Contribution of the seismic monitoring at the Belgian Princess Elisabeth base to East Antarctica ice sheet dynamics and global seismicity studies

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SUMMARY

Owing to the implantation of the « Princess Elisabeth » polar base in East-Antarctica, the Royal Observatory of Belgium undertook research in seismology by installing in February 2010 a permanent broadband seismic station on the bedrock near the base. Due to the poor coverage of permanent seismic stations in Antarctica and the small number build on the bedrock, the station (code name: ELIB) is an interesting new source of information for global seismicity studies.

Since its installation, the station also records numerous local and regional seismic events related to the interaction between the ice sheet flow and the bedrock. To study this seismicity, we installed five additional temporary broadband seismic stations separated by 25-30 km distance in January 2014. All those stations were operational from January to April 2014, which allowed locating different spots of ice-related seismicity in a radius of 200 km around ELIB and studying the processes at their origin.

As many of the ice-related events located by the temporary broad-band seismic network were recorded by ELIB, it is now possible to identify similar events when only ELIB is working, providing a unique opportunity to follow the evolution of this ice seismicity in some target areas where it would be representative of the ice sheet dynamics evolution.

Mots-clés – Antarctique, base Princesse Elisabeth, séismologie, séismes glaciaires

RÉSUMÉ

L'implantation de la base polaire « Princesse Elisabeth » a permis à l'Observatoire Royal de Belgique d'entreprendre des recherches en séismologie dans l'Antarctique-est par l'installation d'une station sismologique à large bande sur le rocher à proximité immédiate de la base. Etant donné la faible couverture géographique des stations sismiques permanentes en Antarctique et le petit nombre d'entre elles installées au rocher, la station (sigle ELIB) est une nouvelle source intéressante d'information pour les études de sismicité globale.

Depuis son installation, cette station a également permis d'enregistrer de nombreux événements sismiques locaux et régionaux reliés à l'interaction entre les mouvements de la calotte glaciaire et le rocher sous-jacent. Pour étudier cette sismicité, cinq stations temporaires additionnelles éloignées de 25-30 km les unes des autres ont été installées en janvier 2014. Toutes ces stations large-bande ont été opérationnelles de janvier à Avril 2014, ce qui a permis d'identifier différentes zones de sismicité glaciaire dans un rayon de 200 km centré sur ELIB et d'étudier les processus à leur origine.

Comme beaucoup des événements localisés par le réseau temporaire à large-bande ont été enregistrés par ELIB, il est possible d'identifier des événements similaires quand ELIB est l'unique station opérationnelle dans la région, offrant une opportunité unique de suivre l'évolution de cette sismicité de glace dans des zones ciblées où elle apparaît comme représentative de l'évolution dynamique de la calotte glaciaire.

Trefwoorden: Antarctica, Prinses Elisabethbasis, seismologie, ijsbevingen

SAMENVATTING

De oprichting van de poolbasis "Prinses Elisabeth" heeft de Koninklijke Sterrenwacht van België in staat gesteld om seismologisch onderzoek in Oost-Antarctica uit te voeren. Hiervoor werd een breedbandseismometer geïnstalleerd op de rots in de onmiddellijke omgeving van de basis. Gezien de beperkte geografische dekking van permanente seismische stations op Antarctica, waarvan er bovendien maar een klein aantal op rotsgrond staan, vormt dit station (codenaam ELIB) een interessante nieuwe bron van informatie voor studies van wereldwijde seismiciteit.

Sinds de installatie heeft het station ook tal van lokale en regionale seismische gebeurtenissen geregistreerd die verband houden met de interactie tussen de bewegende ijskap en het onderliggende gesteente. Om dit fenomeen in meer detail te bestuderen werden in januari 2014 vijf bijkomende tijdelijke stations geïnstalleerd met een onderlinge afstand van 25-30 km. Deze breedbandseismometers waren allemaal operationeel tot in april 2014 en hebben ons toegelaten om verschillende zones met ijsbevingen te identificeren in een straal van 200 km rond ELIB en om de processen te bestuderen die eraan ten oorsprong liggen.

Aangezien veel bevingen gelokaliseerd door het tijdelijk breedbandnetwerk ook door ELIB werden gedetecteerd, is het mogelijk om gelijkaardige fenomenen te identificeren wanneer ELIB als enige station operationeel is in de regio. Dit biedt een unieke gelegenheid om de evolutie van ijsbevingen op te volgen in specifieke doelgebieden waar deze seismiciteit representatief lijkt voor de dynamische evolutie van de ijskap.

INTRODUCTION

The building of the Princess Elisabeth polar base (PES) during the International Polar Year 2007-2008 and its completion in 2008-2009 (BELSPO, 2008, 2011) furnishes the opportunity to the Royal Observatory of Belgium (ROB) to install a permanent seismic station at the base in February 2010 and to initiate a scientific program in seismology with three different axes. The first axis is associated to the Belgian contribution to the worldwide exchange of seismic data. As the spatial distribution of permanent seismic stations is relatively poor in Antarctica, providing data to the international seismic data centres from a bedrock station filling this geographical gap is a significant contribution to the study of the global seismicity (Figure 1). A second objective is to exploit seismic signals recorded by the station to investigate the crustal and lithospheric structure of the area around the Princess Elisabeth base, which is located at the limit of two overlapping Pan-African mobile belts (Mieth et al., 2014). The third axis of research concentrates on ice quakes monitoring, which is now well recognized as furnishing information on the internal deformation of glaciers or polar ice streams and on the processes at their origin and is therefore of strong support in the field of environmental sciences (Podolskiy and Walter, 2016). To investigate this seismicity, we installed a broadband seismic network allowing a temporary monitoring of the area extending from the Roi Baudouin ice shelf to the polar plateau. In this publication, we briefly present and discuss some of the results already obtained from these investigations.

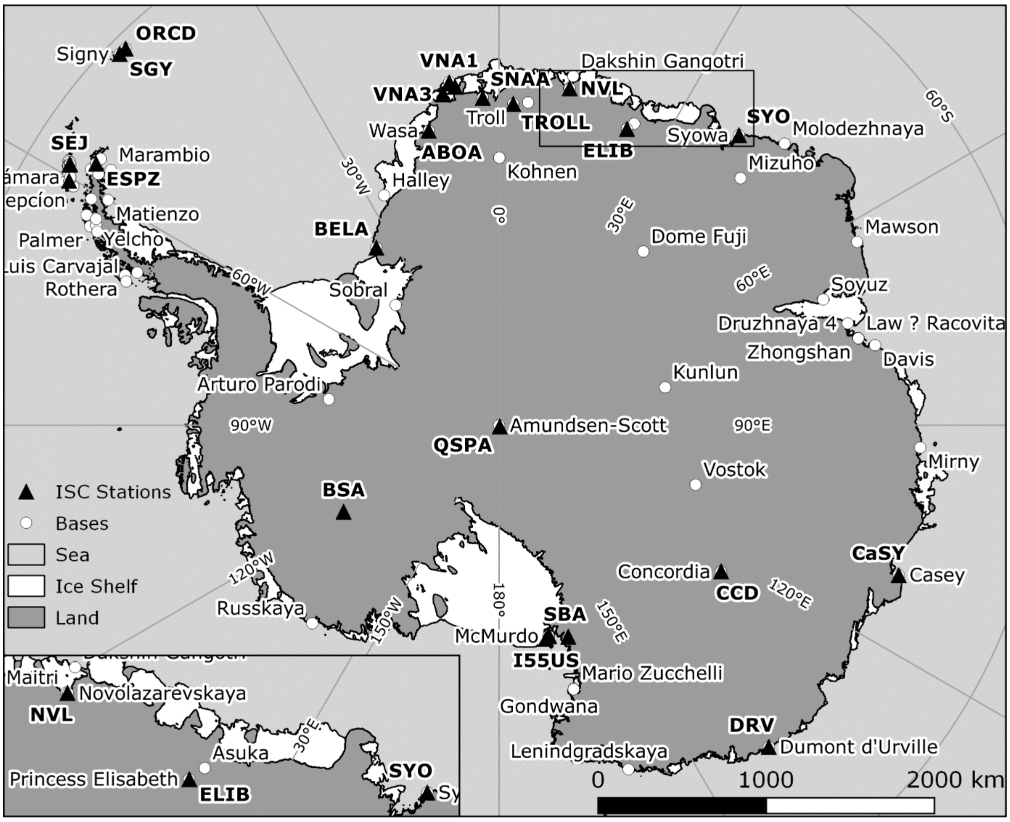

Figure 1: Seismic stations in Antarctica reported by the International Seismograph Station Registry (http://www.isc.ac.uk/registries).

1. A PERMANENT SEISMIC STATION AT THE PRINCESS ELISABETH BELGIAN BASE

In February 2010, we installed a broadband borehole seismometer at the Belgian Princess Elisabeth station with the purpose of evaluating the quality of the site and the perspective of establishing a permanent seismic station. We positioned the seismometer in a 13 m deep borehole and installed the data acquisition system in a nearby shelter located at 350 m from the base. This seismic station is located on the same flat granite rock ridge than the Princess Elisabeth station and rises a few ten meters above the snow coverage. Unfortunately, this equipment only worked during short period because it was not able to survive the numerous power supply interruptions occurring at the base during the implementation phase of its facilities (Figure 2). Due to the high repairing costs of the borehole seismometer for a second time, we stopped this experiment in 2014. Nevertheless, it demonstrated the high quality of the site.

Due to the difficulties encountered with the borehole seismometer, we installed another broadband seismometer at the surface of the ridge in the shelter nearby the borehole location in February 2012. This equipment worked continuously up to end of May 2013, but its operations stopped due to power supply failure at the base during the winter 2013. Similar problem occurred during the successive winters of 2014, 2015 and 2016. During these years, the station was only operational during the austral summer (Figure 2). During the austral summer 2016-2017, technical improvements in the electric power distribution allowed providing continuous electrical supply in the different scientific shelters near the base. Therefore, the seismometer is working without any interruption since January 2017. However, a permanent remote connection is not yet possible, which makes difficult a daily control of the seismic data from our remote office in Belgium. The international code of the station agreed by the International Seismological Centre is ELIB.

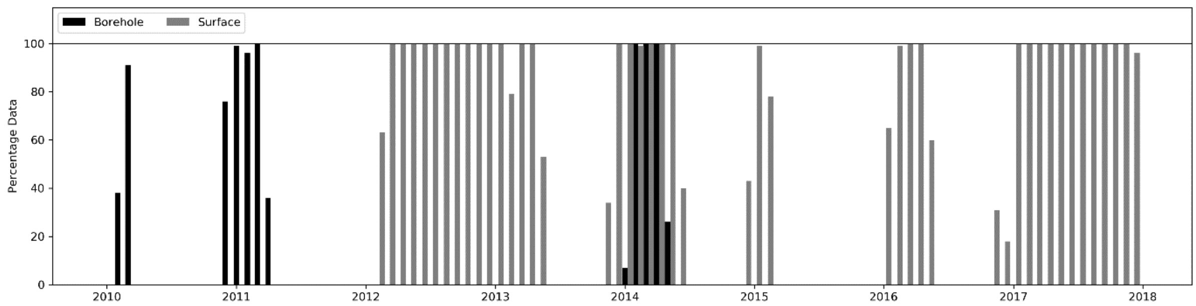

Figure 2: Monthly percentage of working time of the borehole and surface seismometers installed at the PES between 2010 and 2018.

The ability of a seismic station to record the smallest detectable signal from seismic events in the largest possible frequency band attests of its quality. This capacity depends on the type of seismometer and of the seismic noise level in the frequency band of the instrument at the station site. The seismometer installed in 2012 at the Princess Elisabeth polar base is a three-component Nanometrics Trillium TR-120 broadband seismometer with a natural period of 120 s (https://www.nanometrics.ca/products/instrumentation/trillium-120-seismometers). The sampling rate of the seismic signal is 100 samples/s. Therefore, the working flat response bandwidth of the instrument ranges from 0.008 to 50 Hz, allowing to record small local seismic events as well as worldwide large earthquakes.

The absence of noise induced by human activities is an advantage when installing seismic stations in Antarctica. Of course, this benefit diminishes during the occupation periods of polar bases but the human induced noise levels remain low. Therefore, the most important sources of noise have an environmental origin: wind, oceanic loading, atmospheric pressure and temperature changes at low frequencies, etc. In the geophysical shelter, we protected the seismometer against the wind and diminished as best as possible the influence of variations of the atmospheric pressure and temperature. Figure 3 reports the power spectral density of the seismic noise versus its period recorded during 2017 by the vertical component of the ELIB surface station. We also report on this figure the standard curves of the generally expected maximal and minimal limits of noise level conditions observed in seismic stations worldwide. The noise level of the PES seismic station is low over the whole frequency range confirming the excellent site conditions. The capability of the station to detect small local, regional and more distant seismic events also attests of the very low noise level of the station.

2. INTERNATIONAL SEISMIC DATA EXCHANGE

2.1 Contribution of ELIB seismic station to the International Seismological Centre

The "seismology-gravimetry" service of the ROB is contributing to the international seismic data exchange since the beginning of the observational seismology period around the years 1910 by providing seismic phase measurements of worldwide earthquakes recorded by seismic stations in Belgium. Such a contribution is fundamental for international seismic centres to establish a worldwide earthquake catalogue available to the scientific community. Therefore, the installation of a seismic station in a region where their density is poor provides the opportunity to furnish to the scientific community with valuable data at local, regional and global scales. In this context, the ELIB station has two advantages. First, it is one of the easterly station of the whole set of seismic station in East Antarctica (see Figure 1). And second, it directly records ground motions on the bedrock with the consequence that the recordings are less affected by wave reverberation in the ice column contrary to many other stations in Antarctica that are located on the ice.

This is why one of our objectives in establishing a permanent seismic station in Antarctica was to provide to the International Seismological Center (ISC) measurements of arrival times and amplitudes of seismic phases measured at the ELIB station for global, regional and local earthquakes. This activity is time consuming and requires a daily control of the seismic station quality, which needs the certainty of its long-term ongoing working. We already underlined the absence of power supply at the polar base that interrupted the working of the seismic station during several winter seasons. In addition, other technical problems, mainly at the end of February 2015, stopped the working of the station during 10 months. Figure 2 indicates that at the exception of the year 2012, it was not possible to have a continuity of the recordings before November 2016. This explains why we only begun recently to send our measurements to the ISC. ISC asks the contributors to send their measurements with a maximum delay of one year, which allows them to publish the worldwide catalogue of earthquakes with a delay of around two years. After the power supply consolidation in the PES seismic shelter at the beginning of the austral summer 2016-2017 and a real perspective of long-term operation, we decided to begin the measurement routine work and to send ELIB seismic phase measurements to ISC, using the same procedures as for the Belgian seismic stations. Hence, the first data sent to ISC concern the period 12 January to 21 May 2016. For this period, we measured 560 seismic phases for 452 earthquakes. Since 21 November 2016 the station worked without any interruption, up to the date of this final version of the present paper (April 2019). Therefore, we measured phase arrival times and amplitudes of seismic waves for earthquakes that occurred since 21 November 2016 and sent them to ISC. For example, between 21 November 2016 and 4 August 2017, we measured 1387 seismic phases for 1129 earthquakes. We present the location of these seismic events on Figure 4. Presently, the measurements for March 2018 are the last ones that we sent to ISC. The last published seismic bulletin with worldwide earthquake locations and corresponding seismic phase measurements is the one of October 2016. It was delivered by ISC on April 2, 2019.

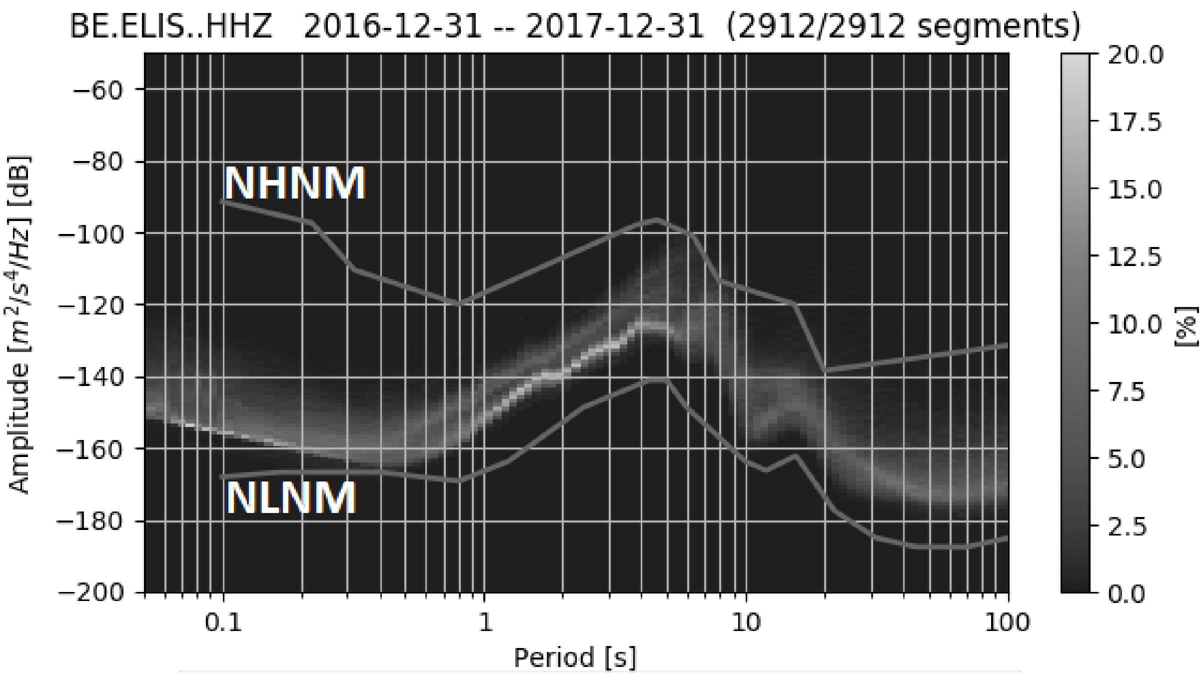

Figure 3: Noise level in function of the period at ELIB station during the whole 2017 year compared with the New High Noise Model (NHNM) and New Low Noise Model (NLNM) (Petersen, 1993). The white curves report how the daily averaged of the noise power density is distributed (percentage scale to the right of the diagram).

Because ISC only handled a few months of ELIB data, it is not yet possible to evaluate the benefit of the measurements done at the ELIB station to the location and characterization of global seismicity. The station will provide a real contribution if it can work permanently to the long term. In this case, its main contribution will concern the monitoring of seismically active regions located between East Antarctica, South America and South Africa, mainly the Mid-oceanic ridges in southern Atlantic and Indian oceans, and inactive regions of East Antarctica.

2.2 Benefit of a seismic station on the bedrock

The installation of the station on the bedrock contributes to minimize in the recordings the influence of wave reverberations in the ice column. Indeed, seismic recordings at a seismic station result from the convolution of the signal radiated by the source of the seismic events with the transfer functions of wave propagation inside the Earth, of the local geotechnical structure near the station, and of the instrument. For a station located on the bedrock, the absence of seismic wave impedance contrasts near the surface strongly diminishes local modifications of the incident seismic signals from seismic sources that travel across the Earth structure. In the case of seismic stations implanted on low consolidated sediments or on ice in polar region, site effects modify the signal, giving them complexity, which makes less evident the evaluation of seismic source parameters and crustal structure. Therefore, having access to data from bedrock stations, like ELIB, is very useful for scientists studying global Earth structure and earthquake mechanisms. This is why we opened freely the ELIB data to the scientific community with a one-year delay and will provide very soon them to the Incorporated Research Institutions for Seismology (IRIS), which is a consortium of institutions dedicated to the operation of science facilities for the acquisition, management, and distribution of seismological data.

3. CRUSTAL THICKNESS AT THE PRINCESS ELISABETH BASE

A second research axis concerns the knowledge of the crustal structure around the Princess Elisabeth Base. With a single seismic station, it is difficult to provide constraints on the crustal structure, at the exception of preliminary information on the crustal thickness by using the receiver function method (Langston, 1979). We briefly explain its background and present its application with the ELIB data in this paragraph.

3.1 The receiver function method to evaluate the Moho depth

The Moho, which is the discontinuity separating the crust and the mantle, is the first strong impedance contrast for seismic waves inside the Earth. When an upcoming direct longitudinal P-wave originating from a distant seismic source encounters the base of the Moho, the part of the seismic energy transmitted to a surface seismic station across the crust divided in two different wave fields: a longitudinal P-wave and a converted vertically polarized S-wave (SV wave component). Compared to the transmitted P-wave, the converted S-wave will arrive with a certain delay at the surface, determined by the crustal thickness and the P-wave on S-wave velocity ratio in the crust. A receiver function is a time series obtained by the deconvolution of the ground motion radial component from the vertical one on a three components teleseismic signal. Receiver function enhances the converted S-wave for teleseismic events with epicentral distance greater than 30° because it is mainly energetic on the radial component. Therefore, it provides a way to estimate crustal thickness knowing the P wave on S wave velocity ratio VP/VS in the crust.

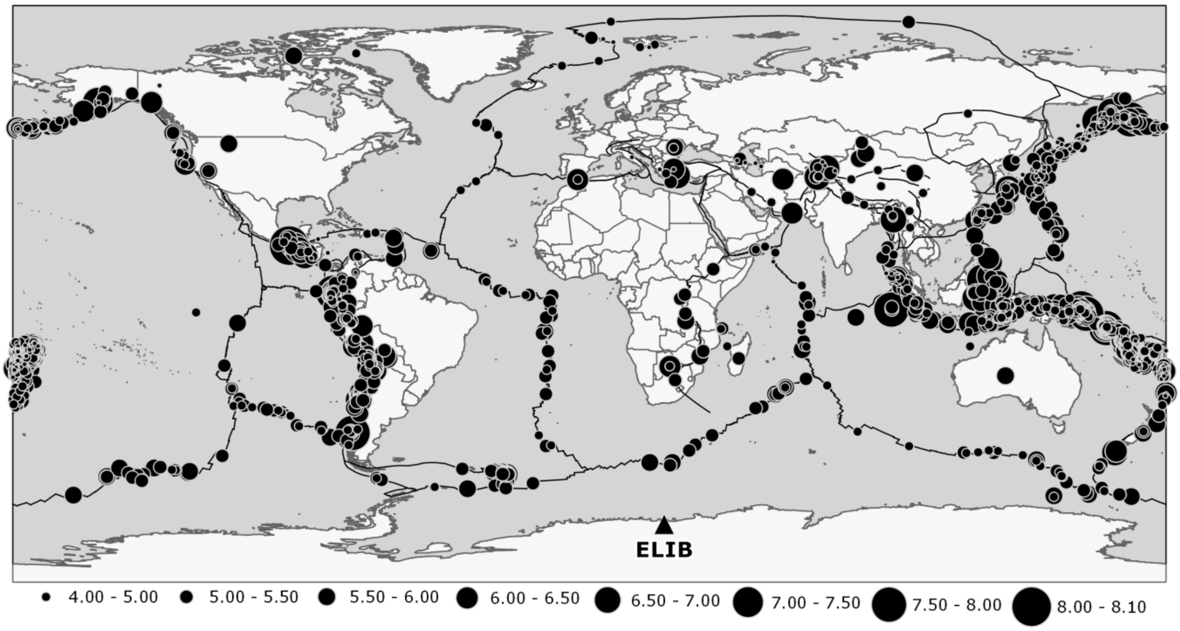

Figure 4: Earthquakes located by ISC including seismic phases measured at ELIB (period: 21 November 2016 – 4 August 2017).

3.2 Application of the receiver function method to ELIB data

In the dataset collected by the borehole seismometer at ELIB, we selected the recordings of 38 earthquakes that occurred in 2011 and were located at more than 30° from the ELIB station to obtain a first evaluation of the crustal thickness by using the receiver function method. We computed a receiver function for each of those events (Figure 5a). The strong energetic phase at the time origin corresponds to the direct P-wave, which is the first seismic phase recorded from a seismic events. In the considered time delay range of 20 seconds, the more energetic observed phase is the converted P to S signal at the Moho interface. It is relatively well visible on individual receiver functions (Figure 5a), but is enhanced by their stacking (Figure 5b). Its time delay of 5.7 s from the direct P-wave suggests a Moho depth in the range of 44 to 50 km, for V_P/V_S of 1.8 and 1.7 respectively that is a typical range of values for continental crust. Applying the same method to the ELIB full data set would not modify significantly this result. However, improving this estimation of the crustal thickness will need better estimation the P- and S-waves velocity model inside the crust, which is only possible with the addition, at least temporarily, of seismic stations at the local scale.

This obtained Moho depth value suggests the presence of an orogenic crustal root beneath the region of the Princess Elisabeth base that may be related to the East Africa Antarctica Orogeny event, which originates from the amalgamation of Antarctica and Africa into the Gondwana supercontinent about 600-500 million years ago (Mieth et al., 2014). This result represents the first estimate of the crustal thickness in this region of East Antarctica, in relatively good agreement with values found in the similar tectonic context of the Wohlthat Massif some 500 km further to the West (Bayer et al. 2009).

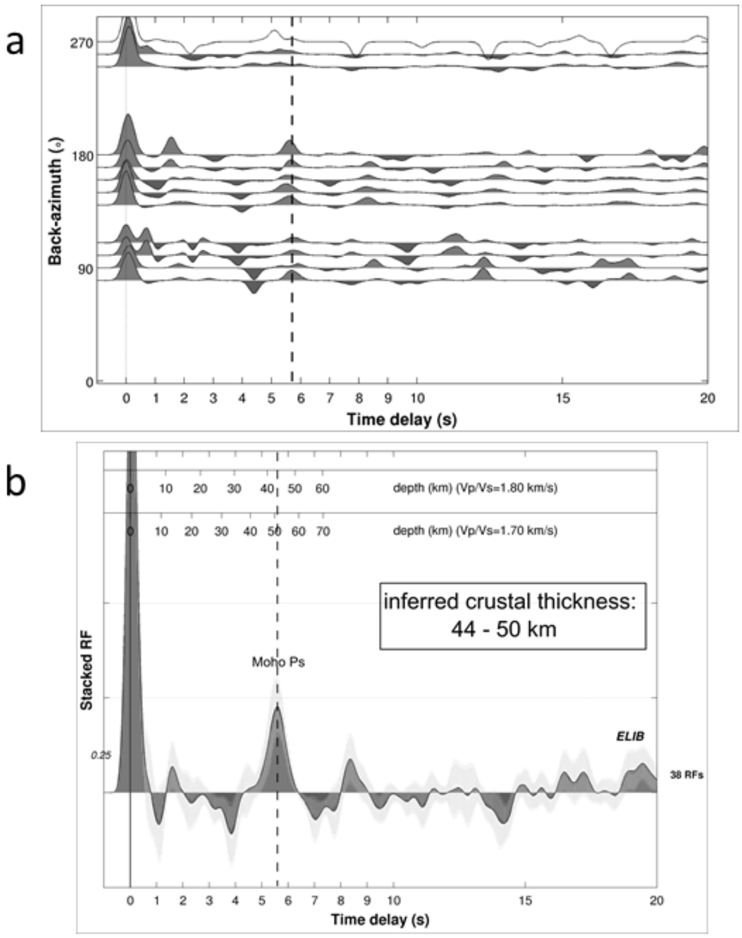

Figure 5: Individual receiver function as a function of a back-azimuth (angle between north and the teleseismic event source location) (a). On the stacked receiver function, the prominent and stable seismic phase at 5.7 s is the converted P-to-S phase at the Moho interface (b)

4. ICE SEISMICITY

As soon as we operated the ELIB station, we observed numerous local seismic events with a pattern different from classical local earthquakes. We interpreted them as related to the deformation of the ice sheet or its interaction with the bedrock. Their ongoing presence in the recordings lead us to initiate researches on their location and source mechanisms.

4.1 Local seismic events identified at ELIB

The recordings of ELIB contain many events showing small amplitudes P and S waves followed by more energetic low-frequency Rayleigh waves (Figure 6 (right)). The time difference between P and Rayleigh waves indicates that some of them occurred up to more than 20 km away from ELIB. Their magnitude is mostly negative. This type of events, frequent in glaciated areas, corresponds to crevasse icequakes (Podolskiy and Walter, 2016). They result from tensile stresses in the ice sheet when they exceed the fracture strength at a given depth in the ice column. As the pressure of the over-burden ice is low near the surface, these events generally grow near the surface to create new or extend existing crevasses. These seismic events usually show compressive P wave first motions, related to the tensile faulting and the low frequency Rayleigh waves are associated to their shallow depth (Podolskiy and Walter, 2016). Their waveforms are relatively similar to quarry blasts recorded in Belgium (Figure 6). This furnishes a means to discriminate them from tectonic earthquakes (see section 4.3).

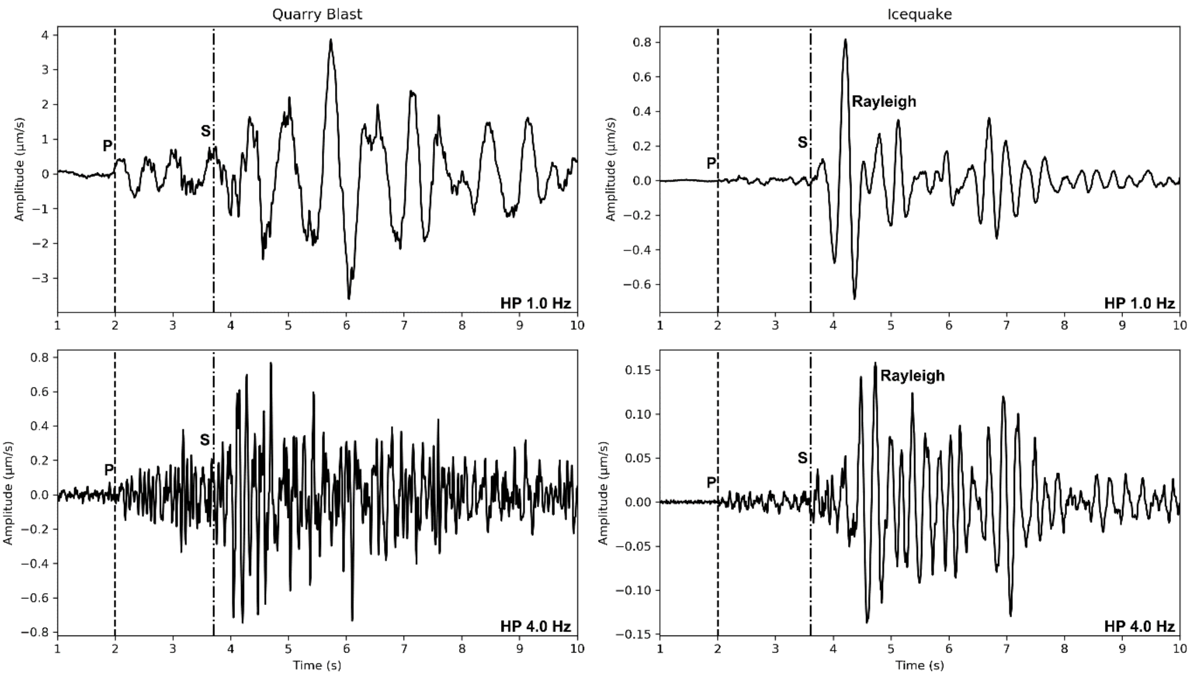

Figure 6: Comparison of the velocity waveform of a quarry blast recorded in Belgium (left) and a crevasse icequake recorded by the ANT network (right), using two different high-pass filters at 1.0 Hz (above) or 4.0 Hz (below).

Among the crevasse icequakes observed at the ELIB seismic station, numerous are very small and lasted maximum a few seconds. Their high frequency content up to 50 Hz (the Nyquist frequency of the data acquisition system) suggests a source located nearby the PES. Lombardi et al. (submitted to Annals of Glaciology) evidenced that a part of them occurred in two different outcropping blue ice areas located at less than 4 km from the PES. The timing of their occurrence may suggest an origin related to thermal stresses acting on the ice at the surface of the ice sheet. Hence, these very small icequakes would be very superficial and would have no relationship with ice sheet stability. Nevertheless, their investigation is of real interest to monitor the thermal state of blue ice areas. Of course, surface crevasse seismicity is mostly an indicator of strain variations of glaciers during their flow. Hence, in a temporary experiment conducted in January 2014 near an ice rise promontory west of the Roi Baudouin ice shelf, we studied crevasse icequakes caused by oceanic tide-induced flexure of the ice shelf (Lombardi et al., 2016).

Moreover, we also observed in the ELIB recordings many other events with longer duration, sometimes lasting more than several tens of seconds. They typically contain two energetic seismic phases corresponding to P- and S-waves, separated by a delay ranging from a few tenth to some dozen of seconds. These observations suggest that a significant regional seismic activity exists around the Princess Elisabeth base.

4.2 The ANT temporary network (January to April 2014)

As it was not possible to investigate this seismic activity with a single station, we installed five additional broadband seismic stations in the Sør Rondane Mountains in January 2014 (Figure

7). These temporary stations define a network with a north-south length of 80 km and a width of 30 km. We implanted four stations ANT1, ANT3, ANT4 and ANT5 on bedrock outcrops. We installed the fifth station, ANT6, south of the Sør Rondane Mountains just under the surface of the ice sheet at a location where its movement is less than 10 m/year. These stations were simultaneously operational up to April 2014 and evidenced a significant low-magnitude seismicity.

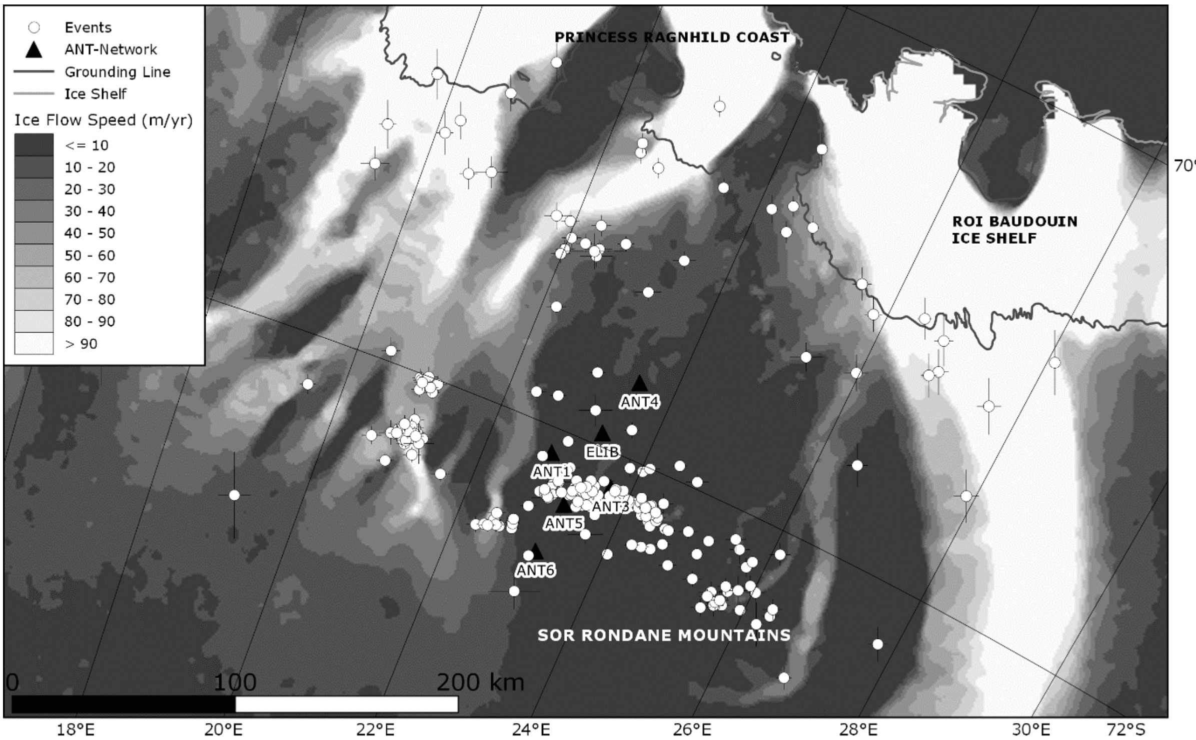

Figure 7: Ice seismicity recorded from 4 January to 12 April 2014 by the temporary seismic network (black triangles) in the Sør Rondane Mountains. We plotted all the seismic events at least recorded by five seismic stations. The length of the two perpendicular axes associated to each event reports the two-sigma uncertainty of their location.

During this three months period, we identified and located 912 seismic events recorded by at least three seismic stations. The spatial distribution of the 230 seismic events recorded by a minimum of five seismic stations and for which it was possible to determine a reliable location are reported on Figure 7. Many of them occur in areas where the presence of the Sør Rondane Mountains constrains the ice sheet flow coming from the Polar Plateau to channel inside the mountain range. Another part of the seismic activity is located in the downstream sections of the outlet glaciers of eastern Dronning Maud Land, where ice flow speed is the highest. This spatial distribution of the seismic activity supports a glacial origin related to the deformation and flow of the ice sheet (Camelbeeck et al., submitted to Geophysical Journal International).

4.3 How well are different the types of seismic events recorded by the ANT network from classical tectonic earthquakes?

Among the large diversity of seismic events observed with the network, we searched for the possible presence of real tectonic earthquake in the dataset, but without any success. Seismic waveforms of small tectonic events recorded by a local seismic network are relatively simple, with clear onset of P and S wave groups (Figure 8A). The displacement spectra of S waves characterized the source of natural earthquakes by comparison to other types of seismic sources. The low frequency part of these spectra is flat up to a corner frequency from which it decreases as the inverse of the square of the frequency (Shearer, 1999). At a given distance from the earthquake hypocentre, the flat low frequency value is proportional to the seismic moment. The inverse of the rupture propagation duration along the fault area affected by the earthquake corresponds to the corner frequency. This duration is equivalent to the affected fault length divided by the average rupture velocity, which is of the order of 2 to 3 km/s.

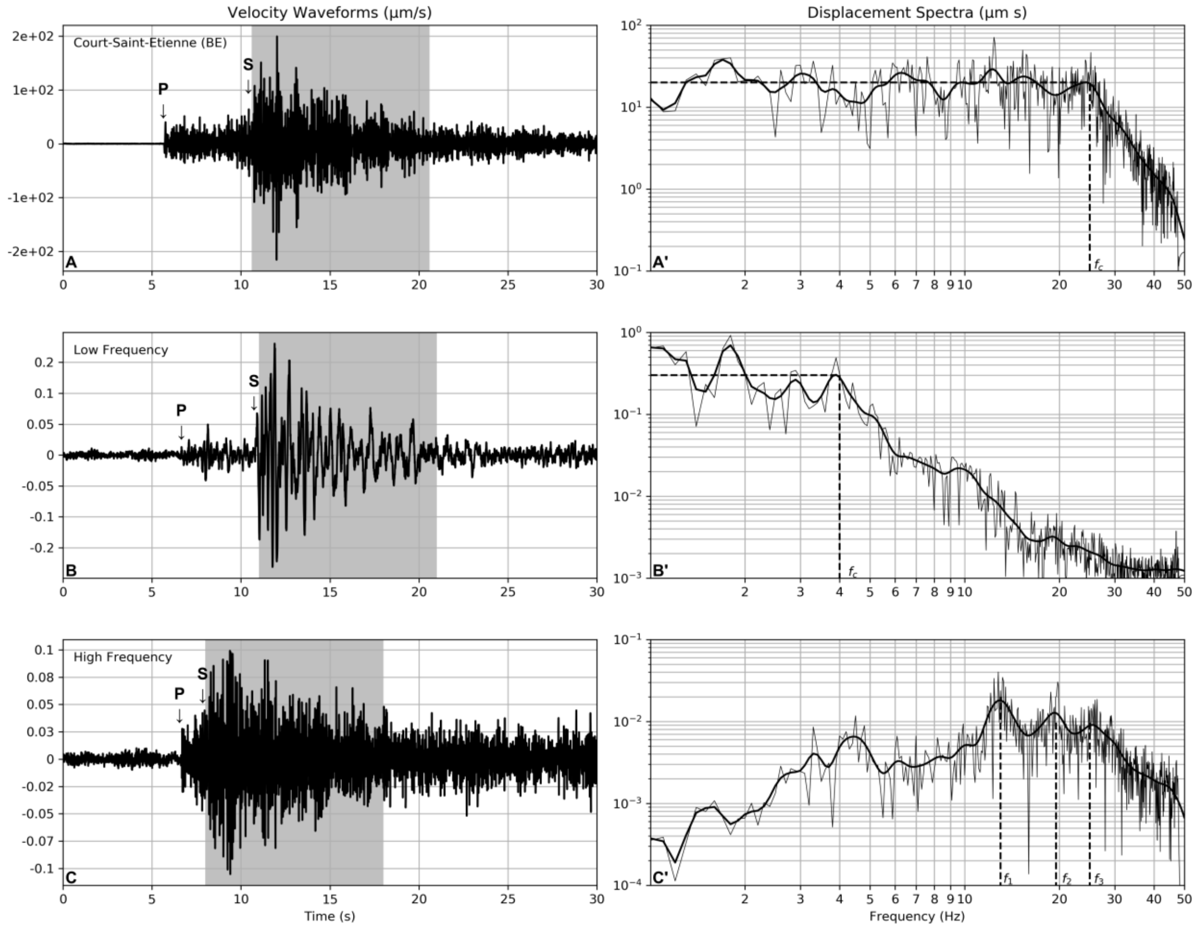

Figure 8: Differences between classical tectonic earthquakes and two types of observed events by the ANT seismic network around the Princess Elisabeth base. The plots present the velocity waveform (left) and S-wave displacement spectrum (right):

A. a local tectonic earthquake in Belgium (M_L = 2.2, 6 km depth) at a distance of 39 km. The low frequency spectral level is 20 µm.s and the corner frequency 25 Hz, corresponding to the slipping on a 50 m radius circular fault (slip velocity of the order of 2 to 3 km/s).

B. a typical low-frequency event (M_L = 0.5) recorded by ANT3 at 32 km distance. The low frequency spectral level is 0.3 µm.s and the corner frequency 4 Hz, corresponding to the slipping on an asperity in the subglacial till with an estimated radius of several meters to several ten meters (slip velocity ranging from a few to a few hundreds m/s).

C. a typical high-frequency event (M_L = -0.5) recorded by ANT1 at 13 km distance. The displacement spectra does not show a low-frequency constant spectral level, but is characterized by three resonant frequencies at 13.5 Hz, 19.5 Hz and 25 Hz.

Discriminating between crevasse icequakes and small tectonic earthquakes from classical broadband recordings cannot be done based on spectral characteristics of P and S waves because the sampling rate (100 sample/s) does not allow to observe their corner frequency, which is higher that the Nyquist frequency. A major difference between the two types of events is the presence of energetic Rayleigh waves on the icequake recordings. They indicate their very shallow focal depth and suggest a focal source close to the surface in the ice column. This discriminant is similar to the one allowing differentiating quarry blasts from small tectonic earthquakes in continental regions (Figure 6). Determining the radiation pattern of the seismic energy would also be a good way to evidence the difference between slip on a crustal fault with tensile faulting ice events, but this would need a seismic network denser than the ANT network.

We present in Figure 8B an example of another type of seismic events recorded by the ANT network. This event seems relatively similar to tectonic earthquakes (Figure 8A). Nevertheless, the corner frequency of its S-waves spectra is only 4 Hz for a M_L = 0.5. Such frequency would correspond to a tectonic earthquake with M_L ranging between 3.5 and 4.5, which is three to four order of magnitude larger than the real magnitude of the event. Therefore, it cannot result from a sudden fault slip in the crust. We attributed the source of these events to stick-slip sliding at the top or inside the subglacial till at the base of the ice sheet. The difference of rigidity, density, S-wave velocity and average rupture velocity in their respective focal region explains the observed difference of scaling between these basal icequakes and earthquakes. Indeed, basal icequakes slip inside the subglacial till or along its limit with the ice while earthquakes slip along a fault inside the crust. Roeoesli et al. (2016), Danesi et al. (2007) and Wiens et al. (2008) provide typical values of these different mechanical parameters for crustal rocks, ice and subglacial till.

Other well-observed seismic event (Figure 8C) also presents well identified P and S-waves. However, their displacement spectra does not show a low-frequency constant spectral level like for a tectonic earthquake or ice events related to basal sliding, but is characterized by three resonant frequencies at 13.5 Hz, 19.5 Hz and 25 Hz. Water drainage inside or at the base of glaciers is a possible cause of such seismic resonance. This type of events might result from the flow of water inside propagating fractures (Helmstetter et al., 2015).

These examples show how the analyses of the waveforms and spectral characteristics of the events recorded by the ANT network allow evaluating their mechanism.

CONCLUSION AND PERSPECTIVES

The building of the Princess Elisabeth polar station encouraged Belgian research in Antarctica, inter alia by the installation of a seismic station by the ROB. Despite the technical difficulties of a remote control during a large part of the year, ROB intends to maintain to the long term uninterrupted operation of the ELIB seismic station. This provides not only a significant contribution to the global earthquake monitoring service, but also a prerequisite for the achievement of ROB scientific research undertaken in this part of East Antarctica.

Moreover, even if ELIB is recording many ice related seismic events, it was impossible locating them without adding at least temporarily other seismic stations. This was the reason of installing the temporary ANT network during the summer field mission of 2013-2014. Up to now, we only published a small part of the analyses done with the large amount of collected data by this network, because no scientist is dedicated full-time to the project since 2015. However, we located 912 seismic events recorded by at least three stations from the ANT temporary broadband stations that worked from January to April 2014. We identified spots of activity and established their possible relationship to the ice flow and deformation, and bedrock characteristics.

As ELIB station recorded many ice related seismic events located by the ANT temporary network, it is possible to retrieve similar events during the periods where only ELIB is working by using identification methods based on the similarity of their waveforms. A PhD student begun in October 2018 to develop these methods. Hence, even with a single station, ELIB, it will be possible to continue the monitoring of the ice seismicity and evaluate its evolution in some identified target areas where it is representative of the ice sheet dynamics. This is an important contribution to the evaluation of the possible relationship between this ice seismicity with environmental and climatic changes.

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