Chapter 10

Summary: Global Seismology and the Polar Region

Masaki Kanao

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Abstract

"Polar Seismology" has been developed since the International Geophysical Year (IGY 1957–1958) and contributed significantly to global seismology in particular through the big project of the International Polar Year (IPY 2007–2008). At present, in the first stage of the twenty-first century, "polar regions" play an important role to monitor and understand the drastic variations in the Earth's system as well as to advance the interdisciplinary studies of the interactions among multispheres within the system.

Keywords: global seismology, polar region, wave propagation, global network, Earth's system

1. Contributions to global seismology

Various kinds of temporal-spatial heterogeneities and their dynamic features from the surface layers to the center of the Earth by using the seismological data obtained from the polar region are summarized in this special issue. High-density geophysical station networks deployed during the IPY in bipolar regions contributed to many kinds of research studies: static structure related to the Earth's history; earthquake occurrence mechanism; inner deformation of lithospheric plates; crustal uplift involving deglaciation, plate motion, and seismic isotropy; and other topics in terms of surface dynamics of the Earth's environment. Moreover, by utilizing the Internet facilities and other useful computer and information technology tools, real-time data transmission from the remote areas of the polar region to all the other locations in global networks, as well as conducting real-time monitoring of variations in the solid Earth viewed from high latitudes, shall be successful. In addition, facilitating disaster prevention on a global scale could be achieved from the tentative "frontier region" of the Earth.

Within the complex system consisting of the solid Earth and adjacent spheres of the Earth, it is essential to collaborate with interdisciplinary approaches, not only by the seismological community but also by the other science branches, to promote fruitful scientific achievements regarding the physical interaction of the multisphere subsystems and the associated field operations. In the bipolar region, a big project named the International Polar Year (IPY 2007–2008) was conducted with various kinds of scientific activities; a significant number of new founds were identified, and interdisciplinary and international collaborations were strongly promoted. The Japanese polar scientists took the initiatives in various categories of activities [1]. However, the IPY was one of the waypoints to be passed through for the long-term monitoring of the Earth's environmental system in the twenty-first century. It is necessary to conduct the long-duration international programs in various categories: searching for new fundamental founds for the development of research and observation methodology and logistic platforms, preserving and providing the retrieved data, and so on.

In Antarctica, the geophysical network stations deployed by the Antarctica's Gamburtsev Province (AGAP) of the Gamburtsev Mountain Seismic Experiment (GAMSEIS) and the Polar Earth Observing Network (POLENET) including the Dome-F station have existed. In addition to the Arctic, POLENET and GLISN have been established during the IPY and beyond (**Figure 1**). These stations in the bipolar region contributed to the studies of the inner structure of the Earth and the earthquake source mechanism with a fine time-space resolution [3]. The inland plateau stations such as Dome-A, -C, and -F have significance not only to the global networks (for instance, FDSN; see Chapters 1 and 2) but also to the regional observation systems in the Antarctic continent and the surrounding Southern Ocean. It is essential to continue observations at these inland plateau stations in addition to the coastal permanent ones such as the Syowa Station, in order to monitor the seismicity of tectonic and glacial earthquakes in the vicinity of the local area along the Antarctic Plate.

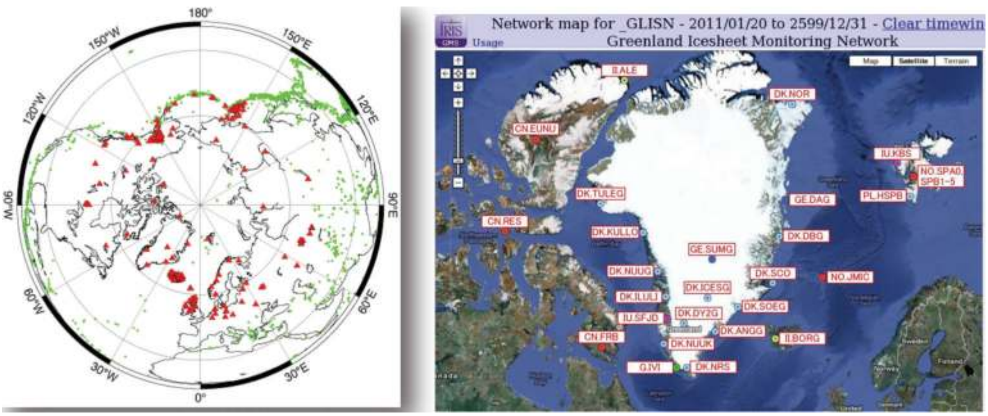

Figure 1. (Left) Distribution of seismic stations in the Arctic (red triangles: IRIS/DMS and PASSCAL) (modified after Kanao et al. [2]). The green circles represent the hypocenters during 1990–2004. (Right) Station distribution of GLISN in 2011 (by IRIS/DMS). (Left) Open Access Journal (CC BY 3.0) (first author is M. Kanao). (Right) Copyright http://www.iris.edu/hq/.

2. Global seismic wave propagation

Before and after the IPY, there were several research studies concerning seismic wave propagation on a global scale by using the data from the polar region.

Loading and gravitational effects of the 2004 Indian Ocean tsunami waves were investigated by using the broadband seismographs and superconducting gravity meter at Syowa Station, Antarctica [4]. T phases and the short-period resonance mode inside the Lützow-Holm Bay (LHB) were studied in order to define the elastic parameters concerning the free oscillation of the Earth. The sea-level changes generated by tsunami waves from the Sumatra-Andaman earthquake on December 2004 were clearly recorded by seismographs at the coastal stations in the Antarctic such as the Syowa Station, giving fundamental information on detecting the long-period oceanic variations and nonstatic events and signals from the deep interiors of the Earth. The ocean bottom pressure gage deployed at the offshore of LHB, moreover, detected the low-frequency static variations [5]. The oceanic expansion area between the circular Antarctic current and the coastal flows of the continent has a role in creating horizontal expansion and upwelling of the oceanic water. The ocean bottom pressure gage observations revealed the features of oceanic mass transportation of the area. Future the further progress in understanding the oceanic mass circulation along the coastal regions of Antarctica is expected in future.

By using the broadband seismic data of Antarctica, the 2008 Eastern Sichuan earthquake (M 7.9) simulated waveforms at Syowa Station, which were compared by utilizing the "Earth simulator" infrastructure [6]. May 30, 2015, Bonin Islands, Japan deep earthquake (M 7.8) was also recorded at the broadband seismographic station in the Greenland ice sheet (Tsuboi, 2017, personal communication). They applied the waveform inversion technique to obtain a slip distribution in the source fault of May 30, 2015, Bonin Islands, Japan earthquake (M 7.8, 680-km depth). They obtained a source rupture model for both nodal planes with a high dip angle (74°) and a low dip angle (26°) and compared the synthetic seismograms with observations to determine the most precise source rupture model. Comparisons of synthetic waveforms with the observations at the Greenland ice-sheet station, ICESG (epicentral distance 83.4°), showed that the arrival time of the P wave for a depth of 680 km matched well, suggesting the earthquake occurred below the 660-km seismic discontinuity. In their forward simulations, the source rupture model with a low-angle fault dipping was likely to better explain the observations.

Moreover, the quasi-axisymmetric finite-difference method was developed involving a realistic and an efficient modeling of regional and global seismic wavefields, by applying the dataset of Antarctica [7]. The new method can be utilized for unique points such as the poles of the globe, together with an investigation of the effect of the existence of the ice sheet. The estimation of the inner structure of the Earth by using the quasi-axisymmetric method was actually acquired through the broadband seismic data from AGAP/POLENET [8]. The same wave modeling method was expanded to the local area and applied to the data from Greenland (GLISN; see Chapters 2 and 7) [9] (**Figure 2**). By adding the information on the thickness of the ice sheet and bedrock topography, the generating scheme of the waves propagating inside the ice sheet (the "ice waves") was theoretically demonstrated.

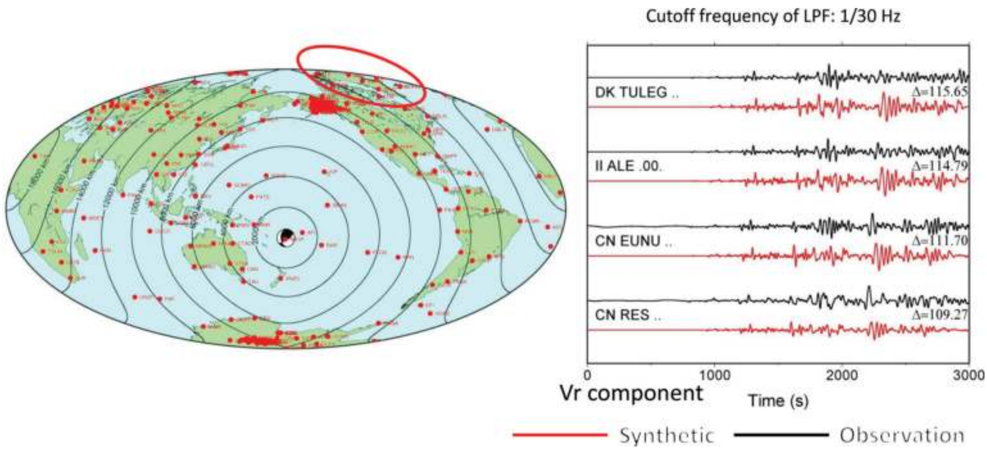

Figure 2. Observed and theoretical seismic waveforms at the GLISN stations (hypocenter); Fiji earthquake (Sep 15, 2011; M = 7.3 and depth = 630 km) (modified after Toyokuni et al. [9]). Copyright Clearance Center (CCC, http://www.copyright.com/). License number: 4280481114467, license date: February 1, 2018.

Regarding the studies of deep interiors, the latitude dependence on the intrinsic frequencies of the Earth's free oscillation (${}_0S_0$, ${}_1S_0$, and ${}_0S_2$) in bipolar regions was investigated by using both broadband seismographs and superconducting gravity meters [10]. The results could not identify the latitude dependence; however, they could constrain the estimation of the heterogeneous structure at the lowermost mantle D" layer.

These series of seismological achievements during the IPY in terms of global aspects were partially summarized in the special issue on "Polar Science" [3].

3. Contributions to the global network

Over the last few decades, to establish a continuous monitoring system for the nuclear tests, a global distribution of seismic and infrasound networks has been established by the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) [11] (**Figure 3**). One of the objectives of CTBTO is to estimate the detection and location capabilities of the networks at the regional and global distances, and the second is to explore the ways to improve these capabilities and enhance the understanding of seismic/infrasonic wave propagation through the solid Earth/atmosphere of the observed events. At present, CTBTO has 60 infrasound stations, each containing at least 4 sensors (arrayed stations), which can detect a several-kiloton TNT-level explosion at a range of ~1000 km. Although the full capability of the global infrasonic network has not yet been established, it could be adequate for monitoring nuclear tests but too sparse for analyzing natural infrasound phenomena in detail. Therefore, increasing the number of stations in the Antarctic and the Arctic, inside or outside CTBTO, could firmly be efficient to contribute in accumulating the precious data viewed from a high latitude in addition to the low-middle latitude regions.

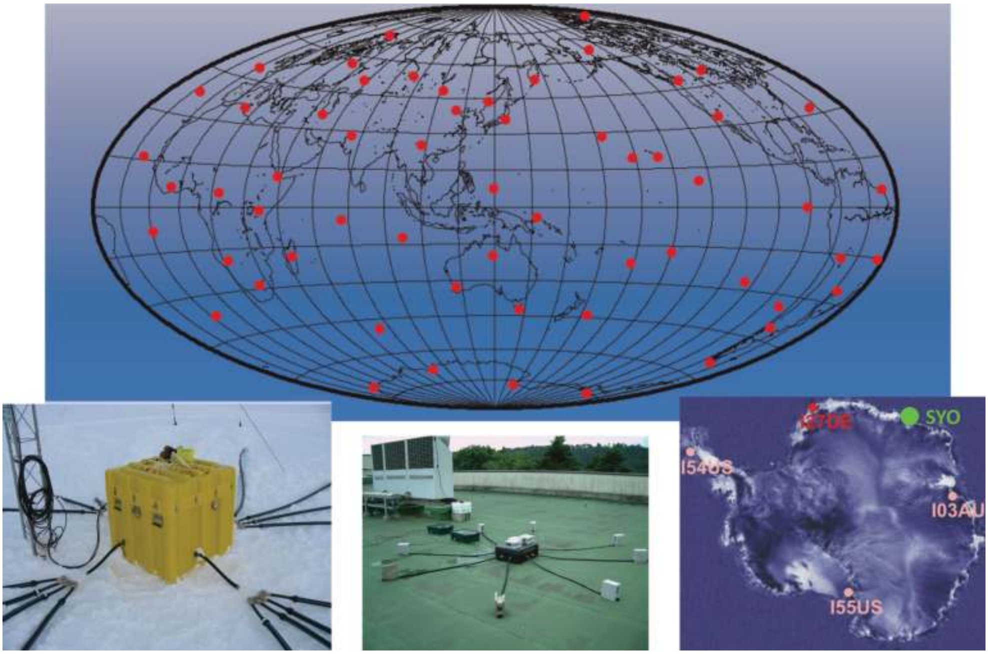

Figure 3. (Upper) Global distribution of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) network. (Lower) From left to right: an infrasound station photo at 155US in West Antarctica, a test running observation at Tohoku University in Japan, and a station distribution in the Antarctic, respectively (modified after Kanao et al. [12]). (Left) Open Access Journal (CC BY 3.0) (first author is M. Kanao).

In addition to the seismic and hydroacoustic networks, infrasound stations in the Antarctic could firmly contribute to both CTBTO and the Pan-Antarctic Observations System (PAntOS) under the Scientific Committee on Antarctic Research (SCAR) of the International Council for Science (ICSU). In order to understand the property of wave propagation within the ocean, hydroacoustic observations would be required from a sufficient number of stations. Hydrophone array observations, for example, were already recorded to investigate seismicity and sea-ice dynamics around the Bransfield Strait, Antarctic Peninsula [13]. Multidisciplinary observations composed of the data from seismic, infrasound, and hydroacoustic sensors would be required for understanding the physical interactions among the atmosphere-ocean-cryosphere-geosphere systems and the temporal-spatial variations in the polar region in more detail. It is also expected that a large quantity of data detected by these three types of sensors accumulated over the past decades by CTBTO will be distributed to the relevant scientific community efficiently.

4. Summary

As treated in several chapters of this special issue on "Polar Seismology," there are a lot of reports to find the characteristic seismic and infrasound vibrations of the solid Earth involving the disturbance and variations in ice sheets, sea ices, oceans, and the atmosphere in the polar region. It is a crucial task to realize the physical processes between the solid Earth and the surrounding environments in terms of the recent climate changes such as global warming; that is, the evolution of sea ices and the dynamics of ice sheets and glacial earthquake activities are now carried out in the surface layers of the polar region.

The next step for “Polar Seismology” after the IPY could be the interdisciplinary research studies combining seismic, infrasound, and acoustic waves and the other significant science disciplines such as geodesy, geology, and glaciology. Moreover, data assimilations, statistic approaches, and other interdisciplinary methodologies might be useful. In addition, based on the significance of long-term monitoring at permanent stations such as Syowa Station, the future perspectives and the improvement of the conditions of the observation infrastructures are required to be considered. The “Polar Region,” as one of the remaining frontiers of the Earth, could surely provide an effective scientific platform to achieve sophisticated knowledge for the evolving environments in the twenty-first century after the IPY. In future, the efficient efforts by the next generations in global seismology are also expected.

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Author details

Masaki Kanao

Address all correspondence to: kanao@nipr.ac.jp

National Institute of Polar Research (NIPR), Organization of Information and Systems (ROIS), Tokyo, Japan

References

[1] Sato N, Ito H, Kanao M, Kanda H, Naganuma T, Ohata T, Watanabe K, Yamanouchi T. Engaging Asian Nations in IPY: Asian Forum for Polar Sciences (AFoPS) (Japanese Section). In: Krupnik I, Allison I, Bell R, Cutler P, Hik D, Lopez-Martinez J, Rachold V, Sarukhanian E, Summerhayes C, editors. Understanding Earth’s Polar Challenges: International Polar Year 2007-2008 – Summary by the IPY Joint Committee. Vol. 5.3. Edmonton, Alberta: Art Design Printing Inc.; 2011. pp. 555-574

[2] Kanao M, Suvorov VD, Toda S, Tsuboi S. Seismicity, structure and tectonics in the Arctic regions. Geoscience Frontiers. 2015;**6**:665-677. DOI: 10.1016/j.gsf.2014.11.002

[3] Kanao M, Zhao D, Wiens DA, Stutzmann E. Recent advance in polar seismology: Global impact of the international polar year – Overview. Polar Science. 2015;**9**:1-4. DOI: 10.1016/j.polar.2014.12.003

[4] Nawa K, Suda N, Satake K, Sato T, Doi K, Kanao M, Shibuya K. Loading and gravitational effects of the 2004 Indian Ocean tsunami at Syowa Station, Antarctica. Bulletin of the Seismological Society of America. 2007;**97**:S271-S278. DOI: 10.1785/0120050625

[5] Hayakawa H, Shibuya K, Aoyama Y, Nogi Y, Doi K. Ocean bottom pressure variability in the Antarctic Divergence Zone off Lützow-Holm Bay, East Antarctica. Deep Sea Research. 2012;**60**:22-31. DOI: 10.1016/j.dsr.2011.09.005

[6] Tsuboi S, Komatitsch D, Ji C, Tromp J. Computations of global seismic wave propagation in three dimensional Earth model. Lecture Notes in Computer Science. 2008;**4759**:434-443

[7] Toyokuni G, Kanao M, Takenaka H. Quasi-axisymmetric finite-difference method for realistic modeling of regional and global seismic wavefield – Review and application. In: Kanao M, Takenaka H, Murai Y, Matsushima J, Toyokuni G, editors. Seismic Waves – Research and Analysis. Rijeka, Croatia: InTech. Publisher; 2012. pp. 85-112

[8] Toyokuni G, Takenaka H, Kanao M, Wiens DA, Nyblade AA. Comparison of global synthetic seismograms calculated using the spherical 2.5-D finite-difference method with observed long-period waveforms including data from the intra-Antarctic region. Polar Science. 2012;**6**:155-164. DOI: 10.1016/j.polar.2012.06.001

[9] Toyokuni G, Takenaka H, Kanao M, Tsuboi S. Numerical modeling of seismic waves for estimating influence of the Greenland ice sheet on observed seismograms. Polar Science. 2015;**9**:80-93. DOI: 10.1016/j.polar.2014.12.001

[10] Shimizu H, Hiramatsu Y, Kawasaki I. Search for latitudinal variation of spectral peak frequencies of low-frequency eigenmodes excited by great earthquakes. Polar Science. 2015;**9**:17-25. DOI: 10.1016/j.polar.2014.07.002

[11] Butler R, Anderson K. Global Seismographic Network (GSN). IRIS Report 6-7. 2008

[12] Kanao M, Maggi A, Ishihara Y, Yamamoto M-Y, Nawa K, Yamada A, Wilson T, Himeno T, Toyokuni G, Tsuboi S, Tono Y, Anderson K. Interaction on seismic waves between atmosphere – Ocean – Cryosphere and geosphere in Polar Region. In: Kanao M, Takenaka H, Murai Y, Matsushima J, Toyokuni G, editors. Seismic Waves – Research and Analysis. Rijeka, Croatia: InTech Publisher; 2012. pp. 1-20. ISBN: 978-953-307-944-8. DOI: 10.5772/1400

[13] Dziak RP, Park M, Lee WS, Matsumoto H, Bohnenstiehl DR, Haxel JH. Tectono-magmatic activity and ice dynamics in the Bransfield Strait back-arc basin, Antarctica. Proceedings of the International Symposium on Polar Science. 2009;**16**:59-68