50 Years of Antarctic Research Expeditions by the Geographical Survey Institute

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Abstract

The Japanese Antarctic Research Expedition (JARE) started in conjunction with the International Geophysical Year (IGY) research program implemented from July 1957 to December 1958. From the first Japanese Antarctic Research Expedition (JARE-1) in 1956 to the latest one, JARE-48, the Geographical Survey Institute (GSI) has dispatched a total of 83 survey engineers to conduct geodetic surveys and take aerial photographs for preparing maps of Antarctica. This report summarizes the changes of surveying and mapping technology, and the achievements during the 50 years' history.

1. Introduction

The Japanese Antarctic Research Expedition (JARE) started in conjunction with the third International Polar Year (IPY) in which the survey coverage area established by the International Geophysical Year (IGY) research program was expanded to the whole globe.

On November 8, 1956, 53 people from the 1st Japanese Antarctic Research Expedition (JARE-1) left Tokyo aboard the *Soya* and took their first step on Antarctica on January 29, 1957. In the fall of 2006, JARE celebrated its 50th anniversary and marked its tremendous achievements including the discovery of the ozone hole, analysis of aurora generation mechanism, analysis of 320,000 years of climate change from ice cores, and so on.

GSI has dispatched 83 survey engineers in total for the last 50 years, at least one engineer dispatched to every JARE.

During the Antarctic expeditions, GSI has conducted control point surveys and taken aerial photographs for preparation of maps, and undertaken gravity and geomagnetic surveys. The achievements include preparation of topographic maps and satellite image maps of the area of the Prince Olav Coast to the east, the Sor Rondane Mountains to the west, and the Yamato Mountain Range to the south as well as Syowa Station and its vicinity, impossible to attain before landing on Antarctica.

In addition, GSI has conducted geophysical observations for analysis of landforms and geophysical phenomena, and GSI published the survey results in order to build a foundation on which future expeditions could expand their research fields. With the development of survey technology, GSI set up continuous Global Positioning System (GPS) observation stations including Syowa Station in order to conduct highly precise observation on such subjects as crustal movement, post-glacial rebound (upheaval of the Earth's crust due to glacial retreat), and performed on absolute gravity measurements for further analysis of geophysical phenomena. In response to the recommendation from the Scientific Committee on Antarctic Research, we also engaged in control point surveys for transition from the old geodetic datum based on astronomical surveys to the Geodetic geodetic datum.

In this report, the achievements during the 50 years' history and the changes of surveying and mapping technology, are described.

2. History from the initiation of Antarctic expeditions to the present

2.1 IGY and IPY

Geophysical research started with a year-long international joint expedition in 1882, the first IPY. Twelve countries, including Japan, participated in the expedition during which 34 observatories at mid-latitude areas and 14 observatories at the North and South Poles were built in order to conduct observations mainly on meteorology, ocean phenomena, terrestrial magnetism and aurora. Fifty years later, the second IPY was held and 44 countries conducted geophysical research on a global scale. Emphasis was placed on the Arctic for the research surveys, and thus no surveys were conducted in the interior of Antarctica. However, surveys were conducted on neighboring islands of Antarctica including South Georgia Island and Kerguelen Island. In 1951, the International Council for Scientific Union (ICSU, now the International Council for Science) adopted a resolution to hold the IGY from 1957 to 1958, 25 years after the second IPY. It was decided that 12 fields would be covered: aurora, airglow (night airglow), cosmic rays, geomagnetism, glaciers, gravity, ionosphere physics, longitude and latitude determinations (precision mapping), meteorology, oceanography, seismology and solar activity. This IGY was positioned as the third IPY, and expeditions to inland Antarctica made a formal start. Japan, Argentina, Australia, Belgium, Chile, France, New Zealand, Norway, Union of South Africa, Union of Soviet Socialist, United Kingdom of Great Britain and Northern Ireland, and United States of America were the twelve countries that built a scientific station in Antarctica. Thus, IGY's global expedition under international collaboration that started on July 1, 1957 and ended on December 31, 1958 was initiated for global expeditions including Antarctica.

With the closing of the IGY in 1959, discussions ensued on the importance of continuing expeditions in many fields in polar science except expeditions to mid- and low-latitude regions, and it was decided that the Special Committee on Antarctic Research (SCAR, now the Scientific Committee on Antarctic Research) that had been established within the ICSU in 1958 would take over the expeditions to the polar region. It was also decided that in addition to geophysical research, emphasis would be placed on physical, geological, biological, geodetic and topographic surveys.

2.2 Participation in Antarctic expeditions

The Antarctic expeditions were launched as part of the IGY global project conducted between July 1957 and December 1958, and GSI was assigned with the survey of geomagnetism and gravity, as well as longitude and latitude determination (precise mapping), all of which are closely related to its activities.

Japan was assigned with observation in the vicinity of 35°E where the Prince Harald Coast lies. The 6th Expedition of Christiansen of Norway mapped this area at a scale of 1:250,000 using oblique aerial photographs in 1937 and the 68th Mechanized Unit of the U.S. Navy took aerial photographs of this area between 1946 and 1947. However, ground survey was not conducted, and thus the shape of the Prince Olav Coast beyond 40°E was not clarified. As an immediate task, the expedition was to determine the longitude and latitude of the area. The second task was to take aerial photographs for advance research on land shape and ice conditions of the area to be covered by the expedition.

Starting with the astronomical survey at Syowa Station in January 1957, various surveys were continued even after the close of the IGY and ended with the aerial photography conducted on JARE-6 in January 1962. During this period, 29 control points including astronomical points were established, and the total distance covered by vertical photographs reached 1,700 km. Thus, it became possible to prepare small-scale maps of the coastal area between 38°E and 45°E. The use of aerial photographs for preparation of maps was demonstrated on this expedition before it was practically introduced for domestic works.

In the meantime, JARE-2 (1957) and later expeditions conducted gravity surveys at the ports of call for the expedition ship on the way to and from Antarctica, the area surrounding the station, and the interior region of the continent. In the 3rd SCAR in March 1958, it was proposed that the area to be mapped by Japan should cover between 30°E and 45°E for mapping. Responding to this proposal, the expedition expanded the mapping area westward beyond 38°E. In addition, mapping of ice-free areas in the inland region, triangulation and traversing of the area surrounding Syowa Station, and surveys on interannual changes of coastal areas were conducted. Observations on gravity and addition of the points were continued and aeromagnetic surveys were conducted. JARE-7 that resumed in 1965 and subsequent JAREs continued conducting surveys.

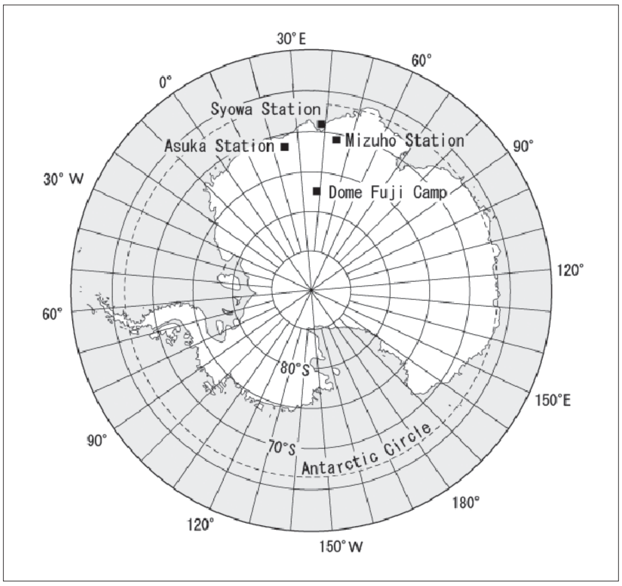

Fig. 1 Entire Area of Antarctica

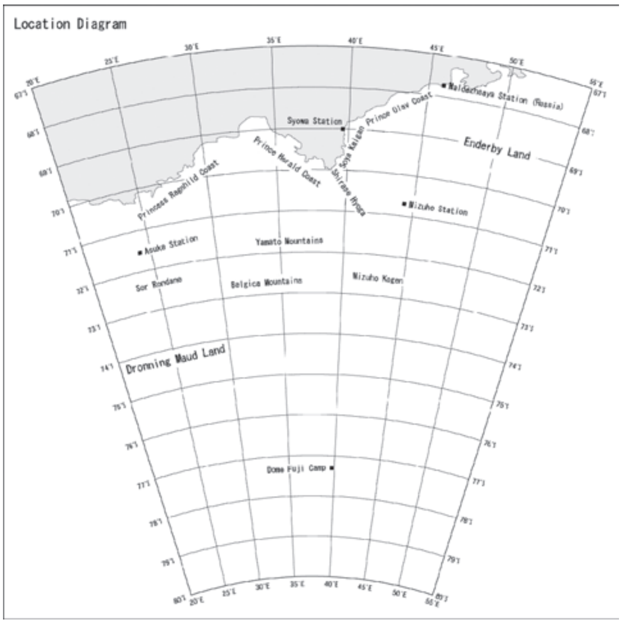

Fig. 2 Location of four Japanese stations

3. Outline of Antarctic expeditions of GSI

3.1 1st - 6th Expedition

Surveys of the Antarctic region started with an astronomical survey at Syowa Station in January 1957 for the purpose of establishing a geodetic datum, and ended with aerial photography on JARE-6 in January 1962. These years are referred to as the *Soya* period as every survey was conducted while the icebreaker *Soya* was in service. All survey activities were done during the summer season in Antarctica from late December to early February. This period, however, faced extreme congestion due to the transport of supplies for the wintering party and the construction work to build stations, which severely restricted survey activities and made it difficult to stay on schedule. Fortunately, when it was decided to end the Antarctic expeditions with JARE-6, the transportation by air reserved for its aerial photography became available and the planned works on survey activities were completed.

In this six-year *Soya* period, the main task was preparation of large-scale maps based on aerial photographs of the area surrounding Ongul Island, which were taken for advance research on candidate locations for a station and the surrounding areas. Thus, control point surveys were conducted only in the areas surrounding East and West Ongul Island at the early stage.

On and after JARE-4 (1959), the network of control points was extended to the opposite coast, and subsequently covered the Langhovde region, Padda Island, New South Rock, and to the ice-free areas on the continent. A small-scale map was prepared based on the control point surveys and aerial photographs taken by JARE-6 (1961).

It was JARE-4 (1959) that first used a microwave distance meter (Photo 1) for control point surveys. With this newly developed meter, it became possible to survey a wider area with greater efficiency and improved precision.

The achievements accomplished up to JARE-6 (1961) include the coverage of a total distance of aerial photography exceeding 1,700 km and the establishment of more than 29 control points including astronomical points. In the coastal area between 37°E and 45°E, data from these achievements and data available from the Australian party responsible for the east neighboring area satisfied the number of control points necessary for mapping by photographic survey. It thus became possible to prepare maps for Prince Olav Island and Holm Gulf at a scale of 1:100,000–250,000. Based on the data, two 1:250,000-scale maps were prepared in 1963.

JARE-6 (1961) conducted detailed gravity surveys during the round trip between Cape Town and

Syowa Station. Using a GSI-type gravity pendulum, the standard gravity value at Syowa Station (Photo 2) was determined.

Furthermore, marine magnetic surveys began by JARE-2 in 1957, and were continuously conducted up to JARE-9 in 1967, except for JARE-7 in 1965.

Photo 1 Observation by microwave distance meter, Tellurometer (JARE-4)

Photo 2 Observation by gravity pendulum at Syowa Station

3.2 7th - 17th Expedition

The Antarctic expeditions were suspended beginning with JARE-6 (1961). In 1963, however, upon conclusion of various arrangements under Cabinet approval, a decision was made "On the resumption of the Antarctic expeditions." The expeditions resumed in 1965. With the revision of the Self-Defense Forces Act, the Defense Agency was assigned with transportation, the expedition ship *Fuji* was built, and two large helicopters were introduced. Accordingly, transportation capability was significantly upgraded. In addition, the decision to continue the Antarctic expeditions made it possible for each JARE to conduct observations on a long-term basis. With this decision, expedition items were allocated to the research observation programs and the continuous monitoring observation programs. The continuous monitoring observation programs are used to obtain basic data and specimens which are indispensable for academic research, and are conducted over extended periods of time, often as part of an international monitoring network. These continuous monitoring observation programs are governed by international reporting standards and have been conducted since JARE-7 (1965). GSI took charge of the geodetic observation program comprising control point surveys and aerial surveys, the geomagnetic observation program focusing on air photo measurement, and the gravity observation program engaged in land gravity and marine gravity surveys as parts of the continuous monitoring observation programs. The Meteorological Agency, the Hydrographic and Oceanographic Department of the Japan Coast Guard, and the Radio Research Laboratory (now the National Institute of Information and Communications Technology) also took charge of parts of the continuous monitoring observation programs. The National Institute of Polar Research (NIPR) affiliated with the Ministry of Education (now Ministry of Education, Culture, Sports, Science and Technology) that was established in 1970 took charge of the coordination for these observations.

In its May 1960 recommendations, the Science Council of Japan placed particular importance on mapping among the activities of JARE. In March 1967, the Antarctic Special Committee of the Science Council of Japan drew up a basic policy for future Antarctic expeditions and indicated that "Japan shall conduct topographic survey of the sectoral area between 30°E and 45°E. In particular, aerial survey of the coastal area and the neighboring area of inland mountains should be conducted at the earliest possible time." This sectoral area was one of the regions proposed by the Soviet Union at the meeting of the Map Subcommittee of the

3rd SCAR in March 1959. Since the region contains Belgium Station and Syowa Station, the Subcommittee recommended that redundant works should be avoided. However, Belgium conducted almost no work on geodesy at the time. Japan decided to conduct geodetic and mapping programs as planned.

The major achievements by GSI between JARE-7 and JARE-17 (1965–1975) are the following.

1) The wintering party conducted geodetic expeditions for the first time on JARE-7 (1975). This made it possible to conduct control point surveys necessary for preparation of large- and medium-scale maps not only in summer but also in spring and winter.
2) The survey engineer from GSI joined the wintering party of JARE-9 on the round trip between Syowa Station and the South Pole. He navigated the party using the pilot surveys and traversing. He also conducted geophysical observations such as of gravity and geomagnetism during the trip.
3) With the development of a GSI-type ocean gravimeter, the survey engineer conducted gravity surveys on the expedition ship (photo 3).
4) Aerial photographs of the inland Yamato Mountain Range were taken and control point surveys were conducted. On JARE-16, a fixed-wing aircraft became available and the necessary crew was permitted to overwinter. Because a relay station was built inland, aerial photographs of inland mountains including the Belgica Mountains and the Riiser-Larsenhaivoya area up to 30°E were successfully taken.
   Infrared aerial and color aerial photographs of glacier basins and biological habitat areas were also taken for the purpose of analysis from the viewpoint of glaciology and biology.
5) For aeromagnetic surveys, JARE-8 (1966) first used a helicopter, and JARE-11 (1969) used a fixed-wing aircraft. This allowed us to locate a geomagnetic anomaly exceeding several hundred nanotesla (nT) on the sea west of West Ongul Island. The achievements in aerial photography were published in January 1972 as the “Contours of total magnetic intensity over Lutzow-Holm Bay and its vicinity” (Tazima, et al., 1972, Fig. 3). Subsequently, aeromagnetic surveys were conducted up to JARE-16 (1974), covering the area from 43°E (around Hinode Misaki on the Prince Olav Coast) to 34°E (from Karamete Misaki to Riiser-Larsenhalvoya), and Lutzow-Holm Bay and the Yamato Mountain Range. In 1974, GSI produced and published the “Contours of total magnetic intensity (the coast area from Hinode Misaki to Langhovde)” (Tazima, et al., 1972) prepared from aeromagnetic surveys of JARE-15 (1973), and clarified the distribution of magnetism in the region.
6) As for equipment, (the microwave distance meter was replaced with the electro-optical distance meter (Photo 4), the electro-optical distance meter was used with the T-3 theodolite), the super-wide-angle aerial camera was introduced to cover expanded shooting areas, and the Worden gravimeter was replaced with the Lacoste gravimeter that has stable constants with less drift. JARE-2 (1957) started with the Zeiss RMK 11.5/18 aero camera, but JARE-11 (1969) replaced it with the Wild RC-9 (Photo 5) that has 30° wider angle than the existing aero camera. Thus, it became possible to reduce the shooting time and decrease the number of paths and distribution density of control points.

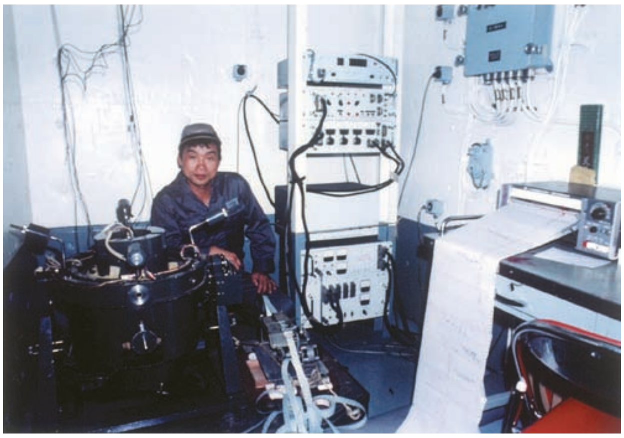

Photo 3 Ocean gravity observation (JARE-13)

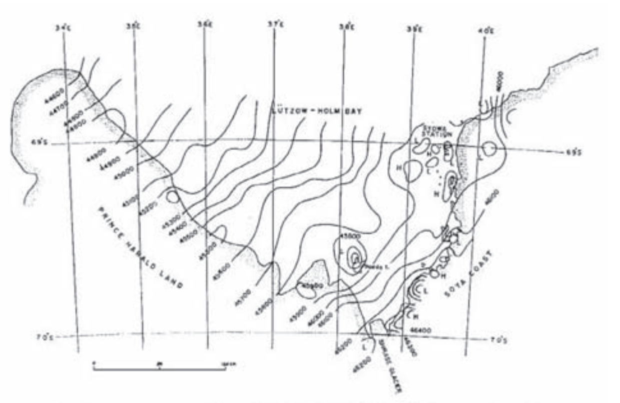

Fig. 3 Contours of total magnetic intensity over Lutzow-Holm Bay and its vicinity

Photo 4 Observation by electro-optical distance meter, Geodimeter 8 (JARE-14)

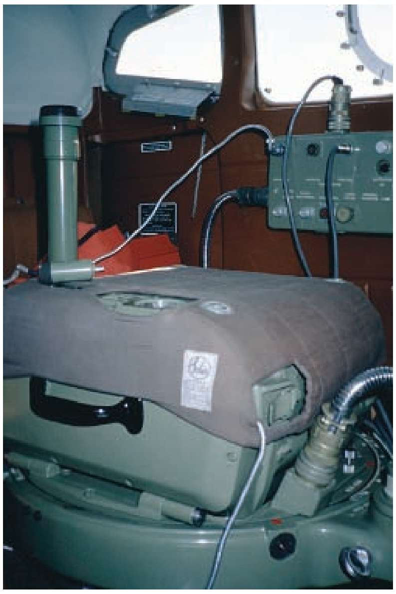

Photo 5 Aerial camera, RC-9, installed in a Cessna

3.3 On and after the 18th Expedition

3.3.1 Mid-term Antarctic expedition plan

The Antarctic research expeditions are carried out in accordance with the "Basic Policy of Japan Antarctic Research Expeditions (March 1976)" and the "Policy of Activities toward the 21st Century (June 2000)" drawn up by the Headquarters for the Japanese Antarctic Research Expedition (JARE Headquarters.) Five years was set as the unit for the expedition plan beginning with JARE-18 (1976) and observation activities were to be effectively and efficiently implemented. Details of each expedition plan are presented in Appendix 1.

Please note, however, that four years instead of five years was adopted as the unit for FY 2009, because the observation ship succeeding the *Shirase* will be put into service in 2009 and a new expedition support system will be introduced, and the end of the mid-term Antarctic expedition plan should coincide with the end of present mid-term plan of NIPR.

3.3.2 Implementation outline of each observation item

The outline of the expedition items implemented on and after JARE-18 (1976) to the present is as follows:

(1) Control point survey

The method used for determining the position of coordinates was astronomical survey up to the summer party of JARE-24 (1982). Exceptionally the wintering party of JARE-26 (1984) also partly used solar observation for control point surveys. From the wintering party of JARE-24 (1982) until JARE-30 (1982), the positioning system used was the Navy Navigation Satellite System (NNSS), which utilizes the Doppler effect. The NNSS was later replaced with GPS, which has been used for control point surveys up to the present.

(a) Navy Navigation Satellite System

JARE-24 (1982) started with a control point survey in Sor Rondane, a huge mountain range in East Antarctica about 700 km west-southwest of Syowa Station, with the objective of preparing topographic maps at a scale of 1:50,000. For the first time, NNSS (Photo 6) replaced the astronomical survey in Antarctica.

GSI conducted control point surveys in collaboration with the expeditionary party to Sor Rondane Mountains on JARE-24 (1982), with the geoscience preliminary research party to Sor Rondane on JARE-25 (1983), and the geoscience research party to Sor Rondane between JARE-26 (1984) and JARE-32 (1990).

In those days, NNSS determined the longitude, latitude, and ellipsoidal height of an observation point by receiving radio waves from 7–8 satellites that went around the polar orbit at an altitude of about 1,100 km over a period of about 107 minutes. The system freed observers from long hours of outdoor survey in a frigid climate. However, this system was not an effective way to observe all control points because it required continuous observation over several days to determine longitude and latitude with a high degree of accuracy. Given this fact, GSI used NNSS for observation in the vicinity of the base camp. Based on the control points determined by NNSS, GSI conducted traversing or triangulation using an electro-optical distance meter and theodolite.

Photo 6 NNSS observation equipment (JMR-4A)

(b) Global Positioning System

As GPS became available in the late 1980s, JARE-30 (1988) conducted trial observation by GPS in the Sor Rondane Mountains. Based on the observation results, JARE-31 (1989) and JARE-32 (1990) conducted independent control point surveys by GPS in the Sor Rondane Mountains. Back then, there were not as many GPS satellites, and the time allowed for observation was 4–5 hours per day. However, GSI conducted surveys for more than three hours at each control point at intervals of five seconds. Because GPS survey does not take as much time as NNSS survey, operating efficiency improved considerably.

Under the proposal of the SCAR Campaign, JARE-33 (1991) conducted a continuous survey for 21 days at the GPS observation point at Syowa Station. With this international collaborative observation, the longitude and latitude of Syowa Station became linked on the global geodetic network with a high degree of accuracy. JARE-34 and JARE-36 took over the international collaborative observation under this Campaign, and it was replaced with the continuous GPS observation station beginning with JARE-37 (1994).

In conjunction with the GPS international collaborative observation, JARE from the 33rd (1991) to the 37th (1994) conducted joint observation of the geodetic network with the help of the existing control points at ice-free areas and carrier phase differential GPS. At the same time, GSI set up new control points in order to prepare color photo maps at a scale of 1:10,000.

Since the International GPS Service (IGS, now the International GNSS service) point “SYOG” was set at Syowa Station on JARE-36 (1994), it was designated as the substantial point of origin on and after JARE-37 (1994). As for the control point survey (Photo 7) of each ice-free area, GSI established or resurveyed control points using carrier phase differential GPS based on this point as the origin.

JARE-40 (1998) revised the survey results of IGS points with those based on both the International Terrestrial Reference System (ITRF) and GRS80 ellipsoid.

On and after JARE-41 (1999), observation and analysis were based on ITRF2000 the origin of which is the IGS point “SYOG.”

The coordinates of the IGS point “SYOG” are determined based on ITRF2000 by combined observation with the Very Long Baseline Interferometry (VLBI) observation point and the Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) observation points. The IGS point “SYOG” was registered with ITRF in March 2001 together with the

VLBI observation point.

Photo 7 GPS observation in the ice-free area

(2) Gravity survey

The Lacoste gravimeter introduced on JARE-8 (1966) is still being used together with the Scintrex gravimeter introduced on JARE-37 (1995). On and after JARE-33 (1991), highly precise absolute gravity measurement was conducted every 3–6 years with Sakuma-type and FG5 absolute gravimeters (hereinafter referred to as FG5).

(a) Relative gravity measurement

JARE-19 (1977) conducted gravity surveys in Ryugu Misaki and in the area surrounding Syowa Station. For the measurement, gravity values based on the International Gravity Standard Network 1971 (IGSN71) and the Japan Gravity Standard Network 1975 (JGSN75) were applied in place of the Potsdam gravity series for the first time in JARE. Because absolute gravity measurement conducted worldwide during this period gradually clarified that the Potsdam gravity series had had systematic errors, IGSN71 was adopted by the International Union of Geodesy and Geophysics (IUGG) as the gravity standard network in place of the Potsdam series, and the replacement was announced in 1974. JGSN75 is based on IGSN71 and the domestic gravity standard network. With this replacement, the gravity standard network entered a new era.

The gravity value based on IGSN71 in Syowa Station had been adopted as the standard value of Syowa Station and its vicinity, before the absolute gravity measurement was carried out on JARE-33 (1991), the new gravimeter room was set up, and the new gravity value of the International Absolute Gravity Base Station Network (IAGBN) point was determined.

In March 1986, GSI compiled the report “Records of Antarctic observation data – gravity and geomagnetism” and it was included in “Records of Antarctic observation data – control point survey, gravity, geomagnetism, aerial photograph and map” (Geographical Survey Institute, 1985.)

On and after JARE-34 (1992), gravity surveys were conducted on each control point in Syowa Station and its vicinity based on the gravity value of the IAGBN point in the gravimeter room. JARE-35 (1995) used the Scintrex gravity meter, which is a digital relative gravity meter introduced in 1995 for surveying ice-free areas and observing vertical slopes. Thereafter, gravity surveys on ice-free areas were mainly conducted by Scintrex gravity meter, although the Lacoste gravimeter is also used on some expeditions.

(b) Absolute gravity measurement

The General Assembly of the 19th IUGG/IAG reached a resolution to establish IAGBN.

IAGBN aims to distribute gravity points worldwide and construct a network on which gravity observation is based (Fig. 4). There are two kinds of points: IAGBN-A is a point set up in regions with stable crustal structure, and IAGBN-B is a point set up in regions where crustal activity is expected. There are three points in Esashi, Tsukuba and Kyoto, all of which are classified as IAGBN-B points. Syowa Station in Antarctica was among the 36 IAGBN-A points. McMurdo Station of the U.S. is the only another point in Antarctica other than Syowa Station that is classified as IAGBN-A.

The gravimeter room was built on JARE-32 (1990) on an ice-free area close to the large multipurpose antenna (Photo 8). The first measurement was conducted by JARE-33 (1991), and GSI conducted absolute gravity measurement between January 4 and 8, 1992 for the first time in JARE history. Introduced by GSI in 1980, the upcast-type absolute gravimeter (GA60), generally called the Sakuma type, was used in this measurement. It uses the measurement principle to determine acceleration (absolute value of gravity) by precisely measuring the height of an upcast object (corner cubic mirror) in vacuum with a laser interferometer. Observation results at Syowa Station were superior to those in Japan because the gravity room at Syowa Station is nearly free from ground vibration.

JARE-36 (1994) conducted observation using FG5 (No. 104 machine) that GSI introduced in 1992. Because FG5 measures gravity in a free-fall system, it is characterized by the ability to conduct automatic continuous measurement and allow for many measurements. It is currently used worldwide as the de facto standard gravimeter, and joint observation under international cooperation confirmed that it can be used to observe gravity values compatible with absolute gravimeters used worldwide.

Later, JARE-42 (2000) conducted the second absolute gravity measurement using FG5 (No. 203 machine) and obtained data for comparison with that using the same equipment for the first time. The comparison data agreed with the gravity values observed by JARE-36 (1994) with an error of 0.001 mGal, indicating highly reproducible values. However, no temporal change in gravity beyond the detection limit was observed at Syowa Station. JARE-45 (2003) conducted the third survey using the FG5 (No. 203 machine) and observed a secular change of gravity.

At Syowa Station and its vicinity, ground deformation is assumed to be due to post-glacial rebound. The results obtained by FG5 agree with model estimates and the results of VLBI and GPS observation regarding the uplift of crust, although there remains a large error as a secular change.

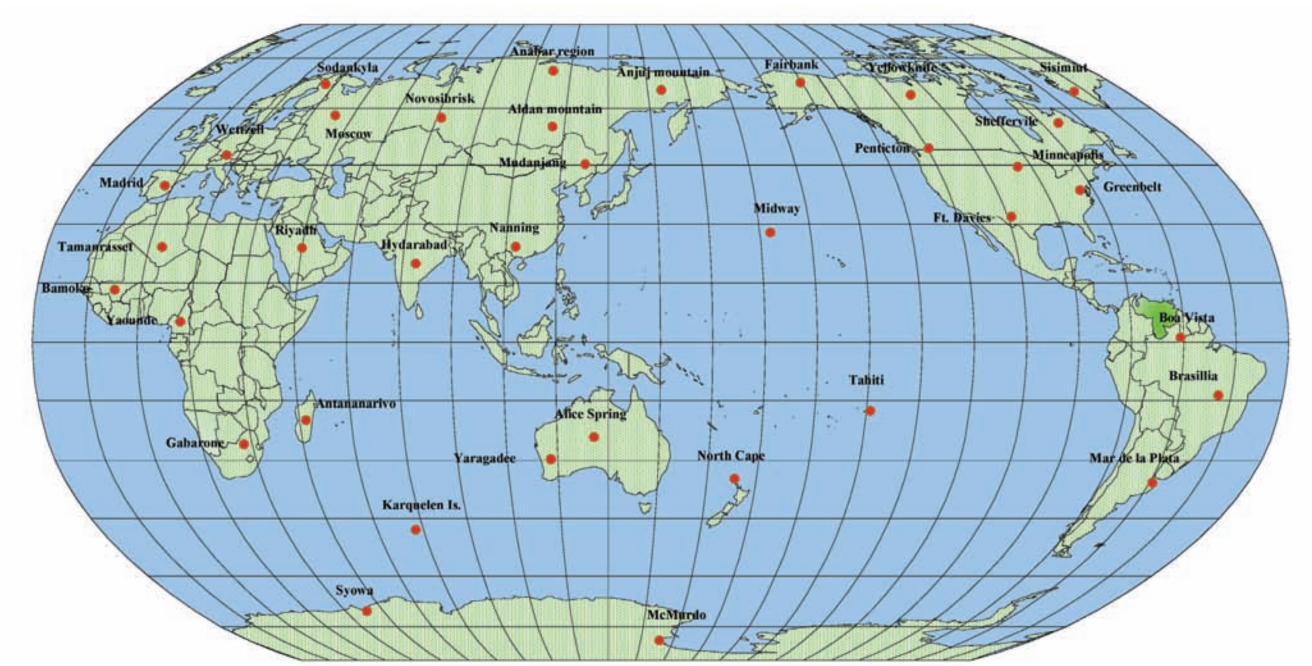

Fig. 4 International Absolute Gravity Basestation Network (IAGBN)
[A points only]

Photo 8 Gravimeter room at Syowa Station

Photo 9 Measurement scene on JARE-45

(3) Geomagnetic survey

As of JARE-47 (2005), GSI has accumulated geomagnetic observation data of 1,757 points in conjunction with ice-free areas research and inland research excluding data obtained by aeromagnetic survey, and GSI has been conducting geomagnetic observation at Syowa Station as well.

At the request of SCAR and Working Group on Solid Earth Geophysics, GSI prepared charts of the geomagnetic distribution in the Antarctic region in 1978. GSI requested deta of observatory and field survey from each country through SCAR in order to compile and create the chart. As a result, GSI obtained data from eight countries including Japan, and the number of data items finally used for publication of the chart was 9,583 including those of three-component observation, and total magnetic force observation.

The published chart was composed of seven sheets displaying the distribution and its annual change rate of each magnetic component using the azimuthal equidistant projection with the Magnetic South Pole in the center, and one sheet displaying anomalies of total magnetic force. The scale is 1:15,000,000 (Fig. 5). GSI sent the chart to relevant organizations both at home and abroad in 1978.

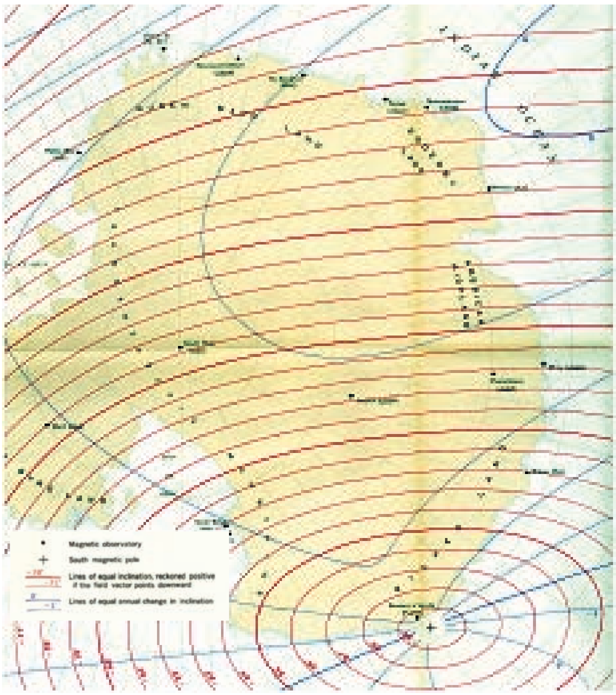

Fig. 5 Antarctic magnetic chart (Part of the magnetic dip chart)

(4) Leveling

Leveling was conducted on East Ongul Island in order to detect the uplift rate of post-glacial rebound confirmed by the crustal activity of the Antarctic area and the coastal area of Antarctica. Leveling was planned because the water's edge of uplift land was observed in ice-free areas and it was assumed that slopes would be detected between on the west and east sides of Ongul Island due to the difference in uplift rate. All leveling was conducted in conformity with the first-order leveling specification used in Japan by GSI.

JARE-20 (1979) and JARE-23 (1982) established the leveling route and conducted leveling on East Ongul Island (8.2 km). The first resurvey of benchmarks on East Ongul Island was made by JARE-32 (1991) and JARE-33 (1992); nine benchmarks were resurveyed including the benchmark at the tide observation station. JARE-43 (2002) subsequently resurveyed all benchmarks using a digital level.

Post-glacial rebound is assumed to be ongoing on East Ongul Island, and observations were conducted three times there. However, any change great enough to prove post-glacial rebound has not yet been observed.

JARE-46 (2004) extended the leveling route up to West Ongul Island to improve the detection of slope changes between both islands due to post-glacial rebound. JARE-47 (2005) surveyed all newly built leveling routes on West Ongul Island (6.5 km) and resurveyed the leveling routes on East Ongul Island (6.3 km), and added a leveling point to the IGS point "SYOG" (Fig. 6).

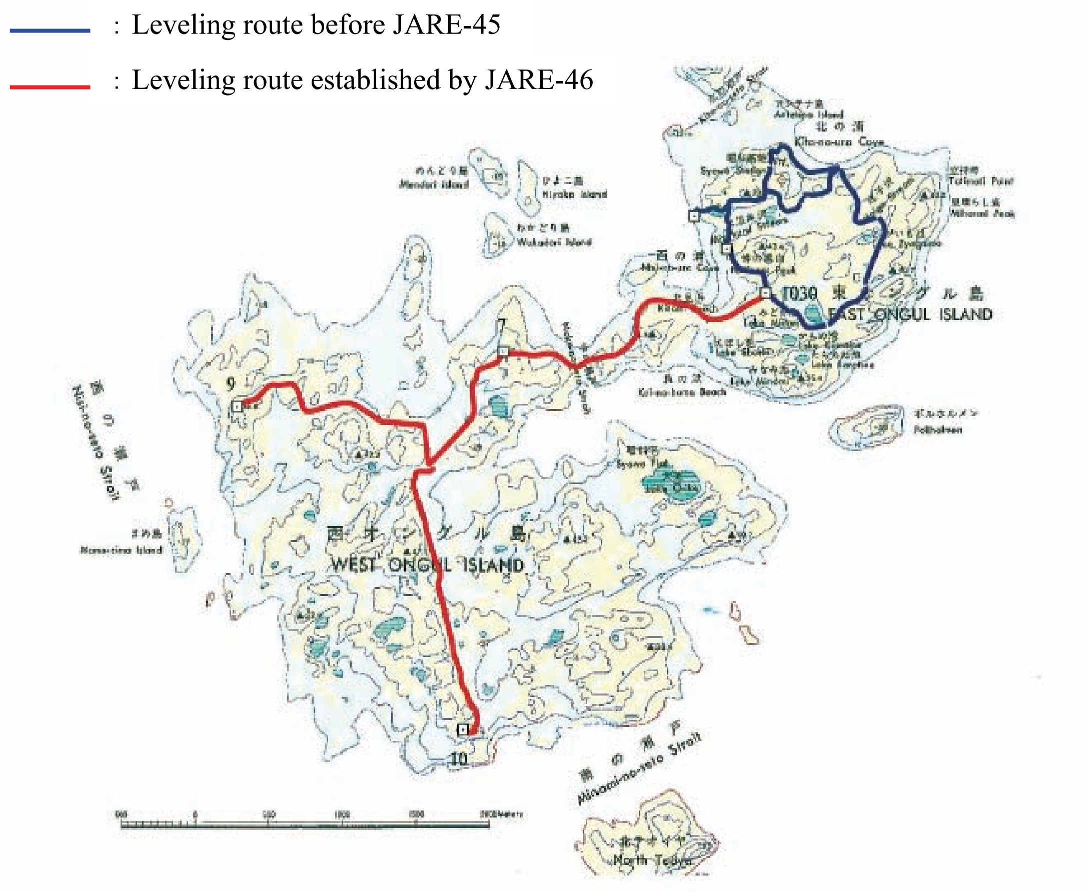

Fig. 6 Map of leveling routes on East and West Ongul Islands

(5) Continuous GPS observation

In the fourth Five-Year Plan (FY 1990–1995), continuous GPS observation was planned. In accordance with this Five-Year Plan, JARE-33 (1991) started participating in the SCAR Campaign observations. JARE-36 (1994) set up a IGS station "SYOG" inside Syowa Station, from which observation data is transmitted to Japan daily (Figs. 7 and Photo 10).

Data from continuous GPS observation was analyzed together with that from other observation stations in the Antarctic region in 1997. Results of analysis were used to calculate coordinates and velocity vectors to estimate the movement of the Antarctic plate (Fig. 8).

The continuous GPS observation station set up in Syowa Station was registered with IGS on May 16, 1999. It is the fifth station of this kind in Antarctica.

There are not so many IGS stations in the southern hemisphere. In particular, because there are few observation stations on the east coast of Antarctica, the continuous GPS observation station in Syowa Station plays an important role in the IGS network.

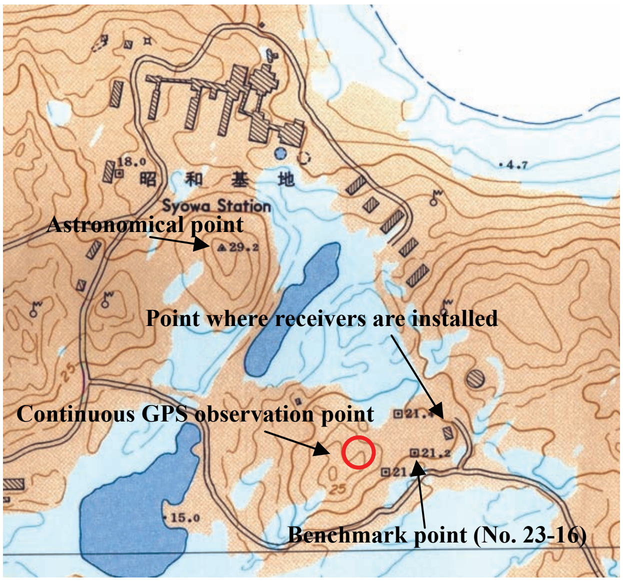

Fig. 7 Location of the continuous GPS observation point

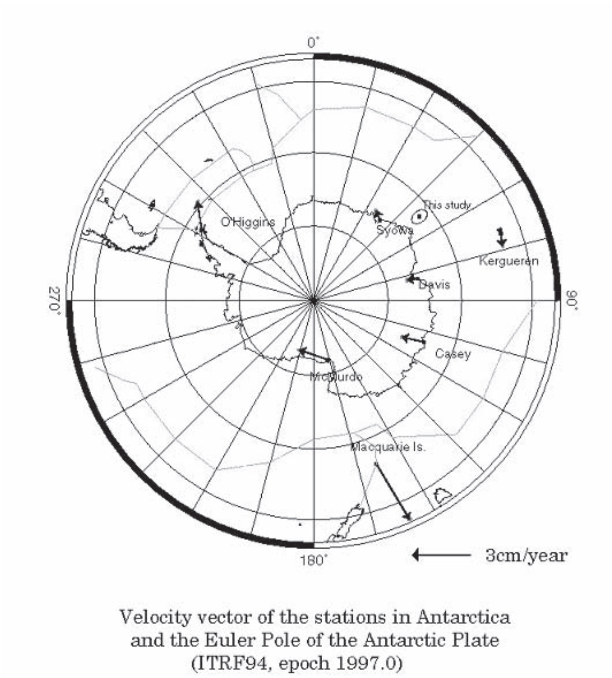

Fig. 8 Velocity vector of the GPS stations in Antarctica and the Euler Pole of the Antarctica plate (Yamada, 1998)

Photo 10 Pillar antenna of continuous GPS observation station and other observation facilities of the surrounding area

(6) GPS survey for measuring movements of ice sheet and detecting crustal movements

JARE-37 (1995) started crustal movement surveys by GPS in Langhovde. JARE-38 (1996) set up observation point "S16" on the ice sheet, and JARE-39 (1997) added observation points "S15" and "S17" on the ice sheet to obtain additional data. Movement of the ice sheet around each observation point has been annually observed by GPS survey (Fig. 9). The results of surveys during JARE-38 (or JARE-39) and JARE-47 show that the points "S15" and "S16" are moving west-northwest at 5.0 m per year, and point "S17" is moving west-northwest at 4.7 m per year. GSI schedules to start measuring rates of ice sheet movements by Synthetic Aperture Radar (SAR) Interferometry in 2007. This method enables wide area movements to be detected. These observation points on the ice sheet will be used for evaluating accuracy.

JARE-41 (1999) established an automatic continuous GPS observation station "LANG" at Yukidori Zawa in Langhovde (Fig. 10 and Photo 11) in order to detect post-glacial rebound. The station is located in an ice-free area and has solar batteries and a wind power generator to supply electricity for GPS observation. This continuous GPS observation station is the first unattended one in the coastal area near Syowa Station, and continuous observation has been conducted since the station was built. Because the observation data is accumulated in a compact memory flash card and processed offline, the recorded data card is picked up once a year in the summer period and brought back to Japan. The observed data is analyzed together with IGS "SYOG" and other IGS points.

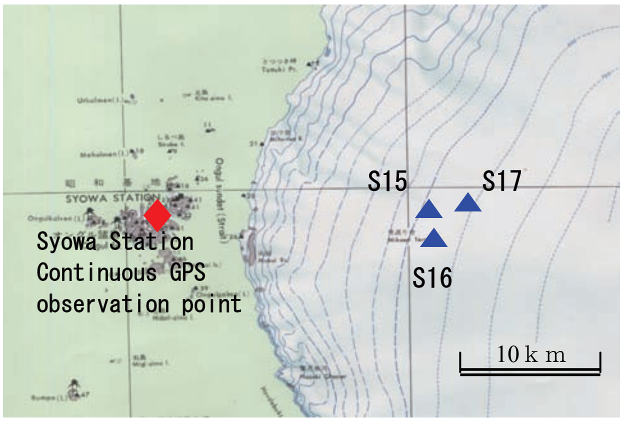

Fig. 9 Syowa Station and observation points around S16

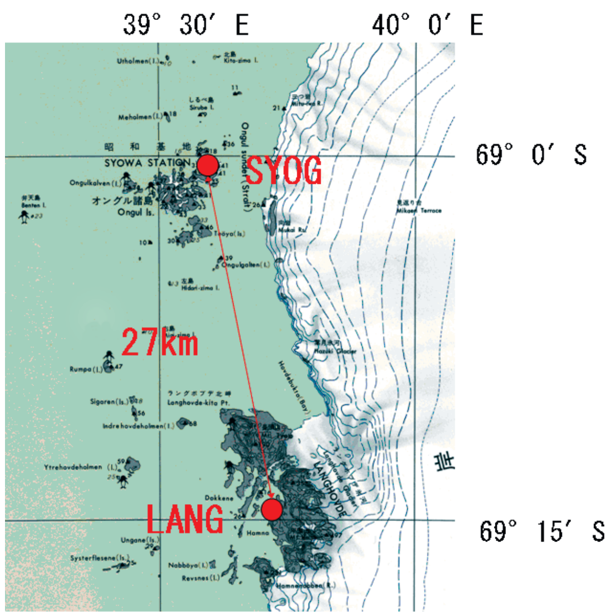

Fig. 10 Location map of continuous GPS observation stations, "SYOG" and "LANG"

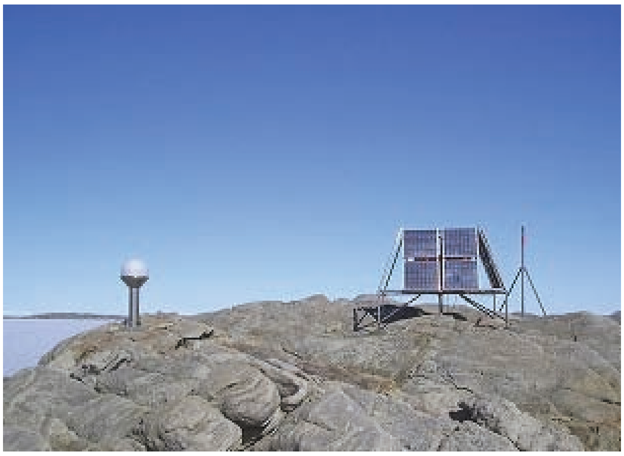

Photo 11 Automatic continuous GPS observation station with solar battery panels at Langhovde

(7) VLBI observation

JARE started regular VLBI observation at Syowa Station in 1998. There is another VLBI observation station in the Antarctic Peninsula (O'Higgins Station). Since 1992, observations have been conducted by O'Higgins Station and most VLBI observation stations in the southern hemisphere, which are currently referred to as OHIG sessions. Syowa Station started to participate in the OHIG session in 1999. This is the first observation using the baseline between Syowa and O'Higgins in Antarctica. Figure 11 shows the distribution of VLBI stations in the southern hemisphere.

VLBI observation at Syowa Station is conducted using the multipurpose antenna installed inside the station. This antenna is parabolic one (11 m in diameter) and used for receiving signals from aurora observation satellites and earth observation satellites (Photo 12).

VLBI observation at Syowa Station initially started as a research observation program of NIPR (currently replaced by the monitoring observation program of NIPR). However, because NIPR did not have any experts on VLBI, GSI dispatched an expert to support the startup of VLBI observation during JARE-40 (1998–2000).

Data obtained at Syowa Station is brought back to Japan once a year, and GSI and NIPR jointly perform the data conversion, correlation processing, and baseline analysis.

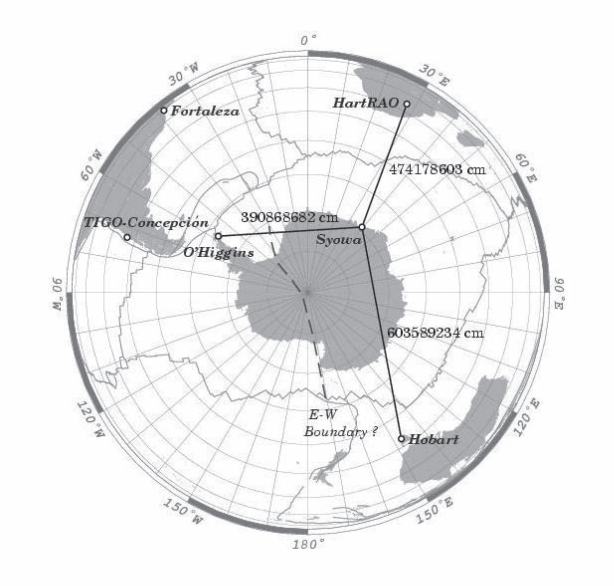

Fig. 11 Distribution map of VLBI observation stations in the southern hemisphere (The epoch time of baseline length is November 8, 1999.)

Photo 12 Multipurpose antenna at Syowa Station
(In the redome at the back, the GPS continuous observation station is at the forefront.)

(8) Aerial photography

Between JARE-17 (1975) and JARE-24 (1982), GSI conducted principal and supplementary projects of aerial photography in the area between 37°E and 45°E in accordance with the plan of 1:25,000 topographic mapping. Thus, the coastal and ice-free areas necessary to map the topography beyond 37°E were successfully covered. Photography was discontinued at that stage, and JARE-24 (1982) changed the target area for aerial photography to the Sϕr Rondane Mountains about 600 km west-southwest of Syowa Station.

A Pilatus Porter PC-6 was deployed on JARE-21 (1979). This plane can cover a longer distance compared to the Cessna, making it possible to take aerial photographs of distant areas that could not previously be covered. In addition, its ability to climb up to 7,000 m made it possible to take aerial photographs of a smaller scale (Photo 13). At the same time, JARE-22 (1980) changed the aerial camera from the Wild RC-9 to the more user-friendly Wild RC-10, successfully increasing efficiency.

In order to ensure that every area was covered by aerial photography, a film-developing machine was transported to Syowa Station, and developing and printing of the photographs was carried out at the site. Color films were processed after being brought back to Japan because processing equipment was not available at the site.

Since Asuka Camp (now Asuka Station) was settled on Sor Rondane Mountains, JARE-28 and JARE-29 conducted aerial photography covering that area. On and after JARE-32 (1990), when filming of the Sor Rondane Mountains was almost finished, color aerial photographs of the Ongul Island area, Langhovde area, and Skarvsnes area started to be taken in order to produce color aerial photograph maps.

Along with the aerial photography, pre-marking and post-marking were also carried out (Photo 14).

Photo 13 Pilatus Porter (left) and Cessna (right) at Syowa Station. Far left is the observation ship *Shirase*.

Photo 14 Three-blade photogrammetric target painted in white

(9) Mapping

Maps of Antarctica were prepared by, in order: aerial photography, astronomical survey for determination of position and direction, setting of control points necessary for mapping, pricking, aerial triangulation, mapping, and editing.

The first map of Antarctica covered East Ongul Island where Syowa Station is located. It was produced at a scale of 1:5,000 using a 2nd class high-precision plotter using nine control points (including astronomical points) set up by the first JARE in 1957 and aerial photographs (Fig. 12).

Because ice-free areas are not covered with plants, it was basically easy to draw contour lines. However, considerable effort was needed to plot the snow covered areas, for which there is no stereoscopic effect due to halation. The ice free exposed area is sometimes very complex terrain created by wind and snow.

In addition, it is not easy to read coastlines precisely because they are covered with snow. Thus, tide cracks are mapped as the shore line in most cases. As for mapping Antarctica, the Antarctic Observation Plans drawn up by the Antarctic Special Committee in March 1967 advocated in its basic policy that topographic survey should cover the fan-shaped area located between 30°E and 45°E. Topography at a scale of 1:25,000 covering Lutzow-Holm Bay, the ice-free areas facing the Prince Olav Coast, and the Yamato Mountains was mapped between 1965 and 1987. A topographic map at a scale of 1:50,000 covering most of the Sor Rondane Mountains was prepared in 1992.

Two topographic maps at a scale of 1:250,000 were published in 1963 to make them compatible with the existing maps prepared by Australia neighboring to the east and Belgium neighboring to the west. The published map was, however, low in precision because of the small number of control points. It was revised in 1990 compiling the 1:25,000 scale maps which had been produced to cover most of the coastal area by 1986 (Fig.13).

The topographic map produced in 1970 at a scale of 1:1,000,000 was the only map that covered the fan-shaped area located between 30°E and 45°E. It was based on a route map that contains various geographic features including observed positions, terrain, and terrestrial magnetism obtained along the previous expedition routes, and was not based on "Standard Symbols for Use on Maps of Antarctica." In 1997, a map covering Eastern Queen Maud Land was drawn in conformity with "Standard Symbols for Use on Maps of Antarctica" and "International Map of the World on the Million Scale." It was published in 1998 with the name changed to Eastern Dronning Maud Land in addition to partially revised contents (Fig. 14).

Between FY 1981 and FY 1988, GSI produced a total of eight satellite image maps at a scale of 1:250,000 using image data of the Multi Spectral Scanners (MSS, resolution 80 m) taken by Landsat-1 and Landsat-2, in the ice-free areas and Sor Rondane Mountains. Figure 15 is one of the satellite image maps created in 1988. In response to the increased demand for new and more precise satellite image maps to ensure safe expedition operations, GSI published new satellite image maps (27 image maps at a scale of 1:250,000 and a single image map at 1:2,000,000) using color images of the Enhanced Thematic Mapper Plus (ETM+, resolution 30 m) taken by Landsat-7 and SAR images (resolution 50 m) taken by RADARSAT (Fig. 16 and 17). By using satellite images, it has become possible to produce wide area image maps economically even in Antarctica where aerial photography is not an easy job.

When topographic mapping finished in 1993, color photo maps were prepared for the purpose of obtaining detailed knowledge and conducting thorough research on the ice-free areas. Color photo maps at a scale of 1:2,500 and 1:10,000 were successfully produced in Antarctica (Fig. 18).

Basically, these maps prepared by GSI comply with the “Standard Symbols for Use on Maps of Antarctica” approved by SCAR. Geographical names displayed in the maps are those approved by JARE Headquarters based on the drafts prepared by the Antarctic Place-names Committee within NIPR.

Index maps and lists of the prepared maps by GSI are shown in Appendix 2 and Appendix 3.

GSI exchanges these maps with the agencies responsible for preparation of Antarctic maps in foreign countries in compliance with the recommendation from SCAR’s Working Group on Geodesy and Geographic Information (now Standing Scientific Group on Geosciences and Standing Committee on Antarctic Geographic Information).

Fig. 12 Topographic map (Scale 1:5,000)
Four colors, duodecimo, printed in 1993

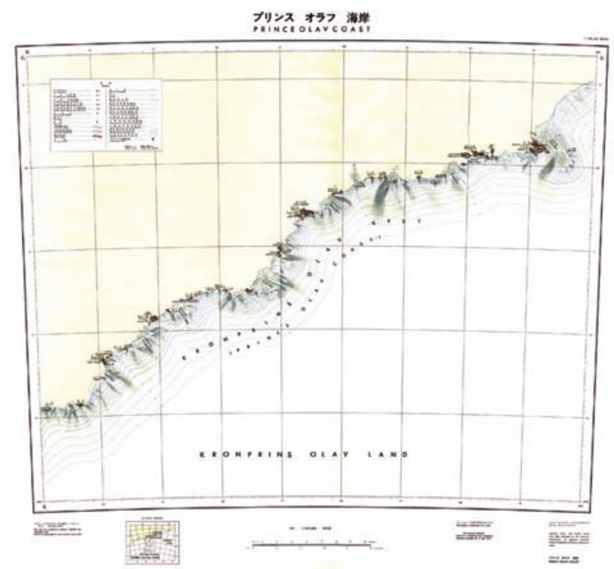

Fig. 13 Topographic map (Scale 1:250,000)
Four colors, duodecimo, printed in 1990

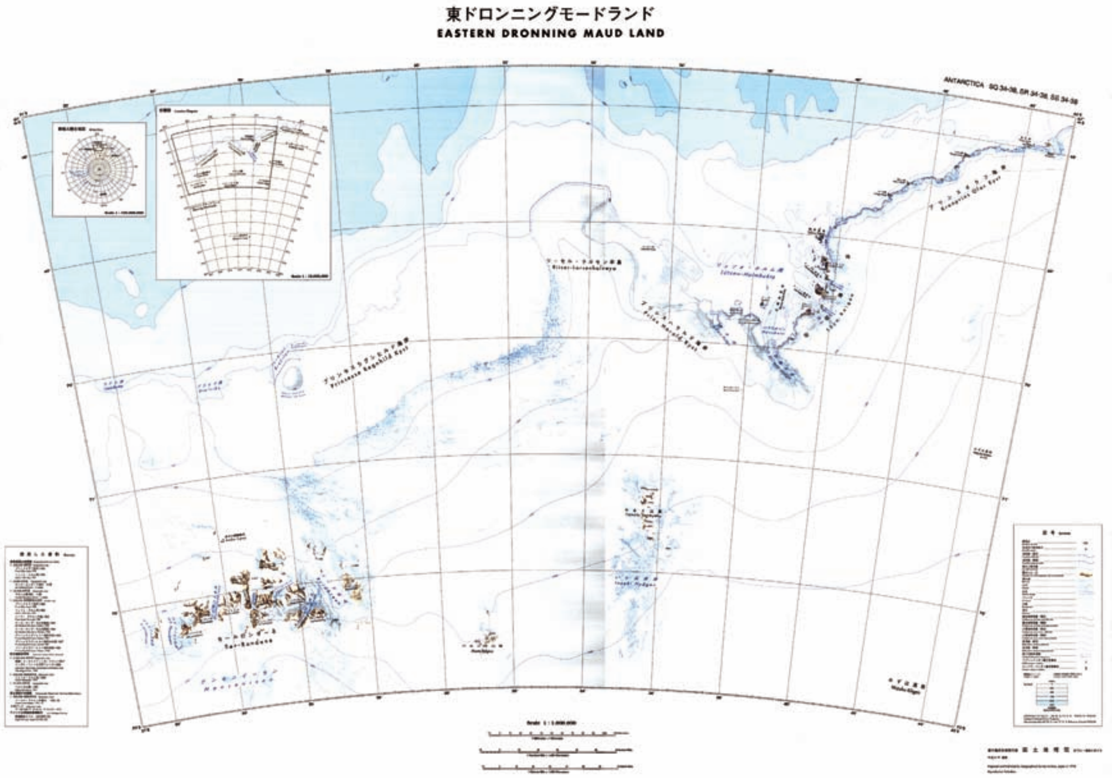

Fig. 14 Topographic map (Scale 1:1,000,000)
Seven colors, Lambert conformal conic projection, printed in 1998

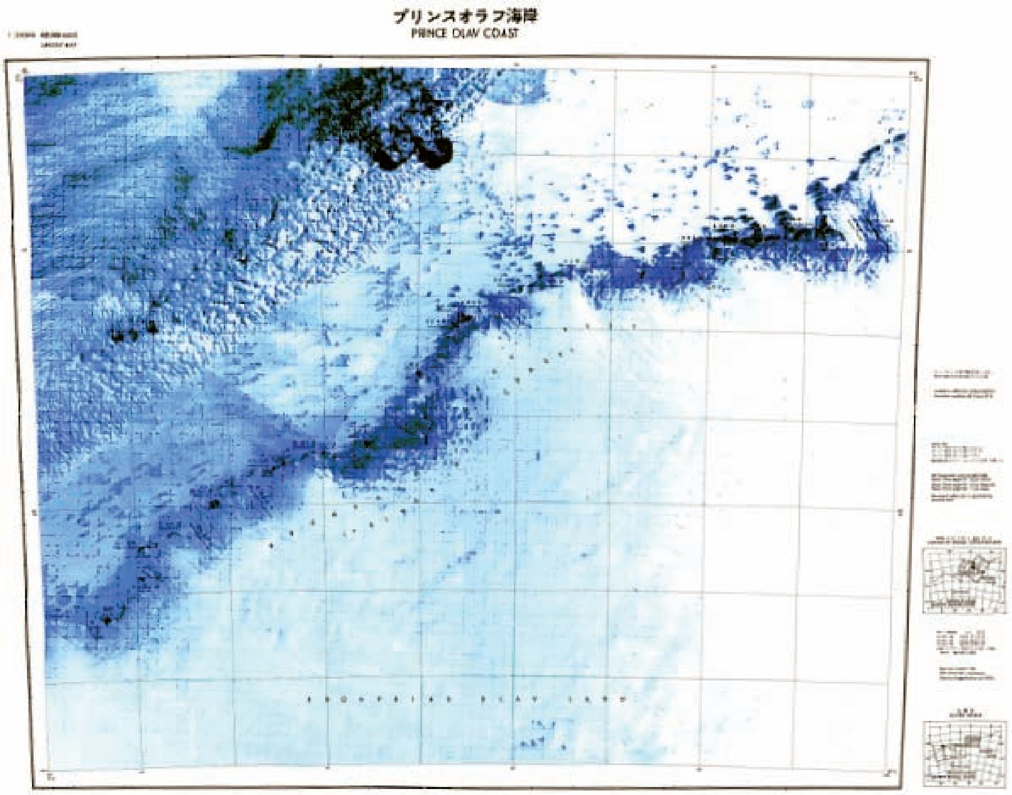

Fig. 15 Satellite image map from Landsat-1 and Landsat-2 (1998)

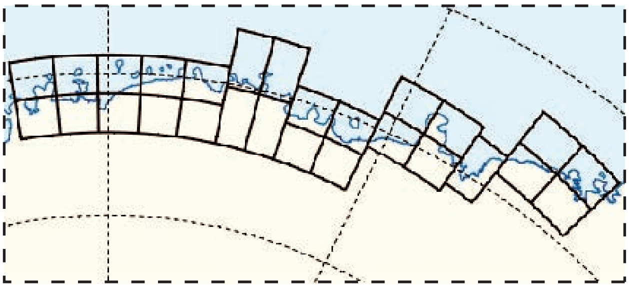

Fig. 16 Coverage of satellite image map from Landsat-7 and RADARSAT (2005)

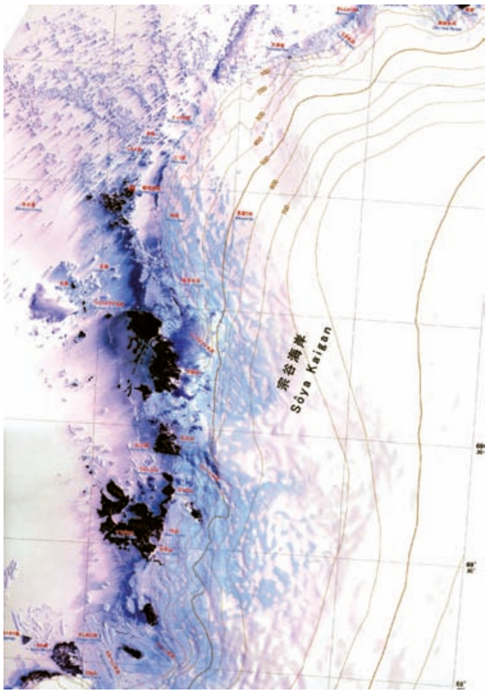

Fig. 17 Part of a satellite image map prepared at a scale of 1:250,000 (2005)

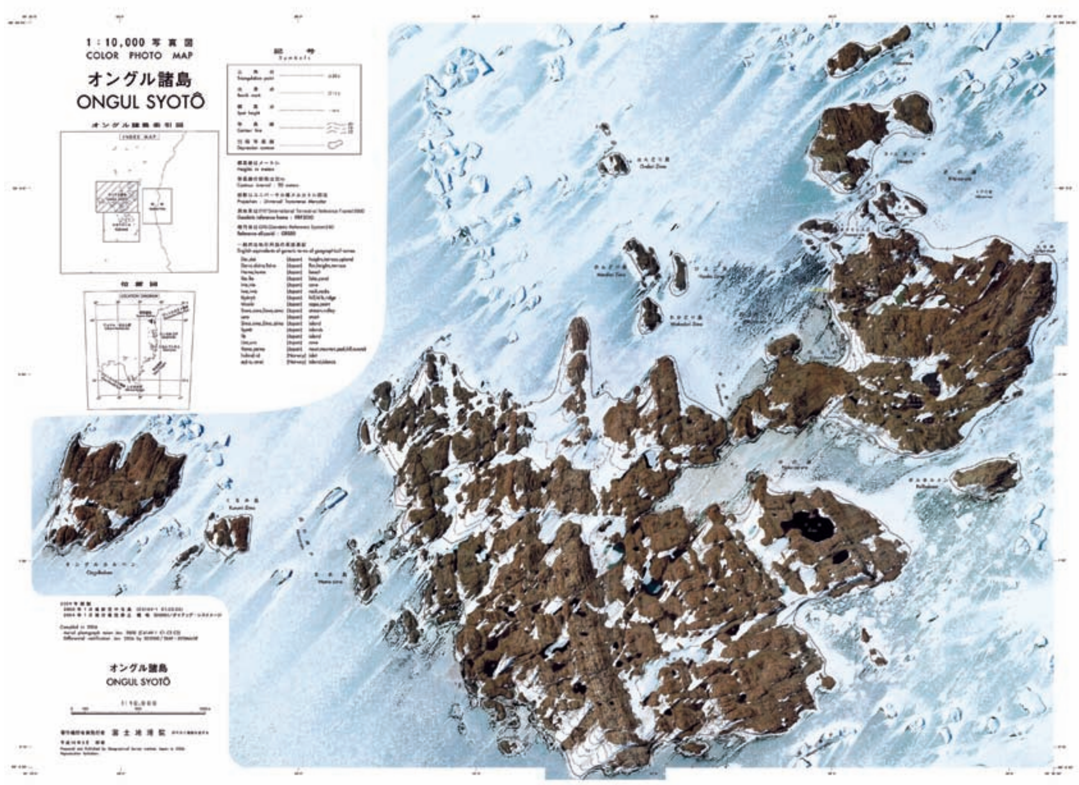

Fig. 18 Color photo map (Scale 1:10,000) of Ongul Island

3.4 Outline of annual expedition

The dispatched personnel, type of survey and remarkable topics on JARE are depicted by year in Appendix 4.

4. Organization of GSI

GSI has participated in every JARE since the beginning. GSI has promoted JARE as one of the activities without establishing a special section within the organization.

Because GSI is mainly engaged in control point surveys, geophysical surveys, aerial surveys, and mapping, JARE is well suited to the Geodetic Department and Topographic Department, both of which participated in JARE with their own business plans.

In the initial stage, GSI underwent several organizational changes, but the system to support JARE remained unchanged. The Geodetic Department took charge of the control point and geophysical surveys, while the Topographic Department was responsible for aerial surveys and mapping. Because of this, GSI had two windows for JARE, making it difficult for people to decide which department they should contact. The Planning Section (now the Planning Department) was established in 1967, and was placed in charge of planning and coordinating JARE operations of GSI. In 1976, the Survey Guidance Division of the Planning Department was established and took over this task. Then, in 1995, the International Affairs Office of the Planning Department was established and took over the task.

As of March 2007, the International Affairs Office of the Planning Department is in charge of planning and coordinating JARE operations of GSI. As in the past, the Geodetic Department and Topographic Department are responsible for observation business, whereas the Geoinformation Department manages maps of Antarctica sent to GSI from abroad. The Head of the Basic Information Division of Topographic Department is a member of the Antarctic Place-names Committee under NIPR.

Maps prepared by GSI are distributed to JARE and researchers through NIPR.

In compliance with the recommendations from SCAR, GSI exchanges maps with agencies in charge of Antarctic maps in foreign countries. GSI organizes the results of JARE such as geodetic surveys as technical reports, and publishes the results of analysis as needed.

The organization and activities on JARE of GSI as of March 2007 are shown in Fig. 19. Appendix 5 illustrates the system of JARE.

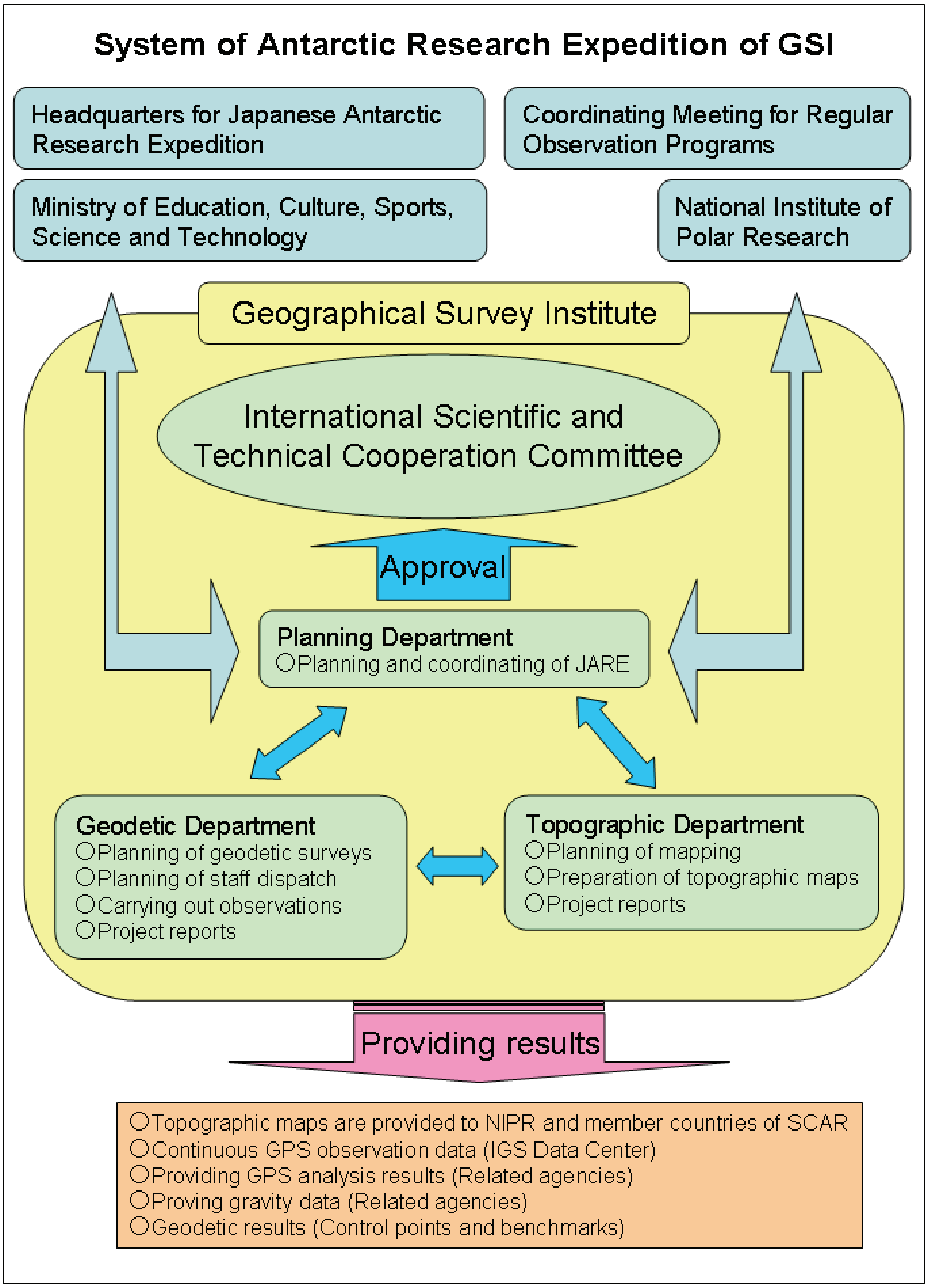

Fig. 19 Organizational chart for Antarctic expeditions by GSI

5. Conclusion

Fifty years have passed since GSI first participated in the JARE. During this period, some independent observation results have been reported in English, but no comprehensive English report has been published. We decided to publish this report to mark the 50th anniversary. Although each project is not covered in detail, we believe that this report will provide useful information for future Antarctic research expeditions.

This is the condensed edition of the corresponding report carried in the Journal of the Geographical Survey Institute, No. 111. Although the original Japanese edition lists numerous references, we have listed here mainly English references and only the essential Japanese ones.

Acknowledgements

We are grateful to the National Institute of Polar Research, the Hydrographic and Oceanographic Department of the Japan Coast Guard, the Ministry of Education, Culture, Sports, Science and Technology, and other related organizations, and many individuals who are/were engaged in JARE for their support of GSI activities.

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Acronyms

DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
GSI	Geographical Survey Institute
GPS	Global Positioning System
IAG	International Association of Geodesy
IAGBN	Absolute Gravity Base Station Network
ICSU	International Council for Scientific Union International Council for Science (since 1998)
IGN	International GPS Service International GNSS (Global Navigation Satellite System) Service (since 2005)
IGSN71	International Gravity Standard Network 1971
IGY	International Geophysical Year
IPY	International Polar Year
ITRF	International Terrestrial Reference System
IUGG	International Union of Geodesy and Geophysics
JARE	Japanese Antarctic Research Expedition
JGSN75	Japan Gravity Standard Network 1975
NIPR	National Institute of Polar Research
NNSS	Navy Navigation Satellite System
SAR	Synthetic Aperture Radar
SCAR	Special Committee on Antarctic Research Scientific Committee on Antarctic Research (since 1961)
VLBI	Very Long Baseline Interferometry