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Intercomparison between absolute and superconducting gravimeters

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This presentation is an updated version of the report distributed at the ICC Special Meeting of August 5th, 1989 during the General Meeting of the JAG in Edinburgh, U.K. A complete quadrennial report will be prepared for the XXth IUGG General Assembly in Vienna in 1991.

On August 20th, 1987 during the XIXth IUGG General Assembly in Vancouver, the International Gravity Commission approved the creation of the ICC-Working Group V: "Monitoring of Non-tidal Gravity Variations

A resolution, first discussed by the present WG-members during a preliminary meeting in Vancouver, has been adopted by the JAG as Resolution n 4 (Bul. Geod. Vol. 62,n 3, p. 278). It supports the work of IGC-WG5. According to the JAG rules, the resolution has been sent officially at that time to all the concerned institutions.

The Terms of Reference of IGG-WG5 are "to link together the existing and future superconducting gravimeters in a network monitored by absolute gravimeters in order to study residuals, after removal of the tides, for geophysical interpretation, leading to the monitoring of non-tidal gravity variations at a global scale".

THE PRESENT STATE OF ABSOLUTE GRAVIMETRY

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ABSTRACT. After about 40 years of development, absolute gravimetry based on the free-fall principle has now reached an operational state. More than ten transportable instruments of different design are available worldwide now, employing laser Interferometry, short time measurement devices, vacuum and vibration absorbing techniques, and on line computer control. An accuracy of +0.1 μms^{-2} or better can be expected in field work, for the mean value of some 100 to few 1000 individual experiments. Thus, absolute gravimetry can be used to establish large-scale gravity control, and to support relative gravimetry with respect to absolute datum, calibration, and drift control. For a more efficient employment of absolute techniques, repeatability and accuracy should be improved, to the order of a few 0.001 and 0.01 μms^{-2}, respectively.

As an example for the present state-of-the-art of free-fall gravimeters, the main characteristics and error sources of the JILAG-3 gravimeter system are presented. This advanced Faller-type instrument is operated by Institut für Erdmessung (IFE), Universität Hannover, since 1986. After laboratory and field tests and hard- and software improvements, the instrument has been used for about 110 absolute gravity determinations, on about 70 different sites in central and northern Europe, Iceland, Greenland, South America, and China. While some of these stations contribute to the global absolute gravity net, most of them serve for regional and local gravimetric control, especially for geodynamic investigations at tectonic plate boundaries, and in intraplate seismic or uplift/subsidence areas.

Based on the analysis of the station specific drop-to drop scatter, on long-term repetition measurements in Hannover and Clausthal (stable bedrock site), and about 40 comparisons with the results of other absolute or relative gravimeters, it has been tried to derive realistic estimates for the repeatability and accuracy of the JILAG-3 system. Present day repeatability may be characterized by standard deviations of +0.01 to 0.08 μms^{-2}, for time intervals of a few days to a few years. The corresponding figures for the accuracy of an absolute gravity determination (mean value) are +0.05 to 0.08 μms^{-2}. Among the main error sources are laser frequency changes, floor recoil effects, model errors of air pressure and earth tide reductions, and unmodeled soil moisture and ground water variations; strategies for attacking these problems are outlined.

On the results of absolute gravity measurements at Potsdam in the period 1976 - 1990

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Abstract

In the Central institute for Physics of the Earth at Potsdam several determinations of the absolute value of gravity were performed by the aid of the soviet absolute gravimeter GABL (Gravimeter absolute Ballistical Laser (equipped)) and the JILAG3;. instrument of the University of Hannover.

The results of seven measurements are presented. The comparison and discussion of these data yields to the suggestion on temporal gravity variations.

Absolute gravimetry: Environmental noise limits

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A continuous one month absolute gravity record was obtained in 1986 using one of the newly developed JILAG absolute gravimeters. The data were corrected for the effects of earth tides, local and global air pressure variations, and ocean loading. The disagreement between the raw gravity data and calculated environmental effects was about 2.0 μGal rms. The rms amplitude of every Fourier transform peak was less than 0.5 μGal and the background noise amplitude was

about 0.05 μGal above about 3 cycles/day in each bin of 1 cycle/month. This corresponds to a linear noise spectral density of about 80 μGal/VHz. The gravimetric factor, found by fitting the gravity data to the tidal potential, agrees with the theoretical value to 0.3% where the predominant uncertainty was given by possible errors in the ocean load model. The observed precision of the JILAG type absolute gravimeters is consistent with environmental gravity noise limitations over a one month continuous observation period.

Absolute and Superconducting Gravimetry in Japan

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Abstract: Two institutes in Japan, National Astronomical Observatory Mizusawa (NAOM) and Geographical Survey Institute (051) have independently developed their absolute gravimeters.

NAOM has 4 sets of absolute gravimeters of which one is of Sakuma 5 original stationary type. The other 3 sets are of transportable type employing a simple free-fall method. The set of the first generation has been working in the laboratory since 1978 and at 9 stations mainly in Tohoku District, north-eastern Japan, since 1984. The stability of single drop measurement as good as 10 μGals was attained with this set. The set of the second generation was accomplished in September 1989 and took part in the Third International Comparison of Absolute Gravimeters held at the BIPM in November 1989. The result of the NAOM gravimeter was very close to the mean value from the other 9 participants. The systematic difference of 20 μ4Gals was found between the gravimeters of the 1st and the 2nd generations. One more set is of a rotating vacuum-pipe type, which has no complicated mechanism inside the vacuum-pipe so that a large number of measurements can be made.

On the other hand, GSI has conducted absolute measurements of gravity with its own gravimeter at 11 fundamental stations in Japan since 1982, for the purpose of revising the Japan Gravity Standardization Net 1975 (JGSN75). The GSI apparatus is that revised from the commercial version of Sakuma's transportable type, especially in the data acquisition unit. Direct comparisons of the 051 with the NAOM absolute gravimeters have been carried out at 4 stations since 1987. Systematic discrepancy as much as 6O μGals was found between the 051 and the NAOM 1st generation gravimeters, The 051 is planning to perform absolute gravity measurements with the 081

apparatus at Syowa Station (Antarctica) , one of the IAGBN category A stations, in 1991, whereas the NAOM has the similar plan with a NAOM gravimeter at the same station in 1992.

As for the superconducting gravimetry, 4 sets of superconducting gravimeters of GWR 11-70 are working at Esashi (NAOM), Kyoto (Faculty of Science, Kyoto University, 2 sets) and Kakioka (Ocean Research Institute, University of Tokyo) for the purpose of both clarifying the fine structure of gravity earth tides and monitoring non-tidal secular gravity changes. We have a plan to install one more superconducting gravimeter also at Syowa Station in 1991.

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INTERCOMPARISON OF THE ABSOLUTE GRAVIMETERS JILAG-3 AND JILAG-5 AT BRUSSELS WITH REFERENCE TO THE SUPERCONDUCTING GRAVIMETER TT3O

Ducarme B., Makinen J., Röder R., Poitevin C.

Abstract In 1989-1990 repeated absolute gravity measurements have been performed at Brussels with JILAC-3 and JILAC-5 instruments.

During the same period JILAC-3 and JILAC-5 have been also intercompared at Clausthal and Paris. The results show clearly an offset of the order 10 μgal (table 1).

In Brussels these values should be compared to an earlier measurement of JILAC-3 in 1987. The discrepancy is larger than 10 μgal although the g value in Brussels should be stable as no important water-level fluctuations did occur in the meanwhile.

The data of the superconducting gravimeter corrected for the polar motion exhibit an annual wave with an amplitude of the order of 5 μgal (extrema in March and September). Unhappily the epochs of the 1989 measurements do not correspond to these extrema.

However we tentatively tried to apply an annual term on the absolute observations at Brussels and Clausthal (table 2). For JIIAC-5 at least this correction decreases the standard deviation in both stations.

KEYWORDS: Absolute gravimeters, Superconducting gravimeters, non tidal gravity variations.

THE SUPERCONDUCTING GRAVIMETERS PRINCIPLES OF OPERATION, CURRENT PERFORMANCE and FUTURE PROSPECTS

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TYPE I **SUPERCONDUCTIVITY**
Temperature dependent penetration of a magnetic field

Superconductivity was discovered when it was observed that the electrical resistivity of certain metals became unmeasurably small below a critical temperature, T_c. The study of these materials later revealed that a simply connected sample, placed in a magnetic field, would expel that field from its interior when its temperature was decreased below T_c. This second property of superconductors is called the Meisner effect after its discoverer. (A useful general reference on superconductivity is:

Tinkham, 1975.

COMPARISON OF TWO SUPERCONDUCTING

GRAVIMETERS AND AN ABSOLUTE METER AT RICHMOND FLORIDA

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INTRODUTION: In a joint effort by NOAA-NGS, UCSD, and 'FAG two superconducting gravimeters have been operating at the Naval Observatory in Richmond, Florida since December 1989. In March 1990, the NOAA group ran one of their absolute meters at this site for 6 days so that the signals from all three instruments could be compared. A preliminary analysis by one of us (JMG) of a seven month record of the two superconducting gravimeters and the six day record from all three is reported here. A complete discussion of these results including a more complete analysis will be provided in future publications.

Calibration of Superconducting Gravimeters

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Abstract: A calibration system for superconducting gravimeters has been developed on the base of additional artificial accelerations. The first experiments demonstrate that the derived calibration factor agrees with the results of other methods within the error bounds. Investigations of the frequency transfer function allow the extrapolation of the results to lower frequency domains. The first experiment shows disadvantages in the present setup and leads to improvements for a final design.

The circumstances of the observations with the SCG of NAO

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This is a status report of the observations with the super conducting gravity meter (SCO) at the Esashi Site of NAC.

The observation started in February, 1988 and continued until Oct. 1989. Now the instrument is under repairs to improve the assembly of the sphere and the coils. Therefore, this report is based on the 17 months data obtained from the beginning of February, 1988.

We describe:(1) installation, (2) environment of the observation, (3) data acquisition system, (4) drift, (5) noise level and (6) the scientific programs of NAO concerned with the SCG.

INTERCOMPARISON BETWEEN AN ABSOLUTE AND A SUPERCONDUCTING GRAVIMETER IN STRASBOURG: CALIBRATION CAPABILITY

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Introduction: The problem of accurately calibrating a superconducting gravimeter is of fundamental importance for any geophysical interpretation of the high quality data provided by this instrument. There are several well-known methods based on mass attraction or inertial acceleration that can be used to estimate the conversion factor (calibration) which transforms the 'gravity' output voltage (in Volt) from the feedback system of the relative meter in true gravity variations (in μgal). Usually, most of the relative meters (including the superconducting ones) are calibrated from the comparison with a parallel registration of another (or several others) relative gravimeters which are themselves precisely calibrated on a calibration line (e.g. Wenzel et al. 1990). We report here on the possibility of calibration of a superconducting gravimeter by using a parallel registration of a continuous set of 24 hours of absolute gravity observations made with a free-fall gravimeter.

PRELIMINARY CALIBRATION AND DRIFT ASSESSMENT OF THE SUPERCONDUCTING GRAVIMETER GWR12 THROUGH COMPARISON WITH THE ABSOLUTE GRAVIMETER JILA2

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Abstract: GWR12 began operation November 7, 1989 at the Canadian Superconducting Gravimeter Installation near Ottawa (Cantley, Que.) and has operated continuously since then with a nearly linear drift of approximately -0.5 μGal/day. A calibration factor was determined by comparison in the tidal bands of the GWR12 data with an extensive series of hourly JILA2 measurements. After tides have been removed comparison of GWR12 and JILA2 data at irregular intervals over a 4-month period shows good correlation when a linear trend of -0.49 μGal/day is removed from the GWR12 data. These data appear also to be related to changes in the water level in a nearby deep well. In the tidal bands an rms error of 0.4% was achieved in determining the gravimetric factors for M_2, Ol and K_1 from the absolute measurements. Comparison of the GWR12 and JILA2 data, corrected for ocean tide and local atmospheric pressure effects, with the theoretical tidal gravity reveals the following: 1. Both GWR12 and JILA2 show the same anomalously large (by about 2%) **~2** tidal gravity. 2. Tidal gravity measured by JILA2 at other frequencies is 0.6% larger than the theoretical for this site. 3. The sensitivity of the GWR12 gravimeter at the tidal frequencies M_2 and Ol has remained constant within the experimental error (0.1%) throughout the eight months of operation.

DETECTION OF NON-TIDAL GRAVITY VARIATION IN CHINA

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Abstract: In recent years, the Chinese Academy of Metrology has successfully developed the second generation absolute gravimeter (NIM-Il), and measured the absolute gravity values in Beijing, Haerbin and Kunming. At the same time, in 1990 China cooperated with Hanover Univ. West Germany and Finland Geodetic Institute to do repeated measurements in the above mentioned places using U.S. meter (JILAG).

Modelisation of the non-tidal gravity variations at Brussels

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Abstract: A superconducting gravimeter GWR is recording at the Royal Observatory of Belgium (Brussels) since April 1982. The data are split in two sections. In the first one (four and an half years), the long-term trend is difficult to model due to instrumental perturbations. When a reliable drift model is built, periodical gravity changes show up at the annual and Chandlerian (430 days) periods. The second part (three years) exhibits a much better signal to noise ratio. Unfortunately the length of the observations does not yet allow a complete separation of the two contributions and a correct evaluation of the amplitude factor 6 associated with the Chandler term. The amplitude of the anomalous annual term reaches 5 microgal (50 n m s^{-2}),

Keywords: Superconducting gravimeter, polar motion, instrumental drift, modelisation.

GRAVITY AND HYDROLOGY AT KILAUEA VOLCANO, THE GEYSERS AND MIAMI

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Introduction: In order to use gravity to measure geophysical phenomena such as vertical crustal motion, other environmental influences on gravity must be identified and measured. Of these, the effect of ground water has been studied least. I discuss here recent data from The Hawaiian Volcano Observatory (HVO) on Kilauea Volcano and from Miami, Florida. The hydrology of these two locations differ substantially. However, the observed response to rainfall in Hawaii is similar to that observed in earlier work at The Geysers geothermal field in California. The major features of the response at Hawaii and The Geysers are explained in terms of models that consist of a small number of discrete aquifers at different elevations which drain from higher to lower. The terrain at Miami is exceptionally flat and homogeneous and the hydrology is influenced by nearby canals rather than flow between aquifers. The analysis presented here is preliminary and more detailed work will be published in the future with coworkers in Hawaii and Miami.

Global Earth Dynamics and Non-Tidal Gravity Changes

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Introduction: The spectrum of vertical gravity changes at the Earth's surface clearly shows effects which vary from local to planetary scales as well as from short periods (less than 1 hour) to secular (several decades) variations. We show here how gravity disturbances that can be observed at the Earth's surface with high-precision gravimeters can be related to planetary-scale dynamics of the Earth. For this we consider the elasto~gravitational deformation of an Earth model with fluid parts (outer core, superficial layer) with the help of a Love number formalism which has been developed elsewhere (Legros 1987; Hinderer and Legros 1989). The relationships between gravity changes and important geodynamic processes of global extent relative to the whole Earth or occurring only in the fluid parts (outer core, atmosphere, ocean) are discussed and some numerical applications are given.

TOTAL EFFECT OF GROUNDWATER AND INTERNAL FLUID PRESSURE VARIATIONS ON GRAVITY

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Abstract: We present a theoretical study of the total effect of groundwater and internal fluid pressure variations on gravity i.e. the effect of the land surface displacement and the attraction variation effect. We comment the numerical values of the effect we obtain on the superconducting gravimeter records at the Royal Observatory of Belgium.

SUBSURFACE WATER AND GRAVITY

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Abstract. We present results from parallel measurements of groundwater level, soil moisture content, precipitation, and gravity. Soil moisture turns out to be as important a source of gravity variation as groundwater. Precipitation alone explains poorly subsurface water storage variations, other variables like evapotranspiration must be accounted for. The attraction of snow and gradient effects are discussed.

The Brasimone experiment: a measurement of the gravitational constant G in the 10-100 m range of distance.

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Summary: An experiment based on the measurement of the variation of local gravity induced by periodic filling of a power storage plant basin, is described. A superconducting gravimeter will be installed in a tunnel under a lake, where water masses of 106 tons are normally displaced every day, in order to store energy in hours of low demand , by pumping water from a low-level basin located at a distance of 5 Km; the measurable effect, due to a maximum variation of 7 m in the water level, is 300 10-6 gal. The purpose of the experiment is to provide evidence for deviations from Newton's gravitational law.

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CONCLUSIONS OF THE WORKSHOP
ECGS - IGC WG V
NON TIDAL GRAVITY CHANGES
WALFERDANGE (G.-D. LUXEMBURG) 5-7 Sept.1990

These **conclusions** have been submitted to all participants to the workshop for correction, improvement and approval before publication in the proceedings: Cahiers du Centre Européen de Géodynamique et de Séismologie Vol. n^0 3.

The repeatability of absolute gravity measurements in a same site seems to be around +/-5μ gal.

That is not enough to put real constraints on the modelization of the long term (secular?) drift of superconducting gravimeters in a stable site.

The calibration of superconducting gravimeters by means of absolute instruments reaches now 0.5%.

Superconducting sites are very interesting for absolute measurements as all geophysical parameters of concern are continuously monitored and short term (up to 1 year?) gravity variations clearly detected by the superconducting gravimeters.

The effect of large water table atmospheric pressure local geophysical parameters variations suspected in the residue curve of superconducting gravimeters can be elucitated if absolute gravity measurements are available before and after the events (!!!) *and vice-versa*

What is to be done?

to encourage development of:

1. Absolute gravimeters with +/- 1μgal precision in order to: constraint the drift of superconducting gravimeters;

· obtain a calibration of superconducting gravimeters at the level of 0.Ox %

2. A network of superconducting gravimeters:

an annual wave (~ 8μ gal p.p.) has been detected by most of the superconducting gravimeters.

Existence of this wave could also be confirmed by absolute measurements at the extrema of this wave.

. induced effect of polar motion: To determine the 6 factor at this frequency.

From the computational point of view, the calculation of the atmospheric pressure correction should be investigated in more details. For long period phenomena it should be necessary to compute mean dayly effects based on a real time global atmospheric model.

Two projects have been introduced during the meeting and have to be considered carefully:

1. A proposal to submit to the EEC to obtain funds to support the purchase of a new Faller's type absolute gravimeters which will be at the disposal of the european scientific community for geodynamical purposes in the frame of activities of the ECGS;

2. G G P

Global Geodynamics Project Exchange of raw superconducting data through an international centre.

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