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6.4 Local seismicity on and near Bear Island (Norwegian Arctic) from a temporary small aperture array installation in 2008

6.4.1 Introduction

As part of the International Polar Year project (IPY) "The dynamic continental margin between the Mid-Atlantic-Ridge system (Mohns Ridge, Knipovich Ridge) and the Bear Island region", a temporary small aperture array was installed on Bear Island (Bjørnøya) during the summer of 2008. The aim of this project was to improve the understanding of the structure, the stress conditions and sources, the dynamics of the continental margin, and to identify active tectonic structures (Schweitzer et al., 2008). Seismicity in the region has been studied with a virtual seismic network comprising the existing permanent stations in the region, the Bjørnøya array, 12 ocean bottom seismometers, and two new broadband seismometers on Svalbard (Hornsund) and Hopen. The network detected large numbers of events along the Mohns and Knipovich ridges and the Senja Fracture Zone, as well as an M=6 event near Svalbard in February 2008 which was followed by an extensive aftershock sequence.

It became clear that the vast majority of the seismic signals recorded at the Bear Island array correspond to relatively local sources. Some of these local sources are likely to be due to human activity at the meteorological station in the northern part of Bear Island, although many are likely to be caused by weather-related phenomena: the melting of snow or the drifting and breaking of ice floes on the rivers and lakes on Bear Island. Rockfall along the steep coastal line or in the mountainous southern part of the island would be another plausible explanation. Tectonic events on or near the island would be of great interest.

Within the framework of a research visit at NORSAR in March and April 2010, financed by the EC Project NERIES (http://www.neries-eu.org/), this study aimed to investigate local events on and around Bear Island. It was assumed that events caused by weather-related phenomena could be identified by finding correspondence between event occurrence and meteorological data.

6.4.2 Array constellation and data processing

The position of Bear Island on the Barents Sea Shelf is shown in Fig. 6.4.1. It is situated half-way between the northern tip of Norway and Svalbard. The array was operative from May 22 to September 29, 2008. It consisted of 13 3-component stations of the type LE3D5s, with a corner frequency of 5 seconds, deployed over an aperture of 5-7 kilometer in the northern and central part of the island (Fig. 6.4.2). Additionally, data from the permanent broadband station BJO1 near the meteorological station were available.

The array was used as a network to localize events with clear body wave onsets, by applying the NORSAR HYPOSAT software (Schweitzer, 2001; 2002). For this purpose an underground model for P-wave velocities was available from reflection and refraction seismic experiments carried out within the framework of the IPY project (Czuba et al., 2010). Since it was not possible to establish an additional model for shear wave velocities by analyzing surface wave dispersion curves of regional events or ambient noise analysis (Wathelet et al., 2008; Endrun et al., 2009), an ideal P- to S-wave velocity ratio of $\sqrt{3}$ was assumed. The velocity of Rayleigh waves could be estimated through array techniques like beamforming and f-k-analysis.

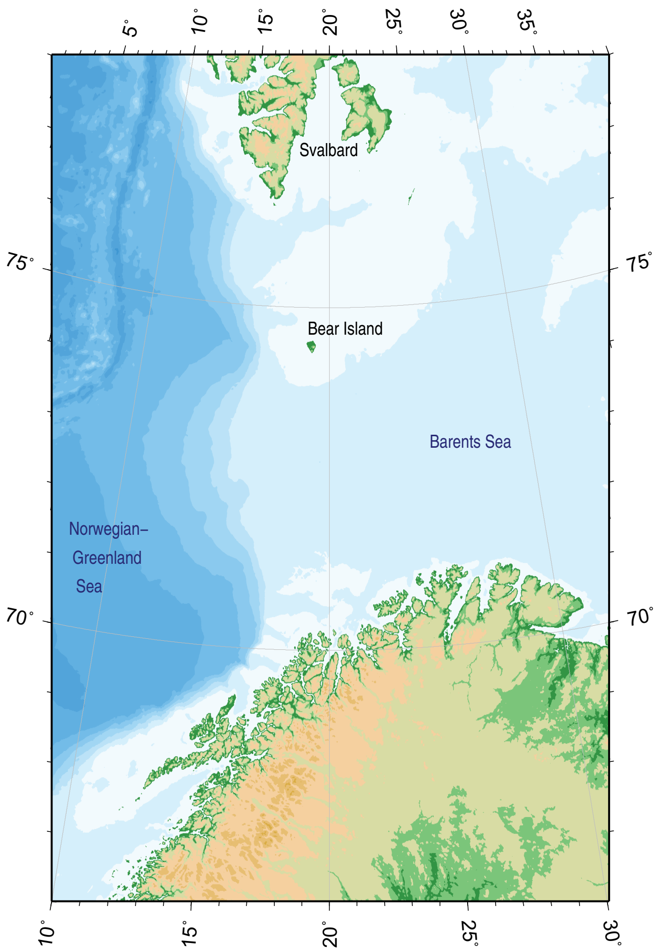


Fig. 6.4.1. Map of the Norwegian-Greenland Sea and the Norwegian continental margin between Fennoscandia and the Svalbard Archipelago (from: The GEBCO_08 Grid, version 20091120, http://www.gebco.net).

The NORSAR processing software for seismic data was applied to data from the Bear Island array. It provided continuous estimates of apparent velocity and backazimuth for arriving signals throughout the whole period of operation. From this processing, different events where located and their locations could be used in this seismicity study.

A waveform correlation detector (Gibbons & Ringdal, 2006) was applied to a number of observed signals in order to identify sources of recurring seismicity. The resulting temporal distributions of some events were compared with weather and climate data supplied by the Norwegian Meteorological Institute via its web site (http://eKlima.met.no). Values of wind direction, wind speed and temperature were available hourly from the weather station on Bear Island, as were values for wave height (every three hours), snow cover (daily) and type and amount of precipitation (daily).

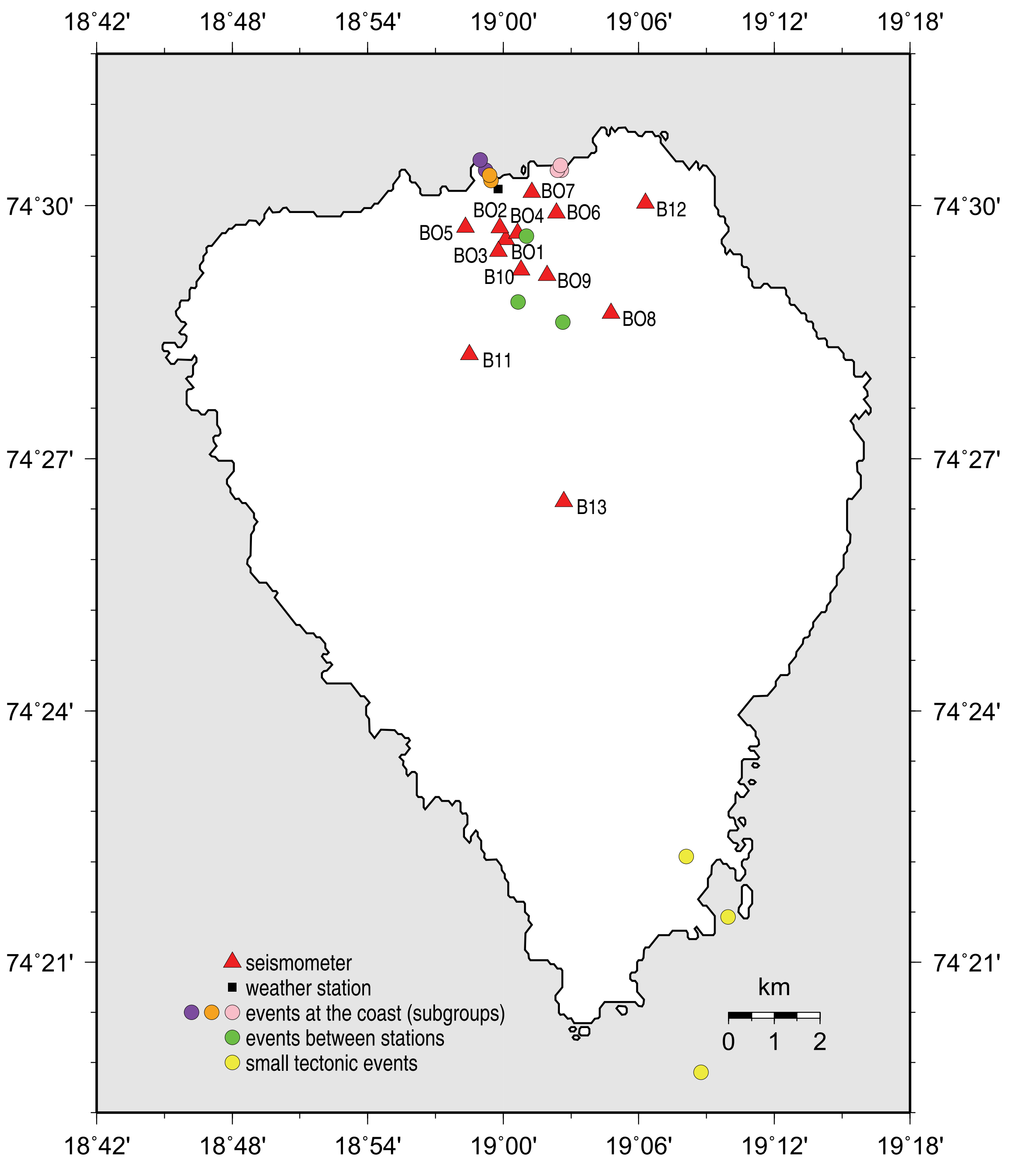


Fig. 6.4.2. Station map of the temporary small aperture array on Bear Island in 2008. The positions of localized events are marked by colored dots, the black square shows the position of the weather station.

6.4.3 Different event groups

In the course of the survey, three major groups of events could be identified and located. The first group can most likely be associated with weather and wave phenomena at the northern coast. A second group consists of events located within or close to the array and which are assumed to correspond to melting snow and breaking of ice floes on the rivers and lakes of the island. The third and probably most interesting group consists of small tectonic events on and near Bear Island. All manual event location estimates are shown in Fig. 6.4.2. A fourth set of observations consists of small acoustic signals, which were detected on several occasions. No event location estimate was possible for these signals since the observations in each case comprised only a single acoustic signal arriving at the array as plane waves from the south west. They are most likely to be associated with ships passing the island.

Events at the northern coast

The vast majority of all detected signals are associated with events located at the northern coast of the island (northcoast events). The signals are just one second long and are primarily recorded at the northernmost stations of the array. The amplitude quickly decreases so that the signals can not be observed at the inland stations. Body- and clear surface-waves arrive with very shallow incidence angles at the seismic stations. The primary onset is dominant on the horizontal components, indicating shallow events nearby. An example for such a signal is shown in Fig. 6.4.3.

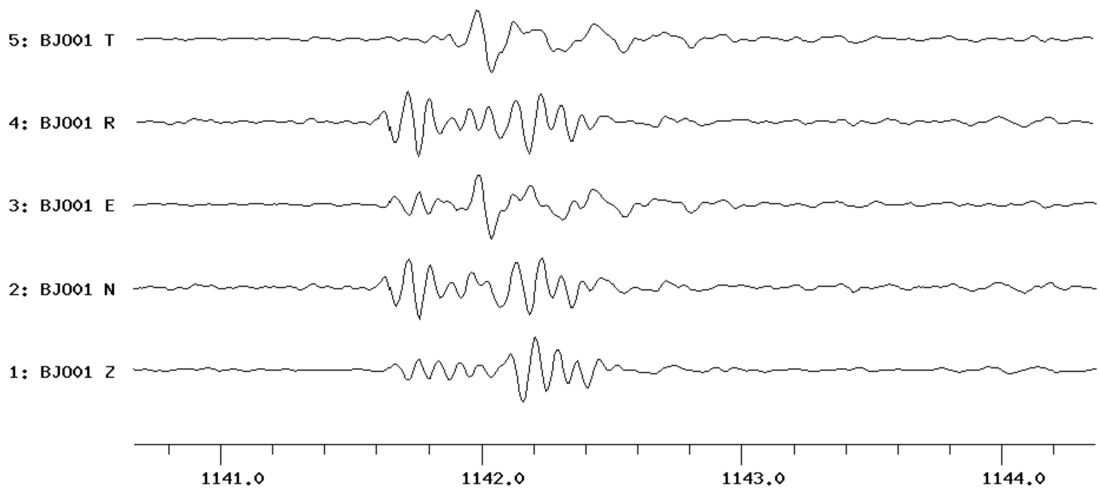


Fig. 6.4.3. Northcoast event from June 1, 2008 recorded at station BJO01. The traces are rotated with a backazimuth of 339° and filtered with a Butterworth bandpass filter from 3-16 Hz. The time axis shows seconds since midnight.

The temporal distribution of the events was determined by waveform correlation and is clearly inhomogeneous (Fig. 6.4.4). No periodicity can be observed. Three subgroups of events could be identified based on differences in their frequency content, their occurrence in time and space and the kind of phases that arrive. The major subgroup consists of about 80,000 events, (purple dots in Fig. 6.4.2) the other two subgroups contain “only” 22,000 (orange dots in Fig. 6.4.2)

and 14,000 events (pink dots in Fig. 6.4.2), respectively.
An emphasis in the analysis was put on the subgroup with the most detected events.

Human activity at the meteorological station can be eliminated as a possible source of these events. The origins do not coincide with the location of the weather station and there is no characteristic day and night cycle that one would assume in connection with human activity. No correlation with temperature and snow melting could be observed so that intensified erosion at the coast, either due to thawing of the permafrost or snow water, can be excluded as well.

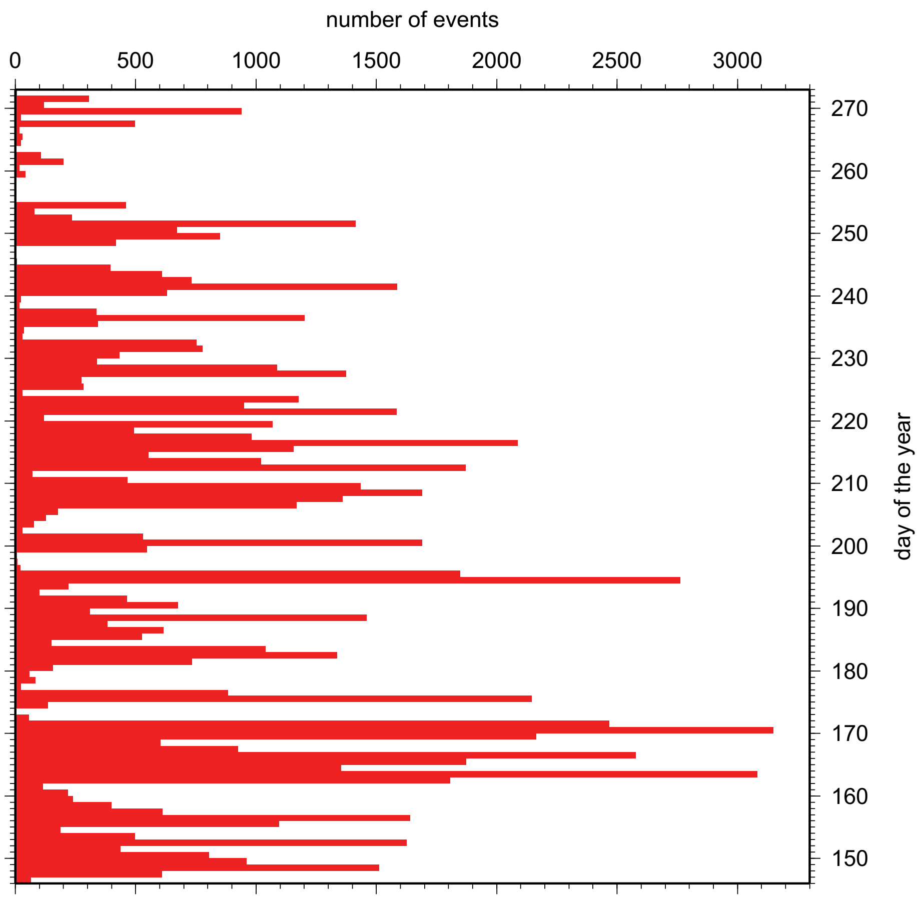


Fig. 6.4.4. Number of northcoast-events per day of the major subgroup (purple dots in 6.4.2).

In Fig. 6.4.5, the absolute occurrence of events per hour and the mean/median of events is plotted against the wind direction. It is slightly evident that there are more events observed when the wind comes from the north. The correlation suggests a dependency of the recorded signals with weather phenomena.

There is a strong connection between the mean amplitude at all stations, measured for ten minutes at the beginning of each hour at the vertical components, and the wind speed of the corresponding hour (Fig. 6.4.5). The mean amplitude is a measure of the noise at the stations. Hence, the noise increases with increasing wind speed and possible occurring events may not be observed, so that the actual temporal distribution is distorted. The number of events decreases with increasing wind speed (Fig. 6.4.5). This way, it is difficult to identify the real cause of the events at the northern coast because every possible relation is overlaid by the noise level due to wind speed.

It was assumed that the events occur due to waves breaking at the steep coast but measurements of the wave height are of no good quality and information about the wave direction are not available. There is no apparent relationship between the wave heights and the number of events for the major subgroup (purple dots in Fig. 6.4.2) but there can be observed a clear correlation (Fig. 6.4.5) for one of the subgroup with less detected events (orange dots in Fig. 6.4.2). The inter-event times between two successive events of the northern signals do not seem to have a characteristic period that would point towards pounding of the waves against the shore line.

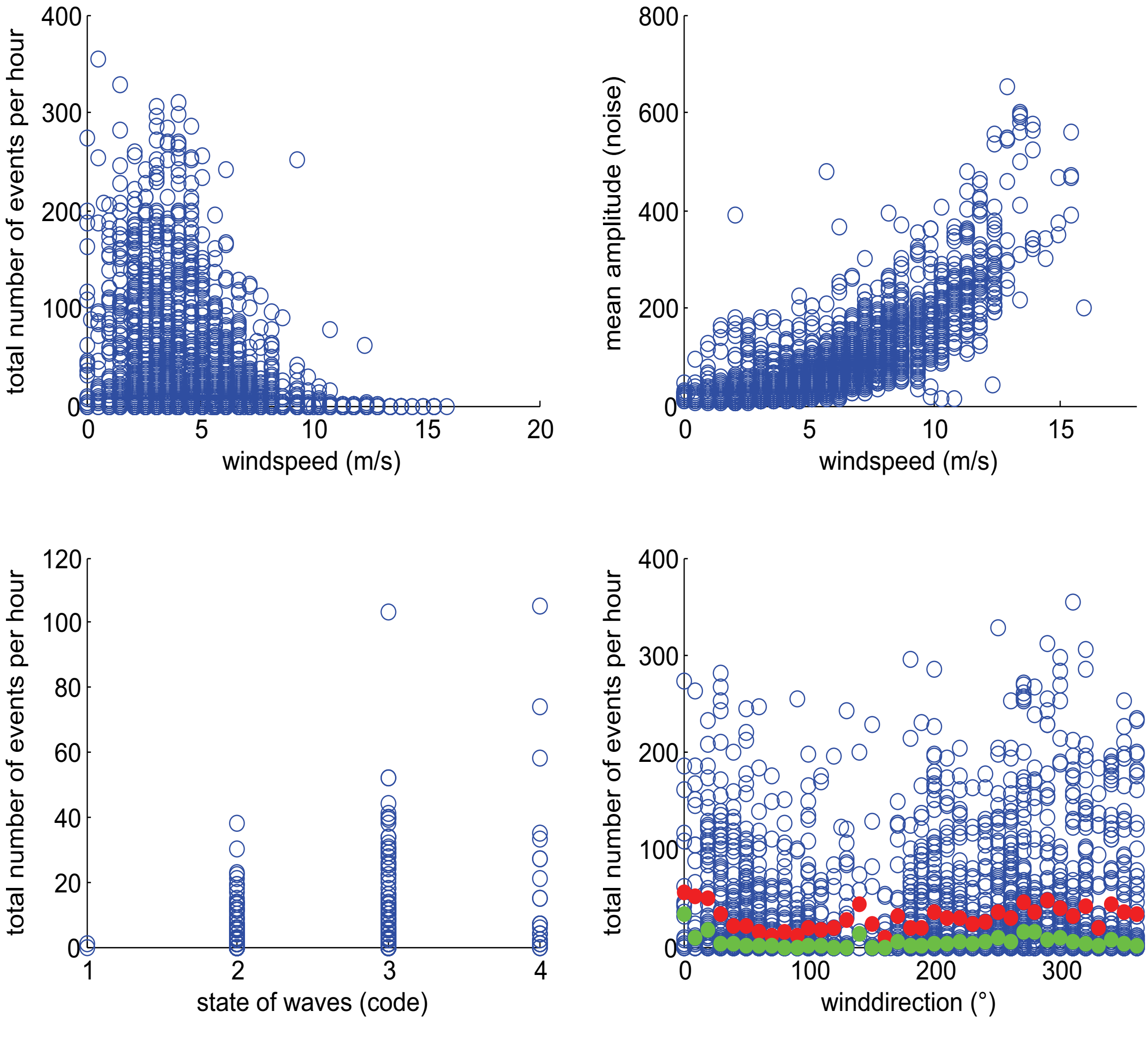


Fig. 6.4.5. Northcoast events. Correlations between: (top left) number of events and wind speed for the largest event group (purple dots in Fig. 6.4.2), (top right) wind speed and noise level at the traces, (bottom left) state of waves and the number of events for the smaller group of events (orange dots in Fig. 6.4.2) and (bottom right) the wind direction and the number of events for the largest event group (purple dots in Fig. 6.4.2). The red and green dots display the mean and median of the number of events, respectively. Code wave heights: 1: 0-0.1 m, 2: 0.1-0.5 m, 3: 0.5-1.25 m, 4: 1.25-2.5 m, 5: 2.5-4 m.

Events inside the network

A second group of events appeared at the beginning of the recording time (see green dots in Fig. 6.4.2). The signals can be located at different positions between the stations of the network often corresponding with the locations of rivers and lakes on the island. They are characterized by strong signal amplitudes at the stations closest to the source origin and no recordings at seismometers at greater distance. In most of the cases just surface waves can be observed, indicating very shallow sources.

It is assumed that this group occurs due to melting snow and the breaking of ice floes on the rivers and lakes of the island. The meteorological station on Bear Island reported a thick snow covering until May 29 and a thin snow covering until June 9. Especially at the beginning of June, several events of this kind were recorded, coinciding with a marked rise in the air temperature. It seems to support the aforementioned assumptions of ice and snow melting effects.

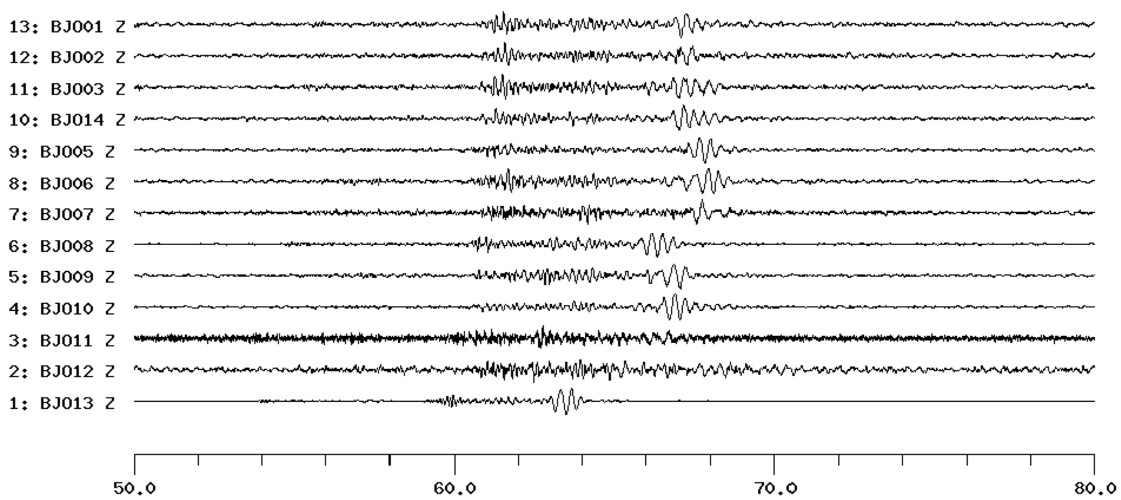
Probable tectonic events

Several small events can be found in the dataset with origin in the southern and southwestern parts and surroundings of the island (see yellow dots in Fig. 6.4.2). They were detected at all seismometers of the network but show significant amplitude variations between the stations. The whole seismograms are five to six seconds long. The source signal duration is about one second and has a dominant frequency for the P-phases of about 5 Hz (Fig. 6.4.6). P-, S- and surface-waves could be observed, arriving with incidence angles of about 50º. The strong surface waves indicate shallow source depths, waveform modelling results suggest source depths of less than 1 km. However, the pronounced SH-wave observations of the events do not agree with hypothetical explosion origins. Besides, we have no knowledge about seismic experiments with explosion sources in this area during the occurrence times of these events. Therefore, we assume that these events could have a tectonic origin.

Three different such signals were used as master events for the waveform correlation code to detect other events of the same type. In total 49 events were discovered, about 20 on the same day. We note that the master events were not detected when using one of the other master events as a template. They therefore do not seem to originate from the same or a very close source location (Gibbons & Ringdal, 2006).

A comparison with geological mapped fault structures is not possible. A geological map for Bear Island exists but no information for the closer surroundings of the island are available. Bear Island is located on the sheared continental margin of the Barents Sea shelf. Rifting and breakup of the former continent began in the Late Cretaceous forming the Norwegian-Greenland Sea (Worsley et al., 2001; Breivik et al., 2003; Worsley, 2006; Faleide et al., 2008). The present day stress field of the island is complicated.

It is possible that there are more recorded tectonic events from different locations but it was not feasible to analyze the whole dataset within this study.



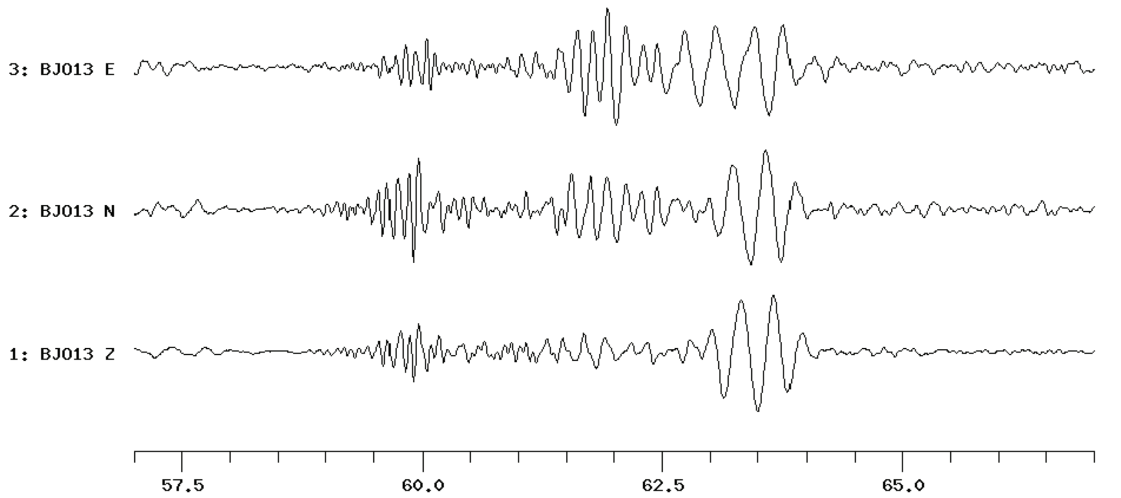


Fig. 6.4.6. Small, most likely tectonic event from August, 4 2008 filtered with a Butterworth band-pass filter from 3-16 Hz. The time axes shows seconds since 11 pm. Top: Vertical components of all stations, absolute amplitudes. Bottom: all three components of station BJO13.

6.4 Conclusions

During the internship, several events could be identified. Weather phenomena, especially the strength of wind, seem to have a great influence on the quality of the recordings in the form of incoherent noise. Other potential noise sources can be found at steep coasts. Although the origin is still in question, such kind of events can disturb the signals of especially smaller tectonic events when occurring in greater numbers. The melting of snow and breaking of ice floes on rivers and lakes acts as a similar noise source in arctic environments.

The presumable tectonic events in the southeast of the array are still under investigation. Signals from events with location estimates will be compared with synthetic seismograms. Depth and kind of source mechanism can be varied until a "best" fitting solution is achieved. A source inversion is planned.

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