Joint inversion of receiver function and gravity data for crustal thickness and velocity ratio

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The H-κ stacking technique in receiver function analysis is popular for estimating parameters of crustal thickness (H) and velocity ratio (κ), and has been widely applied in many areas. However, ambiguities occur in the result of this technique when the phases of multiple waves are not clear, or the structure beneath the station is complicated, resulting in difficulty for picking out optimum H and κ parameters from the H-κ stacking map. In this paper, based on the previous studies, we simplified and improved the algorithm of joint inversion of receiver function and gravity data, to decrease the ambiguities and enhance the precision and efficiency. Herein, the Bouguer gravity anomaly is considered to be composed of the Moho gravity anomaly and the crustal gravity anomaly, in which the former one is related to the crustal thickness and the latter is closely related to the crustal density and velocity ratio. According to the relationship between the gravity anomaly and the H and κ, the Bouguer gravity anomaly can be inverted by using the likelihood estimation approach to obtain the H and κ parameters. The gravity inversion utilizes the initial H and κ parameters from both the gravity interface inversion and the H-κ stacking of receiver function, while its inverted results are used to constrain the H-κ stacking of receiver function. The principle and work flow of the joint inversion between receiver function and gravity data are presented in details in the paper. Tests on both the synthetic data and the real data from the northeastern margin of the Tibetan Plateau demonstrated that the presented approach could effectively decrease the ambiguities with high precision and efficiency.

Keywords: gravity, H-K stacking, Joint inversion

Evaluation of INS/GNSS Integration for Gravimetry with UAV

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The airborne gravimetry system based on Inertial Navigation System and Global Navigation Satellite System (INS/GNSS) integration has been successfully developed to observe the gravity field and estimate the gravity disturbance, which is defined as the difference between the actual gravity and the normal gravity, with the accuracies of approximately 3–4 mGal for vertical component. This technique is more cost-effective than terrestrial gravimeters, and provides higher resolution than satellite missions. Therefore, it currently contributes to geodetic applications and Earth sciences. However, the present airborne gravimetry systems have some shortcomings. It is expensive to rent an aircraft for surveying, and strict rules and regulations exist for acquiring permission to conduct a flight mission. The availability and flexibility of conducting small area surveys or spatial information collection are limited. In addition, detecting short wavelength gravity signals has become a challenge because higher altitude would cause a decrease in the gravity magnitude. Generally speaking, decreasing the altitude of the system is an easy and direct way to overcome these problems.
This research integrates a navigation-grade INS and GNSS for gravimetry based on the use of Unmanned Aerial Vehicle (UAV). The advantages include its high maneuverability and operational flexibility, and it is an intermediate system between the aerial and terrestrial survey in terms of coverage and resolution. The preliminary results show that the internal accuracies of horizontal and vertical gravity disturbance at crossover points are approximately 6–11 mGal and 4 mGal, respectively, with a 0.5-km resolution. As expected, the accuracy in down component is higher than that in horizontal components because the orientation errors could cause large error in horizontal components. The capability of INS/GNSS integration for gravimetry with UAV from determining and de-noising processing has been evaluated in this research.

Keywords: INS, GNSS, Gravity disturbance, UAV

Estimation of Groundwater Content in Mingzhu Basin by Combination of Gravimetry and Electrical Resistivity Tomography

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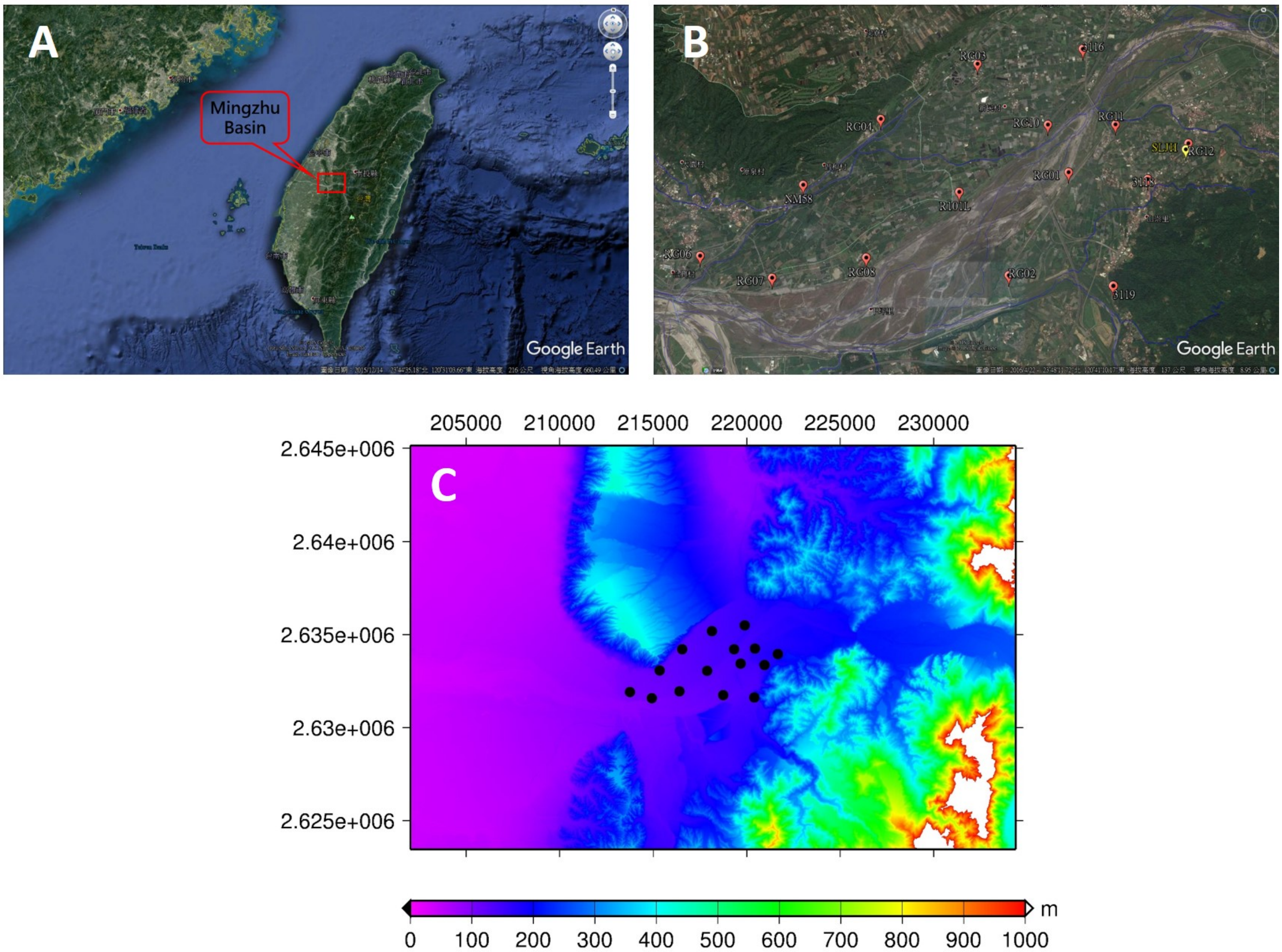
We combine the technologies of gravimetry and electrical resistivity tomography (ERT) to estimate the groundwater content in Minzhu Basin (Fig A). Gravimetry and ERT are used to observe mass variations and groundwater levels, respectively. Four joint surveying missions combing gravimetry and ERT have been carried out in September and December in 2016, and also will be carried out in March and June in 2017, respectively. On field surveys of gravimetry, we use the absolute gravimeter FG5 and relative gravimeter CG5 to collect the gravity observations at 16 gravity stations in Minzhu Basin (Fig B); on field surveys of ERT, we will lay 7 surveying profiles on both sides of Jhuoshuei River to collect the ERT observations. The gravimetry-derived and ERT-derived data will be combined with the data of 5m resolution DEM (Fig C) and ground water wells in Minzhu Basin area in order to estimate groundwater changes during the period from September 2016 to June 2017. The overall goal of this study is to estimate the groundwater content in Minzhu Basin during 2016~2017. To reach this purpose, the following issues have to be considered in advance: (1) analyze the suitability of the gravity and ERT observing stations; (2) determine the best geological density; (3) analyze the influence of gravity observation distance on groundwater change; (4) analyze the influence of groundwater level change on gravity values.

Keywords: Gravimetry, Electrical Resistivity Tomography, Groundwater Content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Combined use of a superconducting gravimeter and Scintrex gravimeters for hydrological correction of precise gravity measurements - A superhybrid gravimetry

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Precise gravity observations are often subject to influence of temporally variable distribution of underground water near the observation sites. It is in general difficult to model and correct such effects from the observed gravity series, because it requires knowledge of the hydrological nature of the underground which varies from place to place. The superconducting gravimeter CT36 at Ishigakijima, Okinawa, Japan also experiences very complicated effects of underground water, apparently combined with the atmosphere and the ocean. Effects of the fluids near the surface on gravity must be precisely corrected so that the possible gravity signals associated with the long-term slow slip events occurring near the Ryukyu trench can be detected.
To overcome this difficulty, we employ combined use of the superconducting gravimeter (SG) and Scintrex CG-5 gravimeters. The latter are used as mobile instruments, measuring relative gravity values with respect to the SG pier as in a local gravity survey. One of the advantages of the CG-5 gravimeter is that it enables continuous measurements and therefore comparison with the SG, thus greatly mitigating the problems of instrumental drift inherent to mobile gravimeters. Under the assumption that temporal gravity changes are common within the survey area, using the SG data as reference helps improving estimates of the local gravity field significantly.
We made an experiment of this kind of measurements (which we term superhybrid gravity measurements) using two CG-5's at Ishigakijima in January 2017. Preliminary analysis of the data has shown that relative gravity values at a particular point measured on different days were in agreement at 1 microgal precision. We will present further results and discuss temporal changes of gravity in relation to the dynamics of underground water.

Keywords: superconducting gravimeter, Ishigakijima, underground water, superhybrid gravimetry

The relationship between groundwater level and soil moisture for reduction of gravity disturbance.

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Tono Research Institute of Earthquake Science (TRIES) has been conducting continuous gravity observations in and around the Mizunami Underground Research Laboratory (MIU) aiming at the detection of earthquake-related gravity change. Quantification of gravity disturbances caused by groundwater level (or pore pressure) fluctuations has been refined by previous studies (Tanaka et al. 2006 G-cubed; 2013 EPS; under review). In particular, the primary factor of the gravity change in the order of a day or less, which is important in monitoring of crust activity, is precipitation (or unconfined groundwater level). By the way, in comparison with the groundwater level observation, soil moisture observation is incredibly easy and has much flexibility to install the instruments. Hence, we want to clarify these relationships based on observation data of gravity, groundwater level, and soil moisture, and then want to estimate gravity response caused by rainfall from soil moisture measurement. We have started parallel observations of an unconfined groundwater level (SBS16 borehole), a combined weather observation system including two soil moisture meters (made by Onset Computer Corp.), and a profile moisture meter (made by Delta-T Devices Corp.), at Syobasama Observation Point about 1.3 km away from the MIU site, since the fall of 2016. Meanwhile, continuous observation using gPhone gravimeters has been continuing inside and outside the MIU. At the time of this writing, because of the small amount of data and insufficient processing of collected data, we still have found no high precipitation or groundwater fluctuation events detectable by the gravimeter (approximately 10 mm on hourly precipitation, 30 mm on daily precipitation). However, when hourly precipitation exceeds about 5 mm, the SBS16 borehole is possible to respond on the order of meters in groundwater level. On 13-14 December 2016, there was a maximum 7 mm on hourly precipitation. At this time, in the soil moisture observations, the volume moisture content increased between 0 to 20%. The 0% was at the depth 30 and 40 cm channels of the profile moisture meter. On the other hand, the 20% was at the depth 10 cm channel of the same meter. The 20 cm depth channel of the profile moisture meter and the two soil moisture meters showed about 5% increase in water content volume. To adopt as a substitute observation for groundwater level observation, such the results indicate that the soil moisture meter should be installed and interpreted carefully because of its susceptibility to the setup situation. In future, we want to estimate these mutual conversion coefficients by comparing both groundwater level and gravity observation data after adequate data accumulation. Furthermore, we will aim to utilize soil moisture meter for correction of gravity observation of a place where groundwater level observation is unavailable.
Acknowledgement: Tono Geoscience Center of JAEA permitted and supported our combined weather observation system including soil moisture observations at Syobasama site.

Keywords: soil moisture, groundwater level, rainfall

Local gravity measurement to detect temporal gravity change in Antarctica

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Relative gravity measurements have been carried out at four times since February 2012 at five sites along Yatude Zawa valley in Langhovde, East Antarctica. Yatude Zawa valley locates in the vicinity of the Langhovde Glacier and we intend to detect gravity changes induced by mass change of the Langhovde Glacier and surrounding Antarctic ice sheet.
Metal markers of the measurement sites were constructed on outcrop rocks on February 4th, 2012 in the JARE53 operation (Doi et al. 2015). Simultaneously, relative gravity measurements with a LaCoste & Romberg (LCR) gravimeter G-1110 were conducted at the sites referring an absolute gravity measurement at AGS01 in Langhovde measured on February 3, 2012 (Kazama et al. 2013). After the first relative measurement, three round-trip measurements were conducted at the five sites at November 25, 2012 with LCR G-805, September 16, 2015 with LCR G-805 and December 27, 2015 with LCR G-1110. Gravity increases of a few hundred micro-gals are observed at the all relative measurement sites for approximately four years, although measurement errors at the all sites are greater than 170 micro-gals at the last measurement. We plan to carry out absolute and relative gravity measurements at the same sites again in 2017-2018 austral summer season. We will use multiple relative gravimeters at the relative measurements to improve the measurement accuracy.
In the presentation, we will show the gravity measurements in detail. We also intend to investigate causes of the temporal gravity increase from the aspect of ice sheet mass changes.

Keywords: Relative gravity measurement, Ice sheet mass change, East Antarctica

Gravimetric Connection with CG type Relative Gravimeter in Kamioka

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Gravimetric connection was executed in October 2016, between four points in and around the Kamioka Observatory, Institute for Cosmic Ray Research, University of Tokyo (ICRR). The measurement was performed by two relative gravimeters, Scintrex CG-3M (National Astronomical Observatory of Japan) and CG-5 (Nagoya University). Before this measurement, we had found by some experiments that the Scintrex CG type relative gravimeter shows hysteresis like behavior after each transportation. This portable type gravimeter shows gravity decrease of several tens of micro-gal just after any state of tilt, and recovers exponentially (Some CG-3 shows gravity increase, contrary). The recovery time seems to depend on its length of time under the tilted state, and sometimes it takes more than several hours. Taking this feature into account, we carefully performed the gravity connection by continuous measurement.
The gravity stations we connected are as follows. 1) Superconducting Gravity (S.G.) measurement station in the CLIO section, ICRR. 2) Absolute Gravity (A.G.) measurement station just ten meters away from the S.G. station. 3) Newly installed station at the Atotsu Entrance of ICRR. 4) Newly installed station at the Atotsu-KAGRA Entrance of ICRR. We first measured at the Atotsu Entrance for about an hour, then moved to the CLIO section. Then we measured each two times at S.G. and A.G. station for about half an hour by two gravimeters, alternately. The measurement time on each station is about 30 minutes to 1 hour like the way denoted above. We also made continuous measurements through the night-time to test the scale factor difference and to stabilize the instruments. As a result, we acquired two continuous sets of gravity data by the two gravimeters. After the earth tide correction, we gave offset values to each measurement sequences at each station, so that all the data are smoothly fitted to one line. Then we adopted the offset values as gravity differences between the stations. The gravity differences from the A.G. station are -0.096 mGal to the S.G. station, -50.084 mGal to the Atotsu-KAGRA Entrance station, and -53.684 mGal to the Atotsu Entrance station.

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Keywords: Gravity, Gravimetric Connection

Twelve Years of Gravity Observation at Kamioka with a Superconducting Gravimeter

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We had been carried out continuous gravity observation at Kamioka using GWR superconducting gravimeter (SG) model TT70#016. We started the observation in October 2004 and finished in April 2016. The observation site belongs to Institute for Cosmic Ray Research, University of Tokyo. The observation site is located about 1km under the ground and it is surrounded by rigid bedrock. The site is expected to provide quite and stable observation environment.

We got several observation results from SG such as Earth tide, free oscillation of the Earth, coseismic and postseismic gravity changes, seasonal change, and secular change. The SG has a low drift rate but it is difficult to distinguish secular gravity change from instrumental drift. To compensate the weakness of SG, we carried out absolute gravity measurements several times at Kamioka. In early time, Micro-g gravimeter FG5#210 of Kyoto University was used. In latter time, FG5#217 of AIST (National Institute of Advanced Industrial Science and Technology) was used. The data of absolute gravity measurements were used to discuss secular gravity change, and used for SG scale factor calibrations.

For the study of coseismic gravity change, we discussed the change caused by the Noto Hanto Earthquake in 2007. For the study of postseimic gravity change, we discovered steady decrease at the rate of about 10 micro gals per year in gravity after the great Tohoku Earthquake in March 2011. For the study of seasonal change, we found large seasonal gravity change of 10-30 micro gal. We investigated ground water behavior, especially the effect of fallen snow, to understand seasonal gravity change. We will report complete gravity observation results for twelve years at Kamioka.

Keywords: suoerconducting gravimeter, gravity change, Kamioka, Tohoku Earthquake

