude using Swedish National Seismological Network (SNSN)

11:10 – 11:30: **Steven J. Gibbons**, Frode Ringdal and Tormod Kværna
Detection and characterisation of seismic phases using continuous spectral estimation on incoherent and partially coherent arrays

11:30 – 11:40: **Closing Remarks**

## List of participants

| | | Affiliation | Country |
|---|---|---|---|
| | | | |
| Asming | Vladimir | Kola Regional Seismological Centre | Russia |
| Assinovskaya | Bela | Central Astronomical Observatory of Pulkovo | Russia |
| Atakan | Kuvvet | University of Bergen | Norway |
| Bjerrum | Louise | University of Bergen | Norway |
| Bungum | Hilmar | NORSAR | Norway |
| Bödvarsson | Reynir | Uppsala University | Sweden |
| Dahle | Anders | NORSAR | Norway |
| Debski | Wojciech | Polish Academy of Sciences | Poland |
| During | Cecilia | FOI | Sweden |
| Franssila | Maija | University of Helsinki | Finland |
| Fyen | Jan | NORSAR | Norway |
| Galiana-Merino | Juan J. | University of Alicante | Spain |
| Gharti | Hom Nath | NORSAR | Norway |
| Gibbons | Steven | NORSAR | Norway |
| Guðmundsson | Gunnar B. | Icelandic Meteorological Office | Iceland |
| Havskov | Jens | University of Bergen | Norway |
| Johnsen | Helge | University of Bergen | Norway |
| Kjærgaard | Anne Lise | University of Bergen | Norway |
| Kortström | Jari | University of Helsinki | Finland |
| Kühn | Daniela | NORSAR | Norway |
| Kværna | Tormod | NORSAR | Norway |
| Lakio | Antti | Åf-Consult | Finland |
| Lang | Dominik | NORSAR | Norway |
| Lindblom | Pasi | University of Helsinki | Finland |
| Lindholm | Conrad | NORSAR | Norway |
| Lund | Bjørn | Uppsala University | Sweden |
| Maupin | Valerie | University of Oslo | Norway |
| Mahajan | A. K. | Wadia Inst. of Himalayan Geology | India |
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| Pirli | Myrto | NORSAR | Norway |
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|---|---|---|---|
| Schøyen | Turid | NORSAR | Norway |
| Shomali | Hossein | Uppsala University | Sweden |
| Soosalu | Heidi | Latvian Environment, Geology and Meteorology Agency | Latvia |
| Stefansson | Ragnar | University of Akureyri | Iceland |
| Storchak | Dimitry | International Seismological Centre | Great Britain |
| Storheim | Berit Marie | University of Bergen | Norway |
| Uski | Marja | University of Helsinki | Finland |
| van Eck | Torild | ORFEUS | Netherlands |
| Vinogradov | Yuri A. | Kola Regional Seismological Centre | Russia |
| Voss | Peter | Geological Survey of Denmark and Greenland | Danmark |

## Two recent earthquakes: linking long-term deformation with present day seismicity and hazard

**Kuvvet Atakan**[1], Lars Ottemöller[2], Mohammad Raeesi[1], and Jens Havskov[1]

[1] Department of Earth Science, University of Bergen, Allégaten 41, N-5007 Bergen, Norway
[2] British Geological Survey, Edinburgh, UK

Two recent earthquakes occurred in two separate and very different tectonic settings. The earthquake in Svalbard (21 February 2008, M=6.2) occurred offshore between the southeastern coast of Spitsbergen and Edgeøya along a passive margin tectonic setting. The earthquake in China (12 May 2008, M=7.9) on the other hand, occurred in an intraplate setting at the eastern termination of an actively deforming Tibetan plateau. Both earthquakes represent rare but significant events linking long-term deformation with present day seismicity and hazard.

The Svalbard earthquake had an oblique-normal focal mechanism with one of the nodal planes oriented almost E-W and the other oriented NW-SE directions. None of the nodal planes fit with the orientation of the major structure in the region, Billefjord fault zone, which trends N-S to NNW-SSE. The location of the earthquake is approximately 50 km SSE of another earthquake sequence that was previously known in the Heer Land zone. Along the southern part of the Storfjorden a pronounced seismic activity was observed during the period 1993 to 1999 with its peak around 1996-1997. In order to understand the true seismic potential of Svalbard region, future studies should focus on linking the long term deformation along the active faults and the temporally intensified earthquake activities.

The Sichuan earthquake had a reverse mechanism with a minor right-lateral strike slip component in line with the NW-SE oriented maximum horizontal compression axis deduced from the GPS data. The source of compression along the Longmen Shan fold and thrust belt is probably related to the resistance of the South China block (Yangtze Craton) to the easterly expansion of the Tibetan plateau across the Sichuan basin. The earthquake ruptured along a 250 km long thrust fault oriented NE-SW dipping gently (33o) to the NW. The preliminary results from the slip inversion shows two major asperities along the fault with maximum slip reaching 9m which extends 20 km in down-dip direction. This earthquake manifests the activity along the Longmen Shan fold and thrust belt and probably marks the eastern termination and arrest of major strike slip systems in Tibet such as the Kunlun, Ganshu, Haiyuan and Xianshuihe fault zones.

## Scenario based ground motion simulations using refined slip models for Izmir and Tuzla faults in Izmir, Turkey

**Louise W Bjerrum** and Kuvvet Atakan
Department of Earth Science, University of Bergen, Allegaten 41, N-5007 Bergen, Norway

Collision of the Arabian and African plates with Eurasia forces the Anatolian micro-plate to move west-ward. In the Aegean Sea, the Anatolian micro-plate rotates counter-clockwise and extends due to the subduction zone along the Hellenic Arc. This deformation results in reactivation of faults on the west coast of Turkey, which results in destructive earthquakes. İzmir, the third largest city in Turkey, has been destroyed by (large) earthquakes several times in recent history, latest in 1778. Our previous ground motion simulations show that the İzmir fault (normal) which lies under the city and the Tuzla fault (strike-slip) southwest of the city pose the largest threat to İzmir, when compared to ruptures on other faults in the vicinity of the city. In this study we compare the ground motion distribution obtained by using a complex fault rupture based on a refined slip model, using information from previous ruptures as the Borah Peak, Idaho (normal) and Kobe, Japan (strike-slip) events. The method adopted is a hybrid broadband frequency ground motion simulation technique, which has previously been validated. The earthquake scenarios are based on existing knowledge about source parameters, local as well as regional. The earthquake rupture scenarios on the faults are found to produce peak ground acceleration values in the centre of İzmir of up to 335 $cm/s^2$ and 225 $cm/s^2$, on bedrock level, for İzmir and Tuzla faults respectively.

# The seismic risk and loss assessment tool SELENA – Recent developments and applications

***Dominik H. Lang**, Sergio Molina, Conrad Lindholm, and Vladimir Gutierrez*

The single most comprehensive work towards earthquake risk calculation until today is condensed in HAZUS, a software system which was prepared by the Federal Emergency Management Agency (FEMA) for use in the United States. The basic approach behind this software is physical-analytical (and hybrid), and large resources had been used to define both capacity and fragility (vulnerability) curves for different building types and levels of design categories. From an engineering perspective this analytical approach is very attractive, however, it quickly becomes complex even for simple buildings, and a calibration to the damage records of historical earthquake events is necessary. Since HAZUS was originally developed to be only applied to U.S. conditions, NORSAR has developed a comparable stand-alone software that can be applied anywhere in the world, and which includes a logic tree-based weighting of input parameters that allows for the computation of confidence intervals. The open-source software package is called SELENA – Seismic Loss Estimation using a Logic Tree Approach.

The SELENA approach is based on the 'capacity-spectrum method' (similar to HAZUS), an iterative procedure to determine the permanent horizontal displacement of a particular building type under a given seismic excitation while accounting for nonlinear effects during the damaging process. The lateral deflection behaviour of the building is represented by its specific capacity curve while the ground-motion input is provided in terms of a response spectrum in spectral acceleration-spectral displacement domain. Vulnerability curves which are developed as lognormal probability distributions from the building capacity curves are used in order to derive damage probabilities for the different building types. By superimposing these results with the building inventory data, absolute numbers of damaged buildings or damage building area can be computed. The damages to the physical environment can then be converted to monetary losses as well as to estimates of casualties (injuries and deaths) using empirical relations.

Output files on the level of minimum geographical units are given in tabular form which can be imported by any appropriate mapping software. Recently, a stand-alone software tool has been developed called *RISe* (Risk Illustrator for SELENA) which allows a quick and easy illustration of the geo-referenced input, inventory and output files of SELENA in Google Earth and will thus substitute the use of any commercial GIS program while additionally providing the user to place satellite images of the building stock underneath his risk and loss results.

# Continued earthquake hazard in Northern Sumatra

Mathilde B. Sørensen[1] and **Kuvvet Atakan**[2]

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The occurrence of two large earthquakes ($M_w$=8.4 and $M_w$=7.9) along the Sumatran west coast on 12. September 2007 has again put the high earthquake hazard of this region into focus. These events were the last in a series of major subduction zone earthquakes starting with the great $M_w$=9.3 event of 26 December 2004 followed by an $M_w$=8.7 event on 28 March 2005. The major subduction zone earthquakes have been propagating southwards along the Sunda trench, and currently the remaining stress is expected to be released along the subduction zone in a long stretch from the Andaman Sea in the north to the southernmost extension of the recent ruptures, especially the southernmost part close to the Sunda Strait. However, there is an additional and significant hazard due to potential earthquakes along the Great Sumatran Fault (GSF), a major right-lateral strike-slip fault parallel to the western coast of Sumatra. The GSF accommodates the trench parallel component of plate convergence where strain partitioning is a result of the oblique collision along the Sunda trench. There has been no significant earthquake during the last two centuries along the northern part of the GSF, which is considered a seismic gap. Furthermore, the occurrence of subduction earthquakes along the Sunda trench has brought the structure closer to rupture. The GSF is assumed to be capable of producing earthquakes with magnitudes up to M=7.9, the largest known event occurred in 1892 with M=7.7 near Sibolga. It is therefore urgent that the seismic hazard in Banda Aceh and its surroundings be re-evaluated in the light of the recent earthquakes. Rupture along the northernmost segment of the GSF is used as a future scenario and the distribution of ground motion is computed based on a hybrid broad-band simulation method. Results indicate that the occurrence of an $M_w$=7.7 event with rupture propagating towards Banda Aceh will have severe consequences for the region. Furthermore, it is emphasized that also smaller earthquakes can cause widespread damage in the region, especially considering possible amplification effects due to local geological conditions.

# Seismic activity near Mt. Upptyppingar, North Iceland. Likely a magma intruding deep in the crust.

**Gunnar B. Guðmundsson**, Steinunn S. Jakobsdóttir, Matthew J. Roberts, Halldór Geirsson and Ragnar Slunga

Since February 2007, anomalous swarms of tectonic earthquakes have been detected near to Mt. Upptyppingar, which forms part of the Kverkfjöll volcano system, extending from the northern flank of the Vatnajökull ice cap. From February to September 2007, clusters of earthquakes were located close to Mt. Upptyppingar but in the autumn the earthquake swarms migrated north-eastward to the Álftadalsdyngja lava shield, where intense swarms occured in December 2007 and also in February and March 2008. Over 9000 earthquakes have been located in these swarms. Using results from the SIL seismic network, we summarise the spatial and temporal changes in ongoing seismicity that began in 2007. The Upptyppingar-Álftadalsdyngja earthquakes concentrate at focal depths ranging from 10 to 20 km and the swarms are dominated by earthquakes < 1 in magnitude with only a few events reaching magnitude 2.

A high b-value of 2.1 characterizes the area. Each swarm has been confined to a small surface area and focal depths have lessened with time.

Spatially,

different parts of the affected region have exhibited seismicity at different times, with swarm sites alternating between distinct areas. Few earthquakes have been detected at shallow depths within the zone of unrest.

A likely reason for the sustained clustering of earthquakes near to Upptyppingar is inflow of magma into the base of the crust. This interpretation is further supported by continuous GPS observations south and southeast of the area showing ongoing deformation that is likely to be caused by magma movements.

# The Pärvie project: Background and current status

**B. Lund**[1], E. Karlsson[1], P. Erlendsson[1], C. Juhlin[1], A. Dehghannejad[1], R. Bödvarsson[1], T. Kvaerna[2], M. Uski[3]

1) Department of Earth Sciences, Uppsala University
2) Norsar
3) Institute of Seismology, University of Helsinki

The Pärvie project, or more correctly "Natural and controlled source seismic studies of end-glacial faults in northern Sweden", is a Swedish Research Council sponsored project to study the end-glacial faults of northern Sweden in general, and the Pärvie fault in particular. The project has participants from Sweden, Norway, Finland and Canada. During the summer of 2007, seven temporary seismic stations were installed along the Pärvie fault. The sensors are Guralp 3ESP-Compact, with frequency range 60 s to 100 Hz, recording at 100 Hz sampling rate. Four of the stations have mobile phone contact with Uppsala and the data is retreived in real-time. The remaining three stations are very remote and record to disk. In September of 2007 a 20 km long seismic reflection profile was acquired across the Pärvie fault. Here we will present the background for the project, the objectives we hope to meet, some of the difficulties encountered and the current status.

## Seismotectonics of Skagerrak

Mathilde B. Sørensen[1], **Peter Voss[2]**, Jens Havskov[3], Søren Gregersen[2], Kuvvet Atakan[3]
[1]GeoForschungsZentrum Potsdam, Section 5.3, Potsdam, Germany
[2]Geological Survey of Denmark and Greenland, Copenhagen, Denmark
[3]Department of Earth Science, University of Bergen, Bergen, Norway

The seismotectonics of the western Skagerrak Sea between Norway and Denmark has been associated with large uncertainties in earthquake locations due to the offshore location on the border between two seismic networks. Recently, the Danish earthquake catalogue has been updated and data from the Norwegian National Seismic Network have been systematically included in the database to increase location accuracy in the border regions significantly. Furthermore, the Norwegian station SNART, in operation since 2003, provides high-quality recordings at a short distance to the earthquake epicentres in Skagerrak, which further improves locations. In the current study, the Skagerrak seismicity has been relocated for the improved dataset. The best-recorded events have been studied in detail to constrain depths in the region at 15-20 km, and new focal mechanisms have been derived. The obtained focal mechanisms are in agreement with the regional stress orientation with maximum horizontal compression in the NW-SE direction. The seismicity seems to follow a N-S orientation which indicates activity on existing fault structures in the Skagerrak Sea. Additionally, some activity seems to be associated with the Sorgenfrei-Tornquist Zone. An interesting finding is that the spatial distribution of earthquake epicentres in the Skagerrak region seems to be time dependent.

# Recent seismology related developments in Lithuania

**A.Pačėsa**, Lithuanian Geological Survey, andrius.pacesa@lgt.lt

Eastern Baltic region and particularly a territory of Lithuania feature very low seismic activity. Therefore, not much attention was paid to seismological investigation in the past. Two moderate earthquakes with epicentres in Kaliningrad enclave, neighbouring to Lithuania, induced public and governmental concern of seismicity of Lithuania. A program of Evaluation of Seismic Conditions of Lithuania was adopted by the government. Beside other items, the program foresaw installation of two new seismic stations associated with GEOFON program. Quite a lot of efforts has been dedicated to find appropriate sites for new seismic stations and to prepare required documentation.

A small seismic network made of four seismic stations was installed around Ignalina Nuclear Power Plant (INPP) in 1999. The seismic system was designed to issue early warning signal in case a strong seismic wave was approaching the INPP and to monitor local seismicity. Unfortunately, number of imperfections of seismic system of INPP has been revealed during its operation. A project of modernization of the Seismic System of INPP was initiated a few years ago. Some original equipment have been replaced with the new one and some optimization has been performed and the project of modernization is close to it's finish currently.

## Anomalies of recordings of strong Spitsbergen earthquakes

**Asming V.E.**, Kola regional seismological centre, Apatity, Russia.

Several years ago we noticed that recordings of many earthquakes occurred in Spitsbergen area have some specific features. For most strong of them one can see first weak arrivals of P-waves. (We even introduced a conventional term 'nose'). Such arrivals can bee seen for S-waves sometimes but rather rarely. We observed many such events in North-East Land and several ones in the rift zone to the West.

Location of earthquakes which recordings have weak first P arrivals but have no same S is often inconsistent. We suspected that the first S arrivals for these events are masked by coda of P waves. If we compute such first arrivals analogous to P and use for location we obtain much more consistent results.

Two strong earthquakes occurred to the South from Svalbard are good examples of location difficulties due to the 'noses'. The earthquake 21/02/2008 2.46:21, coordinates 77.26N, 19.00E (our estimation) had a magnitude 5.9 (NORSAR). It was so strong that almost all recording at Spitsbergen array (SPI, distance 120 km) appeared to be out of scale excluding the very beginning of P arrival. At Kingsbay station (KBS, 246 km) the earthquake was well recorded with clearly seen P 'nose'. But there is no 'nose' at SPI. Attempts to locate the event by first arrivals were inconsistent. P-P line in location map was not in agreement with SPI array backazimuth estimation. We obtain the best agreement when associated first P at SPI with the second (ignoring the 'nose') P at KBS supposing that both these arrivals were Pg. Thus we have to conclude that there might be something that damping body waves probably at depths near Conrad border.

The earthquake 04/07/2003 7.16:54, coordinates 76.39N, 21.48E was more distant from KBS (361 km) and SPI (235 km). Its magnitude by NORSAR was 5.06. For the event there are 'noses' at both stations and again the location appeared to be the most self-consistent when we used second onsets (Pg and Sg).

Both these earthquakes were followed by numerous aftershocks (112 events with magnitudes 2-3.9 for 21/02/2008 earthquake). Near the same number of aftershocks were registered after the first earthquake. Recordings of some of them have specific 'noses' and some of them not. It requires careful study. It is also interesting to compare amplitudes of recordings for these two earthquakes. Magnitude of the first one was 5.06 and 5.9 for the second one. It is clearly seen by near stations recordings (SPI and KBS) that indeed the second event was much stronger and amplitudes of its recordings are about an order of magnitude greater.

But very different ratios of amplitudes were observed at ARCES (distances 772 and 881 km) and Apatity array (1048 and 1163 km). Amplitudes at ARCES were about the same, even greater for the first event. And at Apatity the second amplitude was about 1.5 times greater than the first one. This is strange and could indicate some inhomogeneity of wave conducting medium or existence of some damping objects.

# Preliminary analysis of the Storfjorden, Svalbard, 21st February 2008 earthquake and its aftershock sequence.

Myrto Pirli, Johannes Schweitzer, Berit Paulsen and Tormod Kværna

The broader area of the Svalbard Archipelago is located at the northwestern boundary of the Barents Sea continental platform, in the vicinity of passive continental margins. The largest volume of seismicity in the Svalbard area is directly associated with these major geodynamic structures, there is however a significant amount of intraplate seismicity that appears to be mainly concentrated in the areas of West Spitsbergen near Isfjorden, Heer Land, Storfjorden and Nordaustlandet. Significant seismicity is also observed in the offshore area between Bjørnøya and Hopen Island.

A strong earthquake of regional network magnitude M = 5.9 (mb = 5.9, NEIC) occurred in the offshore area of Storfjorden, on 21st February 2008. The hypocentre is located W of Torell Land, Spitsbergen, approximately 40 km from the shore, at a depth of approximately 15 km. The centroid moment tensor solution, as determined by Harvard, reveals oblique normal faulting with nodal planes trending E-W and NW-SE, and a moment magnitude of Mw = 6.1.

The mainshock was followed by a vast number of aftershocks. Station readings, epicentre parameters and local magnitude values have been reviewed for more than 200 events which have been included in the NORSAR Regional Reviewed Bulletin. Despite the potential for occurrence of larger aftershocks, magnitudes within the first 80 days have been limited to moderate/low levels. A preliminary attempt was made to investigate the temporal distribution of the aftershock occurrence frequency, by employing non-reviewed and automatic results. However, no clear associations could be made between larger changes in daily seismicity rates and the occurrence of larger aftershocks. Regarding the spatial distribution of the aftershock sequence, as represented by the reviewed location results, events appear to be distributed in a general N-S trend, exhibiting high scatter, well away from hypothesized extensions of known active faults and major bathymetry features. An absence of larger aftershocks is observed in the immediate vicinity of the mainshock, while most of the largest events are located in the outskirts of the aftershock area.

Several points for discussion are arising from the observations mentioned above. These mainly concern the temporal evolution of the aftershock sequence and the geometry of the activated fault(s). In order to answer these questions, further research will be conducted, initially focusing on an accurate relocation that can provide insight to the mechanisms controlling this sequence.

## Swedish National Seismic Network (SNSN) today and tomorrow

**Reynir Bödvarsson***, Pálmi Erlendsson, Björn Lund, Hossein Shomali and Ari Tryggvason

The Swedish National Seismic Network (SNSN) now consists of 60 broad-band high-gain seismological stations. More than half of the stations are transmitting data to Uppsala in real-time and the remaining stations will be put on-line before the end of this year.
Until now, the network has mainly been used to locate local earthquakes and evaluation of their source parameters but in the future the network will also be used for location and magnitude estimation of regional and global earthquakes. In this talk we will give an overview of the present status of the network and discuss the ongoing and future development of the SNSN.

## New Norwegian National Seismic Network

**Jens Havskov**, University of Bergen and Jan Fyen, NORSAR

The Norwegian National Seismic Network (NNSN) has entered a new period in its life by the conclusion of a new 5 year contract with Norwegian Oil Industry Association (OLF).
The aim of the contract is to present a comprehensive bulletin to OLF of all events with a magnitude above 2.0 for the purpose of Norwegian offshore risk analysis.

The network will be completely restructured to become a real time network of stations located in Norway and may also benefit from cooperation with surrounding countries by inclusion of real-time data from participating stations in order to improve locations of events in Norway.

The NNSN upgrade will initially consist of:

- Seedlink server at each existing station
- 6 new broad band stations in the south and in the north of Norway
- Inclusion of real time SeedLink stations from all NORSAR arrays and stations
- Inclusion of real time data from 10 stations in UK, Finland and Denmark
- Inclusion of relevant data from ORFEUS
- Inclusion of automatic NORSAR array solutions
- Triggering with EarthWorm
- Storage of all data (real time and events) with public access

Improved monitoring of the earthquake activity in the offshore areas adjacent to Norway will be a high priority for the NNSN, combined with a good capability to detect and locate onshore earthquakes in the region.

All data will be integrated in a SEISAN system at the University of Bergen (UiB) and both automatic and manual solutions will be made. UiB and NORSAR will jointly be doing routine work on the new system, which will be used by both institutions for providing information to the public about Norwegian earthquakes. NORSAR will further develop new routines for better automatic integration of real time network and array data in order to make a new improved real time automatic detections and locations to be used by NNSN.

Currently the new system is being tested with 16 stations from Norway and 8 from surrounding countries.

Once completed, the NNSN (including the NORSAR arrays) will consist of about 40 stations, and through cooperative agreements with neighbouring countries as many as 50 stations may be included in the final bulletin production.

The event locations and the phase readings from the new NNSN will, as before, be forwarded to the University of Helsinki for inclusion in the common Nordic bulletin.

## Automatic Location of Regional Events with Sparse Seismic Network

**Jari Kortström** and Marja Uski, Institute of Seismology, University of Helsinki.

In recent years the number of seismic stations in Finland has increased and almost all of them are now equipped with internet data connection. Instrumentation has also improved. The permanent network is now based on STS2 BB sensors and sensitive 24 bit digitizers. The station network covers the whole country but is still quite sparse in some areas.

### Automatic Event Processing

New system for automatic data processing was taken into use in 2007. It utilizes the whole station network by combining all accessible real time data, both parametric and waveform, to produce automatic bulletin of regional events in Finland and adjacent areas. The idea of automatic processing scheme is shown in Figure 1.

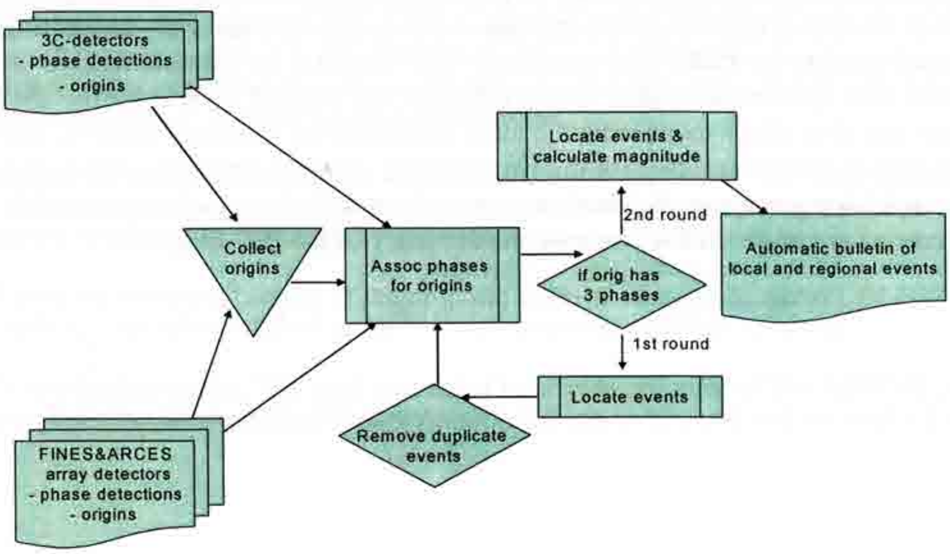


Figure 1.

### Location Capability of Automatic System

The use of 3-C stations improves the location accuracy compared to sole array locations. The location capability was tested at the Siilinjärvi mine which is in central Finland and inside the station network. Distance to the FINES array is 110 km and to the closest 3-C stations SUF 89 km. Magnitudes of the events vary between 1.0 and 1.8. Average distance of the array locations to the midpoint of the mining area is 23 km. With use of the whole net the average distance of locations improves to 8 km.

# ISC: INTERACTION IN NORDIC REGION & FURTHER DEVELOPMENT PLANS

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The International Seismological Centre (ISC) is a non-governmental, non-profit making organization supported by 55 research and operational institutions around the world and charged with production of the ISC Bulletin – the definitive summary of world seismicity based on seismic reports from over 120 institutions. The ISC also runs the International Seismic Station Registry (IR) jointly with NEIC. The ISC is well supported in the Nordic region with bulletin data and monetary contributions from a good number of institutions and networks in Denmark, Finland, Iceland, Lithuania, Norway, Russia & Sweden.

The ISC has a substantial development programme that would ensure that the ISC data will remain an important requirement for geophysicists. This programme includes bringing the ISC edited Bulletin schedule to approximately 15-18 months behind real-time as well as starting collection of provisional reports to make our automatic ISC Bulletin as comprehensive as possible before the final data become available to the ISC and the manual review by the ISC analysts begins. There are also plans to introduce a new International Seismic Network and Station Registry in the ISC operations, modernise the way the ISC computes its hypocentres and magnitudes and to attempt taking some useful measurements from waveforms widely available on-line. These measurements are to be used to improve the accuracy of the ISC Bulletin.

# ORFEUS, EMSC and NERIES: Coordinating European data exchange and archiving

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3) NERIES, Network of Research Infrastructure for European Seismology

NERIES, a European Research Infrastructure project sponsored by the EC aims at creating the core of a European earthquake research data infrastructure. The project is coordinated by ORFEUS in close collaboration with the EMSC and aims at ambitious and challenging developments to facilitate data exchange within Europe and interactive data access through one access point. Main components are the public availability broadband and acceleration waveform data and earthquake and acceleration parameter data (see Figure 1). We will present some major activities and accomplishments.

ORFEUS and EMSC are crucial organization, recognized in the EC and the European community, and powerful mechanisms in realizing coordination of earthquake data exchange in Europe. The tasks are well defined in that the EMSC handles the coordination of parameter data, while ORFEUS coordinates the waveform data exchange and archiving in Europe and its immediate surroundings. Through NERIES both organizations are going through significant developments. We will highlight the current status at both organizations, i.e. its (web) services and activities.

We will also put the European coordination in the context of the International Federation of Digital Seismograph Networks (FDSN) For example the European Integrated waveform Data Archive (EIDA) an activity within is also effectively the regional (European) FDSN archive.

Finally we provide a glimpse of the on-going strategy discussions within ORFEUS, EMSC and a broader earth science community in Europe of the situation after 2010 and beyond.

**Acknowledgements:** The work presented here is a joint effort of the ORFEUS participants, the EMSC members, the Seismological Observatories in Europe and around and the NERIES consortium.

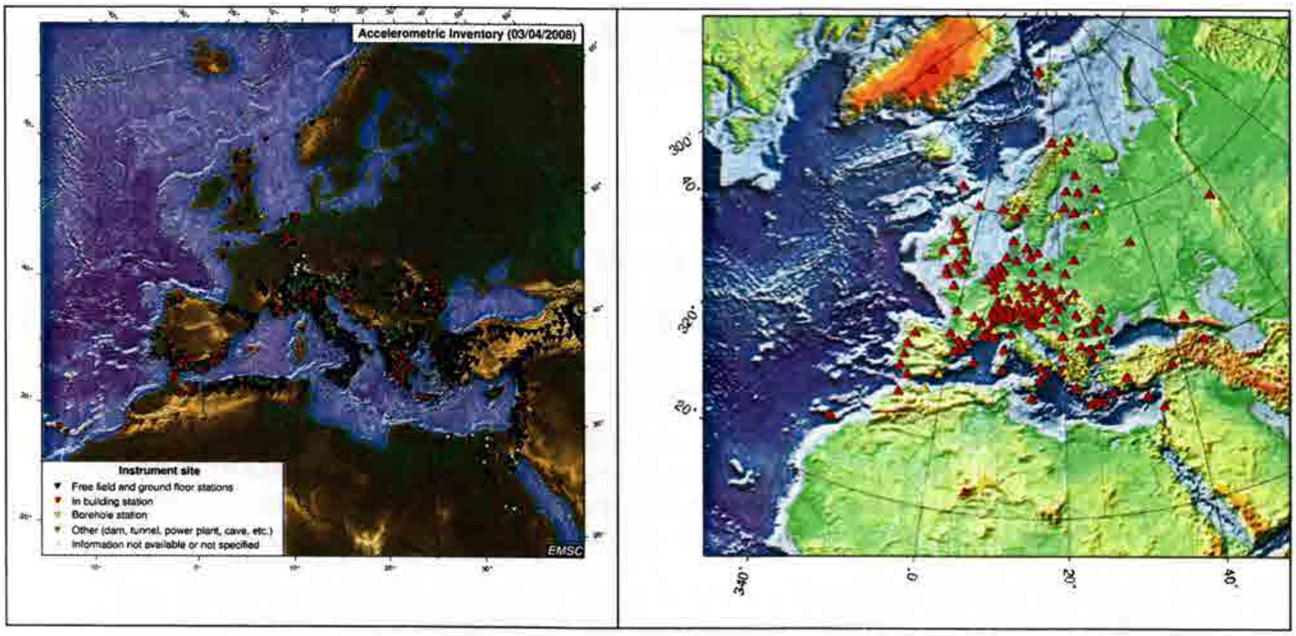


***Figure 1a** (left). Some of the major existing acceleration networks and their stations as compiled by the EMSC **Figure 1b** (right). The VEBSN status as of March 1, 2008 in which more then 270 stations provide near real-time data to the Integrated European Data Archive*

# 2006-2008 Ladoga instrumental seismic events

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The results of two-year permanent seismic registration on Valamo are introduced. The short period seismic station was installed on the southwestern coast of the island close to local weather station in 2006. The seismic equipments were placed in an underground bunker.
The data analysis shows that there are three types of seismic events in spite of well known quarry explosions. As a preliminary all data can be divided on three groups.
The first of them consists of numerous but very simple impulse events of 0.3-0.5 sec duration in a frequency range of 4-17 Hz. As a rule local event features aren't similar to earthquake waveform. The events of this group are widely distributed during fixed time intervals. Their appearance has no connection with man-made activity because they are observed day and night. The polarization analysis points to Rg and Lg surface wave's predominance. It is shown that meteorological processes are responsible for these events origin. Their occurrences are regulated by cyclones passing. Two hypotheses are offered to explain these phenomena.
The second group has an obvious ice origin because it was registered in February-March 2007 only when Ladoga was covered with faulted ice. For example, in February 22-24 2007 more 500 events occurred. The numerous events of this group often look like surface earthquakes with typical rock seismic wave apparent velocities.
The third group is a few felt shallow events probably occurred due to deformation processes on the Ladoga bottom.
This year field seismic network observation will help to determine the true seismicity origin of the Ladoga lake.

## Status of the NORSAR network

**M. Roth**, J. Fyen

We will give an update on the current network of arrays and other permanent stations operated by NORSAR, the type of equipment and methods for data exchange between cooperating institutions. In parallel to the direct data exchange, processing results and waveform data are made available on the NORSAR web pages. The public web pages have been extended by links to near real-time long-period seismogram displays and to daily overviews for the radionuclide data. The internal web pages have been complemented by real-time trace plots of all incoming data streams with the object to improve quality control.
NORSAR installed three microbarometers at the ARCES array in March 2008. The instruments are collocated with seismometers at ARA1, ARA2 and ARB2. We will show initial observations for infrasound events and the ambient noise conditions.

## Current Functioning of the Polish Seismological Network

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Polish Seismological Network (PLSN) maintained by the Institute of Geophysics, Polish Academy of Sciences comprises 6 broadband stations and 4 short period sites. Eight of these stations are providing NRT continuous data which are contributed to the international seismological community. The datacenter of the PLSN makes use of available foreign partner data to create a virtual network of 23 stations in and around Poland. The data is then processed automatically and manually and results are disseminated. Poland is a country of low natural seismicity, therefore much of the attention is given to seismic events induced by mining and to the incorporation of data that is supplied by the mining industry. However, natural seismicity is not totally unexistent. One may recall the earthquakes in 2004 in Podhale region, Poland and Russian Kaliningrad Region that have been felt in much of northern Poland, nevertheless from time to time there happen natural seismic events. In 2007 there has happened a series of microearthquakes in southern Poland near the town of Grybow that has been subject to a special study.

# Crustal velocity models and Moho map for the Kainuu-Peräpohjola region in Finland

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Two-dimensional seismic velocity models and Moho depth map have been compiled for the Kainuu-Peräpohjola region in eastern and northern Finland. The region belongs to the Archean Karelian craton and it includes the areas of most active seismicity in Finland. Our data comprise local earthquakes and quarry blasts recorded by the Finnish permanent seismic network and by mobile stations. The events have been arranged into ten seismic profiles covering the study area. The refracted, reflected and postcritical phases have been modeled using 2-D ray-tracing technique.

The results image a typical three-layer Archean crust with thickness ranging between 40 and 54 km. The upper and the middle crust are 15-20 km thick, with average P-wave velocities of 6.1-6.3 km/s and 6.6-6.7 km/s, respectively. A 5-20 km thick lower crust has velocities varying between 6.9 and 7.3 km/s. In the uppermost layer, Vp/Vs= 1.71 is determined from good quality Pg and Sg wave travel times. For other S-wave phases travel times are correlated as an envelope of arrivals, and the Vp/Vs ratios are 1.74 in the middle crust and 1.76 in the lower crust. For the uppermost mantle a standard value of 1.73 is assumed, which fits quite well observed Sn wave travel times.

The crust is thinnest (40-42 km) under the Pudasjärvi block in north-western part of the area. This block is bordered by Proterozoic schist belts, and its northern margin coincides with the Peräpohja aulacogen. The thickest crust (50-54 km) is found at the south-eastern corner of the area, where the Archean crust is overthrust on younger Svecofennian crust. Another local maxima in crustal thickness is located below the Salla greenstone belt, north-eastern Finland. This feature is tentatively linked to continent-continent type collision of Archean crustal blocks as suggested by FIRE4 data.

# Testing the location and discrimination capability of Nordic-Baltic virtual seismic network in the Baltic region

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The Eastern Baltic region (lat = 53.9 - 59.7N; lon = 19.5 - 28.2E) is characterized by few natural earthquakes and a great number of man-made events. As the area is covered by sparse seismic station network, ambiguity in hypocenter determination arose up even in case of the strong Kaliningrad earthquakes on September 21st, 2004.

During the instrumental period (1976-) only 16 earthquakes have been registered in the region. However, existence of weak local seismic events was confirmed by observations both in Latvia and Lithuania.

In this paper, we tested the potential of a virtual Nordic-Baltic seismic network in locating and discriminating weak seismic events in the area. The joint network consisted of Finnish, Norwegian and Swedish stations as well as all the stations available in the Baltic countries. We used as the test data three spurious seismic events that occurred on January 17th , 2008 near the coast of Lithuania, on March 18th, 2008 in Latvia and on March 29th, 2008 offshore Latvia. The joint event locations were compared with solutions from the bulletins of NORSAR and the University of Helsinki. Discrimination of the events was based on spectrograms.

The results indicate that in order to improve the efficiency of seismic monitoring in the Baltic region, the following issues should be addressed:

1. to accumulate calibrated seismic sources
2. to select optimum regional velocity model of seismic waves
3. to develop national networks of short-period and/or broad band seismic stations
4. to test and use different methods for discriminating seismic events.

## Monitoring Microearthquakes with the San Andreas Fault Observatory at Depth

**Oye V.** and W. Ellsworth

In 2005, the San Andreas Fault Observatory at Depth (SAFOD) was drilled through the San Andreas Fault zone at a depth of about 3.1 km. SAFOD is part of the National Science Foundation's EarthScope Project and has the objective to test fundamental theories of earthquake mechanics. The project is motivated by the need to answer fundamental questions about the physical processes controlling faulting and earthquake generation within a major plate-bounding fault. In the summer of 2002, a 2.2 km deep vertical pilot hole was drilled and instrumented to prepare for SAFOD. In the summer of 2005, the SAFOD main hole was then drilled 1.8 km SW of the surface trace of the fault, beginning as a vertical borehole, then deviating at a depth of 1.5 km to the NE and ending at a total vertical depth of 3.1 km NE of the San Andreas Fault zone. The target of the borehole was a repeating earthquake source zone that was earlier identified by a dense surface seismic network as well as instruments within the SAFOD pilot hole. From geophysical logs as well as the analysis of cuttings from the deviated section of the hole, multiple narrow (<30 m) zones have been identified that are characterized by very low seismic P- and S-wave velocities. These zones probably represent fault core zones, while they belong to a broader (~200 m wide) zone of lower velocities that probably represents the damage zone.

From early 2006 on, the SAFOD main hole had been instrumented with high-frequency geophones and accelerometers. Since the downhole instruments are only about a few hundreds of meters away from some of the target microearthquakes as compared to about 3-10 km for the High Resolution Seismic Network (HRSN, the detection threshold on the downhole instruments is expected to be much more sensitive than on the HRSN, where it is currently about $M_w$ 0 to 1. In this paper we describe how we combine the high frequency borehole data (4000 Hz sampling frequency) with data from the HRSN (up to 250 Hz), where the instruments are deployed in shallow boreholes (~250 m).

The microseismic monitoring software MIMO, developed by NORSAR, has been installed at SAFOD to provide near-real time locations and magnitude estimates using the high sampling rate (4000 Hz) waveform data. To improve the detection and location accuracy, we incorporate data from the nearby, shallow borehole (~250 m) seismometers of the HRSN. The event association algorithm of the MIMO software incorporates HRSN detections provided by the USGS real time earthworm software. The concept of the new event association is based on the generalized beam forming, primarily used in array seismology. The method requires the pre-computation of theoretical travel times in a 3D grid of potential microearthquake locations to the seismometers of the current station network. By minimizing the differences between theoretical and observed detection times an event is associated and the location accuracy is significantly improved.

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

**Svein Mykkeltveit**

NORSAR

Eleven years after the establishment of the Preparatory Commission for the CTBT Organization and its Provisional Technical Secretariat in Vienna, Austria, the build-up of the CTBT verification regime is nearing completion. Approximately 250 of the 321 stations of the International Monitoring System have been built and are providing data to the International Data Center (IDC), which produces an analyst reviewed bulletin containing on average 80 events per day, based on seismic, infrasound and hydroacoustic data. In addition, the IDC issues daily reports on the results of the analysis of spectra from radionuclide monitoring stations. The arrangements for on-site inspections to clarify concerns raised by member states related to events detected and located by the IMS/IDC system, are well advanced and will be tested in a large-scale exercise to be held in Kazakhstan in September 2008.

The presentation will provide a review and assessment of the current status of implementation of the CTBT verification regime. The emphasis will be on current challenges to complete the verification regime in a timely manner, as well as on technical and other factors affecting the progress of the remaining work.

# The application of infrasound monitoring for registration of powerful explosions at long-distances.

*Vinogradov Y.A., Yevtyugina Z.A., Kola regional seismological center, Apatity, Russia.*

The active technogenic activity of humanity causes powerful energy flows in the near-surface zone of the earth's crust and the lower layers of the atmosphere (troposphere and the stratosphere). The study of such energy fluxes, processes of redistribution energies in the system of the interacting geospheres, and also very sources of energy excitation are the tasks of great scientific and practical value. Since 2002, at Kola regional seismological center has been engaged in infrasound research. Now the Apatity infrasound array is a three-element small aperture array co-located with the nine-element short-period regional seismic array. It's located near lake Imandra in the center of Kola Peninsula. The sensors are differential microbarographs of CHAPARRAL Model 5 type, with a sensitivity 20 mV/Pa in 0.1 – 10 Hz frequency range, are installed around the top of the hill, positioned in equilateral triangle configuration with 350 m sides. The wind-reduce star-like tube systems have been installed at all sites to filter out acoustic noise.

For signals extraction the special automatic acoustic detector have been created. A main features of the detector are: beamforming-style detection of acoustic events; statistical evaluation of noise (not STA/LTA as usual); estimation of backazimuths and arrival angles to day surface for each events; the coherencies and signal-to-noise ratio are used for thresholding. The automatic acoustic detector was tested at numerous events induced by explosions at the various open-cast mine located at distances 40 – 250 km and showed a very good effectiveness. All those signals had a coherence >0.85 and SNR >10.

Detector verification for weak signals registration has been carry out on explosions detonated on mines of the Kursk magnetic anomaly (KMA) located on distance of 1725 km to the south of the registration's point. The event with known coordinates and time in the center has been chosen in catalogue REB. The true azimuth and the expected arrival time (proceeding from speed of a sound 0.2 - 0.35 km/s) of infrasound wave has been calculated. After work of the detector all events whose had coherence more than 0.6 and an azimuth of arrival ±10 from true were allocated. The same operation was carried out for the data obtained from infrasonic station I31 of international network IMS, located in Kazakhstan at distance 1560 km eastwards of a point of explosion. 1 event on Apatity infrasound station and 3 consecutive events on I 31 station has been allocated. The error of a location calculated by arrival azimuths, has made 158 km. Expansion of a signal on long-distance distances occurs only if a atmosphere's condition kindly for an acoustic channel creation. By results of processing 25 explosions, charged in KMA area during 2005 - 2007, are drawn conclusions on conditions of formation of such channel.

## Monitoring seismic events in Iran reported in the SSEB-bulletin from the International Data Centre

**Ingvar Nedgård**

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In the Reviewed Event Bulletin (REB), 2266 events were reported by the International Monitoring System (IMS) in Iran and its border regions (25-40N, 44-64E) from January 1, 2000 to April 9, 2008. During the same period 697 REB-events were reported to be in the magnitude interval $m_b$= 4.0 to $m_b$= 5.5 corresponding to the size of a small nuclear explosion around or below 20kt TNT. The International Data Centre (IDC) provides screening parameters estimated from source depth, $m_b(M_s)$-discriminant, regional P/S amplitude ratios and hydroacoustic energy levels and cepstral parameters. Screening criteria based on these parameters are used to sort out events consistent with natural phenomena or non-nuclear, man-made phenomena if one of the screening score values is greater than zero. The criteria are not applied to events below $m_b$= 3.5.

Events in this "Screened out" category are excluded from the Standard Screened Event Bulletin (SSEB). The SSEB contains events with "Insufficient Data" for the screening criteria and events for which the criteria are not satisfied "Not Screened Out". From January 1, 2000 to April 9, 2008 the IMS-system reported 1186 events in the SSEB-bulletin located to Iran and its border regions. Of these events 235 were in the magnitude interval $m_b$= 4.0 to $m_b$= 5.5.

During the year 2007, 25 events in this magnitude interval were reported in the SSEB-bulletin and 7 so far in 2008. Waveforms from these 32 events have been examined and together with origin time, location, available information about depth and magnitudes a "soft decision", presumed nuclear explosion or not, was made for these events. The term "soft decision" is used here to indicate that the decision might be, but not necessarily is, less reliable than a "hard decision" e.g. based on the $m_b(M_s)$- discriminant.

# A New Information System for NDC Purposes

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The Comprehensive Nuclear-Test-Ban Treaty makes it clear that the verification of compliance with the Treaty is the responsibility of each State Party. The technical judgements in practice are performed at National Data Centres (NDC), organizations with technical expertise in the verification technologies. The purpose of the International Monitoring System (IMS) and the International Data Centre (IDC) is therefore to support the States Parties in this effort by providing raw data and data products (information) to help them make these judgements.

At the Swedish NDC, we are in the process of creating a joint NDC comprising seismic as well as radionuclide data stored in a common data base. Through the IDC, we have access to an enormous amount of information but we have chosen to focus on certain areas of interest. To support our ability to decide whether the treaty has been violated or not, we have started to develop an information system. This system includes a graphic interface and a database where we store reference information to help us in the examination of suspicious events.

In this presentation, which will focus on the seismic part, I will give a brief overview of the system and show some examples of how we currently work using the graphic interface.

# JOINT FINNISH-ESTONIAN SEISMIC ANALYSIS OF QUARRY BLASTS IN NE ESTONIA

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Seismic events within the territory of Estonia are routinely detected and located by the Finnish seismic network. The events in Estonia are mainly explosions conducted in oil shale quarries in the NE corner of the country. Events with magnitudes above 1 are well detected by the Finnish system. However, the largest gap between observing stations is typically well over 200 degrees, which impairs the location accuracy. Also, the Finnish stations are located at distances over 130 km from the area of mining activity.

From January 2008 on, automatic detections of the Finnish system are being manually checked at the Geological Survey of Estonia and observations of the three Estonian stations, VSU (58.46° N, 26.73° E), SRPE (59.46° N, 24.38° E) and MTSE (58.71° N, 23.81° E) are included. Events are relocated with a one-dimensional model of constant velocity layers, which is also in use in Finland. This procedure significantly improves the location accuracy.

Two principal quarries, Aidu and Narva, provide us afterwards listings on timing of conducted blasts and the amount of used explosives. This enables us to control the quality of our analysis. Aidu is located within the combined Finnish-Estonian seismic net, but Narva is slightly off. According to our knowledge, oil shale in Aidu is at the moment mined at the southern edge of the quarry. Indeed, also our event locations cluster in the known area of activity. We do not know precisely currently exploited areas in Narva, but the event locations are generally more scattered than those of Aidu.

Also induced seismicity is observed within the NE Estonian mining area. A recent example is a night-time collapse in disused mine shafts, which was recorded at the Estonian and Finnish seismic stations as a magnitude-1.8 event. The signal was distinctly different from those of mining explosions, having long duration and containing principally low frequencies (~0.7-2 Hz).

# Mining induced seismicity in Poland

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Mining is not a spontaneous process. Some particular mining situations may generate more favorable short term seismic response than the others. As the results induced seismicity appears. This build a natural laboratory which fill the gap between a natural seismicity and laboratory rock-sample experiments.

In Poland two active mining area, namely the Lubin copper district in south-western Poland where 3 mines are in operations and the Upper Silesian
Coal Basin where black coal is intensively extract generate a few thousands of seismic events with magnitude ranging up to 4 or so.

In this presentation a short review of some characteristics of the induced seismicity from the copper mine district is presented. Special attention is put on the advanced analysis of the source mechanism of seismic events in mines which provides important information towards our understanding the various modes of rock failure observed in underground mining environments.

# Orientation of Triaxial Borehole Sensor

**Antti Lakio** and Jouni Saari
Åf-Consult Ltd

Two borehole sensors were installed at the nuclear waste repository site to improve location accuracy. Improvement was aimed at greater depths of excavation of the tunnel. Sensors were installed in the same borehole with same grouting tube. Sensor depths were -139.33 and -236.82 meters. Only information of those sensors were sensor coordinates, dip and dip direction of the borehole. To know sensors real orientation its roll had to be defined. After a year there was enough data to orientate the sensor with networks locations. At that time only upper sensor was still working. Orientation was made by comparing networks locations and single triaxial station locations to the get right angles for the sensor.

## Automatic determination of focal mechanisms from P-wave first-motions applied to mining-induced seismicity

**Daniela Kühn**, Hom Nath Gharti, Volker Oye and Michael Roth
NORSAR

Although the analysis of focal mechanisms may provide valuable information on presence and geometry of faults, stress fields and changes thereof, microseismic monitoring is most frequently used to extract information on event location, but rarely on detailed source parameters. We have extended our microseismic monitoring software MIMO to additionally calculate focal mechanisms from P-wave first-motions. The first application is the analysis of mining-induced seismicity in the Pyhäsalmi ore mine, Finland.

The seismic monitoring network in the Pyhäsalmi mine consists of 18 sensors (thereof six 3-component stations) and is operational in a continuous mode since January 2003 (installed by ISS International LTD, monitoring conducted by INMET mining). The most seismically active regions correspond to a chute as well as the most active mining area. Approximately 1500 events per month are detected, 2/3 of them being production blasts.

We based our source code to determine focal mechanisms from P-wave first-motions on the USGS software HASH 1.1 (Hardebeck and Shearer, 2002, 2003). Observed P-wave first-motions (up- and downwards) are mapped on a sphere representing the orientation at which the ray left the source. A set of nodal planes is fit to the observations using a grid search algorithm.

In a first step, synthetic polarities were calculated for a given focal mechanism (e.g. Aki and Richards, 1980). Afterwards, the focal mechanism was re-computed using the synthetic polarities as input. In a second step, P-wave first-motion polarities were automatically identified for synthetically calculated waveforms. The velocity model was constructed from a complete 3-D infrastructure model of the Pyhäsalmi mine including ore bodies and cavities. In a third step, the algorithm was applied to microearthquakes recorded in the Pyhäsalmi mine in December 2005. For testing purposes, only the very best of events were chosen offering more than 75 observation parameters and magnitudes greater than -1, leaving 28 events. Only 4 results must be considered meaningless because of a high number of misfit polarities, whereas 8 focal solutions could reproduce all required polarities and additionally 6 focal mechanisms only had one misfit polarity for an emergent P-wave onset which also is difficult to investigate manually.

Summarising, although the software HASH 1.1 on which we based our source code was developed on regional seismic data obtained from the Southern California Seismic Network, the method works well for the microseismic data from the Pyhäsalmi mine. Despite the much lower magnitudes and high noise level, which can be expected from the actual mining process, P-wave onsets are frequently clear enough to allow for an automatic determination of their polarities.

# An upper mantle S-wave velocity model for Northern Europe from surface wave group velocities

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A new tomographic S-wave velocity model for the mantle below Northern Europe is presented. The model is based on a two-steps inversion of surface wave group velocity measurements for regional events recorded at permanent and temporary networks of stations in the area. Group velocites are measured in the frequency range 15 to 150s for Love and Rayleigh waves. The data are first inverted into group velocity maps using a scheme based on the Fresnel zone sensitivity of each path. The maps at different periods are then inverted with depth to get a three-dimensional mantle model of the SV and SH wave velocites in the area.

Due to the influence of the crustal parameters on the group velocities in our highest frequency range, inaccurate knowledge of the crustal thickness may bias our results in the upper part of the mantle. In order to study the influence of the crust on our model, we inverted the data with different assumptions concerning the crust. A comparison of the different results shows that the mantle below 50km depth is not very sensitive to the crustal parametersand we will discuss our 3D model only below this depth.

Our new model differs significantly from previous global models. We obtain larger contrasts, even after a careful check of the adequacy of the damping used in the inversion. We image in particular a low-velocity anomaly below southern Scandinavia, with a negative perturbation of up to 13% w.r.t. ak135. This anomaly extends downwards towards Iceland. We observe also boundaries in good alignement with ancient plate boundaries in the area.

## The Mid Atlantic Ridge, a look through global travel-time tomography

**Mohammad Raeesi**[1], Jens Havskov[1], and Kuvvet Atakan[1]

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The relatively dense installations of seismic stations in Europe and North America provide a good coverage of the Atlantic Ocean and the mantle below that by body waves. By applying a 3-D global travel-time tomography with enhancements in different aspects of the method and application of a rather unusual filter (regulator), we have reached to a picture (yet unconfirmed) of the Mid Atlantic Ridge. If approved, perhaps for the first time the MOR-side of the Wilsonian Cycle is observed physically. The depth extension of three hotspots (Hawaii, Reunion, Societies) will be presented. A comparison with one of the existing tomographic models will be made. To give a clearer picture of the method, critical points will be explained very briefly in the beginning.

# The M 5.4 October 23, 1904, Oslofjord earthquake: Reanalysis based on instrumental and macroseismic data

**H. Bungum**, J.I. Faleide, F. Pettenati, J. Schweitzer and L. Sirovich:

On October 23, 1904, the Oslofjord region was struck by an M 5.4 earthquake that was widely felt and moreover rocorded at a number of seismic stations in Europe. After a careful selection and weighting of published onset times and readings from the seismic stations in Uppsala, Hamburg, Potsdam, Goettingen, Leipzig and Tartu we have obtained for the first time an instrumental location of the event, as well as an instrumental magnitude. We have also performed a new non-linear inversion of the regional pattern of available macroseismic data, originally collected and analyzed up to 1908. The epicentre obtained from the intensity inversion is consistent with the instrumental determination, giving a location in the lower crust (25-30 km) and close to the east eastern coast of the Oslofjord, near the junction of two major fault zones. The inversion was able to constrain also the fault-plane mechanism with an almost vertical rupture plane striking NNE-SSW and with a mixed mechanism, the ambiguity of which is resolved by the polarities observed at the Uppsala Wiechert recording. A magnitude of 5.4-5.5 has now been independently confirmed both through the new intensity inversion and through the reanalyzed instrumental data.

## Improvements to the processing of earthquake data recorded with the seismological network in Denmark and Greenland

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Recently the processing of earthquakes data recorded in Denmark and Greenland has been changed from a single station phase reporting system to an event based system. The improved data communication between the stations in Greenland and the data center at GEUS have made the event based processing possible.
Previously, a bulletin with single station phase readings was produced weekly and two bulletins for the local earthquakes in Danmark and in Greenland was produced with a latency of several years. Now local, regional and teleseismic earthquakes are located at a daily basis. To improve global coverage international stations like KBS are included in the processing. To improve the location of the local earthquakes in Denmark and Greenland data from neighbour networks like e.g. the Swedish national seismic network (SNSN) and the Canadian National Seismograph Network (CNSN) are included when available.
This new procedure meets the request from the International Seismological Centre of receiving event associated data. Though the earthquake database is now event based the weekly bulletins will still be available. Both the event based bulletin and the weekly bulletin is found at the Internet address http://www.geus.dk and http://seis.geus.net

# The IPY Project "The Dynamic Continental Margin Between the Mid-Atlantic-Ridge System (Mohns Ridge, Knipovich Ridge) and the Bear Island Region"

**J. Schweitzer** and the IPY Project Consortium

In autumn 2007, we began with an active and passive seismological experiment along the continental margin of the Barents Sea near Bear Island and the mid-Atlantic along the Knipovich Ridge. The field experiments comprise the installation and parallel operation of several seismic instruments during 2007-2008. The aims of this study are the investigation of the Earth's structure and dynamics at the continental margin from its top sedimentary cover to its imprint in the upper mantle. In this region the margin includes an extremely thick sedimentary wedge and steep slopes, with at least one major paleo-fracture zone cutting through the wedge. Recent studies in this area indicate very low seismic velocities in the lithosphere, which may be explained by the subcrustal extension of Mohns Ridge. The stress field undergoes an extensional-compressional transition in the region of the margin. It is therefore of particular interest to understand the structural architecture, the stress and the dynamics of the whole region because of its natural hazard exposure, and the processes involved in formation of the margin and opening of the Atlantic. The collection of deep seismic sounding data, and detailed monitoring and analysis of the seismicity between margin and mid-Atlantic ridge system, using temporary broadband stations, are necessary for providing such information. Data from existing seismic stations in the European Arctic will also be analysed.

In September/October 2007, 12 Ocean Bottom Seismometer (OBSs) from the German OBS pool were deployed in the deep sea between Bear Island and the mid-Atlantic ridge system and along the continental margin. In parallel, two new broadband sensors (STS-2) were installed, one at the Polish Polar Station Hornsund and one at the NNSN station on Hopen Island. In May 2008, a small array on Bear Island was installed and for July/August it is planned to conduct active seismic refraction/reflection experiments along two profiles crossing the mid-Atlantic ridge systems, the margin and Bear Island. The profiles will be supplemented with about 40 short-period stations on Bear Island and about 15 OBSs to retrieve the 3D lithospheric structure.

The two seismic station upgrades (Hornsund and Hopen) with broadband sensors are planned as permanent installations to improve the seismological monitoring capabilities in the European Arctic. All other deployments are temporary and will be demobilized in August-October 2008.

After the end of the first part of the project, all recorded data will be exchanged in autumn 2008 between the project partners and from then on a two years long period for data analysis and interpretation is planned.

## A snapshot on the subduction zone processes along the Kurile-arc

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Deformation along the subduction zones are continuous processes in a geological time scale. At shorter time scales, this continuous process is fragmented through discrete events such as individual earthquakes. A snapshot of the subduction zone process along the Kurile-arc has recently been delineated by the occurrence of two large earthquakes in Nov.15, 2006 (M=8.3) and Jan.13, 2007 (M=8.2). The first one occurred along the plate interface as a pure thrust earthquake and the second one was a pure normal earthquake which occurred on the outer rise, within the down-going lithospheric slab. The processes leading to these earthquakes are visible on both the bathymetry and the gravity anomalies of the trench. Trench parallel topography (TPTA) and gravity (TPGA) anomalies are investigated in the light of the recent earthquakes. The slip inversion based on teleseismic data shows clear correlations between the high slip patches (asperities) and the TPGA when the effect of the topography is removed. In addition, the distribution the foreshocks and aftershocks seem to be controlled by the location of the major asperities along the fault planes for both earthquakes. The spatial and temporal analysis of the instrumental seismicity along the entire Kurile-arc reveals that there are significant gaps close to the 2006 and 2007 earthquakes, especially in the Northeast direction. The location of the major asperities seem to have a major role in determining the spatial distribution of the large earthquakes along the arc, however, the size of the individual earthquakes seem to be more dependent on the occurrence of the last large earthquake on adjacent segments of the subduction and their interaction. Furthermore the origin of the asperities is probably related to the location of the sea-mounts.

# Significant results of 20 years of earthquake prediction research projects of the Nordic countries and Europe, and export of the results to other parts of the world.

**Ragnar Stefansson**

The SIL project, "earthquake prediction research in the South Icelandic Lowland", was a common undertaking of the Nordic countries. Among the most significant results of it was the creation of the SIL microearthquake system. In significant parts along the Iceland plate boundary the SIL system has the detection level at around zero magnitude. And the nearly continuously detected signals carry to the surface frequent significant information useful for automatic on-line fault plane solutions and source process analysis. The SIL system became the basis for several multidisciplinary earthquake prediction research projects supported by EU. Many results of theses projects came to test in the two magnitude 6.6 (Ms) earthquakes in the South Iceland seismic zone in year 2000. The successful warnings, on a long and on a short time scale, before these earthquakes has caught attention in many earthquake prone countries. Useful warnings had been presented about the place of both earthquakes and a useful short term warning was issued before the second earthquake. The European PREPARED project found in hindsight new observable long term pre-earthquake changes before the 2000 earthquakes and a few changes in weak signals on a short term before the first earthquake. These changes have been modeled with earth-realistic models, and thus the results can be applied to try to warn before other earthquakes. Activities are now ongoing to apply these results in manual warning systems and by organized manual real time watching. Preparations are now ongoing to export these experiences to other earthquake prone areas in cooperation with Nordic and other European scientists. Also, as concerns geological hazards in general, to export experiences in watching and efforts to mitigate risks stemming from them.

# An Application of "energy-duration" method for fast-estimate of earthquake magnitude using Swedish National Seismological Network (SNSN)

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Energy-duration method, developed recently by Lomax *et al.* (2007), can be used to estimate a scalar seismic moment, $M_0$, and a moment magnitude, $M_{ED}$ of an earthquake in a rapid and robust way. Lomax *et al.* (2007) showed that the $M_{ED}$ energy-duration magnitude can be scaled to correspond to the Global Centroid-Moment Tensor (CMT) moment-magnitude, $M_w^{CMT}$. The CMT calculations are based on long-period *S* and surface wave waveforms but these recordings ,and thus $M_w^{CMT}$, are usually not available until an hour or more after the origin time of an earthquake. However, knowing the earthquake hypocentral location, the $M_{ED}$ magnitude can be calculated within 20min or less after the origin time, since it is based on *P*-wave recordings (*P* to *S* interval) from global seismic stations at 30°–90° distance. The method combines the radiated seismic energy (measured on the *P* to *S* interval of broadband waveforms) and source durations (measured on high-frequency *P*-wave recordings) and focal mechanism variations is averaged-out in the calculation.

The current Swedish National Seismological Network (SNSN) has been operated by Uppsala University since 1998 (Bödvarsson, 1999). The network is currently operated with 60 three-component seismic stations, which are equipped with Guralp CMG-3TD sensors with flat velocity response in the range from 30sec to 50Hz or 120s - 50Hz. Four sensors are STS-2, 120s - 50Hz. The general shape of the network is rather long and narrow and its major axis is believed to be approximately perpendicular to the large-scale tectonic features in the area.

In this study we present the application of the energy-duration methodology to a number of recent, large earthquakes (including 2007/09/12, Southern Sumatera earthquake, $M_w^{CMT}$ 8.5 and 2004/12/2, Sumatra-Andaman mega-thrust earthquake, $M_w^{CMT}$ 9.0) using only SNSN data.

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# Detection and characterisation of seismic phases using continuous spectral estimation on incoherent and partially coherent arrays

**Steven J. Gibbons**, Frode Ringdal and Tormod Kværna

Seismic arrays are employed in the global monitoring of earthquakes and explosions because of their superior ability to detect and estimate the direction of incident seismic arrivals.
Traditional beamforming and f-k analysis require waveform semblance over the full array aperture and cannot be applied in many situations where signals are incoherent between sensors. The NORSAR and MJAR arrays are two primary IMS stations where this is the case for high-frequency regional phases.
Large inter-site distances and significant geological heterogeneity at these arrays result in waveform dissimilarity which precludes coherent array processing in the frequency bands with optimal SNR.
Multitaper methods provide low variance spectral estimates over short time-windows and seismic arrivals can be detected on single channels using a non-linear spectrogram transformation which attains local maxima at times and frequencies characterised by an energy increase.
This detection procedure requires very little a priori knowledge of the spectral content of the signal.
The transformed spectrograms can be beamformed over large-aperture arrays or networks according to theoretical time-delays resulting in an incoherent detection system which does not require waveform semblance at any frequencies. We outline a real-time automatic detection system for regional phase arrivals on the NORSAR array and demonstrate how stable and accurate slowness and azimuth estimates can be obtained for quite marginal signals.
In the case of partially coherent arrays, the procedure described may provide stable, if low resolution, estimates which can subsequently be refined using coherent processing over subsets of sensors. In particular, we illustrate how the spectrogram beamforming method facilitates a stable and accurate slowness estimate for the incoherent high-frequency Pn arrival at the MJAR array in Japan from the 2006 October 9 underground nuclear test in North Korea.