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Field measurements of absolute gravity in East Antarctica

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Abstract This paper reports the results of field-based absolute gravity measurements aimed at detecting gravity change and crustal displacement caused by glacial isostatic adjustment. The project was initiated within the framework of the 53rd Japanese Antarctic Research Expedition (JARE53). Absolute gravity measurements, together with GPS measurements, were planned at several outcrops along the Prince Olav Coast and Sôya Coast of East Antarctica, including at Syowa Station. Since the icebreaker *Shirase* (AGB 5003) was unable to moor alongside Syowa Station, operations were somewhat restricted during JARE53. However, despite this setback, we were able to complete measurements at two sites: Syowa Station and Langhovde. The absolute gravity value at the Syowa Station IAGBN (A) site, observed using an FG-5 absolute gravimeter (serial number 210; FG-5 #210), was 982 524 322.7±0.1 μGal, and the gravity change rate at the beginning of 2012 was –0.26 $\mu\mathrm{Gal}\cdot\mathrm{a}^{-1}$. An absolute gravity value of 982 535 584.2±0.7 μGal was obtained using a portable A-10 absolute gravimeter (serial number 017; A-10 #017) at the newly located site AGS01 in Langhovde.

Keywords **absolute gravity, field measurement, Antarctica, A-10 and FG-5 absolute gravimeters, GPS, JARE**

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1 Introduction

Glacial isostatic adjustment (GIA) and ongoing changes in ice sheet mass in Antarctica cause gravity change and crustal displacement. These changes can be identified by measuring temporal variations in gravity and elevation, using iterative implementation of combined absolute gravity and global navigation satellite system (GNSS) measurements for periods more than 10 a, at an interval of 2–3 a[1–2]. Data regarding viscosity of the Earth's mantle can also be extracted from viscous gravity change and vertical displacement measurements.

Most absolute gravity measurements in Antarctica have been carried out on a stable base, and at an observation station with power supply[3]. Absolute gravity measurements were conducted four times between 1995 and 2010 at the IAGBN (A) site at Syowa Station, using several FG-5 absolute gravimeters[4]. A gravity change rate of −0.27 $\mu\mathrm{Gal}\cdot\mathrm{a}^{-1}$ ($1\ \mu\mathrm{Gal} = 10^{-8}\ \mathrm{m}\cdot\mathrm{s}^{-2}$) was obtained from measurements through 2004[5].

Development of the portable A-10 absolute gravimeter has permitted absolute gravity measurements at a number of field sites. Although nominal accuracy of the gravimeter is 10 μGal[6], it is possible to take more accurate gravity measurements under quiet conditions with no ground vibration.

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To explore in detail gravity changes and vertical displacements associated with GIA and recent changes in mass of the Antarctic ice sheet, gravity and elevation data are required from more sites. Therefore, we planned a combined measurement program during the Japanese Antarctic Research Expedition (JARE) that comprised absolute and relative gravity measurements, as well as GNSS measurements, at several sites on outcrops along the Sôya Coast and Prince Olav Coast.

Accurate absolute gravity values contribute to production of accurate gravity anomaly maps. Absolute gravity measurements from the outcrop areas will also act as reference values for future surveys.

In this paper, we provide an overview of the project, describe measurement procedures during JARE53 (2011–2013), and summarize preliminary results based on our gravity measurements.

2 Project overview

A project with field measurements of absolute gravity in Antarctica was initiated as a general research observation program, within the framework of the eighth phase of the Japanese Antarctic Research Project. The title of the program is “Estimation of Displacement Rate due to Post Glacial Rebound by Means of Repeat Absolute Gravimetry and GPS Measurement” (Code number AP18; Principal Investigator: Koichiro Doi). The research was done between 2010 and 2013, which covered the period from JARE52 to JARE54.

Project objectives were to: (1) Detect gravity changes and crustal displacements associated with GIA, as well as those caused by current changes in ice sheet mass; (2) determine the precise gravity field of East Antarctica. The following measurements were planned: (1) Absolute gravity measurements at Syowa Station, using an absolute gravimeter (FG-5); and (2) field measurements of absolute gravity using an A-10 absolute gravimeter, relative gravity measurements using two LaCoste & Romberg gravimeters, and GPS measurements. Relative gravity measurement lines were designed on several outcrops, to detect seasonal and/or annual gravity change owing to mass change in the ice sheet. Ten sites were identified for the absolute gravity and GPS measurements on outcrops along the Sôya Coast and Prince Olav Coast (Figure 1), and we planned to repeat the measurements several times at the same sites (every three or four years) to determine gravity and crustal displacement rates.

3 Implementation of the project

3.1 Field reconnaissance during JARE52

Our research program commenced during JARE52 (2010–2012), when preliminary field research was being conducted at several potential sites along the Sôya Coast and Prince Olav Coast[8]. The availability of a suitable measurement site, campsite, and helicopter landing field were confirmed, and weather conditions and surrounding topography were noted.

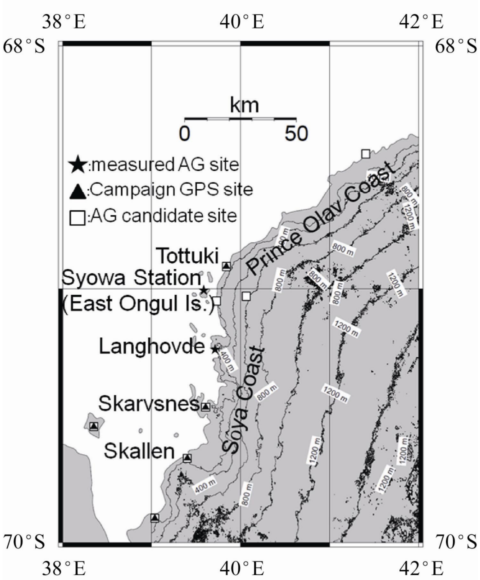

Figure 1 Location of candidate absolute gravity measurement sites (□) and of absolute gravimeter (★) and campaign GPS (▲) measurement sites. This figure is drawn by using GMT(v3.4.5)[7].

3.2 Measurement procedures during JARE53

3.2.1 Problems encountered

During the season between the end of 2011 and beginning of 2012, both sea ice and snow cover on the sea ice were very thick; consequently, icebreaker *Shirase* was unable to moor alongside Syowa Station. In addition, we were unable to use a large helicopter to transport equipment from the *Shirase* to the monitoring sites as planned. Use of a smaller helicopter meant that several flights were necessary to each site, and this restricted the distance that it was possible to travel from Syowa Station. Consequently, the combined field measurements, consisting of absolute measurements, static GPS measurements and relative gravity measurements with a kinematic GPS, were made at only one site, Langhovde.

3.2.2 Gravity measurement at Syowa Station

Absolute gravity measurements with the FG-5 #210 were taken on the IAGBN (A) metal plate with identification number 0417 (IAGBN(A) #0417; 69.006 734 72°S, 39.585 691 9°E), in the gravity hut at Syowa Station between 2–8 January 2012. In addition, gravity measurements using a LaCoste & Romberg gravimeter (G-805) were carried out at benchmark BM2316, and at two newly located sites (AGS03 and BHP01) near Syowa Station. Locations of the measurement sites are shown in Figure 2.

3.2.3 Gravity measurement at Langhovde

Absolute gravity measurements in the field were conducted

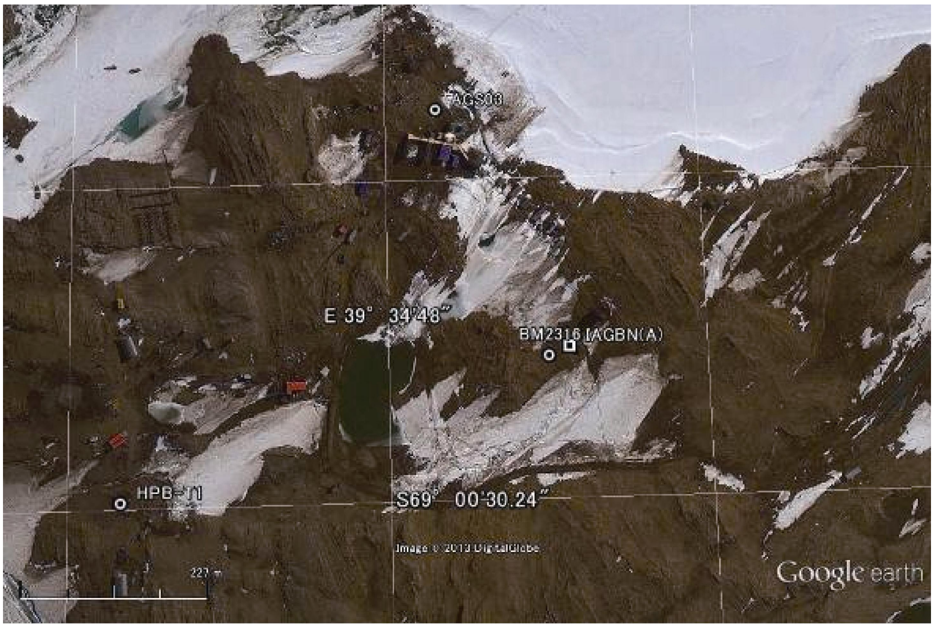

Figure 2 Locations of IAGBN (A) (square) and relative gravity measurement sites near Syowa Station (circles). This image used from Google Earth (v7.0.2; http://earth.google.com/).

for the first time during JARE on an outcrop near the Yukidori Hut in Langhovde on 3 February 2012, using the A-10 #017 gravimeter. A metallic disk was placed at site AGS01 (69.243 26°S, 39.715 97°E). Static GPS measurement was also done for 19 h at the site.

The A-10 gravimeter was installed in a bottomless tent at the AGS01 site, and the controller was set up in an adjacent tent. To guard against power failures, electric power was supplied from four 12 V batteries which were charged with a generator. To prevent artificial gravity change caused by laser cooling, the instrument was warmed for about four hours before the start of measurement[9].

Unfortunately, the A-10 #017 gravimeters 10-MHz rubidium clock had an extraordinarily large frequency drift. Such frequency change causes artificial gravity change. To correct for this artifact, the frequency change was estimated by comparing frequencies with other atomic clocks, such as hydrogen maser and cesium clocks available at Syowa Station. Absolute gravity values were re-determined by entering the estimated frequency drift into g-Soft absolute gravity processing software, which was installed on a laptop attached to the gravimeter[9].

Following the absolute gravity measurement, relative gravity measurements using the G-1110 LaCoste & Romberg gravimeter were made at four sites along Yatude Valley, based on the measurement at AGS01. Locations of these sites are shown in Figure 3.

To validate the absolute gravity measurement at AGS01, absolute gravity measurements using the A-10 were made on two occasions at the IAGBN (A) site at Syowa Station, both before and after the measurement at Langhovde.

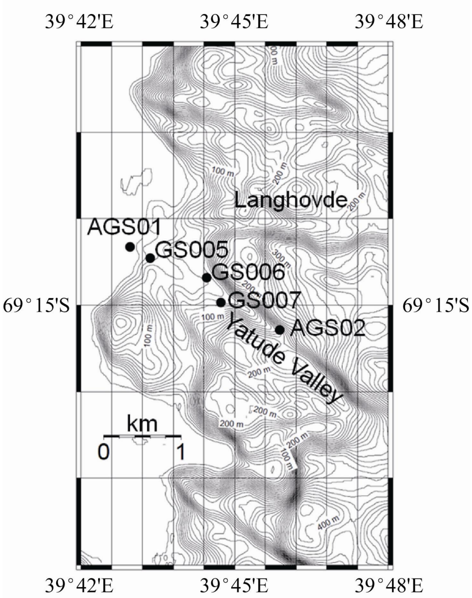

Figure 3 Gravity measurement sites in Langhovde. AGS01 is the reference site, which is an absolute gravity measurement site. This figure is drawn by using GMT(v3.4.5)[7].

4 Results

4.1 Absolute gravity at IAGBN(A)#0417 site, Syowa Station

The absolute gravity value obtained from Syowa Station at site IAGBN (A) was 982 524 322.7±0.1 μGal, and a detailed description of the procedure used to obtain this reading is given in Higashi et al.[10]. Absolute gravity was measured on five occasions at this site since 1995 (JARE36), using three FG-5 absolute gravimeters (serial #104, #203, and #210). The gravity change rate derived from these data is -0.26 µGal·a^{-1}[10].

4.2 Absolute gravity at Langhovde

Absolute gravity determined at Langhovde AGS01 was 982 535 584.2±0.7 µGal. Kazama et al.[9] gave a detailed description of the measurement procedure and parameters used here.

4.3 Relative gravity measurements at Syowa Station and Langhovde

Gravity values measured using the two LaCoste & Romberg gravimeters (G-805 and G-1110) were obtained from four sites, based on the absolute gravimetric value at AGS01 in the Langhovde region, and from three sites at Syowa Station based on the gravity value at site IAGBN (A). The gravity values and locations are shown in Table 1.

Table 1 Monitoring sites and gravity values measured during JARE53

Region	Site	Latitude/°N	Longitude/°E	Gravity value/(µGal)	Instrument
East Ongul Is.	IAGBN(A)	–69.006 730	39.585 690	982 524.323	FG-5 #210
East Ongul Is.	AGS03	–69.003 991	39.581 667	982 525.970	LaCoste & Romberg G-805
East Ongul Is.	BM2316	–69.006 833	39.585 039	982 524.501	LaCoste & Romberg G-805
East Ongul Is.	HPB-T1	–69.008 333	39.571 667	982 525.686	LaCoste & Romberg G-805
Langhovde	AGS01	–69.243 262	39.715 975	982 535.584	A-10 #017
Langhovde	AGS02	–69.252 836	39.764 664	982 509.603	LaCoste & Romberg G-1110
Langhovde	GS005	–69.244 541	39.722 561	982 528.846	LaCoste & Romberg G-1110
Langhovde	GS006	–69.246 802	39.740 880	982 523.767	LaCoste & Romberg G-1110
Langhovde	GS007	–69.249 652	39.745 495	982 518.293	LaCoste & Romberg G-1110

5 Expected gravity changes

Previous studies indicate that the possible rate of gravity change with elevation (dg/dh) is -0.31 µGal·mm^{-1} for the free-air gravity correction[11], and -0.154 µGal·mm^{-1} for the Bouguer gravity correction[1]. Ozono et al.[12] obtained rates of change at five GPS measurement sites on rock outcrops along the Sôya Coast, and we estimated prospective gravity change rates from these observed rates using the above dg/dh ratios. The observed elevation change rates at the five sites and expected gravity change rates based on those ratios are listed in Table 2. Based on an observational accuracy of ±0.7 µGal at Langhovde AGS01 and the expected gravity change rate, repeating absolute gravity measurements at intervals of two or three years should be sufficient to detect gravity change greater than 0.7 µGal at almost all sites.

Table 2 Expected gravity change at five campaign GPS sites

Site	dh/(mm·a^{-1})	Expected dg/(µGal·a^{-1})	
		dg/dh = –0.31 (µGal·mm^{-1})	dg/dh = –0.154 (µGal·mm^{-1})
Tottuki	4.51	–1.40	–0.69
Syowa	2.56	–0.79	–0.39
Langhovde	1.77	–0.55	–0.27
Skarvsnes	1.12	–0.35	–0.17
Skallen	3.00	–0.93	–0.46

6 Summary and future plans

A project to obtain outdoor absolute gravity and GPS measurements was planned and carried out in 2012 within the framework of JARE53, to detect crustal displacement owing to GIA. An absolute gravity value of 982 535 584.2± 0.7 µGal was recorded at site AGS01 on an outcrop of rock at Langhovde, and a new absolute gravity value of 982 524 322.7±0.1 µGal was added to the time series of absolute gravity values at the IAGBN (A) site at Syowa Station. Gravity values were also determined at four sites along Yatude Valley in Langhovde from relative gravity measurements made using a LaCoste & Romberg gravimeter, based on the absolute gravity value at AGS01.

As we were able to complete measurements only at Langhovde during JARE53, measurements at several other sites will be necessary in the near future. In addition, to detect gravity change induced by seasonal ice mass change, relative gravity measurements will be required at least twice a year.

In addition to measurements in coastal regions, measurements are also required from mountainous inland areas of East Antarctica, such as the Sør-Rondane and Yamato mountains. Such data on gravity changes and crustal displacements from the Antarctic interior could be used to constrain the developing ice-melt history of Antarctica.

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