NORSAR – FDSN REPORT 2009

Introduction

NORSAR was established in 1968 when a Government-to-Government agreement between the United States of America and Norway came into effect. The agreement focused on seismic array research with the main purpose to develop means for the verification of compliance with a future nuclear-test-ban treaty. NORSAR was established to fulfil the objectives of this agreement. From 1970 – 1993, NORSAR was a section of the Royal Norwegian Council for Industrial and Scientific Research, and from 1993 – 1999 a section of the Norwegian Research Council. NORSAR became an independent research foundation on July 1st, 1999 and with ratification of the CTBT by the Norwegian Parliament on 15 July 1999, NORSAR has been established as the Norwegian National Data Center (NDC) for treaty verification. NORSAR employs about 50 people.

Figure 1. *Main building of the NORSAR institute in Kjeller, Norway.*

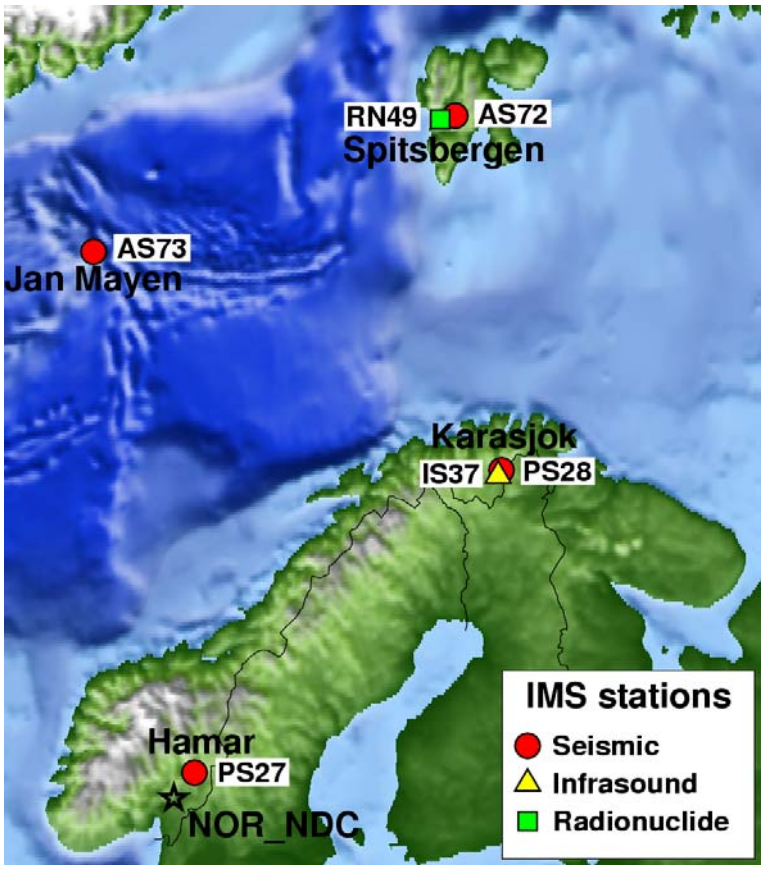

Figure 2. *A map of all existing and planned Norwegian IMS stations. NORSAR, as the Norwegian NDC, is responsible for the seismic auxiliary stations AS72 (SPITS array) and AS73 (3C stations JMIC), the primary stations PS27 (NORSAR array) and PS28 (ARCES array), the yet to be built infrasonic array close to ARCES (IS37) and the radionuclide station on Spitsbergen (RN49).*

Based on a strong international profile, NORSAR conducts research, development and consulting within various fields of seismology and applied geophysics. From the early days of devoted seismic array research, NORSAR has broadened its research activities to include subjects like earthquake hazard & risk assessment and seismic modelling for the petroleum industry. The infrastructure of the institute consists of a data centre and field installations (several seismic array stations) constructed for the recording of seismic signals from earthquakes and underground explosions.

NORSAR is a large seismological observatory specialized in seismic arrays, and with extensive access to data in real time from its own stations and from stations operated by other institutions, and from various data banks. Out of many seismic arrays in northern Europe providing data in real time to NORSAR, four are located on Norwegian territory and the remaining ones in other countries. NORSAR's own data are freely available to the seismological community. NORSAR scientists have involved themselves and their institute extensively in international cooperation over the years regarding various aspects like array design, installation and operation. NORSAR has been a main contributor to the technology presently being implemented at the International Data Centre (IDC) of the Provisional Technical Secretariat of the Comprehensive Nuclear-Test-Ban Treaty Organisation (CTBTO) in Vienna. For further general information on NORSAR see the last Annual Report as published on NORSAR's web-page (http://www.norsar.no/images/Marketing/Company/norsar2007.pdf).

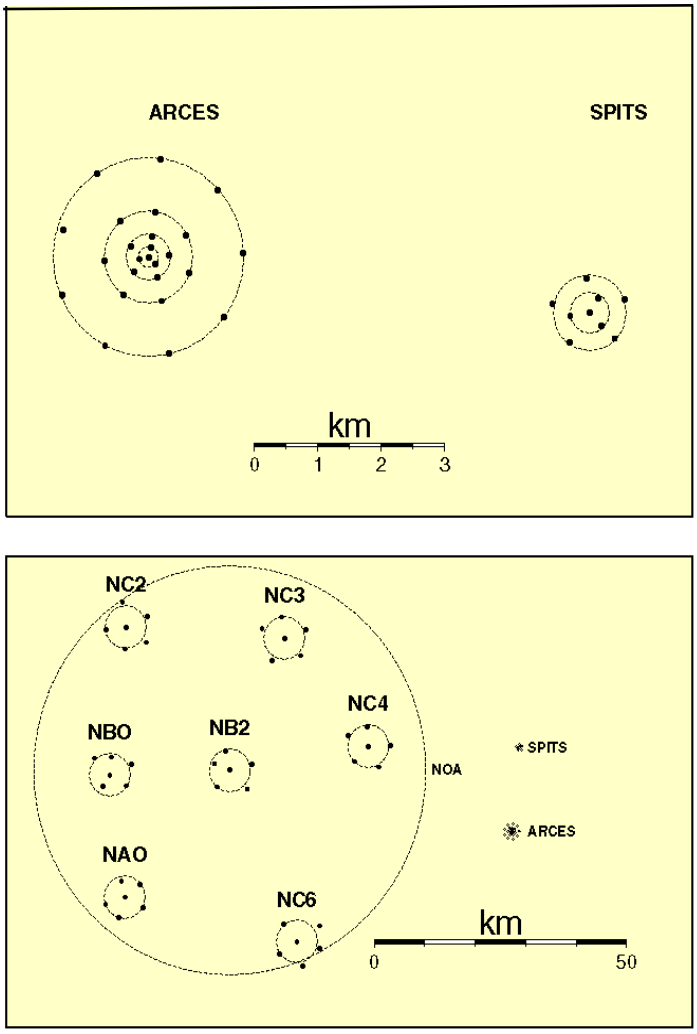

Figure 3. *Geometry and size of the three NORSAR arrays currently in operation NOA, ARCES and SPITS. The NORES array (at the moment out of operation) has a geometry identical to that of ARCES and is co-located with site NC602 of the NOA array.*

The Network

The seismic network currently operated by NORSAR consists of three seismic arrays and one three-component (3C) station (see Fig. 2). Fig. 3 shows geometry and size of the different arrays. All these installations are part of the IMS operated for the CTBT organization in Vienna. A fourth array (the NORES array) co-located with one of the NORSAR subarrays is at the moment out of operation due to a fire caused by lightening, which destroyed most of the electronic equipment. The arrays are located in Southern Norway (NOA, the initial (large) NORSAR array), PS27), the Norwegian Arctic (ARCES array, PS28) and on Spitsbergen, the main island of the Svalbard Archipelago (SPITS array, AS72). The 3C station is located on the Island of Jan Mayen in the North Atlantic between Norway and Greenland (JMIC, AS73). All arrays are equipped with short period or broadband sensors from different vendors but each array has at least one 3C broadband sensor. The 3C station on Jan Mayen is equipped with one STS-2 broadband sensor. Since September 2004, the NORSAR network is member of the Federation of Digital Seismographic Networks (FDSN) and the FDSN network code is NO.

Table 1. *All seismometer sites of NORSAR's network and their actual instrumentation.*

ISC Code	Latitude [°]	Longitude [°]	Elevation [km]	Instrument	Component(s)
NOA (PS27), March 1971 – present					
Subarray NA0 (Brumunddal)					
NAO00	60.8237	10.8324	0.3790	TG 20171-0104	SPZ
NAO01	60.8442	10.8865	0.4260	TG-20171-0104 KS-54000-0105	SPZ BB3C
NAO02	60.8057	10.8971	0.3620	TG 20171-0104	SPZ
NAO03	60.7881	10.8084	0.2230	TG 20171-0104	SPZ
NAO04	60.8105	10.7625	0.2970	TG 20171-0104	SPZ
NAO05	60.8507	10.8193	0.2900	TG 20171-0104	SPZ
Subarray NB2 (Vangsåsen)					
NB200	61.0397	11.2148	0.7170	TG 20171-0104	SPZ
NB201	61.0495	11.2939	0.6130	TG 20171-0104 KS-54000-0105	SPZ BB3C
NB202	61.0069	11.2778	0.6470	TG 20171-0104	SPZ
NB203	61.0107	11.1677	0.7300	TG 20171-0104	SPZ
NB204	61.0498	11.1581	0.6700	TG 20171-0104	SPZ
NB205	61.0710	11.1977	0.6370	TG 20171-0104	SPZ
Subarray NBO (Moelv)					
NBO00	61.0307	10.7774	0.5290	TG 20171-0104 KS-54000-0105	SPZ BB3C
NBO01	61.0616	10.7834	0.5960	TG 20171-0104	SPZ
NBO02	61.0492	10.8569	0.5210	TG 20171-0104	SPZ
NBO03	61.0129	10.8371	0.4290	TG 20171-0104	SPZ
NBO04	61.0119	10.7524	0.3980	TG 20171-0104	SPZ
NBO05	61.0597	10.7219	0.5530	TG 20171-0104	SPZ
Subarray NC2 (Lillehammer)					
NC200	61.2807	10.8354	0.8470	TG 20171-0104	SPZ
NC201	61.2988	10.9138	1.0330	TG 20171-0104	SPZ
NC202	61.2545	10.9110	1.0540	TG 20171-0104	SPZ
NC203	61.2438	10.8318	0.7140	TG 20171-0104	SPZ
NC204	61.2759	10.7629	0.8510	TG 20171-0104 KS-54000-0105	SPZ BB3C
NC205	61.3231	10.8227	0.9580	TG 20171-0104	SPZ
Subarray NC3 (Rena)					
NC300	61.2617	11.4141	0.3660	TG 20171-0104	SPZ
NC301	61.2762	11.4905	0.2900	TG 20171-0104	SPZ
NC302	61.2328	11.4726	0.3000	TG 20171-0104	SPZ
NC303	61.2251	11.3690	0.4010	TG 20171-0104 KS-54000-0105	SPZ BB3C
NC304	61.2784	11.3320	0.3930	TG 20171-0104	SPZ
NC305	61.2979	11.4035	0.3120	TG 20171-0104	SPZ
Subarray NC4 (Elverum)					
NC400	61.0791	11.7189	0.5220	TG 20171-0104	SPZ
NC401	61.0804	11.7994	0.5830	TG 20171-0104	SPZ
NC402	61.0446	11.7573	0.4500	TG 20171-0104	SPZ
NC403	61.0537	11.6683	0.3040	TG 20171-0104	SPZ
NC404	61.0982	11.6456	0.3320	TG 20171-0104	SPZ
NC405	61.1128	11.7153	0.4960	TG 20171-0104 KS-54000-0105	SPZ BB3C
Subarray NC6 (Løten)					
NC600	60.7473	11.4584	0.3210	TG 20171-0104	SPZ
NC601	60.7746	11.5416	0.2480	TG 20171-0104	SPZ
NC602	60.7353	11.5414	0.3050	TG 20171-0104 CMG-3T	SPZ BB3C
NC603	60.7050	11.4807	0.3400	TG 20171-0104	SPZ
NC604	60.7263	11.3956	0.3780	TG 20171-0104	SPZ
NC605	60.7770	11.4103	0.2420	TG 20171-0104	SPZ
ARCES Array (PS28), since October 1987 – present					
ARA0	69.5349	25.5058	0.4030	GS13	SP3C
ARA1	69.5363	25.5071	0.4110	GS13	SPZ
ARA2	69.5338	25.5078	0.3920	GS13	SPZ

ISC Code	Latitude [°]	Longitude [°]	Elevation [km]	Instrument	Component(s)
ARA3	69.5346	25.5019	0.4020	GS13	SPZ
ARB1	69.5379	25.5079	0.4140	GS13	SPZ
ARB2	69.5357	25.5134	0.3970	GS13	SPZ
ARB3	69.5324	25.5106	0.3760	GS13	SPZ
ARB4	69.5328	25.4998	0.3780	GS13	SPZ
ARB5	69.5363	25.4985	0.4050	GS13	SPZ
ARC1	69.5411	25.5079	0.3810	GS13	SPZ
ARC2	69.5383	25.5229	0.3950	GS13	SP3C
ARC3	69.5329	25.5231	0.3760	GS13	SPZ
ARC4	69.5293	25.5117	0.3770	GS13	SP3C
ARC5	69.5300	25.4981	0.3740	GS13	SPZ
ARC6	69.5341	25.4882	0.3950	GS13	SPZ
ARC7	69.5396	25.4937	0.3620	GS13	SP3C
ARD1	69.5483	25.5093	0.3950	GS13	SPZ
ARD2	69.5452	25.5308	0.3660	GS13	SPZ
ARD3	69.5366	25.5483	0.3310	GS13	SPZ
ARD4	69.5271	25.5362	0.3710	GS13	SPZ
ARD5	69.5214	25.5118	0.3510	GS13	SPZ
ARD6	69.5227	25.4900	0.4130	GS13	SPZ
ARD7	69.5294	25.4707	0.4130	GS13	SPZ
ARD8	69.5384	25.4686	0.3680	GS13	SPZ
ARD9	69.5454	25.4857	0.3590	GS13	SPZ
ARE0	69.5349	25.5058	0.4030	CMG-3T	BB3C
NORES Array (currently out of operation), since October 1985 – 11 June 2002					
NRA0	60.7353	11.5414	0.3020	GS13	SP3C
NRA1	60.7366	11.5423	0.2910	GS13	SPZ
NRA2	60.7343	11.5433	0.3110	GS13	SPZ
NRA3	60.7350	11.5387	0.2960	GS13	SPZ
NRB1	60.7381	11.5426	0.2990	GS13	SPZ
NRB2	60.7355	11.5475	0.3150	GS13	SPZ
NRB3	60.7326	11.5440	0.3140	GS13	SPZ
NRB4	60.7333	11.5372	0.2990	GS13	SPZ
NRB5	60.7367	11.5363	0.2890	GS13	SPZ
NRC1	60.7414	11.5434	0.2990	GS13	SPZ
NRC2	60.7383	11.5525	0.3390	GS13	SP3C
NRC3	60.7331	11.5533	0.3520	GS13	SPZ
NRC4	60.7293	11.5452	0.3110	GS13	SP3C
NRC5	60.7301	11.5341	0.2990	GS13	SPZ
NRC6	60.7348	11.5287	0.3030	GS13	SPZ
NRC7	60.7402	11.5331	0.2750	GS13	SP3C
NRD1	60.7486	11.5449	0.3050	GS13	SPZ
NRD2	60.7444	11.5616	0.3720	GS13	SPZ
NRD3	60.7359	11.5689	0.4530	GS13	SPZ
NRD4	60.7271	11.5633	0.3790	GS13	SPZ
NRD5	60.7222	11.5475	0.3480	GS13	SPZ
NRD6	60.7233	11.5288	0.3520	GS13	SPZ
NRD7	60.7302	11.5162	0.3370	GS13	SPZ
NRD8	60.7390	11.5167	0.3010	GS13	SPZ
NRD9	60.7466	11.5266	0.2780	GS13	SPZ
NRE0	60.7352	11.5414	0.3070	KS-36000	BB3C
SPITS Array (AS72), since November 1992 – present					
SPA0	78.1777	16.3700	0.3230	CMG-3TB	BB3C
SPA1	78.1797	16.3755	0.3200	CMG-3TB	BBZ
SPA2	78.1759	16.3766	0.2500	CMG-3TB	BBZ
SPA3	78.1773	16.3588	0.3390	CMG-3TB	BBZ
SPB1	78.1796	16.3906	0.3010	CMG-3TB	BB3C
SPB2	78.1742	16.3846	0.2000	CMG-3TB	BB3C
SPB3	78.1737	16.3584	0.2340	CMG-3TB	BB3C
SPB4	78.1789	16.3482	0.3400	CMG-3TB	BB3C
SPB5	78.1823	16.3683	0.2950	CMG-3TB	BB3C
JMIC (AS73), since October 2003 – present					
JMIC	70.9866	-8.5057	0.160	STS-2	BB3C

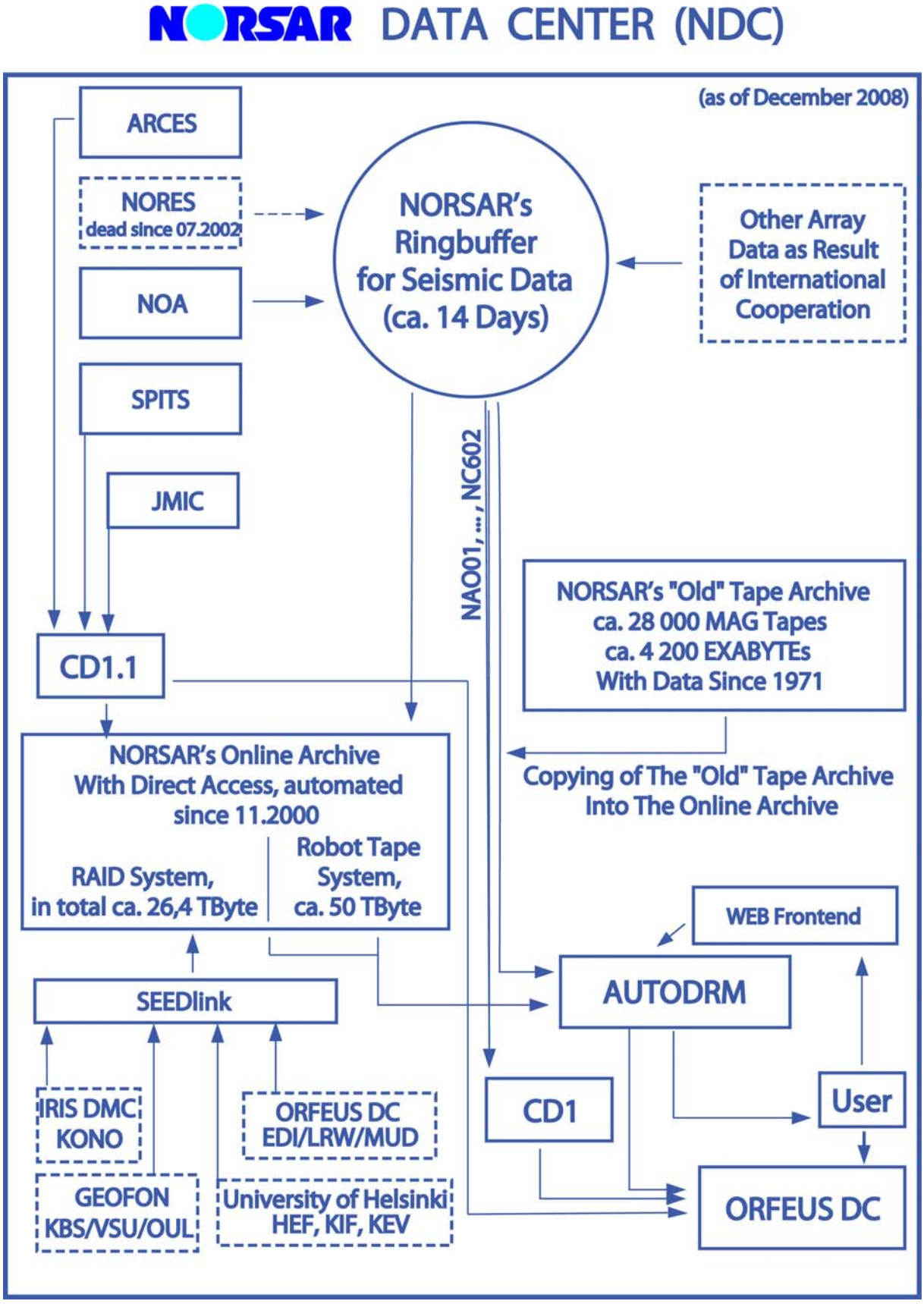

Figure 4. *Structure of NORSAR's data archive and flow of data from and to NORSAR. The data received by NORSAR from other data centres in line with various bilateral co-operative agreements are plotted as broken lines.*

Starting 10 November 2000, NORSAR keeps all new data from its stations including all broadband channels on-line on disk (RAID system with a capacity of about 20 TByte) and all data are copied onto NORSAR's robot-tape archiving system with a capacity of about 50 TByte. All old data were and still are copied from the old tape archive (ExaBytes, MAG tapes) into the RAID and robot-tape archiving systems.

In October 2003, a new broadband station was installed on Jan Mayen, an island in the middle of the North Atlantic. NORSAR is responsible for this new 3C BB station (JMIC), which is an auxiliary station of the IMS of the CTBTO in Vienna.

In August 2004, the long planned refurbishment of the SPITS array could be realized: new data loggers were installed and all seismometers were exchanged to 1C or 3C broadband borehole sensors.

Further details on NORSAR as Norwegian NDC and technical details of the data exchange between the data center at Kjeller and the seismic installations can be found in Fyen & Iranpour (2003, ORFEUS Newsletter (vol5no2)).

(Fast) Exchange of Earthquake Related Parameters

NORSAR has a long tradition in real time location of seismic events. Since its start in the early 1970s, teleseismic events were located by measuring ray parameter and backazimuth of detected P-type onsets with the large NOA array. Since more than one decade, such automatic solutions for larger teleseismic events are automatically distributed via e-mail to EMSC and other interested institutions. The analyst reviewed teleseismic locations are published on NORSAR's web-page (http://www.norsar.no/NDC/bulletins/norsar/).

During the 1980s, NORSAR was heavily involved in developing the concept of single-array locations based on local and regional P- and S-type observations with small aperture arrays. The results of many years of on-line, fully automatic data analysis of small-aperture array data are available on NORSAR's web-page (http://www.norsar.no/NDC/bulletins/dpep/).

At the beginning of the 1990s, NORSAR developed the Generalized Beam Forming (GBF) method which jointly interprets detections from several arrays. The combination of observations from several arrays and location with a grid search algorithm results in a more robust automatic event list at local and regional distances. Also all GBF results are available on NORSAR's web-page (http://www.norsar.no/NDC/bulletins/gbf/).

Based on the GBF results, analyst reviewed data interpretations and event locations are performed and distributed to the community. In addition to the small aperture array results, these analyst reviewed locations may also contain onset readings from non-NORSAR 3C-stations. As shown in Fig. 4, NORSAR receives data from other data centres in line with various bilateral co-operative agreements. The analyst reviewed results for local and regional events are distributed by e-mail to international data centres like ISC or EMSC but also to the University of Bergen and other interested institutions. The results are also copied on NORSAR's web-page (http://www.norsardata.no/NDC/bulletins/regional/).

To inform the public in Norway in the case of felt seismic events, NORSAR developed during the year 2001 an (internal) alert system, which automatically locates seismic events within about 5 to 10 minutes, after a first onset with a high signal-to-noise ratio (SNR) has been observed at one of its stations. This system is also able to locate regional and teleseismic events with large SNR observations. By July 2002, this system was stable enough that its results could be distributed externally. Based on observations at the arrays ARCES, FINES, HFS, NORES, NOA, and SPITS, locations of large(r) seismic events are automatically sent to ORFEUS and the European-Mediterranean Seismological Centre

(EMSC). In addition to triggering activities at the data centres, these alert messages with their included onset parameters are used in particular at the EMSC to calculate very quickly together with other observations more precise event locations. Not all located events are reported to ORFEUS and EMSC: NORSAR reports only those events, which have been located by P onsets from at least 3 arrays. However, all last 40 NEWS locations are available from NORSAR's web-page (http://www.norsar.no/NDC/bulletins/alert/).

Waveform Data Exchange

As part of its CTBT related activities, NORSAR distributes data from several installations to different data centres, to which the whole seismological community may not have free access. As a supporter of an open-data policy, the NORSAR data centre has since several years an email-based AUTODRM system running. In October 2003, after NORSAR received in context of the MEREDIAN project supporting software from ORFEUS, NORSAR could extend this service and install on NORSAR's website a web-page for direct and thereby faster access to the AUTODRM service (http://www.norsar.no/NDC/data/autodrm.html).

Since the end of October 2002, NORSAR sends the continuous broadband data stream of the broadband sensor installed at the ARCES array site E0 (ARE0, see Tab. 1) to ORFEUS. The chosen data format is CD1, a data exchange format developed for on-line data exchange between stations/arrays and the International Data Centre (IDC) of the CTBT organisation in Vienna. On 20 May 2003, NORSAR started with the on-line transmission of one of the 3C broadband sites of the NOA array (NAO01, see Tab. 1). Finally on 7 June 2007, the CD1.1 connection with ORFEUS could be established. Via this connection NORSAR sends the BB 3C data of one of the SPITS array sites (SPA0, see Tab. 1) and of the 3C station on Jan Mayen (JMIC, see Tab. 1) to ORFEUS. Since 25th of March 2008, NORSAR is sending all broadband channels of the NOA array in CD1 format to ORFEUS. However, in September 2008, the data transmission between the ARCES array and NORSAR was changed to CD1.1. This resulted in some software changes at the ODC to include again the ARCES data stream into the ODC data base. From the 3rd of December 2008 on, the broadband data from ARE0, JMIC, and SPA0 are now collected in CD1.1 format at the ODC and forwarded into ODC Antelope system as part of NORSAR's contribution to the VEBSN. As of December 2008 on, NORSAR now contributes with nine BB 3C data streams to the VEBSN. All these data can in real-time retrieved from the ODC by other data centres or institutions.

Table 2. *List of stations, for which NORSAR has agreements on data access and exchange to achieve an improved regional location capability.*

Station	Type	Station Operator(s)
Apatity	Array	Kola Regional Seismological Center
EDI	BB 3C	British Geological Survey
FINES	Array	University of Helsinki
Hagfors	Array	Swedish Defence Research Agency (FOI)
HEF	BB 3C	University of Helsinki
KBS	BB 3C	GEOFON / IRIS / USGS / AWI / University of Bergen
KIF	BB 3C	University of Helsinki
KEV	BB 3C	University of Helsinki
KONO	BB 3C	IRIS DMC / USGS / University of Bergen
LRW	BB 3C	British Geological Survey
MUD	BB 3C	Geologiske Undersøgelser for Danmark og Grønland
OUL	BB 3C	GEOFON / SGO, University of Ouly, Finland
VSU	BB 3C	GEOFON / Geological Survey of Estonia

The improvement in fast and reliable exchange of broadband (BB) data between European institutions was part of the MEREDIAN project. To supplement NORSAR's

location capabilities, NORSAR exchanges through bilateral cooperation data with other seismological institutions. Depending on size and location of an event the reviewed regional bulletins (see above) may contain additional readings from arrays and 3-component broadband stations operated by these institutions. Data from BB 3C stations are retrieved from the international data centres GEOFON in Potsdam, IRIS DMC in Seattle, ORFEUS in DeBilt, and the Seismological Institute of the University in Helsinki.

Data Archiving and Data Retrieval

As seen on Fig. 4, since autumn 2001, NORSAR stores all continuous data at first on disk, either in a diskloop and later on the RAID system, or directly on the RAID system. Today, NORSAR uses a mirroring technique with another 20 TB disk system as quick accessible back-up of the data stored on disk. However, all data are additionally saved on tapes, which are accessible by an automatic tape-robot system. This tape archive is today the data back-up system for NORSAR.

Table 3. *Periods of operation for the different NORSAR stations and direct accessibility to their data (outages due to upgrading or repair activities are not tabled).*

Station	Time Period	Direct Accessibility
Old NORSAR	04.1971 – 09.1976 event triggered	Yes
NOA	09.1976 – 09.1982 event triggered	Yes
NOA	09.1982 – today continuous	yes (not 1994/95)
ARCES	10.1987 – today continuous	1987 – 1989, 1994 – today
NORES	09. 1984 – 06.2002 continuos	1984 – 1989, 1991, 1995 – 06.2002
SPITS	11.1992 – today continuous	1995 – today
JMIC	10.2003 – today continuous	10.2003 – today

Some comments on the table above: NORSAR has digital data back to 1971. The major part of these data was originally archived in the (old) tape archive containing about 28.000 ½ inch magnetic tapes and about 4.200 8 mm data cartridges (EXABYTEs). These tapes are only accessible by operator support.
During the last years, NORSAR has worked hard on copying these old data on disk and into the tape robot archive. Up to now, all data of the large NOA array were retrieved from the old storage media for the years 1971 – 1993 and 1996 – 2000. In addition, all data of the small aperture arrays NORES and ARCES were copied from their earliest data in 1984 (NORES) and 1987 (ARCES) until the end of 1989. Then, NORSAR started copying data from the autumn of 2000 backwards for the small aperture arrays ARCES, NORES and SPITS to get all data directly accessible.

Other aspects

For the future it is planned to reactivate parts of the NORES array, which is non-operational since a lightening caused a fire in the summer of 2002. This plan includes building technical facilities for testing of seismic and infrasound instrumentation as well as various array configurations based on the old NORES array geometry.

The very important retrieval of all digital data from the old tape media will be continued. However, it will take some more years until the whole data volume recorded at NORSAR's stations will be directly accessible.

Literature

Fyen, J. & K. Iranpour (2003): *Near real time data at NORSAR for CTBT monitoring*. ORFEUS Newsletter **5**, (2), see also http://www.orfeus-eu.org/Organization/Newsletter/vol5no2/norsar.html
Schweitzer, J. (2003): *NORSAR's Event Warning System (NEWS)*. NORSAR Scientific Report **1–2003**, 27-31.