MONITORING OF A HOT SPRING AQUIFER USING REPEATED MICROGRAVITY MEASUREMENTS IN THE NORTHERN PART OF BEPPU, JAPAN

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Keywords: *microgravity measurements, monitoring, hot spring aquifer, Beppu*

ABSTRACT

Repeated microgravity measurements for monitoring a hot spring aquifer have been conducted in the northern part of Beppu, Northeastern Kyushu, Japan. We used not only a SCINTREX CG-5 relative gravimeter but also a Micro-g LaCoste A10 absolute gravimeter to assess the gravity changes at the reference station (BGRL). Repeated microgravity measurements were conducted five times at three or four month's intervals from April 2014 to July 2015 at 8 benchmarks including the reference station. Through comparison between the gravity and groundwater level data, we concluded that the obtained gravity changes at BGRL are caused by the seasonal groundwater level changes since the calculated porosity (23.6%) is close to the measured porosity of alluvial fan sediments (20.0%). The distribution map of gravity changes in the second period (from July 2014 to November 2014) shows huge difference in fluctuation amplitude of the observed gravity between the central area (B1, B2, B3) and the northern area (C1, C2, C3, TERUYU). We assume that is due to the thickness of alluvial fan sediments, which is widely distributed in Beppu district, based on a three dimensional gravity analysis. More gravity and groundwater level data should be accumulated, and a hydrological modeling is necessary to extract the gravity changes caused by the binary power plant operation.

1. INTRODUCTION

Beppu is one of the most famous hot spring resorts in Japan, which is located in Northeastern Kyushu, Japan (Fig. 1). There are numerous geothermal manifestations such as fumaroles, hot springs and steaming ground, mainly distributed along and/or around the Asamigawa fault to the south and the Kannawa fault to the north.

The first exploitation of the Beppu hydrothermal system was conducted as early as the 1880s, and intense exploitation of the 1960s-70s caused declines of water level and temperature in the shallow hot spring aquifer (Yusa et al., 2000). From the end of November 2014, a new binary power plant operation (125kW×4), extracting only steam (around 130℃, 2 ton/h) from the existing thermal well to generate electricity, has been started in Ogura, Kannawa hot spring area (Fig. 1). In order to maintain a favorable relationship between a power generation operator and local residents, it is essential to evaluate the sustainability of hot spring resources for the future utilization.

Repeated microgravity measurements are one of the effective methods for monitoring the hot spring aquifer. We applied these methods in the northern part of Beppu to observe the long-term gravity changes. Our final goal in this study is to monitor the gravity changes caused by the steam extraction from the hot spring aquifer associated with the binary power plant operation.

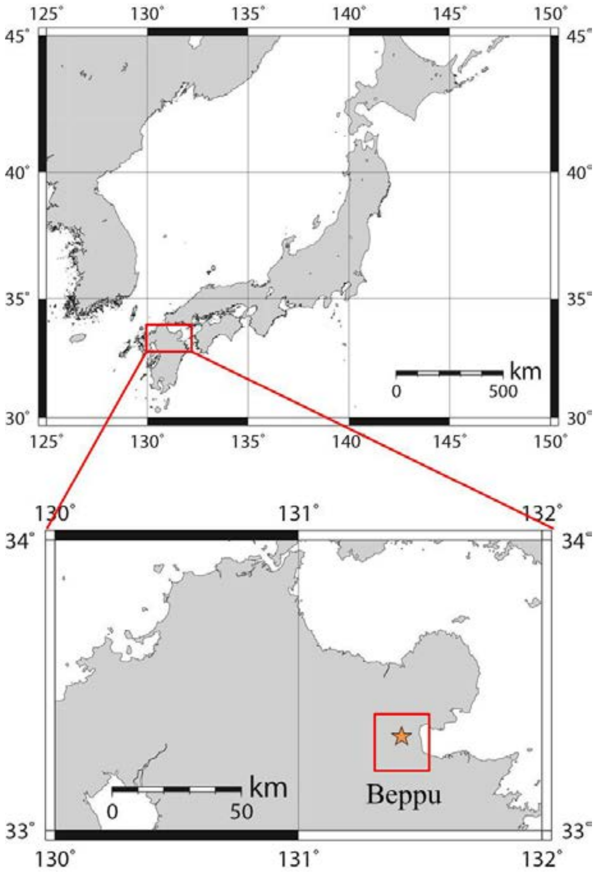

Figure 1: Location map of Beppu and binary power plant shown by solid star.

2. GEOLOGICAL SETTING

Beppu is located at the eastern end of the Beppu-Shimabara Graben under the influence of the Philippine Sea plate convergence (Itoh et al., 2014). Fig. 2 shows the geological map of the Beppu geothermal area (Geological Survey of Japan, 2014). The Beppu geothermal system is situated on the eastern flanks of the Yufu-Tsurumi-Garandake, which is the late Quaternary volcanic center (Yusa et al., 2000). The geological setting in Beppu is composed of Pliocene andesite (Kankaiji andesite), Pleistocene volcanic rocks and fan sedimentary deposits. Driller's logs suggest that the thickness of alluvial sediments and volcanic breccia reaches up to 500 m midway along the coast (Hoshizumi et al., 1988).

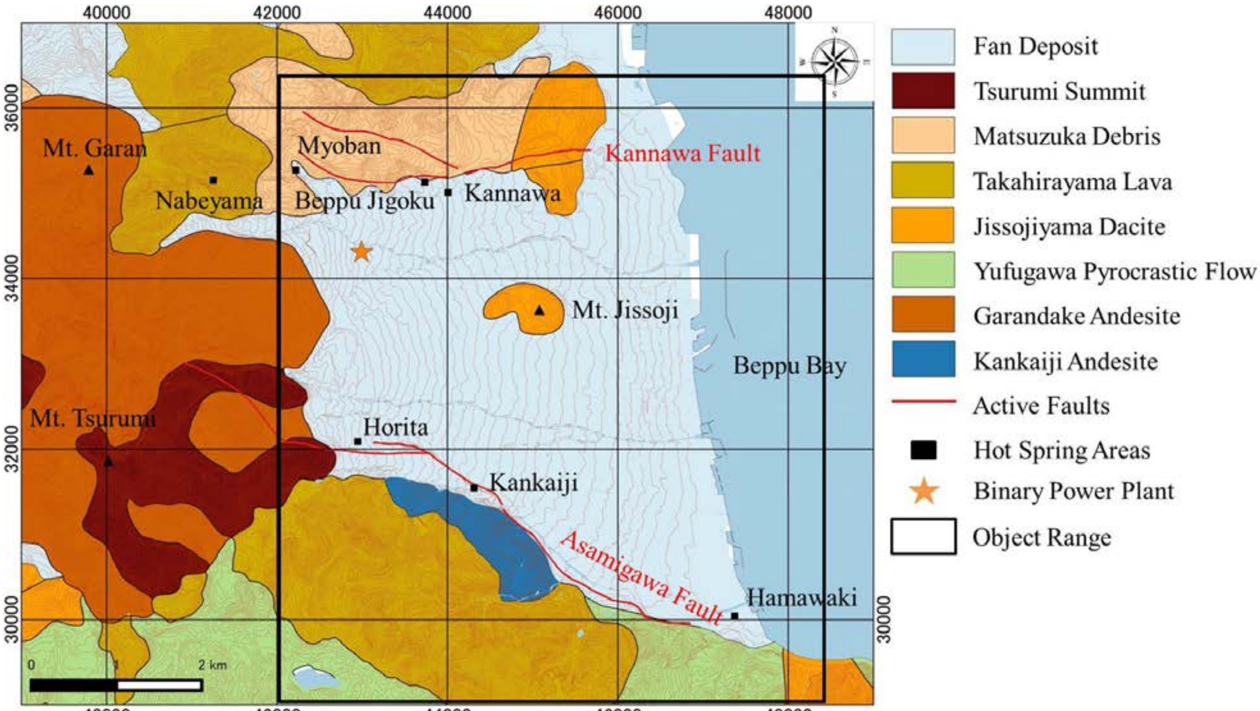

Figure 2: Geological map of Beppu.

3. UNDERGROUND STRUCTURE ANALYSIS

3.1 Gravity data

We analyzed the existing gravity data in Beppu, comprising 231 stations (Geological Survey of Japan, 2013), to obtain the Bouguer anomaly map. In order to calculate the Bouguer anomaly, some corrections such as free-air, Bouguer and terrain condition were processed. The assumed density of 2.3 g/cm^3 was applied based on the previous study (Komazawa and Kamata, 1985). Terrain corrections were calculated using the 50 m-mesh digital elevation map of the Geological Survey of Japan (GSJ).

The depicted Bouguer anomaly map is shown in Fig. 3. Two high Bouguer anomaly zones can be seen in the northern and southern parts of the map, and the low anomaly zone can be seen in eastern coastal regions.

Since the Bouguer anomaly contains the effect of the regional trend, we applied the second-order polynomial trend to reveal the shallow structure (Fig. 4). Through comparison with Fig. 3, the both high and low anomaly zones are clearly depicted in Fig. 4 and the high anomaly zone in southern part is consistent with the location of Kankaiji andesite in Fig. 2. Moreover, the steep slope of Bouguer anomaly along Horita and Kankaiji agrees with the location of Asamigawa fault.

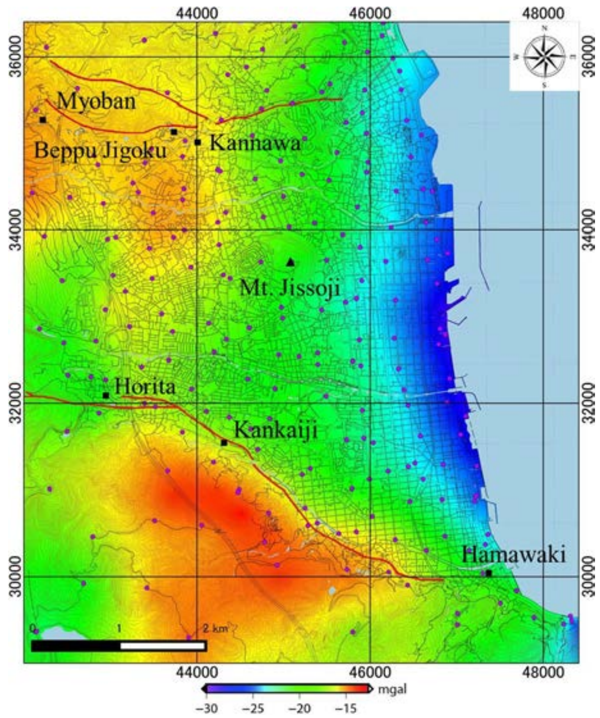

Figure 3: Bouguer anomaly map.

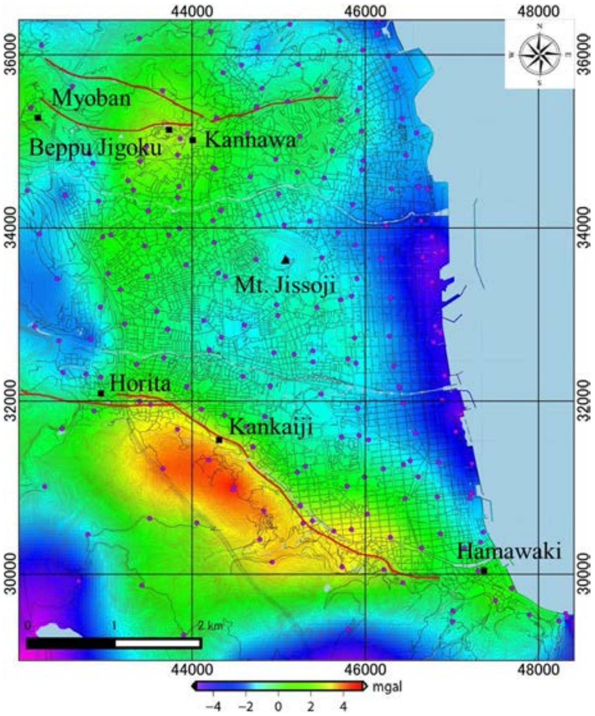

Figure 4: Residual bouguer anomaly map.

3.2 Three dimensional gravity modeling

The three dimensional gravity analysis was performed using Komazawa's method (1995) to calculate the depth of gravity basement. In this method, it's necessary to estimate a density contrast between the surface and basement layers. According to the geological map (Hoshizumi et al., 1988) and stratigraphic column (New Energy Developing Organization, 1990), the survey area can be approximated by Quaternary fan deposit and Neogene-Quaternary volcanic basement rock. The assumed density of fan deposit is 1.9 g/cm^3 and that of basement rock is 2.3 g/cm^3 (New Energy Developing Organization, 1990). Therefore, the density contrast of -0.4 g/cm^3 was assigned to all prismatic cells that form a three dimensional model.

The result of the three dimensional gravity analysis is shown in Fig. 5. Roughly speaking, the uplifts of the gravity basement in the northern and southern parts of the map correspond to the location of the high Bouguer anomaly zone in Fig. 4. The depression of gravity basement reaches up to 700 m along the coastline, and it spreads more widely in the southern part of the fan deposit area.

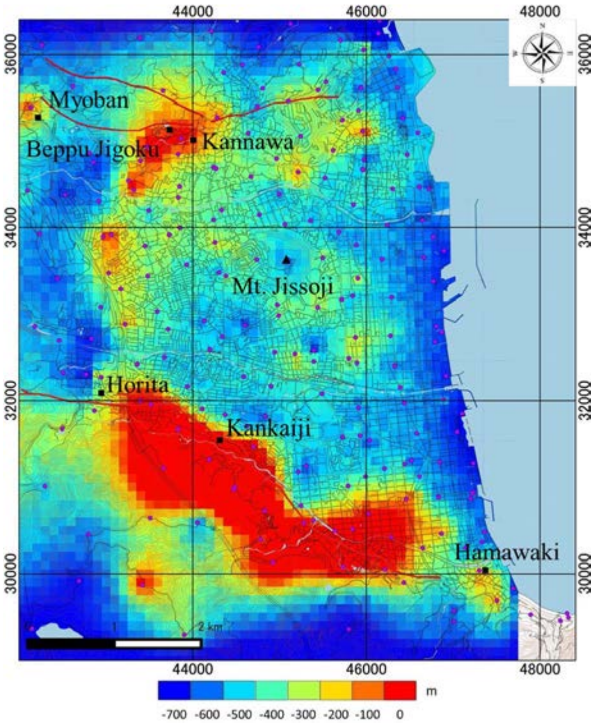

Figure 5: Modelled depth to basement.

4. GRAVITY MEASUREMENTS

4.1 Repeated microgravity measurements

Repeated microgravity measurements have been conducted in the northern part of Beppu. We used not only a SCINTREX CG-5 relative gravimeter (Fig. 6) but also a Micro-g LaCoste A10 absolute gravimeter (Fig. 7) to assess the gravity changes at the reference station (BGRL). Repeated microgravity measurements were conducted five times at three or four month's intervals from April 2014 to July 2015 at 8 benchmarks including the reference station (Table 1). The two-way measurement method was applied to evaluate the instrumental drift and precision of relative gravimeter. We estimated the errors of observation as ±10 μgal at each benchmarks. The background gravity changes were observed in the first half of the measurement period before the commencement of the binary power plant at the end of November 2014. Although the absolute gravity data on July 2, 2015 is missing due to some mechanical problems, it can be assumed that the gravity value didn't change a lot between March 3, 2015 and July 2, 2015 according to the measurement results in the previous year. Therefore, the same value as March 3, 2015 was used for calculating the relative gravity value on July 2, 2015.

Figure 6: SCINTREX CG-5 relative gravimeter.

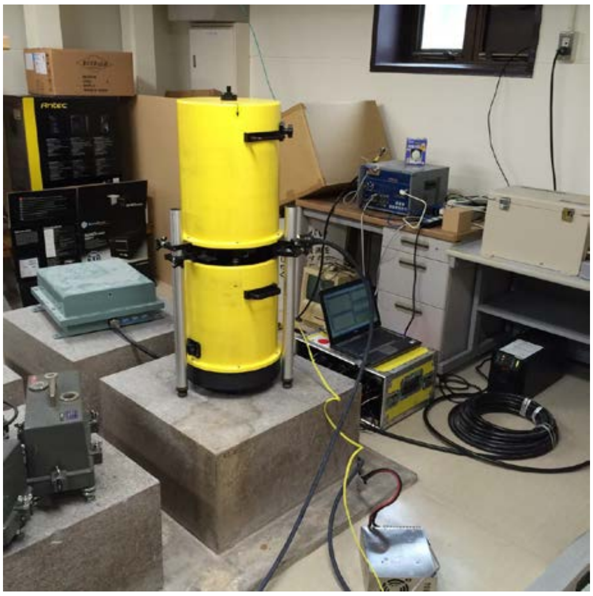

Figure 7: A10 absolute gravimeter.

Table 1: Data acquisition date

Objective	Background			Signal	
Year	2014			2015	
Date	4/24	7/17	11/18	3/3	7/2
A10	→	→	→	→	
CG-5	→	→	→	→	→

4.2 Groundwater level change

The gravity changes at the reference station are generally caused by the seasonal groundwater level changes. It is important to examine the relationship between the gravity and the groundwater level data to confirm the validity of the measurement results.

Fig. 8 shows the comparison between the observed gravity and groundwater level data at BGRL. In qualitative interpretation, it is clear that the observed gravity changes have a good correlation with the groundwater level changes. When the underground aquifer is assumed the semi-infinite flat plate, the relationship between the gravity and groundwater level changes are expressed by

$$\Delta g = 2\pi G\varphi\Delta h_w$$
$$= 0.419\varphi\Delta h_w$$

where Δ g is the gravity changes (µgal), Δh_w is the water level changes (m), G is a gravitational constant, φ is a porosity (%). The calculated gravity fluctuation ($\Delta g/\Delta h_w$) and porosity (%) are 9.88 µgal/m and 23.6%, respectively. Since this value is closed to the measured porosity of alluvial fan sediments (20.0%) (Japanese Association of Groundwater Hydrology, 1979), we concluded that the observed gravity changes at BGRL are caused by the seasonal groundwater level changes.

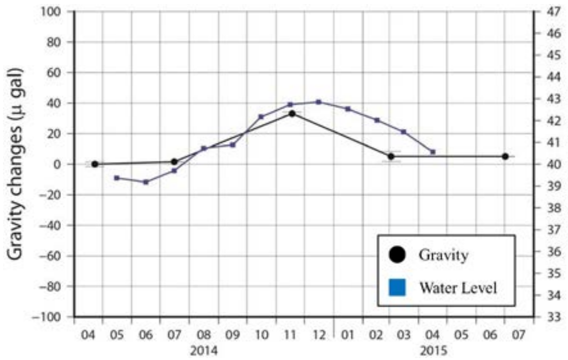

Figure 8: Comparison between the gravity and groundwater level data at BGRL.

4.3 Gravity change

The obtained distribution maps of gravity changes before the commencement of the binary power plant are shown in Fig. 9 and Fig. 10. In the second period, the large gravity increase can be seen in the entire region while the gravity decreased except BGRL in the first period. More specifically, there is huge difference in fluctuation amplitude between the central area (B1, B2, B3) and the northern area (C1, C2, C3, TERYU). The gravity increased as much as 100 µgal in the central area while 60 µgal in the northern area. We infer that is caused by the thickness of alluvial fan sediments, which is widely distributed in Beppu district, based on a three dimensional gravity modeling (Chap. 3.2). As shown in Fig. 5, the gravity basement is depressed deeper in the central area than the northern area, and it represents the difference in thickness of fan deposit between each area. Since the porosity of fan deposit is relatively high, the sediments in the central area can store the larger amount of fluid. Therefore, the local difference of gravity changes occurred.

The residual gravity changes, calculated by subtracting the background gravity changes, are shown in Fig. 11 and Fig. 12. In both periods, the gravity increased on a large scale at all benchmarks, and there are no particular gravity changes nearby the location of the binary power plant. We assume that is because the background gravity changes are not subtracted completely due to the large amount of precipitation in 2015. Therefore, water content within the unsaturated zone should also be taken into consideration beside groundwater level change by performing a hydrological modeling of groundwater disturbances (Kazama, 2009). Since the extraction rates of binary power plant is relatively small compared to geothermal power plant, and only steam is extracted to generate electricity in Ogura, Kannawa hot spring area, more gravity and groundwater level data need to be accumulated to detect the minor gravity changes.

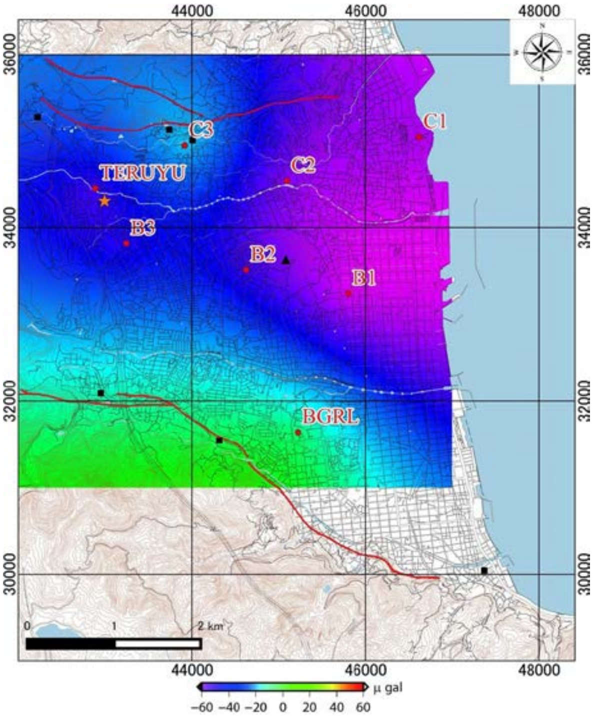

Figure 9: Gravity changes from 2014.04 to 2014.07.

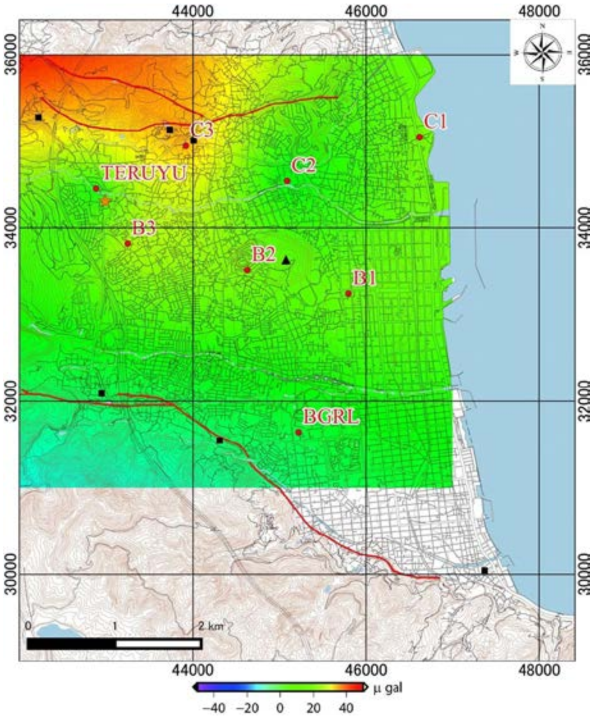

Figure 11: Gravity changes from 2014.04 to 2015.03.

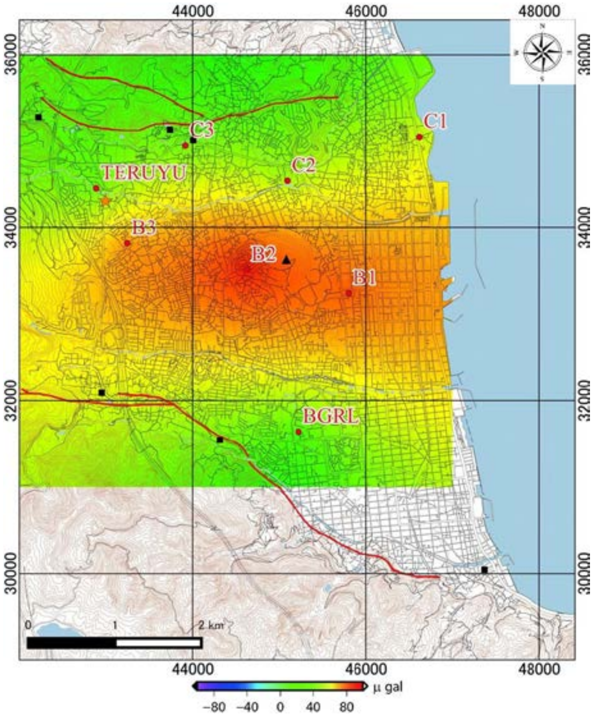

Figure 10: Gravity changes from 2014.07 to 2014.11.

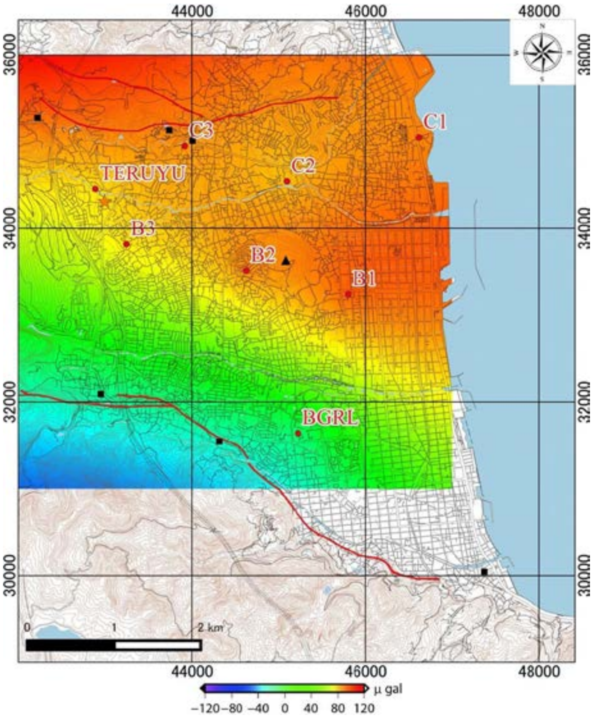

Figure 12: Gravity changes from 2014.07 to 2015.07.

5. CONCLUSION

In this paper, the result of microgravity measurement is presented, and the causes of the gravity changes are discussed by referring to the groundwater level data as well as the three dimensional gravity model. From qualitative and quantitative explanations, the observed gravity changes at reference station (BGRL) have a good correlation with the seasonal groundwater level changes. The distribution map of gravity changes in the second period (from July 2014 to November 2014) shows huge difference in fluctuation amplitude between the central area (B1, B2, B3) and the northern area (C1, C2, C3, TERYU) due to the thickness of alluvial fan sediments. More gravity and groundwater level data, however, should be accumulated, and a hydrological modeling is necessary to extract the gravity changes caused by the binary power plant operation.

ACKNOWLEDGEMENTS

This work was supported by the Research Institute for Humanity and Nature (RIHN). We thank to the financial assistance from RIHN.

REFERENCES

Geological Survey of Japan, AIST: Gravity Database of Japan, DVD Edition, Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology. (2013).

Geological Survey of Japan, AIST (Ed.): Seamless digital geological map of Japan 1:2000. Jan 14, 2014 version. Geol. Surv. Japan, National Institute of Advanced Industrial Science and Technology. (2014).

Hoshizumi, H., Ono, K., Mimura, K., Noda, T.: Geology of the Beppu district. With Geological Sheet Map of 1:50,000 (in Japanese). Geol. Surv. Japan. pp.131. (1988).

Itoh, Y., Kusumoto, S., Takemura, K.: Evolutionary process of Beppu Bay in central Kyushu, Japan: a quantitative study of the basin-forming process controlled by plate convergence modes. Earth, Planets and Space 66, pp.74. (2014).

Japanese Association of Groundwater Hydrology: Handbook of Groundwater (in Japanese). pp.20-25. (1979).

Kazama, T.: Hydrological modeling of groundwater disturbances to observed gravity data toward high-accuracy monitoring of magma transfer in volcanoes. (2009).

Komazawa, M.: Gravimetric analysis of Aso volcano and its interpretation. J. Geod. Soc. Japan 41, pp.17-45. (1995).

Komazawa, M., Kamata H.: Gravity basement structure in Houhi area (in Japanese). Geological Survey Report 264, pp.305-333. (1985).

New Energy Development Organization: Region exploration of Geothermal Fluid Circulation System, Tsurumidake area (in Japanese). National Geothermal Resources Exploration Project (3rd Phase), pp.88. (1990).

Yusa, Y., Ohsawa, S., Kitaoka, K.: Long-term changes associated with exploitation of the Beppu hydrothermal system, Japan. Geothermics 29, pp. 609-625. (2000).