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SYOWA STATION; OBSERVATORY FOR GLOBAL GEODESY IN ANTARCTICA (A REVIEW)

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Abstract: Through the five-year (1992-1997) earth science programs "Synthetic observations and monitoring of dynamic behavior of the Earth's crust", we are planning to make parallel geodetic observations at Syowa Station to study global geodynamics. This report summarizes the present status of VLBI (Very Long Baseline Interferometer) measurements, the GPS (Global Positioning System) international campaign, DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite) beacon installation, PRARE (Precise Range And Range-rate Equipment) tracking, absolute gravity measurements, superconducting gravimeter observations, geomagnetic variometer observation and ocean tide observations.

1. Introduction

Formation of a network for global geodesy using space technology is an important key to the study of global geodynamics such as earth rotation variation and plate tectonic motion. However, it is logistically difficult to install a large antenna for VLBI measurements in Antarctica.

After construction of the 11 m multi-purpose S and X band antenna at Syowa Station (hereafter referred to only as the 11 m antenna) in 1989, Japanese Antarctic Research Expeditions (JAREs) have concentrated on upgrading Syowa Station (Fig. 1) as an observatory for global geodesy through the five-year (1992-1997) earth science programs, "Synthetic observations and monitoring of dynamic behavior of the Earth's crust".

This report briefly summarizes the status of our observations and plans.

2. VLBI Measurements

Figure 2 illustrates the global VLBI network (open circle with a dot). There are few observatories in the Southern Hemisphere including Hartebeesthoek, Santiago, and Tidbinbilla. The 11 m antenna at Syowa Station can be used as the front-end system for the VLBI measurements; the antenna characteristics are summarized in EJIRI *et al*. (1993). Through the test measurements among Kashima, Tidbinbilla and Syowa Station in January 1990 (JARE-30-31), VLBI coordinates of the 11 m antenna reference point were obtained to an accuracy of 8-9 cm (KURIHARA *et al*., 1993) in the VLBI coordinate system. This experiment promises us to

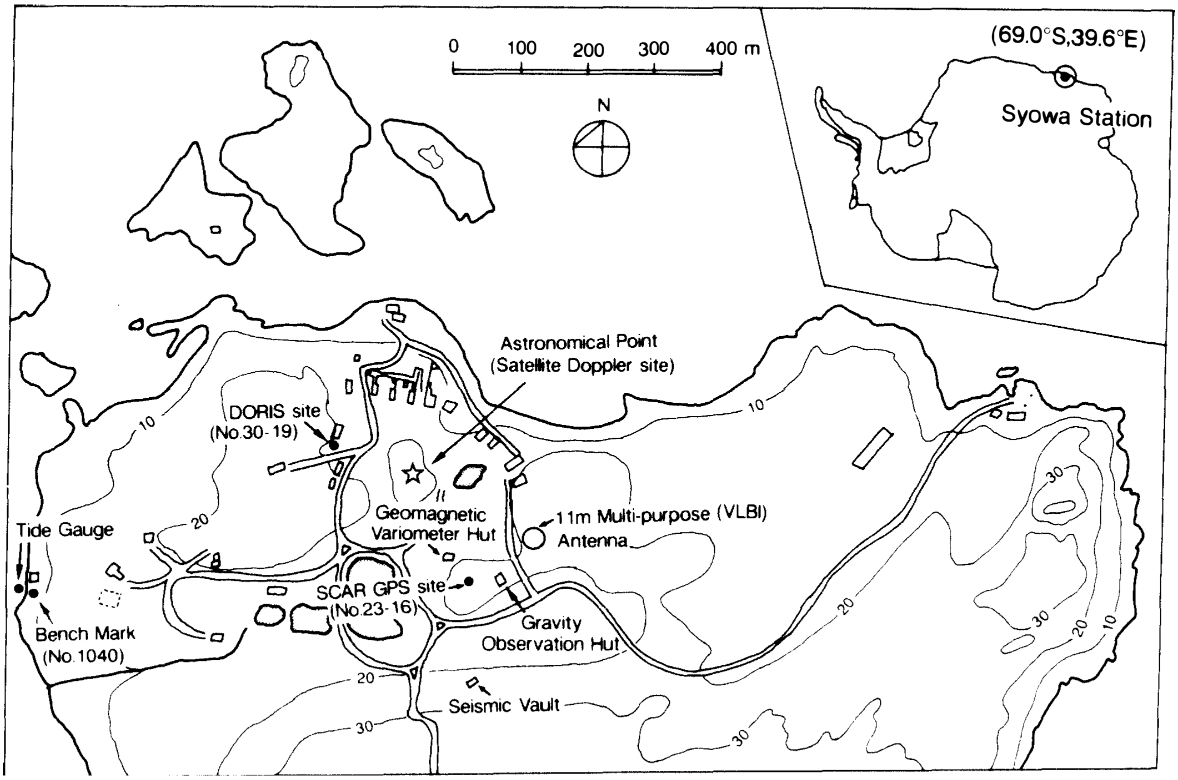

Fig. 1. Observation facilities and geodetic markers at Syowa Station. Shaded areas indicate ponds. Contour interval is 10 m.

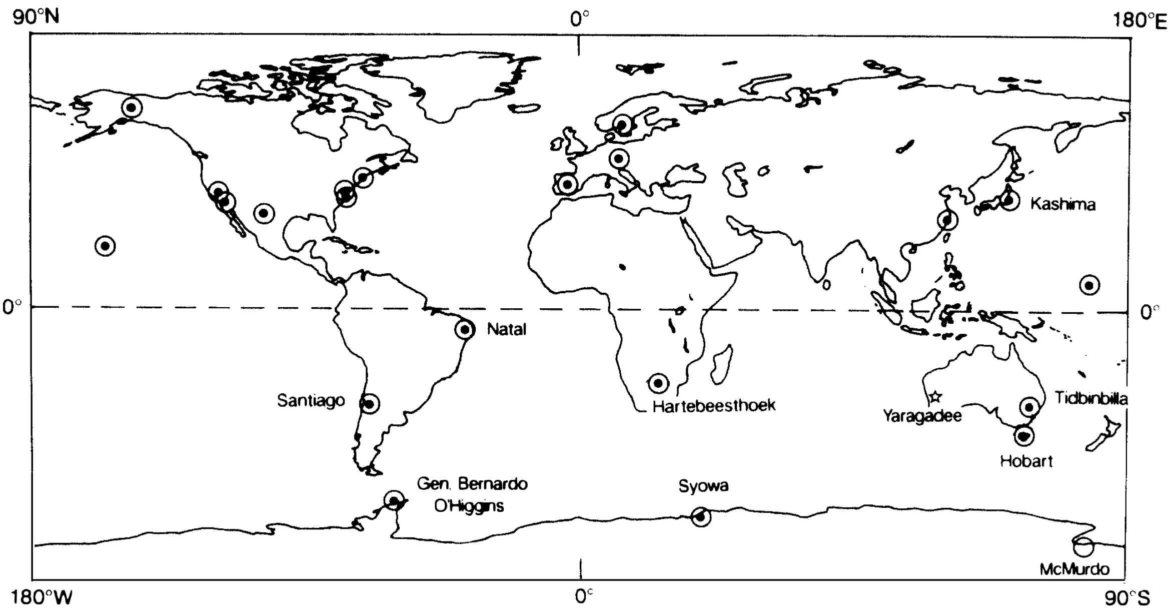

Fig. 2. A summary of global VLBI network (open circle with a dot). McMurdo Station (open circle) is in a planning stage for installation. A star indicates Yaragadee SLR station.

continue regular/routine VLBI measurements for studying the change of earth rotation parameters and plate tectonic motions, although installation of the long-term operating back-end system has not been authorized yet.

Recently Gen. Bernardo O'Higgins Station (hereafter referred to as O'Higgins) joined in the VLBI network with successful fringe detection with the Santiago antenna (CAMPBELL *et al.*, 1993). Installation of a 10 m antenna is also planned at McMurdo Station in the 1994-1995 austral summer season (T. CLARK, personal communication, 1993).

For maintenance of the coordinate values of the 11 m antenna reference point in the International Terrestrial Reference Frame (ITRF), a local geodetic tie to the ground marker is required. Without this tie, the benefits of VLBI-determined coordinates cannot be utilized for local network adjustment nor for monitoring sea level change which may be related to global climate change or uplift of the Antarctic coastal area after deglaciation.

However, for the 11 m antenna at Syowa Station, there was no chance of the above local tie because the radome had to be constructed as soon as possible to protect the antenna from blizzards within a limited operational schedule. We therefore tried GPS relative positioning between the GPS antenna, which was attached to the periphery of the 11 m antenna dish, and the ground GPS site at the geodetic control point (No. 23-16, see Fig. 1), by pointing the dish toward the zenith and by rotating it around the azimuth axis every 30°-60° interval during JARE-33 (measurements were sporadically made during February-December 1992). Together with the design values of the reference point beneath the center of the dish pointing to the zenith, the GPS relative positioning data will give us the relative location of the reference point in the local geodetic system. Preliminary analysis shows 30 cm accuracy of the local tie (KANAO and SHIBUYA, in preparation) to the SCAR GPS site described in Section 3.

3. GPS Campaign

Figure 3 (open circle with a dot) illustrates the Antarctic stations which participated in the 1992 GPS campaign coordinated by the SCAR WGGGI (SCAR XXII, Working Group on Geodesy and Geographic Information held at Bariloche, Argentina, 8-12 June 1992). Outside Antarctica, three VLBI (Tidbinbilla, Hobart, Hartebeesthoek) stations and one SLR (Satellite Laser Ranging) station (Yaragadee ; star in Fig. 2) participated in the campaign. At Syowa Station, the GPS antenna site was chosen to coincide with geodetic control marker No. 23-16 near the gravity observation hut (see Fig. 1) ; the same marker used for the local geodetic tie of the 11 m antenna reference point. A permanent pier is to be installed in the very near future at the above site where the sky is clear without obstacles above 5° elevation in all directions. Using a 30 m coaxial antenna cable, the received signals can be fed to the GPS receiver placed in an air-conditioned room of the gravity observation hut.

Two international campaigns were conducted until March 1993. Since Syowa Station and Yaragadee (Australia ; star in Fig. 2) are collocated with the VLBI/SLR measurements, East Antarctic branch (from Dumont d'Urville to Syowa) has good

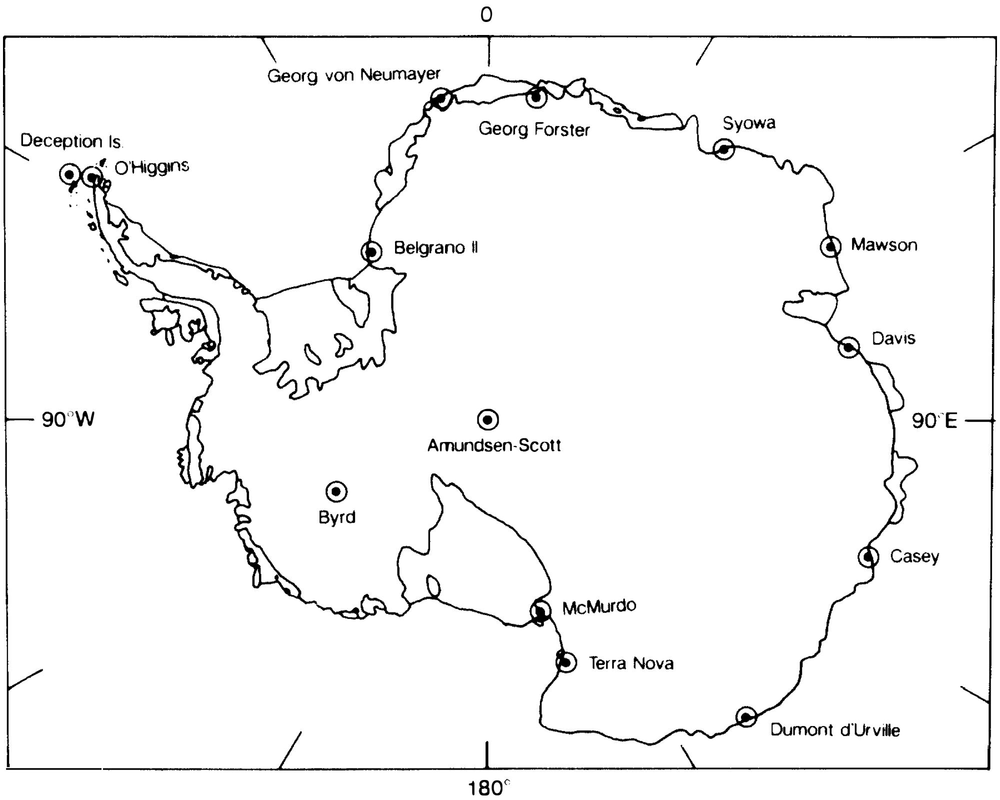

Fig. 3. Antarctic stations which participated in the 1992 SCAR GPS campaign, after B. Murphy (personal communication). Outside Antarctica, three VLBI stations (Hobart, Tidbinbilla, Hartebeesthoek) and one SLR station (Yaragadee) are collocated with the GPS observations (see also Fig. 2).

constraints on both ends for the network solution. The analysis is underway at the University of Canberra using the GAMIT program (KING and BOCK, 1991). The results will be made available around December 1993 (P. MORGAN, personal communication, 1993).

4. DORIS Beacon Installation

DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite) is a space system for orbit determination of SPOT-series and Topex/Poseidon (launched September 21, 1992) satellites and for ground positioning (*e.g.*, DORRER, 1990). Figure 4 (solid circle and open circle with a dot) illustrates the global distribution of the ground beacons (INSTITUT GEOGRAPHIQUE NATIONAL, 1992) for transmitting two (401.25 MHz and 2.036 GHz) radio signals.

Based on a protocol between the National Institute of Polar Research (NIPR) and the Institut Geographique National (IGN, France), the installation at Syowa Station was done at the end of January 1993 (JARE-34). The recovered doppler data and meteorological data at the master station in Toulouse (Centre National D'Etudes Spatiales; CNES) *via* the SPOT-2 and Topex/Poseidon satellites showed that the beacon at Syowa Station was functioning correctly as of March 15, 1993 (M.

LANSMAN, personal communication, 1993).

The accuracy of absolute ground positioning by DORIS is considered to be better than 0.1 m (CAZENAVE *et al*., 1992). When the local tie of the DORIS ground marker (No. 30-19) to the No. 23-16 marker is accomplished, we will have three collocation coordinates, by VLBI, GPS (traversed from Yaragadee), and DORIS.

Determination of precise satellite orbits will simultaneously result in refined gravity field models in the Southern Indian Ocean area, where tracking data at Kerguelen, Tristan de Cunha, Marion, etc. (open circle with a dot in Fig. 4) must be important for such refinement together with the data at Syowa Station.

5. PRARE Tracking

PRARE (Precise Range And Range-rate Equipment) is a space system for precise orbiting of the ERS-series satellites, *e.g*., REIGBER *et al*. (1988). Different from the DORIS beacon ground station, PRARE ground station is a two-way system for receiving the two satellite signals (2.248 GHz and 8.489 GHz) and transmitting (7.225 GHz) the return data to the satellites.

Though installation of the PRARE ground antenna to Syowa Station was planned in 1992, malfunctioning of the space segment on board ERS-1 resulted in delay of the installation schedule.

Since ERS-series satellites have ice-mode radar altimeters, PRARE tracked precise orbits result in precise measurements of ice sheet configuration (0.1-0.2 m accuracy is expected).

Interferometric SAR (Synthetic Aperture Radar) imagery techniques (*e.g*.,

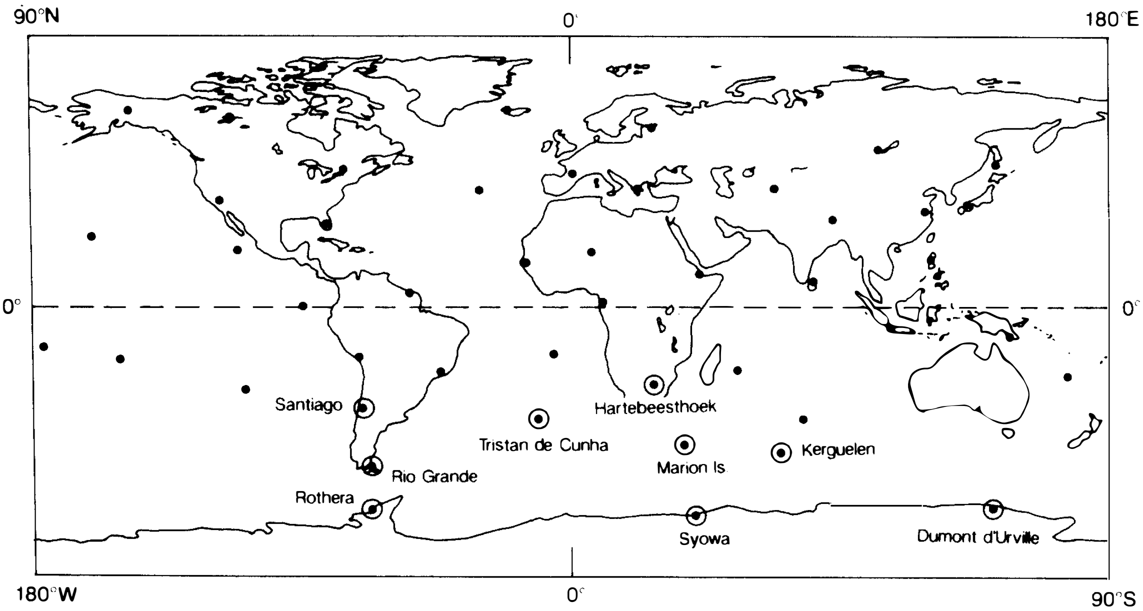

Fig. 4. Global DORIS beacon network for Topex/Poseidon and SPOT-series satellites (solid circle and open circle with a dot). Among the network stations, open circle with a dot indicates important station for the improvement of the geopotential model in the Antarctic Ocean area.

ZEBKER and GOLDSTEIN, 1986) may further delineate fine-scale surface features using PRARE tracked orbits.

Installation at Syowa Station will be rescheduled to the 1995–96 year (JARE-37) program.

6. Absolute Gravity Measurements

In order to monitor the global change of the Earth's gravity field, establishment of the IAGBN (International Absolute Gravity Basestation Network) is proposed (BOEDECKER and FRITZER, 1986). Because of geologically stable and tectonically inactive circumstances, Syowa Station is nominated as one of the category "A" stations (solid circle and open circle with a dot in Fig. 5) along with McMurdo Station in Antarctica.

The gravity observation hut at Syowa Station (Fig. 1) was constructed during the 1990–91 field season (JARE-32), and the first measurements were carried out by JARE-33 (January–February 1992) using the GSI (Geographical Survey Institute, Japan) apparatus which employs the rise and fall method: the results are reported by FUJIWARA and WATANABE (1992: Abstract is available in this volume). Repeated measurements using the NAOM (National Astronomical Observatory of Mizusawa) apparatus which employ the free fall method were made by JARE-34 during January–February 1993. Comparison with the previous results may establish the absolute gravity value within an accuracy of 50–70 μGal (1 μGal$=10^{-8}$ m/s^2).

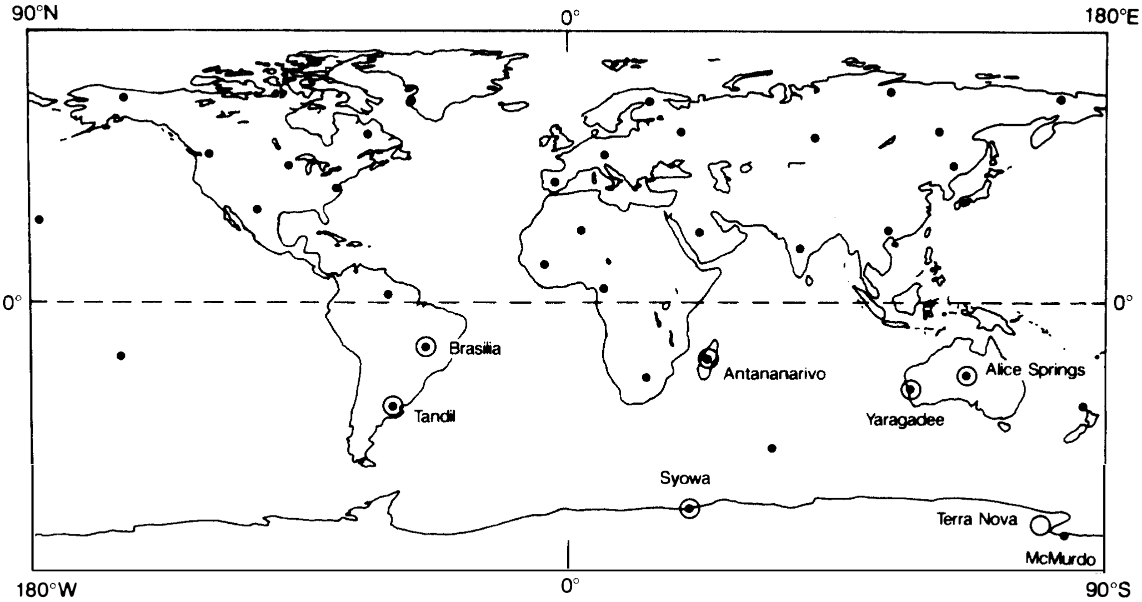

Fig. 5. IAGBN "A" network (solid circle and open circle with a dot) in the world. Open circle with a dot indicates "A" station in the Southern Hemisphere where absolute gravity apparatus was already located. Though Terra Nova Station (open circle) is not included in the "A" stations, the absolute gravity measurements were made by CERUTTI et al. (1992).

Though measurements at McMurdo Station have not been made yet, Terra Nova Station was occupied by the IMGC (Istituto di Metrologia G. Colonnetti, Italy) apparatus using the symmetrical rise and fall method (CERUTTI *et al.*, 1992). Other "A" stations in the Southern Hemisphere which were already occupied by the absolute gravity apparatus are given by the open circle with a dot in Fig. 5 (B. MURPHY, personal communication, 1992).

7. Superconducting Gravimeter Observation

Solid circles in Fig. 6 give a summary of earth tide stations registered in the ICET (International Centre for Earth Tides) data bank (MELCHIOR *et al.*, 1984). In spite of a long history of Antarctic research, there are few observations on solid earth tides on the Antarctic continent. The exceptions are the continuous observations at the South Pole to study the long-period (Sa, Ssa, Mf, Mm, etc.) tides (*e.g.*, SLICHTER *et al.* 1979; RYDELEK and KNOPOFF, 1982) and the observations at Asuka and Syowa Stations to study the diurnal and semidiurnal δ factors (*e.g.*, SHIBUYA and OGAWA, 1993). The 10% discrepancy between the observed M2 δ factor and the theoretical prediction indicates that tidal gravity observations have to be made at many stations on the Antarctic coastline to study the effect of ocean tides in detail. Furthermore, recent progress in the study of the Earth's deep interior (SEDI) has shown the necessity of global distribution of highly sensitive superconducting gravimeters (open circle with a dot in Fig. 6) to detect the Earth's core motion. Installation and start of long-term observation at Syowa Station are being done during JARE-34 program (SATO *et al.*, 1993 in this volume). Together with the observed gravity data at Fairbanks, we may detect the Slichter mode (SLICHTER,

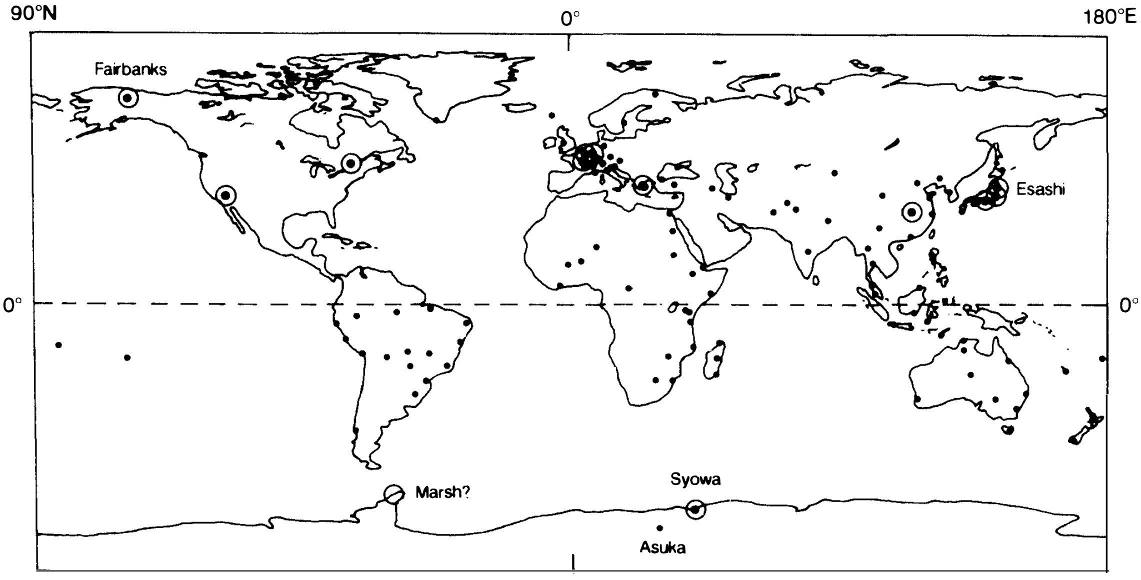

Fig. 6. A summary of the global superconducting gravimeter network (open circle with a dot). Solid circles indicate earth tide stations registered in the ICET data bank (MELCHIOR et al., 1984).

1961).

8. Geomagnetic Variometer Observations

Long-term monitoring of three geomagnetic components gives fundamental data for the study of secular variation of the Earth's geomagnetic field. More than 25 years' continuous geomagnetic variometer observations at Syowa Station contribute to the derivation of the IGRF (International Geomagnetic Reference Field) model (*e.g.*, IAGA Division Working Group I, 1992). In the Antarctic region, the induced effect of external fields which are correlated with solar activity may have an important role in the estimation of the low-order spherical harmonic coefficients of the internal origin. For example, Fig. 7 (upper part) illustrates secular change of the residual geomagnetic total intensity at Syowa Station (the observed value minus IGRF-model value) on geomagnetically quiet days when absolute (variometer) measurements were conducted. We notice good correlation of the residual intensity variation with the sunspot number variation (lower part) until 1980 even for the data on geomagnetically quiet days.

There are unknown processes related to the geomagnetic secular variation over a period of several decades, and geomagnetic variometer observations should be

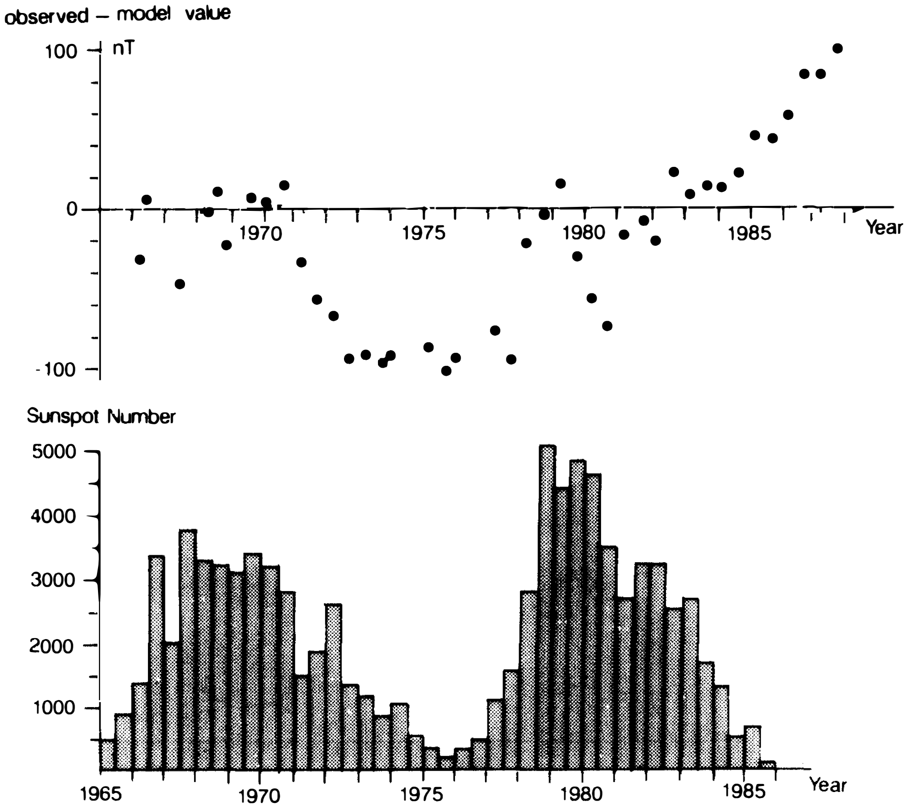

Fig. 7. Variation of residual geomagnetic total intensity (observed minus IGRF model value in the upper part) is correlated with solar activity (sunspot numbers in the lower part) at Syowa Station.

continued as long as possible at the same place. However, continuation of the geomagnetic observations at the Antarctic stations is a difficult task. This difficulty is reflected in the decrease in number of geomagnetic observatories as illustrated in Fig. 8. In the IGY (International Geophysical Year), stations denoted by both solid circle and open circle with a dot reported geomagnetic variometer observation data, but in 1985 only ten stations (open circle with a dot) remain registered in World Data Center C2 for Geomagnetism. Because recent progress in the study of core and deep-mantle geodynamics has made the role of the Antarctic observatories more important than ever, high quality data have to be supplied continuously from Syowa Station.

9. Ocean Tide Observations

Recent concern over global warming has motivated the long-term monitoring of sea level change by a global network, under the international GLOSS (Global Sea-Level Observing System) project (INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION, 1992). Ocean tide observations at Syowa Station have been conducted for more than 30 years by the Japan Hydrographic Department of the Maritime Safety

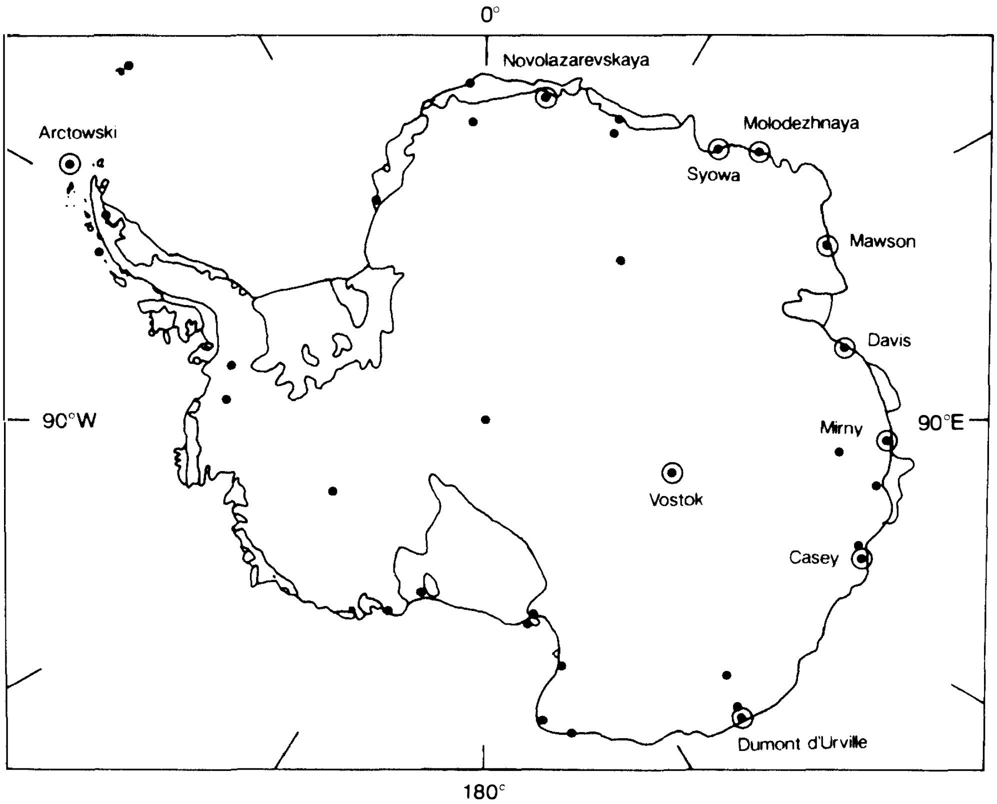

Fig. 8. Magnetic observatories decreased in number in Antarctica. Solid circle and open circle with a dot indicate stations existed in the IGY. However only ten stations (open circle with a dot) are continuously (until 1985) reporting geomagnetic data to World Data Center C2 for Geomagnetism.

Agency, and Syowa Station is registered as one of the Antarctic GLOSS stations.

Contrary to our prediction ODAMAKI *et al.* (1991) reported on sea level drop of ~0.95 cm/y over the last ten years at Syowa Station. It is, however, necessary to monitor the bench mark (No. 1040, see Fig. 1) level in a geocentric coordinate system to separate the effect of crustal uplift after deglaciation in the Antarctic coastal area. Precise local leveling tie between the SCAR GPS site No. 23-16 and the bench mark No. 1040 was done by the classical leveling method in 1983 (JARE-23; KAMINUMA *et al.*, 1984) and by applying the GPS technique in 1992 (JARE-32).

Superconducting gravimeter observations may also detect a secular drift term related to crustal uplift; then precise information on sea level variations can be extracted.

10. Summary

Because of developments in space technology and new technology on gravity measurements, geodetic observations play an essential role in the study of global geodynamics: earth rotation variations, plate tectonic motions, sea level change, etc. The monitoring, however, has to be done by a global network including Antarctic stations. Syowa Station will continue to be one of the key stations in the Southern Hemisphere through the parallel observations described above.

Acknowledgments

The efforts to upgrade Syowa Station as an innovative geodesy observatory in a global network depend on the efforts of the scientists and logistic members who participate in or support the Japanese Antarctic Research Expeditions.

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