Results of the International Comparison of Absolute Gravimeters in Walferdange (Luxembourg) of November 2003

Olivier Francis
University of Luxembourg, 6, rue Coudenhove-Kalergi, L-1359 Luxembourg
and European Center for Geodynamics and Seismology, 19, rue Josy Welter, L-7256 Walferdange

Tonie van Dam
European Center for Geodynamics and Seismology, 19 rue Josy Welter, L-7256 Walferdange

M. Amalvict, M. Andrade de Sousa, M. Bilker, R. Billson, G. D'Agostino, S. Desogus, R. Falk, A. Germak, O. Gitlein, D. Jonhson, F. Klopping, J. Kostelecky, B. Luck, J. Mäkinen, D. McLaughlin, E. Nunez, C. Origlia, V. Palinkas, P. Richard, E. Rodriguez, D. Ruess, D. Schmerge, S. Thies, L. Timmen, M. Van Camp, D. van Westrum, H. Wilmes

Abstract. We present the results of international comparison of absolute gravimeters held in Walferdange, Luxembourg, in November 2003. Overall, the absolute meters agreed with a standard deviation of less than two microgal (if we exclude one prototype instrument from the analysis). For the first time, the ability of the operators was put to the test. The experiment indicates that the errors due to the operator are less than 1 microgal, i.e. within the observational errors.

1 Introduction

On November 3rd to November 7th 2003, Luxembourg's European Center for Geodynamics and Seismology (ECGS) hosted an international comparison of Absolute gravimeters in their Underground Laboratory for Geodynamics in Walferdange (WULG). This is the first time in the history of geophysics that 15 absolute gravimeters will have been brought together in the same location for simultaneous observations. Teams from all over the world including the United States and Brasil as well as teams from Europe participated in the intercomparison (Table 1).

Table 1. Participants in the ICAG-2003 and their gravimeters.

Country	Institution	Absolute gravimeter(s)	Relative gravimeter(s)
Austria	Bundesamt für Eich- und Vermessungswesen (BEV), Vienna	JILAg-6	
Belgium	Observatoire Royal de Belgique (ORB), Brussels	FG5-202	Scintrex CG3M-256
Brazil	Observatorio Nacional , Rio de Janeiro	FG5-223	
Finland	Finnish Geodetic Institute, (FGI), Masala	FG5-221	
France	École et Observatoire des Sciences de la Terre (EOST), Strasbourg	FG5-206	
Germany	Bundesamt für Kartographie und Geodäsie (BKG), Frankfurt	FG5-301	
Germany	Institut für Erdmessung (IfE), Universität Hannover, Hannover	FG5-220	
Italy	Istituto di Metrologia “G. Colonnetti” (IMGC), Turin	IMGC-02	–
Luxembourg	European Center for Geodynamics and Seismology, ECGS	FG5-216	Scintrex CG5
Czech Republic	RIGTC, Geodetic Observatory Pecny	FG5-215	
Spain	Instituto Geográfico Nacional (IGN), Madrid	A10-006	
Spain	Instituto Geográfico Nacional (IGN), Madrid	FG5-211	
Switzerland	Swiss Federal Office of Metrology and Accreditation (METAS), Bern-Wabern	FG5-209	Scintrex CG3M-494
UK	Proudman Oceanographic Laboratory (POL), Bidston	FG5-103	
USA	United States Geological Survey	A10-008	–

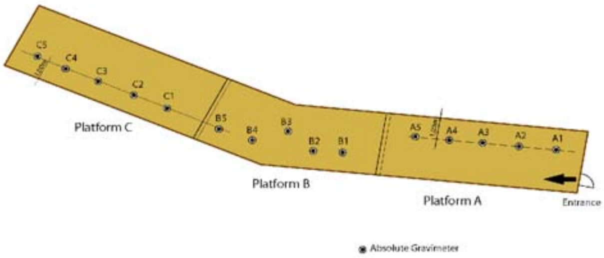

Fig. 1 Underground laboratory where 15 gravimeters can be setup at the same time (40 m length and 3.6 wide)

A few years ago, a laboratory (Figure 1) dedicated to the intercomparison of absolute gravimeters was built within the WULG 100 meters below the surface at a distance of 300 m from the entrance. To transport the 350 kilograms of equipment (the typical weight of an FG5 absolute gravimeter and its peripherals) over the 300 meters to the lab, electric golf carts were used. The cart travels on a smooth newly installed concrete surface.

The lab is environmentally stable (i.e. constant temperature and humidity within the lab), and is extremely well isolated from anthropogenic noise with the power and space requirements that it is able to accommodate up 15 instruments operating simultaneously.

Absolute gravimeters are used for monitoring mass changes within the Earth (i.e. the motion of magma underneath volcanoes), monitoring mass changes within the Earth's upper layers (i.e. the seasonal variations of continental water storage that might be related to global warming), and monitoring deformations of the Earth's crust (i.e. tectonic deformations associated with the build up and release of strain during an earthquake). However, because these instruments are 'absolute', to verify that the instruments are operating properly, they must be regularly compared to other instruments of the same class. Being absolute instruments, these gravimeters cannot really be calibrated. Only some of their components (such as the atomic clock or the laser) can be calibrated by comparison with known standards. The only way one currently has to verify their good working order is via a simultaneous intercomparison with other absolute gravimeters of the same or even of a different model.

During a comparison, we are trying to estimate how accurate the meters are (i.e. uncertainty of the measured value with respect to the true value). We are not looking at the precision of the meters (uncertainty of the measurements). In fact, as we have no way to know the true value, we will provide only the relative offset between instruments. It means that they can all suffer of the same unknown and undetectable offset!

Intercomparisons of this type are difficult to arrange which is why they have only officially been organized every 4 years by the Bureau International des Poids et Mesures (BIPM) in Sèvres, France. This time scale is not sufficient for most users as most also regularly deploy their instruments for field observations.

For the first intercomparison in Walferdange, 15 meters from 13 countries including 5 types of absolute gravimeters were present: one Jilag, FG5s with bulk and fiber interferometer, A10, one prototype from IMGC. For the first time, simultaneous observations were taken. In addition an original experiment was conducted to estimate the error due to the operators.

2 Protocol

Ideally to compare gravimeters, they should measure at the same site at the same time. Obviously, this is practically impossible. The comparison was spread on three days. The first day, each instruments was installed to one of the 15 sites. The second day, as the lab is composed of thee different platforms, all instruments moved to another site on a different platform and again the third day. Overall, all instruments occupied at least 3 sites one on each platform. We also planned in such a way that two different instruments, which occupied the same site, did not measure at another common site again. This allows us to compare each instrument to as many other instruments possible.

Some teams arrived a few days before the comparison and others teams did stay longer afterward. Those extra measurements were also included in the final adjustment.

3 Data processing

Raw data of the absolute gravimeters consist in vectors of time and position of the falling object during the drops. To obtain the gravity value a linear equation representing the equation of motion is fitted to the raw data including the vertical gravity gradient which as been measured with relative meters. The procedures will followed is the same as at the comparisons in Sèvres (Francis and van Dam, 2003). Geophysical corrections are applied to the raw gravity data: earth tides using observed tidal parameters from the Superconducting gravimeter installed in a gallery next to the laboratory, atmospheric pressure using a constant admittance and polar motion effect using pole positions from IERS.

The vertical gravity gradients were measured by three different operators (O. Francis, M. van Camp and P. Richard) with two Scintrex CG3-M and one

Scintrex CG5. Comparisons between the Rubidium clocks and the barometers were carried our by M. van Camp and R. Falk. The results of these comparisons where used in data processing. We did not have any laser calibration as we are not equipped for.

Most of the data were processed with the g-soft version g4.0 from Micro-g Solutions which runs on Microsoft Windows®. However, the Jilag gravimeter operating with old electronics is not compatible and the program, Replay, from Olivia was used. This early version of the software contains the same coded algorithms for computing the g-values and the geophysical corrections as in g-soft. The only difference is in the data input format.

4 Errors due to the operators

An original experiment to estimate the operators' error has been performed with the agreement of all the participants. After the third day, all the operators of the FG5s left their instruments in the hands of experts from Micro-g Solutions, manufacturer of the FG5. The instruments stayed at the same site but were run by Micro-g. The results (Figure 2) show that the measurements agree within the error bar of the observations. There are two exceptions: the FG5#211 due to a bad collimation of the laser corrected by Micro-g and the FG5#216 which was operated during the comparison by Micro-g for which we do not have an explanation yet.

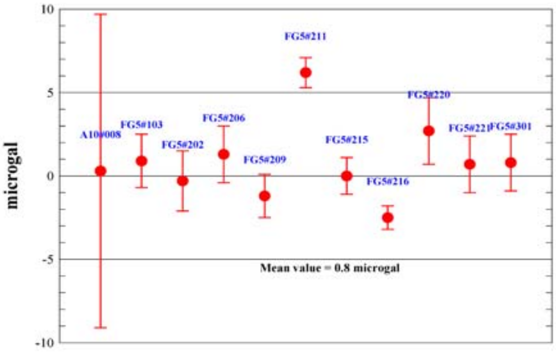

Fig. 2 Difference in the gravity values as measured by the usual operators and the expert operators from Micro-g.

5 Adjustment of the data

Data from one instrument (A10#006) were discarded due to problem with the power supply. Data at one site were not included in the final adjustment as only one instrument occupied the site. The data of the prototype gravimeter IMGC2 were not included in the adjustment because a offset of –46.7 microgal was detected and would spoiled the adjustment. The data from the FG5#211 were corrected for an offset of –2.7 microgal due to the collimation error (see previous section).

All the gravimeters could not occupied all the sites. To compare their measurements, the following least-square adjustment has been performed:

$$g_{ik} = g_k + e_i$$

where g_{ik} is the gravity value at the site k given by the instrument i, g_k is the adjusted value at the station k and e_i is the uncertainty containing a systematic component (the offset) and a stochastic component. We assume a systematic error of 2 microgal for the FG5s and Jilag and 5 microgal for the A10 as specified by the manufacturer. For the stochastic part, we took the average value at each site and calculate for each instrument the difference with the average value. Then we computed the standard deviation of this difference, which was used to estimate the precision (the stochastic part) of each instrument.

The results of the adjustment using the complete set of data are displayed in table 2 and Figures 3.

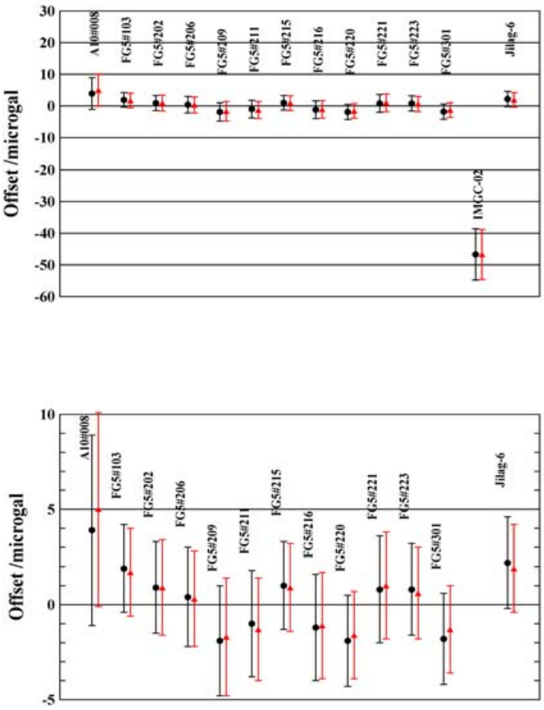

Fig. 3 Relative offsets between the gravimeters for the unweighted (black dots) and weighted (red triangles) adjustments.

The standard deviation of the relative offset between the different instruments varies from 1.8 for the unweighted solution to 1.9 microgal for the weighted solution if we exclude the prototype instrument IMGC-2 which has an offset of –46.7 microgal. It is worth to notice that all the error bars are crossing the zero line. The A-10 shows the biggest offset and uncertainty as we could expected from the specifications of the instruments which should have a precision and accuracy of 10 microgal.

Conclusions

The international comparison of absolute gravimeter in Walferdange shows an agreement between of the involved gravimeters at 1.9 microgal (1 standard deviation) if we exclude one prototypes instrument. This the best agreement ever achieved during comparisons in the past. This excellent result is due to the coincidence of a few favorable factors: a very good site of stability in temperatures and low microsiesmic noise, excellent operators, short duration of the comparison (3 days), interaction between the participants working all together in the same lab, and the last but not the least, Micro-g Solutions experts support during the experiment.

This historic experiment marks the recognition of the WULG as an international absolute gravimeter intercomparison. It is expected, that these intercomparisons will occur every four years alternately with the comparisons at the BIPM.

References

Francis O., van Dam T.M., Processing of the Absolute data of the ICAG01, Cahiers du Centre Européen de Géodynamique et de Séismologie, vol.22, 45-48, 2003.

Table 2. Relative offsets between the gravimeters for the unweighted and weighted adjustments

Instrument	Unweighted offset		Weighted offset		Difference
	Average /microgal	Error /microgal	Average /microgal	Error /microgal	/microgal
A10#008	3,9	5,0	5	5,1	-1,1
FG5#103	1,9	2,3	1,7	2,3	0,2
FG5#202	0,9	2,4	0,9	2,5	0
FG5#206	0,4	2,6	0,3	2,5	0,1
FG5#209	-1,9	2,9	-1,7	3,1	-0,2
FG5#211	-1	2,8	-1,3	2,7	0,3
FG5#215	1	2,3	0,9	2,3	0,1
FG5#216	-1,2	2,8	-1,1	2,8	-0,1
FG5#220	-1,9	2,4	-1,6	2,3	-0,3
FG5#221	0,8	2,8	1	2,8	-0,2
FG5#223	0,8	2,4	0,6	2,4	0,2
FG5#301	-1,8	2,4	-1,3	2,3	-0,5
IMGC-02	-46,7	8,1	-46,7	7,9	0
Jilag-6	2,2	2,4	1,9	2,3	0,3
Std	1,8		1,9		
Mean					-0.09