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

*Lei Shi[1], Lianghui Guo[2]

1. IGP Institute of Geophysics, China Earthquake Administration, 2. China University of Geosciences (Beijing)

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

*Cheng-An Lin[1], Chung-Yen Kuo[1], Kai-Wei Chiang[1]

1. National Cheng Kung University

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

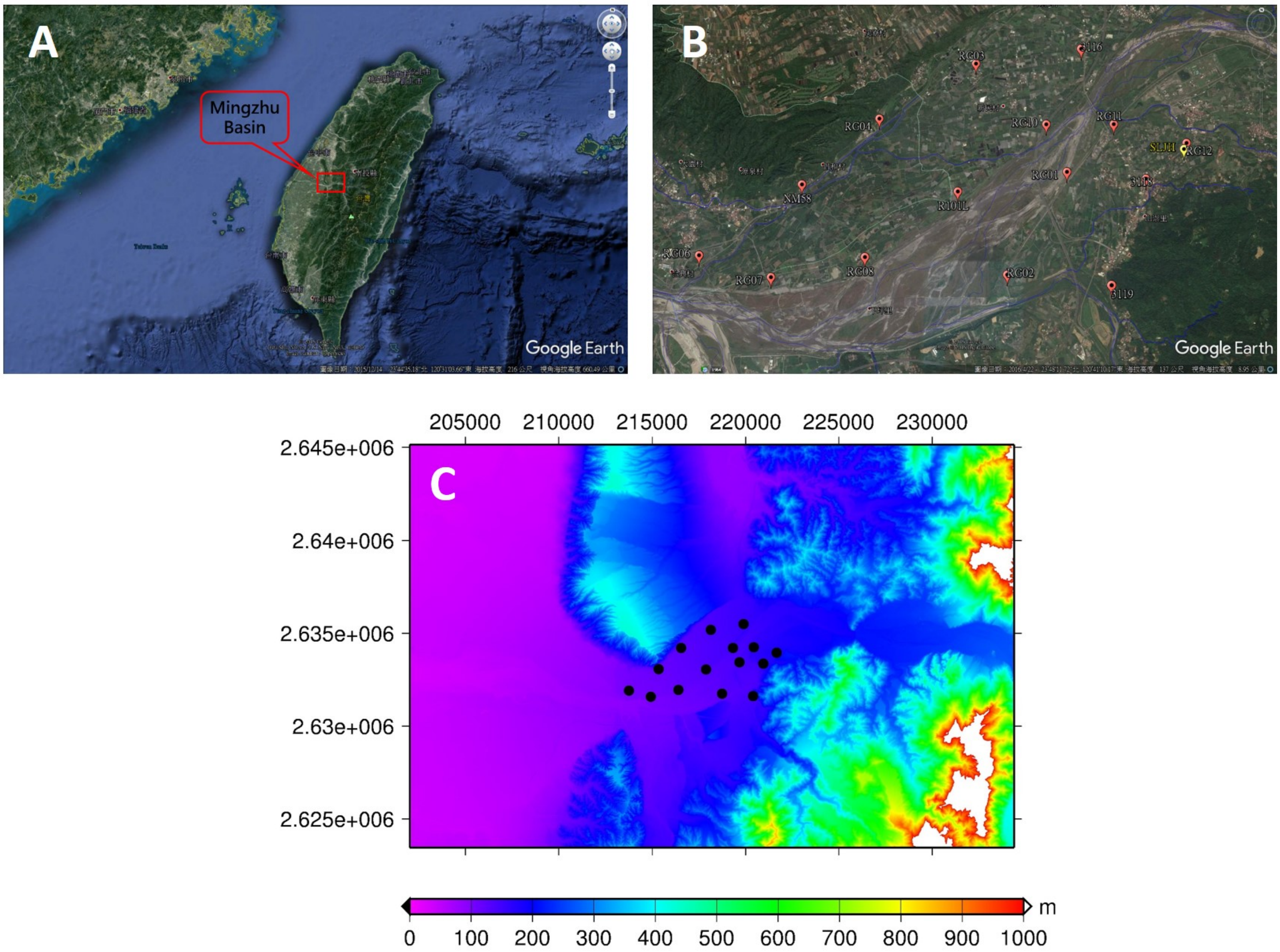
Estimation of Groundwater Content in Mingzhu Basin by Combination of Gravimetry and Electrical Resistivity Tomography

*ChunMin Shih[1], Shen Yu Hsiao[1], LiChun Tseng[1], LiPing Li[1], Chang Jung Chieh[1], FENG SHIH LIN[1]

1. National Chung Hsing University

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


A
Mingzhu
Basin
Google Earth
B
Google Earth
C
205000
210000
215000
220000
225000
230000
2.645e+006
2.64e+006
2.635e+006
2.63e+006
2.625e+006
0 100 200 300 400 500 600 700 800 900 1000
m

Combined use of a superconducting gravimeter and Scintrex gravimeters for hydrological correction of precise gravity measurements - A superhybrid gravimetry

*今西 祐一[1]、名和 一成[2]、田村 良明[3]、池田 博[4]、本多 亮[5]、奥田 隆[6]、大久保 慎人[7]
*Yuichi Imanishi[1], Kazunari Nawa[2], Yoshiaki Tamura[3], Hiroshi Ikeda[4], Ryo Honda[5], Takashi OKUDA[6], Makoto OKUBO[7]

1. 東京大学地震研究所、2. 産業技術総合研究所、3. 国立天文台、4. 筑波大学、5. 山梨県富士山科学研究所、6. 名古屋大学、7. 高知大学
1. Earthquake Research Institute, The University of Tokyo, 2. AIST, 3. NAOJ, 4. University of Tsukuba, 5. MFRI, 6. Nagoya University, 7. Kochi University

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.

キーワード：超伝導重力計、石垣島、地下水、スーパーハイブリッド重力測定
Keywords: superconducting gravimeter, Ishigakijima, underground water, superhybrid gravimetry

地下水位と土壌水分の関係 ー重力観測の補正に向けてー
The relationship between groundwater level and soil moisture for reduction of gravity disturbance.

*田中 俊行[1]、本多 亮[1]
*Toshiyuki Tanaka[1], Ryo Honda[1]

1. 公益財団法人地震予知総合研究振興会東濃地震科学研究所
1. Tono Research Institute of Earthquake Science, Association for the Development of Earthquake Prediction

東濃地震科学研究所では、地震関連の重力変化検出を目指し、瑞浪超深地層研究所を活用した重力連続観測を実施している。これまでの研究により、地下水位（もしくは間隙水圧）変動及ぼす重力擾乱の定量化が精密化されてきた(Tanaka et al., 2006, 2013, under review)。特に、地殻活動監視において重要な、日オーダー以下の時定数の重力変化の主要因は降水（即ち、不圧地下水位）である。ところで、地下水位観測に比べて土壌水分観測は、計器設置が極めて容易で設置場所の自由度も高い。そこで、重力・地下水位（不圧地下水）・土壌水分の観測データに基づいて、これらの関係を明確にし、土壌水分観測から降雨による重力擾乱を推定したい。我々は瑞浪超深地層研究所から約1.3km離れた正馬様観測点にて、不圧地下水位（SBS16号孔）、土壌水分計２台を含む複合気象観測システム(Onset社製）、プロファイル水分計(Delta-T Devices社製）の並行観測を2016年秋より開始した。一方、瑞浪超深地層研究所内外では、gPhone重力計による連続観測を継続している。本稿執筆時点ではデータ蓄積及び回収データの処理が不十分なため、重力計で検出可能なレベルの雨量・地下水位変動イベント（時間雨量で10mm、日雨量で30mm程度以上）は得られていない。しかし、時間雨量が約5mmを越えるようになるとSBS16号孔でメートルオーダーの水位上昇が生じ得る事がわかっている。2016年12月13~14日には、時間雨量で最大7mmの降水があった。この時、土壌水分観測では、0~20%の体積含水率の上昇が生じた。0%はプロファイル水分計の深度30, 40cmのチャンネルで、20%はプロファイル水分計深度10cmチャンネルであった。プロファイル水分計深度20cmとOnset土壌水分計２つは5%程度の変化であった。このことから、土壌水分計は設置状況の影響を受けやすく、地下水位観測の代替指標とするにも慎重を期す必要がある。今後、データ蓄積に努めるとともに、水位観測と重力観測も合わせて比較し、これらの相互変換係数を推定したい。更に、水位観測を実施できない場所での重力観測の補正用として土壌水分計の活用を目指したい。

謝辞：正馬様観測点での土壌水分観測を含む総合気象観測の実施には、原子力機構東濃地科学センターの皆様にお世話になりました。

キーワード：土壌水分、地下水位、降水
Keywords: soil moisture, groundwater level, rainfall

Local gravity measurement to detect temporal gravity change in Antarctica

*土井 浩一郎[1,2]、早河 秀章[1]、東 敏博[3]、青山 雄一[1,2]、福田 洋一[4]
*Koichiro Doi[1,2], Hideaki Hayakawa[1], Toshihiro Higashi[3], Yuichi Aoyama[1,2], Yoichi Fukuda[4]

1. 国立極地研究所、2. 総合研究大学院大学、3. テラグラブ、4. 京都大学
1. National Institute of Polar Research, 2. The Graduate Univ. for Advanced Studies, 3. TerraGrav LLC., 4. Kyoto University

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.

キーワード：相対重力測定、氷床質量変動、東南極
Keywords: Relative gravity measurement, Ice sheet mass change, East Antarctica

CG型相対重力計による神岡での重力点結合
Gravimetric Connection with CG type Relative Gravimeter in Kamioka

*本多 亮[1]、今西 祐一[2]、田村 良明[3]
*Ryo Honda[1], Yuichi Imanishi[2], Yoshiaki Tamura[3]

1. 山梨県富士山科学研究所、2. 東京大学地震研究所、3. 国立天文台水沢VLBI観測所
1. Mount Fuji Research Institute, Yamanashi Prefectural Government, 2. Earthquake Research Institute, The University of Tokyo, 3. National Astronomical Observatory of Japan, Mizusawa VLBI Observatory

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.

Acknowledgement
We appreciate Kamioka Observatory, ICRR for every convenience. We are also thankful to Nagoya University for allowing us to use CG-5 gravimeter.

キーワード：重力、重力点結合
Keywords: Gravity, Gravimetric Connection

神岡における超伝導重力計による重力観測12年
Twelve Years of Gravity Observation at Kamioka with a Superconducting Gravimeter

*田村 良明[1]、今西 祐一[2]、池田 博[3]、名和 一成[4]、杉原 光彦[4]、宮川 歩夢[4]
*Yoshiaki Tamura[1], Yuichi Imanishi[2], Hiroshi Ikeda[3], Kazunari Nawa[4], Mituhiko Sugihara[4], Ayumu Miyakawa[4]

1. 国立天文台水沢VLBI観測所、2. 東京大学地震研究所、3. 筑波大学低温部門、4. 産業技術総合研究所
1. National Astronomical Observatory of Japan, Mizusawa VLBI Observatory, 2. Earthquake Research Insutitute, The University of Tokyo, 3. Cryogenic Division, University of Tsukuba, 4. National Insutitute of Advanced Industrial Science and Technology

岐阜県飛騨市神岡町にある東京大学宇宙線研究所神岡宇宙素粒子研究施設の地下施設において、2004年10月から2016年4月の間、GWR社製の超伝導重力計（SG）TT70型016号機により重力変化の連続観測が行われた。重力計の設置場所は、坑口からは約2km、かぶりが約1kmある場所で、強固な岩盤（飛騨片麻岩）に囲まれており、静穏な環境のもとでSGの特性を生かした高感度で安定した観測を行うことをめざしてきた。

重力変化の観測からは種々な観測データが得られており、地球潮汐、自由振動、地震に伴う重力変化、季節変化、経年変化などの現象が捉えられている。SGによる観測はドリフトが小さいものの、重力の経年変化を議論する場合にはSGの機械的なドリフトと現象を分離することが困難である。そこでSGの観測期間中、SGが設置されている神岡坑内で絶対重力測定がくり返し実施され、SGの弱点を補う観測が行われている。初期には京都大学理学研究科所有のFG5#210により、後期には産業技術総合研究所所有のFG5#217により絶対重力観測が実施された。絶対重力測定は重力の経年変化を捉えることを目的としているが、SGのスケール定数検定にもデータが使われている。

地震発生時の重力変化については、2007年3月の能登半島地震について議論した。また、2011年3月の東北地方太平洋沖地震については、地震発生後、年間約10μgalという高いレートで重力が減少し続けていることを明らかにした。季節変化については10～30μgalと大きな変化が観測されており、陸水の影響、特に積雪の影響については積雪データの収集法を含めて詳細な検討を行っている。これまで行ってきた12年間の観測結果について、改めてまとめの報告を行う。

キーワード：超伝導重力計、重力変化、神岡、東北地方太平洋沖地震
Keywords: suoerconducting gravimeter, gravity change, Kamioka, Tohoku Earthquake

