Progress Report 2016

for

Norwegian National Seismic Network

January 1 to September 30, 2016

Supported by

Norwegian Oil and Gas Association

and

University of Bergen, Department of Earth Science

Prepared by

Department of Earth Science
University of Bergen
Allegaten 41, N-5007 Bergen

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1 Introduction

This annual report describes the operation of the Norwegian National Seismic Network (NNSN) for the first part of 2016. The network is financially supported by the oil industry through the Norwegian Oil and Gas Association and the University of Bergen (UiB). UiB has the main responsibility to run the NNSN. This report covers operational aspects for all seismic stations operated by the Department of Earth Science at the UiB and includes the financial report.

2 Operation

In Norway, UiB operates 34 of the seismic stations that form the Norwegian National Seismic Network (NNSN). Pictures from the newly installed station VADS are shown in Figure 3. NORSAR operates 3 seismic arrays, which also include broadband instruments, and three single seismometer stations (JMIC, JETT and AKN) (Figure 1). In total, NORSAR provides data from 14 broadband stations to the NNSN. The station HSPB is operated jointly between NORSAR and the Geophysical Institute, Polish Academy of Sciences, Warsaw, Poland and the stations located in Barentsburg (BRBA and BRBB) are operated jointly

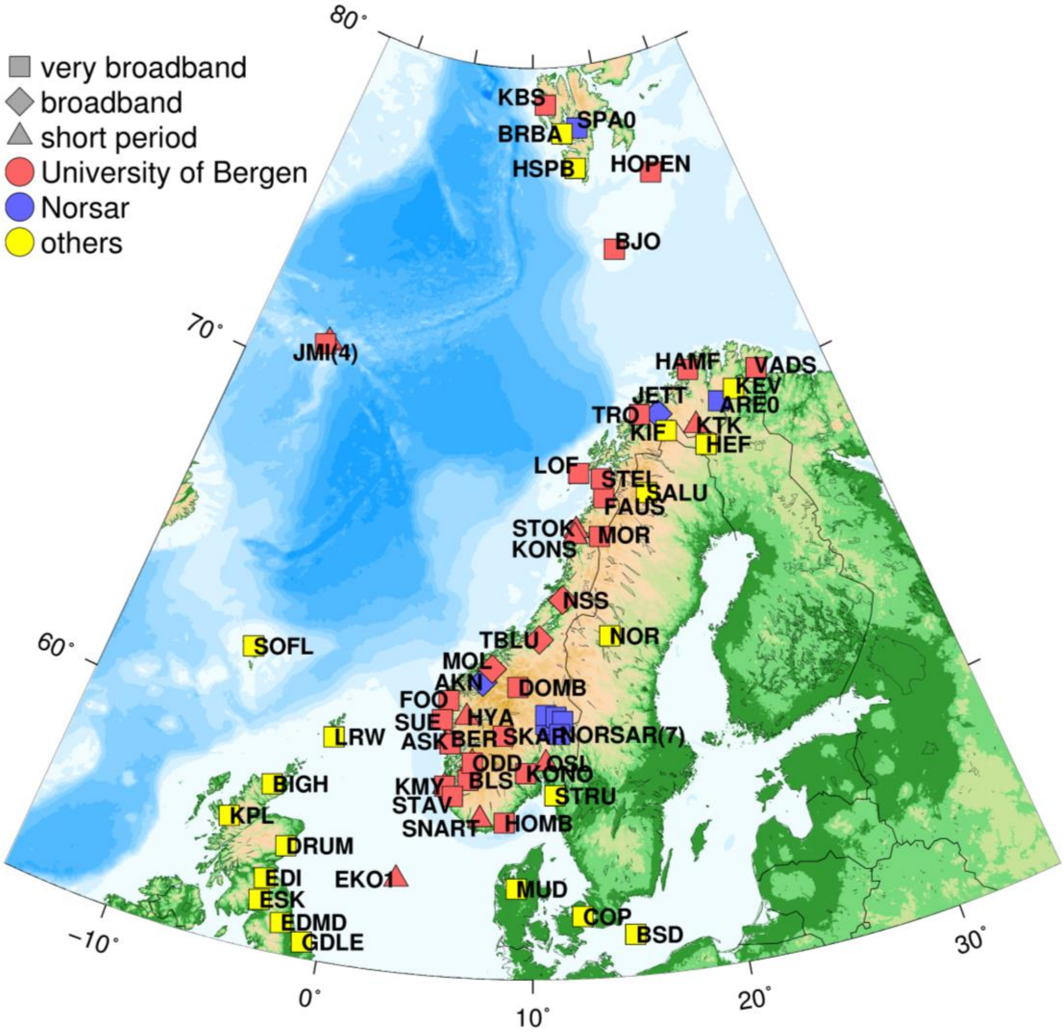

Figure 1. Stations delivering data to the NNSN database. UiB operates 34 stations (red) and NORSAR operates the stations marked in blue, including the three arrays and stations AKN and JMIC.

between NORSAR and the Kola Regional Seismological Centre of Geophysical Service, Russia. As seen on Figure 1 and Figure 2 data from some Swedish, Finish and Danish stations are also available. Data from the Danish stations located on the east coast of Greenland (Figure 2), operated by GEUS, contribute to the location of earthquakes in the Greenland Sea and Artic Sea.

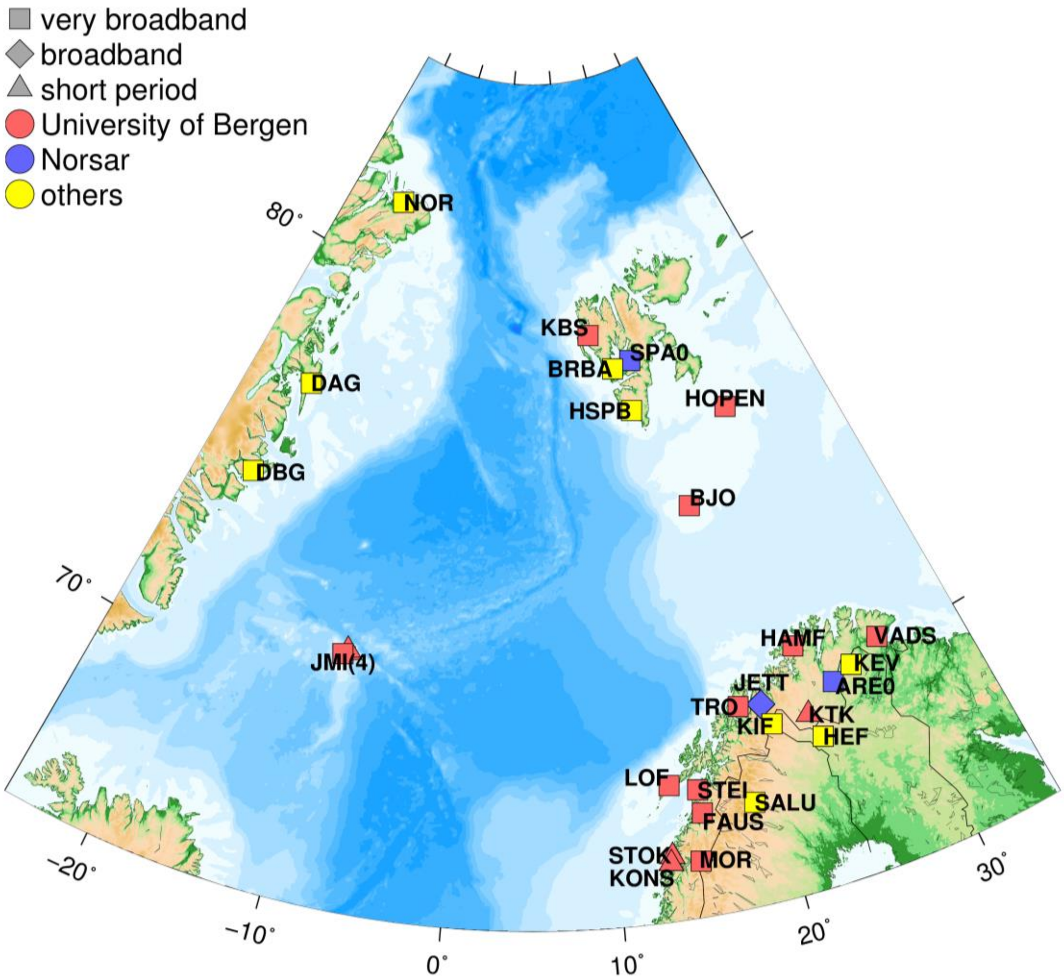

Figure 2. Seismic stations in the arctic area, including the three stations located on Greenland operated by GEUS, Denmark.

Figure 3. Pictures from VADS station.

The seismicity detected by the network is processed at UiB, but also NORSAR integrates their results in the joint database at UiB. Seismicity maps for the reporting period are shown in Figure 4 and Figure 5.

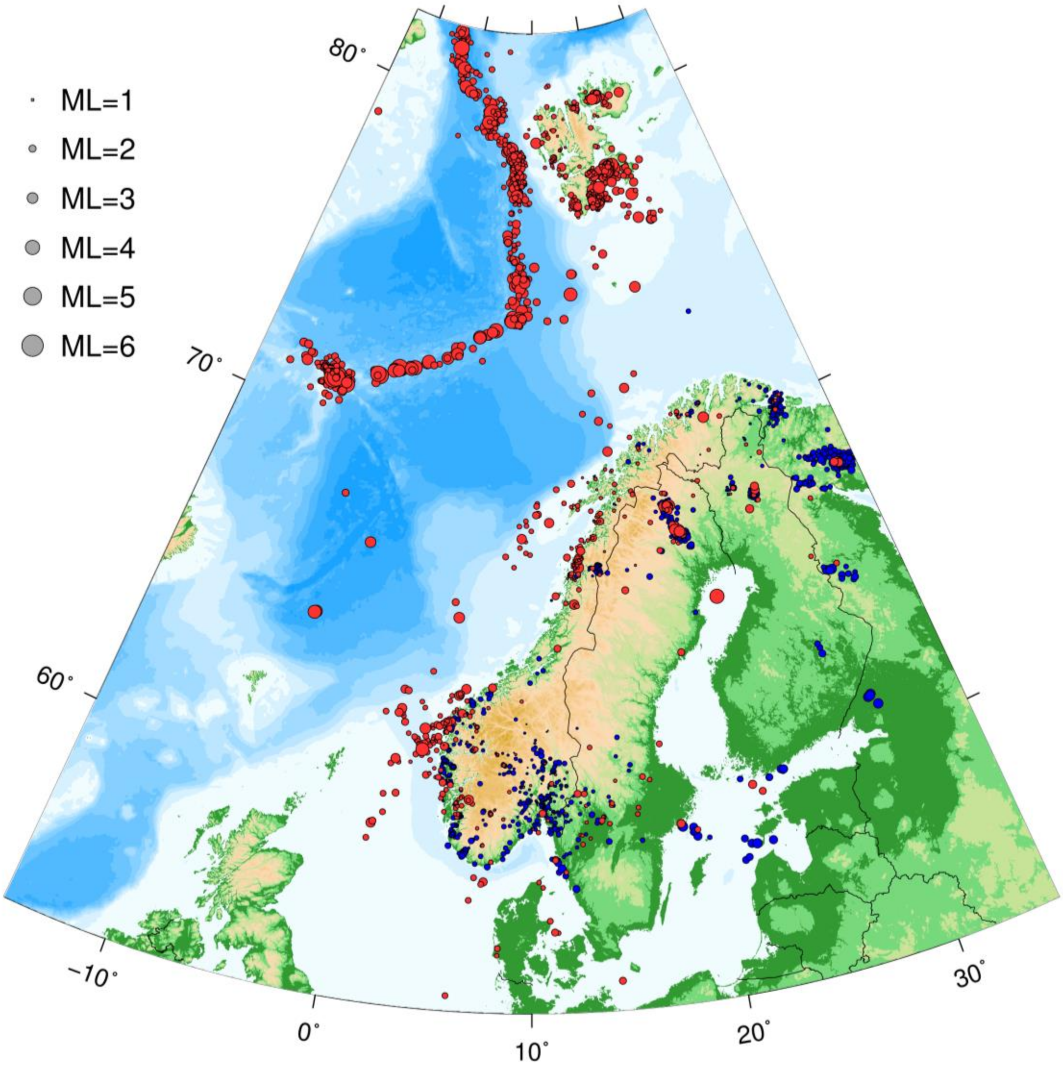

Figure 4. Seismicity map showing earthquakes (red) and explosions (blue) for the period January to September, 2016.

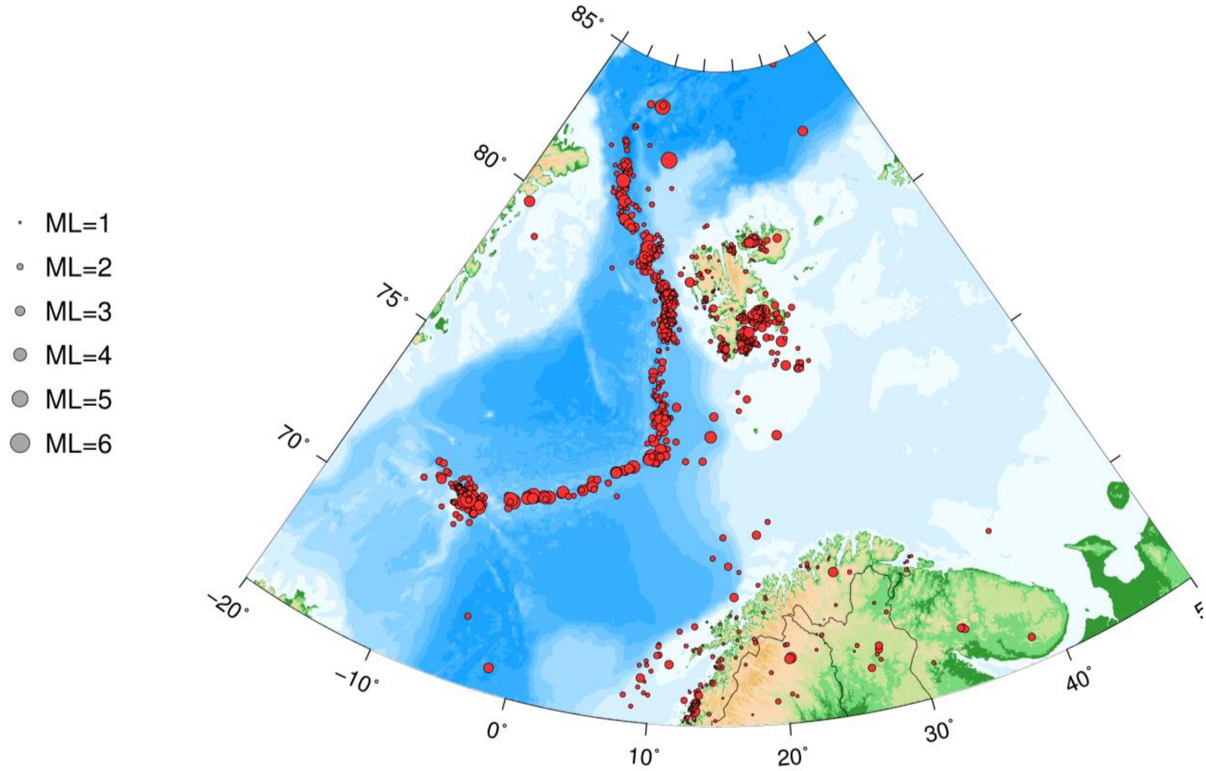

Figure 5. Seismicity in the artic area for the period January to September 2016. Known and probable explosions are excluded.

UiB is in the process of upgrading the NNSN by installing new stations and changing short period (SP) to broadband (BB) seismometers. A further effort is made to install additional high quality digitizers. The current use of seismometers is shown in Figure 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	7	27 (24 with natural period greater than 100 sec)	31 (not real time are 2 short period and 1 broadband station on Jan Mayen)

The operational stability for each station is shown in Table 2. The downtime is computed from the amount of data that are missing from the continuous recordings at UiB. The statistics will, therefore, also show when a single component is not working. This is done as the goal is to obtain as complete continuous data from all stations as possible. 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 downtime for the majority of stations is below 5%. Larger down time were observed for the following stations: HYA and KTK1 (see technical service overview for details). For HYA, the downtime was due to a malfunctioning PC. The KTK1 downtime is due to loss of power to the seismometer.

Table 2. Data completeness in % for January to September 2016 for all stations of the NNSN operated by UiB.

Station	Data completeness in %
Askøy (ASK)	**100**
Bergen (BER)	**100**
Bjørnøya (BJO)	**99**
Blåsjø (BLS)	**100**
Dombås (DOMB)	**100**
Florø (FOO)	**96**
Fauske (FAUS)	**100**
Hammerfest (HAMF)	**100**
Homborsund (HOMB)	**100**
Hopen (HOPEN)	**100**
Høyanger (HYA)	**92**
Jan Mayen (JMI)	**99**
Jan Mayen (JNE)	**99**
Jan Mayen (JNW)	**99**
Karmøy (KMY)	**100**
Kautokeino (KTK)	**90**
Kings Bay (KBS)	**99**

Station	Data completeness in %
Kongsberg (KONO)	**99**
Konsvik (KONS)	**100**
Lofoten (LOF)	**100**
Mo i Rana (MOR8)	**96**
Molde (MOL)	**99**
Namsos (NSS)	**100**
Odda (OOD1)	**99**
Oslo (OSL)	**99**
Skarslia (SKAR)	**98**
Snartemo (SNART)	**99**
Stavanger (STAV)	**100**
Steigen (STEI)	**99**
Stokkvågen (STOK)	**99**
Sulen (SUE)	**99**
Blussuvoll (TBLU)	**100**
Tromsø (TRO)	**98**
Vadsø (VADS)	**100**

3 Field stations and technical service

The technical changes for each seismic station are listed below. It is noted if these changes are carried out by the respective local contact and not by the technical staff of UiB. When a station stops working, tests are made to locate the problem. The different equipment components can be restarted from Bergen, and this sometimes helps to resolve the issue.

Major changes during this reporting period of 2016 were:

Ask (ASK)	12.08.16: Station inspected to find fault with seismometer east component. Seismometer will have to be replaced.
Bergen (BER)	No visit or technical changes
Bjørnøya (BJO1)	No visit or technical changes

Blåsjø (BLS)	No visit or technical changes
Blussuvoll (TBLU)	No visit or technical changes
Dombås (DOMB)	25.07.16: Station down since 23.07 at 00:08 (UTC). Unknown reason. Power on/off restarted the station. 02.08.16: Station down since 30.07 at 22:30 (UTC). Unknown reason. Power on/off restarted the station.
Fauske (FAUS)	26.03.16: Vault checked by local contact. 07.04.16: El. enclosure was inspected by local contact. No humidity or other problems were detected. 18.05.16: Station was visited by UiB staff who was traveling through the area on other fieldwork. Small amount of water was removed from the vault.
Florø (FOO)	No visit or technical changes.
Hammerfest (HAMF)	No visit or technical changes.
Homborsund (HOMB)	No visit or technical changes.
Hopen (HOPEN)	18.03.16: UPS installed by local personnel. 04.04.16: The vault was inspected by local personnel. No problems found.
Høyanger (HYA)	15.02.16: Station down since 29.01.16 due to PC problems after heavy storm. PC replaced by local contact. Data lost. 20.05.16: Station down since 16.05.16 due to power failure. Data lost.
Jan Mayen (JMI)	No technical changes. The station is visited by local personnel.
JNE	No technical changes. The station is visited by local personnel.
JNW	No technical changes. The station is visited by local personnel.
Karmøy (KMY)	23.09.16: New broad band sensor (Trillium 120QA) installed.
Kautokeino (KTK)	19.08.16: Seismometer not working since 29.07.16. Local contact visited and repowered the station, which resolved the problem. Data lost.
Kings Bay (KBS)	No visit or technical changes.
Kongsberg	No visit or technical changes.

(KONO)	
Konsvik (KONS)	15.08.16: Station visited, no changes.
Lofoten (LOF)	No visit or technical changes.
Mo i Rana (MOR8)	08.03.16: New UPS installed by local operator.
Molde (MOL)	No visit or technical changes.
Namsos (NSS)	No visit or technical changes.
Odda (ODD1)	22.09.16: New broad band seismometer (Trillium 120QA) installed. The digitizer was not changed and is a Guralp CMG-DM as before.
Oslo (OSL)	No visit or technical changes.
Skarslia (SKAR)	30.06.16: Vault inspection. A small amount of water was removed. 04.07.16: Station down since 29.06 due to problem with the digitizer. Data lost. 25.07.16: Station down since 25.07 at 04:30 UTC. A digitizer problem. Power off/on and station ok from 08:32. 07.09.16: Station down from 19.08.16. Problem with digitizer. The digitizer replaced by local contact. A small amount of water was removed.
Snartemo (SNART)	No visit or technical changes.
Stavanger (STAV)	No visit or technical changes.
Steigen (STEI)	19.05.16: Station was shortly visited by UiB staff who had fieldwork in the area.
Stokkvågen (STOK)	15.08.16: Station visited, no changes. 22.09.16: Station down some hours due to power failure. Data lost.
Sulen (SUE)	16.02.16: Visit. A new Guralp digitizer was installed, and old digitizer and PC were removed. There had been timing problems for some time and a new GPS antenna was installed.
Tromsø (TRO)	26.07.16: Station down since 24.07. Power reset remotely. Data lost 24-26 July.
Vadsø	

(VADS) 29.09.16: The station was installed with the following equipment: Trillium 120PA sensor and a Guralp CMG-DM24 digitizer.

4 Research

4.1 QLg tomography

By Andrea Demuth, UiB

We analyze the attenuation of Lg waves in Norway and adjacent areas. Attenuation is described by the quality factor Q and is a basic parameter to characterize the crust and mantle. Our goal is to gain a better understanding of the geological structures and tectonic processes in Norway.

In a first step, we use spectral displacement amplitude ratios of Lg-waves and P-waves to determine the lateral variation in wave attenuation in a frequency range of 2 Hz till 5 Hz. In this approach, we assume that the main attenuation of the ratio is due to Lg wave attenuation. Thus, lower ratios are interpreted as high Lg wave attenuation. We used all earthquakes recorded by the NNSN since 1990, which have a local magnitude higher than 2.5 and recordings by 4 or more stations. The ratio for one earthquake station pair was assigned to its corresponding travel path.

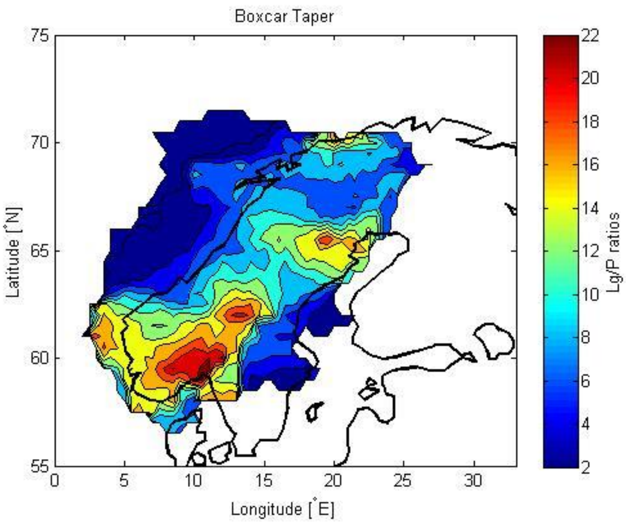

Figure 6 Spectral displacement amplitude ratios of Lg-waves to P waves.

Figure 6 shows our Lg to P amplitude ratios for the areas in Norway with path coverage. It is visible that Lg waves are higher attenuated in offshore areas than onshore. Furthermore, we observe stronger attenuation in northern parts of Norway.

For a more detailed analysis of the Lg attenuation in Norway, we only use spectral displacement amplitude decay of Lg waves to derive the corresponding quality factor. This is done in a tomographic approach. The tomographic code is built on the theory of Barmin et al. 2001. The code inverts for source and site terms of each observed source receiver pair as well as for the quality factor. This is done with a damped least square approach. Additionally we implemented a spatial smoothing matrix. In order to test the code, we generated a checker board test and used our real source receiver configuration (Figure 7a).

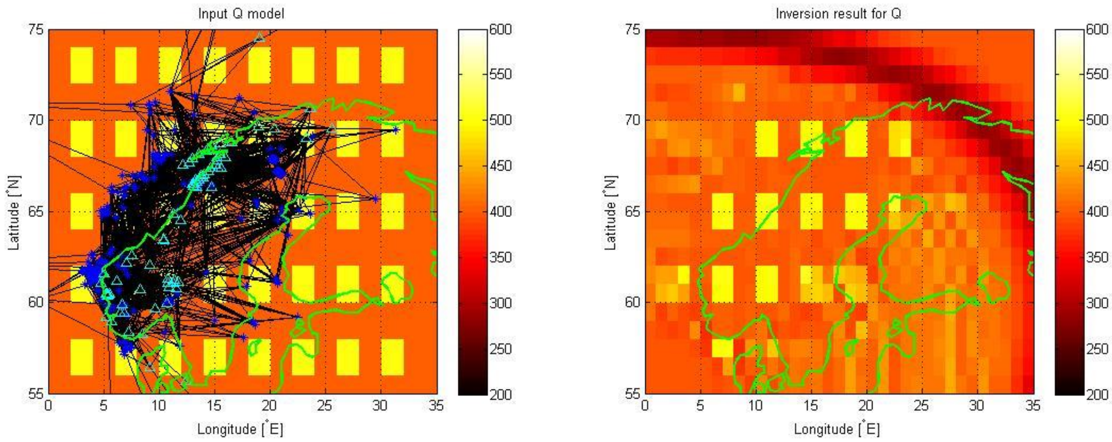

Figure 7 (a) Synthetic Q_{Lg} checker board input model with real path coverage (black lines). Light blue triangles represent stations and dark blue stars earthquakes. (b) Inversion result for Q_{Lg} with the new derived tomographic code.

The checkerboard pattern is well resolved in areas with high path coverage (Figure 7 b). In areas with low to no coverage the Q value is set to the background value of 400. We observe some smearing on the edges of the path covered areas. The input values for the source terms and site terms alternate in a checker board pattern as well and are well resolved.

The next step is to run the tomographic code with the real amplitude values for various frequencies. In order to do that, an average Q_{Lg} value is first determined which is used as starting value for the inversion. The average Q_{Lg} values for various frequencies are going to be used to find a general frequency dependence of Q_{Lg} for Norway.

References:

Barmin, M.P., Ritzwoller, M.H. & Levshin, A.L., 2001. A fast and reliable method for surface wave tomography, Pure appl. Geophys., 158, 1351–1375.

4.2 Relocation of seismicity in southern Norway and the North Sea using a Bayesian hierarchical multiple event location algorithm

By Steven Gibbons, NORSAR

We are continuing our reassessment of seismicity in and around southern Norway involving a critical re-evaluation of waveform data and arrival picks, exploitation of as yet unused seismic data, and application of a probabilistic multiple event location algorithm. We have been combining datasets from NORSAR, the University of Bergen, additional regional networks (for example Denmark, the Netherlands, and the United Kingdom), and – in a few exceptional cases – teleseismic data. For each event, a preliminary location estimate is made using the extended set of seismic arrivals; phases with significant time-residuals, or other indications of poor quality, are removed. The cleaned sets of arrivals are then processed by the Bayesloc multiple event location program (https://www-gs.llnl.gov/about/nuclear-threat-reduction/nuclear-explosion-monitoring/bayesloc) which has been demonstrated to provide enhanced epicenter distributions for clustered seismicity on both regional and global scales.

In classical single-event location algorithms, the traditional measure of uncertainty is an error ellipse calculated from the formal uncertainties surrounding the arrival times used in the inversion. Systematic bias in the applied velocity models is often not accounted for and event location estimates are frequently presented with unrealistically small error ellipses. Bayesloc calculates joint probability distributions both for hypocenters and parametric information for multiple events simultaneously. In providing implicit corrections to traveltime estimates, Bayesloc can be demonstrated to provide more realistic estimates of location uncertainty. For example, an event for which the applied velocity model provides a poor representation of the traveltimes may have a large formal error ellipse due to the high residuals. The uncertainty indicated by Bayesloc may be significantly smaller if these traveltimes are correctly calibrated. Similarly, an event with very few observations may have a very small formal error ellipse, since there exists a location for which these few constraints can be satisfied very precisely. Bayesloc searches a huge parameter space using a Markov Chain Monte Carlo algorithm and can identify that such event locations have a very broad probability distribution. The attributed uncertainty is consequently far larger for the poorly constrained events.

A current snapshot of the multiple event probability distribution is shown in Figure 8. This indicates at a glance those events which appear very well constrained – and these appear to cluster in distinct structures – and those events with poorer constraints which may need a reassessment of the associated seismic data. The dataset is being increased continually and special attention is being paid to events which may have far tighter prior constraints. These may be due to large magnitudes (hence recorded on a far greater number of stations) or events that have been very tightly constrained by temporary deployments. A feature of Bayesloc of special interest for this dataset is the probabilistic attribution of phase identifications. In classical event location, a phase might be attributed a label which doesn't actually correspond well with the true path traveled from source to receiver. We provide Bayesloc with multiple path models and, in the case of erroneous phase identification, Bayesloc will attribute a higher probability to those solutions with the correct phase identification – rather than derailing the location estimate by forcing the error on the final solution.

In the coming months we intend to extend the dataset significantly and update the multiple event distribution systematically with new events and additional constraints. The process is iterative with events with apparently poor constraints being identified and assessed for potentially erroneous input data.

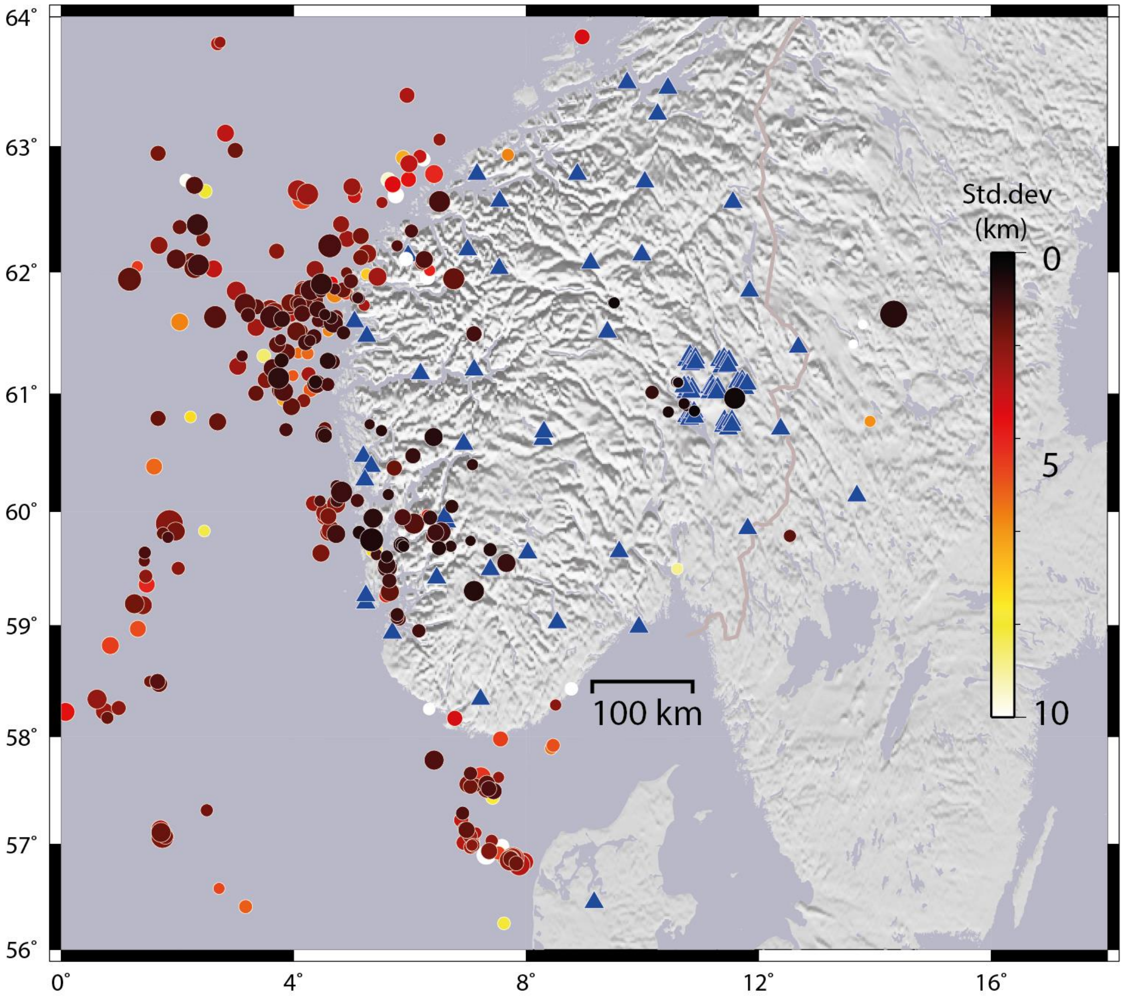

Figure 8. Epicenter estimates for around 300 seismic events in and around southern Norway between 1992 and 2016 located using the Bayesloc program. The blue triangles indicate the locations of permanent seismic stations of the Norwegian National Seismic Network, the NORSAR and Hagfors seismic arrays, station MUD of the Danish national network, and temporary stations of the MAGNUS and NEONOR deployments. Bayesloc returns a joint probability distribution of event locations, corrections to traveltime estimates, precision of arrival-time estimates, and phase labels. For each event, the center of the probability distribution is displayed together with the lateral standard deviation; the darkest symbols indicate the events with the best constrained

4.3 Testing of a method for distinguishing between earthquakes and explosions

By Ilma Janutyte, NORSAR

We have continued testing of a method which helps to objectively distinguish between earthquakes (EQs) and explosions. The method was first developed at the Institute of Seismology, University of Helsinki, Helsinki, Finland (Kortström et al., 2016), and is successfully used there to help in the daily data analysis. During this reporting period we have made a reevaluation of the method for the stations FOO and HYA using an extended dataset as well as using different partitioning of the training and validation data. In addition, we have applied the method to datasets at the stations LOF and MOR8 in northern Norway. The datasets for the stations were compiled from the University of Bergen (UiB) catalogs, and we made attempts to obtain examples of both EQs and explosions originating in different directions from the selected stations. The limit for distance was from 15 to 270 km (Figure 9).

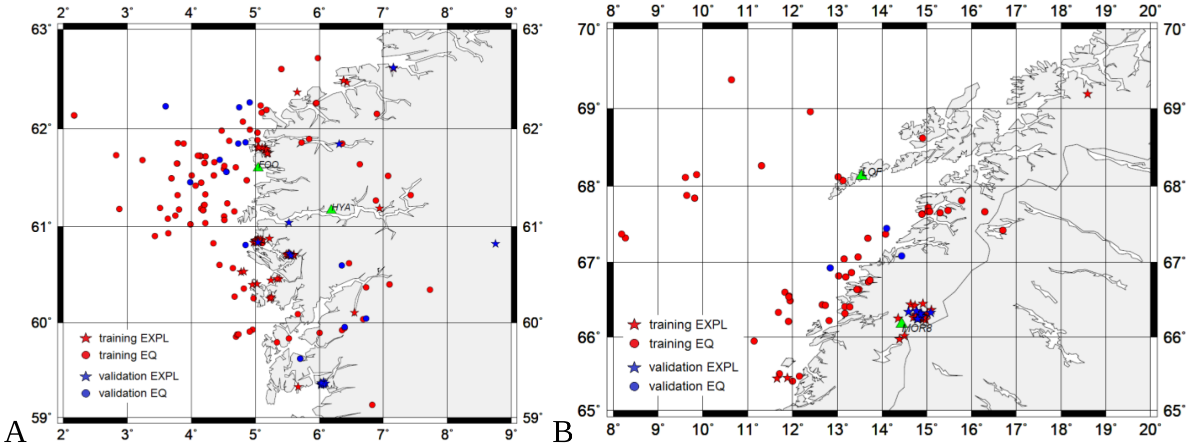

Figure 9. Seismic events used to develop and verify the reference spectral models for the stations: A) HYA and FOO in the south, and B) LOF and MOR8 in the north. The seismic events are marked as circles and stars, while the seismic stations are marked as green triangles.

The results are shown in Figure 10 and Table 3. The prediction shows possible EQs as positive values and possible explosions as negative values. The more the value is positive, the more it tends to be the EQ-like, while the more the negative, the more the explosion-like, while around the zero the prediction is weaker and uncertain.

The test case for FOO and HYA stations in the south shows prediction precision of 100 %, i.e. all the seismic events both EQs and explosions were evaluated as correct. For LOF and MOR8 stations in the north the testing precision is 83 and 87 %, respectively. This might be due to too small datasets and not a sufficient number of training examples for the reference model. Especially for LOF station the total number of reference explosions available in the bulletin is low.

Table 3. Number of seismic events used in the study for obtaining (training) and validation (testing) of the spectral reference models, and the obtained reference model precision (error) and precision of the test dataset (test precision).

Station code	in total		training dataset		testing dataset		model error [%]	test precision [%]
	EQ	EX	EQ	EX	EQ	EX		
FOO	73	57	58	47	15	10	35	100
HYA	82	148	55	108	27	40	21	100
LOF	89	26	69	23	20	3	49	83
MOR8	78	58	58	47	20	11	30	87

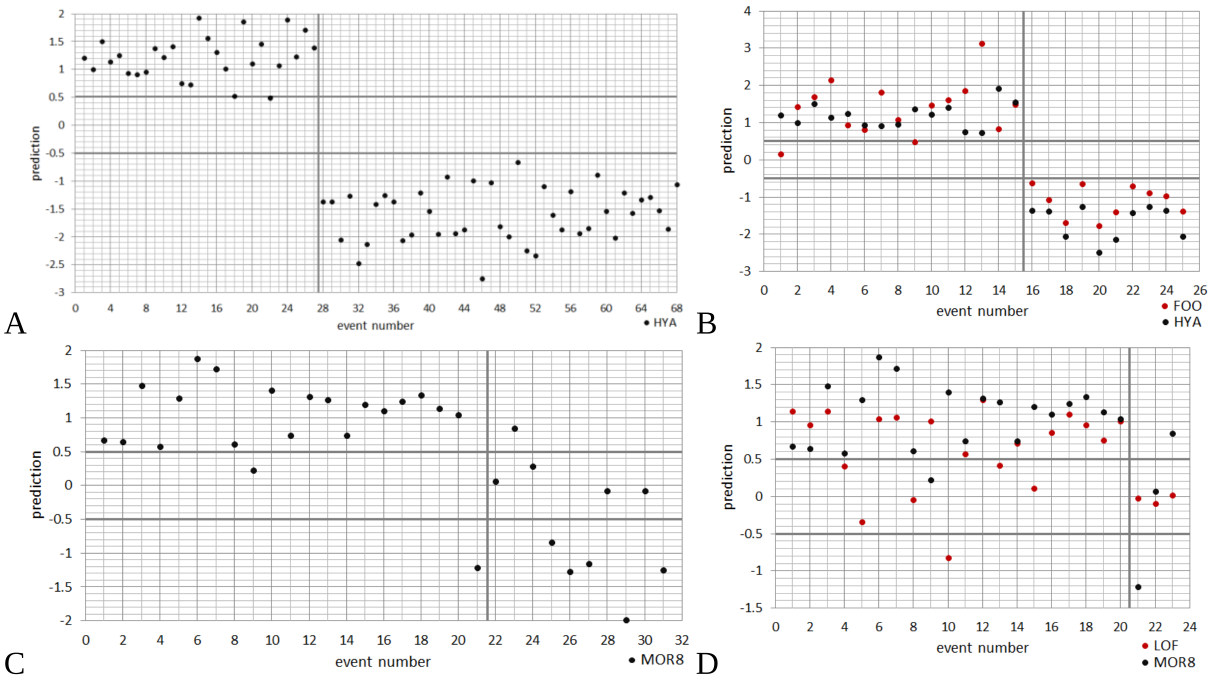

Figure 10. Predictions using the validation datasets for the different reference models:

A) for HYA station EQ data are up to event number 27;

B) the common events for FOO and HYA stations; EQ data are up to event number 15;

C) for MOR8 station EQ data are up to event number 21;

D) the common events for LOF and MORB stations; EQ data are up to event number 21.

Reference:

Kortström, J., Uski, M., and Tiira, T.: Automatic classification of seismic events within a regional seismograph network. Computers and Geosciences, 87, 22-30, 2016, doi: 10.1016/j.cageo.2015.11.006.

5 NNSN 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 will remain mostly stable for now, but it is important to improve the overall network performance.

5.1 Achievements in 2016

- The new broadband station near Vadsø (VADS) on the Varanger peninsula has been completed (Figure 3)
- The two previously short-period stations ODD1 and KMY have been upgraded with broadband seismometers.
- The archiving procedure at UiB has been modified, which together with improved station robustness has resulted in increased data completeness.
- The UiB research has focussed on Lg wave attenuation tomography.
- The UiB magnitude study for the North Atlantic is being finalized and a paper will be submitted in 2016.
- NORSAR have continued their studies on event re-location and source discrimination.
- Under the EPOS project planning and preparation for the 6 Svalbard, 7 Nordland and 2 Jan Mayen stations has started.
- Stations deployed under the NEONOR2 project have been uninstalled, detailed processing of the earthquake swarm near Jektvik that started in April 2015 has been carried out. The data are integrated with the NNSN stations and are part of the NNSN database.

5.2 Plans for 2016/2017

- Upgrade two more stations with broadband seismometers.
- The Kongsberg station will be upgraded by the USGS.
- Implement the new magnitude scale into the processing routines.
- UiB will carry out research on source parameters, automatic detection and determination of fault plane solutions.
- A research workshop will be held between UiB and NORSAR early in 2017.
- The research and development activity will continue in close collaboration between UiB and NORSAR.
- Provide data through IRIS and through a European EIDA node at UiB under the EPOS project.
- Strengthen the collaboration with NORSAR and the other Nordic countries on data processing through technical visits.