Japan Geoscience Union Meeting 2015
(May 24th - 28th at Makuhari, Chiba, Japan)

SGD23-01 Room:102A Time:May 27 16:15-16:30

The new insight for earthquakes, based on the satellite gravimetry.

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The GRACE satellites observe gravity changes by huge earthquakes. Since the GRACE satellites were launched in 2002, several gravity changes have been reported such as the coseismic gravity changes by the 2004 Sumatra-Andaman earthquake, by the 2010 Maule earthquake, and by the 2011 Tohoku-oki earthquake. For the 2004 Sumatra-Andaman earthquake, not only the coseismic gravity change but also the postseismic gravity change has been reported.

I'll explain about three topics:

(1) Topic 1
The mechanisms of coseismic gravity changes by shallow-focus earthquakes have almost been revealed by previous studies. First, I'll introduce the knowledge about it.

(2) Topic 2
I researched the postseismic gravity changes with newer data than those used in previous studies and found the postseismic gravity changes had two components. After decreasing coseismically, the gravity continued to decrease for a first few months and turned to increasing. In my opinion, these two components can be related to afterslip and viscoelastic relaxation. These two phenomena are hard to separate, so they often get into topics in scientific meetings. The result of my study suggests that it would become possible by using the gravity data.

(3) Topic 3
The GRACE satellites also caught the coseismic gravity change of the 2013 Okhotsk deep earthquake (Mw8.3, depth at 604km) and I found it came from the ground deformation. The gravity field is changed coseismically by three main causes, i.e., (1) ground uplift and subsidence, (2) Moho uplift and subsidence, and (3) density changes under the ground. The density changes were dominant in the 2004 Sumatra-Andaman earthquake, the 2010 Maule earthquake, and the 2011 Tohoku-oki earthquake. But in the 2013 Okhotsk deep earthquake, the dominant cause was not density changes but ground deformations. The density changes occurred at a depth of about 600km. This was so deep that the GRACE could not catch it. But the ground uplift and subsidence had so long distance from each other that the GRACE was able to catch the signals. This means that the GRACE is the first tool for the two-dimentional signals of ground deformations by deep earthquakes.

Keywords: GRACE, Postseismic gravity changes, Coseismic gravity changes, Afterslip, Viscoelastic relaxation, Deep-focus earthquakes

Japan Geoscience Union Meeting 2015
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SGD23-02 Room:102A Time:May 27 16:30-16:45

Admittance between gravity and topography show the moon's lithosphere

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The Moon is the only natural satellite of the Earth, and is believed to be formed by an impact of a Mars-sized body with the primitive earth, and the subsequent integration and cooling of fragments formed in the impact. The Moon is an important key to investigate the early history of the solar system because it preserves the ancient surface and is the most accessible planetary body from the Earth. Investigating the formation and evolution of the Moon requires an understanding of the interior structure, heat generation, and differentiation.

The lunar exploration has started with the invention of the optical telescope by Galileo Galilei, which enabled us to see the topographic irregularity of the lunar surface. In the 20th century, scientists sent various probes to the Moon, and have been trying to explore its interiors by various observations with lunar landers and from lunar orbiters.

In this study, we study the relationship between the free-air gravity model from the GRAIL (Gravity Recovery and Interior Laboratory) mission and topographic model from the laser altimetry in the LRO (Lunar Reconnaissance Orbiter) mission. In the GRAIL mission gravity field was derived from the changes in the distance between the two identical satellites on the same orbit. The gravity and topography showed low/high correlation in the low/high degree components. This means that isostatic compensation is highly achieved for long wavelength features due to the ductile flow in the lunar mantle, and that the short wavelength topography is mainly supported by lithospheric strength. For the topography of very short wavelength, with degree/order exceeding 400, the correlation again becomes low due to errors in the gravity model.

It is important to compare the correlation between the gravity and topography of not only the Moon but also other terrestrial planets, such as Mars and Venus, to study degree of isostatic compensation and lithospheric thickness. For example, Mars is larger than the Moon and smaller than the Earth, and its lithospheric thickness and the degree of isostatic compensation will also be between the Moon and the Earth.

In addition to the correlation, we study the admittance, which is defined as the amplitude ratio of topography and gravity anomalies. The admittance is important in the discussion of the thickness of the lithosphere that can support the surface irregularity as an elastic body (referred to as elastic thickness here). Generally, a larger planet has larger surface heat flow and thinner lithosphere. Thin lithosphere would cause high degree of isostasy for the topography of the shorter wavelength. For the Moon, small admittance for long wavelength topographies quickly becomes larger, and the admittance keeps constant at about 110 mgal/km for degrees larger than 50.

Based on the theory in Watts (2001), we estimated the elastic thickness of the Moon as ~14 km. This thickness is comparable to those found in the present Earth in spite of the smaller dimension of the Moon. This may suggest that the majority of the topographic features on the Moon was formed in the early stage of the Moon, when the moon was not so cold as it is today.

In planetary physics, it is important to compare different planets and moons from various aspects. The present study suggests that the Moon still conserves the state of the early-stage isostasy as a fossil to investigate its ancient elastic thickness. After all, it is important to consider not only size but also age of the topography in discussing the elastic thickness of a planet or a moon.

Keywords: the moon, topography, gravity anomaly, lithosphere, correlation, admittance

Japan Geoscience Union Meeting 2015
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SGD23-03 Room:102A Time:May 27 16:45-17:00

Systematic error evaluation of the compact absolute gravimeter TAG-1

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In recent years, absolute gravimeters are used not only for determining static or secular-changing gravity field but for observing dynamic gravity change associated with movement of underground fluid, such as groundwater and magma. For the latter purpose, we have developed a compact absolute gravimeter, TAG-1, to use it for continuous monitoring volcanic activities at a site close to the volcanic vent. As compared to relative gravimeters, absolute gravimeters enable continuous stand-alone measurements without any round-trip comparison to the gravity reference point.

In July of 2013, we carried out a short-term observation at Kirishima volcano observatory (Miyazaki, Japan) using TAG-1 [1]. The statistical error was 0.8 uGal for one-day observation. Measured absolute gravity, however, showed reduction of 20-25 uGal from preceding observation in March of 2012. The regional crustal deformation inferred from GPS data suggested the reduction probably originated from instrumental error of TAG-1. We consider two error sources: recoil vibration and photo-detector response. The recoil force is generated at the time of releasing a free-fall mass and actuates the floor, resulting in vibration of the reference mirror. Slight phase delay determined by the photo detector causes systematic error in the gravity calculated from the quadrature fringe data [2].

In this presentation, both errors are evaluated, and performance of TAG-1 including its accuracy after the error correction is discussed.

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Keywords: absolute gravimeter, systematic error, volcano, Kirishima, recoil, photo detector

SGD23-04 Room:102A Time:May 27 17:00-17:15

Performance evaluation of a test mass launch system including a reaction reduction mechanism for a rise-and-fall AG

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We describe the test mass launch system including a reaction reduction mechanism for the compact rise-and-fall absolute gravimeter (AG). Absolute gravimeters measure the local value of the gravitational acceleration g in the accuracy of few μgal (1μgal = 10^{-8} ms^{-2}). Absolute gravimeters are used to establish the gravity standard network. They can be also used to survey of magma movement in the volcano. The data provide significant information of volcanic activities and various studies are proceeded to estimate volcanic eruptions and underground density structures. Absolute gravimeters are accurate, but the equipment is too bulky and heavy for field observation. As a result, for volcanic observations, a gravity value is usually measured by an absolute gravimeter at a reference point of foot, and then a gravity value of an observation point can be obtained from the gravity difference of a reference point and an observation point measured with the relative gravimeter. Therefore such an observation is troublesome, and requires long time. An apparent gravity change by the drift of the relative gravimeter happens, and measurement accuracy may worsen. Furthermore it is dangerous to observe at a reference point when a volcano erupts. If compact absolute gravimeters are completed and put to a volcanic area, we will acquire accurate data continuously even when the volcano is active. To achieve these, my studies are very important.

We adopt a rise-and-fall method to realize the downsizing of the absolute gravimeters. The measurement of gravity acceleration is based on the reconstruction of the orbit of the test mass thrown up or dropped in vacuum chamber. This method has some advantages. The simple free-fall method has several problems such as bulky mechanism to lift up the test mass, repeated measurements, and long time to take for the preparation. Hence, we developed the launch equipment that has no need for lifting up the test mass and can measure repeatedly. In addition the finite speed of light effect and drag effect are offset. As a result, systematic error becomes small. The equipment can throw up the test mass by 3mm in height simply by applying the signal to a piezoelectric element which is incorporated in the displacement enlarging mechanism. And the reaction reduction system is attached for the purpose of improvement of the measurement accuracy. When the test mass is thrown up, the floor recoil affects the interferometer and generates a systematic error. Specifically, we put the same piezoelectric element and the displacement enlarging mechanism on the other side of the baseplate to which the launch system is attached. These displacement enlarging mechanisms move symmetrically by applying the same signal to the piezos. When the test mass is thrown up, the counter mass fixed by springs is launched downwards at the same time to compensate the recoil effect. Moreover, to avoid the vibration occurrence by movement of displacement enlarging mechanism, we applied the signal of which acceleration is as continuous as possible. We could observe the reaction as much as 20% of peak acceleration without its mechanism. The result of gravity measurement in February and development status will be reported.

Keywords: absolute gravimeter, launch system, reaction reduction mechanism, gravity, prediction of volcanic eruption, estimating a subsurface density structure

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SGD23-05 Room:102A Time:May 27 17:15-17:30

Development of a portable laser-interferometric gravity-gradiometer

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[1]Sachie Shiomi

We are developing a portable laser-interferometric gravity-gradiometer for environmental measurements. In the gravity gradiometer, differential accelerations between two test masses, which are in free fall at different heights in a vacuum tank, are measured by a laser interferometer. A prototype of the gravity gradiometer was built up, and its performance was tested at the Sakurajima Volcanological Laboratory of the Kyoto University. We will report the current status of the development.

Keywords: gravity gradients, environment measurements

Japan Geoscience Union Meeting 2015
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SGD23-06 Room:102A Time:May 27 17:30-17:45

Making of Japanese domestic gravity data which consistent to Japan gravity standardization net 2013

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Geospatial Information Authority of Japan (GSI) have established a new gravity standardization net of Japan, the Japan Gravity Standardization Net 2013 (JGSN2013), from the latest absolute and relative land gravity data which covers all Japanese islands. JGSN2013 have achieved great improvement in accuracy and special coverage by adopting FG5 absolute gravity meter as an instrument, updating station coordinates to ITRF2008 and modifying tidal correction procedure to more consistent manner through all process.

Furthermore, GSI conducted second order gravity survey which covers 14,000 stations all over Japan from 1967 to 1993. The latest gravity data archive of Japan which have higher spatial coverage and consistency with FG5 will be established from the archived data of 14,000 stations by converting them to those which are consistent with JGSN2013.

However, error checking and least square data processing of huge second order gravity data which are same procedures as those of fundamental and first order gravity data will take huge time and efforts. Moreover, second order gravity data has lower precision than first order gravity data because GSI adopted different gravimeter and procedure and the results contain several additional errors including observation errors. In addition, even if we adopt the same data processing as first order gravity data for second order gravity data analysis, we could not get the equivalent precision for second order gravity values to first order gravity values. Therefore, we are trying more efficient methods of converting original second order gravity data to new gravity data set which are consistent with JGSN2013, by developing conversion parameters from JGSN75 to JGSN2013. Our purpose is to develop an interpolation method which gives the most consistent parameters for conversion from original gravity data to JGSN2013 without generating artifacts. The model should express the relationship between two datasets and be consistent with the actual differences.

The development of the method for conversion from original second order gravity data to JGSN2013 is reported in this paper.

Keywords: JGSN2013, second order gravity survey

Japan Geoscience Union Meeting 2015
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SGD23-07 Room:102A Time:May 28 09:00-09:15

Gravity anomalies and ice mass movements around the Japanese Antarctic stations in East Antarctica

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The region from Dronning Maud Land to Enderby Land in East Antarctica, where a Japanese Antarctic station Syowa is located, is a key area for investigating the formation of Gondwana, because reconstruction models suggest a junction of the continents locates in the area. There is Shirase Glacier, one of the major glaciers in Antarctica, which controls the ice sheet floor of the area. Moreover, recent investigations using GRACE, IceSat/Envisat, and other geodetic and/or gloctiological measurements show the mass increase in the area. Therefore the area is also important for glaciological and GIA studies.

To contribute to these investigations as well as enhancing gravimetric networks, the Japanese Antarctic Research Expedition (JARE) has been conducting gravity measurements in the area for a long time. Combining these in-situ gravity data and GOCE EGMs recently released, gravity fields in the area have been newly determined by means of Least Squares Collocation. In addition, JARE-55 (the 55th JARE) conducted the absolute gravity measurements at a gravity base point on the Seal rock near the Asuka station in the Sor-Rondane Mountains. There results have been reported in the previous JpGU meetings and other opportunities.

In the area, JARE-28 conducted gravity measurements along a N-S traverse line from Breid bay to Sor-Rondane Mountains via Asuka station. The absolute gravity value obtained by JARE-55 was employed to reevaluate the gravity anomalies and we conducted detailed analyses of their characteristics by comparing them with the newly determined gravity anomalies, GOCE EGMs and the basement topography of the ice sheet. The result suggests that the lower gravity anomalies between the coastal area and the mountains would be due to the thick ice sheet accumulated in the area. The same structure can be found in a wide area from Dronning Maud Land to Enderby Land, and it is coincident with the area where the ice mass has increased. Although the reason is not obvious, there might be a relation between the ice sheet flow and the basement topography, in addition to the relation between the snowfall and the mountain topography.

Keywords: gravity anomalies, ice mass movements, Glacial Isostatic Adjustment, absolute gravity measurements, GOCE

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SGD23-08 Room:102A Time:May 28 09:15-09:30

Absolute gravity measuremt using A10 absolute gravimeter around Gundih gas field for CCS monitoring

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Indonesia government plans to reduce CO_2 emissions by 26% from 2005 levels by the year 2020. It is thought that one of the large quantities of CO_2 are released into the atmosphere during production of natural gas at gas processing. And it is one of the serious problems for the achievement of the national purpose of a total CO_2 reduction. This problem can be solved by establishing a system for carbon dioxide capture and storage (CCS) technology in which the CO_2 from natural gas production is captured and injected into the ground as a means of directly reducing CO_2 emissions. The SATREPS project "Pilot Study for Carbon Sequestration and Monitoring in Gundih Area, Central Java Province, Indonesia" ,which is funded by JICA and JST, is conducting a research and development of safety storage of CO_2 in the subsurface and to establish monitoring technologies in the Gundih gas field in Central Java, where natural gas production is just started.

We started the absolute gravity measurements using A10 absolute gravimeter (Micro-g LaCoste Inc.) at 6 station. In 2014, we added 3 station near the candidate place for CO_2 injection. The A10 absolute gravimeter is a portable absolute gravimeter produced by Micro-g LaCoste Inc. It operates on a 12V DC power supply (i.e. vehicle battery). We can measure the absolute gravity using the vehicle battery at the field. We measured 10 sets at each measurement, and 1 set consists of 100 drops. We observed gravity decrease (30 micro gal) in KTB1. But we did not detect the significant gravity change. We set the soil moisture meter near KTB1 station in 2013. Though we could not get the data for a long time, but we got about 2 month soil moisture data. Based on this data, we estimated the gravity effect caused by soil moisture change.

We predicted the amount of gravity changes caused by CO_2 injection based on the results of CO_2 injection simulation. We will report the result of the prediction.

Keywords: CCS, Micro-Gravity Monitoring, Absolute Gravity Measurements

Japan Geoscience Union Meeting 2015
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SGD23-09 Room:102A Time:May 28 09:30-09:45

Gravimetrical vertical array observation -the 2014 fiscal year-

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The gravimetrical vertical array, as we call it here, is to suppress the rainfall disturbance with establishing two gPhone gravimeters across the unconfined groundwater surface using the Mizunami Underground Laboratory (MIU). In the 2014 fiscal year, we set up gPhone#130 in the refuge area of the 100m-deep sub-stage (sub-stage is a horizontal tunnel between the Main and Ventilation shafts) and gPhone#90 on the ground surface in the measuring room of the Mizunami Geoscience Academy, and have accumulated data without bad effects of blasting for construction works as those of years past. The sensor drift of #130 is dominated by nonlinear fluctuations because of high-noise level environment due to drainage equipments and elevator machines. The one of #90 is almost linear, and we will be able to evaluate the drift rate by using an absolute gravimeter. As for the atmospheric pressure belowground, the difference from the one aboveground becomes larger, the deeper the observed depth is. Therefore, it is necessary to investigate the reduction methods, both sensor drift and atmospheric disturbance for the sake of sub-microGal variations. In this presentation, we demonstrate the attempt to decrease the nonlinear drift using non-parametric modeling and to assess atmospheric disturbance based on the MANAL atmospheric model by the Japan Meteorological Agency.

Acknowledgements: This work is supported by a promotion grant for the establishment of the underground research facility of the Agency for Natural Resources and Energy, Minister of Economy, Trade and Industry. We thank the JAEA for the cooperation of observations (especially Mr. Y. Aoyagi).

Keywords: continuous gravity measurement, gravimeter, inland water, rainfall, atmospheric correction, measuring method

SGD23-10 Room:102A Time:May 28 09:45-10:00

Independent component analysis of gravity data observed by gPhone gravimeters

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We tested ICA (Independent Component Analysis) for detecting the gravity signals due to various geophysical phenomena. ICA is one of the multivariate analysis methods that decomposes mixed data into uncorrelated components assuming that the original signals are non-Gaussian. Thus far, it has been mainly used for the researches of sound and brain waves because those signals are uncorrelated and non-Gaussian.

Since the signals of gravity changes also can be considered non-Gaussian, we tried to separate those signals using ICA. Using pseudo gravity data sets that were composed by mixing sinusoid waves with different periods, we first conducted numerical tests to decompose the signals. The results showed that the signals can be separated if the length of data is enough longer than its wavelength. However the separation was not satisfactory in the following cases; the signals was shorter than their wavelength, and the signals contained trends. In those cases, the separation can be improved by removing the trend components in advance.

Based on these results, we applied ICA for the analysis of the gravity data obtained by three gPhones #123, #126 and #127 at a gravity base station (Kyoto A) in Kyoto University. The observations were conducted from January to February, 2014 and the data period is 300 hours. The Earth tide signals were removed in advance by using BAYTAP-G program, and the instrumental drift for each gravimeter was corrected by fitting an exponential functions. Since we did not correct the effects of atmospheric pressure, the residual gravity signals, which were used as the input data for ICA analysis, may contain the atmospheric, trends and other common effects. The results of ICA show the effects of the atmospheric pressure and trends have been detected with P-P amplitudes of 5.8～16.0 micro-Gal and 3.5～14.8 micro-Gal, respectively. Moreover the correlation coefficient between the atmospheric components and the data observed by a barometer was 0.7. However the estimated amplitudes varied within the factor of three, although the reason was not clear.

Keywords: Independent Component Analysis, gravity

SGD23-11 Room:102A Time:May 28 10:00-10:15

Effect of horizontal acceleration on the superconducting gravimeter at Ishigakijima

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In 2012, we started gravity observations using a superconducting gravimeter (SG) at Ishigakijima island, near the East China Sea, with the main purpose being detection of possible gravity changes associated with the long-term slow slip events beneath the Yaeyama Islands. Since then we have been faced with various kinds of unexpected problems, which may be peculiar to the natural conditions of such an oceanic island. Among them is the apparent correlation between the ground noise level and the DC offsets of gravity. The amount of gravity changes, as typically observed when typhoons approach the island, reaches about 2 microgals (gravity increasing), comparable to (or larger than) the possible magnitude of slow slip signals. Here we try to interpret this phenomenon not as true gravity signals but as apparent changes originating from nonlinear responses of the gravity sensor. The site is a VLBI station belonging to National Astronomical Observatory Japan, and movements of the 20-meter antenna cause almost monochromatic (~5 Hz) ground noise. Such an event is accompanied with a positive offset of gravity signals in the SG. Analysis of records of seismometers we installed at the same station revealed that gravity changes are proportional to the spectral power of horizontal components of ground motion. This fact indicates that a crosstalk between the vertical and horizontal components of the gravity sensor becomes evident when the level of ground motions is extremely high. A similar mechanism may be applicable to the effect of the enhanced level of 5-second period ground motions on gravity in very bad weather conditions.

Keywords: superconducting gravimeter, slow slip, Ishigakijima, horizontal acceleration

SGD23-12 Room:102A Time:May 28 10:15-10:30

Hydrological disturbances on gravity at Ishigakijima and experiments for their monitoring

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In 2012, we started continuous gravity observation using a superconducting gravimeter (SG) at the VERA Ishigakijima stations, to detect the signal of long-term slow slip that occurs beneath the Yaeyama Islands. Although there are short missing data caused by a power failure (e.g. by typhoon), we have almost continuously acquired the SG data. However, it is not easy to identify the signal originating from the slow slip events, mainly because the effects of the atmosphere, the ocean and the underground water on gravity are correlated with each other in a complicated manner. In addition, microseisms with large amplitude appear to cause nonlinear responses of the gravimeter (Imanishi et al., this meeting). The hydrological effects are regarded as most important, but it is difficult to model them. For the further study of local hydrological gravity disturbances, we newly installed profile-type soil moisture meter and seismometers. In addition, we are planning seismic exploration around the VERA Ishigakijima station. On the SG, we replaced the compressor in August 2014, then, in January 2015, we replaced the refrigerator and carried out the liquid helium refill. Just before this liquid helium refill work, we carried out parallel observation with an absolute gravimeter FG5(#217) and the SG. We will also talk about these maintenances.