Effect of groundwater changes on SG observations in Kyoto and Bandung

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Abstract

In order to estimate hydrological effect on gravity observations using Superconducting Gravimeters in Kyoto (TT-70#009) and Bandung (TT-70#008), we installed groundwater level-meters near the SG stations in Kyoto and Bandung, respectively, in 2000. At the Kyoto station, SG observation was often interrupted because of earthquake vibrations, and artificial noise caused by construction of new buildings in the University. Therefore, we cannot discuss in detail on relation between rainfall, groundwater level change and gravity residual in Kyoto at present stage. As the only significant evidence, the gravity residual at the Kyoto station changed about 9 μGal after heavy rainfalls of 210mm in total during the period of September 11-13, 2000. At that time, the groundwater level showed 2m upheavals at a well about 1.5km away from the SG station. At the Bandung station, time keeping of the SG observation system has not been so good, because the GPS receiver was often broken by the thunderbolt. After correcting time lags, we estimated hydrological effect on SG observation. As a result, gravity residual is closely correlated with groundwater change: 1m upheaval of groundwater level causes 4.2-4.4μGal increase in gravity residual with the time lag of about 13-20 days.

1. Introduction

Two Superconducting Gravimeters (Model TT-70: #008 and #009) were introduced into Kyoto University in 1988. Since then, continuous observation of gravity changes employing two Superconducting Gravimeters had been carried out in Kyoto until December 1997 (Takemoto et al., 1998a). During the period, we investigated instrumental noise (Higashi, 1996), atmospheric effect (Mukai et al., 1995a, 1995c) and the effect of ambient temperature change on gravity measurements (Mukai et al., 1995b). In December 1997, one (#008) of the two Superconducting Gravimeters in Kyoto was shifted to Bandung under the cooperation between the Graduate School of Science (GSS), Kyoto University and the Volcanological Survey of Indonesia (VSI), Directorate General of Geology and Mineral, Ministry of Mines and Energy of the Republic of Indonesia (Takemoto et al., 1998b). We installed the SG #008 in the underground observation room where Baron Melchior and his colleagues carried out gravity observation in 1987 by employing the LaCoste & Romberg gravimeter (L 336) (Melchior et al., 1995).

In this paper, we present a preliminary result about the effect of groundwater changes on SG observations in Kyoto and Bandung.

2. Hydrological effect on gravity observation in Kyoto

In Kyoto, we started observation of water level changes on June 15, 2000 at a well in a private house about 1.5km away from the SG station in Kyoto University by employing a water pressure sensor (KADEC-MIZU type) manufactured by KONA Co. Ltd. (Abe, 2002). **Fig. 1** shows observational results of gravity change obtained from SG#009 as well as atmospheric pressure change, water level change and precipitation during the period from June 15, 2000 to August 31, 2001. Unfortunately, SG observation in Kyoto has often been interrupted because of earthquake vibrations and artificial noise caused by construction of new buildings in the University. Therefore, we cannot discuss in detail on relation between rainfall, groundwater level change and gravity residual in Kyoto at present stage.

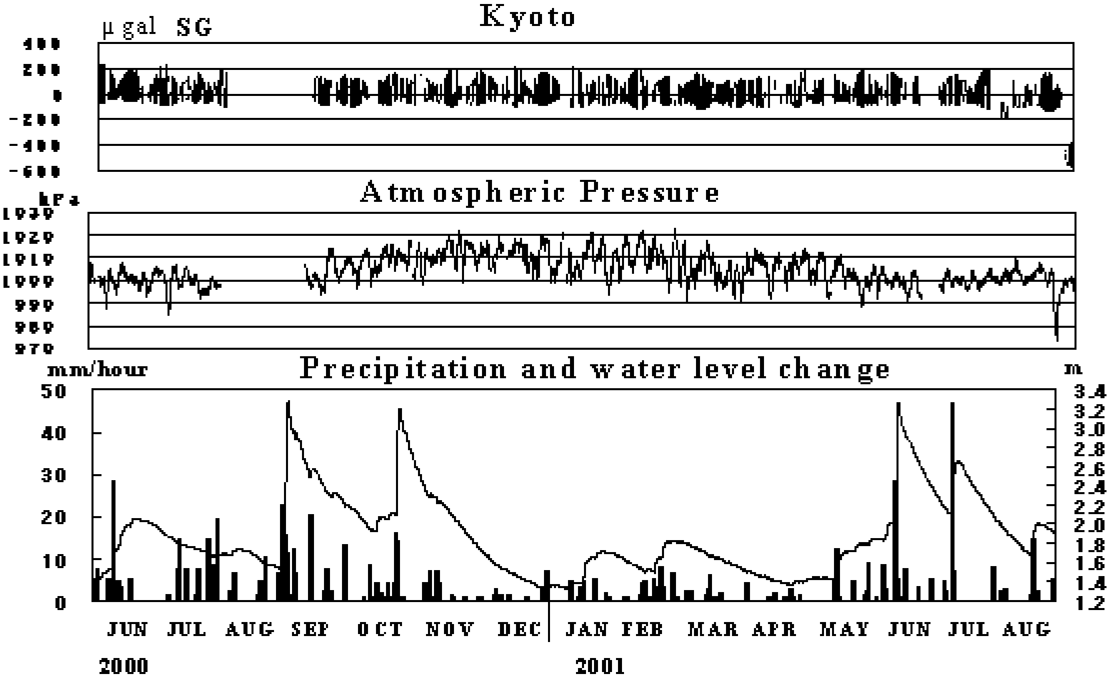

Fig. 1 Observational Result of gravity changes obtained from SG#009, atmospheric pressure changes, precipitation and water level changes in Kyoto during the period from June 15, 2000 to August 31, 2001.

Only significant evidence is shown in **Fig. 2**, in which the gravity residual at the Kyoto station changed about 9μGal after heavy rainfalls of 210mm in total during the period of September 11-13, 2000. This can be acceptable based on a simple calculation using a Bouguer model of water level changes in a semi-finite medium: 1m water level changes correspond to 4.2 μGal gravity changes in case of 10% porosity (Abe, 2002).

As appointed out by Makinen and Tattari (1988), Soil moisture changes will significantly affect on gravity changes in addition to water level changes near the gravity observation site. Accordingly, it is important to measure soil moisture changes in order to precisely interpret gravity residuals observed with SGs. We are now preparing to install soil moisture meters to monitor moisture content around the SG observation site.

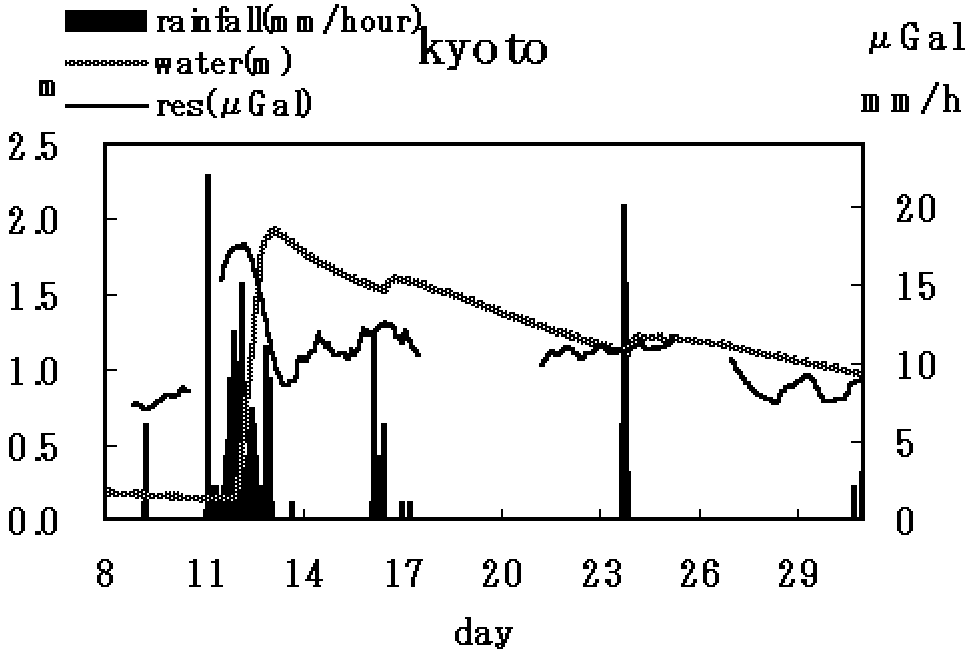

Fig. 2 Comparison of gravity changes and water level changes after the heavy rainfalls of 210mm in total during the period of September 11-13, 2000.

3. Hydrological effect on gravity observation in Bandung

The Bandung SG station (**Ba**) is the third station in the southern hemisphere and only one station existing near the equator in the GGP network. On this point of view, **Ba** is a very important station in GGP.

The observation room in Bandung is located at 06°53' 47" S, 107 °37' 54" E, 713m above the sea level. The distance from the nearest sea is about 50 km. The SG #008 was installed on the concrete base of 1.2m x 1.2m, which was constructed 1 m below the floor in the underground room on the layer of very thick volcanic deposit of sand and other volcanic products (Takemoto et al., 1998b). Observation of gravity variation in Bandung using the SG #008 was smoothly started in December 1997, but interrupted by the unexpected falling of a thunderbolt in April 1998. We repaired the system and observation was restarted in December 1998. Thereafter, continuous record of gravity change has been obtained.

Observation of water level changes in Bandung was started in January 2000 at a well in the campus of VSI about 200m away from the SG station by employing a water pressure sensor of same type as that used in Kyoto.

Fig. 3 shows the observational result of gravity changes observed with the SG#008 and atmospheric pressure changes during the period from February 1999 to October 2001 as well as water level changes in Bandung during the period from January 2000 to October 2001.

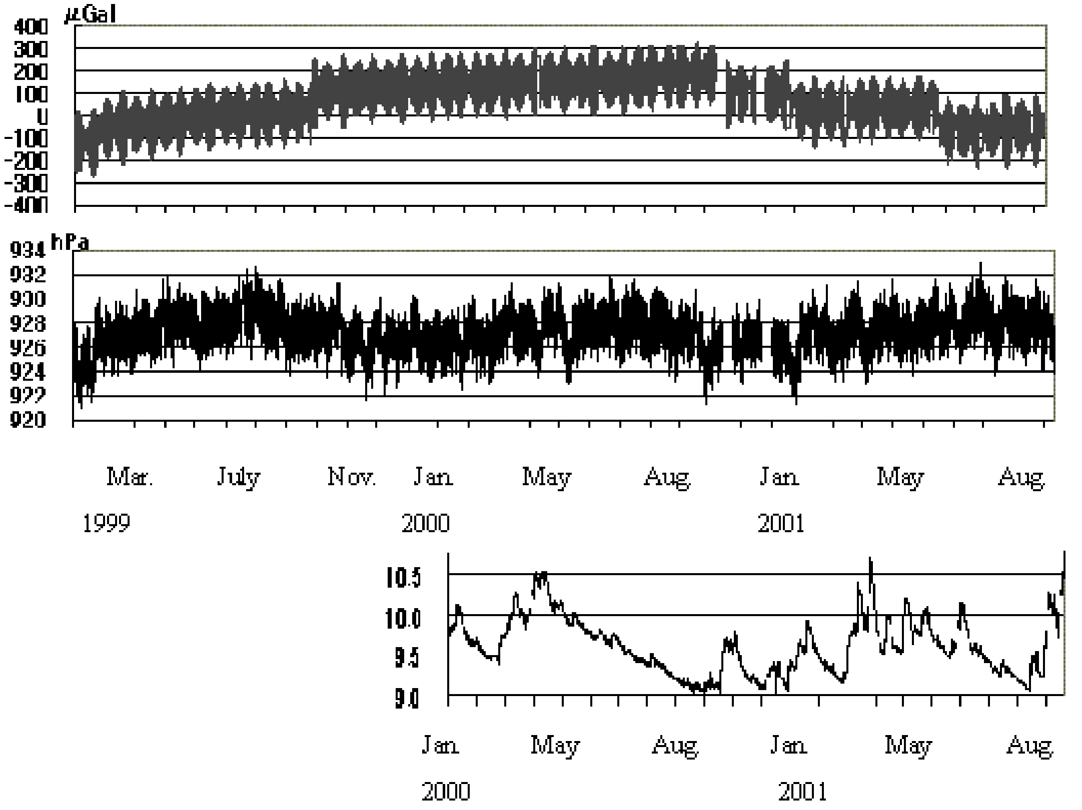

Fig. 3 Gravity changes observed with the SG#008 (upper), atmospheric pressure changes (middle) and water level changes (lower) in Bandung.

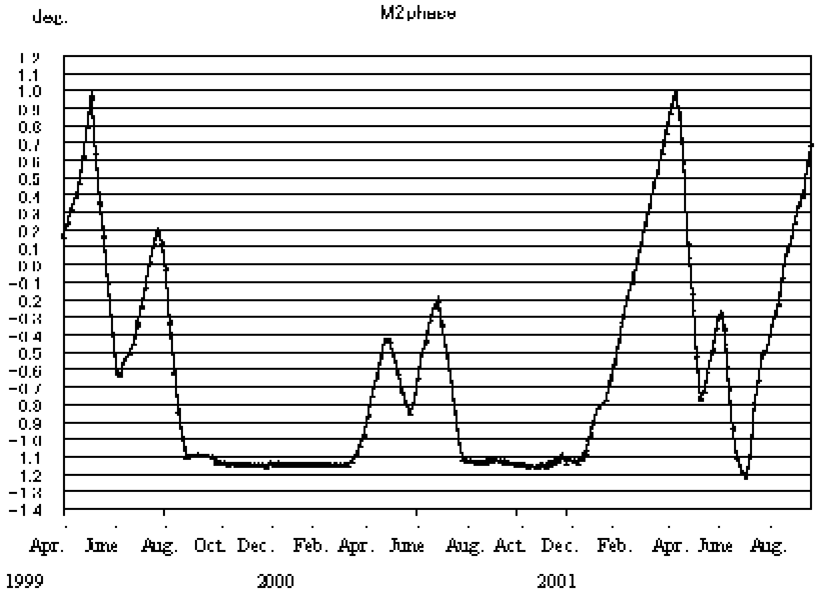

Fig. 4 Apparent phase change of M2 constituent observed with the SG#008 in Bandung.

One of the serious problems in Bandung, however, is the time keeping of SG record. We installed a GPS receiver to control the clock of the data acquisition system in Bandung. But the GPS receiver has often broken by thunderbolts and GPS data have been interrupted. **Fig. 4** shows apparent phase change of M2 constituent without time correction. Based on this data, we corrected the “time” of the data acquisition system in Bandung.

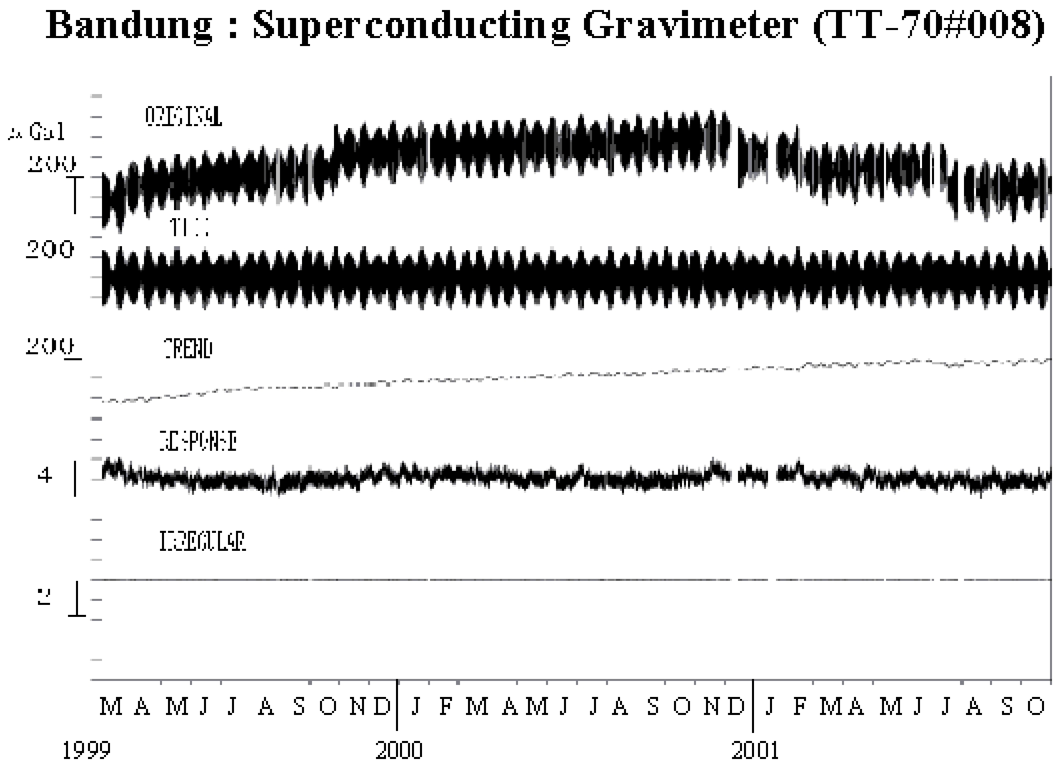

Fig.5 Observational result of SG#008 in Bandung during the period from March 1999 to October 2001.

Fig. 5 shows the observational result of SG#008 during the period from March 1999 to October 2001. Tidal analyses were made by applying the Baysian Tidal Analysis Program ‘BAYTAP-G’ (Tamura et al., 1996) to the observational data obtained in Bandung. In the tidal components (‘TIDE’), it is obvious that semi-diurnal constituents are dominant in Bandung compared with those in Kyoto. In the trend component (‘TREND’), we can also recognize that long period tidal constituents are dominant in Bandung.

After eliminating long period tides and the polar motion effect form the trend component shown in **Fig. 5**, we approximated long term gravity variation with the 3-degree polynomial, and then we estimated hydrological effect on gravity residual.

Fig. 6 shows the trend component, in which contributions from long period tides and polar motion are eliminated, as well as the 3-degree polynomial approximation curve during the period from March 1999 to October 2001.

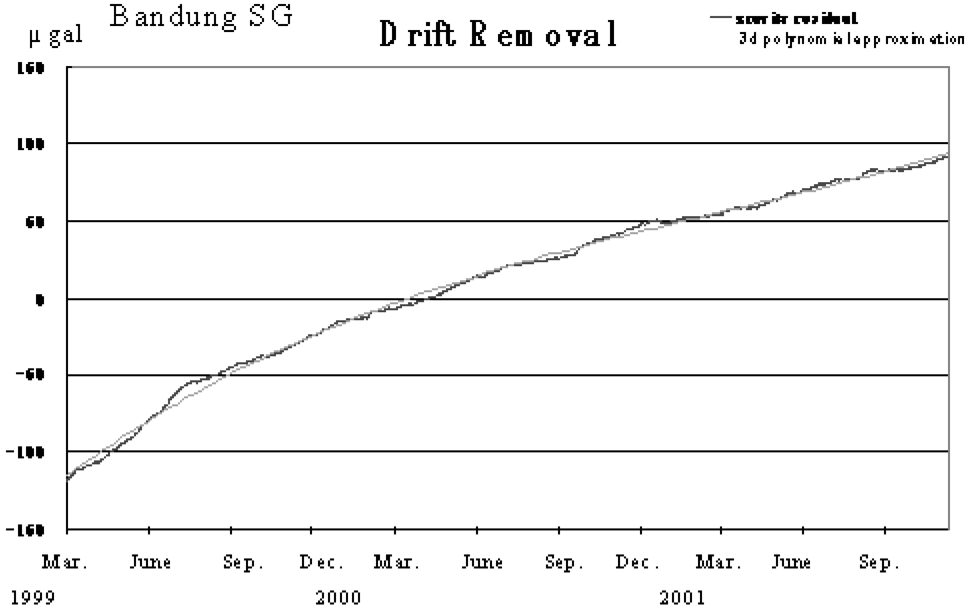

Fig. 6 Trend of gravity variations observed with the SG #008 during the period from March 1999 to October 2001 as well as the 3-degree polynomial approximation curve.

Fig. 7 shows the gravity residual obtained by subtracting the 3-D polynomial approximation from the trend curve, in which contributions from long period tides and polar motion are previously eliminated. Groundwater level change is also shown in **Fig. 7**. Comparing these two curves of gravity residual and groundwater level change, we found out three events in which it should be necessary to add minor correction (about 2μGal) in gravity residual. The first event is the earthquake of Mw = 7.9 in South Sumatra on June 04, 2000, which was the largest earthquake occurred in the area within 1000km from the SG station during the observation period. The second is the artificial noise on September 11-12, 2000 according to maintenance of GPS recorder system by Indonesian colleagues. The third is stop of the recording system continued for a week after the electronic power failure on January 8, 2001.

After correcting gravity residual at these three events mentioned above, we obtained a corrected gravity residual curve as shown in **Fig. 8**. In this figure, we can see that large part of gravity residual is correlating to groundwater level change with phase delay of about 10-20 days.

Although all of the gravity residual would not be related to groundwater level change, we investigated the relation between gravity residual and groundwater level change. **Fig. 9** shows these relations in cases with phase lags of 0-30days of the gravity residual relative to the groundwater level change. In this figure, we can see that the gravity residual is correlated with groundwater changes and the linearity is improved in cases of time lags of 13-20 days in gravity residuals. 1m upheaval of groundwater level causes 4.2-4.4μGal increase in gravity residual with the time lag of about 13-20 days. Since the precipitation data in Bandung are not yet available, we cannot discuss the relation between gravity change and rainfall quantitatively at this time.

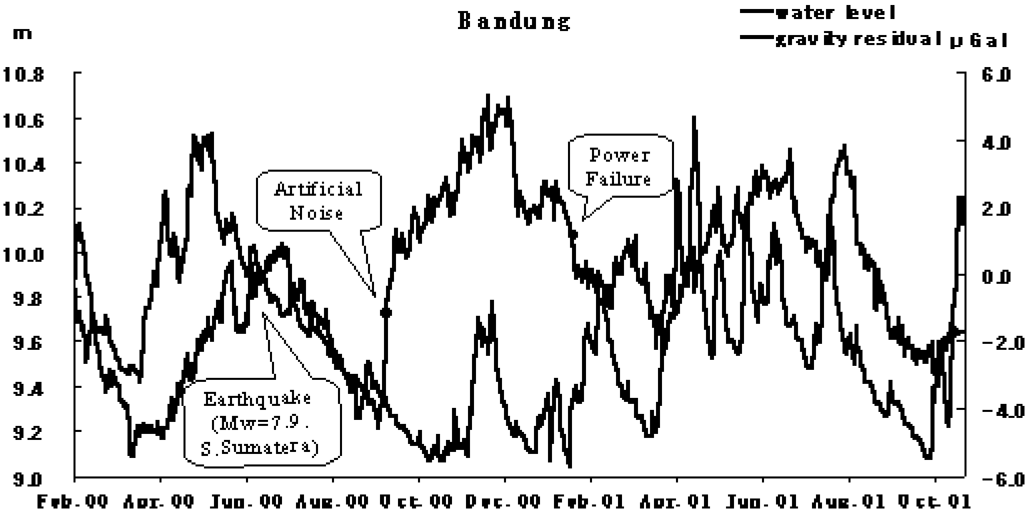

Fig. 7 Comparison of gravity residuals (thick line) and groundwater level change (thin line).

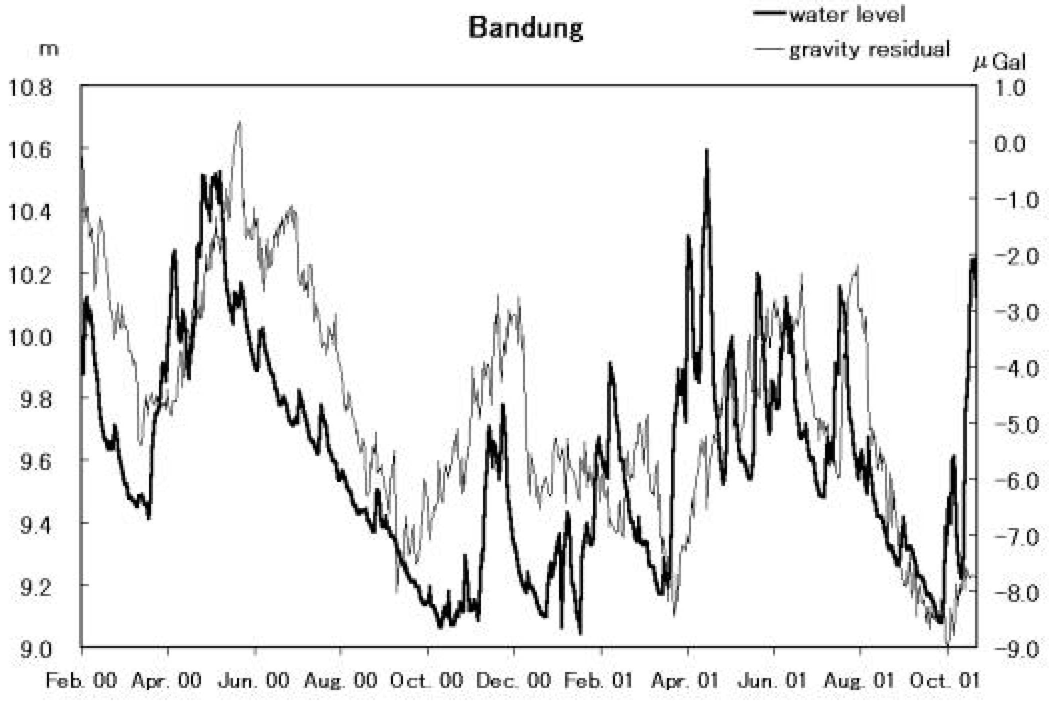

Fig.8 Comparison of gravity residuals (corrected) and groundwater level changes.

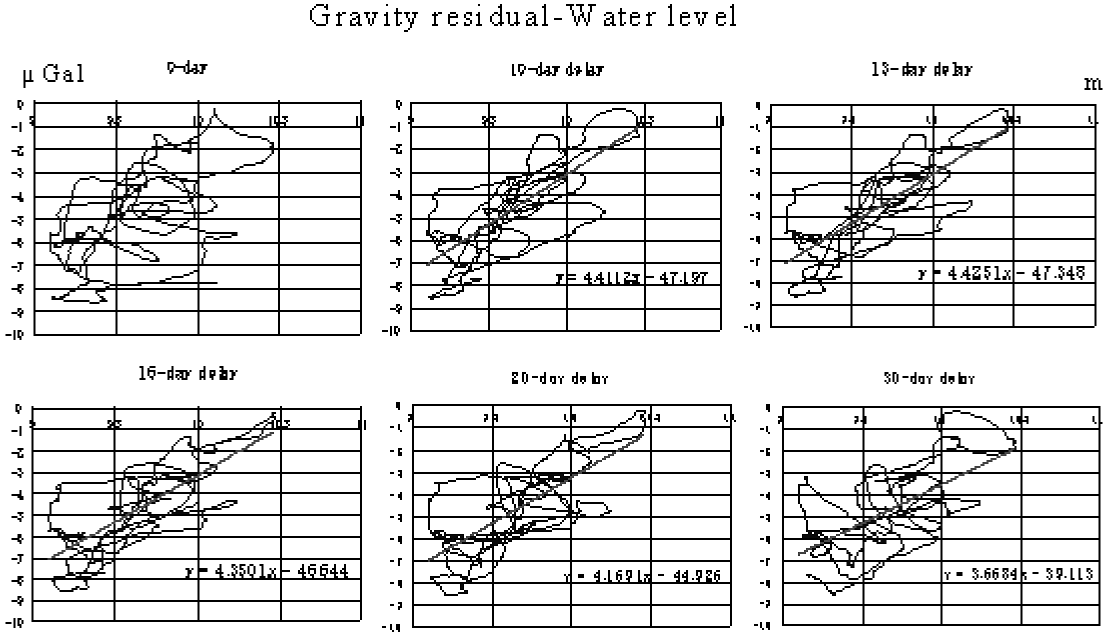

Fig. 9 Relation between the gravity residuals and the groundwater level changes.

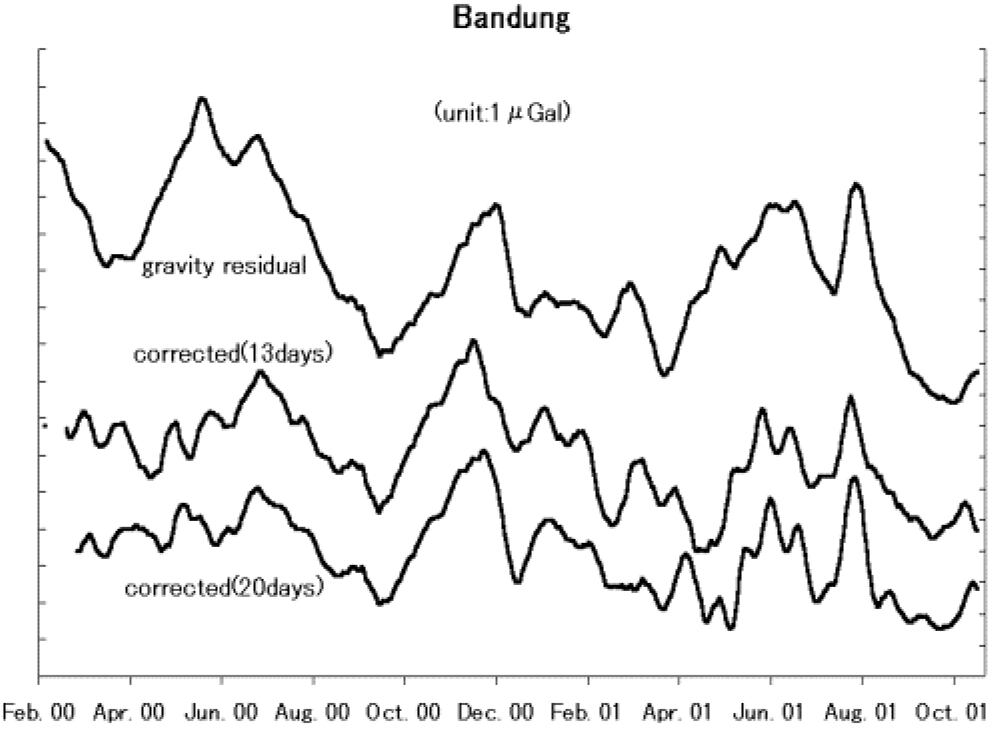

Fig. 10 Corrected curves of gravity residual.

We then attempted to eliminate the effect of groundwater level changes from the gravity residual. **Fig. 10** shows the corrected curves for cases of time lags of 13 and 20days, respectively, together with 10-day running means of the gravity residual that is shown in **Fig. 8**. Each of corrected curves is obtained by applying each coefficient obtained from **Fig. 9**. Even if using these curves, gravity residual seems to be not so much improved. However, it is noticeable that the whole amplitude could be reduced to 5μGal from 8μGal in total.

4. Concluding Remarks

We installed groundwater level-meters near the SG stations in Kyoto and Bandung, respectively, in 2000 and started monitoring of hydrological effect on gravity observation. As a result, it was revealed in both Kyoto and Bandung that 1m upheaval of groundwater level causes about 4μGal increase in gravity residual. This can be acceptable based on a simple calculation using a Bouguer model of water level changes in a semi-finite medium: 1m water level changes correspond to 4.2μGal gravity changes in the case of 10% porosity. In Bandung, the gravity residual decreased to 5μGal from 8μGal by taking the effect of groundwater level change into consideration.

In order to discuss the hydrological effect on precise gravity observation in detail, we are preparing to install soil moisture meters in Kyoto and Bandung. Although precipitation data in Bandung are not available, we are now planning to install a rain gauge in Bandung. This will contribute to detailed interpretation of gravity residual and to search for meaningful gravity signals revealing dynamics of Earth’s interior.

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