Longitudinal Seismic Waves in the Ross Ice Shelf Excited by Whillans Ice Stream Stick-Slip Events

*Douglas Wiens[1], Martin Pratt[1], Rick Aster[2], Andrew Nyblade[3], Peter Bromirski[4], Ralph Stephen[5], Peter Gerstoft[4]

1.Washington University in St Louis, 2.Colorado State University, 3.Penn State University, 4.Scripps Institution of Oceanography, 5.Woods Hole Oceanographic Institution

Rapid variations in the flow rate of upstream glaciers and ice streams may cause significant deformation of ice shelves. The Whillans Ice Stream (WIS) represents an extreme example of rapid variations in velocity, with motions near the grounding line consisting almost entirely of once or twice-daily stick-slip events with a displacement of up to 0.7 m (Winberry et al, 2014). Here we report observations of longitudinal waves from the WIS slip events propagating hundreds of kilometers across the Ross Ice Shelf (RIS) detected by more than 20 broadband seismographs deployed on the ice. The WIS slip events consist of rapid basal slip concentrated at three high friction regions (often termed sticky-spots or asperities) within a period of about 25 minutes (Pratt et al, 2014). Compressional displacement pulses from all three sticky spots are detected across most of the RIS up to about 600 km away from the source. The largest pulse results from the third sticky spot, located along the northwestern grounding line of the WIS. The best fitting propagation velocity, estimated using least squares and assuming the known location of the 2nd sticky spot, is 2.8 km/s. This agrees well with the predicted velocity derived by Press and Ewing (1951) for longitudinal wave propagation in a floating ice shelf. Particle motions are within the horizontal plane and roughly radial with respect to the WIS sticky-spots, but show significant complexity, presumably due to differences in ice velocity, thickness, and the thickness of water and sediment beneath. Strains within the ice shelf during wave passage are on the order of 10^{-6} s^{-1}, which is similar to strains from the surface waves of M_w ~ 9 earthquakes, which are known to trigger icequakes in continental ice sheets (Peng et al., 2014). Study of this phenomenon should lead to greater understanding of how the ice shelf responds to sudden forcing around the periphery.
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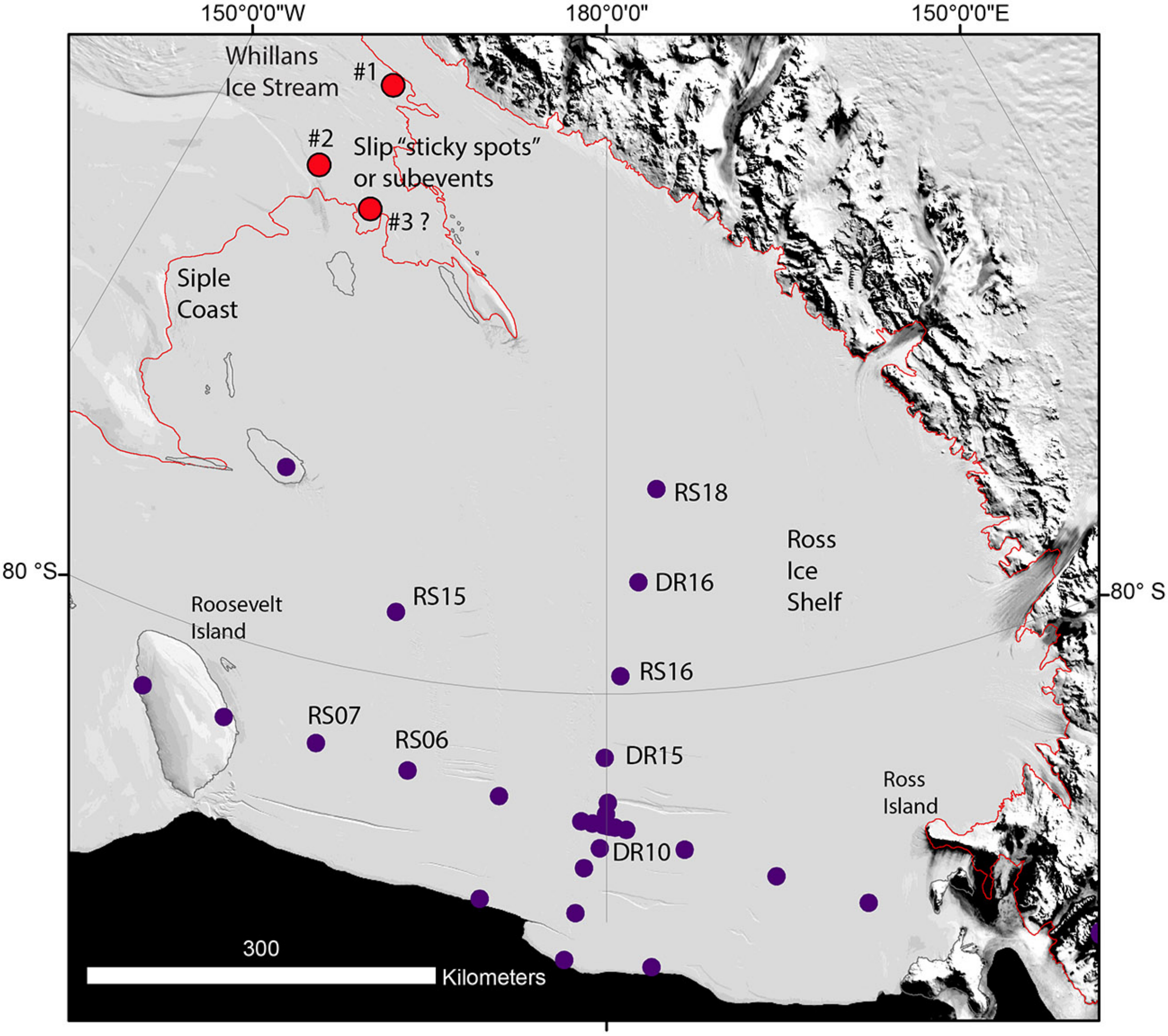
Keywords: glaciers, fault mechanics, Antarctica


150°0'0"W
180°0'0"
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Whillans
Ice Stream
#1
#2
Slip "sticky spots"
or subevents
#3 ?
Siple
Coast
RS18
Ross
Ice
Shelf
80 °S
DR16
-80° S
Roosevelt
Island
RS15
RS16
RS07
RS06
DR15
Ross
Island
DR10
300
Kilometers

Repeating Glacial Earthquakes Reveal Migration of Subglacial Sticky-spots.

*Jeremy Paul Winberry[1], Audrey D Huerta[1], Howard Conway[2], Sridhar Anandakrishnan[4], Richard Aster[3], Michelle Koutnik[2], Andrew Nyblade[4], Douglas Wiens[5]

1.Central Washington University, 2.University of Washington, 3.Colorado State University, 4.Pennsylvania State University, 5.Washington University in Saint Louis

Many glaciers primarily dissipate their gravitational potential energy by sliding along the ice-bedrock interface. In such cases, a glacier’s driving stress is often balanced by regions of enhanced basal traction known as sticky-spots. While the role of sticky-spots in the force budget of glaciers and ice streams has long been recognized, their formation remains less well understood. In this presentation, we leverage recent advances in seismograph coverage in the Transantarctic Mountains (TAM) to study relatively large glacial seismic events (> M2) that can be observed at regional distances. We report on 5 newly discovered and one previously studied sequences of repeating glacial earthquakes. These new sequences reveal that families can remain active for up to 7 years. Additionally, by tracking subtle changes in relative arrival times as well as waveform similarity, we deduce that these sticky-spots originate from migrating bands of basal debris.

Keywords: ice sheet, repeating earthquake, glacier

Characteristic seismic tremors with harmonic overtones in the Lützow-Holm Bay, East Antarctica: 2014-2015

*Masaki Kanao[1]

1.National Institute of Polar Research

At the International Polar Year (IPY2007-2008), the 'Polar Earth Observing Network (POLENET)' was the largest contributions in establishing seismic network in the Antarctic. Several kinds of seismic signals associated with environmental variations within the atmosphere - ocean –cryosphere - solid earth system had been detected in continental margins and surrounding Southern Ocean. Ice-related seismic motions for small magnitude events are generally named ice-quakes (ice-shocks) and can be generated by glacially related dynamics. Such kinds of cryoseismic sources are classified into several kinds; movements of ice sheets, sea-ice, oceanic tide-cracks, oceanic gravity waves, icebergs and the calving fronts of ice caps. Hypocenters of these local events nearby Syowa Station were identified as their location along the coast and edges of the fast-ice in the Lützow-Holm Bay (LHB) region.
In this study, characteristic features of seismic tremors observed around LHB are demonstrated, by taking into consideration a relationship between surface environmental changes in vicinity of the area. 121 seismic tremors are recognized in both the three-component short-period seismographs (HES) and broadband seismographs (STS-1) deploying at Syowa Station, during the period from October 2014 to April 2015. Many of the tremors hold characteristics of strong harmonic overtones, in their frequency content over the 1 Hz, representing nonlinear features (upward and/or downward frequency contents) with duration times from few minutes till few hours. These tremors occur independently with the arrivals of teleseismic phases, as well as are recorded by both the type of sensors (HES and STS-1) simultaneously. The harmonic overtones can be explained by a repetitive source (Powell and Neuberg, 2003), suggesting existence of several inter-glacial asperities which generate the characteristic tremors. It implies the tremor signals might be involved in the local origins, presumably the cryosphere dynamics; discharge of fast-ice from the Bay, collision of icebergs and fast-ices, calving of glaciers.
In the austral winter in 1997, actually, a few tens of hours duration tremor of harmonic overtones were strikingly observed involving the discharge of a large volume of sea-ice (fast-ice) from LHB (Kanao et al., 2012). The similar nonlinear harmonic tremors associated with the glacial earthquakes have been reported at Whillans Ice Stream, West Antarctica (Winberry et al., 2011, 2013), with the colliding icebergs in the Ross Sea (MacAyeal et al., 2008) and nearby the Neumayer Station of Dronning Maud Land (Eckstaller et al., 2007), respectively. In contrast, relatively small tremor signals are estimated to have very local origins, such as ice-shocks in relation to the sea-ice revel changes in relation to oceanic tide variation in LHB. It is noticed that the laming signals by an ice-breaker ship "Shirase" are clearly identified around 11-13 January 2015, when the ship approach nearby Syowa Station. The laming signals hold frequency contents over few Hz with 10-15 min. intervals.
In summary, seismic tremors in terms of cryosphere dynamics are likely to be involved with variations in surface environments, and continuous monitoring of their time-space variability provides indirect evidence of climate change in the Antarctic.

Keywords: seismic tremors, harmonic overtones, cryosphere dynamics

May 30, 2015 Bonin Islands, Japan deep earthquake (Mw7.8) recorded by broadband seismographic station on Greenland ice sheet

*Seiji Tsuboi[1], Takeshi Nakamura[1]

1.JAMSTEC

May 30, 2015 Bonin Islands, Japan earthquake (Mw 7.8, depth 679.9km GCMT) was one of the deepest earthquakes ever recorded. We apply the waveform inversion technique (Kikuchi & Kanamori, 1991) to obtain slip distribution in the source fault of this earthquake in the same manner as our previous work (Nakamura et al., 2010). We use 60 broadband seismograms of IRIS GSN seismic stations with epicentral distance between 30 and 90 degrees. The broadband original data are integrated into ground displacement and band-pass filtered in the frequency band 0.002-1 Hz. We use the velocity structure model IASP91 to calculate the wavefield near source and stations. We assume that the fault is squared with the length 50 km. We obtain source rupture model for both nodal planes with high dip angle (74 degree) and low dip angle (26 degree) and compare the synthetic seismograms with the observations to determine which source rupture model would explain the observations better. We calculate broadband synthetic seismograms with these source propagation models using the spectral-element method (Komatitsch & Tromp, 2001). We use new Earth Simulator system in JAMSTEC to compute synthetic seismograms using the spectral-element method. The simulations are performed on 7,776 processors, which require 1,944 nodes of the Earth Simulator. On this number of nodes, a simulation of 50 minutes of wave propagation accurate at periods of 3.8 seconds and longer requires about 5 hours of CPU time. Comparisons of the synthetic waveforms with the observation at Greenland ice sheet station, ICESG (epicentral distance 83.4 degree), show that the arrival time of pP wave calculated for depth 679km matches well with the observation, which demonstrates that the earthquake really happened below the 660 km discontinuity. In our present forward simulations, the source rupture model with the low-angle fault dipping is likely to better explain the observations.

Keywords: deep earthquake, Greenland icesheet, theoretical seismograms

Array detection of Antarctic microseisms: The effect of sea ice and Southern Ocean storms

*Martin J Pratt[1], Douglas Wiens[1], Paul Winberry[2], Sridhar Anandakrishnan[3], Garrett G Euler[4]

1.Washington University in St Louis, MO, USA, 2.Central Washington University, WA, USA, 3.Pennsylvania State University, PA, USA, 4.Los Alamos National Laboratory, NM, USA

Antarctica is ideally situated for microseism studies because it is surrounded by the Southern Ocean where storm systems are relatively uninhibited by landmasses. Furthermore, the seasonal advancement of sea ice over the surrounding continental shelf has the effect of damping microseism generation in coastal waters. Until recently, ocean-sourced microseism studies in Antarctica have been limited to single station investigations leading to unconstrained microseism source locations. We present results from a 60 km aperture array deployed for two months on the Whillans Ice Stream, West Antarctica. We beamform month- and day-long stacks of noise correlograms to determine the prevailing noise source direction and the velocity of propagating waves for several frequency bands. Single-frequency (~15 s) Rayleigh wave microseisms are located to three coastal source areas of strong microseism generation around the continent with their intensity heavily modulated by the local sea ice extent. Long-period double-frequency (9–11 s) Rayleigh wave microseisms are generated in the deep ocean and correlate with ocean wave hindcast modeling. These deep ocean-sourced microseisms remain strong throughout the year and are relatively independent of sea ice variations. Short-period double-frequency microseisms (5–7 s) are found to contain both coastal-sourced microseisms and deep ocean-sourced body wave microseisms. The strongest arrival in this band is often observed to propagate faster than the predicted fundamental mode Rayleigh wave, slower than potential body waves, and so is interpreted to be an *Lg* phase propagating through Antarctic continental crust. *Lg* sources are likely Rayleigh wave conversions at the ocean-continent transition and body waves are modeled to be sourced in the deep ocean. *Lg* phase generation is switched on only as sea ice retreats over the continental shelves, potentially leaving only deep ocean, body wave sources throughout the winter months.

Keywords: Antarctica, Microseisms, Storms

Seismic interferometry using broadband continuous seismic waveform data from the Greenland ice sheet

*Genti Toyokuni[1], Hiroshi Takenaka[2], Masaki Kanao[3], Seiji Tsuboi[4], Yoko Tono[5]

1.Research Center for Prediction of Earthquakes and Volcanic Eruptions, Graduate School of Science, Tohoku University, 2.Graduate School of Natural Science & Technology, Okayama University, 3.National Institute of Polar Research, 4.Japan Agency for Marine-Earth Science and Technology, 5.Ministry of Education, Culture, Sports, Science and Technology

The GLISN (GreenLand Ice Sheet monitoring Network) is an international project to seismologically monitor changes in the Greenland ice sheet, by deploying a large broadband seismograph network in and around Greenland. This project is currently managed through joint collaboration by 11 countries for operating 32 seismic stations, although only four of them are on the ice sheet. Japan is a partner country from when the project was launched, and has been sending a field team every year since 2011. A joint USA and Japanese GLISN team has ever serviced three stations on ice sheet (station code: ICESG, DY2G, and NEEM) and also three stations on bedrock at the coastal area (NUUK, SOEG, and DBG), which indicates a great effort of this team among the whole GLISN committee. Especially in 2015, the joint team succeeded in relocating a seismometer at ICESG station, by excavation from 5 m depth below the snow surface.

The GLISN broad-band seismic data (20 sps) is available in realtime via the Iridium satellite network. The data is also open to the public at the IRIS Data Management Center (http://www.iris.edu/ds/nodes/dmc/). In this work, we detected the Rayleigh wave by the ambient noise cross-correlation analysis of the GLISN data, to investigate shallow structure including both ice sheet and bedrock in Greenland.

We used the vertical-component records during Jan. 1, 2015 –Apr. 20, 2015 from four GLISN stations on ice sheet (ICESG, DY2G, NEEM, SUMG). Daily cross-correlation functions (CCFs) for all possible pairs of stations are computed by the following procedure. First, we divide the continuous records into 600-s-long segments with 450-s overlap. Second, we correct the instrument response, eliminate segments with event data or error values, and apply the whitening in frequency domain and banalization in time domain. After that we calculate the daily CCFs by stacking CCFs for each segment (e.g., Shapiro & Campillo, 2004; Takagi & Okada, 2012). The final CCFs can be obtained by stacking all daily CCFs for the whole analysis range.

We found, for example, nearly constant Rayleigh wave group velocity of 2.8 km/s, for the period range of 2-14 s, on the CCF of the NEEM-SUMG pair. We also found that the ambient-noise source is well corresponded to a known source of microseisms at the southern tip of Greenland. In the presentation, we will show results for the other station pairs.

Keywords: Greenland, Seismic interferometry, Ice sheet, GLISN

Seismic-infrasound monitoring of a tidewater calving glacier (Bowdoin, Greenland)

*Evgeny A. Podolskiy[1], Shin Sugiyama[2], Martin Funk[3], Riccardo Genco[4], Masahiro Minowa[2], Fabian Walter[3], Shun Tsutaki[2,5], Maurizio Ripepe[4]

1.Arctic Research Center, Hokkaido University, Sapporo, 2.Institute of Low Temperature Science, Hokkaido University, Sapporo, 3.Laboratory of Hydraulics, Hydrology and Glaciology, ETH Zurich, Zurich, 4.Dipartimento di Scienze della Terra, Università di Firenze, Florence, 5.Arctic Environment Research Center, National Institute of Polar Research, Tokyo

Greenland is the second largest ice-covered area worldwide, where recent dramatic recession of outlet glaciers is known to be a key driver for accelerated ice-sheet mass loss. Bowdoin Glacier in northwestern Greenland (~120 km from Thule) is a grounded tidewater calving glacier that has been rapidly retreating since 2008. An observational seismic-infrasound network was installed in July 2015 near the 3-km-wide calving front of the glacier to enable near-source monitoring of frontal dynamics.
One Güralp CMG40T triaxial broadband seismometer was installed on the rocky coast in advance of the calving front, together with a time-lapse camera and a water pressure sensor in the fjord (for recording micro-tsunamis generated by calving). Four Lennartz LE-3D short- and long-period seismometers were arranged on the glacier ice in a triangle-shaped array, ~250 m from the marginal ice cliff, where icebergs are discharged into the fjord. An infrasound array comprising four pressure sensors was installed on a hill located ~3 km behind the calving front. Another two infrasound sensors were collocated with the central station of the on-ice seismic array and the broadband station. The aperture of both arrays was ~150 m. Additionally, three GPS on-ice stations with an on-rock reference station were established along the longitudinal profile of the Bowdoin Glacier to record ice-flow speed. Finally, an automatic weather station was used to record meteorological parameters near a base camp east of the glacier.
Multiple seismic and infrasound events were recorded and linked to surface crevassing, calving, presumably hydrofracturing, iceberg rotations, teleseismic earthquakes, helicopter-induced tremors, etc. Using classic seismological and array approaches (i.e., “Short Term Averaging / Long Term Averaging” and “f-k” analysis), as well as image processing, we explore and inter-compare this unique dataset. The most striking feature of the records is the temporal variability of microseismic events, which were continuously recorded over a period of two-weeks. The results show a double-peak diurnal oscillation in the number of events (up to 600 events per hour). Using high-resolution surface displacement GPS measurements, we show that the correlation between the number of events and tides is relayed through strain-rate variation. The strain rate corresponds to local extensional stretching of the glacial surface, mainly in response to increases in air temperature and falling tide velocity, which reduces back-pressure on the ice cliff.

Keywords: Greenland, tidewater glacier, icequake, seismic, infrasound, calving

Relationship between infrasonic and seismic waves as an example of multi-sphere interaction

*Masa-yuki Yamamoto[1]

1.School of systems engineering, Kochi University of Technology

Infrasound is known as lower frequency pressure waves than the hearable sound by human ears, thus the frequency range is below 20 Hz. The pressure waves can usually be generated by moving surfaces in the atmosphere with a kind of *resonance* situation with a huge moving membrane. In the earth's atmosphere, it can be realized by moving massive geophysical surfaces such as landslides, earthquakes, and tsunamis, for example. Thus, the infrasonic wave is one of the important waves in nature to be continuously and carefully monitored, if we intend to develop disaster prevention system with any kinds of sensor networks. The infrasound can be understood generally being coupled with long scale seismic waves as well as sea waves, atmospheric gravity waves, and planetary scale tidal waves.

The pressure waves can propagate in the atmosphere not only for horizontal direction but also for vertical orientations. When the waves propagate upward from the ground, the waves can enhance their amplitude as the background atmospheric pressure comes to rarefied situation in upper atmosphere, decreasing with “scale height” basis. Thus, such pressure waves with a fixed frequency can collapse themselves in a fixed atmospheric density level, thus at a fixed altitude. At an altitude of collapsing waves, the energy can be released into the molecules there and the remained energy can be thought as a source of another waves. In the mesosphere and thermosphere, many kinds of wave patterns have been found as many remote-sensing methodologies, those are, imaging of airglows and mapping of total electron contents (TEC) by analyzing the GNSS satellites receiving waves, for example.

On the other hand, at a time of meteorites encountering into the earth's atmosphere, the hypersonic entry from the outer space can generate intense pressure waves as shock waves and then propagates vertically to the ground. At the special case of Hayabusa's artificial reentry in 2010, we conducted an experiment on ground to expand many seismic and infrasonic sensors in the desert area of Australia, measuring precise infrasonic waves and its coupling into the ground motion. Such coupling phenomena can usually be detected by seismometers and sea waves monitoring stations on/near the ocean. Coupling between the infrasound in the atmosphere and the seismic waves on ground, sea waves in the ocean, or the sea ice motion on the polar sea, is usually understood as the both directing interaction as the inter-sphere couplings. Here we will introduce some interesting case studies for the inter-sphere coupling processes, showing possibilities to conduct a new disaster prevention technique for tsunami and any other geophysical destructive events and/or a new monitoring proxy for the global warming.

Keywords: Infrasound, Seismic waves, Interaction

Numerical modeling of microbarometric and microseismic oscillations due to ocean surface waves

*Mitsuru Matsumura[1], Masaki Kanao[1]

1.National Institute of Polar Research

Ocean surface waves (OSWs) shake the atmosphere on sea surface and the crust on sea bottom. In order to estimate the amplitude and the propagation directions of the OSWs from the observes oscillations, we need to quantify (1) the amplitude and the propagation directions of the oscillations excited by the OSWs, and (2) the variation of the amplitude after their propagation to observation points. The quantification of (1) have been almost completed by previous mathematical studies: The excited oscillation amplitude is in proportion to the product of two OSWs' and the frequency and wavenumber are the sum of the OSWs’. Here the OSWs need to propagate in the nearly opposite directions, to have nearly the same wavelengths, and to interact nonlinearly. A recent study showed that ocean compressibility is needed for seismic body wave excitation [Ardhuin and Herbers, 2013 (AH2013)]. The quantification of (2) by mathematical approaches are, however, not so easy because it deals with many inhomogeneous and uncertain parameters such as atmospheric wind and temperature, and crust density. In such complicated conditions numerical approaches are more useful. In this paper, we develop a numerical model to quantify both (1) and (2), and validate the model. In our model, the atmosphere, ocean and crust are treated as as a single continuum and described by nonlinear and compressible equations. As the validation we impose two OSWs traveling in the opposite directions and having almost the same frequency and wavelength, analyze the resultant atmospheric and seismic oscillations, and compare them with AH2013. Our analysis shows that the imposed OSWs excite acoustic waves in the atmosphere and in the ocean. The frequency and the wavenumber of the acoustic waves are the sum of the OSWs’. The oceanic acoustic waves propagate to the ocean bottom to excite seismic surface waves with the same frequency and wavelength. In the crust seismic body waves are also excited. The excited amplitudes are consistent with AH2013.

Keywords: microseisms, microbaroms, ocean surface waves

Long-period teleseismic detectability and its response to cryosphere variation around Syowa Station, Antarctica since 1967

*Masaki Kanao[1]

1.National Institute of Polar Research

Phase identifying procedure for teleseismic events at Syowa Station (69.0S, 39.6E; SYO), East Antarctica have been carried out since 1967 after the International Geophysical Year (IGY; 1957-1958). From the development of INTELSAT telecommunication link, digital waveform data have been transmitted to the National Institute of Polar Research (NIPR) for utilization of phase identification. Arrival times of teleseismic phases, P, PKP, PP, S, SKS have been reported to the International Seismological Centre (ISC), and published by "JARE Data Reports" from NIPR. In this paper, hypocentral distribution and time variations for detected earthquakes are demonstrated over the last four decades in 1967-2010. Characteristics of detected events, magnitude dependency, spatial distributions, seasonal variations, together with classification by focal depth are demonstrated. Besides the natural increase in number for occurrence of teleseismic events on the globe, a technical advance in observing system and station infrastructure, as well as the improvement of procedure for reading seismic phases, could be efficiently combined to produce the increase in detection number in last few decades. Variations in teleseismic detectability for longer terms may possibly by associate with cryosphere dynamics and evolution, meteorological environment, as well as the sea-ice spreading area around the Antarctic continent. Recorded teleseismic and local seismic signals have sufficient quality for many analyses on dynamics and structure of the Earth’s as viewed from Antarctica. The continuously recorded data are applied not only to lithospheric studies but also to Earths deep interiors, as the significant contribution to the Federation of Digital Seismological Network (FDSN) from high southern latitude.

Keywords: teleseismic event, ISC, sea-ice variation, Antarctica, phase detection

Classification of ice tremor recorded at Syowa Station in Antarctica

*Yuya Tanaka[1], Yoshihiro Hiramatsu[1], Yoshiaki Ishihara[2], Masaki Kanao[3]

1.Kanazawa Univ., 2.JAXA, 3.NIPR

It was found that tectonic earthquakes and tremors related ice (ice tremor) have been occurred by seismic observations in Antarctica. The ice tremor is the tremor which is originated in collision of sea ice, crack opening and closing, collapse of icebergs and so on (Kanao et al., 2012). However, there are only few reports related to the waveform of ice tremors and seasonality in Antarctica. Purposes of this study are to classify ice tremors based on the feature of their waveforms and to reveal the time variation in the number of generation.
We use the north –south component of the waveform data recorded by STS –1 at Syowa Station. Analysis duration is from January to December in 2014. We made seismic waveform image and spectrogram and counted ice tremors with them. We define here 'ice tremor' as the tremor of which P-wave and S-wave are not clear and duration is longer than 5 minutes.
We found total 231 ice tremors in 2014. Monthly number of ice tremors changed similarily to monthly mean temperature except for from January to March. Monthly cumulative duration of ice tremors changed similarily to monthly mean temperature except for January. The number of ice tremors is low in February, but the cumulative duration is longest. We classified ice tremors into 4 types based on the feature of their spectral time variation. Type A is the ice tremor which duration is long (about ten thousands seconds) and amplitude is small over the waveform. Type B is the one which dominant frequency changes irregularly over the waveform. Type C is the one which dominant frequency continuously decreases and the overtone can be seen. Type D is the one which duration is short (about hundreds) and the amplitude gradually increases and after that gradually decreases.
Microbaroms data are useful tool for characterizing ocean wave climate (Ishihara et al., 2015), so we compared them with seismic data. In summer, both seismic amplitude and microbaroms amplitude is large and the peak of type A is almost same with the peak of microbaroms, so type A is considered to be excited by sea wave. In winter, only the amplitude of microbaroms is large, so ice tremor wave is considered to be not recorded well because of grown coastal ice (Grob et al, 2011). On April in 2006, at Neumayer Stations in Antaectica, an ice tremor was recorded and the source of that is seems to be the iceberg (Eckstaller et al., 2006). The spectral feature of this is similar to which of type C, so type C may be occurred by iceberg.

Keywords: Antarctica, Syowa Station, ice tremor, microbarom

Characteristics of seismic waveform recorded by seismic array at East Ongul Island, Antarctica

*Manami Nakamoto[1], Hiroki Miyamachi[2], Takeshi Matsushima[1], Masaki Kanao[3], Masa-yuki Yamamoto[4]

1.Institute of Seismology and Volcanology, Faculty of Science, Kyushu University, 2.Graduate School of Science and Engineering, Kagoshima University, 3.National Institute of Polar Research, 4.Department of systems engineering, Kochi University of Technology

In polar region, various vibration phenomena are exited in association with physical interaction between solid earth, atmosphere, ocean and cryosphere systems. These phenomena can be observed as seismic and infrasonic waves, and it is important to investigate their features and generation process in order to reveal relationship between their occurrence and environmental variations.
An array observation helps us to get information of incident waves on the stations. In order to detect source locations of seismic event around Showa station, East Ongul Island, East Antarctica, we carried out a seismic array observation from January 2 to February 2, 2015. We installed 7 temporary seismic stations in a rocky area located at 1 km away from Showa station, consisting of 1-Hz three-component seismometers with a site spacing of about 100 m. During this period, two characteristic waveforms were recorded. One occurred from January 11 at 22:40 (UTC) to January 12 at 11:20 (UTC), corresponding to ice-breaking by a ship. The peak frequency was about 10 Hz. The other occurred on January 14 at 3:45 (UTC) and its duration was about 13 minutes. Peak frequencies of the tremor were about 2, 4 and 6 Hz, and these peaks varied over time. It seems that the tremor arrived from south-southeast direction with a small slowness by semblance analysis. We will reveal characteristics of these seismic events in more detail and estimate location of their sources by using data recorded at other seismic and infrasound stations around East Ongul Island.

Keywords: seismic array, tremor, Antarctica

Infrasound signal detected at the Lützow-Holm Bay region, East Antarctica, and their relation to surface environment

*Takahiko Murayama[1], Masaki Kanao[2], Masa-yuki Yamamoto[3], Yoshiaki Ishihara[4], Takeshi Matsushima[5], Yoshihiro Kakinami[6], Manami Nakamoto[5], Yukari Takeuchi[7]

1.Japan Weather Association, 2.National Institute of Polar Research, 3.Kochi University of Technology, 4.Japan Aerospace Exploration Agency, 5.Kyushu University, 6.National Central University, Taiwan, 7.Forestry and Forest Products Research Institute

A single infrasound sensor has been making continuous recordings since 2008 at Syowa Station (SYO; 69.0S, 39.6E) in the Lützow-Holm Bay (LHB) of East Antarctica. The continuously recorded data clearly show the contamination of background oceanic signals (microbaroms) throughout all seasons. In austral summer 2013, several field stations with infrasound sensors were established along the coast of the LHB. Two infrasound arrays of different diameters were set up: one at SYO (with a 100-m spacing triangle) and one in the S16 area on the continental ice sheet (with a 1000-m spacing triangle). In addition to these arrays, isolated single stations were deployed at two outcrops in the LHB.
Detailed and continuous measurements of infrasound waves in Antarctica could prove to be a new proxy for monitoring regional environmental change as well as temporal climate variations in high southern latitudes.
Until now, these arrays clearly detected the propagation direction and frequency content of microbaroms from the Southern Ocean. In addition to the microbaroms, several other remarkable infrasound signals were detected, including regional earthquakes, and so on.
In this presentation, we would introduce detected infrasound signals.

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Keywords: Infrasound, Seismic waves, Antarctica, Microbaroms, icequake, Sensor array

Multi-Sphere interactions in the coastal and marine environment inferred from infrasound and seismic data at Teranova Bay, west Antarctica

*Takahiko Murayama[1], Masaki Kanao[2], Yoshiaki Ishihara[3], Masa-yuki Yamamoto[4], Takuma Oi[5]

1.Japan Weather Association, 2.National Institute of Polar Research, 3.Japan Aerospace Exploration Agency, 4.Kochi University of Technology, 5.Toho Mercantile Co., Ltd

Characteristic features of infrasound waves observed in the Antarctic reveal physical interaction involving surface environments around the continent and Southern Ocean. An infrasound array (100 m spacing) by using three sensors (Chaparral Physics Model 25, with a detectable frequency range of 0.1-200 Hz), together with a broadband barometer (Digiquartz Nano-Resolution Model 6000-16B Barometer, with a detectable frequency range of 0-22 Hz) were installed at Jang Bogo Staion, Tera Nova Bay, West Antarctica in December 2015 by the Korea Arctic and Antarctic Research Program (KAARP). The initial data recorded by the broadband barometer include several signals originated surrounding surface environment, in addition to the local wind noises such as katabatic signals. Clear signals from background oceanic origin (the "microbaroms") are continuously recorded at the austral summer on mid-December with predominant frequency around 5 s. Variations of their frequency context and strength appeared in Power Spectral Density are affected by evolution of the sea-ice surrounding the Tera Nova Bay. In contrast, several infrasound monitoring stations have been conducting around the Lützow-Holm Bay (LHB), East Antarctica by Japanese Antarctic Research Expedition (JARE) since 2008. Two infrasound arrays with different diameter triangles have been deployed at both inside the Syowa Station (100 m spacing) and on the continental ice sheet (1000 m spacing). Besides the arrays, isolated single stations are deployed at three outcrops. These arrays in LHB clearly identified the predominant propagating directions in NWN and their frequency content variations of "microbaroms" from Southern Indian Ocean. In this presentation, characteristic features recorded by the initial data observed at Jang Bogo Staiton is presented, as compared with that obtained at the LHB. Microbaroms measurement is a useful tool for characterizing ocean wave climate, complementing other oceanographic, cryospheric and geophysical data in the Antarctic. Detail and continuous observations of infrasound waves in Antarctica is a new proxy for monitoring a environmental changes such as global warming affecting on polar regions.

Keywords: Infrasound, Antarctica, KAARP, JARE

Seismic observations in Greenland by a joint USA and Japanese GLISN team (2011-2015)

*Genti Toyokuni[1], Dean Childs[2], Masaki Kanao[3], Yoko Tono[4], Tetsuto Himeno[5], Seiji Tsuboi[6]

1.Research Center for Prediction of Earthquakes and Volcanic Eruptions, Graduate School of Science, Tohoku University, 2.IRIS PASSCAL Instrument Center, 3.National Institute of Polar Research, 4.Ministry of Education, Culture, Sports, Science and Technology , 5.Faculty of Economics, Shiga University, 6.Japan Agency for Marine-Earth Science and Technology

Global climate change is currently causing melting of the Greenland ice sheet. Recently, a new type of seismic event, referred to as a “glacial earthquake”, has been recognized. Such earthquakes are generated by the movements of large masses of ice within the terminal regions of glacier, and represent a new approach for monitoring ice sheet dynamics. In 2009, the GreenLand Ice Sheet monitoring Network (GLISN) was initiated as international project to monitor changes in ice sheet by constructing a large broad-band seismological network in and around Greenland.

Japan is a partner country from when the GLISN project was launched, and has been sending an expedition team every year since 2011. In 2011, the joint USA and Japanese GLISN team installed the dual seismic–GPS station ICESG-GLS2 in the middle of the Greenland ice sheet. During 2012-2015, we conducted maintenance of the three stations on ice (ICESG-GLS2, DY2G-GLS1, and NEEM-GLS3), and three stations on bedrock in coastal region (NUUK, DBG, and SOEG).

Especially, in 2014, we had succeeded in real-time transmission of broad-band continuous seismic waveform data from the three ice stations. It was the first time in the world that the seismic data with such a high sampling rate is transferred from the ice sheet. The data is now open to the public and available from the IRIS Data Management Center (http://www.iris.edu/ds/nodes/dmc/). Also in 2015, we relocated a seismic sensor at the station ICESG, which had been covered by snow of 5 m depth due to accumulation for four years. All of the excavation and reinstallation processes were achieved within two days by human labor of only three workers.

This presentation will summarize our field activities, and introduce the future plans. The Japanese GLISN team has been supported by JSPS KAKENHI 24403006.

Keywords: Greenland, Seismic observation, ice sheet

A review of seismicity, structure and tectonics in the Arctic region

*Shigeru Toda[1], Masaki Kanao[2], Genti Toyokuni[3], Seiji Tsuboi[4]

1.Department of Earth Sciences, Faculty of Education, Aichi University of Education, 2.National Institute of Polar Research, 3.Research Center for Prediction of Earthquakes and Volcanic Eruptions, Graduate School of Science, Tohoku University, 4.JAMSTEC, Center for Earth Information Science and Technology

The “Arctic” region, where the North Pole occupies the center of the Arctic Ocean, has been affecting the environmental variation of the Earth from geological time to the present. However, the seismic activities in the area are not adequately monitored. Therefore, by conducting long term monitoring of seismic phenomenon as sustainable parameters, our understanding of both the tectonic evolution of the Earth and the dynamic interaction between the cryosphere and geosphere in surface layers of the Earth will increase. In this paper, the association of the seismicity and structure of the Arctic region, particularly focused on Eurasian continent and surrounding oceans, and its relationship with regional evolution during the Earth’s history is studied. The target areas cover representative tectonic provinces in the Eurasian Arctic, such as the wide area of Siberia, Baikal Rift Zone, Far East Russia, Arctic Ocean together with Greenland and Northern Canada. Based on discussion including characteristics of seismicity, heterogeneous structure of the crust and upper mantle, tectonic history and recent dynamic features of the Earth’s surface in the Arctic are summarized.

Keywords: Arctic region, seismicity, crustal structure, tectonics, glacial earthquakes

