NORSAR

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Semiannual Technical Summary

1 July - 31 December 2007

Frode Ringdal (ed.)

Kjeller, February 2008

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14. ABSTRACT
This report describes the activities carried out at NORSAR under Contract No. FA2521-06-C-8003 (T/6110) for the period 1 July - 31 December 2007. In addition, this report provides summary information on operation and maintenance (O&M) activities at the Norwegian National Data Center (NDC) during the same period. Research activities described in this report are largely funded by the United States Government, and the United States also covers the cost of transmission of selected data to the US NDC. The O&M activities, including operation of transmission links within Norway and to Vienna, Austria, are being funded jointly by the CTBTO/PTS and the Norwegian Government, with the understanding that the funding of O&M activities for primary stations in the

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Abstract (cont.)

International Monitoring System (IMS) will gradually be transferred to the CTBTO/PTS. The O&M statistics presented in this report are included for the purpose of completeness, and in order to maintain consistency with earlier reporting practice. Some of the research activities described in this report are funded by the United States Government, and the United States also covers the cost of transmission of selected data from the Norwegian NDC to the United States NDC.

The seismic arrays operated by NOR-NDC comprise the Norwegian Seismic Array (NOA), the Arctic Regional Seismic Array (ARCES) and the Spitsbergen Regional Array (SPITS). This report presents statistics for these three arrays as well as for additional seismic stations which through cooperative agreements with institutions in the host countries provide continuous data to NOR-NDC. These additional stations include the Finnish Regional Seismic Array (FINES) and the Hagfors array in Sweden (HFS).

The NOA Detection Processing system has been operated throughout the period with an uptime of 100%. A total of 1,967 seismic events have been reported in the NOA monthly seismic bulletin during the reporting period. On-line detection processing and data recording at the NDC of data from ARCES, FINES, SPITS and HFS data have been conducted throughout the period. Processing statistics for the arrays for the reporting period are given.

A summary of the activities at the NOR-NDC and relating to field installations during the reporting period is provided in Section 4. Norway is now contributing primary station data from two seismic arrays: NOA (PS27) and ARCES (PS28), one auxiliary seismic array SPITS (AS72), and one auxiliary three-component station (AS73). These data are being provided to the IDC via the global communications infrastructure (GCI). Continuous data from the three arrays are in addition being transmitted to the US NDC. The performance of the data transmission to the US NDC has been satisfactory during the reporting period.

So far among the Norwegian stations, the NOA and the ARCES array (PS27 and PS28 respectively), the radionuclide station at Spitsbergen (RN49) and the auxiliary seismic stations on Spitsbergen (AS72) and Jan Mayen (AS73) have been certified. Provided that adequate funding continues to be made available (from the PTS and the Norwegian Ministry of Foreign Affairs), we envisage continuing the provision of data from these and other Norwegian IMS-designated stations in accordance with current procedures. The IMS infrasound station at Karasjok (IS37) is expected to be built during 2008, provided that the local authorities grant the permissions required for the establishment of the station.

Summaries of four scientific and technical contributions are presented in Chapter 6 of this report.

Section 6.1 is a paper which was presented at the 29th Seismic Research Review and which contains a progress report of a project entitled “Basic research on seismic and infrasonic monitoring of the European Arctic”. This project represents a three-year research effort aimed at improving seismic and infrasonic monitoring tools at regional distances, with emphasis on the European Arctic region, which includes the former Novaya Zemlya test site. The project has three main components: a) to improve seismic processing in this region using the regional seismic arrays installed in northern Europe, b) to investigate the potential of using combined seismic/infrasonic processing to characterize events in this region and c) to carry out experimental operation, evaluation and tuning of the seismic threshold monitoring technique, with application to various regions of monitoring interest.

We have continued our studies of seismic and infrasonic recordings of a set of more than 100 surface explosions in northern Finland, carried out for the purpose of destroying old ammunition. Waveform correlation analysis indicates that these explosions were very closely spaced, and occurred at most within a few hundred meters of each other. This is a unique set of events given the repeatable nature of the source. Very similar waveforms and amplitudes are observed for the seismic phase arrivals, indicating a similar explosion yield and source function for each event. In contrast, the infrasonic recordings show great variation between events, both with regard to the number and amplitudes of detected infrasonic phases, as well as their travel times. A variation of several tens of seconds in travel times for corresponding phases for different events is observed at a distance of about 175 km.

An important aspect of the infrasonic studies is the availability of data from a distributed network of arrays. The Swedish infrasound array network provides a useful supplement to the seismic and infrasonic arrays in Norway and NW Russia. We have begun exploiting the data from this network, which will allow a much improved joint seismic/infrasonic regional processing at NORSAR. We continue our work towards developing and evaluating a joint seismic/infrasonic bulletin for northern Fennoscandia and adjacent regions. This bulletin would be similar to the automatic seismic bulletin that we are currently providing on the NORSAR Web pages, but it would also contain infrasonic phase associations. Furthermore, we will experimentally attempt to generate an infrasonic event bulletin using only the estimated azimuths and detection times of infrasound phases recorded by stations in the Nordic network.

The recent upgrade of the Spitsbergen seismic array, which has included installation of five new three-component seismometers, as well as an increase in the sampling rate from 40 to 80 Hz, has resulted in significant improvements in high frequency signal characterization as well as S-phase detection. We demonstrate some results from analysis of recent small seismic events near Novaya Zemlya and in the Barents Sea.

We have analyzed the recorded waveforms from the 9 October 2006 North Korean nuclear explosion in order to investigate the capability of the seismic IMS network to monitor the North Korean test site for possible future explosions. Our analysis is based upon the so-called Site-Specific Threshold Monitoring (SSTM) approach. Using actual seismic data recorded by a given network, SSTM calculates a continuous “threshold trace”, which provides, at any instance in time, a probabilistic upper magnitude bound on any seismic event that could have occurred at the target site at that time. We find that the current IMS primary network has a typical “threshold monitoring capability” of between mb 2.3 and 2.5 for the North Korean test site. Not unexpectedly, it turns out that the Korean array (KSRS) is of essential importance in obtaining such low thresholds. Non-IMS stations could also make important contributions, and we find that by adding the nearby IRIS station MDJ in China, the threshold monitoring capability is improved to between magnitude 2.1 and 2.3. For comparison, the three-station network detection threshold is found to be typically one magnitude higher than these numbers. We note, however, that the SSTM approach is not aimed at detecting events, but rather to supplement traditional detection processing by enabling the analyst to focus on and analyze extensively instances where a possibly undetected event of monitoring interest could have occurred.

Section 6.2 describes an investigation of recorded infrasound signals from four confirmed rocket launches at the Plesetsk Cosmodrome in northwest Russia as well as studies of infrasound signals from five possible (unconfirmed) launches from the same site. We have in particular attempted to obtain an understanding of the overall signal characteristics as well as the inherent variability among these signals. We have used available recordings both from the Apatity infrasound array and from the stations of the Swedish Infrasound Network. In order to obtain a good overview of the signal characteristics we have processed the infrasound data using vespagram analysis.

For two of the confirmed launches, we have sufficiently good quality recordings from three arrays. We find that the closest array (Apatity, at a distance of 628 km), has high signal-to-noise ratio for the infrasound recordings, and that the signal duration is almost 10 minutes. Two of the Swedish arrays (Kiruna and Jämtön, at a distance of about 1000 km) also have adequate recordings of these events, but with a lower SNR. The signal duration for the Swedish arrays is about 5 minutes. The backazimuths estimated during the wavetrains show some significant variations, with a deviation from the theoretical values by up to about 10 degrees. Particularly interesting is the azimuthal pattern at the Apatity array, which shows a clear trend of changing backazimuths with time, thus giving indications of a moving source. For the remaining two confirmed launches, we have only recordings from one array (Apatity), and again we see a time-varying trend, but in one of the cases the direction of change is reversed. This may be explained by differences in rocket takeoff directions relative to the Apatity station.

For the five unconfirmed events (which all occurred during one day - 23 January 2007) we see signal characteristics that are generally consistent with the observations of the confirmed launches, although there are some clear differences. When plotting the sectors corresponding to the observed backazimuth ranges for each array, we find a small area of overlap between the sectors, but this cannot be confidently interpreted as representative for the actual source location. Nevertheless, all the sectors contain the Plesetsk site, and it seems likely that they correspond to actual (unconfirmed) Plesetsk launches.

As a final step in our analysis we calculated differential travel-times for onsets of the infrasound signals at the Jämtön and Kiruna stations relative to Apatity. The onsets were read visually from the vespagrams, and had a rather high uncertainty. Similarities in the vespagram patterns were also used to infer the onsets. We find that we cannot separate the source location for the unknown signals from the verified Plesetsk launches based on these differential travel-times, and this is then consistent with our assertion that they may possibly be rocket launches from this site.

Section 6.3 descibes a project under the International Polar Year entitled ”The Dynamic Continental Margin Between the Mid-Atlantic-Ridge System (Mohns Ridge, Knipovich Ridge) and the Bear Island Region”. The project is being carried out by a consortium consisting of NORSAR (lead institution), the University of Bergen, the University of Oslo, the Alfred Wegener Institute in Bremerhaven, the University of Potsdam, the University of Warsaw and the Institute of Geophysics-Polish Academy of Sciences, Warsaw.

The project started in 2007 and is scheduled to be completed in 2010. This contribution gives an overview of the principal project objectives and the field activities which are planned or have already been carried out. The official project webpage (http://www.norsar.no/seismology/IPY/) is regularly updated.

The project is divided into two main parts. The first phase is an active / passive experiment and the second phase will be devoted to data processing and interpretation. The combination of active and passive experiments and the data from the distributed seismological arrays and stations will provide a unique opportunity to study the region of interest.

The passive experiment will monitor the seismic activity and thereby the actual tectonic stress field of the region by mapping regions of active seismicity and estimating the needed fault plane solutions.

The active profiling experiment will provide detailed information about the velocity structure and the distribution of major geological and tectonic elements down to the upper mantle. This information will then be utilized in (re)locating all seismic events in the region on the basis of a new, improved velocity model for the region.

The project involves installation of 12 ocean-bottom seismometers, one new three-component broadband seismometer at Hornsund, Spitsbergen, one three-component broadband seismometer on the island of Hopen, and installation of a small seismic array (13 three-component seismometers) on the Bear Island. These data will be coordinated with existing data from seismic arrays and networks in the region.

Section 6.4 is entitled “Overview of NORSAR system response”. Since the end of the 1960s, when the NORSAR array was first installed, until the current installation, the NORSAR array has been repeatedly reconfigured, once by reducing its size and numerous times by modifying the instrumentation. Consequently, the instrument response of the array has changed many times during the 40 years of its operation. Clearly, detailed knowledge of a seismographic system instrument response is critical for the correct interpretation of its recordings, since it affects both the amplitude and the phase of the recorded waveforms.

This contribution provides a brief summary of an ongoing project aiming to recalculate and organize all NORSAR system instrument responses, from the time of the first installation to the present. All sources of information are being catalogued and archived. Furthermore, detailed documentation is being compiled, describing the methodology followed to obtain the necessary information, the calculation of the responses, as well as more practical issues, such as organizing and storing the results for future usage. Therefore, no information such as individual instrument poles and zeroes, serial numbers, sensitivity values, etc. are provided here, the reader being referred to the relevant NORSAR internal documentation.

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Project Manager	:	Frode Ringdal +47 63 80 59 00
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The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

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The operational activities of the seismic field systems and the Norwegian National Data Center (NDC) are currently jointly funded by the Norwegian Government and the CTBTO/PTS, with the understanding that the funding of appropriate IMS-related activities will gradually be transferred to the CTBTO/PTS.

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1 Summary

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This contribution provides a brief summary of an ongoing project aiming to recalculate and organize all NORSAR system instrument responses, from the time of the first installation to the present. All sources of information are being catalogued and archived. Furthermore, detailed documentation is being compiled, describing the methodology followed to obtain the necessary information, the calculation of the responses, as well as more practical issues, such as organizing and storing the results for future usage. Therefore, no information such as individual instrument poles and zeroes, serial numbers, sensitivity values, etc. are provided here, the reader being referred to the relevant NORSAR internal documentation.

Frode Ringdal

2 Operation of International Monitoring System (IMS) Stations in Norway

2.1 PS27 — Primary Seismic Station NOA

The mission-capable data statistics were 100%, the same as for the previous reporting period. The net instrument availability was 98.915%.

There were no outages of all subarrays at the same time in the reporting period.

Monthly uptimes for the NORSAR on-line data recording task, taking into account all factors (field installations, transmissions line, data center operation) affecting this task were as follows:

2007		Mission Capable	Net instrument availability
July	:	100%	99.455%
August	:	100%	99.862%
September	:	100%	99.208%
October	:	100%	98.298%
November	:	100%	98.251%
December	:	100%	98.405%

B. Paulsen

NOA Event Detection Operation

In Table 2.1.1 some monthly statistics of the Detection and Event Processor operation are given. The table lists the total number of detections (DPX) triggered by the on-line detector, the total number of detections processed by the automatic event processor (EPX) and the total number of events accepted after analyst review (teleseismic phases, core phases and total).

	Total DPX	Total EPX	Accepted Events		Sum	Daily
			P-phases	Core Phases		
Jul	6377	746	291	97	388	12.5
Aug	7623	860	323	80	403	13.0
Sep	10061	792	228	64	292	9.7
Oct	10233	894	222	69	291	9.4
Nov	10536	839	193	71	264	8.8
Dec	12700	1052	246	83	329	10.6
	57530	5183	1503	464	1967	10,67

Table 2.1.1. *Detection and Event Processor statistics, 1 July - 31 December 2007.*

NOA detections

The number of detections (phases) reported by the NORSAR detector during day 182, 2007, through day 365, 2007, was 57,530, giving an average of 313 detections per processed day (184 days processed).

B. Paulsen

U. Baadshaug

2.2 PS28 — Primary Seismic Station ARCES

The mission-capable data statistics were 99.994%, as compared to 99.846% for the previous reporting period. The net instrument availability was 99.182%.

The main outages in the period are presented in Table 2.2.1.

Day	Period
Nov 24	16.38-16.45
Dec 18	05.16-05.24

Table 2.2.1. *The main interruptions in recording of ARCES data at NDPC, 1 July - 31 December 2007*

Monthly uptimes for the ARCES on-line data recording task, taking into account all factors (field installations, transmission lines, data center operation) affecting this task were as follows:

2007		Mission Capable	Net instrument availability
July	:	100%	99.702%
August	:	100%	97.014%
September	:	100%	98.474%
October	:	100%	100%
November	:	99.984%	99.923%
December	:	99.982%	99.982%

B. Paulsen

Event Detection Operation

ARCES detections

The number of detections (phases) reported during day 182, 2007, through day 365, 2007, was 196,037, giving an average of 1065 detections per processed day (184 days processed).

Events automatically located by ARCES

During days 182, 2007, through 365, 2007, 10,825 local and regional events were located by ARCES, based on automatic association of P- and S-type arrivals. This gives an average of 58.8 events per processed day (184 days processed). 58% of these events are within 300 km, and 83% of these events are within 1000 km.

U. Baadshaug

2.3 AS72 — Auxiliary Seismic Station Spitsbergen

The mission-capable data for the period were 89.160%, as compared to 100% for the previous reporting period. The net instrument availability was 84.016%.

The main outages in the period are presented in Table 2.3.1.

Day	Period
Sep 03	18.05-23.59
Sep 04	00.00-23.59
Sep 05	00.00-14.05
Sep 08	08.45-23.59
Sep 09	00.00-23.59
Sep 10	00.00-23.59
Sep 11	00.00-06.34
Sep 12	07.00-13.52
Sep 12	13.53-13-54
Sep 13	17.30-23.59
Sep 14	00.00-14.04
Sep 14	16.09-23.59
Sep 15	00.00-07.44
Sep 19	15.57-23.59
Sep 20	00.00-23.59
Sep 21	00.00-23.59
Sep 22	00.00-23.59
Sep 23	00.00-23.59
Sep 24	00.00-23.59
Sep 25	00.00-19.03
Nov 14	08.44-23.59
Nov 15	00.00-08.03
Nov 16	14.41-23.59
Nov 17	00.00-23.59
Nov 18	00.00-12.11
Nov 18	12.12-12.13
Nov 21	09.28-11.29
Nov 21	16.42-16.55
Dec 07	08.56-23.59
Dec 08	00.00-23.59
Dec 09	00.00-23.59
Dec 10	00.00-23.59

Day	Period
Dec 11	00.00-16.35

Table 2.3.1. *The main interruptions in recording of Spitsbergen data at NDPC, 1 July - 31 December 2007.*

Monthly uptimes for the Spitsbergen on-line data recording task, taking into account all factors (field installations, transmissions line, data center operation) affecting this task were as follows:

2007		Mission Capable	Net instrument availability
July	:	100%	97.633%
August	:	100%	95.238%
September	:	57.786%	53.101%
October	:	100%	99.999%
November	:	90.125%	83.338%
December	:	86.067%	73.768%

B. Paulsen

Event Detection Operation

Spitsbergen array detections

The number of detections (phases) reported from day 182, 2007, through day 365, 2007, was 417,409, giving an average of 2,413 detections per processed day (173 days processed).

Events automatically located by the Spitsbergen array

During days 182, 2007, through 365, 2007, 40,807 local and regional events were located by the Spitsbergen array, based on automatic association of P- and S-type arrivals. This gives an average of 235.9 events per processed day (173 days processed). 80% of these events are within 300 km, and 93% of these events are within 1000 km.

U. Baadshaug

2.4 AS73 — Auxiliary Seismic Station at Jan Mayen

The IMS auxiliary seismic network includes a three-component station on the Norwegian island of Jan Mayen. The station location given in the protocol to the Comprehensive Nuclear-Test-Ban Treaty is 70.9˚N, 8.7˚W.

The University of Bergen has operated a seismic station at this location since 1970. A so-called Parent Network Station Assessment for AS73 was completed in April 2002. A vault at a new location (71.0^{o}N, 8.5^{o}W) was prepared in early 2003, after its location had been approved by the PrepCom. New equipment was installed in this vault in October 2003, as a cooperative effort between NORSAR and the CTBTO/PTS. Continuous data from this station are being transmitted to the NDC at Kjeller via a satellite link installed in April 2000. Data are also made available to the University of Bergen.

The station was certified by the CTBTO/PTS on 12 June 2006.

J. Fyen

2.5 IS37 — Infrasound Station at Karasjok

The IMS infrasound network will include a station at Karasjok in northern Norway. The coordinates given for this station are 69.5˚N, 25.5˚E. These coordinates coincide with those of the primary seismic station PS28.

A site survey for this station was carried out during June/July 1998 as a cooperative effort between the CTBTO/PTS and NORSAR. The site survey led to a recommendation on the exact location of the infrasound station. There was, however, a strong local opposition against establishing the station at the recommended location, and two alternative sites were identified. The appropriate applications were sent to the local authorities to obtain the permissions needed to establish the station at one of these alternative locations. Both applications were turned down by the local governing council in June 2007. Discussions are currently underway with local stakeholders, in an attempt to identify a location for the station that will be acceptable to all parties.

A site preparation contract has been signed with the PTS. Due to scarce vegetation, possible high winds and difficult arctic operating conditions, the PTS has accepted our proposal to build a station comprising 9 elements.

J. Fyen

2.6 RN49 — Radionuclide Station on Spitsbergen

The IMS radionuclide network includes a station on the island of Spitsbergen. This station is also among those IMS radionuclide stations that will have a capability of monitoring for the presence of relevant noble gases upon entry into force of the CTBT.

A site survey for this station was carried out in August of 1999 by NORSAR, in cooperation with the Norwegian Radiation Protection Authority. The site survey report to the PTS contained a recommendation to establish this station at Platåberget, near Longyearbyen. The infrastructure for housing the station equipment was established in early 2001, and a noble gas detection system, based on the Swedish “SAUNA” design, was installed at this site in May 2001, as part of PrepCom’s noble gas experiment. A particulate station (“ARAME” design) was installed at the same location in September 2001. A certification visit to the particulate station took place in October 2002, and the particulate station was certified on 10 June 2003. Both systems underwent substantial upgrading in May/June 2006. The equipment at RN49 is being maintained and operated in accordance with a contract with the CTBTO/PTS.

S. Mykkeltveit

3 Contributing Regional Seismic Arrays

3.1 NORES

NORES has been out of operation since lightning destroyed the station electronics on 11 June 2002.

B. Paulsen

3.2 Hagfors (IMS Station AS101)

Data from the Hagfors array are made available continuously to NORSAR through a cooperative agreement with Swedish authorities.

The mission-capable data statistics were 99.980%, as compared to 97.877% for the previous reporting period. The net instrument availability was 98.845%.

The main outages in the period are presented in Table 3.2.1.

Day	Period
Jul 03	10.00-10.03
Jul 05	04.40-04.43
Jul 11	10.00-10.04
Jul 12	06.00-06.04
Aug 08	11.01-11.03
Aug 19	07.01-07.04
Aug 27	20.21-20.24
Aug 28	19.01-19.04
Sep 15	11.01-11.04
Oct 08	08.30-08.33
Oct 09	09.02-09.05
Oct 23	19.22-19.25
Nov 01	14.02-14.05
Nov 05	02.42-02.45
Nov 20	16.02-16.06
Dec 12	19.43-19.46

Table 3.2.1. *The main interruptions in recording of Hagfors data at NDPC, 1 July - 31 December 2007.*

Monthly uptimes for the Hagfors on-line data recording task, taking into account all factors (field installations, transmissions line, data center operation) affecting this task were as follows:

2007		Mission Capable	Net instrument availability
July	:	99.971%	95.105%
August	:	99.972%	98.106%
September	:	99.990%	99.988%
October	:	99.976%	99.975%
November	:	99.978%	99.978%
December	:	99.993%	99.991%

B. Paulsen

Hagfors Event Detection Operation

Hagfors array detections

The number of detections (phases) reported from day 182, 2007, through day 365, 2007, was 164,539, giving an average of 894 detections per processed day (184 days processed).

Events automatically located by the Hagfors array

During days 182, 2007, through 365, 2007, 3866 local and regional events were located by the Hagfors array, based on automatic association of P- and S-type arrivals. This gives an average of 21.0 events per processed day (184 days processed). 75% of these events are within 300 km, and 92% of these events are within 1000 km.

U. Baadshaug

3.3 FINES (IMS station PS17)

Data from the FINES array are made available continuously to NORSAR through a cooperative agreement with Finnish authorities.

The mission-capable data statistics were 96.691%, as compared to 99.445% for the previous reporting period. The net instrument availability was 95.279%.

Many short outages (not more than 10 seconds) occurred from August 23 to August 31.

The main outages in the period are presented in Table 3.3.1.

Day	Period
Jul 12	12.07-12.09
Jul 15	02.26-02.28
Jul 18	09.43-09.53
Jul 24	21.36-21.51
Jul 25	03.04-03.21
Jul 25	06.23-06.27
Jul 25	07.17-07.22
Jul 25	08.11-08.16
Jul 25	08.41-08.42
Jul 25	10.00-10.04
Jul 25	11.40-11.45
Jul 26	17.04-17.19
Jul 26	17.23-17.27
Jul 26	17.28-18.04
Jul 27	13.59-23.59
Jul 28	00.00-23.59
Jul 29	00.00-23.59
Jul 30	00.00-23.59
Jul 31	00.00-23.59
Aug 01	00.00-23.59
Aug 02	00.00-09.07
Aug 02	09.11-09.28
Aug 03	00.59-04.23
Aug 03	04.28-04.36
Aug 03	04.42-05.03
Aug 03	15.59-16.00
Aug 27	09.55-09.56
Sep 20	16.50-16.51

Table 3.3.1. *The main interruptions in recording of FINES data at NDPC, 1 July - 31 December 2007.*

Monthly uptimes for the FINES on-line data recording task, taking into account all factors (field installations, transmissions line, data center operation) affecting this task were as follows:

2007		Mission Capable	Net instrument availability
July	:	85.393%	79.194%
August	:	94.969%	94.535%
September	:	99.997%	99.480%
October	:	100%	99.9885
November	:	100%	98.729%
December	:	100%	100%

B. Paulsen

FINES Event Detection Operation

FINES detections

The number of detections (phases) reported during day 182, 2007, through day 365, 2007, was 38,148, giving an average of 213 detections per processed day (179 days processed).

Events automatically located by FINES

During days 182, 2007, through 365, 2007, 2102 local and regional events were located by FINES, based on automatic association of P- and S-type arrivals. This gives an average of 11.7 events per processed day (184 days processed). 86% of these events are within 300 km, and 95% of these events are within 1000 km.

U. Baadshaug

3.4 Regional Monitoring System Operation and Analysis

The Regional Monitoring System (RMS) was installed at NORSAR in December 1989 and has been operated at NORSAR from 1 January 1990 for automatic processing of data from ARCES and NORES. A second version of RMS that accepts data from an arbitrary number of arrays and single 3-component stations was installed at NORSAR in October 1991, and regular operation of the system comprising analysis of data from the 4 arrays ARCES, NORES, FINES and GERES started on 15 October 1991. As opposed to the first version of RMS, the one in current operation also has the capability of locating events at teleseismic distances.

Data from the Apatity array was included on 14 December 1992, and from the Spitsbergen array on 12 January 1994. Detections from the Hagfors array were available to the analysts and could be added manually during analysis from 6 December 1994. After 2 February 1995, Hagfors detections were also used in the automatic phase association.

Since 24 April 1999, RMS has processed data from all the seven regional arrays ARCES, NORES, FINES, GERES (until January 2000), Apatity, Spitsbergen, and Hagfors. Starting 19 September 1999, waveforms and detections from the NORSAR array have also been available to the analyst.

Phase and event statistics

Table 3.5.1 gives a summary of phase detections and events declared by RMS. From top to bottom the table gives the total number of detections by the RMS, the number of detections that are associated with events automatically declared by the RMS, the number of detections that are not associated with any events, the number of events automatically declared by the RMS, and finally the total number of events worked on interactively (in accordance with criteria that vary over time; see below) and defined by the analyst.

New criteria for interactive event analysis were introduced from 1 January 1994. Since that date, only regional events in areas of special interest (e.g, Spitsbergen, since it is necessary to acquire new knowledge in this region) or other significant events (e.g, felt earthquakes and large industrial explosions) were thoroughly analyzed. Teleseismic events of special interest are also analyzed.

To further reduce the workload on the analysts and to focus on regional events in preparation for Gamma-data submission during GSETT-3, a new processing scheme was introduced on 2 February 1995. The GBF (Generalized Beamforming) program is used as a pre-processor to RMS, and only phases associated with selected events in northern Europe are considered in the automatic RMS phase association. All detections, however, are still available to the analysts and can be added manually during analysis.

	Jul 07	Aug 07	Sep 07	Oct 07	Nov 07	Dec 07	Total
Phase detections	156,264	203,836	157,498	154,224	133,318	165,404	970,544
- Associated phases	5,036	8,349	5,814	6,421	5,196	5,458	36,274
- Unassociated phases	151,228	195,487	151,684	147,803	128,122	159,946	934,270
Events automatically declared by RMS	1,031	1,952	1,288	1,456	1,079	1,129	7,935
No. of events defined by the analyst	48	39	60	53	57	62	319

Table 3.5.1. RMS phase detections and event summary 1 July - 31 December 2007.

U. Baadshaug

B. Paulsen

4 NDC and Field Activities

4.1 NDC Activitities

NORSAR functions as the Norwegian National Data Center (NDC) for CTBT verification. Six monitoring stations, comprising altogether 132 field sensors plus radionuclide monitoring equipment, will be located on Norwegian territory as part of the future IMS as described elsewhere in this report. The four seismic IMS stations are all in operation today, and all of them are currently providing data to the CTBTO on a regular basis. PS27, PS28, AS73 and RN49 are all certified. The infrasound station in northern Norway is planned to be established within next year. Data recorded by the Norwegian stations is being transmitted in real time to the Norwegian NDC, and provided to the IDC through the Global Communications Infrastructure (GCI). Norway is connected to the GCI with a frame relay link to Vienna.

Operating the Norwegian IMS stations continues to require significant efforts by personnel both at the NDC and in the field. Strictly defined procedures as well as increased emphasis on regularity of data recording and timely data transmission to the IDC in Vienna have led to increased reporting activities and implementation of new procedures for the NDC. The NDC carries out all the technical tasks required in support of Norway's treaty obligations. NORSAR will also carry out assessments of events of special interest, and advise the Norwegian authorities in technical matters relating to treaty compliance. A challenge for the NDC is to carry 40 years' experience over to the next generation of personnel.

Verification functions; information received from the IDC

After the CTBT enters into force, the IDC will provide data for a large number of events each day, but will not assess whether any of them are likely to be nuclear explosions. Such assessments will be the task of the States Parties, and it is important to develop the necessary national expertise in the participating countries. An important task for the Norwegian NDC will thus be to make independent assessments of events of particular interest to Norway, and to communicate the results of these analyses to the Norwegian Ministry of Foreign Affairs.

Monitoring the Arctic region

Norway will have monitoring stations of key importance for covering the Arctic, including Novaya Zemlya, and Norwegian experts have a unique competence in assessing events in this region. On several occasions in the past, seismic events near Novaya Zemlya have caused political concern, and NORSAR specialists have contributed to clarifying these issues.

International cooperation

After entry into force of the treaty, a number of countries are expected to establish national expertise to contribute to the treaty verification on a global basis. Norwegian experts have been in contact with experts from several countries with the aim of establishing bilateral or multilateral cooperation in this field. One interesting possibility for the future is to establish NORSAR as a regional center for European cooperation in the CTBT verification activities.

NORSAR event processing

The automatic routine processing of NORSAR events as described in NORSAR Sci. Rep. No. 2-93/94, has been running satisfactorily. The analyst tools for reviewing and updating the solutions have been continually modified to simplify operations and improve results. NORSAR is currently applying teleseismic detection and event processing using the large-aperture NOA array as well as regional monitoring using the network of small-aperture arrays in Fennoscandia and adjacent areas.

Communication topology

Norway has implemented an independent subnetwork, which connects the IMS stations AS72, AS73, PS28, and RN49 operated by NORSAR to the GCI at NOR_NDC. A contract has been concluded and VSAT antennas have been installed at each station in the network. Under the same contract, VSAT antennas for 6 of the PS27 subarrays have been installed for intra-array communication. The seventh subarray is connected to the central recording facility via a leased land line. The central recording facility for PS27 is connected directly to the GCI (Basic Topology). All the VSAT communication is functioning satisfactorily. As of 10 June 2005, AS72 and RN49 are connected to NOR_NDC through a VPN link.

Jan Fyen

4.2 Status Report: Provision of data from Norwegian seismic IMS stations to the IDC

Introduction

This contribution is a report for the period July - December 2007 on activities associated with provision of data from Norwegian seismic IMS stations to the International Data Centre (IDC) in Vienna. This report represents an update of contributions that can be found in previous editions of NORSAR's Semiannual Technical Summary. All four Norwegian seismic stations providing data to the IDC have now been formally certified.

Norwegian IMS stations and communications arrangements

During the reporting interval, Norway has provided data to the IDC from the four seismic stations shown in Fig. 4.2.1. PS27 —NOA is a 60 km aperture teleseismic array, comprised of 7 subarrays, each containing six vertical short period sensors and a three-component broadband instrument. PS28 — ARCES is a 25-element regional array with an aperture of 3 km, whereas AS72 — Spitsbergen array (station code SPITS) has 9 elements within a 1-km aperture. AS73 — JMIC has a single three-component broadband instrument.

The intra-array communication for NOA utilizes a land line for subarray NC6 and VSAT links based on TDMA technology for the other 6 subarrays. The central recording facility for NOA is located at the Norwegian National Data Center (NOR_NDC).

Continuous ARCES data are transmitted from the ARCES site to NOR_NDC using a 64 kbits/s VSAT satellite link, based on BOD technology.

Continuous SPITS data were transmitted to NOR_NDC via a VSAT terminal located at Platåberget in Longyearbyen (which is the site of the IMS radionuclide monitoring station

RN49 installed during 2001) up to 10 June 2005. The central recording facility (CRF) for the SPITS array has been moved to the University of Spitsbergen (UNIS). A 512 bps SHDSL link has been established between UNIS and NOR_NDC. Data from the array elements to the CRF are transmitted via a 2.4 Ghz radio link (Wilan VIP-110). Both AS72 and RN49 data are now transmitted to NOR_NDC over this link using VPN technology.

A minimum of seven-day station buffers have been established at the ARCES and SPITS sites and at all NOA subarray sites, as well as at the NOR_NDC for ARCES, SPITS and NOA. In addition, each individual site of the SPITS array has a 14-day buffer.

The NOA and ARCES arrays are primary stations in the IMS network, which implies that data from these stations is transmitted continuously to the receiving international data center. Since October 1999, this data has been transmitted (from NOR_NDC) via the Global Communications Infrastructure (GCI) to the IDC in Vienna. Data from the auxiliary array station SPITS — AS72 have been sent in continuous mode to the IDC during the reporting period. AS73 — JMIC is an auxiliary station in the IMS, and the JMIC data have been available to the IDC throughout the reporting period on a request basis via use of the AutoDRM protocol (Kradolfer, 1993; Kradolfer, 1996). In addition, continuous data from all three arrays is transmitted to the US_NDC.

Uptimes and data availability

Figs. 4.2.2 and 4.2.3 show the monthly uptimes for the Norwegian IMS primary stations ARCES and NOA, respectively, for the reporting period given as the hatched (taller) bars in these figures. These barplots reflect the percentage of the waveform data that is available in the NOR_NDC data archives for these two arrays. The downtimes inferred from these figures thus represent the cumulative effect of field equipment outages, station site to NOR_NDC communication outage, and NOR_NDC data acquisition outages.

Figs. 4.2.2 and 4.2.3 also give the data availability for these two stations as reported by the IDC in the IDC Station Status reports. The main reason for the discrepancies between the NOR_NDC and IDC data availabilities as observed from these figures is the difference in the ways the two data centers report data availability for arrays: Whereas NOR_NDC reports an array station to be up and available if at least one channel produces useful data, the IDC uses weights where the reported availability (capability) is based on the number of actually operating channels.

Use of the AutoDRM protocol

NOR_NDC's AutoDRM has been operational since November 1995 (Mykkeltveit & Baadshaug, 1996). The monthly number of requests by the IDC for JMIC data for the period July - December 2007 is shown in Fig. 4.2.4.

NDC automatic processing and data analysis

These tasks have proceeded in accordance with the descriptions given in Mykkeltveit and Baadshaug (1996). For the reporting period NOR_NDC derived information on 425 supplementary events in northern Europe and submitted this information to the Finnish NDC as the NOR_NDC contribution to the joint Nordic Supplementary (Gamma) Bulletin, which in turn is forwarded to the IDC. These events are plotted in Fig. 4.2.5.

Data access for the station NIL at Nilore, Pakistan

NOR_NDC continued to provide access to the seismic station NIL at Nilore, Pakistan, through a VSAT satellite link between NOR_NDC and Pakistan's NDC in Nilore. On 10 December 2006, the VSAT ground station in Nilore was damaged by lightning. It was brought back into operation on 14 December 2006 through use of spare units stored on-site.

Current developments and future plans

NOR_NDC is continuing the efforts towards improving and hardening all critical data acquisition and data forwarding hardware and software components, so as to meet the requirements related to operation of IMS stations.

The NOA array was formally certified by the PTS on 28 July 2000, and a contract with the PTS in Vienna currently provides partial funding for operation and maintenance of this station. The ARCES array was formally certified by the PTS on 8 November 2001, and a contract with the PTS is in place which also provides for partial funding of the operation and maintenance of this station. The operation of the two IMS auxiliary seismic stations on Norwegian territory (Spitsbergen and Jan Mayen) is funded by the Norwegian Ministry of Foreign Affairs. Provided that adequate funding continues to be made available (from the PTS and the Norwegian Ministry of Foreign Affairs), we envisage continuing the provision of data from all Norwegian seismic IMS stations without interruption to the IDC in Vienna.

U. Baadshaug
S. Mykkeltveit
J. Fyen

References

Kradolfer, U. (1993): Automating the exchange of earthquake information. *EOS, Trans., AGU*, 74, 442.

Kradolfer, U. (1996): AutoDRM — The first five years, *Seism. Res. Lett.*, 67, 4, 30-33.

Mykkeltveit, S. & U. Baadshaug (1996): Norway's NDC: Experience from the first eighteen months of the full-scale phase of GSETT-3. *Semiann. Tech. Summ., 1 October 1995 - 31 March 1996*, NORSAR Sci. Rep. No. 2-95/96, Kjeller, Norway.

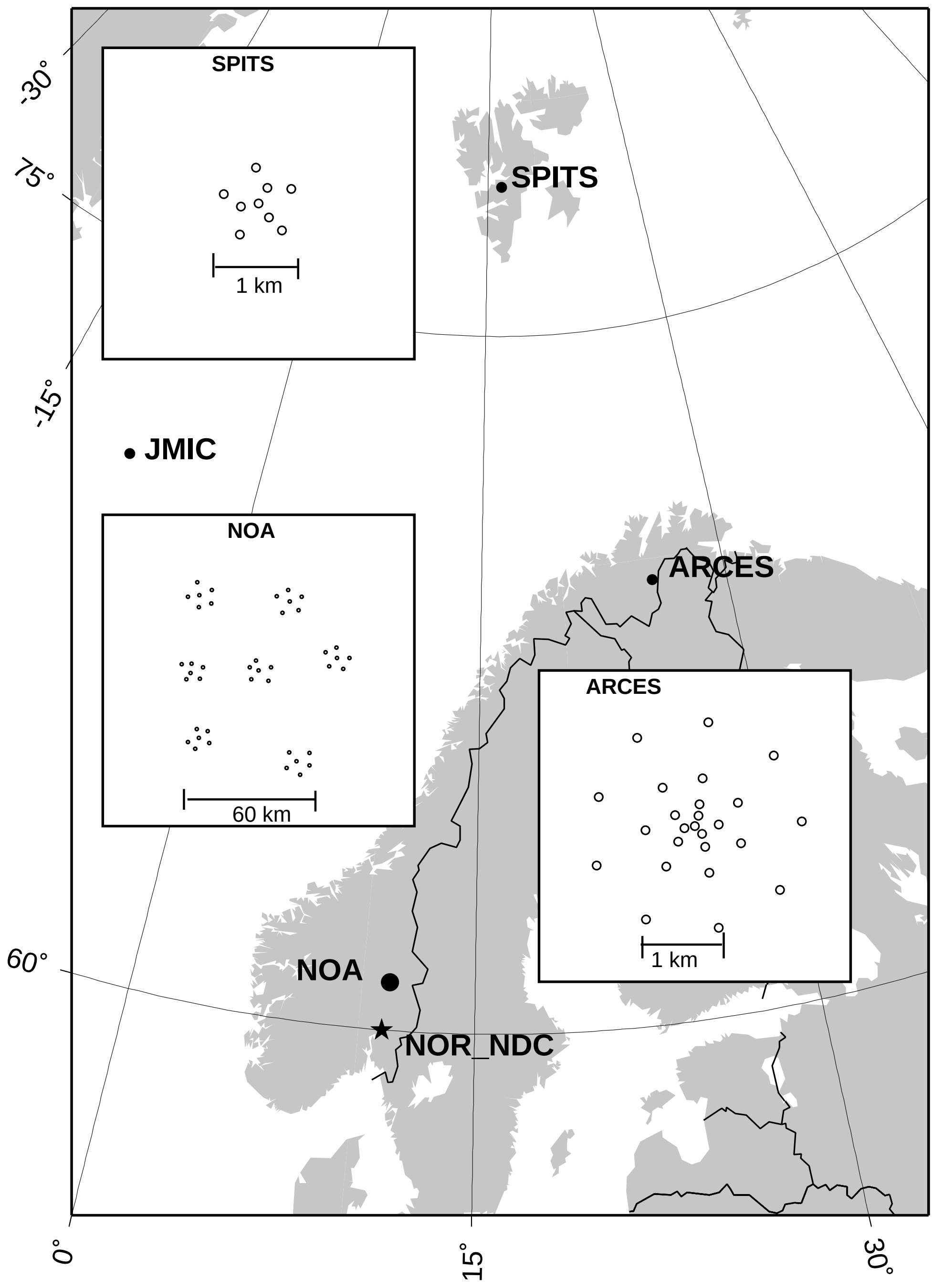

Fig. 4.2.1. The figure shows the locations and configurations of the three Norwegian seismic IMS array stations that provided data to the IDC during the period July - December 2007. The data from these stations and the JMIC three-component station are transmitted continuously and in real time to the Norwegian NDC (NOR_NDC). The stations NOA and ARCES are primary IMS stations, whereas SPITS and JMIC are auxiliary IMS stations.

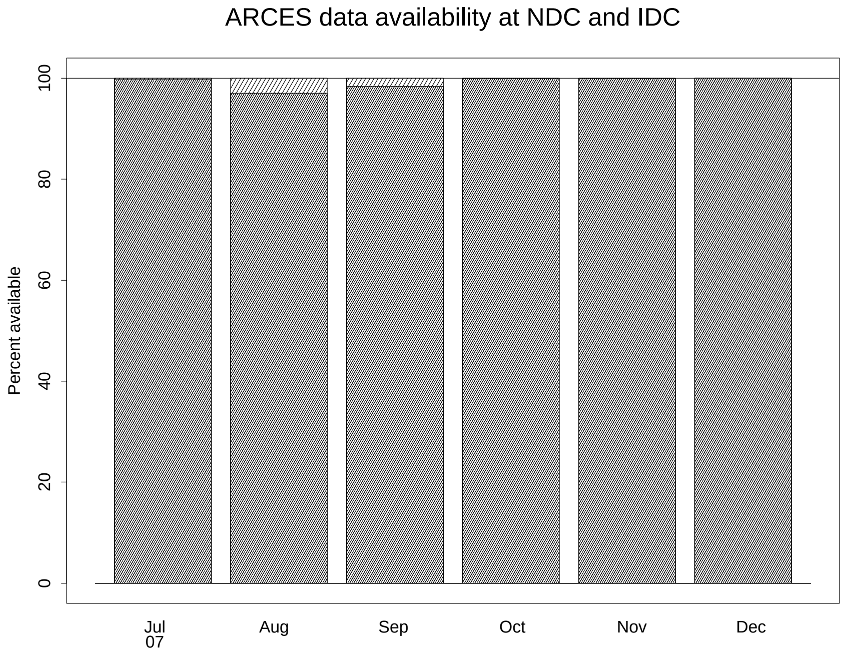

Fig. 4.2.2. The figure shows the monthly availability of ARCES array data for the period July - December 2007 at NOR_NDC and the IDC. See the text for explanation of differences in definition of the term "data availability" between the two centers. The higher values (hatched bars) represent the NOR_NDC data availability.

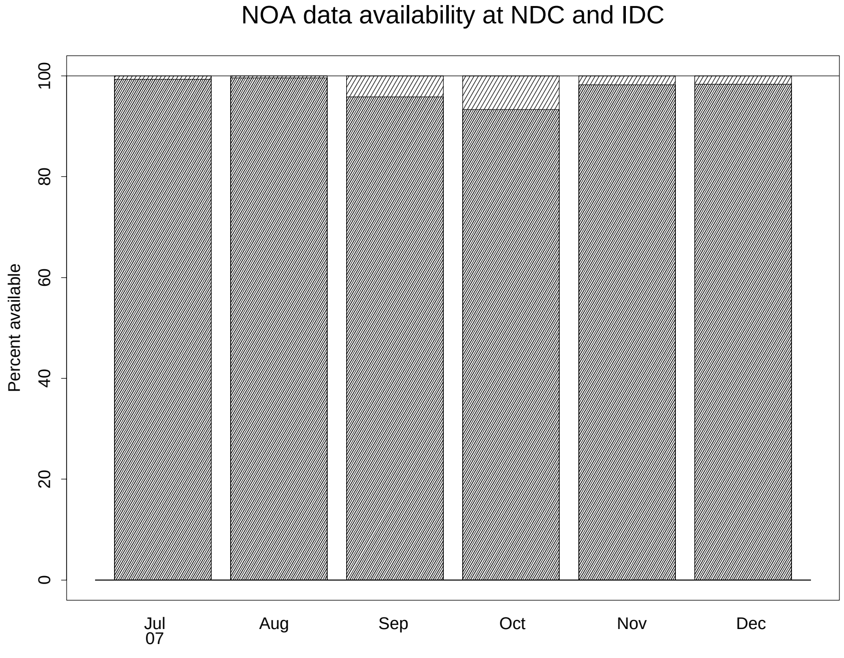

Fig. 4.2.3. The figure shows the monthly availability of NORSAR array data for the period July - December 2007 at NOR_NDC and the IDC. See the text for explanation of differences in definition of the term "data availability" between the two centers. The higher values (hatched bars) represent the NOR_NDC data availability.

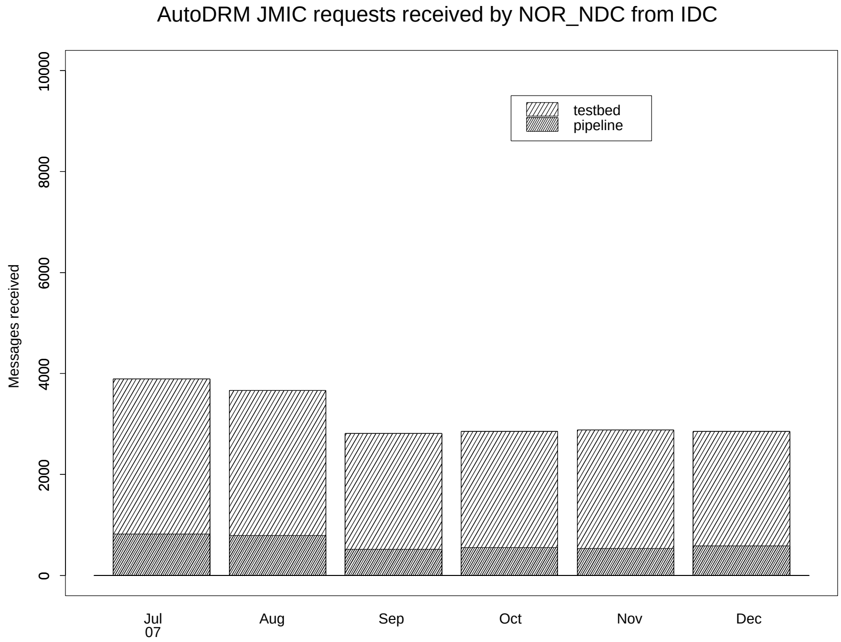

Fig. 4.2.4. The figure shows the monthly number of requests received by NOR_NDC from the IDC for JMIC waveform segments during July - December 2007.

Reviewed Supplementary events

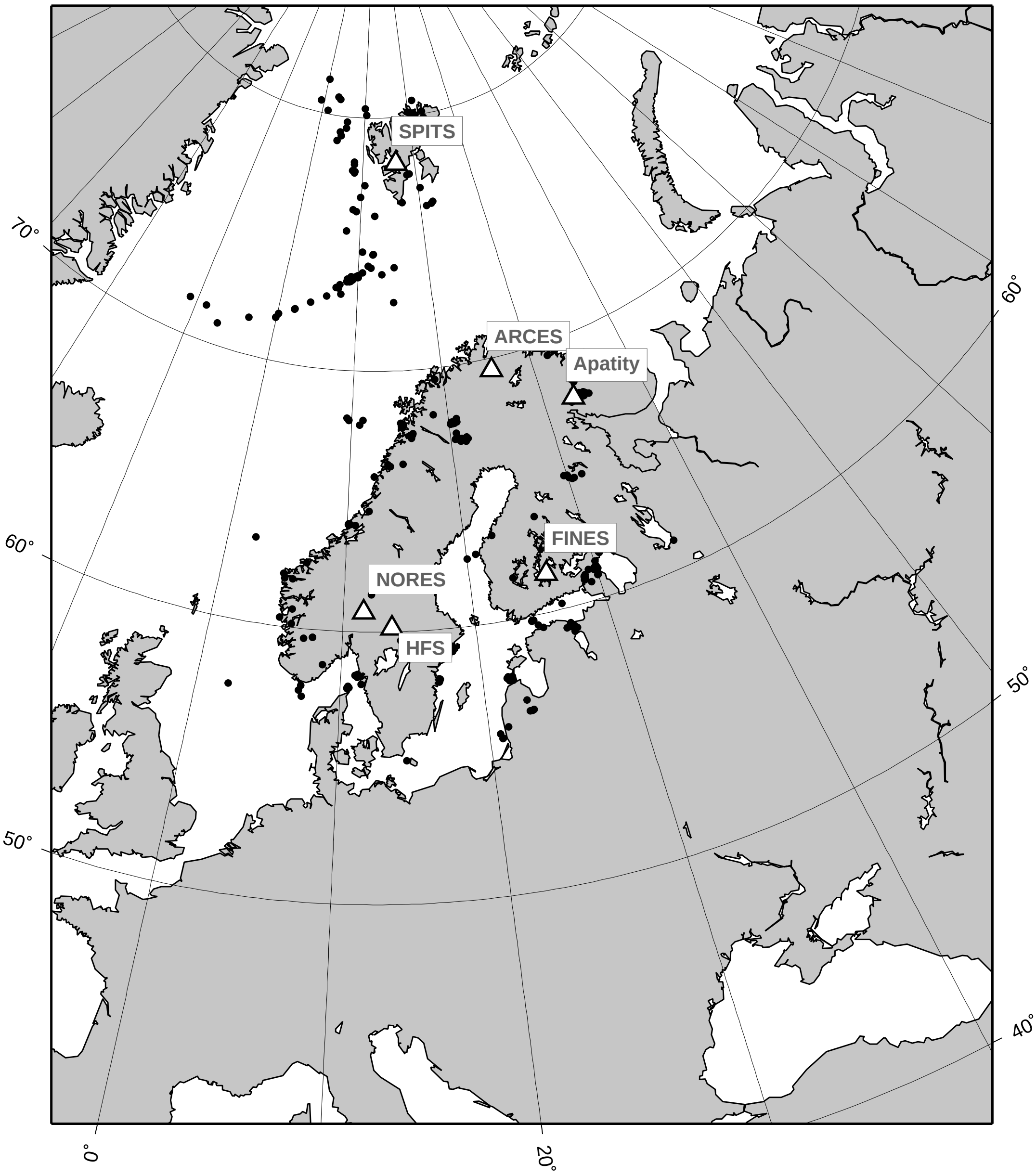

Fig. 4.2.5. The map shows the 330 events in and around Norway contributed by NOR_NDC during July - December 2007 as supplementary (Gamma) events to the IDC, as part of the Nordic supplementary data compiled by the Finnish NDC. The map also shows the main seismic stations used in the data analysis to define these events.

4.3 Field Activities

The activities at the NORSAR Maintenance Center (NMC) at Hamar currently include work related to operation and maintenance of the following IMS seismic stations: the NOA teleseismic array (PS27), the ARCES array (PS28) and the Spitsbergen array (AS72). Some work has also been carried out in connection with the seismic station on Jan Mayen (AS73), the radionuclide station at Spitsbergen (RN49), and preparations for the infrasound station at Karasjok (IS37). NORSAR also acts as a consultant for the operation and maintenance of the Hagfors array in Sweden (AS101).

NORSAR carries out the field activities relating to IMS stations in a manner generally consistent with the requirements specified in the appropriate IMS Operational Manuals, which are currently being developed by Working Group B of the Preparatory Commission. For seismic stations these specifications are contained in the Operational Manual for Seismological Monitoring and the International Exchange of Seismological Data (CTBT/WGB/TL-11/2), currently available in a draft version.

All regular maintenance on the NORSAR field systems is conducted on a one-shift-per-day, five-day-per-week basis. The maintenance tasks include:

- Operating and maintaining the seismic sensors and the associated digitizers, authentication devices and other electronics components.
- Maintaining the power supply to the field sites as well as backup power supplies.
- Operating and maintaining the VSATs, the data acquisition systems and the intra-array data transmission systems.
- Assisting the NDC in evaluating the data quality and making the necessary changes in gain settings, frequency response and other operating characteristics as required.
- Carrying out preventive, routine and emergency maintenance to ensure that all field systems operate properly.
- Maintaining a computerized record of the utilization, status, and maintenance history of all site equipment.
- Providing appropriate security measures to protect against incidents such as intrusion, theft and vandalism at the field installations.

Details of the daily maintenance activities are kept locally. As part of its contract with CTBTO/PTS NORSAR submits, when applicable, problem reports, outage notification reports and equipment status reports. The contents of these reports and the circumstances under which they will be submitted are specified in the draft Operational Manual.

P.W. Larsen
K.A. Løken

5 Documentation Developed

Gibbons, S.J., F. Ringdal & T. Kværna (2007): Joint seismic-infrasonic processing of recordings from a repeating source of atmospheric explosions. J. Acoust. Soc. Am., 122, EL158-EL164.

Gibbons, S.J. (2007): Joint seismic-infrasonic processing of recordings from a repeating source of atmospheric exposions in Northern Finland. In: In: Semiannual Technical Summary, 1 July - 31 December 2007, NORSAR Sci. Rep. 1-2008, Kjeller.

Gibbons, S.J., D. Gubbins & K. Zhang (2007): Convection in rotating spherical fluid shells with inhomogeous heat flux at the outer boundary. Geophys. & Astrophys. Fluid Dynamics, 101, 347-370.

Kværna, T. (2007): Investigation of infrasound signals from rocket launches at the Plesetsk Cosmodrome, Northwest Russia. In: Semiannual Technical Summary, 1 July - 31 December 2007, NORSAR Sci. Rep. 1-2008, Kjeller.

Kværna, T, F. Ringdal & U. Baadshaug (2007): North Korea's nuclear test: the capability for seismic monitoring of the North Korean test site. Seism. Res. Lett., 78/5, 487-496.

Levshin, A.L., J. Schweitzer, Ch. Weidle, N. Shapiro & M.H. Ritzwoller (2007): Surface wave tomography for the Barents Sea and surrounding regions. Geophys. J. Int., 170, 441-459.

Olivieri, M. & J. Schweitzer (2007): An empirical procedure for rapid magnitude estimation in Italy. Bull. Seis. Soc. Am., 97, 1750-1755.

Pirli, M. & J. Schweitzer (2007): Regional and teleseismic event detection capability of the small-aperture Tripoli seismic array, Greece. Proc. 11th Int. Congress of the Geological Society of Greece, Athens, 24-26 May. Part 3 in: Bull. Geolog. Soc. Greece, 40, 1246-1256.

Pirli, M. & J. Schweitzer (2007): Overview of NORSAR system response. In: Semiannual Technical Summary, 1 July - 31 December 2007, NORSAR Sci. Rep. 1-2008, Kjeller.

Ringdal, F., S.J. Gibbons & D.B. Harris (2007): Adaptive waveform correlation detectors for arrays: Algorithms for autonomous calibration. In: Proceedings, 29th Monitoring Research Review, Denver, CO, 26-28 September 2007.

Ringdal, F., T. Kværna, S. Mykkeltveit, S.J. Gibbons & J. Schweitzer (2007): Basic research on seismic and infrasonic monitoring of the European Arctice. In: Proceedings, 29th Monitoring Research Review, Denver, CO, 26-28 September 2007.

Schweitzer, J. (2007): The International Polar Year 2007-2008 Project "The Dynamic Continental Margin between the Mid-Atlantic Ridge System (Mohn's Ridge, Knipovich Ridge and the Bear Island Region". In: Semiannual Technical Summary, 1 July - 31 December 2007, NORSAR Sci. Rep. 1-2008, Kjeller.

Schweitzer, J. & B.L.N. Kennett (2007): Comparison of location procedures -- The Kara Sea event of 16 August 1997. Bull. Seis. Soc. Am., 97, 389-400.

Svenningsen, L., N. Balling, B.H. Jacobsen, R. Kind, J. Schweitzer & K. Wylegalla (2007): Crustal thickness beneath the highlands of southern Norway from teleseismic receiver functions. Geophys. J. Int., 170, 1129-1138.

Svenningsen, L., N. Balling, B.H. Jacobsen, R. Kind, K. Wylegalla & J. Schweitzer (2007): Accurate depth to Moho beneath the highlands of southern Norway resolved by teleseismic receiver functions. Geophys. Res. Abstr., 9, 12719.

Weidle, Ch., V. Maupin, J. Ritter, T. Kværna, J. Schweitzer, N. Balling, H. Thybo & J.I. Faleide (2007): MAntle investiGations of Norwegian Uplift Structure (MAGNUS) -- A flying start into Topo Europe. Geophys. Res. Abstr., 9, 03820.

6 Summary of Technical Reports / Papers Published

6.1 Basic research on seismic and infrasonic monitoring of the European Arctic

(Paper presented at the 29th Seismic Research Review)

ABSTRACT

This project represents a three-year research effort aimed at improving seismic and infrasonic monitoring tools at regional distances, with emphasis on the European Arctic region, which includes the former Novaya Zemlya test site. The project has three main components: a) to improve seismic processing in this region using the regional seismic arrays installed in northern Europe, b) to investigate the potential of using combined seismic/infrasonic processing to characterize events in this region and c) to carry out experimental operation, evaluation and tuning of the seismic threshold monitoring technique, with application to various regions of monitoring interest.

We have continued our studies of seismic and infrasonic recordings of a set of more than 100 surface explosions in northern Finland, carried out for the purpose of destroying old ammunition. Waveform correlation analysis indicates that these explosions were very closely spaced, and occurred at most within a few hundred meters of each other. This is a unique set of events given the repeatable nature of the source. Very similar waveforms and amplitudes are observed for the seismic phase arrivals, indicating a similar explosion yield and source function for each event. In contrast, the infrasonic recordings show great variation between events, both with regard to the number and amplitudes of detected infrasonic phases, as well as their travel times. A variation of several tens of seconds in travel times for corresponding phases for different events is observed at a distance of about 175 km.

An important aspect of the infrasonic studies is the availability of data from a distributed network of arrays. The Swedish infrasound array network provides a useful supplement to the seismic and infrasonic arrays in Norway and NW Russia. We have begun exploiting the data from this network, which will allow a much improved joint seismic/infrasonic regional processing at NORSAR. We continue our work towards developing and evaluating a joint seismic/infrasonic bulletin for northern Fennoscandia and adjacent regions. This bulletin would be similar to the automatic seismic bulletin that we are currently providing on the NORSAR Web pages, but it would also contain infrasonic phase associations. Furthermore, we will experimentally attempt to generate an infrasonic event bulletin using only the estimated azimuths and detection times of infrasound phases recorded by stations in the Nordic network.

The recent upgrade of the Spitsbergen seismic array, which has included installation of five new three-component seismometers, as well as an increase in the sampling rate from 40 to 80 Hz, has resulted in significant improvements in high frequency signal characterization as well as S-phase detection. We demonstrate some results from analysis of recent small seismic events near Novaya Zemlya and in the Barents Sea.

We have analyzed the recorded waveforms from the 9 October 2006 North Korean nuclear explosion in order to investigate the capability of the seismic IMS network to monitor the North Korean test site for possible future explosions. Our analysis is based upon the so-called

Site-Specific Threshold Monitoring (SSTM) approach. Using actual seismic data recorded by a given network, SSTM calculates a continuous “threshold trace”, which provides, at any instance in time, a probabilistic upper magnitude bound on any seismic event that could have occurred at the target site at that time. We find that the current IMS primary network has a typical “threshold monitoring capability” of between mb 2.3 and 2.5 for the North Korean test site. Not unexpectedly, it turns out that the Korean array (KSRS) is of essential importance in obtaining such low thresholds. Non-IMS stations could also make important contributions, and we find that by adding the nearby IRIS station MDJ in China, the threshold monitoring capability is improved to between magnitude 2.1 and 2.3. For comparison, the three-station network detection threshold is found to be typically one magnitude higher than these numbers. We note, however, that the SSTM approach is not aimed at detecting events, but rather to supplement traditional detection processing by enabling the analyst to focus on and analyze extensively instances where a possibly undetected event of monitoring interest could have occurred.

OBJECTIVE

The objective of the project is to carry out reseach to improve the current capabilities for monitoring small seismic events in the European Arctic, which includes the former Russian test site at Novaya Zemlya. The project has three main components: a) to improve seismic processing in this region using the regional seismic arrays installed in northern Europe, b) to investigate the potential of using combined seismic/infrasonic processing to characterize events in this region and c) to carry out experimental operation, evaluation and tuning of the seismic threshold monitoring technique, with application to various regions of monitoring interest.

RESEARCH ACCOMPLISHED

Establishing a Nordic network of infrasound arrays

An important aspect of the infrasonic studies is the availability of data from a distributed network of arrays. The Swedish infrasound array network provides a useful supplement to the seismic and infrasonic arrays in Norway and NW Russia. We have begun exploiting the data from this combined network, which will allow a much improved joint seismic/infrasonic regional processing at NORSAR. The Apatity infrasound array is a three-element array co-located with the nine-element Apatity short-period regional seismic array, which was installed in 1992 on the Kola Peninsula, Russia by the Kola Regional Seismological Centre (KRSC). For further details see Baryshnikov (2004). The 25 element ARCES array is a short-period regional seismic array, located in northern Norway. ARCES has no infrasound sensors, but because of special near surface installation conditions, many of its seismic sensors are also sensitive to infrasound signals (see e.g., Ringdal & Schweitzer, 2005). Current plans are to install an infrasound array near the ARCES site in 2007/2008. The Swedish Infrasound Network (Liszka, 2007) has been in operation since the beginning of the 1970s. Operated by the Swedish Institute of Space Physics, the network has until recently comprised four infrasound stations: Kiruna, Jamton, Lycksele and Uppsala. The station in Uppsala was moved to Sodankyla, Finland, during the summer of 2006. The currently available network of arrays for infrasound processing in the Nordic region is shown in Figure 6.1.1.

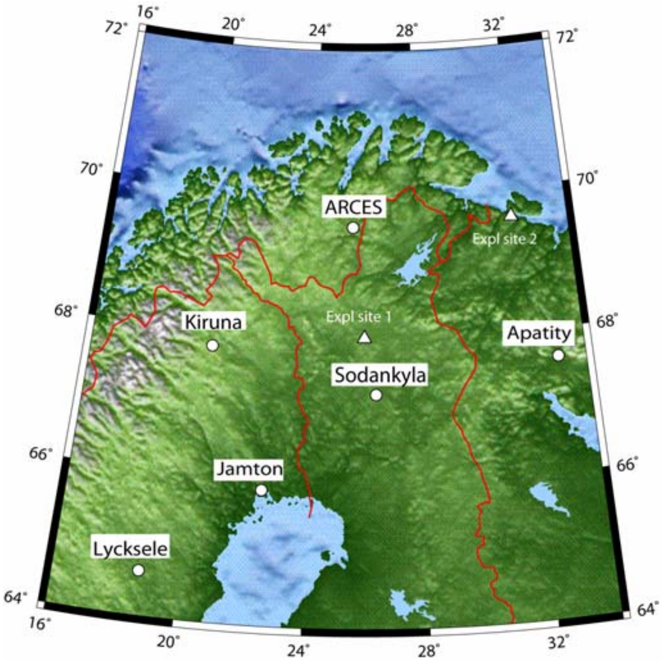

Fig. 6.1.1. Locations of the arrays used for infrasonic processing in the Nordic countries. The site of the explosions in northern Finland discussed in this paper is marked on the map.

Case study of explosions in northern Finland

Each year between mid-August and mid-September, a series of explosions in the north of Finland is recorded by the stations of the Finnish national seismograph network and also by the seismic arrays in northern Fennoscandia and NW Russia. Based upon event locations given in the seismic bulletin of the University of Helsinki, the geographical coordinates of the explosion site are assumed to be approximately 68.00^{o}N and 25.96^{o}E. The explosions are carried out by the Finnish military in order to destroy outdated ammunition and are easily identified from the automatic seismic bulletins at NORSAR for several reasons. Firstly, they are always detected with a high SNR on the ARCES array, secondly they register very stable azimuth estimates on the detection lists, and thirdly they take place at very characteristic times of day (the origin time indicated by the seismic observations almost invariably falls within a few seconds of, typically, a full hour or half-hour in the middle of the day).

Between 2001 and 2006, a total of 141 events were found which appeared to fit the general attributes of explosions from this site. The fully automatic GBF location estimates displayed a somewhat surprisingly large geographical spread and, assuming that these events are in fact essentially co-located, the origin times would be correspondingly spurious. We applied a waveform correlation procedure, which confirmed that the explosions were indeed closely spaced, probably within an area of some hundred meters in diameter (for details, see Ringdal and Gibbons, 2006).

The signals recorded by the ARCES seismic array provide an excellent perspective of the differences in seismic and infrasonic recordings of the explosions, as illustrated in Figure 6.1.2 for the year 2002. A large amplitude infrasonic signal approximately 600 seconds after the origin time is observed for almost all of these events, but unlike the seismic signals which are almost identical for each explosion, the temporal characteristics and the amplitudes of the infrasonic arrivals differ greatly among events. There is also significant variability in the travel time of the infrasonic phases from event to event, and there is evidence of multiple infrasonic arrivals as well. The similarity of the seimic waveforms for these explosions not only constrains the events to be almost co-located but rule out the possibility of multiple explosions as is common for ripple-fired mining blasts (e.g. Gibbons et al., 2005). We conclude that differences in the occurrence and appearance of infrasonic arrivals from event to event are the result of atmospheric conditions alone. The seismic data also indicate very similar waveform amplitudes for the events from which we conclude very similar explosion yields. This will provide a useful measure of the variability in yield estimation from the sound waves.

To obtain a better overview of the occurrence of signals with typical sound velocities, we calculated a detection statistic, C(t), which is essentially identical to that defined in Equation (15) of Brown et al. (2002). Figure 6.1.3 displays a color-scaled indication of C(t) for the ARCES array for a five-minute long time-window following each of the events subject to C(t) exceeding a threshold of 0.01 and the estimated slowness and azimuth falling in the indicated ranges. The vast majority of the events register a candidate acoustic phase between approximately 620 and 660 seconds after the event. A smaller number of events also indicate an earlier arrival from approximately 500 seconds. This figure confirms that evidence of one or more atmospheric sound arrivals was observed for almost every explosion, even in cases where the signal amplitude was smaller than the ambient noise level. The most common arrivals occur approximately 600 seconds after the event with a superimposed variation which appears to vary quite smoothly ove a several day time-scale.

There are many interesting questions which need further investigation. For the recordings at ARCES, the infrasonic arrivals after approximately 650 seconds are quite consistent despite showing far greater variation than the corresponding seismic signals. On the other hand, the arrivals at approximately 550 seconds occur relatively seldom and, when they occur, they appear to produce a larger amplitude seismic response than the later signals. In several cases where an early arrival was observed (e.g. Aug 26., Aug 27, Sep 03) no later phase was observed. More detailed information about the atmospheric conditions along the path from the explosion site to the ARCES array would be useful in order to address these questions.

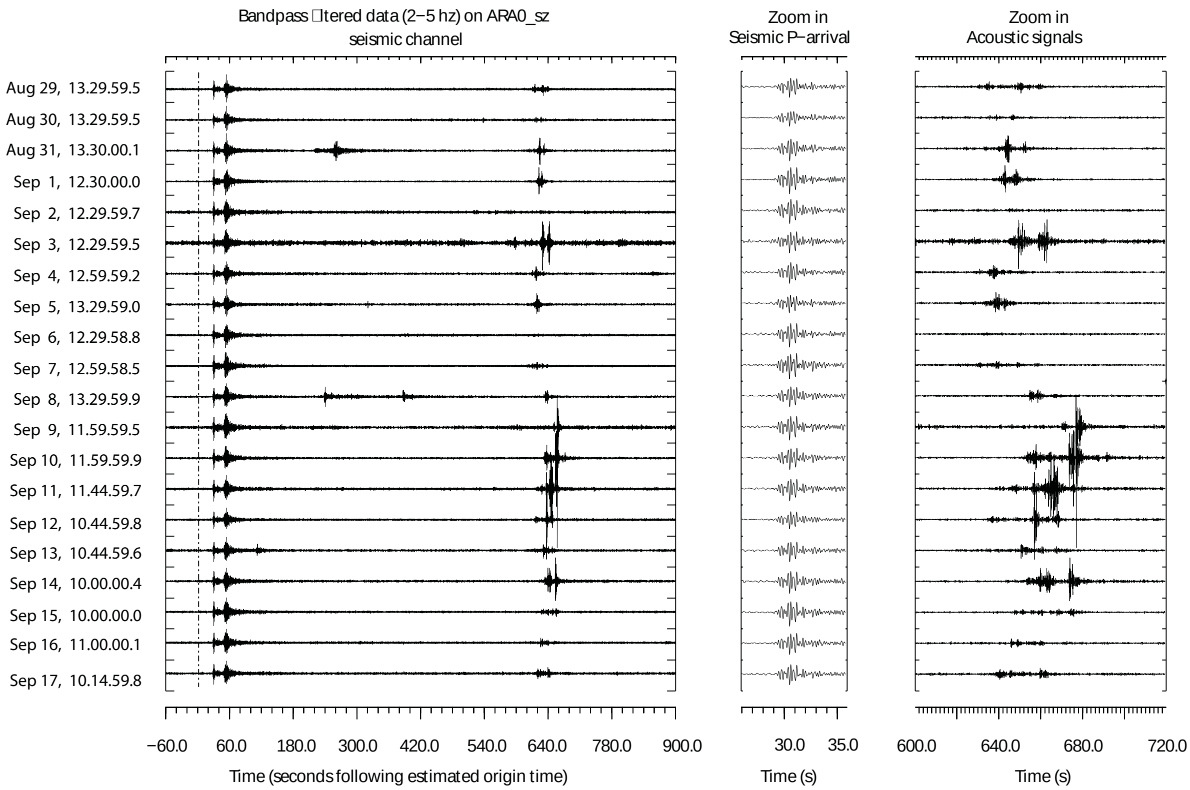

Fig. 6.1.2. Recordings on the ARCES seismic array (channel ARA0_sz) of 20 events at the Finnish explosion site in August and September 2002. The time provided to the left is the estimated event UTC origin time. All waveforms are aligned to the maximum correlation coefficient and have identical vertical scaling. Signals arriving between 450 and 700 seconds after origin time are demonstrated by array analysis to propagate with sound velocity fro an approximate 173 degrees backazimuth. All arrivals between 200 and 450 seconds correspomnd to unrelated seismic events.

Detection of small seismic events near Novaya Zemlya

The recent upgrade of the Spitsbergen seismic array, which has included installation of five new three-component seismometers as well as an upgrading of the sampling rate from 40 to 80 Hz, has resulted in a significant improvements in the processing of seismic events at regional distances. As shown by Ringdal et al. (2006), S-phase detection at the array has been significantly improved. Furthermore, the increased sample rate has made possible more detailed studies of high-frequency propagation in the vicinity of the array. Since January 2006 four small seismic events near Novaya Zemlya have been detected (Table 6.1.1).

Table 6.1.1. Seismic events near Novaya Zemlya detected during 01/2006-06/2007

Date	Origin time	Latitude (N)	Longitude (E)	Magnitude (mb)
05/03/2006	23.17.35.7	76.80	66.04	2.65
14/03/2006	20.57.02.4	75.07	53.05	2.23
30/03/2006	10.46.02.8	70.79	51.50	2.30
26/06/2007	03.19.05.0	73.45	53.43	2.75

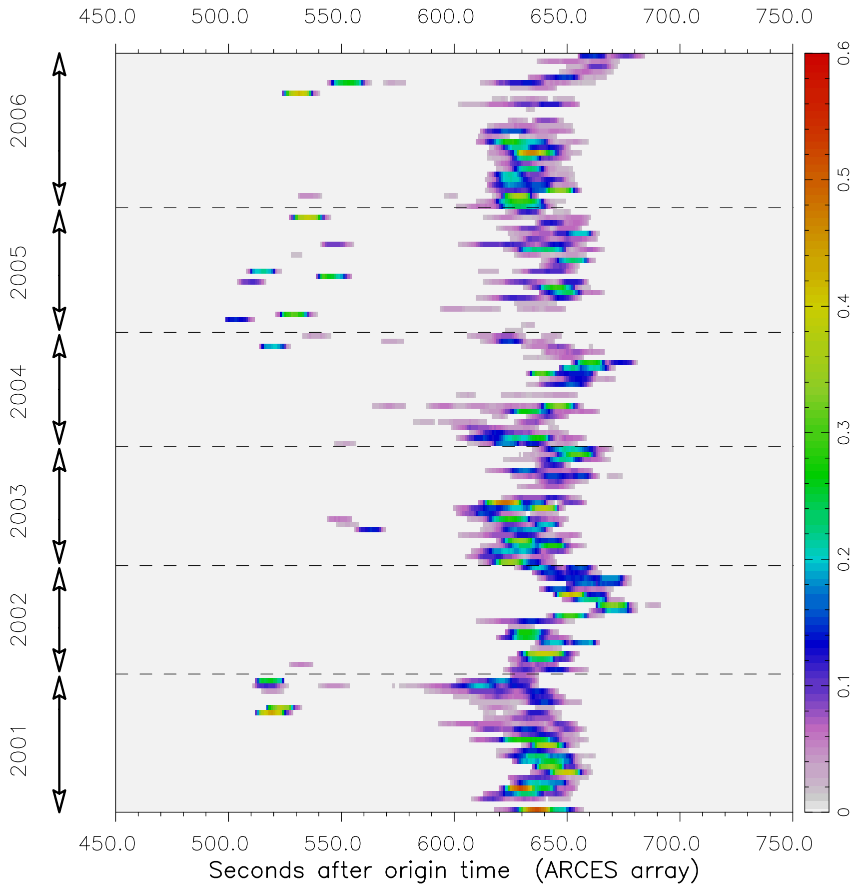

Fig. 6.1.3. Detection statistics over the full ARCES seismic array within the time windows as indicated following each of the 141 identified explosions in northern Finland between 2001 and 2006. A pixel is drawn every second, at time t, for each event provided that the preferred slowness and backazimuth evaluated over the 10.0 second long window beginning at time t fall within an acceptable range for acoustivc waves from the given source. The color indicates the value of the detection statistic.

Figure 6.1.4 shows spectrograms of the Spitsbergen B1 seismometer (vertical component) for the Novaya Zemlya event on 5 March 2006. The top part is the original spectrogram using 80 Hz sampling, the bottom part is converted to the response of the previous Spitsbergen system, with 40 Hz sampling. The most noticeable feature of the original spectrogram is the the remarkable amount of high-frequency energy, taking into account the large epicentral distance (more than 1000 km). We note that there is significant P-wave energy even above 20 Hz. A similar observation can be made for the other events in Table 6.1.1.

It is interesting to compare this spectrogram to the bottom spectrogram in Figure 6.1.4, which shows how the same event would have been recorded with the previous array configuration (40 Hz sampling rate). It is not surprising that the high frequency information would have been lost, and we will never know whether the interesting Novaya Zemlya events in the past several years have shown similar characteristics. It might be considered to upgrade other seismic systems located in areas of good high-frequency propagation and low noise (e.g. the ARCES array) to a higher sampling rate in the future.

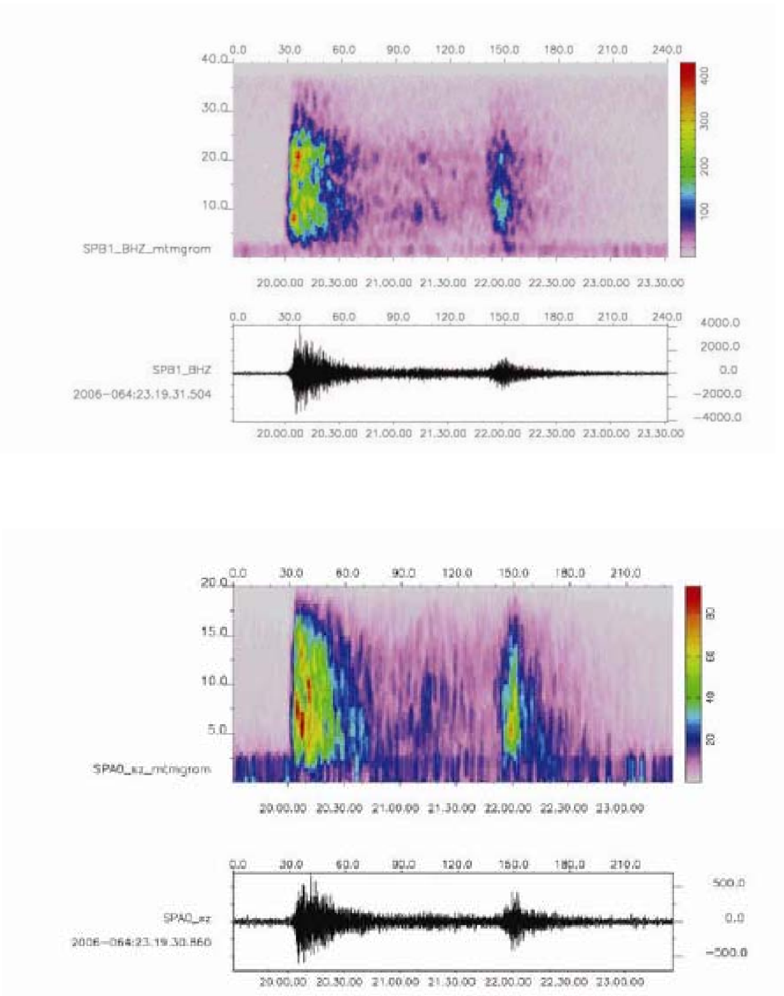

Fig. 6.1.4. Spectrograms for the Spitsbergen B1 seismometer (vertical component) for the Novaya Zemlya event on 5 March 2006. The top part is the original spectrogram using 80 Hz sampling, the bottom part is converted to the response of the previous Spitsbergen system, with 40 Hz sampling.

Threshold monitoring of the North Korean nuclear test site

On 9 October 2006 the Democratic Peoples Republic of Korea (DPRK) conducted an underground nuclear explosion at a test site near Kimchaek. The explosion was detected by several seismic stations in the International Monitoring System (IMS), and was also reported by the United States Geological Survey (USGS). We have analyzed the recorded waveforms at selected seismic stations in order to investigate the capability of the global seismic network to monitor the DPRK test site for possible future explosions. Our analysis is based upon the so-called Site-Specific Threshold Monitoring (SSTM) approach. Using actual seismic data recorded by a given network, SSTM calculates a continuous threshold trace, which provides, at any instance in time, an upper magnitude bound on any seismic event that could have occurred at the target site at that time.

Let us first emphasize that a large number of seismic stations world-wide recorded this event, and that many of these stations were not analyzed as part of this study. Our main reason for not including such stations is that in a site-specific capability study of the type discussed here, the resulting threshold is dominated by a few stations of exceptionally high detection capability. We have focused our analysis on these exceptional stations. In fact, as will be shown later in this study, the monitoring capability of our selected network (9 stations) for the North Korean test site is essentially defined by the best three stations in that network. Additional stations would be useful for resolving instances of excessive noise at one or more of these three stations, and would also be helpful during interfering earthquakes, but will generally have only a modest contribution to an overall lowering of the monitoring threshold.

The network selected for this study comprises in general those IMS stations which had the best signal-to-noise ratio (SNR) for the 9 October explosion plus the Chinese station at Mudanjiang (MDJ), about 370 km north of the test site. MDJ data is openly available through the IRIS data management center. We note that data from the Korean Seismic array (KSRS) in South Korea was not operationally available from the IDC for the time period of the test. We are grateful to KIGAM for providing us with the KSRS data for our analysis.

Using the nuclear test for calibrating the signal propagation characteristics at the various stations, we carried out a site-specific tuning of the network stations. The details are desribed in Kvaerna et al. (2007). We then applied the methodology described in Kvaerna and Ringdal (1999) to obtain the threshold processing results. We will show two different types of threshold traces for the North Korea nuclear test site:

- The *detection threshold traces*, which estimate, (at the 90% probability level) the smallest seismic event that can be detected by 3 or more stations in the network (SNR>4).
- The *monitoring threshold traces,* which estimate (at the 90% probability level) the largest seismic event that could possibly have occurred.

In each of the following figures, the *detection threshold traces* are marked in red, the *monitoring threshold traces* are marked in blue.

Figure 6.1.5 shows the results for the day of the nuclear test (9 October 2006), using only those stations that were operational at the IDC during that day. We note that the detection threshold is typically around 4.0 or slightly below. At the time of the test, the detection threshold is around 3.75. The monitoring threshold averages about one magnitude unit lower than the detection threshold, i.e. close to magnitude 3.0.

Figure 6.1.6 shows a one-day plot of detection traces (red) and monitoring traces (blue) for 15 November 2006, when a large earthquake occurred in the Kurile Islands. By that time, the KSRS array was operational in the IDC, and we also extracted a full day's data from the MDJ station in China. The top panel uses the IMS network (including KSRS); the middle panel shows the effect of adding the MDJ station and the bottom panel shows results from using only the three stations KSRS, MDJ and MJAR. We can make the following observations:

- The operational IMS network (now with KSRS available) shown in red on the top panel has a detection threshold of about magnitude 3.8, which is almost unchanged from the threshold observed in Figure 6.1.5 when KSRS was not available.
- In contrast, the monitoring trace (blue) on the top panel is lower by more than half a magnitude unit compared to the corresponding trace in Figure 6.1.5 where KSRS was not available
- When adding MDJ to the IMS network (middle panel) we obtain a modest decrease (to about 3.5) for the detection trace (red), whereas the monitoring trace (blue) is now as low as 2.0 on the average. (Here we assume that detection processing is carried out for MDJ)

Finally Figure 6.1.6 gives an indication of how a regional netwok, comprising only the best stations, would compare to a global network. This is illustrated in the bottom panel of the figure, which shows that using the network of MJAR, KSRS and MDJ appears to perform almost as well as the "full" network. However, this does not mean that the remaining stations are unimportant. In fact, during interfering events these additional (teleseismic) stations may help lower the thresholds. This is particularly evident for the detection traces (red). Also, if one of these three stations should have abnormally high noise conditions, or (worse) being out of operation, it is important to have additional stations that can contribute to reducing the resulting decline in capabilities.

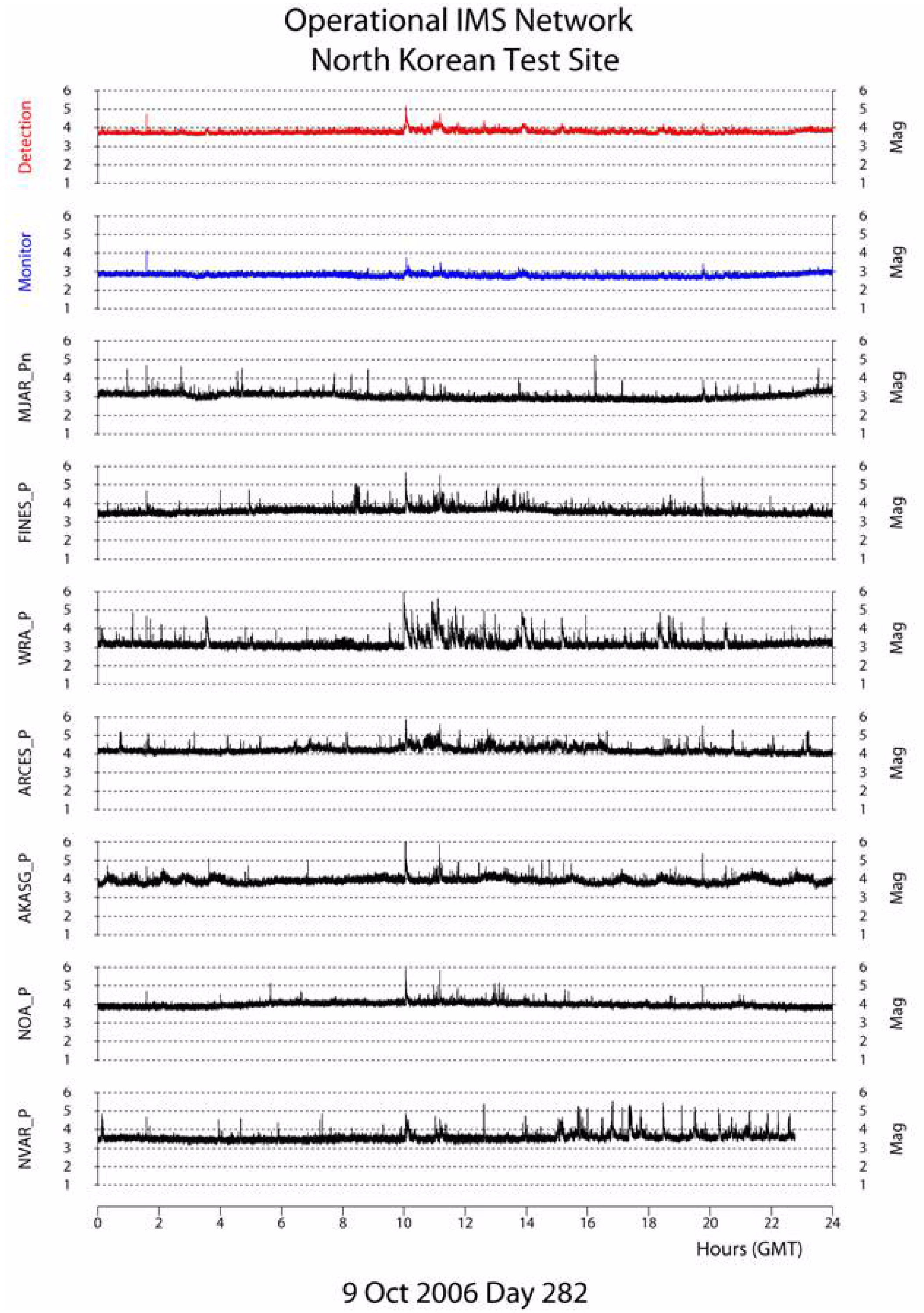

Fig. 6.1.5. Threshold monitoring results for the day of the nuclear test (9 October 2006). In this figure we have used only those of our selected stations that were operational at the IDC during that day. Detection thresholds (red) are close to magnitude 4.0 or slightly below, except for occasional increases during the nuclear test (at 01.35) and during some interfering events later in the day. The monitoring thresholds (blue) average about magnitude 3.0. The individual station P-thresholds (black) are also shown.

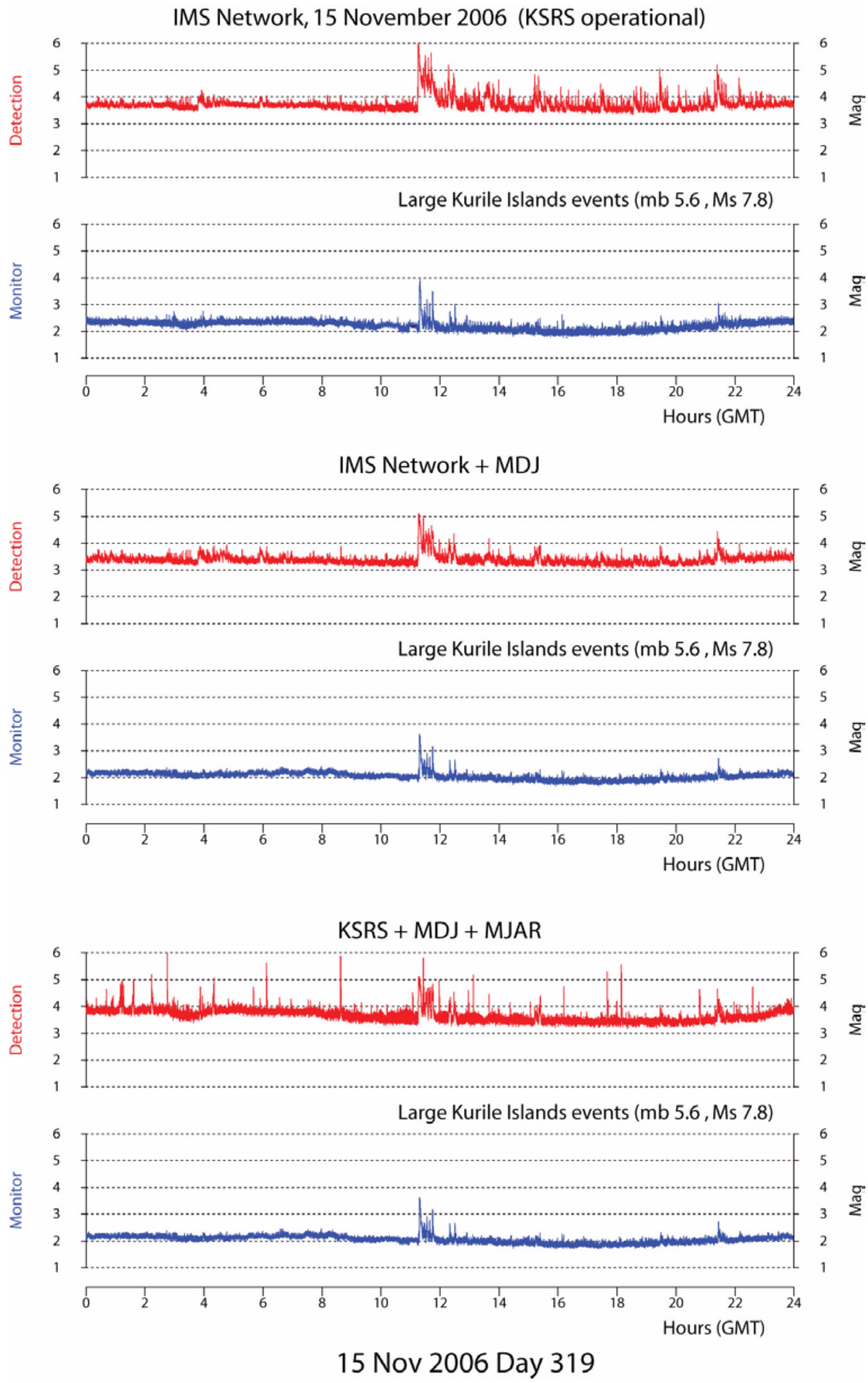

Fig. 6.1.6. This figure shows a one-day plot of detection traces (red) and monitoring traces (blue) for 15 November 2006. The top panel uses IMS stations (including KSRS); the middle panel shows the effect of adding the MDJ station and the bottom panel shows results from using only KSRS, MDJ and MJAR.

CONCLUSIONS AND RECOMMENDATIONS

The data set of more than 100 surface explosions in northern Finland in almost exactly the same place recorded by the ARCES and Apatity arrays has provided an excellent opportunity for studying infrasonic versus seismic phase propagation characteristics. Very similar waveforms and amplitudes are observed for the seismic phase arrivals, indicating a similar explosion yield and source function for each event. In contrast, the infrasonic recordings show great variation between events, both with regard to the number and amplitudes of detected infrasonic phases, as well as their travel times. A variation of several tens of seconds in travel times for corresponding phases for different events is observed at a distance of about 175 km.

The Swedish infrasound array network provides a useful supplement to the seismic and infrasonic arrays in Norway and NW Russia. We have begun exploiting the data from this network, which will allow a much improved joint seismic/infrasonic regional processing at NORSAR. We continue our work towards developing and evaluating a joint seismic/infrasonic bulletin for northern Fennoscandia and adjacent regions. This bulletin would be similar to the automatic seismic bulletin that we are currently providing on the NORSAR Web pages, but it would also contain infrasonic phase associations. Furthermore, we will experimentally attempt to generate an infrasonic event bulletin using only the estimated azimuths and detection times of infrasound phases recorded by stations in the Nordic network.

The recent upgrade of the Spitsbergen seismic array, which has included installation of five new three-component seismometers, as well as an increase in the sampling rate from 40 to 80 Hz, has resulted in significant improvements in high frequency signal characterization as well as S-phase detection.

We have analyzed the recorded waveforms from the 9 October 2006 North Korean nuclear explosion in order to investigate the capability of the seismic IMS network to monitor the North Korean test site for possible future explosions. We find that the current IMS primary network has a typical “threshold monitoring capability” of between mb 2.3 and 2.5 for the North Korean test site. Not unexpectedly, it turns out that the Korean array (KSRS) is of essential importance in obtaining such low thresholds. Non-IMS stations could also make important contributions, and we find that by adding the nearby IRIS station MDJ in China, the threshold monitoring capability is improved to between magnitude 2.1 and 2.3. For comparison, the three-station network detection threshold is found to be typically one magnitude higher than these numbers.

REFERENCES

Baryshnikov, A.K. (2004). Research of infrasound background characteristics for estimation of threshold sensitivity of infrasound method for nuclear test monitoring. Final Technical Report ISTC 1341-01 (Part 1 of total 2), International Science and Technology Center (ISTC), Moscow, 255 pp.

Brown, D. J., Katz, C. N., Le Bras, R., Flanagan, M. P., Wang, J., and Gault, A. K. (2002). Infrasonic Signal Detection and Source Location at the Prototype International Data Centre, Pure appl. geophys., 159, pp. 1081-1125.

Gibbons, S. J. and Ringdal, F. (2006). The detection of low magnitude seismic events using array-based waveform correlation, Geophys. J. Int., 165, pp. 149-166. Cansi, Y. (1995). An automatic seismic event processing for detection and location: The P.M.C./C. method, *Geophys. Res. Lett.*, **22**, 1021-1024.

Liszka, L. (2007): Infrasound - A summary of 35 years of infrasound research, Manuscript submitted for printing, 150 pp

Ringdal, F. and S.J. Gibbons (2006). Seismic/Infrasonic Processing: Case study of explosions in north Finland. Semiannual Technical Summary, 1 July – 31 December 2005, NORSAR Sci. Rep. **1-2006**, 54-68.

Ringdal, F., and T. Kværna (1989). A multi-channel processing approach to real time network detection, phase association, and threshold monitoring, *Bull. seism. Soc. Am.*, **79**, pp. 1927-1940.

Ringdal, F. & J. Schweitzer (2005). Combined seismic/infrasonic processing: a case study of explosions in NW Russia. Semiannual Technical Summary, 1 January – 30 June 2005, NORSAR Sci. Rep. **2-2005**, 49-60.

6.2 Investigation of infrasound signals from rocket launches at the Plesetsk Cosmodrome, Northwest Russia

Introduction

Infrasound observations of Russian rocket launches has been demonstrated by Asming et al. (2008) who addressed both launches from the Plesetsk Cosmodrome as well as from submarines in the Barents Sea. In this study we will further extend the analysis of the infrasound signals from the Plesetsk rocket launches to obtain an understanding of the overall signal characteristics as well as the inherent variability among these signals.

The Plesetsk Cosmodrome is located about 800 km north of Moscow, with geographical coordinates 62.92 N 40.52 E. Plesetsk is used especially for military satellites placed into high inclination and polar orbits. However, global overviews on spaceflights, e.g., *http://en.wikipedia.org/wiki/2005_in_spaceflight* show that geosynchronous satellites also are launched from this site.

We have initially focused our attention on two launches, one on 19 June 2003 and another on 21 June 2005. See Table 6.2.1 for details.

Table 6.2.1. Rocket launches at the Plesetsk Cosmodrome observed at the infrasound stations in Apatity, Jämtön and Kiruna

Launch Year/Date/Time	Rocket	Orbit	Mission/Function
2003 19 June 20:00 GMT	Molniya M (R-7 8K78M)	Highly elliptical (Molniya)	Communications Satellite
2005 21 June 00:49 GMT	Molniya M	Geosynchronous	Communications Satellite

We have analyzed signals from these rocket launches recorded both at the Apatity infrasound array (Vinogradov and Ringdal, 2003) and by the stations of the Swedish Infrasound Network. The Swedish Infrasound Network (Liszka, 2007) has been in operation since the beginning of the 1970s. Operated by the Swedish Institute of Space Physics, the network has until the end of 2006 consisted of four infrasound stations: Kiruna, Jämtön, Lycksele and Uppsala. The station in Uppsala was moved to Sodankylä, Finland, during the fall of 2006. Figure 6.2.1 shows the location of the infrasound stations currently in operation and the Plesetsk Cosmodrome. Table 6.2.2 gives information on the distance and back-azimuth for the different stations to Plesetsk.

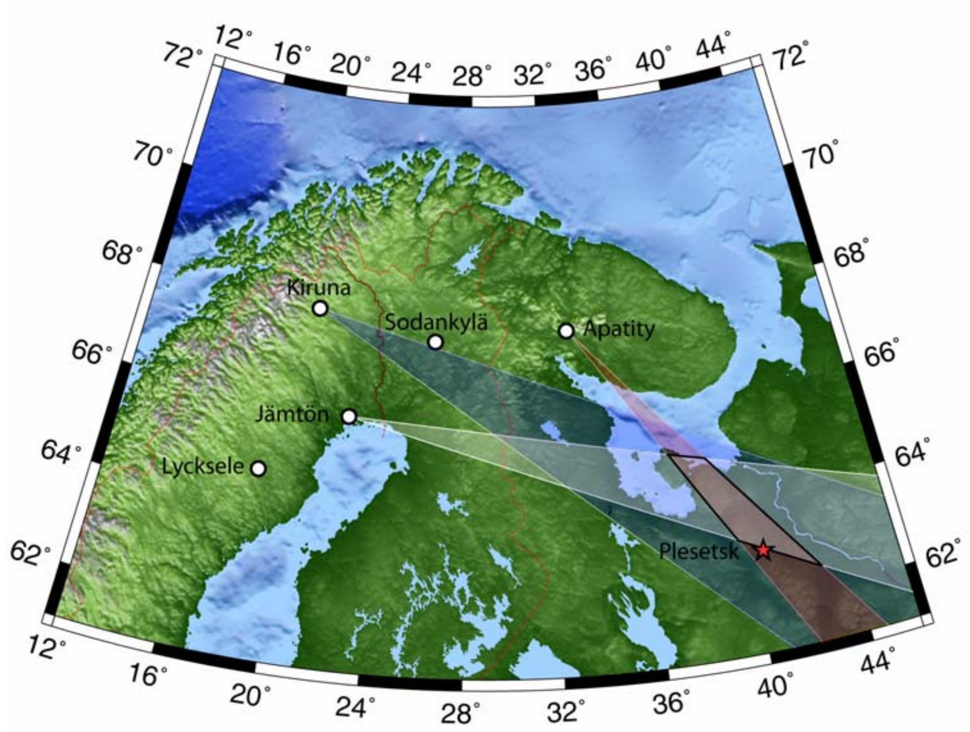

Figure 6.2.1. Map showing the location of existing infrasound stations in Sweden, Finland and NW Russia (filled white circles). The location of the Plesetsk Cosmodrome is shown by the red star. The azimuthal sectors from Kiruna, Jämtön and Apatity represent the range of back-azimuth estimates during the wavetrain of infrasound signals from the 2003 and 2005 rocket launches.

Table 6.2.2. Distances and back-azimuths from given infrasound stations to the Plesetsk Cosmodrome

Station	Latitude (N)	Longitude (E)	Distance (km)	Back-azimuth (^{0})
Apatity	67.60	32.99	628	142.6
Sodankylä	67.42	26.39	828	120.6
Jämtön	65.86	22.51	925	102.4
Kiruna	67.86	20.42	1077	111.1
Lycksele	64.61	18.75	1085	90.1

Data Processing

In order to get an overview of the signal characteristics we have processed the infrasound data using vespagram analysis. Using a fixed apparent sound velocity of 0.333 km/s, we have calculated the resulting normalized beam power for a range of back-azimuths, where the maximum represent an estimate of the back-azimuth of the arriving signal. In our calculations we have used a window length of 10 seconds and a window step of 1.0 second. The Apatity infrasound data were processed in the 1 - 3 Hz frequency band, whereas the stations of the Swedish Infrasound network were all processed in the 2 - 5 Hz band. Figure 6.2.2 shows the results for the 2003 and 2005 Plesetsk rocket launches, given in Table 6.2.1 for the stations Apatity, Jämtön and Kiruna. We observe the following general characteristics:

Apatity:

1) Some differences in waveforms between the 2003 and 2005 events.
2) Quite similar azimuthal vespagrams, with a trend of changing back-azimuths versus time. Such observations are indicative of a moving source.
3) Signal durations of almost 10 minutes. High SNR signals.
4) Back-azimuths ranging between 145 and 137 degrees

Jämtön:

1) Quite similar waveforms and vespagrams for the 2003 and 2005 events
2) Signal duration of about 5 minutes. Moderate SNR signals.
3) Back azimuths ranging between 91 and 102 degrees

Kiruna:

1) Quite similar waveforms and vespagrams for the 2003 and 2005 events
2) Signal duration of about 5 minutes. Low SNR signals with influence of local noise.
3) Back azimuths ranging between 101 and 118 degrees

For two additional Plesetsk rocket launches in 2005 and 2007 (see Table 6.2.3) we have also quite good recordings at the Apatity array. These are shown in Figure 6.2.3, together with the Apatity observations of the 2003 and 2005 reference events. We see that the 2007 event has a low SNR and is influenced by local noise at the station, and it is difficult to interpret the results. However, the 27 October 2005 signal has a characteristics similar to the 2003 and 2005 reference events, but with the exception that the trend of back-azimuthal change versus time is reversed. This may be explained by differences in rocket takeoff directions relative to the Apatity station.

In order to find how the direction estimates compare with the direction to the Plesetsk Cosmodrome, we have in Figure 6.2.1 plotted azimuthal sectors from Apatity, Jämtön and Kiruna spanning the range of azimuth estimates observed during the different infrasound wavetrains. It is interesting to notice that the area of overlap between the different sectors include the actual launch site. However, additional factors like atmospheric inhomogeneities, the wind field along the infrasound propagation path and the altitude and location of the infrasound source (the rocket) will most likely introduce biases in the azimuth estimates relative to the predicted Plesetsk direction.

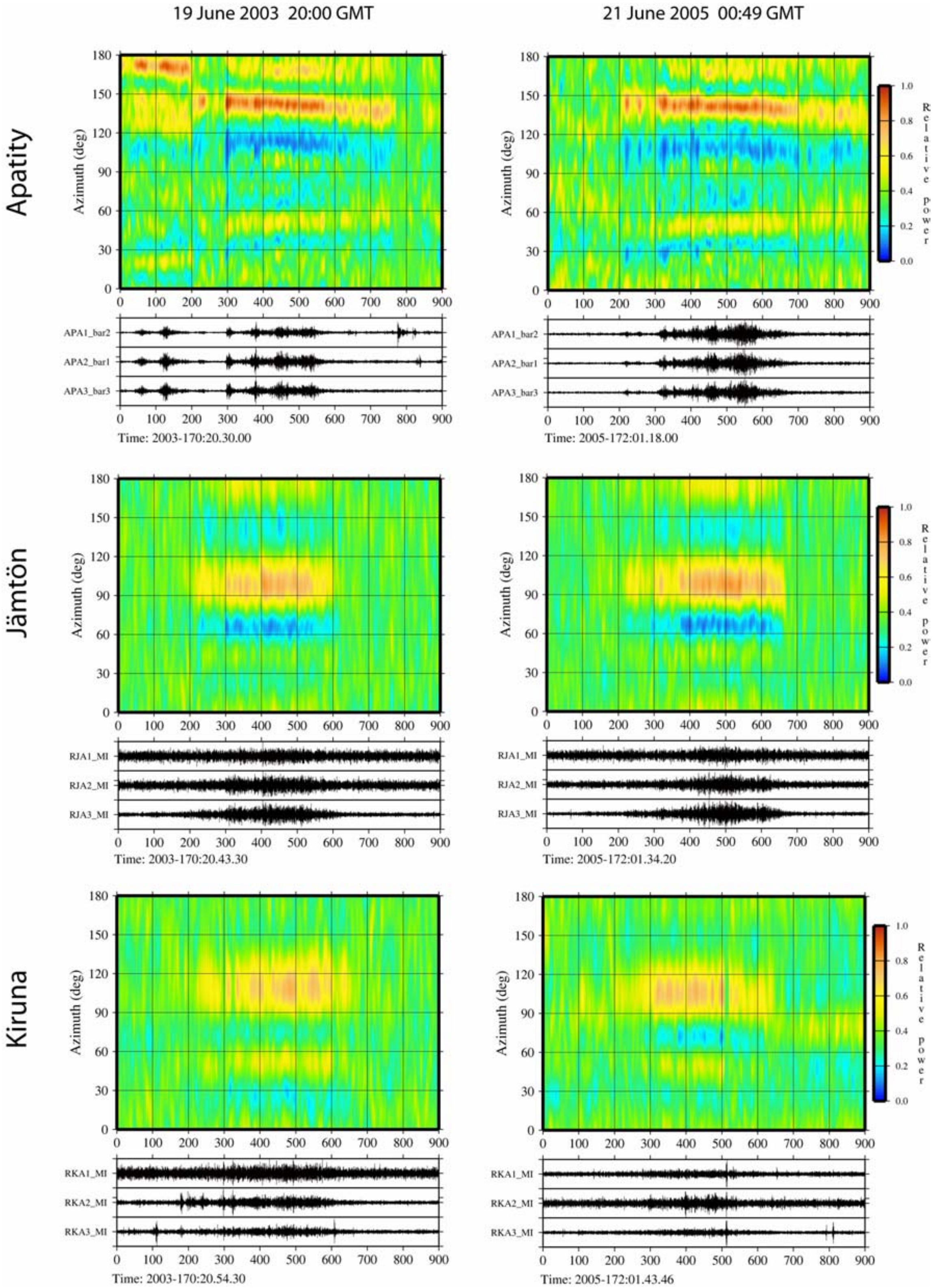

Figure 6.2.2. Each panel shows the infrasound waveforms from Apatity, Jämtön and Kiruna as well as the corresponding azimuthal vespagram of the signals from the 2003 and 2005 Plesetsk rocket launches given in Table 6.2.1

Table 6.2.3. Rocket launches at the Plesetsk Cosmodrome observed only at the Apatity infrasound station

Launch Year/Date/Time	Rocket	Orbit	Mission/Function
2005 27 October 06: 52 GMT	Kosmos-3M	Low Earth Orbit	Civilian mission, multiple payloads
2007 25 December 13:10 GMT	RS-24	Multiple re-entry vehicles	ICBM test

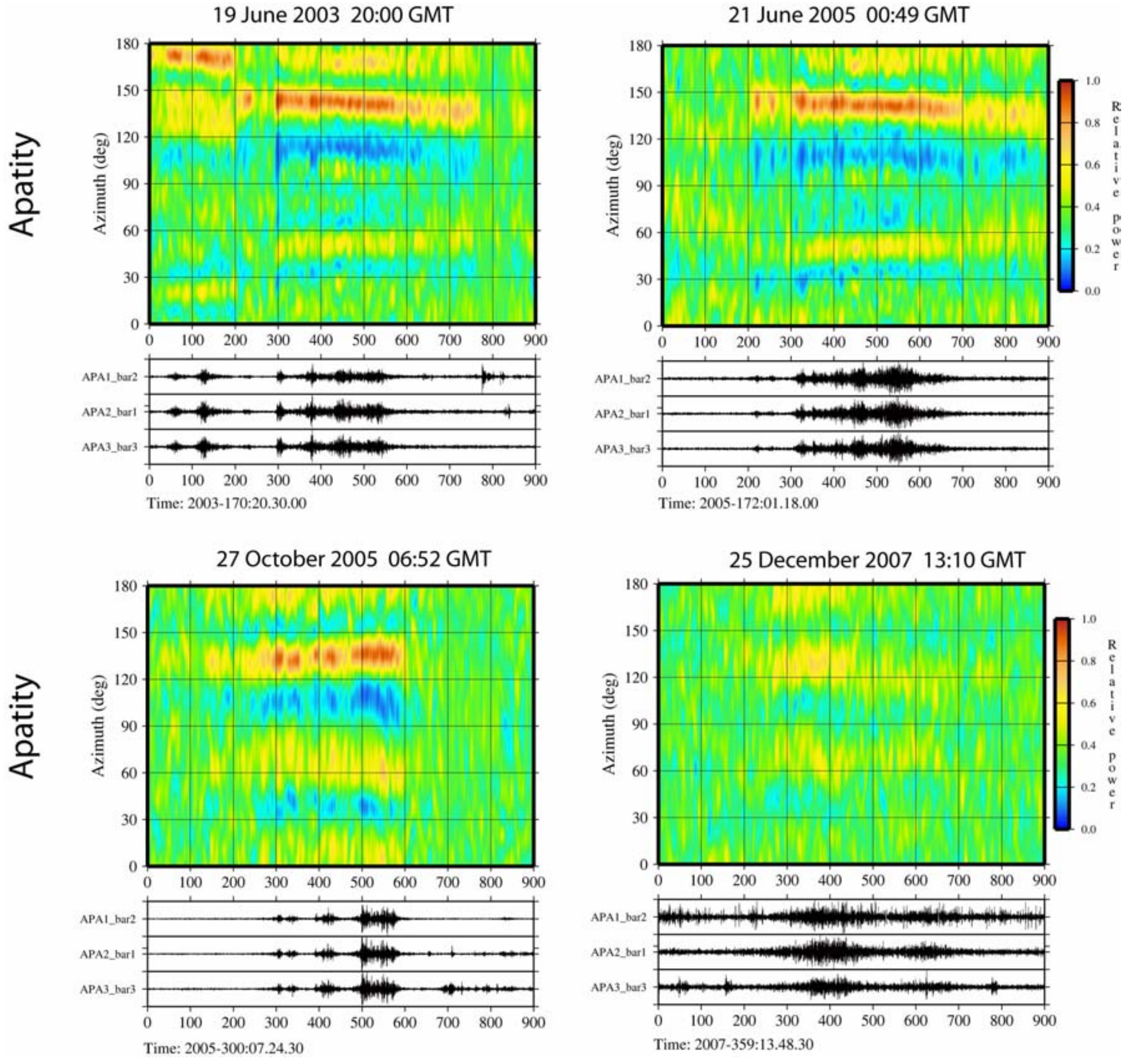

Figure 6.2.3. The two lower panels show Apatity data and vespagrams for the 2005 and 2007 Plesetsk rocket launches listed in Table 6.2.3. The two upper panels show similar plots for the 2003 and 2005 events listed in Table 6.2.1

Signals observed on 23 January 2007

During an exercise with processing of continuous data from the infrasound stations shown in Figure 6.2.1, we detected for 23 January 2007 a series of 5 very interesting signals. At the Apatity station, the waveforms had a duration of 5 - 8 minutes and time-varying back-azimuths. The directions were a bit to the south of the back-azimuth estimates obtained for previously analyzed Plesetsk rocket launches. The similarity with / difference between the 23 January 2007 signals and the reported Plesetsk rocket launches can be observed by comparing Figure 6.2.4 with Figure 6.2.3.

For two of the events (at 10:30 and 13:00) we had also detections at the Jämtön and Kiruna stations, and Figure 6.2.5 shows the corresponding panels with Apatity, Jämtön and Kiruna data. Figure 6.2.5 can be compared with Figure 6.2.2 in order to see how the Jämtön and Kiruna data compare with signals from known Plesetsk rocket launches.

During the fall of 2007 the Swedish infrasound station in Uppsala was moved to Sodankylä, Finland. Four of the 23 January 2007 events were also detected at this station, and the corresponding data and vespagrams are shown in Figure 6.2.6.

We were not able to find any reports on rocket launches from the Plesetsk Cosmodrome on 23 January 2007, but the signals has some striking similarities with those from the 2003 and 2005 verified rocket launches. In particular this concerned the duration of the signals (5-8 minutes) and the observation of time varying azimuths (in both directions) at the Apatity array.

The main difference were in the back-azimuth estimates, where the 23 January events were generally 10-15 degrees more to the south than those for the verified rocket launches.

We have in Figure 6.2.7 plotted azimuthal sectors from Apatity, Sodankylä, Jämtön and Kiruna spanning the range of azimuth estimates observed during the different infrasound wavetrains on 23 January 2003. Except for Sodankylä, the azimuth sectors are biased southwards relative to the Plesetsk Cosmodrome. As seen from the figure, there exists a small area of overlap between the sectors, but this cannot be confidently be interpreted as representative for the actual source location. Nevertheless, all the sectors contain the Plesetsk site, and it seems likely that they correspond to actual (unconfirmed) Plesetsk launches.

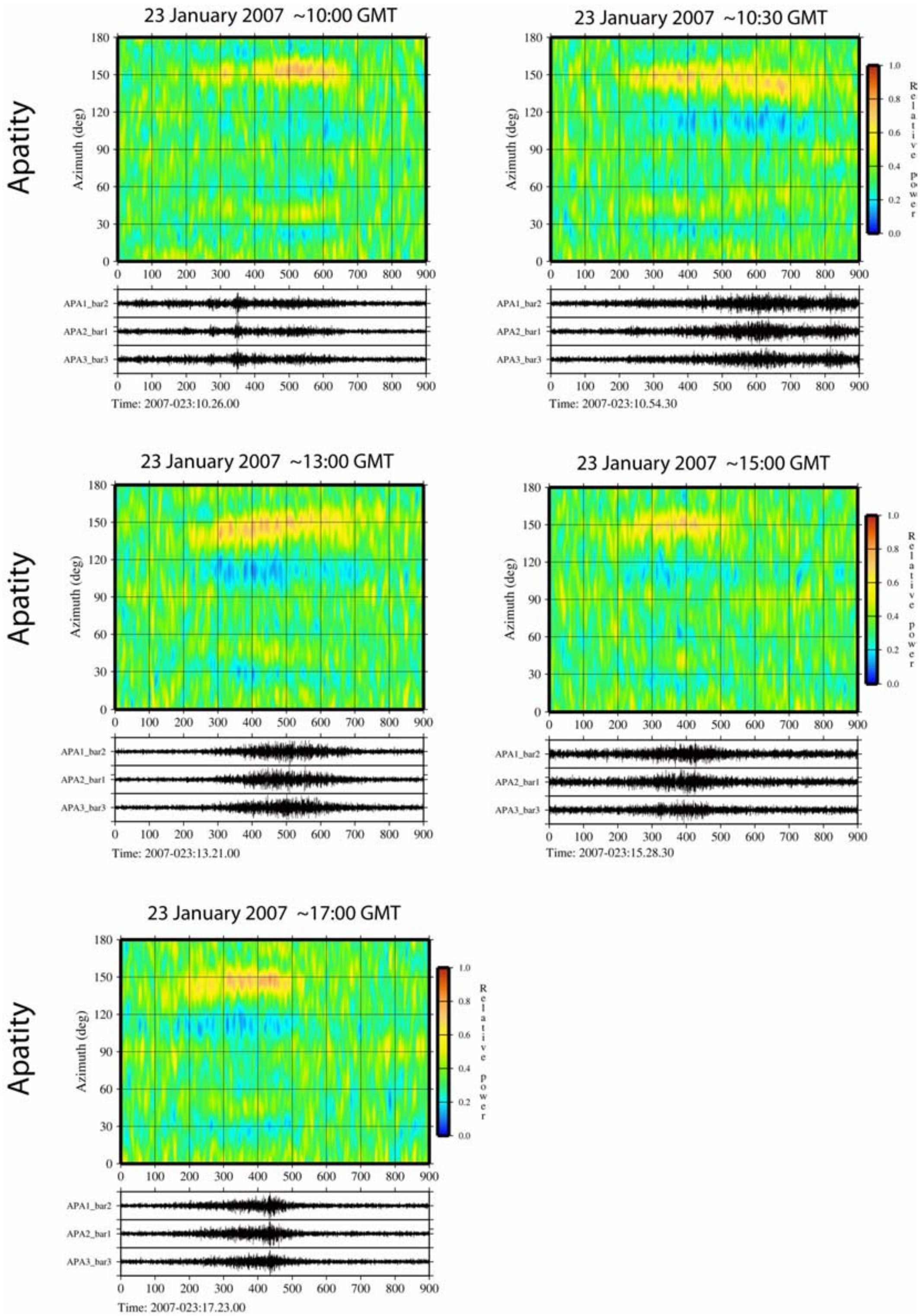

Figure 6.2.4. Apatity data and vespagrams for the 5 infrasound signal recorded on 23 January 2007. Approximate origin times (to the nearest half hour) are given above each event panel.

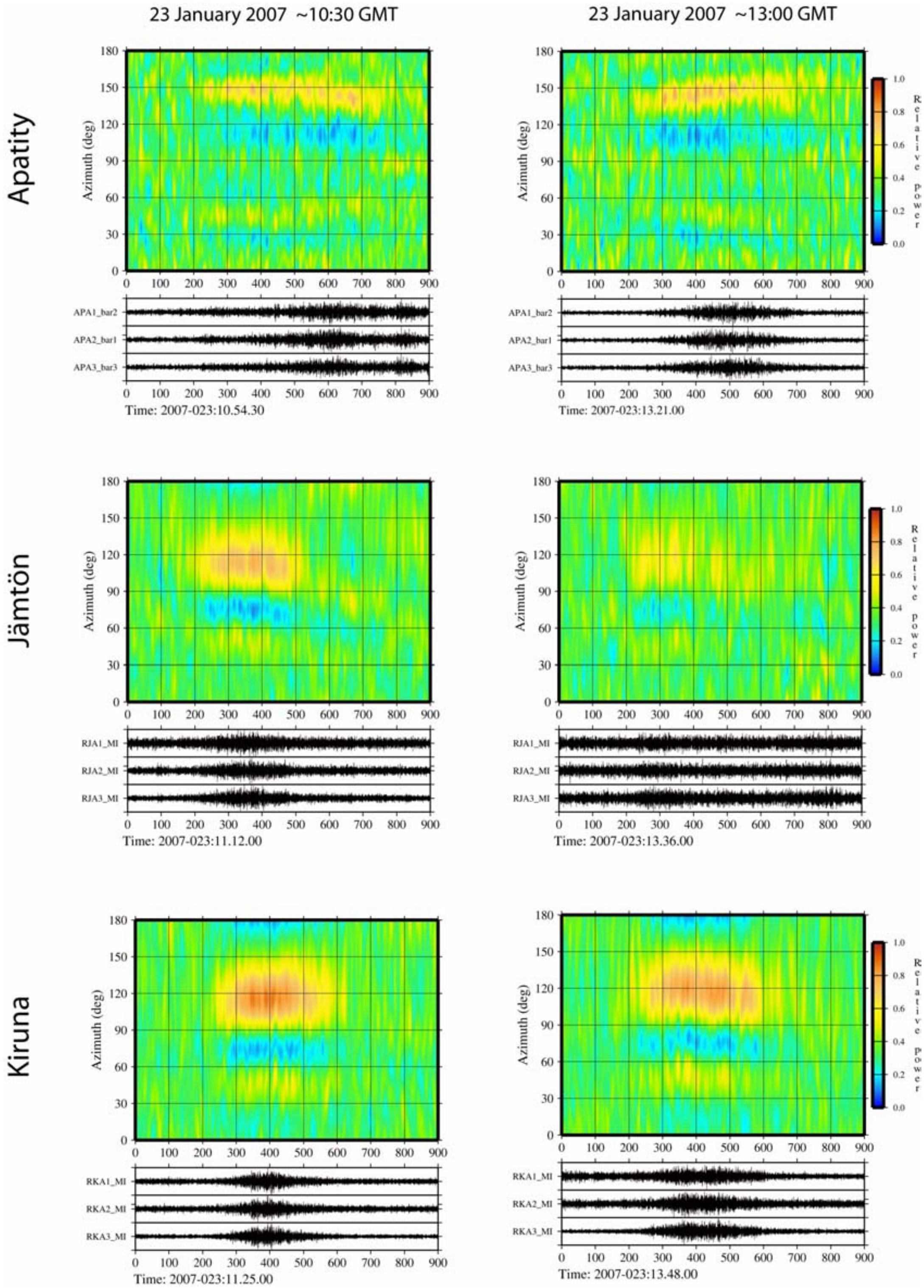

Figure 6.2.5. Each panel shows the infrasound data and azimuthal vespagram of the signals from two of the events on 23 January 2003.

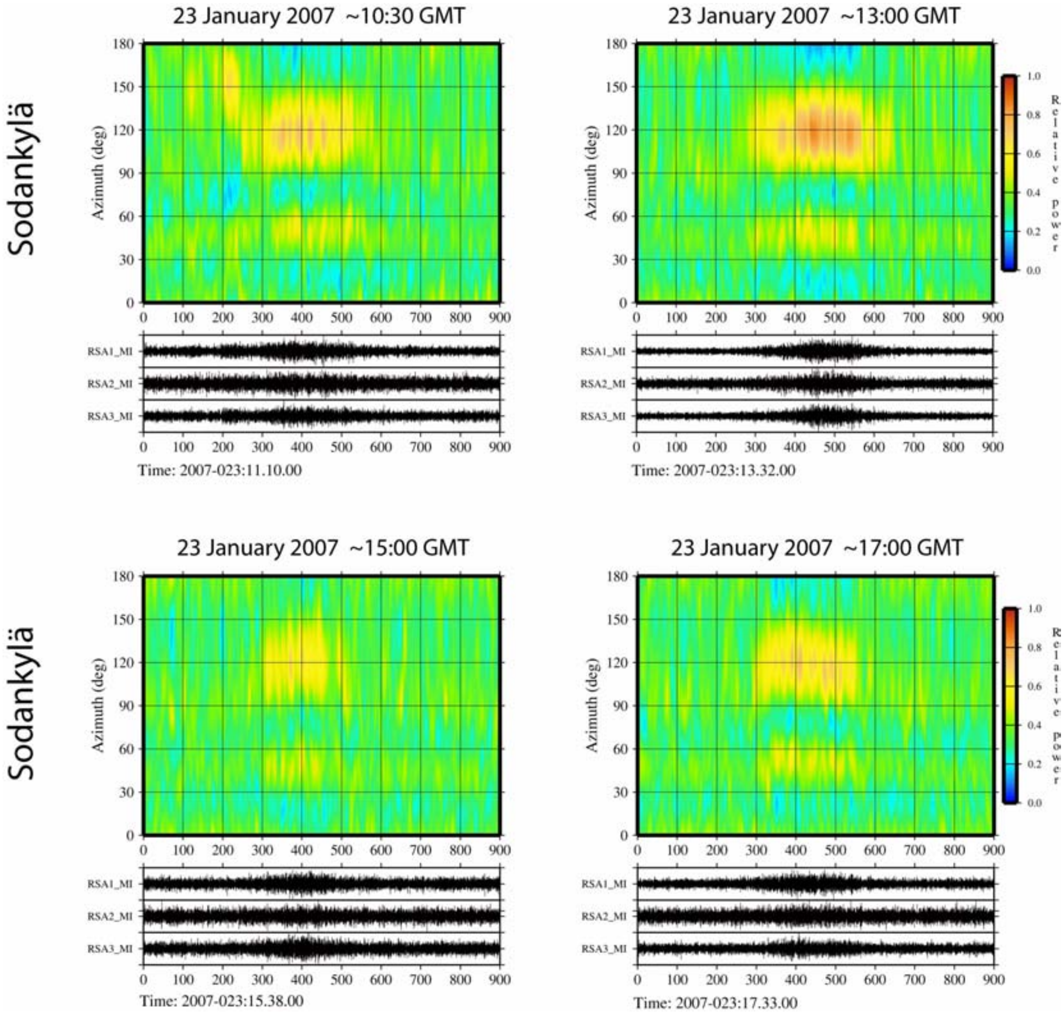

Figure 6.2.6. Sodankylä data and vespagrams for 4 of the infrasound signal recorded on 23 January 2007. Approximate origin times (to the nearest half hour) are given above each event panel.

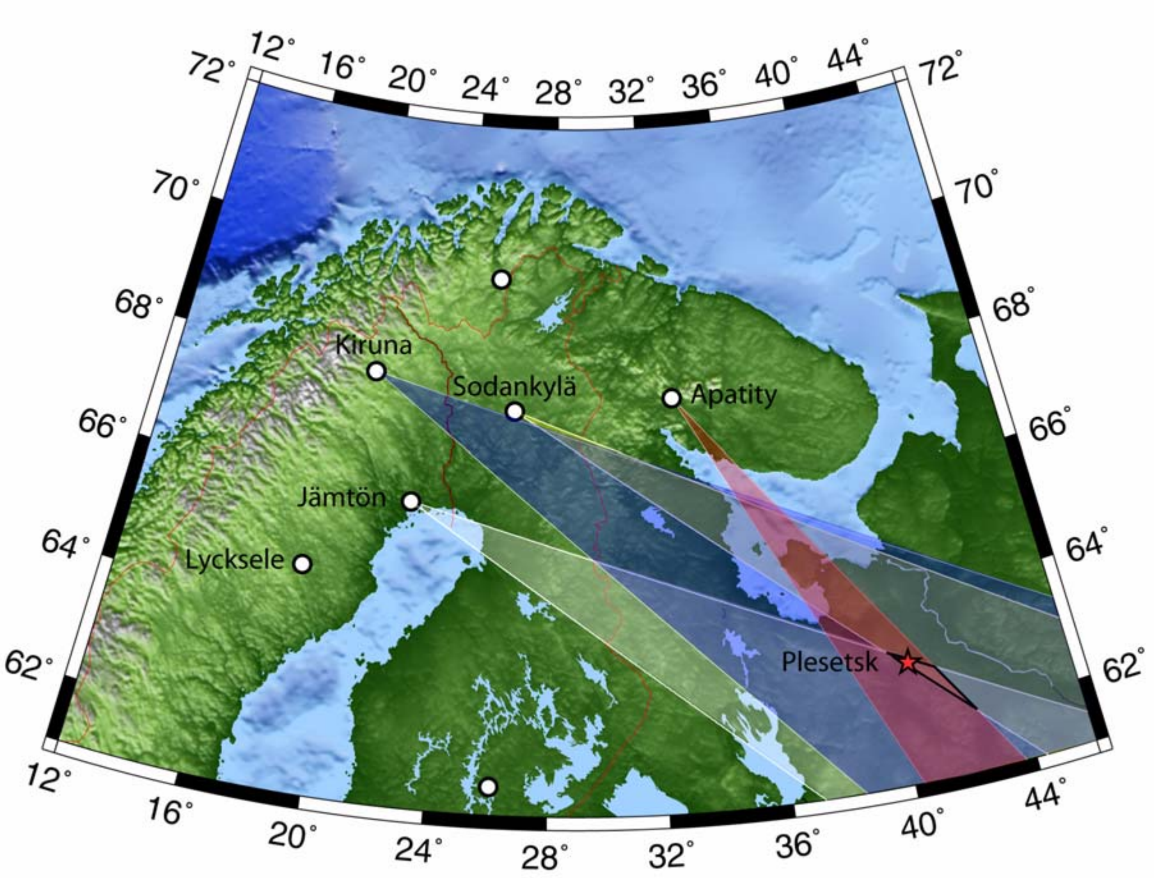

Figure 6.2.7. Map showing the azimuthal sectors from Kiruna, Sodankylä, Jämtön and Apatity that represent the variability of back-azimuth estimates calculated during the wavetrain of infra-sound signals recorded on 23 January 2003.

Discussion

As a final step in our analysis we calculated differential travel-times for onsets of the infra-sound signals at the Jämtön and Kiruna stations relative to Apatity. The onsets were read visually from the vespagrams, and had a rather high uncertainty. Similarities in the vespagram patterns were also used to infer the onsets. The results are given in Table 6.2.4, and we find that we cannot separate the source location for the unknown signals from the verified Plesetsk launches based on these differential travel times.

Table 6.2.4. Differential travel times relative to the Apatity infrasound signal

Event Year/Date/Time	Jämtön	Kiruna
Plesetsk launch 2003 19 June 20:00 GMT	13 min. 32 s (812 s)	25 min. 58 s (1558 s)
Plesetsk launch 2005 21 June 00:49 GMT	17 min. 50s (1070 s)	27 min. 6 s (1626 s)
Unknown origin 2007 23 January ~10:30 GMT	19 min. (1140 s)	30 min. 30 s (1830 s) Low SNR, most probably late onset
Unknown origin 2007 23 January ~10:30 GMT	15 min. (900 s)	26 min. (1560 s)

This study has provided us with very useful information on the characteristics of infrasound signals from the Plesetsk Cosmodrome in Northwest Russia. The signals exhibit significant similarities with respect to signal duration and overall back-azimuths. In particular the trend of changing back-azimuth versus time (both directions) at the Apatity station is a pronounced feature. There are large variability within the differential travel times and also within the back-azimuth estimates calculated during a given infrasound wavetrain.

We have not been able to locate the origin of the sources of the infrasound signals on 23 January 2007. Generally they have several characteristics in common with the Plesetsk rocket launches, indicating moving sources. For Apatity, Jämtön and Kiruna the general back-azimuths are 10-15 degrees to the south of those from the verified Plesetsk rocket launches.

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Tormod Kværna

References

Asming, V., Yu. Vinogradov, E.O. Kremenetskaya, Z.A. Yevtyugina, A.V. Fedorov (2008): Infrasound observations at Apatity array. Presentation made at NORSAR's infrasound seminar, January, 2008

Liszka, L. (2007): Infrasound - A summary of 35 years of infrasound research, Manuscript submitted for printing, 150 pp.

Vinogradov, Yu. and F. Ringdal (2003). Analysis of infrasound data recorded at the Apatity array, NORSAR Scientific Report: Semiannual Technical Summary No. 1 - 2003. NORSAR, Kjeller, Norway. pp. 68-77.

6.3 The International Polar Year 2007-2008 Project “The Dynamic Continental Margin between the Mid-Atlantic-Ridge System (Mohn’s Ridge, Knipovich Ridge) and the Bear Island Region”

6.3.1 Introduction

In 2005, NORSAR submitted to the International Polar Year (IPY) Organization a proposal for a project with the title ”The Dynamic Continental Margin Between the Mid-Atlantic-Ridge System (Mohns Ridge, Knipovich Ridge) and the Bear Island Region”. The submission was made on behalf of a consortium consiting of NORSAR (lead institution), the University of Bergen, the University of Oslo, the Alfred Wegener Institute in Bremerhaven, the University of Potsdam, the University of Warsaw and the Institute of Geophysics-Polish Academy of Sciences, Warsaw.

This proposal was supported by the IPY Organization and became one part of the proposed IPY project cluster “Plate Tectonics and Polar Gateways in Earth History (PLATES & GATES)” (http://www.platesgates.geo.su.se/). In 2006, NORSAR submitted the full proposal to the Norwegian Research Council (NFR), which awarded the project as one of the 26 Norwegian IPY projects after an additional reviewing and selection process with in total 6 000 000 NOK.

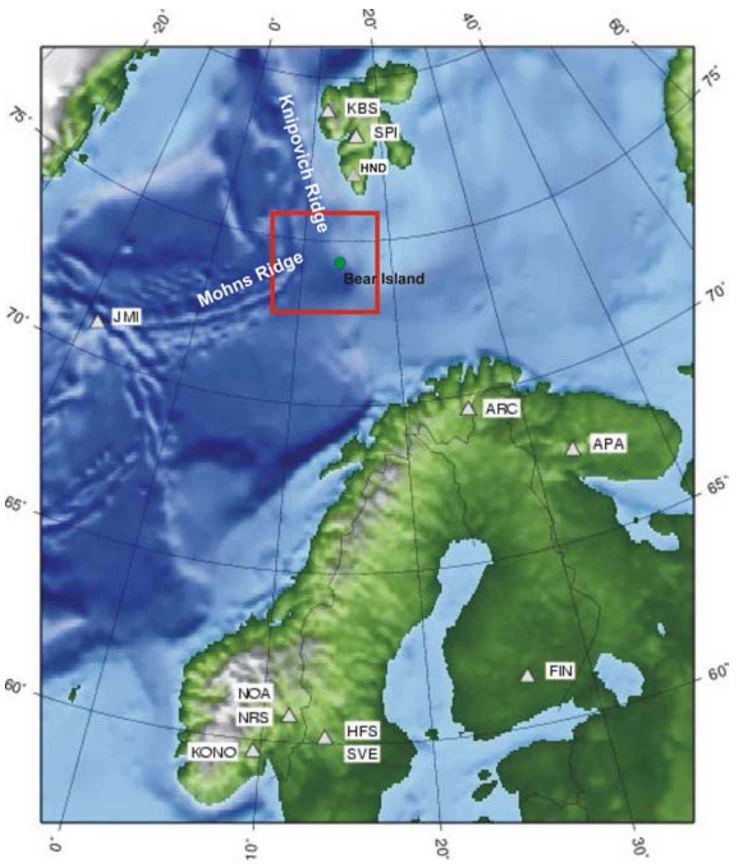

Fig. 6.3.1. Map showing the area of interest for this project (red rectangle) on the background of the main tectonic elements. Grey triangles show locations of seismic arrays and seismic stations of major importance for the project.

The project started as planned in 2007 and this contribution will give an overview on the principal project objectives and the planned or already carried out field activities. The official project webpage (http://www.norsar.no/seismology/IPY/) is regularly updated.

6.3.2 Project Background and status of knowledge

The continental margin along the northern Atlantic Ocean (Fig. 6.3.1) has been extensively studied in the past by active and passive seismic experiments (see e.g., Husebye et al., 1975; Mitchell et al., 1990, Bungum et al., 1991; Sellevoll et al., 1991; Eiken, 1994; Høgden, 1999; Bykjeland et al., 2000; Faleide, 2000, Faleide et al., 2000; Mjelde et al., 2002). These studies have shown that a complete understanding of continental margins is only possible, when also the deeper crustal and mantle architecture beneath the margins is recovered.

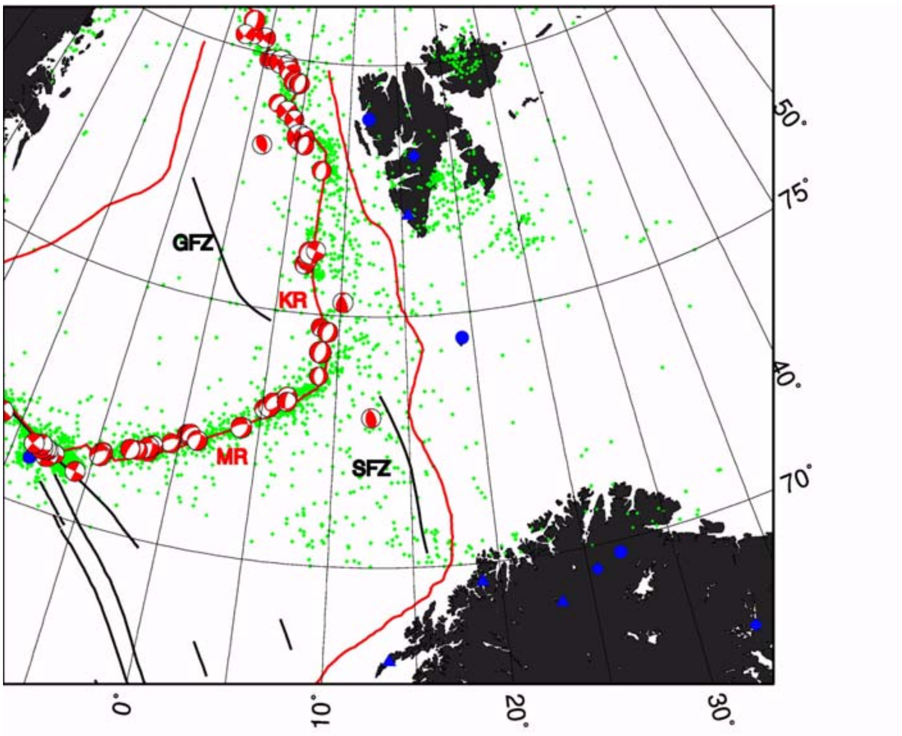

Fig. 6.3.2. Seismotectonic map of the region of interest. The red lines show the continental slope (margin) and the mid-Atlantic ridge with Mohns Ridge (MR) and the Knipovich Ridge (KR), the black lines show main tectonic fracture zones, namely the Senja Fracture zone (SFZ) and the Greenland Fracture Zone (GFZ). The fault-plane solutions are copied from the Harvard CMT Catalogue (1976–09.2001) for events with magnitude M > 4.7. The blue points, triangles and diamonds show locations of permanent seismic stations (broadband stations, short period stations, and seismic arrays, respectively) in the region. The small green dots show all locations of seismic events north of latitude 70˚, as far as they are published in the ISC catalogue for the period from 1900 until the end of 1999.

The western Barents Sea – Svalbard continental margin developed mainly as a sheared margin in response to the Cenozoic gradual northward opening of the Norwegian-Greenland Sea (Faleide et al., 1991, 1993, 1996, Breivik et al., 1999). A rifted margin segment associated with volcanism southwest of Bear Island links sheared margin segments to the south and north. Repeated tectonic and volcanic events at this margin segment reflect a complex plate tectonic evolution of the adjacent oceanic basin involving jump(s) in the spreading axis. The continentocean transition occurs over a narrow zone and is covered by a thick sedimentary wedge comprising major depots (submarine fans) along the margin.

The Senja Fracture Zone (SFZ) extends from the Norwegian mainland to the area west of Bear Island, and is generally interpreted as a sheared margin segment resulting from the Early Eocene opening of the North Atlantic (Fig. 6.3.2). The present-day active oceanic spreading ridge, the Knipovich Ridge (KR), gradually approaches the West Spitsbergen sheared margin obliquely northwards, and we consider the study area as a key region for revealing the continental breakup processes. Furthermore, the area is essential for understanding the interplay between accretion of oceanic crust and passive (sheared) margin formation further north, where the eastern part of the ridge crest is covered by a thick sedimentary wedge.

On the western side of the KR the Greenland Fracture Zone (GFZ) can be addressed as a similar structure. However, this fracture looks simpler than the SFZ because it does not define in addition the border between continental and oceanic crust.

Mohns Ridge (MR) (Fig. 6.3.2), which is nearly perpendicular to the KR and the SFZ, has a strike pointing directly to the continental margin. Therefore, it has been proposed that the MR is migrating further to the east and possibly into a relatively weak continental lithosphere. Recently achieved surface-wave-tomography results show relatively low S-wave velocities in this region (Levshin et al., 2005; 2007). A detailed knowledge of the lithospheric margin dynamics, from its top to its bottom, is needed there, and our experiment will focus on this.

The very slow spreading KR shows an active but diffuse seismicity pattern and no clear alignment of earthquakes along active segments or transform faults (Fig. 6.3.2). In addition, the deep sea between the mid-Atlantic ridge system and the continental margin of the Barents Sea show an unusually high but diffuse seismicity. It is unclear if this is an artefact due to location uncertainties of the events or an expression of the interaction of the ridge with the nearby continental margin. The observed seismicity appears to correlate with the distribution of young (< 2.3 mill. years) sediments in the major fans along the NE Atlantic margins (Byrkjeland et al. 2000).

Because of the large distances between this seismically active area and the installed seismic 3C broadband stations and arrays in the region (ARCES, Apatity, BJO1, JMIC, KBS, KEV, SPITS) (see Figs. 6.3.1 and 6.3.2) and the relatively high noise level at many of the stations due to the ocean generated microseisms, the epicenter locations of the events in the region around Bear Island are currently associated with relatively large errors. Moreover, there is little control on the event depths and in addition the regional seismicity reported by the ISC has a relatively high cut-off magnitude at about M = 4. Therefore, new well-located (lower magnitude) events will dramatically improve our capabilities to understand the seismicity and seismotectonics of this region.

Only a few earthquake source mechanisms have so far been estimated for this region. They all come from larger events for which moment-tensor solutions could be estimated from globally distributed stations. More and better focal mechanism solutions, either estimated with standard methods or full moment tensor inversions, are necessary to characterize the active structures near the ridge, in the oceanic crust between the ridge and the shelf region and in the shelf region itself. Of particular interest is here the northern "tip region'' of the SFZ. It is not known whether the SFZ intersects with the narrow margin near Bear Island and whether it may be somehow connected with the Knipovich-Mohns-Ridge system. If so, a seismogenic stress release on this fracture zone could bear a major potential for the triggering of submarine slides. In fact, major slides have been identified along the southern part of the Barents slope and the Lofoten-Vesterålen slope (Dehls et al., 2000). Focal solutions are also important to understand the crustal stress field in the region. To a first order, stress is extensional along the ridge system and compressional on Svalbard (Mitchell et al., 1990). The state of stress on Bear Island is however not known and moreover it is unknown if the transition from extensional to compressional stress may be occurring in the region of our experiment. Mitchell et al. (1990) have proposed that ridge push forces are controlling this stress transition.

6.3.3 The project objectives

Within the PLATES&GATES consortium, the proposed project will aim at improved understanding of the structural architecture, the stress conditions and sources, and the dynamics of the continental margin near Bear Island. This will be accomplished by:

- Improved determination of earthquake hypocenters along the mid-Atlantic ridge system (Mohns Ridge, Knipovich Ridge), within the oceanic basin between the ridge systems, and along the continental margin to identify active tectonic structures.
- Investigation of possible migration of seismicity along Mohns Ridge towards the continental shelf, and to investigate the reactivation potential of the Senja Fracture Zone.

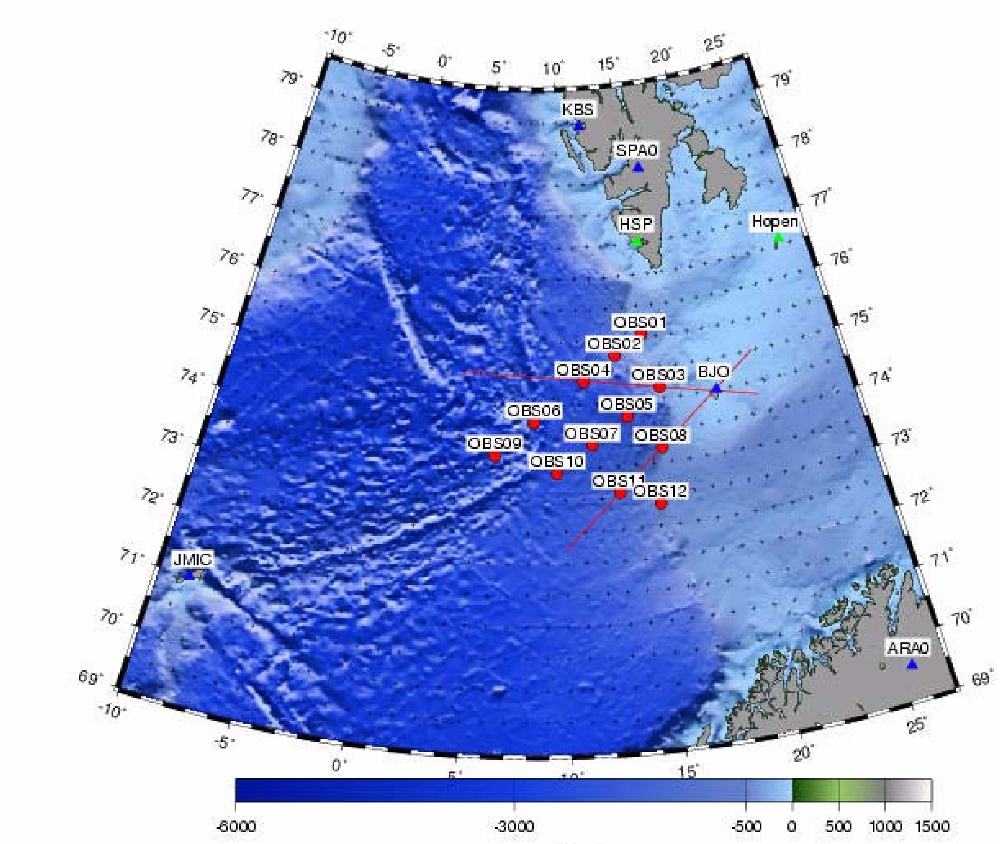

Fig. 6.3.3. Positions of the different instrumental (planned) installations during the field experiment: Red points OBSs, green triangles broadband stations on Hopen and at Hornsund, near the blue triangle the Bear Island array, and red lines the reflection/refraction profiles.

- Mapping of crustal deformation of the continental margin in a region of steep slopes with a high potential for geohazards such as submarine slides.
- Detailed recovery of the lithospheric structure from active experiment data, surface wave analysis, receiver-function methods, and S-wave anisotropy assessment.
- Calculation of focal mechanisms (standard methods and full moment tensor inversions) to investigate details of the faulting processes and to understand better the complex regional stress field in this region.
- Contribute to more detailed knowledge of seismic velocities to advance our understanding of the crustal composition and to improve the accuracy of existing and future earthquake locations in the region.

6.3.4 The (planned) project

This project is divided into two main parts. The first phase is the active / passive experiment and the second phase will be devoted to data processing and interpretation. The combination of active and passive experiments and the data from the distributed seismological arrays and stations will provide a unique opportunity to study the region of interest.

The passive experiment will monitor the seismic activity and thereby the actual tectonic stress field of the region by mapping regions of active seismicity and estimating the needed fault plane solutions.

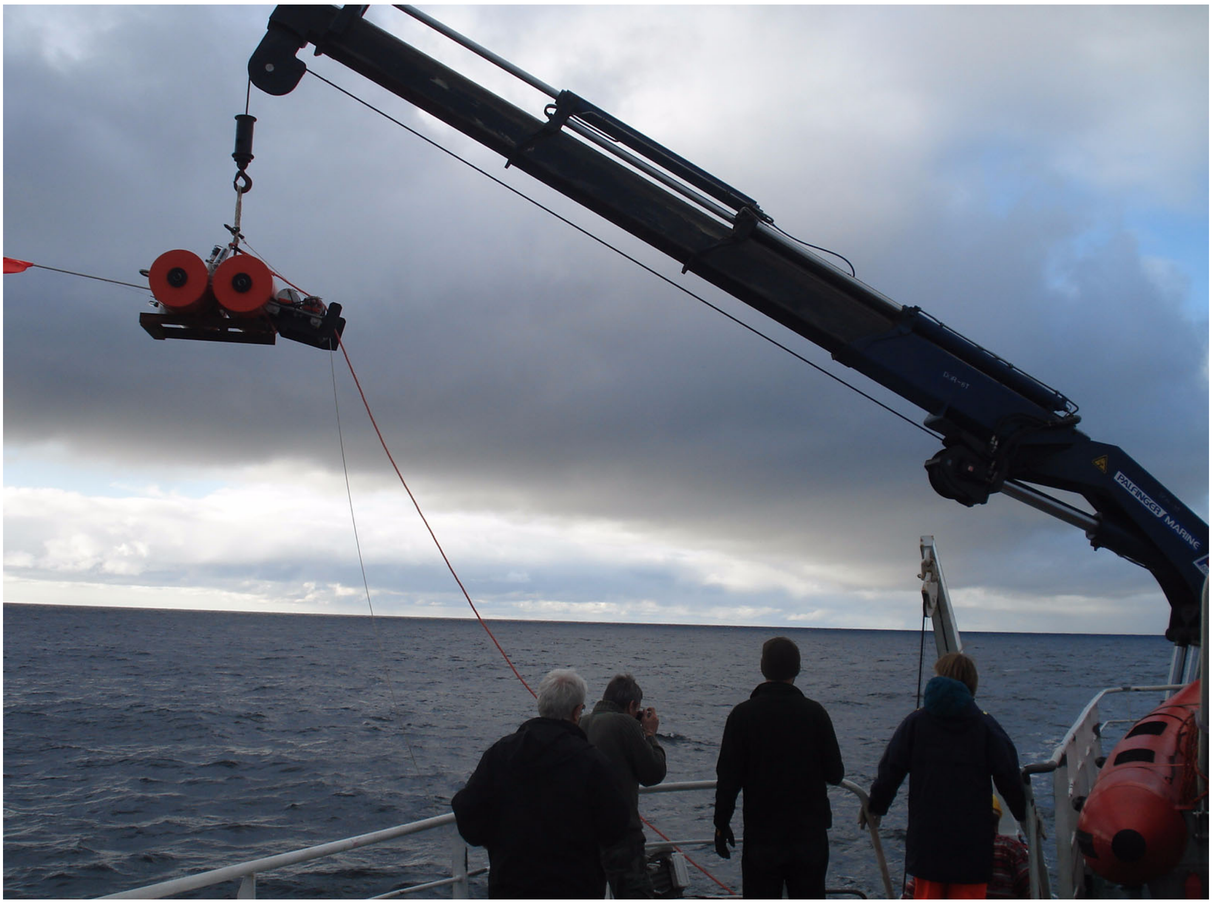

Fig. 6.3.4. Watering of one of the 12 OBSs (Photo: Frank Krüger, University of Potsdam).

The active profiling experiment will provide detailed information about the velocity structure and the distribution of major geological and tectonic elements down to the upper mantle. This information will then be utilized in (re)locating all seismic events in the region on the basis of a new, improved velocity model for the region.

First Phase: The Field Activities (2007 – 2008)

1) Installation of 12 broadband ocean bottom seismometers (OBSs) provided by the German pool for amphibian seismology (DEPAS, http://www.awi-bremerhaven.de/php/GPH/link-web.php?page=obs). The 12 OBSs have been installed at the end of September 2007 in the deep sea from the mid-Atlantic ridge system (MR, KR) to Bear Island, and along the continental margin to the north to form a profile of stations together with the new broadband station at Hornsund and the existing stations on Svalbard (see Fig. 6.3.3). The OBSs have been deployed by colleagues from the University of Potsdam, the Alfred Wegener Institute, KUM (Kiel), and the staff of the polish vessel HORYZONT II, which had been hired by the Polish Academy of Sciences, Geophysical Institute. The disassembly of these 12 stations is planned for autumn 2008 after the planned active experiment. Fig. 6.3.4 shows the deployment of one of the 12 OBSs.

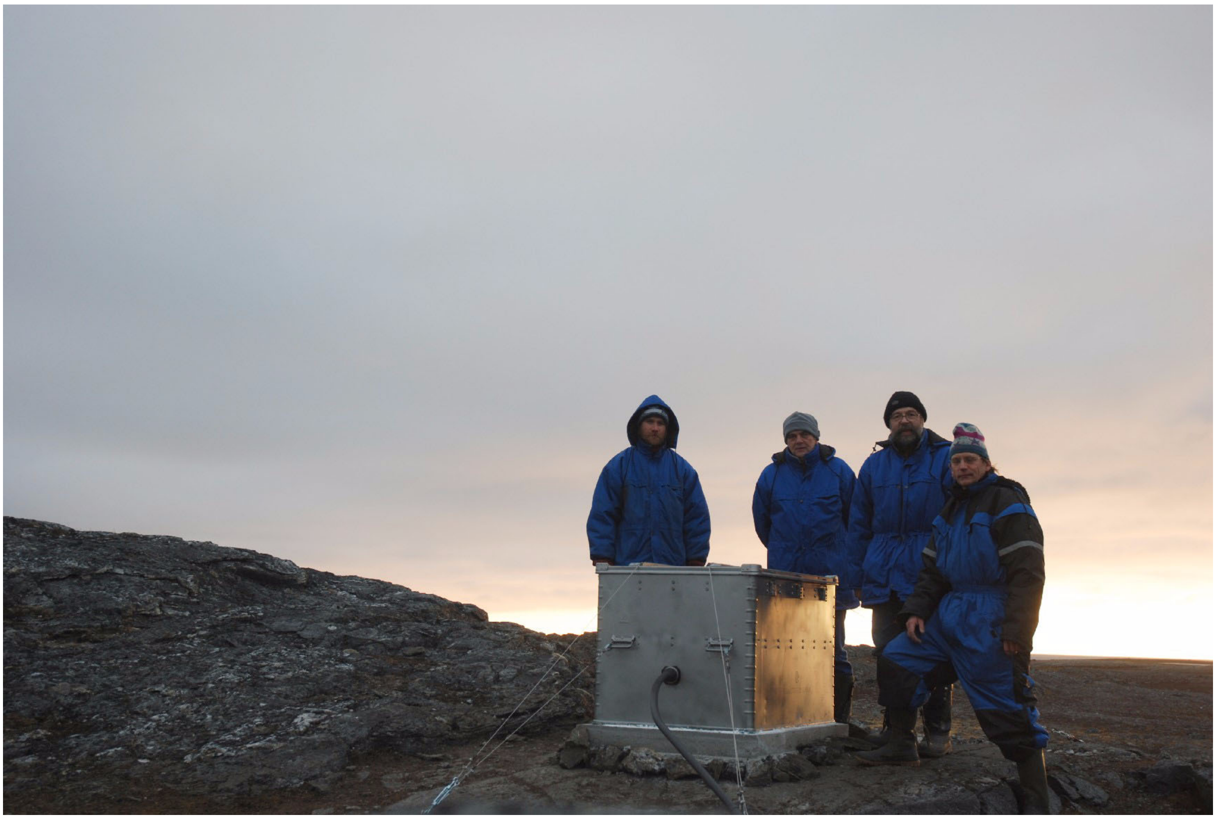

Fig. 6.3.5. The new STS-2 site at the Polish Polar Station Hornsund with the installation team (from left) Michal Sawicki, Andrzei Skizynski, Jerzy Suchcicki (all Geophysical Institute of the Polish Academy of Sciences, Warsaw), and J. Schweitzer.

2) Installation of two new STS-2 broadband seismometers (green triangles, Fig. 6.3.3) one at the Polish Polar Station Hornsund on Spitsbergen (HSP) and one on Hopen Island. Both new stations are operating in parallel to the 12 OBSs since late September 2007.

The STS-2 broadband seismometer at Hornsund has been installed in close co-operation with colleagues of the Geophysical Institute of the Polish Academy Sciences. Fig. 6.3.5 shows the new broadband site at Hornsund, which had been especially prepared for minimizing the influence of the temperature changes and protecting against humidity and Fig. 6.3.6 shows the recordings from this site of a small (NORSAR ml = 2.6) event at an epicentral distance of about 60 km close to the southern tip of Spitsbergen (2007/11/30, 12:14:03, 76.602° N, 16.967° E).

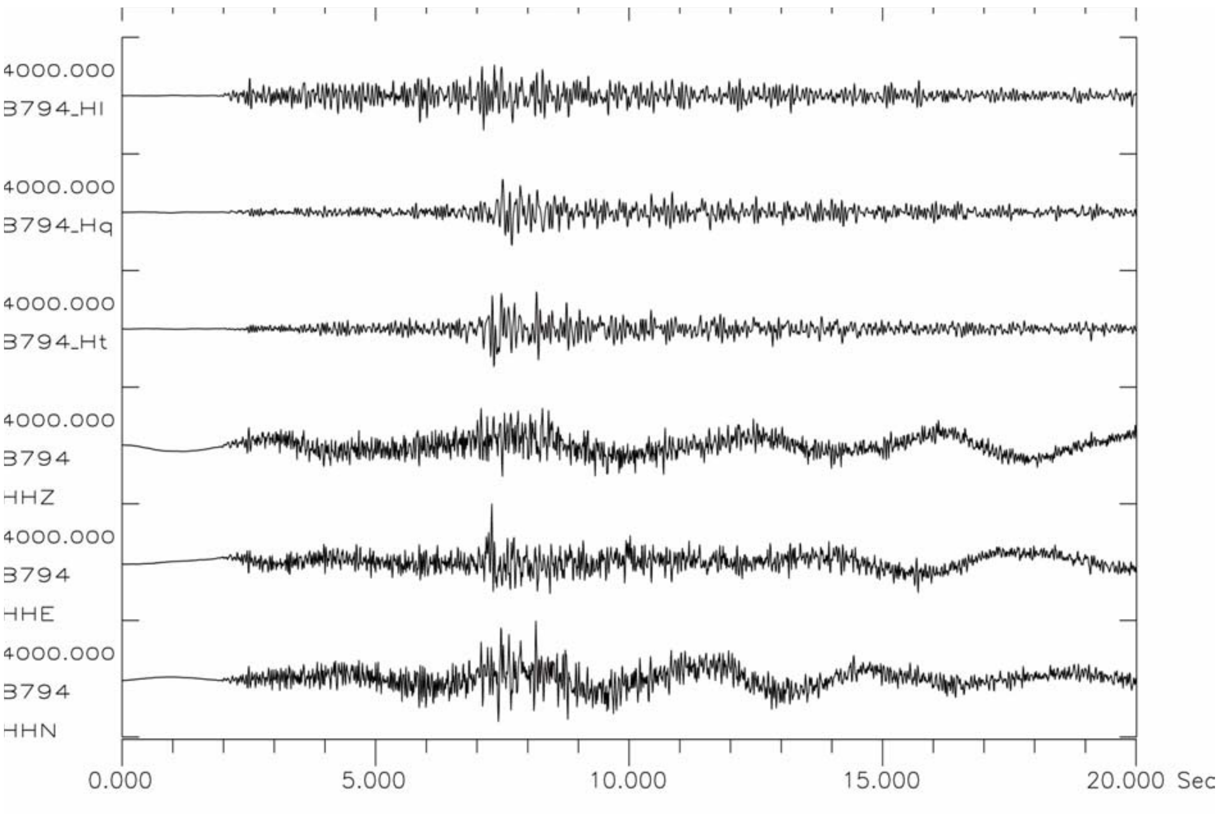

Fig. 6.3.6. STS-2 records from the newly installed broadband station at the Polish Polar Station Hornsund. The plot shows as lower traces the original three-component recordings and on top ray-oriented rotated and Butterworth bandpass filtered (1 - 20 Hz) components.

3) The broadband seismometer on Hopen Island has been installed as an upgrade of the existing Norwegian National Seismological Network (NNSN) short period seismometer by the University of Bergen. Fig. 6.3.7 shows the new installed STS-1 at the Hopen site.

4) Installation of a small seismic array (13 three-component seismometers) on Bear Island (close to the blue triangle on Bear Island in Fig. 6.3.3) for the summer season 2008 (University of Potsdam). It is planned to install the array in late May, 2008. However, because of the snow and ice conditions on Bear Island, the installation of this array may be delayed until late June, 2008. We plan to operate the array until September / October, 2008, depending on access possibilities of the island.

Fig. 6.3.7. The newly installed STS-2 broadband sensor at the NNSN station Hopen (Photo: Helge Johnsen, University of Bergen).

5) An active seismic refraction/reflection experiment along two profiles crossing the margin and Bear Island (see the red lines in Fig. 6.3.3). The plan is to observe the airgun shots and small yield explosion sources fired along these two lines with about 50 short period seismometers temporaly installed along the costa of Bear Island (University of Warsaw and Polish Academy of Sciences), a 3 km long digital multichannel streamer, and 10 – 15 OBSs (both provided by the University of Bergen). The active experiment is planned for late summer / autumn 2008. Both profiles of about 450 to 500 km length will start about 20 to 30 km east of Bear Island and continue in a westward direction from the island. In addition, gravity and magnetic data will be acquired.

The first profile is planned to the northwest, crossing the continental margin and the KR at about 75˚ North. The second profile will go to the southwest in direction of the sedimentary wedge covering the (unknown) continuation of the SFZ. In addition, all active sources along these two profiles will be also observed with the temporary small aperture array on Bear Island, the ocean bottom network, the about 50 Polish mobile stations on Bear Island, and depending on the source yield with the arrays and the single three-component stations on Hopen, Spitsbergen and in Northern Fennoscandia.

Second Phase: The Data Processing and Analysis (2008 – 2010)

The groups in Bergen and Warsaw have a long tradition and expertise in collecting and interpreting refraction and wide-angle reflection seismic data. Standard analysis tools for modelling and travel-time tomography will be used to analyze the data. Gravity and magnetic data will further constrain the density model and help to identify structural anomalies.

In addition, the observation of the active sources with seismic stations will give us valuable data to calibrate the installed seismic network, but also the permanent stations, which observe these sources (Taylor, 1999; Schweitzer, 2000). It is known (e.g., Schweitzer, 2001) that backazimuth and slowness observations of seismic phases as recorded by small aperture arrays, have to be calibrated. The calibration of the Bear Island array will be a special part of the planned data analysis at NORSAR.

One main goal of the analysis is to obtain a 3D structural and geological picture of this continental margin. Therefore, the data from the passive experiment will be analyzed using seismological techniques like receiver function analysis for P and S waves, S-wave splitting, and surface wave dispersion analysis, to map in more detail the crustal thickness in the area, to investigate the stress distribution in the lithosphere, and to retrieve mean S-velocity models outside the profiles of the active experiment, in particular along the continental margin.

All new data will be integrated with the existing geophysical and geological data that the University of Oslo has compiled and interpreted during more than 25 years of margin studies in the region. The goal is to build a 3D geological model for the study area. High-resolution bathymetry data and high-resolution shallow seismics are important tools to study the neotectonic structures on the seafloor.

Efforts will also be made to identify and study potentially unstable sediment masses along the continental slope, as expressed by shallow micro-earthquakes indicating neotectonic faults. In the geological past giant debris avalanches have occurred in the area of investigation. Such events may potentially re-occur today, leading to flood catastrophes (tsunamis) and other geohazards. In this context the two reverse-faulting earthquakes, as reported in the Harvard catalogue, are of special interest. They may have occurred at shallower depths than estimated by the seismological data centers, thereby indicating larger movements in the sedimentary cover of the oceanic crust.

Johannes Schweitzer
The IPY Project Consortium Members

References

Breivik, A.J., J. Verhoef & J.I. Faleide (1999): Effect of thermal contrasts on gravity modeling at passive margins: Results from the western Barents Sea. J. Geophys. Res. 104, 15293-15311.

Bungum, H., A. Alsaker, L.B. Kvamme & R.A. Hansen (1991): Seismicity and seismotectonics of Norway and nearby continental shelf area. J. Geophys. Res. 96, 2249-2265.

Bungum, H., E.S. Husebye and F. Ringdal (1971): The NORSAR array and preliminary results of data analysis. Geoph. J. R. astr. Soc. 25, 115-126.

Byrkjeland, U., H. Bungum & O. Eldholm (2000): Seismotectonics of the Norwegian continental margin. J. Geophys. Res. 105, 6221-6236.

Dehls, J. F., O. Olesen, L. Bockmann, H. Brekke, H. Bungum, E. Hicks, C. Lindholm & F. Riis (2000): Neotectonic Map, 1:3 Million. In NEONOR: Neotectonics in Norway, Final Report 2000, NGU Report 2000.02, 83-86.

Eiken, O. (ed.) (1994): Seismic atlas of Western Svalbard. Norsk Polarinstitutt Meddelelser 130, 73 pp.

Faleide, J.I. (2000): Crustal structure of the Barents Sea – important constraints for regional seismic velocity and travel-time models. In: Semiannual Technical Summary, 1 October – 31 March 2000, NORSAR Scientific Report 2–1999/2000, 119-129.

Faleide, J.I., J. Schweitzer, H. Bungum & E. Møllegaard (2000): Synthetic travel times for regional crustal transects across the Barents Sea and the adjacent western continental margin. In: Semiannual Technical Summary, 1 April – 30 September 2000, NORSAR Scientific Report 1–2000/2001, 89-97.

Faleide, J.I., S.T. Gudlaugsson, O. Eldholm, A.M. Myhre & H.R. Jackson (1991): Deep seismic transects across the western Barents Sea continental margin. Tectonophysics 189, 73-89.

Faleide, J.I., A. Solheim, A. Fiedler, B.O. Hjelstuen, E.S. Andersen & K. Vanneste (1996): Late Cenozoic evolution of the western Barents Sea-Svalbard continental margin. Global and Planetary Change 12, 53-74.

Faleide, J.I., E. Vågnes & S.T. Gudlaugsson (1993): Late Mesozoic-Cenozoic evolution of the southwestern Barents Sea. In: Parker, J.R. (ed.) Petroleum geology of Northwest Europe: Proceedings of the 4th Conference. Geological Society, London, 933-950.

Høgden, S. (1999): Seismotectonics and crustal structure of the Svalbard Region. Cand. Scient. Thesis, Department of Geology, University Oslo, 142 pp.

Husebye, E.S., H. Gjøystdal, H. Bungum & O. Eldholm (1975): The seismicity of the Norwegian and Greenland Seas and adjacent continental shelf areas. Tectonophyics 26, 55-70.

Levshin, A., Ch. Weidle & J. Schweitzer (2005): Surface wave tomography for the Barents Sea and surrounding regions. In: Semiannual Technical Summary, 1 January – 30 June 2005, NORSAR Scientific Report 2ñ2005, 37-48.

Levshin, A., J. Schweitzer, Ch. Weidle, N. Shapiro & M. Ritzwoller (2007): Surface wave tomography of the Barents Sea and surrounding regions. Geophys. J. Int., 170, 441-459, 2007, doi: 10.1111/j.1365-246X.2006.03285.x

Mjelde, R., A.J. Breivik, H. Elstad, A.E. Ryseth, J.R. Skilbrei, R.R. Opsal, H. Shimamura, Y. Murai & Y. Nishimura (2002): Geological development of the Sørvestsnaget Basin, SW Barents Sea, from ocean bottom seismic, surface seismic and potential field data. Norwegian Journal of Geology 82, 183-202.

Mitchell, B.J., H. Bungum, W.W. Chan & P.B. Mitchell (1990): Seismicity and present-day tectonics of the Svalbard region, Geophys. J. Int. 102, 139-149.

Schweitzer, J. (2000): Recent profiling experiments in the Spitsbergen area — calibration data for the SPITS array. In: Semiannual Technical Summary, 1 October 1999 – 31 March 2001, NORSAR Scientific Report 2–1999/2000, 93–105, Kjeller, Norway, May 2000

Schweitzer, J. (2001): Slowness corrections — one way to improve IDC products. Pure appl. geophys. 158, 375-396.

Sellevoll, M. A., S.J. Duda, A. Guterch, J. Pajchel, E. Perchuc & F. Tyssen (1991): Crustal structure in the Svalbard region from seismic measurements. Tectonophyics 189, 55-71.

Taylor, L., J. Schweitzer & T. Kværna (1999): Eurobridge – ground truth observations at the Fennoscandian arrays (1999). In: Semiannual Technical Summary, 1 April – 30 September 1999, NORSAR Scientific Report 1–1999/2000, 108-121.

6.4 Overview of NORSAR system response

6.4.1 Introduction

Since the end of the 1960s, when it was first installed, to the current installation, the NORSAR array has been repeatedly reconfigured, once by reducing its size and numerous times by modifying the instrumentation. Consequently, the instrument response of the array stations has changed many times during the 40 years of its operation. However, the detailed knowledge of a seismographic system instrument response is critical for the correct interpretation of its recordings, since it affects both the amplitude and the phase of the recorded waveforms.

An attempt is under way to recalculate and organize all NORSAR system instrument responses, from the time of the first installation to the present. All sources of information are being catalogued and archived. Furthermore, detailed documentation is being compiled, describing the methodology followed to obtain the necessary information, the calculation of the responses, as well as more practical issues, such as organizing and storing the results for future usage. Therefore, no information such as individual instrument poles and zeroes, serial numbers, sensitivity values, etc. are provided here, the reader being referred to the relevant NORSAR internal publication.

6.4.2 NORSAR array configurations

A brief history of the development of the NORSAR array is necessary in order to catalogue the different instrumentations employed since the first installation of the array. This took place in 1968 and involved 22 subarrays (Fig. 6.4.1), comprising as a total 132 short-period and 22 long-period instruments.

In the short-period vaults (SPVs), the sensors (Hall-Sears HS-10-1 vertical seismometers) were connected to an amplifier (Texas Instruments RA-5) and via a several kilometer long cable to the Central Terminal Vault (CTV), where the SLEM (Short and Long Period Electronic Module by Philco-Ford) unit was residing. The main components of the latter, relevant to instrument response calculations, were the Line Terminating Amplifier (LTA), which included two analog filters, a high-pass RC filter and a low-pass Chebyshev filter, and the SLEM A/D converter, a gain-ranged digitizer of 14-bit resolution. The standard instrumentation chain was different for the long-period instruments (Geotech 7505B vertical and 8700C horizontal seismometers). The sensors were connected to an Ithaco amplifier, which was directly connected to the LTA, without the latter employing any low-pass filter.

Several minor modifications, mainly concerning the LTA filter cards were made until 1976, when a large number of sites from the original configuration were shut down. 7 subarrays remained in operation (Fig. 6.4.1), each one of them consisting of six elements. These modifications resulted in a series of ‘alternate versions’ of the standard NORSAR instrumentation and are tabulated, together with the instrumentations to be discussed next, in Table 6.4.1. Some more drastic modifications involving test configurations with S-13 or S-500 triaxial seismometers, took place in the late 1970s.

From 1979 on, a small-aperture seismic array (NORESS) started being tested on subarray 06C of the NORSAR array. The initial configuration employed 6 sites, including NORSAR site 06C02 under the name NRA0, whereas since the end of October 1980 a ‘new’ NORESS consisted of 12 sites equipped with vertical sensors (Mykkeltveit and Ringdal, 1980). The final

NORESS installation came in operation in 1984. Employed instrumentation during the test phase was standard NORSAR however, the NORESS tests required changes in data channel assignment for the NORSAR array (Nilsen, 1980).

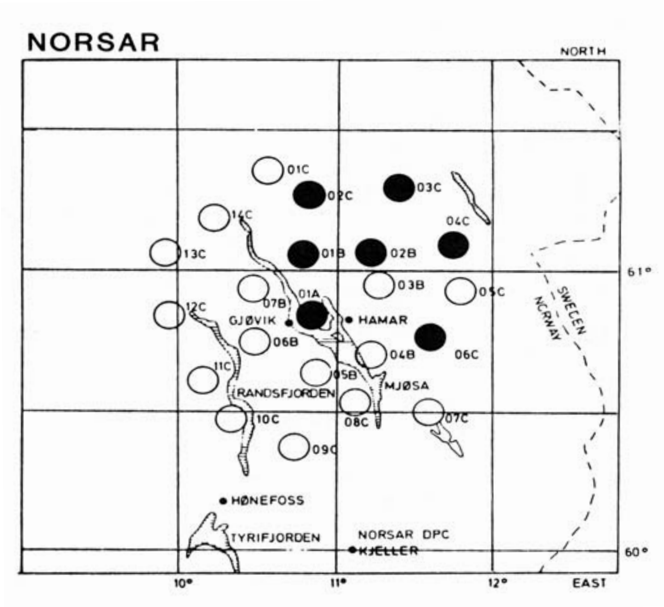

Fig. 6.4.1. Location and naming of the NORSAR subarrays. Still operating subarrays are noted with filled circles and closed down subarrays with open circles (Ringdal, 1981).

The 1976 instrumentation continued until the end of 1993, beginning of 1994, when the NORSAR Backup System came in operation. It employed 7 Nanometrics RD6 (6-channel) digitizers to backup the entire system, after extensive problems with the communications system. The rest of the equipment remained unmodified.

At the end of 1994, the RD6 were exchanged with Science Horizons AIM24 digitizers. A general refurbishment took place in 1995, when the array became equipped with the instrumentation it's carrying today. A Geotech 20171A short-period sensor is installed at each site, while each subarray also has a 3-component, broadband KS54000 sensor. Finally, the broadband instrument installed at site 06C02 was replaced in 2000 with a broadband Güralp CMG-3T seismometer, in order to acquire CTBT certification for the NORSAR array as IMS primary station PS27.

The above mentioned instrumentations for which different instrument responses needed to be calculated are presented in Table 6.4.1. Each case is mentioned together with information about the time interval it could be met, the GSE response file Respid (in parenthesis), which is an identifier for each different calculated response, the corresponding channel sensitivity (Calib in nm/count) and the calibration period (Calper in s). It should be noted that a large number of exchanges between the different variations of the standard configuration took place in numerous channels, and that precise documentation of these modifications with respect to array site and time interval is outside the scope of this contribution. Furthermore, NORESS test configurations are not specifically mentioned here, unless the instrumentation itself differs from listed NORSAR configurations.

Table 6.4.1. The different instrument configurations of the NORSAR array from its installation to the present. Calib values are in nm/count and Calper in seconds.

Time	Installation Name	Components	Calib	Calper
1968-1994	Standard_SP (SPSLEM1)	HS-10-1 RA-5 LTA 4.75 Hz Chebyshev low-pass SLEM	0.042722	1.00
1977-1994	SP_var1 (SPSLEM2)	HS-10-1 RA-5 LTA 8.00 Hz Chebyshev low-pass SLEM	0.042722	1.00
1986	SP_var2 (SPSLEM6)	HS-10-1 RA-5 LTA Unknown filter SLEM	0.042722	1.00
1986-1989	SP_var3, SVZ, NRA0 (SPSLEM5)	HS-10-1 RA-5 LTA ‘prototype’ Butterworth bandpass SLEM	0.042722	1.00
1968-1994	SP_var4 (SPSLEM3)	HS-10-1 RA-5 LTA no low-pass SLEM	0.042722	1.00
1976-1994	SP_var5, attenuat. SLZ (SPSLEM4)	HS-10-1 RA-5, attenuated -30 db LTA 4.75 Hz Chebyshev low-pass SLEM	1.351000	1.00
1976, 1978, 1980	SP_var7, S-13 (SPSLEM7)	S-13 RA-5 LTA 4.75 Hz Chebyshev low-pass SLEM	0.042722	1.00
1978	SP_var8, S-500 (SPSLEM8)	S-500 RA-5 LTA 8.00 Hz Chebyshev low-pass SLEM	0.099500	1.00

1968-1994	Standard_LP (LPSLEM1, LPSLEM2)	7505B/8700C Ithaco LTA SLEM	2.4700	25.0
1975-1976	LP_var1, attenuat. (LPSLEM3, LPSLEM4)	7505B/8700C Ithaco, attenuated -30 db LTA SLEM	2.4700	25.00
1994	NB2_SP (RDSP1)	HS-10-1 RA-5 LTA no low-pass RD6	4.2717e-04	1.00
1994	NB2_SP, attenuat. (RDSP2)	HS-10-1 RA-5, attenuated -30 db LTA no low-pass RD6	1.3508e-02	1.00
1994	NB2_LP (RDLP1)	7505B/8700C Ithaco LTA RD6, auxiliary SOH channel	0.95	25.0
1994-1995	old_AIM_SP_CTV (AIM1)	HS-10-1 RA-5 LTA AIM24-1 in CTV, gain 1x	1.669e-04	1.00
1994-1995	old_AIM_SP_SPV 06C sites (AIM2)	HS-10-1 AIM24-1 in SPV, gain 100x	0.006529	1.00
1994-1995	old_AIM_SP_CTV attenuated (AIM3)	HS-10-1 RA-5, attenuated -30 db LTA AIM24-1, gain 1x	0.0052773	1.00
1995	old_AIM_LP (AIM4, AIM5)	7505B/8700C RA-5 LTA AIM24-3BB	0.01543	1.00
1995-…	current_SP (AIM0SP)	20171A Brick AIM24-1	0.006430*	1.00
1995-…	current_BB (AIM0BB)	KS54000 AIM24-3BB	0.019325	1.00
2000-…	current_BBG (AIM0BBG)	CMG-3T AIM24-3BB	0.12009*	1.00

* Indicative value. The sensitivity is site specific.

The Calib values presented in Table 6.4.1 can all be considered as 'nominal' channel sensitivity values, except for the cases marked with an asterisk, where the values are indicative. As will be explained in further detail later, for all configurations prior to 1995, the whole system was being tuned to a predetermined sensitivity value, by adjusting the voltage at the output of the amplifier components. This approach is not followed in the current installation, where each channel has an own sensitivity value.

There have also existed some experimental configurations, from which no data are available today and thus these are not mentioned in Table 6.4.1. Such cases are for instance the NORSAR short-period analog station and the broadband analog (KIRNOS) station (e.g. Bungum et al., 1974; Dahle, 1975).

In the following section, a brief description will be made of the methodology applied to calculate the responses of the 20 different configurations listed in Table 6.4.1.

6.4.3 Methodology

The approach to NORSAR system response calculation initially involved the validation of all information necessary for the calculations. This meant gathering all available information, either in the form of published material, instrumentation manuals, datasheets, etc. or derived from related macros and subroutines or information obtained directly from NORSAR staff. According to this information, a 'history' of modifications in array development was compiled and used as a guide for the identification and categorization of the different cases for which a new response had to be determined, similar to the listing of Table 6.4.1.

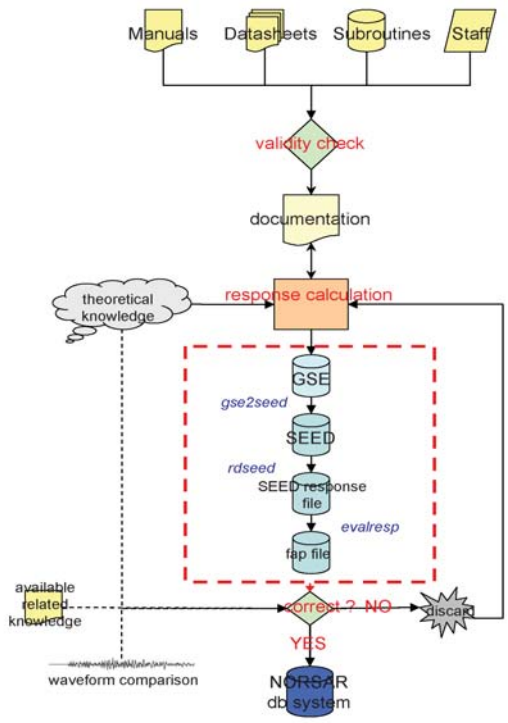

Fig. 6.4.2. Flowchart describing the NORSAR systems instrument response calculation procedure followed in this study.

The responses were calculated and organized in GSE2.0 format (GSETT-3, 1997). Corresponding GSE response files include short descriptions of each system component (e.g. sensor, amplifier, A/D converter), mainly referring to instrument model, used parameter values and normalization information. SEED response files and corresponding fap tables (frequency-amplitude-phase triplets) were constructed from the GSE files and the validity of the results was assessed, based on theoretical considerations (e.g. expected form of the amplitude and phase graphs), available information (e.g. accordance in gain with previously reported results and calculated magnitudes) and comparison against waveforms of known instrument responses. Finally, validated calib and calper values were introduced in the NORSAR db system. A schematic description of the methodology mentioned above is provided in the flowchart of Fig. 6.4.2.

6.4.4 Results

For all NORSAR configurations until the refurbishment of the array in 1995, a common instrument sensitivity for all channels was ensured by constantly tuning the system to a predetermined value. For the NORSAR short-period channels, this value was set to 0.0427 nm/qu +/- 10% at 1 Hz, in accordance to the overall scaling put forward by IBM/SAAC in their Proposed Composite Specification for Array Instrumentation System, dated 27.02.70 (Dalland, 1971). Similarly, such 'nominal' channel sensitivity values exist for the long-period channels, as well as the configurations involving the combination of HS-10-1 and long-period sensors with RD6 and AIM24 digitizers (see Table 6.4.1, field Calib). The task was achieved by measuring and appropriately adjusting the circuits in the amplifiers that were part of the array configuration. The amount of adjustment varies significantly for each channel, since a rather wide spread is observed in individual instruments parameter values (NORSAR, 1969a,b; Johansen, 1970; Dalland, 1971; Steinert and Nilsen, 1973). It is noteworthy that observed variations in seismometer damping ratios and natural frequencies were so large, that is was deemed necessary to review and modify tolerance limits to a wider acceptable value range (Steinert and Nilsen, 1972).

In this respect, the different NORSAR instrumentations were divided into two main groups. The one included cases for which a 'generic' response could be used for all array elements, since the channel sensitivity had been adjusted to be the same in all cases and the instrument-specific group, which includes cases where a different response is calculated for each array site. Thus, the first group includes almost all configurations prior to the NORSAR 1995 refurbishment, while the second group includes the current instrumentations.

Regarding the first group of responses, recalculation was a demanding task, mostly due to the fact that a lot of the original information sources are not available any longer and the existing ones were not archived in an organized way. As obvious from Table 6.4.1, a larger number of configurations existed, where the system was being tuned to the same channel sensitivity value of 0.0427 nm/count. This essentially ascertains that all sites have comparable amplitudes, but leaves open the question of different phase responses, in the case that different filters were employed (i.e., some sites with a 4.75 Hz Chebyshev filter and some with a 8.00 Hz Chebyshev filter or no low-pass filter at all). These responses were calculated separately and were introduced and stored in the system under different file names. The careful documentation of the various modifications in the GSE files ensures the correct linking between each different configuration and the appropriate response file (fap table).

SP-CALIBRATION FLOW CHART

Input calibration voltage	E_1 =	20 V
Line impedance	: R_L = 55 ohm/km loop	
	C_L = 52 nF/km loop	
Calibration network resistance	: R_N = 50 kΩ	
Calibration coil resistance	: R_c = 20 Ω	
Calibration coil current	: $Ic = Ei/\Sigma R$	400 µA
Calibration coil motor constant	: G_c = 0.0326 N/A	
Applied force	: $F = G_c \cdot I_c$	13.04 µN
Mass	: m = 0,825 kg	
Force to (Relative to seismometer): Acceleration	: $a1 = \frac{F}{m} \cdot \frac{s^2}{s^2+2\delta w_o s+w_o^2}$	11.3 µm/s²
Velocity	: $V1 = \frac{F}{m} \cdot \frac{s}{s^2+2\delta w_o s+w_o^2}$	1.8 µm/s
Distance	: $X1 = \frac{F}{m} \cdot \frac{1}{s^2+2\delta w_o s+w_o^2}$	.287 µm
Equivalent earth motion: Acceleration	: $a = \frac{F}{m}$	15.9 µm/s²
Velocity	: $V = \frac{F}{m} \cdot \frac{1}{s}$	2.54 µm/s
Distance	: $X = \frac{F}{m} \cdot \frac{1}{s^2}$	.400 µm
Data coil generator constant	: G_m = 1020 V/m/s	
Data coil output at 1 Hz	: $E_m = G_m \cdot V1$	1.83 mV
Attenuation (Damping resistance)	: D_m = 240/290	1.52 mV
Amplifier gain (74.6 dB)	: A = 5400	
Amplifier output	: $E_o = A \cdot E_m \cdot D_m$	8.2 V
Amplifier output impedance	: R_o = 1200 ohm	
Line impedance as above	: R_L/C_L	
LTA input impedance	: R_1 = 200 kΩ	
Signal voltage at LTA	: $E_L = E_o \cdot \frac{200}{\Sigma R}$	~8.1 V
Gain LTA amplifier	: A_L = 0.714	
Adjustable gain-pot setting	: 0 to -12 dB	2.86 V
Filter and gain	: 0.038 Hz, Gain = 2	
SLEM voltage at TP1	:	5.72 V

(Relative-motion values: $s = j\omega_o$, $\delta = 0.7$, $f = 1.0$)

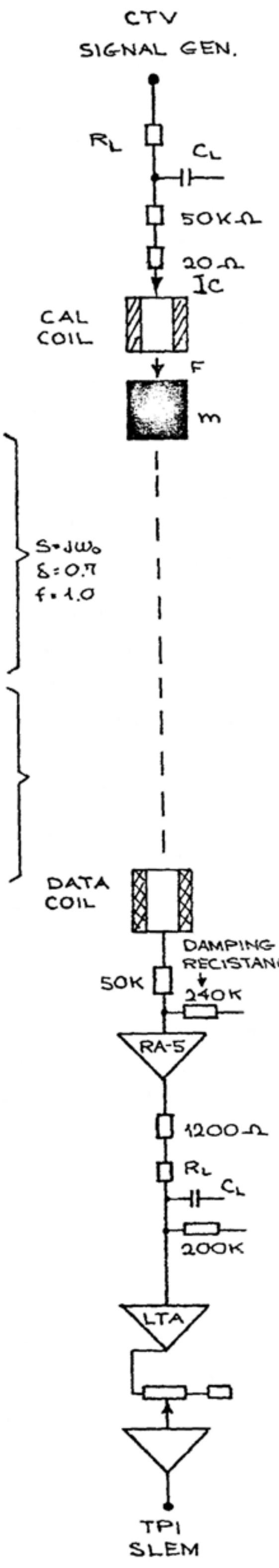

Fig. 6.4.3. Short-period calibration flowchart for the standard NORSAR configuration (Dalland, 1971).

A description of the most important points for the calculation of system responses will be provided in the following paragraphs, sorted by different digitizer, since this makes the greatest difference in each configuration. For a detailed description of system components and variations, Table 6.4.1 should be consulted.

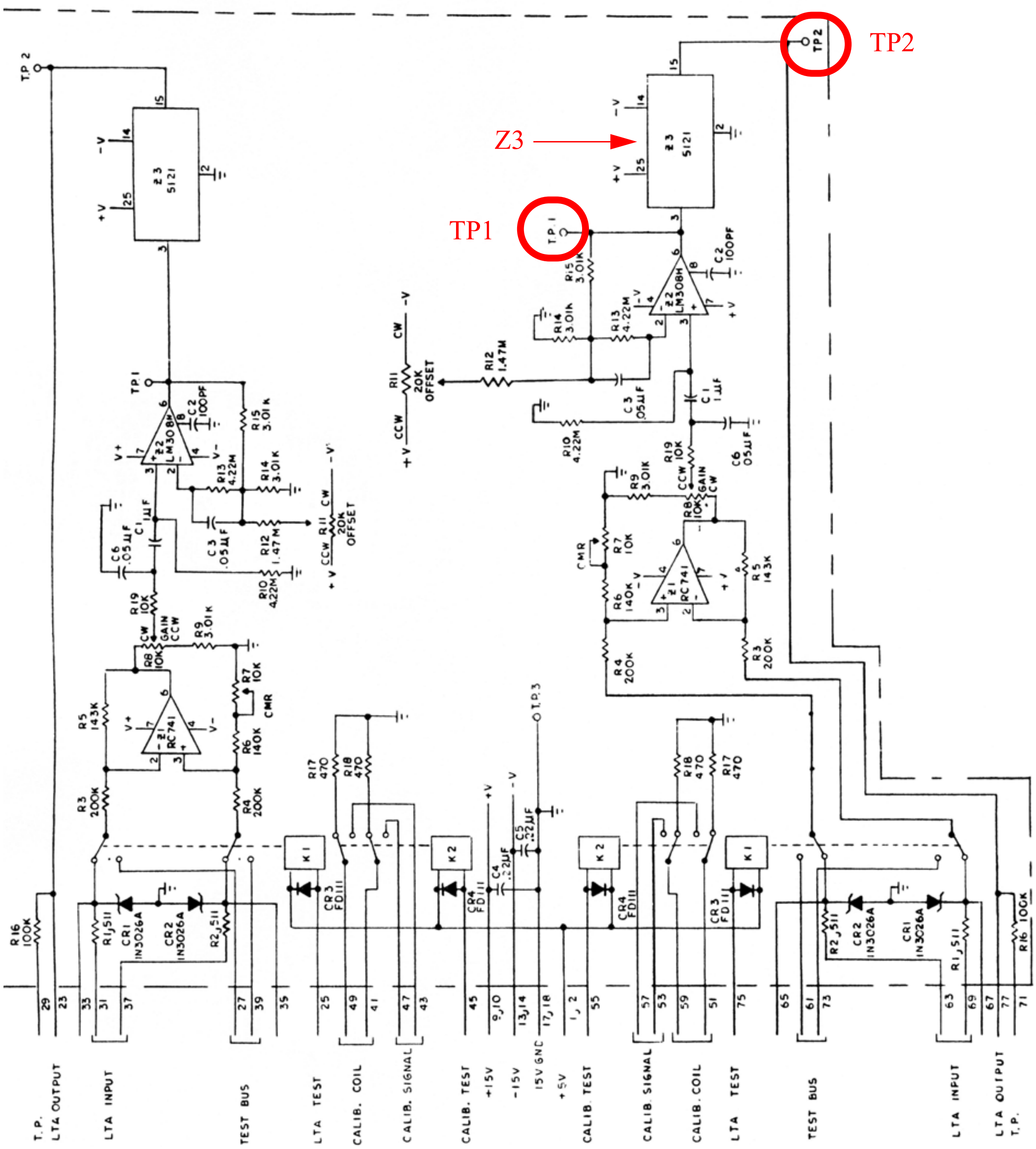

Fig. 6.4.4. Schematic diagram of the short-period Line Terminating Amplifier (Philco-Ford, 1970). Z3 is the low-pass, 24 dB/octave Chebyshev filter and TP1, TP2 are two voltage measuring/ adjusting points.

Standard NORSAR - SLEM

The standard NORSAR instrumentation chain is presented in Fig. 6.4.3, where the short-period instrument calibration chain is described.

The calibration procedure for the short-period sites initiates with a 20 V peak-to-peak, 1 Hz sinusoidal signal, generated at the CTV and going out to the sensors. The resistances of the calibration network are arranged so that the calibration current I_c is in the order of 400 μA. This current produces a force F on the moving mass of the seismometer, which depends on the calibration coil motor constant G_c and the current I_c. The applied force is converted into motion according to the sensor transfer function (see Fig. 6.4.3 for actual values). The equivalent ground motion in this case is equal to 0.400 μm and the actual amplitude of the induced voltage is 1.83 mV. This is however reduced to 1.52 mV by the resistance attenuator, consisting of the seismometer internal resistance and the external damping resistance. This voltage is the input to the RA-5 amplifier, which has a gain of 5400 (= 74.6 db), thus amplifying the output voltage to 8.2 V peak-to-peak. When reaching the CTV, this voltage is actually slightly attenuated due to the RA-5, line and LTA impedance. Finally, the gain setting of the LTA is adjusted to a voltage of 5.72 V peak-to-peak at test point TP2 in the SLEM, so that the overall system scaling is set to 0.0427 nm/count (Dalland, 1971), taking into consideration that the SLEM A/D converter is a 14-bit digitizer with a least significant bit of 0.61 mV/count. In the case that the low-pass filter card of the LTA is omitted, the voltage adjustment is made at test point TP1 (Fig. 6.4.4). In accordance to this, the short-period standard instrumentation response calculation is made using the nominal values and the appropriate adjustments to obtain a channel sensitivity of 0.0427 nm/count. The displacement amplitude and phase responses, up to 100 Hz, for this configuration as well as two of its variations are depicted in Fig. 6.4.5. Responses are coded according to the Respid included in Table 6.4.1 (SPSLEM1, SPSLEM2 and SPSLEM4).

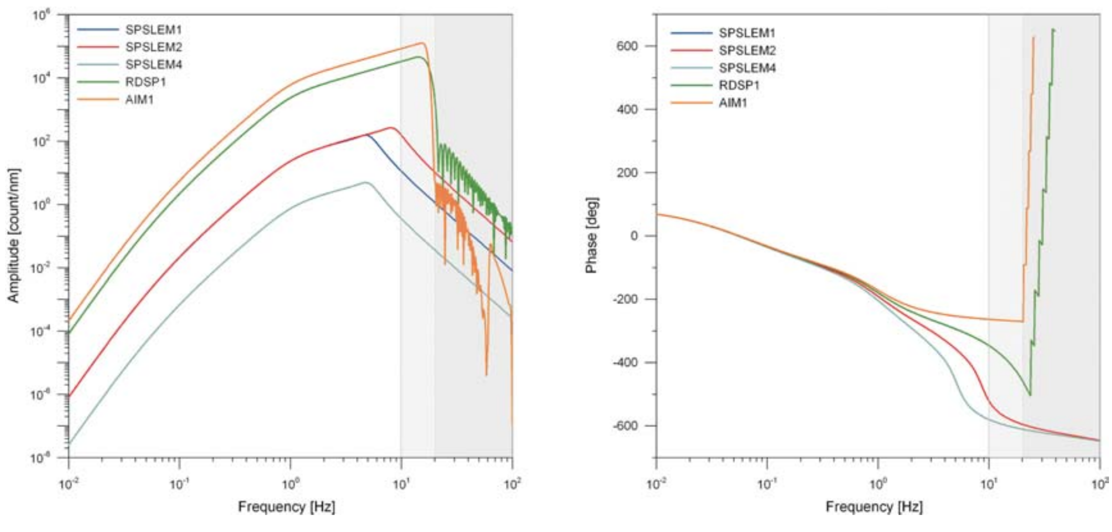

Fig. 6.4.5. Displacement amplitude and phase response for the NORSAR short-period configurations employing an HS-10-1 seismometer. The standard NORSAR (SPSLEM1), the 8.00 Hz Chebyshev filter LTA variation (SPSLEM2), the attenuated channel (SPSLEM4), the RD6 installation (RDSP1) and the first AIM24-1 installation in the CTVs (AIM1) are depicted. The shaded areas represent the range beyond the Nyquist frequency (10 Hz for the SLEM and 20 Hz for the RD6 and AIM24 configurations).

Regarding the long-period instruments, a similar calibration procedure is followed to the one described in the previous paragraph, with a 20 V peak-to-peak, 0.04 Hz sinusoidal signal being used. Part of an unknown document provides a schematic description of the procedure, which was unfortunately impossible to reconstruct with the scarce information available. Therefore, the long-period instrument response will be described here according to information assembled from documents NORSAR Report 40 and 58 (Steinert and Nilsen, 1972; Falch, 1973) and the Ithaco amplifier manual (Ithaco, 1968). As already mentioned, the overall channel sensitivity was being adjusted to a predetermined value for all original NORSAR installations, which in this case equaled 2.47 nm/count. To achieve this, a first adjustment was made in the output of the Ithaco amplifier. The final adjustment was made after the LTA amplifier, for a calibration period of 25 s. The long-period version of the LTA amplifier employed only a high-pass RC filter, with a cut-off frequency at 0.00373 Hz. The adjustments were thereby made at test point TP1, as in the case of no low-pass anti-alias filter for the short-period channels (Z3 in Fig. 6.4.4). The displacement amplitude and phase response for the standard NORSAR long-period configuration (LPSLEM1) is depicted in Fig. 6.4.6.

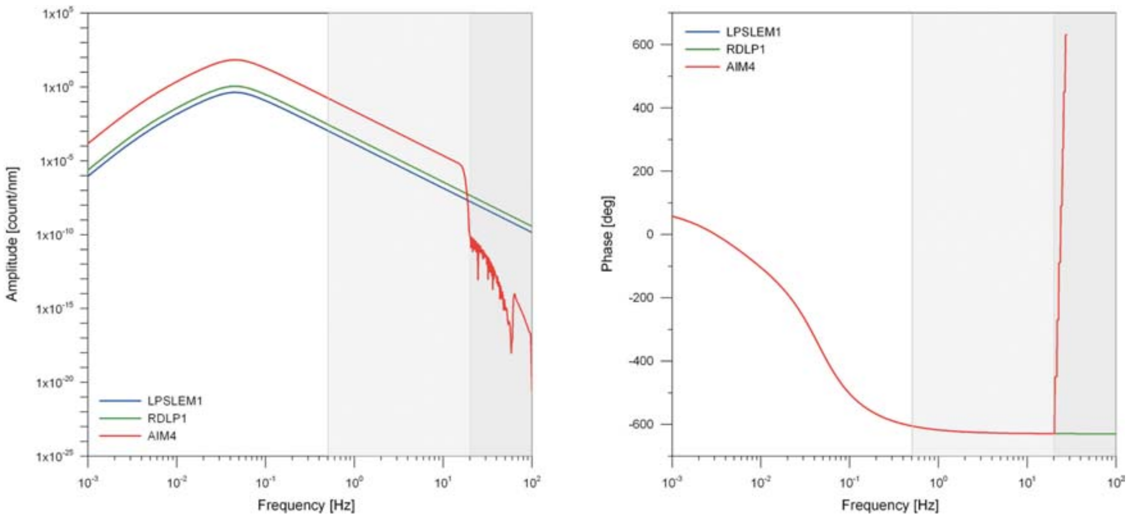

Fig. 6.4.6. Displacement amplitude and phase response of the NORSAR long-period installations. The standard NORSAR (LPSLEM1), the RD6 (RDLP1) and the AIM24-3BB (AIM4) configurations are depicted. The shaded areas represent the range beyond the Nyquist frequency (0.5 Hz for SLEM and RD6 and 20 Hz for AIM24 configurations).

RD6 configurations

The same instrumentation as the standard NORSAR has been employed also for the NORSAR Backup System, except for the digitizer that was a Nanometrics RD6 model, a gain-ranged, 16-bit, 6-channel A/D converter, with a sensitivity of 6103.5 nV/bit (Nanometrics, 1992). The version installed at the NORSAR array employs an analog 5^{th}-order low-pass Butterworth anti-alias filter, with cut-off frequency at 23 Hz and a digital low-pass FIR filter with -3 db point at 40 Hz and 68 coefficients. The displacement amplitude and phase response for the short-period channels is depicted in Fig. 6.4.1 (RDSP1), and for the long-period channels in Fig. 6.4.6 (RDLP1).

AIM24 configurations

The third digitizer to be installed at the NORSAR array, and the one that is still in use today, is the Science Horizons AIM24. It is a 24-bit A/D converter, with a seismometer dependent gain. There are two versions installed at NORSAR, the AIM24-1, which is used with the short-period, vertical seismometers and the AIM24-3BB, used with the 3-component broadband sensors. The unit consists of a preamplifier front end, a 24-bit delta sigma A/D converter chipset, digital signal processor, a very stable clock source and a microprocessor which controls the entire operation (Ingate, 1995).

Regarding the short-period installations, the AIM24-1 digitizer was first installed in the Central Terminal Vaults (CTVs) together with the old, standard NORSAR instrumentation, except for subarray 06C, where it was installed in the Short Period Vaults (SPVs). The displacement amplitude and phase response for the CTV version is depicted in Fig. 6.4.5 (AIM1).

The current short-period installation, which came in operation in 1995, employs a 20171A seismometer by Geotech. The desired relative damping value of the sensor can be achieved by applying the appropriate combination of resistances, since

$$R_t = \frac{R_{CDR}}{\lambda_0} ,$$

where R_t is the total circuit resistance, R_{CDR} the critical damping resistance and λ_0 the relative damping. The generator constant for the data coil can be determined from the following formula:

$$G = \sqrt{4\pi f_0 M R_{CDR}(1-\lambda_x)} \text{ , in V/(m/s)}$$

where f_0 is the natural frequency and λ_x the open-circuit damping. The resulting constant however is not the sensitivity value to be used for calculating the instrument's response. That is obtained by the formula (Teledyne-Brown, 1995):

$$w = G\frac{R_0}{R_c + R_0} .$$

All necessary values are either provided by the manufacturer or can be measured in the lab, so a different set of values is available for each individual seismometer, sorted by serial number. This means that a different response is calculated for each array site.

The AIM24 digitizer version (AIM24-1) installed with the 20171A short-period seismometers and the Brick amplifier has a 32 V peak-to-peak full scale dynamic range and a selectable gain of 1 V/V, 10 V/V or 100 V/V. For the short-period channels of the NORSAR array, gain was set to 10 V/V after testing various combinations with the Brick amplifier, since this provided the best SNR for frequencies above 2 Hz (Fyen, 1995).

The AIM24-1 employs the Crystal Semiconductor CS5322/5323 chipset (Cirrus Logic, 1995). The CS5323 chip is an analog modulator with an input bitstream clocking of 40960 Hz, while the CS5322 chip employs 3 successive linear phase FIR filters, which decimate down to the desired sampling rate. The first filter applies a decimation factor of 8, the second one can decimate by 4, 8, 16, 32, …, 256, and the third filter by a factor of 2. The sampling rate used for the NORSAR array is 40 sps and in order to achieve it the following succession of FIR filters was selected:

FIR1, decimating by 8, 33 coefficients
FIR2, decimating by 64, 13 coefficients
FIR3, decimating by 2, 101 coefficients

FIR2 consists of a succession of 6 equal FIR filters, each of them decimating by a factor of 2. The overall digitizer response can be constructed with the following sequence of FIR filters:

$$40960Hz \xrightarrow{FIR1(8)} 5120Hz \xrightarrow{6xFIR2(2)=64} 80Hz \xrightarrow{FIR3(2)} 40Hz \; .$$

The least significant bit of the AIM24-1 unit equals to:

$32V/(2^{24}-1)counts = 1907{,}734\ nV/count$ or *sensitivity* = 524288 *counts/V*.

Taking into consideration the 10 V/V gain, then the total sensitivity of the unit at 1 Hz is equal to 5242880 counts/V. The displacement amplitude and phase response for the current short-period channels is depicted in Fig. 6.4.7 (AIM0SP).

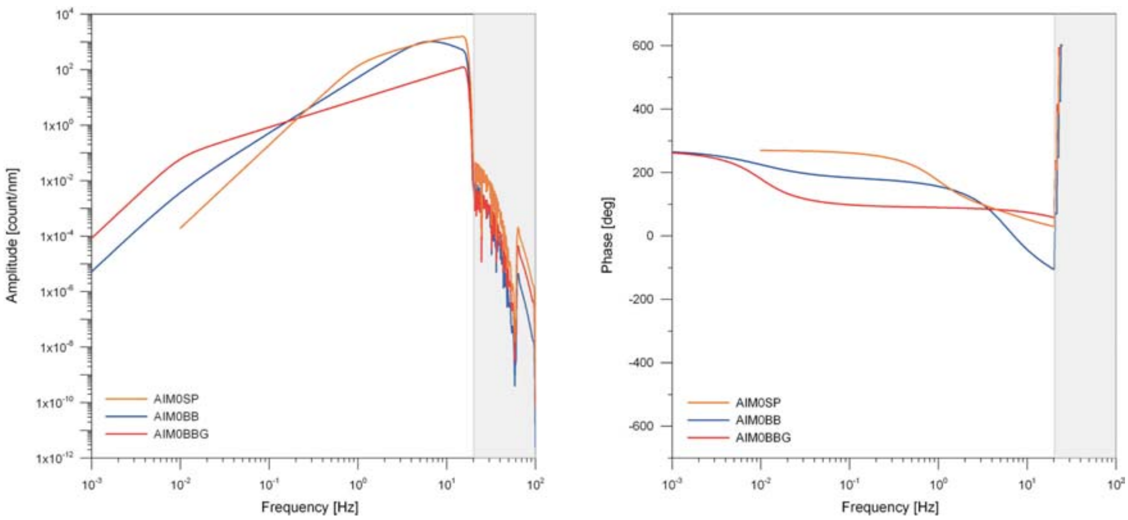

Fig. 6.4.7. Displacement amplitude and phase response for the current short-period 20171A (AIM0SP) and broadband NORSAR installations (KS54000 = AIM0BB, CMG-3T = AIM0BBG). The shaded area represents the range beyond the Nyquist frequency (=20 Hz).

Regarding the broadband installations, the AIM24-3BB version connected to the 3-component broadband seismometers has a gain of 1 V/V and a full-scale dynamic range of 64 V. It employs the Crystal Semiconductor CS5321/5322 chipset. The least significant bit is equal to: $64V/(2^{24}-1)counts = 3.81469\ \mu V/count$ and sensitivity equals 262144.5 *counts/V*.

Initially, AIM24-3BB digitizers were connected to the old NORSAR long-period instruments. The displacement amplitude and phase response for this installation is depicted in Fig. 6.4.6 (AIM4).

Currently, the AIM24-3BB units are employed together with 3-component broadband sensors. The amplitude and phase response for displacement for the KS54000 (AIM0BB) and CMG-3T (AIM0BBG) broadband configurations is depicted in Fig. 6.4.7.

Myrto Pirli
Johannes Schweitzer

References

Bungum, H., Nilsen, A.K. and Steinert, O. (1974): Experimental analog stations at NORSAR. NORSAR Sci. Rep. **4-73/74**, NORSAR, Kjeller, Norway, 60-65.

Cirrus Logic, Inc. (1995): CS5322/5323 24-bit variable bandwidth A/D converter. Cirrus Logic, Inc. DS70F1, March ’95, Austin, Texas, 40 p.

Dahle, A. (1975): A KIRNOS seismograph in the NORSAR seismic array. NORSAR Internal Rep. **4-74/75**, NORSAR, Kjeller, Norway, 25 p.

Dalland, L.J. (1971): NORSAR SP seismometer instrumentation chain. A/S Tele-plan, Lysaker, Norway, 14 p.

Falch, K. (1973): Technical description and operational instruction Ithaco amplifier and test panel. NORSAR Techn. Rep. **58**, NORSAR, Kjeller, Norway, 18 p.

Fyen, J. (1995): Improvements and modifications. NORSAR Sci. Rep. **1-95/96**, NORSAR, Kjeller, Norway, 69-72.

GSETT-3 (1997): Provisional GSE 2.1 Message Formats and Protocols. Operations Annex 3, May 1997, 123 p.

Ingate, S.F. (1995): Validating the frequency response of the Science Horizons, Inc. AIM24 high-resolution 24-bit digitizers. Science Horizons Report #IR-95-0001, Encinitas, California,15 p.

Ithaco Inc. (1968): Instruction and maintenance manual Ithaco long period seismic amplifier model 6083-82. Ithaco Inc., Ithaca, New York, 25 p.

Johansen, T. (1970): Preliminary report on the spread in natural frequencies of the HS-10-1 ARPA seismometer. A/S Tele-plan, Lysaker, Norway, 22 p.

Mykkeltveit, S. and Ringdal, F. (1980): Further development of the NORESS small-aperture array. NORSAR Sci. Rep. **1-80/81**, NORSAR, Kjeller, Norway, 33-36.

Nanometrics, Inc. (1992): NORSAR RD3 User Guide, Version 3 Software & Version 5 Software. Nanometrics, Inc., Ontario, Canada, 70 p.

Nilsen, A.K. (1980): Array instrumentation and facilities. NORSAR Sci. Rep. **1-80/81**, NORSAR, Kjeller, Norway, 20-26.

NORSAR (1969a): Check-out of short and long period field instrumentation – Procedures. NORSAR PHASE 2, 1968-1969 PROGRAM, DOCUMENT IV, PART 1, 50 p.

NORSAR (1969b): Check-out of short and long period field instrumentation – Collected data. NORSAR PHASE 2, 1968-1969 PROGRAM, DOCUMENT IV, PART 2.

Philco-Ford (1970): Seismic Short and Long Period Electronic Modules (SLEM). Philco-Ford, Corp., December 1970, 3 volumes.

Ringdal, F. (1981): Location of regional events using travel time differentials between P arrival branches. NORSAR Sci. Rep. **2-80/81**, NORSAR, Kjeller, Norway, 60-69.

Steinert, O. and Nilsen, A. (1972): Array monitoring and field maintenance report. NORSAR Rep. **40**, NORSAR, Kjeller, Norway, 89 p.

Steinert, O. and Nilsen, A. (1973): Array monitoring and field maintenance report. NORSAR Rep. **60**, NORSAR, Kjeller, Norway, 45 p.

Teledyne Brown Engineering (1995): Operation and maintenance manual of the shallow-hole seismometer, model 990-20171-0104. **20171D4_.W60**, Dallas, Texas, 85 p.