Annual report for the

Norwegian National Seismic Network

2017

Supported by

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CONTENTS

1 Introduction

This annual report for the Norwegian National Seismic Network (NNSN) covers operational aspects for the seismic stations contributing data, presents the seismic activity in the target areas and the associated scientific work carried out under the project. The report is prepared by the University of Bergen with contributions from NORSAR.

The NNSN is supported by the oil industry through the Norwegian Oil and Gas Association and the University of Bergen (UiB).

All the data stored in the NNSN database are available to the public via Internet, e-mail or on manual request. The main web-portal for earthquake information is www.skjelv.no. It is possible to search interactively for specific data and then download the data from ftp://ftp.geo.uib.no/pub/seismo/DATA. Data are processed as soon as possible and updated lists of events recorded by Norwegian stations are available soon after recording. These pages are automatically updated with regular intervals.

2 Operation

2.1 NNSN

The University of Bergen (UiB) has the main responsibility to run the NNSN and operates 34 of the seismic stations that form the NNSN located as seen in Figure 1. NORSAR operates 3 seismic arrays, which also include broadband instruments, and three single seismometer stations (JETT, JMIC and AKN).

In addition to the NNSN stations, waveform data from selected stations in Finland (University of Helsinki), Denmark (GEUS), Sweden (University of Uppsala), Island (The Islandic Meteorological Office, IMO) and Great Britain (BGS) are transferred in real time and included in the NNSN database. More than 20 stations located in or operated by neighbouring countries are recorded continuously in Bergen and can be used for locating earthquakes, see Figure 1 and Figure 2. Phase data from neighbour countries and from arrays in Russia (Apatity), Finland (Finess), Sweden (Hagfors) are also included.

One station with real-time data is provided from the Ekofisk field by ConocoPhillips and also data from the Grane and Oseberg fields operated by Statoil are transferred to Bergen and used in locations. The station HSPB is operated jointly between NORSAR and the Geophysical Institute, Polish Academy of Sciences, Warsaw, Poland and the stations BRBA and BRBB, both located in Barentsburg, Svalbard, are a collaboration between NORSAR and the Kola Science Centre, Russian Academy of Sciences, Apatity, Russia. In total, NORSAR provides data from 12 broadband stations to the NNSN.

The seismicity detected by the network is processed at UiB, however NORSAR also integrate their results into the joint database at UiB. At NORSAR the parameters of analyst-reviewed events are converted into parameter files in Nordic format and forwarded via ftp to UiB on a weekly basis. The magnitude threshold is set to about M=1.5 for regional events of potential interest for the NNSN.

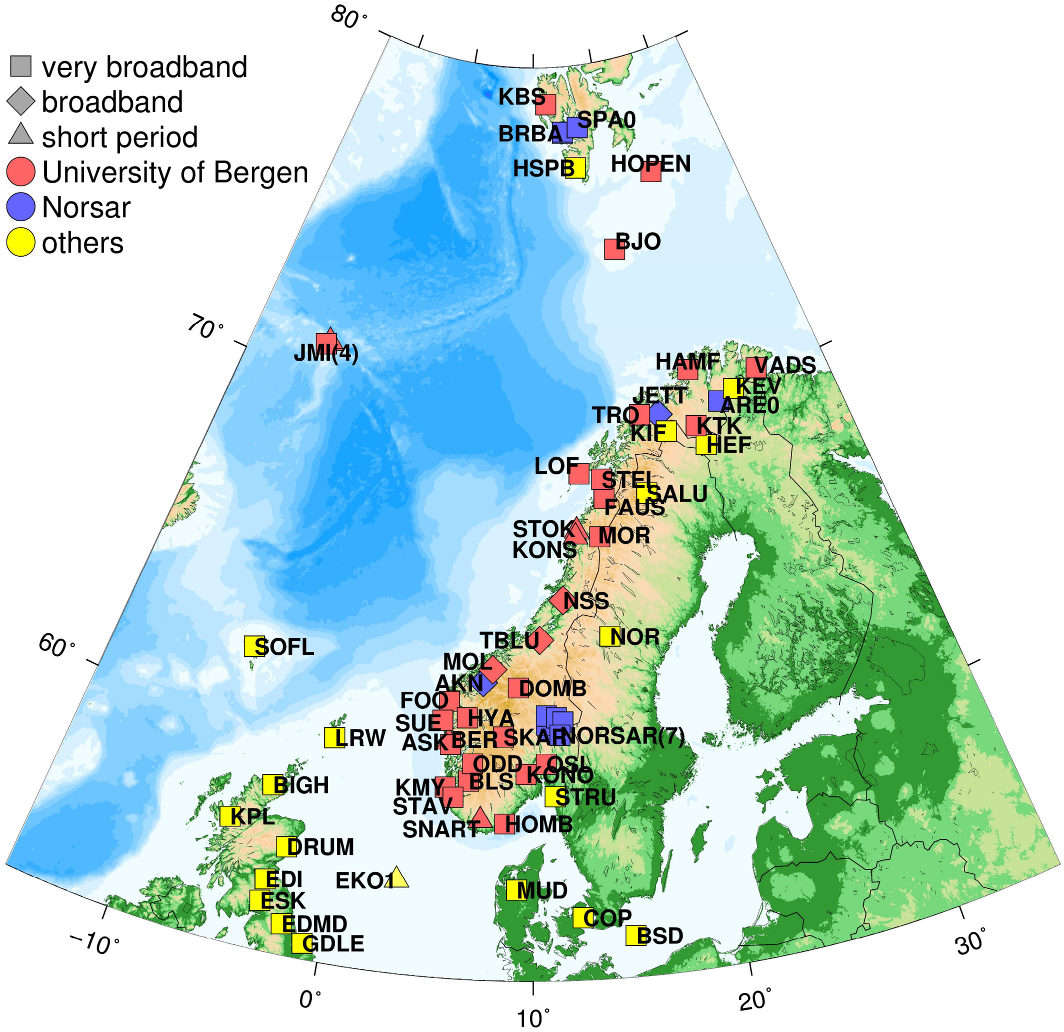


Figure 1. Stations contributing to the Norwegian National Seismic Network (NNSN). UiB operates 34 stations (red) and NORSAR operates the stations marked in blue, including the three arrays and stations AKN and JMIC.

Seismic data recorded at stations located on Greenland and Island are included in the NNSN real-time processing, Figure 2. These data are important for the location of earthquakes south and west of Jan Mayen and along the entire northern Mid-Atlantic ridge.

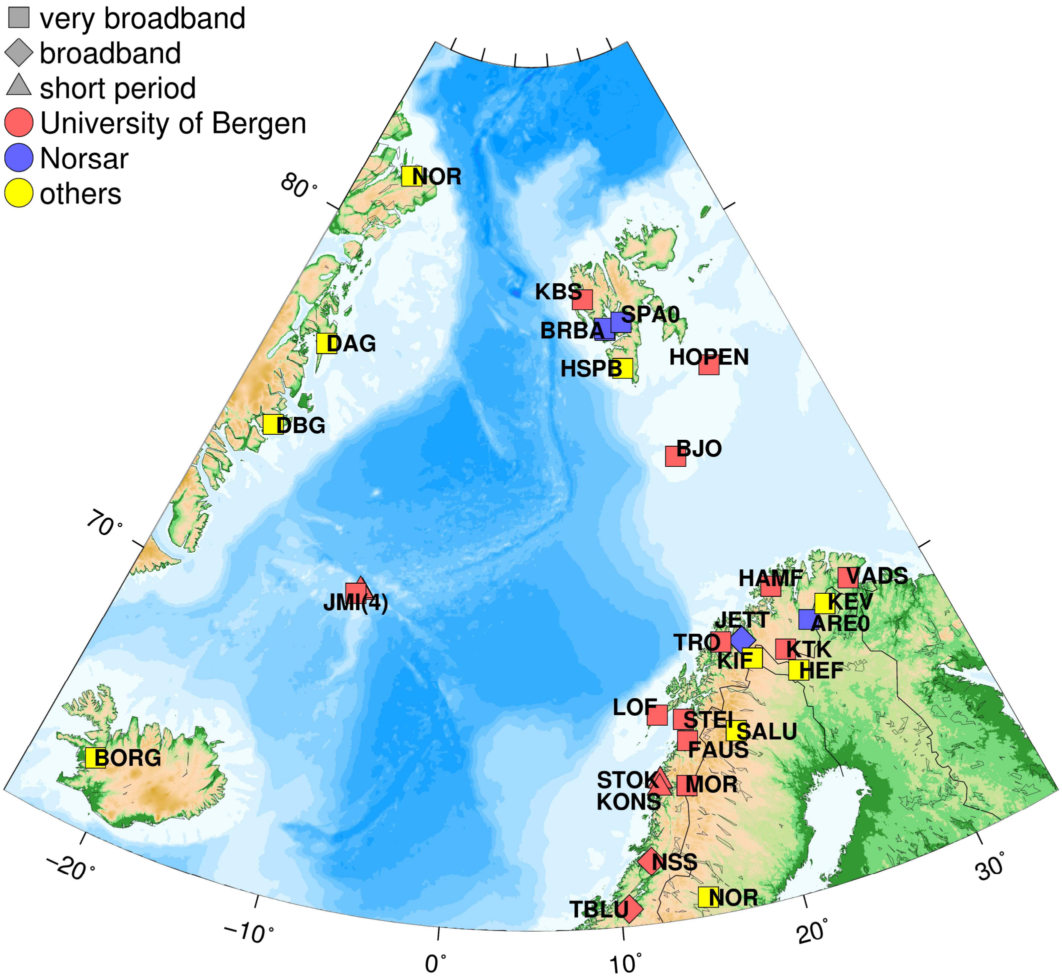


Figure 2. Seismic stations in the arctic area.

UiB is in the process of upgrading the NNSN by changing short period (SP) to broadband (BB) seismometers. The current status of this upgrade is shown in Table 1. As of today the numbers of SP, BB stations and stations with real time transmission are listed in Table 1.

Table 1. Overview of UiB seismic stations

	Short Period	Broadband	Real time
Number of stations	6	28 (24 with natural period greater than 100 sec)	34

The operational stability for each station is shown in Table 2. The down time is computed from the amount of data that are missing from the continuous recordings at UiB. This is done as the goal is to obtain as complete continuous data from all stations as possible. The statistics will, therefore, also show when a single component is not working. Also, communication or computing problems at the centre will contribute to the overall downtime. In the case of communication problems, a station may not participate in the earthquake detection process, but the data can be used when it has been transferred. Thus, the statistics given allow us to evaluate the data availability when rerunning the earthquake detection not in real-time.

The data completeness for the majority of the stations is above 95%, except for the BJO1, STOK and the three Jan Mayen stations (see technical service overview for details).

Table 2. Data completeness in % for 2017 for all stations of the NNSN operated by UiB.

Station	**Data completeness %**		**Station**	**Data completeness %**
Askøy (ASK)	99		Kongsberg (KONO)	99
Bergen (BER)	100		Konsvik (KONS)	100
Bjørnøya (BJO)	**77**		Lofoten (LOF)	98
Blåsjø (BLS)	100		Mo i Rana (MOR8)	98
Dombås (DOMB)	100		Molde (MOL)	99
Fauske (FAUS)	100		Namsos (NSS)	100
Florø (FOO)	100		Odda (OOD1)	100
Hammerfest (HAMF)	100		Oslo (OSL)	100
Homborsund (HOMB)	99		Skarslia (SKAR)	100
Hopen (HOPEN)	97		Snartemo (SNART)	100
Høyanger (HYA)	98		Stavanger (STAV)	100
Jan Mayen (JMI)	**Ca. 50**		Steigen (STEI)	99
Jan Mayen (JNE)	**Ca. 50**		Stokkvågen (STOK)	**80**
Jan Mayen (JNW)	**Ca. 50**		Sulen (SUE)	98
Karmøy (KMY)	100		Blussuvoll (TBLU)	97
Kautokeino (KTK1)	100		Tromsø (TRO)	99
Kings Bay (KBS)	99		Vadsø (VADS)	100

2.2 NNSN field stations maintenance

The technical changes for each seismic station are listed below. It is mentioned when these changes are carried out by the respective local contact and not by the staff of UiB. When a station stops working, tests are made to locate the problem. Sometimes the reason cannot be found and the cause of the problem will be marked as unknown.

List of station maintenance operations during this reporting period of 2017 were:

Ask (ASK)	04.05.17: Visit. Problem with cable and data from the horizontal components are missing from March 30th. Cable changed and cable protection was later installed by local contact. 20.11.17: Station stopped 17.11.2017. SMS power cycling command sent and normal operation resumed. Data lost November 18-19.
Bergen (BER)	No visit or technical changes
Bjørnøya (BJO1)	10.01.17: Communication down from 20.12.16. USB memory corrupted. Data lost 1-9 January. 01.02.17: New external USB memory installed. 02.05.17: Vault flooded and data collection stopped. Data lost between 2nd and 22st May when seismometer and digitizer were reinstalled. 03.09.17: data lost since 30.08.18. Unknown reason. 15.09.17: Local contact started the work with water-proofing the vault. Station down. 02.11.17: Station in normal operation after rehabilitation. Data lost between 15 September to 2 November 2017.
Blussuvoll (TBLU)	29.05.17: Power cable reconnected, it had been pulled out by mistake. Data lost for period 19.05.-29.05 due to power loss.
Blåsjø (BLS)	No visit or technical changes
Dombås (DOMB)	No visit or technical changes
Fauske (FAUS)	13.09.17: Station and vault inspected by local contact. A small amount of water was removed. 11.11.17: Station stopped. Restarted by power cycling command sent via sms.
Florø (FOO)	No visit or technical changes.

Hammerfest (HAMF)
: No visit or technical changes.

Homborsund (HOMB)
: 02.01.17: Communication down since 27.12.16. No data lost.

Hopen (HOPEN)
: 10.01.17: Communication down since 20.12.16. Data lost between 20th December and 1st January.
: 08.06.17: Vault inspected and local personnel installed a seismometer insulation cover. Data lost since 5-7 June 2017.
: 22.07.17: During the time-period May-July there has been satellite telemetry anomalies. The cause was difficult to find, but was fixed by removing some equipment (not UiB) from the network.
: 05.08.17: Telemetry problems solved by removing some equipment from network.
: 30.11.17: Station restarted. Data lost since 29.11.17.

Høyanger (HYA)
: 21.12.17: Visit. The station was upgraded with Nanometrics Trillium 120QA and Centaur digitizer.

Jan Mayen (JMI)
: 07.07.17: New cable was installed to the site in Trolldalen. Data lost between February to August 2017. The local staff at Jan Mayen spent some time to identify the problem which was a defect cable. A temporary station (JMIM) was installed near the base at 8th May and stopped 12th August.
: 18.08.17: Visit. A Nanometrics Centaur digitizer was installed to replace the Guralp DM24. New Ethernet connection was established in the pit. A 3-channel digitizer had to be used, resulting in the accelerometer not being connected.
: 06.11.17: Three channel digitizer is replaced with six channel version to record both seismometer and accelerometer data.

JNE
: 05.01.17: The digitizer, which is shared with JNW was defect.
: 08.02.17: New digitizer installed. Data lost since 05.01.17.

JNW
: Data quality reduced due to telemetry issues. Cable break at the station discovered and fixed by local person contact.
: 05.01.17: The digitizer, which is shared with JNE was defect.
: 08.02.17: New digitizer installed. Data lost since 05.01.17.

Karmøy (KMY)
: 02.01.17: Communication down since 26.12.16. Data lost.

Kautokeino (KTK)
: No visit or technical changes.

Kings Bay (KBS)	No visit or technical changes, which involves UiB personnel.
Kongsberg (KONO)	No visit or technical changes, which involves UiB personnel.
Konsvik (KONS)	No visit or technical changes.
Lofoten (LOF)	12.07.17: Data lost 11-17 July due to communication problems.
Mo i Rana (MOR8)	02.01.17: Communication down since 24.12.16. 05.08.17: Power break caused by lightning 29.07.17. Data lost.
Molde (MOL)	04.01.17: Station down since 30.12.16 due to power loss. All data lost.
Namsos (NSS)	No visit or technical changes.
Odda (ODD1)	No visit or technical changes.
Oslo (OSL)	No visit or technical changes.
Skarslia (SKAR)	10.07.17: Vault inspection. A small amount of water was removed.
Snartemo (SNART)	No visit or technical changes.
Stavanger (STAV)	No visit or technical changes.
Steigen (STEI)	No visit or technical changes.
Stokkvågen (STOK)	31.10.17: Station stopped. Not possible to restart. 22.11.17: Temporary station installed in the garage. Trillium 120QA with Nanometrics Centaur digitizer. Data lost in the time period 31.10 – 22.11.17.
Sulen (SUE)	27.07.17: Data lost since 18.07, due to power break. Switch inside 230 V distribution box was defect.
Tromsø (TRO)	No visit or technical changes. Data lost between 25-28 August, reason unknown.

Vadsø (VADS) 02.08.17: The vault was inspected by local contact.

2.3 The NORSAR stations and arrays

NORSAR is providing data to the NNSN from the following main data streams (Figure 3):

- NOA (southern Norway, array, 7 3C broadband sensors)
- ARCES (Finnmark, array, 1 3C broadband seismic sensor)
- SPITS (Spitsbergen, array, 1 3C broadband sensors)
- JMIC (Jan Mayen, 3C broadband sensor)
- AKN (Åknes, Møre og Romsdal, 3C broadband sensor)
- JETT (Jettan, Troms, 3C broadband sensor)
- I37H0 (Bardufoss, 3C broadband sensor)
- HFS (Hagfors, Sweden, array, 3C broadband sensor, operated by the Swedish Defence Research Agency, Stockholm, Sweden)

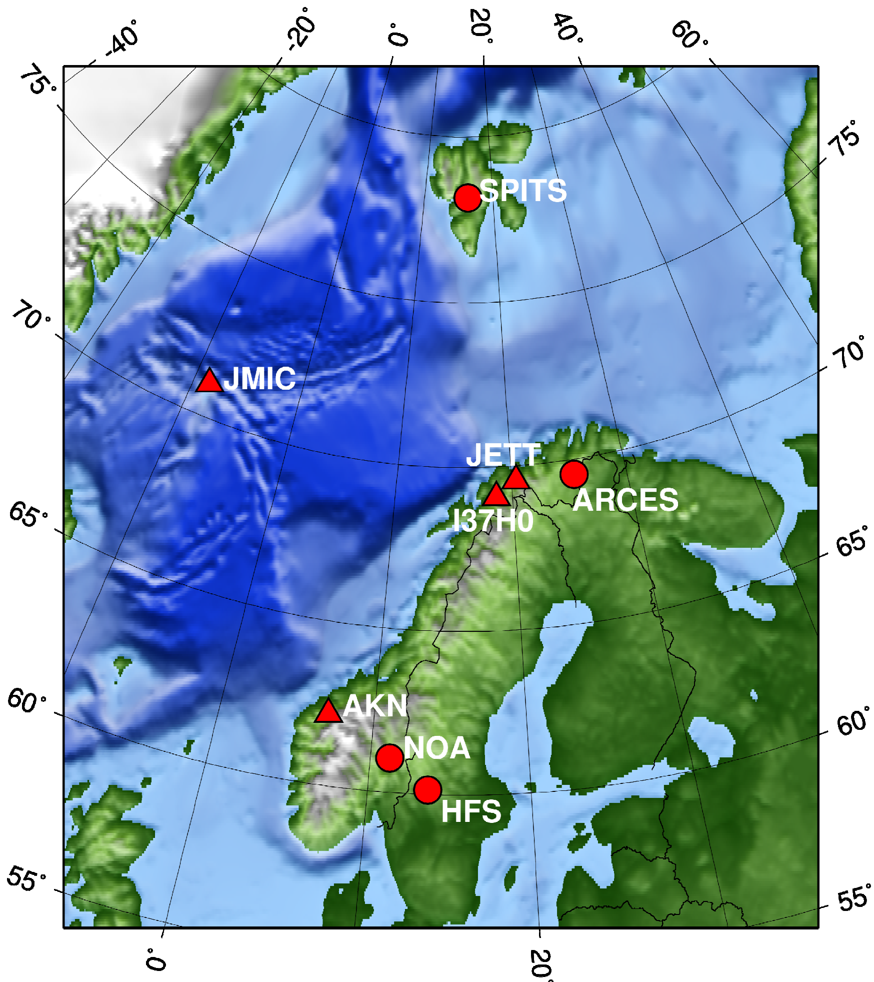


Figure 3. NORSAR seismic arrays/stations (NOA, ARCES, SPITS, JMIC, AKN, I37H0) and contributing arrays/stations (HFS).

2.3.1 Data availability

All data recorded at NORSAR are continuous. The following table (Table 3) provides a monthly overview on the data availability of 14 main data streams provided by NORSAR to the NNSN.

Table 3. Systems recording performance (in % of data completeness) for 14 main data streams provided from NORSAR to NNSN.

	ARA0	JMIC	NAO01	NBO00	NB201	NC204	NC303
Jan	99.99	99.99	99.99	99.99	99.99	99.98	99.99
Feb	99.99	99.78	99.91	99.97	99.92	99.93	99.94
Mar	100.00	100.00	99.92	99.94	99.91	99.92	99.89
Apr	100.00	99.99	99.98	100.00	100.00	100.00	100.00
May	99.98	90.26	100.00	99.98	99.98	99.98	99.98
Jun	100.00	99.95	100.00	100.00	100.00	100.00	100.00
Jul	99.96	99.90	100.00	100.00	100.00	100.00	100.00
Aug	100.00	99.91	100.00	100.00	100.00	100.00	100.00
Sep	100.00	100.00	100.00	99.97	100.00	100.00	100.00
Oct	100.00	99.97	100.00	100.00	100.00	100.00	100.00
Nov	100.00	99.94	99.99	100.00	99.99	100.00	99.99
Dec	100.00	99.96	100.00	100.00	100.00	100.00	100.00

	NC405	NC602	SPA0	AKN	JETT	HFC2	I37H0
Jan	100.00	99.93	100.00	99.99	99.98	99.95	100.00
Feb	99.91	99.97	100.00	100.00	100.00	99.95	100.00
Mar	99.92	100.00	100.00	100.00	100.00	99.95	99.99
Apr	100.00	100.00	100.00	100.00	100.00	61.16	100.00
May	99.98	100.00	99.99	95.49	100.00	99.96	99.99
Jun	100.00	100.00	100.00	100.00	100.00	99.91	100.00
Jul	100.00	100.00	100.00	100.00	100.00	99.95	100.00
Aug	100.00	100.00	99.99	99.99	100.00	99.96	100.00
Sep	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Oct	100.00	100.00	100.00	100.00	98.20	99.98	100.00
Nov	100.00	100.00	89.93	100.00	99.99	99.96	100.00
Dec	100.00	100.00	100.00	99.99	100.00	99.98	100.00

2.3.2 Detections

The NORSAR analysis results are based on automatic phase detection and automatic phase associations which produce the automatic bulletin. Based on the automatic bulletin, a manual analysis of the data is prepared, resulting in the reviewed bulletin. The automatic bulletin for northern Europe is created using the Generalized Beam Forming (GBF) method. This bulletin (www.norsardata.no/NDC/bulletins/gbf/) is subsequently screened for local and regional events of interest in Fennoscadia and in Norway, which in turn are reviewed by an analyst.

Table 4 gives a summary of the phase detections and events declared by GBF and the analyst.

Table 4. Phase detections and event summary.

	Jan.	Feb.	March	April	May	June
Phase detections	257060	208164	244452	192107	220361	238592
Associated phases	5307	4881	5562	5153	6342	4879
Un-associated phases	251753	203283	238890	186954	214019	233713
Screened GBF events for Fennoscandia/Norway	481	436	497	461	587	457
No. of events defined by the analyst	29	23	40	22	48	31
	July	**Aug.**	**Sep.**	**October**	**Nov.**	**Dec.**
Phase detections	259342	325745	331534	350600	243002	229647
Associated phases	4704	5273	5227	4737	4795	5986
Un-associated phases	254638	320472	326307	345863	238207	223661
Screened GBF events for Fennoscandia/Norway	410	492	501	472	442	554
No. of events defined by the analyst	23	29	24	20	19	34

3 NNSN achievements and plans

The overall purpose of the NNSN is to provide data both for scientific studies, but equally important for the routine observation of earthquakes. This in principle means that broadband seismometers are desired at all sites. However, in areas where additional stations are deployed for local monitoring, short-period seismometers are sufficient. The number of broadband seismometers in the network will be increased to replace existing short period instruments. A general goal for the future development has to be to achieve better standardization in particular with the seismometers and digitizers. The total number of stations for now should remain stable, but it is important to improve the overall network performance.

3.1 NNSN achievements in 2017

- A research workshop was held between UiB and NORSAR in January 2017.
- Technical staff at NORSAR visited UiB, May 15-16, 2017.
- Some of the macroseismic data in the NNSN database are available on the website skjelv.no. The technical implementation was done through the EPOS-Norway project.
- Data from all Jan Mayen stations is transmitted to Bergen in real-time.
- Oseberg and Grane (Statoil) seafloor recordings are made available for integration into the NNSN processing. The data flow started in March 2018.
- Spectrogram analysis has been integrated into the UiB processing package to help with the discrimination of explosions.

- Work on North-Atlantic magnitude scale has been published. The new and improved magnitude scale is included in the daily processing from January 2018.
- Station HYA is upgraded with broadband seismometer. Data from the Icelandic station BORG is now included in the real time data transfer. Other IMO stations are expected to become available.

3.2 NNSN plans for 2018

- A major upgrade will be made at the Jan Mayen stations through the EPOS-Norway project. All three stations will after the upgrade be three component broadband stations.
- All macroseismic data (currently it is reviewed data only) in the NNSN database will become available on the website.
- Upgrade two more stations (KTK1 and ASK) with broadband seismometers.
- If approval is given by Sysselmannen at Svalbard, new seismic station will be installed at Svalbard through the EPOS-Norway project.
- Research fill focus on detection and the interpretation of earthquakes in the North Sea and south-western Norway.
- The Oseberg and Grane data will be used for event detection and combined with the NNSN data.
- Provide data through IRIS and through a European EIDA node at UiB under the EPOS-Norway project.
- Improve macroseismic questionnaire in collaboration with other Scandinavian countries.

4 Seismicity of Norway and surrounding areas for 2017

The earthquake locations presented have been compiled from all available seismic stations as described above. All phase data are collected by UiB and all located local and regional earthquakes recorded on NNSN stations are presented on the web pages. The largest are also e-mailed to the European-Mediterranean Seismological Centre (EMSC) and the International Seismological Center (ISC) to be published on their respective web pages. When all available data is collected, a monthly bulletin is prepared and distributed. A brief overview of the events published in the monthly bulletins is given in this annual report. Macroseismic data for the largest felt earthquakes in Norway are collected, and macroseismic maps are presented.

Local, regional and teleseismic events that are detected by the UiB network are included. The merging of data between NORSAR and UiB is based on the following principles:

i) All local and regional events recorded by NORSAR that are also detected by the NNSN network are included.

ii) Local and regional events with local magnitude larger than 1.5 detected by NORSAR and not recorded by the NNSN are included. However, probable explosions from the Kiruna/Malmberget area are not included.

iii) All teleseismic events recorded by NORSAR and also detected by the NNSN are included.
iv) All teleseismic events with NORSAR magnitude $M_b \geq 5.0$ are included even not detected by the NNSN.

Data from the British Geological Survey (BGS) and the Geological Survey of Denmark and Greenland (GEUS) are included in the database in Bergen following similar criteria as mentioned above, however only events located in the prime area of interest, 54-85°N and 15°W-35°E, and with magnitude ≥ 2.0 are included. From the Greenland area only earthquakes recorded on NNSN stations are included. Phase data and locations from University of Helsinki and University of Uppsala are included NNSN database to improve NNSN locations for events in the eastern parts of Norway or possibly for larger events elsewhere.

4.1 Velocity models and magnitude relations

The velocity model used for locating all local and regional events, except for the local Jan Mayen events, is shown in Table 5 (Havskov and Bungum, 1987). Event locations are performed using the HYPOCENTER program (Lienert and Havskov, 1995) and all processing is performed using the SEISAN data analysis software (Havskov and Ottemöller, 1999).

Table 5. Velocity model used for locating all local and regional events, except for the local Jan Mayen events (Havskov and Bungum, 1987).

P-wave velocity (km/sec)	Depth to layer interface (km)
6.2	0.0
6.6	12.0
7.1	23.0
8.05	31.0
8.25	50.0
8.5	80.0

Local magnitude M_L is computed for all earthquakes based on measuring instrument corrected ground amplitudes A (nm) and applying the M_L scale by Alsaker et al. (1991):

$$M_L = \log(A) + 0.91 \cdot \log(D) + 0.00087 \cdot D - 1.67$$

where D is the hypocentral distance in km.

For the North Atlantic region M_L is not appropriate, and the mb(pn) and mb(sn) magnitude scales that are based on Pn and Sn amplitudes, respectively, are used. The details of the mb(Pn) scale are explained in Kim and Ottemöller (2017). The formula used is:

$$m_b(Pn) = \log_{10} A \text{ [nm]} - 1.86 \log_{10} (100/\Delta) \text{ [km]} + C + E + 1.62$$

where A is the zero-to-peak amplitude of Pn wave on the simulated vertical Wood-Anderson seismogram in nanometers (technically read in the same way as the M_L amplitude), Δ is the epicentral distance in kilometers, 1.86 represents amplitude attenuation, C is the station correction, E is the source region correction and 1.62 anchors the $m_b(Pn)$ to the moment magnitude (M_w).

The moment magnitude M_w is calculated for selected earthquakes on mainland Norway from the seismic moment M_0 using the relation (Kanamori, 1977)

$$M_w = 0.67 \cdot \log(M_0) - 6.06$$

The unit of M_0 is Nm. The seismic moment is calculated from standard spectral analysis assuming the Brune model (Brune, 1970) and using the following parameters:

Density: 3.0 g/cm^2
$Q = 440 \cdot f^{0.7}$
P-velocity = 6.2 km/s
S velocity = 3.6 km/s

In the analysis, the seismic moment is measured from attenuation corrected source displacement spectra (Havskov and Ottemöller, 2003).

For the Jan Mayen area, a local velocity model (see Table 6) and coda magnitude scale is used (Andersen, 1987).

Table 6. Velocity model used for locating local Jan Mayen events.

P-wave velocity (km/sec)	Depth to layer interface (km)
6.33	18
8.25	50

The regional and teleseismic events recorded by the network are located using the global velocity model IASPEI91 (Kennett and Engdahl, 1991).

Body wave magnitude is calculated using the equation by Veith and Clawson (1972):

$$Mb = \log(A/T) + Q(D,h)$$

Here h is the hypocentre depth (km), A is the amplitude (microns), T is period in seconds and Q(D,h) is a correction for distance and depth.

Surface wave magnitude Ms is calculated using the equation (Karnik et al., 1962):

$$Ms = \log(A/T) + 1.66 \cdot \log(D) + 3.3$$

where A is the amplitude (microns), T is period in seconds and D is the hypocentral distance in degrees.

Starting from January 2001, the European Macroseismic Scale, EMS98, (Grünthal, 1998) has been used. All macroseismic intensities mentioned in the text will refer to the EMS98 instead of the previously used Modified Mercalli Intensity scale. The two scales are very similar at the lower end of the scale for intensities less than VII.

4.2 Events recorded by the NNSN

Based on the criteria mentioned above, a total of 8,687 local and regional events, were detected by the NNSN during 2017. Of these local and regional events, 25% were large enough to be recorded by several stations and hence could be located reliably, and are not classified as explosions (LP or LE). The numbers of local/regional and teleseismic events, recorded per month in 2017 are shown in Figure 4. The higher number of recorded events during April-June is mainly due to the increased earthquake activity in the Hornsund area, Svalbard (see Section 4.3.3).

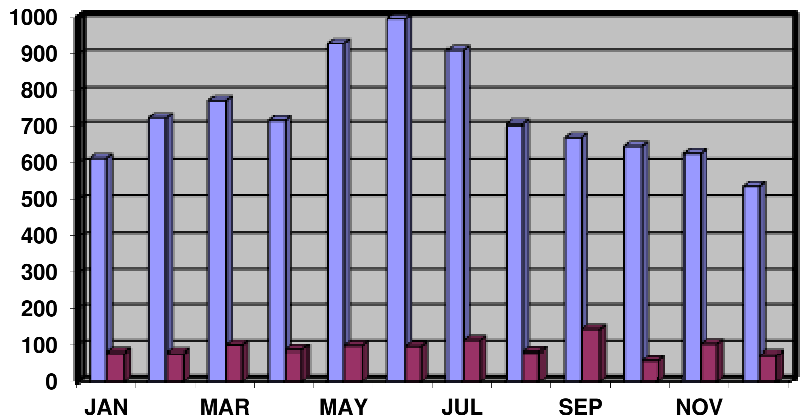


Figure 4. The number of recorded local/regional (blue) and teleseismic (red) events during 2017. The average number of local and regional events recorded per month is 724 (682 in 2016).

A total of 1119 teleseismic events were recorded in 2017, giving a monthly average of 93 events. In addition to the locations determined at UiB and NORSAR, also preliminary locations published by the USGS (United States Geological Survey) or the EMSC (European Mediterranean Seismological Centre) based on the worldwide network are included for earthquakes registered by NNSN stations.

During the years there has been an increase in the number of local/regional (L/R) events recorded into the NNSN database. A large number of recorded L/R events are believed to be explosions, but improved methods for identifying explosions are used and an increased number of explosion are identified. As can be seen from Figure 5 the number of teleseismic (D) earthquakes recorded are relative stable while the number of recorded local/regional events have increased the last four years. Technical problems at Jan Mayen caused that the number of small, located events in the area is reduced. Judged by the increase in the number of recorded events during 2017 it seems likely that most earthquakes are detected but some is not located. The number of recorded earthquakes is expected to continue to increase with the planned installation of new stations on Svalbard and Nordland, due to a decreased detection-level in those areas.

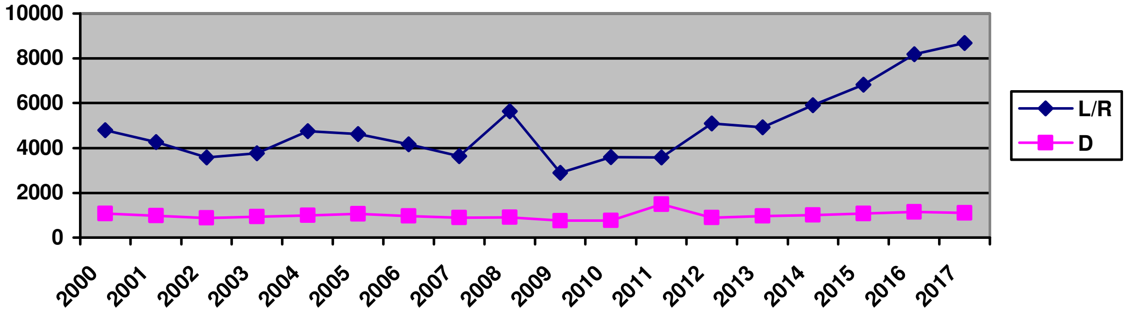


Figure 5. Number of local/regional (blue) and teleseismic (pink) events recorded in the NNSN database since 2000

UiB, as an observatory in the global network of seismological observatories, reports local and teleseismic phases to the International Seismological Center (ISC). All events (teleseismic, regional and local) recorded from January to December 2017 with M ≥ 3 are plotted in Figure 6.

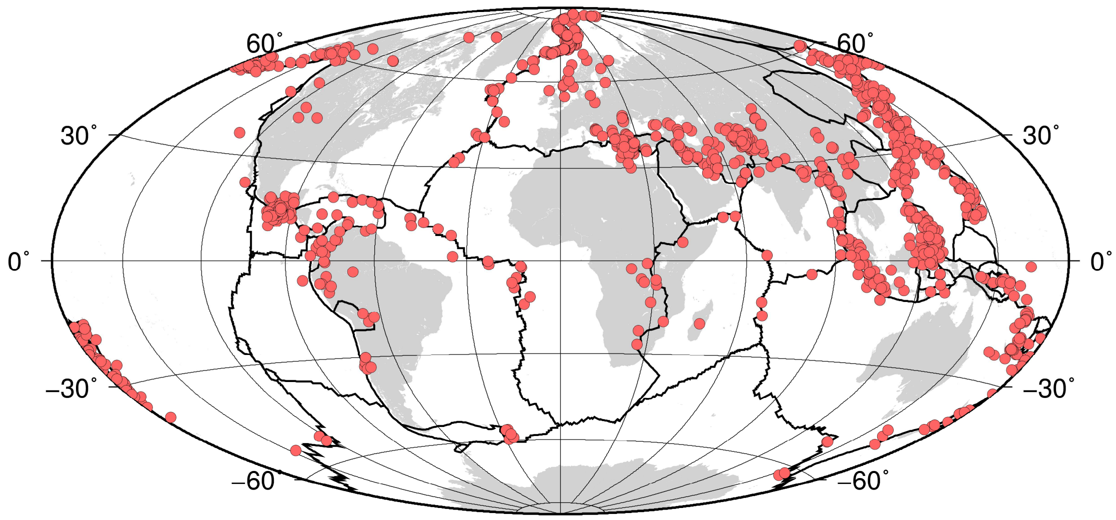


Figure 6. Epicentre distribution of earthquakes with M≥3.0, located by the NNSN from January to December 2017. Teleseismic events recorded only by NORSAR have M≥5.0.

Monthly station recording statistics from January to December 2017 are given in Table 6 and 7. This table shows, for each station, local events recorded on more than one station, and recorded teleseismic events. The statistics is based on the analysed data and are taken from the database. Table 6 and 7 show both earthquakes and explosions. Identified or suspected explosions will only be located with a minimum number of stations. Therefore, some stations (e.g. KTK, MOR8, VADS, FAUS, SNART) will have a higher number of detections.

The following was observed from Table 6 and 7:

- At Jan Mayen there was a problem with the digitizer, cable problems to two stations and communication problems reduced the number of earthquakes triggered and located since summer 2016. A major upgrade is planned for all three stations, during summer 2018.
- There are no teleseismic detections on JMI, JNE and JNW as currently the system on Jan Mayen is only detecting local events, and realtime data is not available at UiB.
- TBLU and OSL are recording mostly teleseismic earthquakes, which is as expected due to their location in noisy environment. Stronger local earthquakes will, however, be detected.
- The seismic activity in the Hornsund, Svalbard area increased during spring 2017, which increase the number of events recorded at the stations KBS, HOPEN and SPA0.
- Due to periods with communication and technical problems at BJO in addition to the higher noise-level at this site, the large increase of detected earthquake seen on Hopen is not seen here.
- The stations KONS, STOK and MOR8 continue to record a relatively large number of small earthquakes and explosions in the area. Technical problems at STOK in October and November has decreased this number until a temporary station was installed in November 2017.
- The number of events at stations KTK and VADS varies a lot depending on which station is picked for identified explosion. (For explosions at known mines and quarries only two P-wave onsets are identified.)

Table 7. Monthly statistics of events recorded at each station for January-June 2017. Abbreviations are: L = Number of local events recorded at more than one station and D = Number of teleseismic events recorded at the station.

	JANUARY		FEBRUARY		MARCH		APRIL		MAY		JUNE	
STATION	**L**	**D**	**L**	**D**	**L**	**D**	**L**	**D**	**L**	**D**	**L**	**D**
ASK	35	15	46	16	51	17	36	19	43	37	55	24
BER	13	11	15	14	13	16	10	15	13	30	21	25
BJO1	3	3	4	6	14	12	13	12	17	5	27	21
BLS5	41	29	53	26	71	40	52	17	58	43	76	39
DOMB	22	34	28	35	26	45	20	34	18	55	26	42
FAUS	88	54	72	41	109	63	62	45	43	76	53	53
FOO	18	8	27	11	33	17	26	13	33	29	40	25
HAMF	36	24	48	30	61	38	9	33	29	66	56	47
HOMB	20	18	22	18	44	25	24	13	32	29	41	28
HOPEN	35	5	47	8	106	32	86	23	165	30	70	10
HYA	34	21	42	13	52	27	43	16	54	35	61	26
JMI	1	0	0	0	0	0	0	0	0	0	0	0
JMIC	2	3	2	1	7	7	10	4	30	7	37	10
JNE	0	0	0	0	4	0	6	0	22	0	24	0
JNW	0	0	0	0	2	0	7	0	25	0	25	0
KBS	90	18	78	15	120	29	135	31	231	48	258	45
KMY	29	4	36	8	48	5	32	4	38	17	59	12
KONO	14	30	23	32	39	47	45	30	44	54	34	38
KONS	68	22	70	14	85	27	65	19	58	57	80	28
KTK1	145	55	140	49	174	74	55	51	66	78	104	63
LOF	21	17	24	18	34	24	32	20	25	53	39	37
MOL	7	10	14	18	11	20	11	15	13	36	15	28
MOR8	65	46	60	44	77	54	51	39	40	63	47	43
NSS	6	32	13	38	17	47	9	34	10	54	14	43
ODD1	41	25	61	25	86	41	49	23	29	30	34	25
OSL	8	18	6	11	12	23	10	23	12	37	12	27
SKAR	72	36	94	36	134	52	70	34	83	65	124	45
SNART	25	20	30	20	49	28	35	17	43	29	54	32
STAV	7	11	18	14	20	17	12	13	7	26	32	21
STEI	61	46	60	41	84	59	51	42	36	75	77	57
STOK	64	8	67	8	78	10	58	5	54	24	72	20
SUE	27	11	41	14	52	12	39	11	41	31	49	25
TBLU	1	13	1	13	5	14	0	17	5	24	3	29
TRO	36	41	34	35	44	52	18	37	21	71	41	56
VADS	107	37	111	29	126	47	14	28	27	63	57	40
AKN	23	18	39	23	46	34	32	24	35	39	44	33
JETT	44	47	51	35	62	56	39	43	35	68	57	53
NORSAR	1	71	5	60	11	86	5	77	10	96	6	74
ARCES	163	54	169	51	220	75	133	53	147	76	157	63
SPITS	96	41	85	36	139	64	142	44	244	67	277	63

Table 8. Monthly statistics of events recorded at each station for July-December 2017. Abbreviations are: L = Number of local events recorded at more than one station and D = Number of teleseismic events recorded at the station.

	JULY		AUGUST		SEPT		OCT		NOV		DEC	
STATION	**L**	**D**	**L**	**D**	**L**	**D**	**L**	**D**	**L**	**D**	**L**	**D**
ASK	35	31	46	21	46	38	39	9	30	19	23	14
BER	17	37	17	20	19	40	12	6	18	24	6	16
BJO1	27	28	24	20	1	7	0	0	9	17	4	4
BLS5	61	48	68	35	60	59	39	12	33	32	31	20
DOMB	43	67	27	37	21	73	13	20	22	49	19	34
FAUS	103	77	70	54	72	80	56	32	39	60	62	11
FOO	27	36	29	16	34	44	24	6	19	23	17	8
HAMF	62	60	21	43	14	64	14	27	12	55	10	30
HOMB	34	28	40	21	26	35	20	8	12	16	11	15
HOPEN	66	16	87	18	73	20	25	8	37	18	17	6
HYA	47	42	51	21	48	45	46	9	40	28	21	15
JMI	0	0	6	1	18	10	17	3	13	10	22	1
JMIC	60	17	11	8	19	12	19	2	15	10	22	0
JNE	33	0	5	0	15	1	16	0	7	0	22	0
JNW	46	0	1	0	0	0	0	0	0	0	0	0
KBS	148	39	155	33	125	46	115	20	108	35	93	17
KMY	45	25	55	8	38	5	30	3	22	5	18	3
KONO	26	63	29	36	40	54	26	12	43	44	18	26
KONS	86	41	54	27	71	46	51	14	37	38	43	27
KTK1	154	85	109	60	43	90	47	35	78	67	118	42
LOF	34	35	27	26	28	47	21	15	24	38	26	21
MOL	10	34	20	23	14	43	9	15	10	25	12	15
MOR8	48	56	40	27	68	76	40	27	34	54	29	39
NSS	34	64	15	40	19	69	8	25	19	56	17	30
ODD1	38	41	38	22	32	43	23	7	31	27	24	21
OSL	13	39	7	27	15	52	4	13	8	34	1	20
SKAR	92	69	98	44	72	62	64	18	76	47	40	30
SNART	38	38	49	20	35	46	26	6	24	23	20	20
STAV	26	26	18	18	10	28	6	6	13	22	7	13
STEI	118	82	67	54	63	85	41	29	37	60	50	33
STOK	71	24	48	17	68	24	45	6	17	5	31	22
SUE	36	28	46	15	47	42	39	4	29	21	31	9
TBLU	2	31	2	21	2	41	1	8	5	27	2	12
TRO	62	76	27	49	20	78	16	27	17	62	21	34
VADS	79	60	50	50	26	61	26	25	9	50	32	26
AKN	43	49	43	33	48	63	40	20	33	28	27	26
JETT	85	70	54	49	23	79	24	31	22	60	65	37
NORSAR	10	95	7	74	8	136	5	57	6	85	13	67
ARCES	195	72	113	60	100	92	82	34	88	67	83	44
SPITS	154	72	166	47	126	66	120	26	112	53	98	28

4.3 The seismicity of Norway and adjacent areas

This section first gives an overview of the seismicity in the monitoring area before presenting the activity in specific areas in more detail.

The main area of interest is defined as 54-82N and 15W-35 Figure 7. We also show the seismicity for the Arctic region including the Barents Sea defined by coordinates 65-85°N and 25°W-50°E, Figure 10. A total of 4346 of the recorded events are located inside the NNSN prime area. During analysis and using the explosion filter (Ottemöller, 1995), 52% of these events were identified as confirmed or probable explosions, or induced events. Figure 7 shows all local/regional events in the prime area, analysed and located during 2017. Among these, 155 are located in the vicinity of the Jan Mayen Island.

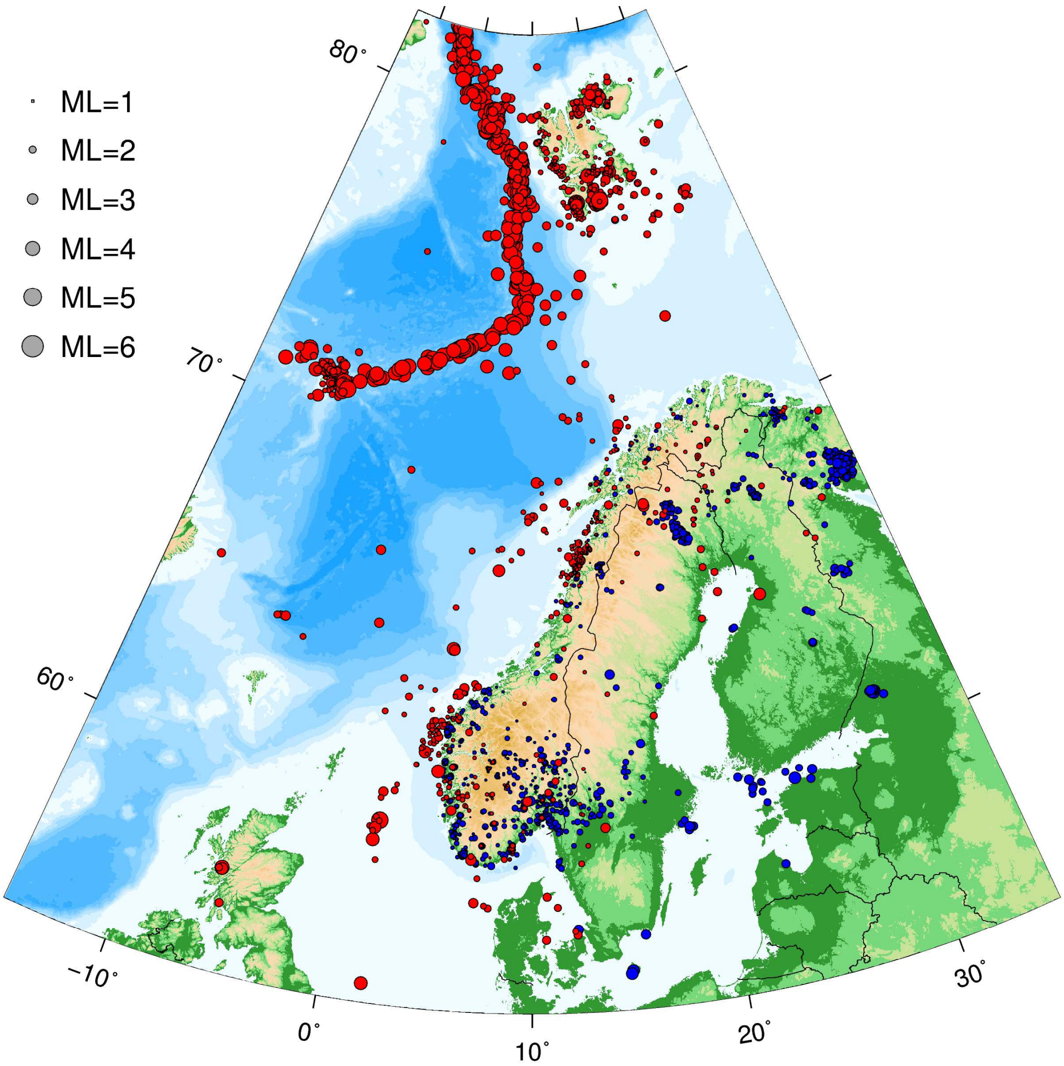


Figure 7. Epicentre distribution of events analysed and located in 2017. Earthquakes are plotted in red. Probable and confirmed explosions and induced events are plotted in blue.

Figure 8 shows the location of earthquakes (induced events, known and probable explosions removed) located within the prime area with one of the calculated magnitudes above 3. Table 9 lists the same earthquakes with all earthquakes located close to the Mid-Atlantic ridge excluded.

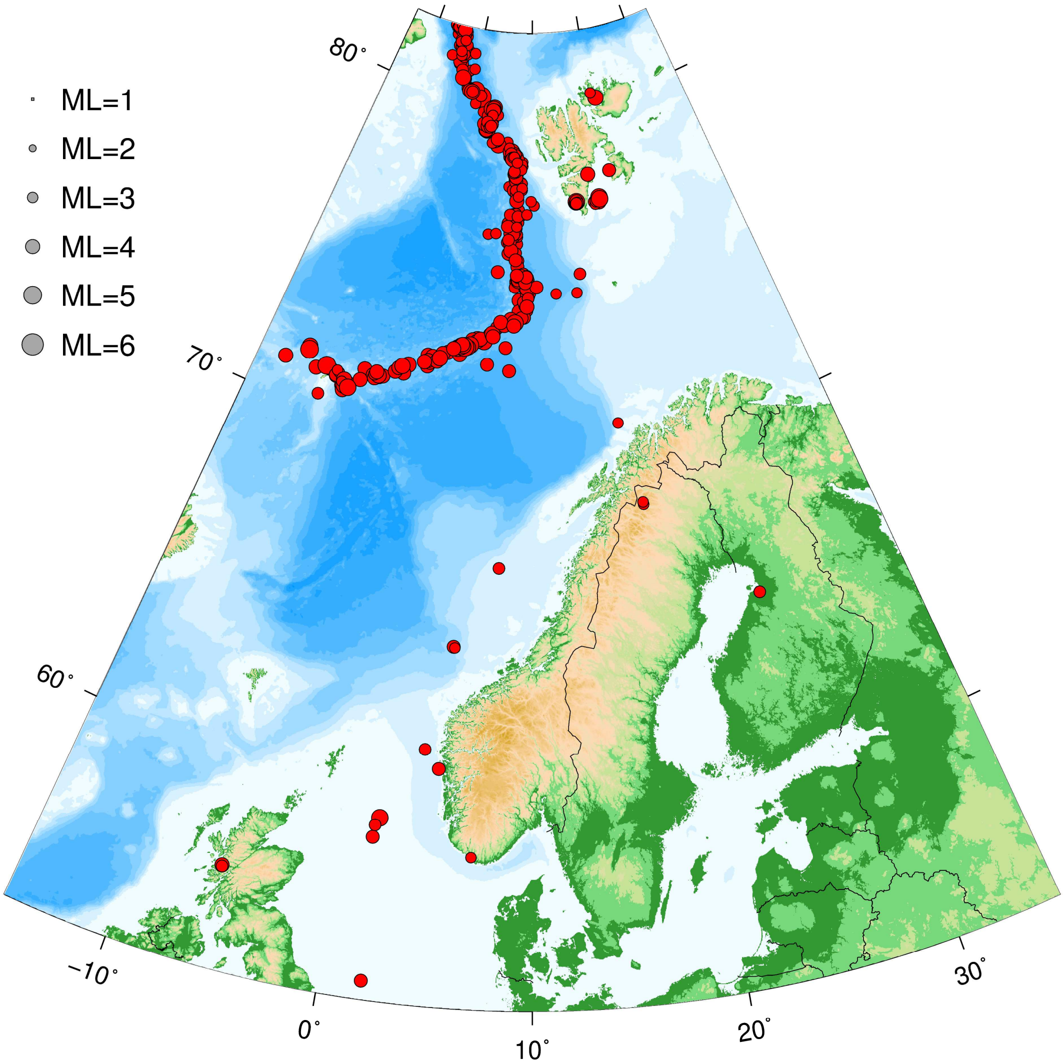


Figure 8. Epicentre distribution of located events with one of the calculated magnitudes above or equal to 3.0. For station location, see Figure 1.

The largest local or regional earthquake in 2017, recorded on Norwegian stations and within the prime area, was an earthquake that occurred on June 09th at 20:49 (UTC) in the area Spitsbergen fracture zone / Molloy Ridge (80.026N 1.275E). The earthquake magnitude is calculated to $M_{N(BER)}$=5.5 and $M_{L(NAO)}$=4.7, while the global CMT catalogue reports M_W=5.3. Seismograms for the earthquake recorded at Barentsburg (BRBA), Hornsund (HSPB), Hopen (HOPEN) and Kings Bay (KBS), are shown in Figure 9.

Another significant earthquake occurred June 30th at 13:33 (UTC) in the North Sea. The earthquake is located to 58.996N 1.789E with magnitude $M_{L(BER)}$=4.2 and the calculated magnitude from BGS is $M_{L(BGS)}$=4.7. This earthquake was felt in the Shetland and Orkney islands, in Scotland, Stavanger (1 report) and Sleipner A and is marked in yellow in Table 9.

Table 9. Earthquakes located in the vicinity of mainland Norway and in the Svalbard area (grey background) with any reported magnitude above or equal to 3.0 for the time period January through December 2017. In cases where all BER magnitudes are below 3 but the event still is included in the list, NORSAR (NAO), GEUS- Geological Survey of Denmark and Greenland (DNK), University of Uppsala (UPP), University of Helsinki (HEL) or the British Geological Survey (BGS) has reported a magnitude of 3.0 or larger. Abbreviations are: HR = hour (UTC), MM = minutes, Sec = seconds, L = distance identification (L=local, R=regional, D=teleseismic), Latitud = latitude, Longitud = longitude, Depth = focal depth (km), F = fixed depth, AGA = agency (BER=Bergen), NST = number of stations, RMS = root mean square of the travel-time residuals, Ml = local magnitude and Mw = moment magnitude.

Year	Date	HRMM	Sec	L	Latitud	Longitud	Depth	FF	AGA	NST	RMS	ML	ML NAO	Mw	ML
2017	1 3	1852	24.3	L	54.494	1.979	15.0	F	BER	36	0.7	3.0	2.9		3.8BGS
2017	1 3	2043	22.2	L	76.919	18.051	14.9		BER	13	0.9	3.0	3.5		
2017	113	0014	59.8	L	67.960	18.546	0.2		BER	26	0.6	3.2	3.6		2.9UPP
2017	130	1411	24.4	L	77.768	20.743	20.8		BER	19	1.0	3.5	3.6		
2017	310	2125	0.3	L	74.305	14.819	26.7		BER	22	0.7	2.0	3.1		
2017	311	1107	55.3	L	74.846	15.383	20.7		BER	25	0.7	2.4	3.3		
2017	428	1326	24.3	L	68.029	18.521	2.2	F	BER	34	0.6	2.8	3.2		3.0UPP
2017	429	2258	50.4	L	58.154	6.790	23.0		BER	31	0.6	3.1	2.9		
2017	5 6	0341	49.0	L	79.953	20.828	22.8		BER	23	0.6	3.5	4.3		
2017	5 9	0309	47.9	L	76.892	18.682	17.7		BER	16	0.5	3.7	4.1		
2017	530	2353	48.2	L	76.974	15.752	2.9		BER	21	0.8	3.1	3.3	3.1	
2017	531	1359	14.2	L	76.979	15.772	2.7		BER	28	1.3	3.7	4.7		
2017	531	1713	55.5	L	76.959	15.678	0.1		BER	16	0.7	3.4	3.7		
2017	531	1733	13.3	L	76.909	15.654	0.0		BER	10	0.4	2.9	3.2		
2017	531	1950	42.6	L	76.927	15.662	0.0		BER	13	0.5	3.3	3.6		
2017	531	2147	33.5	L	76.952	15.722	4.7		BER	20	0.9	3.4	3.7		
2017	531	2344	43.0	L	76.944	15.581	4.5		BER	18	0.8	2.8	3.1		
2017	6 1	0035	58.0	L	76.986	15.770	0.0		BER	15	0.6	3.2	3.4		
2017	6 1	0047	31.5	L	77.006	15.769	0.1		BER	19	0.7	3.4	3.6		
2017	617	0210	53.2	L	74.315	12.567	10.0	F	BER	19	0.7	1.9	3.0		
2017	630	1333	45.5	L	58.996	1.789	4.5		BER	90	0.7	4.2	4.5		4.7BGS
2017	7 7	0142	42.6	L	58.445	1.549	15.0		BER	67	0.6	3.1	3.1		3.6BGS
2017	716	0449	26.6	L	77.045	18.785	15.0		BER	26	1.0	4.0	4.7		
2017	8 2	0215	34.1	L	61.059	3.799	16.1		BER	51	0.6	3.0	3.3		
2017	8 2	1849	0.4	L	66.334	7.614	15.0	F	BER	42	0.7	2.3	3.3		
2017	8 4	1443	39.4	L	56.822	-5.726	4.8		BER	53	0.9	3.5	2.5		4.0BGS
2017	8 4	1445	36.5	L	56.796	-5.705	10.6	F	BER	19	1.1	3.4			3.4BGS
2017	819	1056	1.5	L	76.909	18.353	15.3		BER	19	0.6	3.0	3.4		
2017	821	1444	59.4	L	76.972	18.786	20.1		BER	22	0.6	4.0	4.3		
2017	825	1732	50.9	L	77.741	17.732	19.0		BER	17	1.1	3.5	3.9		
2017	831	2035	12.4	L	76.844	18.231	15.0	F	BER	11	0.7	2.7	3.1		
2017	9 8	1530	9.0	L	76.939	18.379	14.1		BER	19	0.8	3.0	3.6		
2017	914	0814	45.7	L	58.782	1.576	15.0	F	BER	48	0.7	2.8	2.3		3.3BGS
2017	11 7	0846	36.4	L	60.544	4.701	15.0		BER	46	0.6	3.6	3.6	3.7	3.7BGS
2017	1128	1252	19.6	L	64.016	4.930	26.1		BER	42	0.7	2.3	3.7		
2017	1129	1502	14.1	L	76.937	15.887	2.4		BER	9	0.5	3.0	3.5		
2017	12 1	1205	26.5	L	76.931	15.728	1.2		BER	8	0.5	3.1	3.5		
2017	12 7	2232	17.1	L	64.819	25.387	23.0		BER	36	0.8	2.8	3.4		3.3HEL
2017	12 9	0331	13.6	L	63.986	4.989	21.5		BER	25	0.5	2.5	3.2		
2017	1228	0425	44.1	L	80.118	19.998	15.0		BER	8	0.8	2.6	3.0		
2017	1231	1550	25.0	L	76.983	18.835	19.6		BER	30	1.1	4.4	4.7		

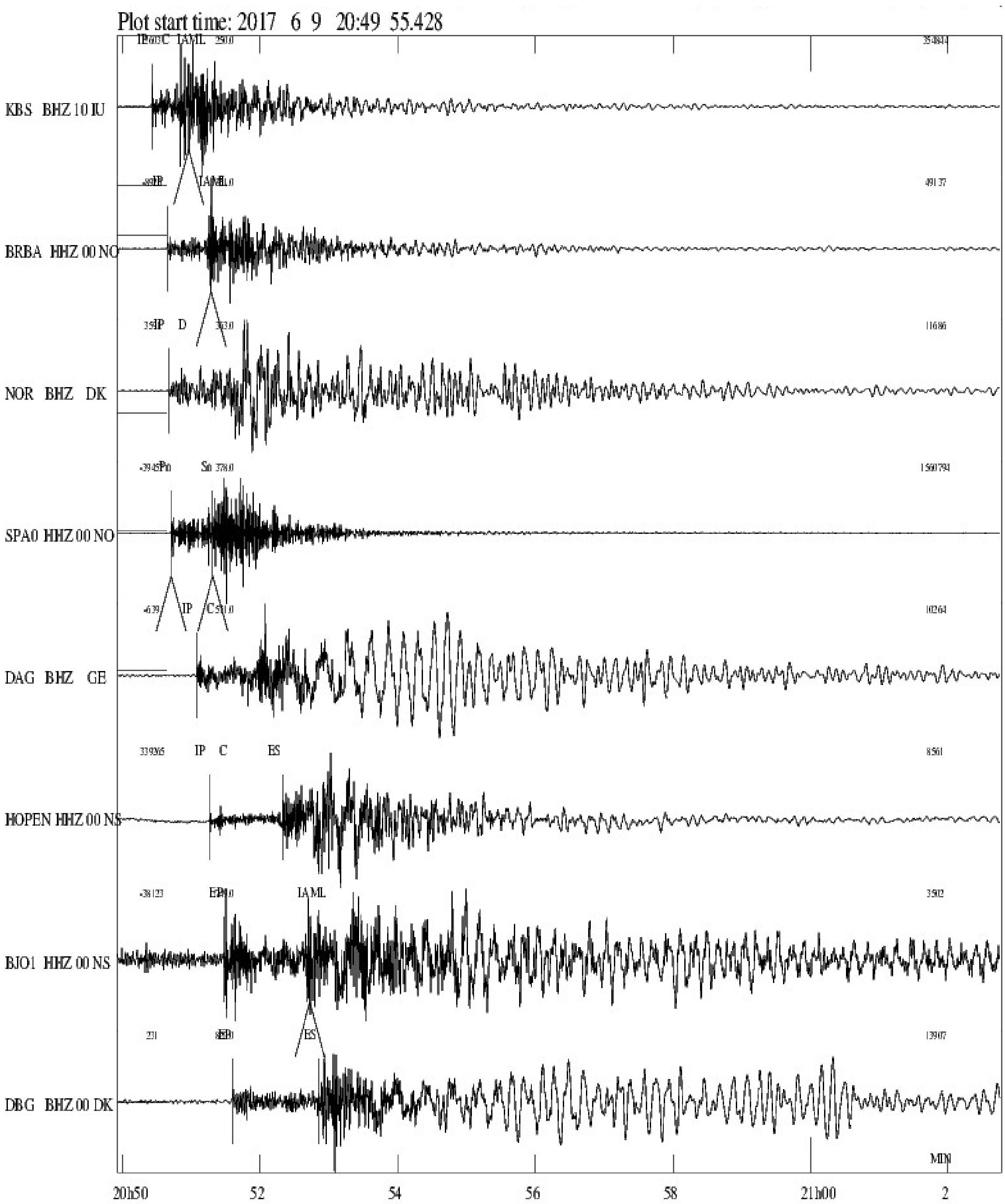


Figure 9. Seismogram of the earthquake felt at Svalbard in June 2017.

With the mainland stations on the Lofoten, in Tromsø, Hammerfest and Vadsø, the network on Jan Mayen, and stations on Bjørnøya, Hopen and Svalbard, the network detection capability in the arctic area is relatively good. We define the arctic area as the region 65-85°N and 25°W-50°E. Most of the activity falls into three areas: Jan Mayen, the Mid-Atlantic ridge and Storfjorden southeast of Svalbard, as can be seen in Figure 10. Since 2014 data from Danish stations on Greenland (see Figure 2) and since June 2017 the BORG station located in Island, were included in the daily processing which has increased the location capability for earthquakes south and west of Jan Mayen, and northwest of Svalbard. The number of earthquakes recorded on enough stations to be located, has increased.

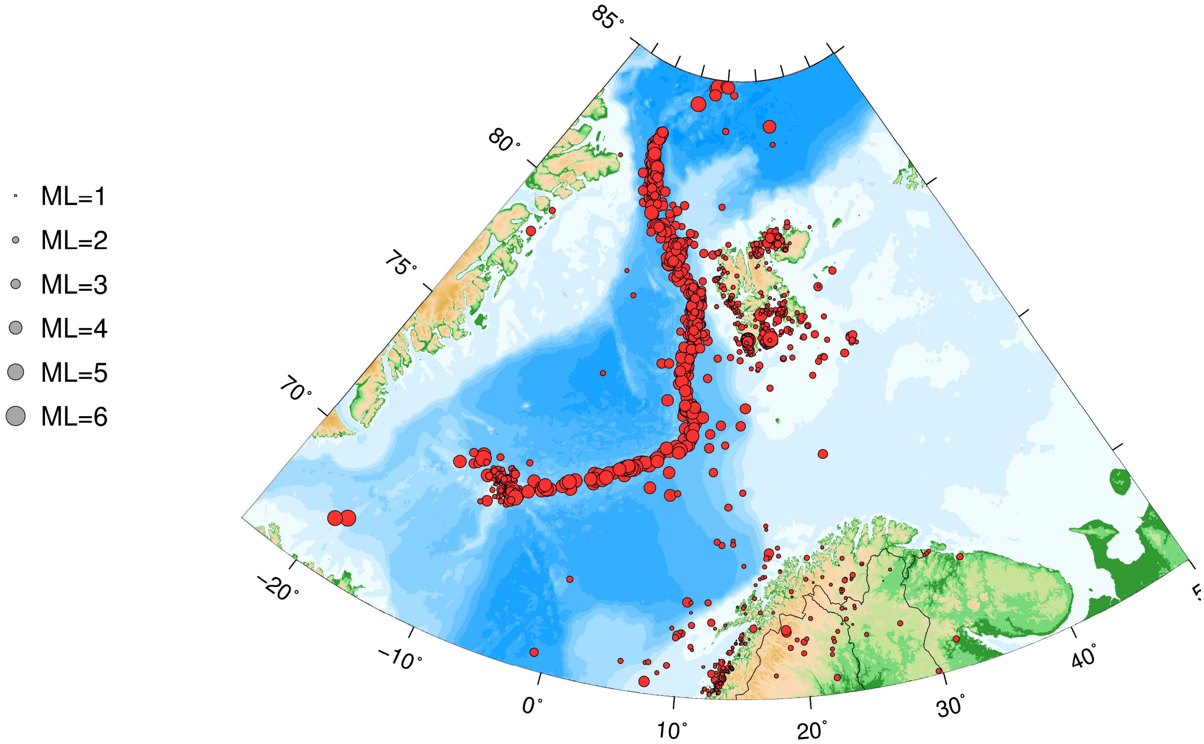


Figure 10. Seismicity in the Norwegian arctic area during 2017. A total of 1911 located earthquakes.

4.3.1 Seismicity in Nordland

Figure 11 shows the seismicity in Nordland since 2000. The area includes the locations of earthquake swarm activity such as Meløy (66.8N, 13.5E), Steigen (67.8N, 15.1E) and Stokkvågen (66.3N, 13.1). The Steigen area was more active between 2007 and 2008, then it was relatively quiet until 2015 when 44 earthquakes appeared. In spring 2016 the temporary stations deployed during the NEONOR2 (2013-2016) project were taken down. The decreased station-density in the area has resulted in fewer events with low magnitude being located (Figure 12).

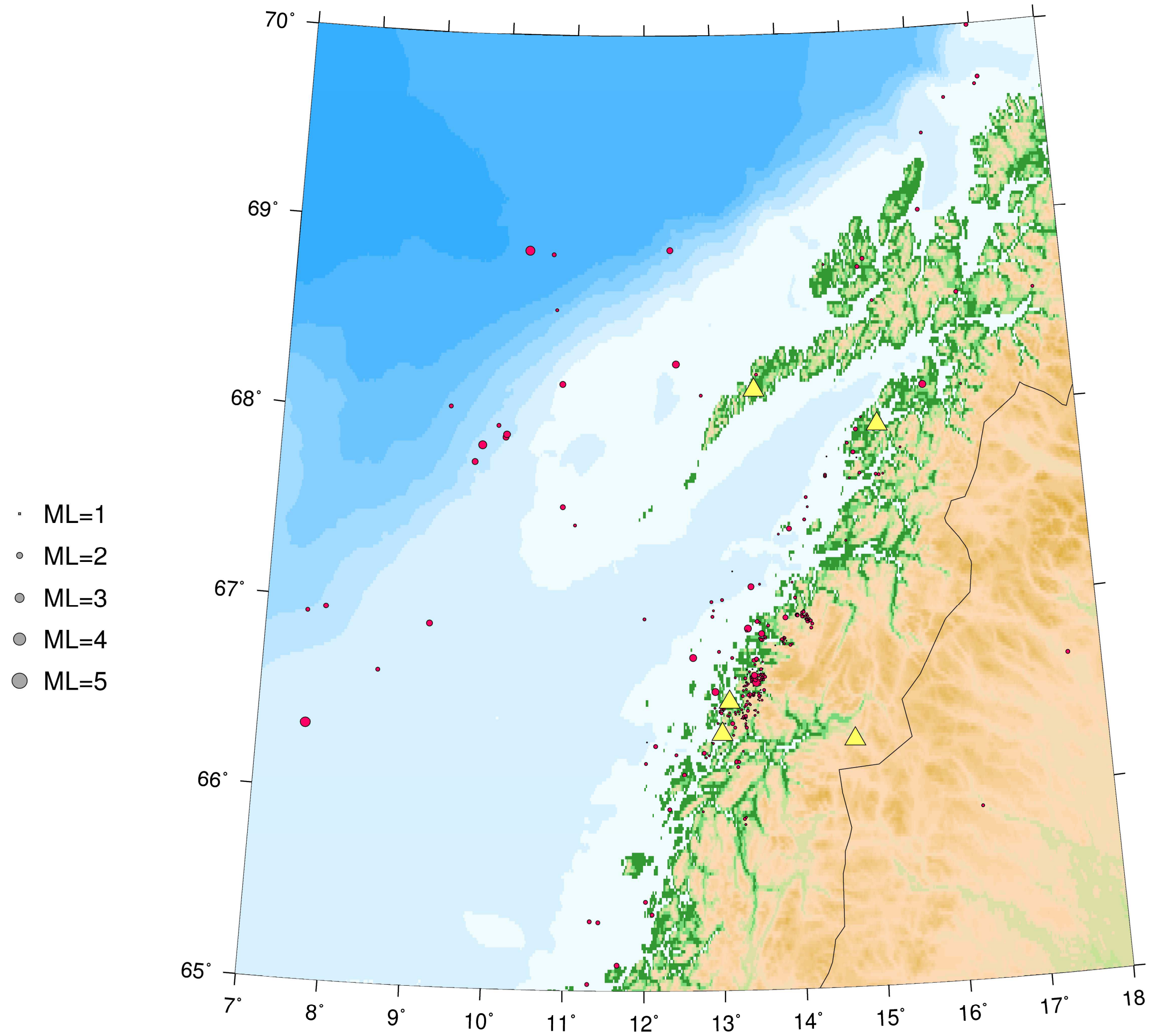


Figure 11. Seismicity in the Nordland area. Red circles show seismicity for 2017 and yellow triangle is NNSN seismic stations. Only probably earthquakes are included.

As seen in Figure 11, the most active area onshore is in Jektvik area (66.6N,13.5E) just west for the Svartisen glacier with 293 located earthquakes during 2017. The earthquake-activity is at the same level as during 2016 (Figure 12) when 295 earthquakes were located to the area.

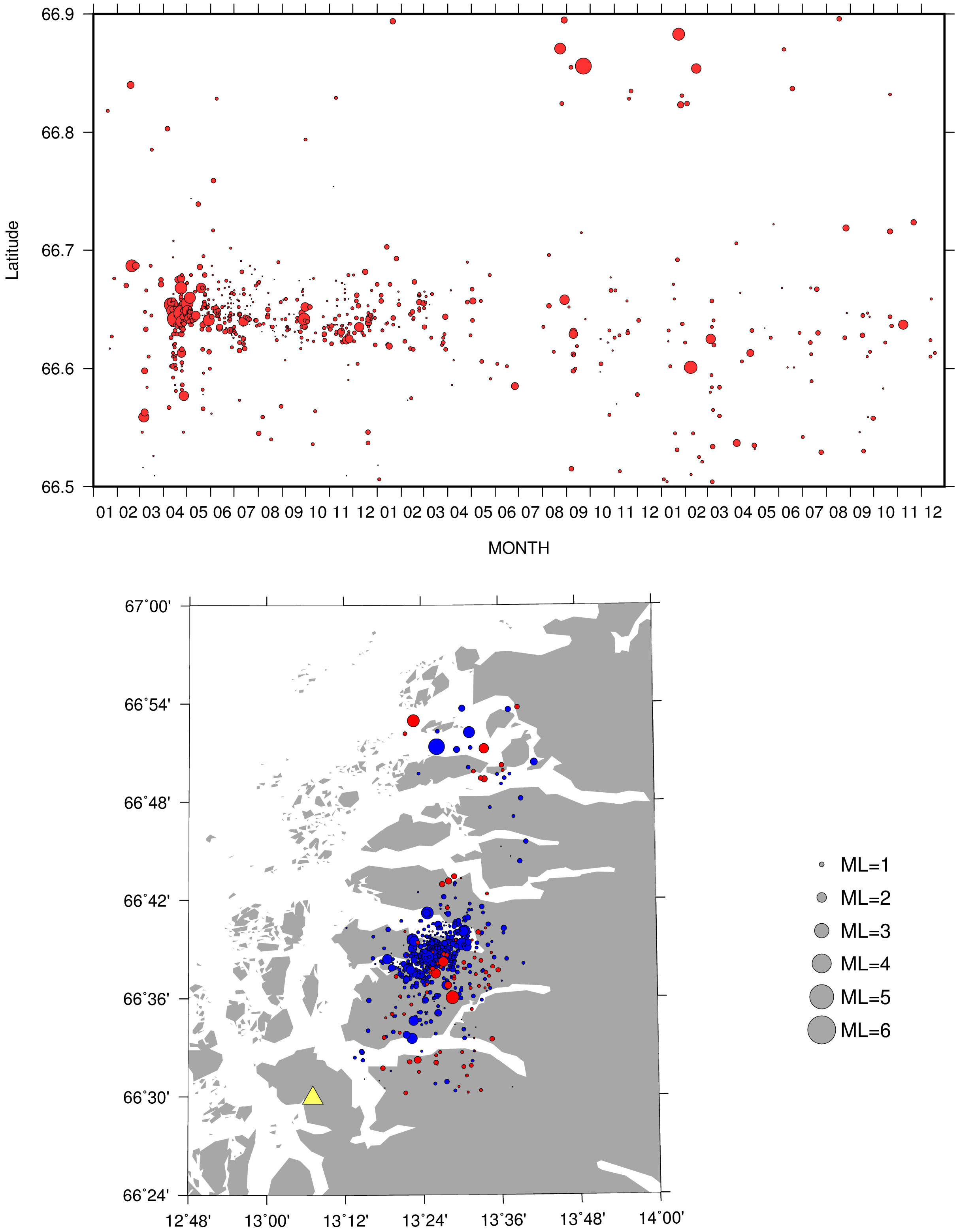


Figure 12 Time distribution (upper) and location (lower) of the earthquake swarm located in the Jektvik area, southwest of the Svartisen glacier. Earthquakes occurring during 2017 are marked in red and earthquakes recorded in 2015 and 2016 are marked in blue. Note! The events shown are limited by 66.5-66.9N and 13.2-13.7E, a smaller area than shown on the map. The location of the permanent NNSN station (KONS) are marked with a yellow triangle on the map.

4.3.2 Seismicity in the Jan Mayen area

Jan Mayen is located in an active tectonic area with two major structures, the Mid Atlantic ridge and the Jan Mayen fracture zone, interacting in the vicinity of the island. Due to both tectonic and magmatic activity in the area, the number of recorded earthquakes is higher than in other areas covered by Norwegian seismic stations. NNSN are operating three of the four seismic stations on the island (see Figure 13). During 2017, a total of 155 earthquakes were located as seen in Figure 13 and of these, 27 had a magnitude equal to or above 3.0. During the fall of 2016 the digitizer used to register data from JNW and JNE started to malfunction. The number of located earthquakes during the start of 2017 in the Jan Mayen area are therefore reduced, as can be seen from the monthly distribution of earthquakes in Figure 13.

The largest earthquake in the Jan Mayen region in 2017 occurred on 21st October at 12:56 (UTC) and the magnitude is estimated to 5.3L(BER), 5.5N(BER) and 5.1L(NAO). The earthquake is located southeast of Jan Mayen along the Jan Mayen Fracture Zone.

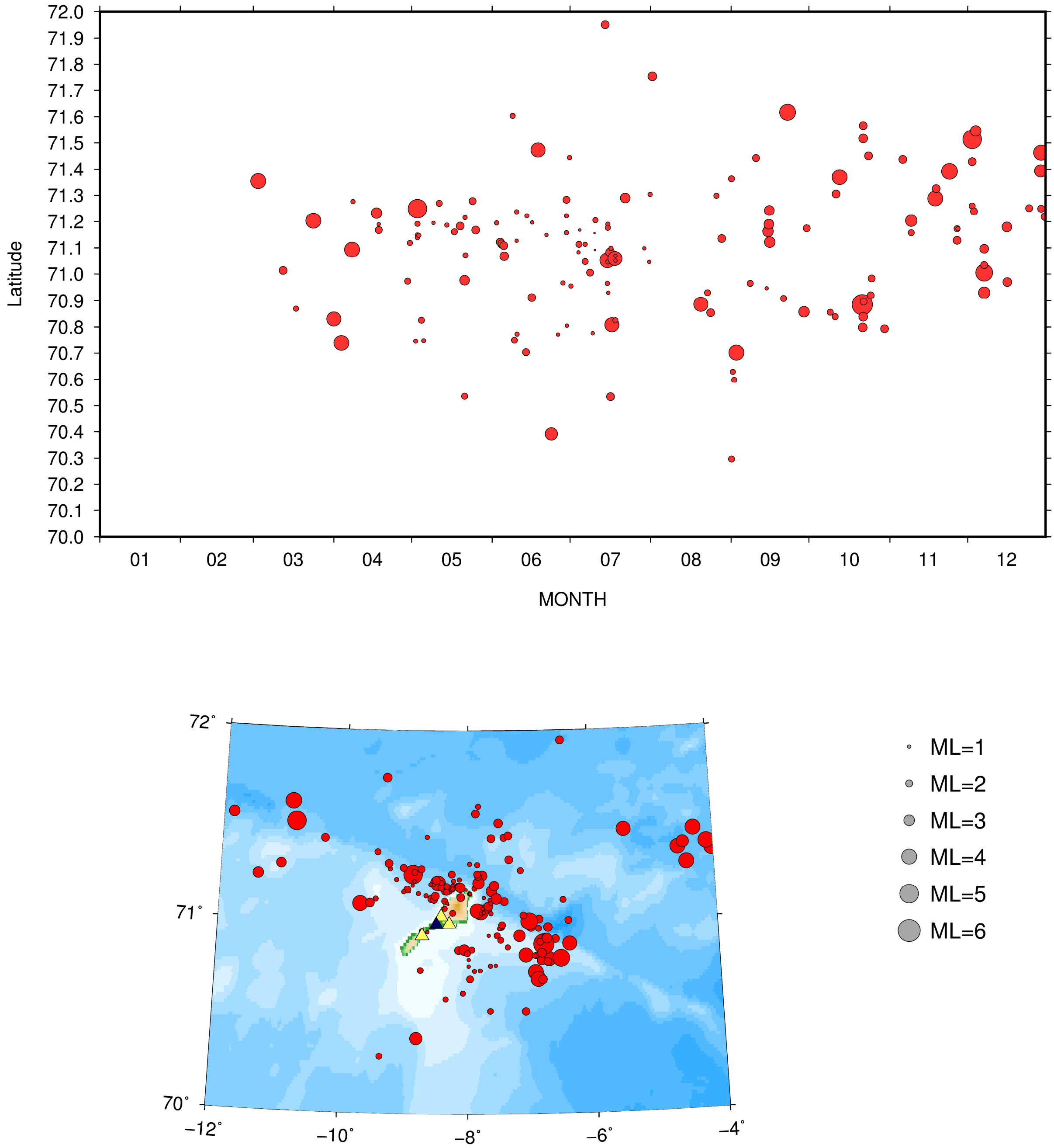


Figure 13. Earthquakes located in the vicinity of Jan Mayen during 2017. The time distribution is shown in the upper part. The reduced seismic activity observed for the first part of 2017 might be due to a malfunctioning digitizer. The seismic stations operated by NNSN are marked with yellow triangles and the seismic station operated by NORSAR is marked in black.

The number of recorded earthquakes in the Jan Mayen area has varied over the last years (Figure 14). The number of relatively strong earthquakes (M≥3) shows smaller time variation than for the smaller earthquakes. The increases in 2004 and 2005 were due to the M=6.0 earthquake in 2004 and its aftershocks (Sørensen et al., 2007). The same is true for 2011, where the M=6.0 earthquake on 29th January was followed by a sequence of aftershocks. The 30th August, 2012 earthquake (M=6.3) with its fore and aftershocks clearly increases the number of recorded events in 2012 compared with previous years, making it the largest number of recorded events yearly for more than 10 years. For the following years after 2012, the number of located smaller earthquakes has increased slightly, while the number of larger (M≥3.0) earthquakes is relative stable. The decrease in located small earthquakes during 2016 and 2017 is caused by the different technical problems (see technical section above).

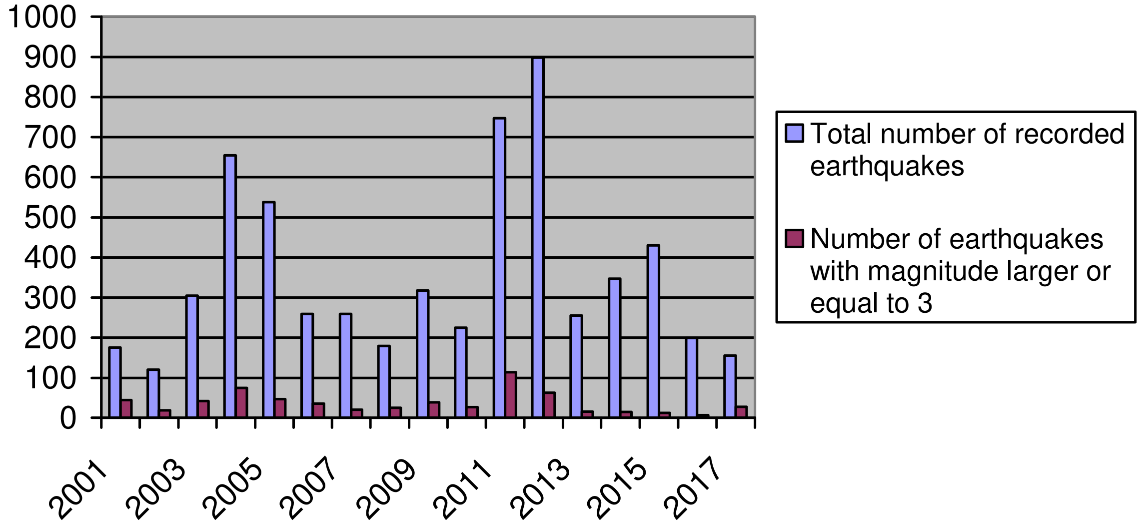
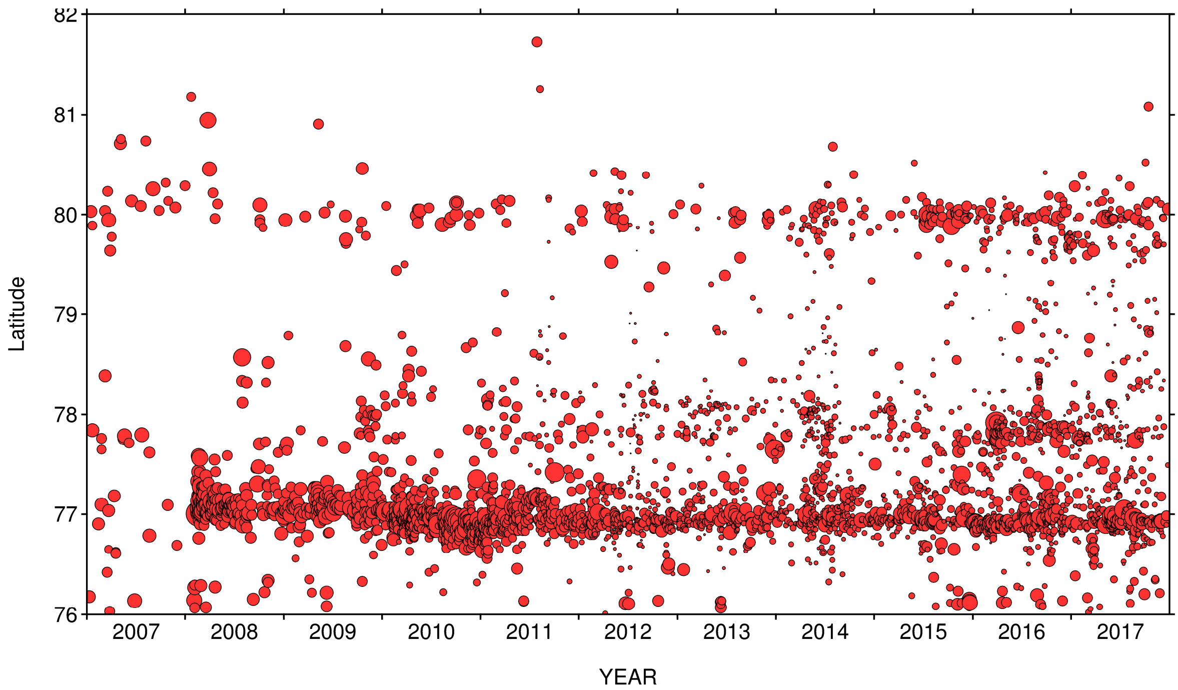


Figure 14. Yearly distribution of earthquakes located in the Jan Mayen area since 2001. The area is as shown in Figure 13.

4.3.3 Seismicity at Svalbard

The seismicity in the Svalbard area is presented in Figure 15, showing both a map with the seismicity since 2007 and the distribution of events over time. There are several seismically active areas in this region. This report will focus on three main areas: the Storfjorden area including Heer Land (on the northwest side of Storfjorden) and Diskobukta (the area west of Egdeøya), Sørkappland (the area at the very southwest coast of Spitsbergen) and Nordaustlandet.



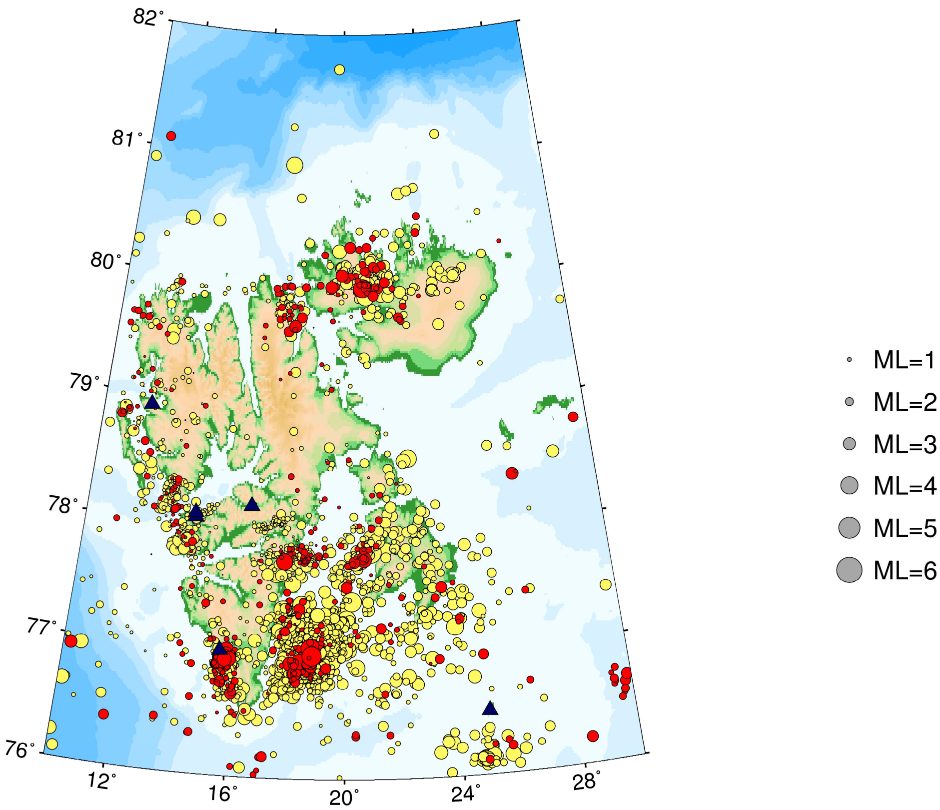


Figure 15. Seismicity in the Svalbard area. Bottom: Earthquakes occurring in 2017 are plotted in red circles. Yellow circles show seismicity for 2007-2016. The blue triangles give the station locations. Top: Seismicity in the same area is plotted as latitude as function of time.

Storfjorden

The Storfjorden area southeast of Svalbard, defined by latitude 76.5-78N and longitude 16-22E, has been more seismically active since the M_w=6.0 earthquake on 21st February 2008. The earthquake was the starting point of a prolonged earthquake sequence. The yearly variation in the number of detected earthquakes in Storfjorden area is shown in Figure 15. An increase in the number of located earthquakes is clearly seen in 2008 explained by the M6 earthquake and its aftershocks.

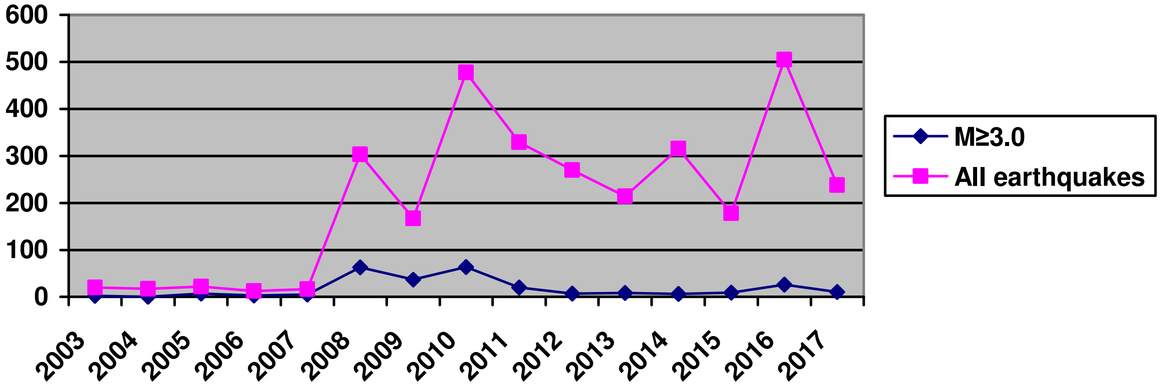


Figure 16. Yearly number of earthquakes located to the Storfjorden area.

The increase in 2010 is mostly explained by an increase in the number of smaller earthquakes as seen by the almost constant levels of earthquakes with M>3.0 since 2008. The better detection was due to usage of the data from the Hornsund (HSPB) and Barentsburg stations, from 2010 and 2012, respectively. There is a clear increase in 2016 related to the activity in both Storfjorden and the Heer Land region. Heer Land has been seen to be active in the past, going back to the 1970s. A total of more than 39 earthquakes with magnitude larger than M=4 have occurred in the area since 2008.

The total number of events located in the Storfjorden area in 2017 was 238, which presents a decrease from 2016 when the corresponding number is 505. Figure 15 shows both a map with the seismicity since 2007 and the distribution of events over time. In Diskobukta (77.6-78.1N, 19.3-22.0E), where the seismic activity was relatively high in 2016, the seismicity has decreased significantly but is still higher than the expected normal level.

The largest earthquake in the Storfjorden area during 2017 occurred December 12th at 15:50(UTC) located 76.985N 18.826E, with a magnitude M_L=4.4 (BER). During 2017 four earthquakes with magnitude above 4.0 occurred in this area where also the major M=6.0 earthquake in 2008 was located.

Sørkappland

At Sørkappland, located at the southwestern coast of Spitsbergen (76.4-77.2N, 14-17E), the earthquake activity has increased the last three years, as can be seen from Figure 17.

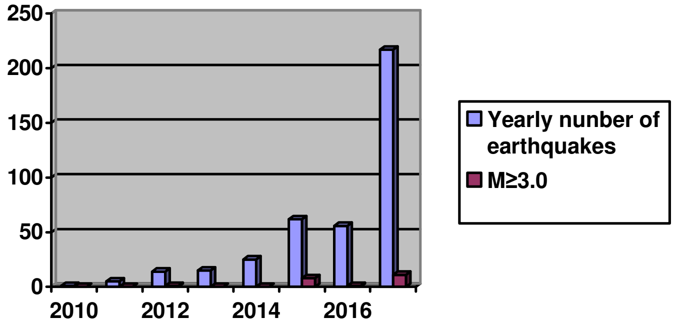


Figure 17. Yearly number of earthquakes recorded in the Sørkappland area.

The earthquakes located the last five years are plotted in Figure 18. Digital data from the seismic station at Hornsund, Svalbard (HSPB) was routinely included in the NNSN data prosessing from November 2009, and increased the number of small located earthquakes. The last years there is an increase in earthquakes located to the area as can be seen on Figure 17. During 2017, 217 earthquakes were located here and 11 had a magnitude above 3.0. The largest occurred May 31st, 2017 at 13:59 (UTC) with magnitude ML(BER)=3.7 and ML(NAO)=4.7. The earthquake was reported felt in Longyearbyen and can be seen on Figure 18 marked in yellow. Smaller earthquakes were recorded both before and after this event. Additional events were seen in the continuous data, which due to their small size and the station coverage were not automatically detected. There is also reasonable uncertainty in the location of the events in this area. Most of the 217 earthquakes recorded in 2017 (red) define a cluster located slightly to the west of the ca 60 earthquakes recorded in 2015 (blue) when the activity in this area were seen for the first time.

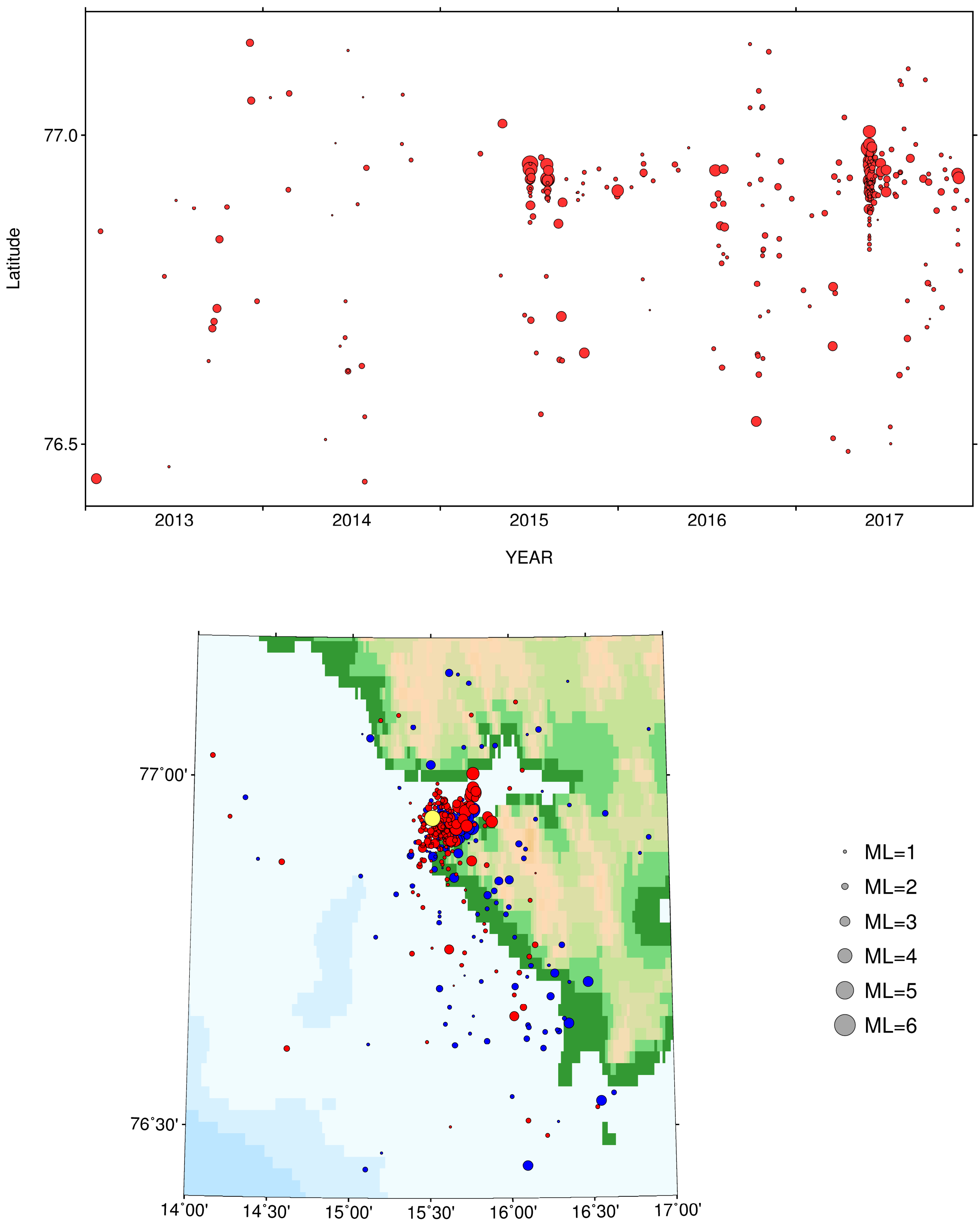
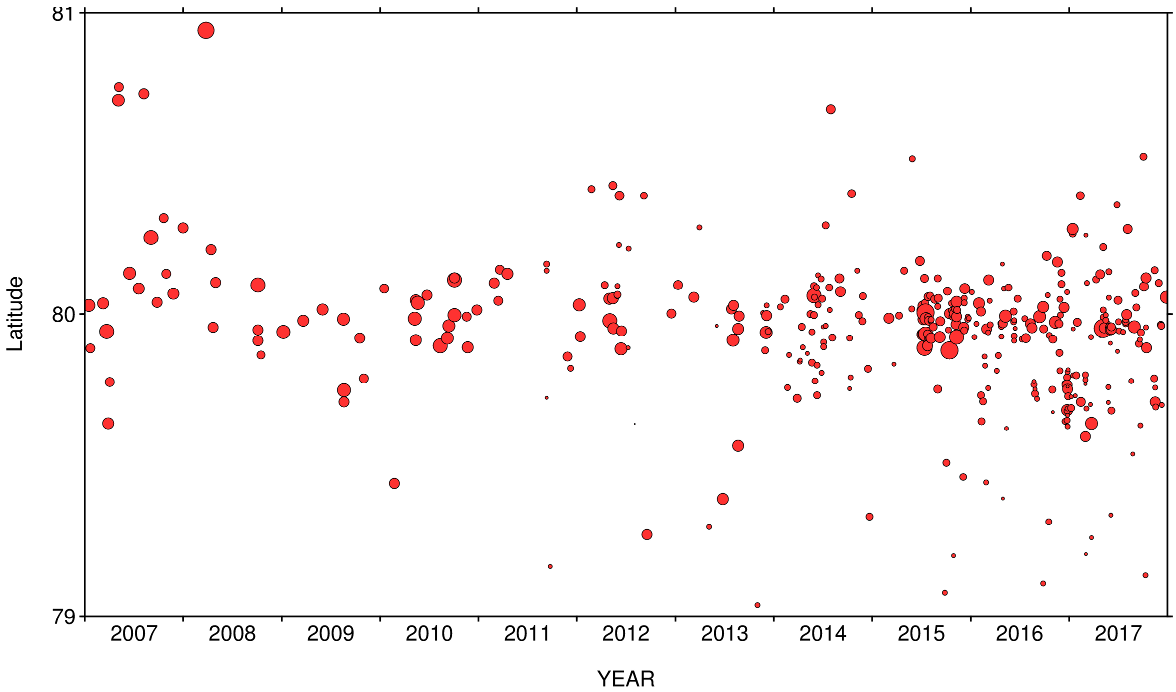


Figure 18. Earthquakes in the NNSN database since 2013. Earthquakes detected 2013-2016 (blue), 2017 (red) and the largest earthquake in 2017 (yellow).

Nordaustlandet

Nordaustlandet is a well-known seismically active area. Earthquakes located since January 2007 are presented in Figure 19. In 2016, an independent small cluster developed to the west of the regular activity, on the western side of the Hinlopenstretet. During 2017, 83 earthquakes were located at Nordaustlandet. The earthquakes are marked in red in Figure 19. As can be seen from the figure the earthquake activity located onshore west of the Hilopenstretet continues.

It should be noted that the location accuracy in this area is rather sensitive to the seismogram interpretation and small changes may change the epicentre by tens of kilometres. However, the separation of this new cluster from the regular pattern is likely to be real.



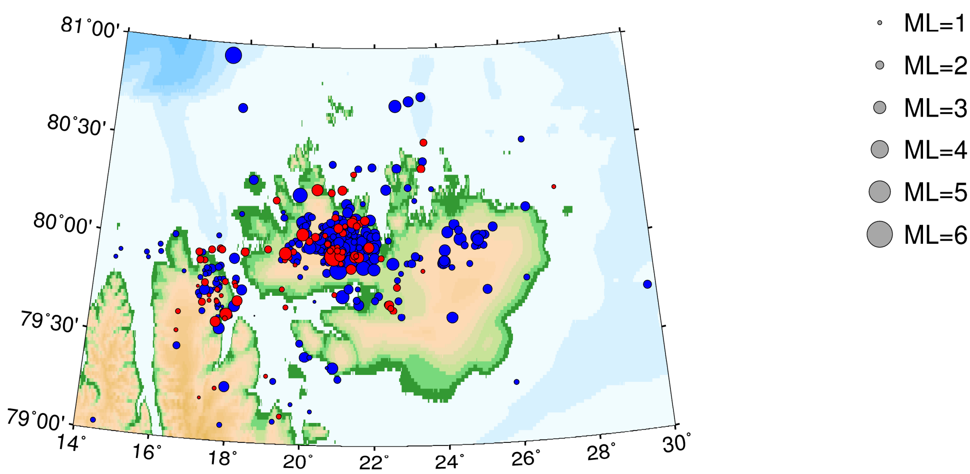


Figure 19. Earthquakes located at Nordaustlandet during 2017 (red) and between 2007-2016 (blue).

4.3.4 Earthquakes in the southern North Sea

The North Sea area is in this report defined by 54-60N and 1W-5E. During 2017, 13 earthquakes were detected and located in the North Sea, Table 10. The earthquake highlighted in yellow is the largest recorded in the area during 2017. The yearly distribution of earthquakes in the area since 2000, is presented in Figure 20. The largest of the events occurred on 30th June with a magnitude of M_L=4.2(BER) and M_L=4.7(BGS). The earthquake was located to 58.996N 1.789E, using data from NNSN, BGS, HEL, UPP, GEUS and NORSAR. The BGS reports that this earthquake is reported felt from the Shetland Islands, the Orkney Islands and Scotland. NNSN received one report from Stavanger and a report from the Sleipner A platform were several people felt this earthquake. At Sleipner A it is described that the earthquake was felt like a when a large wave hits the platform. All earthquakes located to the area since 2007 and their distribution over time, are presented in Figure 21.

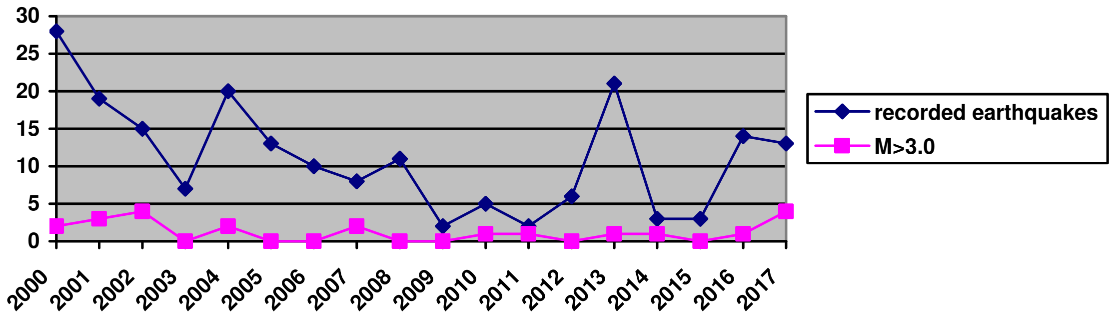
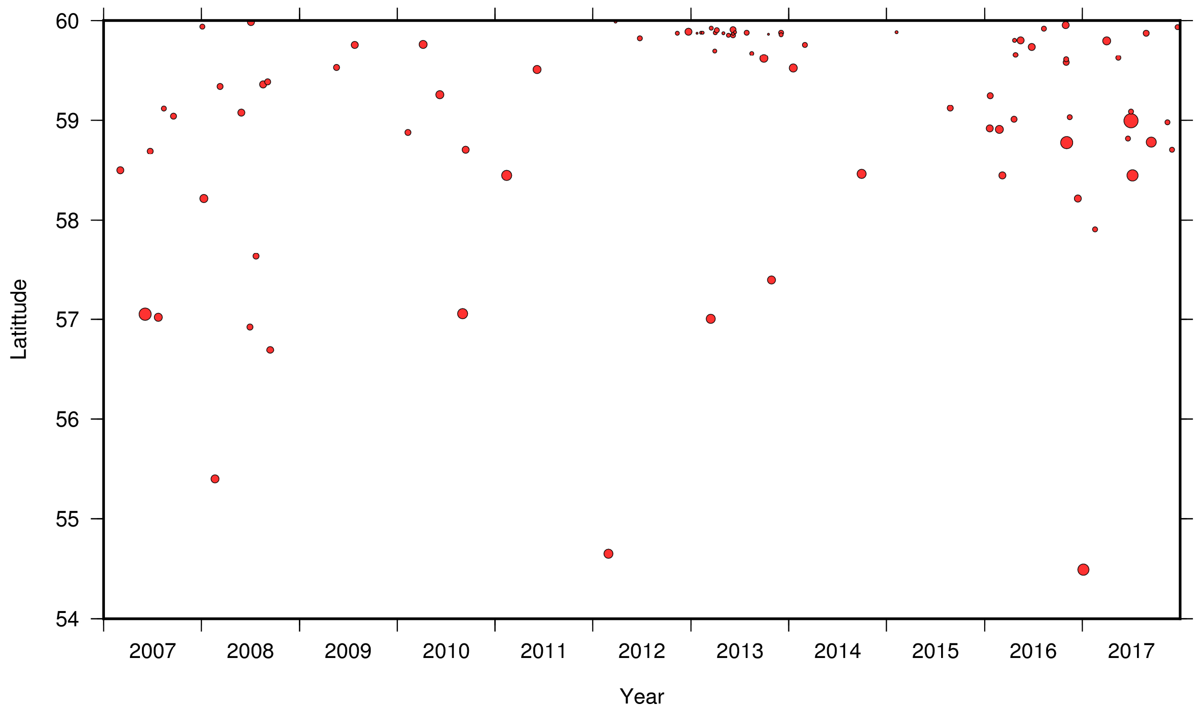


Figure 20. Number of recorded earthquakes in the area 54-60N, 1W-5E.

Table 10. Earthquakes recorded during 2017 and located in the area limited by 54-60N and 1W-5E.

Year	Date	HRMM	Sec	L	Latitud	Longitud	Depth	AGA	NST	RMS	ML BER	ML NAO	ML BGS	MW BER
2017	1 3	1852	24.3	L	54.494	1.979	15.0	BER	36	0.7	3.0	2.9	3.8	
2017	215	2028	30.3	L	57.908	1.813	16.7	BER	15	0.5	1.8			
2017	331	2224	45.7	L	59.798	1.759	20.6	BER	30	0.7	1.9	2.0	2.4	2.8
2017	513	1806	41.2	L	59.622	1.657	15.0	BER	15	1.0	1.8			
2017	618	1341	10.1	L	58.817	1.280	15.3	BER	22	0.5	1.6			
2017	630	1333	45.5	L	58.996	1.789	4.5	BER	90	0.7	4.2	4.5	4.7	
2017	7 1	0812	17.6	L	59.087	1.553	21.0	BER	17	0.5	1.6			
2017	7 7	0142	42.6	L	58.445	1.549	15.0	BER	67	0.6	3.1	3.1	3.6	
2017	826	2347	40.1	L	59.874	2.346	10.0	BER	18	0.8	1.6		2.0	
2017	914	0814	45.7	L	58.782	1.576	15.0	BER	48	0.7	2.8	2.3	3.3	
2017	1114	0714	51.0	L	58.980	1.770	22.4	BER	11	0.6	1.6			
2017	1130	2010	10.7	L	58.705	1.487	27.4	BER	22	0.5	1.8			
2017	1222	0521	51.4	L	59.932	4.878	12.1	BER	17	0.5	1.7		1.5	



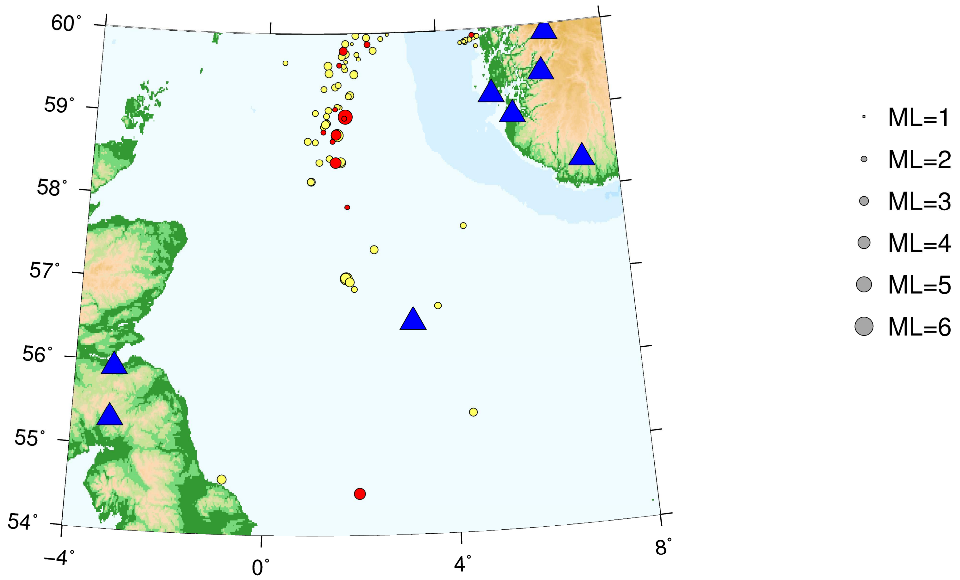


Figure 21. Time distribution (upper) and location (lower) of the earthquake located within 54-60N and 1W-5E in the southern North Sea (Note that the map is larger than the area used for selection of earthquakes). Earthquakes recorded during 2017 are marked in red, while earthquakes from 2007-2016 are yellow. Seismic stations are marked with blue triangles.

4.3.5 Felt earthquakes

In total, 29 earthquakes were reported felt and located within the target area during 2017 (see Table 11 and Figure 22). For the Jan Mayen Island and the area southwest of the Svartisen glacier, the number of felt earthquakes is expected to be larger than reported.

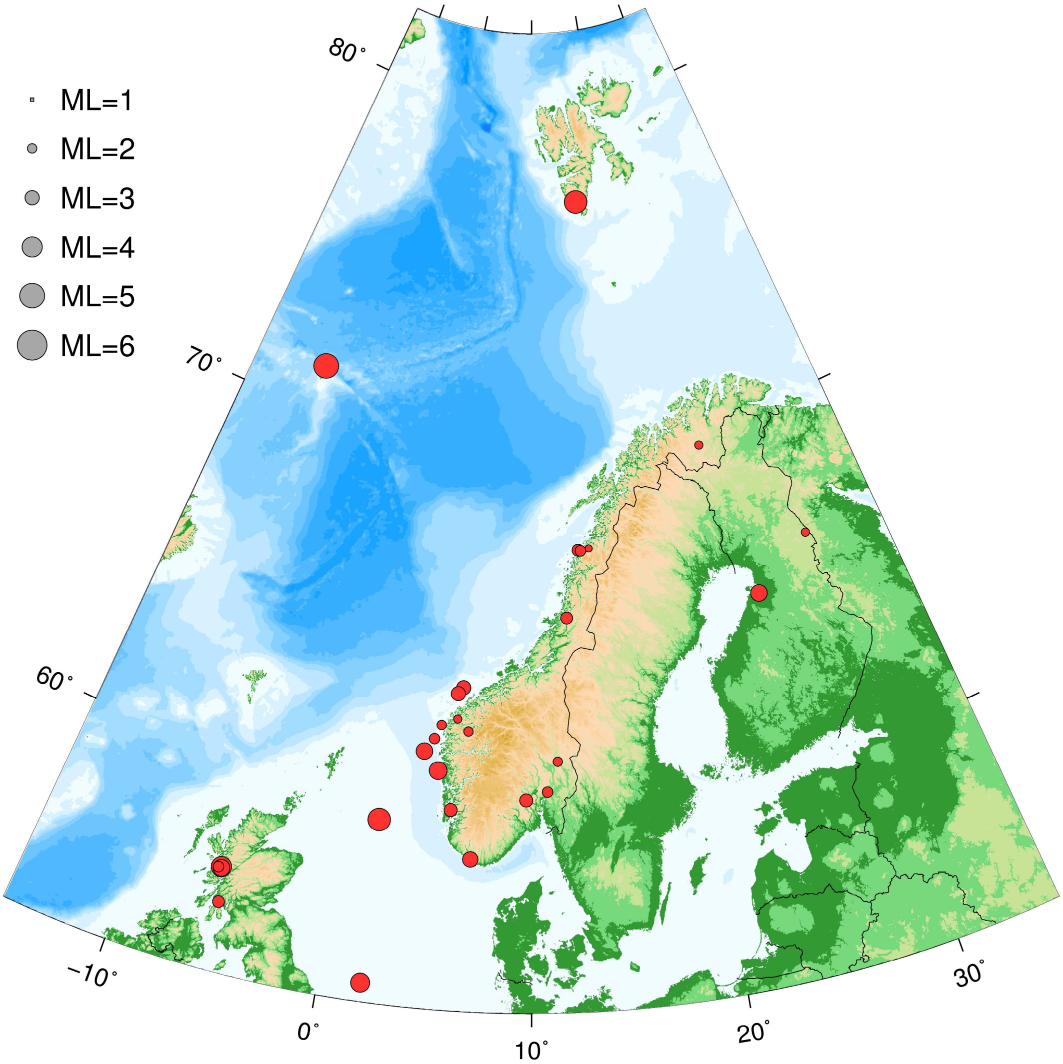


Figure 22. Location of the 28 earthquakes reported felt during 2017 within the target area.

Large felt earthquakes are mostly reported to UiB shortly after the origin time, and location information and questionnaires are available for the public on the site www.skjelv.no. Smaller felt earthquakes may be reported by the public to local newspapers or other institutions and then reported to UiB. Depending on the time-delay for these reports to be available at UiB, the information on the web might be accordingly delayed. For any felt earthquake the public has to be made aware of the questionnaire, which is done by informing on web and when UiB is contacted by media, private persons or other institutions. Earthquakes large enough to be felt and occurring in heavily populated areas increases the number of people using the web reporting the intensities.

Table 11. Earthquakes reported felt in the BER database in 2017. Abbreviations are: M_L = local magnitude and M_w = moment magnitude, W: questionnaires received on web (Yes/No/Mail). The largest felt earthquakes are marked in red and earthquakes located in the North Sea are marked in yellow. Earthquakes marked in blue are located in Great Britain or Finland.

Nr	Date	Time (UTC)	Max. Intensity (MMI)	Magnitude (BER)	Instrumental epicentre location	W
1	03.01.17	1:52		M_L=3.0, M_L=3.8(BGS)	54.49N / 1.98E	-
2	05.01.17	07:24	IV	M_L=2.3, M_L=2.4(UPP)	64.95N / 12.36E	N
3	23.01.17	03:22	III	M_L=1.6, M_W=1.9, M_L=2.5(NAO)	66.88N / 13.38E	N
4	01.02.17	23:22	III	M_L=2.0, M_L=2.0(NAO)	60.91N / 11.50E	Y
5	14.02.17	14:43	III	M_L=1.6, M_W=2.1, M_L=2.1(NAO)	66.85N / 13.56E	N
6	27.02.17	01:58	III	M_L=1.4	66.91N / 14.18E	N
7	29.04.17	22:58	IV	M_L=3.1, M_L=2.9(NAO)	58.15N / 6.79E	Y
8	03.05.17	05:08	V	M_L=4.7, M_N=5.2, M_W=4.1, M_L=5.0(NAO)	71.25N / 8.89W	Y
9	03.05.17	20.56	III	M_L=2.0, M_W=2.1, M_L=1.7(NAO)	61.43N / 4.31E	N
10	15.05.17	03:49	III	M_L=1.9, M_L=1.9(NAO)	61.84N / 4.64E	N
11	31.05.17	13:59	IV	M_L=3.7, M_L= 4.7(NAO)	76.98N / 15.77E	Y
12	25.06.17	11:55	IV	M_L=2.6, M_L=2.7(NAO)	59.49N / 5.57E	Y
13	30.06.17	13:33	IV	M_L=4.2, M_L=4.7(BGS)	58.99N / 1.79E	Y
14	01.08.17	12:04		M_L=1.6, M_L= 1.7(HEL)	66.07N / 29.67E	-
15	02.08.17	02:15	V	M_L=3.0, M_L=3.3(NAO)	61.06N / 3.80E	Y
16	04.08.17	14:43		M_L=3.5, M_L=4.0(BGS)	56.82N / 5.73W	-
17	04.08.17	14:45		M_L=3.4(BGS)	56.80N / 5.70W	-
18	04.08.17	17:35		M_L=2.1, M_L=2.2(BGS)	56.80N / 5.87W	-
19	07.08.17	07:59	IV	M_L=2.6, M_W=2.8, M_L=2.6(NAO)	62.94N / 5.78E	M
20	25.09.17	19:07	III	M_L=1.7, M_L=1.9(NAO)	61.71N / 6.25E	Y
21	01.10.17	10:04	V	M_L=1.7, M_L=1.5(NAO)	62.03N / 5.85E	Y
22	12.10.17	07:05	III	M_L=1.4, M_L=1.8(NAO)	69.36N / 23.84E	M
23	29.10.17	01:07	IV	M_L=2.2, M_L=2.2(NAO)	60.07N / 10.91E	Y
24	01.11.17	20:59		M_L=2.5, M_L=2.5(BGS)	55.88N / 5.39W	-
25	07.11.17	08:46	V	M_L=3.6, M_W=3.7, M_L=3.7(BGS)	60.54N / 4.70E	Y
26	08.11.17	18:52	IV	M_L=3.0, M_L=2.9(NAO), M_L=3.8(BGS)	54.49N/ 1.97E	Y
27	22.11.17	09:09	IV	M_L=2.5, M_W=2.6, M_L=2.6(NAO)	59.84N / 9.71E	Y
28	07.12.17	22:32		M_L=2.8, M_L=3.3(HEL)	64.82N / 25.39E	-
29	13.12.17	18:17	III	M_L=2.9, M_L=2.9(NAO)	62.75N / 5.48E	Y

The largest felt earthquake during 2017 occurred on 3rd May at 05:08 (UTC time). The earthquake is located north of Jan Mayen and was reported felt with intensity V at the island.

The largest felt earthquake close to the Norwegian mainland occurred 7th October and was located slightly northwest of Bergen. The earthquake was reported felt from most of western

Norway and more than 900 questionnaires were submitted to UiB. A map showing the intensities reported is shown in Figure 23.

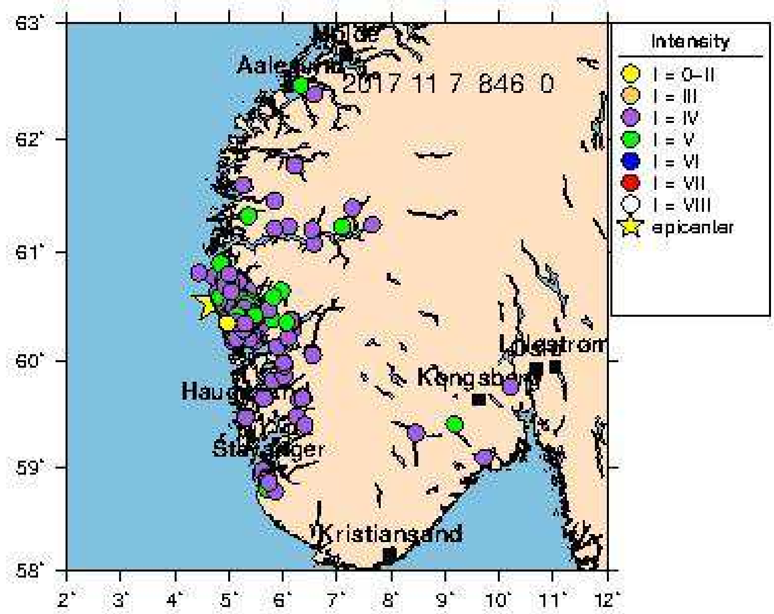


Figure 23 Intensities reported from the earthquake 7th November 2017. More than 900 intensities are plotted. The instrumantal location is marknad with a yellow star.

5 Scientific studies

This section gives an overview of research work that is carried out under the NNSN project in 2017. The main objective of this work is to improve the understanding of earthquakes and the seismological models in the region, mostly by using data recorded by the NNSN. Results will be used to improve the NNSN monitoring service.

5.1 The new mb(Pn) magnitude

(by W.Y. Kim and L. Ottemöller)

A new magnitude scale mb(pn) and has been developed to better estimate magnitude of earthquakes in the North Atlantic region from Pn phase amplitudes (Kim and Ottemöller, 2017). An additional scale for Sn is currently being developed and results shown here are based on the mb(sn) scale. The reason for developing the scales for Pn and Sn was that the standard ML scale for Norway (Alsaker et al., 1991) was developed for Lg waves that are the dominant seismic phase across the continental areas of Norway. However, Lg does not propagate in the oceanic crust and standard amplitude measurements were done on Sn waves. Calculating ML from these amplitudes is not correct as attenuation of Pn/Sn differs from Lg. Here, we compare event magnitudes computed with the mb(sn) and Lg scales (Figure 24). It is seen that ML is underestimated by 1.44 magnitude units on average (Figure 25). The computation of mb(pn/sn) has been integrated into the processing package and has been applied since the start of 2018. The earthquake catalogue will also be updated to include the new magnitudes that will overwrite previous ML values.

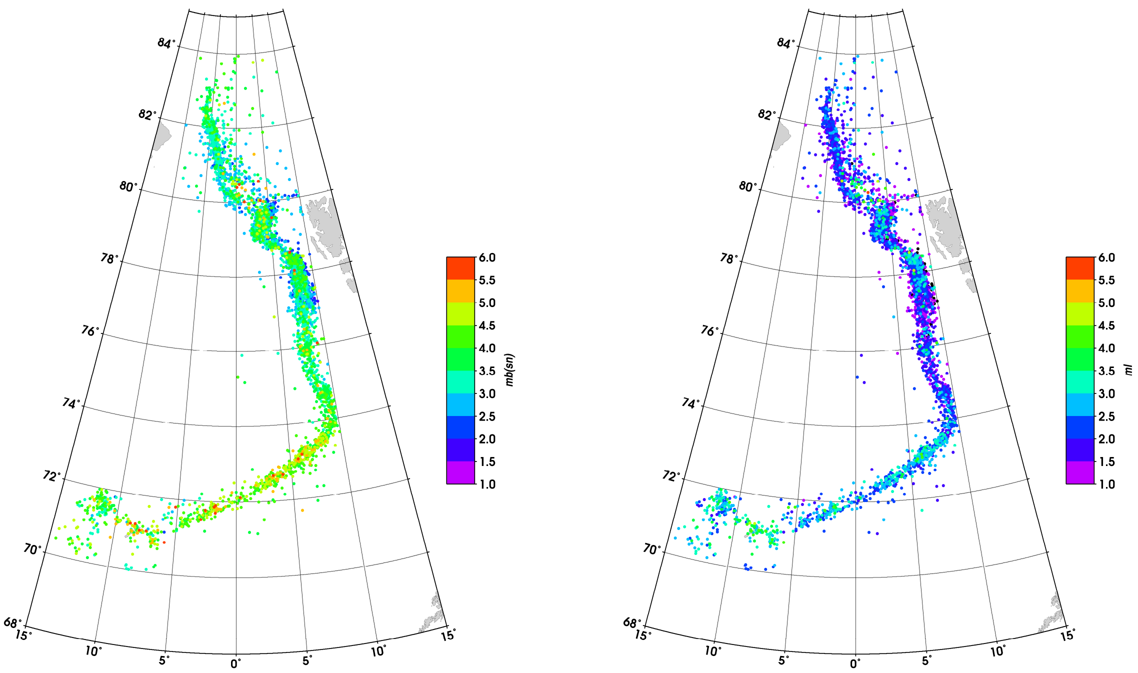


Figure 24. Comparison of magnitudes for events between 1990 and 2017 in the North Atlantic. The map on the left shows the mb(sn) magnitude while the map on the right shows ML results that have been the default in the catalogue until now.

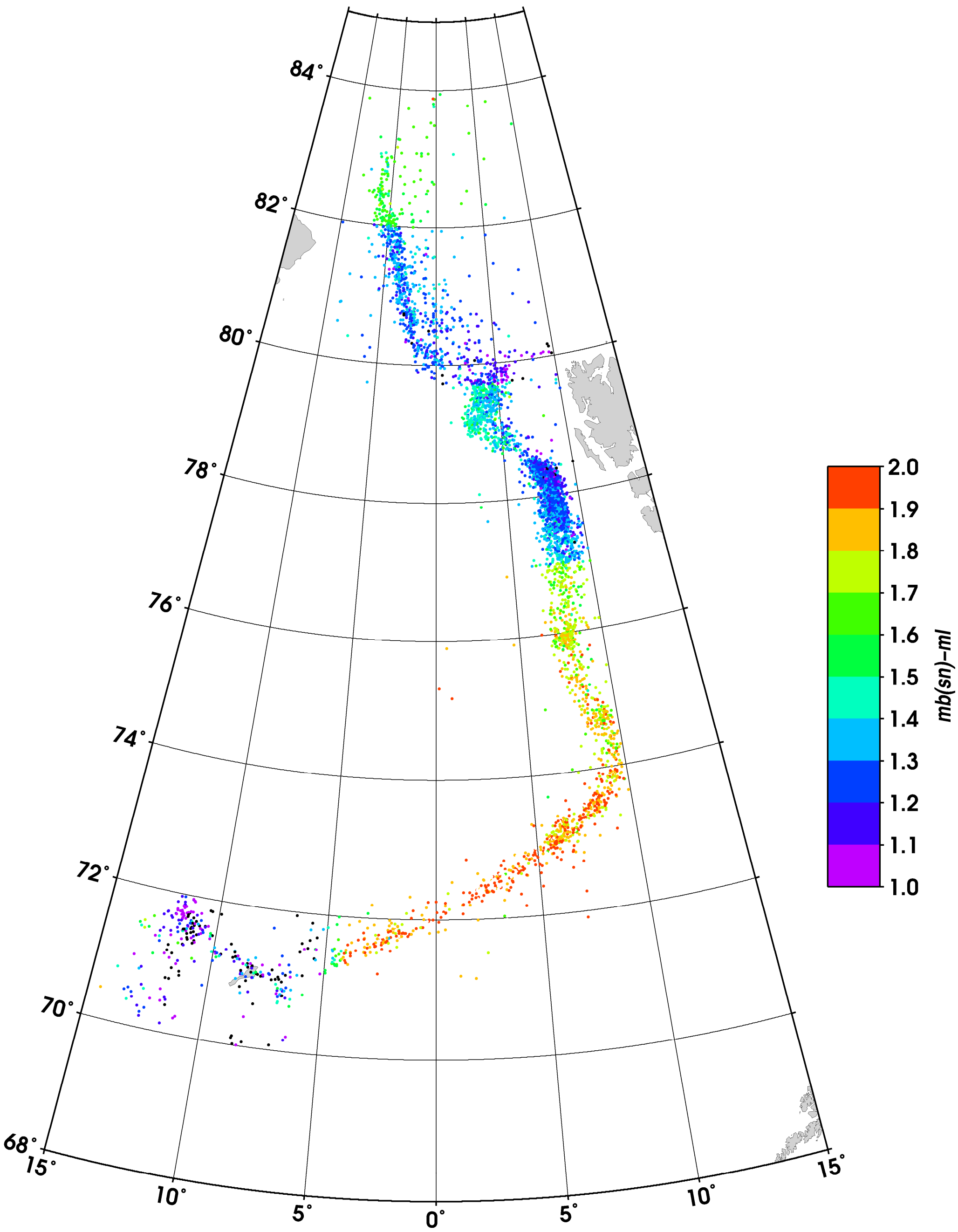


Figure 25. This map gives the difference mb(sn)-ml to show the increase in computed magnitude. On average mb(sn) values are 1.44 magnitude units larger.

5.2 Attenuation tomography

(by Andrea Demuth, Henk Keers and Lars Ottemöller)

The current attenuation model used at regional scale for Norway was developed by Kvamme et al. (1995). With the additional data recorded since then, we wanted to see if more detailed lateral variations can be found when applying a tomographic inversion. Amplitudes are measured on vertical component displacement spectra and amplitudes are averaged over narrow frequency bands. A total of about 2000 travel paths in the distance range 150-1500 km were used to compute tomographic Q images for a range of frequencies. Figure 26 gives the result for a frequency of 3 Hz. The main features that are resolved are the relatively higher attenuation offshore northwestern Norway and in the North Sea. Smaller lateral features are not resolved. The result for the North Sea matches previous studies on the Lg blockage in the area likely due to sudden changes in the crustal structure. In northern Norway, the higher attenuation compared to the mainland can be explained by changes either in structure or the thick sedimentary offshore basins. Apart from the tomographic results, a relationship for the average frequency dependant Q of Lg waves has been developed. The new relation $Q(f)= 434 f^{0.54}$ compares to $Q(f)=440 f^{0.70}$ by Kvamme et al. (1995).

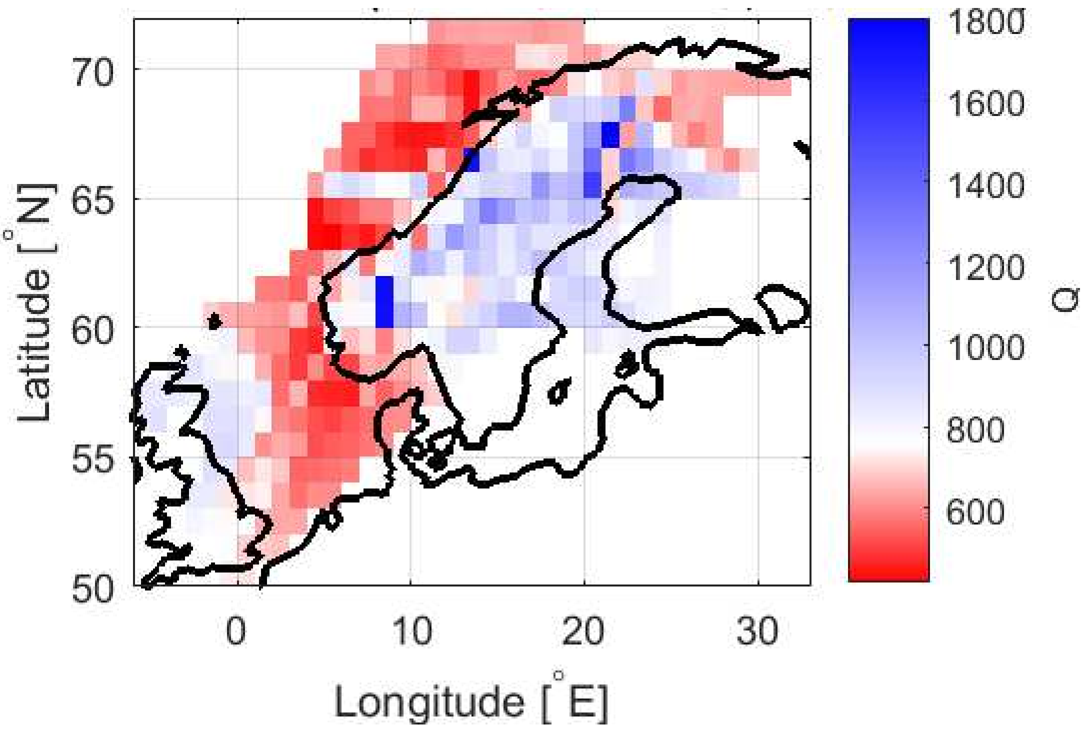


Figure 26. Result of QLg tomography for 3 Hz.

5.3 Location of the 30 June 2017 North Sea earthquake

(by A.E. Jerkins, T. Kværna, J. Schweitzer and S. J. Gibbons)

On 30 June 2017 at 13.33 UTC a magnitude 4.5 earthquake occurred in the Viking graben of the North Sea. When recorded, the event was the largest in the area for several decades, and was reported felt in North-East Scotland, Fair Isle, Orkney, Norway and on the Shetland Islands. Instrumentally, the earthquake was observed with high signal-to-noise ratios at stations of the Norwegian National Seismic Network (NNSN) and British Geological Survey (BGS). Since there are several offshore platforms related to oil and gas production in the area, an accurate location and depth estimate of this event is important for risk assessment related to production.

Different from most other events in the North Sea, this moderate size event has been recorded by stations at both regional and teleseismic distances. Using observed depth phases at teleseismic distances, can potentially help constrain event depth, which usually has the largest uncertainties in the location procedures. For this earthquake, depth phases were observed at several stations, with a wide azimuthal distribution. We located the event using different methods: The HYPOSAT algorithm, a grid search algorithm using the LLNL-3D velocity model and a grid search using the global ak135 1D velocity model. For calculation of more accurate pP and sP travel times, the HYPOSAT algorithm was extended to accommodate the use of local velocity models for the source region, combined with global models (as ak135). In the HYPOSAT algorithm we included P, S and depth phases (at various distances and azimuths) and tested three different local and regional 1D velocity models. The local model most representative for the source region included local low velocity sedimentary layers. This resulted in a depth estimate of approximately 4 km.

Secondly, the event was located using a standard 3D grid search with the LLNL-3D and ak135 velocity models. Two grid searches were done for each velocity model, one which included only teleseismic P-phases and one which included these same phases as well as depth phases. Vertical sections from the grid searches done using the ak135 velocity model are shown in Figure 27. The different colors represent residuals, while the red stars represent the grid points with the lowest residuals, which are also the estimated hypocenters. The grid search performed only using P-phases, gave an unconstrained hypocenter at the surface. Including depth phases on the other hand improved the resolution in depth significantly and resulted in an event depth of 15 km. Similar searches were done for the LLNL-3D velocity model, excluding and including depth phases resulted in depths of 3.5km and 8.5km respectively.

We put by far the most confidence in the depth estimate provided by HYPOSAT which in this case used of a local velocity model around the source area which included low velocity sedimentary layers. The depth estimate is strongly dependent on the model propagation velocities between the hypocenter and the surface reflection point of the depth phase. As neither of the ak135 and LLNL-3D models include sedimentary layers for the source region, as are known to be found in the North Sea area, we expect both the ak135 and LLNL-3D depth estimates to be largely overestimated.

Figure 28 shows the positions of the different earthquake locations with respect to each other in the North Sea. The red, yellow, purple and green dots represent the estimated locations from the grid search which included depth phases for the LLNL-3D and ak135 velocity models, the event location from the NNSN bulletin and the location from the HYPOSAT algorithm which included the local velocity model with sedimentary layers. In addition, contours of existing oil fields in the area as given by the Norwegian Petroleum Directorate (NPD) FactGlobe has been included on the map. None of the estimated event locations coincide with the areas of the existing oil fields. The event is therefore reckoned to be natural and has most likely not disturbed any of the oil activity in the area.

From this study it is concluded that depth estimation is challenging. The estimation strongly depends on choice of method, velocity models and phases used for locating the event. However, we reckon that the HYPOSAT algorithm which includes a local model provides the best solution, since this estimation includes the velocity model that best represents the source region.

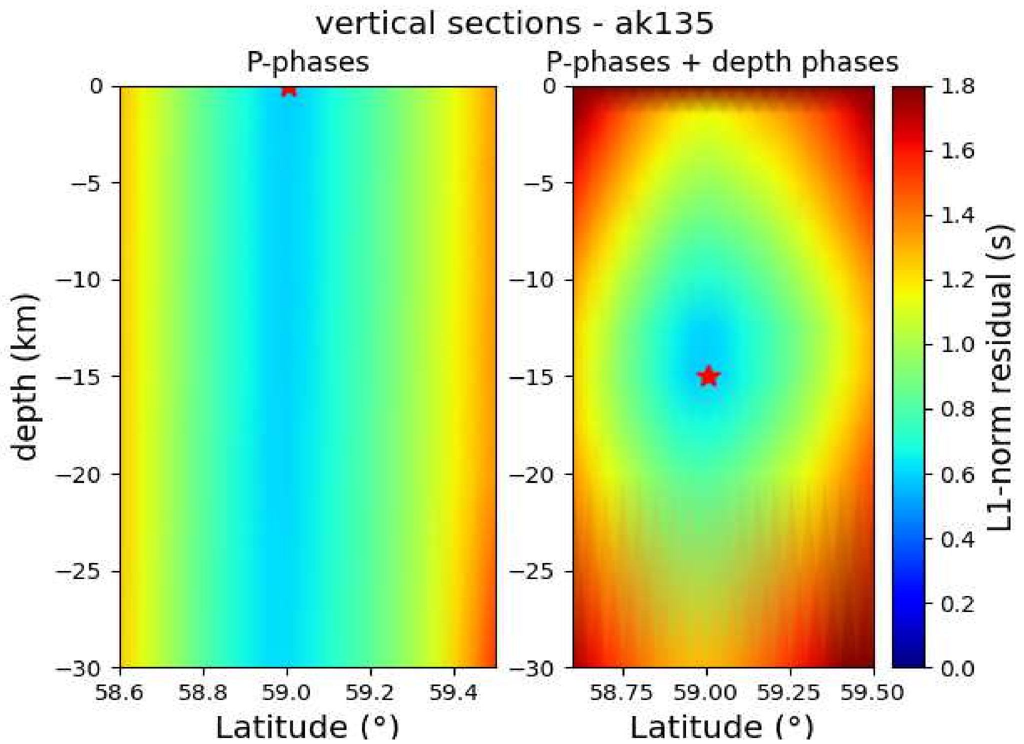


Figure 27 Vertical sections from the two grid searches performed using the ak135 global velocity model to estimate the predicted travel times. The vertical section on the left shows the results from the search which only included teleseismic P-phases, while the section on the right shows the search which included both P and depth phases. The different colors represent L1-norm residuals. Latitude is shown on the horizontal axis and depth is displayed on the vertical axis. The red stars represent the estimated hypocenters. The vertical section on the left shows that only including teleseismic P-phases give no resolution in depth. Including depth phases improves the depth resolution significantly, which clearly can be seen from the vertical section on the right.

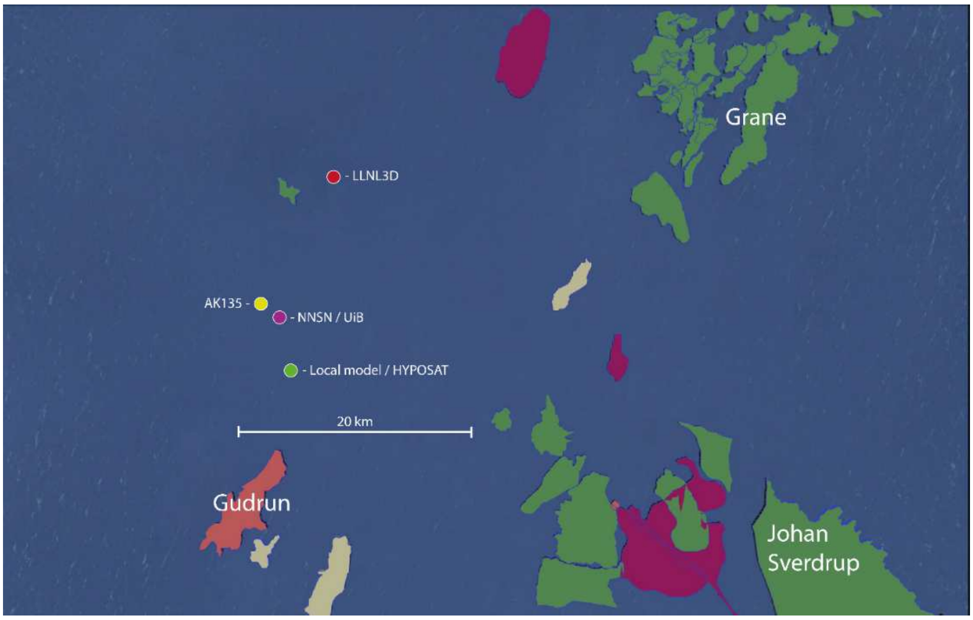


Figure 28. Earthquake locations and surrounding oil fields in the North Sea. The red, yellow, purple and green dots represent the earthquake locations of the LLNL-3D grid search which included depth phases, the ak135 grid search which included depth phases, the solution from the NNSN bulletin and the location from the HYPOSAT algorithm respectively. In addition, the contours of oil fields in the area are included. None of the estimated locations fall within the areas of existing oilfields

5.4 Identification of explosions

(by Marte Louise Strømme, Berit Marie Storheim and Lars Ottemöller)

A large part of the seismic events recorded by the NSNN are explosions and previous efforts were made to automatically discriminate between explosions and earthquakes based on Kortstrom et al. (2016). A useful tool in the identification process is to look at the spectral signal content. Therefore, spectrograms were implemented into the processing package and are used in the daily operation.

Different types of explosions are commonly detected by the NNSN. Larger industrial explosions are often ripple fired, meaning that explosives are fired in a series with some time delay to spread the energy over time. The time delay causes waves at certain frequencies to interfere constructively or destructively, seen as horizontal bands in the spectrograms (Figure 29). For single charge explosions, like larger chemical explosions or mine detonations on land and at sea, the energy is more evenly distributed. The frequencies are generally lower than for an earthquake, with gradually lower frequencies towards the s-coda (Figure 30). Earthquakes often have clear P- and S-wave onsets, and gradually higher frequencies towards the s-coda (Figure 31).

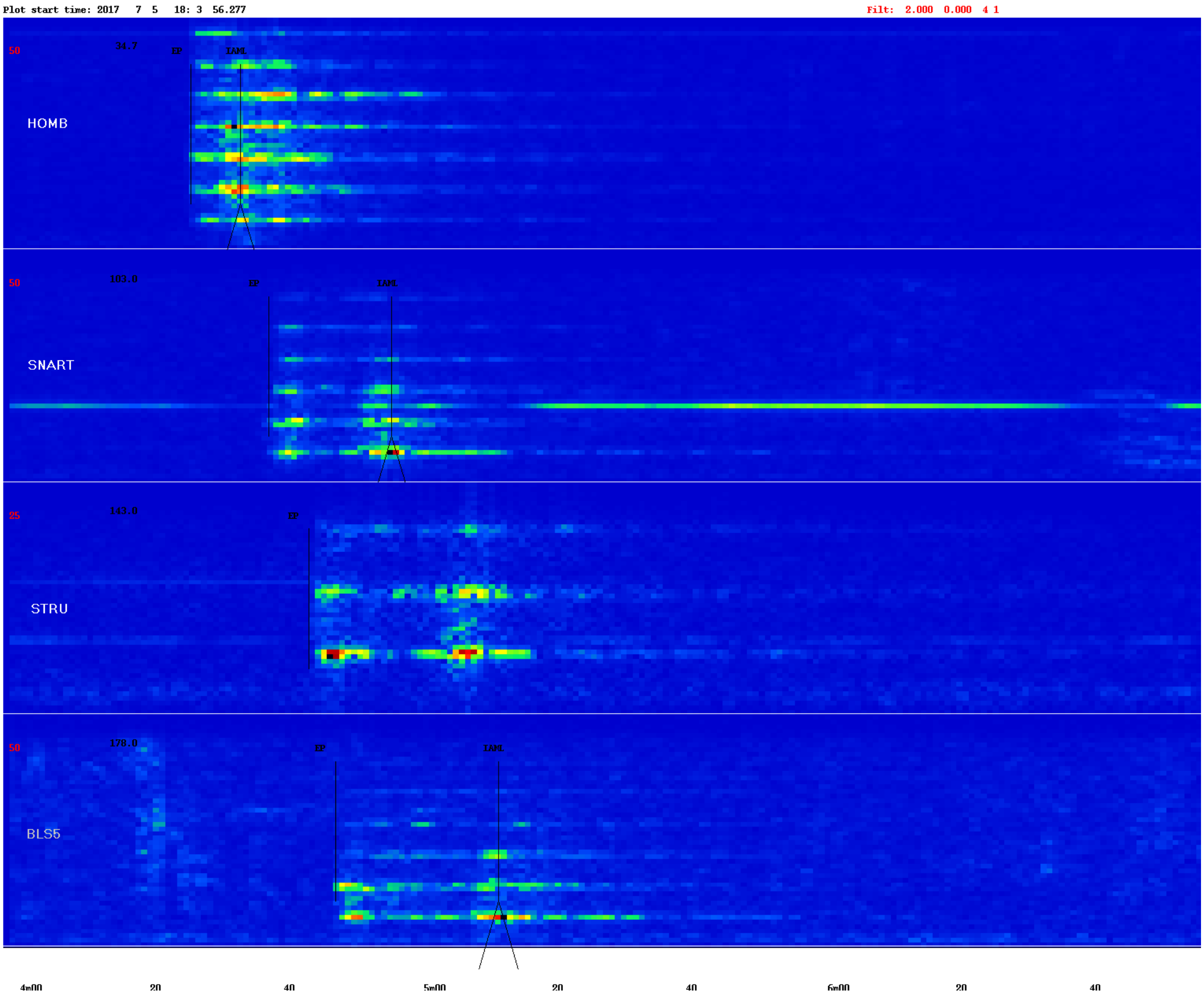


Figure 29 Spectrograms for a ripple fired explosion in a quarry near Homborsund, Aust Agder. Stations are, from top, Homborsund (HOMB), Snartemo (SNART), the station Strømstad (STRU) from the Swedish National Seismic network and Blåsjø (BLS5). Approximately duration of plot is 180 sec.

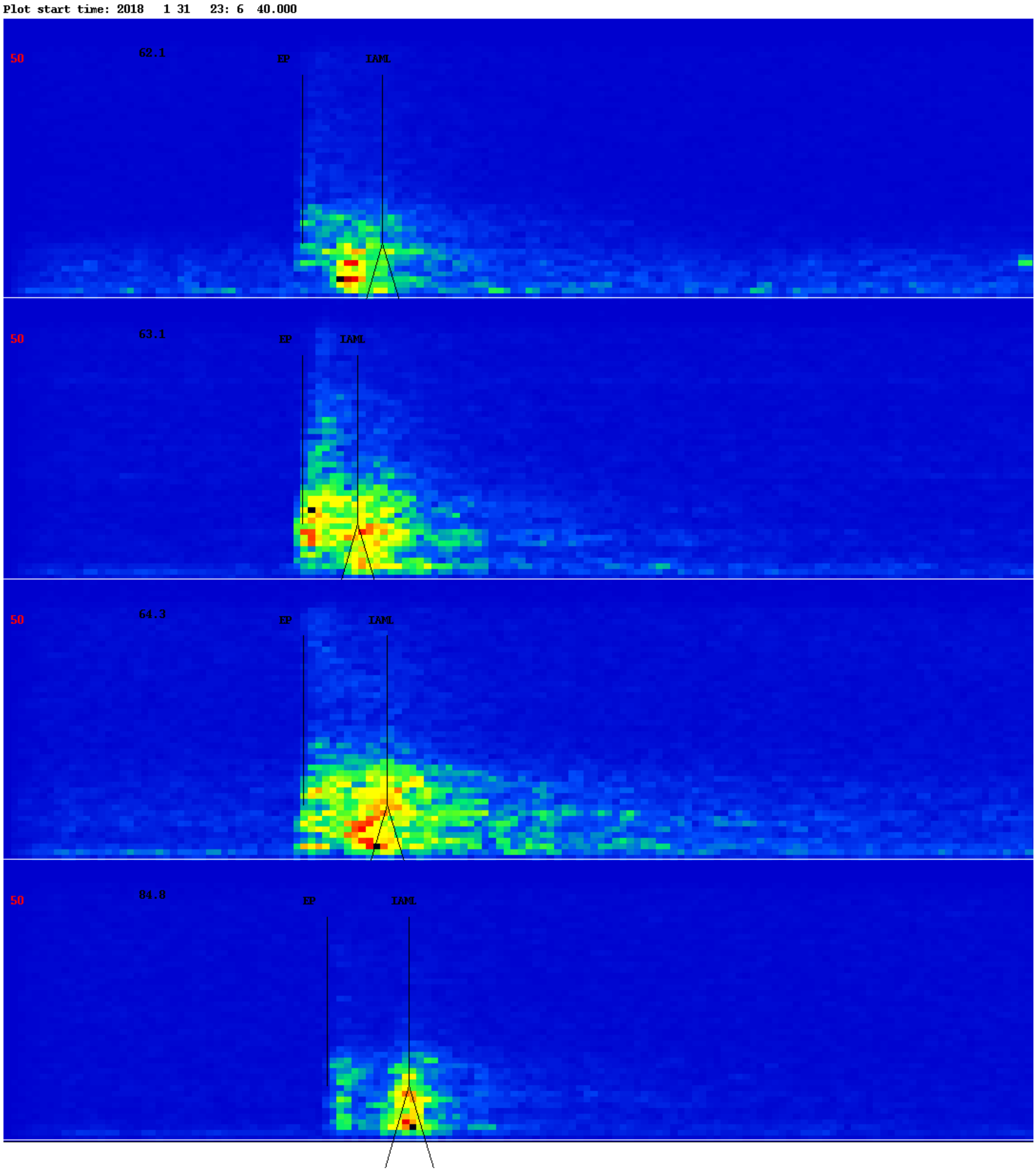


Figure 30 Spectrogram from an underwater single explosion at Kverner, Stord, Hordaland. Stations are, from top, Karmøy (KMY), Blåsjø (BLS5), Odda (ODD1) and Askøy (ASK). Approximately duration of plot is 180 sec.

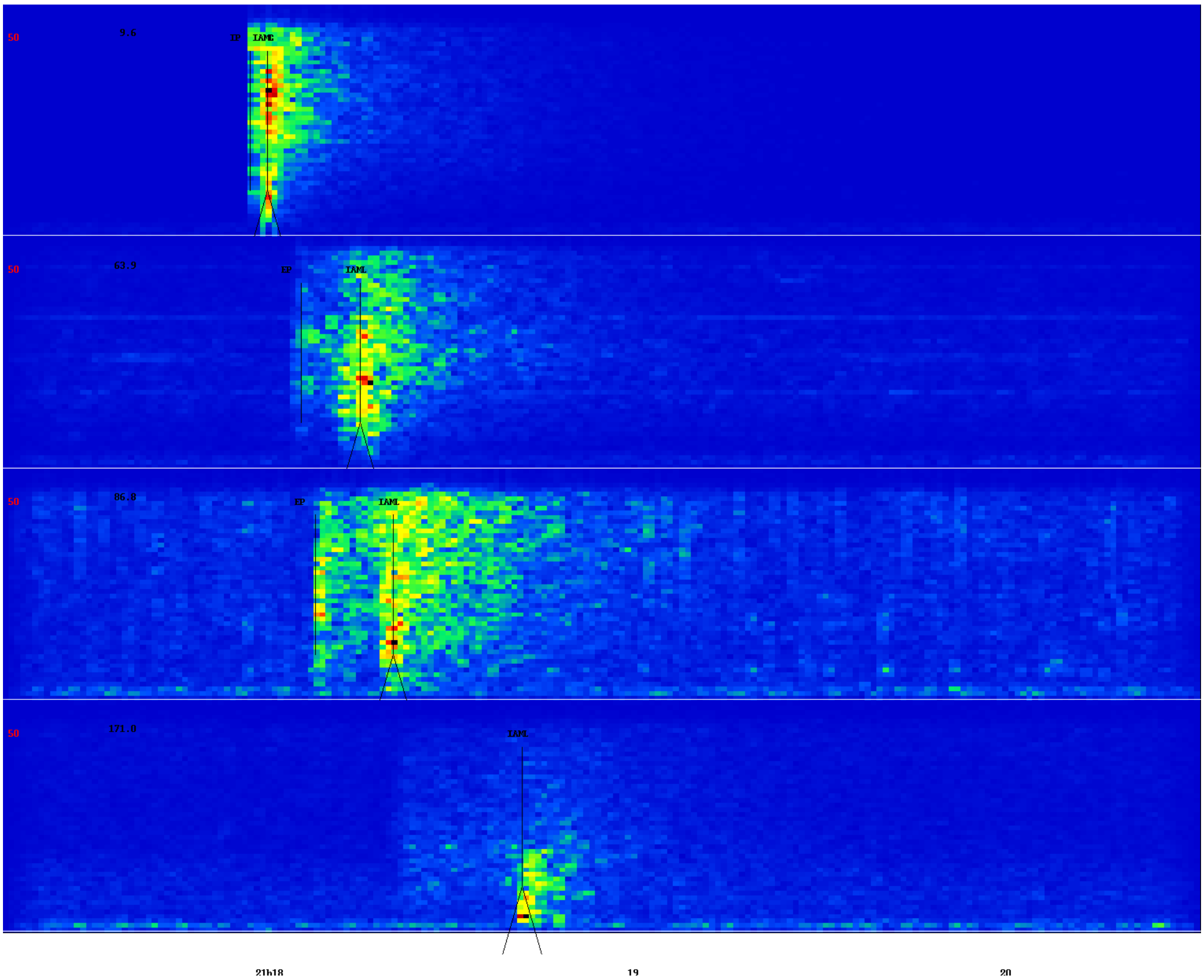


Figure 31 Spectrograms for a local earthquake near Hardbakke, Sogn og Fjordane. Stations are, from top, Sulen (SUE), Florø (FOO), Høyanger (HYA) and Odda (ODD1). Approximately duration of plot is 180 sec.

6 Publications and presentations of NNSN data during 2016

Data collected on Norwegian seismic stations are made available through the Internet and is provided on request to interested parties. Therefore it is difficult to get a comprehensive overview on the use and all publication based on Norwegian data. The following reference list shows publications and presentations of UiB and NORSAR scientists for the reporting period, based on data of NNSN and NORSAR stations.

6.1 Master of Science Thesis, UiB

Tjåland, N. (2017). Double-Difference Relocation and Empirical Green's Function Analysis of Storfjorden Earthquakes, MSc thesis at UiB.

Vestly, M.F. (2017). Submarine Landslides in Norway, MSc thesis at UiB.

6.2 Publications

Gibbons, S. J., D. B. Harris, T. Dahl-Jensen, T. Kværna, T. B. Larsen, B. Paulsen and P. H. Voss (2017). Locating Seismicity on the Arctic Plate Boundary Using Multiple-Event Techniques and Empirical Signal Processing, *Geophysical Journal International*, **211,** pp. 1613-1627, http://dx.doi.org/10.1093/gji/ggx398

Kim, W.Y., & Ottemöller, L. (2017). Regional Pn body - wave magnitude scale mb(Pn) for earthquakes along the northern mid - Atlantic Ridge. *Journal of Geophysical Research: Solid Earth*, 122, 10,321–10,340. https://doi.org/10.1002/2017JB014639

6.3 Oral presentations

Gibbons, S.J. (2017). Accurate Seismic Event Location: A Question of Context, *British Seismology Meeting, Reading*, United Kingdom, 5-7 April 2017

Michalek J. and L. Ottemöller (2017). Seismicity and tectonic structures offshore and onshore Nordland, NEONOR2 project meeting, Trondheim, November 2017.

Ottemöller L. and J. Michalek (2017). Seismicity recording and interpretations, NEONOR2 project meeting, Trondheim, June 2017.

Schweitzer, J., Y. Konechnaya, A. Fedorov, S. Gibbons and M. Pirli (2017). A New Seismic Bulletin for the European Arctic, *77. Jahrestagung der Deutschen Geophysikalischen Gesellschaft*, Potsdam, März 2017

Schweitzer, J. (2017). Upgrade of NORSAR's Event Warning System (NEWS), *AFTAC – NORSAR Joint Scientific Commission Meeting*, Kjeller, 9 – 11 May 2017

Schweitzer, J. (2017). NORSAR's Research Activities in Arctic and Antarctic, *JSPS Japan–Norway Symposium*, Bergen, 6 – 8 June 2017

Schweitzer, J. (2017). Over 20 years of HYPOSAT: Newest developments, *IAG-IASPEI Joint Scientific Assembly, Kobe, Japan*, 30 July 30 – 4 August 2017

Schweitzer, J, Y. Konechnaya , A. Fedorov, S. Gibbons and M. Pirli (2017). Compilation of a Seismic Bulletin for the European Arctic, *IAG-IASPEI Joint Scientific Assembly, Kobe, Japan*, 30 July 30 – 4 August 2017

Sørensen, M.B. (2017). Seismisitet og historiske jordskjelv i Norge, presentation at Nasjonal Geografikonferanse, Lørenskog, January 2017.

Sørensen, M.B. (2017). Geohazards research at GEO and the new course GEOV217: Geohazards, presentation at GEO partner day, February 2017.

Sørensen, M.B. (2017). Geohazards in Norway - Earthquakes, landslides and gigantic tsunami waves, lunch presentation at GEUS, Copenhagen, May 2017.

Sørensen, M.B. and Voss, P. (2017). Investigation of macroseismic data for earthquakes in Norway and Denmark, presentation at 48th Nordic Seismology Seminar, Helsinki, June 2017.

Vestly, M.F., Sørensen, M.B., Hjelstuen, B.O. (2017). Jordskjelvtriggede undersjøiske skred i Norge, Presentation at Geofaredagen, Trondheim, October 2017.

6.4 Poster presentations

Schweitzer, J., Y. Konechnaya, A. Fedorov, S. Gibbons and M. Pirli (2017). A New Seismic Bulletin for Svalbard and the European Arctic, *Svalbard Science Conference 2017*, 6 – 8 November 2017

Pirli, M and J. Schweitzer (2017). Earthquake activity in Storfjorden, Svalbard: current knowledge and implication, *Svalbard Science Conference 2017*, 6 – 8 November 2017

6.5 Reports

Schweitzer and M. Roth (2017). The NORSAR Data Center in 2017 (FDSN Network Code NO), *Biannual Report prepared for the FDSN Meeting during Joint IAG-IASPEI Scientific Assembly in Kobe*, 14 pp, 2017

Schweitzer, J, G. Antonovskaya and Joint Norwegian-Russian Project GEOPROC Consortium (2017). Seismological research related to geophysical processes in the European Arctic (project GEOPROC), *Annual Technical Summary, 1 January – 31 December 2016*, NORSAR Scientific Report, 31-37, 2017

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