NORSAR Scientific Report No. 1-2012

Semiannual Technical Summary

1 October 2011 – 30 June 2012

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1 Summary

This report provides summary information on operation and maintenance (O&M) activities at the Norwegian National Data Center (NOR-NDC) for CTBT verification during the period 1 October 2011 – 30 June 2012, as well as scientific and technical contributions relevant to verification in a broad sense. The O&M activities, including operation of monitoring stations and transmission links within Norway and to Vienna, Austria are being funded jointly by the CTBTO/PTS and the Norwegian Government, with the understanding that the funding of O&M activities for primary stations in the International Monitoring System (IMS) will gradually be transferred to the CTBTO/PTS. The O&M statistics presented in this report maintain consistency with long-standing reporting practices. Research activities described in this report are mainly funded by the Norwegian Government, with other sponsors acknowledged where appropriate.

A summary of the activities at NOR-NDC relating to field installations, data acquisition, data forwarding and processing during the reporting period is provided in chapters 2 – 4 of this report. Norway is contributing primary station data from two seismic arrays: the Norwegian Seismic Array NOA (IMS code PS27) and the Arctic Regional Seismic Array ARCES (IMS code PS28), one auxiliary seismic array SPITS (IMS code AS72), and one auxiliary three-component station JMIC (IMS code AS73). These data are being provided to the International Data Centre (IDC) in Vienna via the Global Communications Infrastructure (GCI).

This report presents statistics for NOA, ARCES and SPITS as well as for additional seismic stations which through cooperative agreements with institutions in the host countries provide continuous data to NOR-NDC. These additional stations include the Finnish Regional Seismic Array (FINES, IMS code PS17) and the Hagfors array in Sweden (HFS, IMS code AS101).

So far among the Norwegian IMS stations, the NOA and the ARCES arrays (PS27 and PS28, respectively), the radionuclide station at Spitsbergen (RN49) and the auxiliary seismic stations on Spitsbergen (AS72) and Jan Mayen (AS73) have been certified. Provided that adequate funding continues to be made available (from the CTBTO/PTS and the Norwegian Ministry of Foreign Affairs), we envisage continuing the provision of data from these and other Norwegian IMS-designated stations in accordance with current procedures. As part of NORSAR's obsolescence management, a recapitalization plan for PS27 and PS28 was submitted to CTBTO/PTS in October 2008, with the purpose of preventing severe degradation of the stations due to lack of spare parts. The installation of new equipment for PS27 started in 2010.

The IMS infrasound station originally planned to be located near Karasjok (IS37) will be established at another site, since the local authorities did not grant the permissions required. A site at Bardufoss, at 69.1^0 N, 18.6^0 E, is currently being pursued with landowners and the municipal authorities for installation of IS37. The CTBTO Preparatory Commission has approved a corresponding coordinate change for the station.

Four scientific and technical contributions presented in chapter 6 of this report are provided as follows:

In *section 6.1* we report on an investigation to adapt processing pipelines to create pattern detectors (i.e., correlation, subspace and matched field detectors) that discover and organize repeating waveforms in data streams from a network of seismic arrays. A first version of a processing framework is up and running, and quite encouraging result are obtained for aftershocks of the 2005 Kashmir earthquake (M_w 7.6) when processing data from the Kazakhstan arrays KKAR (~10.5° distance) and ABKAR (~19.5° distance).

Section 6.2 describes equipment, installation, transfer function and noise performance of NORSAR's new broadband station TROLL in Dronning Maud Land, Antarctica. Although exposed to the harsh Antarctic climate, the station shows under favorable weather conditions a very low background noise level for signal periods smaller than 1 s, around 10 s and around 100 s.

Section 6.3 presents the first data and analysis results from NORSAR's new permanent, broadband seismic station (TROLL) in Dronning Maud Land, Antarctica. Earthquakes at local and regional distances from TROLL shed light on the seismicity of the Antarctic continent that has long been considered largely aseismic; the increasing establishment of seismic stations in Antarctica, however, shows that this is not the case. Apart from earthquakes, TROLL records multitudes of icequakes generated by the dynamic processes within the surrounding Antarctic ice sheet. A different class of cryosignals recorded at TROLL involves signals generated by large icebergs drifting along the Dronning Maud Land shoreline and the interaction of these icebergs with the ocean bottom and/or the ice shelf.

Section 6.4 summarizes results from a technical cooperation between the United Kingdom and Norway on disarmament verification. Specifically, the UK-Norway Initiative (UKNI) has addressed some of the technical and procedural challenges that verifying the dismantlement of nuclear warheads could pose. UKNI has included both technical development and a number of unique, ground-breaking exercises.

Svein Mykkeltveit

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

2.1 PS27 — Primary Seismic Station NOA

During this reporting period, NOA has undergone a complete refurbishment. See chapter 4 for details.

The mission-capable data statistics were 99.940%, as compared with 99.975% for the previous reporting period. The net instrument availability was 96.330%. There were no outages of all subarrays at the same time in the reporting period.

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

	Mission Capable	Net instrument availability
October 2011:	99.993%	91.919%
November 2011:	99.979%	99.553%
December 2011:	99.991%	99.602%
January 2012:	99.997%	99.144%
February 2012:	99.765%	97.837%
March 2012:	99.910%	98.619%
April 2012:	99.850%	98.014%
May 2012:	99.993%	93.349%
June 2012:	99.982%	88.936%

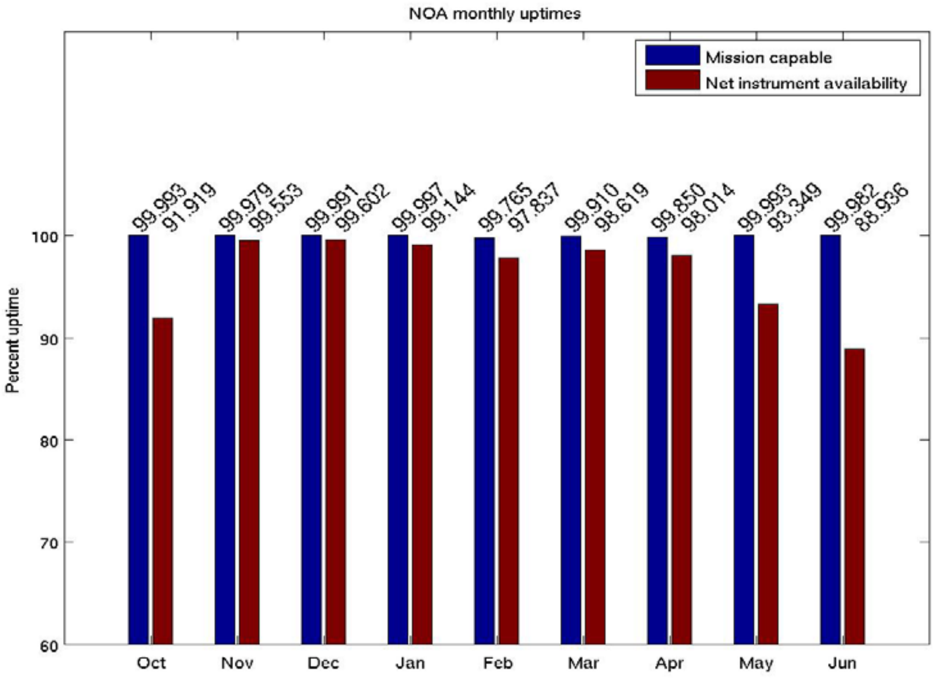

Fig. 2.1.1 Monthly uptimes for NOA for the period October 2011 – June 2012.

B. Paulsen

2.1.1 NOA Event Detection Operation

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

	Total DPX	Total EPX	Accepted events		Sum	Daily average
			P-phases	Core Phases		
Oct 2011	11555	1056	251	88	339	10.9
Nov	9312	900	211	59	270	9.0
Dec	11606	906	220	67	287	9.3
Jan 2012	12137	926	212	71	283	9.1
Feb	12701	1149	275	71	346	11.9
Mar	11830	1162	300	63	363	11.7
Apr	10124	1061	339	67	406	13.5
May	7550	1045	327	58	385	12.4
Jun	7799	1047	256	93	349	11.6
	94614	9252	2391	637	3028	11.0

Table 2.1.1. Detection and Event Processor statistics, 1 October 2011 - 30 June 2012.

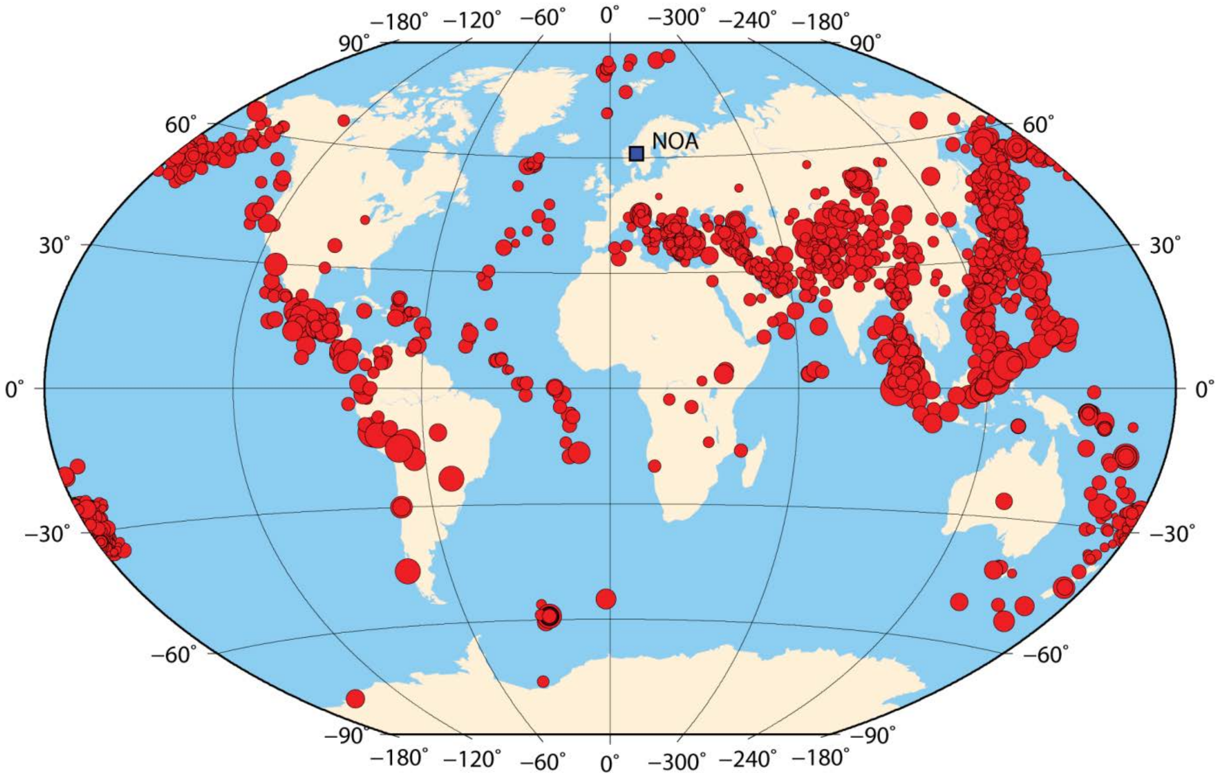

Fig. 2.1.2 Distribution of NOA one-array event locations in NORSAR's teleseismic reviewed bulletin for the time interval 1 October 2011 - 30 June 2012. Event symbols are scaled proportionally to event magnitude. The location of NOA is noted with a blue square.

NOA detections

The number of detections (phases) reported by the NORSAR detector during day 274, 2011, through day 182, 2012, was 94,614, giving an average of 345 detections per processed day (274 days processed). During the refurbishment of NOA May-June, 2012, there was a mix of new and old instrumentation with quite different system responses (short period and broadband). Thus, all data were converted into one common short period system response before processing.

B. Paulsen
U. Baadshaug

2.2 PS28 — Primary Seismic Station ARCES

The mission-capable data statistics were 98.408%, as compared with 99.729% for the previous reporting period. The net instrument availability was 92.509%.

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

Day	Period
Nov 17	16.18-23.59
Nov 18	00.00-17.42
Feb 05	09.47-23.59
Feb 06	00.00-21.50
Apr 12	14.10-23.59
Apr 13	00.00-23.59
Apr 14	00.00-07.45

Table 2.2.1. The main interruptions in recording of ARCES data at NDPC, 1 October 2011 – 30 June 2012.

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

	Mission Capable	Net instrument availability
October 2011:	100%	100%
November 2011:	96.451%	95.129%
December 2011:	100%	97.125%
January 2012:	100%	95.174%
February 2012:	94.995%	90.400%
March 2012:	100%	97.222%
April 2012:	94.223%	85.315%
May 2012:	100%	86.106%
June 2012:	100%	86.110%

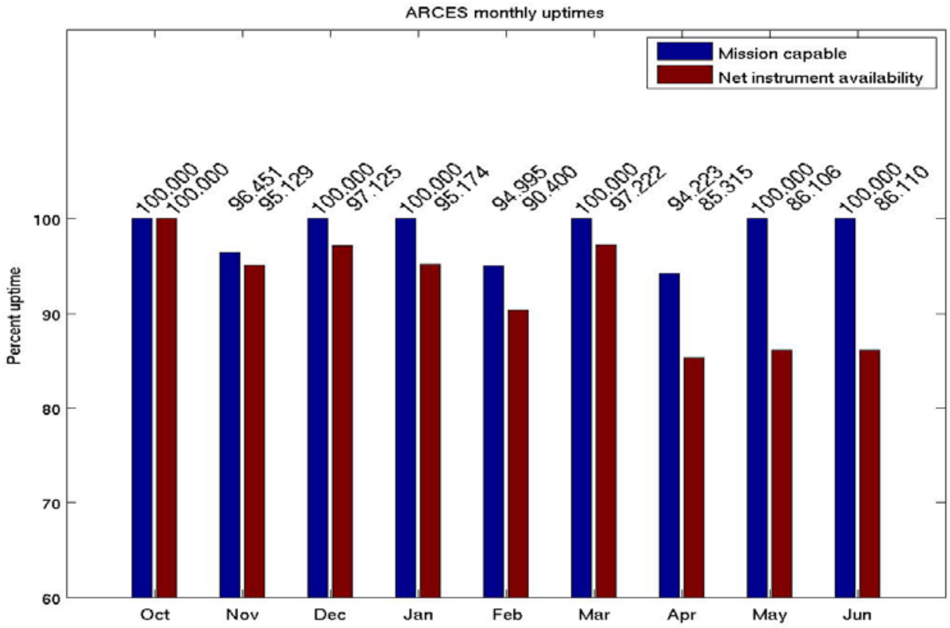

Fig. 2.2.1 Monthly uptimes for ARCES for the period October 2011 – June 2012.

B. Paulsen

2.2.1 Event Detection Operation

ARCES detections

The number of detections (phases) reported during day 274, 2011, through day 182, 2012, was 295,041, giving an average of 1,081 detections per processed day (273 days processed).

Events automatically located by ARCES

During days 274, 2011, through 182, 2012, 14,948 local and regional events were located by ARCES, based on automatic association of P- and S-type arrivals. This gives an average of 54.8 events per processed day (273 days processed). 74% of these events are within 300 km, and 92% of these events are within 1000 km.

U. Baadshaug

2.3 AS72 — Auxiliary Seismic Station SPITS

The mission-capable data for the period were 99.727%, as compared with 98.574% for the previous reporting period. The net instrument availability was 99.980%.

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:

	Mission Capable	**Net instrument availability**
October 2011:	99.963%	99.956%
November 2011:	99.996%	99.993%
December 2011:	99.996%	99.994%
January 2012:	99.994%	99.992%
February 2012:	99.989%	99.987%
March 2012:	99.995%	99.961%
April 2012:	99.995%	99.984%
May 2012:	99.994%	99.992%
June 2012:	99.959%	99.957%

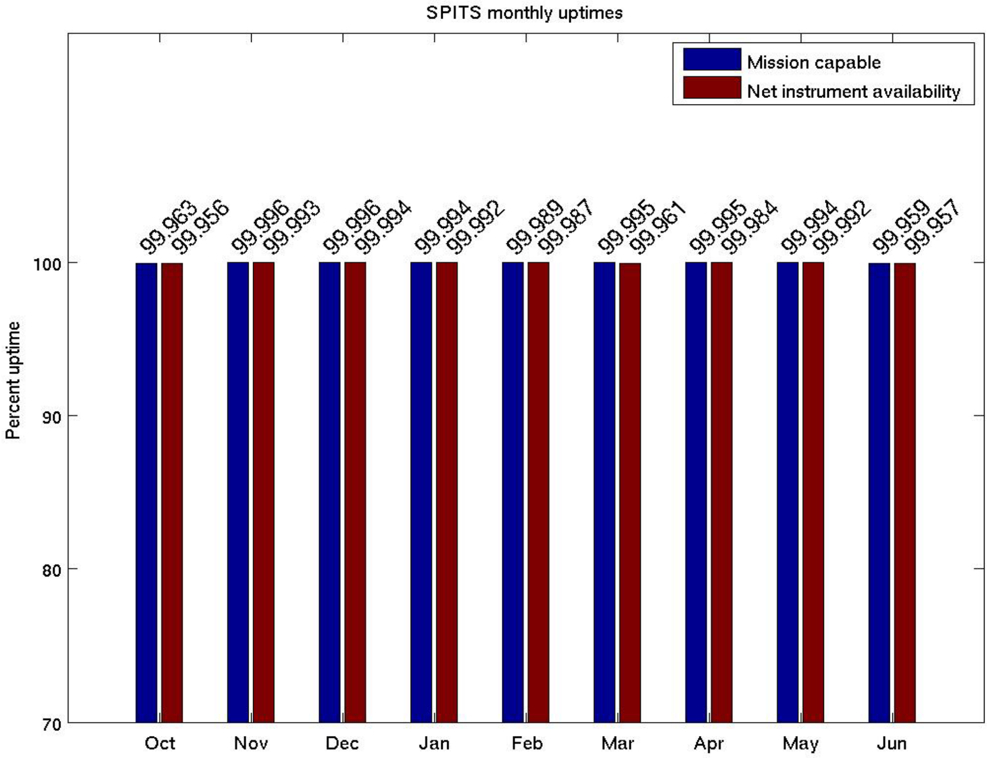

Fig. 2.3.1 Monthly uptimes for SPITS for the period October 2011 – June 2012.

B. Paulsen

2.3.1 Event Detection Operation

Spitsbergen array detections

The number of detections (phases) reported from day 274, 2011, through day 182, 2012, was 586,886, giving an average of 2,142 detections per processed day (274 days processed).

Events automatically located by the Spitsbergen array

During days 274, 2011 through 182, 2012, 51,949 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 189,6 events per processed day (274 days processed). 78% of these events are within 300 km, and 92% of these events are within 1000 km.

U. Baadshaug

2.4 AS73 — Auxiliary Seismic Station on Jan Mayen

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

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

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

J. Fyen

2.5 IS37 — Infrasound Station

The IMS infrasound network will, according to the protocol of the CTBT, 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.

It has, however, proved very difficult to obtain the necessary permits for use of land for an infrasound station at Karasjok. Various alternatives for locating the station at Karasjok were prepared, but all applications to the local authorities to obtain the permissions needed to establish the station were turned down by the local governing council in June 2007.

In 2008, investigations were initiated to identify an alternative site for IS37 outside Karasjok. A site at Bardufoss, at 69.1° N, 18.6° E, is currently being pursued with landowners and the municipal authorities, with the purpose of establishing IS37 at this site in cooperation with the CTBTO/PTS. The CTBTO preparatory Commission has approved the corresponding coordinate change for IS37.

J. Fyen

2.6 RN49 — Radionuclide Station on Spitsbergen

The IMS radionuclide network includes a station on the island of Spitsbergen. This station has been selected to be among those IMS radionuclide stations that will monitor for the presence of relevant noble gases upon entry into force of the CTBT.

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

S. Mykkeltveit

3 Contributing Regional Arrays

3.1 NORES

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

The station has been rebuilt and is operational in an experimental mode (9 inner sites instrumented with 3-component sensors) since December 2011. The array is part of the NORSAR instrument test facility co-located with NC602 of PS27 – NOA. The purpose of this station is array configuration experiments, in particular to optimize three-component array processing as well as direct instrument tests. The NORES array is thus not considered an operational station, as configuration and instrumentation may change from time to time. Operational statistics are thus not reported.

B. Paulsen

3.2 Hagfors (IMS Station AS101)

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

The mission-capable data statistics were 99.939%, as compared with 67.588% for the previous reporting period. The net instrument availability was 95.266%.

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

	Mission Capable	Net instrument availability
October 2011:	100%	91.667%
November 2011:	100%	91.667%
December 2011:	100%	91.667%
January 2012:	100%	91.667%
February 2012:	100%	91.667%
March 2012:	99.866%	99.475%
April 2012:	100%	100%
May 2012:	100%	100%
June 2012:	99.581%	99.582%

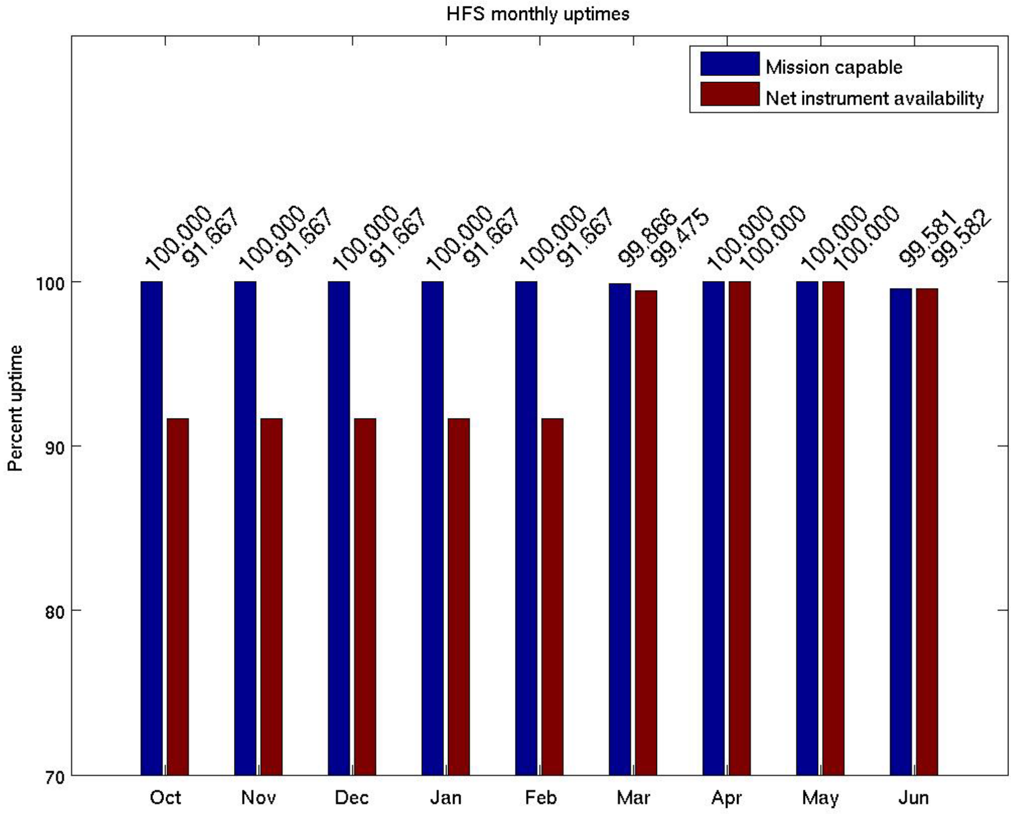

Fig. 3.2.1 Monthly uptimes for HFS for the period October 2011 – June 2012.

B. Paulsen

3.2.1 Hagfors Event Detection Operation

Hagfors array detections

The number of detections (phases) reported from day 274, 2011, through day 182, 2012, was 184,205, giving an average of 672 detections per processed day (274 days processed).

Events automatically located by the Hagfors array

During days 274, 2011, through 182, 2012, 6,113 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 22.3 events per processed day (274 days processed). 75% of these events are within 300 km, and 92% of these events are within 1000 km.

U. Baadshaug

3.3 FINES (IMS Station PS17)

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

The mission-capable data statistics were 99.935%, as compared with 98.917% for the previous reporting period. The net instrument availability was 99.954%.

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:

	Mission Capable	**Net instrument availability**
October 2011:	100%	100%
November 2011:	99.989%	99.989%
December 2011:	99.979%	99.980%
January 2012:	99.997%	99.997%
February 2012:	100%	100%
March 2012:	100%	100%
April 2012:	100%	100%
May 2012:	99.446%	99.622%
June 2012:	100%	100%

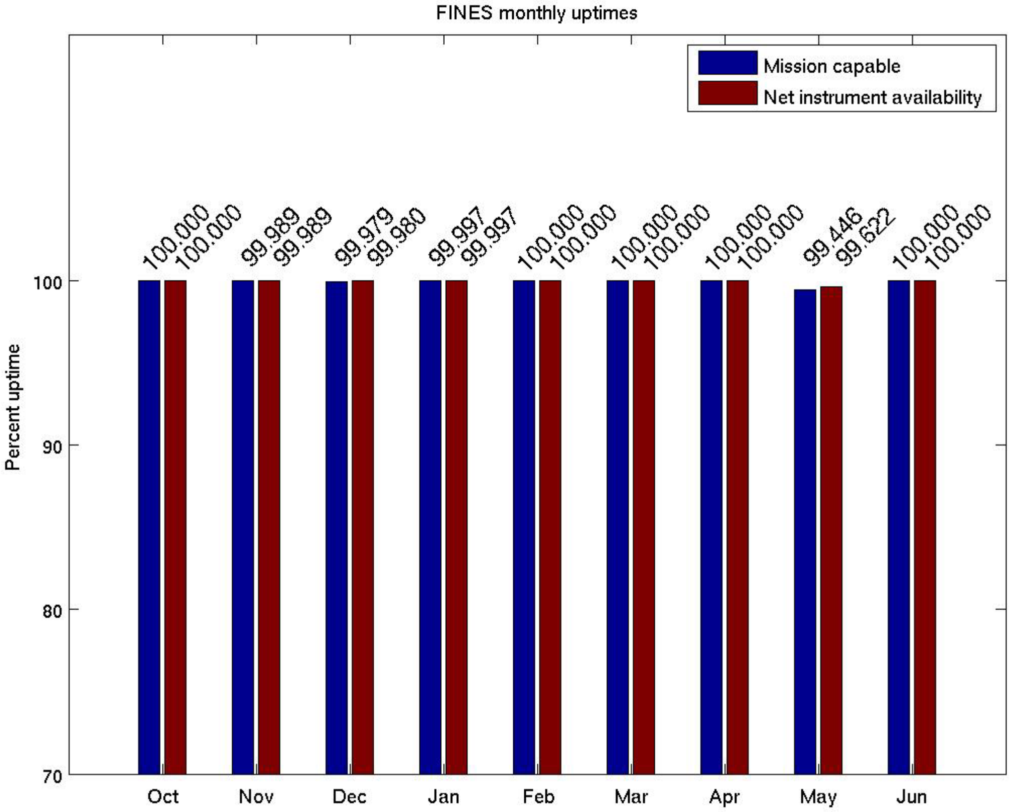

Fig. 3.3.1 Monthly uptimes for FINES for the period October 2011 – June 2012.

B. Paulsen

3.3.1 FINES Event Detection Operation

FINES detections

The number of detections (phases) reported during day 274, 2011, through day 182, 2012, was 59,506, giving an average of 217 detections per processed day (274 days processed).

Events automatically located by FINES

During days 274, 2011, through 182, 2012, 3,626 local and regional events were located by FINES, based on automatic association of P- and S-type arrivals. This gives an average of 13.3 events per processed day (274 days processed). 89% of these events are within 300 km, and 95% of these events are within 1000 km.

U. Baadshaug

3.4 Regional Monitoring System Operation and Analysis

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

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

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

3.4.1 Phase and event statistics

Table 3.4.1 gives a summary of phase detections and events declared by RMS. From top to bottom the table gives the total number of detections by the RMS, the number of detections that are associated with events automatically declared by the RMS, the number of detections that are not associated with any events, the number of events automatically declared by the RMS, and finally the total number of events worked on interactively (in accordance with criteria that vary over time; see below) and defined by the analyst.

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

To further reduce the workload on the analysts and to focus on regional events in preparation for Gamma-data submission during GSETT-3, a new processing scheme was introduced on 2 February

1995. The GBF (Generalized Beamforming) program is used as a pre-processor to RMS, and only phases associated with selected events in northern Europe are considered in the automatic RMS phase association. All detections, however, are still available to the analysts and can be added manually during analysis.

	Oct 11	Nov 11	Dec 11	Jan 12	Feb 12	Mar 12	Apr 12	May 12	Jun 12	Total
Phase detections	161251	159100	178099	158092	150345	144362	126972	108740	118010	1304971
Associated phases	8252	6409	6835	6053	5508	6870	5108	6543	5694	57272
Unassociated phases	152999	152691	171264	152039	144837	137492	121864	102197	112316	1247699
Events automatically declared by RMS	1910	1436	1423	1208	1157	1245	1065	1207	1305	11956
No. of events defined by the analyst	60	48	59	69	74	81	61	84	47	583

Table 3.4.1. RMS phase detections and event summary 1 October 2011 - 30 June 2012.

U. Baadshaug
B. Paulsen

4 NDC and Field Activities

4.1 NDC Activities

NORSAR functions as the Norwegian National Data Center (NDC) for CTBT verification. Six monitoring stations, comprising altogether 126 field sensors plus radionuclide monitoring equipment, will be located on Norwegian territory as part of the future IMS as described elsewhere in this report. The four seismic IMS stations are all in operation today, and all of them are currently providing data to the CTBTO/PTS on a regular basis. PS27, PS28, AS72, AS73 and RN49 are all certified. Data recorded by the Norwegian stations are being transmitted in real time to the Norwegian NDC, and provided to the IDC through the Global Communications Infrastructure (GCI). Norway is connected to the GCI with a frame relay link to Vienna.

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

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

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

International cooperation
The Norwegian Government has over the years supported efforts by NORSAR to build capacity at National Data Centers in various countries. In recent years, efforts have concentrated on cooperation with and assistance to countries in Central Asia. A training center for technical functions related to CTBT verification has been established in Almaty, Kazakhstan for trainees from countries in Central Asia.

After entry into force of the treaty, a number of countries are expected to establish national expertise to contribute to the treaty verification on a global basis. Norwegian experts have been in contact with experts from several countries with the aim of establishing bilateral or multilateral cooperation in this field.

NORSAR event processing

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

Communication topology

Norway has implemented an independent subnetwork, which connects the IMS stations AS72, AS73, PS28, and RN49 operated by NORSAR to the GCI at NOR-NDC. A contract has been concluded and VSAT antennas have been installed at each station in the network. Under the same contract, VSAT antennas for 6 of the PS27 subarrays have been installed for intra-array communication. The seventh subarray is connected to the central recording facility via a leased land line. The central recording facility for PS27 is connected directly to the GCI (Basic Topology). All the VSAT communication is functioning satisfactorily. As of 10 June 2005, AS72 and RN49 are connected to NOR-NDC through a VPN link.

Jan Fyen

4.2 Status Report: Provision of Data from Norwegian Seismic IMS Stations to the IDC

Introduction

This contribution is a report for the period October 2011 – June 2012 on activities associated with provision of data from Norwegian seismic IMS stations to the International Data Centre (IDC) in Vienna. This report represents an update of contributions that can be found in previous editions of NORSAR's Semiannual Technical Summary. All four Norwegian seismic stations providing data to the IDC have been formally certified.

Norwegian IMS stations and communications arrangements

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

During the reporting period, the intra-array communication for NOA utilized a land line for subarray NC6 and VSAT links based on TDMA technology for the other 6 subarrays (this was changed to DVB/RCS technology in September 2012). The central recording facility for NOA is located at the Norwegian National Data Center (NOR-NDC).

Continuous ARCES data were during the reporting period transmitted from the ARCES site to NOR-NDC using a 64 kbits/s VSAT satellite link, based on BOD technology (changed to DVB/RCS technology in October 2012).

Continuous SPITS data were transmitted to NOR-NDC via a VSAT terminal located at Platåberget in Longyearbyen (which is the site of the IMS radionuclide monitoring station RN49 installed during 2001) up to 10 June 2005. The central recording facility (CRF) for the SPITS array has been moved to the University of Spitsbergen (UNIS). A 512 bps SHDSL link has been established between UNIS and NOR-NDC. Data from the array elements to the CRF are transmitted via a 2.4 Ghz radio link (Wilan VIP-110). Both AS72 and RN49 data are now transmitted to NOR-NDC over this link using VPN technology.

A minimum of 14-day station buffers have been established at the ARCES and SPITS sites and at all NOA subarray sites, as well as at the NOR-NDC for ARCES, SPITS and NOA. In addition, each individual site of the SPITS array has a 14-day buffer. All data collected at the NOR-NDC are online on disk on one file system using CSS 3.0 format. Any data collected from 1971 up to now can be easily accessed. All data have online disk backup.

The NOA and ARCES arrays are primary stations in the IMS network, which implies that data from these stations are transmitted continuously to the receiving international data center. Since October 1999, these data have been transmitted (from NOR-NDC) via the Global Communications Infrastructure (GCI) to the IDC in Vienna. Data from the auxiliary array station SPITS — AS72 have been sent in continuous mode to the IDC during the reporting period. AS73 — JMIC is an auxiliary station in the IMS, and the JMIC data have been available to the IDC throughout the reporting period on a request basis via use of the AutoDRM protocol (Kradolfer, 1993; Kradolfer, 1996), as well as in continuous mode. In addition, continuous data from all three arrays are transmitted to the United States NDC.

Uptimes and data availability
Figs. 4.2.2 and 4.2.3 show the monthly uptimes for the Norwegian IMS primary stations ARCES and NOA, respectively, for the reporting period given as the hatched (taller) bars in these figures. These bar plots reflect the percentage of the waveform data that is available in the NOR-NDC data archives for these two arrays. The downtimes inferred from these figures thus represent the cumulative effect of field equipment outages, station site to NOR-NDC communication outage, and NOR-NDC data acquisition outages.

Figs. 4.2.2 and 4.2.3 also give the data availability for these two stations as reported by the IDC in the IDC Station Status reports. The main reason for the discrepancies between the NOR-NDC and IDC data availabilities as observed from these figures is the difference in the ways the two data centers report data availability for arrays: Whereas NOR-NDC reports an array station to be up and available if at least one channel produces useful data, the IDC uses weights where the reported availability (capability) is based on the number of actually operating channels.

NDC automatic processing and data analysis
These tasks have proceeded in accordance with the descriptions given in Mykkeltveit and Baadshaug (1996). For the reporting period NOR-NDC derived information on 593 supplementary events in northern Europe and submitted this information to the Finnish NDC as the NOR-NDC contribution to the joint Nordic Supplementary (Gamma) Bulletin, which in turn is forwarded to the IDC. These events are plotted in Fig. 4.2.4.

Current developments and future plans

NOR-NDC is continuing the efforts towards improving and hardening all critical data acquisition and data forwarding hardware and software components, so as to meet the requirements related to operation of IMS stations.

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

The two stations PS27 and PS28 have both been suffering from lack of spare parts over the last few years. The PS28 ARCES equipment was acquired in 1999, and it is no longer possible to get spare digitizers. A recapitalization plan for both arrays was submitted to the PTS in October 2008. Installation of new equipment for PS27 started in 2010 and was completed, except for one site, during this reporting period.

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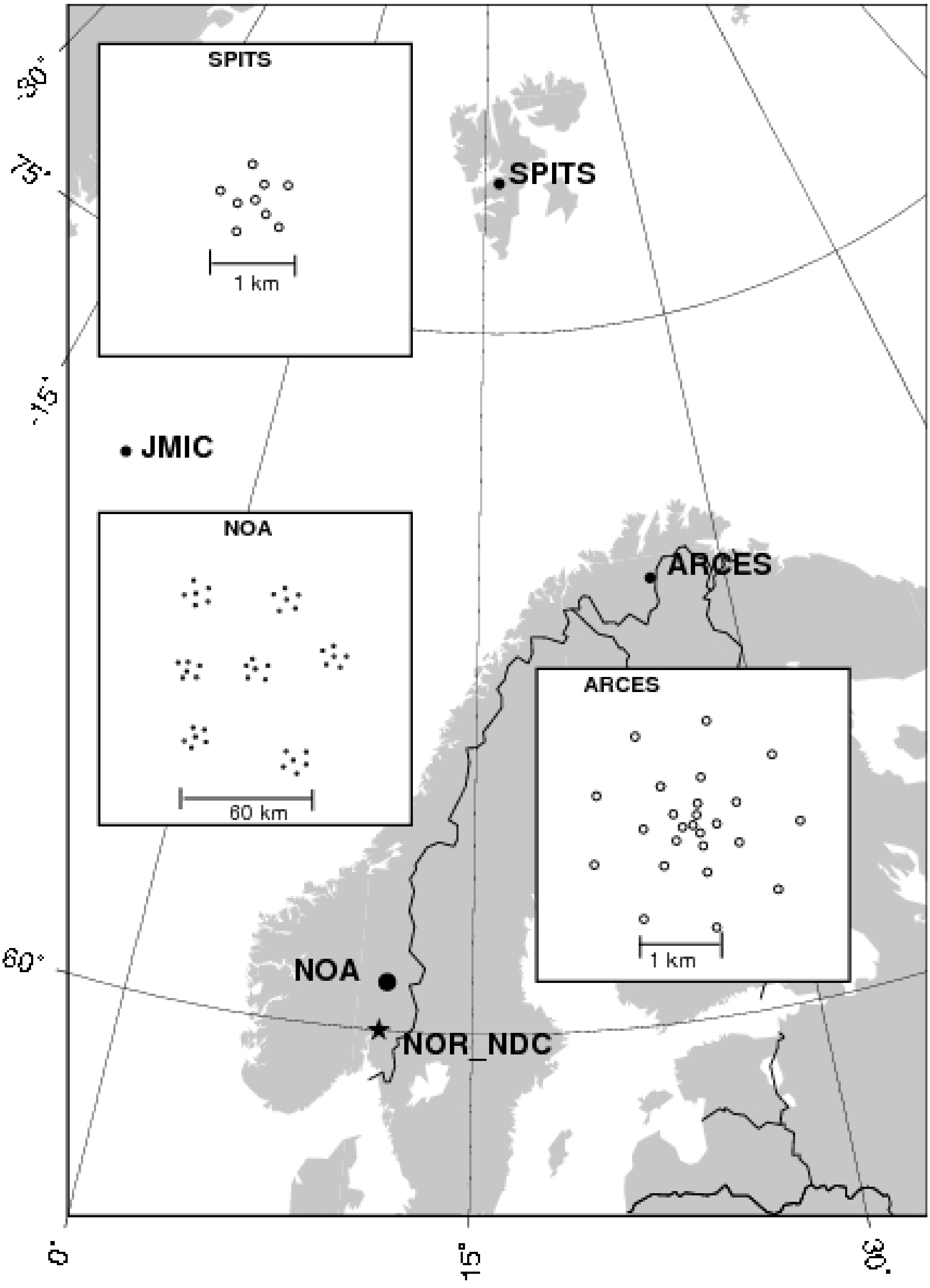

Fig. 4.2.1. The figure shows the locations and configurations of the three Norwegian seismic IMS array stations that provided data to the IDC during the period October 2011 – June 2012. The data from these stations and the JMIC three-component station are transmitted continuously and in real time to the Norwegian NDC (NOR-NDC). The stations NOA and ARCES are primary IMS stations, whereas SPITS and JMIC are auxiliary IMS stations.

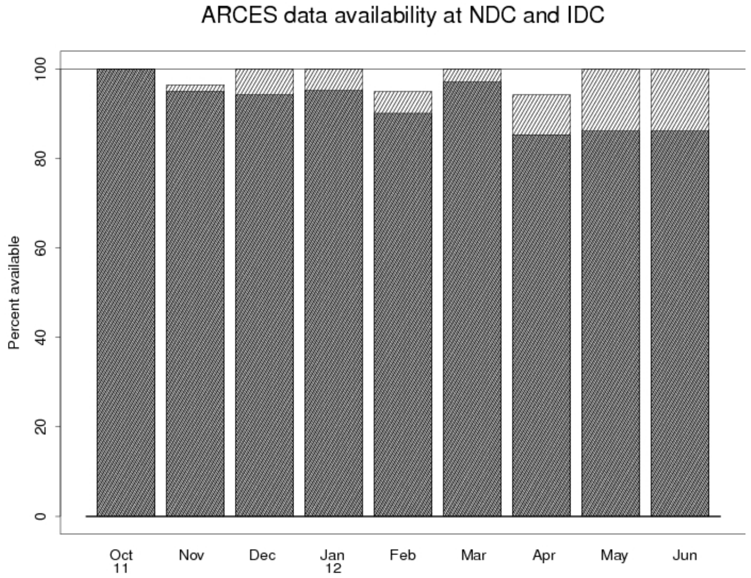

Fig. 4.2.2 The figure shows the monthly availability of ARCES array data for the period October 2011 – June 2012 at NOR-NDC and the IDC. See the text for explanation of differences in definition of the term "data availability" between the two centers. The higher values (hatched bars) represent the NOR-NDC data availability.

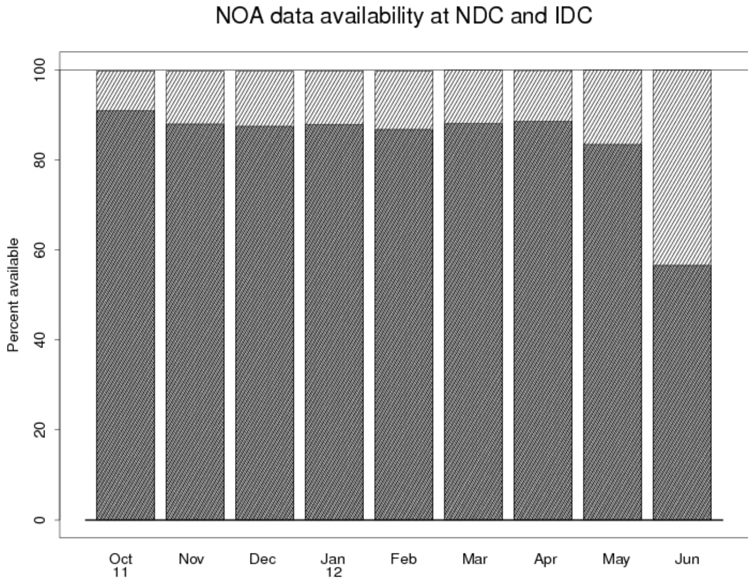

Fig. 4.2.3 The figure shows the monthly availability of NORSAR array data for the period October 2011 – June 2012 at NOR-NDC and the IDC. See the text for explanation of differences in definition of the term "data availability" between the two centers. The low value for data available at the IDC for June is due to the upgrading effort for NOA. The higher values (hatched bars) represent the NOR-NDC data availability.

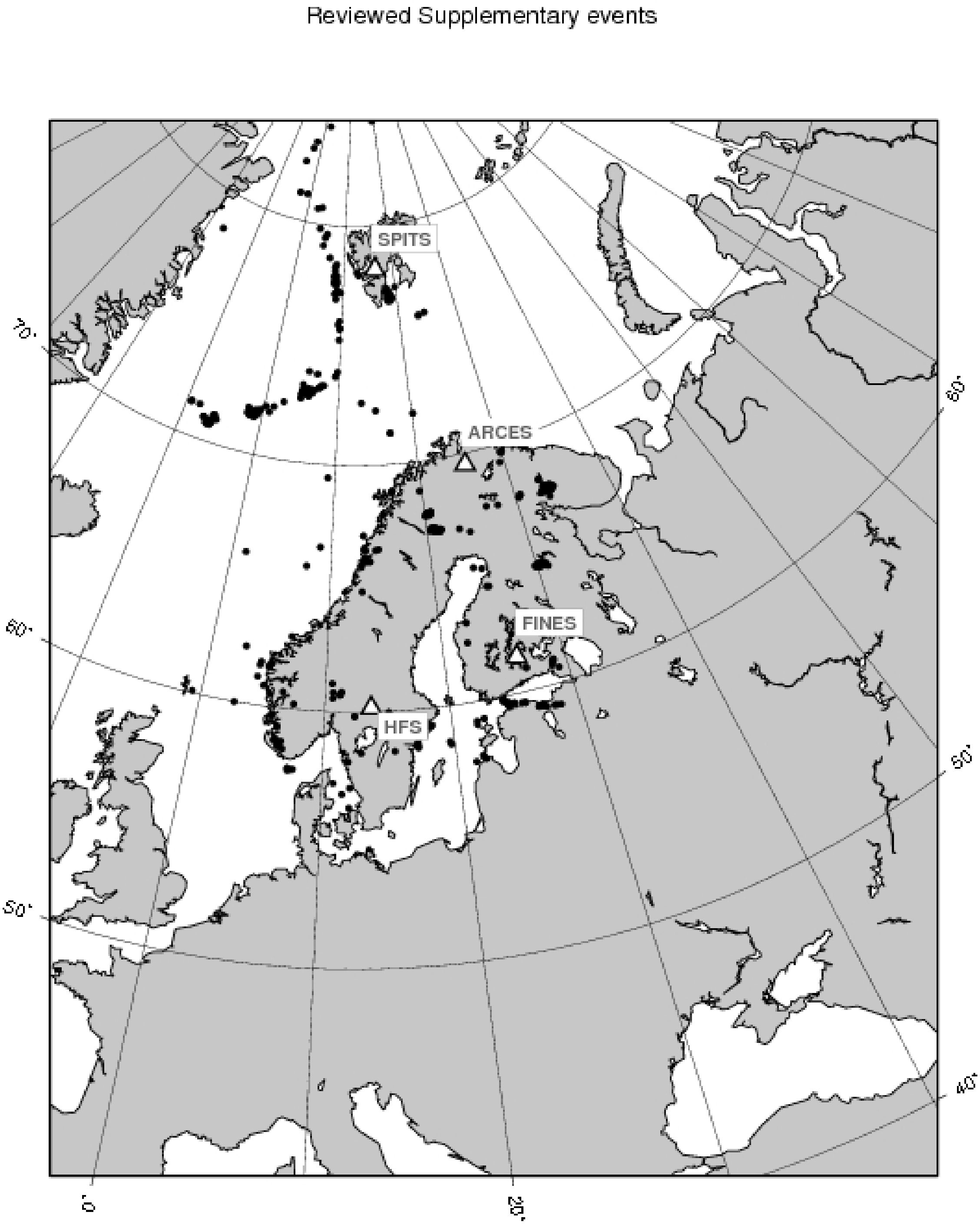

Fig. 4.2.4 The map shows the 593 events in and around Norway contributed by NOR-NDC during October 2011 – June 2012 as supplementary (Gamma) events to the IDC, as part of the Nordic supplementary data compiled by the Finnish NDC. The map also shows the main seismic stations used in the data analysis to define these events.

4.3 Field Activities

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

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

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

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

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

During this reporting period, extensive work has been performed in preparation and installation of new equipment in PS27 – NOA. It included long-term testing of the new Güralp digitizer as well as the Güralp broadband sensor with hybrid response. Additionally, problems related to providing power and communication over up to 14 km long and 40 years old buried cables have been overcome. New NORSAR Communication and Power Control Boxes and new NORSAR Junction Boxes for PS27 have been developed and tested. The upgrade of each of the 35 short-period sites comprised the removal of the old Teledyne Geotech 20171 borehole seismometer, the Science Horizons AIM24 digitizer, the power control box, the junction box and the GPS antenna, and the installation of the new Güralp CMG-3T hybrid broadband vertical borehole seismometer, new Güralp CMG-DM24S3EAM digitizer, new control box, new junction box and new Güralp GPS antenna. In each of the 7 long period vaults, a Geotech borehole 20171 seismometer and a borehole KS54000 seismometer and two AIM24 digitizers were removed and a new three-component Güralp hybrid broadband seismometers with Güralp CMG-DM24S3EAM digitizers were installed (already in the summer of 2011). In addition, also the control and junction boxes were replaced.

The recapitalization of PS27 with 42 instrument sites has been an extensive project. The testing of Güralp instruments and consequent factory and field adjustments was time consuming. By installing first new hybrid broadband systems in parallel with the old system in the 7 long period vaults, we succeeded in upgrading this part of PS27 with no loss of broadband data at NOR-NDC and the IDC. For the short-period sites, it was necessary to first prepare new control and junction boxes from spares before installing in field. Thereafter old equipment was modified before the next field installation. With this, all control and junction boxes were modified and re-used. First, 6 remote sites were upgraded in October 2011 so that the remaining short period array was mission capable. Then finally, the remaining 29 short period vaults were upgraded within only a one-month time window (May-June 2012). Note that this was achieved by a field crew of 2-3 persons which at the same time was responsible for the O&M of the other two IMS arrays in Norway.

The last short period site was upgraded on 5 July 2012 in the presence of the CTBTO/PTS IMS director.

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K.A. Løken

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6 Technical Reports / Papers Published

6.1 Adapting Pipeline Architectures to Track Developing Aftershock Sequences and Recurrent Explosions
(*Paper Presented at the 2012 Monitoring Research Review*)

Abstract

Pattern detectors (e.g., correlation, subspace, and matched field detectors) fuse the signal detection and source identification processes into a single operation. The organization of repeating waveforms for efficient analyst interpretation may result in significant gains in productivity when analyzing extensive aftershock sequences and explosions from repeating sources. Under current practice, pattern detectors run entirely independently of the pipeline signal detectors and the preparation and supervision of pattern detectors is relatively labor-intensive. It is the aim of this two-year study to investigate algorithms for adapting processing pipelines to create and supervise pattern detectors semi-automatically for incoming multi-channel data streams. A functional model of an operational detection pipeline is being constructed with extensions that create and manage pattern detectors under a variety of spawning policies. The system is being tested on two aftershock sequences: that for the 8 October 2005, M=7.6, Kashmir earthquake and that for the 23 October 2011, M=7.1, Eastern Turkey event. Both cases are representative of challenging aftershock sequences given the vast numbers of events and relatively large source regions.

Pattern detectors that are coherent over multiple arrays and 3-component stations can constitute exquisitely sensitive detectors that increase the detection capability greatly for events in the immediate geographical vicinity of the master events. An alternative strategy would be to operate pattern detectors coherently over single arrays or other limited subsets of sensors, and combine the results incoherently across the complete network. This alternative strategy may allow a greater geographical region to be covered by given templates. The merits and limitations of the two strategies are being investigated for a range of different case studies. For correlation detectors on single arrays the validity of detections can be assessed by performing f-k analysis on single-channel detection statistic traces, eliminating enormous numbers of false alarms and allowing a significant reduction in the detection threshold.

Policies for triggering and spawning of correlation detectors are being studied extensively. The simplest trigger is using an STA/LTA detector on an array beam steered towards the slowness of anticipated first P-wave arrival from the source region considered, with the classification of the detected phase being confirmed using classical f-k analysis. This strategy is reinforced significantly when considering multiple observing stations. Considering only detections which are confirmed on multiple stations, with limits on the time-delays determined by the dimensions of the source region, will lead to fewer detectors generated by false triggers.

The most promising triggering algorithm considered so far is the single phase empirical matched field detector (EMFD). This narrow frequency band approach mitigates the effects of, and indeed exploits, the scattering which frequently confounds classical array processing. Correlation detectors using a waveform template from the main event are frequently very unsuccessful at detecting large number of aftershocks, since large spectral differences between the main shock and aftershocks may lead to

significantly different waveforms. The empirical matched field processing recognizes the characteristic spatial structure of the incoming wavefronts over the array aperture in each of many narrow frequency bands and this appears to be a more stable characteristic of a given source region than the temporal structure of the waveforms on each sensor. For both the Turkey and Kashmir sequences, the EMFD readily detects many very low signal-to-noise ratio (SNR) signals which are all confirmed by stations in the vicinity of the source region to correspond to real events in the sequences.

6.1.1 Objectives

This two-year study will investigate the adaptation of processing pipelines to create pattern detectors (i.e., correlation, subspace and matched field detectors) that discover and organize repeating waveforms in data streams from a network of seismic arrays. The monitoring applications of this technology will include real-time responses to major developing aftershock sequences to ameliorate analyst overload, and autonomous discovery of repetitive explosions.

A functioning model of the detection stage of a pipeline implementing conventional beam recipes will be constructed, but extended to create and manage pattern detectors under a variety of spawning policies. This system will be used to test a number of strategies for discovering repeating waveform patterns and organizing detected occurrences for efficient interpretation by analysts. The system will be tested using the four regional Kazakhstan arrays as a network observing the 2005 Kashmir earthquake aftershock sequence. For additional system testing, we also plan to analyze signals from the October 2011 Van sequence in Turkey recorded at the Kazakhstan arrays. For this sequence a bulletin of quite accurate event locations and magnitudes, provided by the local Turkish network, form a good reference for evaluating the pipeline performance.

It will be investigated as to whether pattern detector waveform templates should be limited to individual arrays or extended to coherent operation across the network, and whether templates can be improved as observations accumulate. An autonomous supervisory function will be introduced that keeps track of detector performance, and culls, updates or merges detectors to improve overall system performance. This includes periodic reprocessing of the data stream with the suite of maturing pattern detectors, to be conducted as a parallel operation so as not to slow the main detection process.

Alternative pattern detector spawning policies will be examined, one with new detectors created only from special analyst-designated primary detectors and another with spawning from all of the conventional STA/LTA or F detectors implemented on recipe beams. System performance will be graded, with the ultimate metric being a measure of the consolidation of detections into efficiently-interpreted families. This includes checks to ensure that this autonomous system does not screen events of interest from analyst evaluation, by superimposing waveforms from other events among the Kashmir aftershocks.

6.1.2 Research accomplished

The Framework

The detection framework that we are building (Figure 6.1.1) models the detection front end of many pipelines that process array data, using an object-oriented architecture to allow different types of detectors to be added to the system dynamically and with any number of instances. The heart of the system is a list of detectors that can hold traditional beamformers with STA/LTA detectors and also several types of pattern-matching processors: correlation, subspace and matched-field detectors. The idea behind the system is to allow traditional power detectors (and one type of targeted pattern detector) to spawn new pattern detectors for specific aftershock families as they are detected and add them to the pipeline in real time. These pattern detectors are intended to sweep up some fraction of the aftershocks into groups for efficient interpretation later in the pipeline.

The system supports or will support other innovations, such as the ability to construct pattern detectors that span more than one array in the network and a capability to reprocess older data in a developing aftershock sequence with detectors created late in the sequence. Coherent pattern detectors with a larger network footprint may obviate some association problems that lead to incorrect event formation in automatic associators. They also should build event clusters that may be assumed to be families with a very high degree of confidence, which may lead to strategies for efficient use of analyst resources. The reprocessing capability (complete as of this writing) allows pattern detectors formed late in an aftershock sequence to sweep up similar events early in the sequence. This function may prove useful if analysts get behind by reducing the backlog of events to be reviewed.

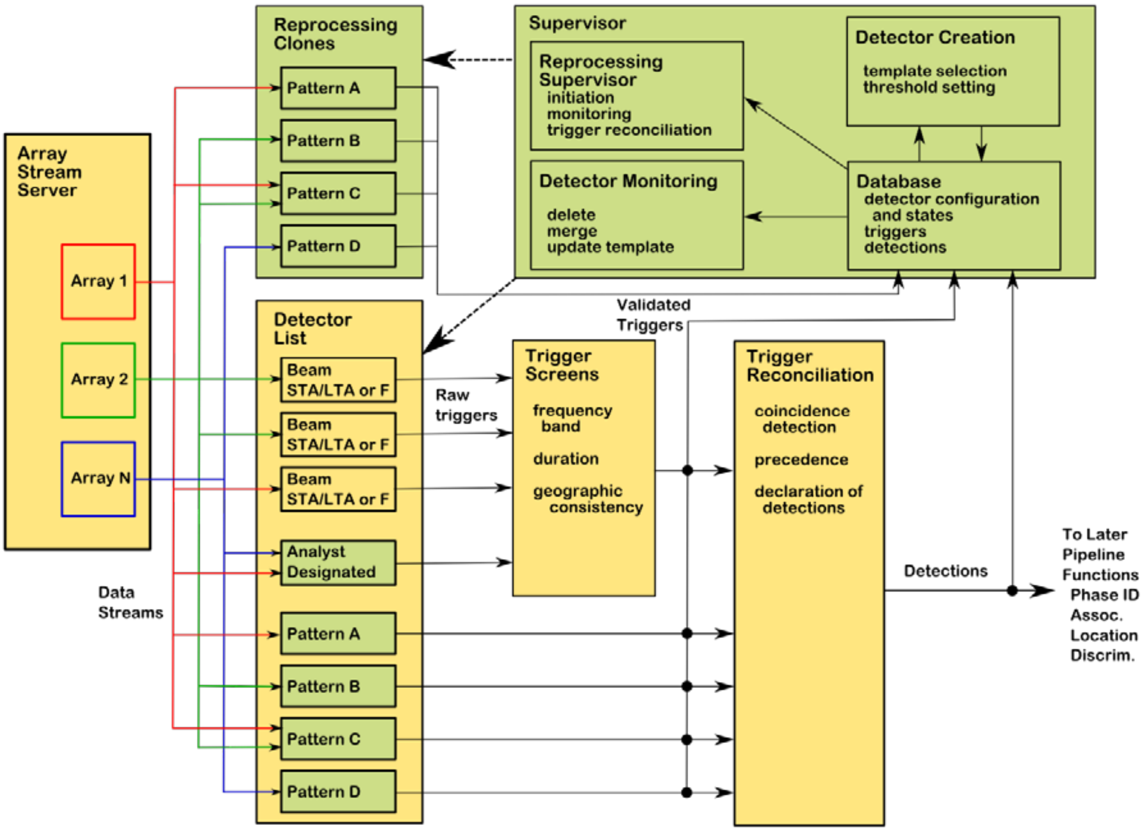

Fig. 6.1.1 Block diagram of the detection processor being developed to test pattern detector creation and management strategies. The boxes in yellow indicate functions approximately shared with a conventional pipeline detection processor. Those in green represent entirely new functions. Note that some detectors may process data from more than one array, possibly coherently.

To simplify the construction of detectors that span multiple arrays, we have completed an Array Stream Server function that acquires continuous stream data from different types of sources (flat files, database or conceivably real-time streams) and, so to speak, puts it on a common footing. By that we mean it resamples data to a common sampling rate and interpolates all samples to fall on the same time instants. This function simplifies selection of data from disparate stations to be combined (possibly coherently) in a single detector.

The other innovation is a supervisory function that creates detectors and monitors their performance. It incorporates an extensive database archiving the configuration of all detectors either designated by the system operators or created autonomously by the framework, all triggers produced by the detectors and the detections that emerge from a process of reconciliation and ranking of nearly simultaneous triggers. The archive supports tests of policies for updating (and possibly retiring and combining) detectors, as well as extensive post-operation analysis of overall system behavior and the performance of individual detectors. We are contemplating an ability to track and adapt the templates of detectors with new observations as they occur.

The kind of tests that we contemplate performing with this framework might be appreciated from an example. We would like to investigate how a subspace detector might be constructed automatically with a template that spans several arrays. One question is how to choose the receiver aperture of the template, i.e., which arrays to combine. Several possible strategies emerge. In a conservative approach, we might allow the system to operate for a time on a developing aftershock sequence to see if detectors are created among the arrays that have many triggers in common (discovered by examining whether patterns emerge in the relative timing of triggers made by the detectors). The absolute trigger times and the pattern of observed relative arrival times then could be used to extract waveforms for a correlation template. Alternatively, with a single event detected and under the assumption that we know the approximate location of the aftershock sequence, we could use a trigger time from a single station to predict arrival times at other stations for waveform extraction. We could operate the detector for a while to see whether it performed as well (had as many triggers) as a single-array correlation detector.

Because the pattern detectors we are using have efficient implementations, it may make sense to try fairly liberal spawning policies (such as the one just described), operate a fairly large number (thousands) of detectors, measure their performance and prune off the ones that don’t perform well. In this view the system could come to implement a kind of natural selection for empirical detectors.

Single Phase Empirical Matched Field Processing for Spawning Detectors

A pipeline which generates pattern detectors autonomously needs sensitive but robust criteria for spawning new detectors. Harris and Dodge (2011) classified an extensive aftershock sequence effectively by using triggers on an STA/LTA trace for the beam on a single array steered optimally to detect the initial P-arrivals from events in the source region. An ideal strategy for triggering the generation of a new pattern detector would be a correlation detector which simply took a waveform template from the main event and declared a detection on each occasion that the correlation coefficient trace attained a significant value. In practice, for large earthquakes, the contrast in source dimensions, magnitude, and consequent form of the signals usually make the mainshock signals very poor waveform templates for identifying aftershocks. This is demonstrated in the lowermost trace of Figure 6.1.2 where a 15 second long template for a teleseismic P-arrival from a magnitude 7.1

earthquake essentially fails to detect any of the aftershocks convincingly in the window displayed. The situation is improved considerably by considering the zero-moveout correlation stack on the array (trace 4) and it is possible that the noise floor could be lowered further by a flattening of the amplitudes in the incoming data stream (Gibbons et al., 2012).

Harris and Kværna (2010) present an application of empirical matched field processing (EMFP) on array signals to identifying the source of mining blasts. EMFP is a narrow frequency band procedure which matches the spatial structure of the incoming wavefield over the set of sensors, rather than the temporal structure of each time-series. EMFP outperforms waveform correlation for most mining sources since the ripple-fired nature of the shots makes the wavetrains from different blasting sequences very dissimilar, whereas the narrow band representations of the waveforms are relatively insensitive to the events' source-time functions and are highly characteristic for a given source region. EMFP also outperforms classical plane wavefront array methods since it takes templates from existing records from the relevant source region, producing pattern detectors which are uniquely calibrated for each source and account for the deviations that heterogeneous Earth structure imposes upon the arriving wavefront.

Wavefronts propagating to a distant array from an aftershock sequence will propagate along a very similar path. Therefore, the characteristic phase and amplitude relations between signals on the different sensors of the array are likely to be very similar from event to event and will comprise a fairly characteristic spatial seismic fingerprint for the sequence. Correlators ideally use the full wavetrain to maximize the signal's time-bandwidth product, and this can be problematic in rapidly unfolding sequences of events when the delay between events is often shorter than the wavetrains. Harris and Kværna (2010) demonstrated that a short window surrounding the initial P-arrival was a highly effective "information carrier" meaning only a short data segment may be required for each event. This will mitigate problems due to overlapping wavetrains. A further possible advantage of EMFP over waveform correlation in relating a large main event to subsequent smaller aftershocks results from the narrowband nature of the procedure. Correlation between the signals generated by the main event and aftershocks will usually be diminished by the significant spectral differences. In EMFP, in which the template is defined by the spatial structure of the wavefield in each narrow frequency band, the spectral content of each incoming wavefront is likely to be less significant.

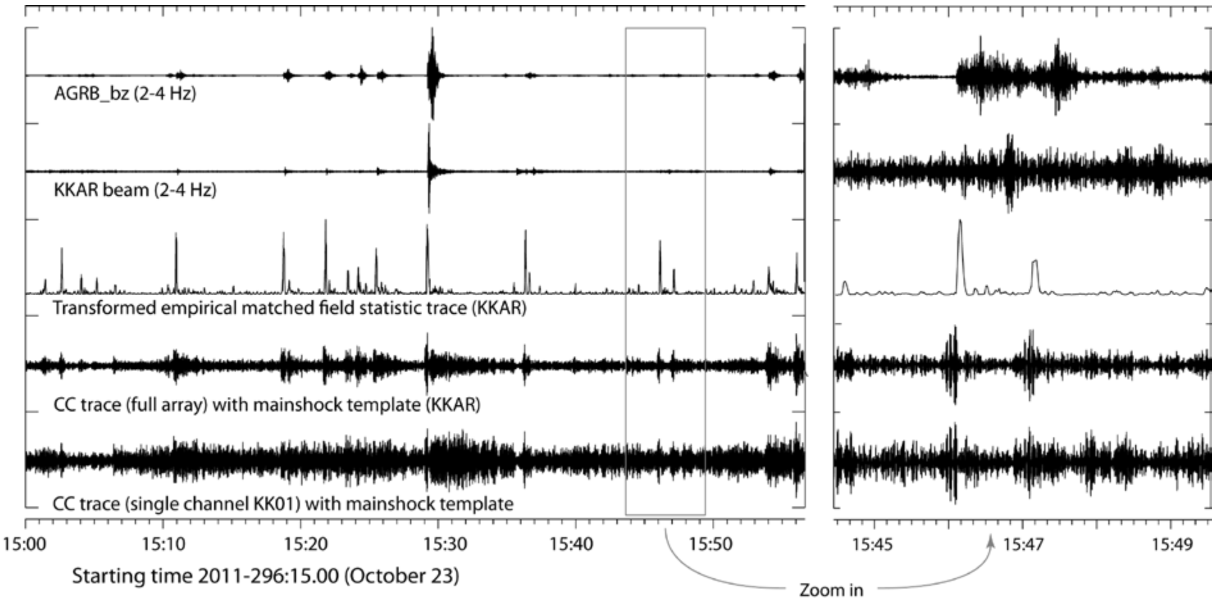

Fig. 6.1.2 Comparison of empirical matched field and correlation detectors on the KKAR array where both the empirical steering vectors and waveform template are taken from the initial P-arrival at time 2011-296:10.46.04 from the October 23, M=7.1 Van earthquake, Turkey (38.733°N, 43.483°E). The covariance matrix used to calculate the empirical steering vector was calculated using a data segment with 256 samples (6.4 seconds) and 26 narrow frequency bands between 1.09 and 5.00 Hz were used. The waveform correlation calculations were performed with a 15 second waveform template filtered 1-5 Hz. Data from the AGRB station (approximately 1 degree from the mainshock) is delayed by 266 seconds to provide an optimal alignment of initial P arrivals with the P phases at KKAR.

A matched field statistic trace can be evaluated for consecutive windows of incoming data, in a given narrow frequency band, for a given template or empirical steering vector. The third trace in Figure 6.1.2 displays the mean over 26 narrow frequency bands of transformed matched field statistic traces, where the transformation (described in Gibbons et al., 2008) results in local maxima at times characterized by an increase. There are numerous clear peaks in this function which can all, on closer inspection, be associated with events visible in data from far closer stations. The zoom panel makes it clear that the matched field statistic, measuring the spatial characteristics of the wavefield over the array, provides a significant improvement in SNR over an optimal beam steered with the appropriate time-delays. Times of arrival are clearer on the matched field traces than the correlation traces and this may be particularly useful if valid event hypotheses are to be validated by observations over multiple arrays.

STA/LTA detectors on a beam return many detections that are unrelated to the source region of interest (a strong signal from a completely different direction is likely to result in an increase of energy on all beams). The same may occur for the matched field detector. Just because sensitivity is optimal for the direction of the template steering vectors, this does not mean that the response to wavefronts arriving from other directions will be negligible. Gibbons and Ringdal (2006) demonstrate how vast numbers of false alarms using correlation detectors on arrays can be eliminated fully automatically by performing f-k analysis on the correlation coefficient traces, essentially testing whether or not directions other than the one corresponding to the master event are preferred. We here demonstrate an equivalent procedure for matched field detections.

Figure 6.1.3 shows f-k analysis in two different narrow frequency bands, at 2 Hz and 4 Hz, for the Pn phases for the main October 8, 2005, Kashmir event (left) and a selected aftershock (center). The similarity between the f-k grids strengthens the claim that two earthquakes in the same sequence (in this case separated by over two units of magnitude) will result in wavefronts with similar phase and amplitude relations between sensors in the various narrow bands. As anticipated, the relative beam power at 4 Hz is less than that at 2 Hz with greater sidelobes resulting from aliasing and incoherence. The differences between the 2 Hz and the 4 Hz slowness grids provide some of the motivation for using EMFP as opposed to the simple plane-wave model.

If a detection is made using a given empirical steering vector, for example from a “mainshock”, then we can scan slowness space in the same way that we do in classical f-k analysis, only that the phase shifts for the theoretical plane-waves are superimposed onto the phase shifts specified by the empirical steering vector.

In the right panels of Figure 6.1.3, we map out the f-k spectrum at the time of the Pn arrival at KKAR from the aftershock, relative to the empirical steering vector obtained from the Pn arrival from the mainshock. At both 2 Hz and 4 Hz, the maximum relative beam power is obtained close to the zero slowness vector, indicating that the detected phase is very likely to be from the same direction as the master event phase.

These results suggest that a single-phase empirical matched field primary detector designed from the main or early events of an on-going earthquake sequence would provide a robust and sensitive tool for spawning new pattern detectors. When used in combination with the described screening procedure, this primary detector can operate with a low false-alarm at a low detection threshold.

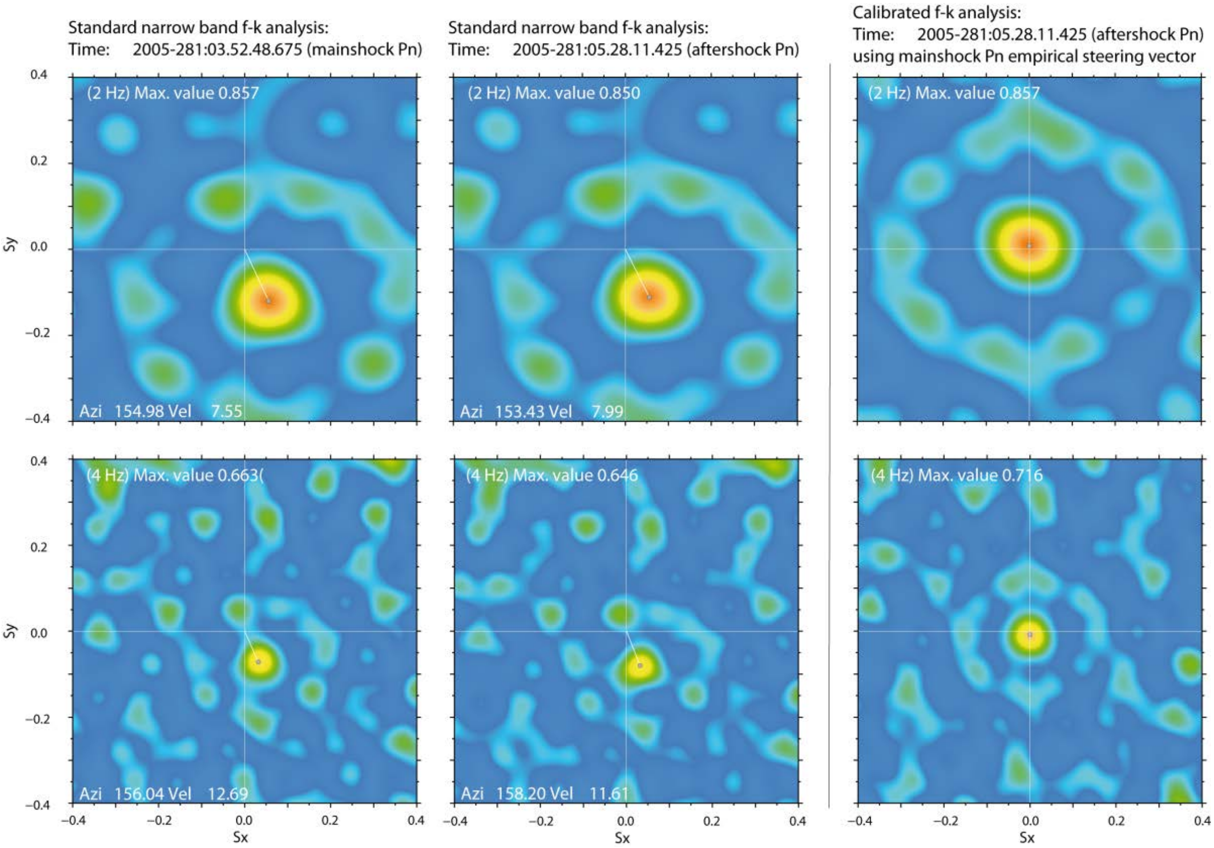

Fig. 6.1.3 Narrow band f-k analysis performed at the times indicated at 2.0 Hz and 4.0 Hz. The procedure employs the multitaper subroutines of Prieto et al. (2009). In the panels on the right, the phase shifts in the empirical steering vector are imposed and the zero slowness vector indicates that the wavefront observed comes from the same direction as the master signal.

The framework operating on aftershocks of the 2005 Kashmir earthquake

Our eventual goal is to enable the framework automatically to create detectors that operate on individual arrays or combinations of arrays. While an algorithm for creating (spawning) individual-array detectors is in place, we are experimenting with procedures for spawning detectors that operate across a network of arrays. Subspace detectors with a wider geographic footprint (on the receiver end) will have advantages in defining groups of events that are reliably related (families) and may obviate association problems among multiple stations. We are emulating manually parts of the eventual automatic process with tests on a ten-day period (2005:281-290) with data from the Kazakh arrays.

In our initial test, the spawning detectors were power detectors (STA/LTA) operating on beams directed at the backazimuths and slownesses of the initial P phase of the Kashmir mainshock (determined by FK analysis) for stations KKAR and ABKAR. KKAR is 10.5 degrees from the mainshock and ABKAR is 19.4 degrees distant. After some experimentation, we found that a two-pass process works well to define initial groups of correlated events. For example, we performed an initial run of the framework in which the spawned correlators were given a detection threshold of 0.6 (KKAR) and 0.4 (ABKAR) and template lengths of 160 and 310 seconds respectively. Following the initial pass all detectors with fewer than 4 detections (at KKAR) and 2 detections (at ABKAR) were removed from the system, and the framework was run again (with no spawning) with the surviving correlation detectors operating at lower thresholds (0.1).

Table 6.1.1 summarizes the number of detections made in the second pass. Statistics are shown only for the detectors that made 4 or more detections on the second pass. We emphasize that the two arrays were treated independently until this point.

Table 6.1.1 Numbers of detections made by automatically-created correlation detectors on a second pass.

KKAR Detectors		ABKAR Detectors	
DETECTORID	Detection Count	DETECTORID	Detection Count
52037	631	54422	467
52204	67	54470	14
52150	61	54902	5
52583	44	54442	5
52130	26	54610	5
52181	26	54823	4
52085	21	54512	4
52182	19	54558	4
52090	16		
52349	14		
52264	14		
52424	13		
52101	11		
52128	11		
52135	7		
52199	7		
52139	6		
52369	5		
52681	4		

Figure 6.1.4 displays seismograms from the most prolific detectors (52037 at KKAR and 54422 at ABKAR). Although most detail is not visible at the scale of these plots, nonetheless, the arrivals of P and S waves are clear with S-P times of about 110 seconds at KKAR and 210 seconds at ABKAR.

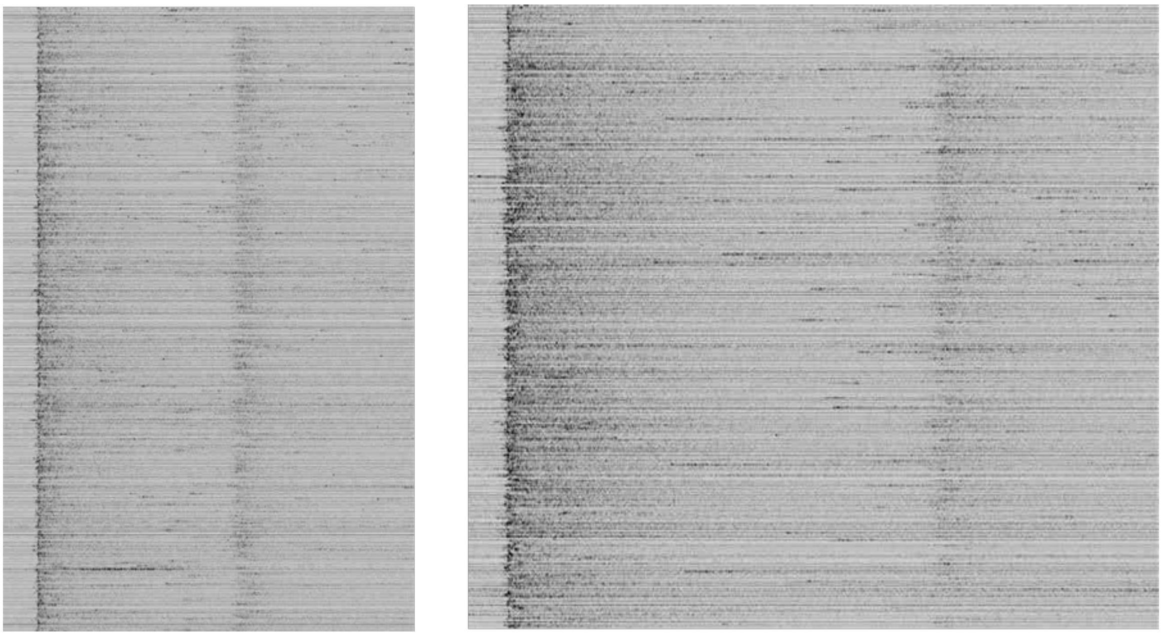

Fig. 6.1.4 Aftershocks of the 2005 Kashmir event recorded at KKAR (left) and ABKAR (right). The plot at left displays 631 events found by automatically-created detector number 52037 (220 second window of data) and the plot at right displays 467 events found by detector 54422 in a window 320 seconds long.

Our next step was to determine which detectors found events in common. For this purpose, we searched for events with common offsets in trigger times between the arrays, based upon observed P travel times (143 seconds for KKAR and 260 seconds for ABKAR; 117 second offset) on a sample of 10 detected aftershocks. Table 6.1.2 shows the result for all pairs of detectors that had more than 4 detections in common (in fact, perhaps twice as many detector pairs had at least one detection in common).

To create a trial joint detector, we used the 172 common detections between KKAR detector 52037 and ABKAR detector 54422. The template was 380 seconds long and included the 9 KKAR SHZ channels and the 9 ABKAR SHZ channels. A subspace detector was built with an energy capture threshold of 0.9, resulting in a very high rank (128) detector. Electing caution in our first attempt, we reprocessed that combined data stream of the two arrays for the ten days 2005:281 – 290 with a conservative detection threshold of 0.2. The detector collected 507 detections, compared with 631 for detector 52037 operating at KKAR alone, with few or no false triggers. Figure 6.1.5 displays plots of the extracted detections first at KK01 and then at ABK01.

Table 6.1.2 Numbers of detections found in common between pairs of independently-created detectors at stations KKAR and ABKAR.

KKAR Detector ID	ABKAR Detector ID	Common detections
52037	54422	172
52204	54422	22
52150	54422	14
52182	54422	11
52090	54422	10
52583	54422	9
52181	54422	8
52085	54422	6
52424	54422	5
52037	54610	5
52349	54422	4
52101	54422	4
52128	54422	4
52369	54422	4

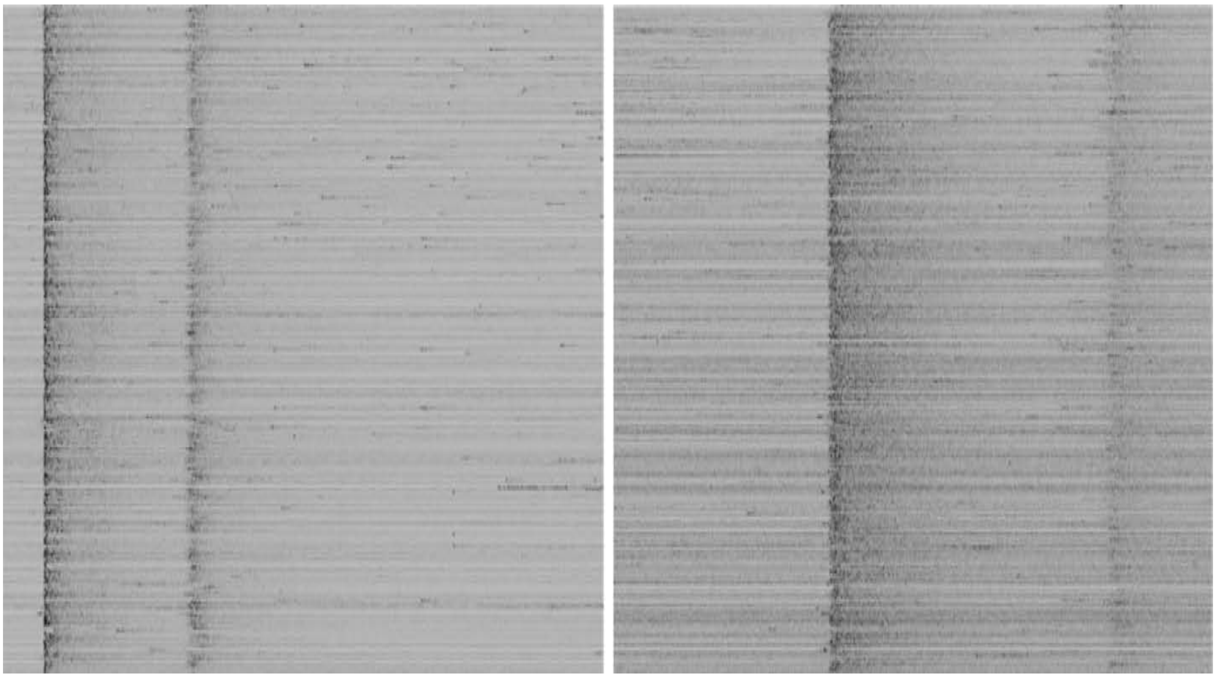

Fig. 6.1.5 Plots of 507 events at station KK01 (left) and ABK01 (right) detected by the joint subspace detector of rank 128.

6.1.3 Conclusions and recommendations

Correlation and subspace detectors are the principal methods for event detection and grouping. However, correlators using templates from extremely large earthquakes are often ineffective at spawning new pattern detectors for classifying large numbers of far smaller aftershocks. This is due to waveform dissimilarity resulting from the disparity of event magnitudes and source dimensions. While STA/LTA detectors on array beams steered towards the source region of interest, followed by f-k analysis for verification of direction and slowness, constitute an intuitive triggering algorithm for detector spawning, we argue that single-phase EMFP is both a sensitive and robust method for triggering new pattern detectors. EMFP operates on short data segments, which mitigates the problems associated with overlapping signals from consecutive events in a sequence. EMFP is a narrowband procedure, measuring the spatial structure of an incoming wavefront over an array of sensors, and may be less susceptible to differences in the spectral content between the signals from different events. We have demonstrated clear detections of confirmed aftershocks using EMFP for which the signal-to-noise ratio on the beam itself is so low that detection using an STA/LTA detector would not be feasible. It is also noted that false alarms from the EMFP detector are readily screened out by scanning the slowness space relative to the imposed template empirical steering vector.

Our initial trial of a detector operating across two arrays (KKAR and ABKAR) produced a very high-dimension (128) subspace detector that swept up a large number (507) of aftershocks from the 2005 Kashmir sequence. Because the dimension of the detector was so large, we elected to use the detector with a relatively high correlation power threshold (0.2, comparable to 0.45 linear correlation). Probably because the template was so large (TB > 10,000) and encoded very precise and large time delays across the combined aperture of the two arrays, few or no false alarms were detected. This fact suggests that the threshold could be reduced substantially to allow an even larger collection of aftershocks to be swept up in a correlated group. We plan to experiment with lower thresholds and to build joint detectors from additional pairs independently-defined single-station event clusters. We intend to automate the process (manual to this point) of forming joint detectors, experimenting with several different policies for initiating joint detectors.

Acknowledgements

We are grateful to the Kazakhstan National Data Center for permission to use the data from the KKAR array. Data from the AGRB station in Turkey was obtained through ORFEUS and is courtesy of the Kandilli Observatory Digital Broadband Seismic Network.

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NORSAR[1], Deschutes Signal Processing, LLC[2], and Lawrence Livermore National Laboratory[3]

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6.2 The New Three-Component Very Broadband Seismic Station at Troll, Antarctica

6.2.1 Introduction

NORSAR has for a long time pursued the idea of installing a permanent broadband seismometer station at the Norwegian Antarctic Research Base Troll in Dronning Maud Land, Antarctica (Fig. 6.2.1). In spring 2011, the Norwegian Polar Institute (NPI) published together with the Norwegian Research Council a call for new research projects related to Troll in context to the activities of the Norwegian Antarctic Research Expedition (NARE) 2011 – 2014. NORSAR applied for installing a permanent, high quality, very broadband seismic station during the Antarctic summer season 2011/12 and the project was funded.

Most of the Antarctic continent is covered by a thick layer of ice. Therefore, seismic stations are often installed on ice, which is not really optimal: the thick ice layers disturb the pulse shape of seismic signals. In addition, seismic stations move along with the dynamic ice shield. The horizontal movements can be easily tracked and station coordinates corrected for, but in particular the horizontal components of seismic sensors are dependent on a stable horizontal leveling, which moving ice cannot guarantee. Then, sensors have to be leveled quite often, which makes a proper permanent operation dependent on regular maintenance.

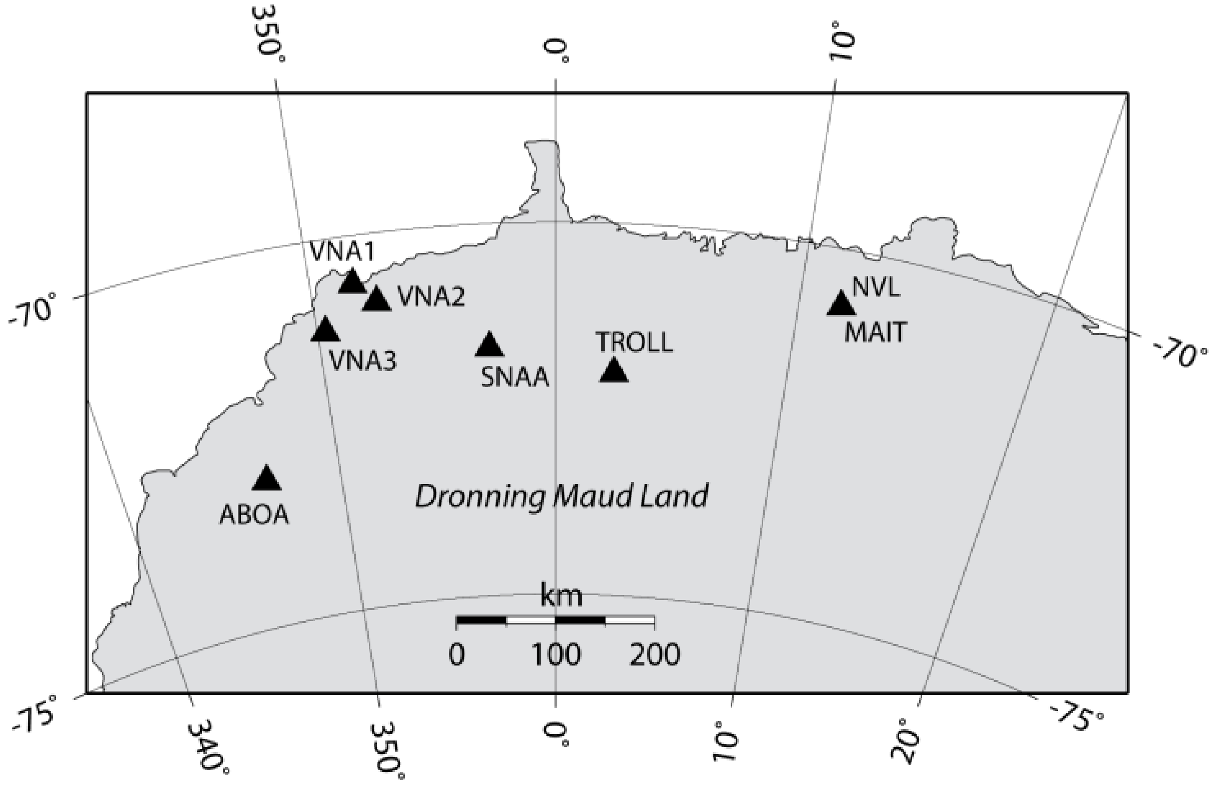

Fig. 6.2.1 Locations of seismic stations in Dronning Maud Land. Seismic data from TROLL, VNA(1-3) and SNAA are accessible in real time.

6.2.2 Station installation

Troll is located on a bedrock outcrop (Jutulsessen nunatak), consisting of metamorphic, heterogeneous migmatite. Here, a seismic station can be operated without signals being disturbed by the (moving) ice sheet. Fig. 6.2.1 shows how the new station supplements the existing network of permanent seismic stations in Dronning Maud Land.

All equipment was purchased in autumn 2011 and was extensively tested during December 2011 and January 2012 at NORSAR's test facility Stendammen (Løten, Hedmark). At the end of January 2012, NORSAR staff traveled to Troll and installed the station, which has been operational since 5 February 2012. Since then, the station has been running continuously except for two short outages due to Ethernet connection problems. The station is equipped with a Streckeisen STS-2.5 broadband seismometer, which can measure ground movements in the frequency range from below 1 mHz up to about 50 Hz. The chosen digitizer is a Quanterra Q330HR, which converts the analogue seismometer signals with an over 150db dynamic range (26 bit AD converter) and samples the data streams with rates of 100 Hz, 40 Hz, 1 Hz, 10 s and 100 s.

All seismic data are transfered from the digitizer to a laptop in the main research base building. There, the data are stored as back-up and simultaneously transmitted in real time via the Internet to NORSAR. NORSAR adds the data to its database and sends them to ORFEUS, the European data center for seismic broadband data, so that they are accessible to the entire seismological community.

Fig. 6.2.2 The picture shows the selected seismometer site with bedrock surface and natural shielding for some directions against the strong Antarctic storms.

The ground near the research station consists mostly of weathered bedrock or moraine material. A very favorable place to install the seismometer was found south of the top of Nonshøgda on a small bedrock plateau (see Fig. 6.2.2). Here, the building of a foundation for the station was easy. The site is close (about 60 m distance) to a small cabin called Huttetu with access to power and Ethernet . The distance to the main Troll research base (building, power plant, workshop, etc) is about 400 m, far enough to have low exposure to man-made noise. To achieve a low noise level, in particular for long period signals, the station has to be protected against rapid temperature and air pressure changes (Forbriger, 2012). Pictures of building and protecting the station are shown in Fig. 6.2.3.

The geographic ccordinates of the new station were measured with GPS and compared with high resolution maps of Nonshøgda provided by NPI. The station is located (WGS84 coordinate reference sytem) at:

Latitude: 72.0082° South
Longitude: 2.5300° East
Elevation: 1399 m above mean sea level

The station is registered in the international station registry of seismic stations with the code TROLL.

Fig. 6.2.3 Pictures from building the new seismometer station TROLL (progress from top to bottom and left to right): Flattening the bedrock surface; making a small fundament of cement; placing the oriented seismometer on a granite base; packing the seismometer in a first-aid-sheet for temperature protection; filling a steel casing with insulation material and placing it over the seismometer to avoid thermal convection of the air around the seismometer and protect it against rapid air pressure changes; installing cables, digitizer and GPS antenna; covering the whole with a double walled plastic dome, which is screwed to the bedrock; work done.

6.2.3 The seismic background noise level at the new station

After the first days of operation, it became clear that the new station is very sensitive to direct sunlight exposure. Zürn and Otto (2000) described strong tilt effects due to small temperature changes in seismometers vaults. Their interpretation was that temperature variations deform the vault surface and thereby tilt the seismometers. Following this observation, the surroundings of the station were at the end of March covered with stones by staff members of the Troll research station, so that the bedrock surface is no longer exposed to direct sunlight. The effect is obvious when comparing very long period filtered data from time intervals before and after the change. Fig. 6.2.4

shows one week of very long period filtered 3C data (Butterworth low-pass with a period of 5000 s) recorded before (upper three traces) and after covering (lower three traces) the surrounding with stones. All traces are equally normalized with an amplitude of 30000 counts. A daily signal is still visible, but it is much smaller than before the surroundings were covered with stones. To reduce this effect even more, we plan during the coming austral summer (2012/13) to install more insulating material around the steel casing and to paint the orange plastic dome white (see Fig. 6.2.3).

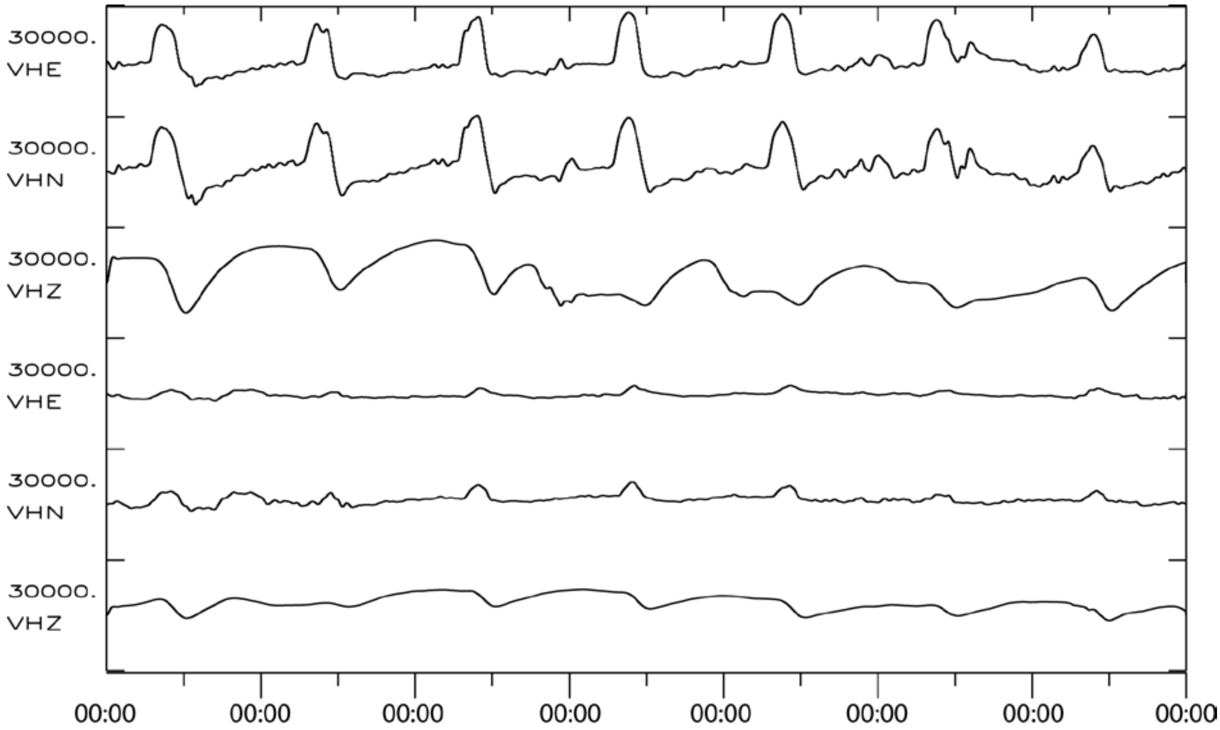

Fig. 6.2.4 Seven days of very long period filtered data (Butterworth low pass 5000 s) for the time periods 22 – 29 March 2012 (upper three traces) and 3 – 10 April 2012 (lower three traces). All traces are normalized to a maximum amplitude of 30000 counts.

Further inspection of the data led to the identification of additional noise sources. In the higher frequency range, we see a noise spike at 12.5 Hz and its overtones at 25 and 37.5 Hz. The source is presumably the power transformator in the nearby cabin. How exactly this noise couples into the seismic data is at the moment unknown. Another spike in the noise spectrum is observed at about 160-170 s. We assume that this is a beat frequency caused by the power generator for the research base: there are installed two different power generators and we could observe a change in the beat frequency when the two power generators were switched. However, all these noise amplitudes are quite small and when analysing usual seismic signals they have only minor influence on the data.

In conclusion, the installation of a very broadband seismometer station at the Norwegian Research Base Troll was very succesful. This can also be seen when comparing the power-spectral density (PSD) for a long time period between data from TROLL and the seismic station at the South Pole (quite zone station, QSPA60). TROLL has a very similar equipment to QSPA60. Although located about 1000 km closer to the open ocean and therefore more exposed to microseismic noise, TROLL shows a much lower seismic noise level. Fig. 6.2.5 shows PQLX-plots, which display the distribution of the PSD through a Probability Density Function (PDF) for the vertical components. The PQLX plot for QSPA60 has been calculated at IRIS and for TROLL at ORFEUS, both for the data observed in 2012 until the end of July. The mean noise level, represented by the blueish and greenish colors is much closer to the New Low Noise Model (NLNM, Peterson, 1993; see lower gray line in Fig. 6.2.5) at TROLL than at QSPA60.

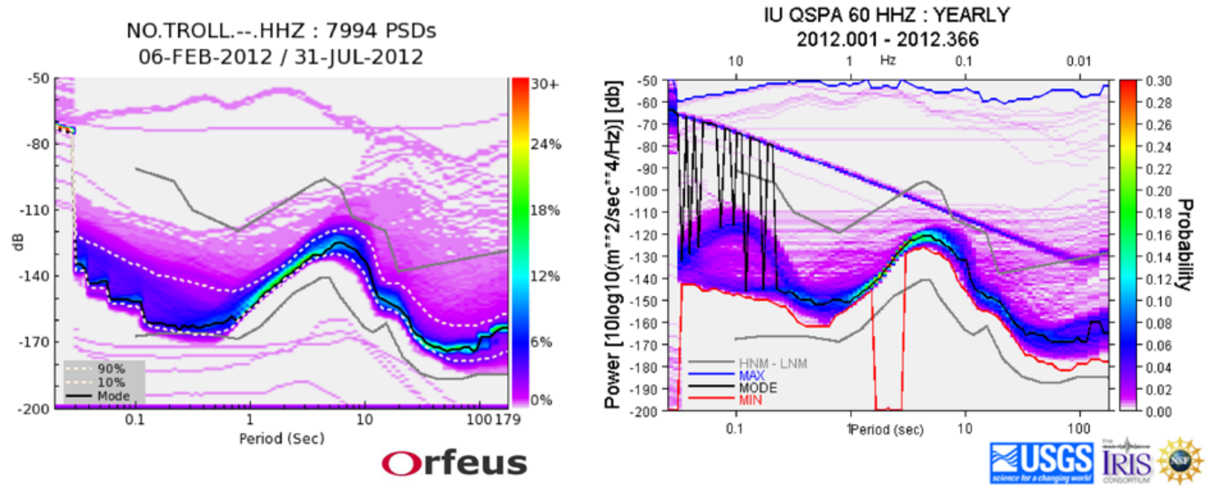

Fig. 6.2.5 PQLX plots for seismic data recorded at TROLL and the South Pole Station (QSPA60) as calculated at the international data centers ORFEUS and IRIS. For more details see text.

6.2.4 TROLL station instrument response

The broadband station TROLL is equipped with a Streckeisen STS-2.5 triaxial seismometer and a Quanterra Q330HR digitizer. The seismometer has the serial number #110644 and the digitizer #4629. The response characteristics (poles/zeros, sensitivity values and digital filters) are listed below.

Table 6.2.1. Poles and zeros for velocity response in rad/s for the vertical component of the STS-2.5 seismometer #110644 installed at TROLL station, Antarctica.

	Real part	**Imaginary part**
Poles (7)		
Highpass pole	-0.037124934	0.0370312
Highpass pole	-0.037124934	-0.0370312
High frequency double real pole	-16.063333	0
High frequency double real pole	-16.063333	0
Double real pole	-336.1	113.94333
Double real pole	-336.1	-113.94333
Phase shift pole	-958.5	0
Zeros (8)		
Double real zero	-15.71	0
Double real zero	-15.71	0
Inverse filter double zero	-556.1	936.2
Inverse filter double zero	-556.1	-936.2
Inverse filter zero	-630.2	0
Phase shift zero	958.85	0
Zero @ 0	0	0
Zero @ 0	0	0

The poles and zeros listed above in Table 6.2.1 correspond to the vertical component of the sensor. The pole/zero set for the two horizontal components differs slightly and can be found in the corresponding GSE response files distributed by NORSAR. The gain of the seismometer is equal to 1500 V/m/s at 2 s.

The sensitivity of the 26 bit Q330HR digitizer is equal to 1677721.6 count/V for all channels.

TROLL is set to output 5 different sampling rates: 100 sps at the HHZ/N/E channels, 40 sps at the BHZ/N/E, 1 sps at the LHZ/N/E, 0.1 sps at the VHZ/N/E and 0.01 sps at the UHZ/N/E channels. The digital filter(s) used to output these sampling rates are listed in Table 6.2.2. Software filters are used to output sampling rates below 1 sps.

Table 6.2.2. Digital FIR filter characteristics and cascades, used to output the selected sampling rates for the TROLL station data.

Sampling rate	Channel name	Digital filter	Decimation	Symmetry	N coeff.
100 sps	HH	Quanterra FLbelow100-100	1	asymmetric	65
40 sps	BH	Quanterra FLbelow 100-40	1	asymmetric	39
1 sps	LH	Quanterra FLbelow 100-1	1	asymmetric	31
0.1 sps	VH	Quanterra FLbelow 100-1	1	asymmetric	31
		FIR DEC 10	10	symmetric even	400
0.01 sps	UH	Quanterra FLbelow 100-1	1	asymmetric	31
		FIR DEC 10	10	symmetric even	400
		FIR DEC 10	10	symmetric even	400

The displacement amplitude and phase response curves for the vertical component, 100 sps channel of TROLL are shown in Fig. 6.2.6. The TROLL station configurations described above and corresponding Respid flags (Pirli, 2010) are listed in Table 6.2.3.

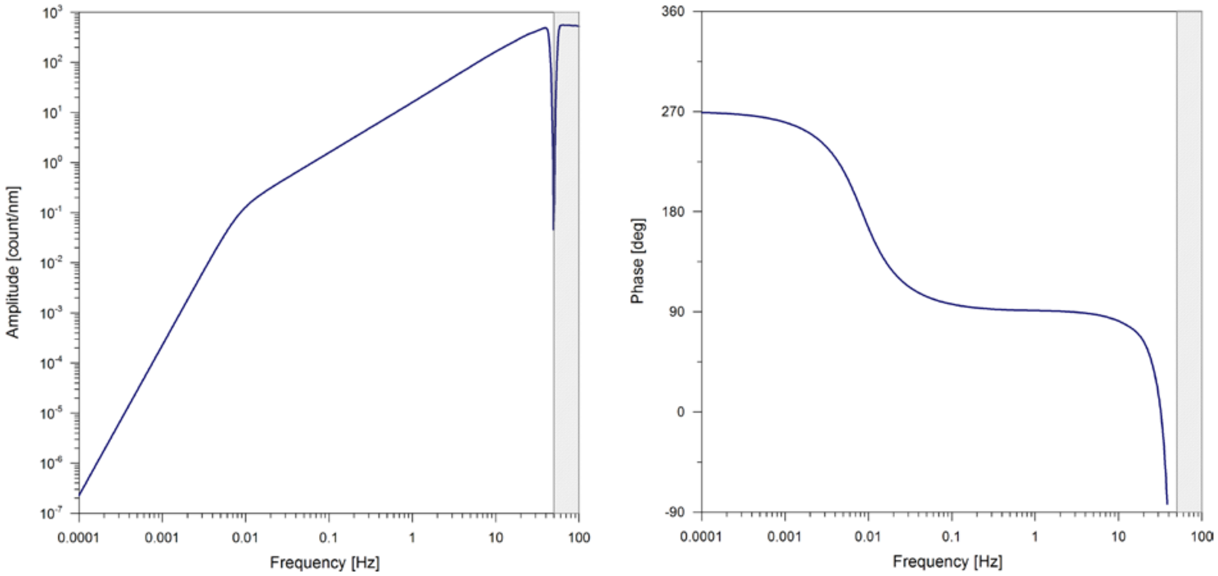

Fig. 6.2.6 Displacement amplitude and phase response for the vertical component of the 100 sps channel (HHZ) of TROLL. Shaded areas show the frequency range beyond the Nyquist (50Hz).

Table 6.2.3. The instrument configurations of the TROLL station. Overall channel sensitivity values are equal for the different sampling rates and shown only once.

Time	Installation name Respid(s)	System components	Calib [nm/count]	Calper [s]
2011/12/07 – 2012/01/13	Test installation			
	TROLLHH1a	STS-2.5	0.062978	1
	TROLLHH2a	Q330HR digitizer	0.062981	
	TROLLHH3a		0.062976	
2012/02/05 – …	Current installation			
	TROLLHH1	STS-2.5	0.062978	1
	TROLLHH2	Q330HR digitizer	0.062981	
	TROLLHH3		0.062976	
	TROLLBH1			
	TROLLBH2			
	TROLLBH3			
	TROLLLH1			
	TROLLLH2			
	TROLLLH3			
	TROLLVH1			
	TROLLVH2			
	TROLLVH3			
	TROLLUH1			
	TROLLUH2			
	TROLLUH3			

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6.3 First Data and Analysis Results from the New, Permanent Seismic Station TROLL, Dronning Maud Land, Antarctica

6.3.1 Introduction

This contribution will focus on the presentation of the first data and analysis results from NORSAR's new seismic station TROLL (Fig. 6.3.1), installed close to the Norwegian research base Troll, in Dronning Maud Land, Antarctica (for details about station installation and technical characteristics, see Schweitzer et al., 2012 in this volume).

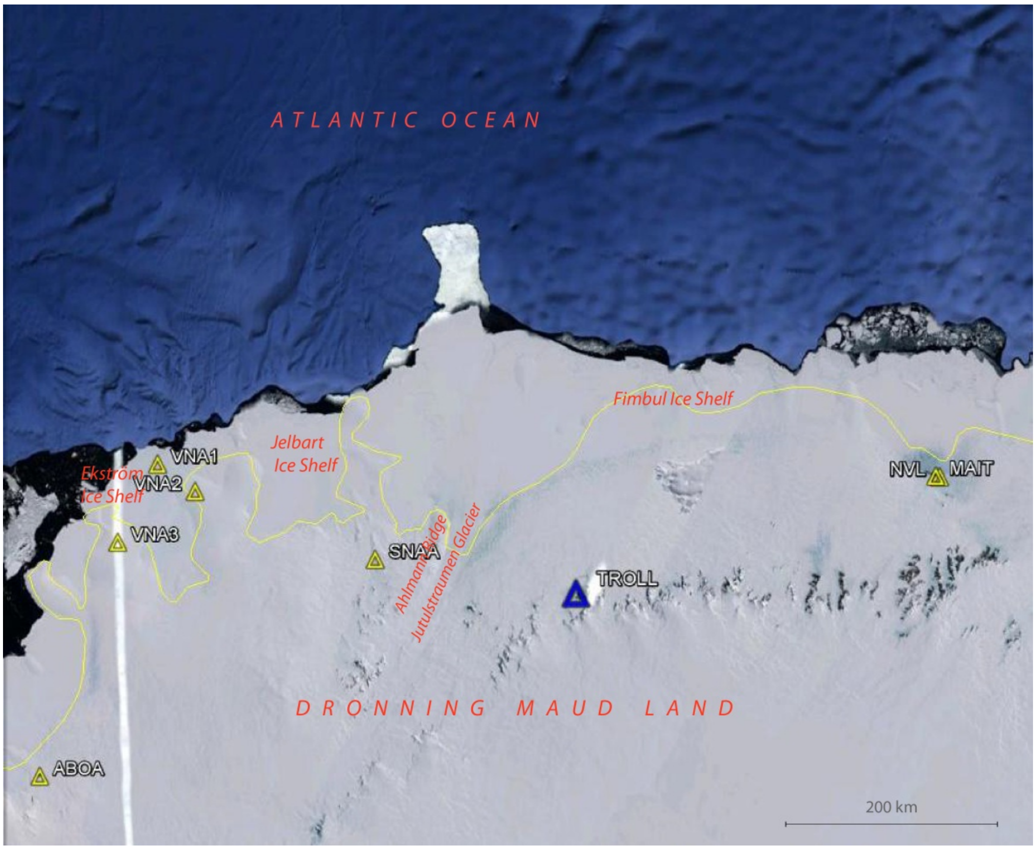

Fig. 6.3.1 Google™ earth image of Dronning Maud Land, showing the locations of the pre-existing, international, seismic network (yellow) and the location of the new station TROLL (blue). Station ABOA is operated by Finland, station MAIT by India, station NVL by Russia, stations VNA1-3 by Germany, while SNAA is a CTBTO auxiliary station, operated in cooperation between Germany and South Africa. VNA2 is the central element of a short-period seismic array. The yellow line notes the continent – ice shelf boundary. Main ice shelves and some geomorphological units are named.

The station targets the entire spectrum of seismological observations, from global seismicity, with emphasis on the Southern Hemisphere to Antarctic seismicity, as well as seismic signals generated by processes related to the ice sheet, such as icequakes and iceberg harmonic tremor. Each of these individual targets has its own significance:

- For NORSAR, expansion to the Southern Hemisphere is anticipated to cover gaps in its teleseismic event bulletin, thus complementing its seismicity monitoring activities. At the same time, reporting phase readings to international bulletins and databases enhances global coverage, especially when considering the sparseness of the global seismographic network in the South.

- Monitoring of Antarctic seismicity is of particular interest, since the Antarctic continent has long been considered rather aseismic, a view which has been gradually revised with the installation of more seismic stations (e.g., Reading, 2007 and references therein). The establishment of more, modern seismic stations will help to investigate the actual extent of the ice-cap's effect on suppressing seismicity (e.g., Johnstone, 1987). In particular for stations like TROLL, which are installed on bedrock, it is anticipated that their data help in separating this effect more concretely from the consequences of the installation of seismic stations on the ice sheet, which can reduce the quality of seismic data, especially the registration of shear waves. Furthermore, each new station constitutes a contribution in enhancing the density of the sparse, already existing network (for the seismic network at Dronning Maud Land, see Fig. 6.3.1).
- Finally, glaciogenic seismicity studies, with the information they yield on the dynamics and evolution of the ice sheet, are of interest to a much wider scientific community than that of seismologists.

6.3.2 Data and methods

The TROLL station has been now in operation for half a year, since 5 February 2012, with only small data outages (a total of 5½ days), related to technical problems with the Ethernet connection. The first two months of data are being used as a test dataset to set up and optimize automatic event detector schemes. These will help integrate the new station in NORSAR's routine analysis system and develop methodologies that will assist us to extract as much information as possible from TROLL records. Consequently, teleseismic activity presented herein is restricted to this two-month dataset.

The greatest challenge for setting up an efficient power detector scheme is related to the significant diversity of signals recorded at TROLL, as well as the quality of the data in terms of noise. The noise spectrum is discussed in detailed in Schweitzer et al. (2012), but icequakes and strong wind can be named here as two great contributors of noise for high frequencies (> 2 Hz), which can impair the observation of local and regional phases. At quiet intervals, TROLL is as efficient in the 1 – 10 Hz frequency range as it is at long periods (> 10 s).

Currently, the tuning of the STA/LTA detection algorithm is ongoing, results for teleseismic arrivals being compared to the listings of IDC's reviewed bulletin (IDC REB) and the readings of CTBTO station SNAA, close to the South African research base Sanae, at a distance of about 190 km from TROLL.

Regarding local and regional phases, a waveform cross-correlation detector (Gibbons and Ringdal, 2006) is employed for master templates with satisfactory signal-to-noise ratio (SNR).

For the moment, only a crude localization of local and regional events is being performed, based on backazimuth estimates and S-P arrival time differences at TROLL and SNAA. Backazimuth estimate is achieved by three-component, broadband f-k analysis (Kværna and Ringdal, 1986) for P-type phases and by three-component polarization analysis for P-type and secondary phases. The rotation of the horizontal components with the resulting backazimuth estimate is used as a control means to assess the validity of the result, as well as to improve phase picking.

6.3.3 Observations and results

Fig. 6.3.2 shows the IDC REB locations for the 249 teleseismic events detected at TROLL during February and March 2012 (red symbols), while NORSAR array (NAO) contributions to NORSAR's teleseismic reviewed bulletin for the same time interval are shown in blue.

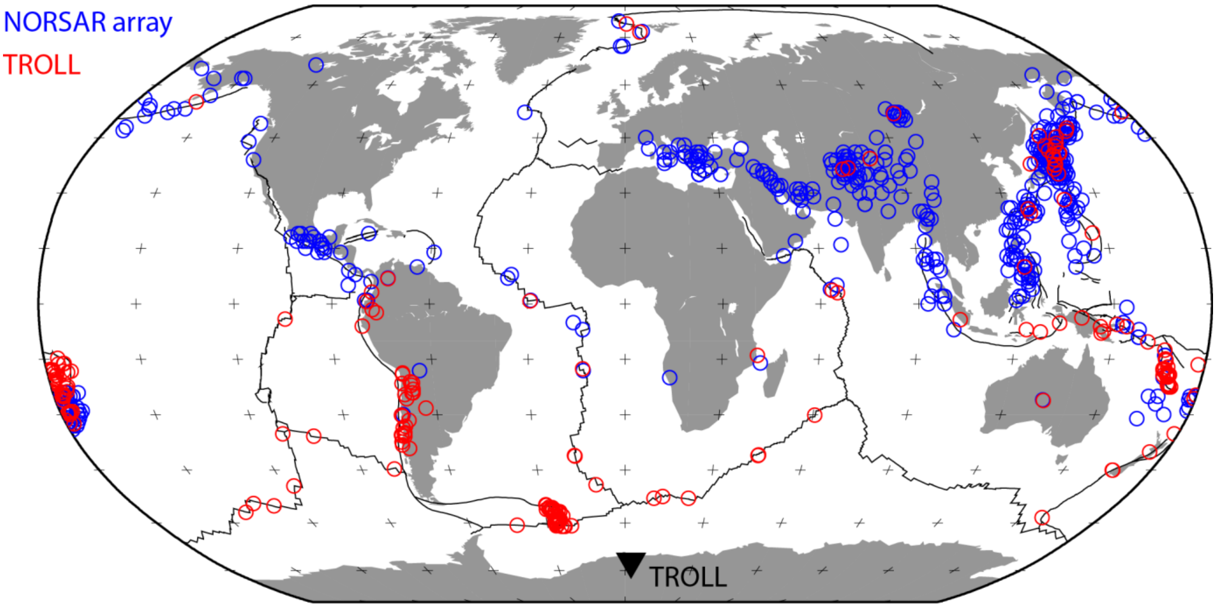

Fig. 6.3.2 Distribution of events in NORSAR's teleseismic reviewed bulletin (blue) and events detected at TROLL (red) for the time interval 5 February – 31 March 2012. TROLL detections are mapped according to corresponding IDC REB locations. The location of TROLL is noted with a black, inverted triangle.

The vast majority of the detected phases are P onsets from the events along the plate boundaries in the southern oceans, as well as South America and the island chains of the South Pacific (e.g., Fiji, Solomon, Tonga, Vanuatu and Loyalty Islands), while a significant number of PKP onsets has been detected, predominantly from Japan, but also the European Arctic. The latter is of particular interest, since it opens possibilities for focal depth determination of larger magnitude events in regions such as the Knipovich Ridge and Svalbard. Regarding the magnitude of the detected events, the global threshold for P phases for this particular dataset and the current capability of the detector is mb 3.8 (determined by IDC), while for PKP it is mb 4.5. Slightly lower thresholds are observed for the Fiji Islands region (mb 3.5) and Japan (mb 4.2), suggestive of a path effect, which however needs to be further investigated when the detector is properly tuned and a larger dataset is available. A special case, due to its relevant proximity to Dronning Maud Land, which places it in the far-regional distance for TROLL, is the South Sandwich Islands region. The inclusion in the IDC REB mainly of larger magnitude events from this region (mb > 4) highlights the difficulties involved in seismicity monitoring. Several events were detected at TROLL which are only reported by other stations in Antarctica (e.g., the Neumayer stations operated by AWI), according to the ISC On-line Bulletin (ISC, 2010). The figure illustrates clearly the gain for NORSAR from the establishment of the TROLL station, in particular when considering the fundamentally different detection capabilities of a single station and an array of the size of NORSAR.

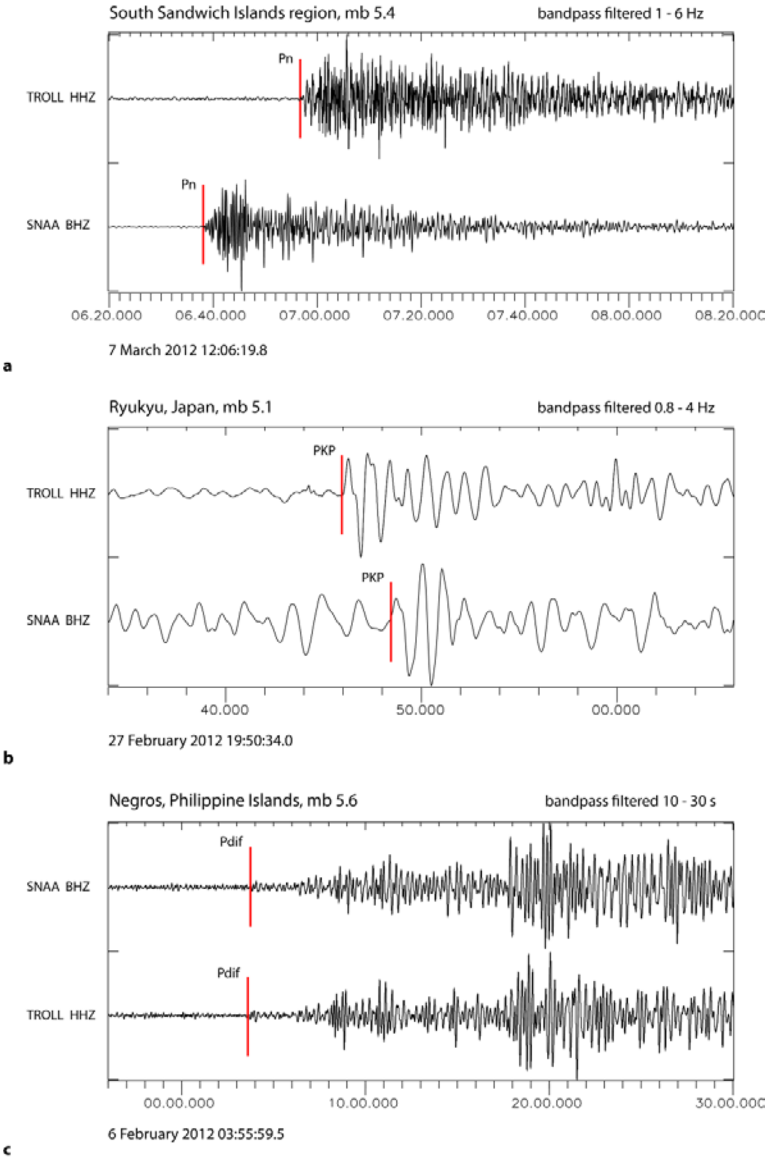

Fig. 6.3.3 Examples of waveforms of far-regional and teleseismic events recorded at TROLL and SNAA. Only the vertical component is shown. (a) P-wavetrain from a far-regional event with mb 5.4 from the South Sandwich Islands region (IDC REB solution: origin time 12:02:43.72, location -58.0158°N, -25.3964°E, focal depth 0), (b) A teleseismic PKP onset from an event in Ryukyu, Japan (IDC REB solution: origin time 19:31.51.04, location 25.6087°N, 127.1991°E, focal depth 38 km), and (c) The first 25 min of a teleseismic event from the Philippine Islands (IDC REB solution: origin time 03:49:10.79, location 9.9404°N, 123.1064°E, focal depth 0).

Figure 6.3.3 offers waveform examples from (a) an mb 5.4 event from the South Sandwich Islands, (b) an mb 5.1 event from Ryukyu, Japan, and (c) an mb 5.6 event from the Philippines, as recorded at TROLL and SNAA. Only in the case of the South Sandwich Islands event does SNAA show a better SNR than TROLL, whereas for frequencies lower than about 1 Hz, TROLL has better SNR than SNAA. This is consistent with the TROLL station's good performance in the low frequency and long period range (see Schweitzer et al., 2012).

As mentioned in the Introduction, the monitoring and analysis of Antarctic seismicity is one of the main targets of the TROLL seismic station. Fig. 6.3.4 shows approximate locations of seismic events in the region around TROLL.

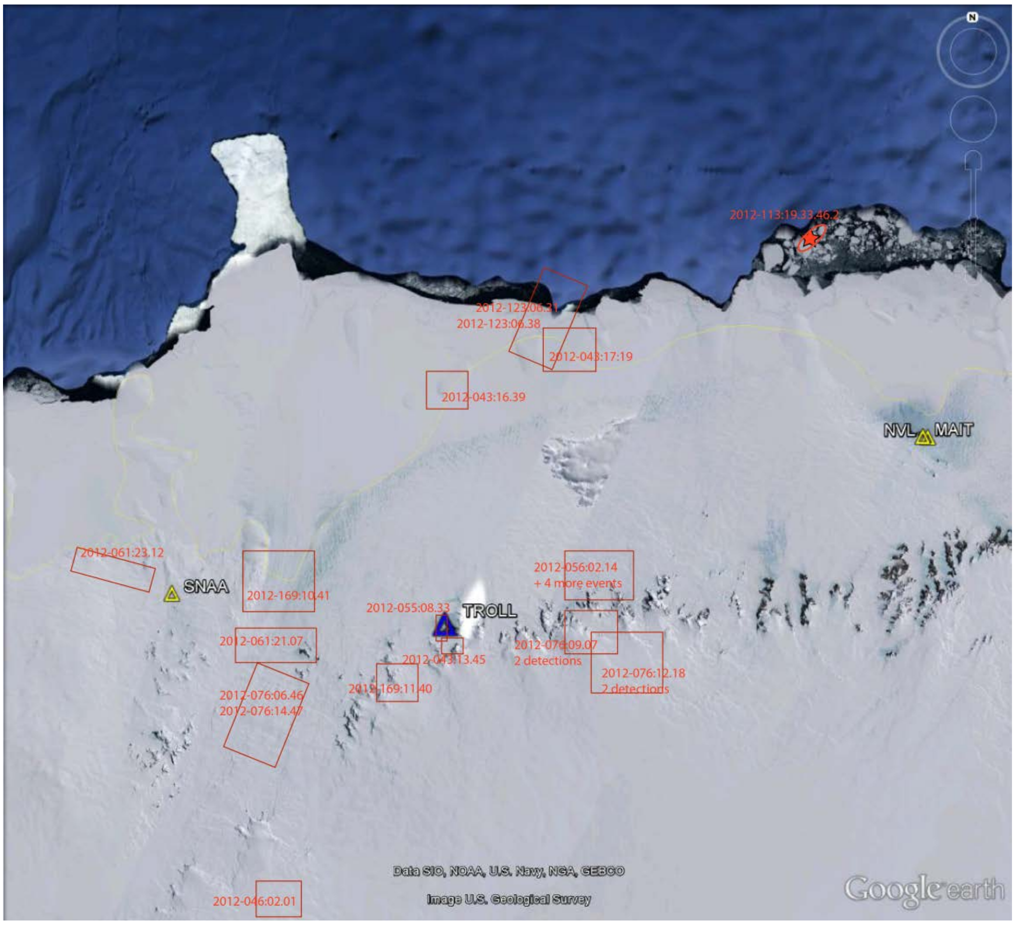

Fig. 6.3.4 Google™ earth image of the region of Dronning Maud Land around TROLL, showing areas of seismic activity recorded at TROLL. The time of each event and number of detections based on waveform similarity, where available, are noted. Rectangles correspond to crude location estimates with only TROLL and SNAA data, their size indicating backazimuth and S-P arrival time difference uncertainty. One event (red star) is located with three stations (TROLL, NVL and SNAA). The 95% confidence level error ellipse is shown.

Most of the approximate locations mapped in the figure are based on backazimuth and S-P arrival time differences measured at TROLL and SNAA, and only one event is located with the use of data from three stations. An effort has been made to give an impression of the uncertainty involved in these measurements, shown by the size of the rectangles denoting the areas of activity. In two cases, the application of the waveform cross-correlation detector has yielded a couple of detections associated with the located events. Most of the events are observed close to the mountain chain including the Jutulsessen nunatak, where TROLL is located, while others are observed at the boundary between the continental shelf and the ice shelf, and at major glaciers, such as Jutulstraumen. Many more small events have been identified in TROLL records, but most of them are very weak and cannot be picked at any other station in the region.

Whether these seismic events are attributed to tectonic activity or to processes within the ice sheet is a question to be investigated further. Although these events cannot be categorized as icequakes just at face value, an abundance of icequakes has been recorded at TROLL. These are events from the immediate vicinity of the station, with a strong Rg character. Their occurrence follows a clear temporal pattern, showing a strong correlation to the coldest time of day, between midnight and the early morning hours. A characteristic example is shown in Fig. 6.3.5. This particular case highlights also the difficulties that coinciding icequakes create in picking and detecting regional phases, since it shows quite clearly that they share the same frequency range with local and regional seismic events.

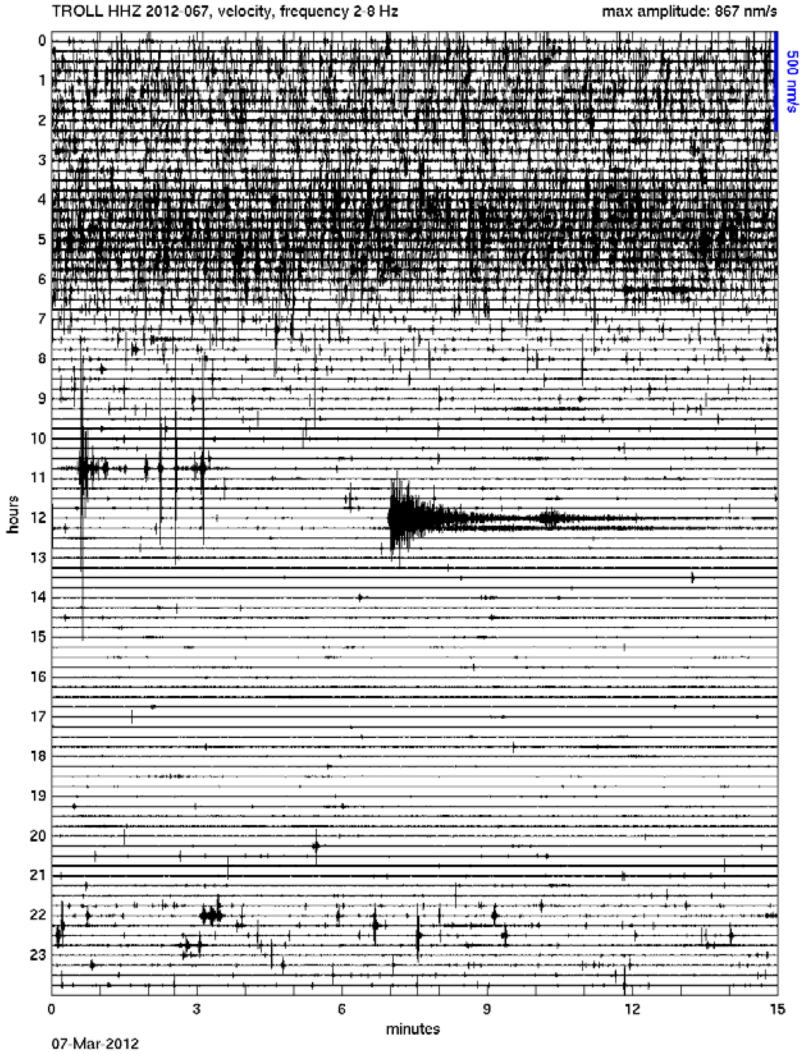

Fig. 6.3.5 "Helicorder plot" of the vertical component of TROLL for 7 March 2012, bandpass filtered between 2 and 8 Hz. The record is dominated by very local icequakes for the time interval between midnight and 07:00 in the morning. Regional events, such as the South Sandwich Islands earth-quake of Fig. 6.3.3(a), can also be seen on the same day's records.

A different category of cryosignals recorded at seismic stations are those related to the evolution and drifting of icebergs. Processes include calving, collision and scraping against the ocean floor, the ice shelf or against other icebergs, etc. (e.g., Müller et al., 2005; MacAyeal et al., 2008; 2009; Martin et al., 2010). More than 100 such signals have been recorded at TROLL during its first six months of operation. They exhibit a wide variety of forms and variation in frequency structure, from harmonic overtones to signals of completely chaotic character, but their vast majority has in common a frequency content of 0.6 to 12 Hz. The strength of the signals is also very variable and the weaker ones can be mistaken for noise due to weather or weak teleseisms. The most secure way to identify them as such is through the inspection of their spectrograms. The correspondence with particular icebergs drifting along the shoreline is achieved through the spatiotemporal correlation of signals and their backazimuth estimates with satellite images (e.g., http://rapidfire.sci.gsfc.nasa.gov/imagery/subsets/?mosaic=Antarctica) and/or iceberg tracking databases (e.g., http://www.scp.byu.edu/data/iceberg/database1.html). This correlation is supported by the records of other stations at Dronning Maud Land, such as SNAA, NVL and VNA1-3.

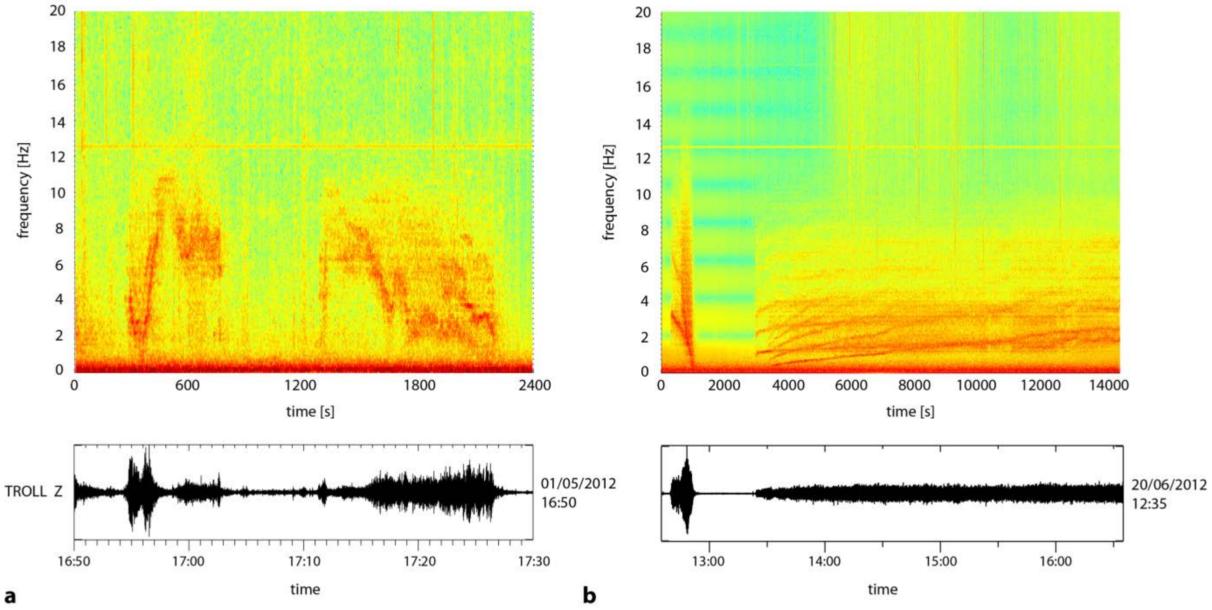

Fig. 6.3.6 Spectrograms (top row) and corresponding waveforms of TROLL's vertical component for two examples of iceberg generated signals. (a) A 40 min record containing two signals associated with an iceberg NE of TROLL. The spectrogram is computed from raw data, while the waveform has been bandpass filtered between 2 and 6 Hz. (b) A 4 hour record containing two signals associated with an iceberg NNE of TROLL. In this case, the waveform has been bandpass filtered between 1 and 6 Hz. Only the first 3 hours of the 1 day long harmonic tremor are shown.

Fig. 6.3.6 shows two waveform and corresponding spectrogram examples of such incidents, composed by signals of structured (non-chaotic), but quite different character. The spectrograms are computed for unfiltered data, but have been truncated to 20 Hz to enable detailed observation. The corresponding waveforms are bandpass filtered to the frequency band of optimum SNR. The first example (a) constitutes a complex of two signals whose main characteristic is intense and arbitrary frequency gliding. The two signals, separated by an aseismic interval of about 7 min, exhibit reverse dispersion patterns, while the second one has towards its end two well-defined overtones in addition to the dominant frequency band. The second example (b) is composed by a strong signal that lasts about 14 min followed by harmonic tremor of total duration of approximately 1 day, although only the first 3 hours are shown in Fig. 6.3.6. The first signal is composed by a strong dominant frequency band with two easily distinguishable overtones gliding from higher to lower frequencies in a parabolic manner, as well as a more chaotic and lower energy content part reaching up to 14 Hz towards its end. The tremor signal is composed by two different sets of harmonics, each set reaching up to 10 overtones, not easily visible at this scale.

The exact mechanisms behind the generation of these iceberg related signals are subject to further study. Several mechanisms have been proposed until now for iceberg harmonic tremor, including the superposition of a rapid succession of strike-slip events generated by stick-slip motion in the case of colliding icebergs (MacAyeal et al., 2008) and the flow of water through crevasses inside the drifting iceberg in a similar mechanism to that of volcanic tremor (Müller et al., 2005).

6.3.4 Summary

A wide variety of seismic signals have been recorded during the first half year of operation of NORSAR's new station TROLL in Antarctica. The first data and results of their preliminary analysis are indicative of the station's contribution both to global and Antarctic seismicity monitoring, as well as a source of data and information on the dynamics of the Antarctic ice sheet.

A more robust image of the station's performance is anticipated when it is fully integrated to NORSAR's routine processing and the necessary schemes have been developed to exploit fully the information contained in its records.

Acknowledgements

Data from the CTBTO auxiliary station SNAA at Sanae are retrieved from the IDC. Data from the Russian station NVL at Novolazarevskaya are kindly provided by the Geophysical Service of the Russian Academy of Sciences.

M. Pirli

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6.4 Research into Nuclear Disarmament: The UK-Norway Initiative on Nuclear Warhead Dismantlement Verification (UKNI)

6.4.1 Introduction

Both the UK and Norway are as signatories to the Nuclear Non-Proliferation Treaty (NPT) committed to the long-term goal of a world without nuclear weapons. NPT Article VI requires all states parties to the NPT to undertake to pursue "negotiations in good faith on effective measures relating to cessation of the nuclear arm race at an early date and to nuclear disarmament, and on a Treaty on general and complete disarmament under strict and effective international control". Any future disarmament process would need to be underpinned by a verification regime that can demonstrate with confidence that nuclear disarmament has taken place. With this principle in mind, the UK and Norway have been working together since 2007 in a technical collaboration referred to as the UK-Norway Initiative (UKNI) to address some of the technical and procedural challenges that verifying the dismantlement of nuclear warheads could pose. UKNI has included both technical development and a number of unique, ground-breaking exercises.

UKNI has been a process of building trust and cooperation in an area which presents significant technical and political challenges to both parties. The principal objectives for the collaboration are:

- To create scenarios in which Norwegian and United Kingdom participants can explore issues relating to nuclear arms control verification without the risk of proliferation
- To promote understanding between a Nuclear Weapon State (NWS) and a Non-Nuclear Weapon State (NNWS) on the issues faced by the other party
- To promote discussion on how a NNWS can be involved in a nuclear arms control verification process.

Specifically, UKNI focuses on increasing the role of NNWS and has brought together a NWS and a NNWS for the first time to discuss what verification tools and methods could be required to verify nuclear disarmament, and also to explore how all states parties to the NPT can contribute and cooperate to this end.

Results from UKNI have been presented in various forums, and in particular at meetings of the NPT Preparatory Committee and at the 2010 NPT Review Conference. This contribution is based on material extracted from such recent presentations, in particular Backe et al. (2012), UKNI (2010) and UKNI (2012).

6.4.2 Initialization of collaboration and areas of work

Early in 2007, representatives from four Norwegian laboratories, the Norwegian Radiation Protection Authority (NRPA), the Institute for Energy Technology (IFE), the Norwegian Defence Research Establishment (FFI) and NORSAR, met with representatives from the UK Ministry of Defence, the Atomic Weapons Establishment (AWE plc) and the Non-Governmental Organisation VERTIC to discuss a potential cooperation on matters related to the technical verification of nuclear arms control. It was agreed that an unclassified exchange within this field of research was feasible and that a programme of work should be developed. Under this initiative, two areas of research have so far been pursued: Information Barriers and Managed Access.

In its simplest state, an Information Barrier takes data from a measurement device, processes the data relative to predetermined criteria and provides a pass/fail output. Crucially, the Information Barrier must prevent the disclosure of sensitive measurement data to ‘uncleared’ personnel. Information Barriers are an important concept when considering future inspections, as inspectors would not be given unrestricted access to nuclear warheads, as such access would breach the mutual non-proliferation obligations of the NPT, as well as reveal national security-sensitive information. In 2007, the United Kingdom and Norway therefore embarked on the joint development of a robust, simple and relatively inexpensive Information Barrier system capable of identifying radiological sources. Such systems are intended to be used by the inspectors to verify if sealed containers hold Treaty Accountable Items or not. Used in combination with other inspection techniques, an Information Barrier system is a tool for maintaining a chain of custody and to verify that the disarmament takes place in accordance with a declaration by the country subjected to an inspection (the host country). The use of an Information Barrier system thus enables the parties to meet the requirements of the NPT and prevents disclosure of national security-sensitive information.

In a future verification regime for nuclear warhead dismantlement, inspecting parties are likely to request access to highly sensitive facilities and weapon components. Such access will have to be managed carefully by the inspected party to prevent the disclosure of sensitive information, both in compliance with the NPT and in consideration of national security. At the same time, it will be incumbent on the inspectors not to gain proliferation-sensitive information. Managed Access is the process by which ‘uncleared’ personnel are given access to such sensitive facilities, or supervised areas, under the terms of an agreed procedure or protocol.

6.4.3 Managed Access Exercises in 2008/2009

The first major element in UKNI was the conduct of Managed Access exercises in 2008 and 2009, as detailed in the following.

Preparatory work

The first stage in the UK-Norway investigation into Managed Access was the creation of a framework for the conduct of practical exercises. This framework was developed by a joint UK-Norway planning team, with VERTIC acting as an independent observer. The core element of the framework was a hypothetical treaty and its associated Verification Procedure, between two hypothetical countries, the “Kingdom of Torland,” a NWS, and the “Republic of Luvania,” a NNWS. In an initial declaration, Torland stated its intention to dismantle its ten remaining Odin class nuclear weapons (gravity bombs). Torland invited Luvania to verify the dismantlement process for one of these weapons. The Verification Procedure allowed for the Luvanian inspectors to undertake a Familiarization Visit to Torland’s nuclear weapon complex, and to subsequently carry out a Monitoring Visit to the same facilities to verify the dismantlement of one Odin class bomb. The dismantlement would be considered complete once the Odin pit (the pit is the notional fissile component within the Odin nuclear weapon) had been placed in a monitored store. The exercise was designed to have a broad enough scope to provide an overview of the whole dismantlement and verification process.

The key objective for Luvania was to establish confidence in the declaration made by Torland with regards to the Treaty Accountable Item (the Treaty Accountable Item was the Odin pit) and to demonstrate, to the satisfaction of both parties, a chain of custody through the dismantlement process. Luvania, as the inspecting party, would produce an inspection report in accordance with the

Verification Procedure. The key objective for Torland was to demonstrate compliance with their obligations under the treaty whilst protecting national security and proliferation sensitive information.

Several steps were taken during the planning stages for the Managed Access exercises to minimize the risk of proliferation. Initially, and continuously during the work, each of the parties assessed their roles and obligations related to NPT Articles I and II and implemented several measures including:

- For the purpose of the Managed Access exercises, it was decided that the United Kingdom and Norway would 'swap roles'. Norway would play the NWS while the United Kingdom would play the NNWS. This also gave the participants the opportunity to explore the problem from the other side's viewpoint
- It was decided that the exercises would take place in Norway
- Although the exercise play was based on a framework involving "the Odin class nuclear weapon," the actual object used during the notional dismantlement process was based on a cobalt-60 radiological source
- The development of Torland's "Atomic Weapons Laboratory", where the Managed Access exercises took place, was undertaken via discussions of a generic facility model comprising simple, logical building blocks which might conceivably be present within any nuclear weapon complex.

Conduct of the exercises

Prior to the Monitoring Visit, Luvanian inspectors visited Torland's "Atomic Weapons Laboratory" in December 2008 to familiarize themselves with the facilities (see Fig. 6.4.1; 'TAI' is the Treaty Accountable Item), the level of access, access controls and the timeline for the dismantlement. During this Familiarization Visit, broad agreement was reached in terms of the permissible inspection activities, and the control measures which would be instigated by the host.

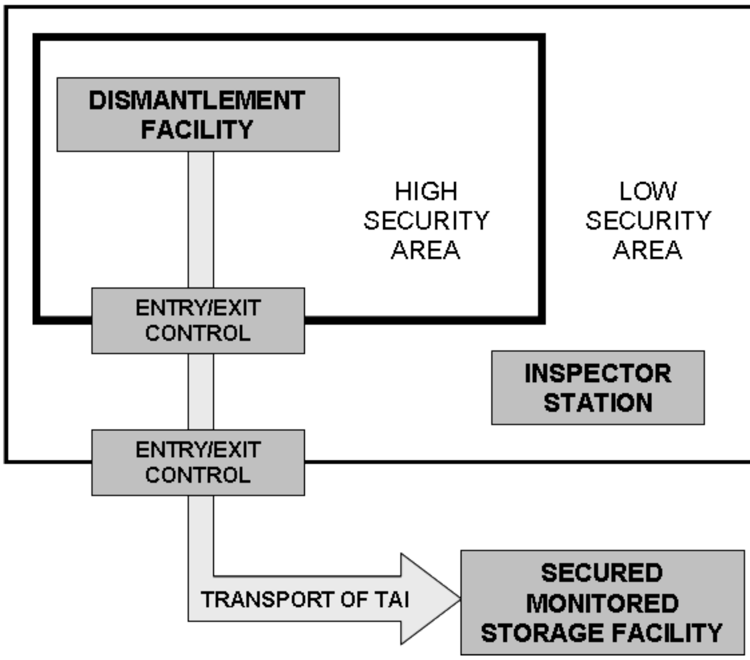

Fig. 6.4.1 Torland's "Atomic Weapons Laboratory" for the Managed Access exercises in 2008/2009.

During the Monitoring Visit in June 2009, the Odin weapon was dismantled in stages in a process that took several days to complete. The Inspectors were presented with the containerised Treaty Accountable Item at agreed points in this process; each point involved the use of a different sealed container. Two jointly designed Information Barrier prototypes were tested during the Monitoring Visit exercise; this was the first field test of the Information Barrier technology developed as part of the UK-Norway Initiative. At the end of each day, the item was stored in an interim storage area. This storage area was secured so that the inspectors were confident that no tampering or diversion activities had occurred. At the end of the dismantlement process, the Treaty Accountable Item was transported from the dismantlement facility to a secured monitored storage facility (Fig. 6.4.1). Pictures taken at various stages of the dismantlement process are shown in Figs. 6.4.2 through 6.4.7.

Fig. 6.4.2 The picture shows the inspectors (in orange coats) in their first contact with the Odin "nuclear weapon", held within a transport container.

The inspectors were provided with an "Inspector Station," which was located within a low security area (Fig. 6.4.1). Within this facility restrictions on activities were minimal, allowing the inspectors to pursue negotiations, review documentation, write reports and perform data analysis.

At the beginning of each day, the inspecting party and the host party met within the Inspector Station to review the facilities and operations scheduled for that day including the dismantlement and inspection activities to be performed. The inspectors were then taken through an entry/exit control point into the high security area (Fig. 6.4.1) where the host deployed a number of Managed Access techniques to ensure that the inspection activities did not breach health and safety regulations, disclose proliferative information or reveal information related to national security.

At the end of the inspection process, Luvania produced a report commenting on the degree to which the monitoring activities had demonstrated Torland’s compliance with the initial declaration, and their level of confidence in the overall chain of custody. Torland responded with their observations on Luvania’s report.

Host techniques for controlling inspection activities

The Torian host team deployed a number of tactics in order to handle security and inspection activities:

- Identity checks before and during the visit
- Security briefings
- Change of clothing and metal detector checking
- Escorting and guarding
- Shrouding and exclusion zones
- Host control of equipment and measurements
- Documentation and information control including numbered notepads.

Fig. 6.4.3 An inspector watches as a host representative performs measurements using the Information Barrier system. Measurements are performed on the Odin “nuclear weapon”, which is still inside the transport container.

Torland ensured that Luvania could not carry any covert monitoring devices during the facility based inspection activities, by requesting that "contraband" items (such as mobile phones or watches) were surrendered prior to taking the inspectors into the high security area. Torland confirmed that all such items had been handed over by asking the inspectors to (notionally) change into clothing provided by Torland and by using a metal detector to perform a search. Whilst within the high security area, escorts and guards were assigned to ensure that the Luvanian inspectors only performed agreed activities within designated areas. Torland used shrouding to conceal items which could provide sensitive or proliferative information. Exclusion zones were marked to identify areas prohibited to inspectors.

Notionally, Torland ensured that the equipment used by the inspectors did not contain any covert monitoring features and did not measure parameters which would be considered sensitive or proliferative. In order to achieve this, all inspection equipment was notionally agreed, authenticated and certified for use within the facility prior to the commencement of the exercise. The equipment used within the high security area was host supplied. It was agreed that Torland facility staff should undertake all measurement and sealing activities under Luvanian supervision.

Fig. 6.4.4 The Odin "nuclear weapon" is taken out of the transport containers. The inspectors were not allowed to watch this step.

The inspection process was documented and signed off by both parties; the measurement data were held jointly until officially released by Torland for use within the Inspector Station. All numbered notepads and pens used within the high security area were supplied by Torland. These were issued just before entrance into the high security area and collected before exiting. Torland reviewed all notes to ensure that no sensitive information had been recorded.

Many of the above measures were primarily based on security concerns, however, health and safety was also an overriding consideration for the host. Many areas within a nuclear weapon complex are subject to strict regulations and the host must ensure that these are followed during the course of the visit. Torland provided additional health and safety briefings along with appropriate protective and restrictive measures.

Inspection activities

The Luvanian inspectors deployed a number of techniques and processes in order to support the verification activities as agreed during the Familiarization Visit:

- Radiation monitoring
- Tags and seals
- Digital photography of the tags and seals
- CCTV cameras (closed-circuit television)
- Information Barrier system for gamma measurements
- Photography of inspection relevant items, in-situ and with inspectors present
- Review of documentation relating to the Odin device, and visual observations and dimensional measurements of the Odin weapon and containers.

All necessary equipment was supplied by the host to ensure compliance with health, safety and security requirements. The inspectors were permitted to use their own equipment at the Inspector Station, but not inside the dismantlement facility. Authentication of host supplied equipment was not carried out in the exercise. However, some of these issues were addressed in the Information Barrier project.

Prior to any activities being undertaken within the dismantlement facility, the inspectors needed to convince themselves of the absence of materials and sources which could impinge on the inspection activities. Radiation monitoring activities were undertaken using gamma and neutron count rate monitors supplied by Torland. The overall sweeping concept was designed to gain confidence in the integrity of the inspection activities. Once the Inspectors had ensured that the area was clear, all personnel, equipment and containers were monitored in and out of the area. The only exceptions were sealed containers declared to contain the Odin weapon or its components. This procedure was repeated once the dismantlement was complete, to ensure that no treaty relevant materials had been left within the facility.

Tags and seals were used for three reasons: to be able to uniquely identify any containers with the Odin weapon or its components, to ensure that no containers had been opened and to ensure that during dismantlement no materials had been removed from the facilities. Tags and seals were applied to the inside of the facilities immediately after sweeping. The deployed, commercial tags and seals were based on research undertaken in the United States of America and for the International Atomic Energy Agency. The method relied on the inherent tamper-indicating properties of the seals, with the inspectors adding unique random particulate identification tagging (RPIT) to each seal.

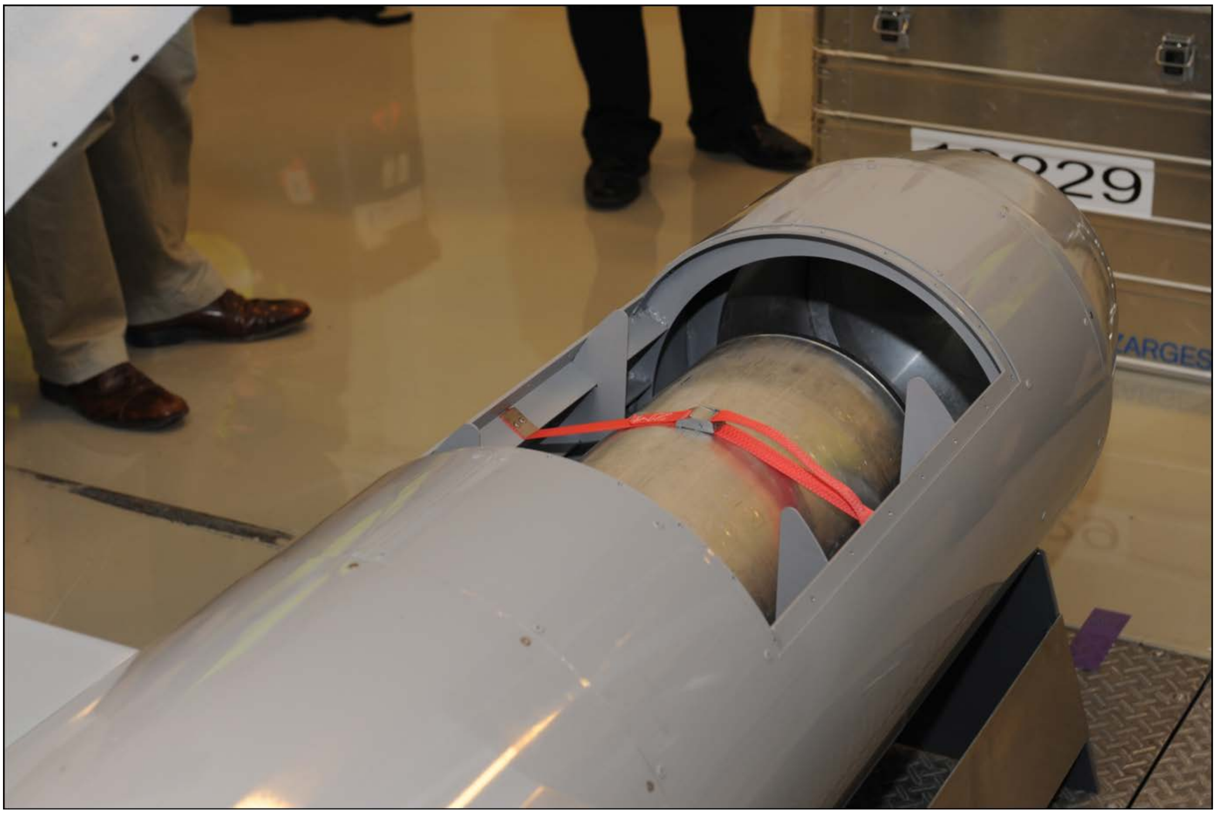

Fig. 6.4.5 The picture shows the Odin pit (fissile component) within the Odin “nuclear weapon” after removal of a hatch. Inspectors were not permitted to see the weapon at this step in the dismantlement process.

The tags and seals were verified by photographing the RPIT. For the exercise, the RPIT consisted of simple glitter supplied by the inspectors and randomly encapsulated in an adhesive. This was applied to the host supplied seals in the Inspector Station shortly before use in the facilities. It is important that the Inspectors are able to impose their own unique identifying feature, particularly if the seals are host supplied, to ensure that the seals cannot be swapped. During the exercise, the images of the seals were taken to the Inspector Station to be compared via a blink comparison technique. Undertaking this in the Inspector Station allowed the inspectors to use their own software to ensure high confidence in the results.

CCTV cameras were deployed notionally at points of interest where the information, within the agreed field of view, was considered to be insensitive by the host. The CCTV cameras provided a direct visual confirmation that no personnel or material had entered or left the facility while the inspectors were not present. Examples include views of ceilings within dismantlement facilities and of exit doorways, which the host had agreed would not be used during the dismantlement activities.

The Information Barrier system was used to confirm that the initial container, declared to contain the Odin weapon system, had a gamma radiation signature compatible with the host’s declaration. After each stage of dismantlement, the Information Barrier system was used to confirm that the container declared to hold the Treaty Accountable Item met this agreed signature. All other containers were then monitored with the non-barriered radiation detectors to confirm the absence of any radioactive material. Once a container was confirmed as empty of radioactive material, it could be removed from the facility. The container with the Treaty Accountable Item was sealed to ensure the further chain of custody.

Some redacted documents containing a limited history of the Odin device with serial number, dates and signatures were provided by the host. Prior to the dismantlement, a limited number of inspectors were allowed to see the outer casing of the Odin device. Some documents were provided by the host to show physical parameters and serial numbers which could be verified by the inspectors on the systems as presented to them. The collection of documents made available to the inspectors by the host was intended to provide further confidence that the item under verification was indeed an Odin system.

Fig. 6.4.6 Information Barrier measurements are performed on the Odin pit contained inside the blue barrel. Both Information Barrier prototypes were used.

Strategy and negotiations

Neither party had developed a comprehensive strategy prior to the exercise, though both had elements in place. All of the participants understood that national security and non-proliferation commitments were an overriding consideration.

During negotiations, the Torian hosts were reminded that they had invited Luvania to inspect the dismantlement process. This, coupled with the non-reciprocal nature of the agreement, placed Torland in what was regarded as a slightly weaker negotiating position. However, as the exercise progressed the Luvanian team became more aware that their actions and conclusions would be the subject of scrutiny by the international community, increasing the pressure on the Luvanian Inspectors to deliver what had been agreed.

A number of issues were subjects of negotiation: facility schematics, images of inspectors within facilities, physical measurements on the weapon itself, the use of open source images, serial numbers and surfaces interfacing with seals. Even though both parties had considered that most issues were resolved by the end of the Familiarization Visit, it soon became apparent that a large number of details still required negotiated agreement before monitoring activities could proceed.

Torland's negotiating stance allowed concessions to be made on points where national security or non-proliferation was not an issue. This fitted well with Luvania's view of a co-operative process which inspired trust and confidence. As the negotiations progressed, and the Luvanian Inspectors continued to request activities beyond the initially agreed scope, the Torland Hosts began to adopt a firmer stance to Luvania's demands.

Lessons learned

The exercise emphasised the key challenge facing the host during any verification regime operating within a nuclear weapon complex: how to provide the inspectors with the opportunity to gather sufficient evidence, while at the same time protecting sensitive or proliferative information. The host will share in the responsibility to ensure that the verification regime has been applied comprehensively. The host will not want to be unjustly accused of hindering the inspection activities or indeed cheating.

The host has to take care when considering national security and proliferation concerns, that the information provided to satisfy individual inspector requests does not become sensitive when it is aggregated. The host might consider agreeing to requests "in principle" until all of the Inspector requests have been collated.

The escorting concept deployed during the exercise focused on controlling the inspectors. Both guards and facility staff were involved in escorting duties, although there was some confusion amongst the facility staff as to their responsibilities, as they also had to facilitate the inspection activities. It was clear that the Torian team did not have enough staff to support both the security escorting and the technical inspection activities. At times the inspectors outnumbered the host staff allowing the opportunity for some of the inspectors to perform unsupervised measurements.

Shrouded objects are an issue, particularly where the shrouding is hiding tooling which will be used in the dismantlement process – these items cannot be sealed. Unsealed shrouded objects could be hiding shielded covert sources or shielded containers to be used during material diversion. This is an issue that requires further thought.

The tagging and sealing process highlighted a number of issues. Over time some of the seals started to peel off the painted walls. This indicates how important it is to consider the surfaces that the seals will be applied to, not just the seals themselves. Whilst it was possible to place the seals in almost any location, taking images of the RPIT was difficult in awkward positions. Over an extended period of time, any vulnerability could be exploited by the host, who after all has all the resources of a state party. If the seals were only going to be relied on for a short time, the deployed solution might be adequate; for longer periods, new ideas must be considered. The large number of seals proved to be time consuming to deploy and evaluate, while the vehicles proved almost impossible to seal to the inspectors' satisfaction.

The concept of CCTV needs further consideration if it were to be deployed within a nuclear weapon complex. However, the exercise has shown that CCTV can be usefully deployed in situations without significant security or proliferation risks, such as the monitoring of ceilings and of entrances not used during dismantling activities.

The inspectors felt that to effectively deploy chain of custody measures, the team needed to give greater consideration to the threat and the vulnerabilities. Such an assessment would form part of a risk/benefit analysis where the inspectors would consider the threat, the likelihood of the scenario occurring and the confidence levels associated with the deployment of a particular concept. The inspectors commented that it would have been better to have stepped back and considered the area more thoroughly rather than rushing in to complete the work. It should be noted that schematic drawings are unlikely to have sufficient three-dimensional detail to satisfy all the requirements of the inspectors in developing comprehensive chain of custody measures.

Radiation monitoring, sealing and the deployment of CCTV cameras have to be considered as parts of a unified strategy for securing an area. Overall, it is the consideration of the entire verification system that is important rather than each element in isolation. The inspectors will always be looking for anomalies relative to the regime as a whole. The concept of multiple layers of protection proved to be particularly important.

Host/inspector interactions became friendlier as the week progressed. This phenomenon has been observed in other exercises, as well as in real inspections, and can be instrumental in building trust. However, this does need to be managed so that professional detachment is maintained.

The exercise did emphasise the importance of considering the movement of information and equipment across areas with differing security restrictions. It was deemed very important for the inspectors to have access to an Inspector Station where they could work with a minimum of restrictions (this includes the use of equipment to record and analyse inspector observations and measurement data). This Inspector Station would need to be outside all host sensitive facilities. The movement of information and equipment between the sensitive facilities and the Inspector Station is a complex issue that should not be underestimated. All such transfers will need host approval and be under host control. For example, written notes on host-supplied paper or photographs of a seal are likely to be approved, while computers, electronic equipment and complex data files are unlikely to gain approval. Inspectors must carefully consider such issues when designing their verification approach.

The remit of the verification regime is driven by the host’s declaration as the inspectors can only confirm what has been declared. The choice and capabilities of the equipment will then need to reflect this information. For example, the Information Barrier system cannot incorporate a mass threshold if no indication of mass has been given. The problem for the host is what the declaration can say, given the non-proliferation and security requirements. The host will need to perform a rigorous risk assessment considering proliferation and security concerns with respect to the overall potential gains in inspector confidence. This is both a technical and political matter for further consideration.

Inspector/host confidence

The Luvanian inspector team wrote an inspection report which was issued to Torland for comment. In summary, the inspectors made the following observations:

- The inspectors were able to deploy all the techniques deemed necessary to sustain an unbroken chain of custody of the item declared by Torland as the Treaty Accountable Item, from start to finish of the inspection
- The Information Barrier system was successfully deployed four times during the inspection process – the presence of the notional weapons grade plutonium (in reality, radioactive cobalt) was confirmed each time
- The co-operation from Torland was exemplary
- As a result of the above, the inspection team was able to confirm with a high degree of confidence that the objects declared as the Odin weapon, and its associated containers, moved through the declared dismantlement process
- Further scientific measurements and documentation indicating provenance could, in future dismantlement processes, provide greater reassurance that the object was the Odin system.

The Torian host team added the following observations to the inspection report:

- Torland was satisfied that their national security had not been compromised and that non-proliferation obligations had been observed at all times
- Torland felt that Luvania’s requests for additional information had been reasonable and acceptable
- Torland agreed that further technological development was necessary, particularly in the area of Information Barrier measurements, in order to confirm the identification of the Odin system.

Despite obvious weaknesses in the verification technologies and procedures and in the host security arrangements, both teams had high confidence that they met their obligations.

Several points were highlighted where the host might have considered diverting materials or performed a spoofing scenario. However, as these opportunities could not have been predetermined and were unlikely to be repeated, would the host risk taking advantage of them? Overall, the inspectors need to take a rigorous, but risk-based approach – the inspectors will never be 100 % confident.

None of the verification measures used could confirm that the object was an Odin class weapon as declared. The Information Barrier measurements, along with the documentary evidence, built confidence but were not definitive proof. It was not the intention of this series of exercises to solve this “initialisation problem”; however, they have highlighted the issue.

If the international community is to have a discussion on the issues of inspector/host “confidence” or “trust,” ideally some form of metric for these parameters needs to be developed.

Conclusions

The text above has mainly described the exercise from the perspective of the players Torland and Luvania. In the following, we try to summarize conclusions from the out-of-play perspective of Norway and the United Kingdom.

As stated earlier, Article VI of the NPT sets out, among other elements, that each of the parties undertakes to pursue effective measures relating to arms control and disarmament, and their verification, NNWS and NWS alike. Establishing effective verification measures will be an important precondition for fulfilling the goals of Article VI. During this exercise, the UK-Norway Initiative (with the Non-Governmental Organisation VERTIC as an independent observer) explored activities in line with these obligations, with both parties mindful of their roles and obligations under international agreements and national regulations.

The broad scope of the Monitoring Visit scenario provided the participants with a global view of how all of the elements of the verification regime would fit together in order to support the inspection process. A number of Managed Access concepts were deployed in order to control inspection activities within the facilities. The exercise process emphasized the importance of controlling the movement of information, equipment and personnel across areas of differing security restrictions and the need to improve on procedures supporting this process.

A variety of inspection techniques were deployed in order to create a multi-layer approach to the chain of custody and overall inspection activities. It was noted that to effectively deploy these chain of custody measures, a rigorous risk assessment considering the potential threats and vulnerabilities needs to be undertaken. Radiation monitoring, sealing and surveillance technologies have to be considered in one unified strategy for securing an area prior to inspection activities. The practical experience from the use of these techniques highlighted many lessons, for example, the resource intensive nature of seal deployment and verification demonstrated the need to investigate alternative approaches. The concepts of authentication, certification and chain of custody of inspection equipment were only played notionally; however, these aspects are recognized as being vital elements within a verification regime.

The jointly developed Information Barrier systems were successfully deployed throughout the exercise. The exercise remit for the Information Barrier system was to confirm the presence of (notional) weapons grade plutonium. This alone would not be sufficient to give the inspectors confidence that the host had not cheated. Future proposed developments to the system include the ability to confirm material grade and perform a mass threshold measurement. The project will continue to look to incorporate the concepts of authentication and certification. It was felt that this technological concept would only ever be able to confirm that the measured attributes are consistent with the presence of a nuclear weapon, but would not be able to provide a definitive identification. This calls into question the ability of the inspecting party to initialise the verification process, in other words, to confirm that the item presented is indeed the declared nuclear weapon (known as the “initialisation problem”). Attempts were made to compensate for this deficiency by requesting documentation related to provenance, but this will only have limited value unless it is linked to measurements and other supporting evidence.

Fig. 6.4.7 The picture shows the participants from Norwegian and UK institutions, as well as VERTIC, after completion of the Managed Access Monitoring Visit exercise in Norway in June 2009.

The United Kingdom and Norway believe that it should be possible to maintain a chain of custody for nuclear warhead dismantlement to a high degree of confidence when the relevant technologies have been developed to the necessary level of functionality. The initialization problem is an ongoing issue which requires further consideration before a technical solution could be proposed.

This technical exchange showed that a NWS and a NNWS can collaborate within this field and successfully manage any risks of proliferation. It has been found that many of the underpinning issues can be posed in generic terms which would allow NNWS to contribute to technological developments; the development of flexible, generic solutions means that the results could be tailored to support a number of future, “real life” scenarios. The participants felt that the involvement of NNWS would be vital in creating international widespread acceptance of, and trust in, a proposed verification regime. The United Kingdom found that the Norwegian participants brought a fresh perspective to the problems which challenged long-standing opinions and viewpoints.

6.4.4 Managed Access exercise in 2010

The lessons learned from the 2008/2009 exercises were wide ranging, but two in particular were singled out when a potential follow on exercise was initially discussed:

- National security and proliferation concerns permeate through everything
- The implications of Health and Safety regulations must not be underestimated.

The Norwegian facilities used to host the 2008/2009 exercises were not ‘high security’ facilities; therefore the security aspects of the scenario could only be played lightly. Health and Safety regulations were included in the scenario, but again it was felt that these did not quite match the level that would be experienced in an actual nuclear weapons complex. It was decided that a ‘focused exercise’ was required which would more realistically explore the impact of host security measures on the Inspection regime and demonstrate some aspects of the safety regulatory environment associated with a nuclear weapons complex. In order to achieve the level of realism required, it was agreed the exercise would take place at a UK facility with the UK now taking the role of the host NWS party Torland.

Preparatory work

It was decided that the focused exercise would use the same documentation as in 2008/2009; however the players were warned that the implementation of the scenario would be different. The exercise focused on a Familiarization Visit to an initial storage/receipt facility. The inspecting Luvanian team (Norway) was tasked to:

- Understand relevant processes, routes and facilities by obtaining access to the initial storage/receipt facility
- Become familiar with the container types that would be used in the dismantlement process
- Consider a strategy for a future monitoring regime. The exercise provided an opportunity to trial potential seal types on the containers
- Maintain the safety and security of the team and comply with obligations under the NPT.

In order to play this scenario with an increased level of realism, the UK suggested the use of a low security facility within the boundaries of one of the AWE sites. Simulated facilities were set up to demonstrate increasing levels of security that would have to be negotiated in order to access an inner Storage/Receipt facility (Fig. 6.4.8). This arrangement had two advantages:

- It provided an opportunity for Norway to play the inspecting party (Luvania)
- The exercise benefited from the expertise of AWE’s staff and utilisation of AWE’s existing infrastructure. Although the actual facility used was in a low security area not associated with the dismantlement process, AWE’s security and facility team were asked to create a facility that mimicked many of the techniques and processes which might be deployed to manage access within a typical nuclear weapons complex.

The host team (Torland) was given the same primary objective as in 2008/2009, to demonstrate compliance with their obligations under the treaty whilst protecting national security and proliferation sensitive information. However, whereas during 2008/2009 both teams were instructed that the process was collaborative, for the 2010 exercise the planners decided to change the emphasis for the host team. In this exercise, the Torian host was described as:

- Having a heavy emphasis on security as a first priority
- Inexperienced in dealing with inspection activities
- Reactive rather than proactive.

The planners were aware that the above changes would result in a more confrontational scenario than had been played in 2008/2009, but this was considered to be in keeping with the overall objective of the focused exercise. The exercise was set up to maximize host security intrusion; given this, the planners accepted that the inspectors might not be completely satisfied with the outcome of their inspection activities. For the planners, a successful conclusion to the exercise was ensuring that the impact of security on the inspection process had been fully explored.

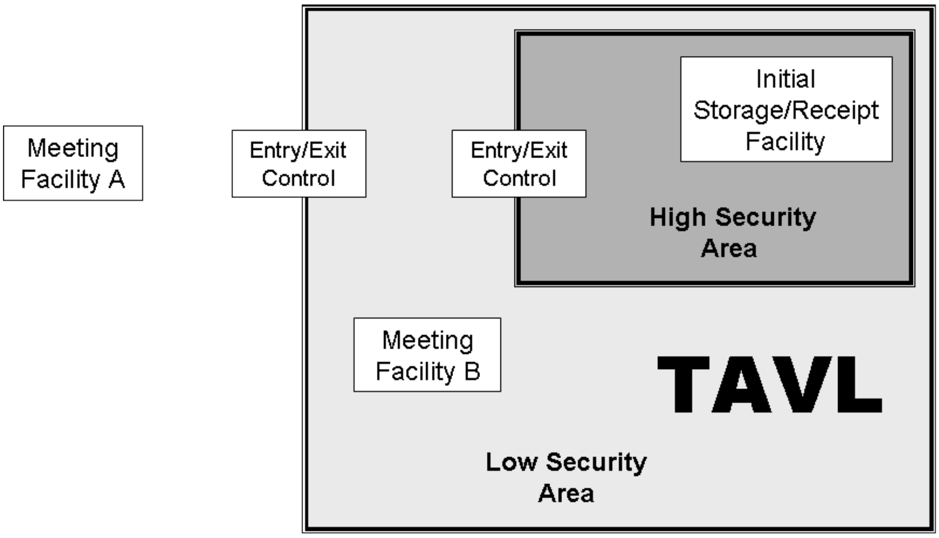

Fig. 6.4.8 TAVL, Torland's "Atomic Weapons Laboratory" for the Managed Access exercise in 2010.

Conduct of the exercise

The Luvanian inspecting party arrived at Meeting Facility A (Fig. 6.4.8) with pre-prepared procedural documentation and a structure for the inspection report. The team anticipated that the host would provide a full, detailed briefing on the facilities and processes prior to the on-site visit. A Health and Safety plan had been developed, and a request was made for a side discussion to agree the contents. It was anticipated that the inspectors would have full access to all areas of relevance to the inspection process, along with supporting schematics which would allow them to identify potential material diversion routes. In order to fully understand the role of the facility within the dismantlement process, Luvania also requested details of the operations which would take place within the facility, including any associated transport phases. Furthermore, they wished to confirm the location of the site and relevant facilities with a GPS system.

Torland pointed out that TAVL, Torland's "Atomic Weapons Laboratory", was a high security facility, and that Torland had a responsibility to maintain the physical security surrounding assets, staff and operations. Torland regarded the exact layout and design of the facilities as an integral part of the physical security of the site, therefore, maps and schematics could not be released. Torland also pointed out that no-one, including host personnel, would be allowed to take GPS readings on-site. The physical security surrounding transport phases was particularly sensitive for Torland. Consequently no information was provided regarding the transport vehicles or the timetable for transport phases; inspectors would not be allowed to witness transport phases.

Torland noted a misunderstanding in terms of the function of the Storage/Receipt facility. This was not a long term storage area but an area that had been set aside to support inspection activities. A containerised Odin weapon would be brought to the facility at the beginning of the inspection process; inspectors would be given the agreed level of access at that point. Host concerns over site physical security measures meant that they were not prepared to reveal the location or design of the long term storage facility to Luvania. It was noted that the function of the Storage/Receipt facility had not been adequately defined within the initial documentation.

The Torian host team welcomed the inclusion of the Luvanian pre-prepared documentation and was prepared to discuss the Health and Safety plan. The Host team pointed out that the Storage/Receipt facility was subject to both explosive and radiological safety regulations. As a result, Torland intended to limit the time within the Storage/Receipt facility to a maximum of 75 minutes with only four inspectors per visit. Torland suggested two visits so that all the inspectors would have an opportunity to see the facility. It should be noted that Torland had a secondary security based motive to limit time and numbers, as this made the visit easier to manage. By insisting on the host supply and operation of equipment, Torland could ensure that it would not be possible for Luvania to take covert measurements within the facility.

The host provision and operation of equipment impacted on Luvanian plans to trial seals on the containers. This was primarily required to test whether the proposed seal types were fit for purpose. Luvania pointed out that both sides needed to have trust in the equipment. It was agreed to trial a “random sampling” regime which would allow the inspecting party to take away a sample of the host provided seals for testing. Also, the inspecting party insisted that they be allowed to check the seals once they had been applied. It was jointly agreed that the discussion of the sealing system should extend to a consideration of the seal reader and the management of any measurement data.

In addition to the ‘guards, guns and gates’ which are associated with the TAVL site, Torland deployed several additional levels of security to manage the Luvanian access onto the Storage/Receipt facility:

- Initial entry into the protected area involved identification checks, searches and the removal of prohibited items (such as cameras, phones and recording devices)
- Shrouding was deployed to ensure that inspectors only viewed areas of site directly related to the inspection process
- The inspectors were escorted and monitored at all times
- Entry into and egress from the high security area involved additional identity checks and the deployment of search and detection equipment
- Entry into and egress from the Storage/Receipt facility was via a Change Barrier (a change into protective clothing). As well as meeting Health and Safety requirements, the implementation of the barrier provided an added a layer of security assurance
- Movement within the facility was restricted to prescribed walkways; the inspecting party was not allowed to approach the container or the walls of the facility
- Additional escorts were deployed within the facility
- Shrouding was used within the facility to conceal items which could provide sensitive or proliferative information
- Notepads were issued on entry to the Storage/Receipt facility and retained by Torland on exiting the facility. The notepad content was checked by Torland security and photocopies of cleared documents were provided to the Inspectors
- All equipment was supplied by Torland
- All equipment was operated by Torland. One inspector was allowed to approach the container to check the integrity of the deployed seals.

The inspectors were based inside Meeting Facility B (Fig. 6.4.8) for the day and were moved to the Storage/Receipt facility, one group at a time, for the two agreed visits. The level of security came as a surprise as the briefing had not given full details of the Managed Access procedures that would be deployed. As a definition of the function and extent of the facility had not been agreed, there was a misunderstanding with regard to the time allotted to each visit. The inspectors defined the facility as the room in which the container was housed whereas the host defined the facility as the whole building including the Change Barrier area. The Change Barrier process took a significant amount of time away from the agreed inspection activities. However, the inspectors did successfully gain entry into the facility and visual access to the container.

The procedure for seal deployment began with a random selection activity. Torland presented a selection of seals to Luvania; the seals were of a jointly agreed type and had not previously been taken into the high security area. Luvania randomly selected two sample sets:

- The inspectors were allowed to keep set 1. These were taken off site and destructively analysed
- Set 2 were placed in a clear plastic bag and were held in dual custody. The host party had physical possession of the seals, but the inspecting party had visual contact at all times. These seals remained within the facility following application.

In the facility, the Torian staff applied the seals to the container and took reference photographs. A Luvanian inspector was then allowed to approach the container to physically check the integrity of the seal. Although the random selection process was successful, both sides lost visual custody of the seals at points during the period between selection and deployment within the facility. Despite the increased escorting activities within the Storage/Receipt facility, the escorting team found it challenging to manage the agreed sealing activity.

Lessons learned

Although lessons should be learned from past experience within other regimes (i.e., that of the Chemical Weapons Convention), this scenario also offered some unique challenges for the inspecting party. Observations were made on the difficulty, particularly from the viewpoint of a NNWS, of inspecting such an unfamiliar environment and process. Multiple Familiarization Visits would probably be required to support the inspection process.

The primary objective for the Inspectors was to understand relevant processes, routes and facilities by obtaining access to the initial Storage/Receipt facility. Host security and proliferation concerns meant that the preliminary information provided during the negotiation phase was limited. Ambiguity in the language used to describe the facility, both during discussions and within the supporting documentation, meant that there was a fundamental misunderstanding with regard to the function of the Storage/Receipt facility. Inspectors successfully negotiated access to the facility with a view to clarifying the situation and compensating for the lack of building schematics. However, Torland's Managed Access procedures limited time within the facility and did not provide the freedom of movement to fully explore inside the facility or view adjoining areas. As a result, potential material diversion routes could not be identified. The inspectors left with an overview of the facility and related operations, but not how those operations linked to the overall dismantlement process.

The second objective for the inspectors was to consider a strategy for a future monitoring regime. The two concepts that were discussed were a sealing strategy for the container and the deployment of a radiation detector behind an Information Barrier. Torland was unwilling to discuss the construction of the container because of security concerns; this made it hard to assess the effectiveness and vulnerability of the proposed technologies. A lack of information about the facility in which the radiation measurement system was to be deployed again prompted questions in terms of the host's ability to 'spoof' the measurement.

The inspecting team felt that the safety regime was more intrusive than expected. The primary impact experienced by the Inspectors in this exercise scenario was in terms of the limit on the number of inspectors allowed into the facility. This safety measure results from a combination of explosives and fire regulations. This had two effects on the inspection regime: time and communication. The time required for the inspection process increased because multiple visits were required to the facility. The inspection team was split between multiple buildings which made communication, and consequently coordination, increasingly difficult.

Conclusions

The focused 2010 Managed Access exercise showed how the security/safety regime implemented by the host state could impact on the inspectors' ability to assess the potential threats to, and vulnerabilities of, a potential future monitoring regime. It should be noted that despite the intrusive levels of the host security and safety arrangements, the inspecting party still managed to complete the objectives of the Familiarization Visit, albeit with a low level of confidence in the outputs from the visit. A comparison between the adversarial environment of the 2010 exercise and the collaborative environment of the 2008/2009 exercises indicate that a collaborative environment, and a proactive host, could help to facilitate the inspection process and increase confidence levels in the overall verification regime. However, even in a cooperative environment, security and safety will still have a significant impact on the inspection regime.

In conclusion, the exercise provided a common understanding within the UKNI collaboration of the impact that host security and safety could have on an inspection regime. This is essential for technology and procedural development in the future.

6.4.5 Workshop in 2011

During 7-9 December 2011, the UK and Norway hosted a three day workshop which aimed to bring together Non-Nuclear Weapon States to discuss verification tools and methods needed to verify nuclear dismantlement, and to explore how all States Parties to the NPT can contribute to their NPT Article VI obligations. The workshop drew upon the results and methods from the UK-Norway Initiative to date. It demonstrated how a NWS and a NNWS could work together to make significant contributions to nuclear disarmament verification research. It was also an important opportunity for the UK and Norway to gain feedback on their research progress to date.

Twelve NNWS attended, along with the United States as subject matter experts on arms control verification research. Invitations were sent to those countries that had previously expressed an interest in the UK-Norway Initiative.

Workshop agenda and format

The workshop programme covered both policy and technical issues. Technical topics covered included discussion of concepts such as managed access, information barriers and chain of custody (i.e. containment and surveillance). Broad themes were: the background to the Initiative, some of the joint exercises that have taken place, the creation of the Information Barrier technology and future steps for the Initiative. Technical and policy officials from Non-Nuclear Weapons States were invited. This included negotiators or inspectors involved in arms control regimes or nuclear safeguards, or those with experience as a facility manager with responsibility for controlling access of foreign inspectors to a sensitive site.

Each day featured a number of presentations on different aspects of the UKNI, followed by an opportunity for discussion amongst the delegates. The workshop sought to promote active participation through small working groups. Participants were encouraged to be prepared to discuss relevant tools and methods, both technical and non-technical, and also to think about how both NWS and NNWS can contribute to nuclear disarmament research using their own technical expertise. With this in mind, the UKNI arranged an informal poster and technical demonstration session to which states were invited to contribute; several states took this opportunity to present on technically relevant topics.

Day 1 of the workshop provided an opportunity for delegates to discuss the ‘challenge’ of nuclear warhead dismantlement verification. Discussion topics included:

- The scope of the UKNI programme
- A generic facility concept
- Host and inspector viewpoints
- The potential impact of security and proliferation concerns.

Day 2 looked at how the UKNI has attempted to address the technical challenges associated with nuclear warhead dismantlement verification. This was an opportunity for the delegates to offer feedback, ideas and perspectives on the current UKNI research programme, and discuss technologies which have an application within a verification regime. The following topics were outlined and discussed:

- The planning, conduct and lessons learned from the 2008 and 2009 Managed Access exercise programme
- The Information Barrier project.

Day 3 was about future research. The objectives, conduct and new lessons learned from the 2010 Managed Access exercise were outlined. The broader lessons and challenges ahead in the verification of nuclear disarmament were considered. Finally, delegates discussed the future direction of the UK-Norway Initiative, and opportunities for the work of others.

Workshop discussions

Throughout the three days of the workshop, delegates were provided with opportunities to discuss topics relevant to the workshop. Some of the main topics had been extensively addressed in the exercises reported above, and included the initialization problem, declarations, confidence, host/inspector relationships, and national security and non-proliferation.

Delegates were asked to give feedback, ideas and perspectives on the current UKNI research programme:

General Feedback: Delegates commented that the scenario developed within UKNI was 'realistic' when compared with experience from other 'real world' regimes, but it was also noted that real world regimes may present a more hostile environment in comparison with the cooperative scenario discussed by UKNI. Both inspectors and host have an incentive for the regime to succeed since failure would reflect badly on the overall process and might adversely affect the international reputation of the host. This point of view was evident in the discussion sessions and as a key learning point from the UKNI.

Exercises: The programme of exercises was viewed as an effective way of identifying new issues, exploring scenarios and minimising the risk of failure in the future. But it was noted that the application of different cultures/background/personalities/experiences could yield different results. There was some discussion on the possible involvement of a third party (e.g. NGOs) in the inspection process but no conclusion was reached.

Information Barrier: This was recognised as an important technology requiring further development as this would allow measurements of treaty relevant items while still protecting nationally sensitive or proliferative information. The UKNI instigated a 'step-by-step' approach to Information Barrier development which promoted a mutual understanding of the technology and issues, whilst ensuring that non-proliferation obligations were met.

During the discussion session, a number of broader themes were also covered. Some of these were the question of whether designated or dedicated facilities for nuclear warhead dismantlement would mitigate the national security or proliferation sensitivities, the role of language, culture and understanding, lessons learned from other regimes and organisations, and the credibility of any future regime with the international community.

Workshop summary

It was recognized that all states parties to the NPT have an obligation under Article VI to contribute to the development of verification regimes but that active NNWS involvement in the inspection process brought both benefits and risks. However, it was felt that NNWS involvement would be essential if the verification regime was to be internationally credible and transparent. The UKNI has demonstrated that successful and productive collaborative verification research is possible between NWS and NNWS, whilst still fulfilling NPT Articles I and II.

There was widespread acceptance that major technological development is still required to produce jointly trustable systems for deployment in the verification of nuclear warhead dismantlement. Collaborative disarmament verification research will be necessary in order to achieve effective and mutually trusted approaches and solutions to support any possible future multilateral disarmament regime. It was also highlighted that the issue of inspector and host confidence requires much greater consideration. Key questions in this regard are: how to define it, how to measure it and most importantly, how to establish what can be considered sufficient in the context of verifying the dismantlement of a nuclear warhead.

The technical focus of the UKNI still represents an effective means of advancing the UK and Norway's shared goal of a world without nuclear weapons. The UKNI workshop was an important opportunity for education and outreach on disarmament verification research, and helped to enhance the transparency of the initiative. The workshop provided NNWS with the opportunity to peer review and influence the future direction of the UKNI.

6.4.6 Future work

The requirement for future work was discussed from two perspectives; firstly the next stage of the UKNI technical collaboration was presented and discussed, and secondly delegates were asked how they thought the broader international community might be able to contribute to the field of nuclear warhead disarmament verification.

The main points made on the UKNI next steps were:

- It will remain a bilateral technical cooperation between the UK and Norway
- It will continue testing and developing the joint Information Barrier system and will look to develop the procedures for trusted deployment
- It will continue development of the verification process based on lessons learned from the UKNI exercises
- It will strive for a better understanding of inspector/host confidence referring initially to its experience of the previous UKNI exercises
- It will undertake focused exercises as required to explore the above issues
- It will look to other international regimes to ensure that any and all potential lessons are properly assimilated
- It will continue to report progress on the margins of the NPT Preparatory Commissions and Review Conferences, together with presenting technical updates to appropriate professional forums
- It will endeavour to encourage and advise any new initiative in this field that may request it.

Discussion on the wider engagement by the international community was interesting and a number of key points emerged:

- NNWS should get involved as a way of meeting commitments under Article VI of the NPT
- NNWS could get involved in the technical development process and such involvement could add real value
- Academia and NGOs could also make significant contributions.

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