

Report on the Absolute Gravity Measurements in Mongolia

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Abstract

The Geospatial Information Authority of Japan (GSI) conducted absolute gravity measurements in three cities in Mongolia, in accordance with the Memorandum of Cooperation signed by the GSI and the General Authority for Land Administration, Geodesy and Cartography of Mongolia (GALAGaC). The FG5 absolute gravimeter (#203), consistent with international standards, was used in the measurements. According to GALAGaC, the gravity standardization network in Mongolia was constructed based on the results of gravity measurements by the Soviet Union in the 1980s. However, the measurement reports are no longer available, and the gravity values measured in Mongolia have not been verified. The newly measured gravity value in each city is around 0.05 mGal smaller than the values obtained by the Soviet Union.

1. Introduction

Absolute gravity measurement is a method for directly determining the gravitational acceleration (hereafter referred to as “gravity value”) without relying on any reference points. The FG5 absolute gravimeter, which is currently used for measurements worldwide, can determine the gravity value with an accuracy of a few μGals using a mirror inside a vacuum-controlled dropping chamber. When the mirror drops, the FG5 precisely measures its position and the time using a laser and an atomic clock, respectively.

In 2015, the International Association of Geodesy (IAG) agreed to construct a new gravity standardization network based on the International Comparison of Absolute Gravimeters (ICAG) to ensure the traceability of gravity measurements (IAG, 2015). The ICAG is held every four years in cooperation with the *Comité International des Poids et mesures* (CIPM) and the International Association of Geodesy (IAG). The consistency between the FG5 owned by the Geospatial Information Authority of Japan (GSI) and international standards is evaluated through a comparison with the FG5 (#213), which is owned by the National Institute of Advanced Industrial Science and Technology (AIST) and calibrated regularly through the implementation of ICAG.

According to the General Authority for Land Administration, Geodesy and Cartography of Mongolia

(GALAGaC), the gravity standardization network of Mongolia was constructed based on the gravity measurements carried out by the Soviet Union in the 1980s. However, the measurement reports are no longer available, which means that the instruments, as well as the measurement and calculation methods are unknown, and the reliability of the gravity values measured in Mongolia could not be verified. Thus, absolute gravity values consistent with international standards were needed.

Accordingly, GSI and GALAGaC signed a Memorandum of Cooperation on absolute gravity measurements in Mongolia in 2024. GSI sent two experts to Mongolia to carry out the measurements from August to September 2024.

2. Measurements and Calculations

2.1 Gravity Points

We conducted absolute gravity measurements at three gravity points (Figure 1) where the Soviet Union had previously performed gravity measurements in the 1980s. None of the gravity points have been moved since the 1980s. Table 1 presents detailed information on each gravity point and Photos 1–3 show each gravity point. All gravity points were located on the basement floor of buildings, where the temperature was maintained at 20–24°C throughout the day,

which is suitable for operating the FG5.



Fig. 1 Map showing the approximate locations of cities with gravity points. Base map sourced from the Ministry of Foreign Affairs of Japan. (<https://www.mofa.go.jp/mofaj/area/mongolia/index.html>)

Table 1 Measurement site information

City	Number	Type of gravity point	Latitude	Longitude	Elevation (m)
Ulaanbaatar	0001	Origin point	106° 56' 12" N	47° 55' 27" E	1317
Choibalsan	0033	First order	114° 31' 57" N	48° 04' 32" E	743
Dalanzadgad	0017	First order	104° 25' 38" N	43° 34' 25" E	1465



Photo 1 Gravity Point in Ulaanbaatar



Photo 2 Gravity Point in Choibalsan



Photo 3 Gravity Point in Dalanzadgad

2.2 Absolute Gravity Measurements

The absolute gravity measurements were carried out using the FG5 (#203) owned by GSI. During the measurements, the mirror was dropped every 15 seconds, with 160 drops constituting one set. After one set ended, the instrument paused for 20 minutes and then resumed the measurements. Power was supplied through a rectifier and an uninterruptible power supply (UPS) and proper grounding was secured. These are important measures to protect the instrument from power failure and overcurrent, and also to avoid a negative impact on the measured gravity values.

The measurement data was corrected in the following way. First, we used the Micro-g LaCoste g9.0 software package (Micro-g LaCoste, 2012) to correct the earth tide effects, polar motion, and standard atmosphere. In this package, ETGTAB software (Wenzel, 1996) was used for solid-earth tide corrections, where the δ factor for the permanent tide was set to 1.0. The polar motion was corrected based on the Earth Orientation Parameters (EOPs) provided by the International Earth Rotation and Reference Systems Service (IERS) as Bulletin B (Petit and Luzum, 2010). The standard atmospheric pressure was calculated from the equation recommended by the International Gravimetric Bureau (BGI) (ICG-WG II, 1988). Next, we calculated the ocean tide correction using the global version of the GOTIC2 software (Matsumoto et al., 2001) with the NAO99b model (Matsumoto et al., 2000).

After carrying out the above corrections, the most

probable gravity value was obtained as follows. First, we determined acceptable and rejected drops based on the dispersion of the gravity values in each set (those that deviated from the mean by more than three standard deviations were rejected). Next, we eliminated sets that were determined to be outliers by evaluating the significance of the dispersion among multiple sets using the analysis of variance method. The most probable values were obtained by weight-averaging the gravity values of all accepted sets. The number of accepted drops in each set was utilized as the weighting value. More details on the calculation processes can be found in Yahagi et al. (2018), where the same method was used.

Lastly, we conducted vertical gravity conversion from the instrument height (about 1.30 m) to the top of the gravity points. The reason for this is that the final gravity values are defined as the values at the top surface of each gravity point. The instrument height is defined as the position where the mirror is released inside the dropping chamber. In this process, the vertical gravity gradient values measured at each gravity point were used (see Section 2.3).

2.3 Vertical Gravity Gradient Measurements

We used two relative CG-5 gravimeters to measure the difference in gravity values between heights of 0.00 and 1.20 m just above each gravity point. We defined a fifteen-minute simultaneous and continuous measurement at each height as one set and repeated it for five sets. The upper and lower gravimeters were switched between sets.

The measured data were then corrected for ocean and solid-earth tides and instrument heights. Next, the drift coefficient was linearly estimated for each gravimeter using the least-squares method. After correcting for drift, the most probable vertical gradient at each gravity point was obtained by weight-averaging the two values obtained from the two gravimeters. The inverse of the variance of the measured data was defined as the weighting value for each gravimeter.

3. Results and Conclusion

The final gravity value at each gravity point is shown in Table 2. At every gravity point, the new gravity value is around 0.05 mGal smaller than that measured by the Soviet Union (Table 3).

Gravity values can be influenced by errors within the

gravity standardization network itself. For example, in Japan, when the gravity standardization network was updated in 2017, there was a nationwide trend of a decreasing gravity value (-0.04 mGal on average) (Yahagi et al., 2018). It is suggested that the former gravity standardization network of Japan (JGSN75) had systematic errors attributed to the International Gravity Standardization Network 1971.

Old gravity values in Mongolia may contain some type of systematic error, although there is no clear reason that can explain the difference between the old and new gravity values.

A time series of cumulative means of gravity value, and the standard deviation per drop are shown in Figs. 2 and

3, respectively. Figure 2 shows that the gravity values converge well within 0.001 mGal at all gravity points. Despite the short measurement time in Ulaanbaatar (27 sets = 27 hours) due to instrument issues, the value is sufficiently reliable. Indeed, Fig. 3 shows that the standard deviation of the gravity value per drop in Ulaanbaatar converges to around 0.002 mGal within several hours, which means that vibration noise that can affect the measurements was quite small.

In conclusion, we successfully obtained gravity values consistent with international standards, which makes it possible for Mongolia to construct a reliable gravity standardization network.

Table 2 Results of absolute gravity measurements in Mongolia

City	Measurement period	Sets	Accepted drops	Gravity (mGal)	Standard deviation per drop (mGal)	Vertical gravity gradient (mGal/m)
Ulaanbaatar	August 23–25, 2024	27	2497	980,430.565	0.004	-0.2837
Choibalsan	August 31–September 3, 2024	65	7894	980,646.265	0.009	-0.2874
Dalanzadgad	September 6–11, 2024	117	11534	980,010.830	0.004	-0.2921

Table 3 Comparison of old and new gravity values in Mongolia

City	Gravity (mGal)		
	New value	Old value	New – Old
Ulaanbaatar	980,430.565	980,430.623	-0.058
Choibalsan	980,646.265	980,646.31	-0.04
Dalanzadgad	980,010.830	980,010.88	-0.05

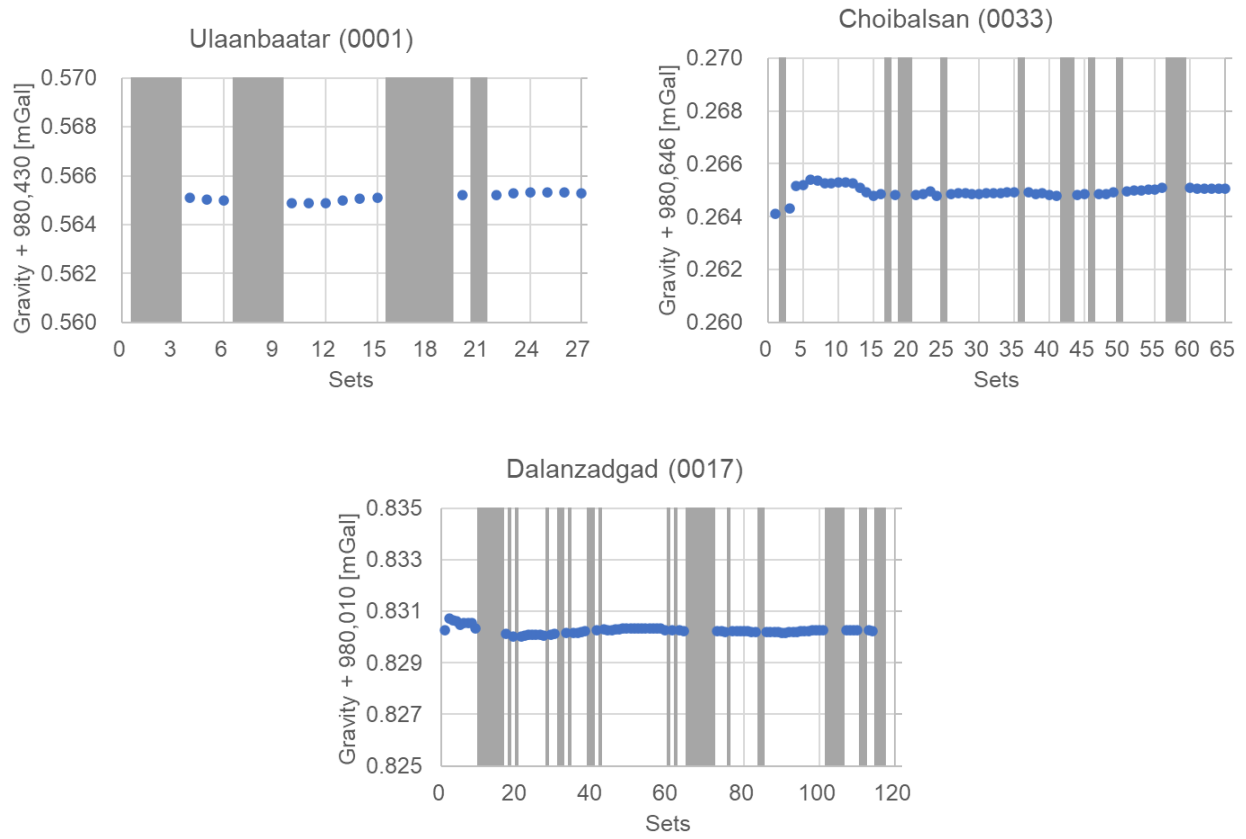


Fig. 2 Time series of cumulative gravity values. Sets determined as outliers are shaded in gray.

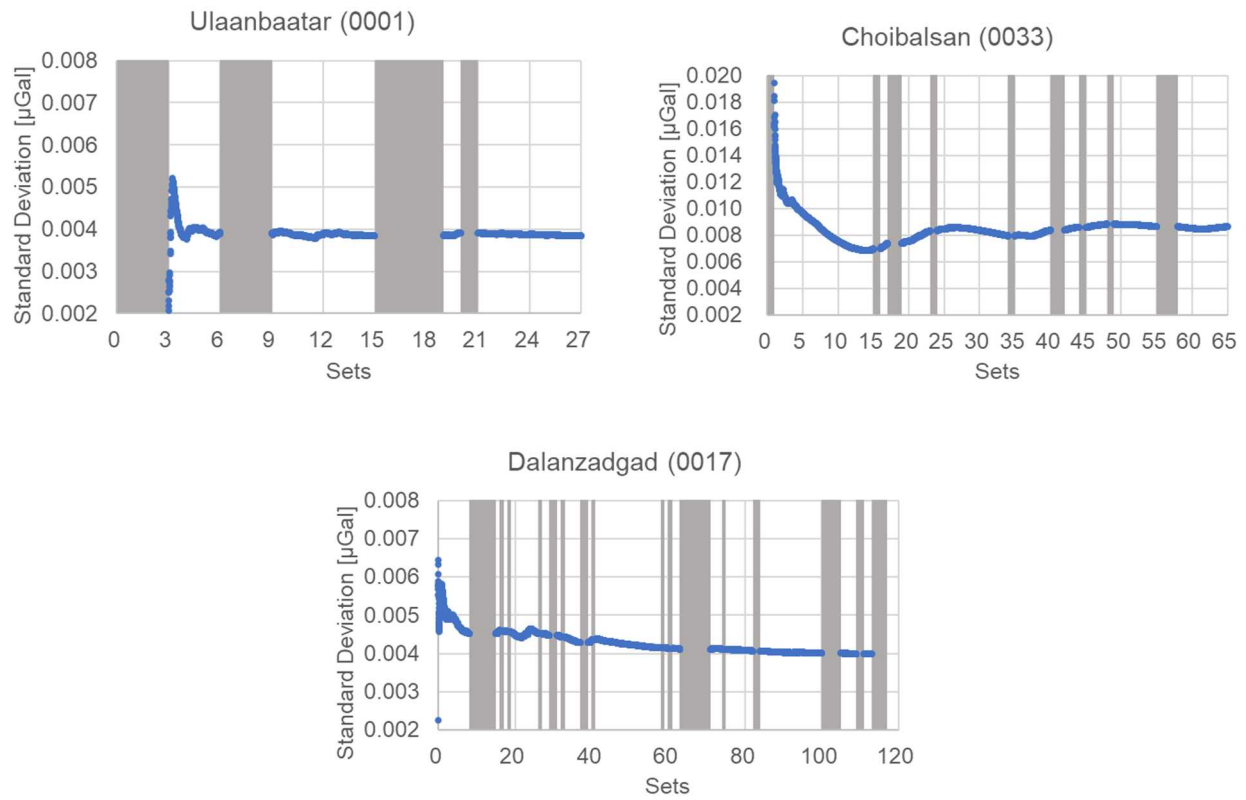


Fig. 3 Time series of standard deviations of gravity value per drop. Sets determined as outliers are shaded in gray.

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