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Infrasound Signals in Coastal Environment at Jang Bogo Station, Terra Nova Bay, Antarctica

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Abstract

Infrasound signals in Antarctica reflect physical interaction in the surface environments around the recorded area. In December 2015, an infrasound array by three sensors in the detectable frequency range of 0.1 - 200 Hz, combined with one broadband barometer was deployed at Jang Bogo Station, Terra Nova Bay, Antarctica. The two years of data by the broadband barometer contain characteristic signals that caused by surface environment nearby the station, mixing with local noises such as katabatic winds. Clear continuous signals by oceanic swells (microbaroms) were recorded with a predominant frequency of around 0.2 s. Variations of frequency context and amplitudes in the Power Spectral Density were considered as affected by sea-ice dynamics surrounding the Terra Nova Bay. Monitoring of microbaroms could contribute to understanding ocean wave climate, with other oceanographic, cryospheric and geophysical data in Antarctica. Infrasound data in Terra Nova Bay might be a new proxy for estimating environmental variations affected by global warming, cryosphere dynamics, together with volcanic eruptions in Victoria Land.

Keywords

Infrasound Signals, Antarctica, Terra Nova Bay, Microbaroms, Surface Environment

1. Introduction

The "Infrasound" is a pressure wave with a frequency range from cut-off of the sound (3.21 mHz, for a 15˚C isothermal atmosphere) to the lowest limit of human audible band (20 Hz) [1]. The frequency band could be a new horizon for remote sensing of the physical environment of Earth's atmosphere. The infrasound waves are considered to be generated by many environmental sources, such as volcanic eruptions, ocean swells, earthquakes, thunders, sprites, fireballs, meteorite falls, artificial re-entry of the vehicles, auroral activities in polar regions and others [2]-[8] (**Figure 1**). At the Sumatra earthquake of 26 December 2004, for instance, simultaneously the occurrence of great "tsunami waves", infrasound waves were generated and propagated to the upper atmosphere [9]. The other striking example was the 2011 Tohoku-Oki, Japan earthquake (Mw = 9.0), which also generated infrasounds associated with large tsunamis [10].

In polar regions, in contrast, the effects of generating infrasound signals by oceanic swells were well explained by evolution of sea-ices surrounding Antarctica in a line with atmosphere-ocean-cryosphere interactions [11]. For example, the infrasound observed at the Lützow-Holm Bay (LHB) of Antarctica was identified to have seasonal variations associated with thickness and spreading area of the sea ice [12] [13] [14] [15] [16]. The observations of infrasound in Antarctica might be useful information for characterizing ocean wave climate and global storm intensity, revealing physical interaction among multi-spheres in polar regions. The infrasound could possibly prove environmental changes such as global warming, cryosphere evolution, seismicity, and volcanic eruption in the southern high latitude.

The Korean station (Jang Bogo; 74˚37.4'S, 164˚13.7'E) was established in February 2014. The station is located in Terra Nova Bay, Northern Victoria Land on eastern flank of Ross Sea rift, a part of the West Antarctic rift system, which is one of the large tectonic provinces of the Earth formed by Cretaceous to Cenozoic extension (**Figure 2**). The rift shoulder consists of Transantarctic Mountains, which is a dividing zone between East and West Antarctica [17] [18]. A seismic network around the Terra Nova Bay was carried out in 2010 by Korea Arctic and Antarctic Research Program (KAARP) in order to understand a deep crustal and upper mantle structure, as well as monitor seismicity and volcanic activity with Mt. Melbourne [19]. The infrasound deployments were started in austral summer on December 2015 by collaboration between Korea Polar Research Institute (KOPRI) and National Institute of Polar Research (NIPR), Japan; the initial data with their characteristics were demonstrated [20].

In this report, characteristic signals of infrasound data recorded at Jang Bogo are treated by demonstrating two years of data from 2015. Background signals with a peak of a few seconds in its intrinsic period are investigated, involving far-field loading effects from the Southern Pacific Ocean. Time variations in infrasound data amplitudes and frequency content are especially investigated by power spectral densities (PSD) of the recorded data, in order to evaluate environmental effects such as global warming, cryosphere dynamics and volcanic eruptions in Victoria Land.

2. Scientific Project and Observation

During austral summer in 2015-2016, a multi-desciplinary international project was carried out at Terra Nova Bay in order to understand physical interaction in atmosphere-ocean-cryosphere-solid earth system, as one of the major projects

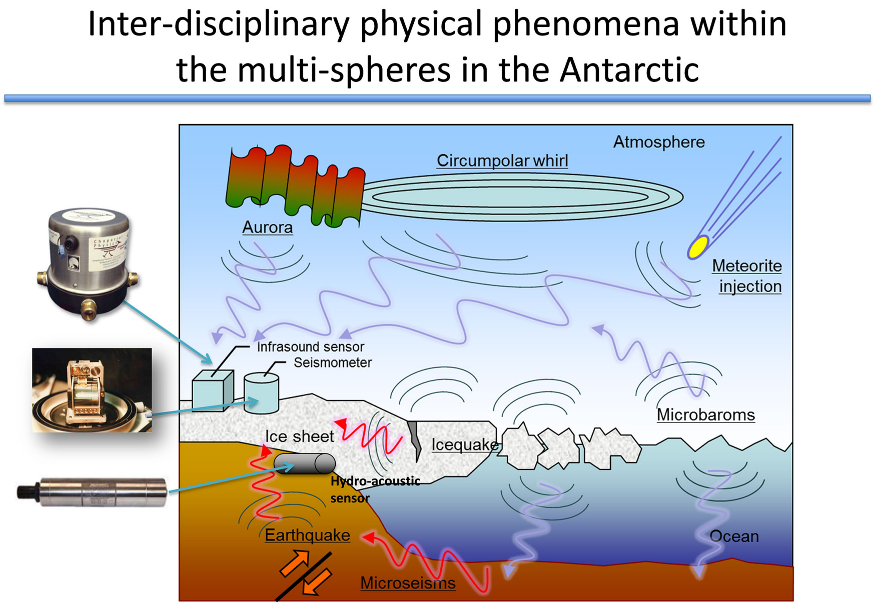


Figure 1. Schematic illustration of infrasound propagation and their generating sources in the Antarctic margins. Interaction among atmosphere-ocean-cryosphere-solid earth system is involved in generating seismic, infrasonic and hydro-acoustic waves in polar region. Photos of each sensor (seismic, infrasound and hydro-acoustic) are included in the figure. Modified after Figure1 of [14].

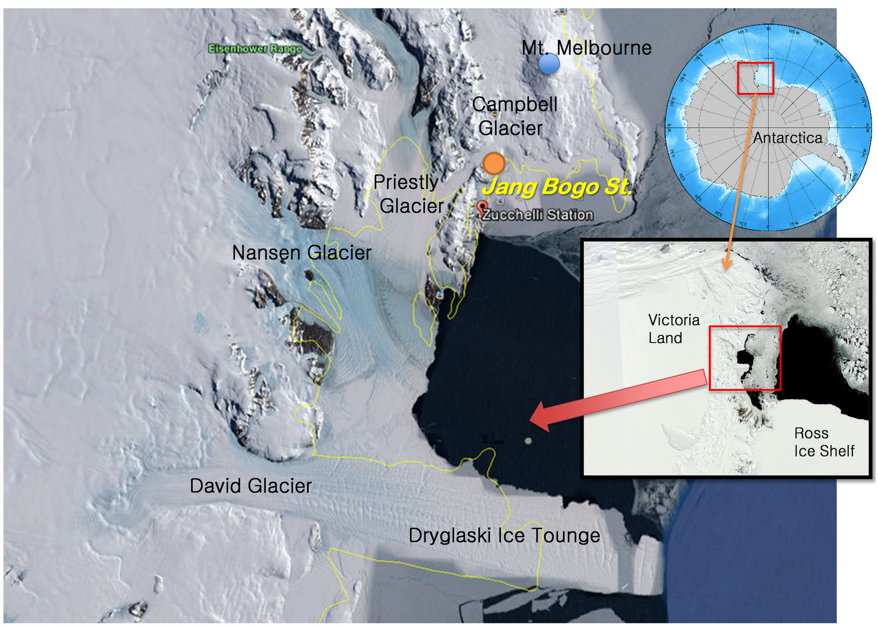


Figure 2. (Upper right) Location map of Jang Bogo Station in Terra Nova Bay, Northern Victoria Land of Antarctica. (left; main figure) Expanded area map of Terra Nova Bay and surrounding region in Victoria Land and Ross Sea, Antarctica. Background image is the MODerate resolution Imaging Spectroradiometer (MODIS) satellite on December 02, 2015 (by NASA; https://worldview.earthdata.nasa.gov).

of KAARP. The project was conducted by international group named "Extreme Geophysics Group (EGG)", consisted of 20 scientists and engineers coming from Korea, USA, New Zealand, Australia and Japan. The EGG activities in 2015-2016 austral summer contain field surveys both at onshore and offshore by conducting different approaches in seismology, geodesy, glaciology and marine geophysics. The offshore operations were carried out by using specific instruments on ice-breaker vessel "Araon". They include multi-narrow beams to imaging topography of seafloor, hydro-acoustic surveys and Conductivity-Temperature-Depth (CTD) monitoring around the Bay.

In contrast, onshore surveys were composed by maintenance of geophysics stations around the Bay, Mt. Melbourne, major ice-streams (Priestly, Nansen and David Glaciers) (**Figure 2**). Field geophysical stations around Jang Bogo were composed of eleven seismic stations, fifteen GNSS stations, two glacier tilt-meter stations and five meteorological stations (AMIGOS), respectively. These onshore stations were deployed in aiming to detect long-term variations caused by cryosphere dynamics, involved interactions between ocean, atmosphere and solid earth. In addition to thsese field stations, inside the Jang Bogo, long-term mointoring observations were conducting by seismometers, the Global Navigation Satellite System (GNSS), gravity meter as well as infrasound sensors. During the summer in 2015-2016, previously deployed seismic station was moved from near geophysical observation hut to a new location where 500 m northwest from main buildings of Jang Bogo (**Figure 3**).

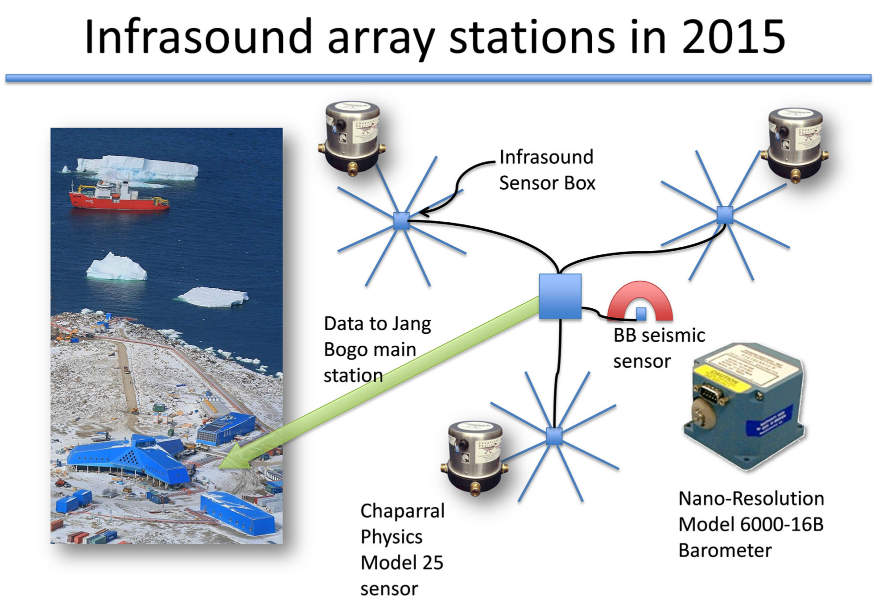


Figure 3. (Left) Photo of Jang Bogo Station and the Korean ice-breaker vessel "Araon". (right) An infrasound array (100 m spacing) by three low-frequency microphone sensors (the Chaparral Physics Model 25 sesnors with a detactable frequency range of 0.1 - 200 Hz), conbinded with a broadband nano-resolution barometer (the Digiquartz Nano-Resolution Model 6000 - 16 B Barometer with a detectable frequency range of 0 - 22 Hz) were installed at Jaog Bogo Station.

Together with other geophycsial observations at Jang Bogo, the infrasound tripatite array (100 m spacing) was initiated by coupling of three same-speck infrasound sensors (Chaparral Physics Model 25, with a detectable frequency range of 0.1 - 200 Hz), where 500 m northwest from the main buildings of Jang Bogo and geophysical observation hut. The Chaparral Physics sensors used for the array were attached on outcrops and installed inside adiabatic wooden boxes, equipped with eight air-pipes (hose arrays; **Figure 3**). The purpose of the hose array alignment was to reduce the wind noises, which was similar mechanism with adopting analogue low-pass filtering. The similar hose array system has been used near Japanese Syowa Station (see Figure 6 of Murayama *et al.*, 2015). In addition to the array by using Chaparral Physics sensors, a broadband barometer (Digiquartz Nano-Resolution Model 6000 - 16 B Barometer, with a detectable frequency range of 0 - 22 Hz) was set inside geophysical observatory hut, in order to merge the data retreieved from Chaparral sensors. A triangle shape air-pipes were attached to the Barometer for the same purpose of reducing wind noises. The data have been logging in the acquisition system for each sensors, followed by sending partial data to KOPRI office by using both the LAN and Intersat telecommunication system from Jang Bogo.

The above deployments were conducted on December 2015 by corraboration between KOPRI and NIPR, as one of the activities of EGG project [20]. The infrasound observations continued over few years to detect a long-term variability of the signals. During winter seasons, appropriate supports for instrumentation maintenance were given by overwintering members at Jang Bogo.

3. Infrasound Data

Here the characteristics of several data after two years from December 2015 retrieved by the Nano-Resolution Model 6000 - 16 B Barometer are introduced; the sensor were deploying inside geophysical observation hut of Jang Bogo. **Figure 4** represents PSDs and their original time-domain infrasound signals for four days on 12-15 December 2015 by the Nano-Resolution Model 6000 - 16 B Barometer for the frequency band of 1 - 10 Hz (4a) and 0.01 - 2 Hz (4b), respectively. In the figures, predominant continuous signals with approximately 0.2 Hz are identified, which correspond to microbaroms from Southern Ocean surrounding Antarctica. Local wind noises (caused chiefly by "katabatic winds") are also recognized in several time windows during the days. In particular, the latter half on 12 December was the time window with the strongest and the longest duration. Time variations in frequency context are not identical within these days, therefore, it is necessary to monitor long-period over few months or few years in order to detect long-term variability including seasonal dependence.

Figure 5-1 shows an example of characteristics of observed infrasound signals on 9 May 2017. a) The PSD of observed atmospheric pressure data for frequency band of 0.01 - 5 Hz (03:15-03:25 UTC) (5-1a), time series of atmospheric pressure data (0.01 - 5 Hz band-pass filter was applied) (5-1b) and spectrum of the observed atmospheric pressure data for 30 min. length (5-1c) are shown, respectively.

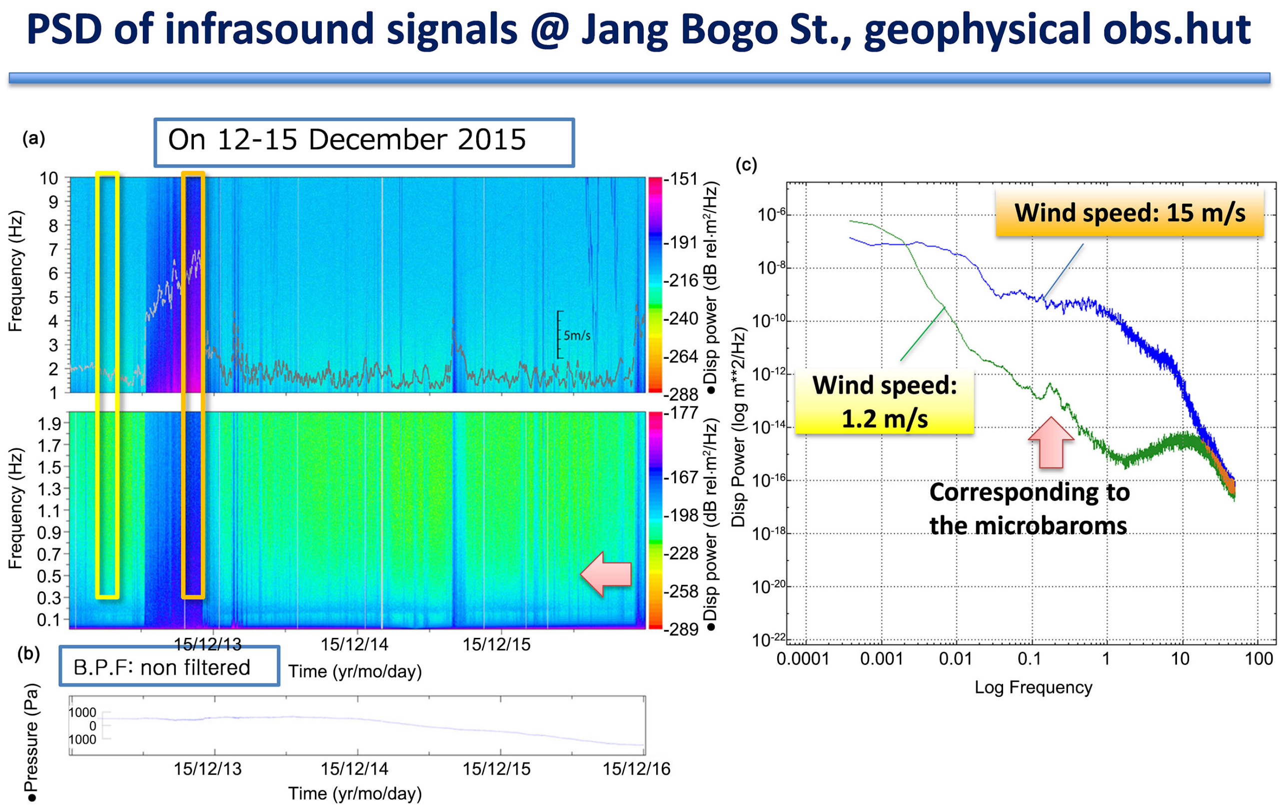
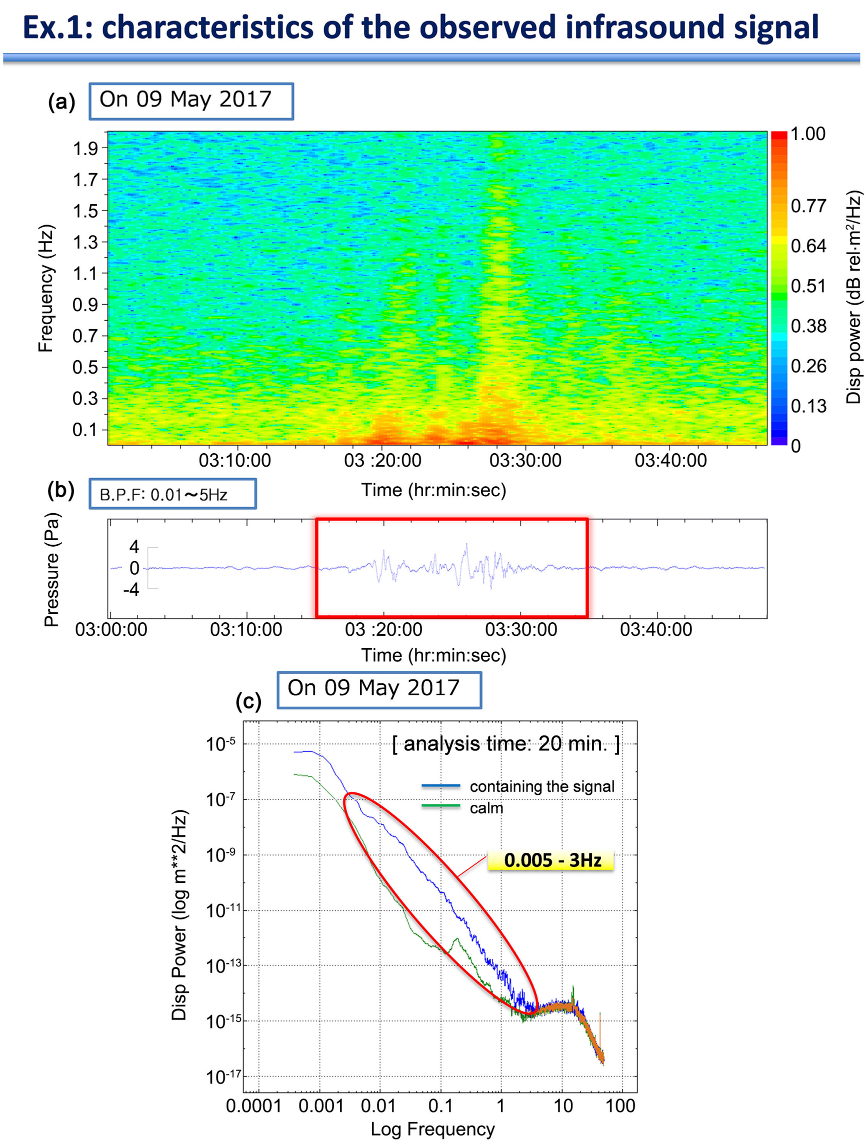


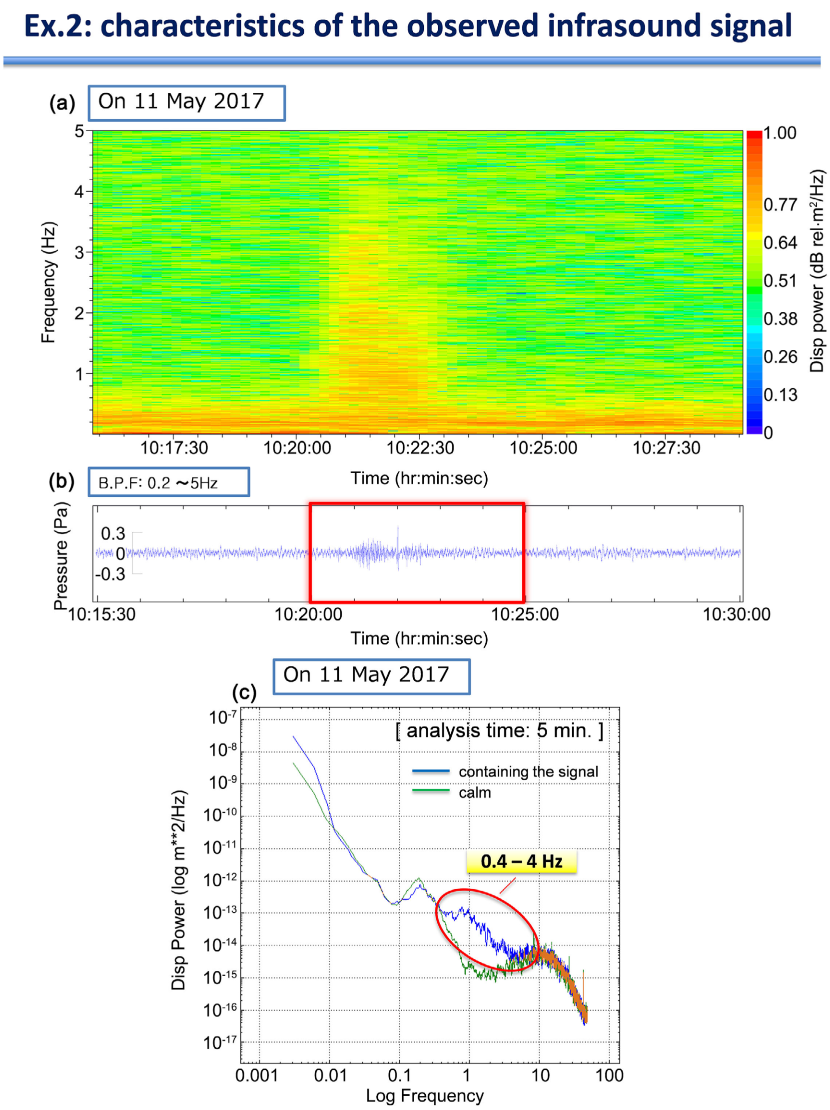
Figure 4. (a) Power spectral densities (PSD) of infrasound signals for frequency band of 0.01 - 10 Hz (Nano-Resolution Model 6000 - 16 B Barometer at Jang Bogo, geophysical observation hut) for 4 days data on 12-15 December 2015. The vertical axis of right-hand side indicates "Displacement Power" with the unit by (dB relative to m^2/Hz). Wind speed data of the Station is also plotted by broken line. (b) Original (no filtered) time-domain infrasound signals corresponding to the upper figure of PSD. (c) Spectrum of the observed atmosphere pressure data for 30 min. length. Continuous signals with predominant frequency around 0.2 Hz can be seen, which correspond to the microbaroms from the Ocean. Local wind noises (caused mainly by katabatic wind) are identified in several time windows during the four days.

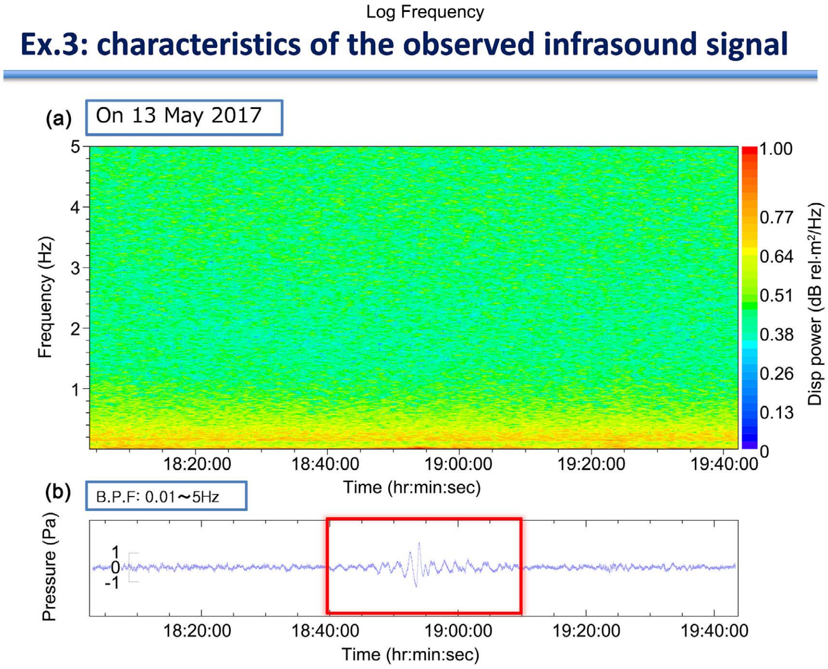
Figure 5-2 indicates an example of characteristics of observed infrasound signals on 11 May 2017. The PSD of observed atmospheric pressure data for frequency band of 0.01 - 5 Hz (10:15-10:30 UTC) (5-2a), time series of atmospheric pressure data (0.2 - 5 Hz band-pass filter was applied) (5-2b) and spectrum of the observed atmospheric pressure data for 30 min. length (5-2c) are shown, respectively. **Figure 5-3** corresponds an example of characteristics of observed infrasound signals on 13 May 2017. The PSD of observed atmospheric pressure data for frequency band of 0.01 - 5 Hz (18:05-19:45 UTC) (5-3a), time series of atmospheric pressure data (0.01 - 5 Hz band-pass filter was applied) (5-3b) and spectrum of the observed atmospheric pressure data for 30 min. length (5-3c) are indicated, respectively.

The above examples in May 2017 have similar characteristics with including "microbaroms" frequency ranges in their peaks around 0.2 Hz, in spite of the difference of with containing characteristic signals or without them *i.e.*, the "calm" condition time-windows. However, difference frequency contents in high energy signals were identical in each day. For instance, wide band high energy signals appeared (0.005 - 3 Hz) on 9 May (**Figure 5-1**), however, relatively narrow-band and high frequency contents signals were included (0.4 - 4 Hz) on 11 May, moreover longer frequency ranges can predominantly be recognized (0.005 - 0.06 Hz) on 13 May 2017, respectively. The difference in frequency contents within the wind noises might be involved in the time-space variability in the surface environment of the Terra Nova Bay, generated by the migration of several storms, ktabatic winds, oceanic swells and currents.

Intrinsic periods for "microbaroms" recording in these infrasound data correspond to co-oscillation with oceanic loading effects on solid earth ("microseisms") which came from Southern Ocean, as seen in seismographs [11]. The prominent microbaroms peaks with approximately 0.2 Hz are caused by nonlinear interaction of interfering ocean wave components that produce a pressure perturbation at same frequency on infrasound signals. The peak is generated near coasts, where coastal swell reflection could provide requisite opposing wave




Ex.2: characteristics of the observed infrasound signal
(a)
On 11 May 2017
Frequency (Hz)
Disp power (dB rel·m²/Hz)
1.00
0.77
0.64
0.51
0.38
0.26
0.13
0
10:17:30
10:20:00
10:22:30
10:25:00
10:27:30
Time (hr:min:sec)
(b)
B.P.F: 0.2 ∼5Hz
Pressure (Pa)
0.3
0
-0.3
10:15:30
10:20:00
10:25:00
10:30:00
Time (hr:min:sec)
(c)
On 11 May 2017
[analysis time: 5 min.]
containing the signal
calm
0.4 – 4 Hz
Disp Power (log m**2/Hz)
Log Frequency
0.001
0.01
0.1
1
10
100


Ex.3: characteristics of the observed infrasound signal
(a)
On 13 May 2017
Frequency (Hz)
Disp power (dB rel·m²/Hz)
1.00
0.77
0.64
0.51
0.38
0.26
0.13
0
18:20:00
18:40:00
19:00:00
19:20:00
19:40:00
Time (hr:min:sec)
(b)
B.P.F: 0.01∼5Hz
Pressure (Pa)
1
0
-1
18:20:00
18:40:00
19:00:00
19:20:00
19:40:00
Time (hr:min:sec)

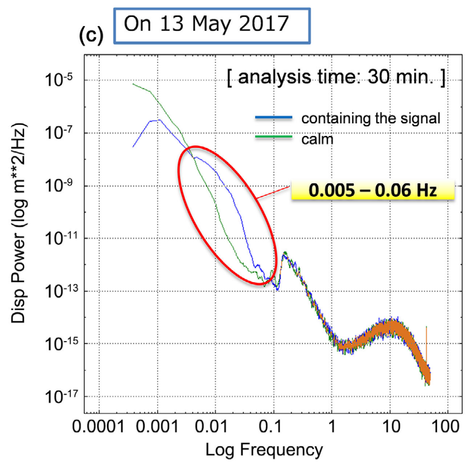


Figure 5. -1. Example of characteristics of the observed infrasound signals on 9 May 2017. (a) PSD of the observed atmospheric pressure data for frequency band of 0.01 - 5 Hz (03:15-03:25 UTC). (b) Time series of atmospheric pressure data (0.01 - 5 Hz band-pass filter was applied). (c) Spectrum of the observed atmospheric pressure data for 20 min. length; -2. Example of characteristics of the observed infrasound signals on 11 May 2017. a) PSD of the observed atmospheric pressure data for frequency band of 0.01 - 5 Hz (10:15-10:30 UTC). (b) Time series of atmospheric pressure data (0.2 - 5 Hz band-pass filter was applied). (c) Spectrum of the observed atmospheric pressure data for 5 min. length; -3. Example of characteristics of the observed infrasound signals on 13 May 2017. (a) PSD of the observed atmospheric pressure data for frequency band of 0.01 - 5 Hz (18:05-19:45 UTC). (b) Time series of atmospheric pressure data (0.01 - 5 Hz band-pass filter was applied). (c) Spectrum of the observed atmospheric pressure data for 30 min. length.

components. These period ranges corresponding to "microbaroms" are dictated by physics of gravity wave generation and are constrained by speed and extent of Earth's surface winds. In Antarctica, microseism amplitudes are attenuated during local winter for microseisms [21]. This could be explained by presence of sea-ice extent impeding both direct ocean-to-continent coupling and coastal reflection which are important components in generating microseisms. In this regard, a similar phenomenon of seasonal change could appear in "microbaroms" at Jang Bogo when we continue to monitor the data over a few years or longer period.

4. Significance of Long-Term Recordings

Monitoring a dynamic response of ice sheet in a line with ocean–atmosphere–solid earth interactions (**Figure 1**), might be crucial in long-term effort to observe climate change. Infrasound field stations have been conducting around the LHB, near Syowa Station since 2008 [13] [22]. Two set of arrays have been deployed at both inside Syowa (100 m spacing) and on continental ice sheet (1000 m spacing) from 2012-2013 austral summer [14] [15]. The arrays in LHB clearly recordied predominant propagating directions from Southern Ocean and their frequency content variations of microbaroms. When making array analysis on retrieved data from infrasound stations of Jang Bogo, it is expected to provide robust information about propagating directions and apparent velocity from infrasound sources around Terra Nova Bay. The precise location of the infrasound sources could probably help us to figure out candidates of generating sources in local environment near the Bay.

Recently, cryo-seismicity triggered by ice mass discharge at David Glacier was investigated using subglacial hydrographic network deployed by Itarian gruop [23]. In addition to these seismic researches, infrasound data at Terra Nova Bay could help us to give rise to a new image involving dynamics of the Antarctic ice sheet and glaciers in margins of Victoria Land. As a future study, in addition, theoretical modeling [24] would be helpful to determine actual source location and occurring mechanism of the infrasound signals. It is also important to compare these signals with other data, such as seismograms and hydro acoustics which have similar frequency bands with infrasound [25]. In this concern, monitoring of infrasound signals in Antarctica, as southern margins of Southern Ocean, would be a new proxy for identifying regional environmental change among complex global system. There is still a lot to be learned about physical interaction among atmosphere-ocean-cryosphere system in Antarctica and surrounding oceans, around Terra Nova Bay, Ross Sea, and Northern Victoria Land.

5. Summary

Characteristic signals of infrasound data were recorded at Terra Nova Bay, Northern Victoria Land of Antarctica by using a broadband barometer deployed at Jang Bogo Station in December 2015. Two years of data retrieved by the barometer include characteristic signals caused by surrounding surface environment, by mixing contamination of local noises involving katabatic winds from continental ice-sheet to Terra Nova Bay. Continuous recording signals of oceanic origin (microbaroms) were clear in austral summer with predominant frequency content around 0.2 s. Variabilities of their frequency and amplitude strength in Power Spectral Density might be influenced by a seasonal evolution of sea-ices surrounding the Bay. By utilizing an infrasound array combined with other three barometric sensors deployed inside Station, multi-sphere interaction among surface environments around the coastal area and Southern Ocean could be investigated in the future. Microbarom measurement in Antarctica could be a useful tool for characterizing ocean wave climate. Continuous infrasound observations in the Terra Nova Bay surely give rise to a proxy for understanding environmental changes associated with global warming, cryosphere dynamics, and volcanic eruption in vicinity of Victoria Land.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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