An International Reference Station for Inter-comparison of Absolute Gravimeters (ISIAG) in Walferdange, Luxembourg: the GRAVILUX Project

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Abstract.

The Grand Duchy of Luxembourg is establishing a new International Reference Station for Intercomparisons of Absolute Gravimeters (ISIAG). The station is located in the Walferdange Underground Laboratory for Geodynamics 100 meters below the surface. Since 1967, the laboratory has been used for Earth tides research and from that work has gained an international reputation as a seimogenically quiet location where sensitive instruments can be tested and evaluated. A permanent staff of scientists and a technical engineer from the European Centre for Geodynamics and Seismology (ECGS) maintain the laboratory under the authority of the National Museum of Natural History of Luxembourg (NMNH) and the Royal Observatory of Belgium (ROB).

Four Luxembourg institutes including the NMNH, ECGS, Institut Supérieur de Technologie (IST) and the Administration du Cadastre et de la Topographie (ACT), have recently joined together to manage the station under the framework of the new GRAVILUX project. GRAVILUX is a program established to enhance geodynamics research within Luxembourg. The project has added two geophysicists in 2000 and is expected to add two additional technical engineers in 2001. The instrumentation to support the project includes a superconducting gravimeter, which is currently being built, an absolute gravimeter, which will be purchased in 2001, and other ancillary equipment necessary to support research.

Introduction.

The Walferdange Underground Laboratory for Geodynamics (WULG) is located at the far end of a long labyrinth of galleries which originally have been established for the commercial extraction of very pure gypsum (Figure 1). Exceptional temperature and humidity stability, the absence of water and human perturbations, distance from the ocean and easy access, were some of the motivations for initially choosing this site for instrumentation and Earth tide research. Instruments to measure the micro-deformations produced by the tidal forces have been developed and tested in the Laboratory for more than 30 years. Ground deformations and earthquakes are recorded continuously by means of spring gravimeters, vertical and horizontal pendulums, long base water-tube tiltmeters, vertical and horizontal strain meters, short period and broad band seismometers. Meteorological parameters (temperature, humidity and atmospheric pressure), as well as radon gas emissions, are also continuously monitored in various locations within the mine.

Close collaborations have been pursued for the last 30 years with many different organizations including (but not limited to): the Royal Observatory of Belgium, GeoForschungZentrum (Potsdam) and Bonn Univeristy (Gemany), Institute of Astronomy and Geodesy of the University of Madrid (Spain), Nordic Volcanological Institute of Reykjavik (Iceland), Osservatorio Vesuviano and University Federico II, Napoli (Italy), Instituto Superior Tecnico (Lisboa, Portugal), State Seismological Bureau of Wuhan (China), Russian Academy of Science, University of Savoie and Insitut de Physique du Globe (France), Finnish Geodetic Institute (Finland), and Kyoto University (Japan).

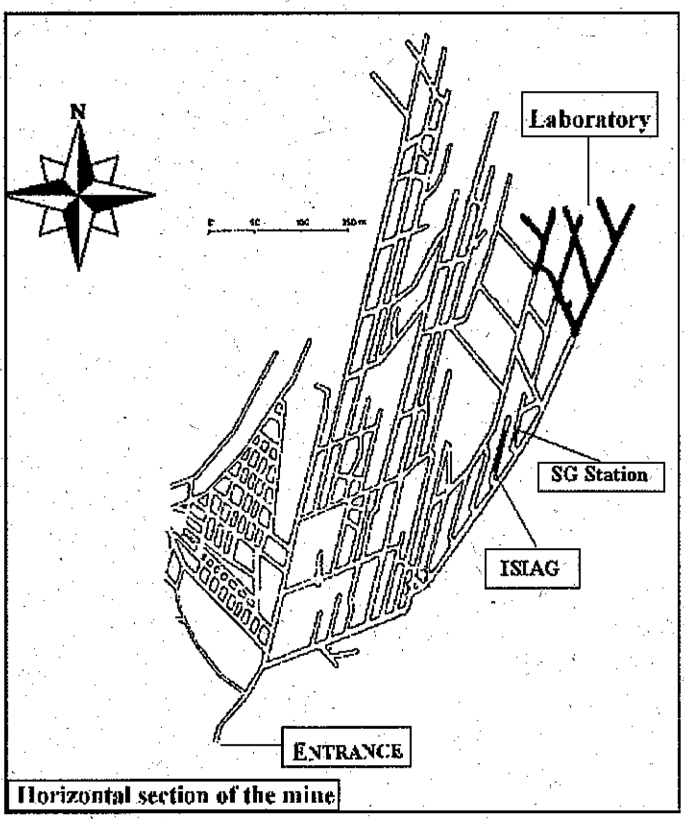

Figure 1: Horizontal cross-section of the Walferdange Mine.

The GRAVILUX project.

Although not very common, absolute gravimeters are used worldwide to measure the instantaneous-absolute value of the gravitational acceleration. The precision and accuracy of these instruments currently reaches one microgal (1 microgal = 10^{-8} m/s^2), i.e. one billionth of the mean gravity on the surface of the Earth. The acceleration of gravity at the surface of the Earth varies in time and space due to mass changes above and below the Earth's surface and changes in the height of that surface. Hence, absolute gravity observations can be used to constrain the geoid, to calibrate local gravity networks, and to measure small crustal deformations such as those associated with post-glacial rebound, sea level, tectonics and environmental loading. In addition, they may also be used to monitor magmatic intrusions on volcanoes, changes in local hydrology, or changes in the ice mass of glaciers and ice sheets.

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. Intercomparisons of this type are difficult to arrange which is why they have only officially been organized every 4 years by the BIPM. This time scale is not sufficient for most users as most also regularly deploy their instruments for field observations.

In the case of regular field deployments, the users must be sure that there isn't an offset in their measured values of gravity caused by instrument malfunction. To be sure that an instrument is indeed in good working condition, the instrument needs to be regularly checked by measuring gravity in a place where gravity is well known. But as mentioned above, gravity at any given location will change with time due to Earth tides, ocean or atmospheric loading effects, or water table variations. So, gravity changes of the reference station must be carefully monitored in time. The best way to achieve this with enough precision is to continuously measure the gravity variations by means of a superconducting gravimeter. Those relative gravimeters operate by measuring the voltage required to maintain the position of a levitating sphere in a magnetic field. The field is produced by an electric current caught in a coil at the temperature of the liquid helium. At that temperature (about 4 °K, i.e. -269 °C), the current circulates without any resistance and produces a very stable magnetic field. Superconducting gravimeters reach a precision of a few nanogal (10^{-12} m/s^2), i.e. one thousandth of a billionth of the mean gravity on the surface of the Earth) on diurnal and semi-diurnal periods by integrating over 2 or 3 years.

The establishment of a quiet gravity reference station in the WULG was one of the motivations behind the establishment of the GRAVILUX project. The current infrastructure, scientific knowledge, technical support, and the scientific instruments to be obtained will allow for 1) international comparisons of all absolute gravimeters at a seismically quiescent site in Europe and 2) a gravity reference site where temporal changes in gravity are continuously monitored.

The gravity stations

Many structural renovations and other practical matters needed to be addressed to convert our old gypsum mine into an underground laboratory appropriate for absolute gravity intercomparisons. For the sake of safety, the first 300 meters of the entrance of the mine were recently shored up by using large steel I-beams and concrete. To transport the 500 kilograms of equipment (the typical weight of an FG5 absolute gravimeter and its peripherals) over the 400 meters to the gravimetric stations, an electric golf cart was purchased. The cart travels on a smooth newly installed concrete surface.

Two stations, in neighbouring galleries, were especially constructed and outfitted with power, UPS, and internet access for the GRAVILUX gravity instrumentation intercomparison goal: the smallest room ('SG station', 20 m^2) will house the superconducting gravimeter (figure 2). The larger room ('ISIAG station', 150 m^2), built in a dead end gallery, is large enough to accommodate as many as 15 absolute gravimeters operating simultaneously (figure 3). (At the Table Mountain Gravity Observatory in Boulder, Colorado and at the BIPM, where previous intercomparisons have been held, only 5 and 6 absolute instruments respectively, can operate simultaneously.)

Figure 2: the SG station.

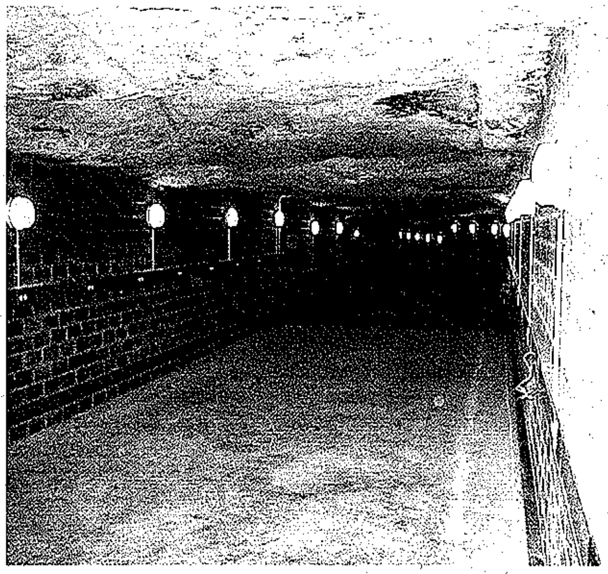

Figure 3: the ISIAG station.

In 1997 and 1998, absolute gravity observations were undertaken in the Underground Laboratory by the team from the ROB (Tables 1 and 2) using the FG5-202 absolute gravimeter. The precision (set standard deviation) of the measurements is about 1 microgal. The drop-to-drop scatter (mean standard deviation) is between 7.8 and 10.0 microgal. (For comparison, the drop-to-drop scatter is 21.4 microgals and 7.8 microgals at the BIPM and TMGO respectively for the same instrument.) This was the lowest value observed by the ROB team with that instrument in all of 1997, confirming the quality of the WLUG as a quiet "gravimetric" site. (It is interesting to note that at the time of the 1997 observations, the electronics of the FG5-202 had been not yet upgraded with the fast data rate card. And, in 1998, the superspring was not perfectly tuned due to electronic problems. We would thus expect even better performance with the new FG5.)

In addition to the absolute gravity measurements, vertical gravity gradients have been measured at the absolute gravity point as well as at 4 different places within the gallery where the absolute gravimeter intercomparisons are expected to take place. To determine the vertical gravity gradient, gravity differences have been measured between 3 different height levels (floor, 0.9 m and 1.3 m) using a Scintrex spring gravimeter. The values of the vertical gradient in the gallery are very close, with values in the range -2.77 and -2.79 +- 0.01 microgal/cm. Moreover, no strong non-linearities in the vertical values were observed.

A small gravity network has also been established connecting the entrance of the gallery to the different points where the vertical gravity gradients have been measured. We obtained a 1.697 milligal difference in gravity between the site at the entrance to the mine and the Laboratory at the end of the gallery where the absolute gravity measurements were carried out. We also determined a difference of 1.110 milligal between the Laboratory and the gallery where the new absolute gravity stations will be established. So in addition to providing a location for absolute gravity intercomparisons, the laboratory also maintains a relative gravity calibration line in a seismogenically quiet site with no temperature variations. In the future, regular absolute gravity observations will be performed at the two extremities of the calibration line further enhancing its usefulness.

In tables 3-5, we display the results of the absolute gravity measurements carried out at the Centre Universitaire de Luxembourg. The site is located on the University Campus in Luxembourg city. The first measurements were taken there by Jaakko Maakinen with the Jilag-5 in 1991. We can see the remarkably low noise level for a gravity station located within an urban environment.

Acknowledgements

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Table 1.

STATION: WALFERDANGE			
City:	Walferdange	Country:	Grand-Duché de Luxembourg
Location:	Laboratoire souterrain	Particularity:	
Situation:	Laboratoire	Remarks:	
Date:	July 10-11, 1997		

Code number:	
Latitude:	49.6647 degrees
Longitude:	6.1528 degrees
Elevation:	295 m
Gradient:	-2.522 µgal/cm
Reference height:	502.5 mm
Meter:	FG5
S/N:	202

Ocean loading correction (µgal, -local phase- degree)

Waves	M_2	S_2	K_1	O_1	N_2	P_1	K_2	Q_1	M_f	M_m	S_{sa}
Ampl.	0.184	0.060	0.021	0.015	0.037	0.007	0.015	0.042	0.0	0.0	0.0
Phase:	299.1	328.1	297.1	190.3	283.2	284.5	329.5	126.2	0.0	0.0	0.0

Polar motion correction			Air pressure correction	
X-coordinate:	0.0550	arc seconds	Nominal air pressure:	978.31 mbar
Y-coordinate:	0.5342	arc seconds	Barometric admittance factor:	0.3 µgal/mbar

Gravity

Set gravity mean:	**9 80 963 955.4**	microgal
Set std. dev.:	1.186	microgal
Mean std. dev.:	7.79	microgal
Number of sets:	25	
Number of drops per set:	100	
Drop interval:	10 seconds	
Set interval:	60 minutes	
Nominal/datum height:	0.0 cm	

Local Contact: Nicolas d'Oreye

Author: O. Francis — Observatoire Royal de Belgique

Date: October 12, 1999

Table 2.

STATION: WALFERDANGE			
City:	Walferdange	Country:	Grand-Duché de Luxembourg
Location:	Laboratoire souterrain	Particularity:	
Situation:	Laboratoire	Remarks:	
Date:	December 16-18, 1998		

Code number:	
Latitude:	49.6647 degrees
Longitude:	6.1528 degrees
Elevation:	295 m
Gradient:	-2.522 µgal/cm
Reference height:	500.5 mm
Meter:	FG5
S/N:	202

Ocean loading correction (µgal, -local phase- degree)

Waves	M_2	S_2	K_1	O_1	N_2	P_1	K_2	Q_1	M_f	M_m	S_{sa}
Ampl.	0.184	0.060	0.021	0.015	0.037	0.007	0.015	0.042	0.0	0.0	0.0
Phase:	299.1	328.1	297.1	190.3	283.2	284.5	329.5	126.2	0.0	0.0	0.0

Polar motion correction			**Air pressure correction**	
X-coordinate:	0.1379	arc seconds	Nominal air pressure:	978.31 mbar
Y-coordinate:	0.3157	arc seconds	Barometric admittance factor:	0.3 µgal/mbar

Gravity

Set gravity mean:	**9 80 963 952.6**	microgal
Set std. dev.:	1.098	microgal
Mean std. dev.:	10.00	microgal
Number of sets:	37	
Number of drops per set:	100	
Drop interval:	10 seconds	
Set interval:	60 minutes	
Nominal/datum height:	0.0 cm	

Local Contact: Nicolas d'Oreye

Author: O. Francis Observatoire Royal de Belgique

Date: October 12, 1999

Table 3.

STATION: LUXEMBOURG			
City:	Luxembourg	Country:	Grand-Duché de Luxembourg
Location:	Centre Universitaire	Particularity:	
Situation:	Cave	Remarks:	Site occupied by Jaakko Mäkinen
Date:	20/21 August 1996		with a Jilag-5 in March 1991

Code number:	
Latitude:	49.6278 degrees
Longitude:	6.1153 degrees
Elevation:	328 m
Gradient:	-2.782 µgal/cm
Reference height:	503.5 mm
Meter:	FG5
S/N:	202

Ocean loading correction (µgal, -local phase- degree)

Waves	M_2	S_2	K_1	O_1	N_2	P_1	K_2	Q_1	M_f	M_m	S_{sa}
Ampl.	0.184	0.060	0.021	0.015	0.037	0.007	0.015	0.042	0.0	0.0	0.0
Phase:	299.1	328.1	297.1	190.3	283.2	284.5	329.5	126.2	0.0	0.0	0.0

Polar motion correction			**Air pressure correction**	
X-coordinate:	0.29248	arc seconds	Nominal air pressure:	974.4 mbar
Y-coordinate:	0.38644	arc seconds	Barometric admittance factor:	0.3 µgal/mbar

Gravity

Set gravity mean:	**9 80 960 407.5**	microgal
Set std. dev.:	1.534	microgal
Mean std. dev.:	13.54	microgal
Number of sets:	12	
Number of drops per set:	181	
Drop interval:	10 seconds	
Set interval:	60 minutes	
Nominal/datum height:	0.0 cm	

Local Contact: Antoine Kies (352) 46 66 44 328

Author: O. Francis — Observatoire Royal de Belgique

Date: August 30th, 1996

Table 4.

STATION: LUXEMBOURG			
City:	Luxembourg	Country:	Grand-Duché de Luxembourg
Location:	Centre Universitaire	Particularity:	
Situation:	Cave	Remarks:	Site occupied by Jaakko Mäkinen
Date:	11/12 July 1997		with a Jilag-5 in March 1991

Code number:	
Latitude:	49.6278 degrees
Longitude:	6.1153 degrees
Elevation:	328 m
Gradient:	-2.782 µgal/cm
Reference height:	503.0 mm
Meter:	FG5
S/N:	202

Ocean loading correction (µgal, -local phase degree)

Waves	M_2	S_2	K_1	O_1	N_2	P_1	K_2	Q_1	M_f	M_m	S_{sa}
Ampl.	0.184	0.060	0.021	0.015	0.037	0.007	0.015	0.042	0.0	0.0	0.0
Phase:	299.1	328.1	297.1	190.3	283.2	284.5	329.5	126.2	0.0	0.0	0.0

Polar motion correction			**Air pressure correction**	
X-coordinate:	0.0610	arc seconds	Nominal air pressure:	974.4 mbar
Y-coordinate:	0.5355	arc seconds	Barometric admittance factor:	0.3 µgal/mbar

Gravity

Set gravity mean:	**9 80 960 410.3**	microgal
Set std. dev.:	1.524	microgal
Mean std. dev.:	8.48	microgal
Number of sets:	15	
Number of drops per set:	100	
Drop interval:	10 seconds	
Set interval:	60 minutes	
Nominal/datum height:	0.0 cm	

Local Contact: Antoine Kies (352) 46 66 44 328

Author: O. Francis — Observatoire Royal de Belgique

Date: July 13th, 1997

Table 5.

STATION: LUXEMBOURG			
City:	Luxembourg	Country:	Grand-Duché de Luxembourg
Location:	Centre Universitaire	Particularity:	
Situation:	Cave	Remarks:	Site occupied by Jaakko Mäkinen
Date:	22 December 1998		with a Jilag-5 in March 1991

Code number:	
Latitude:	49.6278 degrees
Longitude:	6.1153 degrees
Elevation:	328 m
Gradient:	-2.782 μgal/cm
Reference height:	502.0 mm
Meter:	FG5
S/N:	202

Ocean loading correction (μgal, -local phase degree)

Waves	M_2	S_2	K_1	O_1	N_2	P_1	K_2	Q_1	M_f	M_m	S_{sa}
Ampl.	0.184	0.060	0.021	0.015	0.037	0.007	0.015	0.042	0.0	0.0	0.0
Phase:	299.1	328.1	297.1	190.3	283.2	284.5	329.5	126.2	0.0	0.0	0.0

Polar motion correction			Air pressure correction	
X-coordinate:	0.1430	arc seconds	Nominal air pressure:	974.4 mbar
Y-coordinate:	0.3082	arc seconds	Barometric admittance factor:	0.3 μgal/mbar

Gravity

Set gravity mean:	**9 80 960 410.9**	microgal
Set std. dev.:	0.850	microgal
Mean std. dev.:	10.16	microgal
Number of sets:	14	
Number of drops per set:	100	
Drop interval:	10 seconds	
Set interval:	60 minutes	
Nominal/datum height:	0.0 cm	

Local Contact: Antoine Kies (352) 46 66 44 328

Author: O. Francis Observatoire Royal de Belgique

Date: January 5, 1999