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# Semiannual Technical Summary

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## 6.2 The New Three-Component Very Broadband Seismic Station at Troll, Antarctica

### 6.2.1 Introduction

NORSAR has for a long time pursued the idea of installing a permanent broadband seismometer station at the Norwegian Antarctic Research Base Troll in Dronning Maud Land, Antarctica (Fig. 6.2.1). In spring 2011, the Norwegian Polar Institute (NPI) published together with the Norwegian Research Council a call for new research projects related to Troll in context to the activities of the Norwegian Antarctic Research Expedition (NARE) 2011 – 2014. NORSAR applied for installing a permanent, high quality, very broadband seismic station during the Antarctic summer season 2011/12 and the project was funded.

Most of the Antarctic continent is covered by a thick layer of ice. Therefore, seismic stations are often installed on ice, which is not really optimal: the thick ice layers disturb the pulse shape of seismic signals. In addition, seismic stations move along with the dynamic ice shield. The horizontal movements can be easily tracked and station coordinates corrected for, but in particular the horizontal components of seismic sensors are dependent on a stable horizontal leveling, which moving ice cannot guarantee. Then, sensors have to be leveled quite often, which makes a proper permanent operation dependent on regular maintenance.

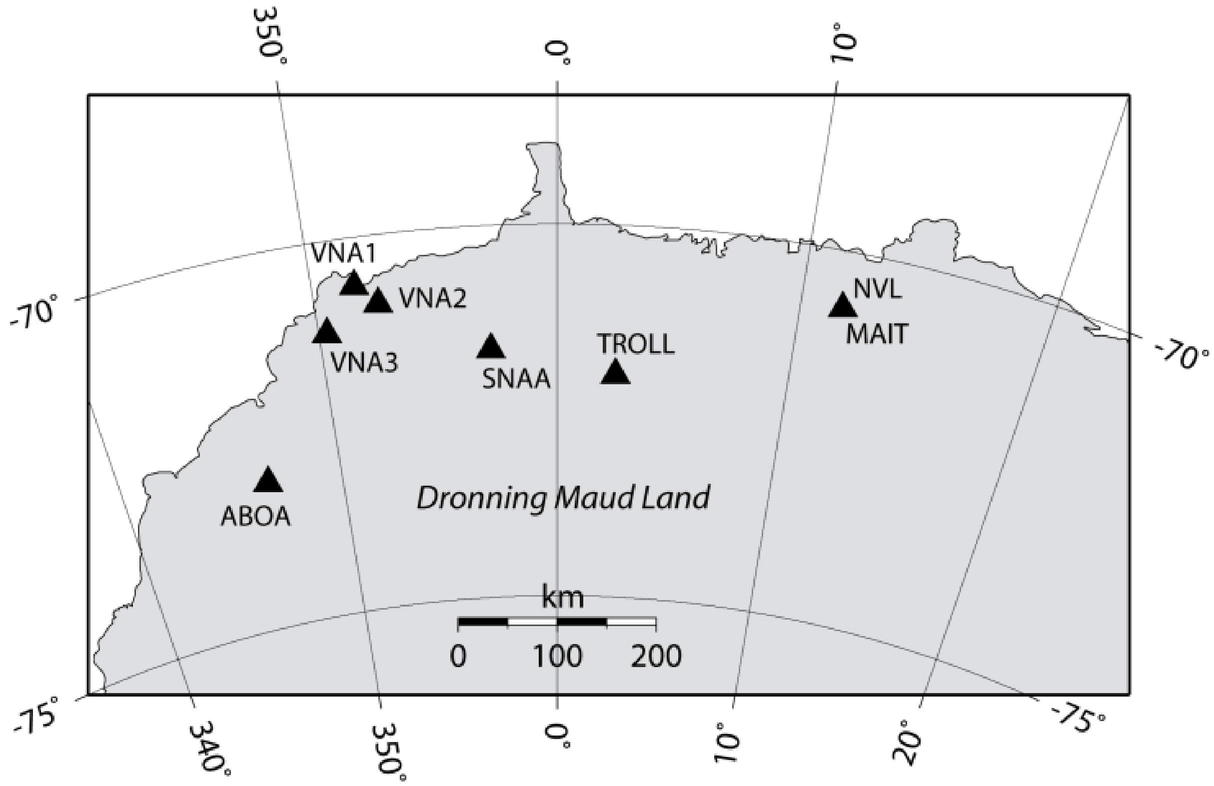


*Fig. 6.2.1 Locations of seismic stations in Dronning Maud Land. Seismic data from TROLL, VNA(1-3) and SNAA are accessible in real time.*

### 6.2.2 Station installation

Troll is located on a bedrock outcrop (Jutulsessen nunatak), consisting of metamorphic, heterogeneous migmatite. Here, a seismic station can be operated without signals being disturbed by the (moving) ice sheet. Fig. 6.2.1 shows how the new station supplements the existing network of permanent seismic stations in Dronning Maud Land.

All equipment was purchased in autumn 2011 and was extensively tested during December 2011 and January 2012 at NORSAR's test facility Stendammen (Løten, Hedmark). At the end of January 2012, NORSAR staff traveled to Troll and installed the station, which has been operational since 5 February 2012. Since then, the station has been running continuously except for two short outages due to Ethernet connection problems. The station is equipped with a Streckeisen STS-2.5 broadband seismometer, which can measure ground movements in the frequency range from below 1 mHz up to about 50 Hz. The chosen digitizer is a Quanterra Q330HR, which converts the analogue seismometer signals with an over 150db dynamic range (26 bit AD converter) and samples the data streams with rates of 100 Hz, 40 Hz, 1 Hz, 10 s and 100 s.

All seismic data are transfered from the digitizer to a laptop in the main research base building. There, the data are stored as back-up and simultaneously transmitted in real time via the Internet to NORSAR. NORSAR adds the data to its database and sends them to ORFEUS, the European data center for seismic broadband data, so that they are accessible to the entire seismological community.

*Fig. 6.2.2 The picture shows the selected seismometer site with bedrock surface and natural shielding for some directions against the strong Antarctic storms.*

The ground near the research station consists mostly of weathered bedrock or moraine material. A very favorable place to install the seismometer was found south of the top of Nonshøgda on a small bedrock plateau (see Fig. 6.2.2). Here, the building of a foundation for the station was easy. The site is close (about 60 m distance) to a small cabin called Huttetu with access to power and Ethernet . The distance to the main Troll research base (building, power plant, workshop, etc) is about 400 m, far enough to have low exposure to man-made noise. To achieve a low noise level, in particular for long period signals, the station has to be protected against rapid temperature and air pressure changes (Forbriger, 2012). Pictures of building and protecting the station are shown in Fig. 6.2.3.

The geographic ccordinates of the new station were measured with GPS and compared with high resolution maps of Nonshøgda provided by NPI. The station is located (WGS84 coordinate reference sytem) at:

| | |
|---|---|
| Latitude: | 72.0082° South |
| Longitude: | 2.5300° East |
| Elevation: | 1399 m above mean sea level |

The station is registered in the international station registry of seismic stations with the code TROLL.

*Fig. 6.2.3 Pictures from building the new seismometer station TROLL (progress from top to bottom and left to right): Flattening the bedrock surface; making a small fundament of cement; placing the oriented seismometer on a granite base; packing the seismometer in a first-aid-sheet for temperature protection; filling a steel casing with insulation material and placing it over the seismometer to avoid thermal convection of the air around the seismometer and protect it against rapid air pressure changes; installing cables, digitizer and GPS antenna; covering the whole with a double walled plastic dome, which is screwed to the bedrock; work done.*

### 6.2.3 The seismic background noise level at the new station

After the first days of operation, it became clear that the new station is very sensitive to direct sunlight exposure. Zürn and Otto (2000) described strong tilt effects due to small temperature changes in seismometers vaults. Their interpretation was that temperature variations deform the vault surface and thereby tilt the seismometers. Following this observation, the surroundings of the station were at the end of March covered with stones by staff members of the Troll research station, so that the bedrock surface is no longer exposed to direct sunlight. The effect is obvious when comparing very long period filtered data from time intervals before and after the change. Fig. 6.2.4

shows one week of very long period filtered 3C data (Butterworth low-pass with a period of 5000 s) recorded before (upper three traces) and after covering (lower three traces) the surrounding with stones. All traces are equally normalized with an amplitude of 30000 counts. A daily signal is still visible, but it is much smaller than before the surroundings were covered with stones. To reduce this effect even more, we plan during the coming austral summer (2012/13) to install more insulating material around the steel casing and to paint the orange plastic dome white (see Fig. 6.2.3).

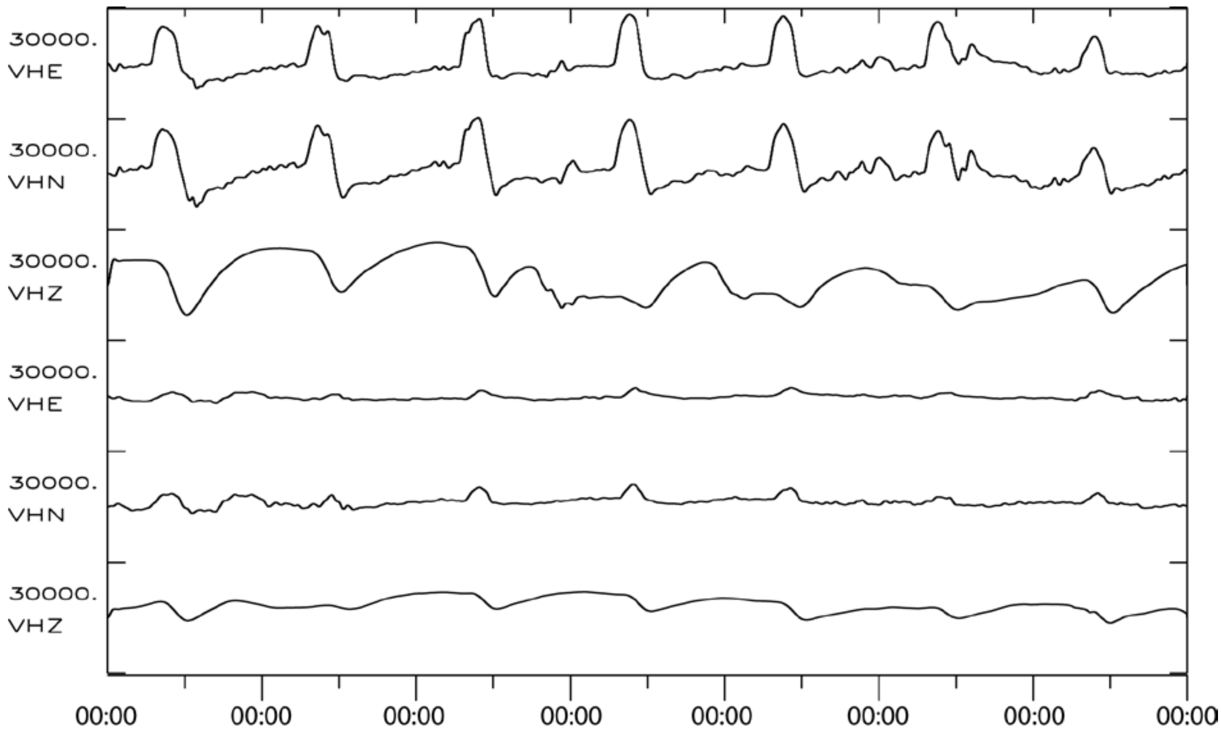


*Fig. 6.2.4 Seven days of very long period filtered data (Butterworth low pass 5000 s) for the time periods 22 – 29 March 2012 (upper three traces) and 3 – 10 April 2012 (lower three traces). All traces are normalized to a maximum amplitude of 30000 counts.*

Further inspection of the data led to the identification of additional noise sources. In the higher frequency range, we see a noise spike at 12.5 Hz and its overtones at 25 and 37.5 Hz. The source is presumably the power transformator in the nearby cabin. How exactly this noise couples into the seismic data is at the moment unknown. Another spike in the noise spectrum is observed at about 160-170 s. We assume that this is a beat frequency caused by the power generator for the research base: there are installed two different power generators and we could observe a change in the beat frequency when the two power generators were switched. However, all these noise amplitudes are quite small and when analysing usual seismic signals they have only minor influence on the data.

In conclusion, the installation of a very broadband seismometer station at the Norwegian Research Base Troll was very succesful. This can also be seen when comparing the power-spectral density (PSD) for a long time period between data from TROLL and the seismic station at the South Pole (quite zone station, QSPA60). TROLL has a very similar equipment to QSPA60. Although located about 1000 km closer to the open ocean and therefore more exposed to microseismic noise, TROLL shows a much lower seismic noise level. Fig. 6.2.5 shows PQLX-plots, which display the distribution of the PSD through a Probability Density Function (PDF) for the vertical components. The PQLX plot for QSPA60 has been calculated at IRIS and for TROLL at ORFEUS, both for the data observed in 2012 until the end of July. The mean noise level, represented by the blueish and greenish colors is much closer to the New Low Noise Model (NLNM, Peterson, 1993; see lower gray line in Fig. 6.2.5) at TROLL than at QSPA60.

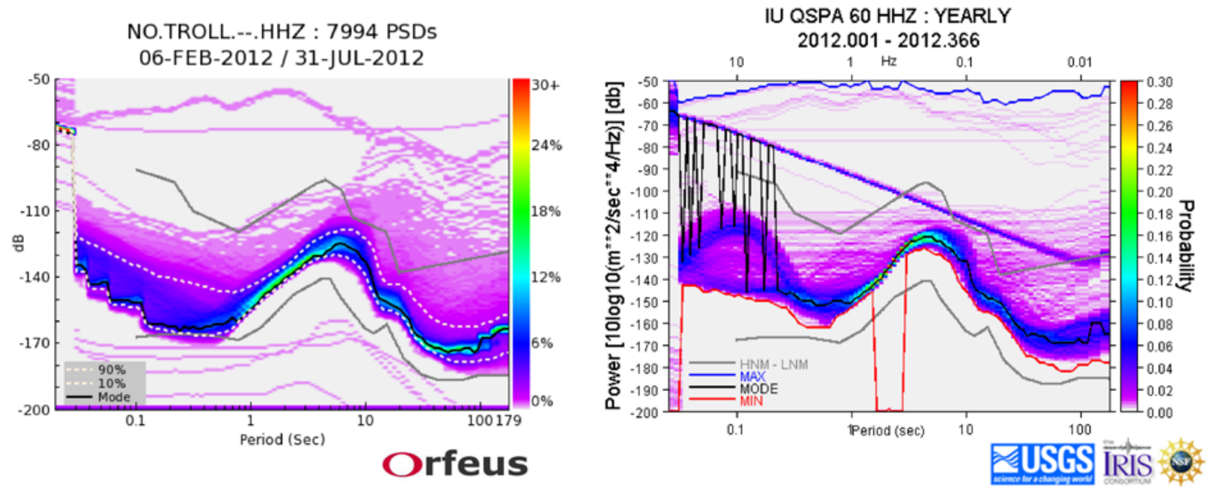


*Fig. 6.2.5 PQLX plots for seismic data recorded at TROLL and the South Pole Station (QSPA60) as calculated at the international data centers ORFEUS and IRIS. For more details see text.*

### 6.2.4 TROLL station instrument response

The broadband station TROLL is equipped with a Streckeisen STS-2.5 triaxial seismometer and a Quanterra Q330HR digitizer. The seismometer has the serial number #110644 and the digitizer #4629. The response characteristics (poles/zeros, sensitivity values and digital filters) are listed below.

***Table 6.2.1. Poles and zeros for velocity response in rad/s for the vertical component of the STS-2.5 seismometer #110644 installed at TROLL station, Antarctica.***

| | **Real part** | **Imaginary part** |
|---|---|---|
| **Poles (7)** | | |
| Highpass pole | -0.037124934 | 0.0370312 |
| Highpass pole | -0.037124934 | -0.0370312 |
| High frequency double real pole | -16.063333 | 0 |
| High frequency double real pole | -16.063333 | 0 |
| Double real pole | -336.1 | 113.94333 |
| Double real pole | -336.1 | -113.94333 |
| Phase shift pole | -958.5 | 0 |
| **Zeros (8)** | | |
| Double real zero | -15.71 | 0 |
| Double real zero | -15.71 | 0 |
| Inverse filter double zero | -556.1 | 936.2 |
| Inverse filter double zero | -556.1 | -936.2 |
| Inverse filter zero | -630.2 | 0 |
| Phase shift zero | 958.85 | 0 |
| Zero @ 0 | 0 | 0 |
| Zero @ 0 | 0 | 0 |

The poles and zeros listed above in Table 6.2.1 correspond to the vertical component of the sensor. The pole/zero set for the two horizontal components differs slightly and can be found in the corresponding GSE response files distributed by NORSAR. The gain of the seismometer is equal to 1500 V/m/s at 2 s.

The sensitivity of the 26 bit Q330HR digitizer is equal to 1677721.6 count/V for all channels.

TROLL is set to output 5 different sampling rates: 100 sps at the HHZ/N/E channels, 40 sps at the BHZ/N/E, 1 sps at the LHZ/N/E, 0.1 sps at the VHZ/N/E and 0.01 sps at the UHZ/N/E channels. The digital filter(s) used to output these sampling rates are listed in Table 6.2.2. Software filters are used to output sampling rates below 1 sps.

***Table 6.2.2. Digital FIR filter characteristics and cascades, used to output the selected sampling rates for the TROLL station data.***

| Sampling rate | Channel name | Digital filter | Decimation | Symmetry | N coeff. |
|---|---|---|---|---|---|
| 100 sps | HH | Quanterra FLbelow100-100 | 1 | asymmetric | 65 |
| 40 sps | BH | Quanterra FLbelow 100-40 | 1 | asymmetric | 39 |
| 1 sps | LH | Quanterra FLbelow 100-1 | 1 | asymmetric | 31 |
| 0.1 sps | VH | Quanterra FLbelow 100-1 | 1 | asymmetric | 31 |
| | | FIR DEC 10 | 10 | symmetric even | 400 |
| 0.01 sps | UH | Quanterra FLbelow 100-1 | 1 | asymmetric | 31 |
| | | FIR DEC 10 | 10 | symmetric even | 400 |
| | | FIR DEC 10 | 10 | symmetric even | 400 |

The displacement amplitude and phase response curves for the vertical component, 100 sps channel of TROLL are shown in Fig. 6.2.6. The TROLL station configurations described above and corresponding Respid flags (Pirli, 2010) are listed in Table 6.2.3.

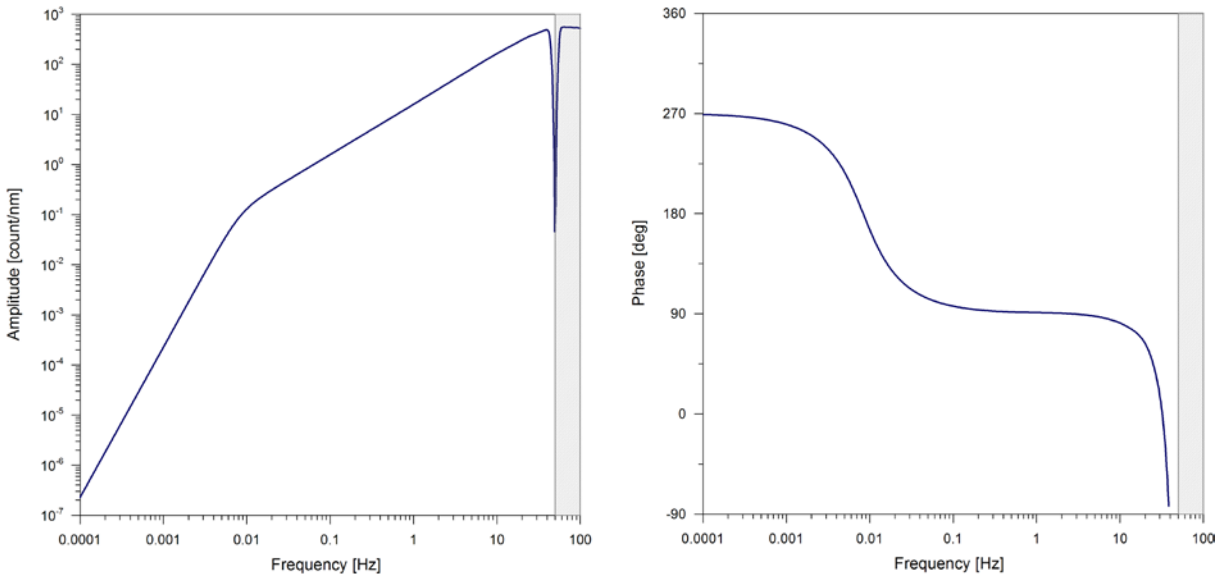


*Fig. 6.2.6 Displacement amplitude and phase response for the vertical component of the 100 sps channel (HHZ) of TROLL. Shaded areas show the frequency range beyond the Nyquist (50Hz).*

***Table 6.2.3. The instrument configurations of the TROLL station. Overall channel sensitivity values are equal for the different sampling rates and shown only once.***

| Time | Installation name Respid(s) | System components | Calib [nm/count] | Calper [s] |
|---|---|---|---|---|
| 2011/12/07 – 2012/01/13 | Test installation<br>TROLLHH1a<br>TROLLHH2a<br>TROLLHH3a | <br>STS-2.5<br>Q330HR digitizer | <br>0.062978<br>0.062981<br>0.062976 | <br>1 |
| 2012/02/05 – … | Current installation<br>TROLLHH1<br>TROLLHH2<br>TROLLHH3<br>TROLLBH1<br>TROLLBH2<br>TROLLBH3<br>TROLLLH1<br>TROLLLH2<br>TROLLLH3<br>TROLLVH1<br>TROLLVH2<br>TROLLVH3<br>TROLLUH1<br>TROLLUH2<br>TROLLUH3 | <br>STS-2.5<br>Q330HR digitizer | <br>0.062978<br>0.062981<br>0.062976 | <br>1 |

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