Introduction: Progress of Seismology in Polar Region

Masaki Kanao

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.78550

Abstract

Several kinds of seismological investigations have been conducted in the polar region, which include the areas of both the Arctic and the Antarctic regions, in various depth ranges from the surface layers to the deep interiors of the Earth. The polar region has an advantage in order to seek inside the physical condition of the Earth as a "window" viewed from high latitudes. In this chapter, historical issues and progress of seismic research and its observations in the polar region are demonstrated during the last half-century from the era of the International Geophysical Year (IGY 1957–1958).

Keywords: seismology, polar region, Arctic, Antarctic, seismic observations, International Geophysical Year

1. Introduction

The polar region, as a "window" in order to seek the interiors of the Earth, has an advantage to investigate the inner structure and dynamics of the solid Earth by using time-space variations and changes of physical parameters determined from seismological methods. A significant number of scientific research have been carried out from the surface layers to the deeper parts of the Earth, by taking into account the research merits from high latitudes. In this book, progress and achievements by seismological studies in the polar region are summarized from the mid-twentieth century to the present. Characteristics of seismic wave propagation, heterogeneous structure, and dynamics of the Earth's interiors are demonstrated, which have been conducted by many international research in both areas of the Arctic and the Antarctic regions. Practically, the following scientifically achieved results are introduced by using seismic waves and travel-time data: inner structure and dynamics of the crust and mantle in high latitudes, seismicity and focal mechanism, seismic wave propagation within the global point of view,

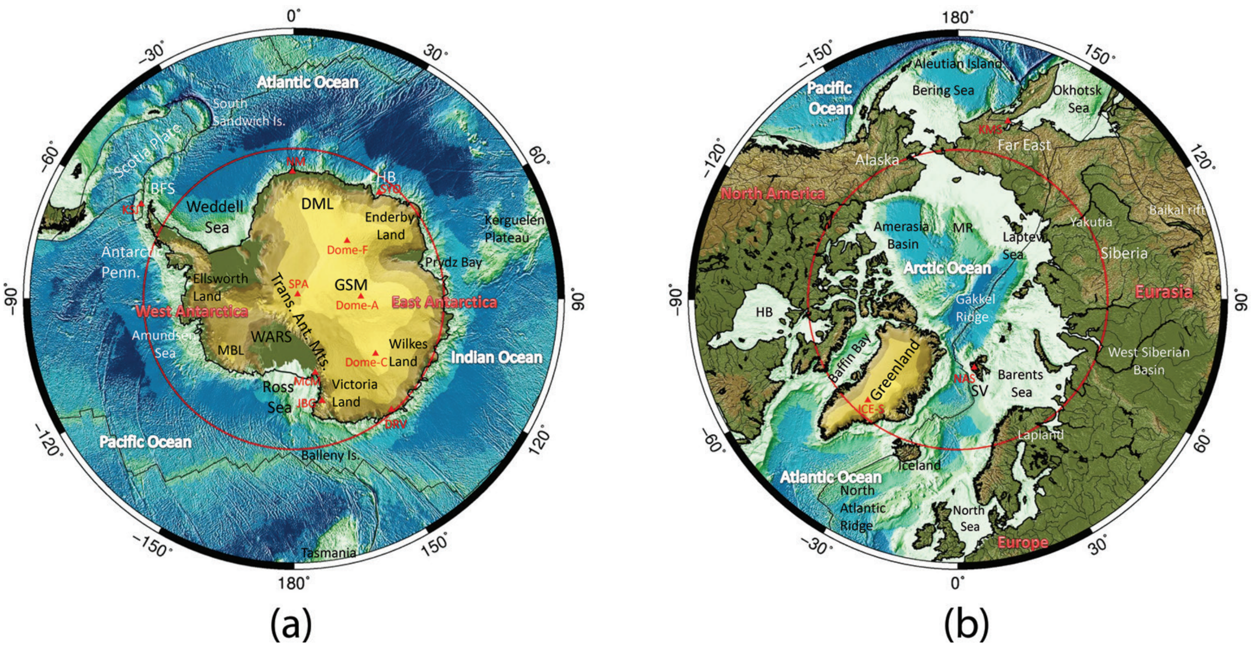

Figure 1. (a) Surface topography and bathymetry in the Antarctic (ETOPO1, [17]) with major geographic location names treated in this chapter. Plate boundaries are after [18]. Red solid circle represents the "Antarctic circle" (66.6°S). Abbreviations are as follows: LHB, Lützow-Holm Bay; DML, Dronning Maud Land; GSM, Gamburtsev Subglacial Mountains; Trans. Ant. Mts., Trans-antarctic Mountains; WARS, West Antarctic Rift System; MBL, Marie Byrd Land; and BFS, Bransfield Strait. Red solid triangles are the permanent stations. SYO, Syowa Station; NM, Neumayer Station; Dome-F (Fuji); Dome-A (Argus); Dome-C (Charlie); DRV, Dumont D'urville; SPA, South Pole Station; McM, McMurdo Station; JBG, Jang Bogo Station; and KSJ, King Sejong Station (original figure prepared for this InTech book). (b) Surface topography and bathymetry in the Arctic (ETOPO1 [17]) with major geographic location names treated in this review paper. Plate boundaries are after [18]. Red solid circle represents the "Arctic circle" (66.6°N). Abbreviations are as follows: SV, Svalbard; MR, Mendeleev Ridge; and HB, Hudson Bay. Red solid triangles are the permanent stations. KMS, Kamenskoye Station; NAS, Ny-Alesund Station, ICE-S (South). (Original figure prepared for this InTech book.)

seismotectonics in the Earth's history, and other involved topics in terms of "polar seismology." Major location names in both polar regions are illustrated in **Figure 1a** and **b**.

The International Polar Year (IPY 2007–2008) program had been conducted as a half-century anniversary from the International Geophysical Year (IGY 1957–1958), when the Antarctic expeditions for scientific purposes started with the involved countries in the polar region. The IPY 2007–2008 was a big international program composed of multidisciplinary science branches such as upper atmosphere, meteorology, glaciology, geosciences, oceanography, and biosciences conducted by a significant number of polar scientists involved [1]. In this book, many of the seismological achievements are carried out by the IPY, including contributions from Japanese seismologists. In addition, the recent trend in scientific investigation for physical interaction between multi-sphere system within the polar surface environment (i.e., atmosphere-ocean-cryosphere-solid Earth) is especially introduced. "Cryoseismology," most of all, is a new and recent progressing topic of seismic approach to investigate characteristics of seismic waves and seismicity in terms of long-term climate changes such as global warming. The most recent seismic achievements in both polar regions are compiled in the special issue on "Polar Science" [2].

It is noticed that, moreover, the index introduced in this book intends to demonstrate the present status of the polar region not only to the global seismologists but also to all the general public who are interested in this topic. It is hoped that this book could provide remarkable knowledge and new understanding about the present environments and past history within the dynamics of the global system. The reader could surely attain fruitful information on the advancement of frontier research in the polar region, which is currently progressing, from this book.

2. Seismic observation in the Antarctic

In this section, historical issues on seismic observation mainly conducted at the Japanese Antarctic stations are presented. During the IGY, the Japanese Antarctic Research Expedition (JARE) started the main base camp Syowa Station (SYO; 69.0°S, 39.6°E; **Figure 1a**), Eastern Dronning Maud Land, in the Lützow-Holm Bay (LHB) of East Antarctica. Seismological observations at Syowa Station began since 1961 by the 3rd JARE (JARE-3) as one of the monitoring stations in the Antarctic within the global observation network. In this regard, the seismic observations, similar to the other long-term observations such as meteorological and aurora research, have been carried out over the half-century. During the past few decades, infrastructure systems and data logging huts/buildings have been replaced according to the development of observation techniques and logistical background of the polar region. Moreover, characteristics, kinds, and purpose of the observational data varied drastically during the long period. Sincerely maintained by winter-over expedition members, seismic observations at Syowa Station continued over all the seasons without any serious problems. Since 2004, digital seismic waveform data have been transmitted from Syowa Station to the National Institute of Polar Research (NIPR), Tokyo, Japan, by using the "Intelsat" satellite telecommunication system. The transmitted data have also been stored in huge data library system of NIPR and opened to the global seismological community [3, 4]. For example, the seismic waves caused by a huge earthquake in the Tohoku region, in northeast Japan (M = 9.0; March 11, 2011), as well as another large disaster earthquake that occurred at Christ Church, New Zealand (M = 6.3; February 22, 2011), were clearly recorded, and continuous monitoring observations have been carried out until now at SYO [5].

In order to cover the high-latitude areas of the Earth, several seismic stations belonging to the Federation of Digital Seismographic Network (FDSN) [6] have been increasing in the Antarctic since the 1980s. Many of the stations have been located at the margins of the continent, where the permanent winter-over stations of corresponding nations have individually been existed (**Figure 2a** and **b**). The East Antarctic continent, where Syowa Station is located, and the Greenland in the Arctic have advantages of recording teleseismic events occurring over the globe with a sufficient signal-to-noise ratio. There are some reasons for the advantages: stable Precambrian-aged continent composed of hard rock areas on the surface layer and deep "lithosphere" underneath, low local seismicity in the vicinity of the recording stations because of the same reason of old and stable continents, low artificial noises because of far distance from major human activity regions in particular for the Antarctic, and so on. The Syowa Station has provided precious seismic data to the global community as one of the major stations of FDSN in the Antarctic continent, as well as one of the Japanese contributing global network (POSEIDON/PACIFIC-21). The seismic data from SYO (travel times, waveforms, hypocentral information, etc.) have been offered to several international centers

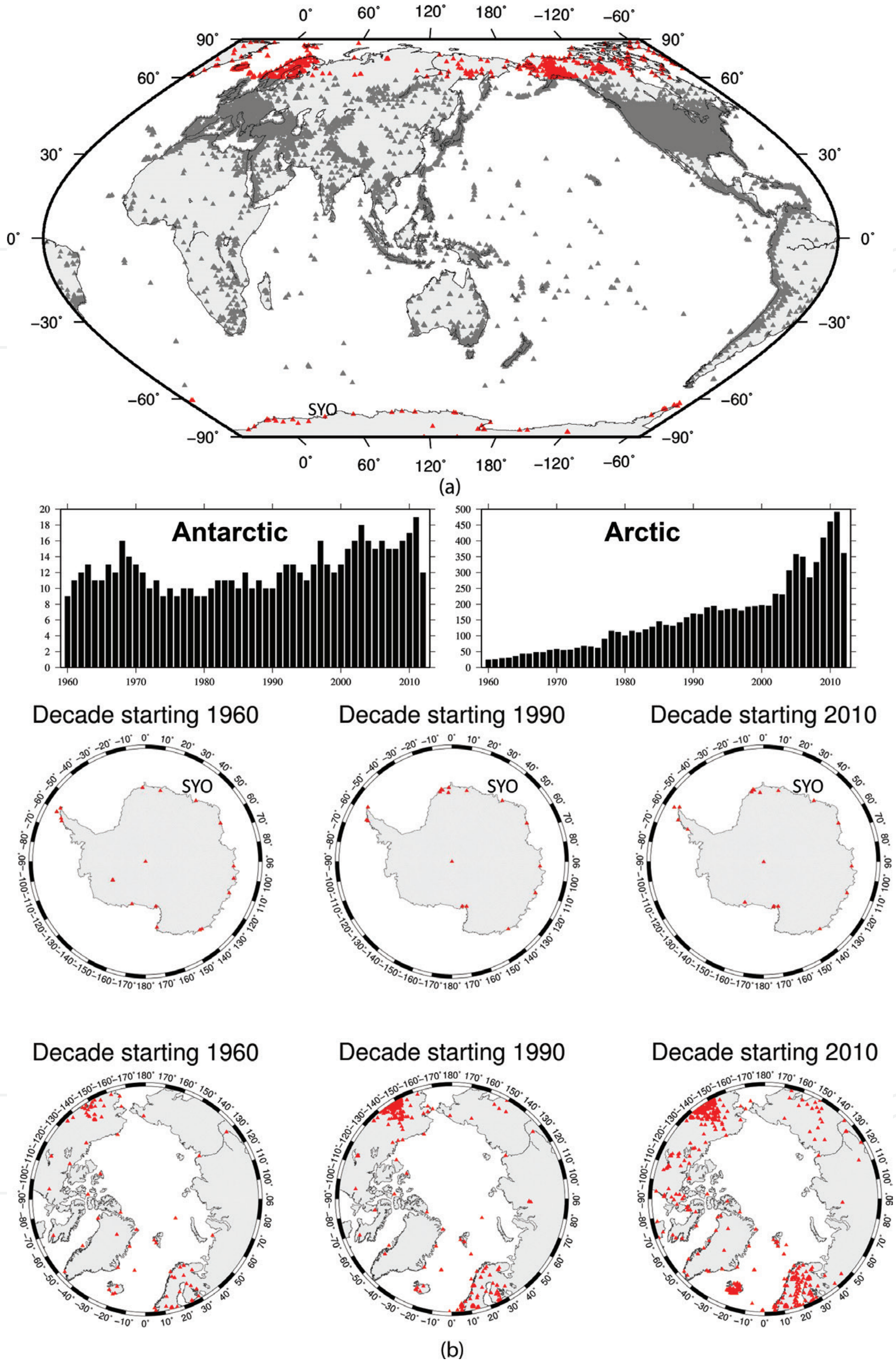

Figure 2. (a) Upper: global distribution of the seismic stations (gray triangles) including those in polar regions (red triangles). SYO indicates Syowa Station. Lower: variation in the number of seismic stations reporting bulletin data to the ISC from the Antarctic (left) and the Arctic (right) regions. All figures are modified after [19]. Copyright Clearance Center (CCC, http://www.copyright.com/). License number: 4278040314413, license date: January 29, 2018. (b) Distribution of the permanent seismic stations in polar regions (upper: the Antarctic; lower: the Arctic) for each decade in 1960, 1990, and 2010, respectively (after [19]). Copyright Clearance Center (CCC, http://www.copyright.com/). License number: 4278040314413, license date: January 29, 2018.

and organizations via NIPR, for example, to the International Seismological Center (ISC), the National Earthquake Information Center of the United States Geological Survey (NEIC/USGS), the Data Management System of the Incorporated Research Institutions for Seismology (DMS/IRIS), and others. In addition, seismic data of SYO have been provided to the Japanese National Data Center of PACIFIC-21 network, that is, the Earth Information Center inside the Japan Agency for Marine Science and Technology (JAMSTEC) [4]. It is noticed that details of the data archive and publication procedure from NIPR are described in the meta-database portal server (http://scidbase.nipr.ac.jp/).

At the majority of stations belonging to FDSN in the polar region, high-resolution and wide dynamic–range broadband seismographs (Streckeisen Seismometer type 1; STS-1) have been installed and operated in the last three decades. The STS-1 has been known as the most standard seismographs in global seismology, and almost all teleseismic events with magnitude over four occurring on the globe are recordable at Syowa Station. After a rapid spread of FDSN stations over the Earth in the 1980s, continuous observations by using STS-1 started in 1989 at the Syowa Station. By combining the data from both the STS-1 and the short-period seismographs hagiwara erectric seismometer (HES) that started observation during the IGY, teleseismic events detected at SYO have been varying within few hundreds of their identified number during the last two decades [4] (**Figure 3**). Long-period variations in teleseismic detectability since the era of IGY are summarized [5]. Seismological studies by using the data at SYO are classified into heterogeneous structure and dynamics of the inner core and surrounding mantle viewed from southern high latitudes, crustal structure, seismicity and earthquake source mechanism of the Antarctic Plate and the Antarctic continent, crustal movement and ice-related seismic activities associated with cryosphere dynamics, and the other topics. A significant number of achievements by seismological investigations and new findings are demonstrated in more detail in the succeeding chapters of this book. As an example, long-term data at SYO were utilized to reveal a superrotation of the inner core of the deep interiors over 30 years based on the analog record from IGY [7]. In this regard, long-term compiled data such as the research of dynamics in deeper parts of the Earth have efficiently been used. Therefore, the seismic station in the polar region including the Syowa Station is expected to continue offering the high-quality data as an important permanent observation site in southern high latitude among global seismology.

In the vicinity of Syowa Station, several field stations of broadband seismographs have been conducted around the LHB region since 1997 (**Figure 1a**) [8–10]. The portable broadband array stations have contributed to the Global Alliance of Regional Networks (GARNET), together with the international projects conducted during the International Polar Year (IPY 2007–2008). Details about the IPY projects and observation networks are given in Chapter 2. On the contrary, deep seismic surveys (DSSs) using active seismic sources were also carried out in 2000 and 2002 on the ice-sheet plateau nearby Syowa Station in LHB. The DSSs consist of the observations/analysis specks of the wide-angle reflection/refraction methods as a major part of the "Structure and Evolution of East Antarctic Lithosphere (SEAL)" project [11] by JARE. From the DSS, seismic velocity model of the crustal structure and seismic reflection section of the lithosphere of the LHB region were investigated, which are situated between the Western Enderby Land and the Eastern Dronning Maud Land (DML; **Figure 1a**). Detailed results of the DSS are given in Chapter 4.

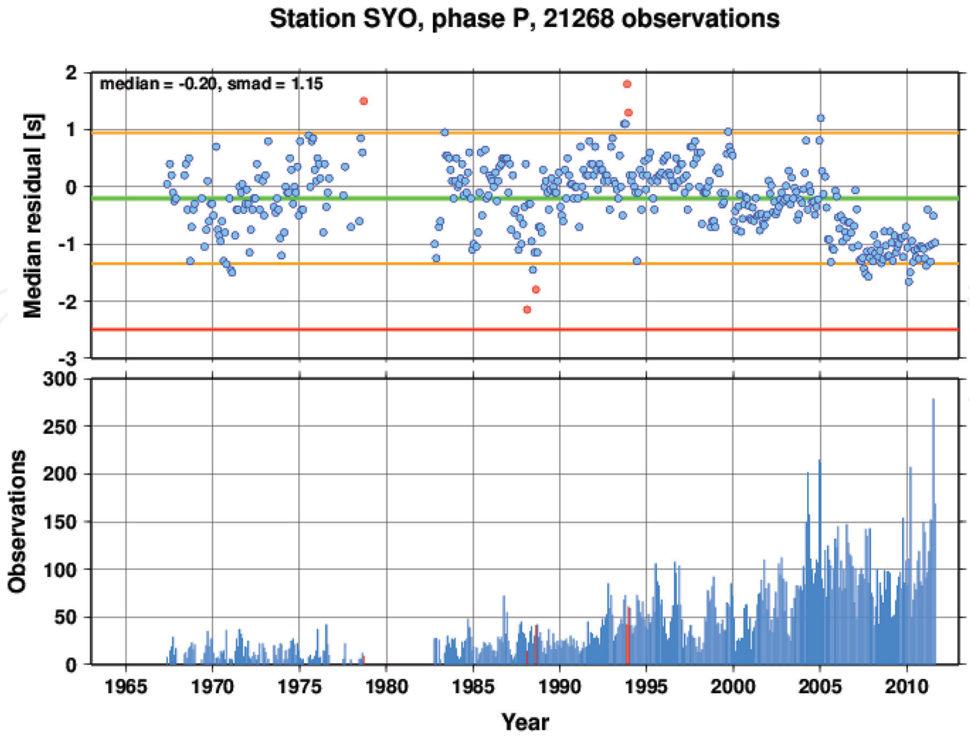

Figure 3. Historical reporting features of the Antarctic station (SYO) based on the ISC Bulletin. The upper panel shows the timeline of variations in the travel-time residuals for P waves at SYO. Each dot represents the median residual for 1 month of data. The green line is the overall median; the orange line shows the standard deviation based on the median absolute deviation, while the red line shows twice the standard deviation. The red dots represent those months when the absolute value of the annual median residual exceeds the long-term median by more than a standard deviation. The bottom panel shows the reported number of teleseismic events at SYO in 1967–2011 by ISC (after [19]). Copyright Clearance Center (CCC, http://www.copyright.com/). License number: 4278040314413, license date: January 29, 2018.

It is also noticed that the international collaboration project was carried out in the USA and New Zealand (the International Mount Erebus Seismic Study; IMESS) at the Ross Island of Ross Sea, West Antarctica, for few years since 1980 (near McM station; **Figure 1a**). From the project, microseismicity associated with volcanic eruptions of Mount Erebus was investigated in detail [12]. Moreover, ocean bottom seismic observations were held at the Antarctic Peninsula in 1990–1991, in collaboration with Polish geoscience group. Precise crustal structure and extension regime around the area were studied at the Bransfield Strait (BFS; **Figure 1a**) [13].

3. Seismic observation in the Arctic

In contrast to the Antarctic, there have been no permanent seismic stations in the Arctic region by Japan (more than 66°N; **Figure 2**); however, several temporary observations have been done in Eastern Asia including in Far East of Russia. In 1994, a seismic station at KMS (**Figure 1b**), the northern root of Kamchatka Peninsula, Far East of Russia, was installed by Nagoya University as the northernmost station of the Japanese global network (POSEIDON). In spite of the difficult access from Japan, the station has continued observation until now.

The noise level of the KMS station has been quite low and can record a significant number of microseismicity involving seismic fault system near the station. After the North Sakhalin earthquake (M = 7.6, May 1995), microseismic and global positioning system (GPS) observations started around the large area including KMS station in collaboration/cooperation with the Russian Academy of Science. In 2005, a big project started in order to reveal the stagnant slab and relation with mantle dynamics by using broadband seismic regional network. From the temporary network observations, amalgamation mechanism of the stagnant slab (subducting Pacific Oceanic plate) in the upper mantle depths beneath the East Asia region was obtained. Moreover, seismic activities around the North Sakhalin area have been advanced by using the obtained data. From 2009 to 2012, large temporary seismic array stations have been carried out (NECESSArray) at northeastern China mainland, in collaboration with China, the USA, and Japan. Several major seismological targets were achieved such as the formation mechanism of the China mainland continent, shape of the subducting stagnant slab underneath the stations, and source mechanism of huge mantle plumes under the Pacific Ocean [14]. Besides, temporal observation using broadband seismographs was conducted at the Baikal Rift Zone (BRZ; **Figure 1b**) in 2004–2006 in collaboration with the Russia Academy of Science (RAS). Crustal structure and seismicity at BRZ were investigated in detail [15, 16].

Including the abovementioned studies before the IPY, internationally collaborated seismic network in Greenland will be introduced in detail in Chapter 6. The regional network aimed to investigate the relationship between the glacial seismicity and the global warming process in the Arctic region.

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] Krupnik I, Allison I, Bell R, Cutler P, Hik D, Lopez-Martinez J, Rachold V, Sarukhanian E, Summerhayes C. Understanding Earth's Polar Challenges: International Polar Year 2007-2008 – Summary by the IPY Joint Committee. Edmonton, Alberta: Art Design Printing Inc.; 2011. pp. 457-476

[2] 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

[3] Iwanami S, Kanao M. Seismological bulletin of Syowa Station, Antarctica, 2011. JARE Data Reports. 2013;**325**(Seismology 47):1-190

[4] Kanao M. Detection capability of teleseismic events recorded at Syowa Station, Antarctica – 1987-2007. Antarctic Record (New Zealand). 2010;**54**:11-31

[5] Kanao M, Storchak D, Dando B. Evaluation of long-period detectability of teleseismic events at Syowa Station, Antarctica. International Journal of Geosciences. 2012;**3**:809-821

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

[7] Isse T, Nakanishi I. Inner-core anisotropy beneath Australia and differential rotation. Geophysical Journal International. 2001;**151**:255-263

[8] Negishi H, Kanao M. Field seismic observations by portable broadband seismometers in the Lützow-Holm Bay Region, East Antarctica. Antarctic Record. 1998;**42**:179-189

[9] Kanao M, Kaminuma K. Seismic activity associated with surface environmental changes of the Earth system, around Syowa Station, East Antarctica. In: Futterer DK, Damaske D, Kleinschmidt G, Miller H, Tessensohn F, editors. Antarctica: Contributions to Global Earth Sciences. Berlin Heidelberg, New York: Springer-Verlag; 2006. pp. 361-368

[10] Kanao M, Usui Y, Inoue T, Yamada A. Broadband seismic deployments for imaging the upper mantle structure in the Lützow-Holm Bay region, East Antarctica. International Journal of Geophysics. 2011;**2011**:1-15

[11] Kanao M, Ishikawa M, Yamashita M, Kaminuma K, Brown LD. Structure and evolution of the East Antarctic lithosphere: Tectonic implications for the development and dispersal of Gondwana. Gondwana Research. 2004;**7**:31-41

[12] Kaminuma K, Baba M, Shibuya K, Dibble RR. Explosion earthquakes of Mount Erebus, Antarctica. Memoirs of National Institute of Polar Research. 1985;**37**:29-39

[13] Grad M, Shiobara H, Janik T, Guterch A, Shimamura H. Crustal model of the Bransfield rift, West Antarctica, from detailed OBS refraction experiments. Geophysical Journal International. 1997;**130**:506-518. DOI: 10.1111/j.1365-246X.1997.tb05665.x

[14] Tang Y, Obayashi M, Niu F, Grand SP, Chen YJ, Kawakatsu H, Tanaka S, Ning J, Ni JF. Changbaishan volcanism in Northeast China linked to subduction-induced mantle upwelling. Nature Geoscience. 2014;**7**:470-475. DOI: 10.1038/ngeo2166

[15] Ananyin LV, Mordvinova VV, Gots MF, Kanao M, Suvorov VD, Tatkov GI, Thubanov TA. Velocity structure of the crust and upper mantle in the Baikal rift zone on the long-term observations of broad-band seismic stations. Doklady Earth Science. 2009;**428**:1067-1071. DOI: 10.1134/S1028334X09070058

[16] 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

[17] Amante C, Eakins BW. ETOPO1 1 Arc-Minute Global Relief Model: Procedures, Data Sources and Analysis. NOAA Technical Memorandum NESDIS NGDC-24. National Geophysical Data Center, NOAA; 2009. DOI: 10.7289/V5C8276M

[18] Bird P. An updated digital model of plate boundaries. Geochemistry, Geophysics, Geosystems. 2003;**4**:1027. DOI: 10.1029/2001GC000252

[19] Storchak DA, Kanao M, Delahaye E, Harris J. Long-term accumulation and improvements in seismic event data for the polar regions by the International Seismological Centre. Polar Science. 2015;**9**:5-16. DOI: 10.1016/j.polar.2014.08.002