Calibration/Validation of GRACE-derived gravity fields using the ground data obtained in the JARE area and Syowa Station, Antarctica

Kazuo Shibuya and 10 co-investigators
National Institute of Polar Research

Abstract

Syowa Station (right figure) is the JARE main station and precise geodetic observations with VLBI, GPS, DORIS, absolute gravimeter (AG), superconducting gravimeter (SG), etc. have been carried out since early 1990s. As the GRACE Science Team from Japan, NIPR-JARE group conducted calibration/validation research activities during 2003-2005; they include

I. Glacial isostatic adjustment in the JARE research area – space geodesy

II. Glacial isostatic adjustment in the JARE research area – gravimetry

III. An experiment of precise gravity measurements on the ice sheet

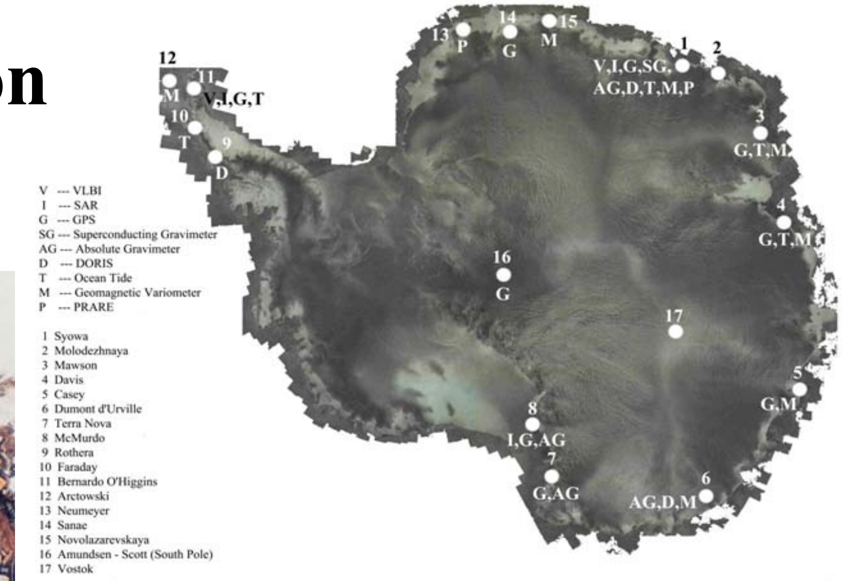
IV. Ocean dynamics around the Lützow-Holm Bay region

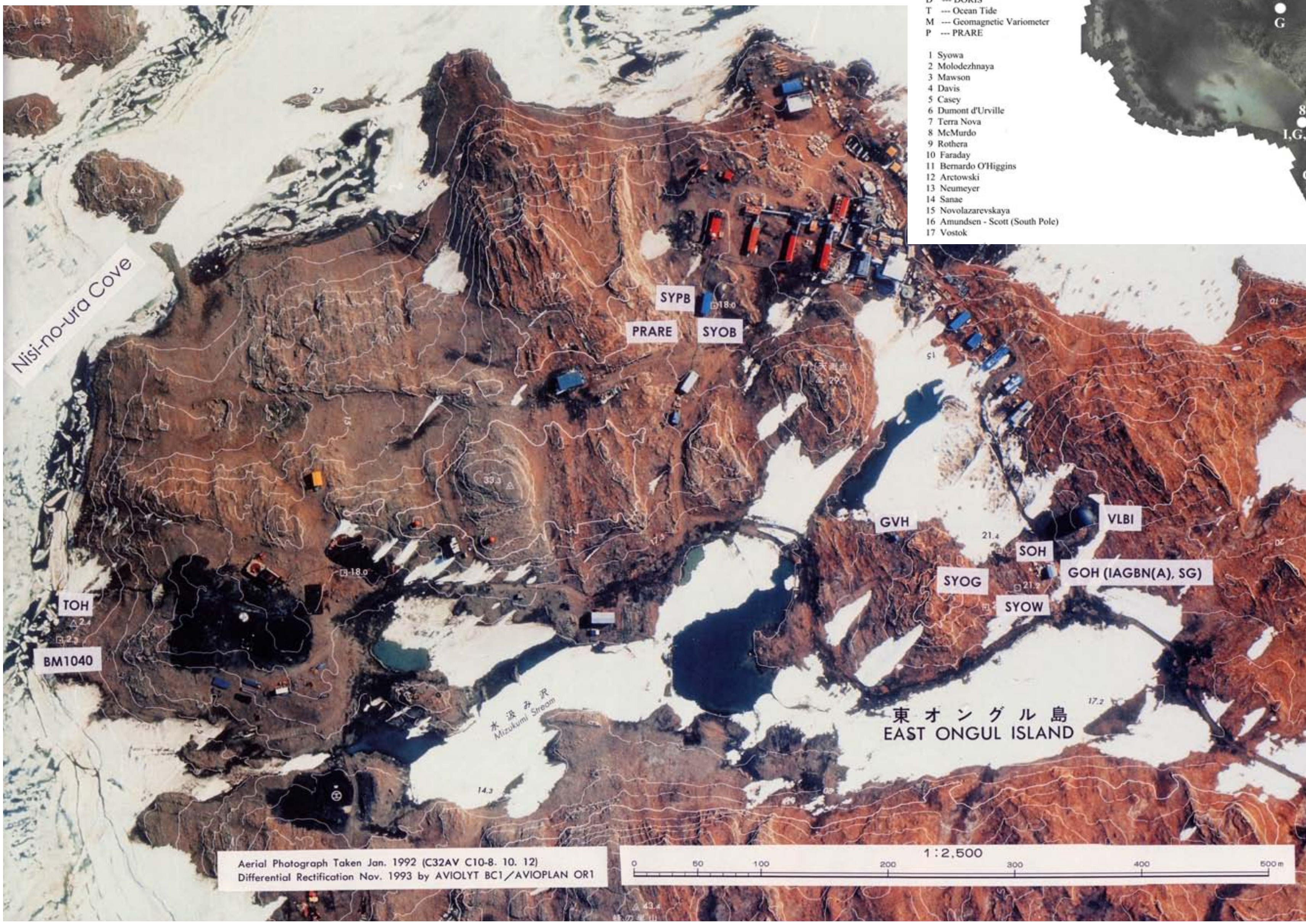
V. Water mass variation of the Antarctic ice sheet derived from the GRACE gravity fields

VI. ERS-1/ERS-2 InSAR derived grounding lines in the region from 30˚W to 40˚E

We present the results by a series of posters. In the end, we present research program of 2006.

Syowa Station (69.0^{o}S, 39.6^{o}E) on East Ongul Island, Antarctica.





I. Glacial Isostatic Adjustment in the JARE Research Area – Space geodesy

Within Syowa Station, There are three space geodesy monuments with the IERS DOMES Number.

For the IGS/GPS mark (Fig. a), the height of the ARP above the mean sea level is measured as 28.933 m. With the obtained ellipsoidal height of 50.009 m above the GRS80 Ellipsoid, the geoid height N can be estimated as N_{Syowa} = 21.076 m.

Syowa Station has an 11-m S/X band Cassegrain antenna (Fig. b) for geodetic VLBI observations and receiving of JERS-1/ERS-1/ERS-2 SAR data. Until now, 25 sessions during May 1999 – January 2003 were analized using the CALC/SOLVE analysis software developed by NASA/GSFC.

The first-generation DORIS beacon (SYOB) was installed in 1993, but the tower was blown down by heavy blizzards in May 1998. The second-generation beacon (SYPB, see Fig. c) started operation from February 1999. The pillar is very stable.

JARE/GSI installed an unmanned GPS pillar in the bare-ice outcropped areas called Langhovde (40 km south of Syowa Station, see Fig. d). Round-year data acquisition became possible (from 2002) with the backup solar batteries.

The crustal uplift rate at Syowa Station is estimated as 2.5±0.3 mm/yr (GPS), 3.6±0.2 mm/yr (DORIS) and 4.6±2.2 mm/yr (VLBI), respectively as summarized in Table 1. These geodetic estimates are very roughly consistent with the geomorphological estimate of 15 m/6300 yr = 2 mm/yr from the evidence of 13-17 m raised beach with the carbon dated marine fossils of 7200-5500 ybp.

Table 1. Topocentric velocities of the Syowa Reference Points

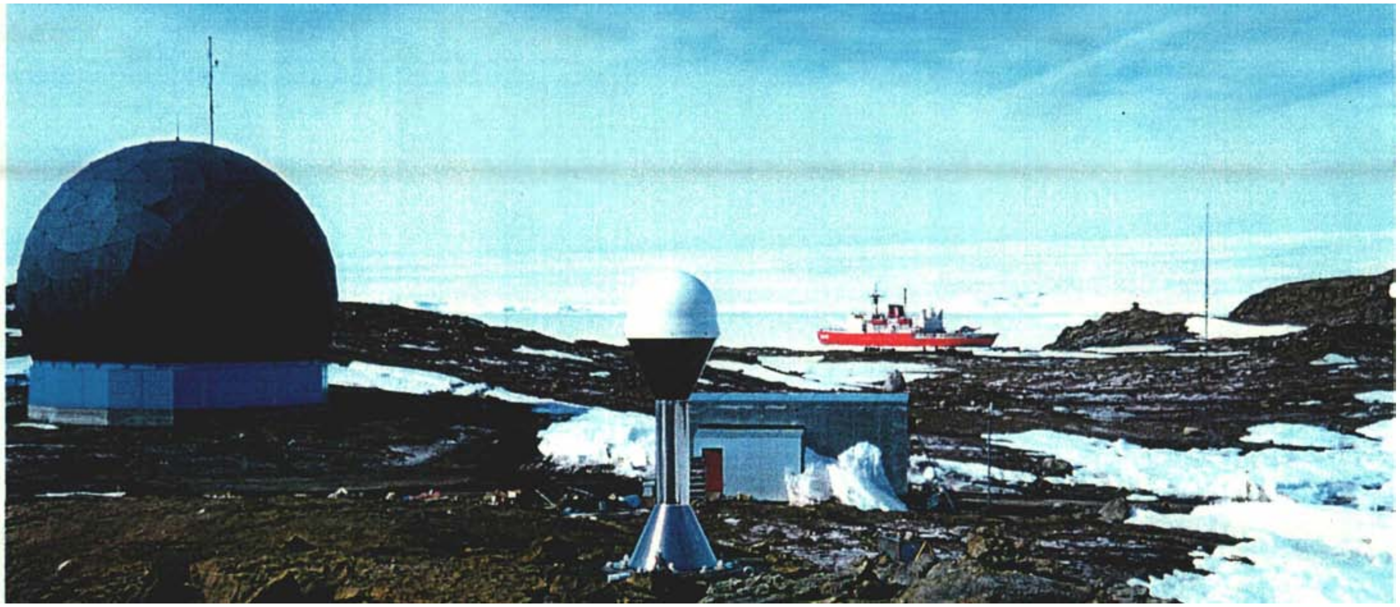
	Up (mm/yr)	East (mm/yr)	North (mm/yr)	Period	Reference
VLBI	4.6±2.2	- 2.5±0.6	4.0±0.7	1999-2003	Fukuzaki et al. (2005)
GPS	2.3±0.3	- 4.4±0.2	- 0.2±0.2	1999-2003	Fukuzaki et al. (2005)
	2.5±0.3	- 5.4±0.1	0.8±0.1	1999-2004	JPL website (2005)
DORIS	8.6±1.9	- 0.3±1.3	1.5±1.9	1999-2002	IDS website (2005)
	3.6±0.2	- 6.5±0.8	3.2±0.9	1999-2004	IGN04D02*

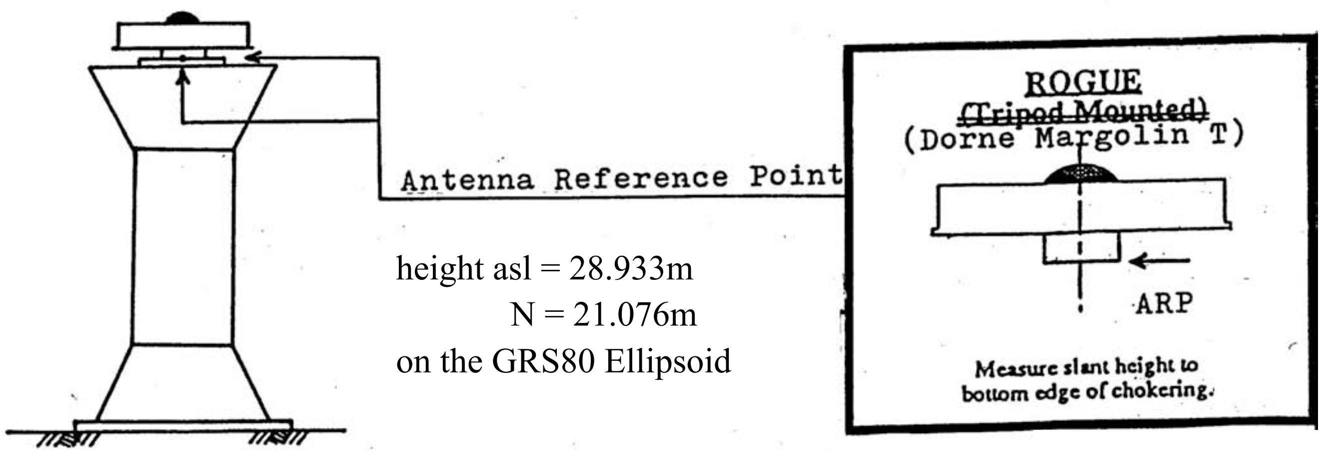
Fukuzaki, Y., Shibuya, K., Doi, K., Ozawa, T., Nothnagel, A., Jike, T., Iwano, S., Jauncey, D.L., Nicolson, G.D. and McCulloch, P.M. (2005): Results of the VLBI experiments conducted with Syowa Station, Antarctica. J. Geod., DOI 10.1007/S00190-005-0476-8

*Amalvict, M., Willis, P. and Shibuya, K. (2005): Status of DORIS stations in Antarctica for precise geodesy. Submitted to J. Geodyn.

(a)

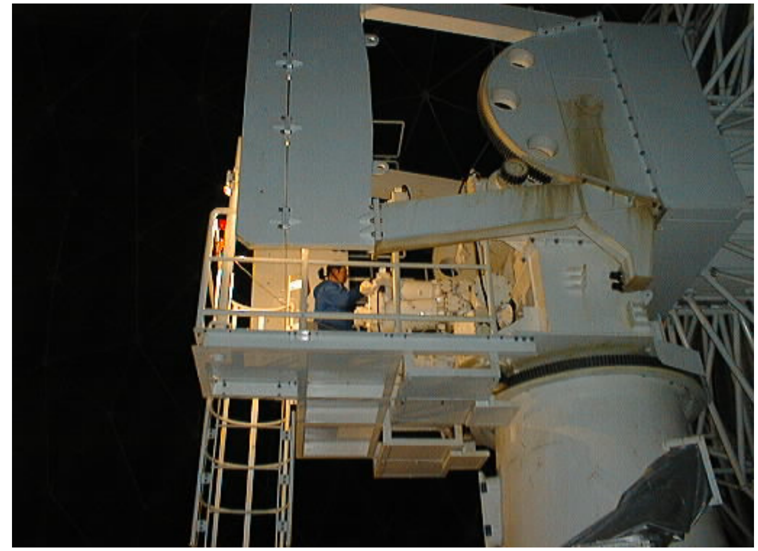
IGS/GPS

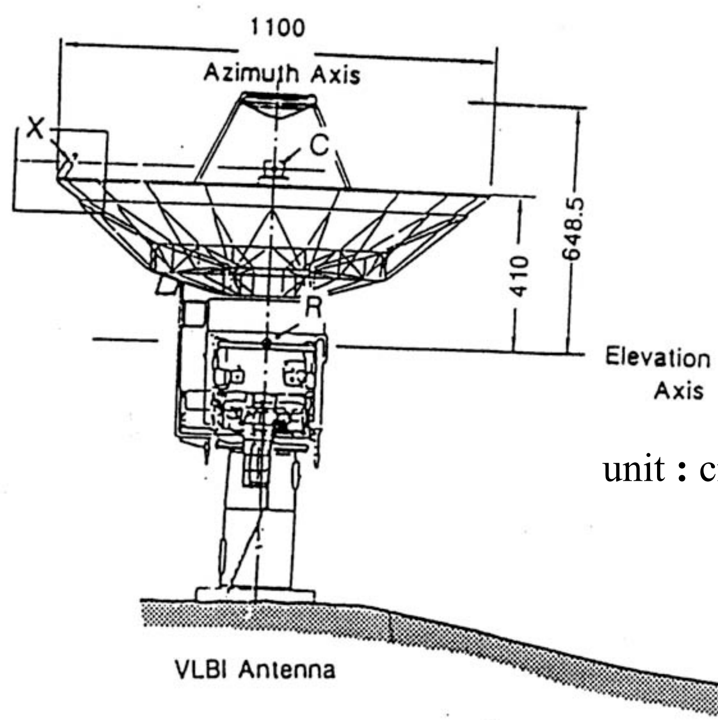



Antenna Reference Point
ROGUE
~~(Tripod Mounted)~~
(Dorne Margolin T)
ARP
Measure slant height to bottom edge of chokering.
height asl = 28.933m
N = 21.076m
on the GRS80 Ellipsoid

(b)

VLBI

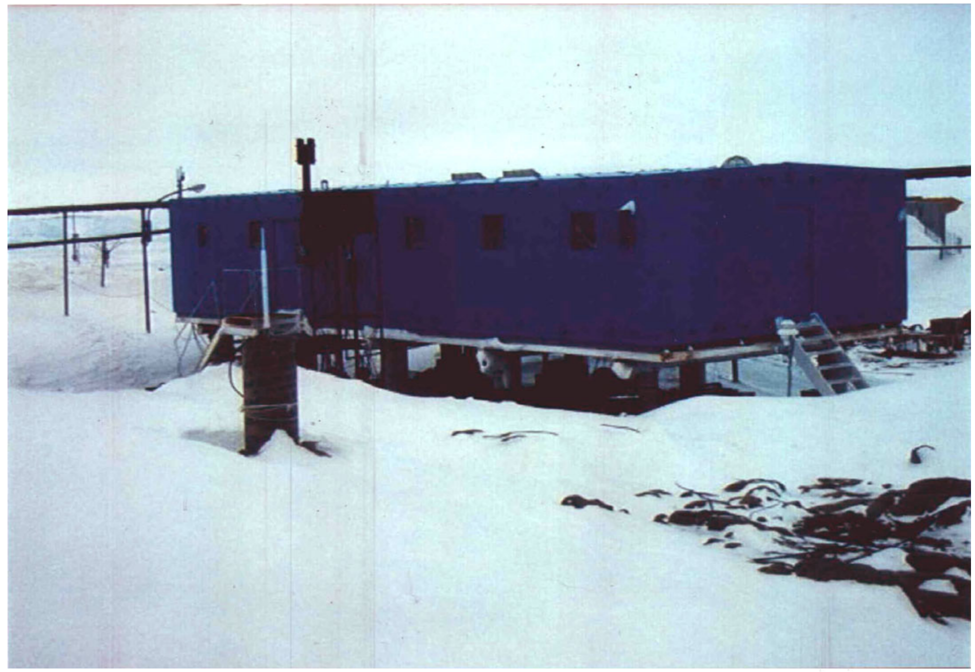


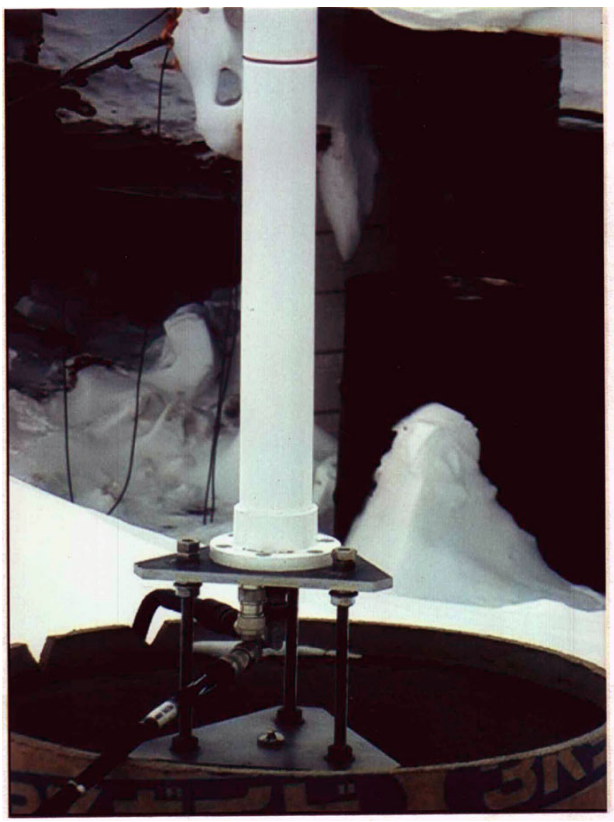


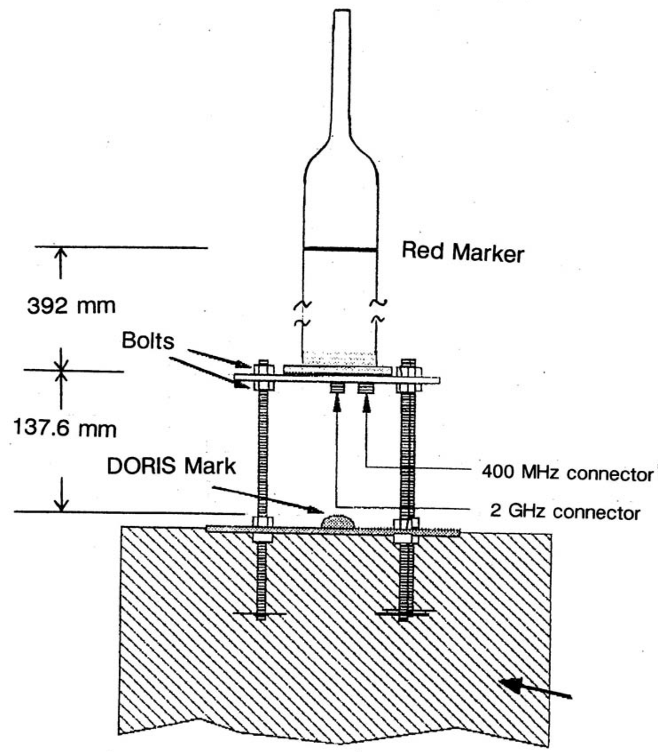
unit : cm

(c)

DORIS






Red Marker
392 mm
Bolts
137.6 mm
DORIS Mark
400 MHz connector
2 GHz connector

(d) unmanned GPS (Langhovde)

II. Glacial Isostatic Adjustment in the JARE Research Area – Gravimetry

In the JARE Earth science program, we are continuing SG observations from 1993. We also carried out AG measurements three times using an FG5 during these 10 years. The instruments are installed in the Gravity Observation Hut (GOH), see Fig. a.

Although the uncertainty is still large, we obtained the gravity decrease of –0.27±0.42 μGal/yr from the three repeated AG measurements (Fig. b left). Ten years' Syowa data from the GWR TT70#016 SG are archived in three DVDs with an explanatory CD-ROM (Fig. c) and they are made available to the scientific users. Using these 10 years' SG data, long-period tidal gravimetric factors (Msm, Mm, Msf, Mf, Mstm, Mtm, Msqm and Mqm) are estimated (e.g. Fig. b right).

The TT70#016 SG was replaced with a CT#043 SG by anticipating less-noise and less drift. The comparison, however, showed larger CT drift as shown in Fig. d.

We will continue AG/SG observations, and they will give us more reliable secular gravity change and seasonal/annual non-tidal gravity variations which are related with global atmospheric/oceanographic circulation.

For details, see

Fukuda, Y., Higashi, T., Takemoto, S., Iwano, S., Doi, K., Shibuya, K., Hiraoka, Y., Kimura, I., McQeen, H. and Govind, R. (2004): Absolute gravity measurements in Australia and Syowa Station, Antarctica. IAG International Symposium, Gravity, Geoid and Space Mission GGSM2004. IAG Symposia, Springer.

Iwano, S., Fukuda, Y., Sato, T., Tamura, Y., Matsumoto, K. and Shibuya, K. (2005): Long period tidal factors at Antarctica Syowa Station determined from ten years of superconducting gravimeter data. J. Geophys. Res. In press.

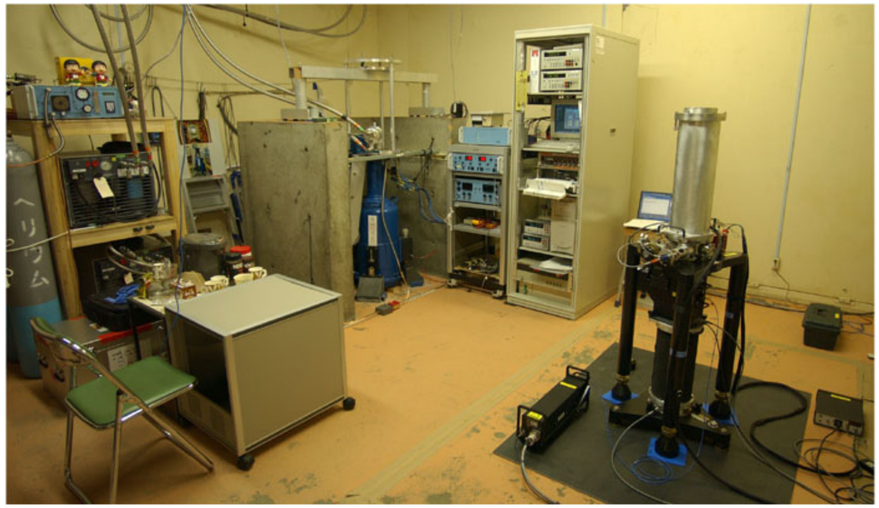
Ikeda, H., Doi, K., Fukuda, Y., Tamura, Y. and Shibuya, K. (2005): Installation of the superconducting gravimeter CT(#043) at Syowa Station, Antarctica. Polar Geosci., 18, 49-57.

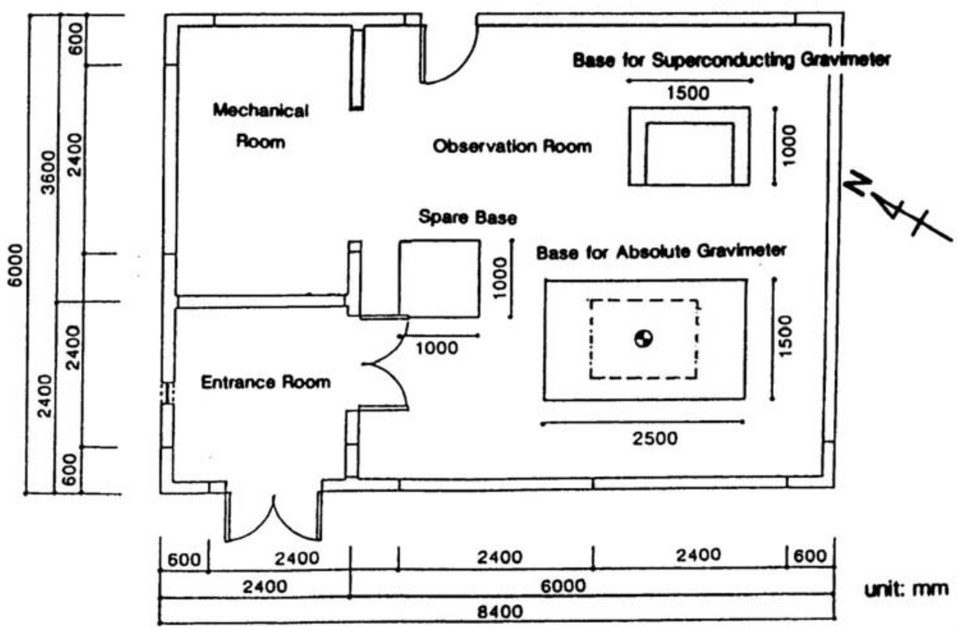
Shibuya, K., Doi, K., Fukuzaki, Y. and Iwata, M. (2005): Geodesy reference points within Syowa Station, Antarctica, and their local geodetic ties. Polar Geoscience, 18, 130-161.

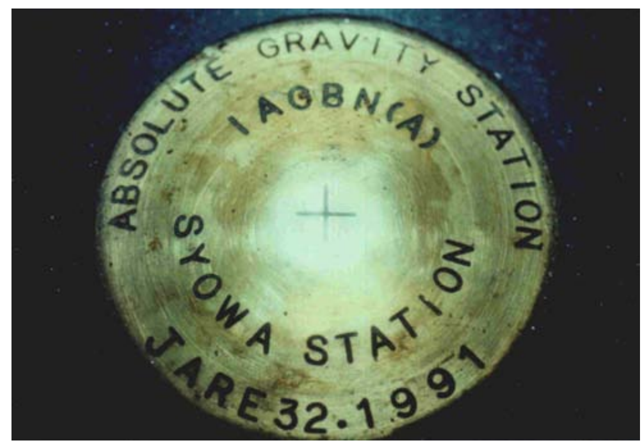
Shibuya, K., Doi, K., Sato, T. and Tamura, Y. (2005): Syowa superconducting gravimeter raw data and associated expedition reports (explanatory CD-ROM). JARE Data Reports, No. 283 (Earth Science 6), 34p.

(a)

AG/SG




Mechanical Room
Observation Room
Base for Superconducting Gravimeter
Spare Base
Base for Absolute Gravimeter
Entrance Room
1500
1000
1000
1000
1500
2500
600
2400
3600
6000
2400
2400
600
600
2400
2400
2400
600
2400
6000
8400
unit: mm


ABSOLUTE GRAVITY STATION
IAGBN(A)
SYOWA STATION
JARE 32.1991

(b)

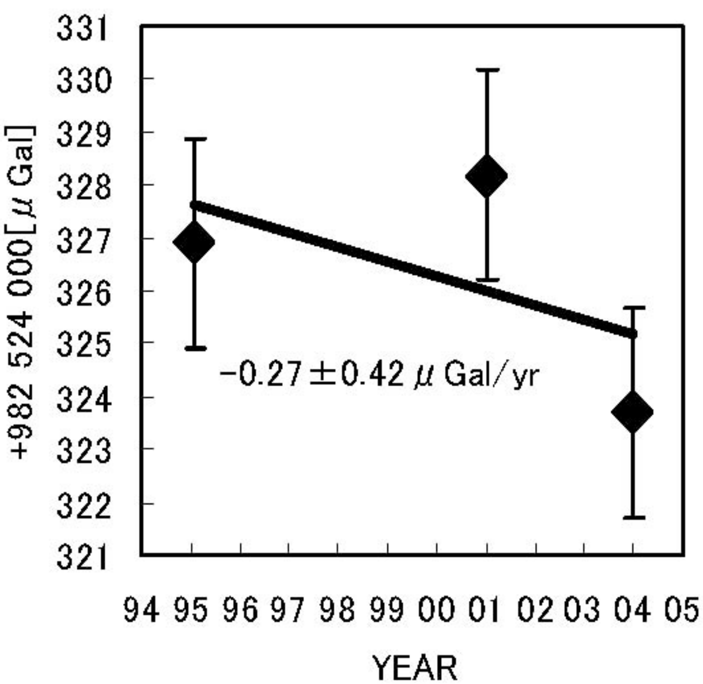


Table 2. (a) Estimated ocean tide effects. The second and third columns are estimated by using ocean model data and the forth and fifth columns by the observed values on a grid within 1 degree from Syowa Station. (b) Corresponding tidal parameters which are corrected for the ocean tide effects. The theoretical values for the elastic and inelastic solid Earth models by Dehant et al. [1999] are also shown. Phase lags are positive values.

(a)

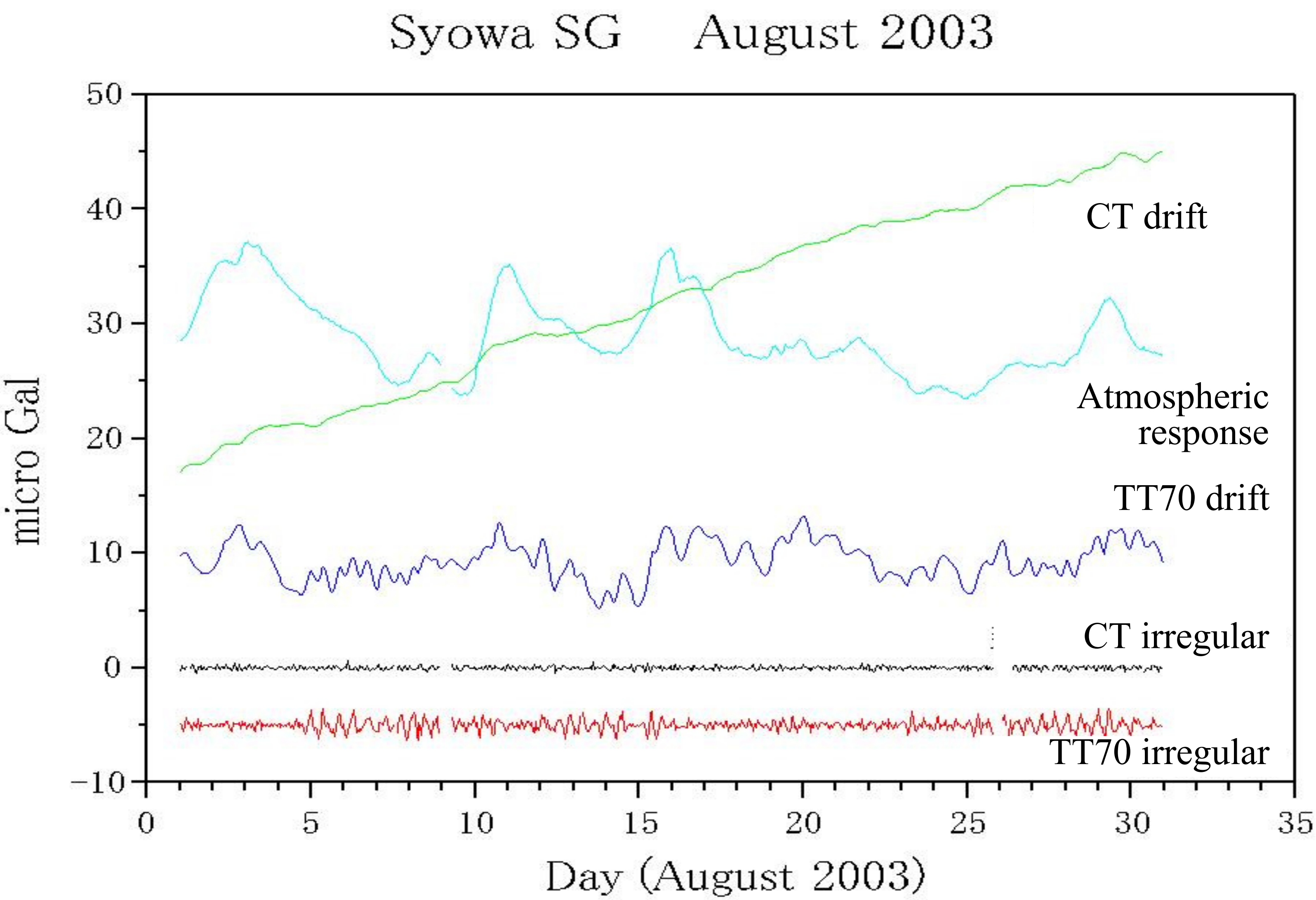
	Using ocean model data		Using observed values	
	Amplitude [μGal]	Phase [degree]	Amplitude [μGal]	Phase [degree]
NAO.99L				
Mm	0.239	190.399	0.239	189.023
Mf	0.416	197.343	0.403	198.558
Mtm	0.072	203.425	0.071	201.789
FES99				
Mm	0.209	182.039	0.211	182.689
Mf	0.418	189.524	0.386	192.574
TPXO6.0				
Mm	0.232	188.816	0.235	187.541
Mf	0.416	198.943	0.404	199.940
SCH				
Mm	0.228	185.880	0.232	187.215
Mf	0.372	200.389	0.364	201.223

(b)

	Using ocean model data		Using observed values		Theory Elastic	Inelastic
	δ factor	Phase [degree]	δ factor	Phase [degree]	δ factor	δ factor
NAO.99L						
Mm	1.1568	0.08	1.1570	0.03	1.1547	1.1574
Mf	1.1614	-0.16	1.1600	-0.14	1.1547	1.1571
Mtm	1.1609	0.93	1.1608	0.87	1.1547	1.1570
FES99						
Mm	1.1520	-0.24	1.1523	-0.22	1.1547	1.1571
Mf	1.1629	-0.42	1.1596	-0.36	1.1547	1.1570
TPXO6.0						
Mm	1.1557	0.01	1.1563	-0.03	1.1547	1.1571
Mf	1.1611	-0.11	1.1598	-0.10	1.1547	1.1570
SCH						
Mm	1.1552	-0.10	1.1558	-0.05	1.1547	1.1574
Mf	1.1568	-0.15	1.1559	-0.14	1.1547	1.1571

(c) Ten years' Syowa SG data archive

(d)



Syowa SG August 2003
micro Gal
Day (August 2003)
50
40
30
20
10
0
−10
0
5
10
15
20
25
30
35
CT drift
Atmospheric response
TT70 drift
CT irregular
TT70 irregular

III. An Experiment of Precise Gravity Measurements on the Ice Sheet

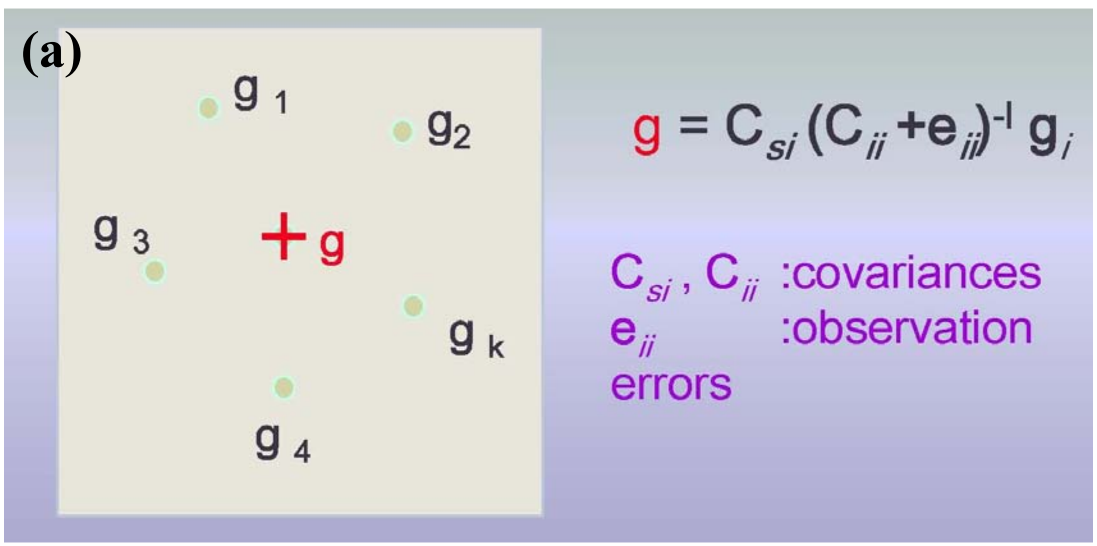
There are basically (i) 3 causes with (ii) 5 factors in the gravity change on the ice sheet. They are (i) mass change, density change and height change with (ii) snow accumulation/ablation, ice sheet flow, melting, compaction and post-glacial rebound.

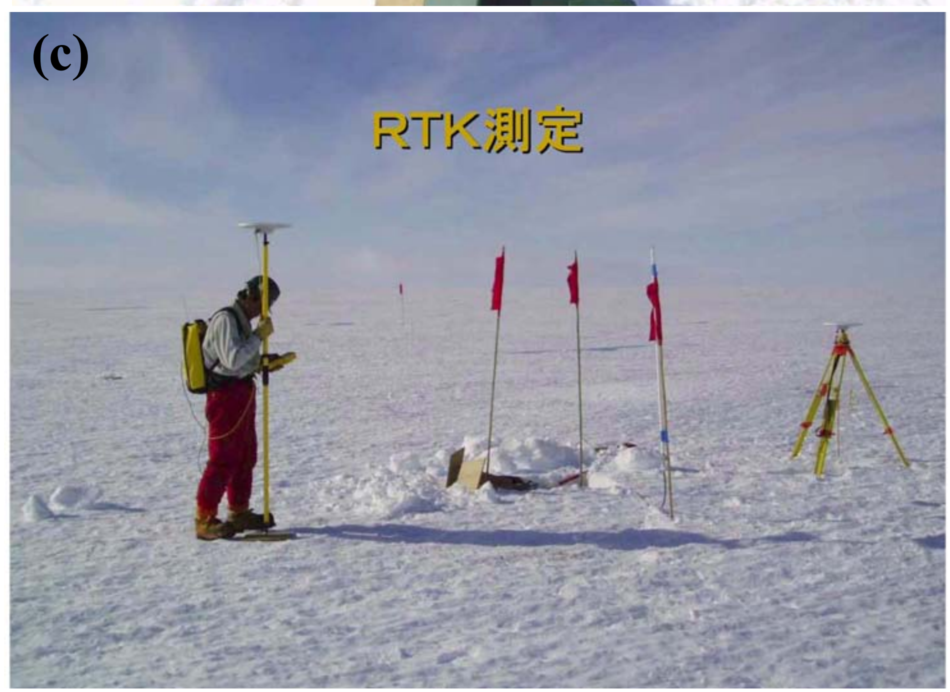
With the network grids of 10 m intervals in the area of 50 m by 50 m, the gravity value at some specified point can be estimated with the combination of 25 observed values as schematically given by Fig. a.
b. Is the relative gravity meter capable of measuring the gravity value accurate to 10 μGal? → YES
c. Is the RTK-GPS capable of measuring the 3D position accurate to 1 cm? → YES

How about the operational feasibility?
→Some know-how is required to deploy measuring points and accomplish the survey within 1 day. Portable AG of 1-2 μGal accuracy is desired at the specified point for the detection of several μGals by a repeated survey (1 year after).

For details, see

Fukuda, Y., Hiraoka, Y. and Doi, K. (2005): An Experiment of Precise Gravity Measurements on the Ice Sheet, Antarctica, presented at the Dynamic Planet 2005, Cairns, Australia, Aug. 25, PTH0090, p292.





IV. Ocean Dynamics around the Lützow-Holm Bay Region

Seasonal and long-term water mass variation in the Antarctic region is of greater concern from the viewpoint of global environmental change.

In addition a pressure-transducer type sensor at the Nisi-no-ura Cove (Fig. a) at Syowa Station, we deployed two OBPs (Fig. b) 260 km north of Syowa Station in the Southern Ocean on December 15, 2004, and picked up one on February 10, 2005, where their sites are shown in Fig. c. The both sensors recorded the T-phase and the main tsunami waves from the disastrous Sumatera Earthquake of December 26, 2004 (see Fig. d).

Preliminary comparison of the tidal factors of principal waves is summarized in Table 1.

For details, see

Shibuya, K., Doi, K., Fukuzaki, Y. and Iwata, M. (2005): Geodesy reference points within Syowa Station, Antarctica, and their local geodetic ties. Polar Geoscience, 18, 130-161.

Doi, K., Shibuya, K., Nogi, Y. and Ishikawa, N. (2005): Observation by ocean bottom pressure gauges in the Antarctic Ocean, presented at the Dynamic Planet 2005, Cairns, Australia, Aug. 25, PTH0087, p291.

Table 1. Tidal factors of principal waves observed by the OBP

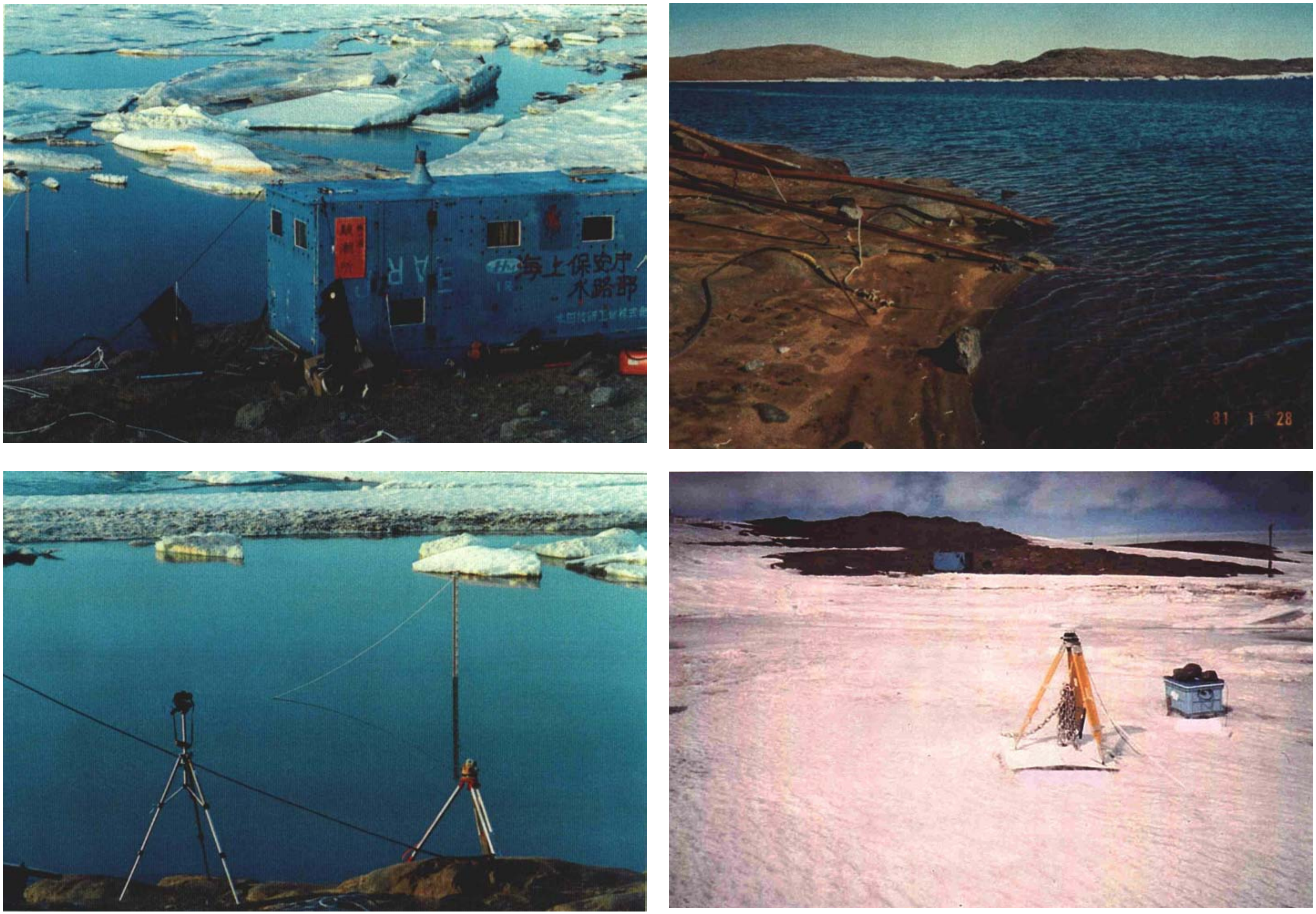
Wave	Amplitude (cm)	RMSE (cm)	Phase (°) (local, lag:negative)	RMSE (°)
Q1	4.988	0.220	−162.342	2.531
O1	21.477	0.267	−171.695	0.711
P1S1K1	19.105	0.200	−178.361	0.599
N2	3.679	0.062	−159.799	0.967
M2	21.239	0.079	−161.774	0.212
S2K2	16.236	0.083	−176.004	0.292

Table 2. Tidal factors for principal waves observed by the BPG at the Nishi-no-ura Cove

Wave	Amplitude (cm)	RMSE (cm)	Phase (°) (local, lag:negative)	RMSE (°)
Q1	6.306	0.089	−159.461	0.810
O1	25.937	0.107	−170.756	0.236
P1S1K1	23.184	0.086	−176.648	0.212
N2	4.379	0.071	−159.917	0.927
M2	26.341	0.091	−160.326	0.198
S2K2	21.090	0.102	−176.002	0.276

(a)

Nisi-no-ura Cove



(b) Southern Ocean (66.9°S, 37.8°E)

(c) Ocean tide observations

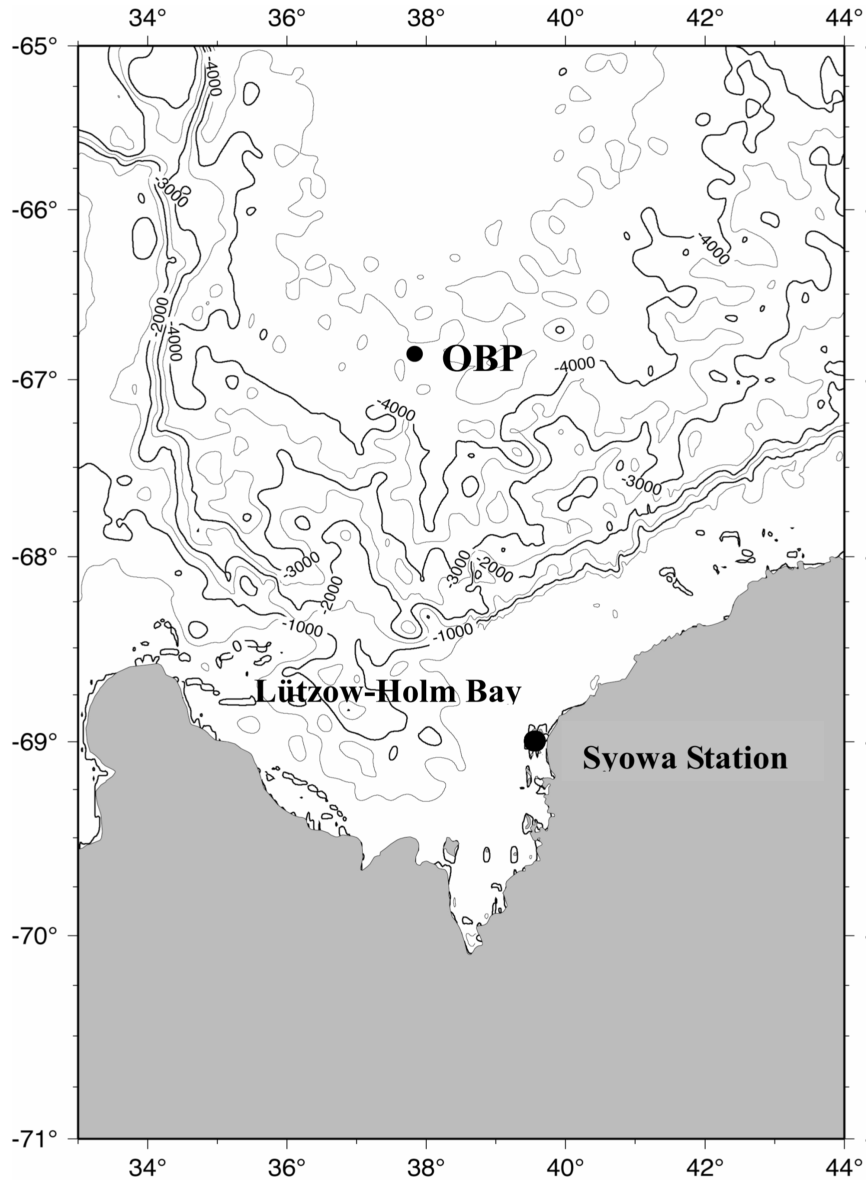
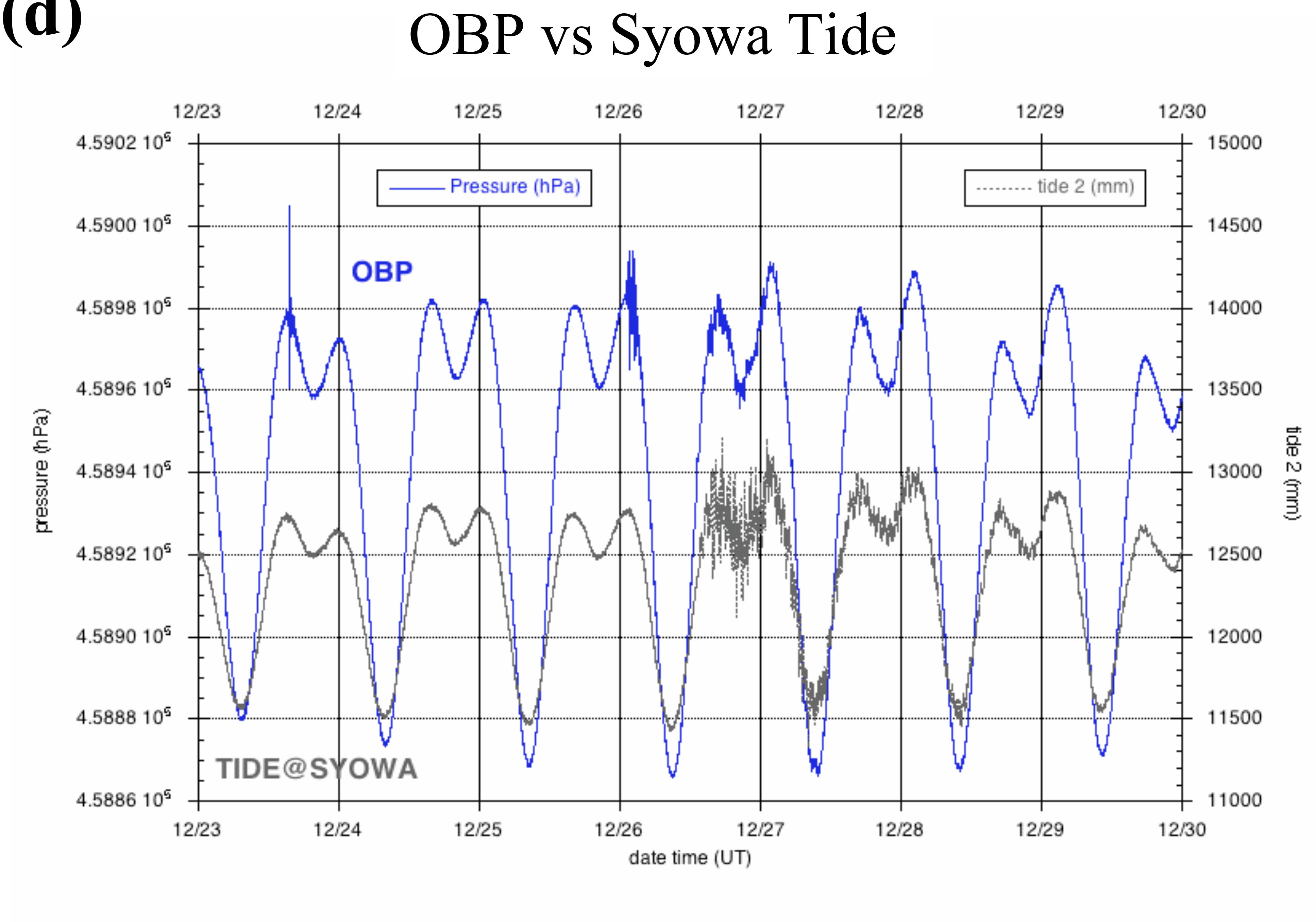


Fig. 1 Location where the OBP was set.

(d)



OBP vs Syowa Tide
12/23
12/24
12/25
12/26
12/27
12/28
12/29
12/30
Pressure (hPa)
tide 2 (mm)
OBP
TIDE@SYOWA
4.5902 10⁵
4.5900 10⁵
4.5898 10⁵
4.5896 10⁵
4.5894 10⁵
4.5892 10⁵
4.5890 10⁵
4.5888 10⁵
4.5886 10⁵
pressure (hPa)
15000
14500
14000
13500
13000
12500
12000
11500
11000
tide 2 (mm)
date time (UT)

V. Water Mass Variation of the Antarctic Ice Sheet Derived from the GRACE Gravity Fields

We utilized the released 22 GRACE Level-2 monthly gravity field solutions (4/5, 8, 9, 10, 11 of 2002, 2, 3, 4, 5, 7, 8, 9, 10, 11, 12 of 2003, and 1, 2, 3, 4, 5, 6, 7 of 2004) to the degree and order of 120 (or 70). Effects of ocean pole tides were corrected for based on Wahr (1985). Effects of atmospheric tides Sa and Ssa for the degree > 10 were also corrected for. Then we calculated the average gravity fields. We subtracted the average gravity fields from each monthly solution to obtain variation fields. This procedure is shown in the upper half of Fig. a.

Based on Swenson and Wahr (2003), we designed the regional filter of the Gaussian type to obtain the optimized shape by minimizing the "leakage error plus measurement error". For this filter design, we considered three cases of the whole Antarctica (Fig. b left), West Antarctica (Fig. b middle) and East Antarctica (Fig. b right).

We calculated the mass variation by averaging thus filtered signals and by converting the geoid height variation to the water equivalent thickness. The results are shown in the lower half of Fig. a, which indicate a few centimeter thickness water equivalent variation. The results highlight that (1) the amplitude of annual variation is larger in 2003 as compared with that in 2002, and that (2) the amplitude of variation range is larger in West Antarctica than that in East Antarctica.

This study will be presented at the 25th Symposium on Antarctic Geosciences held in October 13-14, 2005 at NIPR by K. Yamamoto and Y. Fukuda.

Fig. c shows the anticipated effect of geoid variation due to ice sheet thinning in the Shirase Glacier region for the typical cases of wider extent (left panel) and narrower extent (right panel). We will continue our study to detect ice mass change in the region concerned from the integrated researches presented today.

(a)

Estimate of regional mass variation

GRACE Level 2 data

↓

Correct for ocean pole tide

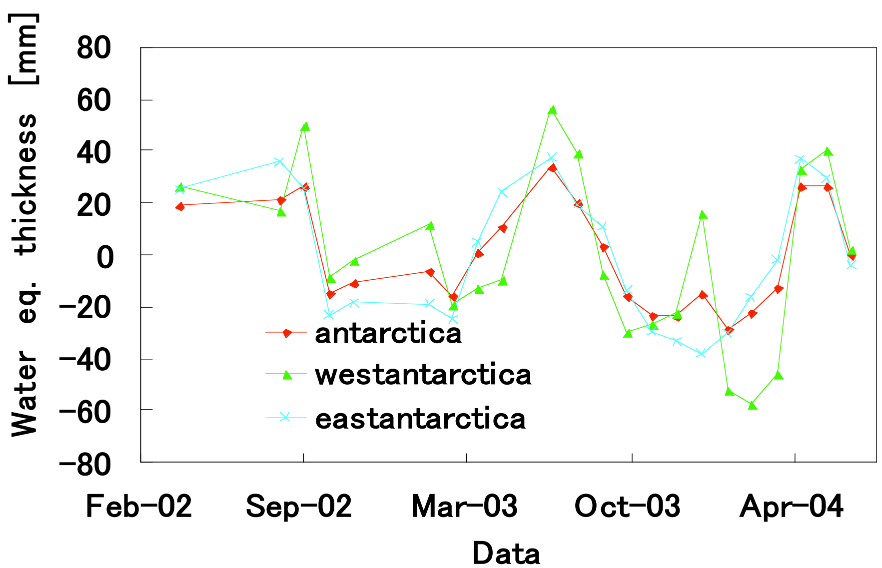
Correct for Sa and Ssa effect for the degree > 10

↓

Reduce average fields of 22 monthly data

↓

Calculate regional average of mass variation after filtering



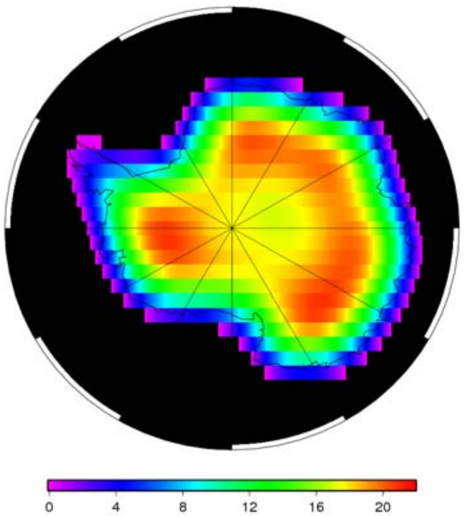
Results

- The amplitude of the 2002-year annual variation is larger than that of the 2003-year.
- The amplitude of variation is larger in West Antarctica than in East Antarctica.

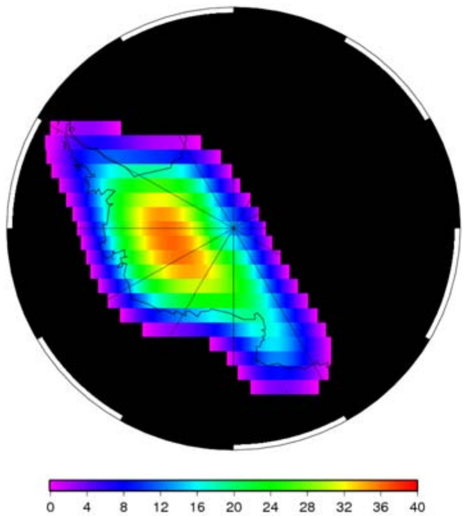
(b)

Design of regional filter in Antarctica is
Based on Swenson and Wahr (2003)
Gaussian-type and minimizing "leakage error + measurement error"
In a least-squares

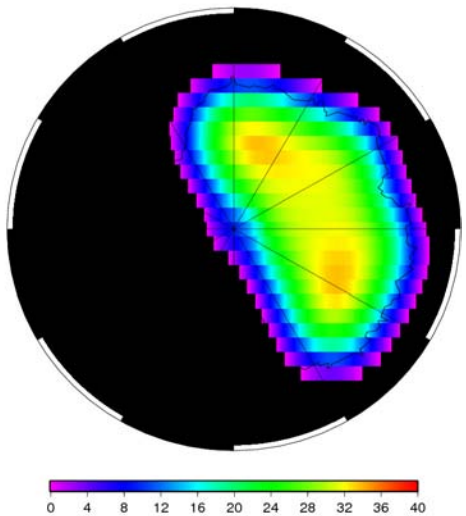
Designed Filter
(Mean radius of the Gaussian filter = 500 km)



Whole Antarctica



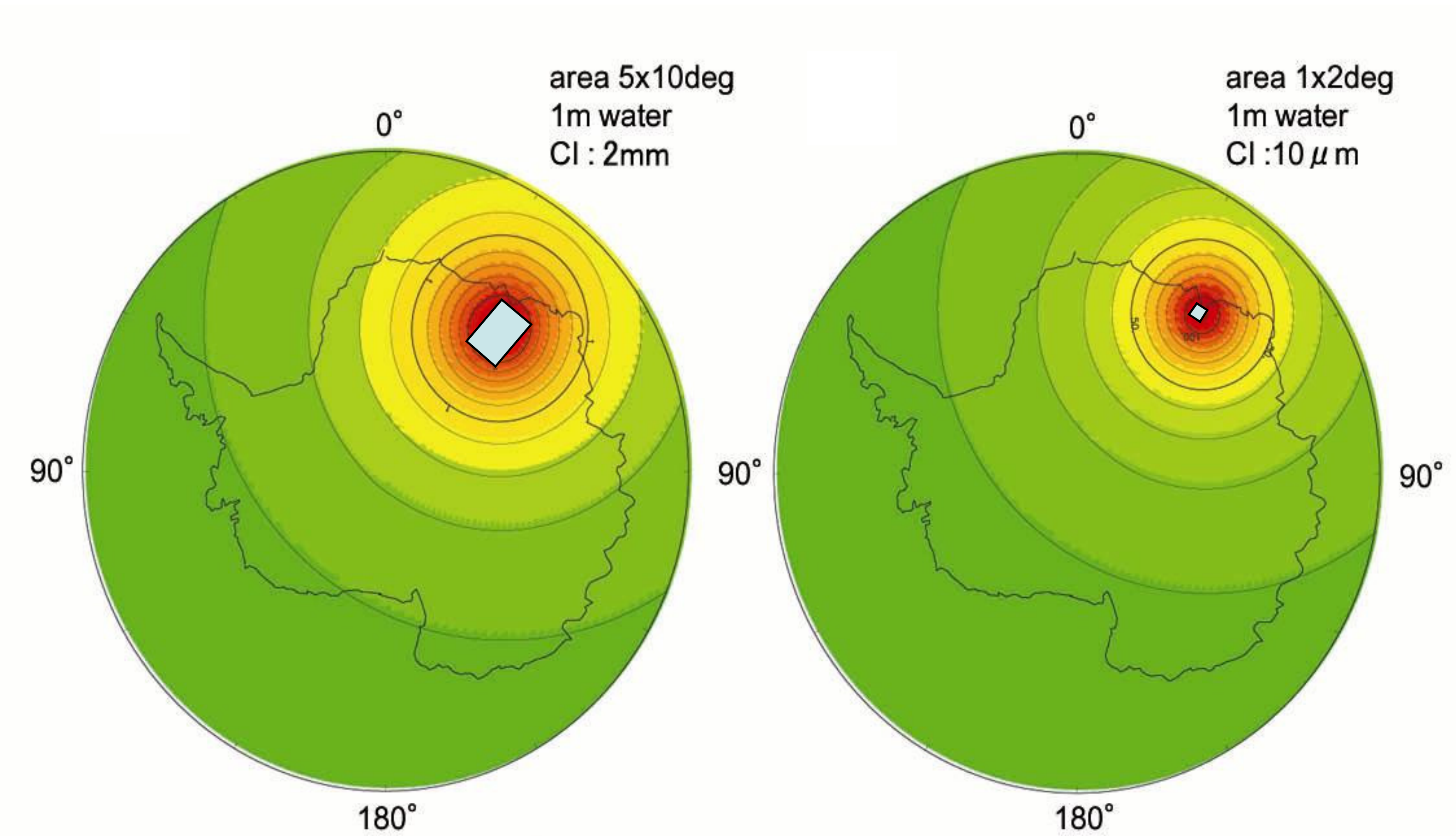
West Antarctica
Longitude: 150-330
(Includes ice shelf)



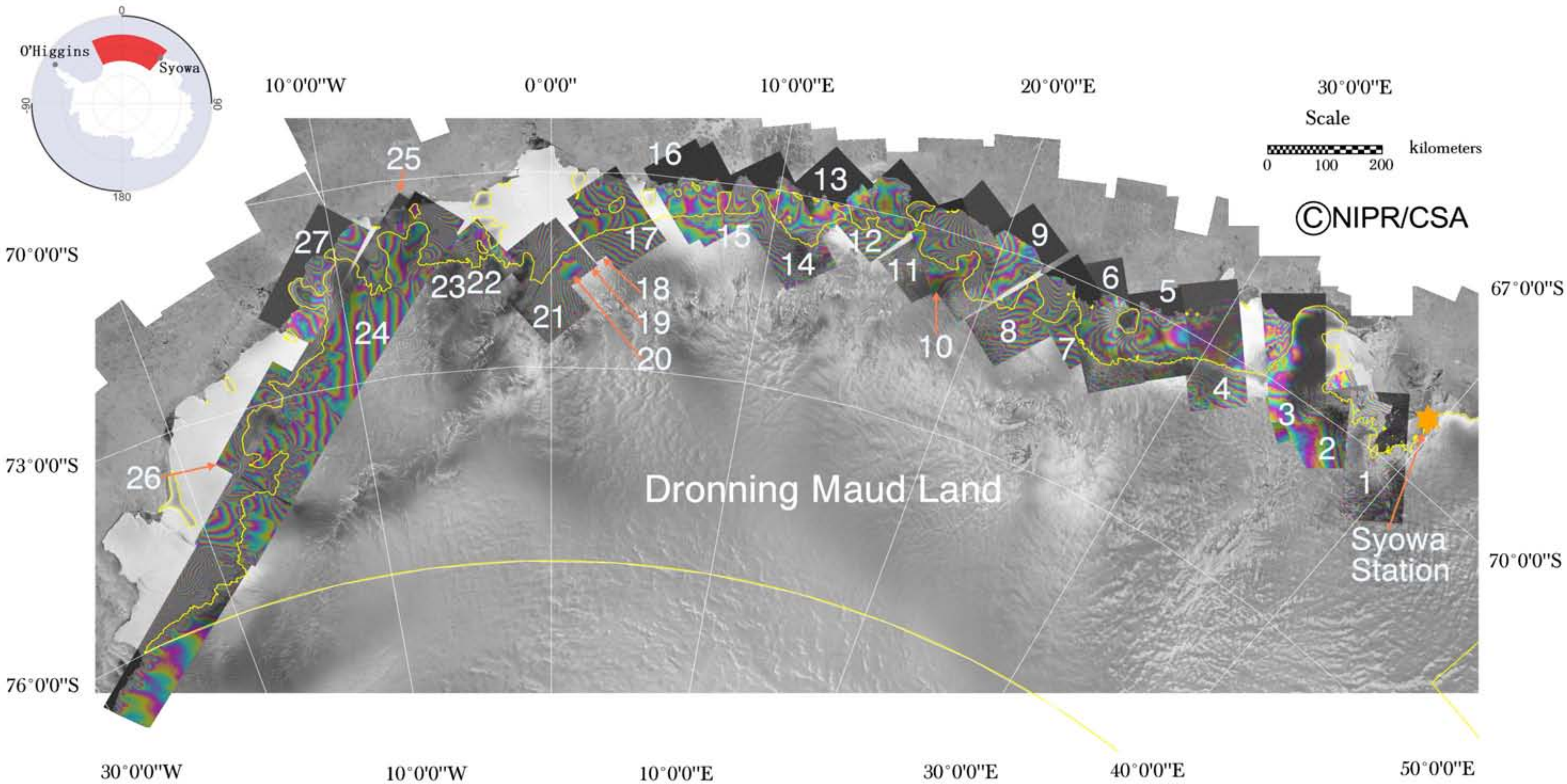
East Antarctica
longitude: 0-150, 330-360

(c)

Geoid Variation due to Ice Sheet Thinning



VI. ERS-1/ERS-2 InSAR derived grounding lines in the region from 30°W to 40°E



The InSAR derived grounding lines delineated detailed shape and accurate position as compared to those in the Antarctic Digital Database (ADD Consortium, 2000)

Details are given by

Yamanokuchi, T., Doi, K. and Shibuya, K. (2005): Validation of grounding line of the East Antarctic Ice Sheet derived by ERS-1/2 interferometric SAR data. Polar Geosci., 18, 1-14.

GRACE Science Team Meeting
October 13-14, 2005
Center for Space Research, University of Texas at Austin

Calibration/Validation of GRACE-derived gravity fields using the ground data obtained in the Japanese Antarctic Research Expedition area and Syowa Station, Antarctica

Kazuo Shibuya and 11 co-investigators

Short Title : Validation of GRACE data from Syowa data

Research Program of 2006 by the NIPR-JARE Group

-Ice sheet thinning of the Shirase Glacier drainage basin

We will conduct airborne geophysics surveys by using POLAR4 of DLR in collaboration with AWI, Germany. The planned profiles are shown in Fig. a.

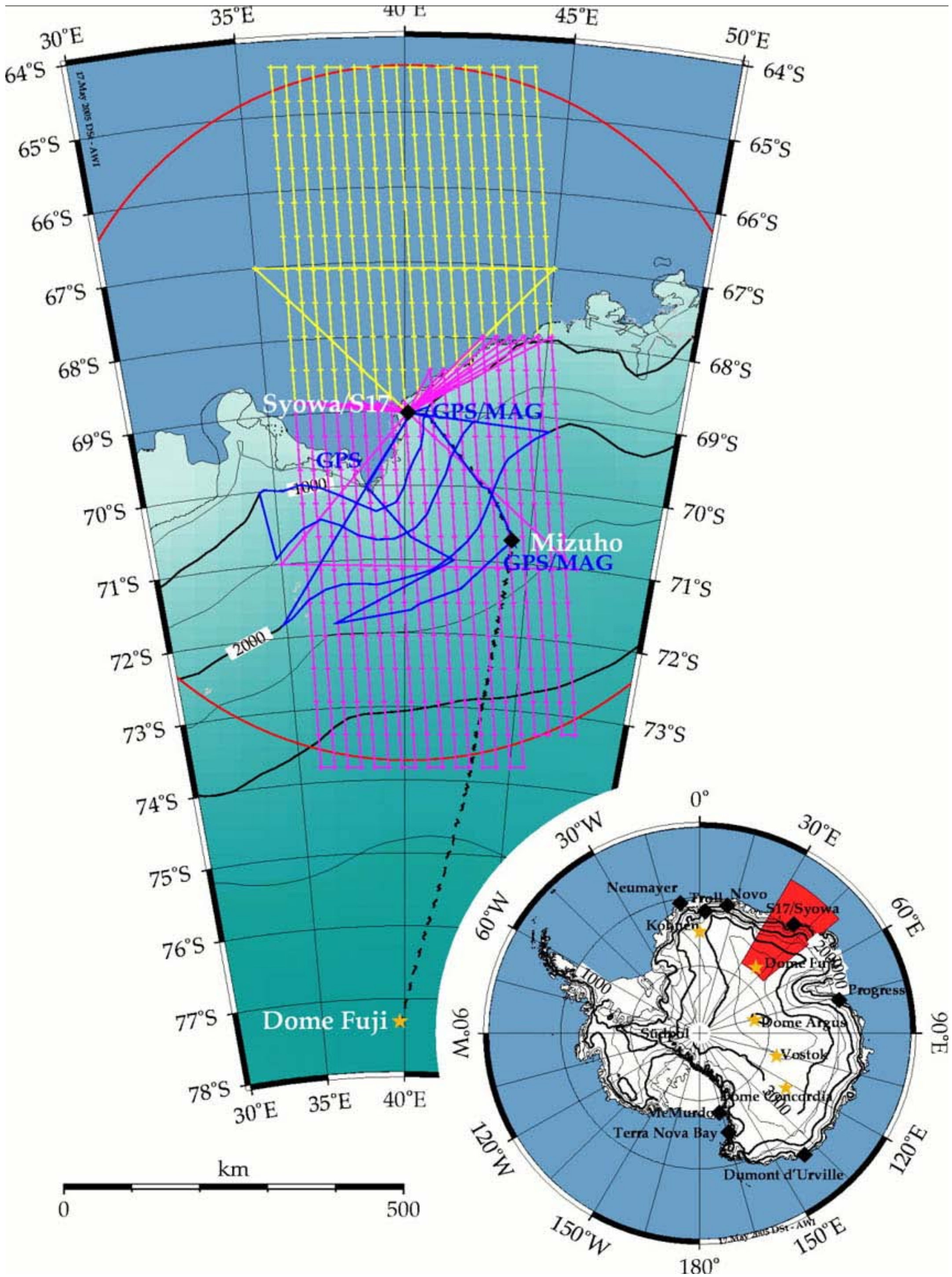
-Ocean dynamics around the Lützow-Holm Bay region

Sea bottom topography / stratigraphy is little known, and we will conduct tests for acoustic sounding system as the JARE-47 wintering program. The planned system is shown in Fig. b.

-Postglacial rebound in the JARE research area

Station and regional geodesy programs will continue as in Fig. c.

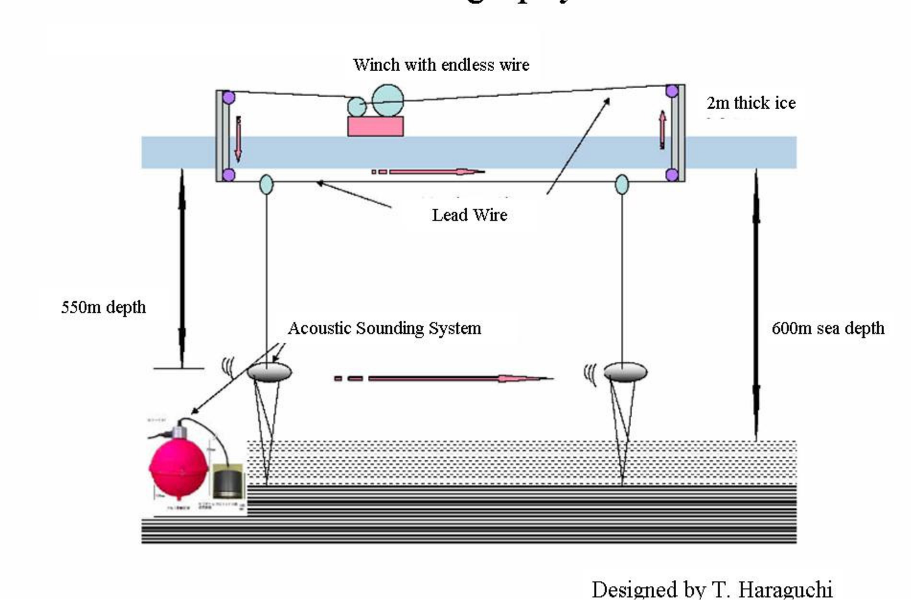
(a)

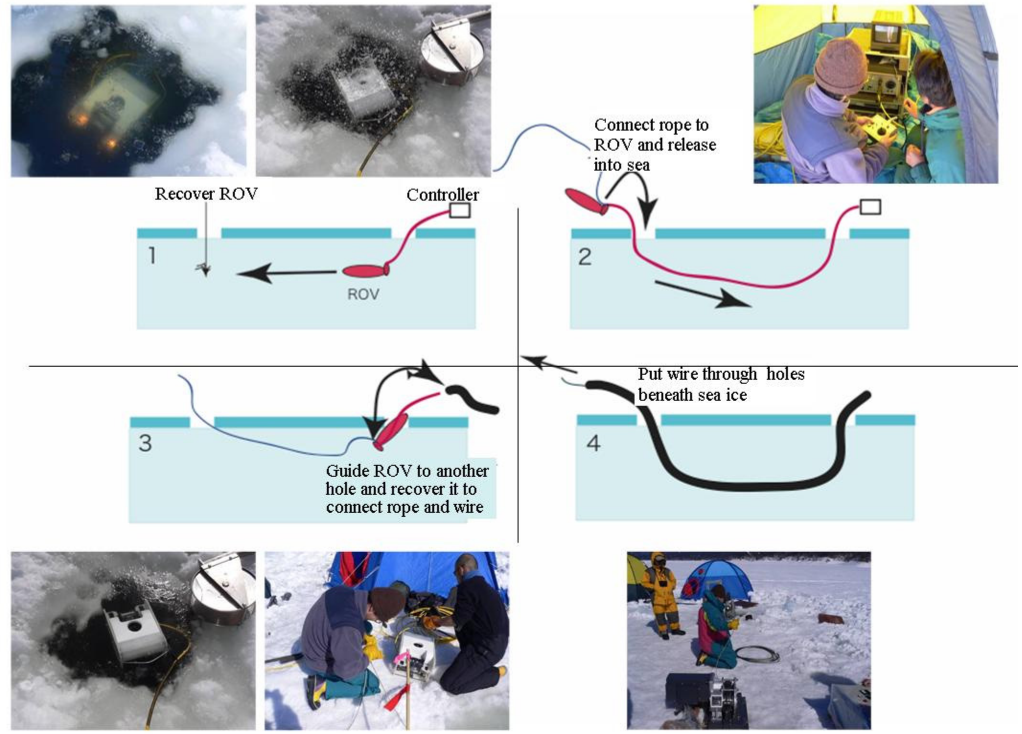


30°E
35°E
40°E
45°E
50°E
64°S
65°S
66°S
67°S
68°S
69°S
70°S
71°S
72°S
73°S
74°S
75°S
76°S
77°S
78°S
Syowa/S17
GPS/MAG
GPS
1000
Mizuho
GPS/MAG
2000
Dome Fuji
km
0
500
0°
30°W
30°E
60°W
60°E
90°W
90°E
120°W
120°E
150°W
150°E
180°
Neumayer
Troll
Novo
S17/Syowa
Kohnen
Dome Fuji
Progress
Dome Argus
Vostok
Dome Concordia
McMurdo
Terra Nova Bay
Dumont d'Urville

(b)

Proposed Acoustic Sounding System for Bottom Stratigraphy from Sea-Ice Sueface

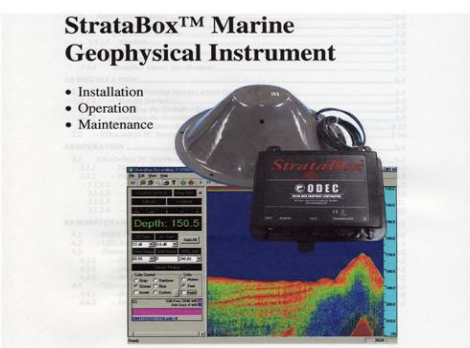




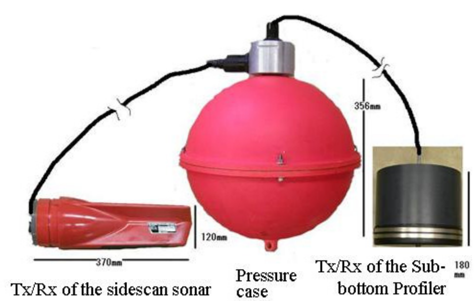
Dvices for the Proposed Acoustic Sounding System

Prototype of the Winch/wire System

Utilization of StrataBox



Coufiguration of the sub-bottom Profiler and Sidescan Sonar



Operation reguires know-how, but we succeeded in putting wire through the two holes at 200m distance

(c) *Observation Schedule*