NORSAR

NORSAR Scientific Report No. 2-98/99

# Semiannual Technical Summary

1 October 1998 - 31 March 1999

Kjeller, May 1999

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19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

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*Abstract (cont.)*

Beginning 1 January 1999, the responsibility for funding the operational activities of the seismic field systems and the Norwegian National Data Center (NDC) has been taken over by the Norwegian Government, with the understanding that the funding of IMS-related activities will gradually be arranged through the CTBTO/PTS. Research activities described in this report are continuing to be funded by the United States Department of Defense.

The NORSAR Detection Processing system has been operated throughout the period with an average uptime of 99.92%. A total of 1655 seismic events have been reported in the NORSAR monthly seismic bulletin for October 1998 through March 1999. The performance of the continuous alarm system and the automatic bulletin transfer to AFTAC has been satisfactory. Processing of requests for full NORSAR and regional array data on magnetic tapes has progressed according to established schedules.

This Semiannual Report also presents statistics from operation of the Regional Monitoring System (RMS). The RMS has been operated in a limited capacity, with continuous automatic detection and location and with analyst review of selected events of interest for GSETT-3. Data sources for the RMS have comprised all the regional arrays processed at NORSAR. The Generalized Beamforming (GBF) program is now used as a pre-processor to RMS.

On-line detection processing and data recording at the NORSAR Data Processing Center (NDPC) of NORESS, ARCESS, FINESS and GERESS data have been conducted throughout the period. Data from two small-aperture arrays at sites in Spitsbergen and Apatity, Kola Peninsula, as well as the Hagfors array in Sweden, have also been recorded and processed. Processing statistics for the arrays as well as results of the RMS analysis for the reporting period are given.

The operation of the regional arrays has proceeded normally in the period. Maintenance activities in the period comprise preventive/corrective maintenance in connection with all the NORSAR subarrays, NORESS and ARCESS. Other activities have involved repair of defective electronic equipment, cable splicing and work in connection with the small-aperture array in Spitsbergen. Work is also progressing in making the modifications required for formal station certification of the large NORSAR array.

A summary of the activities related to the GSETT-3 experiment and experience gained at the Norwegian NDC during the reporting period is provided in Section 4. Norway has been contributing primary station data from three arrays: ARCESS, NORESS and NORSAR and one auxiliary array (Spitsbergen). Norway's NDC is also acting as a regional data center, forwarding data to the IDC from GSETT-3 primary and auxiliary stations in several countries. The work at the Norwegian NDC has continued to focus on operational aspects, like stable forwarding of data using the Alpha protocol, proper handling of outgoing and incoming messages, improvement to routines for dealing with failure of critical components, as well as implementation of other measures to ensure maximum reliability and robustness in providing data to the IDC. NOR_NDC will continue the efforts towards improvements and hardening of all critical data acquisition and data forwarding hardware and software components, so as to meet future requirements related to operation of IMS stations to the maximum extent possible.

The PrepCom has tasked its Working Group B with overseeing, coordinating and evaluating the GSETT-3 experiment until the end of 1999. The PrepCom has also encouraged states that operate IMS-designated stations to continue to do so on a voluntary basis and in the framework

of the GSETT-experiment until such time that the stations have been certified for formal inclusion in IMS. In line with this, we envisage continuing the provision of data from Norwegian IMS-designated stations without interruption to the PIDC, and later on to the IDC in Vienna, via the new global communications infrastructure currently being established.

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

*Section 6.1* is entitled "Recommendations for seismic event location calibration development". During the May and August, 1998 meetings of Working Group B of the CTBTO Preparatory Commission, the International Data Centre (IDC) Expert Group identified the need for highly-focused work to provide regionalized travel times to improve seismic location methods used in the IDC. The Expert Group suggested that initial focus should be given to three geographical regions: North America, Eurasia and Australia.

To assist with the developments of the IDC applications software relating to the location calibration problem, an informal meeting of the IDC Technical Experts Group on Seismic Event Location was held in Oslo, Norway on 12-14 January, 1999. Forty technical experts, coming from nine signatory countries and the Provisional Technical Secretariat, participated in the meeting. Dr. Frode Ringdal of Norway chaired the meeting.

The purpose of the workshop was to develop plans and recommendations for how regional location calibration information could be incorporated into processing at the International Data Center (IDC) for the CTBT International Monitoring System (IMS). The Release 3 applications software will be developed during 1999 for delivery to the IDC prior to the start of the full-scale testing of the IDC. An important element in Release 3 capabilities will be the use of calibration information for event location in specific geographical regions.

The meeting was organized into four sessions, including Working Group discussions to address the technical issues in detail during the meeting. Topics were:

- Collection of Calibration Information
- Application of Calibration Information
- Validation of Calibration Information
- Specific recommendations for IDC Release 3

Detailed recommendations were developed for each of these subject matters, and were presented to Working Group B in Vienna during its February 1999 session.

*Section 6.2* is entitled "Seismic Location Calibration for the Barents Region" and is a summary of a paper presented at the Oslo location workshop. A crustal velocity model has been developed for Fennoscandia, the Baltic shield and adjacent areas. This model represents a simplified average of various models developed for parts of this region. We show that P-wave travel times calculated with this model provide an excellent fit to observations at the Fennoscandian, KRSC and IRIS station networks for a set of seismic events with known or very well-constrained locations. The station-event paths cover large parts of Western Russia and the Barents Sea, thus indicating that this model, which we denote the Barents model, is appropriate for this entire region. We show by examples that significant improvements in event location precision can be achieved compared to using the IASPEI model. We finally use the Barents model to calculate locations of some recent small seismic events in the Novaya Zemlya region of interest in a CTBT monitoring context.

*Section 6.3* is entitled "Monitoring the European Arctic Using Regional Generalized Beamforiming". This paper desribes some recent improvements made to the Generalized Beamforming (GBF) process which has been running operationally at NORSAR for the past 10 years. Among the improvements are:

- Inclusion of the SPITS array in the GBF procedure
- Expansion of the beam grid coverage, especially in the Arctic region
- Increased density of the beampacking grid to allow more accurate epicenter determinations
- Improved detector and f-k recipes for five of the arrays used in GBF

We have included an evaluation of the improvements relative to the previous version. The coverage of the European Arctic is vastly improved, with a much larger number of valid detected events, and correspondingly better locations. Mainly, this improvement is due to the inclusion of the very sensitive SPITS array. Using various criteria to reduce the occurrence of spurious phase associations, we also conclude that there are significant improvements in the detection and location performance in other regions covered by the regional network. We note that, compared to the GBF-based association process (GA) currently used by the IDC, the NORSAR GBF system is capable of detecting and locating seismic events up to one order of magnitude smaller than the IDC. This is due to a combination of better regional array coverage and less strict event definition criteria.

*Section 6.4* is entitled "Global Seismic Threshold Monitoring: Internet Access and Examples of Results". Data from the seismic stations in the International Monitoring System (IMS) network are currently processed continuously at the Prototype International Data Center (PIDC) in Arlington, Virginia, in support of the Comprehensive Nuclear Test Ban Treaty. The ability of this network to detect seismic events can be assessed using the Threshold Monitoring software developed at NORSAR. Daily results from the Threshold Monitoring component of the IMS are now available to the public via the PIDC internet site **http://www.pidc.org/**. In this paper we describe how to access the Threshold Monitoring results and provide examples of application. The results consist of three sets of maps and plots:

- The **"detplot"** map shows the average and worst case worldwide thresholds for the given hour. The IMS should be able to detect any event that is larger than the threshold level at any given time. In the case of a large event, this ability is degraded in the vicinity of the event (and to a lesser extent worldwide).
- **"Status"** plots of the data from each station used in Threshold Monitoring show when and if each station was functioning during that hour, and the peaks on the trace plots also indicate any larger events which may have occurred.
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Examples for selected time intervals are shown. These time intervals include both a "quiet" period and a period during which a large earthquake (mb=5.8) occurred. The Threshold Monitoring displays are expected to provide useful information, not only on the continuous assessment of network detection capability, but also on the individual station data quality and station operational performance.

*Section 6.5* is entitled “Observed Characteristics of Regional Seismic Phases and Implications for P/S Discrimination in the Barents/Kara Sea Region”. In this paper, we use data from the regional networks operated by the Kola Regional Seismological Centre (KRSC) and NORSAR to study the seismicity and characteristics of regional phases of the Barents/Kara Sea region. While the detection and location capability of the regional network is outstanding, source classification of small seismic events has proved very difficult. In particular, the seismic event near Novaya Zemlya on 16 August 1997 at 02:11 GMT has been the subject of extensive analysis in order to locate it reliably and to classify the source type. It has been argued that this event could be confidently classified as an earthquake, especially based on observed P/S ratios. We consider some of this evidence in light of other observations of earthquakes and explosions in the region, including NORSAR recordings of past underground nuclear explosions.

We show that there is an apparent source scaling of the P/S ratio of Novaya Zemlya explosions recorded at NORSAR in such a way that the larger explosions have a relatively high P/S ratio. Such an effect would make a reliable comparison difficult between P/S ratios of small and large events. Furthermore, this amplitude ratio shows large variability for the same source type and similar propagation paths, even when considering closely spaced observation points. This effect is most pronounced at far-regional distances and relatively low frequencies (typically 1-3 Hz), but it is also significant on closer recordings (around 10 degrees) and at higher frequencies. Our conclusion from this study is that the P/S ratio even at high frequencies is, with present knowledge, not sufficiently stable to be used as a reliable discriminant between earthquakes and explosions. Future application of this discriminant will require extensive regional calibration and detailed station-source corrections.

**Frode Ringdal**

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The research presented in this report was supported by the Advanced Research Projects Agency of the Department of Defense and was monitored by AFTAC, Patrick AFB, FL32925, under contract no. F08650-96-C-0001.

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NORSAR Contribution No. 668

# Table of Contents

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**Frode Ringdal**

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

## 2.1 PS27 — Primary Seismic Station NOA

The average recording time was 99.92% as compared to 99.77% for the previous reporting period.

Table 2.1.1 lists the main reasons for and times of outages in the reporting period.

| Date | Time | Cause |
|---|---|---|
| 20 Jan | 1321 - 1340 | Problems at NDPC |
| 22 Jan | 1352 - 1607 | Problems at NDPC |
| 05 Mar | 1131 - 1214 | Problems at NDPC |

***Table 2.1.1. The major downtimes in the period 1 October 1998 - 31 March 1999.***

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:

| | | |
|---|---|---|
| October 1998 | : | 99.99% |
| November | : | 100.00% |
| December | : | 100.00% |
| January 1999 | : | 99.65% |
| February | : | 99.99% |
| March | : | 99.90% |

**J. Torstveit**

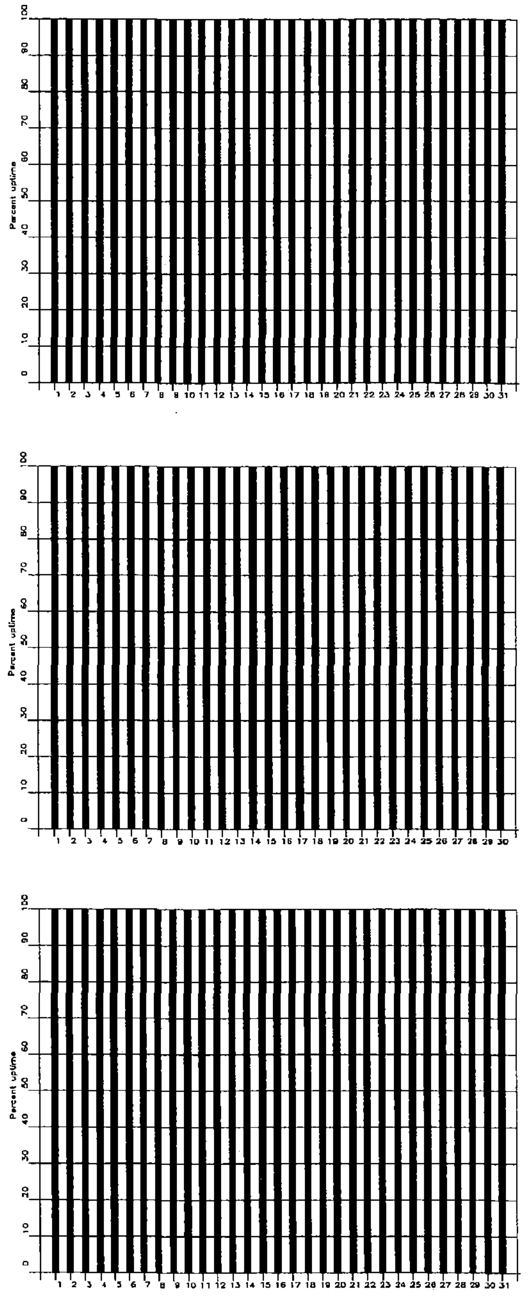

*Fig. 2.1.1 shows the uptime for the data recording task, or equivalently, the availability of NOA data in our tape archive, on a day-by-day basis, for the reporting period. (Page 1 of 2, Oct-Dec 1998)*

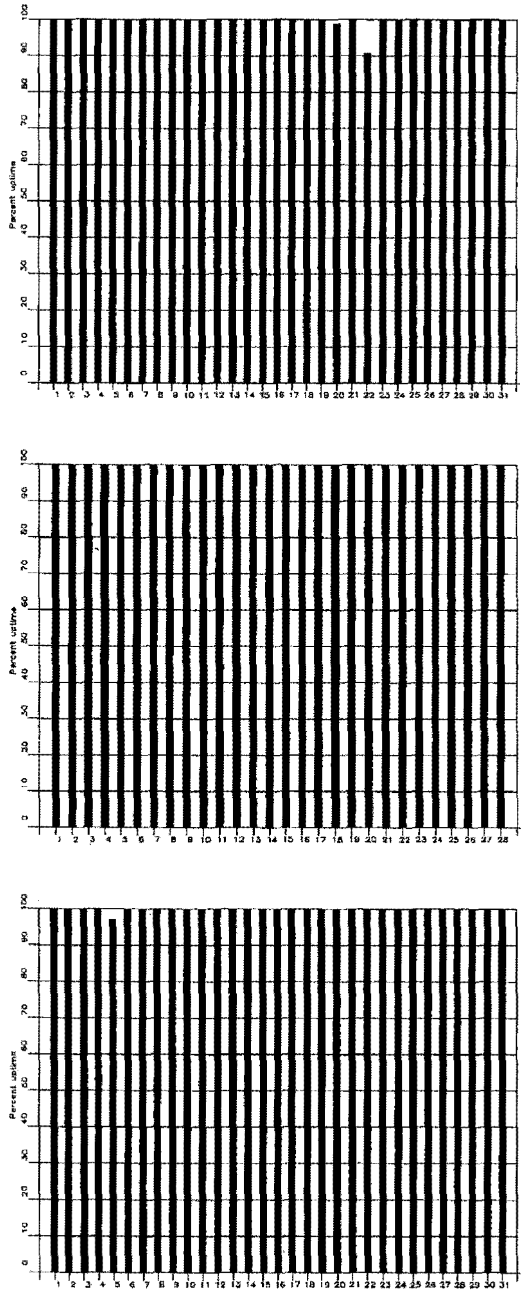

*Fig. 2.1.1. (cont.) (Page 2 of 2, Jan-Mar 1999)*

### 2.1.1 NOA Event Detection Operation

In Table 2.1.2 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 | | |
| Oct 98 | 9665 | 742 | 221 | 60 | 281 | 9.1 |
| Nov 98 | 8995 | 787 | 235 | 56 | 291 | 9.7 |
| Dec 98 | 11433 | 765 | 187 | 32 | 219 | 7.1 |
| Jan 99 | 9958 | 781 | 225 | 39 | 264 | 8.5 |
| Feb 99 | 10164 | 892 | 194 | 41 | 235 | 8.4 |
| Mar 99 | 9700 | 880 | 311 | 54 | 365 | 11.8 |
| | 59915 | 4847 | 1373 | 282 | 1655 | 9.1 |

*Table 2.1.2. Detection and Event Processor statistics, 1 October 1998 - 31 March 1999.*

*NOA detections*

The number of detections (phases) reported by the NORSAR detector during day 274, 1998, through day 090, 1999, was 62,338, giving an average of 343 detections per processed day (182 days processed).

**B. Paulsen**
**U. Baadshaug**

## 2.2 PS28 — Primary Seismic Station ARCES

The average recording time was 94.84% as compared to 99.72% for the previous period.

Table 2.2.1 lists the main reasons for and times of outages in the reporting period.

| Date | Time | Cause |
|---|---|---|
| 12 Jan | 1422 - | Hub failure |
| 15 Jan | - 0822 | |
| 31 Jan | 0453 - | Satellite sender failure |
| 06 Feb | - 0618 | |
| 11 Feb | 0120 - 0238 | Power break NDPC |
| 25 Feb | 0122 - 0201 | Power break NDPC |

*Table 2.2.1 The main interruptions in recording of ARCES data at NDPC 1 October 1998 - 31 March 1999.*

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

| | | |
|---|---|---|
| October 1998 | : | 99.95% |
| November | : | 99.99% |
| December | : | 99.79% |
| January 1999 | : | 88.40% |
| February | : | 80.91% |
| March | : | 99.99% |

**J. Torstveit**

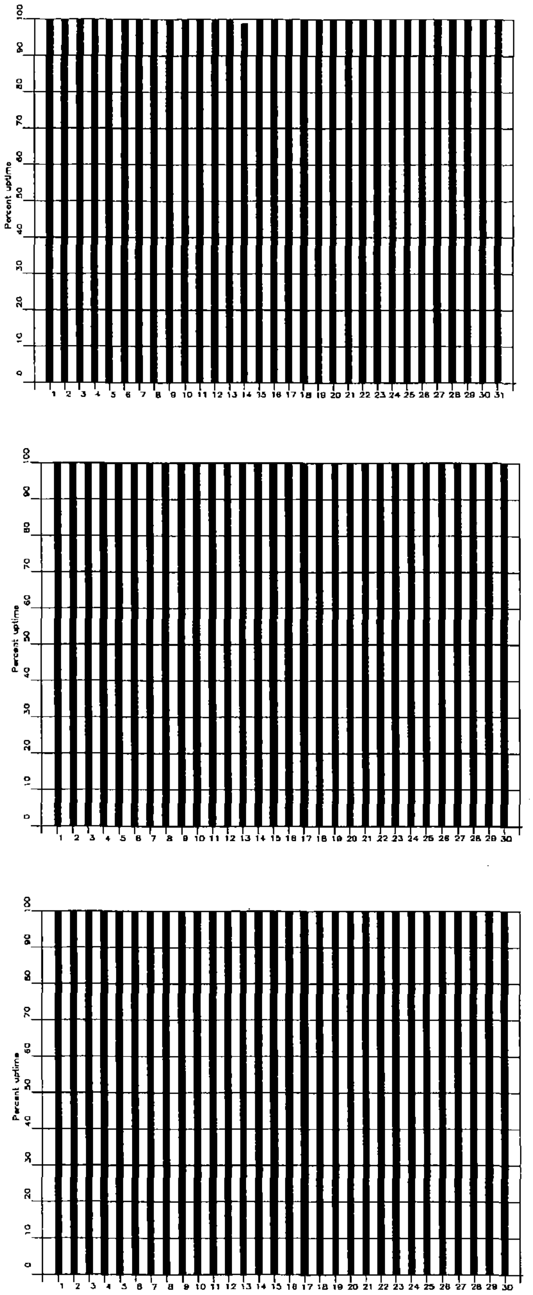

*Fig. 2.2.1. The figure shows the uptime for the data recording task, or equivalently, the availability of ARCES data in our tape archive, on a day-by-day basis, for the reporting period. (Page 1 of 2, Oct-Dec 1998)*

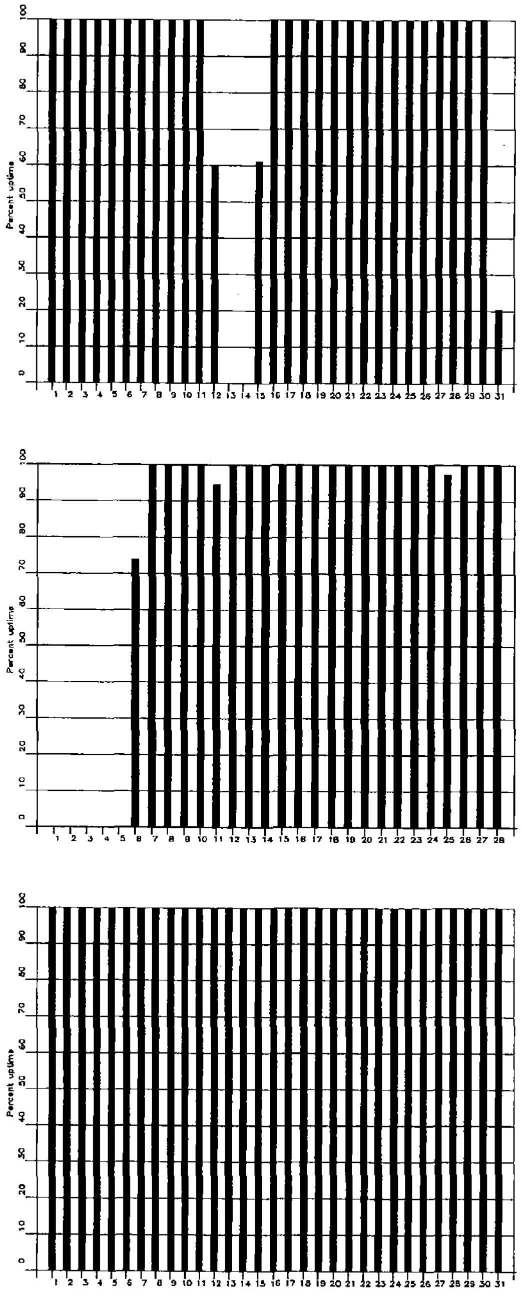

*Fig. 2.2.1. (cont.) (Page 2 of 2, Jan-Mar 1999).*

### 2.2.1 Event Detection Operation

*ARCES detections*

The number of detections (phases) reported during day 274, 1998, through day 090, 1999, was 75,373, giving an average of 431 detections per processed day (175 days processed).

*Events automatically located by ARCES*

During days 274, 1998, through 090, 1999, 5274 local and regional events were located by ARCES, based on automatic association of P- and S-type arrivals. This gives an average of 30.0 events per processed day (176 days processed). 53% of these events are within 300 km, and 86% of these events are within 1000 km.

**U. Baadshaug**

## 2.3 AS72 — Auxiliary Seismic Station Spitsbergen

The average recording time was 97.53% as compared to 99.07% for the previous reporting period.

Table 2.3.1 lists the main reasons for nd time periods of downtime in the reporting period.

| Date | Time | Cause |
|---|---|---|
| 06 Oct | 1136 - 1235 | Communication failure |
| 06 Oct | 1311 - 1235 | Communication failure |
| 06 Oct | 1440 - 1446 | Communication failure |
| 06 Oct | 1452 - 1505 | Communication failure |
| 06 Oct | 1507 - 1514 | Communication failure |
| 06 Oct | 1517 - 1546 | Communication failure |
| 06 Oct | 1636 - 1649 | Communication failure |
| 14 Oct | 1505 - 1545 | Communication failure |
| 14 Oct | 1505 - 1545 | Communication failure |
| 14 Oct | 1652 - 1705 | Communication failure |
| 14 Oct | 1710 - 1722 | Communication failure |
| 14 Oct | 1735 - 1753 | Communication failure |
| 07 Nov | 0638 - 0650 | Communication failure |
| 07 Nov | 0713 - 0726 | Communication failure |
| 07 Nov | 0808 - 0820 | Communication failure |
| 11 Nov | 1355 - 1407 | Communication failure |
| 16 Nov | 0000 - 0018 | Communication failure |
| 21 Nov | 0210 - 0222 | Communication failure |
| 26 Nov | 1247 - 1302 | Communication failure |
| 09 Dec | 1829 - 1850 | Communication failure |
| 10 Dec | 0152 - 0206 | Communication failure |
| 10 Dec | 0215 - 0658 | Communication failure |
| 10 Dec | 2057 - 2112 | Communication failure |
| 14 Dec | 0900 - 0932 | Communication failure |
| 14 Dec | 1021 - 1036 | Communication failure |
| 15 Dec | 1052 - 1107 | Communication failure |
| 17 Dec | 1224 - 1237 | Communication failure |
| 22 Dec | 0509 - 0521 | Communication failure |
| 22 Dec | 0535 - 0551 | Communication failure |
| 22 Dec | 0955 - 1012 | Communication failure |

| Date | Time | Cause |
|---|---|---|
| 22 Dec | 1107 - 1122 | Communication failure |
| 22 Dec | 1201 - 1216 | Communication failure |
| 22 Dec | 1252 - 1306 | Communication failure |
| 23 Dec | 0526 - 0540 | Communication failure |
| 23 Dec | 0803 - 1534 | Communication failure<br>3 hours 35 min.missing |
| 24 Dec | 0515 - 0531 | Communication failure |
| 24 Dec | 1536 - 2352 | Communication failure<br>3 hours 34 min. missing |
| 25 Dec | 0452 - 2352 | Communication failure<br>13 hours 50 min. missing |
| 26 Dec | 0007 - 1053 | Communication failure |
| 27 Dec | 1331 - 1446 | Communication failure |
| 27 Dec | 1506 - 1519 | Communication failure |
| 27 Dec | 1556 - 1637 | Communication failure |
| 28 Dec | 0457 - 1540 | Communication failure<br>3 hours 12 min. missing |
| 29 Dec | 0450 - 2346 | Communication failure<br>7 hours 12 min. missing |
| 30 Dec | 0007 - 2359 | Communication failure<br>12 hours 39 min. missing |
| 31 Dec | 0000 - 2359 | Communication failure no data |
| 01 Jan | 0000 - 0101 | Communication failure |
| 12 Jan | 0934 - 1809 | Communication failure<br>7 hours 41 min. missing |
| 13 Jan | 0052 - 0220 | Communication failure |
| 11 Feb | 0119 - 0238 | Power outage NDPC |
| 22 Feb | 0544 - 0559 | Communication failure |
| 23 Feb | 0540 - 0556 | Communication failure |
| 25 Feb | 0122 - 0205 | Power outage NDPC |
| 25 Feb | 0536 - 0549 | Communication failure |
| 26 Feb | 0535 - 0542 | Communication failure |
| 27 Feb | 0538 - 0556 | Communication failure |
| 28 Feb | 0538 - 0553 | Communication failure |
| 01 Mar | 0536 - 0550 | Communication failure |
| 02 Mar | 0540 - 0554 | Communication failure |
| 03 Mar | 0537 - 0544 | Communication failure |

| Date | Time | Cause |
|---|---|---|
| 04 Mar | 0537 - 0551 | Communication failure |
| 05 Mar | 0537 - 0548 | Communication failure |
| 06 Mar | 0539 - 0556 | Communication failure |
| 08 Mar | 0537 - 0550 | Communication failure |
| 12 Mar | 0538 - 0716 | Communication failure |
| 15 Mar | 0538 - 0550 | Communication failure |
| 15 Mar | 1222 - 1352 | Communication failure |
| 16 Mar | 0545 - 0559 | Communication failure |
| 17 Mar | 0539 - 0556 | Communication failure |
| 18 Mar | 0536 - 0543 | Communication failure |

***Table 2.3.1. The main interruptions in recording of Spitsbergen data at NDPC, 1 November 1998 - 31 March 1999.***

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:

| | | |
|---|---|---|
| October 1998 | : | 99.34% |
| November | : | 99.78% |
| December | : | 88.77% |
| January 1999 | : | 98.59% |
| February | : | 99.44% |
| March | : | 99.26% |

**J. Torstveit**

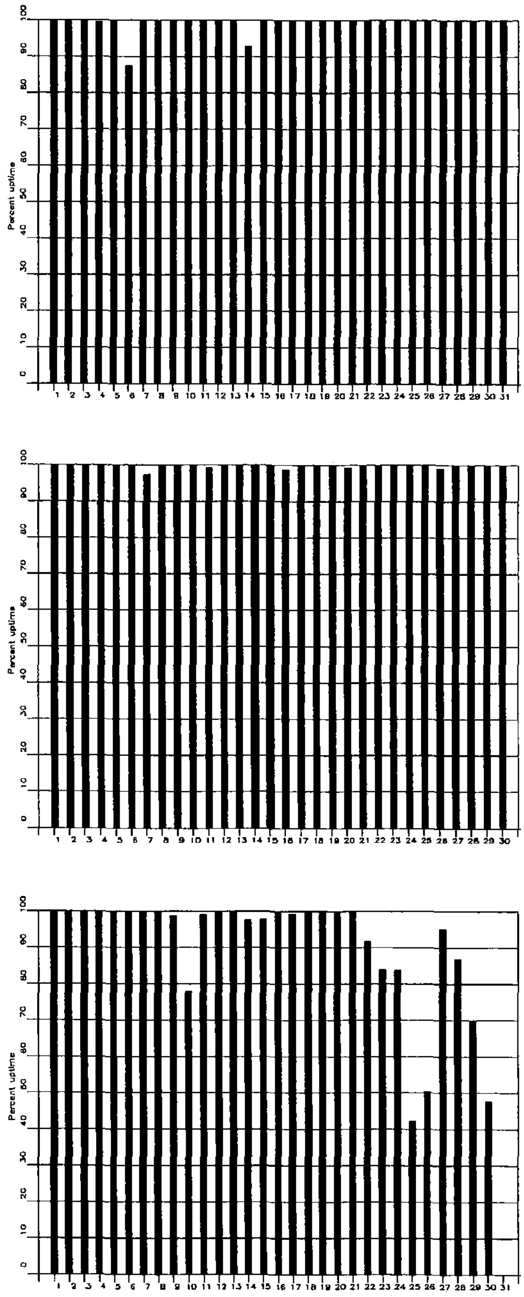

*Fig. 2.3.1. The figure shows the uptime for the data recording task, or equivalently, the availability of Spitsbergen data in our tape archive, on a day-by-day basis, for the reporting period. (Page 1 of 2, Oct-Dec 1998)*

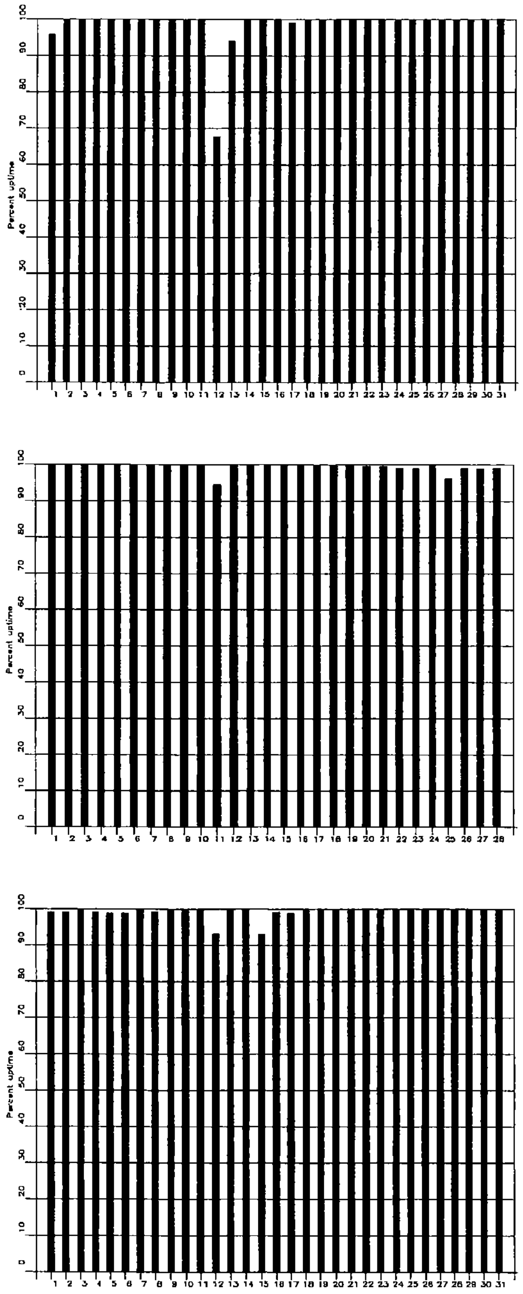

*Fig. 2.3.1. (cont.) (Page 2 of 2, Jan-Mar 1999)*

### 2.3.1 Event Detection Operation

*Spitsbergen array detections*

The number of detections (phases) reported from day 274, 1998, through day 090, 1999, was 166,487, giving an average of 920 detections per processed day (181 days processed).

*Events automatically located by the Spitsbergen array*

During days 274, 1998, through 090, 1999, 16,640 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 91.4 events per processed day (182 days processed). 51% of these events are within 300 km, and 77% of these events are within 1000 km.

**U. Baadshaug**

## 2.4 AS73 — Auxiliary Seismic Station Jan Mayen

The IMS auxiliary seismic network will include a three-component station at 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. An investment in the new station at Jan Mayen will be made in due course and in accordance with PrepCom budget decisions. In the meanwhile, NORSAR will, in cooperation with the University of Bergen, look into technical possibilities of transmitting data from the existing station at Jan Mayen to the NDC at Kjeller. Such data may also be forwarded to the IDC in Vienna.

**S. Mykkeltveit**

## 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 Provisional Technical Secretariat of the CTBTO and NORSAR. Analysis of the data collected at several potential locations for this station in and around Karasjok will soon be completed. The results of this analysis will lead to a decision on the exact location of the infrasound station. We expect that the new station will be installed some time during the summer or fall of year 2000.

**S. Mykkeltveit**

## 2.6 RN49 — Radionuclide Station on Spitsbergen

The IMS radionuclide network will include a station at Longyearbyen on the island of Spitsbergen, at location 78.2°N, 16.4°E. These coordinates coincide with those of the auxiliary seismic station AS72. According to PrepCom decision, this station will also be 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 will be carried out in August of 1999 by NORSAR, in cooperation with the Norwegian Radiation Protection Authority. The station will be established in year 2000 or later, depending on future PrepCom decisions.

**S. Mykkeltveit**

# 3 Operation of Regional Seismic Arrays

## 3.1 NORES

Average recording time was 99.33 as compared to 97.46 for the previous period.

Table 3.1.1 lists the main reasons for and times of outages in the reporting period.

| Date | Time | Cause |
|---|---|---|
| 11 Feb | 0120 - 0237 | Power break NDPC |
| 25 Feb | 0122 - 0202 | Power break NDPC |

***Table 3.1.1. The main interruptions in recording of NORES data at the NDC 1 October 1998 - 31 March 1999.***

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

| | | |
|---|---|---|
| October 1998 | : | 99.98% |
| November | : | 100.00% |
| December | : | 99.95% |
| January 1999 | : | 99.99% |
| February | : | 99.69% |
| March | : | 99.99% |

**J. Torstveit**

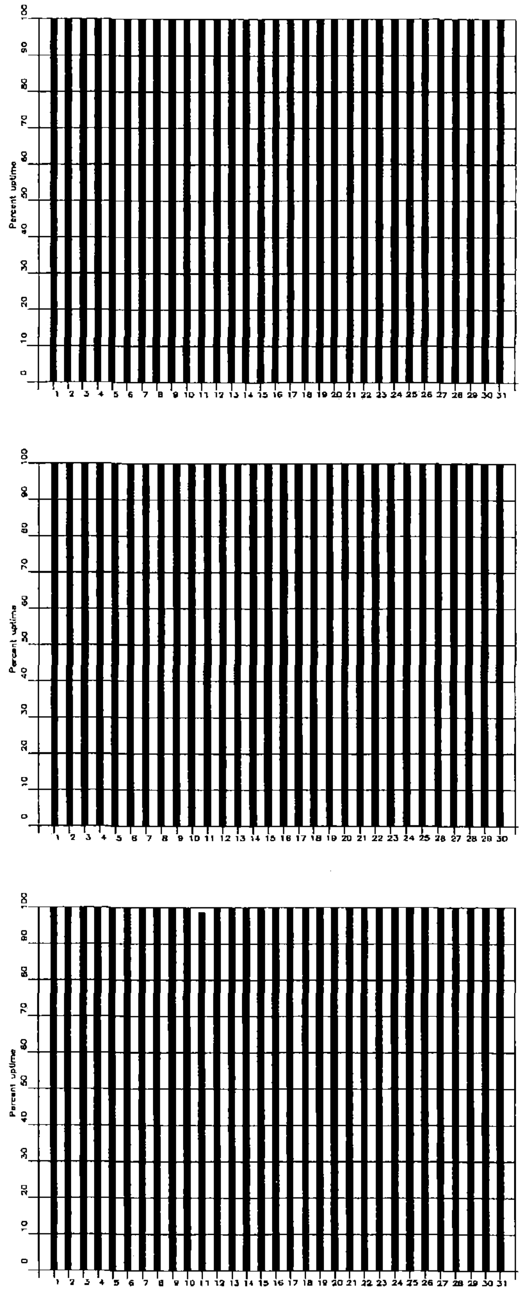

*Fig. 3.1.1. The figure shows the uptime for the data recording task, or equivalently, the availability of NORES data in our tape archive, on a day-by-day basis, for the reporting period (Page 1 of 2, Oct-Dec 1998).*

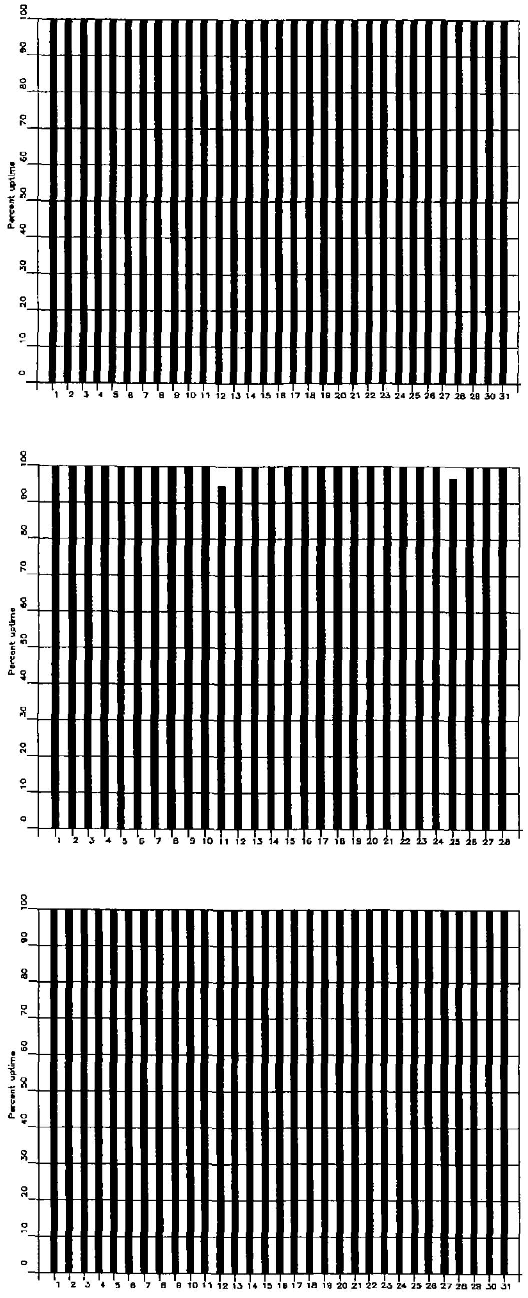

*Fig. 3.1.1. (cont.) (Page 2 of 2, Jan-Mar 1999)*

### 3.1.1 NORES Event Detection Operation

*NORES detections*

The number of detections (phases) reported from day 274, 1998, through day 090, 1999, was 59,345, giving an average of 326 detections per processed day (182 days processed).

***Events automatically located by NORES***

During days 274, 1998, through 090, 1999, 2627 local and regional events were located by NORES, based on automatic association of P- and S-type arrivals. This gives an average of 14.4 events per processed day (183 days processed). 57% of these events are within 300 km, and 81% of these events are within 1000 km.

**U. Baadshaug**

## 3.2 Hagfors (IMS Station AS101)

The average recording time was 99.99% in the reporting period.

Table 3.2.1 lists the main reasons for and times of outages in the reporting period.

| Date | Time | Cause |
|---|---|---|
| 09 Oct | 1142 - 1220 | Testing of hardware in the array |

***Table 3.2.1. The main interruptions in Hagfors recordings at the NDC, 1 October 1998 - 31 March 1999.***

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:

| | | |
|---|---|---|
| October 1998 | : | 99.92% |
| November | : | 100.00% |
| December | : | 100.00% |
| January 1999 | : | 100.00% |
| February | : | 100.00% |
| March | : | 100.00% |

**J. Torstveit**

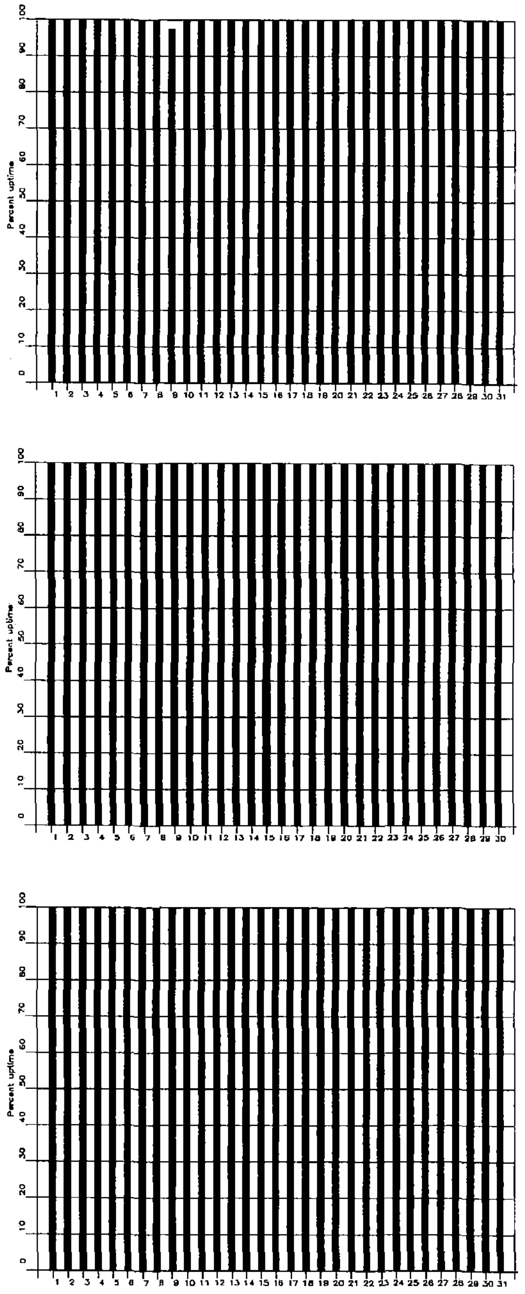

*Fig. 3.2.1. The figure shows the uptime for the data recording task, or equivalently, the availability of Hagfors data in our tape archive, on a day-by-day basis, for the reporting period (Page 1 of 2, Oct-Dec 1998).*

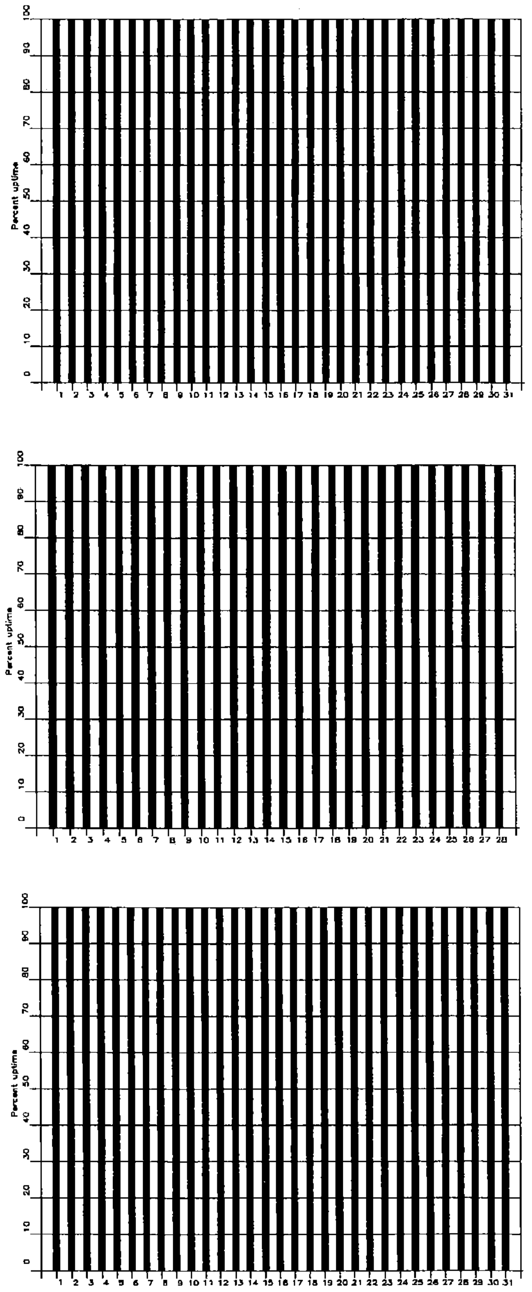

*Fig. 3.2.1. (cont.) (Page 2 of 2, Jan-Mar 1999)*

### 3.2.1 Hagfors Event Detection Operation

*Hagfors array detections*

The number of detections (phases) reported from day 274, 1998, through day 090, 1999, was 62,856, giving an average of 345 detections per processed day (182 days processed).

*Events automatically located by the Hagfors array*

During days 274, 1998, through 090, 1999, 1843 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 10.1 events per processed day (183 days processed). 33% of these events are within 300 km, and 76% of these events are within 1000 km

**U. Baadshaug**

## 3.3 FINES

The average recording time was 99.68% as compared to 97.71% for the previous reporting period.

Table 3.3.1 lists the main reasons for and times of outages during the reporting period..

| Date | Time | Cause |
|---|---|---|
| 11 Nov | 0352 - 0544 | Power failure in Helsinki |
| 26 Nov | 0555 - 0716 | Communication failure in Finland |
| 15 Jan | 0205 - 0220 | Communication failure in Finland |
| 15 Jan | 0241 - 0647 | Communication failure in Finland |
| 04 Feb | 1552 - 1719 | Problems in Helsinki |
| 16 Feb | 0122 - 0346 | Problems in Helsinki |
| 16 Feb | 0540 - 0741 | Problems in Helsinki |

***Table 3.3.1. The main interruptions in FINES recordings at the NDC, 1 October 1998 - 31 March 1999.***

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:

October 1998 : 100.00%
November : 99.56%
December : 100.00%
January 1999 : 99.39%
February : 99.13%
March : 100.00%

**J. Torstveit**

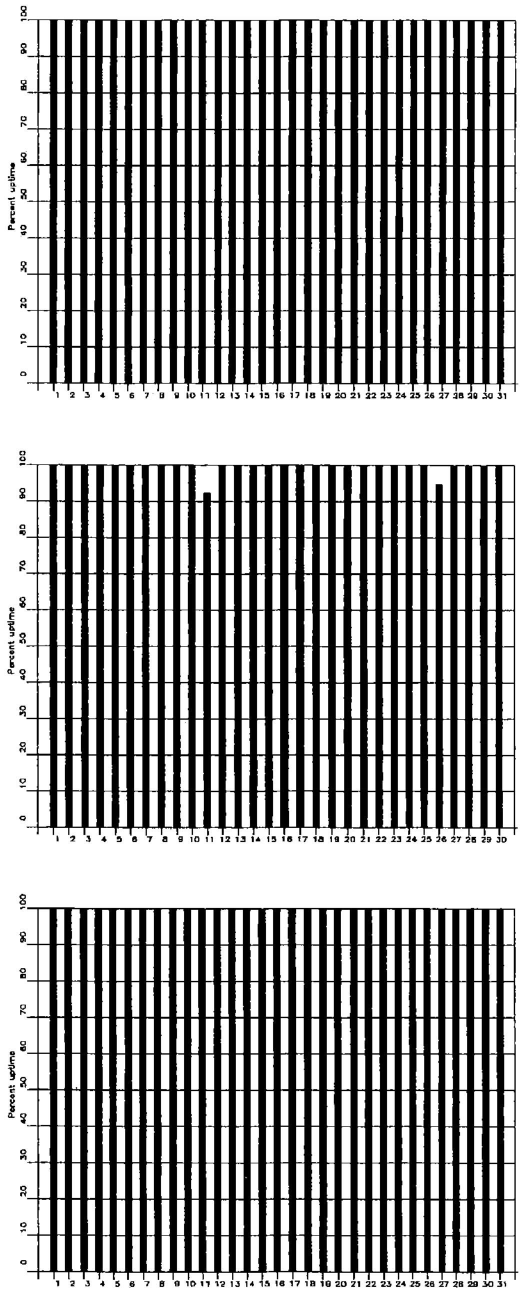

*Fig. 3.3.1. The figure shows the uptime for the data recording task, or equivalently, the availability of FINES data in our tape archive, on a day-by-day basis, for the reporting period (Page 1 of 2, Oct-Dec 1998).*

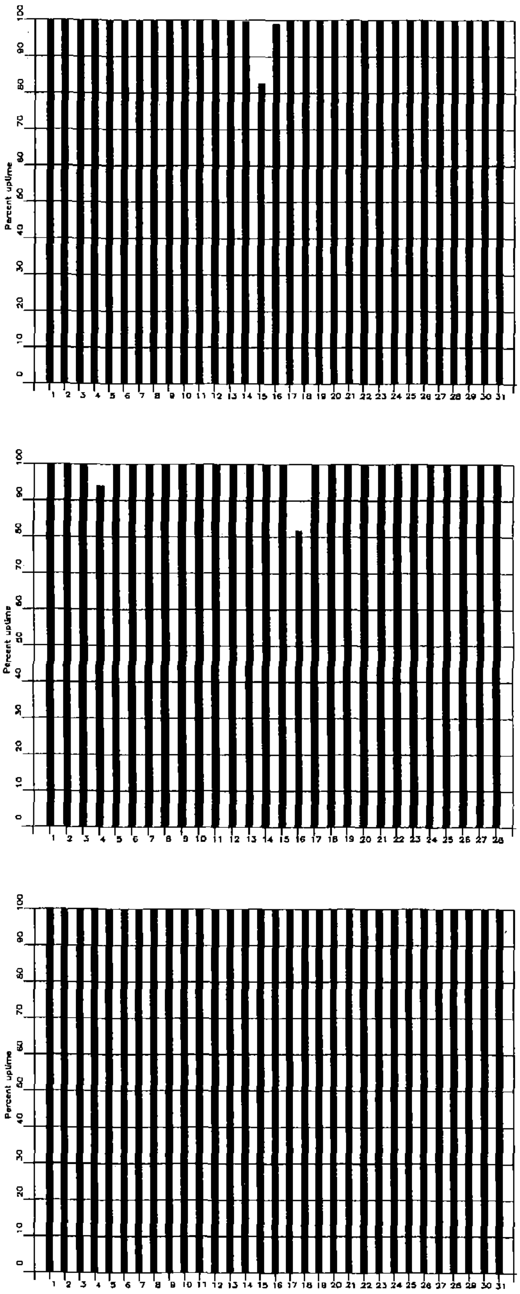

*Fig. 3.3.1. (cont.) (Page 2 of 2, Jan-Mar 1999)*

### 3.3.1 FINES Event Detection Operation

*FINES detections*

The number of detections (phases) reported during day 274, 1998, through day 090, 1999, was 60,664, giving an average of 333 detections per processed day (182 days processed).

*Events automatically located by FINES*

During days 274, 1998, through 090, 1999, 3124 local and regional events were located by FINESS, based on automatic association of P- and S-type arrivals. This gives an average of 17.1 events per processed day (183 days processed). 76% of these events are within 300 km, and 88% of these events are within 1000 km.

**U. Baadshaug**

## 3.4 Apatity

The average recording time was 98.98 in the reporting period.

Table 3.4.1 lists the main reasons for and times of outages during the reporting period.

| Date | Time | Cause |
|---|---|---|
| 21 Oct | 1811 - | Stop in Apatity |
| 22 Oct | - 0428 | |
| 28 Oct | 1647 - | Stop in Apatity |
| 29 Oct | - 0424 | |
| 29 Oct | 2346 - | Stop in Apatity |
| 30 Oct | - 0537 | |
| 04 Nov | 0717 - 0827 | Stop in Apatity |
| 06 Nov | 0306 - 0615 | Stop in Apatity |
| 19 Nov | 1138 - 1220 | Stop in Apatity |
| 19 Nov | 1249 - 1324 | Stop in Apatity |
| 19 Nov | 2315 - | Stop in Apatity |
| 20 Nov | - 0538 | |

*Table 3.4.1. The main interruptions in Apatity recordings at the NDC, 1 October 1998 - 31 March 1999.*

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

October 1998 : 96.20%
November : 98.21%
December : 99.99%
January 1999 : 99.98%
February : 99.51%
March : 99.98%

**J. Torstveit**

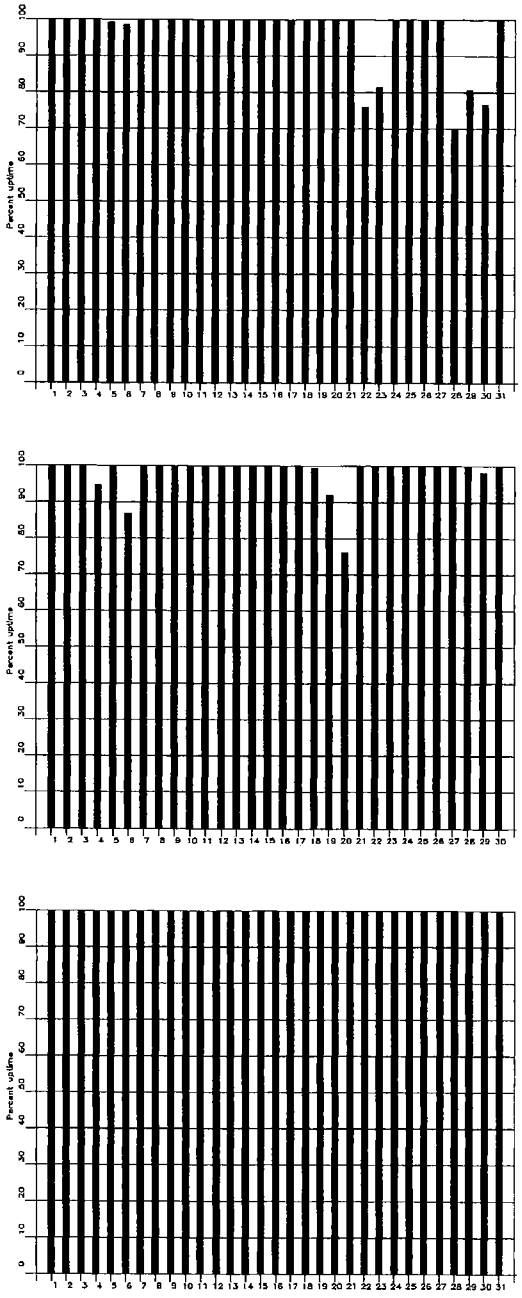

*Fig. 3.4.1. The figure shows the uptime for the data recording task, or equivalently, the availability of Apatity data in our tape archive, on a day-by-day basis, for the reporting period (Page 1 of 2, Oct-Dec 1998).*

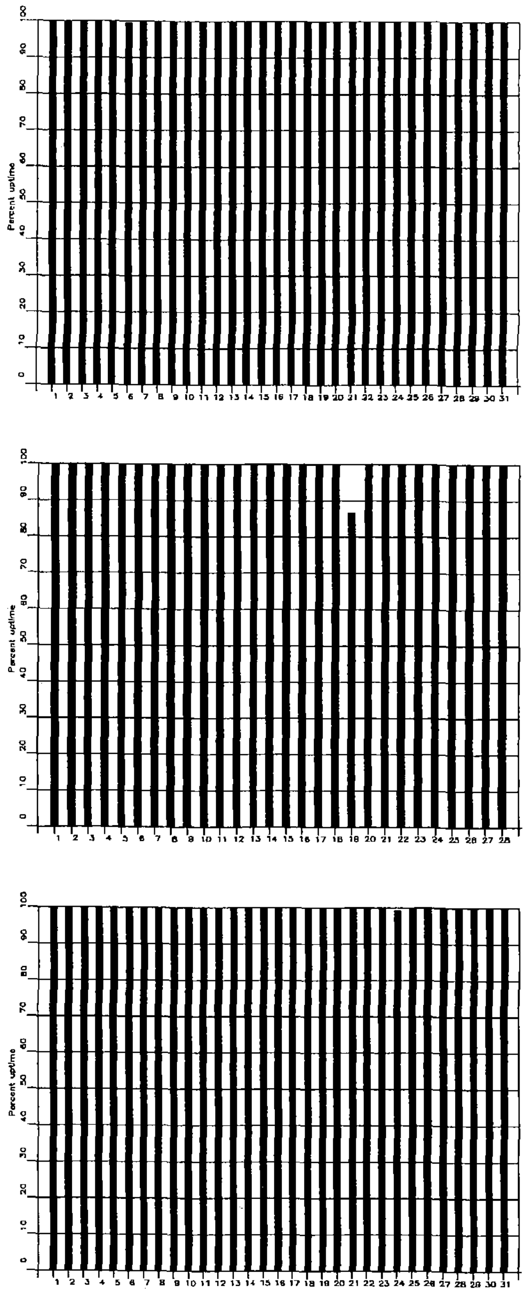

*Fig. 3.4.1. (cont.) (Page 2 of 2, Jan-Mar 1999)*

### 3.4.1 Apatity Event Detection Operation

*Apatity array detections*

The number of detections (phases) reported from day 274, 1998, through day 090, 1999, was 77,311, giving an average of 425 detections per processed day (182 days processed).

As described in earlier reports, the data from the Apatity array are transferred by one-way (simplex) radio links to Apatity city. The transmission suffers from radio disturbances that occasionally result in a large number of small data gaps and spikes in the data. In order for the communication protocol to correct such errors by requesting retransmission of data, a two-way radio link would be needed (duplex radio). However, it should be noted that noise from cultural activities and from the nearby lakes cause most of the unwanted detections. These unwanted detections are “filtered” in the signal processing, as they give seismic velocities that are outside accepted limits for regional and teleseismic phase velocities.

*Events automatically located by the Apatity array*

During days 274, 1998, through 090, 1999, 2333 local and regional events were located by the Apatity array, based on automatic association of P- and S-type arrivals. This gives an average of 12.7 events per processed day (183 days processed). 30% of these events are within 300 km, and 65% of these events are within 1000 km.

**U. Baadshaug**

# 3.5 GERES

## 3.5.1 GERES Event Detection Operation

### *GERESS detections*

The number of detections (phases) reported from day 274, 1998, through day 090, 1999, was 47,873, giving an average of 263 detections per processed day (182 days processed).

### *Events automatically located by GERESS*

During days 274, 1998, through 090, 1999, 3825 local and regional events were located by GERESS, based on automatic association of P- and S-type arrivals. This gives an average of 20.9 events per processed day (183 days processed). 60% of these events are within 300 km, and 85% of these events are within 1000 km.

**U. Baadshaug**

## 3.6 Regional Monitoring System Operation and Analysis

The Regional Monitoring System (RMS) was installed at NORSAR in December 1989 and was operated at NORSAR from 1 January 1990 for automatic processing of data from ARCESS and NORESS. 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 ARCESS, NORESS, FINESS and GERESS 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 distance.

Data from the Apatity array were 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.

The operational stability of RMS has been very good during the reporting period. In fact the RMS event processor (pipeline) has had no downtime of its own; i.e., all data available to RMS have been processed by RMS.

### *Phase and event statistics*

Table 3.6.1 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, the total number of events defined by the analyst, and finally the number of events accepted by the analyst without any changes (i.e., from the set of events automatically declared by the RMS).

Due to reductions in the FY94 funding for RMS activities (relative to previous years), new criteria for 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 were analyzed as before.

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 to 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.

There is one exception to the new rule for automatic phase association: all detections from the Spitsbergen array are passed directly on to the RMS. This allows for thorough analysis of all events in the Spitsbergen region.

| | Oct 98 | Nov 98 | Dec 98 | Jan 99 | Feb 99 | Mar 99 | Total |
|---|---|---|---|---|---|---|---|
| Phase detections | 102889 | 90701 | 86583 | 84403 | 103317 | 76253 | 544146 |
| - Associated phases | 2414 | 2598 | 2397 | 1823 | 1922 | 2585 | 13739 |
| - Unassociated phases | 100475 | 88103 | 84186 | 82580 | 101395 | 73668 | 530407 |
| Events automatically declared by RMS | 401 | 363 | 419 | 348 | 381 | 438 | 2350 |
| No. of events defined by the analyst | 63 | 93 | 71 | 55 | 65 | 76 | 423 |
| No. of events accepted without modifications | 0 | 0 | 0 | 01 | 0 | 0 | 0 |

***Table 3.6.1. RMS phase detections and event summary.***

**U. Baadshaug**
**B. Paulsen**

# 4 NDC and Field Activities

## 4.1 NDC Activitities

NORSAR will function as the Norwegian National Data Center (NDC) for treaty verification. Six monitoring stations, comprising altogether 119 field instruments, 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, with three of them contributing data to GSETT-3. The infrasound station in northern Norway and the radionuclide station at Spitsbergen will need to be established within the next few years. Data recorded by the Norwegian stations will be transmitted in real time to the Norwegian NDC, and provided to the IDC through the Global Communications Infrastructure (GCI).

Operating the Norwegian IMS stations will require increased resources and additional personnel both at the NDC and in the field. It will require establishing new and strictly defined procedures as well as increased emphasis on regularity of data recording and timely data transmission to the IDC in Vienna. Anticipating these requirements, a new organizational unit has been established at NORSAR to form a core group for the future Norwegian NDC for treaty monitoring. The NDC will carry 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.

### *Verification functions*

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.

### *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.

### *Information received from IDC*

The IDC will provide regular bulletins of detected events as well as numerous other products, but will not assess the nature of each individual event. An important task for the Norwegian NDC will 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.

### *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 to establish 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 continuously modified to simplify operations and improve results. NORSAR is currently applying teleseismic detection and event processing using the large-aperture NORSAR array as well as regional monitoring using the network of small-aperture arrays in Fennoscandia and adjacent areas.

### *Y2K related problems*

NORSAR is currently cooperating with AFTAC in ensuring that all systems at the NDC and in the field are Y2K compliant, Also, the GPS week-rollover problem is being addressed.

### *Technical Training Program*

The Norwegian NDC organized the first international training program for seismic station operators at NORSAR in the fall of 1998, with participation from 17 countries in all areas of the world. The course contents included functions at the NDC as well as field maintenance procedures, with emphasis on hands-on demonstrations. The program was carried out very successfully, and will probably be followed by additional such training courses in the future.

### *Certification of PS27*

IMS station PS27-NOA is currently being considered by the PTS for formal certification. PTS personnel visited the station in June 1998, and carried out a detailed technical evaluation. As a result of this inspection and subsequent discussions between NORSAR and the PTS, and following further discussions of the certification requirements during Working Group B meetings, it is now concluded that PS27 needs the following enhancements:

- A tamper detector to be emplaced at every seismometer and at the subarray central vaults
- A centralized authentication process in each subarray as well as at the central array recording facility
- Establishment of a GCI connection at the central array facility
- Addition of a 3-component seismometer in order to satisfy the technical requirements for short-period 3-component recording.

These enhancements will be implemented during the summer of 1999.

### *Establishing an independent subnetwork*

Norway has elected to use the option for an independent subnetwork, which will connect with all the IMS stations operated by NORSAR with an interface to the GCI. We are now in the process of negotiating a contract for installing VSAT antennas at each station in the network.

Currently, the Norwegian NDC cooperates with several institutions in other countries for transmission of IMS data to the Prototype IDC during GSETT-3, using a variety of data communications solutions in combination with a high speed link between the Norwegian NDC and the Prototype IDC:

- Data from IMS station PS17 — FINES array — is buffered in Helsinki and thereafter forwarded to the Norwegian NDC, where data is also buffered. From the Norwegian NDC, the data is reformatted and transmitted to the PIDC.
- Data from IMS station PS19 — GERES array — is transmitted via simplex satellite from the array to the Norwegian NDC, where it is buffered, reformatted and transmitted to the PIDC.
- Data from IMS station PS40 — Sonseca array — is transmitted from Madrid to the PIDC, using a satellite connection between the Norwegian NDC and Spain NDC. At the Norwegian NDC, the data is routed through to the PIDC.
- Continuous data from IMS station AS101 — Hagfors array — is transmitted by VSAT from Hagfors to the Norwegian NDC, where the data is buffered for data requests from PIDC.
- Data from the station Nilore in Pakistan can be requested by the PIDC, using a VSAT connection between Pakistan and the Norwegian NDC.

It is anticipated that after these stations have been connected to the GCI, these communication links will be discontinued.

*Upgrade of PS28*

IMS station PS28-ARCES has been selected by the PrepCom for hardware upgrade in 1999. Current plans are to replace all the digitizers and data acquisition equipment. We anticipate that a contract for delivery of equipment will be awarded by the PTS in May, 1999, and subsequently NORSAR will negotiate a contract with the PTS for the necessary site preparation and installation work.

**Jan Fyen**

## 4.2 Status Report: Norway's Participation in GSETT-3

### *Introduction*

This contribution is a report for the period October 1998 - March 1999 on activities associated with Norway's participation in the GSETT-3 experiment, which is now being coordinated by PrepCom's Working Group B. This report represents an update of contributions that can be found in the previous five editions of NORSAR's Semiannual Technical Summary.

### *Norwegian GSETT-3 stations and communications arrangements*

During the reporting interval 1 October 1998 - 31 March 1999, Norway has provided data to the GSETT-3 experiment from the three seismic stations shown in Fig. 4.2.1. The NORSAR array (station code 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. ARCES is a 25-element regional array with an aperture of 3 km, whereas the Sptisbergen array (station code SPITS) has 9 elements within a 1-km aperture. ARCES and SPITS both have a broadband three-component seismometer at the array center.

Data from these three stations are transmitted continuously and in real time to NOR_NDC. The NOA data are transmitted using dedicated land lines, whereas data from the other two arrays are transmitted via satellite links of capacity 64 Kbits/s and 19.2 Kbits/s for the ARCES and SPITS arrays, respectively. From the NOR_NDC, relevant data (see below) are forwarded to the prototype IDC (PIDC) in Arlington, Virginia, USA, via a dedicated fiber optical 256 Kbits/s link between the two centers.

The NOA and ARCES arrays are primary stations in the GSETT-3 network, which implies that data from these stations are transmitted continuously to the PIDC with a delay not exceeding 5 minutes. The SPITS array is an auxiliary station in GSETT-3, and the SPITS data are available to the PIDC on a request basis via use of the AutoDRM protocol (Kradolfer, 1993; Kradolfer, 1996). The Norwegian stations are thus participating in GSETT-3 with the same status (primary/auxiliary seismic stations) they have in the International Monitoring System (IMS) defined in the protocol to the Comprehensive Nuclear Test-Ban Treaty.

### *Uptimes and data availability*

Figs. 4.2.2 - 4.2.3 show the monthly uptimes for the Norwegian GSETT-3 primary stations ARCESS and NOA, respectively, for the period 1 October 1998 - 31 March 1999, given as the hatched (taller) bars in these figures. These barplots reflect the percentage of the waveform data that are available in the NOR_NDC tape 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. 4.2.2-4.2.3 also give the data availability for these two stations as reported by the PIDC in the PIDC Station Status reports. The main reason for the discrepancies between the NOR_NDC and PIDC 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 PIDC uses weights where the reported availability (capability) is based on the number of actually operating channels.

### *Experience with the AutoDRM protocol*

NOR_NDC's AutoDRM has been operational since November 1995 (Mykkeltveit & Baadshaug, 1996).

The PIDC started actively and routinely using NOR_NDC's AutoDRM service after SPITS changed its station status from primary to auxiliary on 1 October 1996. For the month of October 1996, the NOR_NDC AutoDRM responded to 12338 requests for SPITS waveforms from two different accounts at the PIDC: 9555 response messages were sent to the "pipeline" account and 2783 to "testbed". Following this initial burst of activity, the number of "pipeline" requests stabilized at a level between 5000 and 7000 per month. Requests from the "testbed" account show large variations.

The monthly number of requests for SPITS data for the period October 1998 - March 1999 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 period October - March 1999, NOR_NDC derived information on 435 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 PIDC. These events are plotted in Fig. 4.2.5.

### *Data forwarding for GSETT-3 stations in other countries*

NOR_NDC continues to forward data to the PIDC from GSETT-3 primary stations in several countries. These currently include FINESS (Finland), GERESS (Germany) and Sonseca (Spain). In addition, communications for the GSETT-3 auxiliary station at Nilore, Pakistan, are provided through a VSAT satellite link between NOR_NDC and Pakistan's NDC in Nilore. The PIDC obtains data from the Hagfors array (HFS) in Sweden through requests to the AutoDRM server at NOR_NDC (in the same way requests for Spitsbergen array data are handled, see above). Fig. 4.2.6 shows the monthly number of requests for HFS data from the two PIDC accounts "pipeline" and "testbed".

### *Future plans*

NOR_NDC will continue the efforts towards improvements and hardening of all critical data acquisition and data forwarding hardware and software components, so as to meet future requirements related to operation of IMS stations to the maximum extent possible.

The PrepCom has tasked its Working Group B with overseeing, coordinating, and evaluating the GSETT-3 experiment. The PrepCom has also encouraged states that operate IMS-designated stations to continue to do so on a voluntary basis and in the framework of the GSETT-experiment until such time that the stations have been certified for formal inclusion in IMS. In line with this, and provided that adequate funding is obtained, we envisage continuing the provision of data from Norwegian IMS-designated stations without interruption to the PIDC, and later on to the IDC in Vienna, via the new global communications infrastructure currently being established.

The certification process for NOA was initiated by an overview station inspection visit by a PTS (Provisional Technical Secretariat of the PrepCom) team in mid-June 1998. The PTS has pointed out certain modifications that have to be made to the NOA installation to make it fully compatible with the IMS requirements. Implementation of these modifications are now underway.

Data from Norwegian IMS stations will be sent to the IDC in Vienna via the Norwegian NDC at Kjeller. A new line from Kjeller to the IDC will soon be installed, and the current connection to the PIDC will be terminated shortly afterwards.

The PTS is now in the process of procuring equipment for the upgrade of ARCES to IMS standards. This equipment (a new broadband seismometer, new digitizers, and a new data acquisition system) will be installed by NORSAR upon delivery by the vendor selected by the PTS.

**U. Baadshaug**
**S. Mykkeltveit**
**J. Fyen**

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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.

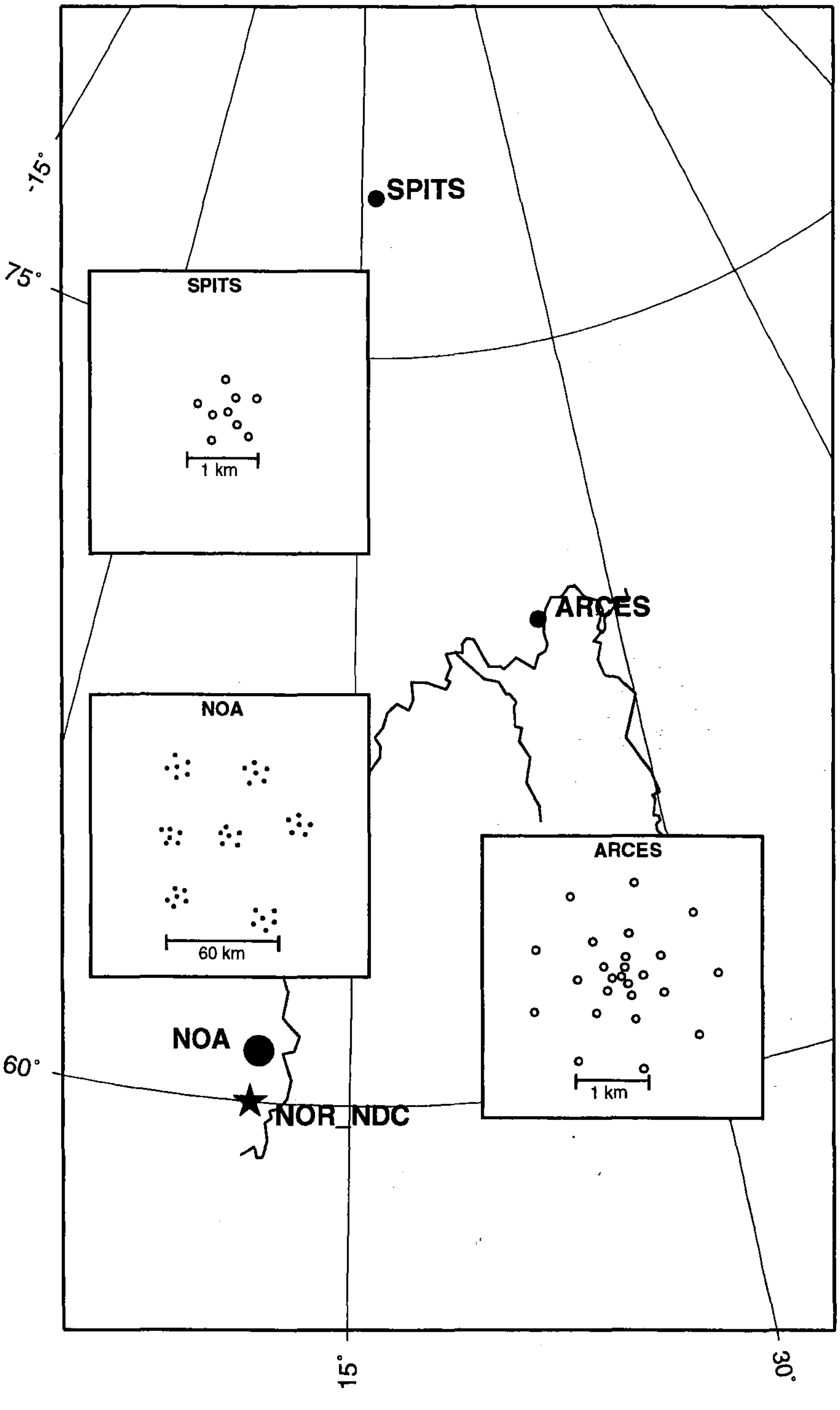

*Fig. 4.2.1. The figure shows the locations and configurations of the three Norwegian seismic array stations that have provided data to the GSETT-3 experiment during the period 1 October 1998 - 31 March 1999. The data from these stations are transmitted continuously and in real time to the Norwegian NDC (NOR_NDC). The stations NOA and ARCES have participated in GSETT-3 as primary stations, whereas SPITS has contributed as an auxiliary station.*

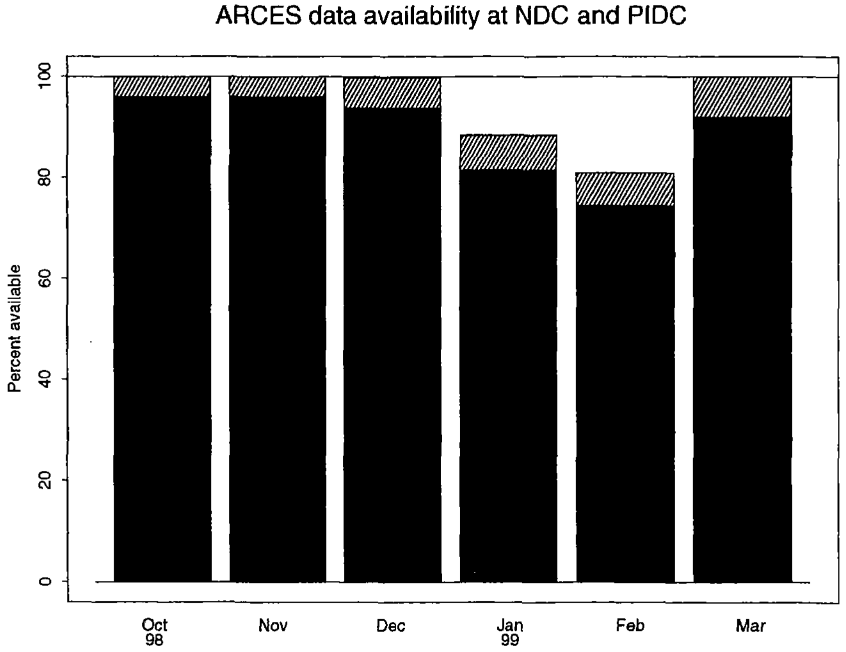

*Fig. 4.2.2. The figure shows the monthly availability of ARCESS array data for the period October 1998 - March 1999 at NOR_NDC and the PIDC. See the text for explanation of differences in definition of the term "data availability" between the two centers. The higher values (hatched bars) represent the NOR_NDC data availability.*

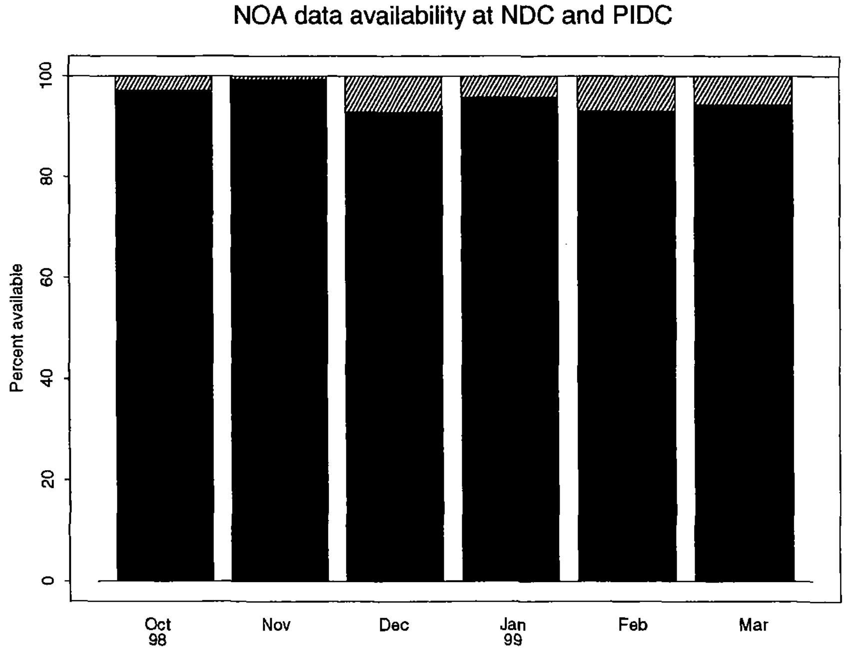

*Fig. 4.2.3. The figure shows the monthly availability of NORSAR array data for the period October 1998 - March 1999 at NOR_NDC and the PIDC. See the text for explanation of differences in definition of the term "data availability" between the two centers. The higher values (hatched bars) represent the NOR_NDC data availability.*

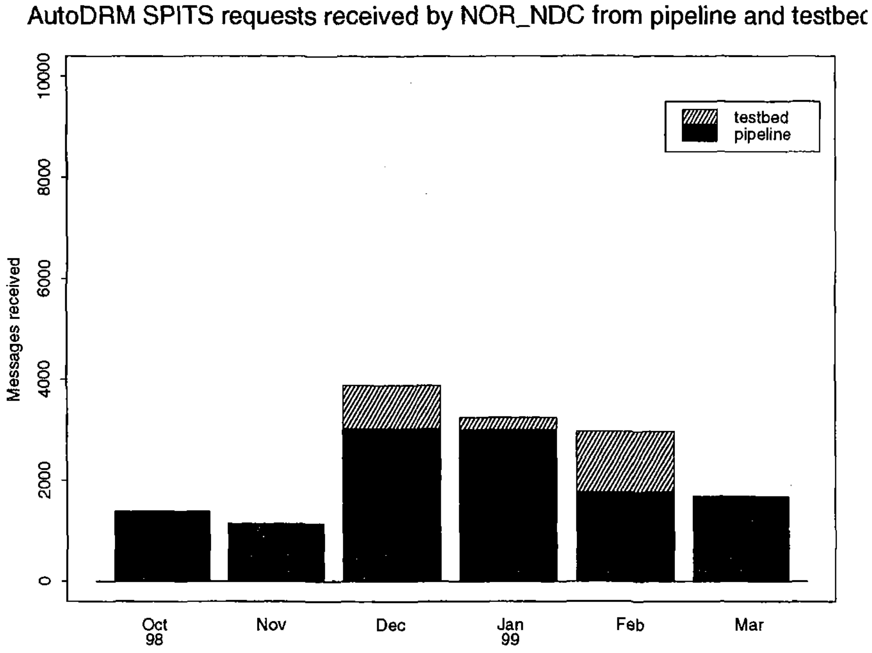

*Fig. 4.2.4. The figure shows the monthly number of requests received by NOR_NDC from the PIDC for SPITS waveform segments during October 1998 - March 1999.*

# Reviewed Supplementary events

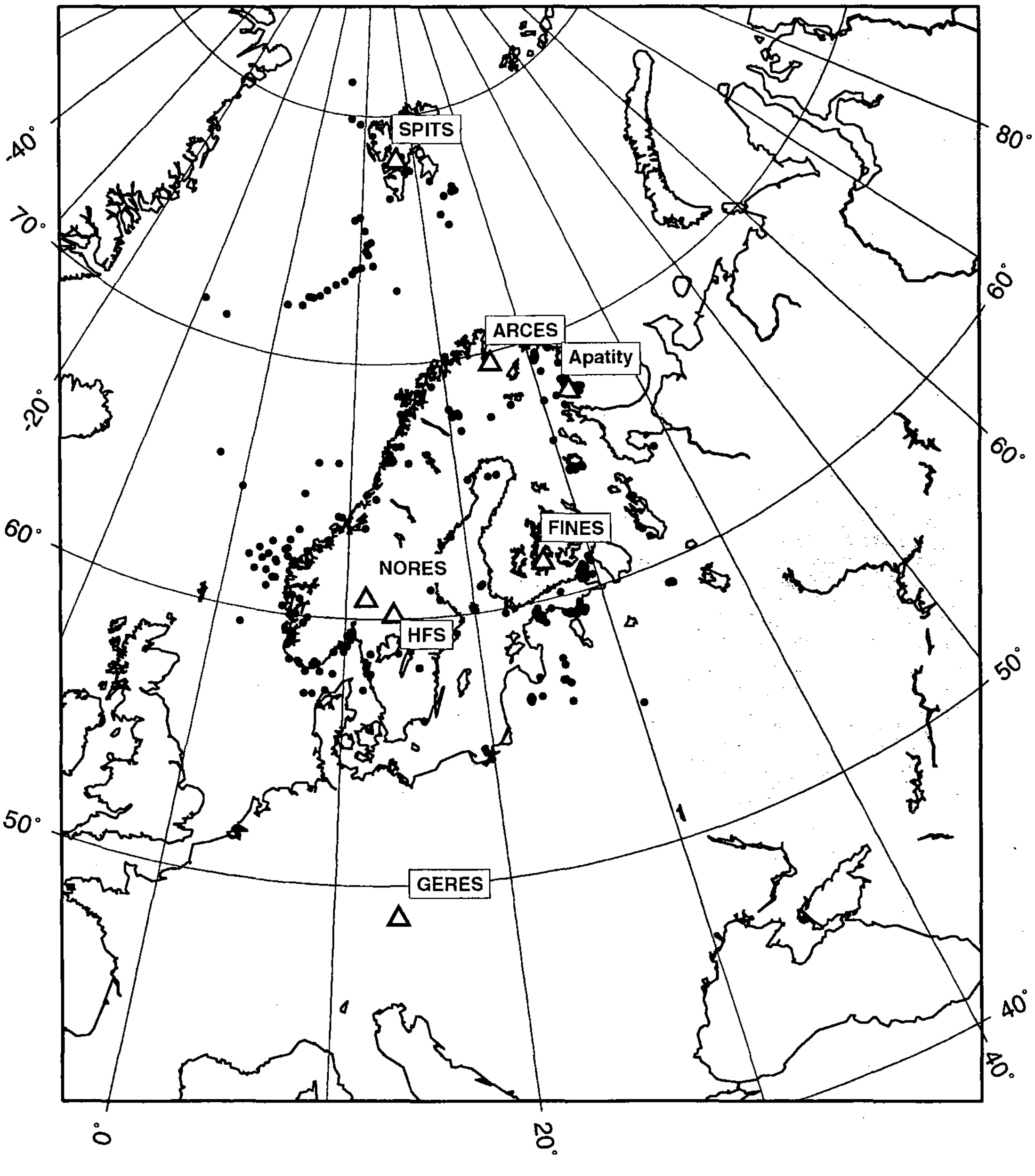

*Fig. 4.2.5. The map shows the 435 events in and around Norway contributed by NOR_NDC during October 1998 - March 1999 as Supplementary (Gamma) data to the PIDC, as part of the Nordic Supplementary data compiled by the Finnish NDC. The map also shows the seismic stations used in the data analysis to define these events.*

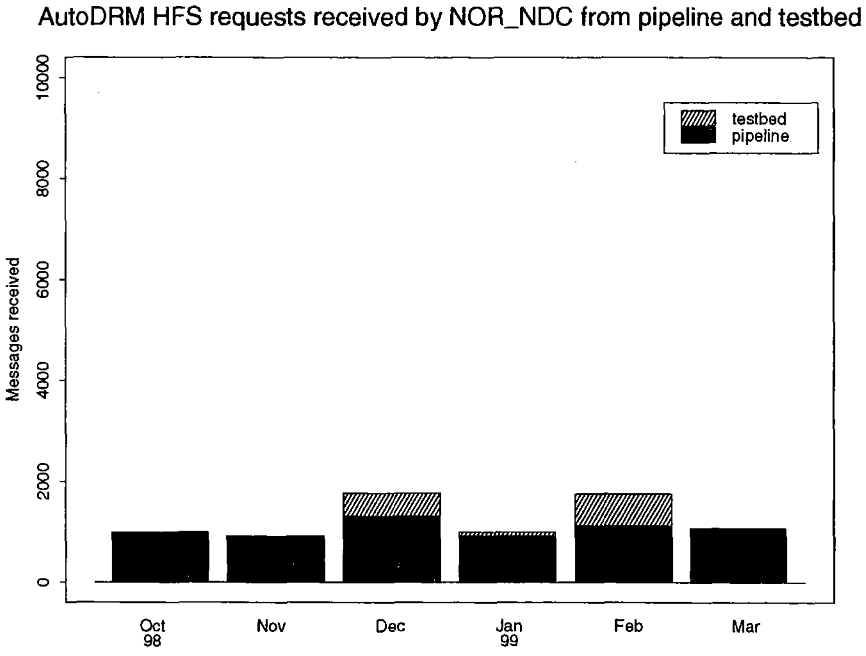

*Fig. 4.2.6. The figure shows the monthly number of requests received by NOR_NDC from the PIDC for HFS waveform segments during October 1998 - March 1999.*

## 4.3 Field Activities

*Activities in the field and at the Maintenance Center*

This section summarizes the activities at the Maintenance Center (NMC) Hamar, and includes activities related to monitoring and control of the NORSAR teleseismic array, as well as the NORESS, ARCESS, FINESS, GERESS, Apatity, Spitsbergen, and Hagfors small-aperture arrays.

Activities also involve preventive and corrective maintenance, planning and activities related to the refurbishment of the NORSAR teleseismic array.

**NORSAR**

Visits to subarrays in connection with:

- Cable splicing
- Replacement of defective equipment
- Preventive maintenance of Central Terminal Vault (CTV) and Long Period Vault (LPV)

**NORESS**

- Repair of power supply card at remote site C4
- Replacement of fiber optical transmitter at remote site C7
- Replacement of digitizer card at remote site C2

**ARCESS**

- Disconnection of remote site C4 from Hub due to problems with spikes
- Replacement of +12VDC power supply in Hub
- Adjustment of all fiber optical links going to remote sites

**NMC**

- Repair of defective electronic equipment

Additional details for the reporting period are provided in Table 4.3.1.

**P.W. Larsen**
**K.A. Løken**

| Subarray/ area | Task | Date |
|---|---|---|
| | *October 1998* | |
| NORSAR | | October |
| 02C | Repaired modem for data transmission from remote site SP03. | 9/10 |
| 01B | Installed 50 Hz notch filters for transmission lines going to remote sites. | 13/10 |
| 01A | Cable splicing SP02. | 20/10 |
| NMC | Repair of defective electronic equipment. | October |
| | *November 1998* | |
| NORSAR | | November |
| 01A | Preventive maintenance in CTV and LPV | 6,9,12/11 |
| 01B | Preventive maintenance in CTV and LPV | 6,13/11 |
| 02B | Preventive maintenance in CTV and LPV | 5,16,17/ 11 |
| 02C | Preventive maintenance in CTV and LPV | 6,11,12/ 11 |
| 03C | Preventive maintenance in CTV and LPV | 4,5,13,17, 18,19/11 |
| 04C | Preventive maintenance in CTV and LPV | 5,13,19, 20/11 |
| 06C | Preventive maintenance in CTV and LPV | 20,23,24/ 11 |
| 03C | Replaced interface card for serial port 1 in the CIM II Master | 9/11 |
| NMC | Repair of defective electronic equipment. | November |

| Subarray/ area | Task | Date |
|---|---|---|
| | *December 1998* | |
| NORSAR | | December |
| 06C | Connected test signal to AIM24 auxiliary channel at SP02. | 28/12 |
| ARCESS | Disconnected remote site C4 from Hub due to problems with spikes. | |
| NMC | Repair of defective electronic equipment. | December |
| | *January 1999* | |
| NORSAR | | January |
| 02C | Found that the control card for the AIM24BB was defective | 21/1 |
| 02C | Replaced the defective control card for the AIM24BB | 22/1 |
| ARCESS | Replaced the +12VDC power supply in the Hub.<br>Adjusted all fiber optical links going to the remote sites | 14-15/1 |
| NMC | Repair of defective electronic equipment. | January |
| | *February 1999* | |
| NORESS | Repaired the power supply card at remote site C4.<br>Replaced the fiber optical transmitter at remote site C7.<br>Replaced the digitizer card at remote site C2 for N-S channel. | February |
| NMC | Repair of defective electronic equipment. | February |
| | *March 1999* | |
| NMC | Repair of defective electronic equipment | March |

*Table 4.3.1. Activities in the field and the NORSAR Maintenance Center during 1 October 1998 - 31 March 1999.*

# 5 Documentation Developed

Baadshaug, U., S. Mykkeltveit & J. Fyen (1998): Status report: Norway's participation in GSETT-3. **In**: *Semiannual Tech. Summ., 1 April - 30 September 1998*, NORSAR Sci. Rep. 1-98/99, Kjeller, Norway.

Kremenetskaya, E., V. Asming, Z. Jevtjugina & F. Ringdal (1998): Study of surface waves and $M_s$:$m_b$ using Apatity LP recordings. **In**: *Semiannual Tech. Summ., 1 April - 30 September 1998*, NORSAR Sci. Rep. 1-98/99, Kjeller, Norway.

Kværna, T., F. Ringdal, J. Schweitzer & L. Taylor (1998): Optimized Threshold Monitoring. **In**: *Semiannual Tech. Summ., 1 April - 30 September 1998*, NORSAR Sci. Rep. 1-98/99, Kjeller, Norway.

Kværna, T., F. Ringdal, J. Schweitzer & L. Taylor (1998): Monitoring the Indian underground nuclear tests of May 1998. **In**: *Semiannual Tech. Summ., 1 April - 30 September 1998*, NORSAR Sci. Rep. 1-98/99, Kjeller, Norway.

Ringdal, F. (1998): Norwegian experience with IDC metrics during GSETT-3. **In**: *Semiannual Tech. Summ., 1 April - 30 September 1998*, NORSAR Sci. Rep. 1-98/99, Kjeller, Norway.

Ringdal, F., E. Kremenetskaya, V. Asming, T. Kværna, J. Fyen & J. Schweitzer (1998): Seismic monitoring of the Barents/Kara Sea region. **In**: *Semiannual Tech. Summ., 1 April - 30 September 1998*, NORSAR Sci. Rep. 1-98/99, Kjeller, Norway.

Schweitzer, J. (1998): Tuning the automatic data processing for the Spitsbergen array (SPITS). **In**: *Semiannual Tech. Summ., 1 April - 30 September 1998*, NORSAR Sci. Rep. 1-98/99, Kjeller, Norway.

# 6 Summary of Technical Reports / Papers Published

## 6.1 Recommendations for Seismic Event Location Calibration Development

***Report from the Oslo Workshop 12-14 January 1999***

### *Introduction*

During the May and August, 1998 meetings of Working Group B of the CTBTO Preparatory Commission, the International Data Centre (IDC) Expert Group identified the need for highly-focused work to provide regionalized travel times to improve seismic location methods used in the IDC. The Expert Group suggested that initial focus should be given to three geographical regions: North America, Eurasia and Australia.

To assist with the developments of the IDC applications software relating to the location calibration problem, an informal meeting of the IDC Technical Experts Group on Seismic Event Location was held in Oslo, Norway on 12-14 January, 1999. Forty technical experts, coming from nine signatory countries and the Provisional Technical Secretariat, participated in the meeting. Dr. Frode Ringdal of Norway chaired the meeting.

### *Background and technical objectives*

The issue of regional location calibration has been discussed by seismologists for decades. While there is a general consensus that such calibration is necessary in order to significantly improve the location precision of internationally reporting earthquake agencies, no attempt has so far been made to include such corrections in routine location processing on a global scale.

The Oslo workshop 12-14 January, 1999 was convened to begin addressing this problem, by developing plans and recommendations for how such regional calibration could be incorporated into processing at the International Data Center (IDC) for the CTBT International Monitoring System (IMS). The Release 3 applications software will be developed during 1999 for delivery to the IDC prior to the start of the full-scale testing of the IDC. An important element in Release 3 capabilities will be the use of calibration information for event location in specific geographical regions.

Working Group B has previously encouraged States Signatories to support these location improvement efforts by supplying relevant location calibration information. The following types of calibration information were proposed in the document CTBT/WGB-6/CRP.26:

- Precise information on location, depth, and origin time of previous nuclear explosions or large chemical explosions
- Similar information on other seismic events that have been located by regional networks with sufficient precision.
- Data as appropriate on seismic travel-time models
- Any other information (e.g., geologic or tectonic maps) that would be useful
- Ground truth data from chemical explosions.

The primary task of the workshop was to assess the status and availability of such calibration information, and to develop recommendations for data, models and procedures for implementing regional location calibration at the IDC, both for Release 3 of the IDC applications software and for implementation in the longer term.

### Technical Objectives

Four technical objectives were addressed in the meeting:

1. Collection and collation of seismic event location calibration information:
    - Current location calibration information at the prototype IDC
    - Seismic event location "ground truth" information in the relevant regions available from open scientific sources and from States Signatories, including "ground truth" information, calibrated regional event bulletins and other data
    - Regionalized velocity models and seismic travel-time data for geographic-specific areas
    - Relevant regionalized tectonic and geologic information for consideration in Release 3 and for operational use
2. Assessing methods for the representation and application of event location calibration information:
    - Procedures currently used at the prototype IDC
    - Slowness and azimuth station corrections
    - Site-specific station corrections
    - One-dimensional travel-time models in combination with IDC standard earth models
    - Interpolation of individual data segments (tapering, boundary fitting, Kriging, etc.)
3. Providing recommendations for the validation and quality assessment of event location calibration data:
    - Current Configuration Control Board practices at the prototype IDC
    - Methods to assess the validity and usefulness of "ground truth" information
    - Quality control methods to be used at the IDC
4. Development of specific recommendations for incorporation into the Release 3 development program:
    - Region-specific location calibration information
    - Geographic limits on use of region-specific location calibration information
    - Methods for operational use of the location calibration information
    - Validation and quality control procedures to be implemented

### *Presentations during the workshop*

For each technical issue, the starting point was an introduction to the present procedures at the prototype IDC. Participants then proceeded to give specific presentations on each subject matter, followed by discussions and suggestions for improvements to current procedures.

### Collection of Calibration Information

Ground truth information is critical to testing and validation of calibration. Several useful databases are available at the prototype IDC in support of calibrations:

- The Reviewed Event Bulletin (REB) provides information for events worldwide within approximately 5 days after events occur.
- The Explosion database contains available information on all the 2041 nuclear explosions worldwide during 1945-1998.
- The Calibration Event Bulletin (CEB) consists of re-analyzed events especially selected from the REB on the basis of the recording quality, location, and magnitude of the events.
- The Ground Truth database includes four categories of events: GT0, GT2, GT10, and GT25, which correspond to location accuracies of 0 km, 2 km, 10 km, and 25 km, respectively.
- The Gamma Bulletin database are contributed by NDCs for events located by national networks. Quality information on locations is sparse in the Gamma Bulletin.

A number of papers relating to the collection of calibration information were presented by participants. Models for regionalization on a global basis were presented and discussed. Specific presentations were made by several experts describing regional velocity models and calibration data for the three general geographic regions being considered initially for calibration in Release 3: North America, Eurasia (Europe and Asia) and Australia.

It was noted that for some regions, information was incomplete or lacking, and the use of default "generic" velocity models for various tectonic regions was discussed in some detail. Valuable new data on ground truth information for seismic events was presented, and will be communicated to the IDC and the prototype IDC. Countries were encouraged to continue to provide relevant calibration data for the purpose of developing accurate seismic travel-time curves for various geographical regions.

The Expert Group on Seismic Event Location has the mandate to collect relevant information from all open scientific sources as well as requesting and compiling such information from all countries participating in the work to develop the IDC procedures. There is a wealth of information that could be relevant for the location calibration problem, and it will be a very large undertaking to assemble and apply essential parts of this information to the IDC processing.

### Application of Calibration Information

The goal of the current work at the prototype IDC is to improve estimates of location uncertainty (error ellipses) as well as to improve location accuracy. Location coverage ellipses are computed based on a-priori estimates of observational error. A-priori observation errors (arrival times, azimuths, and slownesses) are partitioned into measurement error and model error. Measurement error is considered a function of signal-to-noise ratio. Model error is a function of phase, depth, and distance. All corrections to observations (arrival times, azimuths, and slownesses) are also specified with model error.

There is a hierarchy of location calibration parameters. The software can accommodate, 1) slowness and azimuth station corrections as a function of station, phase, slowness, and azimuth, 2) bulk station travel time corrections for each station and phase, 3) one-dimensional regional phase models for each station, and 4) source specific station corrections as a function of station, phase, and source location. Model error must be specified for all such cases.

Reports were presented on a number of modelling studies, some of which showed significant improvement in location precision when applied to test sets of seismic events. For example, one-dimensional regional Pn, Pg, Sn, and Lg travel time curves were shown to provide improvements for the Baltic shield, the Barents region and North America. Three-dimensional models were introduced for North America and Europe and found to provide considerable improvements in location accuracy compared to standard (IASPEI-91) models.

Techniques for improved regional processing using sparse seismic networks as well as improved azimuth determination for regional arrays were presented and discussed. The application of special location techniques such as Joint Hypocentral Determination in a global context was also addressed.

### Validation of Calibration Information

Changes to the Operational System at the prototype IDC are subject to a rigorous review and approval procedure before implementation. A Configuration Control Board (CCB) that consists of senior staff of the prototype IDC is convened as needed to carry out this procedure. A proposal that addresses each of the following issues is required:

- Statement of Objective
- Summary of Proposed Change
- Expected Benefits
- Possible Risks and Dependencies
- Summary of Testing
- Schedule and Plan for Implementation
- Resources Required

The benefits of the change must be demonstrated through both unit testing and integration testing through a testbed system. Metrics have been devised that are appropriate for evaluating new sets of corrections to travel-time, azimuth, or slowness. They require sufficient "ground truth" events to measure the improvement in location and, where appropriate, depth and origin time. It is just as important that the location errors, as expressed for example in confidence ellipses, are realistic as that the locations themselves are improved.

The experience presented by participants included a review of relevant experience from the Experts Group on Screening. The development of event screening criteria for location and depth depends on the accuracy of their measurements and associated uncertainties. Comparisons of REB solutions to local and NDC network solutions indicates that:

- the REB 90% coverage ellipse does not contain the 'true' locations 90% of the time
- the depth uncertainties do not adequately represent the errors in depth

As a consequence the event screening criteria have been tailored to account for the errors in these measurements, resulting in depth and location not being as effective for screening as they could be. To make full use of these criteria, errors in the REB solutions need to be sorted out and the uncertainties minimized. The collection and analysis of calibration events will go a long way in achieving this goal.

### Working Group Discussions

Three Working Groups were established to discuss the technical issues in detail during the meeting:

- Working Group 1: Collection of Calibration Information
- Working Group 2: Application of Calibration Information
- Working Group 3: Validation of Calibration Information

The results of the Working Groups were presented and discussed in a plenary session. These discussions have provided the basis for the recommendations presented below.

#### *Recommendations*

The IDC should locate events accurately, given the limitations of the IMS network and the current scientific knowledge, in support of the requirements for on-site inspection in the CTBT Protocol. The CTBT Protocol provides that the area of an on-site inspection shall not exceed 1000 square kilometers, with no linear distance greater than 50 kilometers in any direction. Therefore, this is the target for location accuracy in the Reviewed Event Bulletin as well as for special event analyses.

The recommendations listed below apply to IMS primary and auxiliary seismic stations. The question of Cooperating National Facilities is not addressed, but such stations could provide important additional calibration information.

Any changes in the parameters or processing algorithms at the IDC will be subject to formal procedures which will be established in the IDC Operational Manual.

### Technical Issue 1: Collection of Calibration Information

#### *General*

1. Regional calibration of the IMS network will be required to achieve a location accuracy of 1000 sq km or better for well-recorded seismic events.
2. Calibration information for this purpose consists of ground truth information plus arrival data and/or waveforms. If the arrival data are not at IMS stations, station coordinates should also be supplied. For location calibration, GT0, GT2, and GT5 data are the highest priority. GT5 should be established as a new category. In general, an effort should be made to collect information for as many seismic phases as possible. Data quality information should be collected along with the ground truth data.
3. The IDC, within its structure, should maintain the calibration databases, coordinate and organize the acquisition of data, including contacts with the NDCs and liaison with non-governmental organizations, obtaining publicly available data, and remaining cognizant with the scientific literature.
4. Encouragement to States Signatories to cooperate in the location calibration of the IMS should be given by the PrepCom. This cooperation should encompass both supplying existing and available data and actively collecting new data through national or multilateral cooperative projects.

*Long Term*

1. Collection of data from the IMS stations and the NDCs for the Calibration Event Bulletin (CEB) should continue indefinitely. The IDC should maintain and update the CEB and make it available to the NDCs. The IDC should also collect ground truth data and organize and maintain it in appropriate databases. The IDC should provide direct access to the calibration and ground truth databases. NDCs should be encouraged to provide ground truth data.
2. The Calibration Event Bulletin should be supplemented by representative, carefully analyzed events from the explosion database, the Ground truth database and the Gamma bulletins. Based on this set of events, an Operational Location Calibration Database (OLCD) should be established (and continually updated). The OLCD should be made operationally available to be used for Joint Hypocenter Determination as required for regular REB production and special event analysis.
3. The ground truth database should be enhanced by collecting information on appropriate mining explosions and earthquakes, as described below. The explosion database should be maintained, updated, and added to as new data becomes available
4. For mining explosions, priority should be given to mines that produce detectable recordings on more than one IMS station. States Signatories should be encouraged to provide accurate timing for such explosions, e.g. by placing a recording instrument close to the mine, and to cooperate with the mining industry in the country to obtain details of charge size, configuration, etc., for explosions that are seen at more than one IMS stations.
5. For earthquakes, the IDC should seek to obtain publicly available information from aftershocks and dense network deployments, e.g. IRIS PASSCAL experiments, for earthquake of location quality of at least GT5 and of magnitude 4 and above. Earthquakes recorded by IMS stations are the most desirable.
6. The IDC should make an inventory of seismic refraction data, its nature and quality. The States Signatories should be encouraged to make appropriate data available to the IDC for location calibration through national or cooperative projects.
7. Even with these data collection efforts, it is not expected to be possible to calibrate the IMS to provide an accuracy of 1,000 sq km error ellipse area or better in all parts of the world. The only additional source of information is calibration explosions, and such future chemical explosions are encouraged. Explosions on land or in water are both suitable for location calibration; explosions in water are particularly effective in terms of charge size

*Short Term*

1. Collecting location calibration information is an important part of the IDCs work.
2. A transition plan needs to be developed to move the calibration databases and their operation and maintenance from the prototype IDC to the IDC. The IDC should identify the appropriate resources that will be needed both for the transition and for continuing operations. Formal collaboration and cooperation between the appropriate groups in the IDC and the prototype IDC will be needed.

3. Under present plans, the databases will be delivered in mid-1999 to the IDC. Upon the delivery, the IDC should start reanalyzing the CEB events that need to be reviewed. Data should be exchanged between the prototype IDC and the IDC in the transition period.
4. An initial version of the Operational Location Calibration Database, intended for operational use in Joint Hypocenter Determination as required for regular REB production and special event analysis, should be developed.
5. Recognizing the importance of auxiliary station data in locations, it is technically desirable to connect the auxiliary stations to the IDC as soon as possible.
6. A review of the scientific literature to identify appropriate ground truth data should be conducted.
7. A technical advisory group should be formed to identify appropriate sources of calibration information.
8. States Signatories should be encouraged to fund the collection of calibration information, including cooperative efforts.

### Technical Issue 2: Application of Calibration Information

*General*

1. Seismic event location at the IDC will be made by developing a global geographic grid system, with station-specific calibration information for each grid point. This means that for each seismic station in the IMS, an associated grid will be implemented with values in each grid point corresponding to the best available phase information (travel times, azimuths, etc.) for regional as well as teleseismic phases.
2. Initially, this grid system may be spaced by 0.5-1 degree, but it could eventually be much denser. While the grid should in principle be equidistant on a global basis, it would in practice be advantageous to make the grid system denser in certain regions, for example, regions where the geology and tectonic structure is complex.
3. The grid system would encompass zero (or shallow) source depth on a global basis, and would be supplemented by grid systems at various depth intervals to allow for optimum processing in regions where deep earthquakes are known to occur.
4. A "generic" travel-time table (e.g. the IASPEI-91 table) is used to compute default travel times for each station-grid-phase combination. As regional velocity models are developed and validated, these models would be used to calculate refined travel times for the appropriate paths. These calculations could be done by modelling in one, two or three dimensions, and the guiding principle would be to include at any time the best validated model available.
5. In addition to these model-based data, a number of actually observed travel times for various phases, using validated calibration events, would be included, and would enable even more precise corrections to be made to the grid surface for events near these calibration sources. The global grid data could thus be continually improved as such events are accumulated. An interpolation mechanism, as well as a series of consistency checks, should be implemented to ensure that these new data retain consistency with the overall models.

6. Updates to the global grid should be made at regular intervals, and should be accompanied by extensive validation and evaluation to verify that they actually improve the location performance of the system.
7. The IDC and the prototype IDC should make all the calibration information openly available to participating National Data Centers (NDCs), so that each NDC can repeat the calculations and verify the results. Furthermore, a record of historical changes should be kept to enable changes to the calibration grid to be traced over time.

*Travel-time models*

1. The general goal should be predicted travel-time, azimuth, slowness, and a-priori uncertainties for each IMS station or array specified as a function of phase, source latitude, longitude, and depth. This should include regional and teleseismic phases. Resolution should allow for 0.5 to 1.0 degree sampling worldwide with embedded regions of higher resolution.
2. In order to reproduce locations, predicted travel times, slownesses, azimuths, and a-priori uncertainties (or corrections with respect to a standard one-dimensional model) should be available to users outside the IDC either in databases tables or through Web-pages.
3. While short term activities may emphasize calibration of regional phases it should be recognized that improved location in many regions depends upon improvements in both regional and teleseismic calibration.
4. Consistency of regional and teleseismic corrections will ultimately depend upon development of a single consistent three-dimensional velocity model for regional and teleseismic propagation.
5. A reasonable goal is to provide predicted travel times, azimuths, and slownesses with uncertainties better than the equivalent uncertainty of +/- 1 second for teleseismic P-waves.
6. Methods for development of travel time models may include interpolation of empiricial travel times from clustered or master events, or development of regional one-, two- and three-dimensional models (tomography, surface waves, deep seismic sounding, etc.) and tectonic regionalization. Model based and regionalization approaches must be validated by independent data sets that test the extension of the model beyond the limits of the original calibration data and phases to the intended phases and regions of applicability.

*Procedures*

1. The best available validated and tested model (for each region, station, or phase) should be included in each system release. The models should not be considered constant and static.
2. The calibrated location models should be updated as better validated models are approved for each region, station, or phase. Location calibration activities should continue indefinitely. Costs of activities should be shared by participating States and CTBTO to facilitate the process of developing, testing, and validating location models in all regions.
3. As location procedures (predicted travel times etc.) are updated, the historical set of procedural changes should be documented to permit unambiguous reproduction of old and new locations.

4. National Data Centers and other parties should be encouraged to provide calibration data, validation data, and cooperative proposals for location calibration. Proposals should be open and transparent for review and comment by outside parties. The US/RF cooperative effort is viewed as an excellent example of a cooperative effort that may include both calibration proposals (new travel time tables) as well as calibration data (original ground truth origins and arrival times) and validation data (additional ground truth origins and arrival times).
5. Calibration model development and testing/validation should be conducted with independent data sets.

### Technical Issue 3: Validation of Calibration Information

*General*

1. A Configuration Control Board (CCB), similar in function to that currently at the prototype IDC, is an appropriate mechanism to validate calibration information and to define rules for acceptable ground truth data. The Provisional Technical Secretariat should establish a Configuration Control Board for the IDC.
2. A Location Calibration Board (LCB) should be established, with the responsibility to oversee the location calibration process. This Board should assess proposals for and recommend updates of relevant parameters and region-specific corrections, and forward its recommendations to the CCB for implementation. The Board should enlist the assistance of experts in each region being considered. It may be appropriate to make proposals related to a calibration of a particular region available to NDCs in that region for comments in advance.
3. Unit test metrics for the validation of proposed improvements should be primarily based upon sufficient relevant Ground Truth (GT) event locations, and should include the following requirements:
    - The median mislocation of GT events should be significantly reduced
    - Mislocation should be reduced by 20% or more for the majority of events
    - Median confidence ellipses should be reduced in area, and the coverage (% of GT events lying within the confidence ellipse) should be the same or better
    - Confidence ellipses should be reduced by 20% or more for the majority of events
    - Fit, as expressed by residuals or their variance, should be similar or better
4. For each area studied, a set of ground truth events, the majority of which should be located by sufficient (for location) IMS stations, should be established. Historic events recorded by sufficient surrogate IMS stations may be included, but should comprise less of half the events used. Any validation should use a set of events that do not include those from which the proposed corrections were determined.

*Data Base Development and Validation*

1. Proposed new calibration parameters should be subject to integration testing in an online (testbed) system with real time data for a period of more than one week, and for at least long enough that the corrections are applied to some events and location improvements demonstrated.
2. Any change in software or parameters that affect the location of events should be approved by the CCB. A complete record of changes in both software and calibration

corrections relevant to location of events should be maintained at both the prototype IDC and the IDC.

3. The Location Calibration Board should recommend criteria for designation of ground truth events and related phase data, and forward these recommendations to the Configuration Control Board for approval. For GT0 and GT2 events, such criteria should include supporting references and/or documentation for each event. For GTx where x>2, specific criteria on station coverage should be met or documentation should be provided. Criteria should also be established for the use of non-IMS stations as surrogates for IMS stations.
4. Responsibility for the Calibration Events Database (CEB) will be transferred from the prototype IDC to the IDC in mid-1999. The IDC should maintain and update the CEB, including carrying out additional waveform analysis, and make it available to NDCs and the prototype IDC. Both the IDC and the prototype IDC should collect ground truth data and exchange it on a regular basis.
5. The IDC and the prototype IDC should provide direct access to the archive database, including calibration and ground truth databases. Full responsibility for calibration work and associated databases should be assumed by the IDC after the final software release is delivered to the IDC by the prototype IDC. NDCs should be encouraged to provide ground truth data, accompanied by supporting documentation.
6. Statistics on the Calibration and Ground Truth databases should be reported to NDCs. Such statistics should include the numbers of events added and analyzed, and the geographical coverage of these databases.
7. CCB proposals and minutes, and related technical reports, should be made available to NDCs, preferably through a convenient Web page mechanisms. An annual report should provide metrics on mislocation and confidence ellipse size and coverage on a region by region basis, taking into account the most recent ground truth information.
8. Expenses associated with the validation of calibration information and results are to be covered by the NDCs and the prototype IDC on a voluntary basis, but some work needs to be funded by the CTBTO if full global coverage is to be accomplished.

### Technical Issue 4: Specific Procedures for IDC Release 3

1. In the work towards developing IDC Release 3 software, the general recommendations described above concerning the collection, application and validation of calibration information should be taken into account.
2. The infrastructure being established for location calibration will enable systematic, ongoing improvements and updates to be made for all areas of the world. IDC Release 3 should begin this development by initially including regional calibration information for North America, Eurasia (Europe and Asia) and Australia.
3. For each region, validated travel-time and velocity models should be incorporated as available. For subregions where no specific such information is available, a generic velocity model (e.g. IASPEI-91) should be used.
4. The best available validated and tested model for generating travel times should be used for each region to be calibrated.

5. Regional calibration information should be implemented only after the corresponding improvements in location accuracy has been documented in accordance with criteria specified in the recommendations provided above for the validation section.
6. An initial Operational Location Calibration Database, intended for operational use in Joint Hypocenter Determination as required for regular REB production and special event analysis, should be delivered as part of Release 3.
7. A transition plan should be established for transferring responsibility to the IDC from the prototype IDC in connection with the Release 3 developments. This plan should incorporate a schedule for the establishment of appropriate infrastructure at the IDC, such as a Configuration Control Board and a Location Calibration Board.
8. Signatories are requested to provide, as early as possible, all relevant location calibration information that they may have available for the regions listed in item 2 above. Experts from Signatories are encouraged to work closely with the prototype IDC, the IDC and the coordinator to assist in the collection and validation of data. This new calibration information should be included to the maximum extent possible in the IDC Release 3 applications software.
9. Additional slowness-azimuth station corrections should be included in Release 3, and such corrections should as a minimum be developed for all existing primary seismic stations.
10. All existing 3-component primary stations should be calibrated with respect to the orientation of the components for Release 3.

**Frode Ringdal**

*Reference*

Technical Documentation from the Workshop on IMS Location Calibration, Oslo, Norway 12-14 January 1999, NORSAR, Kjeller, Norway

## 6.2 Seismic Location Calibration for the Barents Region

*Paper presented at the Oslo workshop 12-14 January 1999*

### *Abstract*

A crustal velocity model has been developed for Fennoscandia, the Baltic shield and adjacent areas. This model represents a simplified average of various models developed for parts of this region. We show that P-wave travel times calculated with this model provide an excellent fit to observations at the Fennoscandian, KRSC and IRIS station networks for a set of seismic events with known or very well-constrained locations. The station-event paths cover large parts of Western Russia and the Barents Sea, thus indicating that this model, which we denote the Barents model, is appropriate for this entire region. We show by examples that significant improvements in event location precision can be achieved compared to using the IASPEI model. We finally use the Barents model to calculate locations of some recent small seismic events in the Novaya Zemlya region of interest in a CTBT monitoring context.

*Key Words: Location, Crustal models, Travel-times, Calibration*

### *Introduction*

Kola Regional Seismological Centre (KRSC) of the Russian Academy of Sciences have for many years cooperated with NORSAR in the continuous monitoring of seismic events in North-West Russia and adjacent sea areas. This work has been based on a network of sensitive regional arrays which has been installed in northern Europe during the last decade in preparation for the global seismic monitoring network under a comprehensive nuclear test ban treaty (CTBT).

KRSC began its seismic network processing in 1982. Initially, this was done primarily by processing data from the KRSC network of seismological stations, but in recent years the analysis has been supplemented with data from IRIS stations (KBS, LVZ, KEV, ARU, ALE, NRI etc.) and the Scandinavian seismic arrays (ARCESS, SPITS, FINESS, HFS, NORESS) for analyzing of the most interesting events.

As part of a project aimed at improving seismic monitoring capabilities under a CTBT, Kola Regional Seismological Centre (KRSC) and NORSAR are conducting a comprehensive study of seismicity, seismic wave propagation and seismic event location in the Barents region. For Fennoscandia, excellent velocity models have previously been developed, and one such model is currently used at the prototype IDC. The velocity model in use at KRSC for the past several years (the Barents Model) is very similar to the model used at the prototype IDC, and is given in Table 6.2.1. In this study, we have studied the improvements that can be achieved when applying the Barents model to seismic events in NW Russia and the Barents Sea region, when compared to the IASPEI 91 model.

### *Data Base*

As a data base for this study we have selected seven well-recorded events in the region, as listed in the first part of Table 6.2.2. For three events, we have been able to obtain ground truth information, as specified in the table. This includes the calibration explosion in Khibiny on 29 September 1996 (Ringdal et al, 1996) and the nuclear explosion near Arkhangelsk on 18 July 1985, for which both the exact location and origin time is known. The Solikamsk event on 5

January 1995 was caused by a collapse associated with a mine, and we have provided an exact location. For four events in Table 6.2.2 we have recomputed the location using available stations in the GSETT-3 network, the Kola network and the IRIS network.

In addition to these seven events, we have provided in the last part of Table 6.2.2 ground truth locations for two events on 28 May 1990 further south in the Ural Mountains. These two events are associated with rockbursts and were large enough ($m_b$=4.4) to be recorded teleseismically. These events are listed for reference purposes, and were not used in the analysis described in this paper. We consider that this information may be important for future studies aimed at developing appropriate velocity models for the southern Urals.

### *Station Network*

The regional seismic network in the Kola Peninsula currently comprises 7 seismic stations, as described by Kremenetskaya and Asming(1999). For the events during 1995-96 in the present study, only those stations with digitally recording equipment have been used. In addition, several stations in Fennoscandia, some IRIS stations, as well as stations contributing to the PIDC have been used. We have only used data from stations within an epicentral distance of approximately 30 degrees for each event, and concentrated on station-epicenter combinations that cross parts of the Barents Region. The station network used in this study together with the station-event paths is shown in Fig. 6.2.1.

### *Barents Velocity Model*

The Barents velocity model in Table 6.2.1 is a crustal model that has been in use at KRSC for many years. It represents a simplified average over various models developed for parts of Fennoscandia and NW Russia. Much of these developments are based upon profiles from explosion seismology in this area. We also note that the Barents model is similar (although not identical) to that described by Mykkeltveit and Ringdal (1981), and it is also quite close to the model currently used at the prototype IDC.

In the data analysis of this paper, it is an important point to make that the model is derived independently of the data. Therefore, the fit of the data to the model will be a true validation of how the model works in practice for this region.

### *Data Analysis*

Using the Barents model, we have located all the reference events apart from those with ground truth information, and calculated the estimated P and S-phase arrival times using the Barents model. The results are shown in Figs. 6.2.2 and 6.2.3, both for the ground truth events (triangles) and the calculated solutions (circles). The Barents model as well as the IASPEI-91 model are shown for comparison. It is evident that the Barents model provides the best fit for the ground truth data, and that this model in fact represents the data very accurately. By definition, the calculated data points will fit the Barents model better than the IASPEI model, but more importantly, it seems to be a good consistency with the Barents model over the entire set of observations, both for P and S phases. Our results therefore indicate the validity of the Barents model for the entire region under consideration.

*Location Experiments*

We have used the two models to calculate epicenters for those events with known ground truth information, and compared the results. Two examples are shown in Figs. 6.2.4 and 6.2.5. For the 18 July 1985 Arkhangelsk explosion (Fig. 6.2.4), the location errors were 17.2 km (IASPEI 91 model) and only 4.4 km (Barents model). For the 5 January 1995 event (Fig. 6.2.5), the errors were 19.5 km (IASPEI 91 model) and 8.5 km (Barents model). It is also noteworthy (although not shown on the figures) that the USGS/ISC global network location errors for both events were about 10 km, thus the regional model shows location improvement in spite of using only a fraction of the available stations.

To validate the model further we have re-located several previous seismic events for which we do not have ground truth, but which are located very accurately by the joint hypocentral determination method. (see Table 6.2.3). As can be seen from this table, and further illustrated in Fig. 6.2.6, the locations by the regional network are within 5-10 km of the locations obtained by joint hypocentral determination (JHD) using world-wide data.

The model therefore seems to be quite adequate for event location in the Barents region. In addition, the documented consistency with precise global network locations is especially important since we are able to use the network to locate regional events far smaller than those which can be detected teleseismically. For example, the KRSC network was the only network with sufficient data to locate reliably the smallest recorded nuclear explosion on the Novaya Zemlya test site ($m_b$=3.8) on August 26, 1984 (Mikhailov et. al., 1996). The result is shown in Fig. 6.2.7. Our estimated epicentral coordinates of this explosion are 73.326N, 54.763E, thus placing the event within the group of explosions shown in Fig. 6.2.6. While we have no other network solution with which to compare our result, we believe this explosion to be rather accurately located.

We have finally used the Barents model to calculate locations of some recent small events near Novaya Zemlya, of interest in seismic monitoring. These events, which was not included in the paper by Ringdal (1997), are shown in Figs. 6.2.8-6.2.10 and comprise a small seismic event near Novaya Zemlya on 23 February 1995 and the two seismic events in the Kara Sea on 16 August 1997. While we do not have ground truth reference for any of these events, we observe that our location of the first event on 16 August 1997 is close to the location published by several other authors (e.g. Ringdal et al, 1997). The second event on that day is less accurately located, since it was much smaller. Our estimated location, based on three station, is about 30 km East of the first event. However, based on a detailed analysis of the signals recorded at Spitsbergen and Amderma, we believe that the two events that day were approximately co-located. The event on 23 February 1995 has to our knowledge not been reported before, and it is difficult to ascertain the accuracy of this location. We note that in all of these location experiments, we have restricted the solution to zero depth. It is interesting to notice that both the 23 February 1995 event and the first event on 16 August 1997 had estimated origin times very close to the minute (using the Barents model and a restricted (zero) depth). This might indicate a man-made source, but we do not wish to speculate on this issue.

### *Effects of Reading Errors*

In practical IDC operation, the location accuracy will be determined not only from the quality of the velocity model, but also from the quality and accuracy of the phase readings used in the location algorithm. We have carried out a preliminary study, using a set of 52 Khibiny explosions detected and located by at least 4 stations (with P detections) in the GSETT-3 network. All 52 events have known ground-truth location. We used phase readings exactly as provided in the PIDC bulletin (REB). Most of these readings are based on automatic timing, and have in many cases been adjusted by the PIDC analyst. In some cases, the analyst have added phase readings not detected automatically.

For each event, we compared locations using the IASPEI model with locations based on the same observations, but with the Barents model. To obtain a simple measure of the results, we calculated the percentage of these 52 events that were located within 18 km of the true epicenter. It should be noted that a circular area of 18 km represents an area of approximately 1000 square km, which is a generally accepted target for location precision in the GSETT-3 network.

It turned out that 21% of the locations using the IASPEI 91 model had errors of less than 18 km, whereas the number of such events was increased to 37% when using the Barents model for the same data. However, we observed that the S-residuals were rather large with the Barents model, and therefore attempted to locate the events using the P-phase data only (with the Barents model). This resulted in 62% of the events being located with an error of less than 18 km, which is a significant improvement over both of the other approaches. It appears from this result that the S-phase readings used in the GSETT-3 bulletins might be less accurate than desirable. The reasons for this is unknown, but will be further investigated.

### *Conclusions*

We conclude that the Barents model is appropriate not only for Fennoscandia, but for the entire Barents region from Spitsbergen to Novaya Zemlya, and also for northwestern Russia. Use of this model would be expected to improve location accuracy considerably compared to the use of IASPEI-91, especially when both P and S phases are used in the location procedure.

We have also observed in this paper that in the absence of a well-calibrated velocity model, it might seem preferable to make epicenter estimates based on P-phases only, since these location estimates are less sensitive to model errors than locations based on a combination of P and S phases. However, it must be noted that the S-phases, even in the absence of a good velocity model, do place important constraints on the distance to the epicenters. The use of S therefore in many cases reduces the likelihood of gross error, which might occur if there are only few P-readings with poor azimuthal distribution. We plan to conduct more detailed studies of this problem in the future.

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### Table 6.2.1: Barents Regional Velocity Model

| Depth (km) | $V_P$ (km/s) | $V_S$ (km/s) | Comment |
|---|---|---|---|
| 0-16 | 6.20 | 3.58 | |
| 16-40 | 6.70 | 3.87 | |
| 40-55 | 8.10 | 4.60 | |
| 55-210 | 8.23 | 4.68 | |
| >210 | | | Same as IASPEI-91 |

### Table 6.2.2: Calibration Events — Barents Region

| Region | Date | Origin time | Latitude (N) | Longitude (E) |
|---|---|---|---|---|
| Arkhangelsk** | 18.07.1985 | 21.15:00.3 | 65.9939 | 41.0381 |
| Solikamsk* | 5.01.1995 | 12.46:02.1 | 59.59 | 56.80 |
| NW from Spitsbergen | 26.04.1995 | 8.55:59.9 | 85.128 | 8.58 |
| Zapolyarny | 7.06.1995 | 11.09:42.7 | 69.43 | 30.835 |
| Barents Sea | 11.06.1995 | 19.27:14.0 | 75.745 | 34.727 |
| Novaya Zemlya | 13.06.1995 | 19.22:39.0 | 75.175 | 56.627 |
| Khibiny** | 29.09.1996 | 6.05:46.19 | 67.675 | 33.728 |
| *Additional ground truth information:* | | | | |
| Ural Mountains* | 28.05.1990 | 00.35:50.0 | 55.17 | 58.72 |
| Ural Mountains* | 28.05.1990 | 02.41:27.0 | 55.17 | 58.72 |
| *) *Known location*<br>**)*Known location and origin time* | | | | |

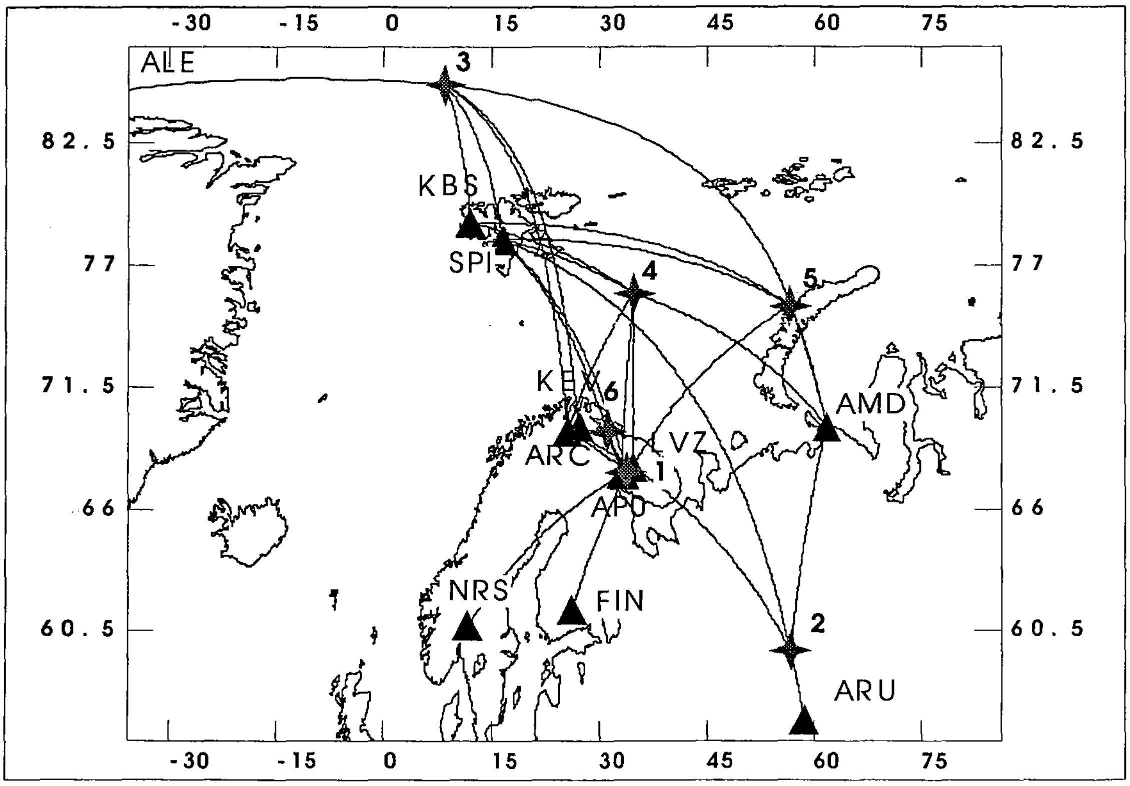


*Fig. 6.2.1. Map showing the calibration events and the station-event paths forming the data base for this study.*

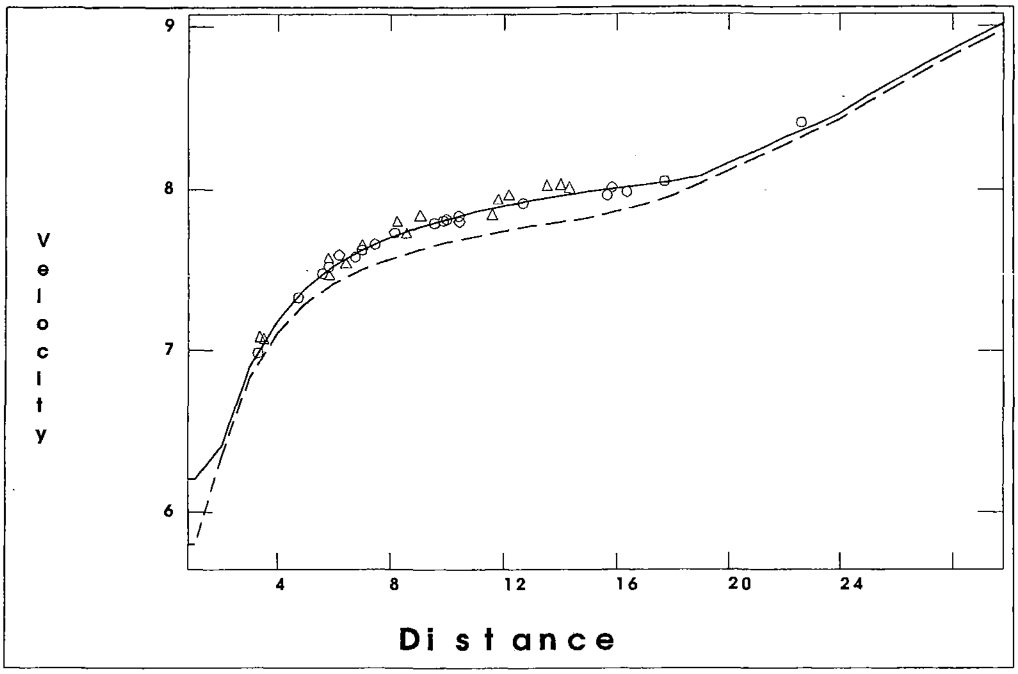


*Fig. 6.2.2. Observed P-wave velocity as a function of epicentral distance for the events in the data base. Ground truth observations are shown as triangles, whereas the circles represent observations using calculated epicenters. The Barents model (solid line) and the IASPEI-91 model (stippled line) are shown for comparison. See text for details.*

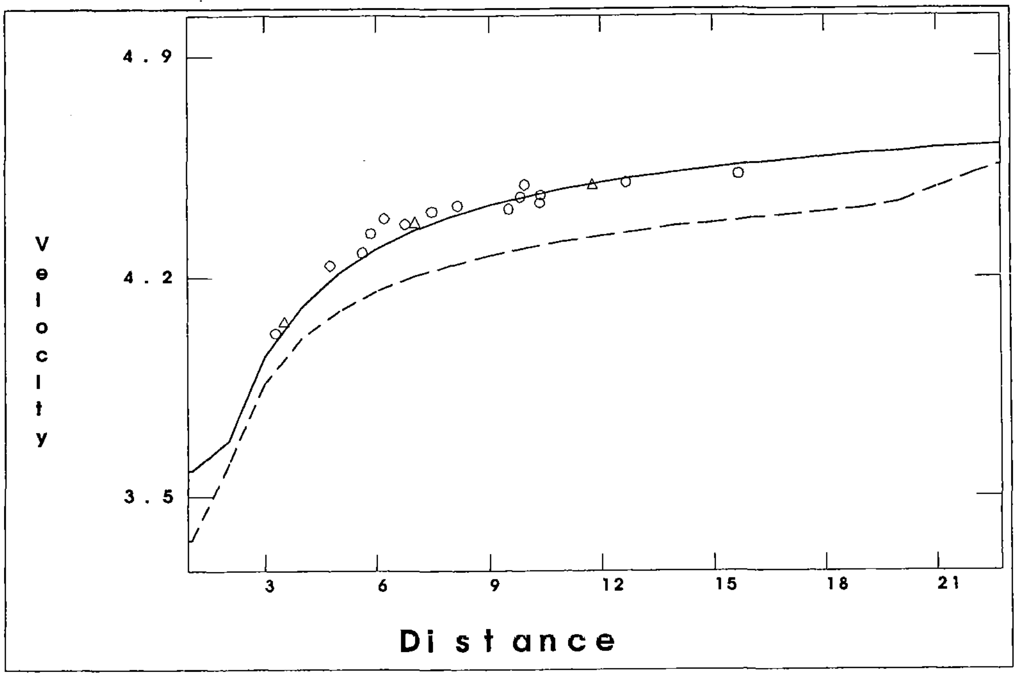
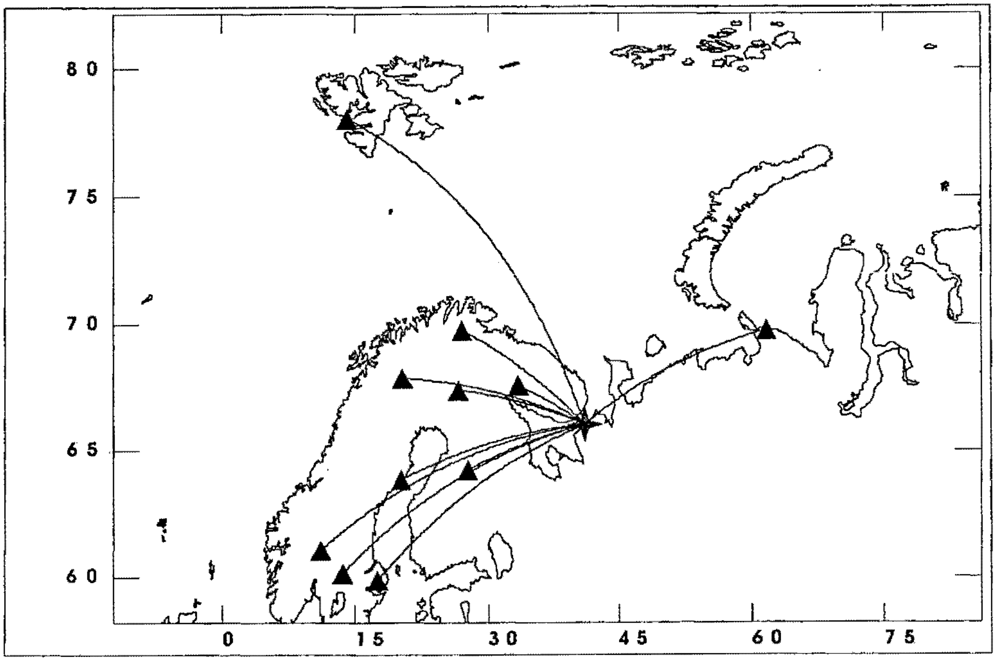


*Fig. 6.2.3. Observed S-wave velocity as a function of epicentral distance for the events in the data base. Ground truth observations are shown as triangles, whereas the circles represent observations using calculated epicenters. The Barents model (solid line) and the IASPEI-91 model (stippled line) are shown for comparison. See text for details.*



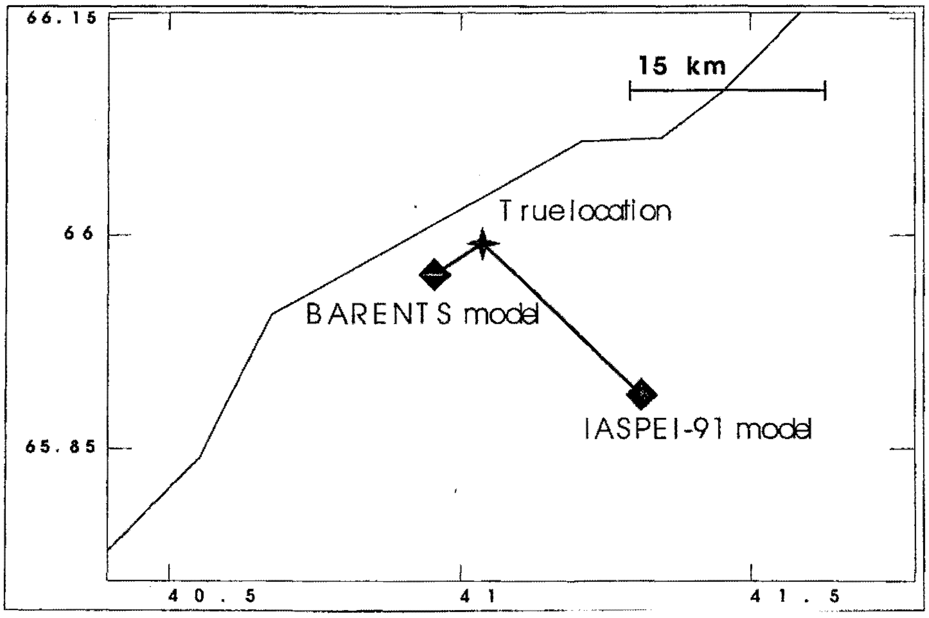


*Fig. 6.2.4. Location comparison using the Barents and IASPEI-91 model for the 18.07.85 nuclear explosion near Arkhangelsk. The stations used in the location procedure are shown separately.*

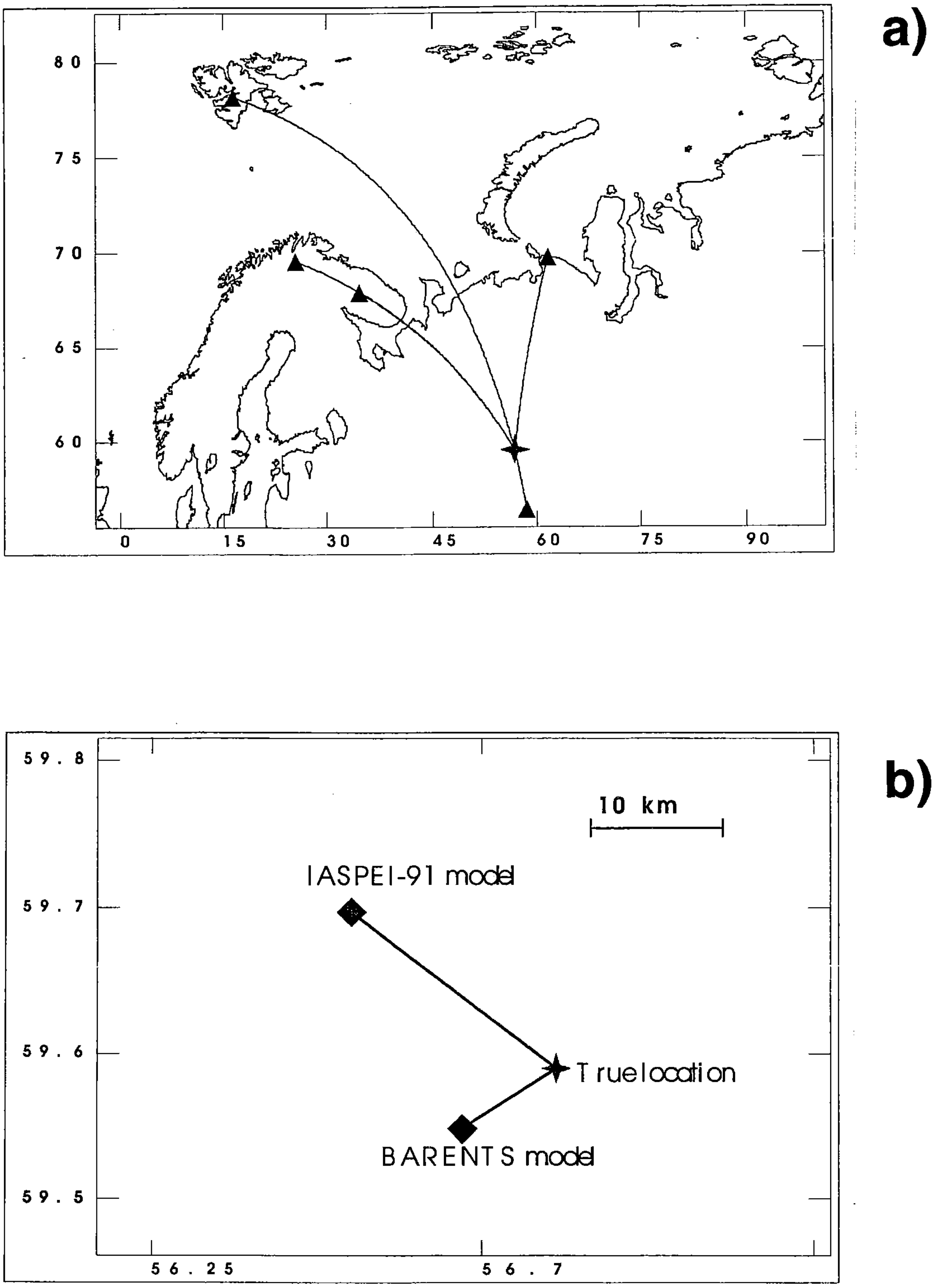


*Fig. 6.2.5.Location comparison using the Barents and IASPEI-91 model for the 05.01.95 mine collapse near Solikamsk. The stations used in the location procedure are shown separately.*

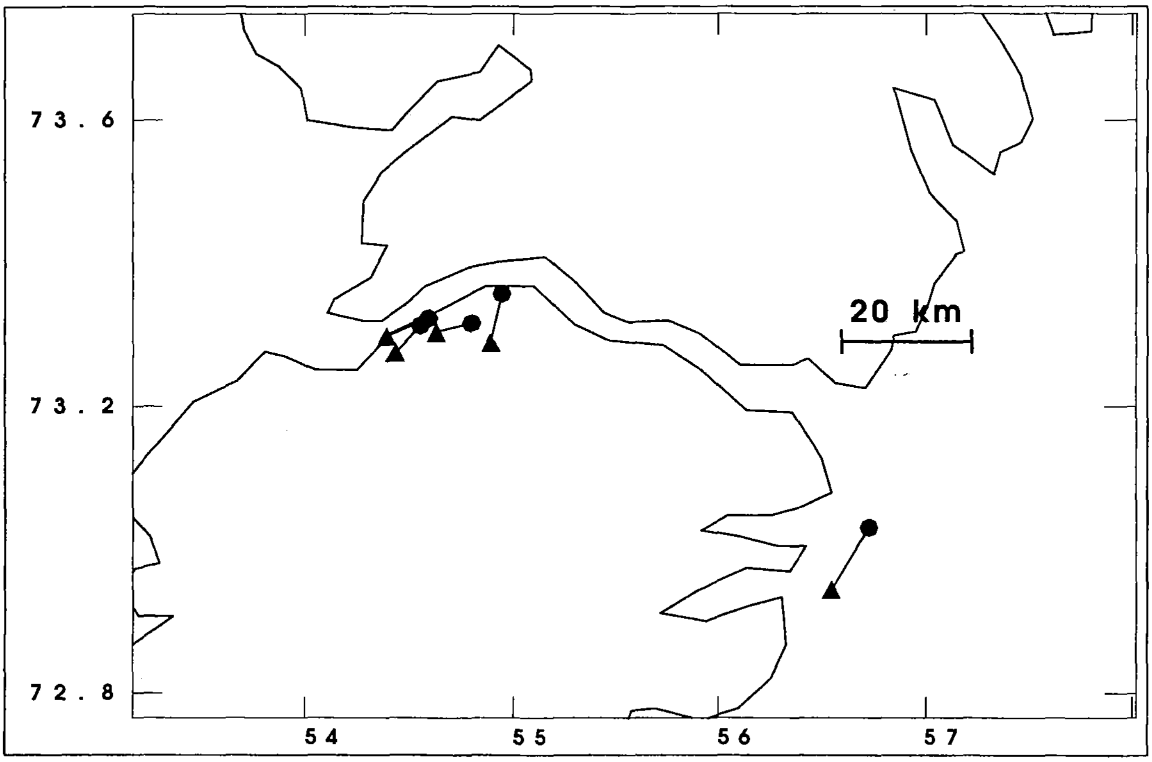


*Fig. 6.2.6. Location comparison of JHD epicenter estimates using a global network and regional location estimates using the Barents model with a regional network. The figure corresponds to the data in Table 6.2.3.*

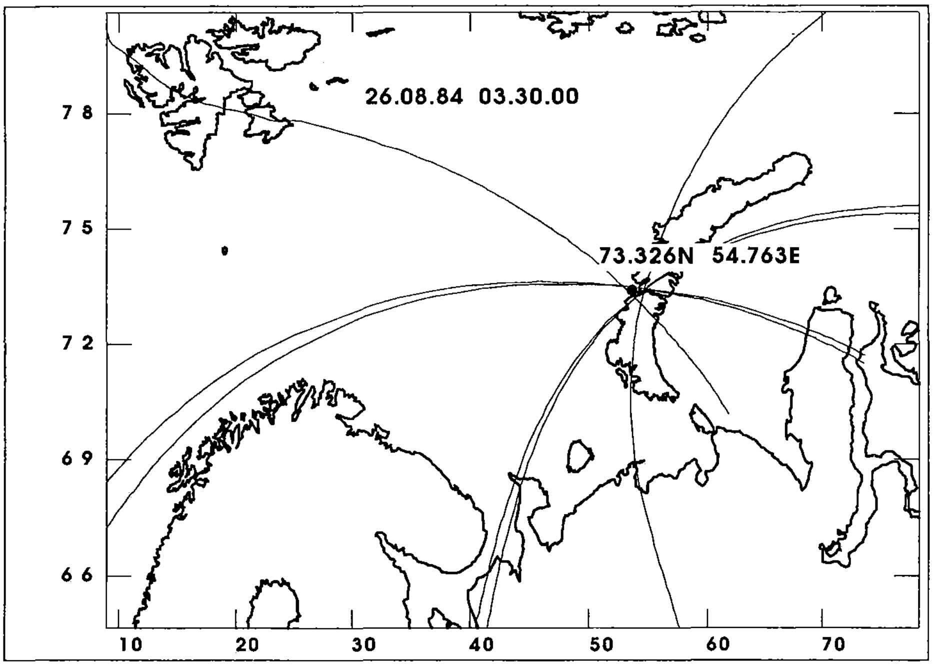


*Fig. 6.2.7. Location of a small nuclear explosion on Novaya Zemlya, using the Barents model with a regional network.*

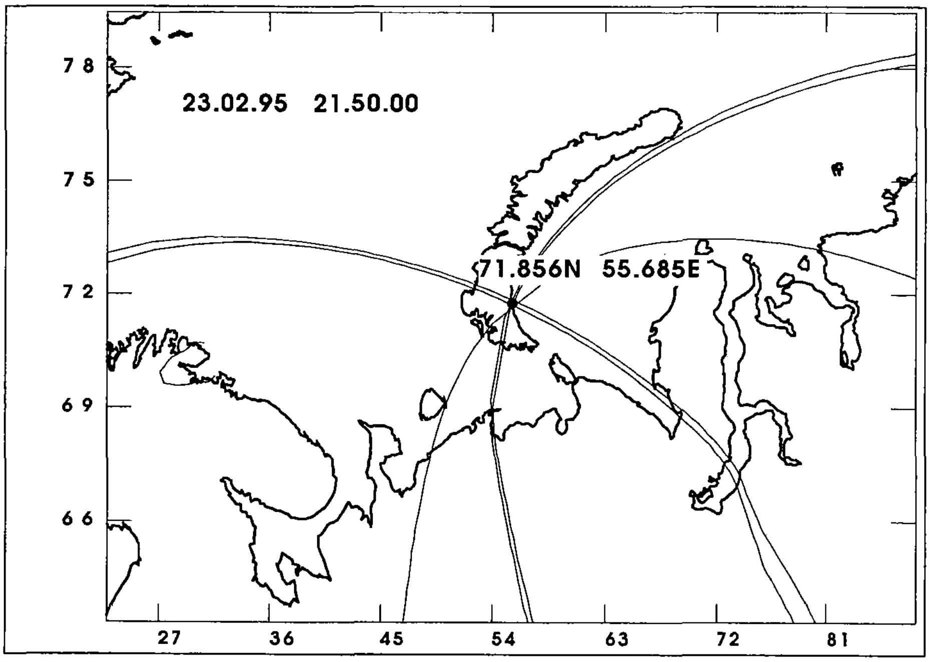


*Fig. 6.2.8. Location of a small seismic event on 23 February 1995, using the Barents model with a regional network.*

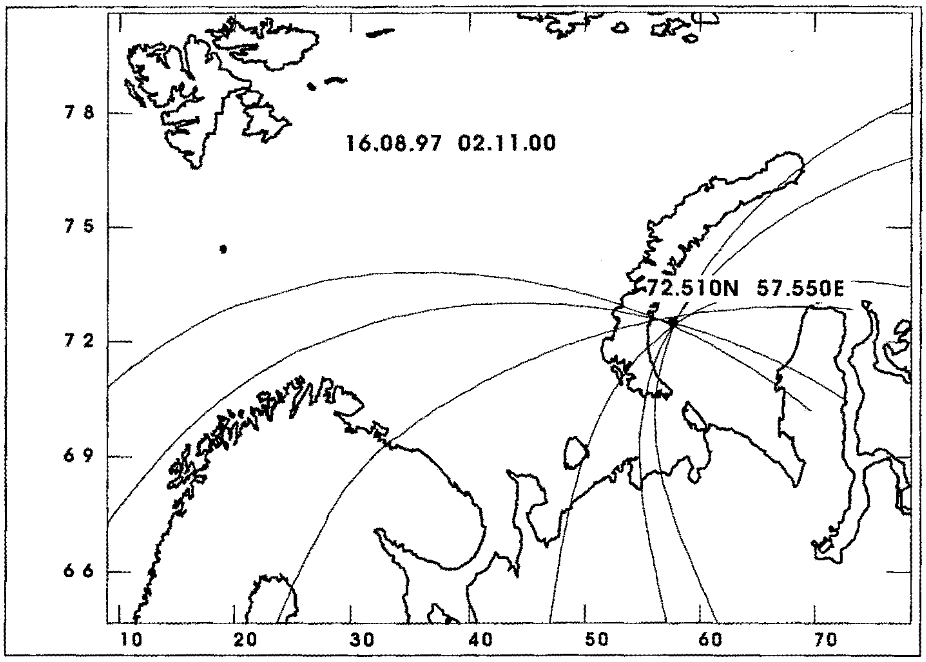


*Fig. 6.2.9. Location of the first seismic event on 16 August 1997, using the Barents model with a regional network.*

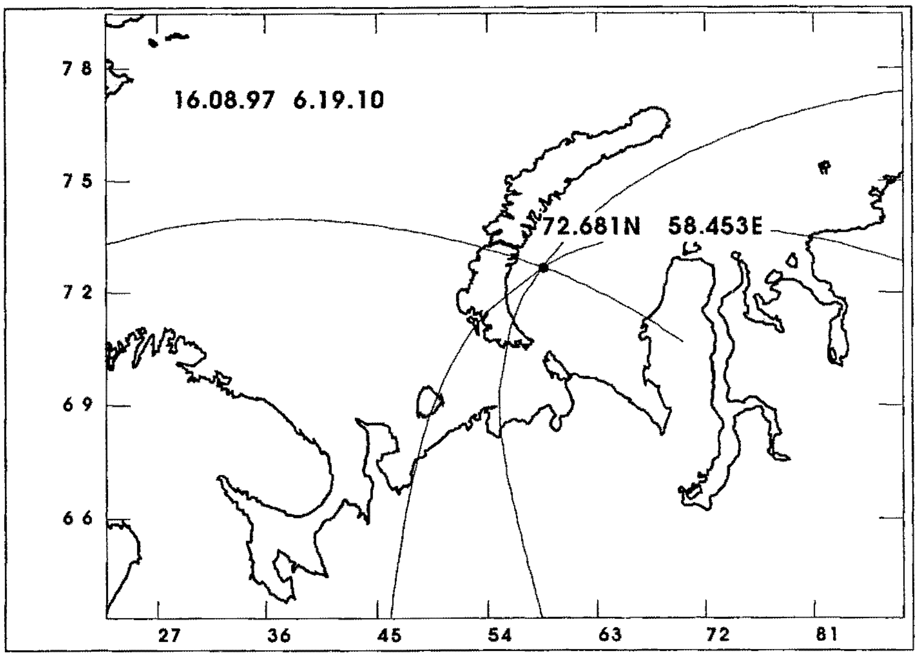


*Fig. 6.2.10. Location of the second seismic event on 16 August 1997, using the Barents model with a regional network.*

## 6.3 Monitoring of the European Arctic Using Regional Generalized Beamforming

### *Introduction*

Since 1 January 1991 the Generalized Beamforming algorithm (GBF) has been running at NORSAR to provide automatic phase associations and event locations from the detection data of the regional arrays (Ringdal and Kværna, 1989). As of February 1999, data from NORES, ARCES, FINES, HFS, GERES, and the Apatity array were jointly processed, using a grid system as shown in Fig. 6.3.4.

In order to efficiently include data from the array at Spitsbergen (SPITS), there was a need to revisit both the signal processing of the individual arrays and the GBF software with respect to functionality, parameter setting and operational stability. The station locations and the new grid system is shown in Fig. 6.3.6. Different from the other arrays recorded at NORSAR, SPITS is located close to a region with relatively high natural seismicity. In addition, the glaciers and mines of Spitsbergen occasionally create a very large number of signals (several thousand per day) which creates problems for both the signal processing (DP/EP) and the automatic phase association process (GBF).

In this contribution, we will first summarize the improvements made to the signal processing of the different regional arrays. This will be followed by a description of the enhancements made to the GBF method. Finally we will illustrate the overall effects of the changes made, in particular resulting in a much improved monitoring capability for the European Arctic.

### *Improved detector and f-k recipes*

During the last years several improvements in the automatic data processing for the regional arrays were developed. These new f-k recipes and detector modifications are since 10 April 1999 implemented in the daily routine analysis at NORSAR and are used for the expanded and improved GBF processing. The following main modifications were included in the routine processing:

### *The detector upgrade for 6 arrays*

Natural seismicity in particular can produce S onsets with relatively small radiated SV energy and the more energetic radiated SH component is more difficult to detect on vertical sensors. Therefore the concept of coherent horizontal beams was developed and extensively tested for regional arrays with more than one 3-component sensor (Schweitzer, 1994). Such detection beams have been implemented for three regional arrays (ARCES, GERES, and NORES). This significantly increased the number of S-phase observations.

The optimized detector recipes for the Spitsbergen array SPITS (Schweitzer, 1998) were developed with special consideration for the low velocities in the sediments below the array. In addition, the high local seismicity due to movements in nearby glaciers and mining induced seismicity required a set of beams with very low velocities. These improvements were necessary before SPITS could be used in the GBF process.

Based on the experience with SPITS, similar detection recipes were developed for the Apatity array (APA) and Hagfors (HFS), and implemented in the automatic processing.

### *The f-k analysis upgrade*

After upgrading the detectors for 6 out of 7 regional arrays, the automatic parameter extraction for each detected onset was also changed and improved. Based on experience gained from the four classical regional arrays ARCES, FINES, GERES, and NORES (Schweitzer, 1994), the f-k analysis recipes were optimized for each array individually. Most important was the development of an algorithm to find an optimal length and the best positioning of the time window used for the f-k analysis.

For GERES, and more importantly for SPITS, it became helpful to correct for elevation differences within the array site during the f-k analysis. The correction for elevation differences was also useful for beamforming prior to measuring the amplitude of the onset.

The numerous Pg and Rg observations at SPITS require additional data processing. The problem is that we observe an overlap between the apparent velocities of Pg and Sn, and that we observe very small apparent velocities for Rg onsets from events at close distances. These Rg phases can be erroneously interpreted because they tend to produce large energy at the side lobes of the SPITS array transfer function. Following the experience with similar effects for the Matsushiro array (MJAR) in Japan (Schweitzer, 1997), a widely optimized set of rules with several f-k analyses for the same detection was developed to estimate apparent velocities and back-azimuths at SPITS (Schweitzer, 1998).

The experiences with these arrays were also used to optimize the signal processing for APA and HFS, so that since 10 April 1999 all regional array data at NORSAR are analyzed with the new processing algorithms.

### *Preprocessing of detection data*

To detect both the P- and S-phases from very local events (within 30 km of the arrays), we have changed the detector recipes for APA, HFS, and SPITS, such that detections now can be reported with time differences down to 0.5 seconds. A side effect of this is an increased number of detections in the coda of regional and teleseismic events. To reduce the number of coda detections, the preprocessor first merges detections that are very close in time (within 2 seconds) and that have similar slowness estimates (azimuth and apparent velocity).

In order to avoid false phase associations by the GBF method, it is important to place restrictions on the use of detected signals. E.g., if the f-k analysis of a given signal at ARCES results in a confident apparent velocity estimate of 7.2 km/s, we can assume that this is not a teleseismic P or a regional S-type phase (Sn, Lg, Rg). If the phase possibly is a Pg, we will restrict the corresponding event location to a 0 to 600 km distance interval from the array. In case the phase is a Pn, we will only allow the event to be located between 160 and 1300 km from the station. The relations between apparent velocity estimates and distance limits of the different phases are obtained from analysis of well-defined events. In addition, the estimated azimuths put additional restrictions on the use of the detected signal in the GBF. E. g., for ARCES we currently do not allow the events to be located outside a sector of ±25 degrees around the estimated azimuth. For each detection, the distance and azimuth limits for a given list of phases (P, Pn, Pg, Sn, Lg, Rg) are stored in a database for use by GBF.

For each array are also attempt to group arrivals which are likely to originate from the same local or regional event. In short, we first search the detection list for phases with typical Pn/Pg apparent velocity estimates. If within a relatively short time interval (~40 seconds), phases are found with S-type apparent velocity estimates, and with comparable azimuths, we assign the phases to the same event. Based on the time difference between the first P and the first S of the group, we are calculating an approximate distance to the event. In the subsequent GBF process the phases in this group can only be associated with events close to the approximate initial location.

As a final preprocessing step we group together subsequent phases with typical teleseismic apparent velocity estimates. The automatic detector often reports several detections within 10-20 seconds after the first teleseismic P, and these coda detections will not be used as defining phases by the GBF process.

The ORACLE database previously used for storing the results from the preprocessor has been replaced by a set of ASCII files. For each station, there is a "circular" database file, an index file, a "control" file, and a set of timestamp files. The number of arrivals which can be held in the circular file is decided by the user and listed in the control file.

The new preprocessor software has been written in C to replace the old FORTRAN routines and consists of two main modules:

**phasescan** This program reads the files with the arrival parameters (FKX files), merges arrivals as necessary, and writes new FKX files. The velocities and azimuths of the possibly merged arrivals are compared to a table of rules governing the initial distance estimates, and the results are written to the ASCII "database" for that station.

**eventscan** This module identifies and updates distance limits for groups of arrivals satisfying the input criteria given in a parameter file. The program is executed three times, first for local events, second for regional events, and finally for the coda of teleseismic events. Arrivals will not be flagged multiple times (*e.g.*, if a set of arrivals is flagged as local, they will not be considered when scanning for regional or teleseismic events).

### *Rules for determining initial distances for arrivals at Spitsbergen*

The GBF preprocessor uses a standard set of tables for estimating the initial distance limits which depend on the apparent velocity estimate alone. However, the observed apparent velocities (and azimuths) are dependent on the actual propagation path between source and receiver (*e.g.*, Schweitzer and Kværna, 1995).

In the case of the SPITS array, large slowness variations are observed, and we initially tried to accommodate these variations with a simple approach. The Pn apparent velocity estimates from a set of manually located SPITS events are shown in Fig. 6.3.1. We see distinctly higher velocities to the northeast, and predominantly low velocities in the southwest. After obtaining geologic information of the crust below the SPITS array (see Fig. 6.3.2), we can explain parts of the effect by dipping sedimentary layers in the uppermost crust. After binning the Pn data in distance and azimuth, a function of the form

$$v = const + f_1 \cdot \Delta + f_2 \cdot \sin(azi + \phi)$$

was fit to the velocities (see Fig. 6.3.3). The value of $\pm 1.5\sigma$ was used as a guideline for deciding velocity limits as a function of azimuth for this phase. The phases Pg, Sn, and Lg show similar patterns and we have for these phases also derived velocity versus azimuth functions.

### *Coverage of the regional grid system*

An input parameter to the GBF algorithm is the grid system of possible event locations. For each grid point, the detection logs of the different arrays are searched for signals matching the predicted travel time, azimuth and slowness of phases originating at the grid point. When a given number of matching phases are found, initial event hypotheses are formed. A denser grid system is then constructed around the grid point providing the largest number of matching phases, and the data are reprocessed for a shorter time interval around the initial origin time.

The coverage and density of the “old” grid system used up to April 1999 is shown in Fig.6.3.4. Also shown are the locations of the arrays used in the GBF processing. The grid nodes are deployed across latitude circles with a distance of 1.5 degrees. Notice the distortion of the grid system in the vicinity of the North Pole. As an example, Fig. 6.3.5 shows the denser grid system constructed around an initial event location in the Kara Sea. The distance between the grid nodes is 0.3 degrees.

In addition to including the SPITS array in the GBF processing, we also needed a more complete grid coverage in the polar region. The gridding algorithm was modified, and the result is shown in Fig. 6.3.6. The distance between the nodes of the coarse grid system is still 1.5 degrees, and the coverage is extended. The new denser and enlarged grid system constructed around the initial event location is shown in Fig. 6.3.7, where the distance between the grid nodes is reduced to 0.2 degrees.

### *A preliminary evaluation of results from the new GBF process*

For comparing the results of the “old” and the “new” GBF processing, data from a 59 day time period from 15 February to 14 April 1999 were processed using both setups. Different from the “old” setup, the “new” GBF included data from the SPITS array, improved detector and f-k recipes, enhanced preprocessor functionality and parameters, an enlarged and more uniform grid system, and a “cleaned” GBF code. In Fig. 6.3.8 we show locations of all events from both runs. Notice in particular the increased number of events in the Arctic region north of $70^o$ latitude, and outside the coverage of the “old” GBF grid system. For the “new” GBF, the events close to the North pole exhibit a “suspicious” geometric pattern. We think that this may be a boundary effect of the parameter setting, and we will further investigate this problem.

All methods for automatic phase association produce false event definitions, but we have not in this first evaluation assessed the false alarm rate of the two runs. In order to sort out possible false event definitions we have in Fig. 6.3.9 plotted events which have at least one station with defining P and S phases, and at least one additional station with a defining P-phase. Particularly striking is the large number of events along the mid-Atlantic ridge system for the “new” GBF.

In Fig, 6.3.10 we have plotted events with at least 3 defining P-phases (from three different stations). This is a criterion similar to that used for defining events at the Prototype International Data Center (PIDC) in Arlington, USA. For the "old" GBF, notice the grid boundary effect in the Mediterranean Sea and some "suspicious" alignments to the west of the Black Sea. For the "new" GBF, there is a better definition of the seismicity along the mid-Atlantic ridge, combined with a visually better clustering of the events at the mining areas in northern Europe. The "new" GBF produces an increased number of events scattered around the Russian territory. We believe that a portion of these may be false phase associations, particularly caused by the new detections at the SPITS array.

Finally, we show in Fig. 6.3.11 the events reported in the Reviewed Event Bulletin (REB) of the PIDC, and the events reported by NEIC for the same time period. Up to 18 March NEIC events are those reported in the weekly bulletins, but after that time only the Quick Epicenter Determinations (QED) were available. When comparing the REB events to the "new" GBF events with at least 3 defining P-phases (see Fig. 6.3.10), it seems that the "new" GBF has captured most of the events reported in the REB. Notice in particular the events located along the mid-Atlantic ridge, in the Mediterranean, and in the Caucasus.

The NEIC events of Fig. 6.3.11 show a very different pattern. Only the largest events along the mid-Atlantic ridge are reported, and no events are reported from Fennoscandia, the Baltic states, or Russia. Due to extensive and timely reporting from many local networks in southern Europe to NEIC, the bulletin has a very good coverage for this region.

### *Conclusion*

Our preliminary assessment of the "new" GBF processing, now including the SPITS array, is that it provides a significant improvement with respect to monitoring of the European Arctic. Because of the less restrictive phase definition criteria, the "new" GBF outperforms the PIDC REB in the regional distance regime from the arrays. However, we need to assess in more detail the false alarm rate and methods to avoid erroneous phase associations.

After updating the recipes for detection and f-k analysis for all regional arrays, the "new" GBF processing was set into operation on 10 April 1999. The operational stability of the "new" GBF is significantly improved compared to the "old". As a rule we have available an automatic network bulletin within 1 - 1 1/2 hours after real time. The results are made available to the public at the NORSAR Web pages
(**http://www.norsar.no**).

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**J. Schweitzer**
**L. Taylor**
**F. Ringdal**

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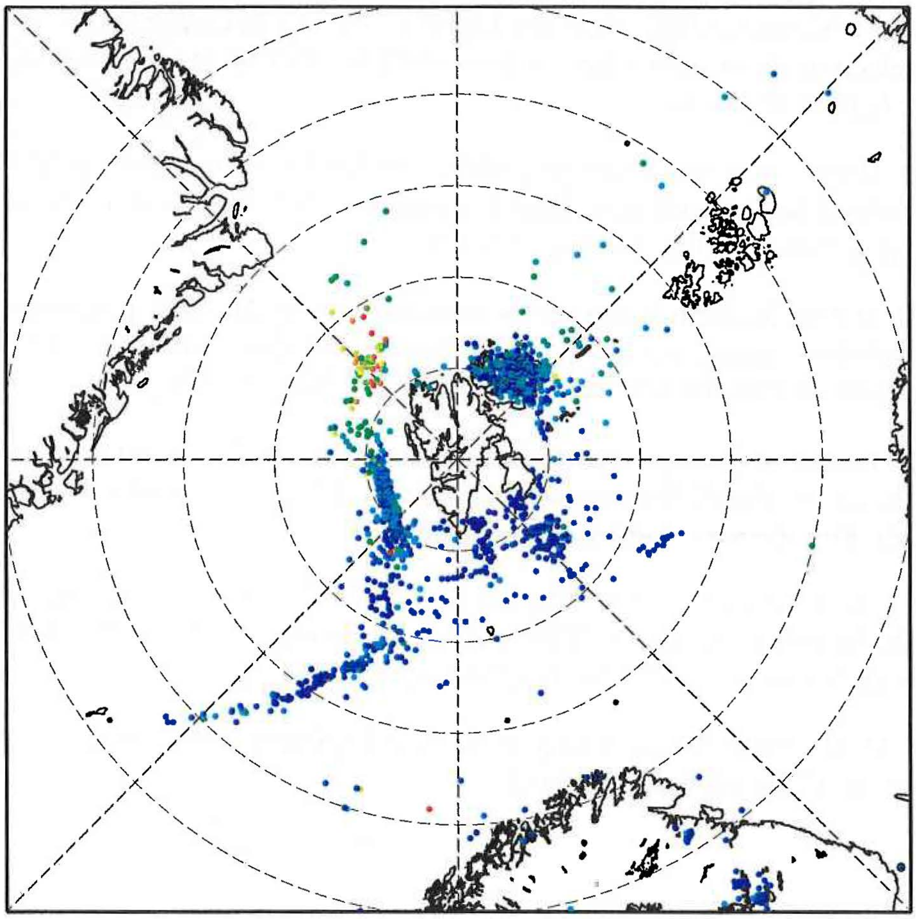
Sigmond, E. M. O. (1992). Bedrock map, Norway and adjacent ocean areas. Geologiske Undersøkelse 1986-1992.



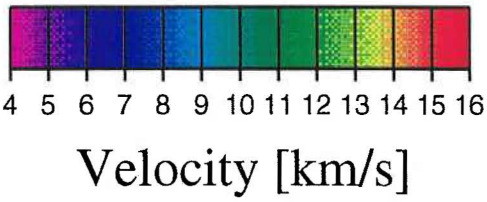


*Figure 6.3.1. Pn apparent velocity estimates for a set of manually located SPITS events.*

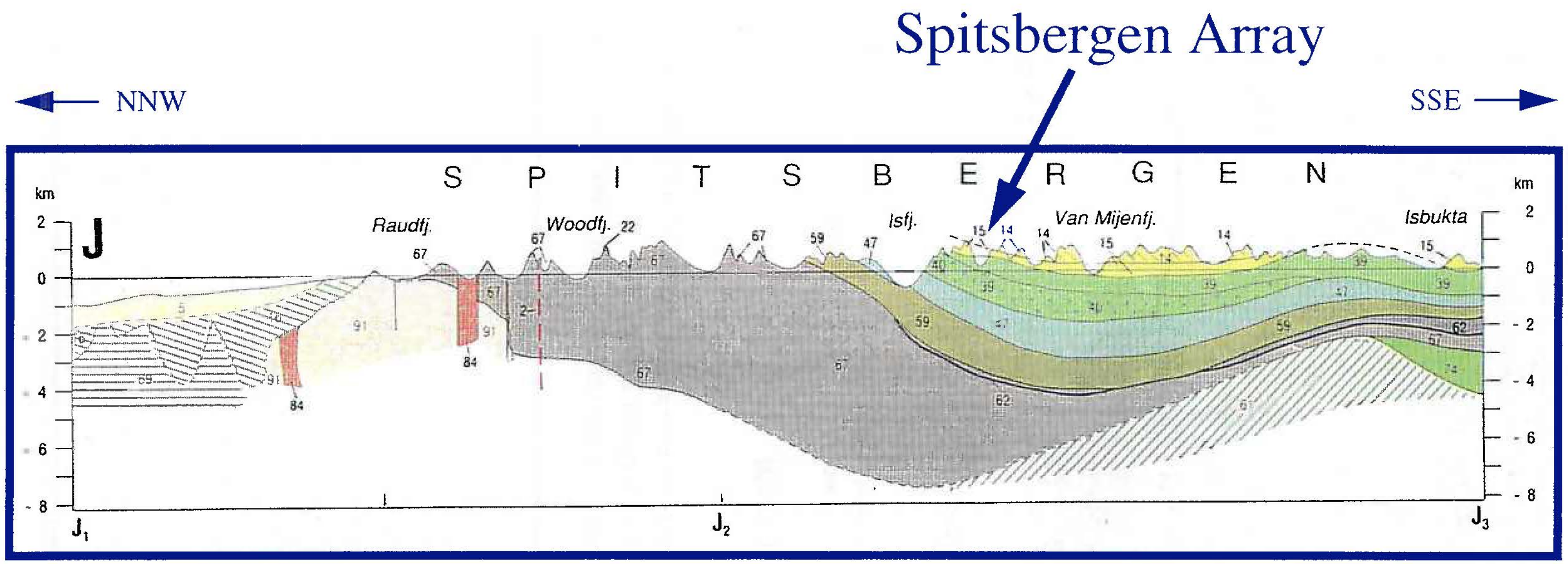


*Fig. 6.3.2. Geological cross-section through the uppermost crust below the SPITS array. Modified after E.M.O. Sigmond, 1992.*

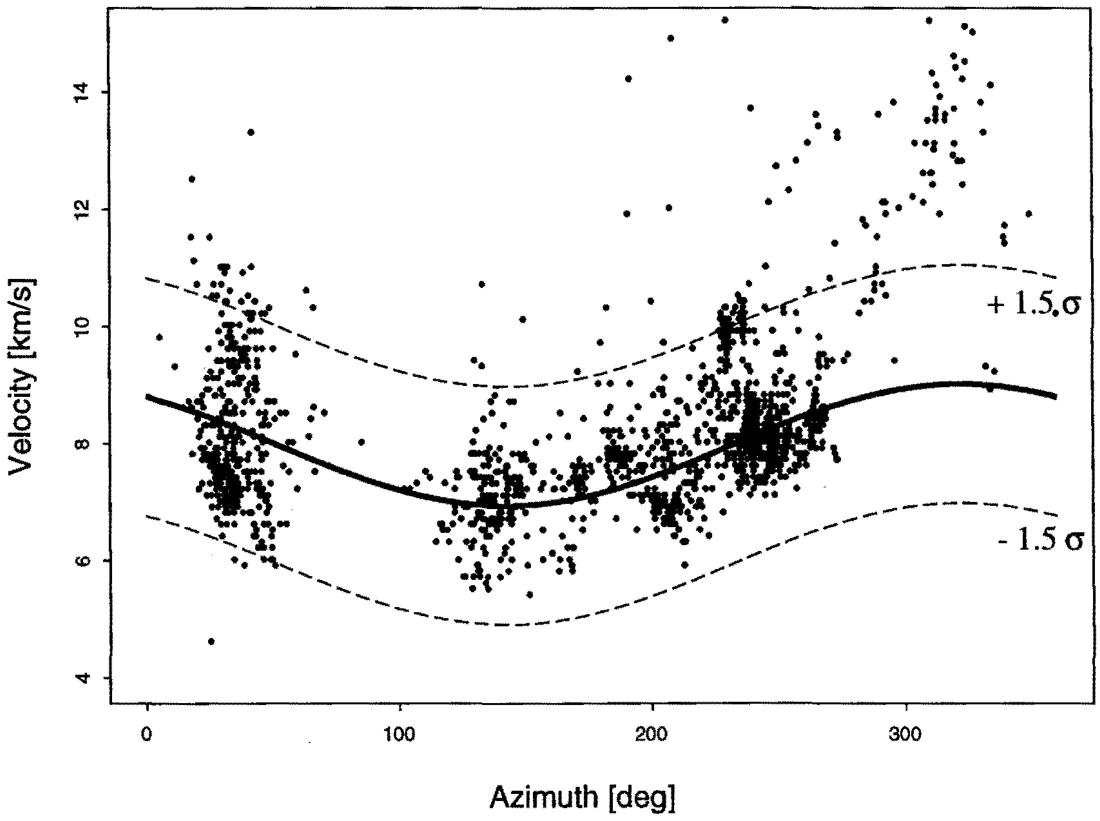


*Fig. 6.3.3. Plot of Pn apparent velocities of Fig. 6.3.1 versus azimuth at the SPITS array. After binning the Pn data in distance and azimuth, a function of the form* $v = const + f_1 \cdot \Delta + f_2 \cdot \sin(azi + \phi)$ *was fit to the velocities. The lines showing the* $\pm 1.5\sigma$ *are also shown.*

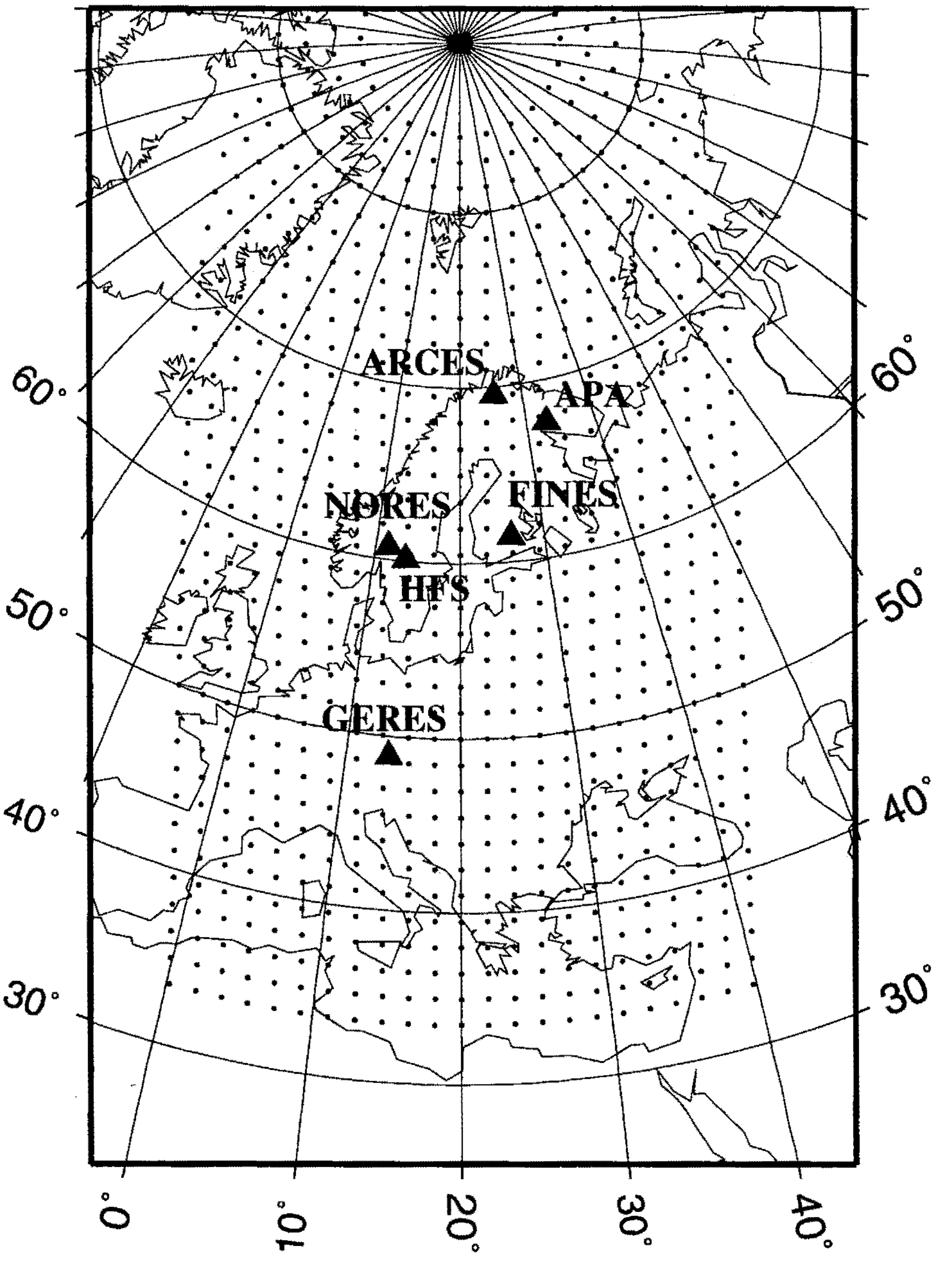


*Fig. 6.3.4. This map shows the stations processed and the initial grid system used by the "old" GBF. The distance between the grid nodes is 1.5 degrees.*

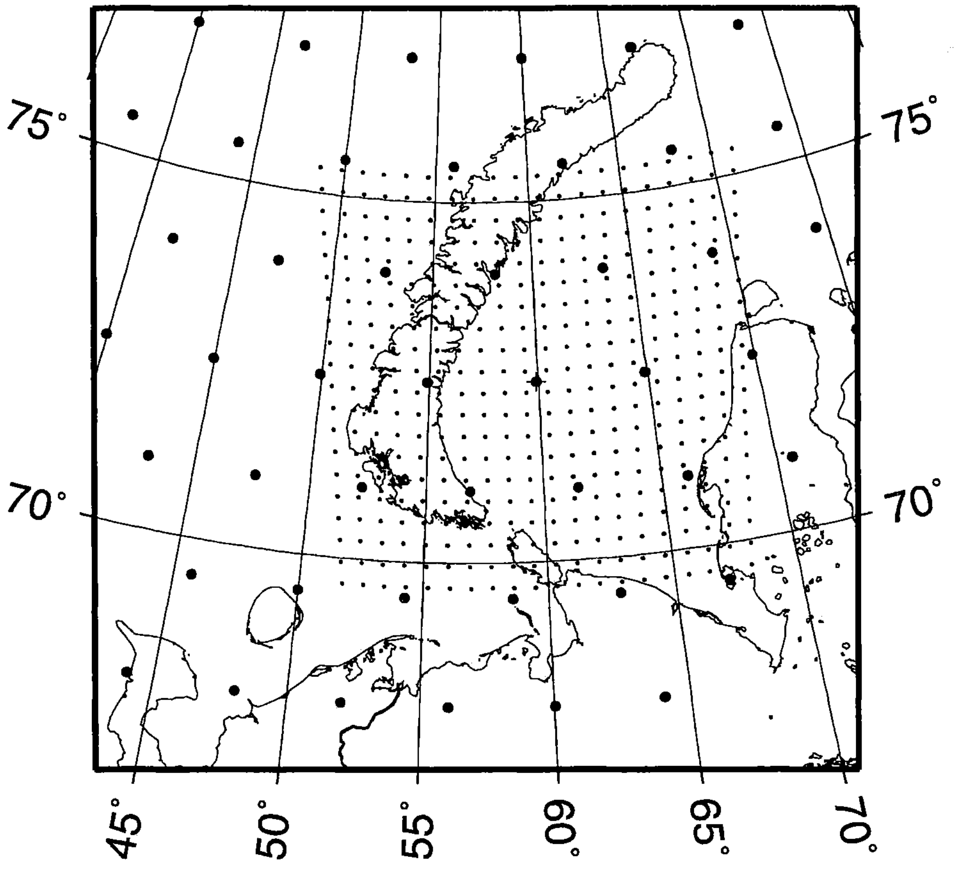


*Fig. 6.3.5. Map of the denser grid system used by the "old" GBF, in this case constructed around an initial event location in the Kara Sea. The distance between the grid nodes is 0.3 degrees.*

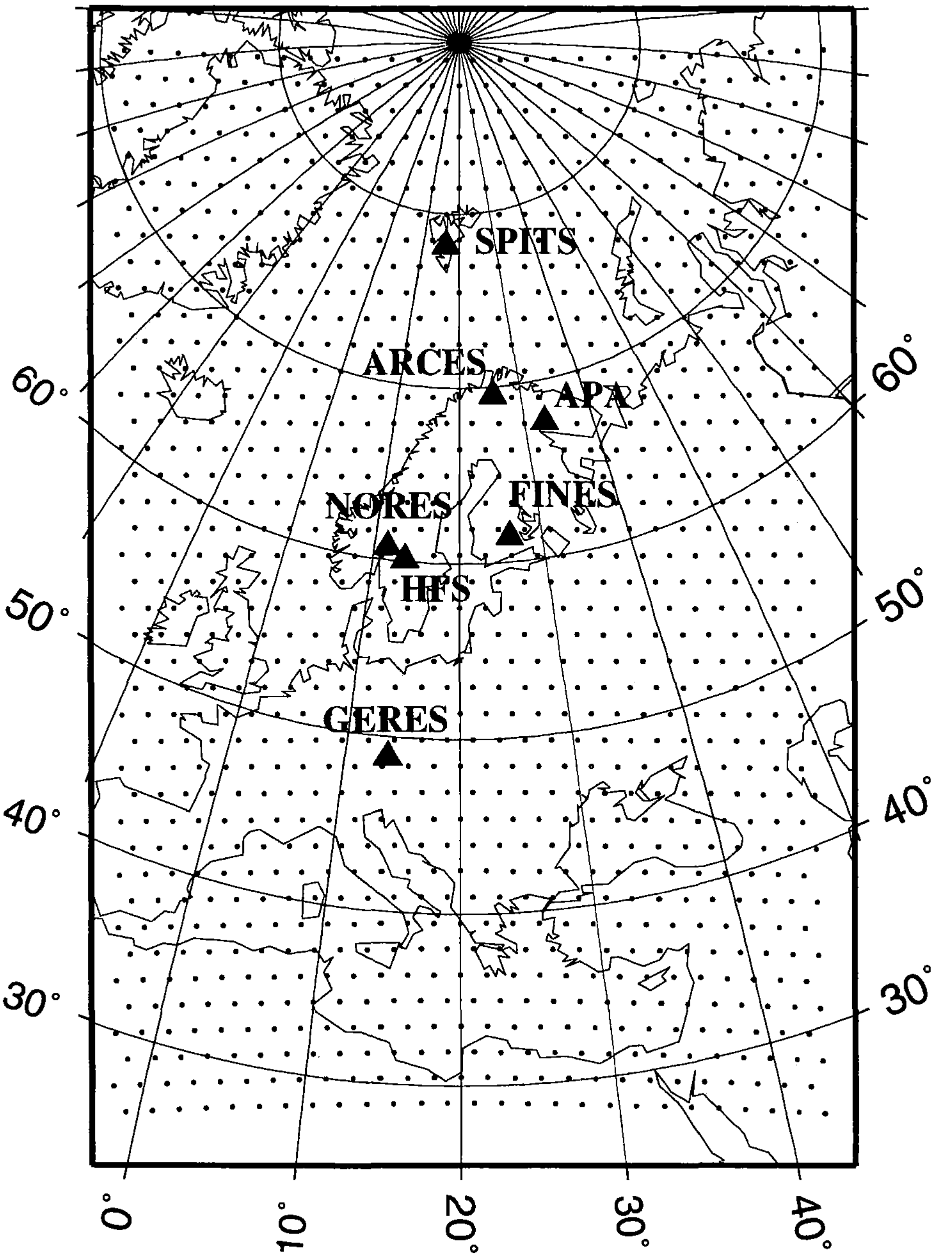


*Fig. 6.3.6. This map shows the stations processed and the initial grid system used by the "new" GBF. The distance between the grid nodes is 1.5 degrees.*

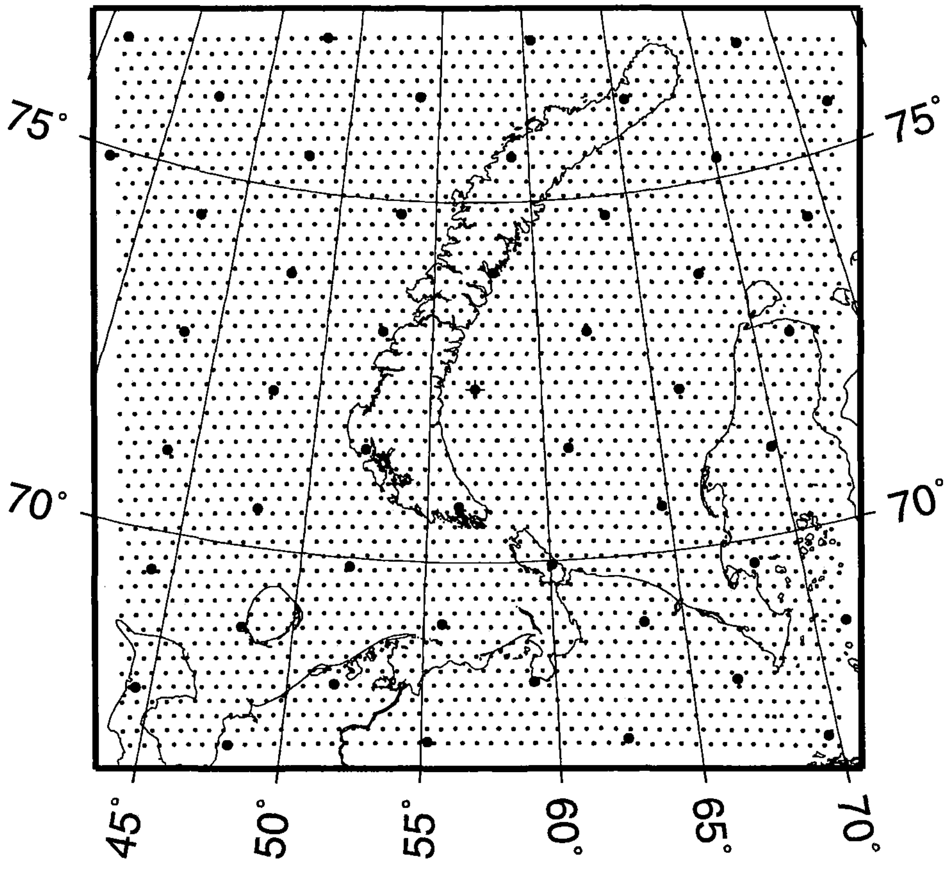


*Fig. 6.3.7. Map of the denser grid system used by the "new" GBF, in this case constructed around an initial event location in the Kara Sea. The distance between the grid nodes is now 0.2 degrees.*

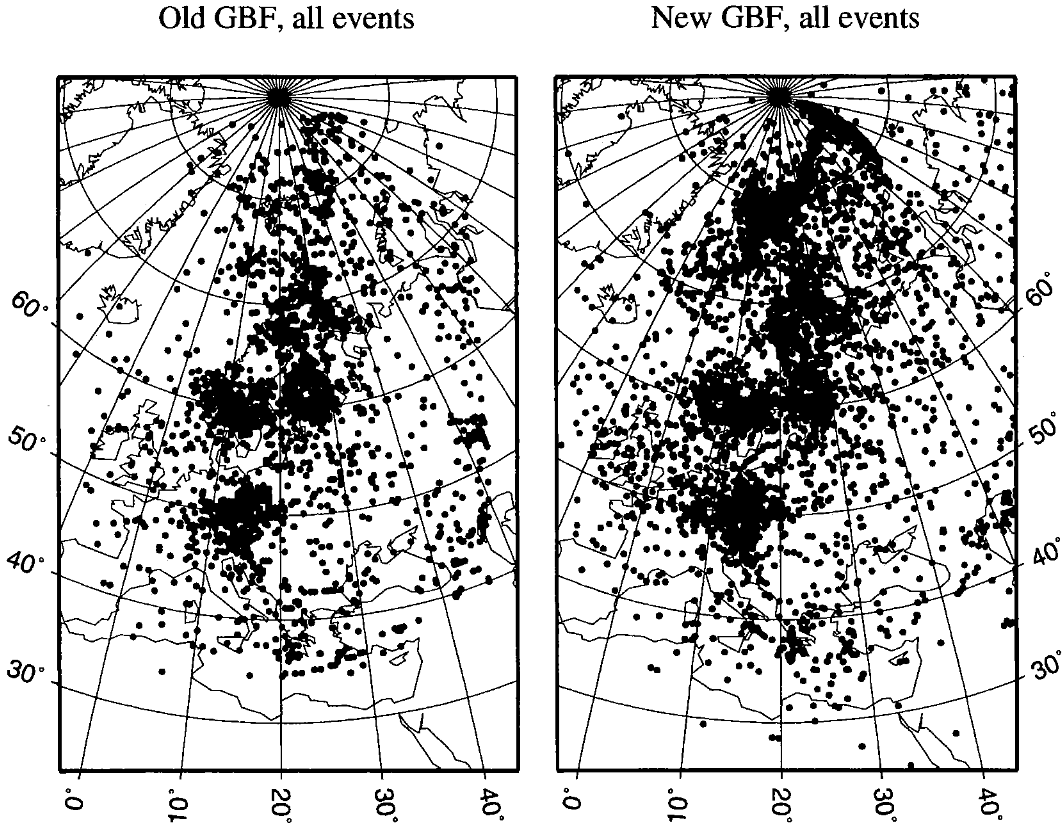
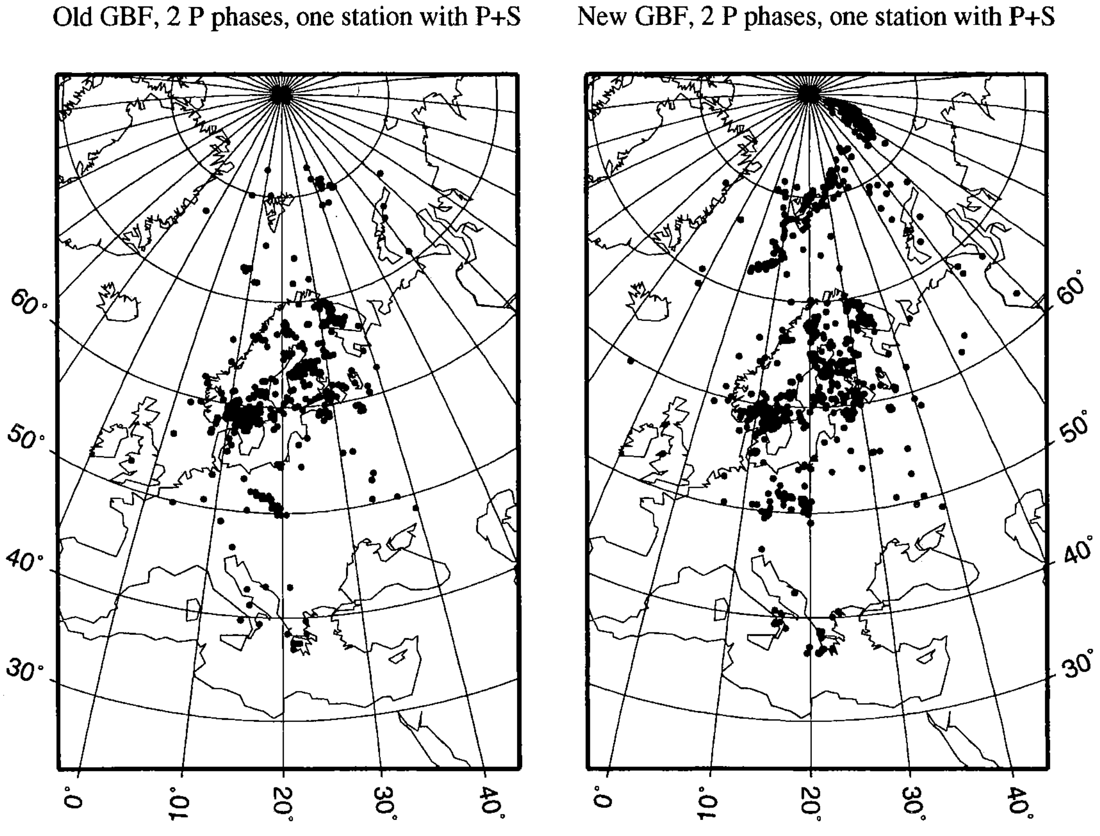
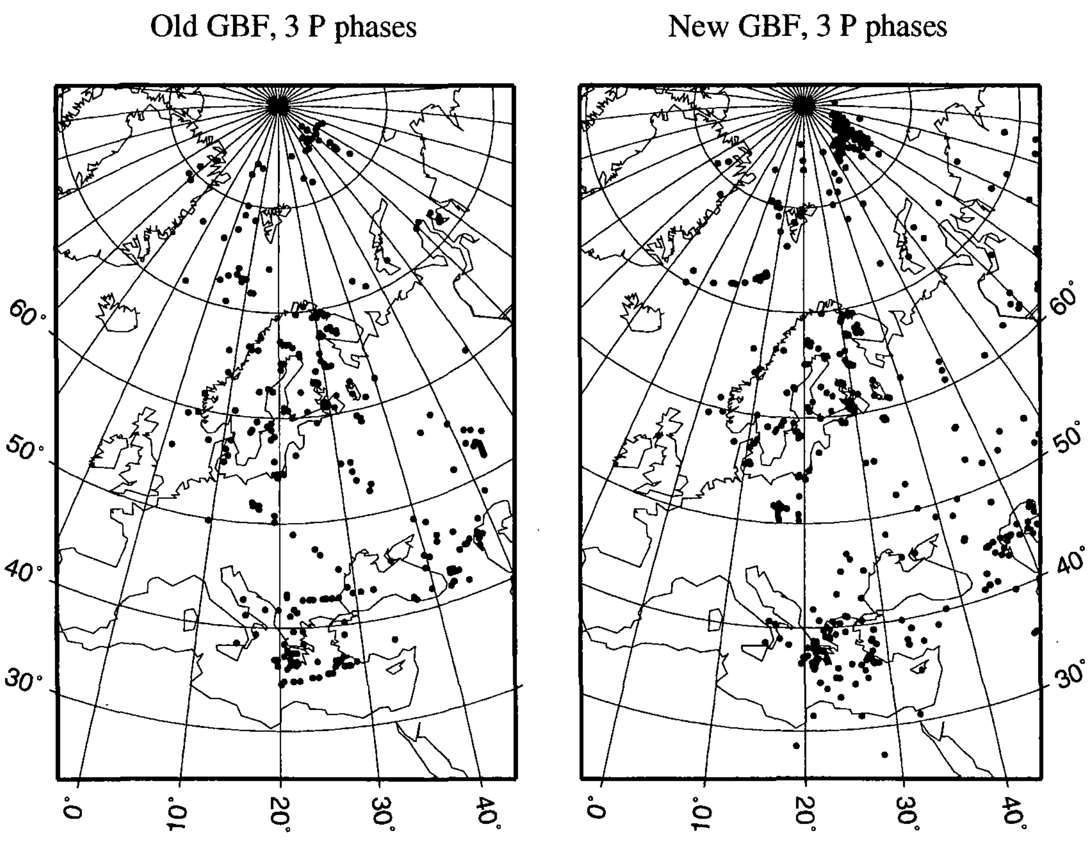


*Fig. 6.3.8. Maps of all events defined by the "old" and the "new" GBF version after processing data from the time period from 15 February to 14 April 1999.*


Old GBF, 2 P phases, one station with P+S

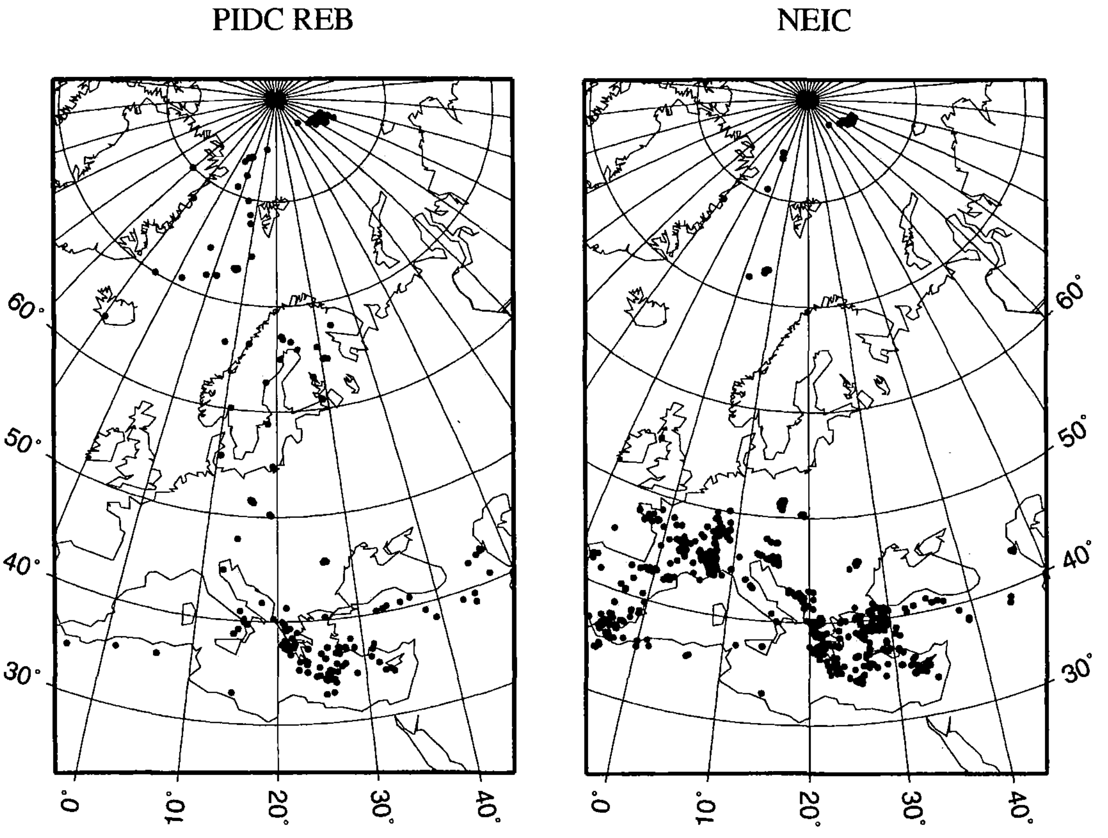
New GBF, 2 P phases, one station with P+S

*Fig. 6.3.9. Maps of events defined by the "old" and the "new" GBF processing which have at least one station with defining P and S phases, and at least one additional station with a defining P. The processed data are from the time period from 15 February to 14 April 1999.*


Old GBF, 3 P phases

New GBF, 3 P phases

*Fig. 6.3.10. Maps of events defined by the "old" and the "new" GBF processing which have at least 3 defining P-phases (from three different stations). The processed data are from the time period from 15 February to 14 April 1999.*


PIDC REB

NEIC

*Fig. 6.3.11. These maps show the events reported in the Reviewed Event Bulletin (REB) of the PIDC, and the events reported by the NEIC for the time period from 15 February to 14 April 1999. Up to 18 March NEIC events are those reported in the weekly bulletins, but after that time only the Quick Epicenter Determinations (QED) were available.*

## 6.4 Global Seismic Threshold Monitoring: Internet Access and Examples of Results

### *Introduction*

Data from the seismic stations in the International Monitoring System (IMS) network are currently processed continuously at the Prototype International Data Center (PIDC) in Arlington, Virginia, in support of the Comprehensive Nuclear Test Ban Treaty. The ability of this network to detect seismic events can be assessed using the Threshold Monitoring software developed at NORSAR. Daily results from the Threshold Monitoring component of the IMS are now available to the public via the PIDC internet site.

### *Location*

The main PIDC web page is located at

**http://www.pidc.org/**

and is being developed and maintained by the PIDC staff. This page has a column of buttons on the left hand side. Clicking on Systems Status will bring up the Systems Status page, shown in Fig. 6.4.1. Click on Threshold Monitoring Status to get to the Threshold Monitoring Status page (shown in Fig. 6.4.2). Select the day of interest, and the next page (see Fig. 6.4.3) gives a choice of times for which Threshold Monitoring results may be viewed.

### Threshold Monitoring Results

The results consist of three sets of maps and plots:

The **"detplot"** map shows the average and worst case worldwide thresholds for the given hour. The IMS should be able to detect any event that is larger than the threshold level at any given time. In the case of a large event, this ability is degraded in the vicinity of the event (and to a lesser extent worldwide).

**"Status"** plots of the data from each station used in Threshold Monitoring show when and if each station was functioning during that hour. By viewing these traces, one can immediately see peaks corresponding to larger events which may have been detected.

The status of each station is also shown on the **"uptime"** map, along with any large events found in the Reviewed Event Bulletin (REB) during that hour.

Examples for a time interval on 4 March 1999 are shown in Figs. 6.4.4, 6.4.5, and 6.4.6. Note the severe degradation of detection capability shown in Fig. 6.4.4. This was caused by an $m_b$ 5.78 event in the Celebes Sea at 08:51:58. Note also that a number of stations were down, as shown in Figs. 6.4.5 and6.4.6. See Fig. 6.4.10 for a list of the REB events which occured during this time interval.

A "quiet" time interval, 1 May 1999 between 23:00 and midnight, is shown in Fig. 6.4.7. Scandinavia has a particularly low threshold in this example. This region is well served by seismic arrays, all of which are operating during this time interval (see Figs. 6.4.8 and 6.4.9).

The Threshold Monitoring software and results are described thoroughly in the Threshold Monitoring Operations Manual (Taylor *et al.*, 1998).

### *Outstanding Issues*

The Threshold Monitoring software is robust, and has recently been shown to be Y2K compatible. However, the results are converted for internet access before the REB has been checked for events. This means that there are currently no events listed on the maps which are available on the web (see Figs. 6.4.6 and 6.4.10). We hope that this problem will be rectified in the near future, so that available REB data will be displayed automatically.

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**T. Kværna**

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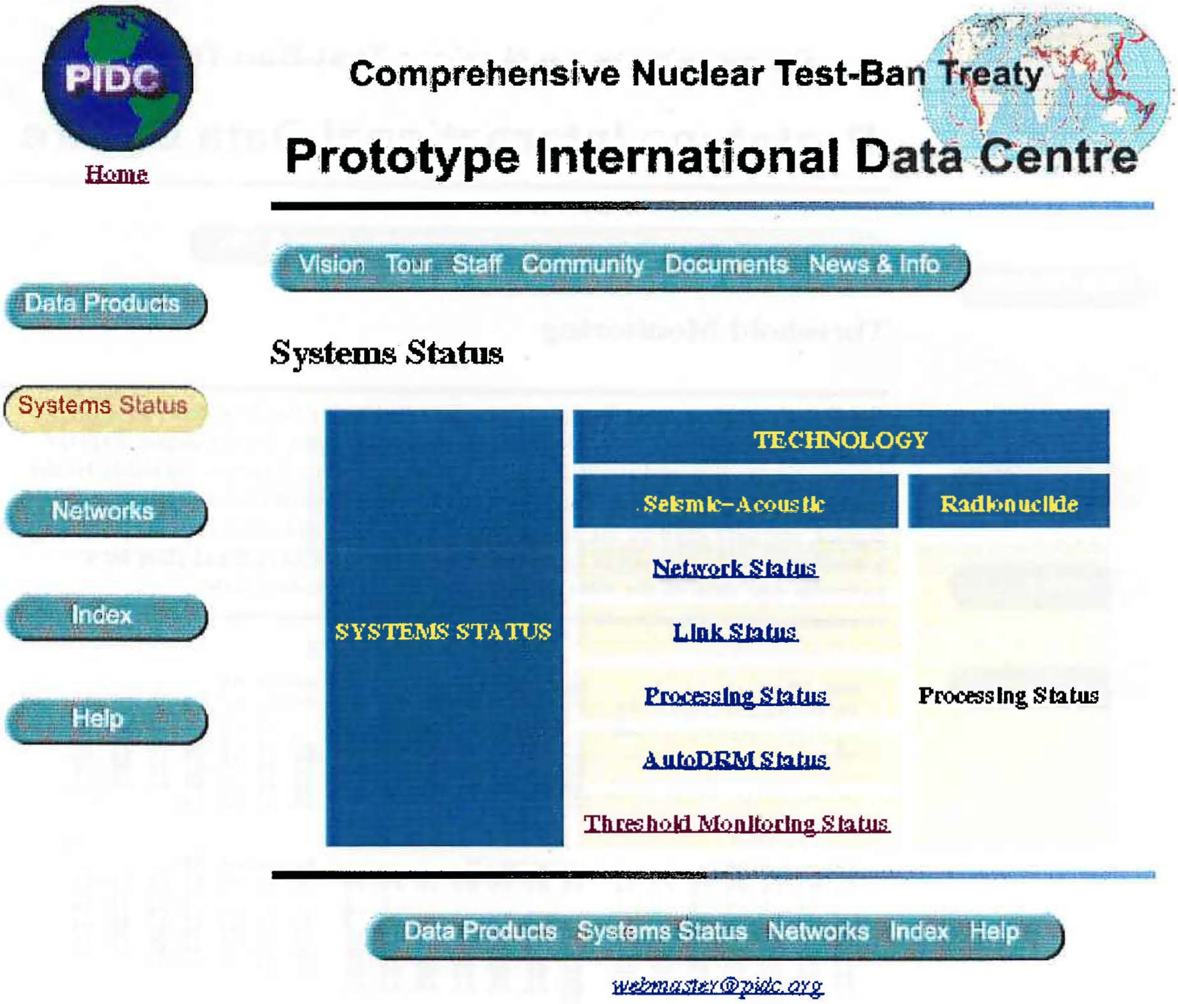
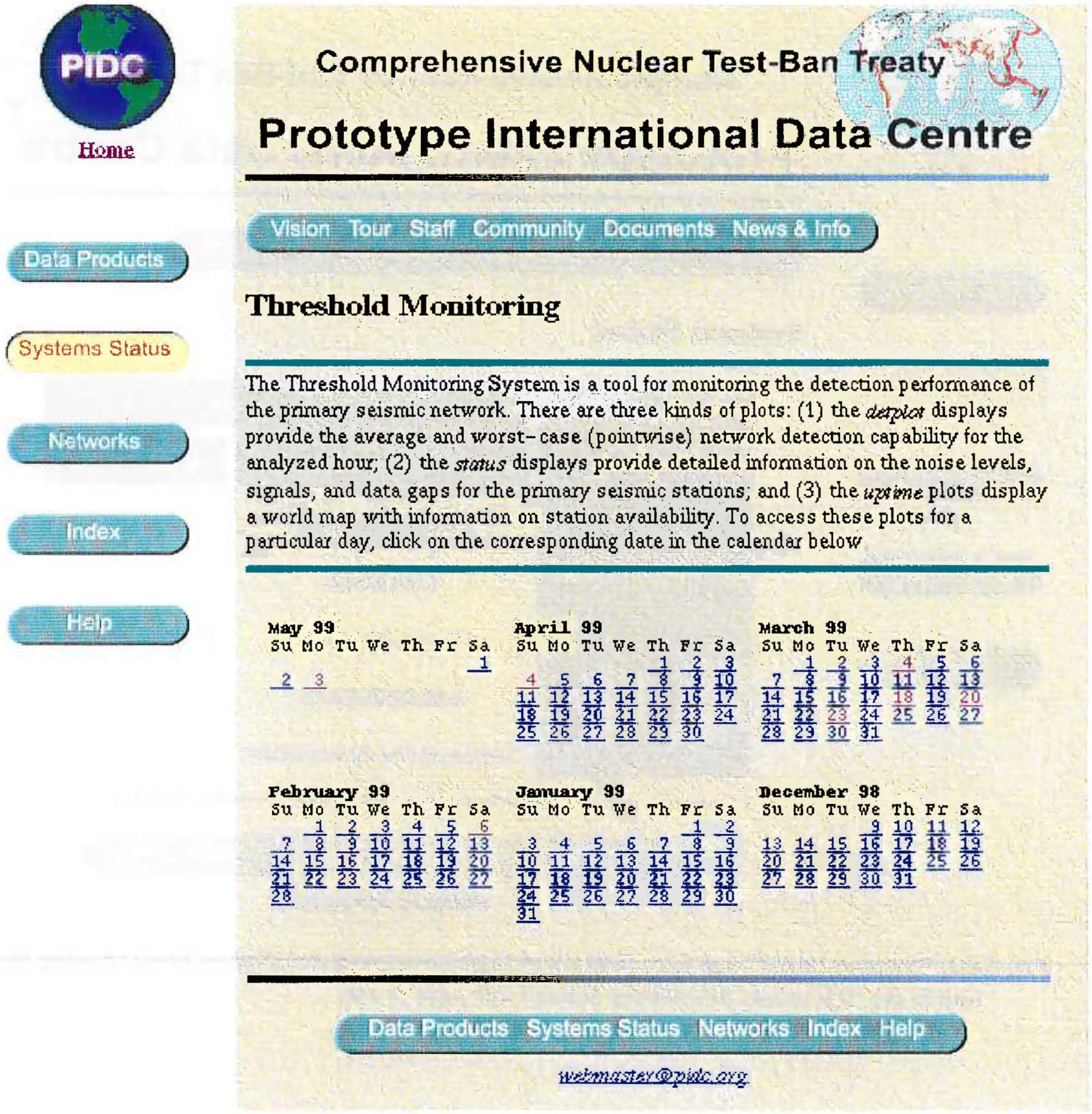


Systems Status

| | TECHNOLOGY | |
|---|---|---|
| | Seismic-Acoustic | Radionuclide |
| SYSTEMS STATUS | Network Status | |
| | Link Status | |
| | Processing Status | Processing Status |
| | AutoDRM Status | |
| | Threshold Monitoring Status | |

webmaster@pidc.org

*Fig. 6.4.1. "Systems Status" web page (http://www.pidc.org/systatusbox/System.html) showing the link to the "Threshold Monitoring Status" web page in red.*



Comprehensive Nuclear Test-Ban Treaty

Prototype International Data Centre

**Threshold Monitoring**

The Threshold Monitoring System is a tool for monitoring the detection performance of the primary seismic network. There are three kinds of plots: (1) the *detplot* displays provide the average and worst-case (pointwise) network detection capability for the analyzed hour; (2) the *status* displays provide detailed information on the noise levels, signals, and data gaps for the primary seismic stations; and (3) the *uptime* plots display a world map with information on station availability. To access these plots for a particular day, click on the corresponding date in the calendar below

**May 99**

| Su | Mo | Tu | We | Th | Fr | Sa |
|---|---|---|---|---|---|---|
| | | | | | | 1 |
| 2 | 3 | | | | | |

**April 99**

| Su | Mo | Tu | We | Th | Fr | Sa |
|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 |
| 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 11 | 12 | 13 | 14 | 15 | 16 | 17 |
| 18 | 19 | 20 | 21 | 22 | 23 | 24 |
| 25 | 26 | 27 | 28 | 29 | 30 | |

**March 99**

| Su | Mo | Tu | We | Th | Fr | Sa |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| 21 | 22 | 23 | 24 | 25 | 26 | 27 |
| 28 | 29 | 30 | 31 | | | |

**February 99**

| Su | Mo | Tu | We | Th | Fr | Sa |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| 21 | 22 | 23 | 24 | 25 | 26 | 27 |
| 28 | | | | | | |

**January 99**

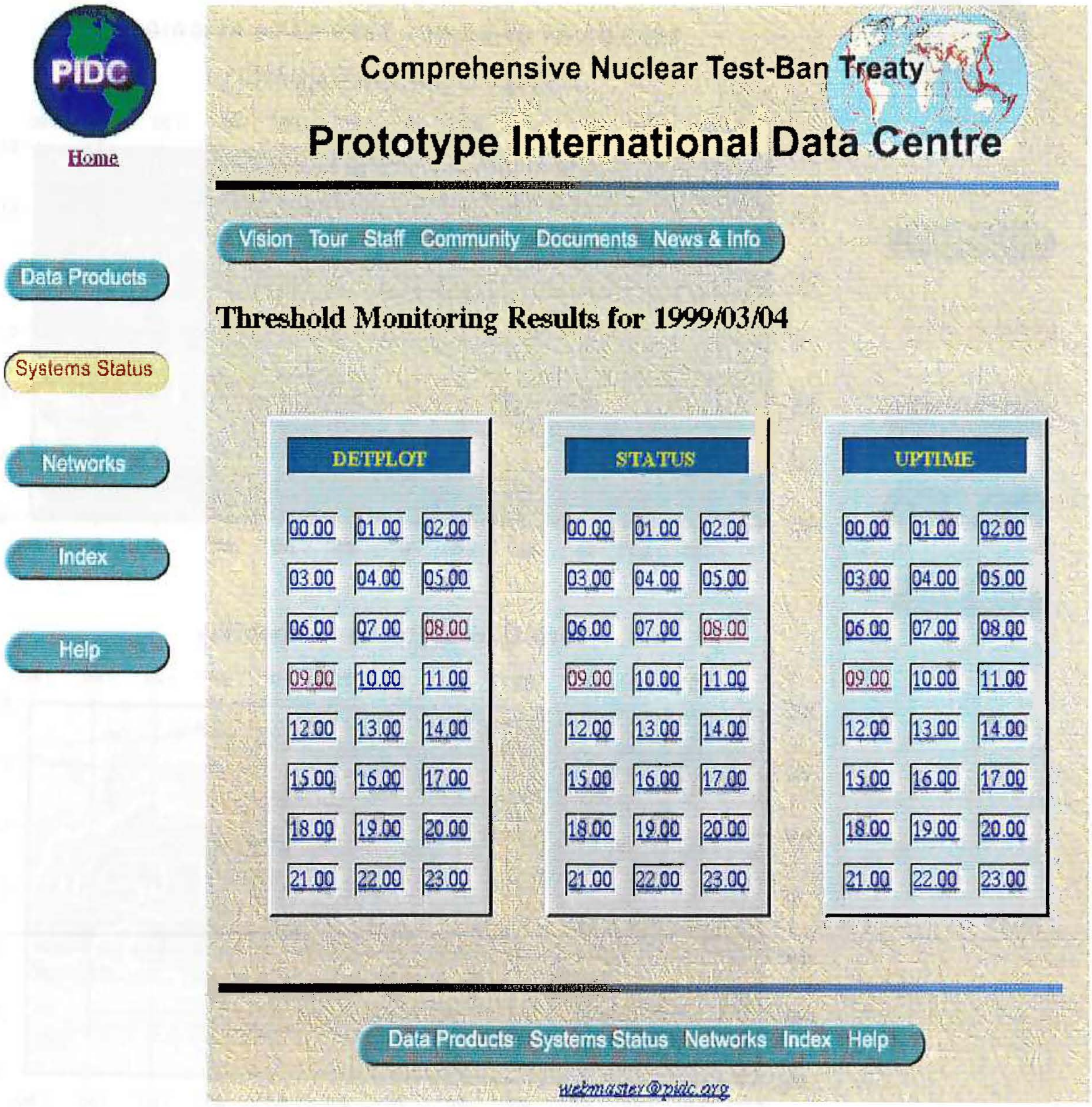
| Su | Mo | Tu | We | Th | Fr | Sa |
|---|---|---|---|---|---|---|
| | | | | | 1 | 2 |
| 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 10 | 11 | 12 | 13 | 14 | 15 | 16 |
| 17 | 18 | 19 | 20 | 21 | 22 | 23 |
| 24 | 25 | 26 | 27 | 28 | 29 | 30 |
| 31 | | | | | | |

**December 98**

| Su | Mo | Tu | We | Th | Fr | Sa |
|---|---|---|---|---|---|---|
| | | | 9 | 10 | 11 | 12 |
| 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| 20 | 21 | 22 | 23 | 24 | 25 | 26 |
| 27 | 28 | 29 | 30 | 31 | | |

webmaster@pidc.org

*Fig. 6.4.2. "Threshold Monitoring Status" web page. The most recent months are shown, and each day for which data are available is a clickable link. There are no data available before 9 December 1998.*



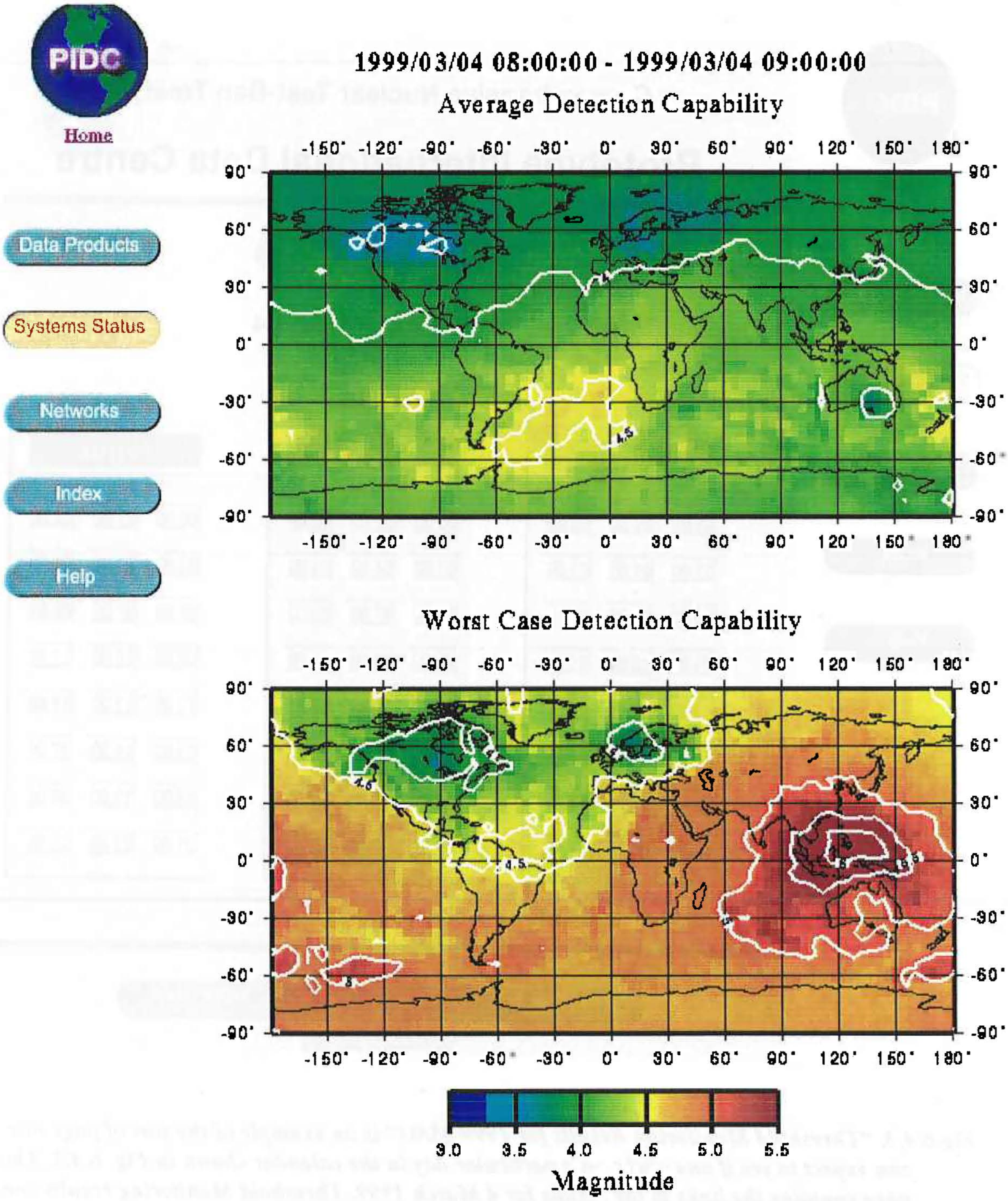
Comprehensive Nuclear Test-Ban Treaty

Prototype International Data Centre

Threshold Monitoring Results for 1999/03/04

webmaster@pidc.org

*Fig.6.4.3. "Threshold Monitoring Results for 1999/05/03" is an example of the sort of page one can expect to see if one clicks on a particular day in the calendar shown in Fig. 6.4.2. This page contains the links to the results for 4 March 1999. Threshold Monitoring results consist of three displays for each hour of the day. The "detplot" display is a pair of maps showing the average and worst-case detection thresholds. The status of each individual IMS station is shown in the "status" plots and the "uptime" map.*



1999/03/04 08:00:00 - 1999/03/04 09:00:00

Average Detection Capability

Worst Case Detection Capability

Magnitude

*Fig. 6.4.4. Average and Worse Case detection capabilities for the one hour interval between 08:00 and 09:00 on 4 March 1999. This was displayed by clicking on "08.00" in the "detplot" panel of the web page shown in Fig. 6.4.3. There was a large event in the Celebes Sea ($m_b$ 5.8) at 08:51:58, causing a major degradation in the ability of the IMS to detect smaller events in that part of the world.*

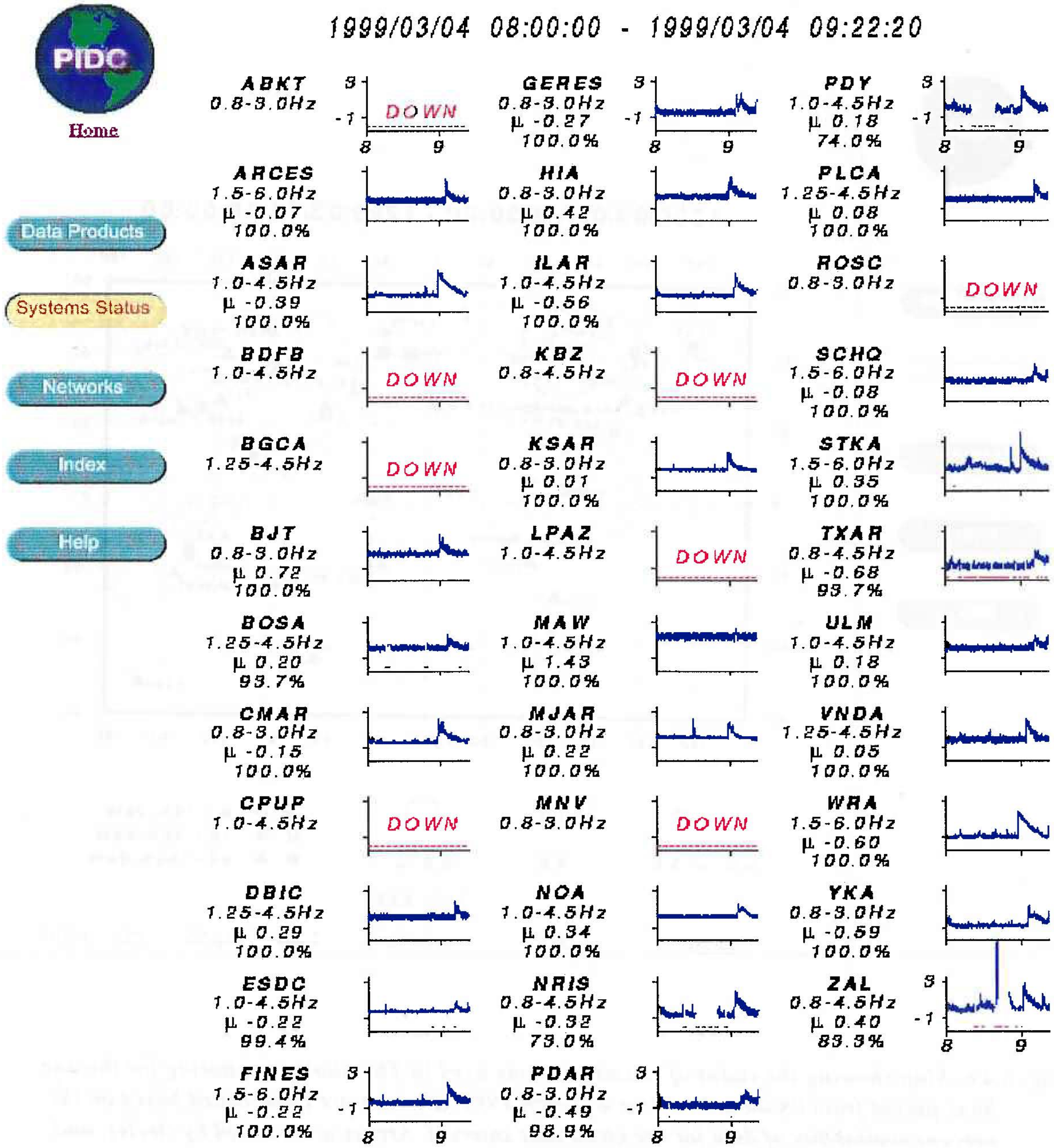
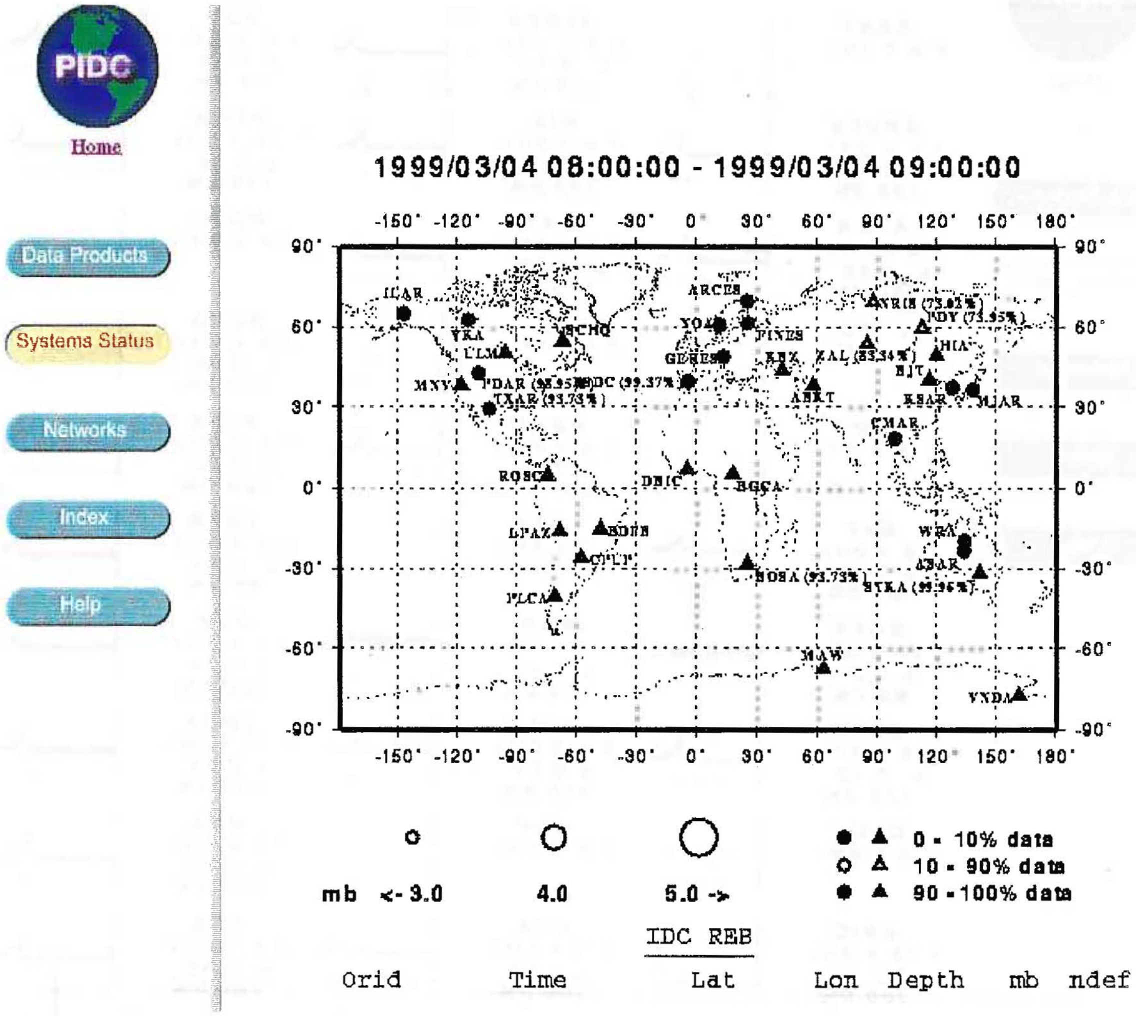


*Fig. 6.4.5. Plots showing the status of each seismic station used in Threshold Monitoring for the hour starting at 08:00 on 4 March 1999. Periods of down time are shown in red, and stations which were down for the entire hour are listed as DOWN. In order to include all events originating within the hour in question, an extra 22 minutes and 20 seconds are included to account for possible travel time delays. The Celebes Sea event originating at 08:51:58 is therefore shown for all functioning stations.*



1999/03/04 08:00:00 - 1999/03/04 09:00:00

mb <- 3.0 4.0 5.0 ->

● ▲ 0 - 10% data
○ △ 10 - 90% data
● ▲ 90 - 100% data

IDC REB

Orid Time Lat Lon Depth mb ndef

*Fig. 6.4.6. Map showing the status of seismic stations used in Threshold Monitoring for the one hour period from 08:00 to 09:00 on 4 March 1999. Stations are color coded based on the percent availability of data for the given time interval. Arrays are marked by circles, and three-component stations by triangles. This is the appearance of the "uptime" display immediately after Threshold Monitoring processing. The Reviewed Events Bulletin has not been completed at this stage, and the Celebes Sea event originating at 08:51:58 is not yet listed. See Fig. 6.4.10 for the "uptime" map after the REB events are included.*

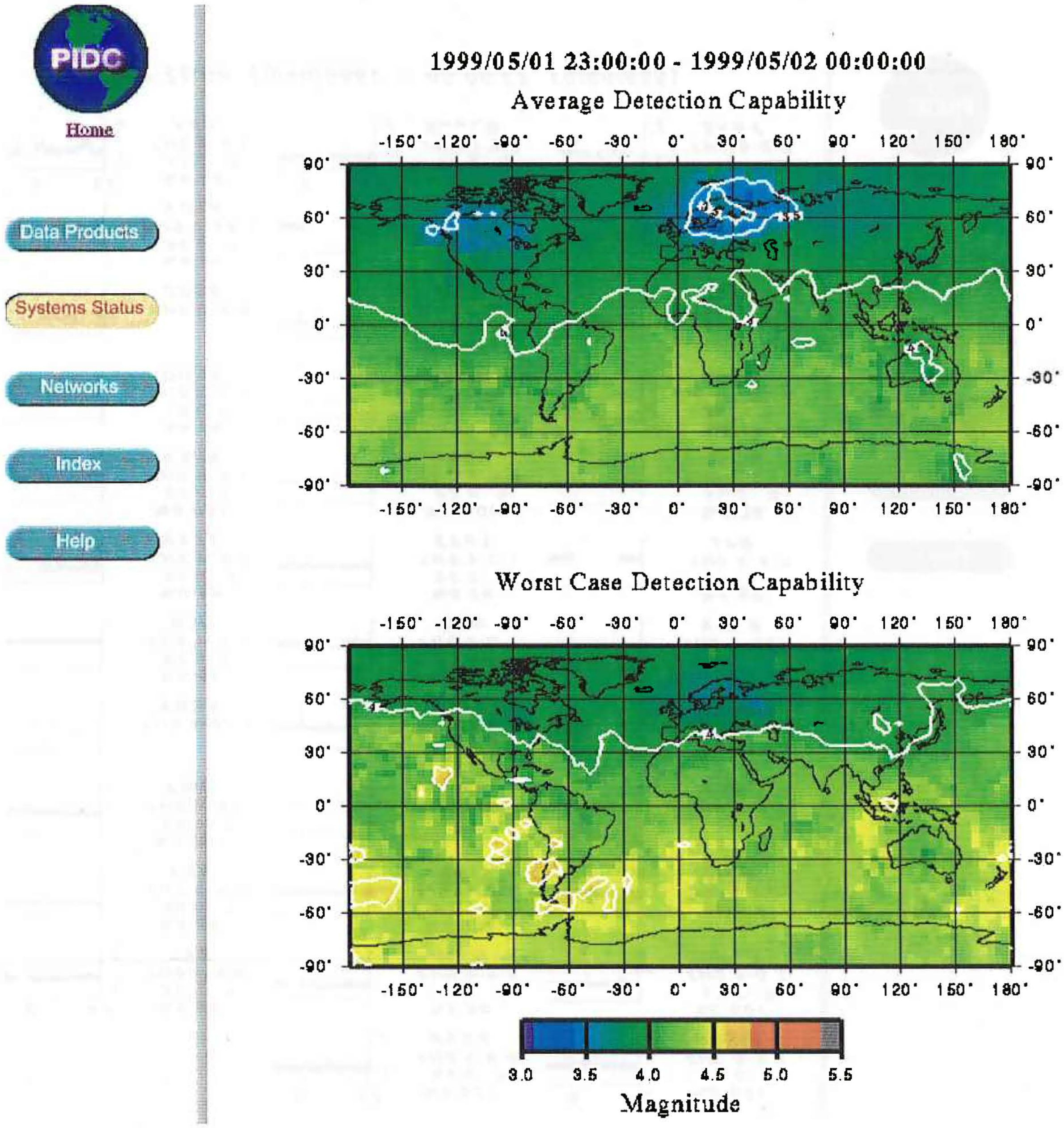


*Fig. 6.4.7. Example of a time interval with a low threshold in Scandinavia. These "detplot" maps are from 1 May 1999 between 23:00 and midnight. It is common for threshold levels to be lower at night. Scandinavia is well covered by seismic arrays, but some other areas, such as South America, are not.*

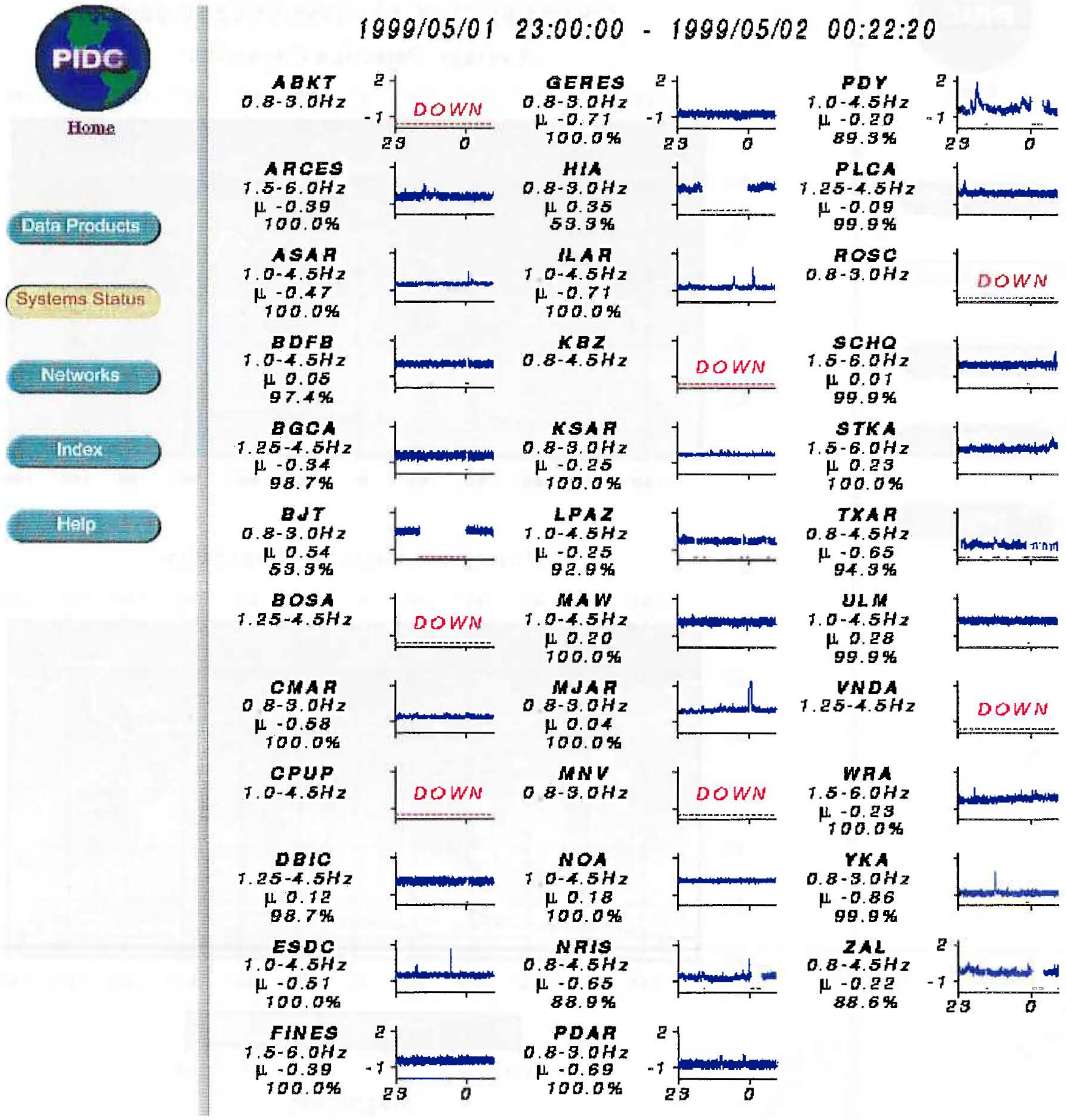


*Fig. 6.4.8. Status plots for 1 May 1999 starting at 23:00. All stations in the vicinity of Scandinavia (ARCES, FINES, GERES, and NOA) show quiet conditions. No obvious event is recorded on more than one station.*

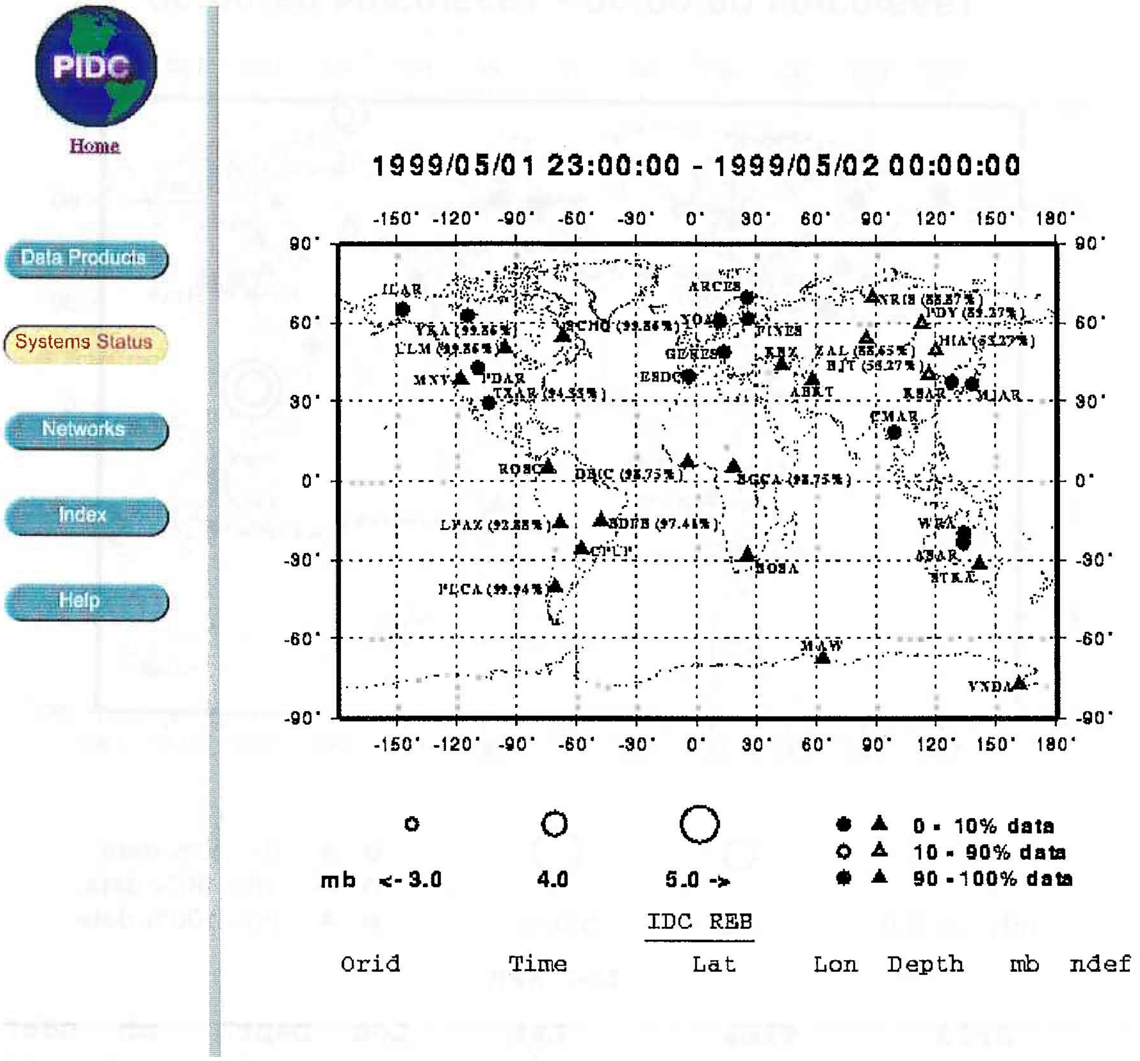
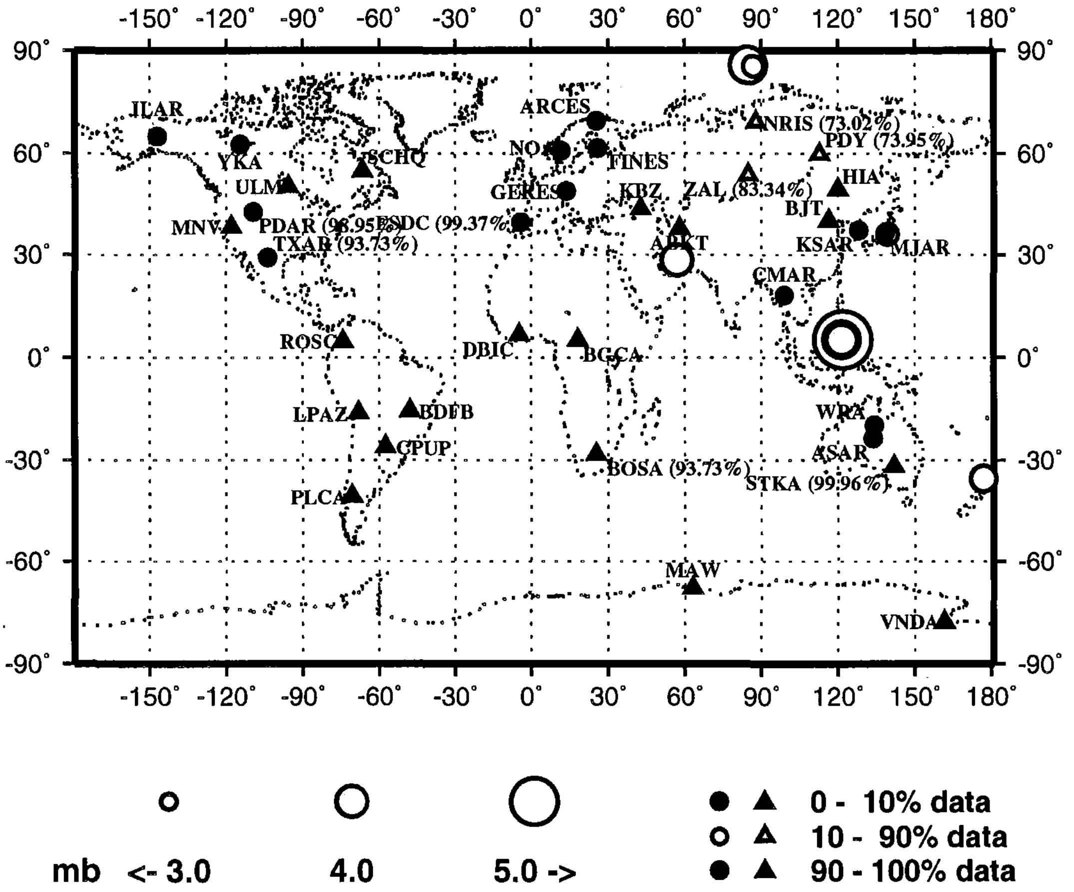


*Fig. 6.4.9. "Uptime" map for 1 May 1999 between 23:00 and midnight. Note that most of the stations which are down are far from Scandinavia, and are all three component stations rather than arrays.*


1999/03/04 08:00:00 - 1999/03/04 09:00:00

**IDC REB**

| Orid | Time | Lat | Lon | Depth | mb | ndef |
|---|---|---|---|---|---|---|
| 20363522 | 07:52:45 | 85.68 | 84.76 | 0.0 | 4.40 | 23 |
| 20363408 | 08:17:45 | 85.34 | 86.72 | 0.0 | 3.35 | 6 |
| 20363405 | 08:17:59 | 8.46 | 125.25 | 700.0 | 2.27 | 4 |
| 20363424 | 08:29:15 | 36.09 | 139.35 | 68.0 | 3.40 | 11 |
| 20363210 | 08:43:11 | 28.20 | 56.94 | 0.0 | 3.64 | 5 |
| 20367943 | 08:46:49 | -35.42 | 176.92 | 22.0 | 3.62 | 5 |
| 20363277 | 08:51:58 | 5.39 | 121.90 | 0.0 | 5.78 | 49 |
| 20363321 | 09:06:50 | 5.19 | 121.69 | 0.0 | 4.30 | 9 |
| 20363326 | 09:16:07 | 5.41 | 121.72 | 0.0 | 4.11 | 5 |
| 20363204 | 09:19:38 | 28.43 | 57.06 | 40.7 | 4.03 | 17 |

*Fig. 6.4.10. Appearance of the "uptime" map shown in Fig. 6.4.6 after events from the Reviewed Event Bulletin have been added to it. At present, these results are not available on the web. We hope this problem will be fixed in the near future.*

## 6.5 Observed Characteristics of Regional Seismic Phases and Implications for P/S Discrimination in the Barents/Kara Sea Region

### *Abstract*

In this paper, we use data from the regional networks operated by the Kola Regional Seismological Centre (KRSC) and NORSAR to study the seismicity and characteristics of regional phases of the Barents/Kara Sea region. While the detection and location capability of the regional network is outstanding, source classification of small seismic events has proved very difficult. In particular, the seismic event near Novaya Zemlya on 16 August 1997 at 02:11 GMT has been the subject of extensive analysis in order to locate it reliably and to classify the source type. It has been argued that this event could be confidently classified as an earthquake, especially based on observed P/S ratios. We consider some of this evidence in light of other observations of earthquakes and explosions in the region, including NORSAR recordings of past underground nuclear explosions. We show that there is an apparent source scaling of the P/S ratio of Novaya Zemlya explosions recorded at NORSAR in such a way that the larger explosions have a relatively high P/S ratio. Such an effect would make a reliable comparison difficult between P/S ratios of small and large events. Furthermore, this amplitude ratio shows large variability for the same source type and similar propagation paths, even when considering closely spaced observation points. This effect is most pronounced at far-regional distances and relatively low frequencies (typically 1-3 Hz), but it is also significant on closer recordings (around 10 degrees) and at higher frequencies. Our conclusion from this study is that the P/S ratio even at high frequencies is, with present knowledge, not sufficiently stable to be used as a reliable discriminant between earthquakes and explosions. Future application of this discriminant will require extensive regional calibration and detailed station-source corrections.

*Key Words: Seismic sources, Discrimination, Wave propagation*

### *Introduction*

NORSAR and Kola Regional Seismological Centre (KRSC) of the Russian Academy of Sciences have for many years cooperated in the continuous monitoring of seismic events in North-West Russia and adjacent sea areas. The overall objective is to characterize the seismicity of this region, to investigate the detection and location capability of regional seismic networks and to study various methods for screening and identifying seismic events in order to improve monitoring of the Comprehensive Test Ban Treaty (CTBT). The research has been based on data from a network of sensitive regional arrays which has been installed in northern Europe during the last decade in preparation for the CTBT monitoring network. This regional network, which comprises stations in Fennoscandia, Spitsbergen and NW Russia (see Fig. 6.5.1) provides a detection capability for the Barents/Kara Sea region that is close to $m_b = 2.5$ (Ringdal, 1997).

The 16 August 1997 seismic event in the Kara Sea has caused a considerable and renewed interest in the seismicity of the region surrounding the Novaya Zemlya islands. Historically, registered earthquake activity in this region has been virtually nonexistent, with the exception of one presumed earthquake (mb=4.3) in the Kara Sea close to the NZ coast on 1 August 1986 (Marshall et al, 1989). The 16 August event (mb=3.5) has been classified as an earthquake by several investigators (Richards and Kim, 1997; Hartse, 1998), mostly based on the P/S ratio observed at high frequencies.

This paper addresses the possibilities and limitations of utilizing the P/S ratio to characterize seismic events at low magnitudes in this region. We note that the P/S discriminant has been extensively studied in many areas of the world, but at present there is no consensus on the applicability of this discriminant on a global basis.

### *Data*

The seismicity of the Barents/Kara sea region is quite low as discussed by Ringdal (1997). Nuclear and chemical explosions were conducted at Novaya Zemlya until 1990, but the availability of regional data for these events is quite limited because most of the regional arrays were established after this time. In addition, these explosions were generally large, except for two smaller nuclear explosion in 1977 and 1984, and two chemical explosions in 1978 and 1987 (Ringdal, 1997, Khristoforov, 1996). A small presumed earthquake occurred on Novaya Zemlya near the nuclear test site in 1986. To our knowledge, there is no available digital recordings at near-regional distances (less than 12 degrees) for any of these smaller events. Although there has been several low-magnitude seismic events detected near Novaya Zemlya in recent years, they are difficult to use for establishing or testing regional discriminants, since there is usually no confirmed evidence as to their source type.

In other parts of the European Arctic, there is a quite good selection of reference earthquakes and mining explosions. For example, there are some well-known mining areas in the Kola Peninsula and Vorkuta south of Novaya Zemlya. The seismic event occurrence is also very high in the Spitsbergen area and offshore Norway (to the north and west). These events are presumably mostly earthquakes.

We have made a selection of known nuclear explosions, known earthquakes and some unknown events as a basis for this study. The events are listed in Table 6.5.1 and shown in Fig. 6.5.1 together with the station network. Some of the smaller events have been located by Kremenetskaya et al (1999).

### *P/S Ratios Observed at NORSAR*

#### **Novaya Zemlya events**

The NORSAR large array (Bungum et. al., 1971) has an extensive database of recordings from events near Novaya Zemlya, including some nuclear explosions of magnitudes similar to those of the 16 August event and the nearby presumed earthquake of 1 August 1986. The large aperture of NORSAR makes it possible to study the spatial variability of signal characteristics for the same seismic event over an area extending up to 100 km across. We will in the following compare the P/S ratios as recorded by individual sensors in the array. Fig. 6.5.2 shows, as an example, recordings at the center seismometer of the 7 NORSAR subarrays for the nuclear explosion of 9 Oct 1977. The magnitude is 4.5 and the epicentral distance is about 20 degrees. The data have been filtered in the band 1.0-3.0 Hz. The following observations can be made:

- The P/S ratios show very large variability (about an order of magnitude) across the array.

- This variability is dominated by strong P-wave focusing effects across NORSAR (see also Ringdal, 1990)

It may be concluded from the variability shown in this figure that P/S in the 1-3 Hz frequency band is not a very promising discriminant when using data recorded at a single station. Recent studies for Central Asia (Hartse et al, 1997), has shown that the P/S discriminant for that region appears effective at frequencies above 4 Hz, but has a poor performance for frequencies below 4 Hz. At NORSAR, there is almost no significant S-wave energy above 4 Hz, so we are confined to consider the lower frequencies for Novaya Zemlya events.

### Source scaling of the P/S ratio

The NORSAR array data base includes digital recordings of both large and small nuclear explosions from Novaya Zemlya. It is instructive to study the P/S pattern of these explosions as a function of the event size. In order to accomplish this, we have used the one NORSAR sensor (01A01) that has dual gain recording (the usual high-gain channel and a channel that is attenuated by 30dB). The attenuated channel has been available since 1976, and therefore provides a good data base of unclipped short period recordings of Novaya Zemlya explosions.

We have studied the P/S ratio as a function of magnitude (world-wide as well as NORSAR) for 16 Novaya Zemlya nuclear explosions for which attenuated channel data were available. As discussed by Ringdal (1997b), a magnitude-dependent trend is clearly seen, and is similar regardless of the reference magnitude used. This indicates that P-wave focusing effects are not a dominant cause of the trend. There could be other possible explanations, such as systematic differences in depth of burial or source corner frequency effects, but for our purposes, it is sufficient to state that comparing the P/S ratios of large and small events could easily give misleading conclusions.

An illustration for two of these explosions is shown in Fig. 6.5.3. The difference in P/S ratios between these two explosions is in fact at least as large as the differences seen for Kevo recordings comparing the 16 August 1997 event and a nuclear explosion at Novaya Zemlya (Fig. 6.5.4). We note that these Kevo recordings, which compare two events with a magnitude difference of two full units, have been used as an indication of a different source type for these two events. Admittedly, the Kevo recordings are in a higher frequency band (3-5 Hz), but it would seem reasonable that a source scaling as described above might in fact be present also at these higher frequencies.

### NORSAR recordings of Kola nuclear explosion and earthquake

In order to illustrate the behavior of the P/S discriminant at higher frequencies (3-5 Hz), we have investigated the pattern of P/S ratio across the full NORSAR array (22 subarrays, center sensors) for the nuclear explosion in the Kola Peninsula on 4 September 1972 (see Fig. 6.5.5). This explosion had an epicentral distance of only about 11 degrees, and consequently has a fair amount of high-frequency energy both for the P and the S phase. The P/S ratio varies considerably across NORSAR even in the frequency range 3-5 Hz, but the variation is considerably less than for the 1-3 Hz recording of the Novaya Zemlya nuclear explosion shown earlier. This indicates that the P/S ratio may be more promising as a discriminant in this higher frequency band.

In order to assess this further, we show in Fig. 6.5.6 selected NORSAR traces for an earthquake in the Kola Peninsula in 1990 (felt in the Murmansk district) and the Kola nuclear explosion in 1984 (colocated with the 1972 explosion). Both are at an epicentral distance of between 11 and 12 degrees. It appears that the P/S ratio is slightly higher for the explosion, but the difference is not very significant in view of the relative variation in P/S ratios for each event. Thus, the performance of the P/S ratio discriminant is questionable even in the 3-5 Hz frequency band.

### *The 16 August 1997 Event*

On 16 August 1997, the CTBT prototype International Data Center in Arlington, Va. reported a small seismic disturbance located in the Kara Sea, near the Russian nuclear test site on Novaya Zemlya. The event caused considerable interest, since initial analysis indicated that the seismic signals had characteristics similar to those of an explosion.

NORSAR and KRSC worked together on locating this event, each carrying out independent analysis. Since some phase onsets were very difficult to read, this was quite useful, and the results were very consistent. We were very quickly able to confirm beyond doubt that the 16 August 1997 event was located in the Kara Sea, at least 100 km from the Novaya Zemlya nuclear test site.

Perhaps the best indication of an earthquake source would be the presence of several aftershocks, if such could be found. We have carried out a detailed search for aftershocks of the 16 August 1997 event, using both Spitsbergen array data and data that later have become available at KRSC from the Amderma station south of Novaya Zemlya.

Our search of Spitsbergen data, which was conducted by detailed visual inspection of the array beam, enabled us to find a second (smaller) event from the same site a little more than 4 hours after the main event. This second event had Richter magnitude 2.6, and could be quite clearly seen to originate from the same source area (Fig. 6.5.7).

This conclusion was supported when Amderma data became available at KRSC some weeks later. In spite of very careful analysis of both Spitsbergen and Amderma data, we have not been able to identify additional aftershocks during the two weeks following the main event.

### Use of Amderma data for studying P/S ratios

Fig. 6.5.8 shows Amderma vertical component recordings of five seismic events at a similar epicentral distance from the station (about 300 km). The data have been filtered in the 3-8 Hz band. The five events are the two Kara Sea events on 16 August 1997, two mining explosions in Vorkuta south of the station, and a small event at the coast of Novaya Zemlya in 1995 (Kremenetskaya et al 1999).

The recordings are quite instructive. As can be seen by the scaling factor in front of the traces, the events vary in size by about an order of magnitude. It is noteworthy that the two Vorkuta explosions have very different P/S ratios, and encompass the range of P/S ratios for the other three events. This should however, not be taken as an indication of explosive sources for the other events, since we have demonstrated that the P/S ratio does not have sufficient stability to provide confident source identification. Unfortunately, we do not have any confirmed earthquake recordings at Amderma at a similar epicentral distance.

It is of interest to note that for both the event in 1995 and the first event in 1997, the estimated origin times (assuming zero depth) are almost exactly on the minute. These origin times have been calculated by using the Barents travel time model (Kremenetskaya et. al., 1999) , and are estimated to be accurate to within less than 1.0 seconds. This could be taken as indicators that one or both of these two events were man-made. However, it should be noted that the second event on 16 August 1997 did not occur on the entire minute. In any case, our waveform analysis does not support any assertion about the nature of the 16 August event either as an earthquake or as an explosion.

## *Conclusions*

We conclude from this study that the P/S ratio is currently unproven as a seismic discriminant, and should be applied with great caution when attempting to identify the source type of seismic events. Case studies for the Barents/Kara Sea region, some of which are discussed briefly in this paper, have demonstrated that the P/S ratio, even at high frequencies, is rather unstable and should not be relied upon for regional event discrimination..

The Kara Sea event on 16 August 1997 provides an interesting case study for the Novaya Zemlya region. It highlights the fact that even for this well-calibrated region, where numerous well-recorded underground nuclear explosions have been conducted, it is a difficult process to reliably locate and classify a seismic event of approximate $m_b$ 3.5.

We do not believe that the 16 August 1997 events can be positively identified as earthquakes on the basis of seismological evidence. On the other hand, neither is there any evidence based on the observed waveforms to confidently classify these events as explosions. Therefore, the source type of these two events remains unresolved.

It is clear from this study that more research is needed on regional travel-time calibration, regional signal characteristics and application of $M_s$:$m_b$ and other discriminants at regional distances. It would be a particularly useful exercise to carry out a small chemical calibration explosion, in order to improve the seismic calibration of Barents/Kara Sea region. Such an explosion, even if not recorded teleseismically, would provide valuable additional information for future studies.

**Frode Ringdal, NORSAR**
**Elena Kremenetskaya, KRSC, Apatity, Russia**

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Table 6.5.3. Seismic events referenced in this study.

| Date/time | Location | $m_b$ | Comment |
|---|---|---|---|
| 04.09.72/ 07.00.00 | 67.75 N, 33.10 E | 4.3 | Nuclear explosion, Kola Peninsula |
| 09.10.77/ 10.59.58 | 73.414 N, 54.935 E | 4.5 | Nuclear explosion, Novaya Zemlya |
| 10.08.78/ 07.59.58 | 73.293 N, 54.885 E | 6.0 | Nuclear explosion, Novaya Zemlya |
| 27.08.84/ 06.00.00 | 67.75 N, 33.00 E | 4.3 | Nuclear explosion, Kola Peninsula |
| 01.08.86/ 13.56.38 | 72.945 N, 56.549 E | 4.3 | Located by Marshall et.al. (1989) (presumed to be an earthquake) |
| 25.08.87 / 14.00.00 | 73.380 N, 54.780 E | 3.2 | Chemical explosion-974 ton (Khristoforov, 1996) |
| 16.06.90/ 12.43.28 | 68.52 N, 33.09 E | 4.0 | Earthquake, felt in the Murmansk region |
| 24.10.90/ 14.57.58 | 73.360 N 54.670E | 5.6 | Nuclear explosion, Novaya Zemlya |
| 23.02.95/ 21.50.00 | 71.856 N, 55.685 E | 3.5 | Located by Kremenetskaya et. al. (1999) |
| 31.01.97/ 04.23.53 | 67.3 N, 60.6 E | 2.5 | Mining explosion — Vorkuta region |
| 16.08.97 02.11.00 | 72.510 N, 57.550 E | 3.5 | Located by Ringdal et al (1997) |
| 16.08.97 06.19.10 | 72.5 N, 58 E | 2.6 | Probably co-located with preceding event |
| 14.02.98/ 00.49.37 | 67.34 N, 62.9 E | 2.4 | Mining explosion — Vorkuta region |

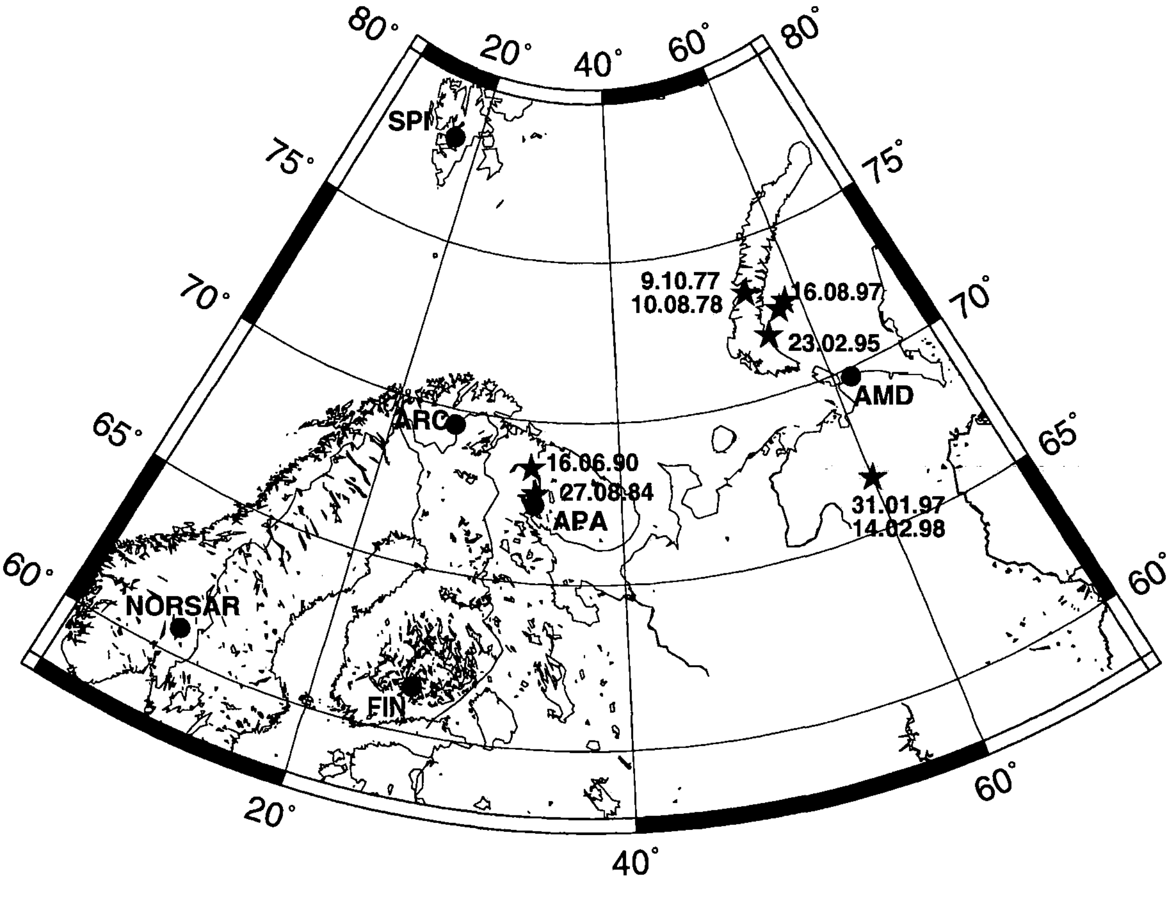


*Fig. 6.5.1. The network of regional arrays in Fennoscandia and adjacent areas. The locations of the seismic events used in this study are indicated.*

**NORSAR Amplitude Pattern**

**Novaya Zemlya explosion 10/09/77**

**Filter 1-3 Hz**

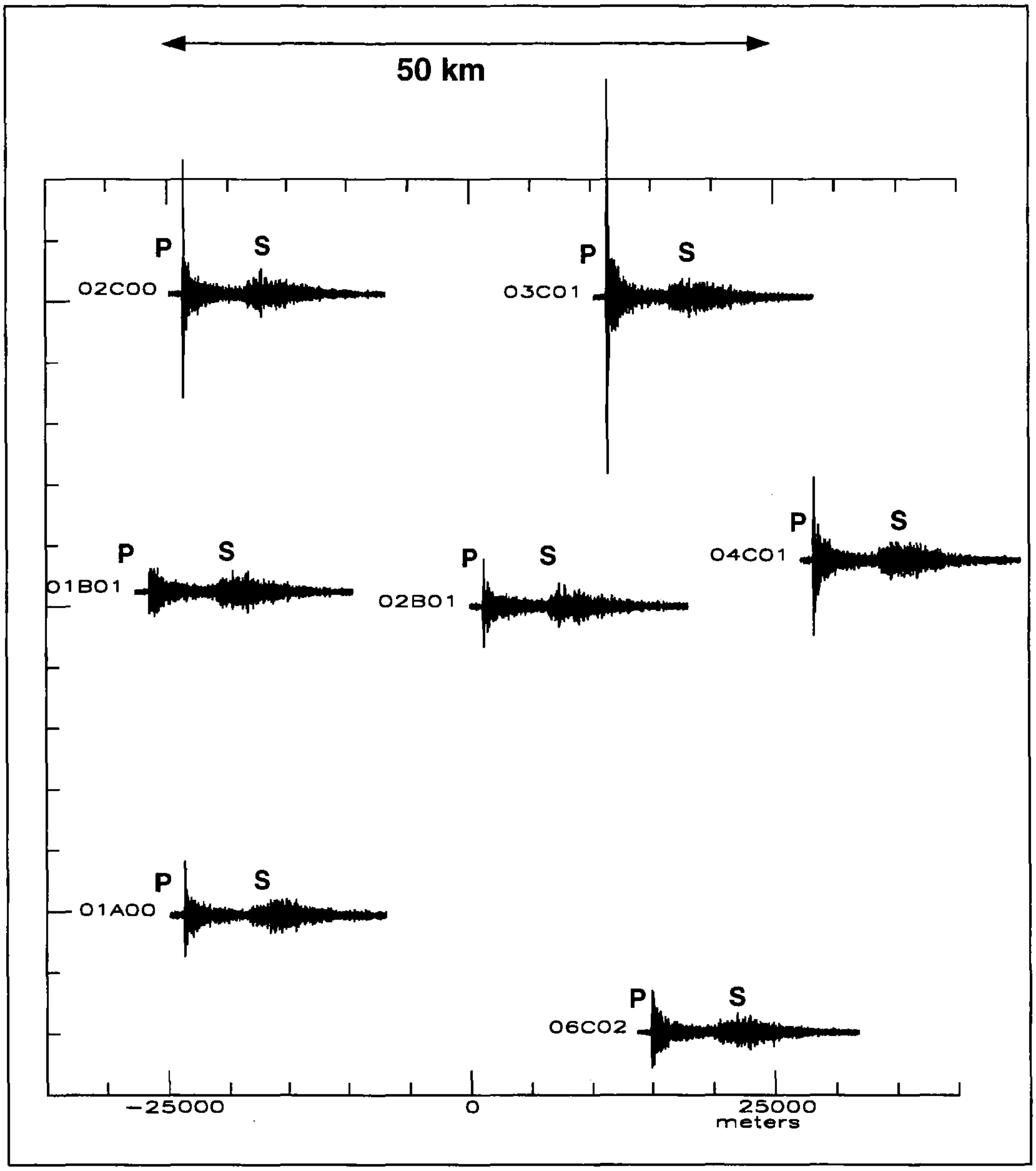


*Fig. 6.5.2. Recordings at the center seismometer of the 7 NORSAR subarrays for the Novaya Zemlya nuclear explosion of 9 Oct 1977. The magnitude is 4.5 and the epicentral distance is about 20 degrees. The data have been filtered in the band 1.0-3.0 Hz. Note the large variation in P/S ratios.*

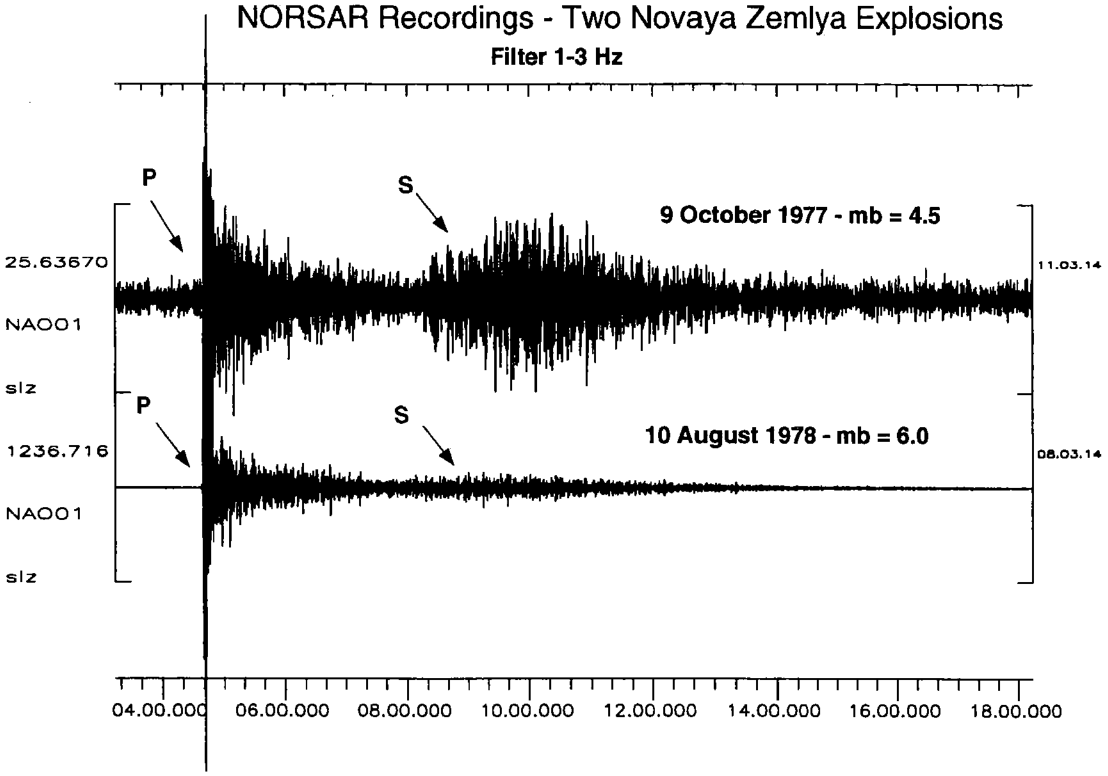


*Fig. 6.5.3. NORSAR recordings (seismometer 01A01) of two Novaya Zemlya nuclear explosions, filtered in the 1-3 Hz band. The top trace shows a small explosion ($m_b$=4.5), whereas the bottom trace shows a large explosion ($m_b$=6.0). The vertical scale has been amplified to highlight the difference in P/S ratio between the two events.*

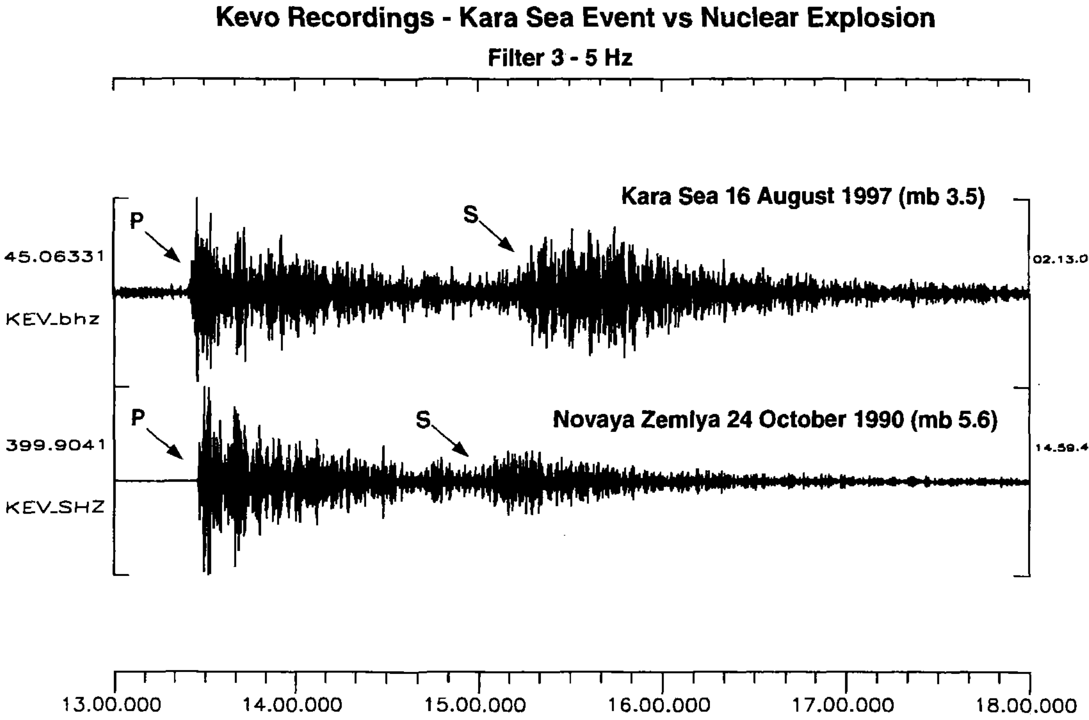


*Fig. 6.5.4. KEVO recordings filtered in the 3-5 Hz band. The top trace shows the 16 August 1997 seismic event ($m_b$=3.5), whereas the bottom trace shows the 24 October 1990 Novaya Zemlya nuclear explosion ($m_b$=5.6).*

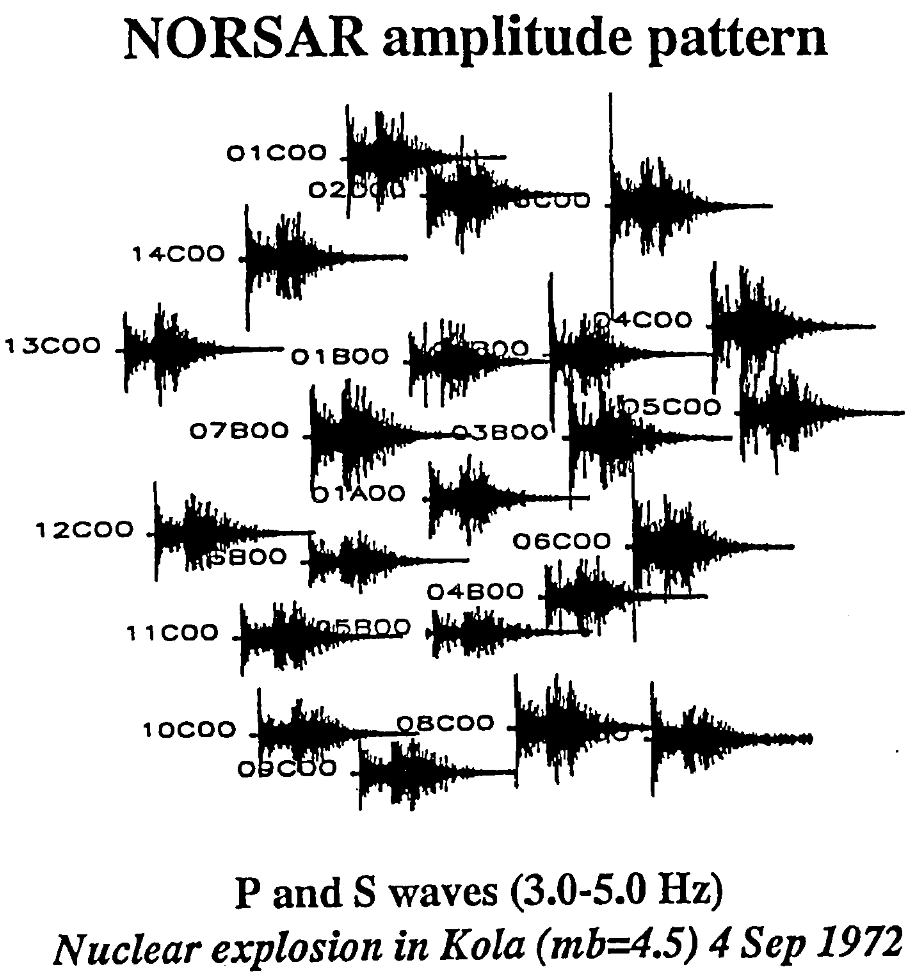
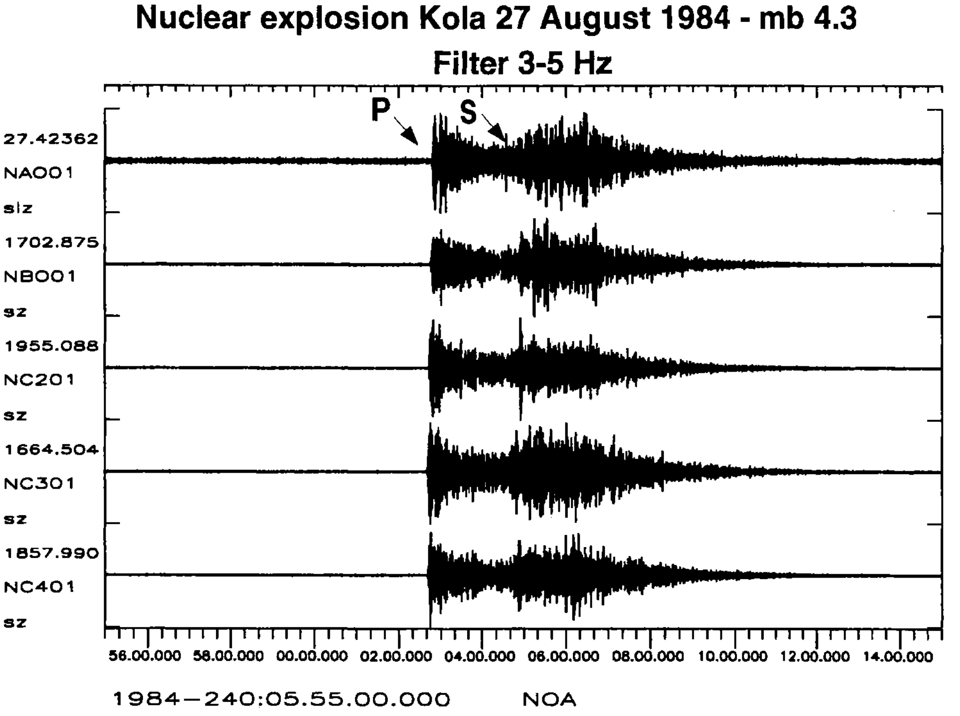


*Fig. 6.5.5. Amplitude pattern across NORSAR for the P and S phase of the Kola nuclear explosion on 4 September 1972 (distance 11 degrees). The data have been filtered in the 3-5 Hz band. Note that there is a strong variation in P/S ratios, although less than what was shown in Fig. 6.5.2 for the 1-3 Hz band.*



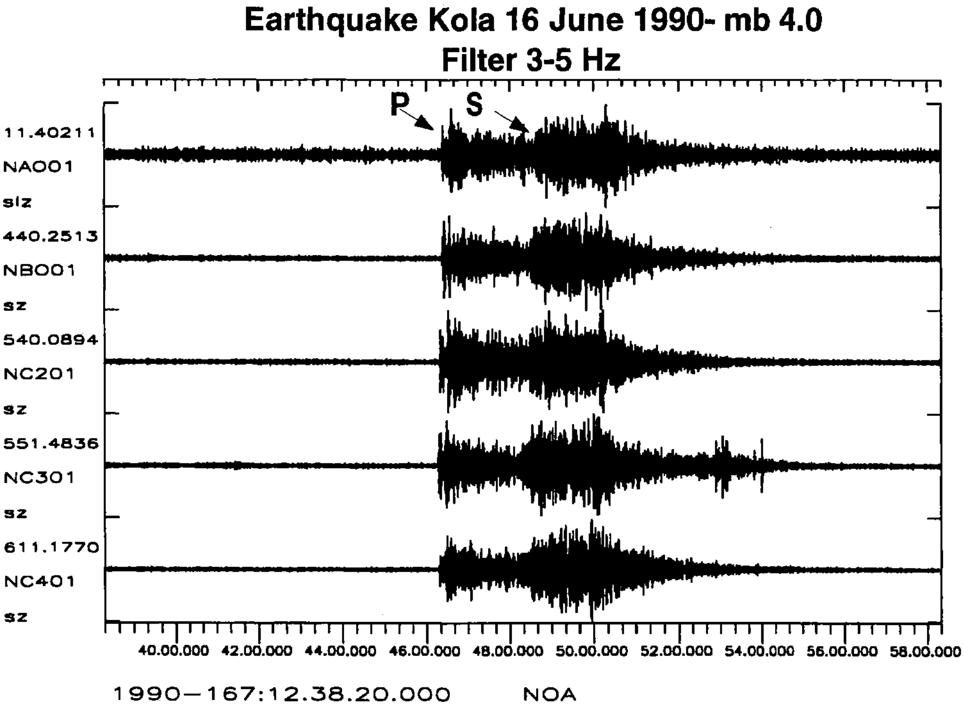


*Fig. 6.5.6. Selected NORSAR traces for an earthquake in the Kola Peninsula in 1990 (felt in the Murmansk district) and the Kola nuclear explosion in 1984 (colocated with the 1972 explosion). Both are at an epicentral distance of between 11 and 12 degrees. The data have been filtered in the 3-5 Hz band.*

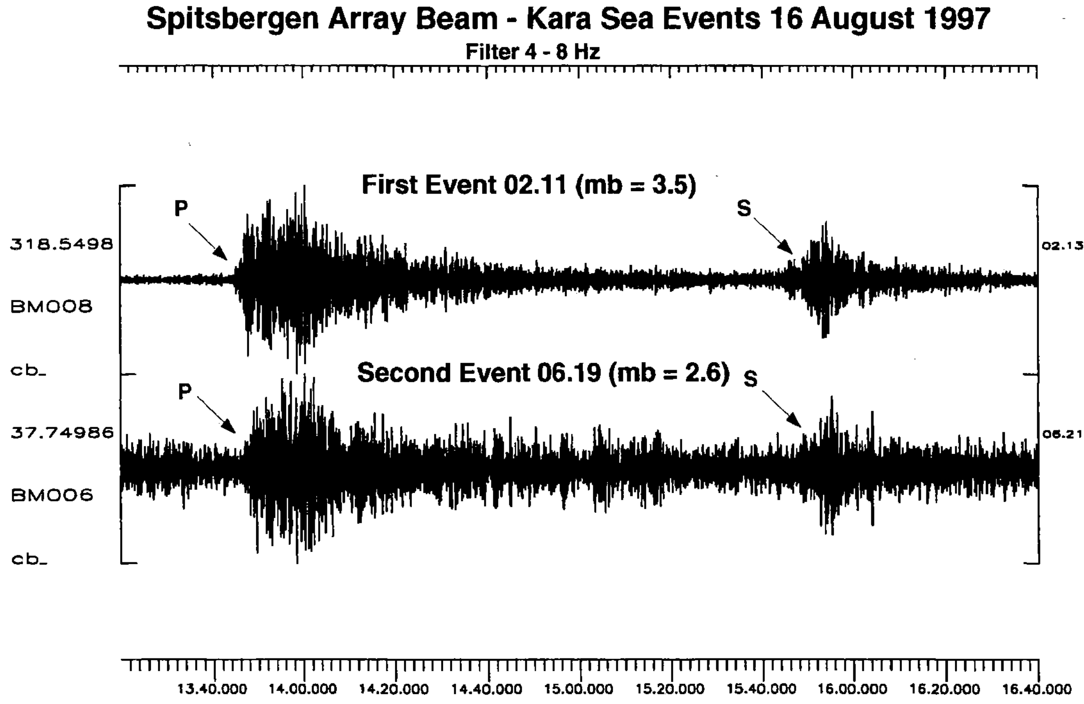


*Fig. 6.5.7. Recordings by the Spitsbergen array of the two events on 16 August 1997. The traces are array beams steered towards the epicenter, and with an S-type apparent velocity in order to enhance the S-phase. The traces are filtered in the 4-8 Hz band. Note that the traces are very similar, although not identical. The scaling factor in front of each trace is indicative of the relative size of the two events.*

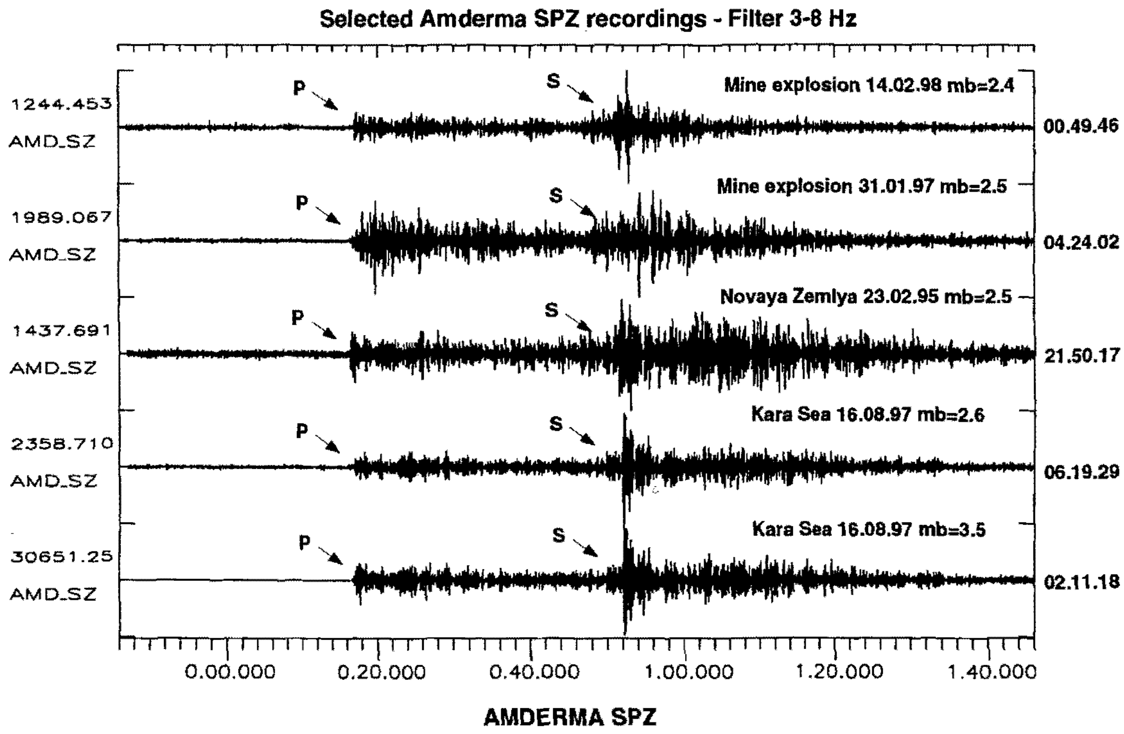


*Fig. 6.5.8. Amderma vertical component recordings of five seismic events at a similar epicentral distance from the station (about 300 km). The data have been filtered in the 3-8 Hz band. The five events are the two Kara Sea events on 16 August 1997, two mining explosions in Vorkuta south of the station, and a small event at the coast of Novaya Zemlya in 1995. The scaling factor in front of each trace is indicative of the relative size of the events.*