FRIDAY 6 AUGUST 2004 AM

Environmental Processes and Gravity

Conveners: C. Kroner, J. Henton, M.S. Bos

PRESIDING

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C: *Contributed*; **I:** *Invited*; **O:** *Oral*; **P:** *Poster*

ETS-06-01

Effect of Underground Water on Gravity Observed at Matsushiro, Japan and Detection of Coseismic Gravity Change Caused by 2003 Tokachioki Earthquake

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On September 25, 2003 (UTC), a large thrust earthquake (Mw = 8.3) occurred off Tokachi area, Japan. This is an almost ideal event for investigating coseismic gravity changes with the continuous observation by means of the Superconducting Gravimeter (SG). Theoretical calculations predict a permanent gravity change as large as +1.25e-9 m/s^2 at the Matsushiro SG station, which is well above the detection limit of the SG. Unfortunately, there was heavy rainfall at Matsushiro just before the occurrence of the earthquake. Since the gravimeter station of Matsushiro is housed inside a tunnel, the observed gravity is affected much by the underground water inside the hill. According to our experiences, gravity reacts to rainfall almost immediately without a time lag. The gravity decreases after rainfall, implying that the Newtonian attraction from the water above the gravimeter has a dominant effect. The amount of gravity change is approximately proportional to the amount of rainfall, implying that the rainfall effect is of additive nature. The gravity excursion due to rainfall returns to the original level very slowly and almost linearly with time, perhaps followed by a slight overshoot. All these observations suggest an application of a simple tank model, in which rainwater percolates into the hill at a constant rate. By using rainfall data as well as gravity data, we have adjusted the model empirically so that it reproduces well the observed trend of gravity. The model is then applied to the data for the Tokachioki earthquake. After rainfall correction, an offset of finite magnitude corresponding to the source time is readily seen in the residual gravity. The amount of offset is estimated as (+1.0e-9 +/- 0.1e-9) m/s^2, which agrees well with the theoretical prediction. Similar results have also been obtained on this event at other SG stations in Japan. Thus, this is the first systematic identification of coseismic gravity changes smaller than 1 microGal (1e-8 m/s^2) with the SG network.

ETS-06-02

Study of the seasonal gravity signal in superconducting gravimeter data

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Thanks to their high sensibility and their long-term stability, superconducting gravimeters (SG) are able to record surface gravity changes on a wide frequency band (periods from a few seconds to secular variations). We focus in this presentation on the seasonal gravity changes measured by about 20 worldwide SG.

We model all well-known sources of long-term gravity changes, i.e. solid Earth tides, polar motion and length-of-day as well as global atmospheric and tidal and non-tidal ocean loading effects. These corrections lead to gravity residuals characterized by a strong seasonal signal with an amplitude of a few microgals.

We compare these residuals with loading estimates from global hydrology (snow and soil-moisture) models. For most SG, we are able to show a good correlation between the gravity residuals and the estimated continental water storage loading effects. For the other instruments, the discrepancies may be associated with local hydrology effects, which cannot be taken into account in global continental water storage models.

ETS-06-03

On the contributions of local environmental effects to gravity at Metsähovi

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The gravity data for years 1994 2004, observed with the superconducting gravimeter T020 at Metsähovi in Finland, have been investigated purposefully to observe various environmental phenomena effecting on the gravity. Loading by atmosphere and the Baltic Sea has been removed from the gravity data. We are combined air pressure grid data up to 10° distances with nearby tide gauge data. Using these advanced treatments, which remarkable reduce the residuals, the gravity data better reveals temporal variations related to environmental effects of a few microgals. Our studies e.g. bring out the influence related to precipitation, run-off mechanism, soil moisture, snow cover and the level of groundwater. The knowledge and understanding of these phenomena are important now, when we are using the global network of superconducting gravimeters to comparison with gravity satellite data of CHAMP and GRACE. We discuss a possibility to apply gravity observation to environmental studies.

ETS-06-04

Gravity tides and the seasonal gravity variation at Ny-Ålesund, Svalbard in the Arctic

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As the most northern observation station of the GGP network, the observation at Ny-Ålesund with a superconducting gravimeter (SG) was started in September 1999. We have analyzed the short and long period tidal components using the 3-year data obtained from the beginning of the observation. At Ny-Ålesund, since 1998, the measurements with absolute gravimeters (FG5 absolute gravimeters) were conducted four times. Based on these data, we have determined the scale factor of the SG using these absolute gravity (AG) data. The secular gravity rate obtained from the AG data was also used to determine the magnitude of step like changes in the SG records.

The residual gravity signals after subtracting the short- and long-period tides including the effects of annual and semi-annual ocean tides and the polar motion effect show a clear seasonal variation, which is regular in time. Thus, it changes in the sense of decreasing in gravity in around May-June, and its sense switches to increasing in around July-August, although the amplitudes are differ by year (i.e. 8 – 12 microGal for the three years). In order to investigate the origin of this seasonal gravity change, we have analyzed the tide gauge data compiled by the Permanent Service Mean Sea Level. Based on the analysis results for the tide gauge data, we estimate the loading effects on the observed annual and semi-annual gravity changes. The computation results indicate that the sea level changes are not the main source.
We also examined the correlation among three data of the seasonal gravity changes, the room temperature and the air temperature out side the gravimeter room. The linear coefficient estimated from a fitting of the room temperature to the out side air temperature is at the value of +0.03 suggesting that a large out side temperature variations of about 35 degrees in the peak-to-peak amplitude through a year is largely reduced by a simple air condition method using the discharge heat from the chillier and a panel heater. While we have not observed clear correlation between the gravity residuals and the room temperature after the air condition worked, the seasonal gravity changes and the out side temperature

show a good correlation in their time variation. Thus the period of gravity decreasing corresponds to the season when the out side temperature is above 0 degree.
Kuempel and Fabian (2002) investigated the stability/instability of the observation piers of GPS and VLBI antennas at Ny-Ålesund using the tiltmeters for one year from 2000 to 2001, and they pointed out a seasonal thermal instability in the permafrost may be responsible to the observed seasonal tilt motions. It is considered that the seasonal instability of the permafrost is a possible cause of the observed seasonal gravity changes too. Moreover, the changes in the volume of ice and in the water level inside the permafrost may also contribute to the seasonal gravity changes, because large amount of water run off is observed during the short summer season in Ny-Ålesund.

ETS-06-05

Integrated Approach to Understand Local Gravity Variations

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Series of gravity recordings at the stations Wettzell (Germany), Bad Homburg (Germany) and Medicina (Italy) are investigated to separate seasonal gravity variations from long-term trends in gravity. Whereas the superconducting gravimeters provide a high resolution to monitor periodic and long-term small gravity changes, observations with absolute gravimeters allow to determine “g” and to reveal gravity changes over longer periods. The combination of continuous records with superconducting gravimeters and episodic measurements of absolute gravimeters at these stations provide the tool to overcome the instrumental limitations of both measuring systems: calibration, drift and offsets on the one hand, random measurement insecurities as well as small systematic instrument-related offsets on the other. This leads to a combined gravity series in which the variations can be studied. Model quantities are used to reduce the environmental signals. The remaining gravity variations can be used e.g. to understand the relation to height variations determined with geometric geodetic sensors.
In Medicina, a clear seasonal signal is visible in the gravity and height data series, caused by seasonal fluctuations in the atmosphere including mass redistribution, the ocean, and groundwater but also by geo-mechanical effects such as soil consolidation and thermal expansion. In Wett-zell, no seasonal effect could be clearly identified, and the long-term trend in gravity is mainly caused by ground water variations. The derived ratio of gravity to height changes indicates that the long-term trends in height and gravity are likely due to mass changes rather than to tectonic movements. The station Bad Homburg with long-term stable gravity signal opens the chance to investigate studies of periodic atmospheric attraction effects.

ETS-06-06/ ETS-06-09

Comparison of barometric pressure induced noise in horizontal components results from numerical modellings to the observatories Moxa and Schiltach, Germany

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Records of broadband seismometers are of singular importance for studies of the Earth's interior structure and properties. Barometric pressure induced noise in these records is one of the major limiting factors in analyzing the data. The barometric pressure influence originates from the attraction of the air

masses and deformations of the Earth's crust resulting in accelerations, deformations and tilts. Additional factors affecting the pressure influence are due to the topography and the installation site of the instruments. The horizontal components of seismometers and strainmeters are affected strongest. A joint research project between Black Forest Observatory (BFO), Moxa Observatory (MOX) and the German Regional Seismic Network (GRSN) aims at pointing out the main physical transfer mechanisms and to develop reliable reduction methods. Both observatories have high signal-noise-ratios (SNR), but records still show significant noise caused by barometric pressure changes. Due to a similar instrumentation and location, i.e. 400 - 500 km distance to the North Sea and situated in a remote valley, these observatories are used to study the physical transfer mechanisms. These studies are carried out by Finite Element (FE) modelling. Using the software ABAQUS a 3-dimensional FE-model of both observatories and their vicinity was developed. For the computation an elastic rheology is used. For special studies, i.e. the influence of clefts, different rheological properties and position of instruments, the model and its parametrization are modified. Applying different typical atmospheric pressure situations, e.g. high and low-pressure areas, dynamic pressure due to wind and storm fronts, dominant effects could be determined.

It can be shown that all atmospheric pressure conditions are significant for seismometer and strainmeter records even in a depth of 170 m. No pressure condition is predominant. The immediate surroundings of the instruments, i.e. geometry of the chamber, and clefts have a big influence due to cavity effects, i.e. clefts can invert and reduce pressure effects, depending on the location cleft to instrument. As already shown by other groups we find that instruments close to the Earth's surface show significantly larger effects than instruments in a greater depth. The effects depend on the propagation direction of the pressure fronts and the direction of the instrumental component. The modelling also shows how effects are transformed from one direction into another by topography and the internal structure of the observatory. The results obtained from the model are in good agreement with the observed data. The modelling results improve our understanding of observed phenomena related to barometric pressure and are an important prerequisite for the development of correction algorithms.

ETS-06-07

Semi-diurnal and diurnal atmospheric tides and gravity variations

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Global atmospheric loading is one of the most important sources of surface gravity variations on a wide frequency domain. By using global meteorological data sets, we have been able to significantly reduce gravity residuals for periods between a few days and seasonal time scales compared to the classical empirical pressure correction using only local pressure data (Boy et al., 2002). However the diurnal (S1) and semi-diurnal (S2) atmospheric tides are not well taken into account in global atmospheric models. We compute gravity variations induced by Ponte and Ray (2002) atmospheric tidal models and Ray and Egbert (2004) oceanic response loading and compare them to observed gravity variations from about 20 superconducting gravimeters from the GGP (Global Geodynamics Project).

ETS-06-08

An Approach to Detect Hydrological signals in Time Series of the continuous Gravity Measurements due to the hydrological seasonal variation of Lake Nasser

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Lake Nasser started impounding in 1964 and reached the highest water level so far in 1978 with a capacity of 133.8 km^3 and extending 500 km in southern Egypt and northern Sudan, thus forming the second largest man-made lake in the world. The water level fluctuates, between 168 m and 178 m, four times a year according to the cycle of flow and discharge. The variation of the mass of the water of the reservoir change the potential field either by loading or by change of the ground water level. To detect these signals 18 months of continuous gravity measurements has been used from a tidal station installed very close to the Lake, beside three periods of repeated gravity observations along a gravity network pound the lake. As a first approach hydrological signals have been determined applying spectral analysis of the residuals from the tidal analysis of the whole period of observation. To discriminate between signals due to variable load of the lake and variation of the ground water level, Green function has been used to model lake induced load and to predict the gravity signal due to variable induced load of the lake, in addition to well data to control the ground water variation. Another approach is the comparison of the variation of the elastic parameters from the analysis of the continuous gravity observations at different epoch of the seasonal variation of the lake level.

ETS-06-10

Investigation of meteorological effects on strain measurements at two stations in Hungary

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Extensometers and tiltmeters installed at the surface or near the surface of the Earth measure the regional strain/tilt fields that are distorted by local effects (cavity, topography, geology) and respond to meteorological influences, too. In this paper we deal with the investigation of meteorological effects and the correction procedures that should be applied to measurement data to improve the signal to noise ratio and to help in interpretation. By means of earth tide analysis we can examine the interference of meteorological factors with strain tidal signals in a phenomenon with known forcing. Results could also be useful in corrections of other regional strain signals outside the tidal range. We analyse the data of Pécs and Sopron extensometric stations. As the two measurement stations have different geological and structural circumstances a comparison can be taken between strain measurements of different locations. The observatory in Sopron was built in gneiss and the measurement chamber lies within a rock massif at a topographic height of about 200 m. The other observatory in Pécs was established in the uranium mine 1040 m deep within a sandstone formation. There are continuous data series with a length of about ten years for the investigations in both observatories.

ETS-06-11

Two Hydrological Experiments at Moxa Observatory

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At Moxa three principle areas can be identified with regard to hydrological effects observed in the data of the superconducting gravimeter (SG): 1. the hilly area above the SG level, 2. the valley bottom below the SG level, and 3. the heaped-up area on the roof directly above the gravimeter. During strong rain events in spring time we also observe water movement in the gaps which surround the instruments' pillars in the front area of the observatory. The migration path of this water probably runs from the hill flank into which the observatory is built down the contact area between masonry and rock into the solid, but fissured weathering layer below the observatory building. The total hydrological effect is strong enough and of sufficient duration to conceal small geodynamic effects in different time scales. The different contributing areas make the necessary hydrological correction more complex than e.g. for an observatory on a plain as different hydrological phenomena need to be taken into account. The latter makes the observatory interesting for hydrogeologists for the local situation allows to study whether observations of gravity changes could provide a mean to validate and parameterize their hydrological modelling esp. in hilly areas. For this and for the development of a sufficiently effective hydrological correction algorithm we need to know about the appearance, the discharge, and the order of magnitude of the possible hydrological influence in the direct vicinity of the gravimeter. Therefore we carried out two experiments. The first experiment during which a defined amount of water was put on the roof area was reported elsewhere a few years ago. The second experiment comprised the supply of a fixed amount of water in the gap of the gravimeter pillar and the observation of the gravity variation related to the discharge process which was monitored by five water-gauges in the direction of the main discharge.
From the experiments emerged gravity effects in a similar order of magnitude of 12 to 15 nm/s² for the roof area and the area under the observatory. While the effect from the roof area vanishes shortly after the rain event, the hydrological effect from below lasts a couple of days. During the discharge process the water masses successively shift to an area south-west of the SG resulting in a linear on time depending regression coefficient for the hydrological correction. Neither of the two very local areas can be responsible for the seasonal hydrological variation observed in the gravity residuals.

ETS-06-12

Application of a Distributed Hydrological Model to Detect Hydrological Effect on Gravity

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The Global Geodynamics Project (GGP) began in 1997 to record the earth's gravity field with high accuracy at a number of stations (worldwide) using superconducting gravimeters (SG). The new generation SGs and NASA's Gravity Recovery and Climate Experiment (GRACE) promise the possibility of tracking the movement of the water on and beneath the earth surface. Detecting hydrological effects on gravity is promising for hydrologists, in closing the water balance, as well as for other geophysical questions. Therefore a research program was started to investigate the possibility of detecting the variations in river basin water storage from measurements of the time dependent gravity field, and to assess the accuracy of these estimations using models. In this paper we study the hydrological effect

on in-situ gravity measurements by means of water balance modelling. The relatively simple GIS-based Soil Moisture Routing (SMR) model is used to compute time varying storage change of spatially distributed pixels within the observation domain of a SG station near Moxa (Germany). The so-derived mass changes near the gravimeter are then converted into a time varying gravity signal and is compared to the observed gravity residual. The initial results are promising and it is anticipated that this approach will yield valuable insights into the interaction of hydrologically driven mass changes and the in- situ gravity measurements, allowing for a accurate correction and/or interpretation of the data.

ETS-06-13
Hydrological Influences in Long Gravimetric Data Series

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Hydrologically caused changes of the local gravity may reach the same order of magnitude as several other influences to be studied, e.g. the gravity effect of polar motion. As most of the weather phenomena precipitation and consequently groundwater level and soil moisture vary also quasi periodically throughout the year. Therefore hydrological influences have to be eliminated very carefully in all investigations of long-term phenomena, first of all those with nearly yearly period.

Processing several GGP data series, the gravity data had to be corrected for hydrological influences. However, groundwater and precipitation data are available only for some of the stations under investigation (BE, BO, MO, ST, SU, WE). The following examples show, that the problems may be quite different. At Wettzell the modelled gravity effect of precipitation reflects short-term disturbances of the residual gravity while long-term phenomena correlate better with the groundwater variations. Without corrections for the hydrological influences a reliable analysis of the residual gravity is nearly impossible. - The Brussels data show a clear influence of groundwater in the long-term range. Corrections derived from the groundwater data influence significantly the long- term trend of the gravity data. - At the beginning of the Boulder series heavy rainfall occurred in the region of the observatory, which influenced seriously the recorded gravity data. Using a simple exponential model very effective gravity corrections could be derived from the precipitation data.

The results with special concern to the gravity effect of polar motion once again corroborate, that corrections for hydrological influences have to be applied in all studies of small gravity effects. This holds also if for short periods no influences seem to exist.

ETS-06-14
Hydrological effects on the superconducting gravimeter observation in Bandung

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Gravity observation using the superconducting gravimeter (SG: GWR TT- 70#008) in Bandung has been carried out since December 1997. The Bandung SG station (BA) is the only station existing near the equator in the Global Geodynamic Project (GGP) network and belongs to a tropical climatic zone. In rainy season, there are sometimes heavy rainfalls over 30mm/hour associated with the passage of a squall line. In order to estimate this hydrological effect, we installed a groundwater level meter in January 2000, and soil moisture meters and rain gauge in November 2002. We investigated short period gravity changes before and after heavy rain falls. As a result of comparison between gravity residual and rain gauge data, gravity residuals of its order of 1 micro Gal have been observed according to rainfall of 30mm. We are now examining its effects of soil moisture changes and rain gauge data on precise gravity observation in Bandung.

ETS-06-15

3 D Atmospheric Pressure Correction on Gravity Data

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The redistribution of the air masses induces gravity variations (air pressure effect) in the µgal range (about 10 µgal for the Sutherland station). These variations are disturbing signals in the gravity data and they must be corrected very carefully for detecting week gravity signals.
In the past different methods have been developed for modelling of the air pressure effect. These methods are using two dimensional air pressure data measured at the Earth's surface and a standard model for the height dependency of the air pressure.
The air pressure effect consists in the deformation and Newtonian attraction term. The deformation term can be modelled well with 2 dimensional surface pressure data for instance with the Green's function method. For modelling of the Newtonian attraction term 3 dimensional data are required. Results with two dimensional data are insufficient.
From European Centre For Middle Weather Forecasts (ECWMF) are now 3 dimensional air pressure data available. These data are used for modelling of the Newtonian attraction term.
Two models have been developed.

1. mass point attraction of the air masses
2. gravity potential of the air masses

For the Superconducting Gravimeter Station SAGOS (South Africa) these models have been tested. It will be shown how the modelling of the height dependent mass redistribution can increase the correction of the air pressure effect. The results are compared with 2 dimensional models.