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# Seismic Detection in the Inland Plateau of East Antarctica

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Masaki Kanao

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## Abstract

Several international programs to deploy broadband seismic stations over the Antarctic continent were conducted during the International Polar Year (IPY 2007–2008). Antarctica's Gamburtsev Province (AGAP)/Gamburtsev Mountains Seismic Experiment (GAMSEIS), which was a part of AGAP and the Polar Earth Observing Network (POLENET), contributed greatly to establish a geophysical network in Antarctica. AGAP/GAMSEIS was an internationally coordinated deployment of more than 30 seismographs over the crest of the Gamburtsev Mountains and the areas of Dome-A, -C, and -F. The project provided a detailed information on the crust and mantle structures and, key constraints on the origin of the Gamburtsev Mountains and more broadly on the structure and evolution of the East Antarctic craton and subglacial environment. With the data from GAMSEIS and POLENET, the local and regional seismic signals associated with ice movements, oceanic loadings, and local meteorological variations were recorded in addition to a number of teleseismic events around the globe. The characteristic seismic signals of local origin in the inland plateau of the ice sheet were demonstrated with a capability to investigate subglacial environment, particularly at the marginal areas of the East Antarctic continent.

**Keywords:** Antarctic continent, inland plateau, seismic deployments, ice quakes, IPY

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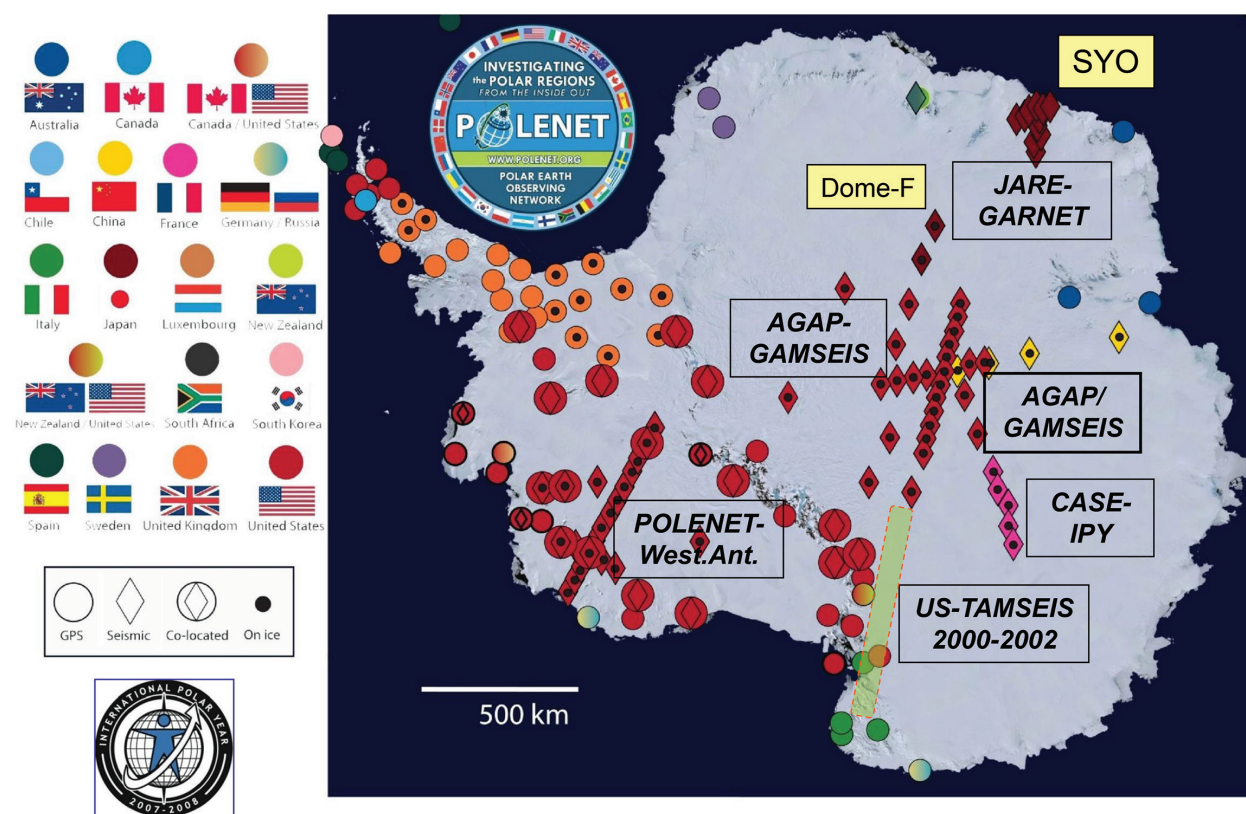
## 1. Introduction

Existing seismic stations belonging to the Federation of Digital Seismographic Networks (FDSN) allowed resolution of the structure beneath Antarctica at a horizontal scale of ~1000 km, which was sufficient to detect fundamental differences in the lithosphere beneath East and West Antarctica, however, not sufficient to clearly define the structure within each sector. The identification of seismicity around the Antarctic continent was limited by sparse

station distribution, and the detection level of earthquakes remained inadequate for making a full evaluation of the tectonic activity [1, 2]. A strategy for achieving a sufficient density of seismic stations over the Antarctic continent allowed for an optimal ray path coverage across the continent and the improvement of seismic tomography resolution [3–5]. The International Polar Year (IPY 2007–2008) provided an excellent opportunity to progress seismic deployments so as to achieve these scientific targets.

After the seismic array project of the Transantarctic Mountains Seismic Experiment (TAMSEIS) [6, 7] during 2000–2002, several projects were conducted to reveal the interior structure of the Antarctic continent (**Figure 1**). The Antarctica's Gamburtsev Province (AGAP), the Gamburtsev Mountains Seismic Experiment (GAMSEIS) as a part of AGAP, and the Polar Earth Observing Network (POLENET) were the largest contributors in establishing a whole seismic network to reveal the Antarctic interiors during the IPY. Moreover, the broadband seismic deployment around the eastern Dronning Maud Land-the Enderby Land by the Japanese Antarctic Research Expedition (JARE) [8, 9] greatly contributed as a part of POLENET and AGAP. From the GAMSEIS and POLENET data, the local and regional seismic signals associated with cryosphere dynamics, oceanic loadings, and local meteorological variations were recorded with a significant number of teleseismic events.

In this chapter, field operations over the inland plateau of East Antarctica and seismic event data retrieved from AGAP/GAMSEIS/POLENET are demonstrated. In addition to reviewing

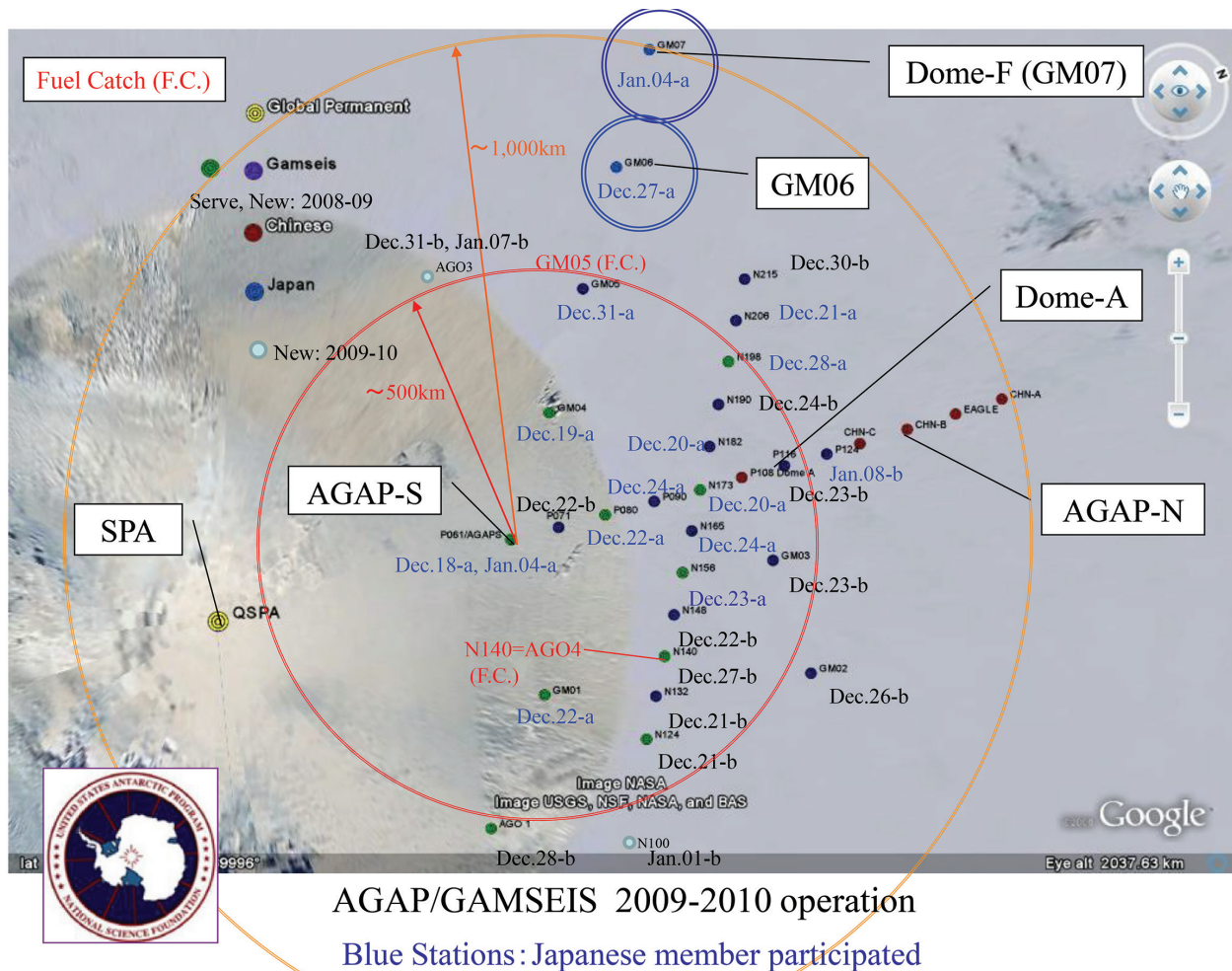


**Figure 1.** Map of seismic and other geophysical stations deployed by major projects during the IPY 2007–2008 (modified after [21]). The project names are labeled as JARE-GARNET, AGAP-GAMSEIS, CASE-IPY, POLENET-West. Ant. and US-TAMSEIS (2000–2002), respectively. All stations in the Antarctic continent have contributed to the POLENET program as a whole. Open Access Journal (CC BY 3.0) (first author is M. Kanao).

achievements of seismological studies of the crust and upper mantle, emphasis was on the description about local seismicity of the inland plateau over the ice sheet.

## 2. Field operations in the inland plateau

Revealing the inner structure of the underlying ice sheet, present dynamics, and tectonic evolution of a broader part of East Antarctica, AGAP was an internationally coordinated program composed of airborne geophysics, seismic, and ice-core drilling teams [10]. Multinational collaboration between scientific studies and field logistics was carried out by the USA, Japan, China, France, Italy, and Australia. Two field base camps were established at AGAP-N and AGAP-S, at opposite sides of the Chinese station in Dome-A (**Figure 2**). Moreover, the Chinese traverse team conducted seismic deployment along the routes from the Zhongs station to Dome-A. The GAMSEIS team deployed a few tens of broadband seismographs over a wide area of the continental ice sheet from the Gamburtsev Subglacial Mountains (GSM), Lake



**Figure 2.** Map showing the broadband seismic location of stations by AGAP/GAMSEIS during 2009–2010 austral summer season. Two circles in different distances of 500 and 1000 km are indicated with their center at AGAP-S. The visiting (installed) dates for each station are labeled: (a) first flight and (b) second flight of the day. The fuel catches were prepared in some places approximately at 500 km from AGAP-S. The original local map is taken from Google Earth™. (Original figure prepared for this InTech Book.)



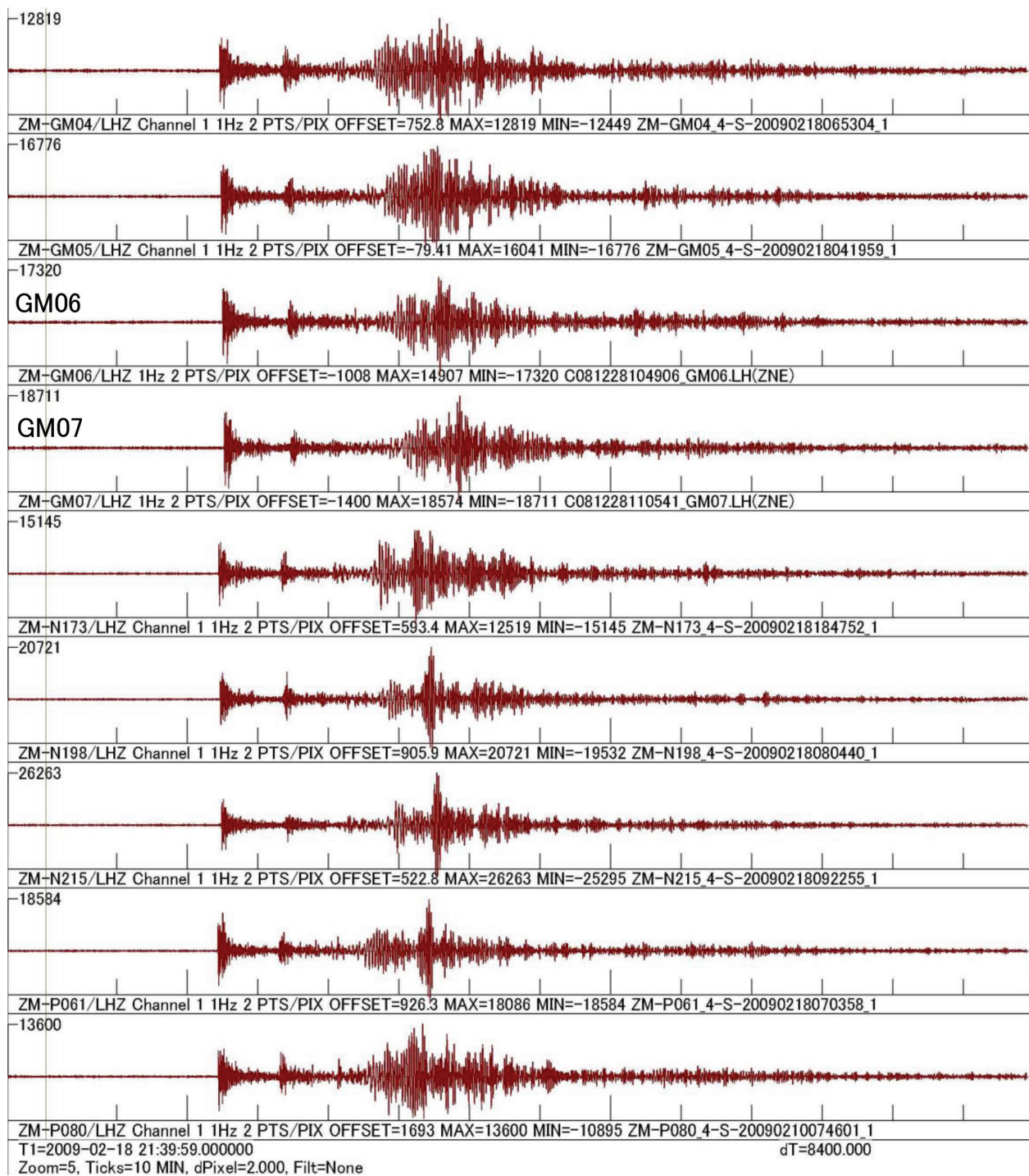
Vostok, and the vicinity of the Dome-F station (**Figure 2**). A significant number of flights were conducted by Twin Otter aircrafts in order to install seismic stations over the ice sheet. The Japanese Dome-F (GM07) station was the most distant one, which was almost 1000 km away from AGAP-S.

Seismic instrumentations used for GAMSEIS/POLENET were majorly provided by the Program for Array Seismic Studies of the Continental Lithosphere (PASSCAL) of the Incorporated Research Institutions for Seismology (IRIS). PASSCAL polar instruments were developed with inputs from the community of Antarctic seismologists, and the main specifications are summarized as follows [11, 12]: seismometer, Guralp CMG-3T with a special configuration to operate at  $-55^{\circ}\text{C}$ ; Datalogger, Quanterra Q-330 with a flash memory (operating at  $-55^{\circ}\text{C}$ ); enclosures; insulated vacuum to keep at  $\sim 15^{\circ}\text{C}$  above the ambient temperature without additional heating; solar panels; and AGM batteries for summer power and lithium batteries for winter power. These instruments were optimized for ease of deployment from Twin Otter aircrafts. In addition to these PASSCAL observation systems, originally coordinated seismic station systems were developed by the Japanese team (Dome-F (GM07) and GM06 stations; **Figure 2**), as well as by other groups from China and France. The Japanese instrument system used the same sensor and datalogger as those of the PASSCAL's; however, electric power supply and enclosures were independently developed with the technical support of PASSCAL staff. The seismic data were recorded in MiniSEED format, which has been an international standard in global seismology. Logistic supports were provided by the US researchers and staff at the AGAP-S camp for the installation of Japanese stations in GM06 and GM07.

### 3. Seismic data and local events

During the IPY, a significant number of teleseismic events, as well as many local seismic signals, were recorded by AGAP/GAMSEIS/POLENET stations in East Antarctica. **Figure 3** shows waveforms of the earthquake in the Kermadec Islands region (February 18, 2009, Mb 6.8) detected by the GAMSEIS stations, including the Japanese Dome-F (GM07) station. These teleseismic data provided detailed information on crustal thickness and mantle temperatures beneath the East Antarctic continent. Data collected from AGAP/GAMSEIS were capable of providing key constraints on the origin of GSM as a crustal root associated with ancient orogenic events [13] and more broadly on the structure and evolution of the entire area of the East Antarctic craton [14–16]. Understanding the origin of GSM and seismological structure of the East Antarctic craton can be linked to the geologic history of the adjacent terrains, the role of its topography and heat flow in the Earth's climate and glacial history, and the geophysical and geologic controls of subglacial lakes [17]. A map of the crustal thickness beneath GSM showed large values, over 55 km, which imply that an ancient mountain range might have been supported by the thick, buoyant crust [13, 14]. These new findings of the crust and upper mantle aided in understanding the evolution of the Gondwana supercontinent in the Earth's history.

Several kinds of seismic signals associated with the atmosphere-ocean-cryosphere system were also detected. The dynamic movement of the cryosphere was capable of causing small-magnitude earthquakes, generally named "ice quakes" (or "ice shocks") for their relationship between glacial dynamics and evolution [18–21]. Such cryoseismic sources have been classified into the



**Figure 3.** Teleseismic waveforms of the earthquake in Kermadec Is. region (February 18, 2009, Mb 6.8) recorded by several stations of AGAP/GAMSEIS, including Dome-F (GM07). (Original figure prepared for this InTech Book.)

movement of ice sheets, sea ices, oceanic tide cracks, oceanic swells, and icebergs and the calving fronts of ice caps. These cryoseismic sources were likely to be influenced by environmental conditions of the surface layers of the Earth, and the detailed studies of their temporal variations may provide indirect evidence of climate change in the polar region. In addition to these cryoseismic signals, atmospheric vibrations were also recorded on seismographs deployed in the Antarctic inland area. **Figure 4** represents an example of seismic waveforms in the period of storms (i.e., the

names of the “blizzard” in the polar region) overlapping with several seismic events during the austral summer in 2009 recorded by the GAMSEIS stations, including Dome-F (GM07). In spite of the limited time periods, temporal variations were investigated by detecting seismic events in GM06 (Figure 5). Variations in the number of detected teleseismic events, estimated local events, and noise or undefined events and in the periods of storms were compared. The shadowed areas in Figure 5 appeared to correspond with the time periods of storms, which are also supposed to generate high amplitudes of the “microseismic” signals generated from the oceanic swells. More detailed studies can be carried out by comparing these observations with meteorological data, including the data from the autonomous weather stations (AWS) deployed over the Antarctic. The detection of these types of cryoseismic signals could be a new proxy to understand the effects among the atmosphere-ocean-cryosphere system in the central part of the continent.

Figure 6 presents hypocentral information of local seismic events detected by the AGAP network in 2009, in addition to those detected by the TAMSEIS network in 2002 [22]. These local events occurring inside the ice sheet were considered to have cryodynamic origins. These sources, termed “firn quakes,” were characterized by dispersed surface wave trains with frequencies of 1–10 Hz, propagating distances up to 1000 km [22]. They proposed that these events were linked to the formation of small crevasses in the firn layers at the surface of the

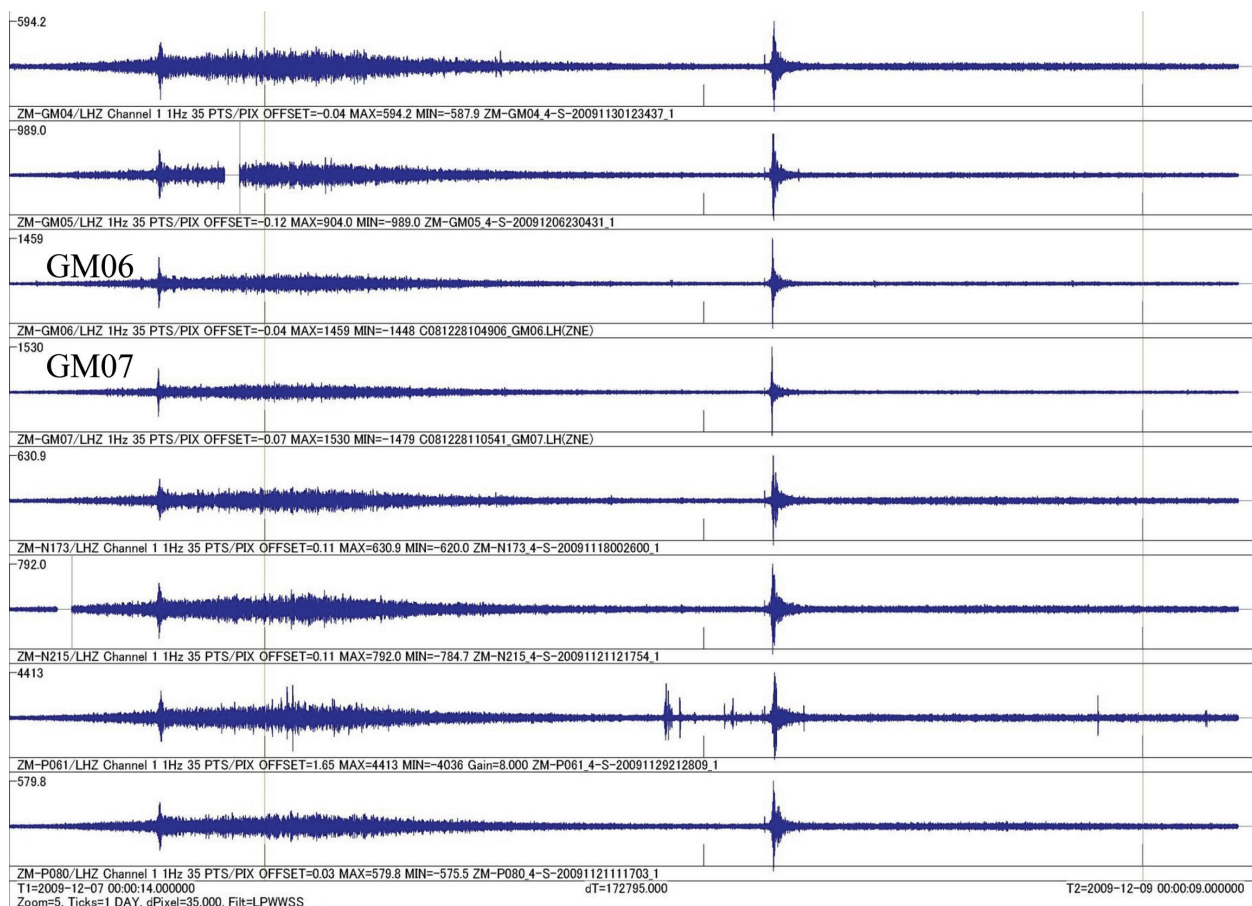
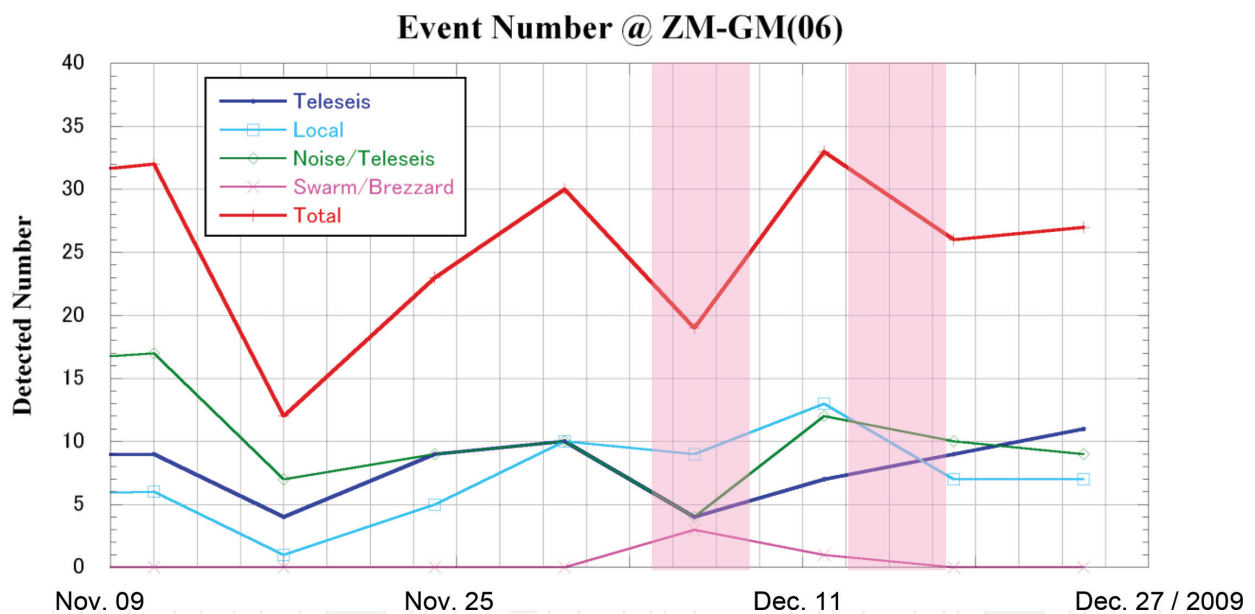
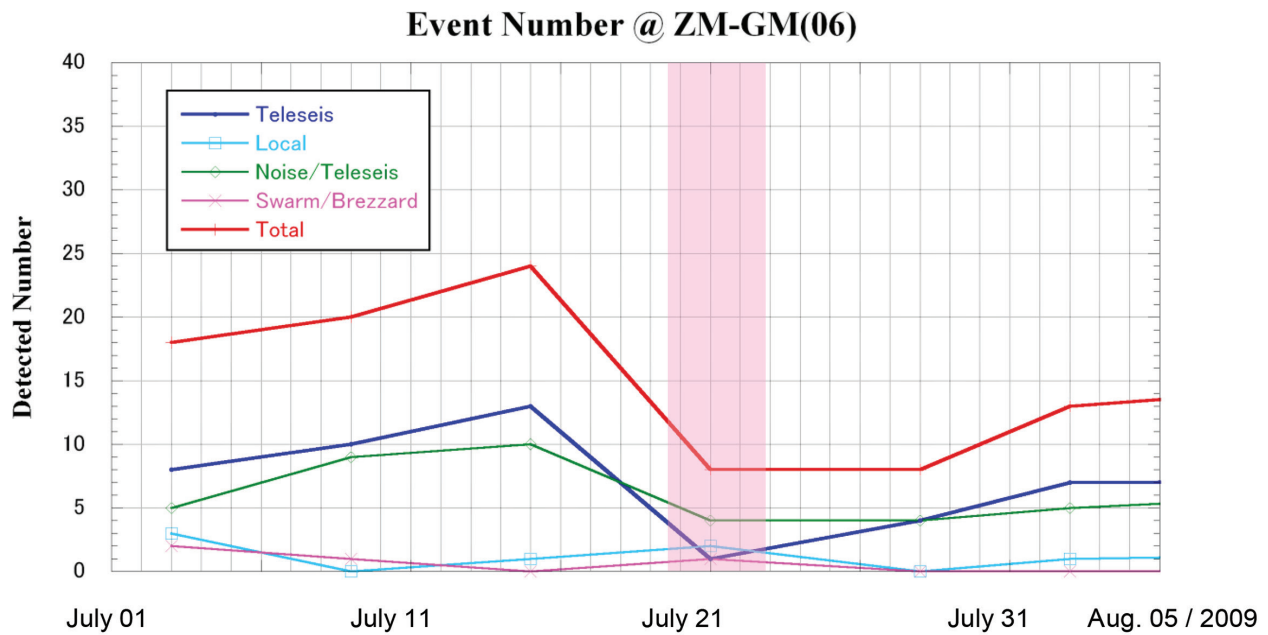


Figure 4. Waveforms of the blizzard and seismic events after the low-pass filters (February 6–9, 2009) recorded by several stations of AGAP/GAMSEIS, including Dome-F (GM07). (Original figure prepared for this InTech Book.)

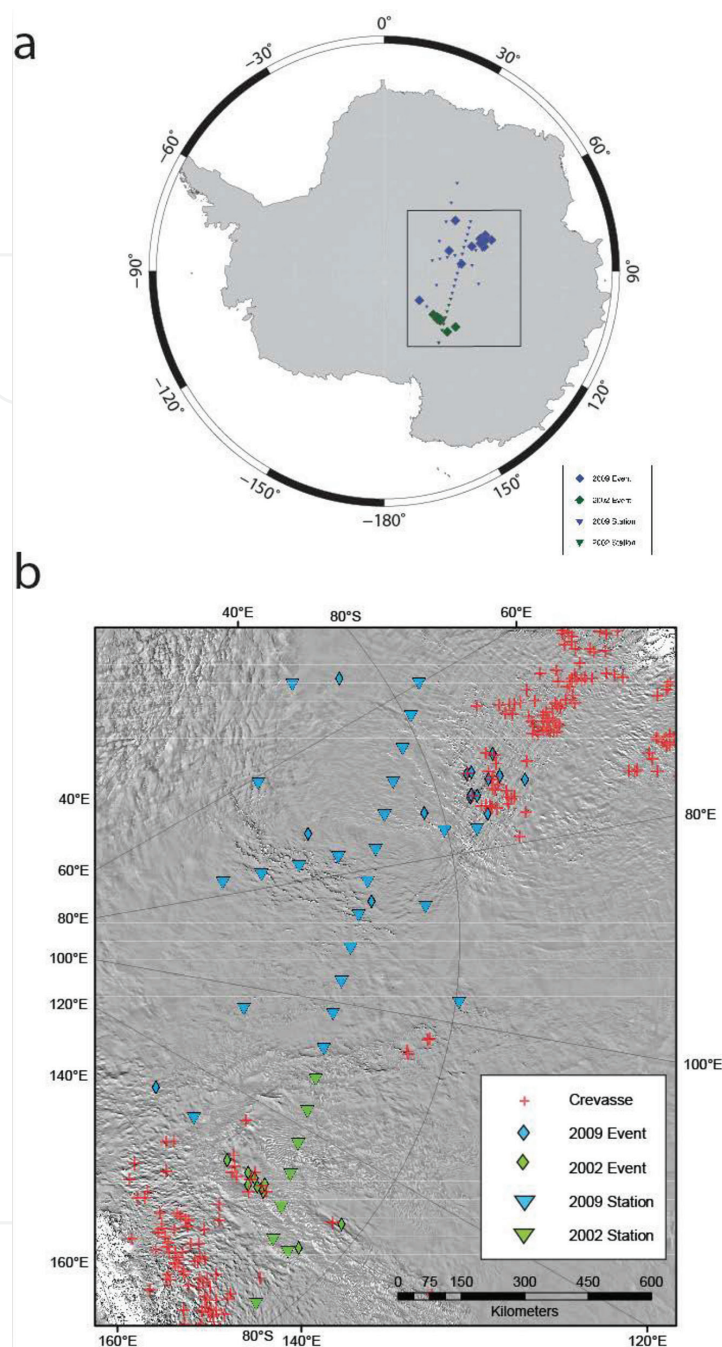




**Figure 5.** Temporal variations in detecting the seismic events in the GM06 station for July-August 2009 (upper) and November-December 2009 (lower), respectively. Several solid lines in different colors represent the variations in teleseismic events (blue), local events (light blue), noise (undefined) events (green), swarm/blizzard (pink), and total events (red). The shadowed areas appear to correspond with the time periods when passed by the swarm/blizzard phenomenon. (Original figure prepared for this InTech Book.)

ice sheet, and several events could correlate with shallow crevasse fields mapped on satellite imagery. The hypocentral location of these events appeared to be close to the location of the existing crevasses, that is, near the upstream of the Lambert Glacier and inland area of the Transantarctic Mountains. The local events detected by the GM06 station could possibly include some of these events detected by Lough et al. [22].





**Figure 6.** Local seismic events detected by the AGAP network (2009, blue diamond) and the GAMSEIS network (2002, green diamond; refer [22]). Red crosses indicate the location of crevasses. Copyright Clearance Center (CCC, <http://www.copyright.com/>). License Number: 4282210713648, License date: February 04, 2018.

#### 4. Summary

By deploying broadband seismic instruments over the whole area of Antarctica, more detailed understanding of the tectonics and upper mantle structure can be obtained. After combining these data from numerous IPY projects in seismology and geophysics, it was possible to provide constraints on the origin of GSM and the broader structure of Precambrian cratons, as well as the subglacial environment near the region. The detection

of seismic signals associated with basal sliding of the ice sheet and ice streams [7, 19, 23, 24] is expected in future, together with the detection of outburst floods from subglacial lakes. Temporary seismic stations along the inland traverse routes on the continental ice-sheet plateau can be installed using snow vehicles with sufficient support from air transport. These field observation stations over the ice sheet may also be utilized for other science studies, such as geophysics, meteorology, glaciology, and biology. Multidiscipline inland data collected around the Antarctic continent can be utilized by the nations involved in the Antarctic research in order to monitor long-term variations especially under cold temperature environments.

The IPY 2007–2008 provided an excellent opportunity to make significant advances in geophysical monitoring in the bipolar region. The advances served as an important contribution to the studies of the global network of FDSN, the projects of GARNET/POLENET, and other science bodies and communities. The high-quality data obtained from the Antarctic can be efficiently utilized to clarify the characteristics of local seismicity and heterogeneous structure of the Earth. From the AGAP/GAMSEIS data obtained during the IPY, the local and regional seismic signals associated with the ice-sheet movement and meteorological variations were recorded, together with a significant number of teleseismic events. The detection of seismic signals from the phenomenon at the base of the ice sheet, such as outburst floods from subglacial lakes, can be expected from detailed analyses in future.

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