40th Nordic Seminar on Detection Seismology

FOI Conference Facility in KISTA
October 14 -16, 2009
Stockholm, Sweden

Wednesday October 14

12:30	Registration at FOI conference facility
13:30	**Welcome and opening remarks** Nils Olsson and Nils-Olov Bergkvist
13:40	**Session I: Seismic Networks and Arrays** **Chairman: Pekka Heikkinen**
13:40	Swedish National Seismic Network (SNSN) – present status and plans for the future <u>Reynir Bödvarsson</u>, Björn Lund, Hossein Shomali and Ari Tryggvason
14:00	Routine location of seismic events in 1D and 3D earth models at SNSN <u>Ari Tryggvason</u> , Reynir Bödvarsson, Hossein Shomali and Björn Lund
14:20	Noise levels and observations from the Norwegian National Seismic Network Lars Ottemöller
14:40	Improving the station network in Western Lapland, Finland Pasi Lindblom
15:00	Small Scale Focused Test – Calibration of FINES Array Jari Kortström
15:20	Coffee
15:50	**Session II: Seismic Data Processing** **Chairman: Peter Voss**
15:50	Construction and Application of Time-Delay Correction Surfaces for Improved Detection and Estimation on Seismic Arrays <u>Steven J. Gibbons</u>, Jan Fyen and Frode Ringdal
16:10	Processing earthquake data <u>Jens Havskov</u> and Lars Ottemöller
16:30	A duration–energy procedure for rapid estimate of earthquake magnitude using early part of P waveforms Hossein Shomali, <u>Reynir Bödvarsson</u>, Björn Lund and Ari Tryggvason
16:50	A critical assessment of the estimation of Green's functions via ambient noise cross correlation. <u>Roland Roberts</u>, Olafur Gudmundsson, Ari Tryggvason, Hossein Shomali, Björn Lund and Reynir Bödvarsson
17:10	New Features on NORSAR's webpages <u>Michael Roth</u>, Ulf Baadshaug and Nils Schøyen

Thursday October 15

09:00 **Session III: Comprehensive Nuclear-Test-Ban Treaty (CTBT) related studies**
Chairman: Michael Roth

09:00 The verification regime of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) – current status of implementation
Svein Mykkeltveit

09:20 Delicious leaks and Google games
Lars-Erik De Geer

10:20 **Poster Session – short presentations**

Interpretation of wide-angle reflection and refraction recordings of Vibroseis signals and 3-D gravity modelling along FIRE4 profile, northern Finland
<u>Hanna Silvennoinen</u>, Elena Kozlovskaya, Jukka Yliniemi and Timo Tiira

Earthquake tremor observed in magnetic measurements
<u>Peter Voss</u>, Cathrine Fox Maule, Lars W. Pedersen, Jürgen Matzka, Anna Nilsson, Søren Gregersen

A duration–energy procedure for rapid estimate of earthquake magnitude using early part of P waveforms
Hossein Shomali, <u>Reynir Bödvarsson</u>, Björn Lund and Ari Tryggvason

A map of non-tectonic seismic sources in the East Baltic region
Bela Assinovskaya, Valery Nikulin, <u>Heidi Soosalu</u>, Andrius Pacesa

Probabilistic Seismic Hazard Analysis for Latvia
Valery Nikulin

Spot-checking of IMS location accuracy
<u>Nils-Olov Bergkvist</u> and Peder Johansson

10:40 Coffee / Demo of an IMS radionuclide station (SEP63, SEX63) – 3 groups
Catharina Söderström

11:40 **Session III: Comprehensive Nuclear-Test-Ban Treaty (CTBT) related studies (continued)**

11:40 Analysis of small events near Semipalatinsk
Ingvar Nedgård

12:00 Observation of Infrasound signals refracted from thermospheric altitudes generated by near-surface explosions
Steven J. Gibbons

12:20 Lunch at FOI conference facility

13:20 Session IV: Event studies
Chairman: Roland Roberts

13:20 The December 16th, 2008 earthquake in southern Sweden and recent development of the seismological network in Denmark and Greenland
Peter Voss

13:40 Wenchuan Earthquake of May 12, 2008, Mw = 8.0. Reconnaissance Report
Kuvvet Atakan, Louise W Bjerrum and Mathilde B. Sørensen

14:00 Strong ground motion simulation of the M = 8.0, May 12 2008 Wenchuan earthquake, using various slip models
Louise W Bjerrum, Mathilde B. Sørensen and Kuvvet Atakan

14:20 Coffee

14:40 The earthquakes in the Gulf of Bothnia area on 15 and 23 June 1882
Päivi Mäntyniemi and Rutger Wahlström

15:00 Seismological studies of the Pärvie endglacial fault system, northern Sweden
Eva Karlsson, Björn Lund, Pálmi Erlendsson, Christopher Juhlin, A. Dehghannejad, Reynir Bödvarsson, Tormod Kvaerna, Marja Uski

16:30 **Bus Departure** to Conference Dinner
17:30 – 20:00 Conference Dinner, Restaurang Prinsen

Friday October 16

09:00	**Session IV: Event studies (continued)**
09:00	And the beat goes on! Is the resurgent activity along the Reykjanes peninsula similar to what we have observed in the last decade? Björn Lund, Marie Keiding and Þóra Árnadóttir
09:20	Seismic detection and on-site survey of mine collapses in Estonia Heidi Soosalu, Ingo Valgma and Kalmer Sokman
09:40	**Session V: Crustal and Lithospheric Studies; Seismic Hazard** **Chairman: Lars Ottemöller**
09:40	POLENET/LAPNET-a multidisciplinary seismic array research in northern Fennoscandia Elena Kozlovskaya, Hanna Silvennoinen, Teppo Jämsen & POLENET/ LAPNET Working Group
10:20	Coffee
10:50	3-D crustal velocity model for Lithuania and surroundings and its application to local event studies Elena Kozlovskaya, Mantas Budraitis, I. Janutyte, Gediminas Motuza and PASSEQ Working Group
11:10	**Any other business**
11:30	**Closing Remarks**

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Swedish National Seismic Network (SNSN) - present status and plans for the future

Reynir Bödvarsson, Björn Lund, Hossein Shomali and Ari Tryggvason

The Swedish National Seismic Network (SNSN) now consist of 60 broad-band high-gain seismological stations. All stations are now transmitting data to Uppsala in real-time. Data from ten stations are now transmitted via Internet to Orfeus and bilateral discussions with Denmark, Finland and Norway regarding data exchange.

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.

Routine location of seismic events in 1D and 3D earth models at SNSN

Ari Tryggvason, Reynir Bödvarsson, Hossein Shomali and Björn Lund

With the fairly dense new station distribution of SNSN (the Swedish National Seismic Netowork), local seismic events may be more accurately located. A prerequisite for computing good event locations is good control of the velocity structure. Epicentral parameters are less sensitive to the velocity models compared to the source depths. Seismic stations in Sweden are distributed over more than 1800 km in the north-southerly direction. The crystalline crust is Archean in the north, and Phanerosoic in the very south. It is therefore unrealistic to expect that a single velocity model will provide accurate event locations in all of Sweden. The first stations in the new SNSN network came into operation along the northern shore of the Bothnian Bay. It is also here that the seismicity is most intense. It thus appeared reasonable to start deriving a new velocity model for this region. Other parts of Sweden were the seismicity is less and the new stations came later into operation, the number of earthquakes is too few to provide good constraints on the velocity structure. To mitigate the lack of seismicity, explosions in the near surface may be used instead. As these explosions are fired not with the purpose of generating good seismic signals, most of the time they are "slow". In this context "slow" implies that the onsets of these recordings are generally emergent, and it is often difficult to pick accurate first-arrivals from this data. A pilot study to extract reliable P- and S-wave first arrival times from data from explosions was initialized in the summer 2009. Concurrent with the work towards improving locations by improving the 1D velocity models, work has been initialized to implement location algorithms providing fast and accurate locations in 3D velocity models. In parts of Sweden it appears that the crustal velocity structure may have strong local variations, thus motivating the need for routine event locations in 3D velocity models. Results from this ongoing work will be presented.

Noise levels and observations from the Norwegian National Seismic Network

Lars Ottemöller

The Norwegian National Seismic Network, operated by the University of Bergen (UiB) and NORSAR, comprises of both short-period and broadband seismic stations. The total of seismic stations is 40 of which 36 are operated by UiB and 4 by NORSAR. This presentation will show the noise levels at the UoB stations. The noise levels are presented as power spectral density plots, which have become the standard for displaying microseismic noise. These plots allow for site evaluation, but are also used as tool to identify equipment problems. Long-period data will be shown from recent large earthquakes in the region, some of which have been used for regional moment tensor inversion. Based on the recorded earthquake catalogue detection levels were computed, which can help to identify regions where additional stations may be required. Future plans for the network include the installation of additional broadband stations, and completion of the transition to real-time data.

Improving the station network in Western Lapland, Finland

Pasi Lindblom

In Finland there are known to be some areas with higher probability of earthquakes, like the valley of river Tornio and Kuusamo area. In the studies of the nature of the earthquakes it is needed to have more data and data with better quality.

Whenever there are thoughts to improve the detection capability of a seismic network, it practically means the need to improve the instrumentations at the existing stations, to install a new station or through international co-operation.

This presentation deals with the idea of installing a new station and gives, hopefully, a practical procedure of the early stages in the site survey and noise measurements.

Small Scale Focused Test – Calibration of FINES Array

Jari Kortström

The Provisional Technical Secretariat (PTS) of Comprehensive Nuclear Test Ban Treaty Organisation (CTBTO) initiated a calibration experiment at FINES array. The aim of the test was to perform a new baseline calibration to the station after its renewal of digitizers. Other important features were to test reporting system of PTS and remote calibration option of new digitizers.

The calibration test was done in three steps: 1. baseline calibration of the whole array before upgrade, 2. baseline calibration after the upgrade and 3. remote calibration of the array.

The baseline calibration was done using Lennartz CT-EW1 calibration table. We use methods and programs CALEX, DISPCAL and TILTCAL developed by Erhard Wielandt. Use of these methods are described in chapter "Seismic Sensors and their Calibration" of New Manual of Seismological Observatory Practise (Wielandt, 2009). The remote calibration was done using Nanometrics Europa-T digitizer's built in signal generator option and Nanometrics software.

As a result we got high quality calibrations values for each channel. The remote calibration experiment is still in progress, because of technical problems of feeding signal to the horizontal channels, but initial results are consistent with baseline calibration. The method will make easier for station operator to meet the requirements of calibrating passive sensors four times per year.

REFERENCES:

Wielandt, E. (2009). Seismic Sensors and their Calibration. In P. Bormann (Ed.), *New Manual of Seismological Observatory Practice (NMSOP)*. Potsdam: Deutsches GeoForschungs Zentrum GFZ. Published online 2009. **:** http://ebooks.gfz-potsdam.de/pubman/item/escidoc:4019:4

Construction and Application of Time-Delay Correction Surfaces for Improved Detection and Estimation on Seismic Arrays

Steven J. Gibbons, Jan Fyen and Frode Ringdal

Array stations are central to the seismic component of the International Monitoring System (IMS) for verifying compliance with the Comprehensive Nuclear Test-Ban-Treaty (CTBT).

Delay-and-stack beamforming lowers the detection threshold for weak seismic signals and provides relatively reliable slowness and azimuth estimates for improved phase association and event location.

Since the earliest days of seismic array operation, it has been appreciated that the predicted and measured slowness vectors can differ significantly. A plane-wavefront model often provides good alignment of coherent signals, such that Slowness and Azimuth Station Corrections (SASCs) may be applied to reduce bias.

For some arrays, the measured time-delays are not well modelled using a plane-wave formulation and beamforming according to theoretical arrival times results in significant waveform misalignment and beam loss.

Beamforming on the large aperture NORSAR array (PS27) has to be performed using empirically determined time-delays, and iterative estimation techniques are required for optimal parameter estimation.

We have identified regions of slowness space for which PS27 phases in the Reviewed Event Bulletin (REB) display systematic residuals in slowness and azimuth, indicating that the current calibrated time-delay models for this array require review and modification.

Given an array of N sensors, our aim is to construct N-1 single-site correction surfaces which, for a hypothetical slowness vector (Sx,Sy), specify perturbations to the theoretical delay times which best preserve the alignment of coherent waveforms with respect to the array reference site.

Such correction surfaces should both provide delay-times for optimal beamforming and allow for one-step direct slowness estimates.

Pointwise estimates for the correction surfaces are provided by the residuals between predicted and measured time-delays, calculated for well-observed phases. An initial set of surfaces for PS27, generated using kriging and least squares inversion, has been demonstrated to provide parameter estimates with smaller bias than in the REB for many regions of slowness space.

Some regions of slowness space are problematic due to waveform dissimilarity between sensors, and others are poorly constrained due to a lack of high-SNR calibration signals.

A significant additional effort will be required to address the optimal processing of partially coherent signals and the extrapolation of correction surfaces to poorly-constrained regions of slowness space.

We note that significant deviations in time-delays exist for even closely spaced elements of PS27, indicating that a similar treatment may provide significant improvements for smaller aperture IMS arrays.

The scalar correction surfaces account for elevation effects as well as velocity heterogeneities and effectively circumvent the need to apply SASCs.

Processing earthquake data

Jens Havskov and Lars Ottemöller

The amount of effort spent on processing data from seismic events is higher than what we use for research on the same data. Yet most reports on results are based on the research, while a condition for doing good research is to have well processed and organized data available. Never-the-less, there does not seem to be any consistent procedures or software available while at the same time many data centers have spent much effort in developing their own procedures, well fitted to their own operation. This sometimes results in standard operations, like calculating m_b, being done differently at different places. The recent 'New Manual of Seismological Observatory Practice' (NMSOP), written by many authors, deals with some of the topics in processing and to a large extent tries to set up standards. We, however, feel there is a need for a book dealing exclusively with processing in more detail, with more examples and exercises than it was possible in NMSOP. We will therefore present our new book on processing.

Our goal is to combine the principles behind earthquake processing and practical examples and exercises in a way not done before so that the reader should be able to get answers to most question in connection with processing earthquakes through hands on experience with an included set of data and software. A how to do book. The main topics are:

- Seismic phase reading
- Location
- Magnitude
- Fault plane solution
- Spectral analysis

while other topics like array analysis, signal processing and routine operation also will be dealt with.

A preliminary version of the book is available at ftp://ftp.geo.uib.no/pub/seismo/ SOFTWARE/SEISAN/processing_earthquake_data.pdf

A duration–energy procedure for rapid estimate of earthquake magnitude using early part of P waveforms

(also presented as a poster)

Hossein Shomali, Reynir Bödvarsson, Björn Lund and Ari Tryggvason

Understanding the earthquake rupture process is the central-point in our understanding of fault systems and rapid magnitude determination. For example in an earthquake early warning system it is essential to be able quickly to determine the size and location of an earthquake. There are a number of procedures for rapid analysis of the magnitude of large earthquakes using seismic P wave portion of seismic waveforms at teleseismic distances. Because these procedures use only the P-wave portion of a seismogram thus the estimate of an event size is potentially available only a few minutes after the P waveform has been recorded at teleseismic distances, that is, in as little as 10–15 min after origin time (OT) at 30° great circle distance (GCD) and about 20 min after OT at 90° GCD.

We introduce a rapid and robust, energy-duration procedure, based on the Haskell, extended source model, to obtain an earthquake moment and a moment magnitude, M_{ED}. Using seismograms at teleseismic distances (30° –90°), this procedure combines radiated seismic energy measures on the P to S interval of broadband signals and source duration measures on high frequency, P-wave signals. The M_{ED} energy-duration magnitude is scaled to correspond to the Global Centroid-Moment Tensor (CMT) moment-magnitude, M_w^{CMT}, and can be calculated within about **20 min or less** after origin time.

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 (Swedish National Seismic Network) data.

A critical assessment of the estimation of Green's functions via ambient noise cross correlation.

Roland Roberts, Olafur Gudmundsson, Ari Tryggvason, Hossein Shomali, Björn Lund and Reynir Bödvarsson.

The estimation of Green's functions via cross correlation of noise signals at two stations has become commonplace. Most commonly, phases corresponding to surface wave phases are detected. Phase velocity estimated from these may be used for tomographic estimation of Earth structure.

We review the basic theory of the link between cross correlation and the Green's functions, and show that except in trival cases the cross corrrelation differs structurally from the Green's function, even if sweeping (and in practice unrealistic) assumptions are made. This has a number of significant implications for how two-station noise data should best be processed in order to obtain velocity information, on how such processed data should be interpreteted, and how it should be used in e.g. tomographic procedures.

New Features on NORSAR's Webpages

Michael Roth, Ulf Baadshaug and Nils Schøyen

In addition to daily short-period period waveform plots of the seismic arrays we are displaying long-period plots for data streams of incoming broadband stations. The plots are available from 2008 onwards and are accessible at http://www.norsardata.no/NDC/lpdata/. The seismograms of the current day are updated every 10 minutes and are in near-realtime. They show the true ground displacement in units of nm for a filterband between 10-30 sec. From these plots one can obtain a quick rough estimate of MS using the formula of Karnik et al. (1962) or Rezapour & Pearce (1998).

We provide power density spectra of all incoming channels from 2009 onwards at http://www.norsardata.no/NDC/spectraplot/. These plots are updated every hour and are about 3 hours delayed to realtime. The power spectral density (PSD) is computed by (i) subdividing a 1-hour time window of raw data into 200-second segments with 100 sec overlap, (ii) computing the periodograms for each segment and (iii) averaging of the periodograms. We are using the PSD-plots to obtain an overview on ambient noise conditions (local noise, microseisms, etc.) and to identify problems of the acquisition system.

We display the content of the Automatic NORSAR Alert Bulletin (http://www.norsardata.no/NDC/bulletins/alert/) in a new map at http://www.norsardata.no/mro/eventmap1.html. The new webpage updates every 5 minutes and displays the events with error ellipses in a Google map.

The verification regime of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) – current status of implementation

Svein Mykkeltveit

The build-up of the CTBT verification regime, led by the Preparatory Commission for the CTBT Organization and its Provisional Technical Secretariat in Vienna, Austria, is nearing completion. As of August 2009, 266 of the 321 stations of the International Monitoring System (IMS) have been installed. Almost all of these stations are providing data to the International Data Center (IDC), which produces an analyst reviewed bulletin containing on average 100 events per day, based on processing of seismic, infrasound and hydroacoustic data. 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 (OSIs) to clarify concerns raised by member states related to events detected and located by the IMS/IDC system, have also reached a mature stage and were tested in a large-scale exercise held in Kazakhstan in September 2008, from which many lessons for the further development of the OSI regime were learned.

The presentation will provide an 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.

Delicious Leaks and Google Games

(Swedish: Läckra läckor och Googlekar)

Lars-Erik De Geer

Through the years FOA/FOI in Sweden has detected radionuclides that leaked from underground nuclear explosions abroad. Although sometimes a victim of semantic discussion these events can be considered violations of the 1963 Partial Test Ban Treaty. More importantly they have given valuable experience that has had an impact on the design of the radionuclide arm of the CTBT verification enterprise that is currently in building.

These detections occurred nine times and they are all described in this talk. In a Google Earth journey we then visit the crime scenes as well as a few other interesting nuclear sites nearby.

Analysis of small events near Semipalatinsk

Ingvar Nedgård

A well-known method to distinguish earthquakes from explosions is to use the measure of the m_b magnitude on the preliminary body wave and compare it to the measure of the M_s magnitude on the Rayleigh surface wave. For small events the M_s magnitude is difficult to measure due to attenuation and bad signal to noise ratio at larger distances. However, local seismic phases and their combinations can be used to gain more information from the events. Another way to get information is to compare the records from a given station with the records of an event in the same area. If the source function, the transfer function, and the receiver function are fairly similar correlation of the signals can show similarities.

Twenty-one events published in the Standard Event Bulletin (SEB) by the International Data Centre have been analysed. The time period covered is from 2002/03/30 to 2009/01/31. The events are located to three sites within the area 50 ± 2N 78 ± 2E with magnitudes M_L 2.6-3.3. One event has a score -0.77 (Rscore) which indicates that this is presumed to be a chemical explosion and not an earthquake. Fifteen events are presumed to be chemical explosions due to clear observed Rg phases that are present when the source is near the surface. The other five events are presumed to be chemical explosions after comparison to events with signals filtered 6-8Hz that also have Rg phases present.

Observation of Infrasound Signals Refracted from Thermospheric Altitudes Generated by Near-Surface Explosions

Steven J. Gibbons

Explosions are carried out at a site in northern Finland every year by the Finnish military to destroy old ammunition. The coordinates of the explosion site are known exactly and any two events are separated by at most ~350 meters. The yield of each event is close to 20000 kg and seismic signals are generated which indicate event magnitudes of ~1.5.

The ARCES seismic array, approximately 175 km to the north, records the seismic signals with a high SNR and provides excellent constraints on the explosion times and event magnitudes. Almost every event is followed by acoustic signals propagating over ARCES with air sound speed, sometimes down to the noise level and, on other occasions, with far higher amplitudes than the P and S phases and coda. The seismic signals are essentially identical from event to event whereas the infrasonic signals exhibit great differences with regard to the number of phases observed, travel times and amplitudes, indicating that differences in the infrasonic observations are the result of atmospheric factors only. ARCES lies inside the geometrical "Zone of Silence" for infrasonic arrivals from this site which makes this dataset of great interest for the study of infrasound propagation at regional distances. On some days, arrivals some 500 seconds after the event are observed at ARCES and these can be explained by ray-tracing given strong and favourable winds in the tropopause (at an altitude of ~10 km). The vast majority of infrasound signals at ARCES are observed between 600 and 650 seconds after explosion time, for which no arrivals are predicted by ray-tracing. These are most likely to be "partial reflections" from local stratified inhomogeneities in the stratosphere and mesosphere.

A temporary microbarograph mini-array was installed within ARCES which recorded 36 of these events in 2008. For 11 of these explosions, additional phases with high apparent velocities were observed at ~900 seconds which are consistent with phases that have propagated through the thermosphere. These are of lower amplitude and are more impulsive than the earlier arrivals. The microbarograph data suggests that the infrasound signals are frequently very emergent and traveltimes may have been overestimated significantly using only the seismometer data. Low-amplitude signals are often observed on the microbarographs up to 40 seconds before the signal on the co-located seismometer exceeds the background noise.

The December 16th, 2000 earthquake in southern Sweden and recent development of the seismological network in Denmark and Greenland

Peter Voss

The earthquake on the morning of DEC 16th, 2008 in southern Sweden was felt over a large part of Denmark. The earthquake caused little damage but due to its unusual occurrence in this region many people were shocked by the tremor. Police and other authorities were therefore flooded by phone calls from anxious persons, who in some cases had evacuated tall buildings. In the weeks after the earthquake GEUS received more that 4000 questionnaires, these have been analyses to map the intensity of the earthquake tremor. Data from the broad band seismic stations in Denmark are all transferred to the data centre at GEUS using Seedlink, the earthquake was therefore located within a few minutes after its occurrence.

The earthquake monitoring in Greenland have improved greatly the recent year. Two new broad band stations have been installed on the Greenland west coast both transmitting data in real-time and three other broad band stations have been upgraded to transmit data in real-time. These new real-time data are shared with several other data centres and registered in a dedicated real-time database at the Geological Survey of Denmark and Greenland. This database includes data from several other stations in the North Atlantic region.

With the support from the US National Science Foundation to the GreenLand Ice Sheet monitoring Network (GLISN) project, the real-time monitoring in Greenland the will improve significantly in the years to come, GLISN has the goal of 25 real-time station in Greenland and around Greenland.

Wenchuan Earthquake of May 12, 2008, Mw = 8.0. Reconnaissance Report

Kuvvet Atakan, Louise W Bjerrum and Mathilde B. Sørensen

The M 8.0 Wenchuan earthquake of May 12, 2008, affected a large area with heavy destruction. The earthquake cost more than 69000 lives and the damage is reported to have left more than 5 million people homeless. It is estimated that 5.36 million buildings have collapsed and 21 million buildings were damaged in Sichuan and the nearby provinces. Economic losses due to the event are estimated to be 86 billion USD. Combination of several factors such as mountainous landscape, strong ground motion, extensive landslides and rock-falls have exaggerated the human and economic consequences of this earthquake. Extensive damage is observed due to the shear size of the earthquake rupture and poor building constructions. Fault rupture complexity has further contributed to the intensity and distribution of damage. Here the rupture directivity effect had both positive and negative consequences, i.e. Chengdu has escaped significant damage, whereas Beichuan was devastated. Emergency response and rescue efforts as well as construction of temporary sheltering for large masses of people were successfully conducted by the Chinese authorities. However, there remain major challenges in cleaning up and permanent reconstruction of the damaged cities in the area. An overview of the earthquake characteristics and the associated damage, secondary effects and damage on buildings and infrastructure are given from field observations at selected fault rupture sites.

Strong ground motion simulation of the M = 8.0, May 12 2008 Wenchuan earthquake, using various slip models

Louise W Bjerrum, Mathilde B. Sørensen and Kuvvet Atakan

On 12 May 2008, a devastating earthquake of M 8.0 occurred in the Sichuan Province of China. The earthquake had disastrous consequences and cost more than 69000 lives. The rupture occurred along an approximately 300 km long fault dipping north-west along the Longmenshan Fold and Thrust Belt, which separates the Longmenshan Mountains of the Tibetan plateau in the north-west from the Sichuan basin in the south-east and is associated with a significant change in the crustal thickness. We simulate the ground shaking due to this event by applying a hybrid broadband frequency strong ground motion simulation technique which combines deterministic simulation of low-frequency (0.1-1.0 Hz) with a semi-stochastic modeling approach for the high frequencies (1.0-10 Hz). We have used three available finite fault slip distributions based on waveform inversion as input models for the earthquake scenarios. The resulting simulations reveal large variation in ground shaking due to the rupture complexity in terms of e.g. the location of asperities and the width of the assumed fault plane. In addition, critical parameters that control the rupture process, such as the stress drop, rupture velocity and rise-time influence the absolute values of the ground motion. In this regard, the simulated ground motion distributions are calibrated with the actual strong motion records of the Wenchuan earthquake at short distances. The applied methodology successfully reproduces the strong ground motion distributions and frequency content of the seismic waves. Comparison with the damage distribution from reconnaissance field observations confirms the fault rupture complexity. The applied simulation methodology provides a promising platform for predictive studies.

The earthquakes in the Gulf of Bothnia area on 15 and 23 June 1882

Päivi Mäntyniemi and Rutger Wahlström

The earthquakes of 15 and 23 June 1882 stand out in the seismicity record of the Gulf of Bothnia. In an interval of just eight days, two events with magnitudes, M_L, of 4.6 and 4.9, respectively occurred (Ahjos and Uski, 1992). The event of 23 June 1882 is usually referred to as the strongest historical earthquake in Finland. The basic parameters rely on the study by Moberg (1891) that provides two isoseismals for the first earthquake and three isoseismals for the second one on his 3-degree intensity scale. The present contribution investigates the primary macroseismic sources available for the two earthquakes, which were felt over large areas in northern Finland and Sweden. The reports were retrieved from questionnaires and a thorough search in contemporary newspapers. The collected material was used to prepare so-called intensity data point (IDP) maps. They show the places for which felt reports of the earthquakes are available. The respective intensities were assessed on the European Macroseismic Scale. The new maps are presented and the consequent changes in earthquake parameters discussed.

Seismological studies of the Pärvie endglacial fault system, northern Sweden

Eva Karlsson, Björn Lund, Pálmi Erlendsson, Christopher Juhlin, A. Dehghannejad, Reynir Bödvarsson, Tormod Kvaerna and Marja Uski

The Pärvie fault extends for over 150 km and is one of the largest known endglacial faults. The fault exhibits reverse faulting throw of more than 10 m and based on studies of Quarternary deposits, landslides and liquefaction structures it is inferred to have ruptured as a one-step event. An earthquake of this size would have had a magnitude of approximately 8. Understanding the mechanics of the Pärvie, and other large endglacial faults, requires knowledge of the prevailing stress field, rock properties and the geometry of the fault. As the causative stress field contained contributions from both tectonic and glacially induced stresses, it is non-trivial to estimate. Assuming the tectonic stress has remained constant throughout the latest glaciation, knowledge of the fault geometry would significantly contribute to our understanding of the mechanics of endglacial faulting.

In an ongoing seismological study of the Pärvie fault, we have acquired a 20 km long seismic reflection profile across the fault. Using seven temporary seismic stations, in addition to the eight permanent northernmost stations of the Swedish National Seismic Network and a collaborating Finnish station, we are currently recording microearthquake activity along the fault. The results of the reflection seismic processing indicate that the surface supracrustals rocks extend to about 1 km depth with the base generating a strong wide-angle reflection. The faults are imaged from the near surface down to about 2 km depth and the profile crosses three surface mapped faults. The seismic stations have recorded numerous small events, many of which are mining induced microearthquakes from the nearby Kiruna iron ore mine. Large numbers of microearthquakes originate from the vicinity of the Pärvie fault system, the current station geometry allows detection and location of events as small as magnitude -2. We present hypocenter locations and focal mechanisms of all recorded events. Clusters of closely located earthquakes have been relocated with both a joint hypocenter determination and a double difference algorithm. We invert the focal mechanisms for the causative state of stress and show how stress estimates vary along strike of the fault.

And the beat goes on! Is the resurgent activity along the Reykjanes peninsula similar to what we have observed in the last decade?

Björn Lund , **Marie Keiding and Þóra Árnadóttir**

During 2009, earthquake activity has resumed in both the Krísuvík and Fagradalsfjall areas on the Reykjanes Peninsula, after a period of relatively low seismicity rate since 2004. During short-lived swarms in January, June and July-August of 2009 more than 350 events per day were recorded in the Krísuvík area, with magnitudes reaching above 4, and elevated activity persists into September. Fagradalsfjall experienced similar swarms in February and May-June of this year, but with a lower background seismicity. The increased seismicity in the Krísuvík area coincides with geodetic observations indicating increased pressure in the geothermal system, or even magmatic activity. What does the resurgent seismicity reveal about this process? Have we seen it before? Here we analyze b-values, focal mechanisms and the state of stress using the 2009 seismicity and compare that to a similar analysis of the Reykjanes seismicity between 1997 and 2006.

During 1997–2006, pronounced swarm activity was observed in both the Fagradalsfjall and Krísuvík areas, as well as moderate mainshocks in the Krísuvík area. A close spatial relationship between the area of high seismicity and the geothermal field in Krísuvík suggests that the geothermal activity has some influence on the seismicity in this area. No geothermal alteration is observed at the surface in the Fagradalsfjall area, and it is not known if there are particular triggering mechanisms behind the swarm activity in this area.

The state of stress estimated by inversion of micro-earthquake focal mechanisms from the 1997 – 2006 SIL catalogue is mainly oblique strike-slip, with a tendency towards a normal stress state. Mapping the directions of the least compressive horizontal stress (S_{hmin}) shows an average direction of N(120   6)   E and a remarkable agreement with the directions of greatest extensional strain rate ($_{Hmax}$) derived from GPS velocities during 2000–2006. The agreement between the directions of stress at depth and strain rate observed at the surface indicates that the earthquakes are primarily driven by plate motion. Geothermal fluids may, however, act as a secondary triggering mechanism of the seismicity in the Krísuvík area.

Seismic detection and on-site survey of mine collapses in Estonia

Heidi Soosalu, Ingo Valgma and Kalmer Sokman

In Estonia, seismicity is monitored by a 3-station national network and the Finnish network of the Institute of Seismology, University of Helsinki. Estonia is a low-seismicity region (in average one earthquake per two years). However, ~70 man-made seismic events (magnitudes < 2) per month are detected. Majority of them are due to blasts in oil shale open cast mines or limestone quarries. Mining companies provide information on their blasting schedules, easing the seismic analysis.

In 2008, two extraordinary seismic events were detected and located to the oil shale mine Estonia: on 21 January at 01:30, local time, (magnitude 1.8) and on 2 July at 01:44 (magnitude 2.0). They occurred in atypical time of day, which raised suspicion of them not being ordinary explosions. Moreover, seismograms differed significantly of signals produced by either mining blasts or local earthquakes.

The mining company Eesti Põlevkivi (currently Eesti Energia Mining) confirmed them as collapses within a room and pillar section that was being exploited in the Estonia mine. Both of them occurred in almost the same location. The primary trigger for main roof failure was a zone of weakness in the layers of sedimentary rocks (limestone) due to karst formation.

Environmental effects of the first occurrence, including ground subsidence and fissures, were observed and measured in field. Although these particular collapses were known, this study shows that seismic monitoring is useful for detecting collapses (also retrospectively), and locating them reasonably accurately, also at sites which could otherwise pass unnoticed.

This study is related to EstSF Grant 7499.

POLENET/LAPNET-a multidisciplinary seismic array research in northern Fennoscandia

Elena Kozlovskaya, Hanna Silvennoinen, Teppo Jämsen & POLENET/LAPNET Working Group

A POLENET (http://polenet.org) - POLar Earth observing NETwork is a multidisciplinary consortium of activities during the International Polar Year 2007-2009 that aims to dramatically improve the coverage in geodetic, magnetic, and seismic data across the polar regions (both Arctic and Antarctic). Compared to other continental regions of the Earth, the polar regions are poorly studied by seismic methods. These regions have unique geodynamic environments where the solid Earth, the cryosphere, the oceans, the atmosphere and the global climate system are closely linked. In the high latitudes, the weight of ice-sheets provides an additional force affecting the state of stress and deformation in the lithosphere. In accordance with the scientific program of POLENET, the main targets of seismic observations in polar regions (bi-polar seismology) can be formulated as follows:

1) Studying the deep structure of the Earth (in particular, the Earth's core)
2) Studying the lithosphere structure of polar regions (including structure and evolution of the Archean lithosphere) and estimation of realistic distribution of mantle viscosity in the areas of glacial isostatic adjustement
3) Studying the cryosphere-lithosphere interaction and glacial seismic events.

One of the sub-projects of POLENET related to seismic studies in the Arctic regions is POLENET/LAPNET – a multidisciplinary seismic array research in northern Fennoscandia The POLENET/LAPNET broadband array, with the average spacing between stations of 70 km, was designed to solve specific tasks of polar seismology. The geographic position of the LAPNET array is favorable for registering seismic phases travelling through the Earth's core, because it is located at epicentral distances of 120-150 deg from seismically highly active area around Fiji, Tonga, Vanuatu and Kermadec Islands in the Pacific Ocean, where the earthquake with the magnitude of more than MW =5.5 are quite usual. In addition, it is continuation of the previous SVEKALAPKO seismic array research in southern and central Finland aiming at studying the lithosphere-asthenosphere system in the suture zone of Proterozoic Svecofennian and Archaean Karelian domains of the Fennoscandian Schield. One of the main targets of the LAPNET research is to obtain a 3D seismic model of the crust and upper mantle down to 670 km (P- and S-wave velocity models, position of major boundaries in the crust and upper mantle and estimates of seismic anisotropy strength and orientation) in northern Fennoscandian Shield.

An important part of the LAPNET project is studying of regional and local seismic events. In Fennoscandia, the natural seismicity is of intraplate type, and, in general, is low-to-moderate in magnitude. In the area covered by the LAPNET array, the local seismic events are quarry blasts and earthquakes originating from several re-activated ancient faults and other zones of weakness in the crust. Studying of local events will help to map these zones and improve understanding of local seismicity and seismic hazard in Fennoscandia.

Compared to the previous seismic array experiments in Fennoscandia (TOR and SVEKALAPKO), which were oriented primarily on recording and storage of waveforms of teleseismic events with relatively low sampling rate of 20 Hz, the LAPNET array records high-frequency continuous data (sampling rate from 50 to 100 Hz) which is pre-processed in Oulu, Grenoble and Prague and stored in the data centre of the University of Grenoble. Due to high sampling rate, the LAPNET dataset can be useful not only for such traditional techniques as teleseismic body wave tomography, surface wave studies, receiver functions and seismic anisotropy studies, but also for the methods based on ambient seismic noise analysis, studying of source mechanisms of local events, discrimination of man-made activities and natural events etc.

The array consists of 32 temporary stations deployed in northern Fennoscandia and of existing permanent broadband stations in northern Finland (Sodankylä Geophysical Observatory of the University of Oulu and Institute of Seismology of the University of Helsinki), Sweden (Swedish National Seismological Network, University of Uppsala) and Norway (NORSAR and the University of Bergen). The equipment for the temporary array was provided by Sodankylä Geophysival Observatory, University of Grenoble and University of Strasbourg (France),Geophysical Institute of Academy of Sciences, Prague (Czech Republic), Institute of Geodesy and Geophysics, Vienna University of Technology (Austria), Institute of Geophysics ETH Zurich (Switzerland), Institute of Geospheres Dynamics, RAS, Moscow (Russia), University of Leeds (UK). The financial support for operating of the LAPNET array was provided by the University of Oulu and by the Academy of Finland.

Most of the stations of the LAPNET temporary array were deployed in May-September, 2007. In summer, 2008 some of the instruments (mainly short-period) were changed to broadband ones and two more temporary station were deployed south of the array, in order to overlap with the previous SVEKALAPKO array. The array continued recording of local, regional and teleseismic events until September, 2009. At the moment, more than 50% data of temporary stations for 2007, 2008 and 2009 is processed and processing continues to the end of 2009.

Probabilistic Seismic Hazard Analysis for Latvia

(also presented as a poster)

Valery Nikulin

An estimation of seismic danger of Latvia in 1998 [Safronovs & Nikulins, 1999] allowed to set possibility of origin of earthquakes with intensity to 7 points for *MSK-64* scale. Probabilistic estimations were not however got.

In accordance with the requirements of the *European Committee for Standardization, Eurocode 8* must be adapted in 2010. The project of *National Annex* for adapting in Latvia *EN 1998-1:2004 (LVS EN 1998-1:2005 "Eurocode 8 – Design of structures for earthquake resistance – Part 1: General rules – Seismic action and rules for buildings")*, and also the proper suggestions project for making alterations in Latvian building codes of *LBN 005 – 99 ("Rules of engineer researches for building"*) was arranged by initiative and by support of Ministry of Economy of Latvia, in accordance with recommendations of *EN 1998-1:2004*.
The decision of task was based on combination of the determined (*Deterministic Seismic Hazard Analysis - DSHA*) and probabilistic (*Probabilistic Seismic Hazard Analysis - PSHA*) approaches with predominance of probabilistic method.

As a result of seismotectonic analysis 8 internal seismic sources zones were selected on Latvian territory. The magnitude-frequency distributing is got for offshore and continental part of Baltic. Values of all magnitudes types are counted to moment magnitude. A function of attenuation of seismic energy (Abramseys *et al*., 2005) depending on a mechanism in earthquake source zone, magnitude type, focal depth and epitsentral distance for territory of Europe and Near East was used for the probabilistic analysis in it investigation. The parameter of seismic activity b was changing from 0.33 (continental part) to 0.38 (offshore part).

As a result calculations by program *CRISIS99* the estimations of *Peak Ground Acceleration* (*PGA*) of hard subsoil of Pre-Quaternary deposits are got with 10%, 5%, 1% and 0.5% by probability of the possible exceeding of calculated seismic intensity during 50 years.

Results and conclusions

1. With probability 10%, during 50 years on hard subsoil, Pre-Quaternary deposits of Latvia, *PGA* can exceed 10 - 13 cm/sek^2 in Sigulda, Riga, Olaine, Aizkraukle, Cesis and their environs.
2. *PGA* does not exceed 0.04g (39 cm/sec^2) on the surface of Pre-Quaternary deposits of Latvia. According to *EN 1998-1:2004* requirements of it corresponds to very low level of seismic risk.
3. Seismic risk includes the estimation of *PGA* on Pre-Quaternary deposits and seismic response of the unconsolidated Quaternary deposits overhead 30-meter layer. Subsoils of A class (Vs > 800 m/s) are characteristic for Pre-Quaternary deposits. For the estimation of seismic vulnerability on the surface of soil, it is necessary additionally to estimate the seismic response of Quaternary deposits. The thickness of Quaternary deposits in Latvia changes from 5 up to 310 m. Preliminary estimations show that in some cases a response spectrum on the surface of Quaternary deposits is more than 0.05 g. In this case, in accordance with recommendations of *EN 1998-1:2004*, expediently to take into account the seismic actions for planning of buildings.

3-D crustal velocity model for Lithuania and surroundings and its application to local event studies

Elena Kozlovskaya, Mantas Budraitis, I. Janutyte, Gediminas Motuza and PASSEQ Working Group.

PASSEQ 2006-2008 project (PASsive Seismic Experiment in TESZ) aimed at studying the lithosphere-asthenosphere system around the TransEuropean Suture Zone (TESZ)- the transition between old Proterozoic platform of north and east Europe and younger Phanerozoic platform in central and western Europe. The experiment was a seismic array research aiming to retrieve the structure of the crust and Earth's mantle down to the mantle transition zone, including mapping of upper mantle seismic velocity variations and discontinuities (Moho, lithosphere-asthenosphere boundary, mantle transition zone) using all available techniques. During the experiment 26 seismic stations (including four broadband stations) were deployed in Lithuania and operated since June, 2006 till January, 2008. One of the main reasons of PASSEQ deployment in Lithuania was identification and characterisation of the local seismic activity. During the data acquisition period a number of local seismic events was recorded. Preliminary location of 36 selected events with good quality of waveforms was made using LocSat algorithm. After that the events were relocated with VELEST software using 1-D velocity model representing the averaged crustal structure beneath Lithuania. These standard procedures are not enough precise for our study area, however, because the thickness of the crust varies significantly in the region (from 45 to 55 km). Another problem was low quality of S-wave arrivals due to thick (up to 2 km) sediments in most part of Lithuania.

In order to improve event location, we compiled a 3-D seismic velocity of the crust of Lithuania and surroundings down to a depth of 60 km. The model samples mainly Precambrian part of the PASSEQ study area and consists of four major layers (sediments, upper crust, middle crust, lower crust and uppermost mantle). The sedimentary layer was compiled from the drilling data, while the velocity in other layers was constrained using 2-D velocity models along previous wide-angle reflection and refraction profiles that were interpolated into 3-D regular grid. The quality of the approximation was analysed using comparison of travel times of P-waves recorded by controlled source experiments and calculated travel times through the 3-D velocity model. The model was converted into a density model using a special procedure, in which the density model is approximated by relationship between seismic velocity and density and the latter is found using inversion of the Bouguer anomaly. Comparison of the inversion result to the observed Bouguer anomaly showed that the upper crustal layer needs to be corrected, in particular, in the areas not covered by the profiles. The corrected velocity model was then used to improve location of local events. The epicenters of events relocated with the use of a 3-D model are less scattered and some of the clusters are confined to known areas of human activity.

POSTERS

Interpretation of wide-angle reflection and refraction recordings of Vibroseis signals and 3-D gravity modelling along FIRE4 profile, northern Finland

Hanna Silvennoinen, Elena Kozlovskaya, Jukka Yliniemi and Timo Tiira

The Finnish Reflection Experiment (FIRE) was a deep CMP reflection seismic survey made by Vibroseis technique along four profiles in Finland during 2001 – 2003. During the experiment thirteen recording stations were deployed along the FIRE4 profile to record wide-angle signal from vibrator sources. The profile is 235 km long. The first arrivals and reflected P-waves penetrate to a depth of 5 km and can be traced to offsets of 20 – 60 km. Using these arrivals, we obtained a P-wave velocity model of the uppermost crust with both forward raytrace modelling and inversion. The major geological units can be seen in the model as horizontal variations in the P-wave velocity. Also some below surface features could be recognized. The most interesting feature in the velocity model is a zone of high P-wave velocity at a depth of about 2 – 3 km inside Central Lapland Granitoid Complex that is marked also by high reflectivity on FIRE4 reflection section. A large-scale maximum of the Bouguer anomaly is also observed above this area. To constrain the depth of this feature and explain it in terms of rock composition, we applied inversion of Bouguer anomaly and calculated a 3-D density model of the uppermost crust for the area around the profile. Our study shows that recordings of Vibroseis sources registered by 1 Hz and 2 Hz geophones can be effectively used for velocity modelling in the uppermost crust. The modelling of reflected and refracted waves made it possible to recover P-wave velocity inhomogeneities in the upper crust down to a depth of 5 km. The quality and the resolutions of wide-angle Vibroseis data is sufficient to distinguish between different lithological units in the upper crust based on velocity differences. Also, the reflectors detected by wide-angle data are partially coincident with reflectors seen in the near-vertical reflection section. Therefore, the method complements efficiently traditional reflection seismic surveys and can be used to investigate the detailed structure in the uppermost crust.

Earthquake tremor observed in magnetic measurements

Peter Voss, Cathrine Fox Maule, Lars W. Pedersen, Jürgen Matzka, Anna Nilsson and Søren Gregersen

The tremor of the December 16th 2008 earthquake in southern Sweden was recorded on magnetometers at two locations in Denmark. The magnetometers are the DMI FGE pendulum fluxgate magnetometer model. This instrument is comparable to seismic sensors since the magnetometer, with 3 orthogonal sensors, is hanging in two leaf springs and movement of the magnetometer is damped by a cylinder hanging in an oil bath. The leaf springs are used to reduce the effect of ground tilt in the magnetic measurement. We have analysed the magnetic recordings of the December 16th earthquake and conducted a laboratory test of the magnetometer to determine whether this type of instrument can be used for earthquake location and magnitude determination. The results of these tests are presented together with the magnetic recordings and selected seismic recordings of the December 16th 2008 earthquake. These results show that the magnetic recording of the earthquake tremor is in many ways similar to seismic recordings. Magnetic recording of earthquake tremor is not unusual which we illustrate by three additional magnetic recordings of two earthquakes in Greenland and one in China.

A map of non-tectonic seismic sources in the East Baltic region

Bela Assinovskaya, Valery Nikulin, Heidi Soosalu and Andrius Pacesa

For evaluating seismic hazard within the East Baltic region (in particular, microzonation of Kaliningrad in connection with the Kaliningrad earthquake), it is needed to estimate seismic risk in Latvia and Baltic States, and to create new catalogues (databases) of earthquakes from mid-1960's (beginning of instrumental observations in the Baltic region) up to present. In addition, modern building codes and rules in Russia, and also European standards (in the EU in particular *Eurocode-8*), require compilation of detailed seismic zoning and estimation of seismic risk, especially for earthquake-prone objects. It is obvious that existent maps of seismic hazard, OSR - 97 in Russia and GSHAP (Global Seismic Hazard Map, Central-northern Europe*),* which are usually made for a time-span of 20 years, have already became somewhat out-of-date in regard with basic seismic data. In addition, these catalogues contain earthquakes with Mw> 3, while detailed evaluation of seismic hazard for territories of low seismic activity usually includes all existent seismic information.

The operative bulletins of Geophysical Service of RAS and EMSC, existent national catalogues, and also world catalogues of ISC, NEIS are presently used in Russia for compilation of specialized catalogues. The indicated reports for the period 1991-2008 on the East Baltic region contain large number of non-tectonic events: blasts in quarries and open or underground mines (extraction of minerals or building material), technological explosions, including geophysical experiments both on land and at sea (for instance, deep seismic sounding (*Eurobridge-95*)), military explosions (such as destruction of war-time mines in the Baltic Sea), unintended man-made or triggered events (e.g. mine collapses), and simply artefacts. As it is generally known, non-tectonic events can create misleading interpretations of catalogues, change presumed seismic properties of the examined area, and lead to erroneous values of Mmax. Eliminating artificial, non-tectonic events from catalogues is very labour-intensive, if the nature of each case needs to be studied separately.

The presented work is devoted for compilation of map of technogenic seismic sources in the East Baltic - *TSSEB-2009*, i.e. a map of non-tectonic, man-made seismic sources for the East Baltic region for the period 1990-2008, which will give a quick overview of the seismic circumstances of the region as a whole. The plan of the authors is that the *TSSEB* map must be constantly updated, because man-made sources will appear and disappear in the course of time. This work is international co-operation of seismologists of Latvia, Lithuania, Estonia and Saint Petersburg region of Russia.

Spot-checking of IMS location accuracy

Nils-Olov Bergkvist and Peder Johansson

It is of the utmost importance that the International Monitoring System (IMS) has a capacity to precisely locate shallow seismic events of low magnitude. The importance is easy to understand in the context of a possible on-site inspection as 1000 km^2 is the maximum allowed search area for an inspection. This poster gives an account of the current IMS location accuracy based on analysis of events from a number of source regions (spot-checking).

The current IMS network detects and locates hundreds of mining blasts and mining associated events per year on a global basis. These events can provide a good spot-checking of the IMS location accuracy as they are both shallow and in a magnitude range of high relevance for the CTBT - the generalized body wave magnitude (mb1) is mostly in the interval 3 to 4.

Around one hundred and fifty events from 8 mining areas and large enough to be included in the Reviewed Event Bulletin (REB), produced by the International Data Center (IDC), have been studied. Three areas are in Europe (Sweden and Poland), two areas in Africa (Republic of South Africa), two in Asia (Kazakhstan) and one in North America (Wyoming, US). Ground truth information has been obtained from various sources. Four areas are covered by regional bulletins with a stated accuracy of 3 to 5 km and the other four areas are single mines whose locations can be obtained from Google Earth. To check the current location accuracy recent events (mostly in 2007-2008) have been used.

The location accuracy varies from one area to another, both in terms of systematic errors and the “random” component.

Systematic errors in the REB locations can be seen in many of the areas. Surprisingly, the largest systematic error (around 20 km) is seen for events in Wyoming although source-specific station corrections are being used for IMS stations in North America.

The 90% confidence ellipses associated to the REB locations are less than 1000 km^2 for all areas except Wyoming where many are larger. In spite of being large only 4 out of 32 confidence ellipses in Wyoming cover the ground truth location. This can be compared to the other extreme, tremors in the mining areas of the Republic of South Africa where 11 out of 12 confidence ellipses cover the ground truth location and all have an area less than 1000 km^2. Averaging over all areas studied the 90% confidence ellipses cover the ground truth location in just around half the cases. This shows that they are often too optimistic and underestimate the scatter.

Although in general the REB locations are useful for an on-site inspection for most of the areas, the locations are very sensitive to the phase identification for stations at regional distances. One single phase change (Pn to Pg, Sn to Lg) can move the event location tens of kilometres. A few examples of this happening are seen in the events studied.