Polar Geosci., **18**, 130–161, 2005

Geodesy reference points within Syowa Station, Antarctica, and their local geodetic ties

Kazuo Shibuya[1]*, Koichiro Doi[1], Yoshihiro Fukuzaki[2] and Masao Iwata[2]

[1]*National Institute of Polar Research, Kaga 1-chome, Itabashi-ku, Tokyo 173-8515*
[2]*Geographical Survey Institute, Kitasato, Tsukuba 305-0811*
**Corresponding author. E-mail: shibuya@nipr.ac.jp*

(Received May 16, 2005; Accepted August 3, 2005)

Abstract: In order to study geodynamics in relation to atmospheric, oceanographic and glaciological interactions on a global scale, adequate distribution of precise geodesy stations over the Earth is important. Syowa Station (69.0°S, 39.6°E), Antarctica, serves as one of the observatories in the Southern Hemisphere. This report briefly summarizes the location coordinates of the geodetic sensors, and chronology of related activity as of 2005, based on standardized format sheets for each sensor monument. Exchange of these formatted sheets among Antarctic stations will give us a data base for reviewing and archiving geodetic activity in Antarctica. Local geodetic ties among their monument marks are updated from the results given by M. Kanao *et al*. (J. Geod. Soc. Jpn., **41**, 357, 1995), including later surveying with improved accuracy.

key words: geodesy observatory, Syowa Station, space geodesy, local tie, precise gravimetry

1. Introduction

The National Institute of Polar Research (NIPR) has been coordinating the geodesy programs of the Japanese Antarctic Research Expeditions (JAREs). Shibuya *et al*. (2003) summarized 10 years' progress of Syowa Station (69.0°S, 39.6°E), Antarctica, from 1993 to 2003 as a global geodesy network site. They described the status as of 2003 of geodetic sensors including Global Positioning System (GPS), Doppler Orbitography Radiopositioning Integrated by Satellites (DORIS), Very Long Baseline Interferometry (VLBI), Precise Range And Range-rate Equipment (PRARE), Absolute Gravimeter (AG), Superconducting Gravimeter (SG), geomagnetic variometer, and Bottom Pressure Gauge (BPG). However, there was no illustration of the sensors in Shibuya *et al*. (2003), and the description was in an arbitrary format and not adequate to compare the progress of each sensor and related references. Therefore we try here to present a standardized format to describe the above geodetic sensors, which will be applicable to describing their status in the future. Although there is no established standardized international exchange format for reference points, this review will serve as an example for the Antarctic geodesy community.

Concerning local geodetic ties among the above geodetic marks, Kanao *et al*.

(1995) summarized the status as of 1995. During these 10 years, conventional surveys and relative GPS positioning were carried out to improve accuracy. There was no operational difficulty to obtain tie vectors of 2–4 mm accuracy, except for the VLBI antenna reference point (ARP). We present here a summary of the updated local geodetic tie vectors.

The acronyms used in this review are summarized in Table 1.

Table 1. Acronyms used in this review.

AG	Absolute Gravimetry, or Absolute Gravimeter
ARP	Antenna Reference Point
BPG	Bottom Pressure Gauge
DORIS	Doppler Orbitography Radiopositioning Integrated by Satellites
GLOSS	Global Sea Level Observing System
GOH	Gravity Observation Hut
GPS	Global Positioning System
GRS80	Geodetic Reference System 1980
GSI	Geographical Survey Institute, Japan
GVH	Geomagnetic Variometer Hut
IAGBN (A)	International Absolute Gravity Basestation Network Category (A)
IERS	International Earth Rotation Service
IGS	International GPS Service
ITRF	International Terrestrial Reference Frame
JARE	Japanese Antarctic Research Expedition
JH (O) D	Japan Hydrographic (and Oceanographic) Department, Japan Coast Guard
NIPR	National Institute of Polar Research, Japan
PRARE	Precise Range And Range-rate Equipment
SCAR	Scientific Committee on Antarctic Research
SG	Superconducting Gravimeter
SOH	Seismic Observation Hut
TOH	Tide Observation Hut
VLBI	Very Long Baseline Interferometry

2. Observatory site sheet and local ties among geodetic sensors

Sheet 1-3 shows the locations of geodetic observation sensors superposed onto an ortho-photometric map of Syowa Station, East Ongul Island. The layout of facilities and number of buildings have changed very much from this map, but the map with 5-m interval contours over a 1:2500 aerial photo highlights well the distribution of geodetic sensors in three-dimensions (Geographical Survey Institute, 1994).

There are two marks for GPS: SYOG and SYOW. There are also two marks for DORIS: SYOB and SYPB. The VLBI mark is put beside the 11-m S/X-band antenna with radome. The PRARE antenna is not seen in Sheet 1-3, similarly as SYOG and SYPB, because this aerial photo was taken in January 1992 before their construction. The AG base and SG instruments are installed in the Gravity Observation Hut (GOH), where AG measurements were conducted by JARE-members from the Geographical Survey Institute (GSI), Japan. The Tide Observation Hut (TOH) is placed at the shore of Nisi-no-ura Cove and sea level to determine the height above mean sea level of

Bench Mark No. 1040 (BM1040) is regularly monitored by JARE-members from the Japan Hydrographic (and Oceanographic) Department, Japan Coast Guard.

We prepared the observatory site sheet (Sheet 1) to explain the environment and facilities of Syowa Station as a whole. This site sheet includes "*station conditions*" such as geological conditions and weather regime, "*overview of geodesy programs*", "*instruments*" and "*references*". Binding of observatory site sheets from other Antarctic stations will give us a brief but current summary of geodetic activities immediately, together with the monument sheets.

3. Monument description sheet

We prepared 8 sheets of "Coordinates of Geodetic Monument at Syowa Station, Antarctica"; this title appears on every Sheet. For the seismic observation hut (SOH in Sheet 1-3) and geomagnetic variometer hut (GVH in Sheet 1-3), corresponding sheets have not been prepared as they do not require 1 cm positioning accuracy. In each Sheet, the items to characterize the geodetic sensor are noted by italic letters from top to bottom. Acronyms are used, when available in Table 1, to avoid lengthy description.

3.1. "Instrument type" and "Identification code"

The 8 sheets corresponding to 8 sensors are: Sheet 2 for SYOG of the International GPS Service (IGS) GPS point, Sheet 3 for SYOW of the Scientific Committee on Antarctic Research (SCAR) GPS campaign point, Sheet 4 for the VLBI ARP, Sheet 5 for SYOB of the DORIS tower, Sheet 6 for SYPB of the DORIS pillar, Sheet 7 for the PRARE ARP, Sheet 8 for the International Absolute Gravity Basestation Network Category A (IAGBN(A)) #0417 of the AG base, and Sheet 9 for BM1040 of the Global Sea Level Observing System (GLOSS) #95 BPG observations.

3.2. "Geocentric (or Geodetic) coordinate values", "Solution", and "Epoch"

For monuments related to space geodesy techniques (Sheets 2, 3, 4, 5, 6 and 7), "*Coordinate values*" should preferably be expressed in the "*Geocentric coordinate system*". The coordinates are associated with corresponding velocities. There is accompanying information on the "*Solution*", for example by Fukuzaki *et al*. (2005), "*Reference frame*" and "*Epoch*". In case of SYOG (Sheet 2), the "*Reference frame*" is International Terrestrial Reference Frame 2000 (ITRF2000; Altamimi *et al*., 2002) and the "*Epoch*" is 2000.0. The VLBI antenna and other marks (SYOG, SYOB and SYPB) have International Earth Rotation Service (IERS) DOMES Number.

In case of Sheet 8 (IAGBN(A)#0417) and Sheet 9 (BM1040/GLOSS#95), the position should preferably be specified by "*Geodetic coordinate values*" as each datum is strongly related to the height h above sea level (asl), for example, $h_{BM1040}=2.338$ m. For latitudes and longitudes we adopt the Geodetic Reference System 1980 (GRS80) Ellipsoid with the semi-major axis $a=6378137$ m and the flattening $1/f=298.257222101$ for coordinate transformation from the Cartesian geocentric coordinates.

3.3. *"Definitions of reference point", "Overview of sensor mark" and "Overview photograph and/or sketch"*

Because 1–3 mm accuracy of the local-tie is discussed, "*Definitions of reference point*" must be described in detail. In order to pin-point this sensor mark, "*Overview photographs*" and "*Site sketches*" help us to recognize how it looks and where is the reference "*point*" we defined.

3.4. *"Offset from the IGS GPS mark"*

This is given by a three-element vector in the Cartesian coordinate system; its origin is IGS GPS mark SYOG. "*Geocentric coordinate values*" plus "*Offset from the IGS GPS mark*" with sign should represent the offset-corrected coordinates of the related monument at SYOG. If there is no error in positioning and surveying, and if the reference system transform is perfect, these coordinates should match to a digit of 1 mm.

3.5. *"Notes"*

We describe here especially the "*local geodetic tie*". The notes give in some detail how the offset vector was obtained from which expedition number and who made the surveys. However, we do not go into the data reduction procedure, to maintain simplicity. The difference between the geocentric coordinates at SYOG and, for example, the offset-corrected VLBI-determined coordinates gives the current consistency of positioning between the two space geodesy methods, VLBI and GPS.

For Sheet 8 (IAGBN(A)#0417) and Sheet 9 (BM1040/GLOSS#95), important "notes" are given on the leveling survey and on how the height above sea level was determined.

3.6. *"Chronology"*

Each sensor/observation has its individual history of such items as when the observations started, how the monument was installed/maintained, what experiments were performed, why the observations stopped, etc. Therefore the description changes from one Sheet to another. For example, Sheet 6 (DORIS SYPB) has only 2 memos during 7 years, while Sheet 9 (BM1040/GLOSS#95) has 7 memos reflecting a long history of maintenance efforts.

When some events occurred, we can paste new information to the end of the current "*Chronology*". Thus we can update the status of the monument and observations, even though irregularly.

3.7. *"References"*

Because of comprehensive geodetic activity at Syowa Station, the number of references reached 70, as described in Shibuya *et al*. (2003). Therefore it may not be easy to find what reference corresponds to which observation item. We sorted the related references according to the "*Instrument*", and put them into the appropriate Sheet. Appearance of one reference is not limited to some specific Sheet, but may be duplicated in several Sheets.

4. Local geodetic ties among geodetic monuments

Following the summary by Kanao *et al*. (1995), local geodetic surveys were continued to improve the accuracy of the baseline between SYOG and the VLBI ARP. Other surveys to tie new marks to existing marks were also carried out. Based on a "*local tie*" item in each monument sheet, we summarize updated local tie vectors as shown in Table 2.

Column 1 (identification code) gives the abbreviated sensor name corresponding to 8 sensors such as IGS GPS point. Parentheses (*e.g.* SYOG) give registered code names in the international network.

Column 2 gives the three components of the offset vector in the geocentric coordinate system, taking SYOG as the origin. By definition, the offset vector of SYOG is $(dx, dy, dz) = (0, 0, 0)$. The most distant point from SYOG is BM1040 for BPG observations; its distance is about 700 m.

The offset vector components have values accurate to a digit of 1 mm; thus, detailed definition of the reference mark is required. Column 3 gives such a definition. For example, the VLBI ARP is defined as the cross point of the elevation and azimuth axes of the 11-m parablic antenna. This point is imaginary and not visible, as explained in VLBI Sheet 4. Other instruments have visible marks, such as brass disk, red ring in a transmitter, etc.

Column 4 gives the sheet number in which the sensor photo and/or a sketch of the reference point are described in detail.

For practical use of 1 cm accuracy, we summarize here the geocentric coordinates of the reference marks in Table 3, where the local tie vector component is subtracted from the corresponding SYOG IGS GPS coordinate value. These geocentric coordinates can be converted into geodetic coordinates on the GRS80 Ellipsoid as summarized in Table 4. The values are adjusted to the ITRF2000 system at the epoch of 2000.0.

Table 2. Results of the local tie of the geodesy monuments within Syowa Station, Antarctica. For details, see text.

Identification code	Offset vector (m)			Definition of reference point	Description
	dx	dy	dz		
GPS IGS (SYOG)	0	0	0	Center and bottom edge of choke ring of the Dorn Margolin T antenna (ARP)	Sheet 2
GPS SCAR (SYOW)	25.240	−46.394	−12.197	Cross point of the marker disk	Sheet 3
VLBI	13.714	−120.574	−24.362	Cross point of the elevation and azimuth axes	Sheet 4
DORIS tower (SYOB)	−291.082	15.929	−85.889	Center of the red marker ring of the beacon	Sheet 5
DORIS pillar (SYPB)	−298.055	23.376	−89.987	Center of the red marker ring of the beacon over the cross point of the brass disk buried at the base pillar	Sheet 6
PRARE	−292.533	39.167	−83.312	Center and bottom edge of the rotating unit	Sheet 7
AG (IAGBN (A))	28.448	−71.868	−17.129	Cross point of the brass disk	Sheet 8
Bench Mark 1040	−416.634	563.293	−14.029	Cross point of the brass disk	Sheet 9

If there is no error in surveying and the transform of the reference system is perfect, $X_{VLBI} + dx_{VLBI}$ with sign $= X_{SYOG}$, etc.

Table 3. Geocentric coordinates of the geodesy monuments within Syowa Station, Antartica in the ITRF2000 system at the epoch of 2000.0.

Identification code	X (m)	Y (m)	Z (m)	Reference
GPS IGS (SYOG)	1766207.854	1460290.348	−5932297.690	Sheet 2
GPS SCAR (SYOW)	1766182.614	1460336.742	−5932285.493	Sheet 3
VLBI	1766194.140	1460410.922	−5932273.328	Sheet 4
DORIS tower (SYOB)	1766498.936	1460274.419	−5932211.801	Sheet 5
DORIS pillar (SYPB)	1766505.909	1460266.972	−5932207.703	Sheet 6
PRARE	1766500.387	1460251.181	−5932214.378	Sheet 7
AG (IAGBN (A))	1766179.406	1460362.216	−5932280.561	Sheet 8
Bench Mark 1040	1766624.488	1459727.055	−5932283.661	Sheet 9

The X-coordinate of VLBI, X_{VLBI}, was calculated by subtracting the x-component of the offset vector, dx_{VLBI} (see raw VLBI in Table 2), from the X-coordinate of SYOG. The other components can be calculated similarly.

Table 4. Geodetic coordinates of the geodesy monuments within Syowa Station, Antartica on the GRS80 Ellipsoid.

Identification code	Latitude (φ)	Longitude (λ)	Ellipsoidal height (height asl)	Reference
GPS IGS (SYOG)	−69.006957355° 69°00′25.0465″S	39.583744006° 39°35′01.4784″E	50.009 m (28.933 m)	Sheet 2
GPS SCAR (SYOW)	−69.006833560° 69°00′24.6008″S	39.585040034° 39°35′06.1441″E	42.244 m (21.155 m)	Sheet 3
VLBI	−69.006324519° 69°00′22.7683″S	39.586285673° 39°35′10.6284″E	51.003 m	Sheet 4
DORIS tower (SYOB)	−69.004888808° 69°00′17.5997″S	39.578800323° 39°34′43.6812″E	46.561 m	Sheet 5
DORIS pillar (SYPB)	−69.004870375° 69°00′17.5384″S	39.578545770° 39°34′42.7648″E	42.960 m	Sheet 6
PRARE	−69.005011641° 69°00′18.0419″S	39.578329461° 39°34′41.9861″E	44.063 m	Sheet 7
AG (IAGBN (A))	−69.006702556° 69°00′24.1274″S	39.585581972° 39°35′08.0951″E	42.569 m (21.493 m)	Sheet 8
Bench Mark 1040	−69.007228076° 69°00′26.0211″S	39.566252599° 39°33′58.5094″E	23.394 m (2.338 m)	Sheet 9

The geodetic coordinates on the GRS80 Ellipsoid was obtained from the geocentric coordinates in Table 3 by using the coordinate transformation software "xyz2blh" by M. Tobita (GSI).

5. Concluding remarks

In order to keep track of the change of geodetic activity without confusion, "*Description Date*" and the "*Author*" must be itemized, as only one Sheet may be referred to. Geodesy reference points at Antarctic stations have to be maintained on a decadal time scale; this standardized format sheet will tell effectively the current activity to future Antarctic geodesists.

Acknowledgments

We thank all the JARE-members who were engaged in the field survey and support.

We thank Mikio Tobita for letting us use his coordinate transformation software "xyz 2blh" and "blh2xyz". We also thank Y. Fukuda and S. Aoki for reviewing the manuscript.

References

Altamimi, Z., Sillard, P. and Boucher, C. (2002): ITRF2000: A new release of the International Terrestrial Reference Frame for each science applications. J. Geophys. Res., **107**, doi: 10.1029/2001JB000561.

Fukuzaki, Y., Shibuya, K., Doi, K., Ozawa, T., Nothnagel, A., Jike, T., Iwano, S., Jauncey, D.L., Nicolson, G.D. and McCulloch, P.M. (2005): Results of the VLBI experiments conducted with Syowa Station, Antarctica. J. Geodesy, 10.1007/500190-005-0476-8.

Geographical Survey Institute (1994): Syowa Station, color photo map, 1: 2500. Based on the aero-photograph taken on January 1992 (C32AV C10-8.10.2). Tsukuba.

Kanao, M., Shibuya, K., Watanabe, K., Fujiwara, S., Ikeda, H. and Okano, K. (1995): A note on geodetic ties among several reference points by different space geodetic techniques at Syowa Station, Antarctica. J. Geod. Soc. Jpn., **41**, 357-364.

Shibuya, K., Doi, K. and Aoki, S. (2003): Ten years' progress of Syowa Station, Antarctica, as a global geodesy network site. Polar Geosci., **16**, 29-52.

Permanent Geodesy Observatory Information on Syowa Station, Antarctica, Sheet 1.

Station conditions:

There are several small islands at the mouth of Lützow-Holm Bay, Eastern Dronning Maud Land, Antarctica. Syowa Station is located on one of the islands, East Ongul Island, with a diameter of about 500 m. The geographical location of Syowa Station is about 39°35'E and 69°00'S; the highest point is 43.4 m above sea level. Geologically East Ongul Island is exposed metamorphosed granitic gneiss 500 my in age. The rocks are very hard, and have P-wave velocity of 6.0 km/s, typical of upper-crust. There is no sedimentary layer which may induce a ground water effect in geodetic observations. Syowa Station is situated in a mild coastal regime. The annual mean air temperature is −10.5°C, and annual mean wind speed is 6.5 m/s. There are 51 buildings of a total area of 6130 m^2. The facilities are maintained by 40 wintering members. The station is powered by 2 diesel-engine generators of 300 kVA, with 2 backup generators of 200 kVA for emergency and crowded summer operation.

Overview of geodesy program:

NIPR has been coordinating the geodesy programs of JAREs. Shibuya (1993) gave a review of the status until 1993. After ten years of the IV−th and V−th five-year programs, Syowa Station has grown to be one of the key stations for the global geodynamics network in the Southern Hemisphere. Shibuya *et al.* (2003) gave a review of 10 years' progress of each observation item.

Instruments:

The instrument location is marked on an ortho-photometric map as illustrated in Sheet 1-3. The description of each instrument is given in the Sheet numbered in the parenthesis.

1. A permanent GPS pillar was constructed in January 1995 and the antenna was registered in the IGS tracking network in June 1999. It is registered as IERS DOMES Number 66006S002; the ARP has the code name SYOG (Sheet 2). During 1993-1996, No. 23-16 local geodetic mark was used for the SCAR GPS campaign; it was coded as SYOW (Sheet 3).

Sheet 1-1.

2. The 11−m multipurpose S/X−band antenna has been used for geodetic VLBI observations. This VLBI antenna has the code IERS DOMES Number 66006S004 (Sheet 4).
3. Syowa Station has been operating the DORIS beacon since 1993. The first beacon on the pylon tower was coded 66006S001 (SYOB; Sheet 5). The tower broke down in May 1998, and was replaced by the second-generation antenna on the pillar in February 1999. It is coded 66006S003 (SYPB; Sheet 6).
4. The PRARE tracking antenna worked 10 months in 1997. The ARP is measured $\triangle h = 7$ mm above the top of the pillar pin. Although we have local-tie vector information, geocentric coordinates of the ARP are not available yet (Sheet 7).
5. The GOH was constructed in February 1991. The IAGBN(A) Syowa marker (identification number 0417; Sheet 8) has been installed. The SG observation by TT70#016 started from March 22, 1993 in the GOH. It was replaced with a new-type SG CT#043 in April 2003, and the observation is continuing as of May 2005.
6. Recording of sea level variation has been continuing since 1976 at Nisi-no-ura Cove using the BPG located at a depth of 10-15 m. It has the GLOSS identification number 95. The mean sea level has been tied to BM1040 nearby the BPG in the austral summer season by in-situ surveying (Sheet 9).
7. Geomagnetic variometer observations are being made at the observation hut (GVH in Sheet 1-3) since 1968.
8. Short-period (1 s) and long-period (10-30 s) seismic observations started from 1959. Broadband seismometer (STS-1) observations started from 1992 (JARE-33) and have been continuing at the seismic observation hut (SOH in Sheet 1-3) since 1997 (JARE-38).

References:

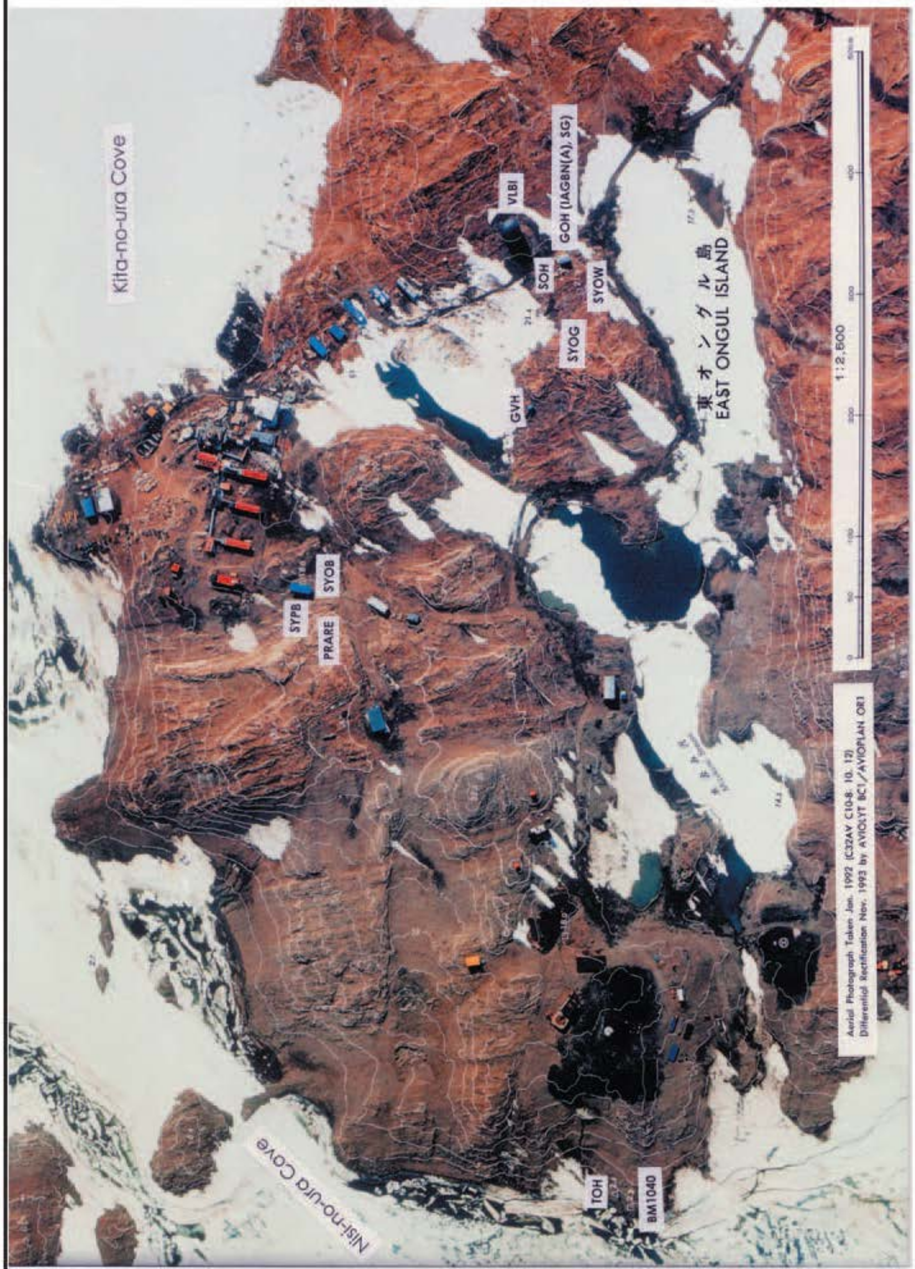
Shibuya, K. (1993): Syowa Station; observatory for global geodesy in Antarctica (a review). Proc. NIPR Symp. Antarct. Geosci., **6**, 26-36.

Shibuya, K., Doi, K. and Aoki, S. (2003): Ten years' progress of Syowa Station, Antarctica, as a global geodesy network site. Polar Geosci., **16**, 29-52.

Description Date: 20 July 2004, modified 1 September 2005.

Author: Kazuo Shibuya, shibuya@nipr.ac.jp

Sheet 1-2.


Kita-no-ura Cove
VLBI
GOH (IAGBN(A), SG)
SOH
SYOW
SYOG
GVH
東オングル島
EAST ONGUL ISLAND
1:2,500
SYPB
SYOB
PRARE
Aerial Photograph Taken Jan. 1992 (C32AV C10-8: 10. 12)
Differential Rectification Nov. 1993 by AVIOLYT BC1/AVIOPLAN OR1
IOH
BM1040
Nisi-no-ura Cove

Sheet 1-3.

Coordinates of Geodetic Monument at Syowa Station, Antarctica, Sheet 2.

Instrument type: GPS Antenna, IGS tracking Station

Identification code: IERS DOMES Number 66006S002 (SYOG)

Geocentric coordinate values:

X_{SYOG} = 1766207.854 m ± 0.7 cm, Vx = 3.27 ± 0.19 mm/yr,

Y_{SYOG} = 1460290.348 m ± 0.8 cm, Vy = −2.99 ± 0.21 mm/yr,

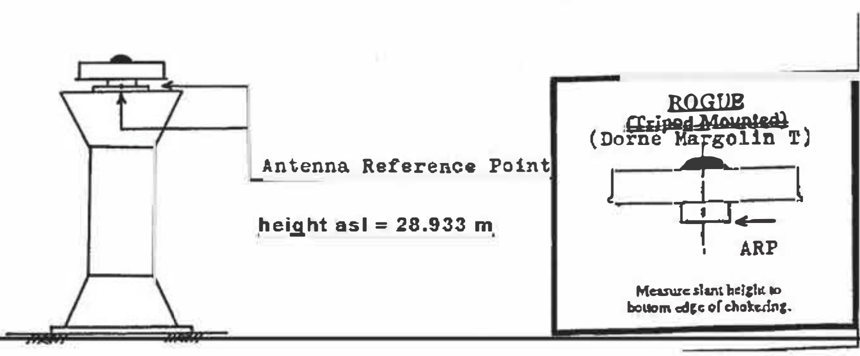
Z_{SYOG} = −5932297.690 m ± 1.2 cm, Vz = −2.26 ± 0.33 mm/yr,

Solution by: Fukuzaki *et al.* (2005)

Reference frame and Epoch: ITRF2000 system at the epoch of 2000.0

Definitions of antenna reference point: Center and bottom edge of choke-ring of the Dorn Margolin T antenna, ARP in the figure below.

Antenna overview: *Sketch of the reference mark:*



Sheet 2-1.

Offset from the IGS GPS mark

By definition, (dx, dy, dz) = (0 m, 0 m, 0 m).

Notes on height of the IGS GPS mark

Ellipsoidal height of SYOG, H_{SYOG} = 50.009 m, can be obtained on the GRS80 Ellipsoid at the epoch of 2000.0. By the leveling survey of 2005.1 by K. Morita (JARE-46), the elevation above mean sea level of SYOG, h_{SYOG} = 28.933 m, was obtained. Therefore, the geoid height at SYOG can be estimated as $N_{SYOG} = H_{SYOG} - h_{SYOG}$ = 50.009 m − 28.933 m = 21.076 m.

Chronology of IGS tracking station

1. A permanent GPS pillar was constructed in March 1995 by K. Maruyama and Y. Aoyama (JARE-36).
2. Participation in the IGS network was delayed until June 1999 because sporadic outliers appeared rather frequently in the daily solutions (Yamada *et al.*, 1998).
3. The outlier problem was solved by the replacement of a Rubidium frequency standard with a Cesium standard in the VLBI Hydrogen maser comparator system during JARE-40 (Y. Fukuzaki) wintering.
4. Until 2004, data were transferred via Inmarsat satellite. From 2004, Intelsat daily raw-data file transfer is continuing regularly.
5. Raw data files from 1995 until 1999 (before participation in the IGS) are archived in GSI and NIPR.
6. A leveling survey of ARP was carried out after removing the radome temporarily and measuring the height difference between ARP and SYOW by K. Morita (JARE-46).

References:

Fukuzaki, Y., Shibuya, K., Doi, K., Ozawa, T., Nothnagel, A., Jike, T., Iwano, S., Jauncey, D.L., Nicolson, G.D. and McCulloch, P.M. (2005): Results of the VLBI experiments conducted with Syowa Station, Antarctica. J. Geodesy, 10.1007/500190-005-0476-8.

Morita, K. (2005): On geoid height at IGS GPS point of Syowa Station, Antarctica. The 24th Symposium on Antarctic Geosciences Program and Abstracts, 13-14 October 2005.

Sheet 2-2.

Yamada, A., Maruyama ,K., Ootaki, O., Itabashi, A., Hatanaka, Y., Miyazaki, SI., Negishi, H., Higashi, T., Nogi, Y., Kanao, M. and Doi, K. (1998): Analysis of GPS data at Syowa Station and IGS tracking stations. Polar Geosci., **11**, 1-8.

Description Date: 12 July 2004, modified 1 September 2005.

Author: Kazuo Shibuya, shibuya@nipr.ac.jp

Sheet 2-3.

Coordinates of Geodetic Monument at Syowa Station, Antarctica, Sheet 3.

Monument type: No. 23-16 geodetic mark, brass disk

Identification code: SCAR GPS campaign mark (SYOW)

Geocentric coordinate values:

X_{SYOW} = 1766182.595 m,

Y_{SYOW} = 1460336.748 m,

Z_{SYOW} = −5932285.491 m,

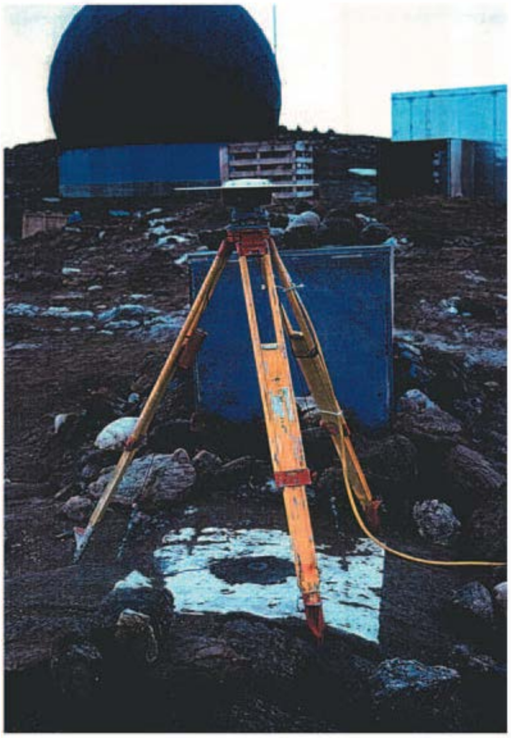
v_N = −3 mm/yr, v_E = −9 mm/yr,

Solution by: Dietrich et al. (2001)

Reference frame and Epoch: ITRF96 system at the epoch of 1998.1

Definitions of the reference point: Cross point in the marker disk, see the photo below.

Mark Overview:



Sheet 3-1.

Offset from the IGS GPS mark:

(dx, dy, dz) = (25.240 m, −46.394 m, −12.197 m).

Notes on local geodetic tie:

K. Maruyama (JARE-36) placed a TurboRogue Dorne Margolin T antenna on a surveying tripod over the No. 23-16 brass disk mark (SYOW mark) and acquired data in the TurboRogue SNR-8000 receiver. The antenna height offset was 1.120 m (true vertical). The observation period was August 8-17, 1995. M. Iwata (JARE-39) repeated the relative GPS positioning by using an Ashtech Z-FX system in January 30, 1998. The repeatability (stability) of the local tie was 3 mm, 4 mm and 2 mm for each (x, y, z) Cartesian coordinate. The SYOW mark is included in the first-order leveling route of East Ongul Island.

Chronology of Syowa participation in the SCAR campaign

1. SYOW mark was occupied during January 20 – February 10 in the 1993, 1994 and 1995 SCAR GPS campaigns.
2. From 1996, the SYOW mark is not used for the international campaigns, but is used for local and/or regional geodetic surveying by JARE.

References:

Dietrich, R., Dach, R., Engelhardt, G., Ihde, J., Korth, W., Kutterer, H.-J., Lindner, K., Mayer, M., Menge, F., Miller, H., Mueller, C., Niemeier, W., Perlt, J., Pohl, M., Salbach, H., Schenke, H.-W., Schoene, T., Seeber, G., Veit, A. and Voelksen, C. (2001): ITRF coordinates and plate velocities from repeated GPS campaigns in Antarctica – an analysis based on different individual solutions. J. Geod., **74**, 756-766.

Description Date: 13 July 2004, modified 1 September 2005.

Author: Kazuo Shibuya, shibuya@nipr.ac.jp

Sheet 3-2.

Coordinates of Geodetic Monument at Syowa Station, Antarctica, Sheet 4.

Instrument type: VLBI Antenna, (11-m S/X band Cassegrain multipurpose antenna)

Identification code: IERS DOMES Number 66006S004

Geocentric coordinate values:

X_{VLBI} = 1766194.125 m ± 0.3 cm, Vx = 5.76 ± 0.98 mm/yr,

Y_{VLBI} = 1460410.920 m ± 0.2 cm, Vy = 1.48 ± 0.77 mm/yr,

Z_{VLBI} = −5932273.309 m ± 0.5 cm, Vz = −2.79 ± 2.01 mm/yr,

Solution by: CALC/SOLVE from 25 sessions (1999.05.13-2003.01.20), Fukuzaki *et al.* (2005).

Reference frame and Epoch: ITRF2000 system at the epoch of 2000.0

Definitions of antenna reference point: Cross point of the elevation and azimuth axes which is marked by R in the sketch of the next page. This ARP is imaginary with no real mark.

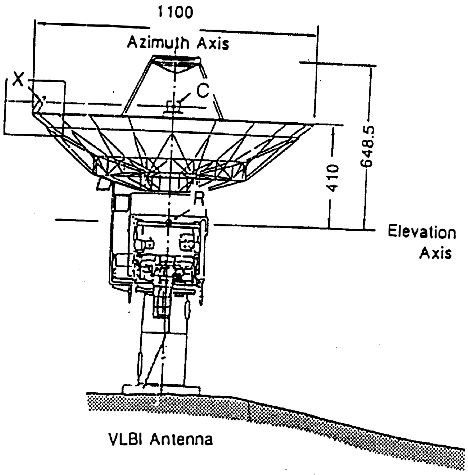
Antenna overview: (Left) The antenna is covered with a 17-m diameter radome. (Right) Close-up of the center-hub. There are two pairs of motors to control vertical (elevation) movement and horizontal (azimuth) movement of the 11-m reflector.

Offset from the IGS GPS mark

(dx, dy, dz) = (13.714 m, −120.574 m, −24.362 m).

Sheet 4-1.

Sketch of the reference mark:



Notes on local geodetic tie:

It was not possible to do a conventional survey before covering the radome at the construction stage of the antenna in 1990. Therefore, an indirect tie was necessary. K. Maruyama (JARE-36, 1995) and Y. Fukuzaki (JARE-40, 1999) attached a dual-frequency GPS antenna to the frame of the 11-m main reflector by a special adapter to measure an offset vector against the GPS antenna placed over the permanent pillar, the IGS GPS point (SYOG). By rotating the main reflector for several selected azimuths with the elevation angle fixed at 90°, such offset vectors were measured and the center point of the trajectory circle (C in the figure) was calculated. With the designed height difference of 410 cm between the plane of the reflector frame and the VLBI ARP (R in the figure), we estimated the offset vector from SYOG. The maximum probable error is considered 1 cm for horizontal components and 2 cm for the vertical component. The difference between the local-offset corrected SYOG coordinates at VLBI ARP and those of observed VLBI is 15 mm for the x-, 2 mm for the y-, and −19 mm for the z-coordinate, respectively.

Chronology of VLBI experiments

1. K4 system and 2 Hydrogen masers were installed in 1998. The Syowa (JA) session started from February 1998.

Sheet 4-2.

2. NIPR participated in the International VLBI Service for Geodesy and Astrometry (IVS) network in 1999, and Syowa Station followed the observation schedule coordinated by IVS.
3. From 1999, 24-hour sessions have been conducted 7-8 times per year. They are named the SYW and OHIG sessions.
4. An SYW session consists of Syowa antenna, 26-m radio telescope of the University of Tasmania in Australia (Hobart), and 26-m radio telescope of the Hartebeesthoek Radio Astronomy Observatory in South Africa (HartRAO).
5. An OHIG session consists of Syowa, Hobart, HartRAO, 9-m Chilean O'Higgins Station telescope in the Antarctic Peninsula, 14-m Fortaleza telescope in Brazil, the Kokee Park 20-m telescope in Hawaii, and from 2002, the Transportable Integrated Geodesy Observatory 6-m antenna in Concepción in Chile.
6. The SYW session terminated at the end of JARE-45 operation (January 2005). Instead, two 24-hour experiments of the CRDS session were included in the JARE-46 observation schedule.

References:

Shibuya, K. and Doi, K. (2005): JARE Syowa Station 11-m antenna, Antarctica. In Behrend, D. and Baver, K.D. (eds) International VLBI Service for Geodesy and Astrometry 2004 Annual Report, NASA/TP-2005-212772, NASA/GSFC, pp. 107-110, Greenbelt, USA.

Fukuzaki, Y., Shibuya, K., Doi, K., Ozawa, T., Nothnagel, A., Jike, T., Iwano, S., Jauncey, D.L., Nicolson, G.D. and McCulloch, P.M. (2005): Results of the VLBI experiments conducted with Syowa Station, Antarctica. J. Geodesy, 10.1007/500190-005-0476-8.

Jike, T., Fukuzaki, Y., Shibuya, K., Doi, K., Manabe, S., Jauncey, D.L., Nicolson, G.D. and McCulloch, P.M. (2005): The first year of Antarctic VLBI observations. Polar Geosci., **18**, 26-40.

Description Date: 12 July 2004, modified 1 September 2005.

Author: Kazuo Shibuya, shibuya@nipr.ac.jp

Sheet 4-3.

Coordinates of Geodetic Monument at Syowa Station, Antarctica, Sheet 5.

Antenna type: DORIS beacon on a pylon tower

Identification code: IERS DOMES Number 66006S001 (SYOB)

Geocentric coordinate values:

X_{SYOB} = 1766498.910 m ± 0.4 cm, Vx = 3.8 ± 0.8 mm/yr,

Y_{SYOB} = 1460274.404 m ± 0.4 cm, Vy = −1.5 ± 0.8 mm/yr,

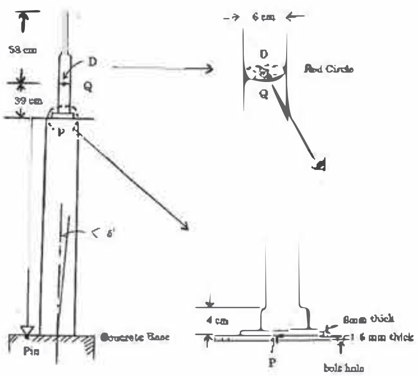
Z_{SYOB} = −5932211.778 m ± 0.5 cm, Vz = −1.5 ± 1.8 mm/yr,

Solution by: IERS Bulletin 2000

Reference frame and Epoch: ITRF2000 system at the epoch of 1997.0

Definitions of antenna reference point: Center of the red marker ring of the beacon, D in the figure below.

Beacon overview and sketch of the reference mark:



Sheet 5-1.

Offset from the IGS GPS mark

(dx, dy, dz) = (−291.082 m, 15.929 m, −85.889 m).

Notes on local geodetic tie

H. Ikeda (JARE-35) placed a total station on a tripod over the geodetic mark nearby the beacon, and over SYOW. A classical conventional survey was carried out; the target was the red ring. Height offset of the red ring from the geodetic mark was measured. The survey was done in January 28, 1994. M. Iwata (JARE-39) did a similar conventional survey again on January 28, 1998. The repeatability of the local tie was 25 mm, 27 mm and 51 mm for each (x, y, z) Cartesian coordinate. The uncertainty is believed to have resulted from position change during 4 years (slight deflection of the tower) together with probably different targeting by the two surveyors because the beacon is about 6 cm thick. The difference of the local-offset corrected SYOG coordinates at SYOB and those of observed SYOB is −15 mm for the x-, −20 mm for the y-, and 18 mm for the z-coordinate, respectively, when we adjust the epoch to 2000.0.

Chronology of SYOB beacon

1. The pylon tower was constructed in January 1993 by K. Okano (JARE-34). Initially the declination from vertical of the tower was within 5”. The tower was taller than 10 m, and vibrated under severe blizzards.
2. It was difficult to have balanced staying. Under the prevailing winds from ENE, the tower seemed to have gradually declined towards the WSW, and the tower broke down in May 1998 during JARE-39 wintering.
3. SYOB was taken over by the next generation beacon SYPB from February 1999.

References:

Boucher, C., Altamimi, Z., Feissel, M. and Sillard, P. (1986): Results and analysis of the ITRF94, IERS Technical Notes, 20, Central Bureau of IERS – Observatoire de Paris, France, 198 pp.

Cretaux, J. F., Soudarin, L., Cazenave, A. and Bouille, F. (1998): Present-day tectonic plate motions and crustal deformation from the DORIS space system. J. Geophys. Res., **103**,

Sheet 5-2.

30,167-30,182.

Shibuya, K., Doi, K. and Aoki, S. (1999): Precise determination of geoid height and free-air gravity anomaly at Syowa Station, Antarctica. Earth Planets Space, **51**, 159-168.

Soudarin, L., Cretaux, J.-F. and Cazenave, A. (1999): Vertical crustal motions from the DORIS space geodesy system. Geophys. Res. Lett., **26**, 1207-1210.

Description Date: 13 July 2004, modified 1 September 2005.

Author: Kazuo Shibuya, shibuya@nipr.ac.jp

Sheet 5-3.

Coordinates of Geodetic Monument at Syowa Station, Antarctica, Sheet 6.

Antenna type: DORIS beacon on a pillar, center of the red marker circle over the brass disk buried in the concrete base.

Identiification code: IERS DOMES Number 66006S003 (SYPB)

Geocentric coordinate values:

X_{SYPB} = 1766505.896 m ± 0.3 cm, Vx = 3.8 ± 0.8 mm/yr,

Y_{SYPB} = 1460266.974 m ± 0.3 cm, Vy = −1.5 ± 0.8 mm/yr,

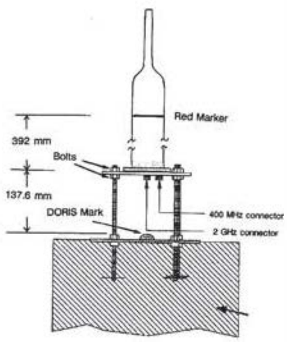
Z_{SYPB} = −5932207.693 m ± 0.7 cm, Vz = −1.5 ± 1.8 mm/yr,

Solution by: IERS Bulletin 2000

Reference frame and Epoch: ITRF2000 system at the epoch of 1997.0

Definitions of antenna reference point: Center of the red marker ring of the beacon over the cross point of the brass disk buried at the base pillar

Beacon overview and Sketch of the reference mark:



Sheet 6-1.

Offset from the IGS GPS mark

(dx, dy, dz) = (−298.055 m, 23.376 m, −89.987 m).

Notes on local geodetic tie:

Y. Fukuzaki (JARE-40) placed an Ashtech Geodetic III L1/L2 antenna on a tripod over the buried brass disk in the pillar. An Ashtech Z-FX receiver was used for data recording. Relative GPS positioning was done from the SYOG mark. The survey was done in May and August of 1999. Offset of the brass disk mark from the SYOG mark is (dx1, dy1, dz1) = (−297.909 m, 23.497 m, −90.481 m). The height offset of the beacon red ring from the brass disk was H_{diff} = 52.96 cm. Thus (dx, dy, dz) can be calculated with (dx1, dy1, dz1) and information on H_{diff}. The consistency of the relative positioning between the May and August surveys was 0 mm, 1 mm and 0 mm for each (x, y, z) Cartesian coordinate. Difference of the local-offset corrected SYOG coordinates at SYPB and those of observed SYPB is −2 mm for the x-, −3 mm for the y-, and 5 mm for the z-coordinate, respectively when we adjust the epoch to 2000.0.

Chronology of SYPB beacon

1. The pillar has remained very stable since its construction in 1999 by JARE-39/-40.
2. During the VLBI experiments, transmission was stopped for 1−2 days to avoid interference.

References:

IDS LEGOS/CLS Analysis Center (2002): DORIS monthly solutions: SYPB.
Available at http://ids.cls.fr/data/legos/images/SYPB_LEGOS_CLS.gif.

Description Date: 13 July 2004, modified 1 September 2005.

Author: Kazuo Shibuya, shibuya@nipr.ac.jp

Sheet 6-2.

Coordinates of Geodetic Monument at Syowa Station, Antarctica, Sheet 7.

Antenna type: PRARE tracking S/X band antenna

Identification code: None

Geocentric coordinate values: We have no data available yet

X_{PRARE} =

Y_{PRARE} =

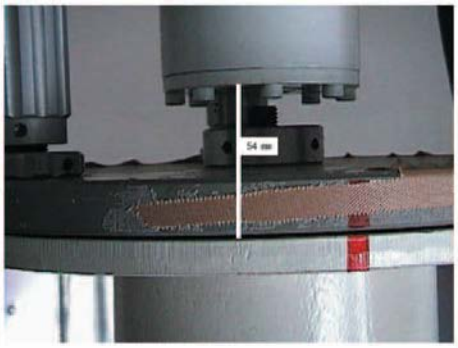
Z_{PRARE} =

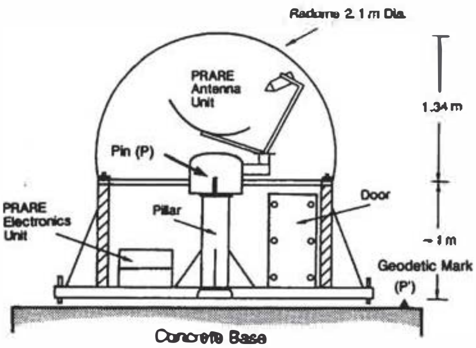
Solution by:

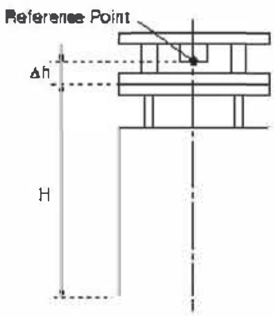
Reference frame and Epoch:

Definitions of antenna reference point: Center and bottom edge of the rotating unit, Reference Point in the figure below.

Antenna overview and sketch of the reference mark:







Sheet 7-1.

Offset from the IGS GPS mark:

(dx, dy, dz) = (−292.533 m, 39.167 m, −83.312 m).

Notes on local geodetic tie:

T. Higashi (JARE-38) placed an Ashtech Geodetic III L1/L2 antenna on a tripod over the pillar pin (P in the figure before), and over SYOW. The survey was done in February 23, 1997. As the system over SYOW had a time-tag problem, RINEX converted data from both SYOG and the receiver over the pillar pin were utilized. Bernese ver.4.0 analysis by T. Ozawa produced the solution with an accuracy of 1 mm for each component. The height offset of the pin-top and the rotating unit was measured by K. Doi (JARE-41) in April 2000. The ARP was measured to be Δh = 7 mm above the pillar pin. The above offset vector is a combined result from these measurements. M. Iwata (JARE-39) buried a brass disk in the concrete base for an auxiliary purpose and did a conventional survey in January 1998 from SYOW.

Chronology *of Syowa PRARE:*

1. The PRARE ground station was installed in February 1997 by M. Kanao (JARE-38) and became operational from week 14 of 1997.
2. It seems that the cabling problem appeared from the week 36, and the number of "Doppler Normal Points" noticeably decreased.
3. After week 48, the number of the Doppler full rate became smaller than 1000.
4. We stopped the operation after October 1997.
5. In spite of several repair efforts thereafter, Syowa PRARE never became active again.

References:

Shibuya, K., Kanao, M., Higashi, T. and Aoki, S. (2000): Installation and operation of PRARE tracking antenna at Syowa Station, Antarctica. Nankyoku Shiryo (Antarct. Rec.), **44**, 14-24.

Description Date: 13 July 2004, modified 1 September 2005.

Author: Kazuo Shibuya, shibuya@nipr.ac.jp

Sheet 7-2.

Coordinates of Geodetic Monument at Syowa Station, Antarctica, Sheet 8.

Monument type: Absolute Gravity Station

Identification code: IAGBN(A) #0417

Geodetic coordinate values:

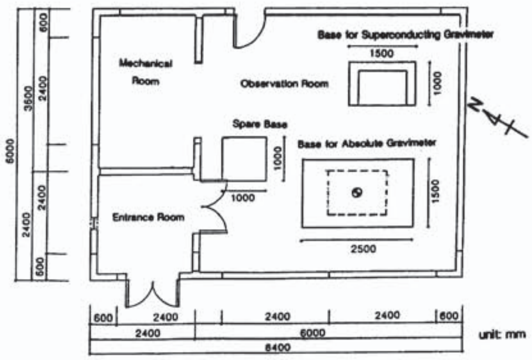
φ_{IAGBN} = 69° 00' 24.1274" S

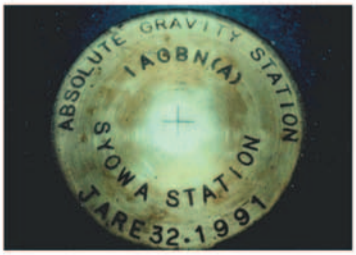
λ_{IAGBN} = 39° 35' 08.0951" E

h_{IAGBN} = 21.493 m

Reference frame and Ellipsoid: ITRF2000 and GRS80 Ellipsoid

Definitions of reference point: Cross point of the brass disk in the concrete base of 1.5 m by 2.5 m in the GOH.





Sheet 8-1.

Offset from the IGS GPS mark

(dx, dy, dz) = (28.448 m, −71.868 m, −17.129 m).

Notes on IAGBN(A)#0417 mark and leveling survey:

The GOH was constructed in February 1991 by JARE-32. A marble plate 1.0 m by 1.4 m was placed within a concrete base 1.5 m by 2.5 m. At the center of the marble plate, a brass disk of 8 cm diameter was buried. The station marker is IAGBN(A) SYOWA STATION JARE32 1991. S. Nakajima (JARE-32) and K. Watanabe (JARE-33) did a leveling survey from the BM1040 height standard to the IAGBN(A)#0417 mark. The height above mean sea level of the mark was h_{IAGBN} = 21.4927 m (1992.0). M. Iwata (JARE-39) did a conventional survey in January 1998 to obtain the station coordinates of the mark.

Notes on local geodetic tie:

Because IAGBN(A)#0417 is situated in the GOH, direct GPS positioning could not be done. The given coordinates are combined results from relative GPS positioning and a conventional survey. There was some inconsistency in the original offset vector (dx, dy, dz) = (28.355 m, −71.933 m, −17.000 m) given by the log note; the vector components were adjusted to give consistent results with the geodetic coordinates reported by the Geographical Survey Institute (2002). For this adjustment, N_{IAGBN} = 21.076 m, the same value as at SYOG, was assumed. This resulted in H_{IAGBN} = 21.493 m + 21.076 m = 42.569 m on the GRS80 Ellipsoid.

Chronology of absolute gravity measurements:

1. Measurements by GSI GA60 (JARE-33), NAOM2 and AGRVP by JARE-34 were described and summarized in the Working Group for Syowa Station Absolute Gravimetry (1994).
2. JARE-36 (H. Yamamoto, GSI) made measurements during January 20 – January 29, and February 1 – 11 of 1995 by using FG5#104.
3. JARE-42 (I. Kimura, GSI) made measurements during December 29, 2000 – January 29, 2001 by using FG5#203.
4. JARE-45 (Y. Hiraoka from GSI, and Y. Fukuda from Kyoto Univ.) made measurements during December 2003 – February 2004 by using FG5#203 (GSI) and FG5#210 (Kyoto

Sheet 8-2.

Univ.).

Parallel observations with a superconducting gravimeter (SG)

1. SG observations with TT70#016 started from March 22, 1993 by T. Sato (JARE-34).
2. A new type SG CT#043 was brought down to Syowa Station by H. Ikeda (JARE-44) and routine observations started from April 2003.
3. Parallel observations of TT70#016 and CT#043 continued from April through October, 2003. However good quality data were only obtained from September to October, 2003.
4. The TT70#016 observation stopped in November 2003, and TT70#016 was removed from the GOH. Then CT#043 was moved to the pier site. The formal start of CT#043 was December 28, 2003. The replacement was done by H. Ikeda (JARE-44) and K. Doi with Y. Fukuda (JARE-45).
5. Ten years of SG raw data and associated explanatory text (CD-ROM) was published as JARE Data Reports No. 283, Earth Science Series 6 in 2005.

References:

Boedecker, G. and Fritzer, T. (1986): International Absolute Gravity Basestation Network, Status Report March 1986, by International Association of Geodesy Special Study Group 3.87. Veröffentlichungen der Bayerischen Kommission für die Internationale Erdmessung der Bayerischen Akademie der Wissenschaften, **47**, 68 p.

Fukuda, Y., Iwano, S., Ikeda, H., Hiraoka, Y. and Doi, K. (2005): Calibration of the superconducting gravimeter CT#043 with an absolute gravimeter FG5#210 at Syowa Station, Antarctica. Polar Geosci., **18**, 41-48.

Geographical Survey Institute (2002): Nankyoku-Chiiki, kijunten, juuryoku, chijiki, kuuchuu-shasin oyobi chizu-seika shuuroku (2) Kokudo-Chiriin Gujutu Shiryo B1-No. 32, 292 p, Kokudo-Chiriin, Tsukuba. (Antarctic Area; Result Report (2) on control surveys, gravity and geomagnetic surveys, aerial photography and maps. Technical Documents B1-No.32, 292p, Geograph. Surv. Inst., Tsukuba.

Hiraoka, Y., Kimura, I., Fukuda, Y., Doi, K. and Shibuya, K. (2005): Gravity measurements with the portable gravimeter FG5 at Antarctica (III). Bull Geogr. Surv. Inst., in press (in

Sheet 8-3.

Japanese).

Kimura, I. (2002): Gravity measurements with the portable absolute gravimeter FG5 at Antarctica (II). Bull. Geogr. Surv. Inst., **97**, 17-23 (in Japanese).

Shibuya, K., Doi, K. and Aoki, S. (2003): Ten years' progress of Syowa Station, Antarctica, as a global geodesy network site. Polar Geosci., **16**, 29-52.

Shibuya, K., Doi, K., Sato, T. and Tamura, Y. (2005): Syowa superconducting gravimeter raw data and associated expedition reports (Explanatory CD-ROM). JARE Data Reports No. 283 (Earth Sci. 6), 34p.

Working Group for Syowa Station Absolute Gravimetry (Nakagawa, I., Shibuya, K., Kaminuma, K., Fujiwara, S., Watanabe, K., Murakami, M., Ishihara, M., Tsubokawa, T., Hanada, H. and Yokoyama, K.) (1994): Absolute gravity measurements at Syowa Station during the Japanese Antarctic Research Expedition. Bull. d'Inform. BGI, **75**, 41-56.

Yamamoto, H. (1996): Gravity measurements with the portable absolute gravimeter FG5 at Antarctica. Bull. Geogr. Surv. Inst., **85**, 18-22 (in Japanese).

Description Date: 13 July 2004, modified 1 September 2005.

Author: Kazuo Shibuya, shibuya@nipr.ac.jp

Sheet 8-4.

Coordinates of Geodetic Monument at Syowa Station, Antarctica, Sheet 9.

Monument type: Bench Mark 1040; Tie point to the bottom pressure gauge (BPG)

Identification code: GLOSS#95

Geodetic coordinate values:

φ_{BM1040} = 69° 00' 26.0211" S

λ_{BM1040} = 39° 33' 58.5094" E

h_{BM1040} = 2.338 m

Reference Frame and Ellipsoid: ITRF2000 and GRS80 Ellipsoid

Definitions of reference point: Cross point of the brass disk. Nearby BM1040, there is a mark with sphere to hold a leveling staff.

Site overview:

Sheet 9-1.

The TOH is placed nearby BM1040 and a leveling staff is seen at far left-side of the upper (left) photo. A level on a tripod is placed over the tie point to measure the variation of sea level as seen in the lower (left) photo. Sea condition changes from year to year around Nisi-no-ura Cove, where the BPG is installed. At the end January of 1981, sea ice over Ongul Strait totally disappeared as seen in the upper (right) photo. From winter 1998, calibration of the BPG by using a GPS receiver over the sea-ice surface has been tried as seen in the lower (right) photo.

Offset from the IGS GPS mark

(dx, dy, dz) = (−416.634 m, 563.293 m, −14.029 m).

Notes on leveling survey

Height above sea level of BM1040 was determined as 2.3380 m at 1981.0 by JHD (now reorganized as JHOD) staff members, S. Fuchinoue and K. Oka of JARE-23, from observation of sea level at Nisi-no-ura Cove, East Ongul Island. The geodetic marks BM1040, IAGBN(A)#0417 and No. 23-16 (SYOW) are on the 3.4 km-long first-order leveling route of East Ongul Island. GSI staff members did leveling surveys several times. S. Nakajima (JARE-32) and K. Watanabe (JARE-33) did a leveling survey during 1991.12.28 – 1992.2.2. The closure error at BM1040 was 0.01 mm. I. Kimura (JARE-37) and O. Ootaki (JARE-38) did a leveling survey during 1996.2.2 – 2.5. The closure error at BM1040 was 0.00 mm. The geodetic coordinates on the GRS80 Ellipsoid were obtained after coordinate transformation of the offset corrected geocentric coordinates of BM1040 as given above. As H_{BM1040} = 23.394 m can be obtained, N_{BM1040} can be estimated as 23.394 m − 2.338 m = 21.056 m.

Chronology of tidal observations

1. Installation and maintenance of the sensor-transducer is done by JARE members from JH(O)D.
2. The period 1960-1970 was a struggling stage to find a stable location and develop a procedure for easy maintenance of the sensor. Year-round observation could not be done during this period.
3. JARE-12 found that Nisi-no-ura Cove was suitable for maintenance, and the site has been

Sheet 9-2.

used since 1970.

4. JARE-16 installed the strain-gauge type bottom pressure gauge (BPG; sensor type is Kyowa Shoko SWL-7) in January 1975, which replaced the previous rubber-bellows-type "sunken bell".
5. Year-round observations became possible from 1979, and a double sensor system has been applied from 1981.
6. There usually appears an open-sea area along the shore of Nisi-no-ura Cove in austral summer. The BPG is calibrated by monitoring sea level variations using level/staff during a flood tide (usually beginning of January).
7. From 1998 of JARE-39, GPS on-ice observations near the BPG location are included several times per year to perform calibrations during the winter-time.

References:

NIPR publishes JARE Data Reports Oceanography Series, Oceanography 1 (August 1982) through Oceanography 27 (March 2005); they cover tidal records from 1979 to 2002.

Hourly records in e-files are available on request to K. Shibuya.

JHOD opens a website to show preliminary variation of sea level at 5 min interval sampling:
http:// www1.kaiho.mlit.go.jp/KANKYO/KAIYO/jare/tide/tide_index.html.

As for GPS on-ice observation, see

Aoki, S., Ozawa, T., Doi, K. and Shibuya, K. (2000): GPS observation of the sea level variation in Lutzow-Holm Bay, Antarctica. Geophys. Res. Lett., **27**, 2285-2288.

As for leveling survey from BM1040, see

Geographical Survey Institute (2002): Nankyoku-Chiiki, kijunten, juuryoku, chijiki, kuuchuu-shasin oyobi chizu-seika shuuroku (2) Kokudo-Chiriin Gujutu Shiryo B1-No. 32, 292 p, Kokudo-Chiriin, Tsukuba. (Antarctic Area; Result Report (2) on control surveys, gravity and geomagnetic surveys, aerial photography and maps. Technical Documents B1-No. 32, 292p, Geograph. Surv. Inst., Tsukuba.

Description Date: 13 July 2004, modified 1 September 2005.

Author: Kazuo Shibuya, shibuya@nipr.ac.jp

Sheet 9-3.