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An Overview of Seismological Projects during the International Polar Year

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Abstract

During the International Polar Year (IPY 2007–2008), many seismological studies had been carried out in bipolar regions; particularly, advances and progresses in observation networks were established for the purpose of detecting precise data regarding geophysical studies. In this chapter, major seismological projects during the IPY, in both the Antarctic and the Arctic regions, are introduced with their fruitful scientific results and involved logistic operations.

Keywords: seismology, International Polar Year, seismological projects, FDSN, POLENET, AGAP, GLISN

1. Introduction

A major program of the International Polar Year (IPY 2007–2008) had been conducted as a half-century anniversary of the International Geophysical Year (IGY 1957–1958), when Japan, one of the member nations of IGY, started the Japanese Antarctic Research Expeditions (JARE). During the IPY 2007–2008, several big international projects with interdisciplinary aspects had been conducted to monitor the rapid variations of the Earth's environment through the “window” at the poles, by checking the effects of global warming at high latitudes with a mind for predicting future human activities in the polar region [1].

Most of the seismic stations in Antarctica, including the Japanese main base camp Syowa Station (SYO; 69.0°S, 39.6°E) in the Lützow-Holm Bay (LHB), which started during the IGY, are located along the coast of the Antarctic continent except for the Amundsen-Scott South Pole Station (ASSPS), Dome-C, and Dome-A (**Figure 1**). Most of the stations belong to the

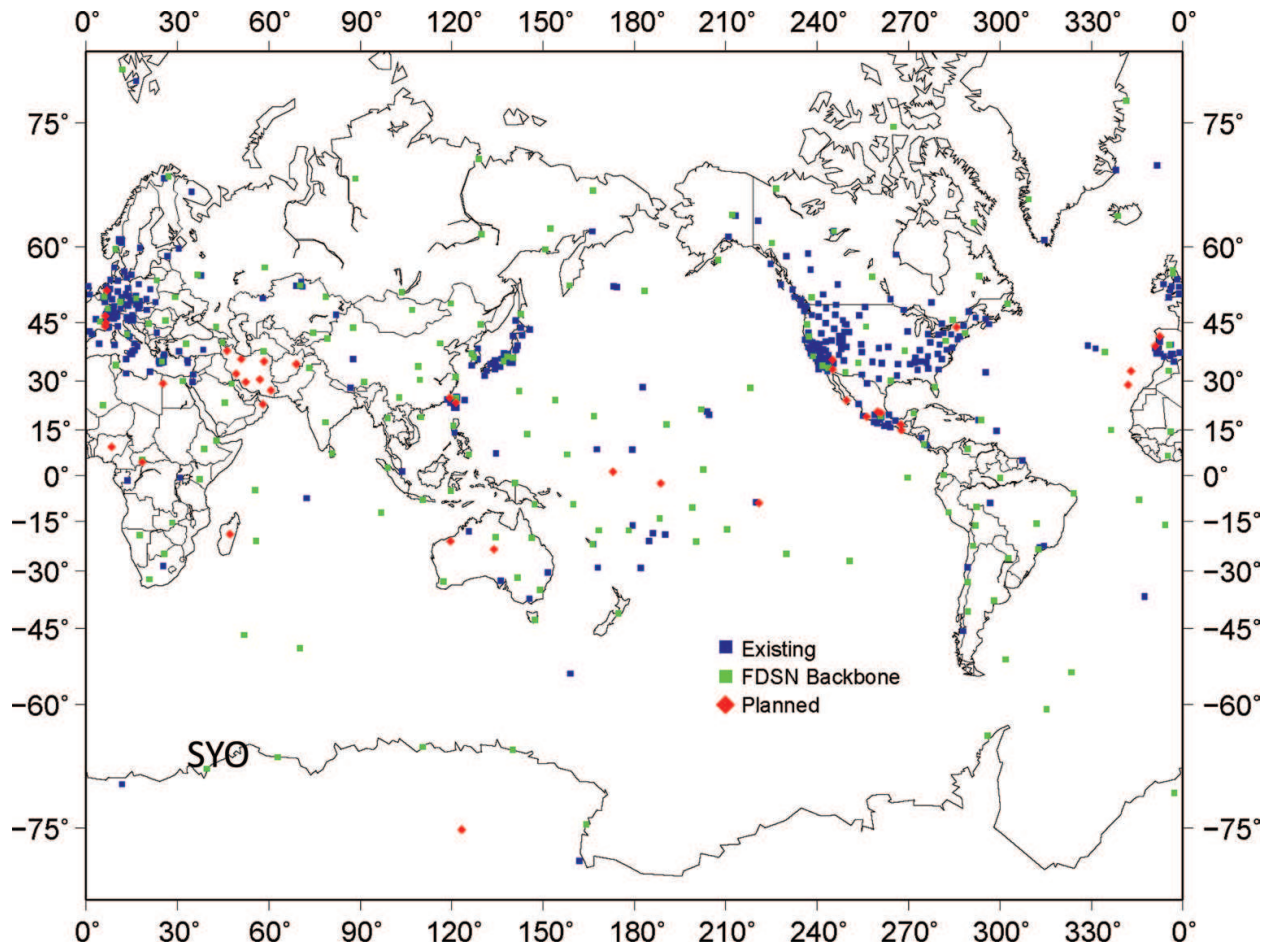


Figure 1. Distribution of seismic stations belonging to FDSN. Copyright: <https://www.fdsn.org/>.

Federation of Digital Seismographic Network (FDSN) [2], providing seismic data for the study of the structure, dynamics, and seismicity over the world. Because of the sparse distribution of the stations over the continent, the space resolution of the inner structure of the Earth detected by seismic investigation such as the surface wave tomography has been quite low, particularly inside the continent. In order to improve the space resolution in seismic investigations, as well as the detection capability of seismicity all over the Earth, an increase in the number of seismic stations (local and regional networks) in the polar region (particularly in the Antarctic continent and the Greenland ice sheet) has been discussed among polar seismology communities in the last few decades. The improved resolution networks, moreover, are effective in the study of the deep interiors of the Earth as viewed from a high latitude, together with a practical estimation of the relationship between global warming and its effect on the surface environment in the polar region, such as the cryosphere dynamics and its evolution, the associated crustal uplift [glacial isostatic adjustment (GIA)], the local seismicity, and so on.

A practical solution to distribute a large number of autonomous seismic stations over a wide area of the Antarctic continent and the Greenland ice sheet, however, has several technical/logistic problems, which should be overcome under extreme weather conditions such as low temperature, dry air, and plenty of snow/ice. Wide area and long-term observations of the ice

sheets on high-inland plateaus of over 3000 m altitude at extremely low temperature have never been conducted after the IGY era. In this regard, the IPY 2007–2008 was an excellent opportunity to carry out the deployment of a large number of seismic stations in the Antarctic and Greenland, in strong international collaboration with the involved scientist community.

In this chapter, major seismological projects during the IPY in terms of climate change affecting the polar region, in both the Antarctic and Arctic regions, are demonstrated with their scientific results, observation operations, and logistic information.

2. Antarctic region

During the IPY 2007–2008, a big geophysical project named the Polar Earth Observing Network (POLENET) [3] had been conducted; over a few tens of seismographs and autonomous global positioning system (GPS) stations were installed over a huge area of the Antarctic ice sheet and the surrounding outcrop areas, in both East and West Antarctica, as well as in the Transantarctic Mountains. These temporary stations were formed in tight international collaboration with seismological community members, in addition to the existing permanent stations along the coast of the continent. **Figure 2** illustrates the station distribution of the POLENET and the other relating projects conducted during the IPY in the Antarctic continent. Several related subinternational and national-based projects of the POLENET stations efficiently covered the whole Antarctic continent; the major contributions were from the USA, the UK, Australia, New Zealand, Italy, France, Germany, China, and Japan.

In West Antarctica, where the Antarctic Peninsula and the Transantarctic Mountains are present, tens of seismographs and GPS stations have been deployed by the US teams, particularly in the wide area of the West Antarctic Rift System (WARS) between the Ellsworth Mountains and the Marie Byrd Land (MBL) (see **Figure 1** of Chapter 1) [4]. The geophysical deployments in West Antarctica investigated the crustal structure of distinguished geological terrains and the heterogeneous mantle structure characterized beneath rift systems [5, 6], as well as the crustal uplift mechanism associated with glacial isostatic adjustment (GIA) (details are introduced in Chapter 3). In other areas in West Antarctica, several local geophysical networks have been established as a part of POLENET: from the Antarctic Peninsula to the Ellsworth Mountains by the UK, the Terra Nova Bay in Northern Victoria Land by Italy, the Ross Sea area near Scott Base by New Zealand, and so on. Moreover, Korea established a new permanent station and seismic network in Terra Nova Bay [Jang Bogo Station (JBG)], in addition to the first station in King George Island [King Sejong Station (KSJ)], Antarctic Peninsula [7]. The local network in Terra Nova Bay aimed to detect the seismic signals involving calving events of the glaciers around the bay and to monitor the volcanic eruptions of Mount Melbourne near JBG. On the contrary, hydroacoustic observations have been carried out in the Bransfield Strait (BFS) near the King Sejong Station, corroborated by the Korea Polar Research Institute (KOPRI) and the National Oceanic and Atmospheric Administration (NOAA). Their deployed hydrophones detected the signals of microseismic events that occurred at the bottom of the ocean, which could not be detected by the onshore seismic networks [8].

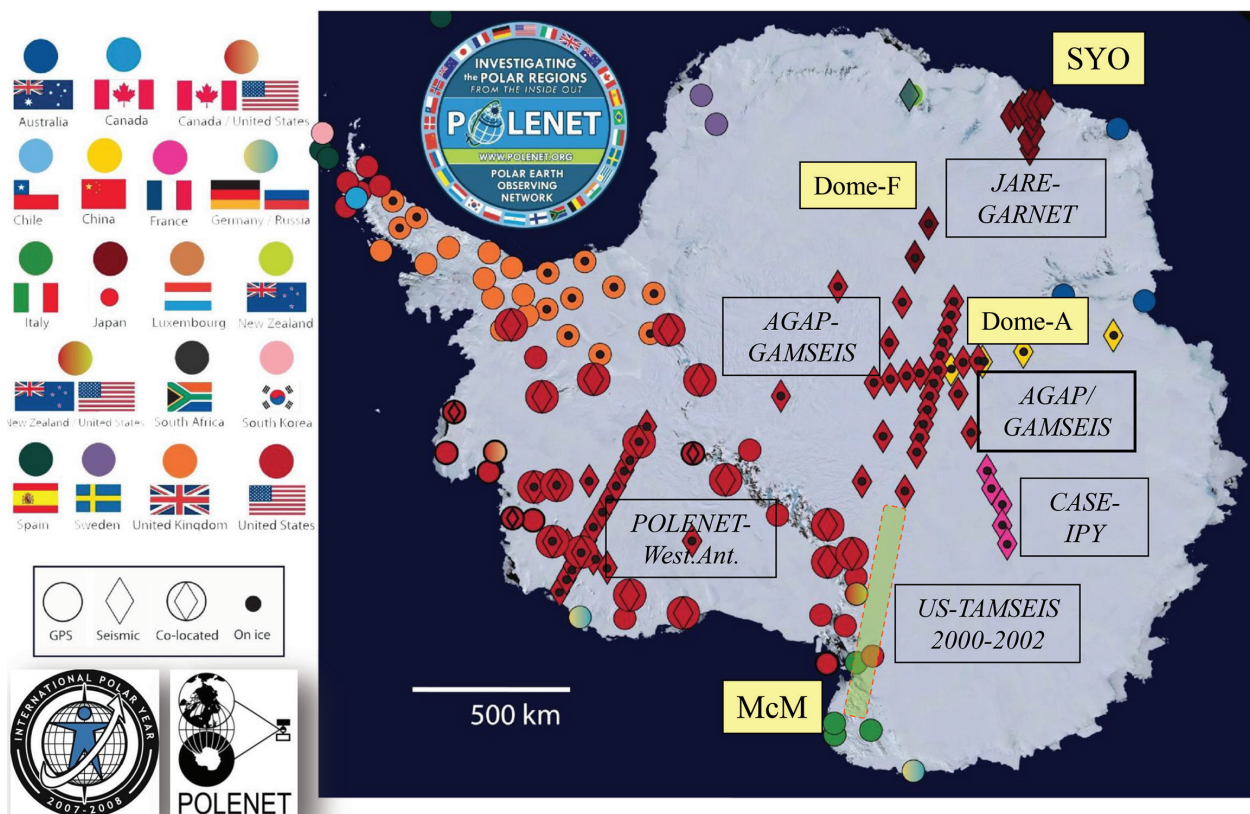


Figure 2. Distribution map of seismic and other geophysical stations deployed during the IPY 2007–2008. A wide area of East Antarctica was covered by the AGAP/GAMSEIS project, in collaboration with other projects in the surrounding area of the continent. All stations in Antarctica contributed to the POLENET bipolar program (modified after [12]). Open Access Journal (CC BY 3.0).

As the largest project of the IPY at the inland plateau of East Antarctica, Antarctica's Gamburtsev Province (AGAP) was conducted to study the deep structure underneath the Gamburtsev Subglacial Mountains (GSM), which are located on the highest plateau of the continent about 4000 m above sea level [3, 9]. The Chinese inland station Kunlun, Dome-A, is located at the middle of the plateau. AGAP was an interdisciplinary geophysical program carried out with tight cooperation of both supporting logistics and research observations with the involvement of eight countries (the USA, the UK, Germany, Australia, China, Italy, France, and Japan; **Figure 2**) [10]. The entire AGAP program was composed of a few international subgroups, such as the geophysical airborne surveys for mapping the gravity, geomagnetism and echo sounding using ice-penetrating radar, the deep ice-core drilling team at Dome-A, and the international team for deploying seismographs and GPS in the wide area of the East Antarctic Plateau. The final targets to be confirmed by AGAP were to reveal the evolution process of the East Antarctic ice sheet, the formation process of the Gamburtsev Subglacial Mountains, the structure and evolution of the subglacial lakes, the evaluation of the influence of the East Antarctic ice-sheet evolution on global climate change, and so on [3]. The predominant result from airborne radar echo soundings is, for instance, the finding of the "supercooling" layers at the base of the ice sheet beneath GSM; the layers are considered to be formed by refrozen ice after melting caused by the friction stress just above the basement rocks under the highest topographical area of GSM [9].

A major part of AGAP, the Gamburtsev Antarctic Mountains Seismic Experiment (GAMSEIS) [4], deployed a few tens of broadband seismic stations over a wide area of the ice-sheet plateau in East Antarctica with international cooperation of the involved countries (**Figure 2**) [10]. The retrieved seismic data revealed several interesting geoscience topics, such as the lithospheric structure and elevation mechanism of GSM, the formation process of the Gondwana super-continent, the bedrock topography and geological structure underneath the ice sheet, and so on (details are introduced in Chapters 3 and 4). GAMSEIS/AGAP also contributed significantly to POLENET as a major component of the geophysical network in East Antarctica.

In addition to the AGAP international program in collaboration with the USA and Japan, autonomous broadband seismic stations have been increased in LHB during the IPY by JARE; the data from these stations also contributed to the Global Alliance of Regional Networks (GARNET; **Figure 2**), and the lithospheric structure, upper mantle discontinuity, and seismic isotropy-related tectonics around the region have been identified [11, 12]. Moreover, the other nations besides Japan, such as the UK, Australia, Italy, France, China, and New Zealand, developed their own new seismic networks near the coastal area of the Antarctic continent, providing precious regional dataset to POLENET.

3. Arctic region

The Arctic domain of POLENET was mainly composed of two regions: Greenland [Greenland Network (G-NET)] and Lapland [Lapland Network (LAP-NET)]. Both broadband seismometers and GPS instruments have been deployed at G-NET and LAP-NET during the IPY. These networks mainly aimed at detecting the cryoseismic signals associated with the recently progressing global warming process in the Arctic; the seismic signals were generated involving the calving events at the edge of glaciers or melting at the bottom of the marginal areas of the ice sheet (details of the cryoseismic signals are introduced in Chapters 6 and 8). In addition, seismic signals related to the crustal uplift in terms of glacial isostatic adjustment (GIA) after deglaciation were reported in the areas that were covered by thick ice sheets in the northern hemisphere (surrounding regions of the Hudson Bay in North America and the Baltic Sea of Northern Europe, etc.) [3, 13]. The whole POLENET station networks in the Arctic have also been targeted to detect the related seismicity. In the Arctic regions around North Atlantic and Svalbard Islands, moreover, there are more permanent seismic stations such as in Isfjorden (NORSAR SPITS) or in Hornsund, or in Bear Island. For instance, the international project the Dynamic Continental Margin between the Mid-Atlantic-Ridge System has been conducted in Mohns Ridge, Knipovich Ridge, and Bear Island Region in a framework of the Panel Plate Tectonics and Polar Gateways during the IPY.

Recently, the Greenland ice sheet has been identified as having decreased in the total volume on the basis of satellite measurements, and the deglaciation speed has been increased so far [14]. Therefore, a significant number of “glacial earthquakes” associated with dynamic deformation, calving events, and discharges at the marginal part of the Greenland ice sheet have been reported in the twenty-first century [15–17]. Understanding the occurrence mechanism, frequency, and time-space distribution of the glacial earthquakes (which mainly occur inside and at the

bottom of the ice sheet) has great significance in realizing the process mechanism of the glacier dynamics and recent climate change in the Arctic. In order to monitor these glacial earthquakes in Greenland, the international project the Greenland Ice Sheet Monitoring Network (GLISN) was initiated after the IPY (**Figure 3**) [18]. The GLISN project is a big international collaboration project involving 14 countries including Denmark, the USA, and Japan and is still a chief contribution to the Federation of Global Seismological Network (FDSN). The Japanese seismologists have been cooperating with GLISN from June 2011, when a new ice plateau station Ice-S was established. Ice-S is a broadband seismic observation and data acquisition station in tight collaboration with the US team led by the staff of the Global Seismological Network (GSN) and the Portable Array Seismic Studies of the Continental Lithosphere (PASSCAL) Instrument Center of the Incorporated Research Institutions for Seismology (IRIS) [19]. By making use of the integrated dataset from related nations of GLISN, the details of seismicity and occurrence mechanism of glacial earthquakes in and around Greenland are expected to be revealed in the near future.

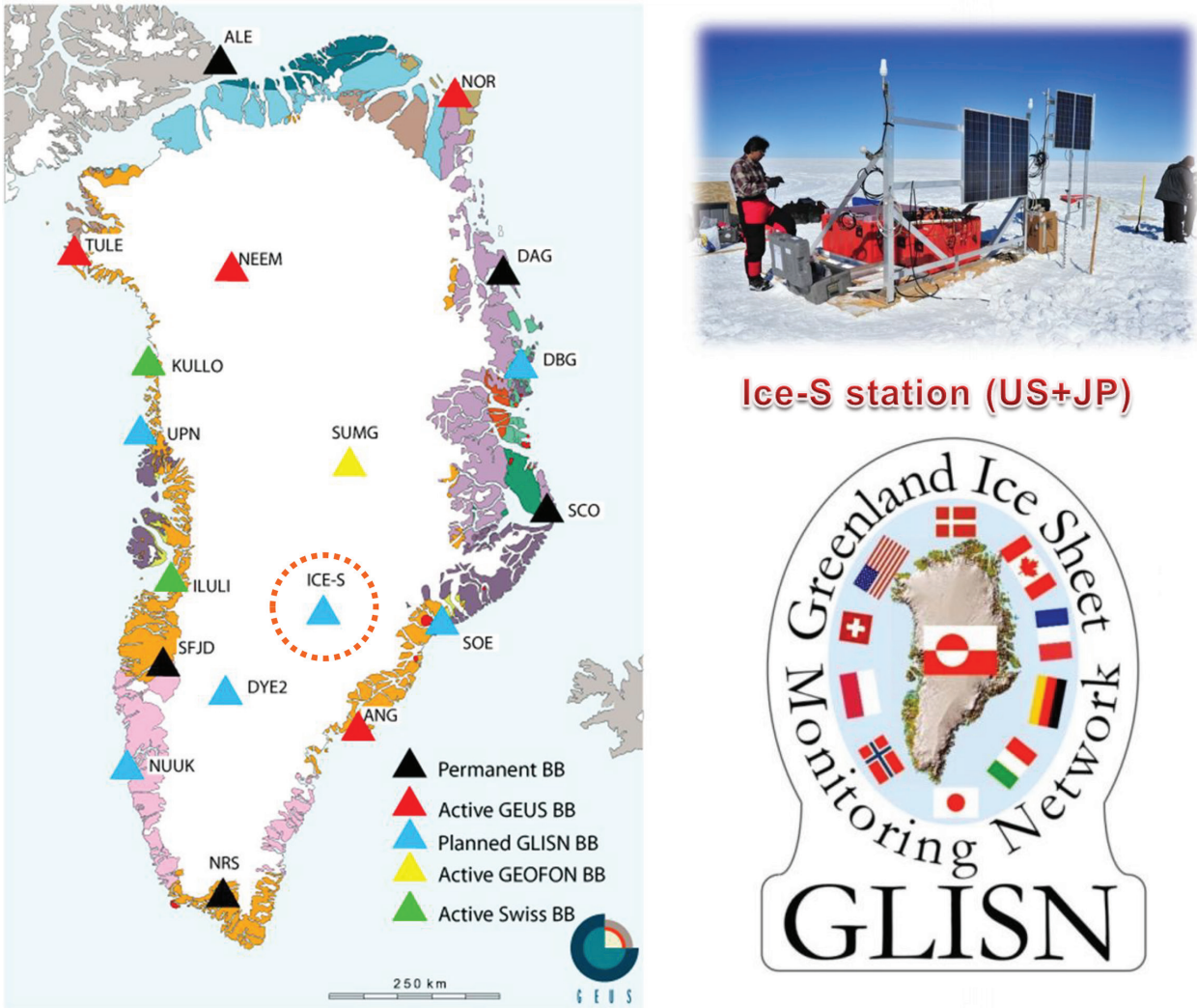


Figure 3. Station distribution of the GLISN project (upper) and photo of the Ice-S station (lower right) and the logo-mark of GLISN (lower left). Copyright: <http://glisn.info/>.

GLISN stations play a crucial role in complementing FDSN in high northern latitudes. In addition, by making use of combined analyses with the data from other FDSN stations, a relationship between global warming and retreatment process of ice sheets, as well as the occurrence mechanism of glacial earthquakes, could be precisely revealed; a new proxy of global warming can also be demonstrated by seismology. The GLISN project, moreover, is expected to be a basic observation platform of the International Polar Decade (IPD), initiated by the World Meteorological Organization (WMO) during the post-IPY era. It is also important in terms of contributing to the community of the Arctic environmental research, by collaborating with the Sustaining Arctic Observing Networks (SAON) [20] of the International Arctic Scientific Commissions (IASC) under the International Council of Science (ICSU), as well as with the Arctic Monitoring and Assessment Program (AMAP) of the Arctic Council (AC).

4. Summary

The geophysical observation networks of POLENET in bipolar regions deployed during the International Polar Year (IPY 2007–2008) contributed greatly in achieving a very fine space resolution in seismological investigations such as the velocity structure beneath the Antarctic Plate and Arctic region. The POLENET networks have also been providing sufficient volume and high-quality data obtained from high latitudes to the global distributing network (FDSN) [2]. The data from the IPY showed several new findings regarding the lithospheric structure, crustal uplift mechanism, formation of supercontinents, and bedrock topography underneath the ice sheet, as well as the geological structure of bipolar regions. Moreover, the data are also expected to provide basic information on the deep interiors of the Earth, inner structure of the ice sheet, subglacial lakes, fine crustal structure, local tectonic earthquakes, and glacial-related seismic events (cryoseismic signals).

In terms of global points in seismology, the polar region at high latitudes has significance in monitoring the structure and dynamics of the deep interiors of the Earth (the heterogeneous structure of the lowest mantle, the “D” layer, the isotropic structure of the inner core, etc.), viewed as a “window to seek into the deep interiors.” By making use of the stations deployed by POLENET and AGAP as a “large spanned array” configuration over the Antarctic continent, investigation related to seismic wave propagation on a global scale and the inner structure of the Earth could be advanced in future.

A part of the POLENET stations in Antarctic has continued the observations after the IPY. The inland plateau stations such as Dome-F, -A, and -C have contributed greatly in expanding the regional observation networks surrounding the Antarctic continent and the Southern Ocean, in addition to those of FDSN from high latitudes. It is necessary to keep the operation running in the inland plateau area of the Antarctic and Arctic such as in Greenland to make long-term monitoring of the stress distribution and seismicity of the Antarctic Plate and Arctic Ocean, together with determination of the seismic source mechanism and hypocentral distribution.

After the IPY, followed by POLENET, the Solid Earth Response to the Cryosphere Evolution (SERCE) project was initiated under the Scientific Committee on Antarctic Research (SCAR) of ICSU. A part of seismic and GPS stations has been kept operational as a legacy of POLENET

by SERCE. In contrast, in the Arctic, the interdisciplinary project SAON plays a crucial role as one of the basic infrastructures after the IPY. The international projects of GLISN as well as G-NET and LAP-NET also continue as the regional networks; therefore, the mutual linkages between regional projects are expected to make up a uniform and systematic observation strategy in the Arctic.

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