Operational Procedures of Agencies Contributing to the ISC

The AWI Network Antarctica

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Operational Procedures of Contributing Agencies

5.1 The AWI Network Antarctica – Alfred-Wegener Institute, Germany

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5.1.1 Introduction

Antarctica is a seismically quiet continent with low earthquake hazard, as subduction zones and large active faults are missing. Apart from some researchers, no population would be endangered by catastrophic earthquakes. Seismic stations in Antarctica are therefore scattered and more of scientific interest: they contribute important data for global Earth models and local events provide information about neotectonic or cryogenic processes.

Most seismometers are installed at research stations, where power and telemetry are available; the site selection is not usually made to provide ideal conditions for a seismic station but is based on logistical considerations. Some autonomous stations are installed away from research bases and thus suffer, for example, from the extreme cold in winter and from long periods of darkness causing serious power shortages and often leading to data gaps during the austral winter months (May to September).

The Alfred Wegener Institute (AWI) is a German research institute for polar science based in Bremerhaven, Germany. AWI operates the regional seismic network with the network code AW in Dronning Maud Land, East Antarctica (Fig. 5.1) increasing the global station coverage and revealing local earthquakes undetected by global networks.

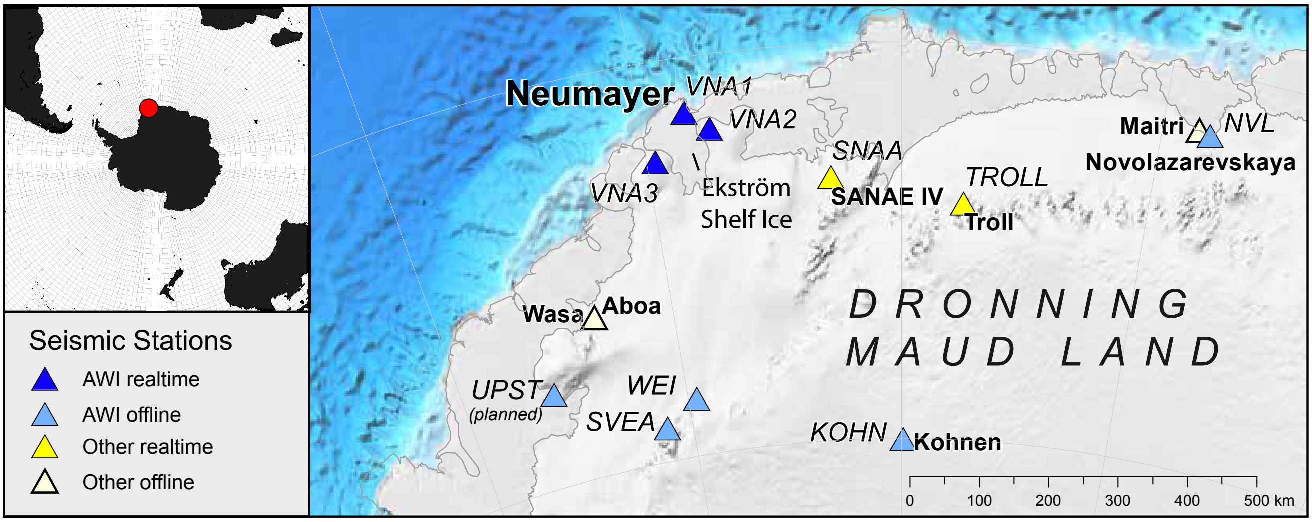

Figure 5.1: *Currently operating long term seismic stations in Dronning Maud Land organzied by AWI and others. The red dot in the upper left overview map indicates Neumayer Station. Grey lines in the map mark the extend of shelf ice.*

5.1.2 Seismicity

Large earthquakes within Antarctica have not been observed so far. Antarctica is surrounded by passive margins and small regional events occur regularly at the oceanic spreading ridges more than 800 km distant. Nevertheless, the unique environment of the ice-covered continent is a source of signals of its own: icequakes caused by moving and breaking ice emit signals similar to earthquakes caused by moving and breaking tectonic plates. Figure 5.2 displays an overview of local, cryogenic and teleseismic events observed by the AW network.

The AW network is very sensitive to teleseismic events from the South Sandwich Island arc, South America, the Fiji/Tonga region and for core phases from Japan (Fig. 5.2B). Many moderate events from the subduction zone at the South Sandwich Island arc (epicentral distance $\Delta = 13-18°$) are not detected by the global network in real-time and are located only during the ISC review process, when AW arrivals and core phases recorded in Japan are analysed simultaneously.

The AW network recorded some local tectonic seismicity in Dronning Maud Land, mainly in the area of the Jutul Penck Graben and around Cape Norvegia (Fig. 5.2A). The events at the continental margin around Cape Norvegia might be isostatic rebound events related to changes in the Antarctic ice mass. The seismic activity at the Jutul Penck Graben is likely to be of tectonic origin, although further analysis is needed to constrain this assumption (*Eckstaller et al.*, 2007). The Jutul Penck Graben is assumed to be a failed rift from the Jurassic (*Grantham and Hunter*, 1991) and represents the tectonic boundary between the Grunehogna Craton and the East African Antarctic orogen (*Mieth and Jokat*, 2014). This old rift might have been reactivated causing the observed seismic activity.

Apart from tectonic events, numerous cryogenic events are detected by the AW network (Fig. 5.2C). Some are similar to earthquakes generated by brittle failure of the ice, while others are related to tides and icebergs (*Hammer et al.*, 2015). While icebergs move along the margin, they collide with the continental shelf from time to time and generate impact events as shown in Figure 5.2C. The frequency content of these events is lower than that of tectonic earthquakes.

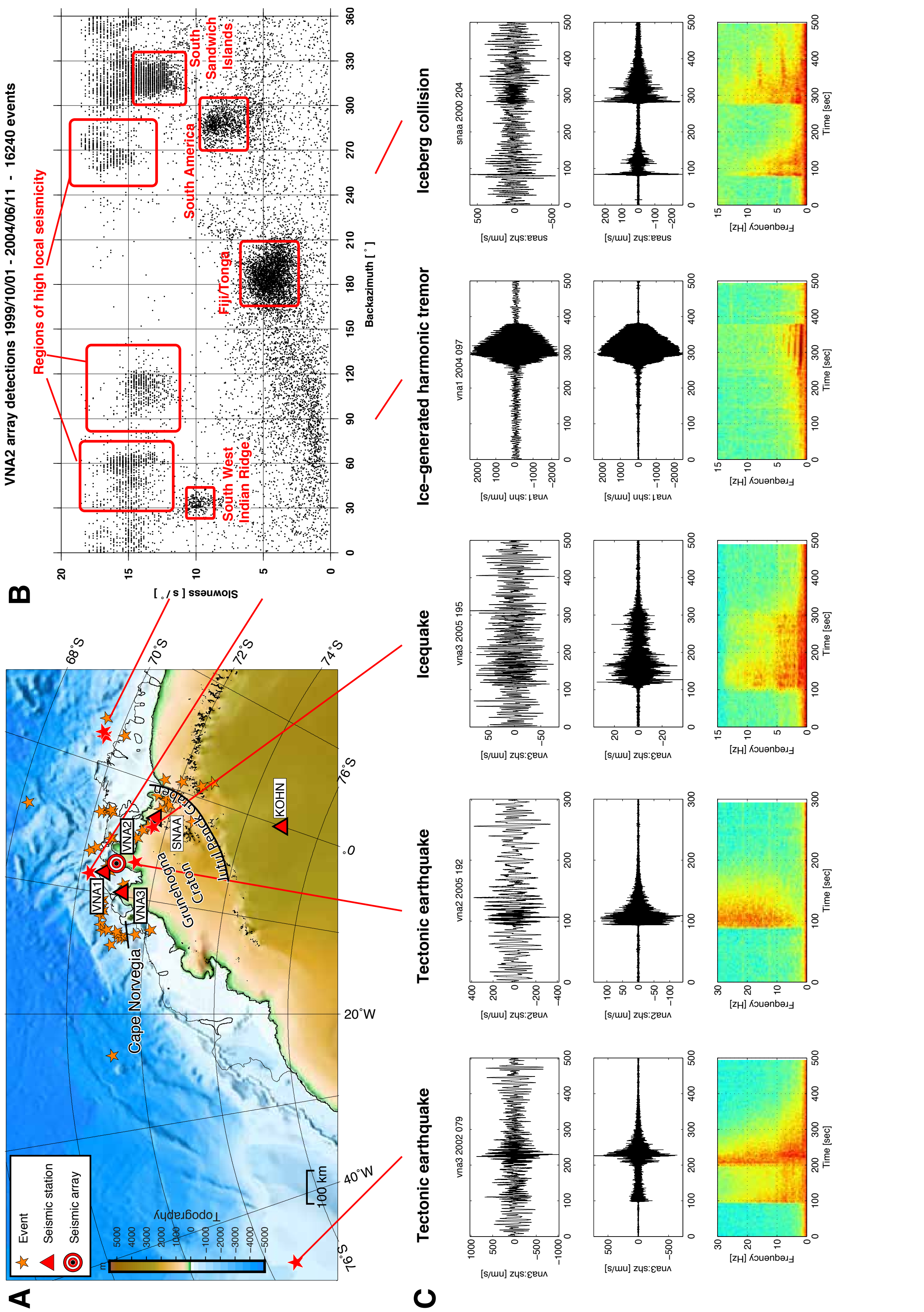

Figure 5.2: *Examples for types of local seismicity observed at the AW-network. (A) Topographic map showing the location of events. (B) Distribution of backazimuth and slowness for events detected at VNA2 array (C) Waveform examples (upper: raw waveform, middle: filtered (0.5-10 Hz), lower: spectrogram). Figure from Eckstaller et al. (2007).*

Another type of cryogenic event is similar to seismic tremors generated at volcanoes. *Müller et al.* (2005) interpret events at Neumayer (see Figure 5.1 and Section 5.1.3) as tremors generated within icebergs moving along the coast. It is also possible to track icebergs locating the tremors.

5.1.3 History

The development of the AW network is coupled to the foundation of the Alfred Wegner Institute in 1980. The first wintering station, Georg-von-Neumayer, was built in 1981 at the Ekström ice shelf and scientific research started a year later. The first seismometer was setup in 1982 (*Augstein*, 1984), but during the early years of research seismometers were not being operated as long-term observatory stations. Instead, small arrays were installed for dedicated studies of icequakes, shelf ice dynamics or crustal structures (*Osten-Woldenburg*, 1990; *Nixdorf*, 1992; *Eckstaller*, 1988; *Eckstaller and Miller*, 1993).

The first long term observatory station VNA1 was registered in 1992 and installed during the construction of the second research base, Neumayer Station 2 (summary in Tab. 5.1). Since then, phase arrival information have been sent to the ISC on a daily base. Four years later, in 1996, data became available from two additional stations (VNA2 and VNA3) at 45 and 83 km distance from VNA1 on grounded ice (Fig. 5.1, *Eckstaller et al.* (1997)). VNA2 was extended by an array of 15 seismometers with an aperture of 1.8 km in 1997 (*Büsselberg et al.*, 2001). All VNA stations were equipped with three component Lennartz seismometers with eigenperiods of 1, 5 or 20 s. The array seismometers at VNA2 are one component 1 Hz vertical Mark L4 sensors. Data was recorded with a Lennartz PCM system – first in triggered mode and since 1999 continuously – and transmitted in real-time via radio links from the remote sites to Neumayer 2 (*Eckstaller et al.*, 1997). The daily bulletin was expanded to arrival information from all three stations. This small local network allowed for the first time the analysis of local seismicity in the remote region of the Dronning Maud Land. Especially, the VNA2 array enabled us to identify the local events shown in Figure 5.2.

In 2006, we installed the first remote station working autonomously and without real-time data transmission at the unmanned Swedish summer station SVEA approximately 450 km south of Neumayer. The next major hardware upgrade of the network was performed during the construction of Neumayer Station III between 2007 and 2009. The sensors of the VNA stations were replaced by broad band seismometers and the recording system was modernized to the current state (see Section 5.1.4 Network Description). The whole network was further extended by autonomous stations at logistically accessible locations for 'easy' maintenance (Fig. 5.1).

5.1.4 Network Description

Currently, the network consists of three broadband stations available in real-time and four offline stations (Fig. 5.1). The real-time stations (VNA1, 2, 3) are equipped with Q330 datalogger and Guralp three-component seismometers (CMG-3ESP 120 s, 50 Hz sampling rate). The four offline stations are equipped with Reftek 130 datalogger and either Guralp (CMG-3ESP 120s) or three component LE-3D 20s seismometers. The data is recorded to memory cards and collected once a year, if possible.

Apart from NVL and VNA1, all stations are in remote areas without power infrastructure and require

Year	Station	Comment
1992	VNA1	Station installation
1988	VNA2,3	Station installation
1996	VNA2,3	Daily analysis routine with triggered data
1997	VNA2	Installation of array seismometers, continuous recording
2006	SVEA	Station installation
2009	KOHN, NVL	Station installation
2010	VNA1,2,3	Major hardware upgrade of acquisition system
2010	WEI	Station installation
2010	VNA2,3	Installation of broadband sensor
2012	VNA1	Installation of broadband sensor
2018	UPST	Planned installation of broadband sensor and mini-array on rock outcrop

Table 5.1: *Historical changes in the AW network. Refer to Figure 5.1 for station locations.*

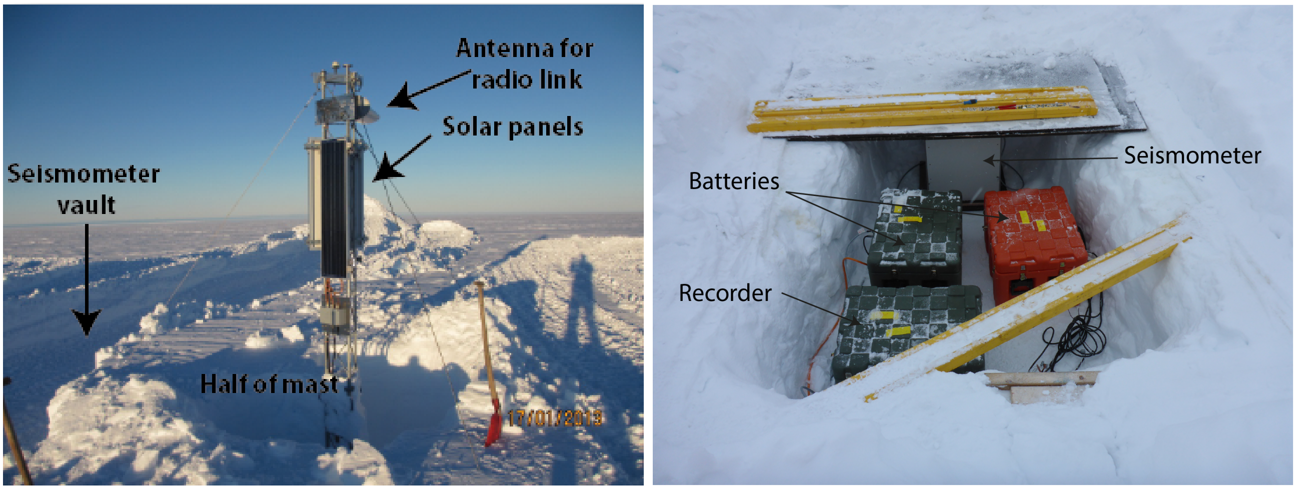

Figure 5.3: *During the yearly maintenance at VNA3 we recover all instruments and constructions, which can be buried under up to 3 m snow (left). The seismometer and all electrical devices are set up in a snow pit (right).*

specialized technical development to withstand the harsh environment including extremely low temperatures of sometimes less than -50°C. Power is supplied by solar panels and, for some stations, by additional wind mills to cover the periods of darkness during the austral winter (Fig. 5.3). Depending on the surroundings, the sensors are either buried in snow pits or installed on bare rock. Snow pits are easy to build and isolate the sensor from large temperature variations and wind induced noise (Fig. 5.3, right). However, ice deformation can cause significant tilting of the sensor during a year. Sensor installation on rock requires more solid housings to shield the sensor from wind, blowing snow and water, since dark rock increases melting during the summer. Bare rocks are rare and not always available for seismometer installations as 95% of the Antarctic continent is ice covered.

5.1.5 Data Processing

Data are recorded and managed with the BRTT Antelope software package. In addition to our own real-time stations, we import additional data from other Antarctic stations via IRIS and Geofon to allow for a simple daily processing routine and event review. The winterer at Neumayer station analyse the data manually and pick teleseismic and potential local events. Seismic Handler calculates azimuth and slowness values for the array at VNA2 greatly facilitating the initial localisation. We use BRTTs GUI dbloc2 for event localisation and association. Nearly all recorded events occur far outside our network, so our own locations have large uncertainties. Instead we associate the picked arrivals with preliminary locations from NEIC or EMSC catalogs. Only if catalog events are absent, we locate the event using dblocsat2 (written by Bratt and Nagy) or genloc (written by Gary L. Pavlis). Finally, all event related data are sent to the ISC. Data from the offline stations is later merged with the data base. We are currently working on automated detection and association routines to add those data to our database and make them available via the ISC database.

5.1.6 Data Quality

The ambient noise level, and therefore the data quality, depends highly on the station location and the weather, whereas man-made noise is mostly irrelevant. We analysed the ambient noise following the procedure published by *McNamara and Buland* (2004) carried out with ObsPy (Fig. 5.4, *Beyreuther et al.*, 2010).

VNA1 shows remarkably high noise levels well above the high noise model in the long periods from 10 to 100 s (*Peterson*, 1993). This noise is unique to all our stations (VNA1 and temporary deployments) on the ice shelf. Since the ice shelf floats on the ocean, it is subject to ocean driven motions such as tides and swell, which can excite infra-gravity waves in this period band (*Bromirski et al.*, 2010; *Tezkan and Yaramanci*, 1993).

The diversification in the period band of the primary microseismic noise between 10 and 30 s is a seasonal variation likely related to the opening of the sea ice cover in front of the shelf ice. Ocean waves reaching shallow waters cause this primary microseismic noise. The opening of the sea ice in front of the shelf

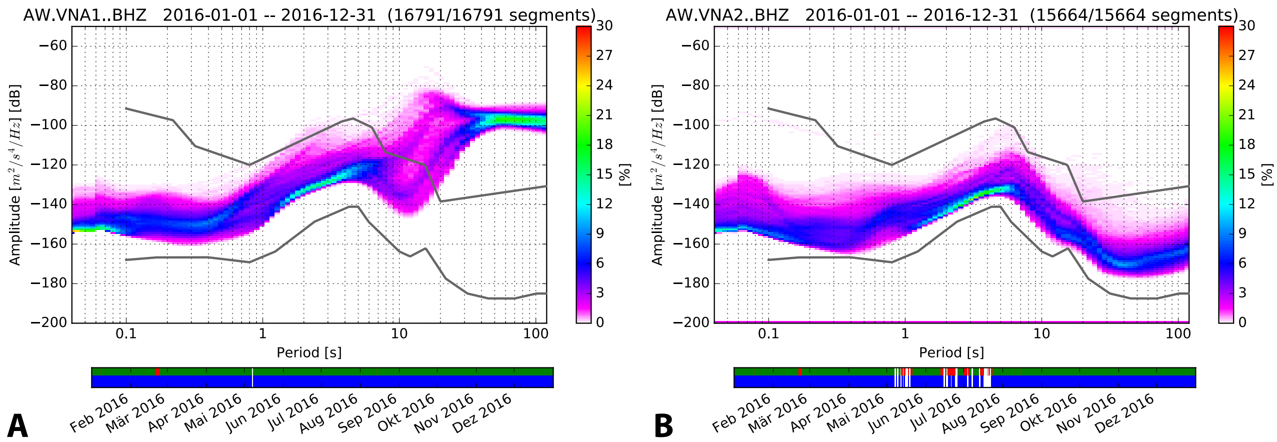

Figure 5.4: *Probabilistic noise spectra for stations VNA1 (left) and VNA2 (right) calculated with ObsPy (Beyreuther et al., 2010) after McNamara and Buland (2004). The high and low noise models after Peterson (1993) are indicated by the black lines. Data coverage is shown below the graphs. 'The top row shows data fed into the PPSD, green patches represent available data, red patches represent gaps in streams that were added to the PPSD. The bottom row in blue shows the single psd measurements that go into the histogram. The default processing method fills gaps with zeros, these data segments then show up as single outlying psd lines.' from ObsPy documentation.)*

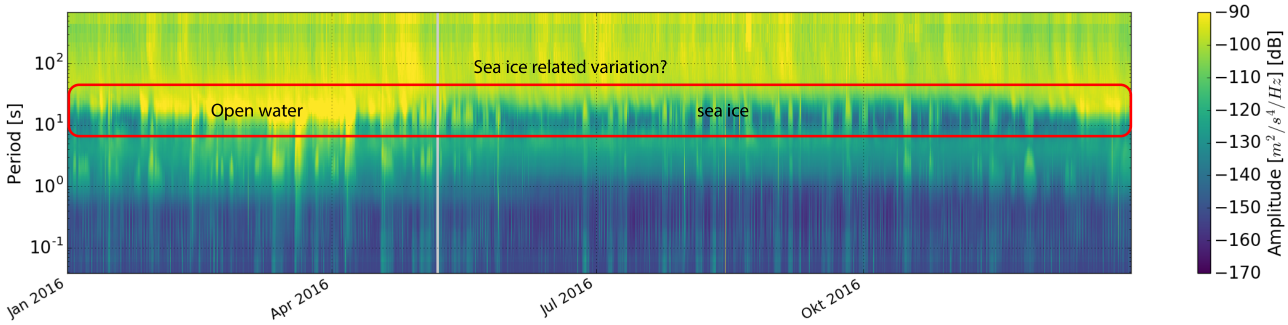

Figure 5.5: *Seasonal probabilistic noise spectra for station VNA1 calculated with ObsPy (Beyreuther et al., 2010) after McNamara and Buland (2004). Note the seasonal variation of the long period noise above 10 s.*

edge moves the 'shoreline' during the late austral summer and early autumn (*Beucler et al.*, 2015: and references therein). This effect was especially strong in 2016 (Fig. 5.5).

The noise level for VNA1 is quite low for frequencies above 1 Hz compared to the noise models, but the location on floating ice has more effects on the data quality not visible in the noise spectra. Even though the noise level is low, the detection threshold for seismic events for VNA1 is higher than for VNA2 and VNA3. Often events are clearly visible at VNA2 and 3, but cannot be observed on VNA1. This is likely an effect of the ocean underneath the shelf ice attenuating ground motions. The water layer also effects the observable phases: S-wave detection is challenging. True S-phases cannot reach the station, only S-waves converted to P-waves can travel through the water column and then be observed. However, much less S-waves are converted to P-waves than theoretically calculated and only strong earthquakes show converted S-phases (*Wüster et al.*, 1992).

The ambient noise levels for VNA2 and VNA3 are generally low, although there is some variation for frequencies higher than 1 Hz (Fig. 5.4b). This wind induced noise depends largely on the local weather. Wind speed often reaches 100 km/h and more causing such elevated noise levels. During storms the sensitivity of the network is strongly affected and small events remain undetected. The noise levels differ between VNA2 and VNA3 because the local wind speed can differ greatly and the snow cover on VNA3 is much thicker compared to VNA2. VNA3 has three metres a year accumulation compared to less than a metre at VNA2. The ice sheet at both stations is grounded on bedrock. Therefore, VNA2 and VNA3 have a better coupling to the ground motion than VNA1.

Timing accuracy is another factor for data quality. While stations VNA1-3 have no timing issues, our remote stations occasionally suffer from failing GPS due to electro-static discharge during storms with blowing snow. In combination with power loss in the winter, this can lead to a complete loss of time information. In this case, time information can be manually recovered using teleseismic earthquakes from regions with accurately known traveltimes. Nevertheless, this recovery can only add crude time information and analysis requiring high accuracy of absolute time should not utilize this data. However, the data can be used for analysis, which only operates on relative time information.

5.1.7 Data Availability

The waveform data for stations VNA1, 2 and 3 are available in real-time through the Geofon data portal (`www.geofon.de`). Archived data can be accessed online for the years from 2006, data before 2006 can be shared on request. The arrival data are available in the ISC catalog for the stations VNA1, 2 and 3 for the whole lifetime of the stations.

Data from our other stations is currently only available on request.

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5.1.8 References

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