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Calibration of the superconducting gravimeter CT#043 with an absolute gravimeter FG5#210 at Syowa Station, Antarctica

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Abstract: For the purpose of calibration of the superconducting gravimeter (SG) model CT#043 at Syowa Station, Antarctica, we carried out parallel observations with the absolute gravimeter (AG) FG5#210. Although the AG measurements were conducted from December 31, 2003 to February 9, 2004, SG measurements before January 17 are found to have suffered artificial sensitivity change. We finally adopted data from January 17 to February 1, 2004, and obtained the scale factor of CT#043 as $-59.461 \pm 0.079\,\mu$Gal/volt by linear regression analysis. The result achieved a relative accuracy of around 0.1%, which is important to modern precise tidal analysis. We also determined the scale factor by comparing the data of parallel observations with the SG TT70#016. Both values showed good agreement, supporting the reliability of the above mentioned value.

key words: superconducting gravimeter, scale factor, calibration, absolute gravity measurements

1. Introduction

It is well known that the superconducting gravimeter (SG) is the most sensitive and stable gravimeter, and SG observations are important for studies of Earth tides, ocean tides, Earth rotation, free core nutation, and various other problems (*e.g.*, Crossley *et al.*, 1999). Especially, SG observations in polar regions have advantages in the studies of long period tides, secular gravity changes due to post-glacial rebound and the Earth's core dynamics. SG observations at Syowa Station in Antarctica started on March 22, 1993 (Sato *et al.*, 1995) by employing an SG model TT70 (TT70#016), and the observations have brought a large number of scientific results (*e.g.*, Sato *et al.*, 1996, 1997a, b, 2001; Tamura *et al.*, 1997; Nawa *et al.*, 1998, 2000, 2003). However SG observation with model TT70 is not an easy task, especially at a remote site like Syowa Station, because complicated operation of a helium liquefier is necessary to obtain liquid helium. This operation periodically caused artificial noise in the SG data. Therefore, a new type of SG (CT#043), which is much smaller than the model TT70 and has a 4K cryo-cooler to free us from complicated operation of the helium liquefier, was installed in March 2003 (Ikeda *et al*., 2004). After more than 6 months of parallel observations, TT70#016 was replaced with CT#043 in November 2003.

In spite of its high sensitivity and stability, SG is a relative gravimeter and requires calibration of a scale factor which transforms the SG output voltage signal to gravity acceleration. In order to utilize SG data for the today's precise Earth tide studies, a calibration factor with accuracy of 0.1% or better is required (*e.g*., Baker and Bos, 2001). So far, TT70#016 has been calibrated was carried out three times: once for one year registration of the LaCoste & Romberg gravimeter D73 in 1994 (Kanao and Sato, 1995; Sato *et al*., 1995); once for parallel observations with an absolute gravimeter (AG) FG5#104 in 1996 (Aoyama *et al*., 1997); and once for parallel observations with FG5#203 (Iwano *et al*., 2003) in 2001. Among these calibrations, Iwano *et al.* (2003) gave the most reliable value of $-58.168\,\mu$Gal/volt with the relative accuracy of 0.10%. This value is commonly employed for the TT70#016 SG data analysis.

On the other hand, no direct calibration has been carried out for the new SG (CT #043) so far. A value estimated from parallel observations with TT70#016 was temporarily employed for the analyses. Therefore, urgent calibration with an absolute gravimeter was required. For the purpose of determining the scale factor of CT#043 as well as detecting secular gravity change at Syowa Station, AG measurements were carried out from December 31, 2003 to February 9, 2004 with two FG5s, #203 and #210, by the 45th Japanese Antarctic Research Expedition (JARE-45) during 2003–2005.

In this paper, we first review the SG observations at Syowa Station and the AG measurements during JARE-45 briefly, and then report the calibration value of CT#043 determined by the AG measurements. We also compare the obtained value with those estimated from the parallel observation with TT70#016.

2. Observations

2.1. *SG observations*

The SG observations at Syowa Station were conducted in the gravity observation hut (Shibuya, 1993; Shibuya *et al*., 2003). Figure 1 shows a sketch of the observation hut. There is a category "A" point of the International Absolute Gravity Basestation Network (IAGBN (A); Boedecker and Fritzer, 1986) on an isolated pier (AG pier) in the observation hut, and TT70#016 was placed on another isolated pier (SG pier) in the same observation hut. The initial installation of CT#043 was conducted from the beginning of February to the end of March, 2003 (Ikeda *et al*., 2004). Then CT#043 was tentatively installed on the AG pier, and about 7 months (from April to October, 2003) of parallel observations with TT70#016 were conducted.

In November 2003, the observation with TT70#016 was terminated, and TT70#016 was removed from the SG pier. In December 2003, CT#043 was moved to the SG pier for routine operation. The observation of CT#043 on the SG pier started formally from December 28, 2003, and has been continuing until now. Figure 2 shows the schedule of the SG observations together with the AG measurements described in the following section.

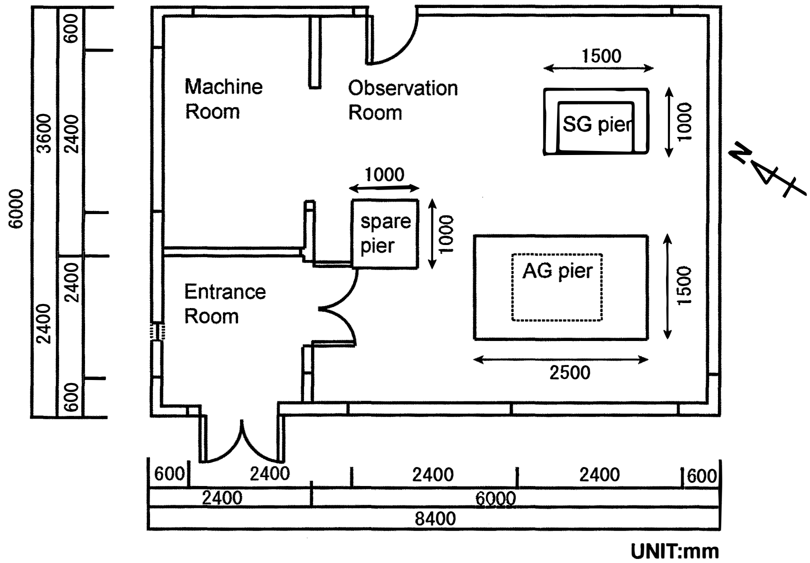

Fig. 1. Sketch of the gravity observation hut.

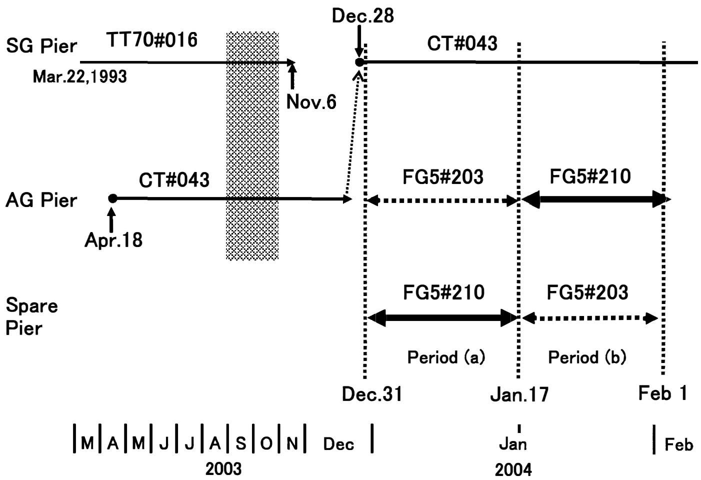

Fig. 2. Observation schedule in the gravity observation hut. Data of the dotted period were employed for the comparison between TT70#016 and CT#043.

2.2. AG measurements

The AG measurements during JARE-45 were conducted in the gravity observation hut after the CT#043 was moved to the SG pier. There is one more isolated pier (spare pier) in the gravity hut for general purposes. In parallel with CT#043 observations, we placed two AGs in the gravity hut so that FG5#203 occupied the AG pier and FG5#210 occupied the spare pier. The occupied AGs were exchanged with each other on January 17, 2004 to check the instrumental offset between the two AGs.

The absolute gravity values obtained are reported in Fukuda *et al.* (2005). Because of unspecified instrumental troubles, the scatter of FG5#203 was 2 to 3 times larger than that of FG5#210, even though the mean values agreed quite well; the difference was 1.7 μGal on the AG pier and 3.4 μGal on the spare pier. For the purpose of calibrating the SG, the smaller scatter of the measurements is important. Thus we decided to employ only the data obtained by FG5#210 for the calibration.

3. Determination of the calibration factor

3.1. Comparison of AG and SG data

Figure 3 shows all the AG and SG data from December 31, 2003 to February 9, 2004. To determine the calibration factor, we basically followed the procedure described in Iwano *et al*. (2003). After correcting for the time lag due to a low pass filter for the SG time series data and removing outliers from the AG time series data, the pairs of SG and AG data which correspond in time were compared.

Usually the SG drift rate is very small, and we do not need to consider it for the regression analyses to determine the scale factor. However, the drift rate of CT#043 is rather large, even though the reason is not known yet. A tentative tidal analysis shows that the drift rate of CT#043 in January 2004 was about 24 μGal/month: this large drift could not be ignored in the regression analyses. We thus estimated the drift rate as well as the scale factor simultaneously in the regression analyses.

Since the occupied AGs were exchanged on January 17 as previously described, regression analyses were conducted for two periods: (a) from December 31 to January 17 and (b) from January 17 to February 1. Figures 4a and b show the AG *vs* SG data corresponding to each of the two periods. The obtained scale factors were -59.232 ± 0.064 μGal/volt for period (a) and -59.461 ± 0.079 μGal/volt for period (b), respec-

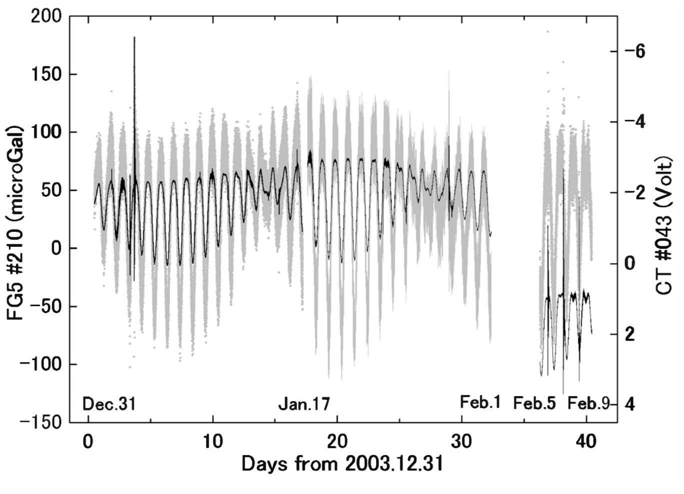

Fig. 3. AG (gray) data obtained by FG5#210 and SG (black) data obtained by CT#043 both from December 31, 2003 to February 9, 2004.

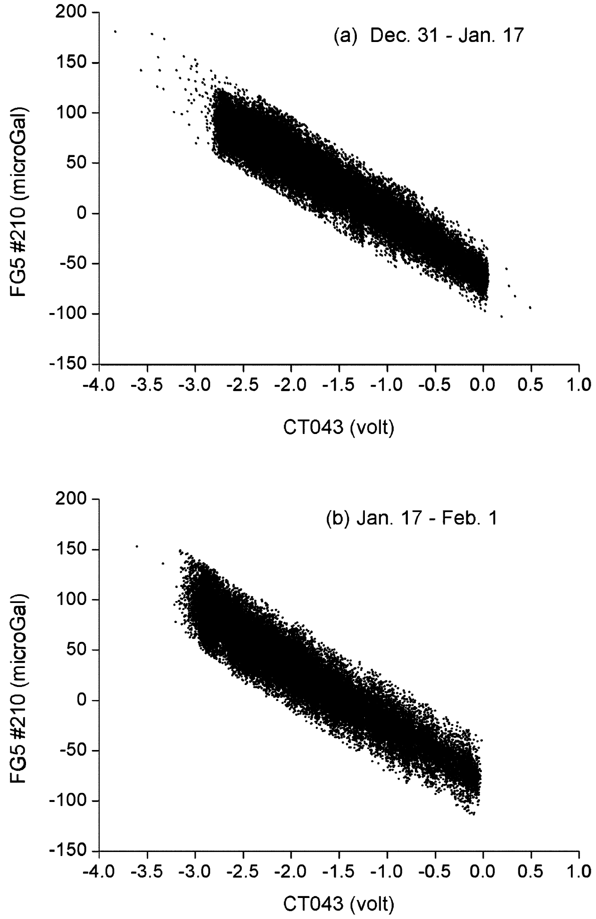

Fig. 4. Data employed for the regression analyses. (a) From December 31, 2003 to January 17, 2004. (b) From January 17 to February 1, 2004.

tively. These two values show an unexpectedly large difference beyond the error level. On January 17, some modification was applied to the data acquisition system of CT#043; the connections of the signal cables from the SG to the data acquisition system were rearranged by employing a junction box. After relocation of the CT#043 to the SG pier in December, the signal cables were temporarily wired until the installation of the junction box. Although we did not have conclusive evidence, we suspected that tangled wiring caused a problem in the electrical ground, and consequently the reference voltage of the data acquisition system was changed. It has been reported that modifications of the observing system, especially electric assemblies, may cause apparent changes of SG sensitivities (Iwano *et al.*, 2005). We thus considered that the scale factor obtained from period (a) suffered such an artificial effect. In contrast, there has been no significant modification in the SG observing system for period (b) since January 17. Therefore we finally adopted the value of $-59.461 \pm 0.079\,\mu$Gal/volt as the CT#043 scale factor. The drift rate simultaneously estimated by the regression analysis was 24.2 μGal/month. This value shows good agreement with the value estimated from tidal analysis.

3.2. Comparison of the scale factors of TT70#016 and CT#043

Because of the complicated field operations of JARE-45, simultaneous observations among TT70#016, CT#043 and FG5#210 could not be made. However, using the parallel observations of TT70#016 and CT#043, we can evaluate the ratio of the scale factors of TT70#016 to that of CT#043. As for the scale factor of TT70#016, it has independently been determined to be −58.168 μGal/volt by Iwano *et al*. (2003). We can therefore indirectly determine the scale factor of CT#043.

TT70#016 and CT#043 data were compared both in the time domain and in the frequency domain. Although parallel observations were conducted for about 7 months, artificial noise due to the initial adjustments of CT#043 limited the duration of available data. To make matters worse, the instrumental condition of TT70#016 was not good during the period. Only data from September to October 2003 could be used for the comparison in the time domain. The comparison was conducted (1) using 1 hour sampling data, and (2) using 1 minute sampling data. The results are summarized in rows 1 and 2 of Table 1.

In the frequency domain, the comparison can be conducted from the amplitude correspondence of two tidal signals. In this case, we do not necessarily require the same period of data. Thus we conducted the comparison in the following two cases; (1) using 10 years' data for TT70#016 and one year's data for CT#043, and (2) using the same period of data from September and October 2003. The results of the comparison are summarized in rows 3 and 4 of Table 1.

Table 1 shows that very similar values are obtained for the ratio of the scale factors with relative differences of only 0.03%. If we employ the average ratio of 0.97839 and assume the scale factor of TT70#016 to be −58.168 μGal/volt, we can calculate the scale factor of CT#043 to be −59.453 μGal/volt, which coincides very well with the scale factor of −59.461 ± 0.079 μGal/volt determined by FG5#210 measurements. Even if we employ another value in Table 1 as the ratio of the scale factors, the final difference between the value estimated from the comparison with TT70#016 and that obtained by FG5#210 is only 0.01–0.02%, almost one order of magnitude smaller than the relative

Table 1. Estimated ratios of the scale factors of TT70#016/CT#043.

Method of the estimation	Ratio	Data employed
(1) Time domain comparison	0.97841	1 hour sampling data from September to October, 2003
(2) Time domain comparison	0.97850	1 minute sampling data from September to October, 2003
(3) Frequency domain comparison	0.97844	10 years of data for TT70#016 1 year of data for CT#043
(4) Frequency domain comparison	0.97819	2 months of data from September to October, 2003
Average	0.97839	

accuracy of the direct calibration. This result suggests also that the apparent sensitivity change appeared only during period (a), when the problem of cables connections was the most probable reason for the apparent sensitivity change.

4. Concluding remarks

By means of parallel observation with an AG, we determined the scale factor of CT#043 to be $-59.461 \pm 0.079\,\mu$Gal/volt. This value was also confirmed by comparison with the scale factor of TT70#016. This means that the calibration of TT70#016 in 2001 (Iwano *et al*., 2003) was indirectly confirmed by the AG measurements of this study.

An important caution is the sensitivity change during the first half of the parallel measurements in January 2004. The apparent sensitivity change is probably due to improper connections of the signal cables. This problem reduced the number of data employed for the calibration by half, and degraded the final estimation error. Some modifications of the system are likely to cause such sensitivity changes.

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