Chapter

Characteristic Infrasound Events Associated with Sea-Ice Discharges in the Lützow-Holm Bay of Antarctica: April 2016

Takahiko Murayama, Masaki Kanao and Masa-Yuki Yamamoto

Abstract

Infrasound waves detected in Antarctica contain information on the physical interaction among the surface environment at the margin of the continent and surrounding ocean. Time-space variation of source location for infrasound excitation during mid-April 2016 was investigated by using a combination of two arrays deployed along the coast of the Lützow-Holm Bay (LHB), East Antarctica. The infrasound array observations detected temporal variations in distance from the sources and propagation direction. A few tens of infrasound events were identified during 10 days of the period, and many of them located in the northward direction from the array stations were inside the LHB and offshore in the Southern Indian Ocean. Many of the events had predominant frequency content of few Hz, which were higher than microbaroms generated from the ocean. By comparing with MODIS satellite image at the same period, these sources were considered to be the ice-related phenomenon associated with the discharge of fast sea ice from the LHB.

Keywords: infrasound, array analysis, sea-ice discharge, Lützow-Holm Bay, Antarctica, cryosphere dynamics

1. Introduction

"Infrasound" is a sub-audible pressure wave with frequency content from the cutoff of a sound (3.21 mHz, for a 15°C atmosphere) to the lowest of the human audible band (20 Hz) and propagates thousands of kilometers along the Earth's surface by considerable excitation energy [1]. There are many examples of infrasound excitation by a couple of plausible sources: volcanic eruptions, oceanic swells, large earthquakes, aircrafts, thunder and sprites, fireballs, meteoroid, reentry of artificial vehicles, aurora activities, etc. [2–6].

In the polar region, time-space variations in atmospheric pressure are generated by physical interaction among multi-spheres (atmosphere, oceans, cryosphere, and the surface of the solid earth). These interactions are actively involved in the surface environment, and their unknown sources can be measured by infrasound networks deployed in the polar region (**Figure 1**). Recently, [7] conducted simultaneous observation by both seismic and infrasound sensors at the Bowdoin Glacier in

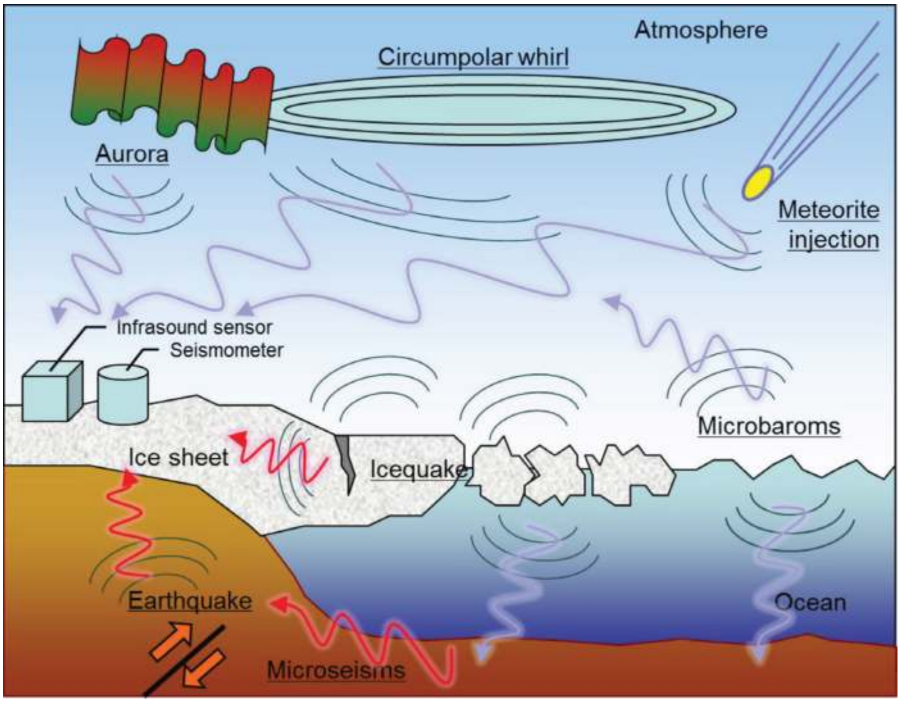

Figure 1.
Schematic illustration of interdisciplinary physical interaction within multi-spheres in the Antarctic. Several kinds of seismic, infrasonic, and hydroacoustic waves are generated by surface environmental sources (after [12]).

Greenland; they found ground validate infrasound sources very precisely by using time-lapse cameras and better-localized sources due to their small size.

In April 2008, infrasound observation was started by using a single sensor at the main Japanese station, Syowa (SYO; 69.0S, 39.6E), in the Lützow-Holm Bay (LHB) of Antarctica. The single infrasound sensor at SYO has been continuously recording the data over the seasons since 2008 and has clearly marked the background contamination signals of oceanic swells (microbaroms) [8], and the first 3-year variability of frequency contents and power spectrograms had been investigated [9].

In austral summer 2013–2014, several field stations of infrasound sensors were established along the coast of LHB (**Figure 2**). In particular, two infrasound arrays with different diameters were deployed both on the outcrop at SYO and the continental ice sheet (S16) near the eastern coast of LHB [10]. They reported the frequency contents and source orientation of the microbaroms from the Southern Ocean for 50 days of data in austral summer in 2013. During the initial observation period of the arrays, as one of the examples of unique data, airburst shock waves emanating from a meteor entering the atmosphere over the Russian Republic were identified on February 15, 2013.

Three infrasound events in 2015 were also identified by using the two arrays deploying at SYO and S16, and the excitation source locations were determined along the coast, inside the sea ice and surrounding the islands [11]. Moreover, the long-term variability of the source location of the infrasound excitation for 8 months in January–August 2015 was investigated by using the same arrays [12]. Plausible source mechanisms of these events were estimated regarding the surface environmental change, in particular, cryosphere dynamics surrounding the LHB. Especially focusing on the facts on mid-April, 2015 were studied associated with the discharge of sea ice together with the collision with icebergs surrounding the LHB.

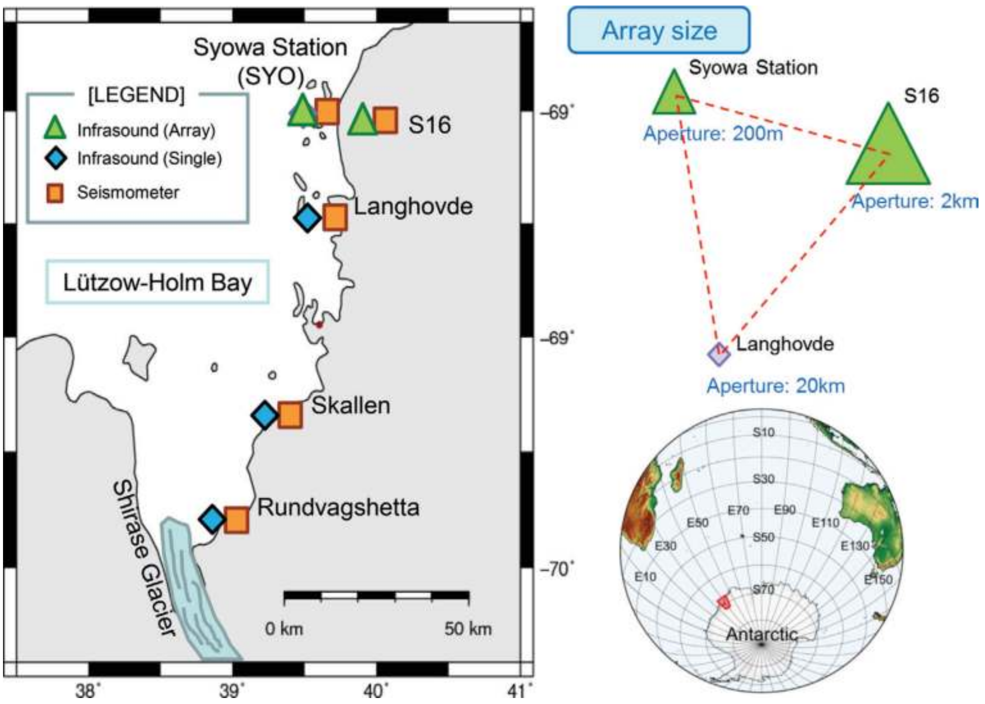

Figure 2.
(Left) locations of array deployment in the Lützow-Holm Bay (LHB). Array stations of infrasound (green triangles), single stations of infrasound (blue diamond), and broadband seismometers (orange squares) are shown. (Upper right) Array configuration of infrasound stations so as to localize the source signals. Tripartite arrays have been deployed by small size (at Syowa Station (SYO); aperture of 200 m), medium size (at S16, S17, P50; aperture of 2 km), and large size (combination of other outcrop stations such as Langhovde, aperture of 20 km or larger).

In this chapter, in addition to these previous works in the target region of LHB, time-space variation of source location for infrasound excitation during mid-April 2016 was investigated by using a combination of two arrays deployed along the coast of LHB, when a significant volume of sea ice was discharged from the Bay to the Southern Ocean.

2. Observation and analysis

A total of nine infrasound instruments have been carried out along the eastern coast of LHB since January 2013 [10]. Two triangle array alignments with different diameters were constructed at SYO (with a 100 m spacing triangle) and the vicinity of S16 over ice sheet (1 km space triangle) where 15 km eastward location from SYO (**Figure 2**). Besides the arrays, single sensor stations have been set at several outcrops in LHB (Langhovde, Skallen, and Rundvagshetta). These complicate that array configuration of these stations was adopted to localize detected signals efficiently by recognizing identical wavelengths with corresponding frequencies for each array size.

The Chaparral Physics microbarometer (Model 25, detectable frequency of 0.1–200 Hz) has been utilized in most of the stations. In these stations, hose arrays were aligned to reduce wind noises by mechanical low-pass filtering [13, 14]. Multiply-connected porous hoses are adopted at the SYO array; in contrast, a single array configuration was utilized in the other stations so as to help simplify their installations. The porous hoses are buried beneath the mounds of stones/snow ice collected from around the observation sites to reduce the vibration effect of winds. Detail configuration of the observation system is given in [10].

In order to speculate propagation directions and locations of infrasound events, multiple-step approach was used; the first was to generate a catalog for each array using a progressive multichannel correlation algorithm (PMCC) [15, 16]; the second was by suing two bulletins of the arrays (SYO and S16). A flowchart of array analysis is as follows: (1) search the pairs of signals within ±80 s of detected time difference on the basis of the bulletin dataset for both arrays on the basis of the distance of two arrays which is about 20 km; (2) calculate the cross point by using a spherical triangle method based on propagation direction and apparent velocities for each array; (3) set the candidate origin as grids around the cross point within ±5 degree range, followed by calculating averaged origin time, and select the most probable grid; and (4) evaluate calculated apparent velocities (V) within the range of (0.28 m/s $\leqq$ V $\leqq$ 0.36 m/s) for both the arrays.

3. Results and discussion

Several examples of detected infrasound signals and their source locations from array analyses are demonstrated in this section. Time-domain infrasound waveforms for three events and resultant array analyses by PMCC algorithm are shown in **Figure 3**. The identified infrasound signals were presumably associated with a series of discharge events of sea ice from LHB. Three examples of the detected waveforms are (1) April 3, 2016 (forecasted origin time, 03:27 UTC; 3 minutes of data duration), (2) April 11, 2016 (forecasted origin time, 22:00 UTC; 6 minutes of data duration), and (3) April 7, 2016 (forecasted origin time, 16:42 UTC; 6 minutes of data duration), respectively. The upper panels of each waveform represent the results of PMCC analysis: back azimuth (station-to-source) direction and the apparent velocities. The lower panels represent band pass-filtered infrasound waveforms observed at SYO array. Green broken squares on the waveforms correspond to the time windows of the detected infrasound events. All three events came from northwest direction to the SYO array as identified from the back azimuth distributions, which correspond to the inside LHB or offshore in South Indian Ocean.

Since these waveforms have relatively high-frequency contents of few Hz and amplitudes between 0.01 and 0.1 Pa, they are not considered to be oceanic swell origins propagating from Southern Ocean (microbaroms; dominant frequency around 0.2 Hz [9]). Ice quakes, calving of glaciers and ice cliffs, the collision of icebergs and sea ice, and other candidates of generating sources involving cryosphere dynamics could produce infrasound signals with sufficient energy that is recordable to the arrays. These kinds of cryoseismic sources are likely to reflect short-term variations in the surrounding environment, and their temporal change may provide indirect evidence of climate change at the local polar region [17]).

These detected infrasound events with high-frequency contents on mid-April 2016 were compared with the MODIS satellite images (provided by NASA) which give cryosphere information at the target area. **Figure 4** represents the MODIS images around LHB on April 3 (upper left), April 5 (upper right), April 8 (lower left), and April 9 (lower right), 2016, respectively. Discharged areas of fast sea ice from LHB are circled by broken red line. Distribution of fragmentations of sea ice (fast ices) and several tips of icebergs are identified outside the Bay. Moreover, other geophysical data of tide gauges deploying at SYO recorded the large amplitude of oceanic swells on April 10 associated with the discharge events during the mid-April period.

Array analysis results of estimated source locations of infrasound excitation overlapping on MODIS image (April 8) during the period from April 3 to April

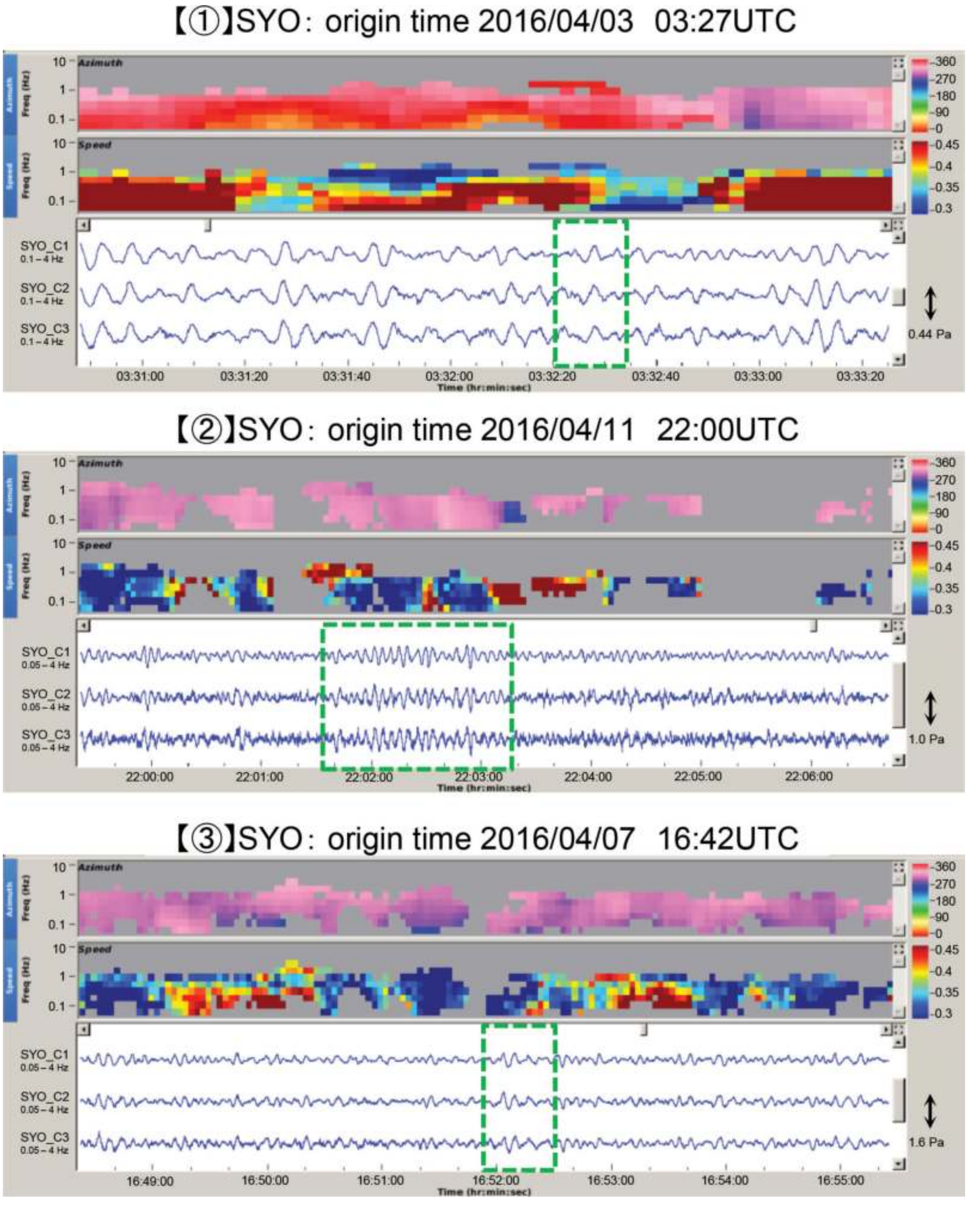

Figure 3.
Detection of infrasonic signals associated with discharge events of sea ices from LHB on (1) April 3, 2016 (forecasted origin time, 03:27 UTC), (2) April 11, 2016 (forecasted origin time, 22:00 UTC), and (3) April 7, 2016 (forecasted origin time, 16:42 UTC). The upper panels show the results of PMCC analysis: Back azimuth (station-to-source) direction and the apparent velocities. The lower panels represent band pass-filtered waveforms observed at SYO array. Green broken squares on the waveforms correspond to the time windows of detected infrasound events.

12 are presented in **Figure 5**. Estimated source locations (N = 175) are colored according to the time from the beginning of April 3. Three events correspond to the waveform examples shown in **Figure 4** which are raveled by red circled numerous. Majority of the infrasound sources were located in the northwest direction from LHB, which appeared to extend toward the Indian Ocean. Besides, more than 10 events are recognized to be located toward the north direction from LHB. Majority of the events are considered to concentrate on the vicinity and the edge of icebergs

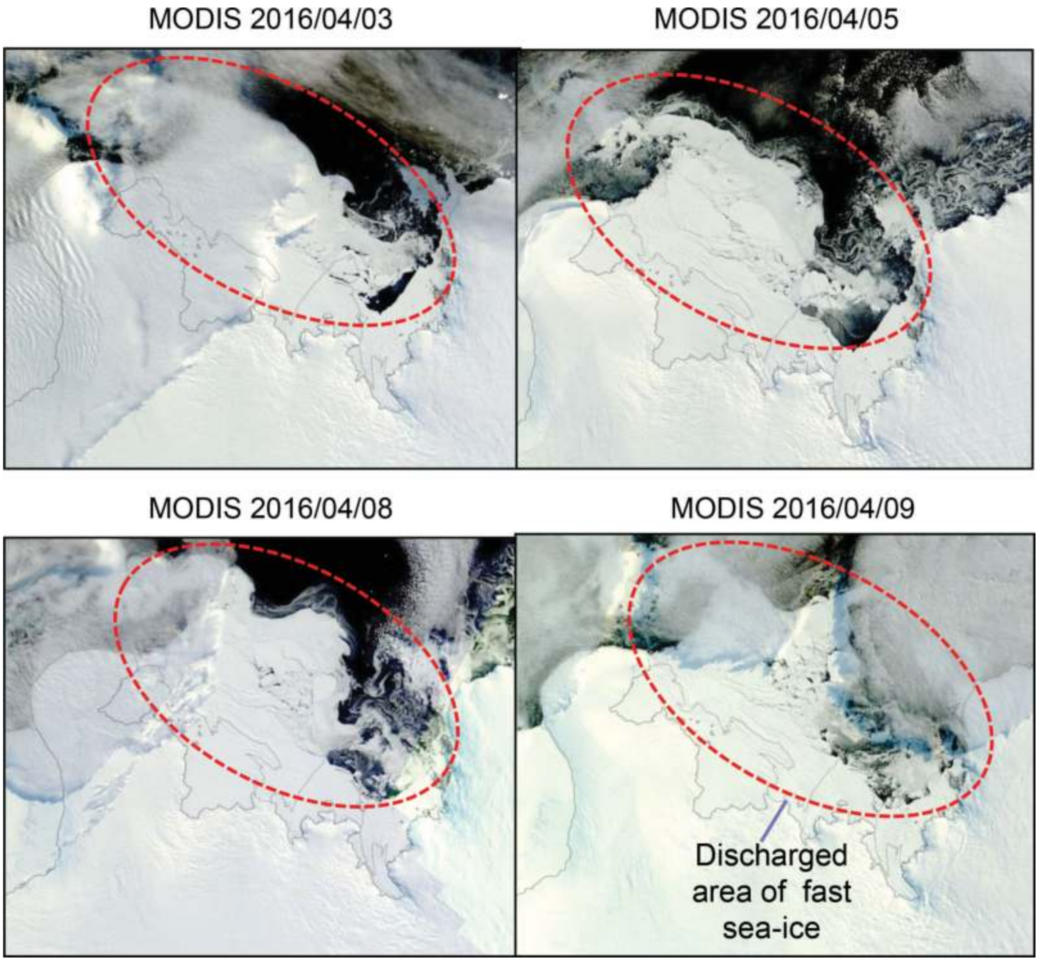

Figure 4.
MODIS satellite images around LHB on April 3 (upper left), April 5 (upper right), April 8 (lower left), and April 9 (lower right), 2016, respectively. Discharged areas of the fast sea ices are circled by red broken lines.

and the pack ice area where cryospheric dynamic movements (crashing, collision, break-off, etc.) involving oceanic swells were considered to generate the infrasound sources. Besides, many of the events occurred after April 11 when the last stage of sea-ice discharge events, just after the large oceanic swells, arrived at SYO as recorded by tide gauge data.

Regarding the effect of oceanic swells, microbaroms varied significantly both in amplitude and frequency contents in relatively long-period waveforms. These variations correspond to local atmospheric conditions, which are related to prevailing weather conditions in the vicinity of the area. As discussed in [12], infrasound signals below 3 Hz frequency content are supposed to contain in some extent the "microbaroms" which can be excited by storms during whole season particular in austral winter. By conducting this study, the array alignment of infrasound stations in LHB was efficiently operating, and it provides precise information on the arrival direction of infrasound excitation sources. The exact location of the generation sources might be compared with those obtained by seismic/geophysical approaches in the future. The oceanic-atmospheric coupling effects on infrasound could be explained by the relationship among complex Earth system in the polar environment. In this regard, infrasound monitoring in the Antarctic is a new proxy for detecting local/regional environmental change within global climate variation.

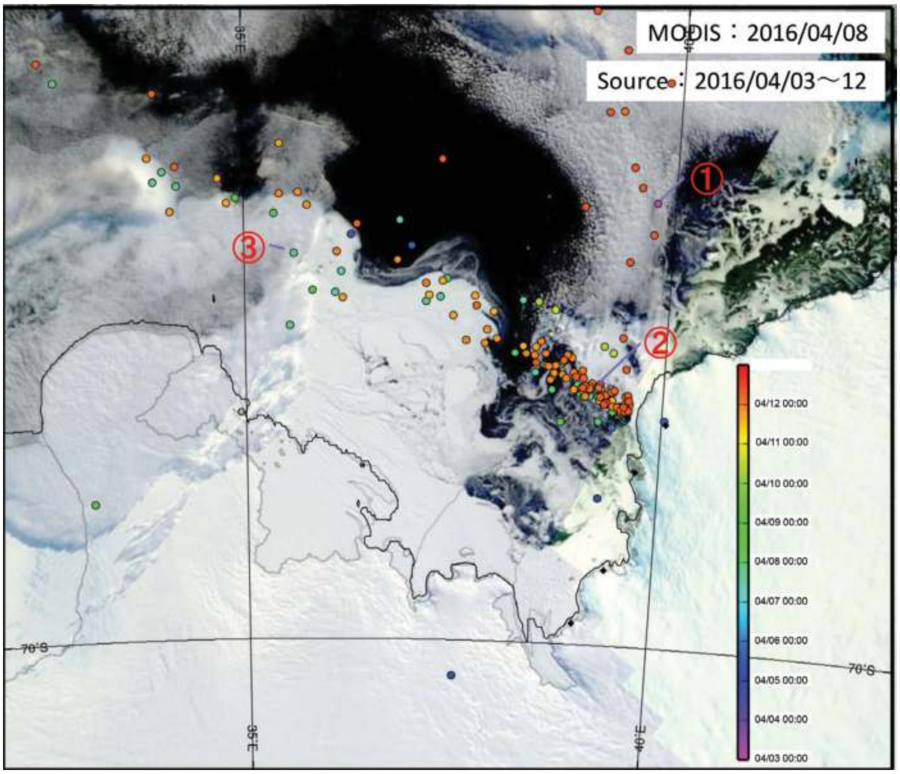

Figure 5.
*Result of estimated source locations of infrasound excitation with MODIS image (April 8) during the period from April 3 to April 12, 2016, by using two arrays (SYO and S16). Black solid diamonds are the infrasound stations in LHB. The estimated source locations (N = 175) are colored according to the time from the beginning of April 3. Three events correspond to the waveform examples (**Figure 4**) are which raveled by red circled numerous.*

4. Conclusion

Time-space variation of source location for infrasound excitation in mid-April 2016 was investigated by using two pair arrays deployed in LHB. A few tens of infrasound sources were determined during the period, and a majority of these events was located in northward orientation inside the sea-ice distributing area, attributed to the cryosphere origins such as the discharge of fast sea ice and collisions with icebergs by comparison with MODIS data. Many of the identified events had frequency contents of few Hz, which were higher than microbaroms from oceanic swells. Continuous observation of infrasound could be a proxy for monitoring surface environment and currently be going on climate change in the Antarctic.

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Author details

Takahiko Murayama[1]*, Masaki Kanao[2] and Masa-Yuki Yamamoto[3]

1 Japan Weather Association, Tokyo, Japan

2 National Institute of Polar Research, Research Organization of Information and Systems, Tachikawa-Shi, Tokyo, Japan

3 Kochi University of Technology, Kami-Shi, Kochi, Japan

*Address all correspondence to: murayama@jwa.or.jp

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