Development of the NORSAR network over the last 50 Years

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Abstract

This contribution describes the development of NORSAR, from its origin 50 years ago as a project for installing a single seismic array in southern Norway, to a seismological research institute operating a network of six arrays and 14 3C stations located in Norway and Antarctica. In addition, we document the different instrumentations from narrowband, mostly short period sensors to today's broadband seismometers installed at almost all sites.

Introduction

The Norwegian Seismic Array (NORSAR) project was established after a Government-to-Government agreement between the United States of America and Norway in 1968. The purpose of the agreement *"… is seismological research and experimentation. The system is primarily designed to produce data valuable as a means of detecting and distinguishing between signals originating from underground explosions and from other sources, especially earthquakes."* To fulfil the objectives of this agreement, the large NORSAR array was built in southern Norway and gave its name to a new institute in Kjeller, on the outskirts of Oslo, with Norway being responsible for the operation of the array. From 1970 – 1993, NORSAR was initially a project and later a section of the Royal Norwegian Council for Industrial and Scientific Research, and from 1993 – 1999 a section of the Norwegian Research Council. On 1 July 1999, NORSAR became an independent research foundation (Stiftelsen NORSAR). With the ratification of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) by Norway on 15 July 1999, NORSAR became the Norwegian National Data Center (NDC) for the CTBT verification. Since the 1980s, NORSAR has been involved in developing new array technologies, deploying new arrays and seismic 3C stations in Northern and Central Europe and Antarctica and is a leading institution for near-real time data exchange and analysis. This contribution will concentrate on the development of NORSAR's network of seismic stations and its data center. Most of NORSAR's seismic stations are today also part of the Norwegian National Seismic Network (NNSN), which is organized by the University of Bergen (UiB). In September 2004, the NORSAR network became a member of the Federation of Digital Seismographic Networks (FDSN) with the FDSN network code NO.

Today, NORSAR contributes with 3 seismic arrays (ARCES, NOA, SPITS) and one 3C seismic station (JMIC) to the International Monitoring System (IMS) of the CTBT Organization (CTBTO). As part of its CTBT related activities and as a supporter of an open-data policy, NORSAR distributes seismic records from several installations to different national and international data centers. Within the EPOS (European Plate Observing System)-Norway project, a joint Norwegian EIDA (European Integrated waveform Data Archive) node has been established at the University of Bergen in cooperation with NORSAR (see Ottemöller et al., 2021). As of December 2020, 203 waveform are forwarded to the node by NORSAR in near-real time from 88 sites, comprising: the arrays ARCES, BEAR, NOA, and SPITS and the 3C component stations AKN, BRBA, BRBB, JETT, JMIC, and TROLL. Fig. 1 shows the location of today's network of NORSAR stations.

The NORSAR Array

The original NORSAR array (Bungum et al., 1971) was planned and built as a smaller version of the Large Aperture Seismic Array (LASA), which had been in operation in Montana (USA) since 1965 (Frosch and Green, 1966). The NORSAR array became fully operational in spring 1971. It consisted of 22 subarrays with 6 seismometer sites each (132 sites in total), distributed over an aperture of approximately 100 km. Each of the132 sites had a short period, vertical, borehole seismometer, with an additional long period 3C station deployed for each the 22 subarrays, 198 sensors in total (Fig. 2). During the first few years of operation, it became clear that the large NORSAR array was an ideal but expensive system for monitoring seismic events at teleseismic distances. In 1976, the original array was reduced to an aperture of approximately 60 km with seven subarrays and 42 sensor sites, with the most sensitive subarrays from the original installation retained for monitoring underground nuclear explosions (Fig. 2). From the beginning in 1971, all data were digitally recorded in near-real time at the NORSAR data center in Kjeller and are still available for research. This provides NORSAR with one of the longest archives of seismological, digital data. More or less continuous recordings of the seismic wavefield in southern Norway for the last 50 years offer unique opportunities for seismological studies which require long time series to investigate source region specific signal characteristics or long trends in seismic activity. As an example, Fig. 3 shows the large signal similarities between the first (18 May 1974) and second (11 May 1998) Indian nuclear tests recorded at identical NORSAR sites (Schweitzer et al., 1998). Due to the limited storage capacities in the early days of digital seismology, NORSAR's archive contains only triggered short period data up until September 1982. However, all long period data were recorded continuously.

The first refurbishment of the array was done in 1994/1996, when the old short period Geo-Space Hall-Sears HS-10-1 borehole sensors were replaced by new borehole Teledyne-Geotech 20171B sensors, and the long period Teledyne-Geotech 7505B and 8700C sensors were replaced by Teledyne-Geotech KS-54000 broadband borehole sensors. At one site (NC602), the broadband borehole sensor was replaced by a Güralp CMG-3T surface sensor in 2000. In summer 2011 began another major refurbishment of NOA. To maintain the well-established high short-period sensitivity of the NORSAR array, but to achieve in addition an enhanced broadband response, a new, hybrid version of the CMG-3T sensor was proposed by NORSAR and built in co-operation with the CTBTO and Güralp Systems (Roth et al., 2011a). A standard broadband sensor that is flat in velocity response over several order of magnitudes of the seismic spectrum would often clip when recording large amplitude surface waves. By lowering the gain to avoid clipping, the array would lose its high sensitivity for higher frequency signals. In contrast, the hybrid sensors have two sensitivity levels – one for lower and one for higher frequencies. A 3C hybrid sensor was installed at each subarray, while vertical-only hybrid sensors were deployed as borehole instruments at all the other subarray sites. Fig. 4 shows the typical velocity response of these vertical borehole instruments. As a result of this refurbishment, the entire NORSAR array with its 60 km aperture has been equipped with 42 broadband sensors since summer 2012. NOA is part of the primary seismic network of the IMS as station PS27, constituting its largest array.

The Regional Arrays

During the operation of NOA it became evident that the geometry of large aperture arrays was not optimal for monitoring seismicity at regional or local distances due to the low coherency of their higher frequency signals. Such monitoring is needed, however, for the detection of low yield nuclear explosions. Therefore, the concept of regional, small aperture arrays was developed and tested at NORSAR, in cooperation with US colleagues from 1979 onwards. After the optimal design was found, the first array of this kind was installed in southern Norway in 1984: the NORESS (Norwegian Experimental Seismic System) array was built with 25 sites distributed on four concentric circles (with an outer circle radius was approximately 1.5 km) around the NOA site NC602 (Mykkeltveit, 1985, Mykkeltveit et al., 1990). The array started its operation in October 1984 with 25 vertical GS-13 short period sensors. In addition, 4 sites were equipped with GS-13 horizontal sensors and the center site with an additional KS-35000 borehole instrument. The array, which was later named NORES, remained out of operation from 2002 to 2011 after a lightning incident where fire destroyed most of the installed electronic equipment. In January 2011, NORES became operational again, first with 3C short period sensors at the nine innermost elements of its originally 25 sites (A- and B-ring). These nine sites were upgraded with 3C broadband sensors (Güralp CMG-ESPC 3C) in August 2015, and in 2017 the seven sites of the C-ring were restored. Today, NORES operates as a 16-element 3C broadband array. Fig. 5 shows this configuration and geometry in common scale with other NORSAR arrays.

After proving the regional array concept, NORSAR built its second regional array, the ARCESS (Arctic Experimental Seismic System) in northern Norway, as a direct copy of NORESS (Fig. 5, Mykkeltveit et al., 1990), the main objective being monitoring the former Soviet nuclear test sites on Novaya Zemlya. The array, which is now named ARCES, has been in operation since October 1987. The most significant upgrade took place in September 2014 and involved the replacement of the old GS-13 sensors at all 25 sites with Güralp 3C hybrid broadband sensors, the same type as developed for NOA (Gibbons et al., 2019). ARCES is the second NORSAR array within the primary seismic network of IMS stations (PS28).

In 1990, NORSAR researchers came in contact with seismologists working at the Kola Regional Seismological Centre (KRSC), at that time belonging to the Kola Branch of the Russian Academy of Sciences in Apatity. In the framework of a joint project based on a common interest in seismic monitoring of the European Arctic and the Kola peninsula, the old analog seismic station in the town of Apatity was upgraded with digital equipment in summer 1991, and a seismic array (APAES) was installed close to Apatity, in autumn 1992 (Mykkeltveit et al., 1991; 1992). With an aperture of approximately 1 km and 9 seismic sensor sites, this array is smaller than NORES and ARCES. After its installation by NORSAR, the array has been operated and maintained by the KRSC.

Furthermore, in 1992, NORSAR built another new 9-element array (SPITS) (see Fig. 5) about 17 km east-southeast of Longyearbyen, on Janssonhaugen, in Adventdalen, Spitsbergen, the main island of the Svalbard Archipelago, to extend the network of small aperture arrays in Northern Europe and to improve the monitoring capabilities in the Arctic (Mykkeltveit et al., 1991; 1992). To avoid movements of instruments due to the seasonal thawing and freezing of the ground, all seismic sensors were installed in boreholes below the permafrost active layer (approximately 6 m at the SPITS site). In 1994, the original instrumentation of Geotech S-500 vertical sensors was replaced by Güralp CMG-3ESP vertical, short period, borehole sensors, and at one site an additional CMG-3T borehole, 3C, broadband instrument was installed. In August 2004, the SPITS array underwent a general upgrade. All seismometers were replaced with new Güralp CMG-3TB broadband, borehole sensors: six sites with 3C sensors and three sites with vertical sensors (Schweitzer & Kværna, 2006). The SPITS array is part of the auxiliary network of the IMS, known as station AS72.

In addition to permanent deployments, temporary seismic arrays have been installed by NORSAR. During an International Polar Year 2007-2008 project led by NORSAR (Schweitzer et al., 2008), a small aperture array of 13 elements had been temporarily operated on Bjørnøya, a small island, half the distance between the northern coast of Fennoscandia and the Svalbard Archipelago. This 5-month long deployment was jointly undertaken with colleagues from the University of Potsdam, Germany, during the Arctic summer season 2008 (Händel et al., 2010). This installation demonstrated the advantages of an array compared to a single 3C station for monitoring the seismicity in the Barents Sea and along the neighboring part of the mid-Atlantic ridge system. Within the framework of EPOS-Norway, it became possible to realize a longer duration deployment on Bjørnøya than the 2008 deployment. The original plan was to install a SPITS-like nine-element array in the center of the island, to reduce the noise from ocean waves hitting the shorelines. However, due to environmental restrictions for this highly protected area, NORSAR was only permitted to install a six-element array (BEAR) in a limited area close to a meteorological station near the northern shoreline – the only inhabited place on the island. The array element locations were chosen to reduce the Rg-wave noise caused by the ocean waves (Händel et al., 2010), but the resulting geometry (Fig. 5) is not optimal for classical array data analysis techniques, such as beamforming or fk- analysis (see e.g., Schweitzer et al., 2012b). All array sites, which are planned to operate at least until 2025, are equipped with Kinemetrics MBB-2 broadband sensors.

In May 2020, a small-aperture, SPITS-like temporary 9-element array was installed on Holsnøy on the west coast of southern Norway (HNAR) as part of a collaborative project between Equinor and NORSAR. The purpose of this array is to establish the level of background seismicity in the Horda platform area, offshore western Norway, which is a designated area for a future subsurface CO_2 storage site. HNAR has an aperture of 900 m and consists of 9 sites equipped with Güralp 3T-120 broadband 3C sensors.

Single Stations

Since autumn 2003, NORSAR has extended its seismic network through the deployment of several single, broadband, 3C stations as part of dedicated projects. The first such station, which is equipped with a broadband STS-2 sensor, was the CTBTO auxiliary station (AS73) JMIC on the island of Jan Mayen in the middle of the North Atlantic.

Within the IPY 2007-2008 project (Schweitzer et al., 2008), the already existing seismic station at Hornsund (HSP), the Polish Polar Research Base in the southern part of Spitsbergen, was upgraded to a broadband station (HSPB) as a joint activity between the Institute of Geophysics of the Polish Academy of Sciences and NORSAR, in September 2007 (Wilde-Piórko et al., 2009). This station is also equipped with an STS-2 sensor and belongs today to the Polish seismological network (FDSN network code PL).

To monitor the unstable rock slopes in Norway NORSAR operates two broadband 3C stations, at Åknes (AKN) since October 2009 and at Nordnes (JETT) since November 2014. Furthermore, to measure seismic ground motion alongside infrasound records, the Norwegian IMS infrasound array IS37 in Bardufoss was augmented at its central array site with a seismic 3C station (I37HO), in July 2015. All of these stations are equipped with Güralp CMG-ESPC broadband sensors.

For a better understanding of seismotectonic and cryoseismicity in the European Arctic it is necessary to densify the seismic network on Svalbard. Therefore, in September 2010, the seismic station in Barentsburg (BRBA), the Russian settlement on Svalbard, was upgraded with a Güralp ESPC sensor as part of a joint project between NORSAR and the KRSC (Roth et al., 2011b). A year later, BRBA was supplemented with a second, identical seismic station

(BRBB) in the same area. Data from both stations are forwarded to the Norwegian EIDA node as part of the NORSAR network.

In the framework of a joint project between NORSAR and the Norwegian Polar Institute, NORSAR installed a broadband 3C station (TROLL) with an STS-2.5 sensor at the Norwegian research base Troll in Dronning Maud Land (DML), Antarctica, in February 2012 (Fig. 6).The scientific purpose of the station is monitoring regional and global seismicity, as well as the dynamics of the Antarctic ice sheet (Schweitzer et al., 2012a; 2014).

Since summer 2018, NORSAR is reusing the short period Teledyne-Geotech GS-13 sensors from the original NORES and ARCES instrumentations in a local network of seven 3C seismic stations around the Oslofjord in southern Norway (OFSN). The purpose of the network is monitoring local seismicity in this densely populated region and thus being able to better inform the public about events that are usually felt over wide areas. In 1904, the southern Oslofjord had been the location of an Ms 5.4 earthquake, which is still the largest instrumentally observed seismic event in mainland Norway (Bungum et al., 2009) and demonstrates the potential for moderate-larger magnitude events in the region.

Between 2012 and 2014, the Norwegian pool of mobile stations was established as a national research infrastructure project. This broadband pool is managed by a committee consisting of representatives from all institutions in Norway with an interest in seismology and is led and hosted by NORSAR. The pool comprises 30 mobile stations consisting of 30 EDR-210 dataloggers, 24 STS-2.5, and 6 CMG-3ESPC sensors.

Data Archiving

In autumn 2001, NORSAR started to store all new data on disk for direct access. During the last decades, NORSAR has transferred all its archived array data that were previously stored across approximately 35,000 magnetic tapes to a modern disk storage system in order to preserve these data for future use. In parallel, all metadata for the data collected in NORSAR’s archive were compiled, quality checked and made available in standard metadata formats (Pirli, 2013). A detailed description of installed sensors and digitizers and the corresponding transfer functions at the different NORSAR stations until 2013 can be found in Pirli (2013). NORSAR is contributing its data and analysis results to the Norwegian National Seismic Network (NNSN, FDSN network code NS, University of Bergen, 1982) operated by the University of Bergen where there is a bilateral data sharing agreement for all NNSN data. Most of the near-real time data as well as a huge amount of the historical data are made accessible to the seismological community via the Norwegian EIDA node (Ottemöller et al., 2021). In addition, NORSAR has a long tradition of exchanging digital data, especially from seismic arrays, with other institutions in Europe and in particular Fennoscandia. These data are also stored in NORSAR’s data archive.

Outlook

Due to the environmental restrictions affecting the deployment of the originally planned 9-element small aperture array on Bjørnøya within the afore mentioned EPOS-Norway project, NORSAR has proposed employing the unused equipment for another small aperture 6-element array at the Polish Research Station Hornsund, close to the southern tip of Spitsbergen. The idea has been supported by colleagues from the Polish Academy of

Sciences, who operates the research station at Hornsund, with the installation of the array initially planned for summer 2020. However, because of the travel restrictions due to the COVID-19 pandemic, the deployment has been postponed to the next available opportunity. Thereafter, the challenge will be to extend the highly sensitive 3C station TROLL in Antarctica to an array. NORSAR would operate then the northernmost and southernmost seismic arrays installed on bedrock, monitoring global and regional seismicity from Pole to Pole.

Data Resources

All data used in this paper came from published sources listed in the references. Figs. 1 and 2 have been plotted using the Generic Mapping Tools (www.soest.hawaii.edu/gmt; Wessel and Smith, 1998). Coordinates and current seismometer equipment of all stations in NORSAR's network are listed in Table 1.

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Table 1. All station sites of NORSAR's current network and their current instrumentation (September 2020).

Station IR* Code	Seismic Sensor	Component(s)	Latitude [°]	Longitude [°]	Elevation [km]
NORSAR array NOA (PS27), March 1971 – present					
Subarray Brumunddal (NA0)					
NAO00	CMG-1V-Hybrid	BBZ	60.8237	10.8324	0.3790
NAO01	CMG-3T-Hybrid	VBB-3C	60.8442	10.8865	0.4260
NAO02	CMG-1V-Hybrid	BBZ	60.8057	10.8971	0.3620
NAO03	CMG-1V-Hybrid	BBZ	60.7881	10.8084	0.2230
NAO04	CMG-1V-Hybrid	BBZ	60.8105	10.7625	0.2970
NAO05	CMG-1V-Hybrid	BBZ	60.8507	10.8193	0.2900
Subarray Vangsåsen (NB2)					
NB200	CMG-1V-Hybrid	BBZ	61.0397	11.2148	0.7170
NB201	CMG-3T-Hybrid	VBB-3C	61.0495	11.2939	0.6130
NB202	CMG-1V-Hybrid	BBZ	61.0069	11.2778	0.6470
NB203	CMG-1V-Hybrid	BBZ	61.0107	11.1677	0.7300
NB204	CMG-1V-Hybrid	BBZ	61.0498	11.1581	0.6700
NB205	CMG-1V-Hybrid	BBZ	61.0710	11.1977	0.6370
Subarray Moelv (NBO)					
NBO00	CMG-3T-Hybrid	VBB-3C	61.0307	10.7774	0.5290
NBO01	CMG-1V-Hybrid	BBZ	61.0616	10.7834	0.5960
NBO02	CMG-1V-Hybrid	BBZ	61.0492	10.8569	0.5210
NBO03	CMG-1V-Hybrid	BBZ	61.0129	10.8371	0.4290
NBO04	CMG-1V-Hybrid	BBZ	61.0119	10.7524	0.3980
NBO05	CMG-1V-Hybrid	BBZ	61.0597	10.7219	0.5530
Subarray Lillehammer (NC2)					
NC200	CMG-1V-Hybrid	BBZ	61.2807	10.8354	0.8470
NC201	CMG-1V-Hybrid	BBZ	61.2988	10.9138	1.0330
NC202	CMG-1V-Hybrid	BBZ	61.2545	10.9110	1.0540
NC203	CMG-1V-Hybrid	BBZ	61.2438	10.8318	0.7140
NC204	CMG-3T-Hybrid	VBB-3C	61.2759	10.7629	0.8510
NC205	CMG-1V-Hybrid	BBZ	61.3231	10.8227	0.9580
Subarray Rena (NC3)					
NC300	CMG-1V-Hybrid	BBZ	61.2617	11.4141	0.3660
NC301	CMG-1V-Hybrid	BBZ	61.2762	11.4905	0.2900
NC302	CMG-1V-Hybrid	BBZ	61.2328	11.4726	0.3000
NC303	CMG-3T-Hybrid	VBB-3C	61.2251	11.3690	0.4010
NC304	CMG-1V-Hybrid	BBZ	61.2784	11.3320	0.3930
NC305	CMG-1V-Hybrid	BBZ	61.2979	11.4035	0.3120
Subarray Elverum (NC4)					
NC400	CMG-1V-Hybrid	BBZ	61.0791	11.7189	0.5220

NC401	CMG-1V-Hybrid	BBZ	61.0804	11.7994	0.5830
NC402	CMG-1V-Hybrid	BBZ	61.0446	11.7573	0.4500
NC403	CMG-1V-Hybrid	BBZ	61.0537	11.6683	0.3040
NC404	CMG-1V-Hybrid	BBZ	61.0982	11.6456	0.3320
NC405	CMG-3T-Hybrid	VBB-3C	61.1128	11.7153	0.4960
Subarray Løten (NC6)					
NC600	CMG-1V-Hybrid	BBZ	60.7473	11.4584	0.3210
NC601	CMG-1V-Hybrid	BBZ	60.7746	11.5416	0.2480
NC602	CMG-3T-Hybrid	VBB-3C	60.7353	11.5414	0.3050
NC603	CMG-1V-Hybrid	BBZ	60.7050	11.4807	0.3400
NC604	CMG-1V-Hybrid	BBZ	60.7263	11.3956	0.3780
NC605	CMG-1V-Hybrid	BBZ	60.7770	11.4103	0.2420
NORES Array, October 1985 – 11/06/2002; 29/12/2010 – present					
NRA0	CMG-ESPC	BB3C	60.7353	11.5414	0.3020
NRA1	CMG-ESPC	BB3C	60.7366	11.5423	0.2910
NRA2	CMG-ESPC	BB3C	60.7343	11.5433	0.3110
NRA3	CMG-ESPC	BB3C	60.7350	11.5387	0.2960
NRB1	CMG-ESPC	BB3C	60.7381	11.5426	0.2990
NRB2	CMG-ESPC	BB3C	60.7355	11.5475	0.3150
NRB3	CMG-ESPC	BB3C	60.7326	11.5440	0.3140
NRB4	CMG-ESPC	BB3C	60.7333	11.5372	0.2990
NRB5	CMG-ESPC	BB3C	60.7367	11.5363	0.2890
NRC1	CMG-ESPC	BB3C	60.7414	11.5434	0.2990
NRC2	CMG-ESPC	BB3C	60.7383	11.5525	0.3390
NRC3	CMG-ESPC	BB3C	60.7331	11.5533	0.3520
NRC4	CMG-ESPC	BB3C	60.7293	11.5452	0.3110
NRC5	CMG-ESPC	BB3C	60.7301	11.5341	0.2990
NRC6	CMG-ESPC	BB3C	60.7348	11.5287	0.3030
NRC7	CMG-ESPC	BB3C	60.7402	11.5331	0.2750
ARCES Array (PS28), October 1987 – present					
ARA0	CMG-3T-Hybrid	VBB-3C	69.5349	25.5058	0.4030
ARA1	CMG-3T-Hybrid	BB-3C	69.5363	25.5071	0.4110
ARA2	CMG-3T-Hybrid	BB-3C	69.5338	25.5078	0.3920
ARA3	CMG-3T-Hybrid	BB-3C	69.5346	25.5019	0.4020
ARB1	CMG-3T-Hybrid	BB-3C	69.5379	25.5079	0.4140
ARB2	CMG-3T-Hybrid	BB-3C	69.5357	25.5134	0.3970
ARB3	CMG-3T-Hybrid	BB-3C	69.5324	25.5106	0.3760
ARB4	CMG-3T-Hybrid	BB-3C	69.5328	25.4998	0.3780
ARB5	CMG-3T-Hybrid	BB-3C	69.5363	25.4985	0.4050
ARC1	CMG-3T-Hybrid	BB-3C	69.5411	25.5079	0.3810
ARC2	CMG-3T-Hybrid	BB-3C	69.5383	25.5229	0.3950
ARC3	CMG-3T-Hybrid	BB-3C	69.5329	25.5231	0.3760
ARC4	CMG-3T-Hybrid	BB-3C	69.5293	25.5117	0.3770

ARC5	CMG-3T-Hybrid	BB-3C	69.5300	25.4981	0.3740
ARC6	CMG-3T-Hybrid	BB-3C	69.5341	25.4882	0.3950
ARC7	CMG-3T-Hybrid	BB-3C	69.5396	25.4937	0.3620
ARD1	CMG-3T-Hybrid	BB-3C	69.5483	25.5093	0.3950
ARD2	CMG-3T-Hybrid	BB-3C	69.5452	25.5308	0.3660
ARD3	CMG-3T-Hybrid	BB-3C	69.5366	25.5483	0.3310
ARD4	CMG-3T-Hybrid	BB-3C	69.5271	25.5362	0.3710
ARD5	CMG-3T-Hybrid	BB-3C	69.5214	25.5118	0.3510
ARD6	CMG-3T-Hybrid	BB-3C	69.5227	25.4900	0.4130
ARD7	CMG-3T-Hybrid	BB-3C	69.5294	25.4707	0.4130
ARD8	CMG-3T-Hybrid	BB-3C	69.5384	25.4686	0.3680
ARD9	CMG-3T-Hybrid	BB-3C	69.5454	25.4857	0.3590
SPITS Array (AS72), November 1992 – present					
SPA0	CMG-3TB	BB3C	78.1777	16.3700	0.3230
SPA1	CMG-3TB	BBZ	78.1797	16.3755	0.3200
SPA2	CMG-3TB	BBZ	78.1759	16.3766	0.2500
SPA3	CMG-3TB	BBZ	78.1773	16.3588	0.3390
SPB1	CMG-3TB	BB3C	78.1796	16.3906	0.3010
SPB2	CMG-3TB	BB3C	78.1742	16.3846	0.2000
SPB3	CMG-3TB	BB3C	78.1737	16.3584	0.2340
SPB4	CMG-3TB	BB3C	78.1789	16.3482	0.3400
SPB5	CMG-3TB	BB3C	78.1823	16.3683	0.2950
Bjørnoya Array (BEAR), August 2019 – present					
BEA1	MBB-2	BB3C	74.499414	19.001426	0.0191
BEA2	MBB-2	BB3C	74.498847	19.010103	0.0265
BEA3	MBB-2	BB3C	74.497758	19.008390	0.0273
BEA4	MBB-2	BB3C	74.496480	19.010766	0.0261
BEA5	MBB-2	BB3C	74.495755	19.005565	0.0230
BEA6	MBB-2	BB3C	74.495954	19.001398	0.0230
Holsnøy Array (HNAR), May 2020 – present					
HNA0	3T-120	BB3C	60.6106	4.9571	0.0398
HNA1	3T-120	BB3C	60.6126	4.9556	0.0184
HNA2	3T-120	BB3C	60.6112	4.9611	0.0497
HNA3	3T-120	BB3C	60.6086	4.9581	0.0386
HNB1	3T-120	BB3C	60.6146	4.9577	0.0186
HNB2	3T-120	BB3C	60.6128	4.9646	0.0335
HNB3	3T-120	BB3C	60.6083	4.9640	0.0398
HNB4	3T-120	BB3C	60.6069	4.9514	0.0461
HNB5	3T-120	BB3C	60.6116	4.9492	0.0292
Jan Mayen (AS73), October 2003 – present					
JMIC	STS-2	BB3C	70.9866	-8.5057	0.160
Åknes, October 2008 – present					
AKN	CMG ESPC	BB3C	62.1783	6.9974	0.508

Joint Norwegian-Russian Seismic Stations in Barentsburg, 2010 / 2011 – present					
BRBA	CMG ESPC	BB3C	78.0588	14.2191	0.070
BRBB	CMG ESPC	BB3C	78.0953	14.2149	0.010
Troll, February 2012 – present					
TROLL	STS-2.5	BB3C	-72.0082	2.5300	01.399
Jettan, November 2014 – present					
JETT	CMG ESPC	BB3C	69.55572	20.40950	0.631
Infrasound array, June 2015 – present					
I37H0	CMG-ESPC	BB3C	69.07410	18.60770	0.078
Oslofjord network, summer 2018 – present					
OFSN1	GS-13	SP3C	59.9753	11.0443	0.118
OFSN2	GS-13	SP3C	59.8401	10.9108	0.016
OFSN3	GS-13	SP3C	59.6666	10.7691	0.083
OFSN4	GS-13	SP3C	59.4654	10.8138	0.044
OFSN5	GS-13	SP3C	59.2547	10.8015	0.103
OFSN6	GS-13	SP3C	59.0939	10.9206	0.110
OFSN7	GS-13	SP3C	59.2650	10.3400	0.038
Norwegian pool of mobile broadband instruments					
24 Stations	STS-2.5	VBB3C			
6 Stations	CMG ESPC	BB3C			

* Code with which the station is registered in the in the International Registry of Seismograph Stations (IR) (International Seismological Centre, 2020).

Figures

Fig 1: A map showing the location of all NORSAR arrays (circles) and 3C station (triangles) in Northern Europe and Antarctica. The square shows the area of the Oslofjord network.

Fig.2: The NORSAR array in 1971 and after its reduction (filled circles) in 1976.

Fig. 3. Observations of the 18 May 1974 and the 11 May 1998 announced explosions at the Indian nuclear test site. To be able to compare the observations from the two explosions, seismograms from the subarray central elements of NOA are sorted pairwise. In each visually aligned pair, the 11 May 1998 explosion is plotted on top and the 18 May 1974 explosion below. All records were filtered with a bandpass between 1 and 3 Hz and normalized with their maximum amplitudes.

Fig. 4. The ground-velocity transfer function of the vertical borehole CMG-3T Hybrid instrument installed at the NOA site NAO03.

Fig. 5. Configuration and geometry of the NORSAR arrays NOA, ARCES, NORES, SPITS and BEAR. The first regional array NORES is located within the NC6 subarray of NOA and originally had an identical geometry to that shown for the ARCES array. After reopening, NORES is now operative with 16 of its original 25 sites (the three innermost rings).

Fig. 6: The very broadband 3C station TROLL in Dronning Maud Land, Antarctica after installation in 2012 (photo: J. Schweitzer).

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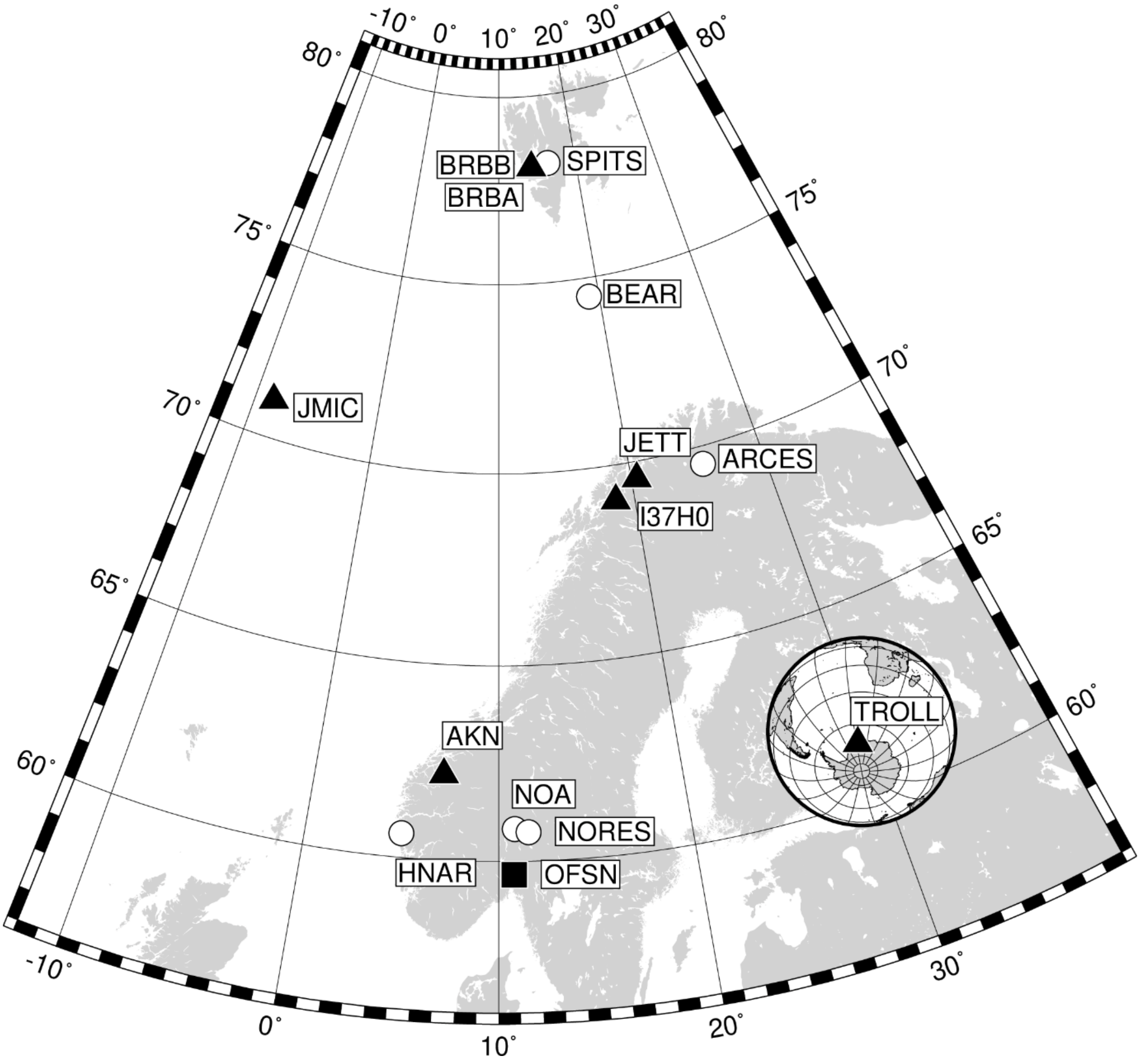

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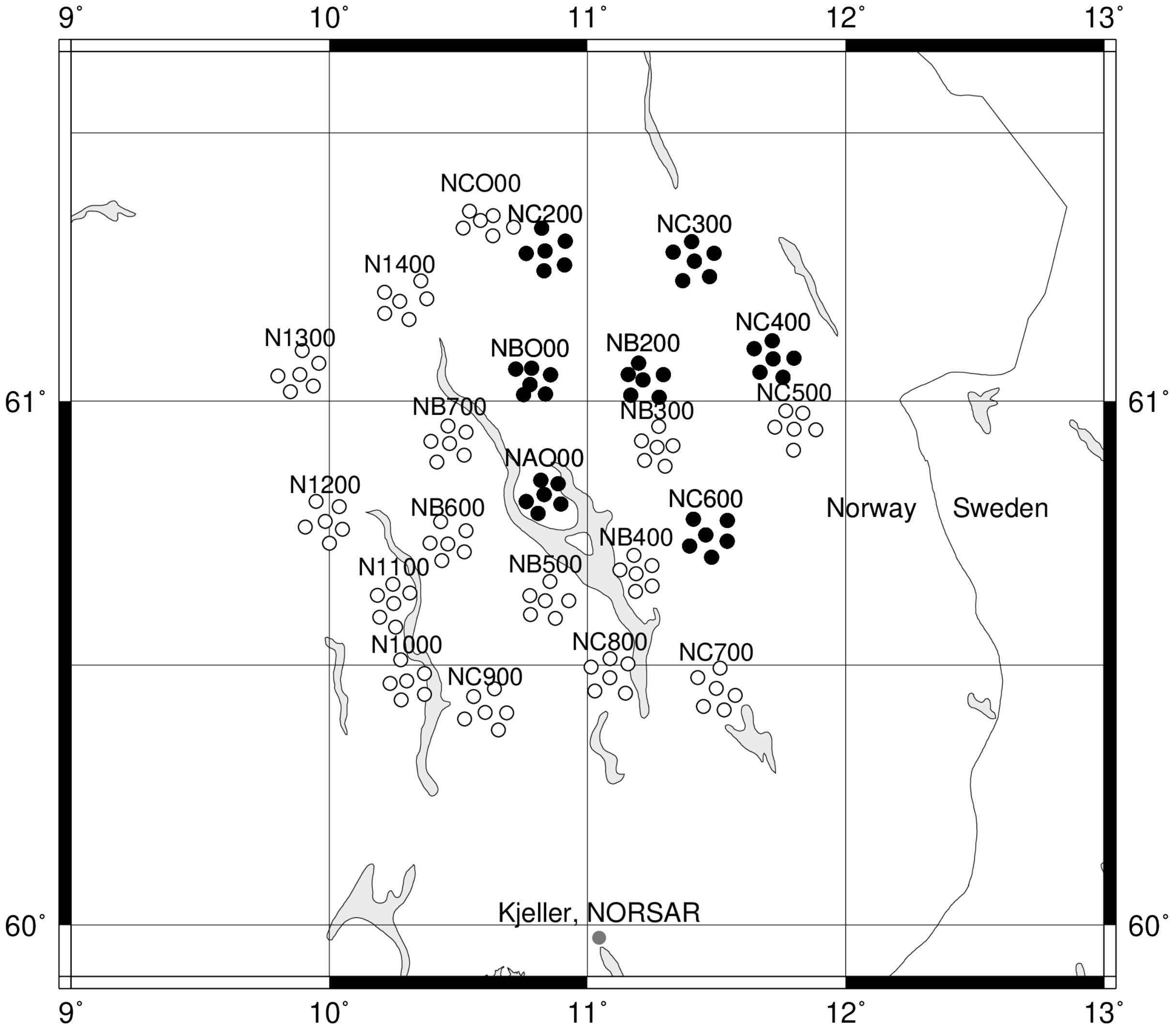

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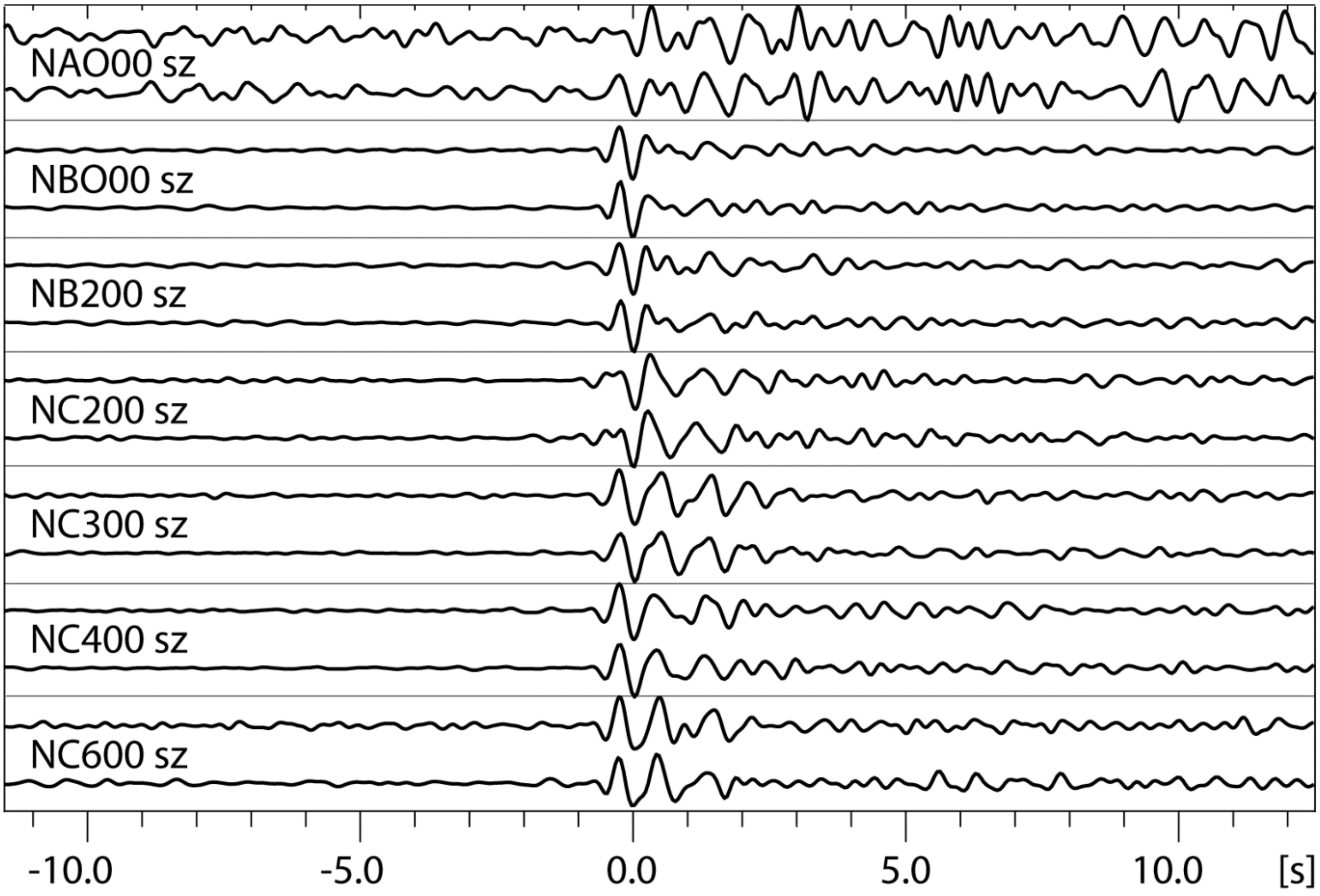

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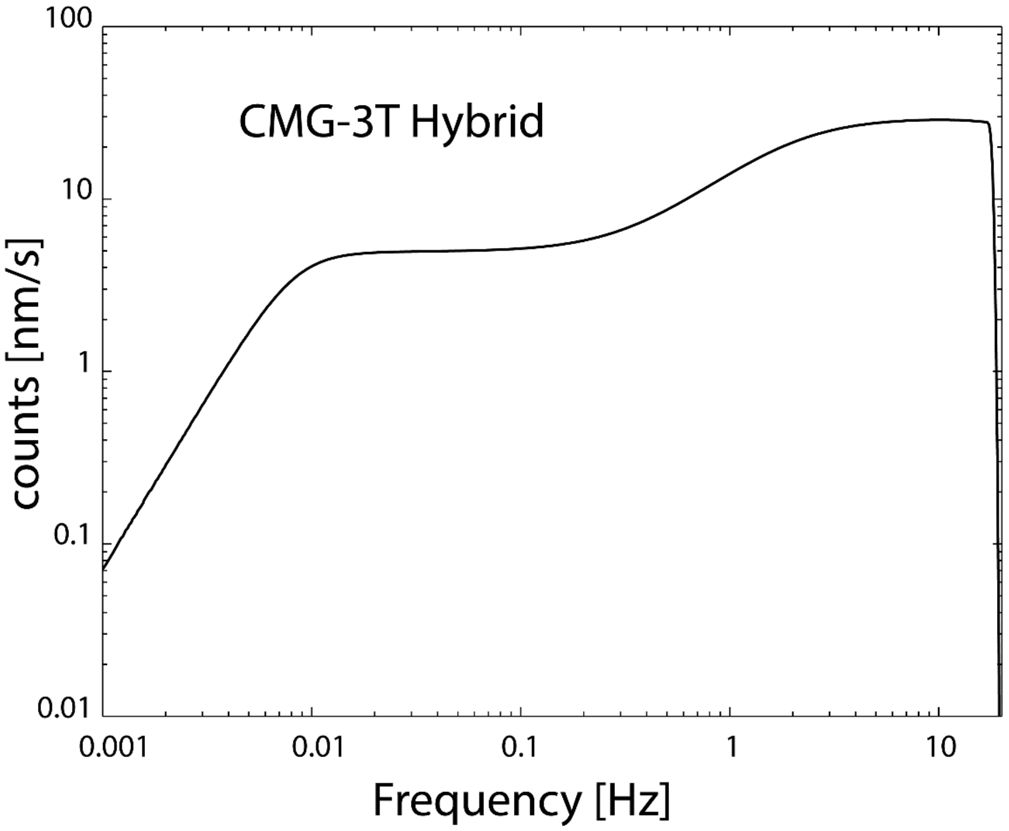

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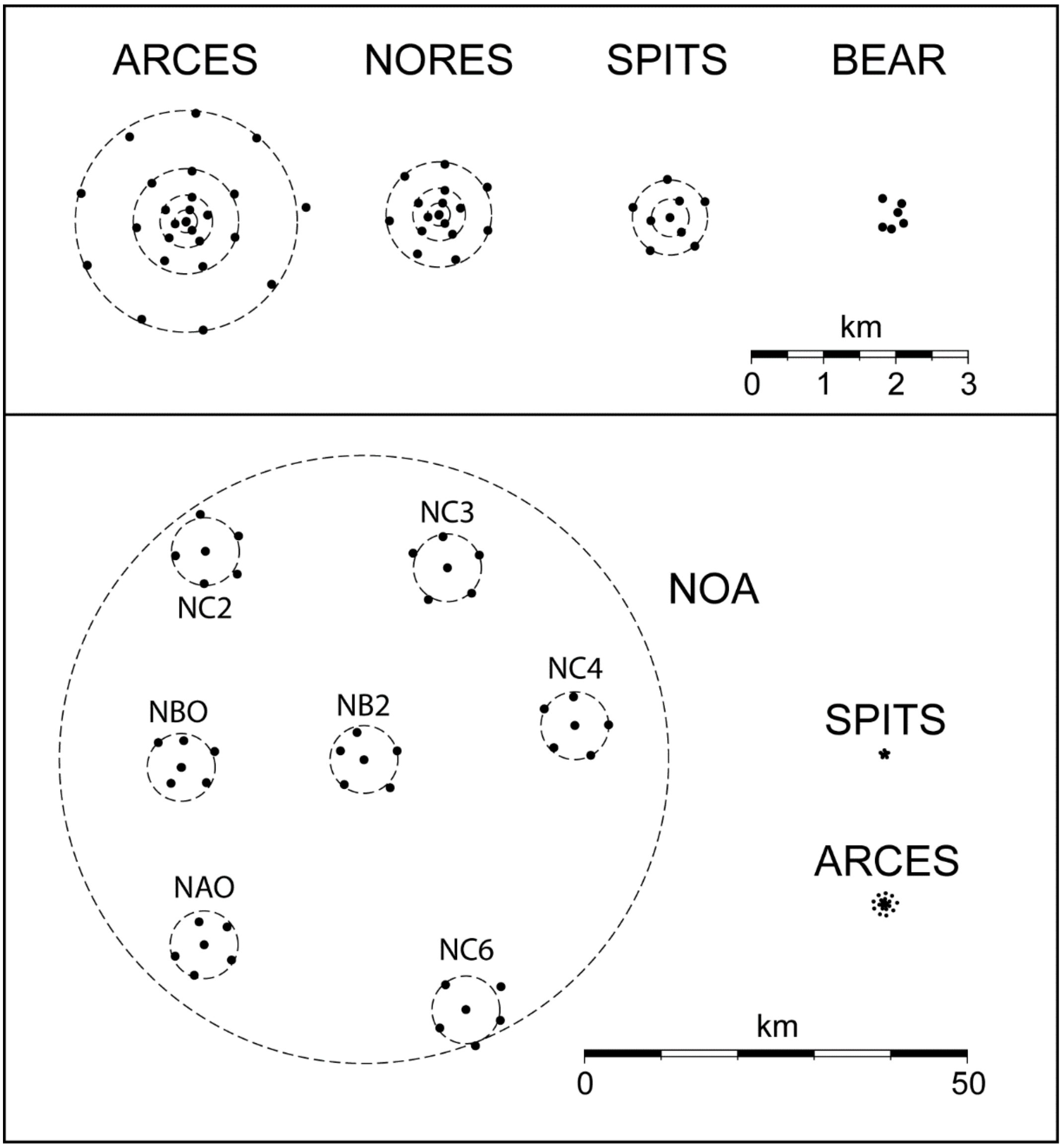

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