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Determination of gravity at MunGyung (Mungyeong) superconducting gravity observatory, Korea

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ABSTRACT: Absolute gravity measurements were made to calibrate Korea's first superconducting gravimeter (SG) at MunGyung (MG, Mungyeong) Observatory. A calibration coefficient (CC) of the MG SG was determined by a parallel registration with an FG5 absolute gravimeter. A total of 8,541 drops were measured over a period of 37 hours between October 8th and 10th, 2007. We first determined the absolute gravity value to be 979,859,179.3 ± 88.481 μGal (μGal=10^{-8} m·s^{-2}) after atmospheric pressure, Earth tide and ocean loading corrections. In a linear regression analysis between the FG5 recordings and the raw SG data, a CC of 64.548 ± 0.224 μGal·volt^{-1} was determined, having previously removed invalid drops and outliers from the data sets. Together with the absolute measurements, a vertical gravity gradient of 2.72 μGal·cm^{-1} was calculated using a Graviton-EG spring gravimeter to take the absolute gravity value down to the SG observatory platform level. The validity of the CC was additionally tested by a comparison between the recorded SG data and the theoretical tides (HW95 and Wahr-Dehant models) as reference. Gravity variations induced by atmospheric pressure and ocean loading were added to the theoretical Earth tides. The CC based on the theoretical tide was determined to be 64.560 μGal·volt^{-1}. The difference between the two coefficients is 0.012 μGal· volt^{-1}, which lies within the standard error of the determined coefficient, 0.224 μGal·volt^{-1}. Therefore, a value of 64.548 μGal·volt^{-1}, determined by the parallel registration with the absolute gravimeter, was accepted as the CC of the SG (GWR Instrument Inc. #045) installed at MG Observatory. During the gravity measurements, the other gravity values and heights such as normal gravity and the gravity gradient, orthometric and dynamic heights were also calculated.

Key words: superconducting gravimeter, MunGyung (Mungyeong), Korea, calibration coefficient, absolute gravity, theoretical tide, orthometric and dynamic heights

1. INTRODUCTION

The problem of accurate calibration for a superconducting gravimeter (SG) is of fundamental importance for any geophysical and geodetic interpretations made from the high-quality data provided by this elegant instrumentation (Hinderer et al., 1991). There are several well-known methods for calibrating SG relative measurements (e.g., Falk et al., 2001; Richter et al., 1995; van Ruymbecke, 1989), and these can be used to estimate the calibration coefficient (CC) or scale factor that transforms the gravity output voltage from any gravimeters in true but relative gravity variations.

A theoretical approach to determine the CC of an SG is based on theoretical tides as reference. The determination of the CC is often performed by a regression analysis between the raw SG data and the theoretical tides. This calculation is based on the Hartmann-Wenzel tidal catalogue HW95 (Hartmann and Wenzel, 1995), which has an accuracy of 1 nGal (nGal = 10^{-11} m·s^{-2}) and the Wahr-Dehant Earth tide model (Dehant, 1987).

The state of the art in the calibration of an SG is the derivation of the CC from a parallel registration of an SG and an absolute gravimeter (e.g., Francis et al., 1997; Imanish et al., 2002; Sato et al., 1996) or a well calibrated spring gravimeter. The CC can be estimated with an accuracy of about ±1 nm·s^{-2}·volt^{-1}, which corresponds to about ±0.1~0.2% by parallel registration with an absolute gravimeter (Hinderer et al., 1998). With the inertial calibration platform at BKG (Bundesamt für Kartographie und Geodäsie – the German Federal Agency of Cartography and Geodesy) in Frankfurt, Germany, for example, an accuracy of ±0.2 nm·s^{-2}· volt^{-1} was achieved (Falk et al., 2001).

We determined the CC of the MunGyung (MG, Mungyeong) SG (GWR Instruments Inc. #045) by using a parallel registration of 37 hours of absolute gravity measurements using an FG5 absolute gravimeter. Along with the absolute measurements, we obtained the vertical gravity gradient with a Graviton-EG spring gravimeter, since the absolute values

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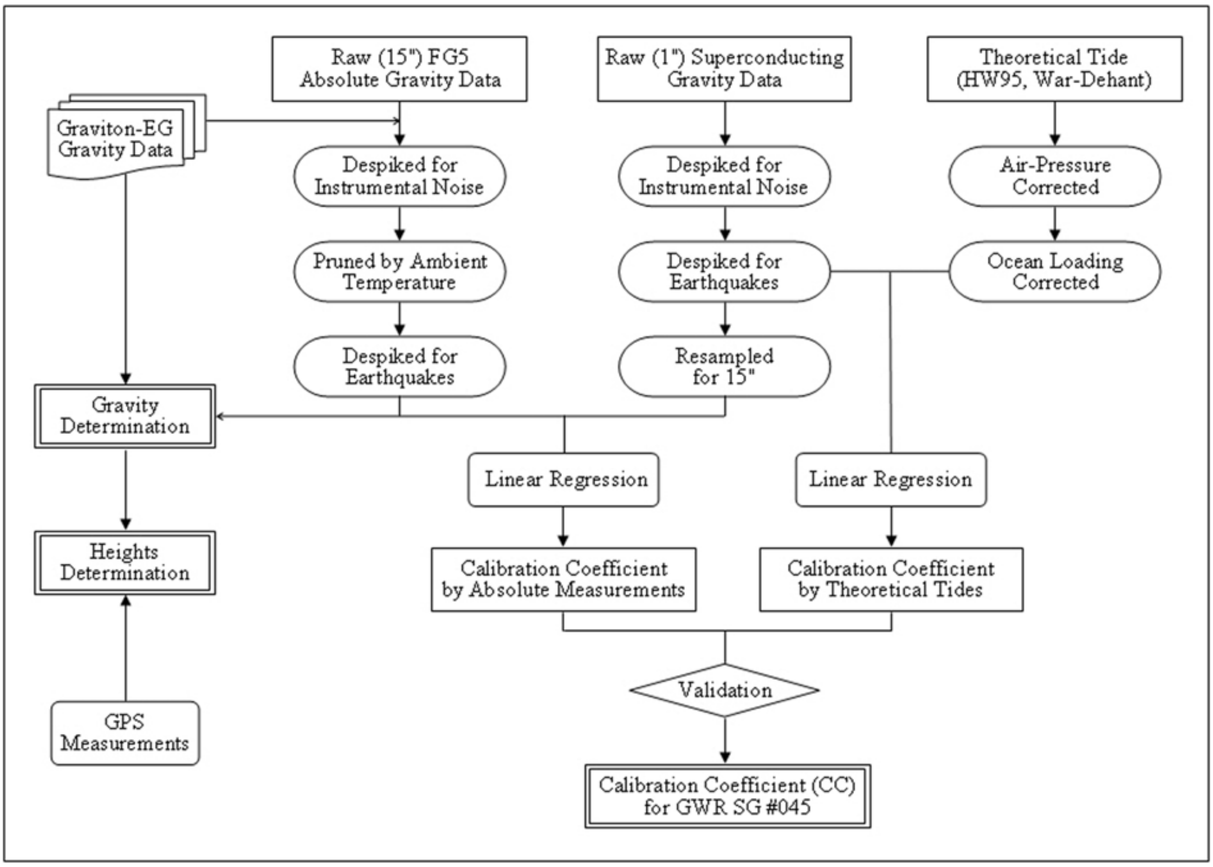

Fig. 1. Flowchart of gravity and height determinations conducted in this study.

were not measured at the SG platform level. We established the absolute gravity after atmospheric pressure, Earth tide and ocean loading corrections. We then tested the validity of the CC by a theoretical approach using the comparison of the recorded SG data with the theoretical tides (HW95 and Wahr-Dehant models) as reference. Gravity variations induced by atmospheric pressure and ocean loading were added to the theoretical Earth tides, since the raw SG data also included these signals. During the gravity measurements, the other gravity values and heights such as normal gravity and the gravity gradient, orthometric and dynamic heights were also calculated. A flowchart of the gravity and height determinations conducted in this study is shown in Figure 1.

2. KOREAN SUPERCONDUCTING GRAVIMETER

The physical working principle of the SG is based on a movement of a test mass (1-inch Nb sphere), which changes its position due to gravity changes according to the law of gravitation. In contrast to the spring gravimeter, the test mass of the SG is levitated by a persistent magnetic force. A small change of gravity yields a large displacement of the sphere which is magnetically levitated. The ultra-stable levitating force accounts for the long-term stability of an SG, when compared to conventional spring type gravimeters, such as those from LaCoste & Romberg or Scintrex. The gravity sensor is enclosed in a vacuum canister to eliminate effects from changes in the external magnetic field, as well as temperature, humidity, and barometric pressure. A liquid helium Dewar tank and a refrigeration system keep the gravity sensing unit inside the Dewar close to 4.2 °K to maintain a superconducting state.

Korea's first superconducting gravimeter was installed at MG Observatory in 2005 within the seismological station operated by the Korea Institute of Geoscience and Mineral Resources, where geodetic and geophysical instruments are grouped for the Korea National Laboratory project "Optimal data fusion of geophysical and geodetic measurements for geological hazards monitoring and prediction", which is supported by the Ministry of Science and Technology (Kim et al., 2005; Kim et al., 2009). MG is located virtually at the center of South Korea with a longitude of 128.2147°E and a latitude of 36.6402°N. The observatory is administratively located at 222-1 Gusan-ri, Hogye-myeon, MunGyung (Mungyeong), Gyeongsang Province. The SG is installed in a measurement hut with a platform that is coupled with the basement rock; and, it has been successfully recording gravity variations since April 2005, with a sampling rate of one second.

3. CALIBRATION BY ABSOLUTE GRAVITY MEASUREMENTS

3.1. Data Preparation

In October 2007, parallel registrations were carried with GWR SG, a Micro-g LaCoste FG5 (#231) absolute gravimeter, and a LaCoste & Romberg Inc.'s Graviton-EG gravimeter provided by the Industrial Technology Research Institute at Hsinchu, Taiwan (Fig. 2).

Two sessions of absolute measurements were conducted during the period between October 8th, 2007, 11:50:49 UTC and October 10th 2007, 00:44:15 UTC. A total of 8,541 drops were measured over approximately 37 hours. Session #1 consisted of 3,323 drops (one starting set of 83 plus 27 sets of 120); and, Session #2 consisted of 5,218 drops (43 sets of 83 plus one final set of 58). Between the two sessions, there was a gap of 78.85 minutes, which corresponded to 315 drops. Figure 3 shows the absolute gravity measured from the FG5 gravimeter (red dots, in mGal) along with the values from the SG (blue line, in volts).

Fig. 2. Parallel gravimetric measurements at the MunGyung (Mungyeong) superconducting gravimeter observatory through absolute measurement by an FG5 gravimeter (black) and relative measurements from Graviton-EG (white with light blue top) and superconducting gravimeters (blue).

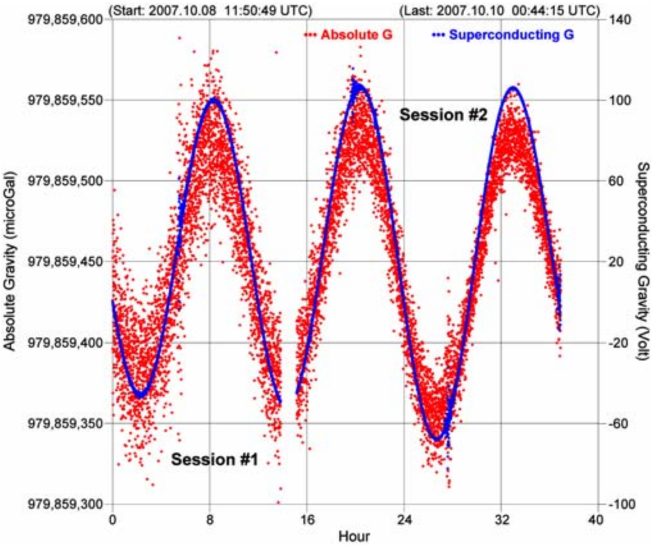

Fig. 3. Gravity measured from the FG5 (red) and superconducting gravimeters (blue).

The FG5 gravimeter operates by using the free-fall method. A corner cube is dropped inside a vacuum chamber, and the rate of descent is accurately monitored using a laser interferometer. Since our absolute measurements were made inside a small observatory, good temperature control was required. Although the FG5 operating temperature range is known to be 10 °C to 30 °C, it is highly recommended that the temperature at the SG site should be maintained within +/-1.5 °C. More importantly, the ambient temperature should remain constant during the measurement (Niebauer et al., 1995). For our measurements, as shown in the left panel of Figure 4, the room temperature varied between 22.26 °C and 22.84 °C during Session #1 and between 20.90 °C and 22.15 °C for Session #2.

For a better result, we removed the first incomplete batch of 83 drops and the last two series of 120 drops from Session #1, as well as the first 120 drops and last series of 58 drops from Session #2 (right panel of Fig. 4). In total, we eliminated 501 out of the original 8,541 drops as an adjustment, in response to either an unstable ambient temperature or an incomplete set of measurements.

During the absolute gravity measurements, four earthquakes were detected. Table 1 summarized the time, location of epicenter, focal depth and magnitude of the earthquakes acquired from the United States Geological Survey (USGS) earthquake catalogue (http://neic.usgs.gov/neis/epic/epic_global. html). These disturbed several of the absolute drop measurements, as well as the SG data. In addition, there was limited but observable noise, with signals possibly due to the redistribution of mass and vertical crustal motions

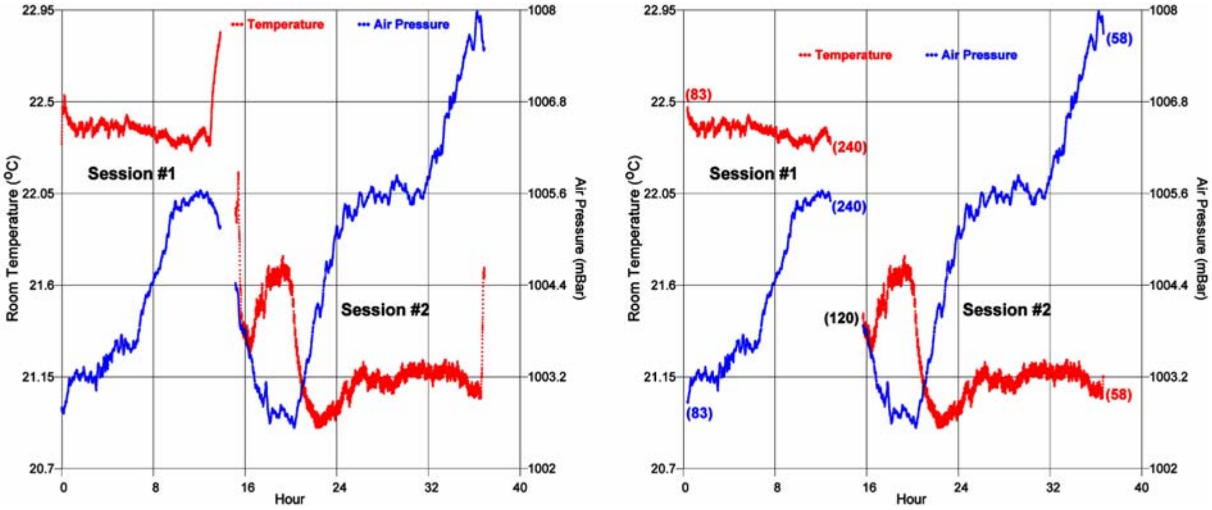

Fig. 4. Variations in room temperature (red) and atmospheric pressure (blue) before (left) and after (right) removing the results of 501 drops in five unstable sets of measurements at the start and end of each session. Numbers in parentheses denote data points removed.

Table 1. Summary of time, location of epicenter, focal depth, magnitude, and the distance from the MunGyung (Mungyeong) Observatory for the four earthquakes observed during the parallel measurements (United States Geological Survey (USGS) earthquake catalogue (http://neic.usgs. gov/neis/epic/epic_global.html)

	Yr/Mn/Date	Orig. Time (UTM)	Lat. (deg)	Lon. (deg)	Depth (km)	Magn. (m)	Distance FromMG (km)
1	2007/10/08	171037.90	43.54	146.74	63	5.8	1751.046
2	2007/10/09	072517.01	19.07	121.12	38	5.2	2066.013
3	2007/10/09	150341.21	-4.81	152.89	39	6.0	5253.305
4	2007/10/10	001916.79	-1.74	99.48	27	6.0	5182.162

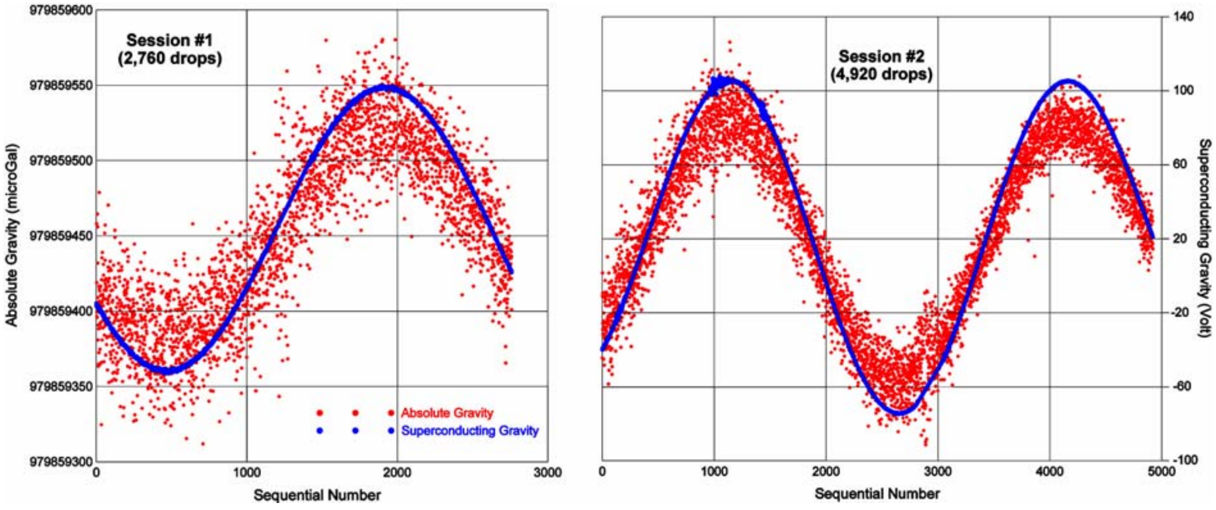

Fig. 5. Remaining gravity after removal of unstable drops, noise and outliers from absolute gravity (red) and superconducting gravity (blue) measurements.

caused by various geodynamic processes. In this study, we eliminated outliers larger than ±3σ (standard deviation) from both data sets before the linear regression analysis between them. The one-second SG data were resampled and synchronized with the 15-second absolute gravity data. Figure 5 shows the remaining gravity after removal of unstable drops, noise and outliers from the absolute gravity (red) and superconducting gravity (blue) measurements.

3.2. Gravity and Height Determinations

It was necessary to calculate the vertical gradient of the

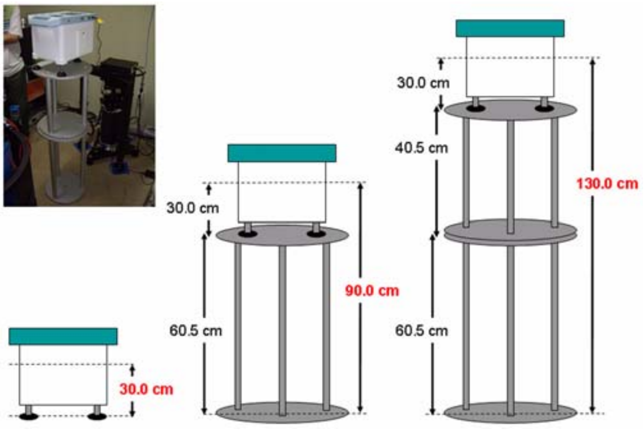

Fig. 6. Calculation of the vertical gravity gradient at MunGyung (Mungyeong) Observatory by a Graviton-EG spring gravimeter with two sets of tripods. Gravity measurements were made at the surface and at 90 and 130 cm above the superconducting gravity platform.

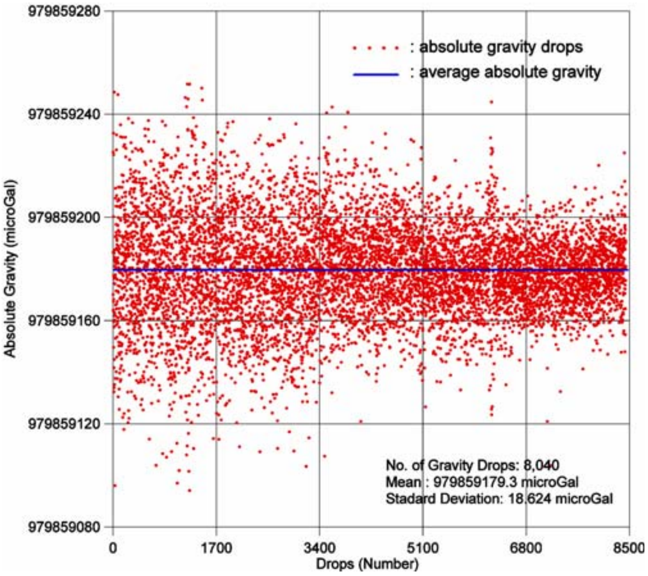

Fig. 7. Determination of the absolute gravity value (blue line) from the 8,040 FG5 drops (red dots) after atmospheric pressure, Earth tide and ocean loading corrections using the FES2002 model.

gravity at the observatory, since the absolute measurements were made 129.72 cm above the SG platform (factory height of 116.37 cm + setup height of 13.35 cm). Accordingly, a Graviton-EG spring gravimeter was used to estimate the gravity gradient along with the absolute measurement. As shown in Figure 6, a vertical gravity gradient at MG Observatory was determined by the Graviton-EG spring gravimeter with two sets of tripods. The heights of the tripods were 60.5 and 40.5 cm, respectively, with an indentation of 0.5 cm when assembled. Gravity measurements were made at 30 (surface), 90 and 130 cm above the SG platform during Sessions #1 and #2, and the gradient was calculated by a simple polynomial approach. For Sessions #1 and #2, we estimated vertical gravity gradients of -0.27835 μGal·cm^{-1} and -0.26500 μGal·cm^{-1}, respectively; and, by averaging those two values, we determined a vertical gravity gradient ($\partial g/\partial H_{out}$) of -0.271675 μGal·cm^{-1}.

After calculating atmospheric pressure, Earth tide and ocean loading corrections using the FES2002 model (Lefevre et al., 2002; Le Provost et al., 2002), an absolute gravity value (g):

$$g = 979{,}859{,}179.3 \pm 88.481\ \mu\text{Gal} \tag{1}$$

was determined from a total of 8,040 drops, as shown in Figure 7. We also used the CSR3.0 ocean tidal model (Eanes and Bettadpur, 1996) for comparison, and we found almost the same absolute gravity value with ignorable errors.

Normal gravity (γ) was derived from the Geodetic Reference System (GRS) 1980 (Moritz, 1980):

$$\gamma_\varphi = 978{,}032.7\ (1 + 0.0053024 \sin^2\varphi - 0.0000058 \sin^2 2\varphi)\ \text{mGal} = 979{,}874{,}475.40\ \mu\text{Gal} \tag{2}$$

where 36.640° was used as the mean latitude of the MG SG observatory.

We adapted up to three digits below the decimal point of the GPS measurements, which generally corresponds to a centimeter level of accuracy. It is also useful to calculate the geopotential number (C_i) at the site, which can be acquired (Vaniček and Krakiwsky, 1986) by (Fig. 8):

$$C_i = W_{MG} - W_0 \approx g \cdot H = 85{,}502.512\ \text{Gal·m} \tag{3}$$

where W_{MG} and W_0 are potentials at the surface of the MG observatory and at the corresponding point on a geoid (MG') along the plumb line, respectively. The orthometric height (H) of 87.26 meters was derived by spirit leveling from the Korea National Bench Mark #05-10-20-04. Previously, an ellipsoidal height (h) of 107.50 meters was determined by a Global Positioning System (GPS) measurement taken during the construction of the observatory.

As shown in Figure 8, height determinations are essential for the gravimetric derivations and their related applications. The orthometric height, H, is not gravimetrically corrected. We further calculated the dynamic height (H^D) and the gravimetrically corrected orthometric height (H^O) using the C_i and the mean gravity value (g_μ) between the surface at MG Observatory and the geoid along the plumb line (Fig. 8). The vertical gravity gradient inside the Earth ($\partial g/\partial H_{in}$) is given approximately as:

$$(\partial g/\partial H_{in}) = (\partial g/\partial h) + 4\pi \cdot G \cdot \rho \approx -0.0848\ \text{Gal·km}^{-1} \tag{4}$$

along the plumb line by applying a Poincaré and Prey reduction with an average crustal density (ρ) of 2.67 g·cm^{-3} and a gravitational constant (G) of 6.67×10^{-11} m^3·kg^{-1}·s^{-2} (Hof-

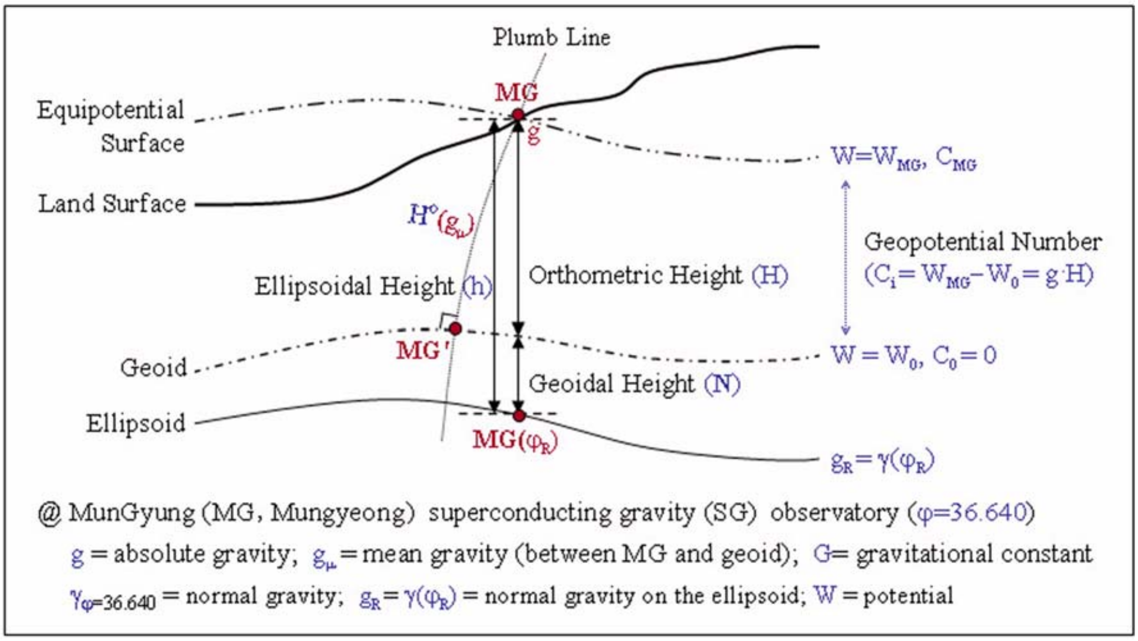

Fig. 8. Geometry of gravity values and heights at the MunGyung (Mungyeong) superconducting gravity observatory.

mann-Wellenhof and Moritz, 2006). From this equation, a mean gravity (g_μ) can be derived from g and a vertical gradient of gravity ($\partial g/\partial H_{in}$) (Vaniček and Krakiwsky, 1986):

$$g_\mu = g - (-0.0848\ \text{Gal}\cdot\text{km}^{-1}\cdot H\,(\text{km})/2) = 979{,}862{,}895.79\ \mu\text{Gal} \qquad (5)$$

Therefore, the dynamic height (H^D) and the orthometric height H^O are determined as shown in Equations 6 and 7, respectively:

$$H^D = C_i/g_R = C_i / \gamma_{\varphi=36.640} = 85{,}502.512\ \text{Gal}\cdot\text{m} / 979{,}874{,}475.40\ \mu\text{Gal} = 87.259\ \text{m} \qquad (6)$$

where g_R can be thought of as the value of normal gravity on the ellipsoid, and

$$H^O = C_i / g_\mu = 85{,}502.512\ \text{Gal}\cdot\text{m} / 979{,}862{,}895.79\ \mu\text{Gal} = 87.260\ \text{m} \qquad (7)$$

3.3. Calibration by Regression Analysis with the Absolute Gravity

To calculate the calibration coefficient (CC) of GWR Instruments Inc.'s superconducting gravimeter (#045), a linear regression analysis was performed between the absolute (Y) and superconducting (X) gravity measurements, the result of which is shown in Figure 9. In the figure, the blue dots and red line denote the gravity values and regression line, respectively. As a result, a linear equation is derived:

$$Y = -64.548\cdot X + 979{,}859{,}598.81 \qquad (8)$$

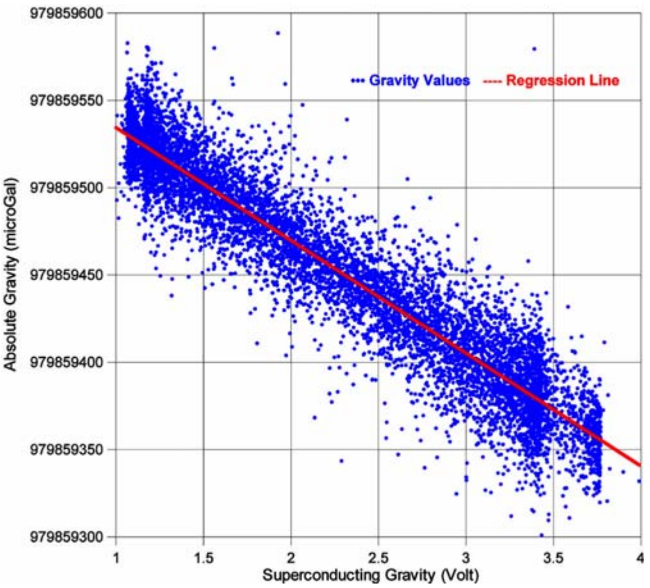

Fig. 9. Linear regression analysis between absolute gravity (Y) and superconducting gravity (X) measurements. The blue dots and red line denote gravity values and the regression line, respectively.

From Equation 8, a CC of 64.548 µGal·volt^{-1} was determined. The correlation coefficient between X and Y and the standard error were –0.9455 and ±0.224 µGal· volt^{-1}, respectively.

4. VALIDATION BY THE THEORETICAL TIDE

A theoretical approach to determine the CC of a SG is based on using theoretical tides as reference. The CC can be determined by regression analysis between the raw SG data and theoretical tides, based on the Hartmann-Wenzel tidal catalogue HW95 (Hartman and Wenzel, 1995), which has an accuracy of 1 nGal, and the Wahr-Dehant Earth tide model (Dehant, 1987).

We tested the validity of the CC that was calculated by parallel measurements using the absolute gravimeter by comparing the gravimetric factor for a reference tidal wave observed with the SG and the theoretic tidal models. Gravity variations induced by atmospheric pressure and ocean loading were added to the theoretical Earth tides, because the raw SG data also included these signals (Kim et al., 2009).

4.1. Data Preparation

Spikes and offsets due to instrumental and other perturbations were carefully removed from the raw SG data using the programs Tsoft (Tsoft, 2002), DETIDE, and DESPIKE from the ETERNA 3.3 Earth tide processing package (Wenzel, 1996). This includes offsets in data due to SG maintenance. Spikes larger than 0.2 mGal were removed. Offsets larger than 1 mGal were also removed if they did not originate from either the atmosphere or groundwater level-induced gravity variations (Kim et al., 2009). These preprocessed gravity and atmospheric pressure data were filtered and reduced to a five-minute sampling rate using the program DECIMATE from the ETERNA package 3.3. Figure 10 shows the theoretical tide between April 1st, 2005 and January 21st, 2007.

4.2. Atmospheric Pressure Correction

The admittance function for atmospheric pressure was determined by regression analysis between the preprocessed and Earth tide reduced gravity data, δg_{cor}, and the ground atmospheric pressure data measured at MG Observatory:

$$\delta g_{cor} = \delta g_{pre} - ET \tag{9}$$

where δg_{cor} and δg_{pre} are corrected and preprocessed gravity, respectively, and ET is the theoretical Earth tide.

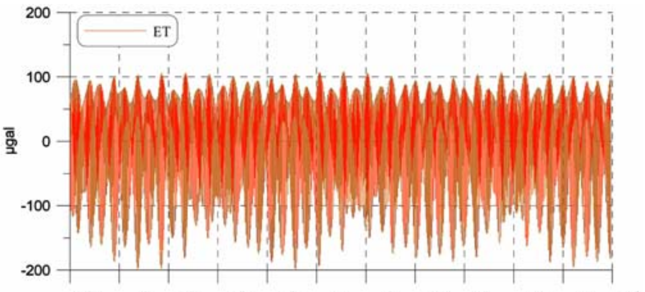

Fig. 10. Theoretical tides (HW95 and Wahr-Dehant models) in μGal between April 1st, 2005 and January 21st, 2007.

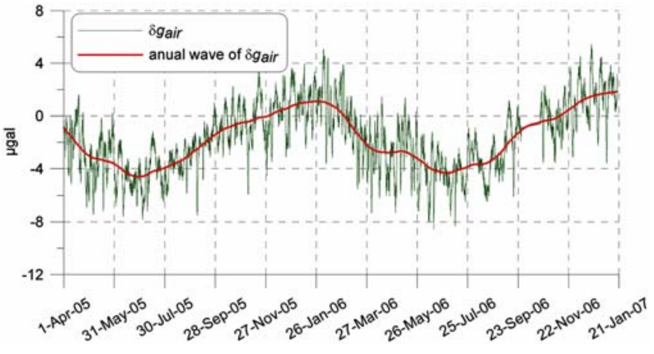

Fig. 11. Atmospheric pressure induced gravity variations, δg_{air}, (green) and annual wave of δg_{air} (red), between April 1st, 2005 and January 21st, 2007 (unit: hPa).

This method yields a satisfactory reduction of the atmospheric pressure effect. Physical approaches with three-dimensional (3-D) atmospheric pressure data models essentially improve the reduction in the long periodic tidal band (Boy and Hinderer, 2006; Neumeyer et al., 2004; Neumeyer et al., 2007). Results at SG stations in Europe show that the seasonal surface pressure-independent gravity effect is about 2 μGal, which should be considered in the future. Unfortunately, no data are at present available for the calculation of the 3-D atmospheric pressure correction.

The single admittance coefficient for the atmospheric pressure data has been determined to be $-0.32\ \mu\text{Gal}\cdot\text{hPa}^{-1}$. The atmospheric correction value, as shown in Figure 11, was calculated by:

$$\delta g_{air} = ap \cdot ap\_adm \tag{10}$$

where ap is ground atmospheric pressure, and ap_adm is the single admittance coefficient for ap. The maximal gravity change in δg_{air} yielded 14 μGal, which was derived from the maximal atmospheric pressure change, dap, of 44 hPa. The maximal annual gravity changes during the observation period yielded 6.5 μGal, derived from the maximal annual atmospheric pressure variation of 20 hPa.

4.3. Ocean Loading Correction

Based on the global ocean tide model FES2002 (Lefevre et al., 2002; Le Provost et al., 2002) and the work of Francies and Mazzega (1990), the ocean loading for the main tidal waves in semidiurnal, diurnal and long periodic tidal bands have been calculated. The gravity variations induced by ocean loading were calculated in the time domain. Their maximal amplitude during the observation period was about 4 mGal. The ocean loading vectors (amplitudes and phases) were also determined for the tidal constituents. Figure 12 shows ocean loading-induced gravity values between April 1st, 2005 and January 21st, 2007.

Figure 13 shows the amplitudes and phases for the main diurnal and semidiurnal tidal waves for MG Observatory in

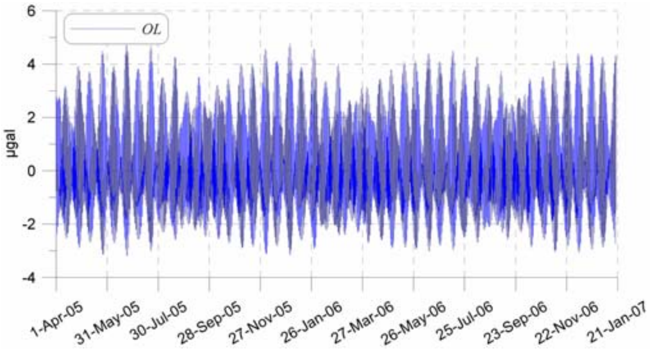

Fig. 12. Ocean loading induced gravity variations between April 1st, 2005 and January 21st, 2007. Based on the global ocean tide model FES2002, the ocean loading for the main tidal waves in semidiurnal, diurnal and long periodic tidal bands have been calculated.

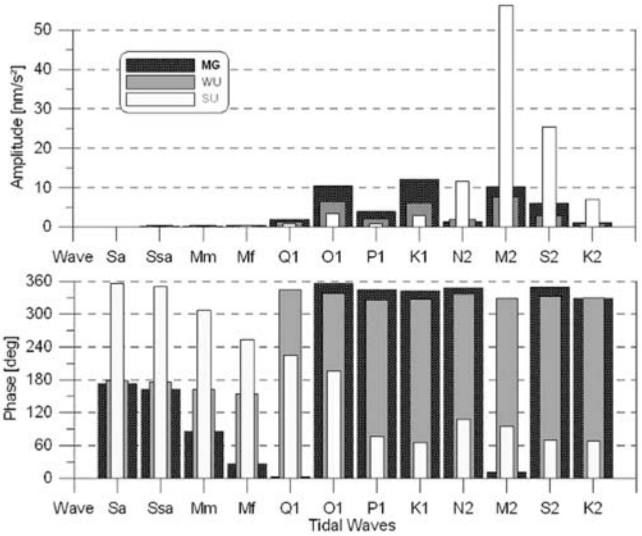

Fig. 13. Amplitudes (upper) and phases (lower) of ocean loading observed at the MunGyung (MG, Mungyeong, Korea), Wuhan (WU, China) and Sutherland (SU, South Africa) sites.

comparison with the Sutherland (SU) SG station in South Africa (32.38°S, 20.81°E) and the Wuhan (WU) SG site in China (30.52°N, 114.49°E). At the MG site, the largest amplitudes were found at wave components of O1 (1.04 mGal), K1 (1.22 mGal), and M2 (1.02 mGal). The MG site is more affected by the ocean tides than WU because MG is located closer to the ocean (distance to the ocean about 100 km) and, therefore, more affected by the regional ocean loading effect, which can be quite different as shown for the SU site (distance to the ocean about 200 km), with larger amplitudes in the semidiurnal band (Kim et al., 2009).

4.4. Determination of Calibration Coefficient by Theoretical Tides

As we discussed earlier, atmospheric pressure and ocean loading-induced gravity variations have been added to the theoretical Earth tides, because the raw gravity data also included these signals. Neumeyer et al. (2002) showed that this method of scaling factor determination gives results in good agreement with a calibration based on absolute gravimeter recordings. Accordingly, a linear regression analysis was performed between the tidal gravity (X) and SG (Y) measurements. In Figure 14, the blue dots and red line denote gravity values and the regression line, respectively. A CC of -64.560 ± 0.025 μGal·volt^{-1} was determined, with a correlation coefficient of -0.9997 and a standard error of 0.025 μGal·volt^{-1}.

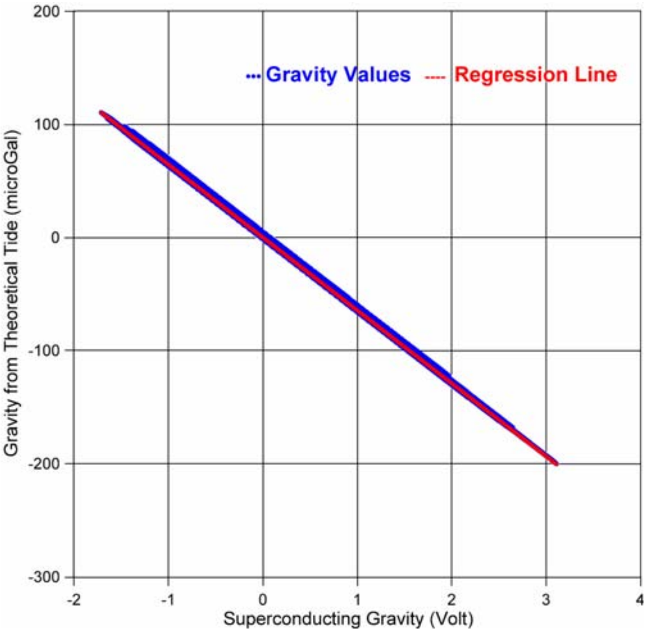

Fig. 14. Linear regression analysis between tidal gravity (Y) and superconducting gravity (X) measurements. The blue dots and red line denote gravity values and the regression line, respectively.

5. RESULTS AND DISCUSSIONS

A calibration coefficient (CC) for the MG SG (GWR #045) was determined through a parallel registration with an FG5 absolute gravimeter. A total of 8,541 drops were made over the period between October 8th, 2007, 11:50:49 UTC and October 10th, 2007, 00:44:15 UTC. In a linear regression analysis between the FG5 drop recordings with a 15-second drop period and the raw SG data with a 15-second sampling period, a CC of -64.548 ± 0.224 mGal·v^{-1} was determined after removing outliers larger than $\pm 3\sigma$ (standard deviation) and unstable measurements from both data sets.

The validity of the CC was tested by comparing the gravimetric factor for a reference tidal wave observed with the SG and the theoretic tidal models. Gravity variations induced by atmospheric pressure and ocean loading were added to the theoretical Earth tides, because the raw SG data included these signals as well. A CC based on the theoretical tide was determined to be –64.560 μGal·volt^{-1}. The difference between the two CCs is 0.012 μGal·volt^{-1}, which lies within the standard error of the determined coefficient, 0.224 μGal·volt^{-1}. Therefore, the value of –64.548 μGal·volt^{-1} determined by the parallel registration with the absolute gravimeter was accepted as the CC of the GWR Instruments Inc. SG (#045) installed at MG Observatory.

Further parallel absolute gravity measurements at a more stable ambient temperature are recommended to improve the result. In fact, when we calculated CCs for Sessions #1 and #2 separately, they were –64.039 and –64,810 mGal·volt^{-1}, respectively. In this case, although the absolute and SG gravity measurements showed better correlation coefficients, we did not accept these values after a comparison with the CC acquired from the theoretical tide. This may indicate that the number of measurements made in a parallel registration is more important than eliminating noise and outliers.

During the absolute gravity measurements, dynamic and orthometric heights were also determined from the normal gravity, gravity gradient and mean gravity. The following gravity values and heights determined at the MG SG observatory are the results of this study.

- Longitude (φ): 128.215°E
- Latitude (λ): 36.640°N
- Ellipsoidal Height (h): 107.50 m
- Orthometric Height (H): 87.65 m (gravity non-corrected)
- Dynamic Height (H^D): 87.26 m (corrected with γ_φ= 36.640°)
- Orthometric Height (H^O): 87.26 m (corrected with g_μ)
- Geopotential Number (C_i): 85,502.512 Gal·m
- Normal Gravity (γ_φ=36.640°): 979,874,475.40 μGal (GRS1980)
- Absolute Gravity (g): 979,859,179.3 ± 88.481 μGal
- Vertical Gradient of Gravity above SG platform ($\partial g/\partial H_{out}$): 2.71675 μGal·cm^{-1}
- Vertical Gradient of Gravity below SG platform ($\partial g/\partial H_{in}$): –0.0848 Gal·km^{-1}
- Mean Gravity between SG platform and geoid (g_μ): 979,862,895.79 μGal
- Calibration Coefficient of Superconducting Gravimeter (GWR #045): –64.560 μGal·volt^{-1}

Determinations of the above gravity values and heights will contribute significantly to further investigations with the Korean SG, including: 1) analysis of co-seismic gravity changes and dislocation modeling, 2) the study of local and regional hydrology-induced gravity variations, 3) improvement of the ocean loading correction in combination with tide gauge measurements, and 4) validation of ongoing satellite gravimetry missions, such as the CHAllenging Minisatellite Payload (CHAMP) (Reigber et al., 1996) and the Gravity Recovery And Climate Experiment (GRACE) (Tapley et al., 2004a; 2004b), or the upcoming Gravity field and steady-state Ocean Circulation Explorer (GOCE) (Balmino et al., 1999).

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