Consultative Committee on Mass and Related Quantities (CCM)
Working Group on Gravimetry (WGG)

9th International Comparison of Absolute Gravimeters ICAG-2013

Walferdange Underground Laboratory for Geodynamics (University of Luxembourg)

Pilot laboratory METAS

CCM.G-K2 Key Comparison and Pilot Study

Technical Protocol

IMPORTANT DEADLINES

We would like to present the results of the comparison as soon as possible. For that, we count on your collaboration to respect the different deadlines.

15 September 2013	Approbation of the Technical Report by all the ICAG-2013 participants.
15 October 2013	Deadline for sending the completed form of **annex A** to the Local Organisation (olivier.francis@uni.lu) and the Pilot Laboratory (Henri.Baumann@metas.ch)
5-14 November 2013	Comparison in the Underground Laboratory for Geodynamics in Walferdange, Grand-Duchy of Luxembourg
30 November 2013	Presentation of the results by the participants to the Local Organisation (olivier.francis@uni.lu) and the Pilot Laboratory (Henri.Baumann@metas.ch) (**Annex B**)
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15 February 2014	Draft A (confidential) presented to the participants
15 April 2014	Deadline for comments on Draft A
15 May 2014	Draft B (public) and publication in Metrologia “Technical Supplement”

Content

Introduction

The International Comparison of Absolute Gravimeters 2013 (ICAG-2013) will be held in the Walferdange Underground Laboratory for Geodynamics (WULG) during the first weeks of November 2013. The primary goal is to allow operators of absolute gravimeters (geophysicists, geodesists, metrologists, etc…) to check that their meter operates properly and to meet requirements of MRA by quantitative measures of the degree of equivalence of national standards for gravity acceleration. All communities are welcome to participate in the comparison.

The ICAG-2013 is registered Key Comparison CCM.G-K2. The comparison is organized in accordance with the CIPM MRA-D-05 of the Consultative Committee on Mass and Related Quantities (CCM).

Only National Metrology Institutes that are signatories of the CIPM Mutual Recognition Arrangement (CIPM MRA) and laboratories officially designated by those institutes can participate in a Key Comparison, their measurements can contribute to the evaluation of the KCRVs (Key Comparison Reference Values) and their degrees of equivalence can be published in the Key Comparison Data Base (KCDB). However, non-designated institutes are allowed to take part in the comparison. The results including their contribution will be the subject of a scientific publication in Metrologia.

METAS has accepted to be the pilot laboratory under the leadership of Dr. Henri Baumann, Prof. Dr. Olivier Francis and Ing. Gilbert Klein from the University of Luxembourg are the members of the local organizing committee.

1. Participants

The list of the participants who have registered so far is given in Table 1. In total, 30 absolute gravimeters from 30 institutes will take part in the comparisons including 6 different types of instruments.

Table 1. Preliminary list of the 30 participants to ICAG-2013

#	Country or Province	Institution	Gravimeter	NMI or Designed Institute	Operator(s)	E-mail
1	Austria	Federal Office of Metrology and Surveying and Surveying (BEV)	FG5-242	YES	Christian Ullrich	christian.ullrich@bev.gv.at diethard.ruess@bev.gv.at
2	Belgium	Royal Observatory of Belgium	FG5-202	NO	Michel van Camp	mvc@oma.be
3	Brazil	Observatório Nacional	FG5-223	NO	Mauro Andrade de Sousa Rodrigo Lima Melhorato	mauro@on.br, mauro.andrade@pq.cnpq.br, rodrigo@on.br, rodrigomelhorato@hotmail.com
4	China	National Institute of Metrology	NIM-3A	YES	Shuqing Wu	wushq@nim.ac.cn
5	China	Tsinghua University	T-2	NO	Hua Hu	huhua@tsinghua.edu.cn
6	China	Institute of Seismology, China Earthquake Administration – Wuhan	FG5-232	NO	Chongyang Shen	shency63@yahoo.com.cn
7	Chinese Taipei	Industrial Technology Research Institute	FG5-224	YES	Chiung-Wu Lee Wen-Chi Hsieh	JohnLee@itri.org.tw nickyhsieh@itri.org.tw
8	Czech Republic	Geodetic Observatoru Pecný	FG5-215	YES	Vojtech Pálinkás Jakub Kostelecký	vojtech.palinkas@pecny.cz jakub.kostelecky@pecny.cz
9	Finland	Finnish Geodetic Institute	FG5X-221	YES	Jaakko Mäkinen Jyri Näränen	Jaakko.Makinen@fgi.fi Jyri.Naranen@fgi.fi Mirjam.Bilker@fgi.fi
10	France	Observatoire Midi-Pyrénées	A10-014	NO	Sylvain Bonvalot	Sylvain.bonvalot@ird.fr
11	France	LNE-SYRTE	CAG-01	YES	Sébastien Merlet Franck Pereira Dos Santos Pierre Gillot	sebastien.merlet@obspm.fr franck.pereira@obspm.fr
12	France	Institut de Physique du Globe de Strasbourg	FG5-206	NO	Jacques Hinderer	jhinderer@unistra.fr
13	France	Géosciences Montpellier – CNRS - Université de Montpellier 2	FG5-228	NO	Nicolas Le Moigne	nicolas.lemoigne@gm.univ-montp2.fr
14	Germany	Leibniz Universität Hannover	FG5X-220	NO	Olga Gitlein Manuel Schilling	gitlein@ife.uni-hannover.de schilling@ife.uni-hannover.de
15	Germany	Federal Agency for Cartography and Geodesy	FG5-101 or FG5-301	NO	Reinhard Falk Herbert Wilmes	Reinhard.falk@bkg.bund.de herbert.wilmes@bkg.bund.de
16	Italy	INRIM-Istituto Nazionale di Ricerca Metrologica	IMGC-02	YES	Alessandro Germak Emanuele Biolcati Claudio Origlia	A.Germak@inrim.it E.Biolcati@inrim.it c.origlia@inrim.it

	Country or Province	Institution	Gravimeter	NMI or Designed Institute	Operator(s)	E-mail
17	Italy	ASI (Agenzia Spaziale Italiana)	FG5-218	NO	Francesco Schiavone	francesco.schiavone@e-geos.it
18	Japan	National Metrology Institute of Japan	FG5-213	YES	Shigeki Mizushima	s.mizushima@aist.go.jp
19	Luxembourg	University of Luxembourg	FG5X-216	NO	Olivier Francis	olivier.francis@uni.lu
20	Norway	Kartverket – Geodetic Institute	FG5-226	NO	Ove Omang	ove.christian.dahl.omang@kartverket.no
21	Poland	Institute of Geodesy and Cartography	A10-020	NO	Jan Krynski Marcin Sękowski Przemysław Dykowski	jan.krynski@igik.edu.pl msek@igik.edu.pl przemyslaw.dykowski@igik.edu.pl
22	Poland	Faculty of Geodesy and Cartography Warsaw University of Technology	FG5-230	NO	Tomasz Olszak	t.olszak@gik.pw.edu.pl
23	Republic of Korea	Korea Research Institute of Standards and Science	FG5X-104	YES	In-Mook Choi	mookin@kriss.re.kr
24	Spain	Instituto Geográfico Nacional	FG5-211 A10-006	NO	Sergio Sainz-Maza Aparicio	ssainz-maza@fomento.es
25	Sweden	Lantmäteriet – the Swedish mapping, cadastral and land registration authority	FG5-233	NO	Andreas Engfeldt Jonas Agren	andreas.engfeldt@lm.se Jonas.agren@lm.se
26	Switzerland	Federal Office of Metrology - Metas	FG5X-209	YES	Henri Baumann	Henri.baumann@metas.ch
27	The Netherlands	Delft University of Technology	FG5-234	NO	René Reudink	r.h.c.reudink@tudelft.nl
28	United Kingdom	N.E.R.C. / Space Geodesy Facility, Herstmonceux Castle	FG5-229	NO	Vicky Smith	vism@nerc.ac.uk
29	USA	National Geodetic Survey	FG5-102	NO	Marc Eckl	Mark.Eckl@noaa.gov
30	USA	Micro-gLaCoste	FG5X-302	NO	Derek van Westrum	derek@microglacoste.com

2. Measurand

The measurand is the mean free-fall acceleration at the reference height corrected for gravimetric Earth tides, atmospheric and polar motion effects on gravity. Corrections are made according to the Resolution 16 of the 18th General Assembly of the IAG 1983 to obtain "zero-tide" values for gravity [3].

The reported time of the measurement shall be the average of the times of the observations contributing to the measurement.

The vertical gravity gradients, the geographical coordinates and elevation of the measuring sites (stations) as well as the observed tidal parameters are listed in Annex D.

The atmospheric pressure and the gravity changes using the WULG superconducting gravimeter OSG-CT040 will be continuously measured during the comparison. Information on these measurements will be available after the comparison (draft A) to the participants.

3. Methods of measurement

The methods of absolute measurements and measuring instruments used by the participants should be described by each participant (Annex A). This information is mandatory for the KC participants.

4. Program of the measurements

A 15-stations gravity network (5 on 3 different platforms) is proposed for all the measurements (Figure 1).

Each gravimeter should measure at least at three gravity stations. The schedule will be arranged in a way that the two same instruments should not measure twice at the same station.

The comparison will be organized in two consecutive sessions. The first one shall take place between the 5th to the 8th of November 2013. The second session will last from the 11th to the 14th of November 2013.

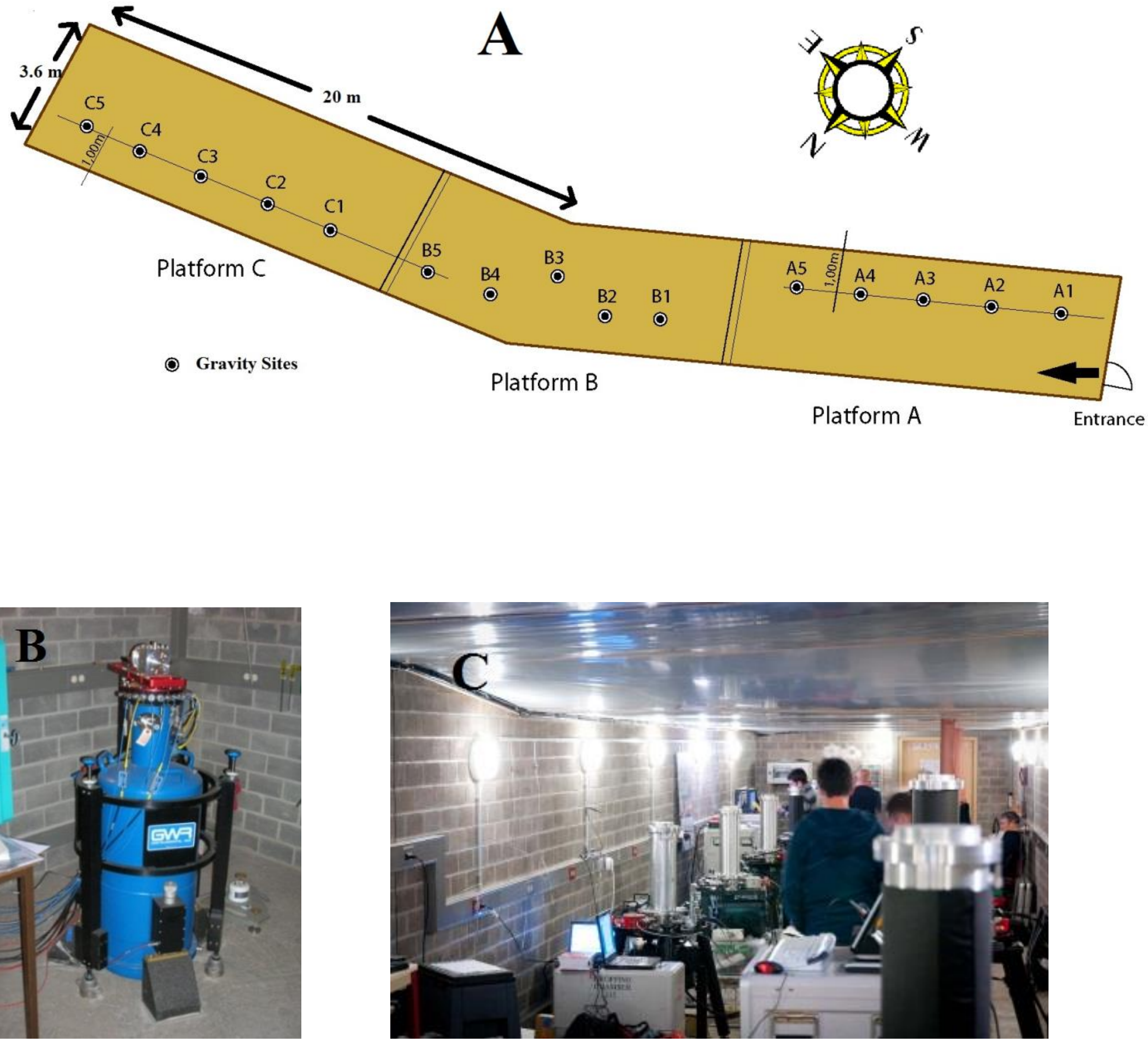

Figure 1. A. Sketch of the underground laboratory allowing for the simultaneous set up of 15 gravimeters (40 m length and 3.6 m wide). **B**. The superconducting gravimeter OSG-CT040 installed in a gallery next to the comparison site. **C**. Picture of the platform A taken during the comparison.

5. Measurement timetable

The preliminary measurement timetable is given in Table 2. There will be two distinct sessions. A gap of a few days is left to allow a smooth transition between the operators who are done and the newcomers.

Table 2. Schedule for the measurements.

#	Gravimeter	5/11	6/11	7/11	11/11	12/11	13/11
1	A10-014	A2	B2	C2			
2	A10-020				C4	A2	B4
3	CAG-01	Will measure before the 5/11/2013 A2 – A4 – B3					
4	FG5-101 (or 301)				C1	A4	B5
5	FG5-102	A5	B5	C5			
6	FG5-202	B3	C2	A4			
7	FG5-206				A3	B4	A2
8	FG5-211				A2	B3	A1
9	FG5-213	C1	A2	B5			
10	FG5-215	B1	C5	A2			
11	FG5-218	B2	C1	A3	B3	C5	C1
12	FG5-221	A4	B4	C4			
13	FG5-223				B4	C1	C2
14	FG5-224				A5	B1	A4
15	FG5-226				C5	A3	B2
16	FG5-228	C3	A4	B2			
17	FG5-229				A1	B2	A5
18	FG5-230	B2	C1	A3			
19	FG5-232	C5	A1	B4			
20	FG5-233	A1	B1	C1			

21	FG5-234				B2	C4	C5
22	FG5-242				A4	B5	A3
23	FG5X-104	B4	C3	A5			
24	FG5X-209	A3	B3	C3			
25	FG5X-220				B1	C3	C4
26	FG5X-216				C2	A5	B1
27	FG5X-302	B5	C4	A1			
28	IMGC-02				B5	C2	C3
29	NIM-3A	C2	A3	B1			
30	T2	C4	A5	B3			

6. Data report

All participants should give the absolute measurement results for every measured point (station) in the table format given in annex B (**mandatory for all participants**).

The deadline for submission of the results to the Pilot lab is 2 weeks after the measurements [1].

7. Uncertainty evaluation

"*A result from a participant is not considered complete without an associated uncertainty, and is not included in the draft report unless it is accompanied by an uncertainty supported by a complete uncertainty budget*" [1].

Uncertainty of measurements should be estimated (mandatory for KC participants) according to the GUM [2]. The calculation of uncertainty can be divided in two steps:

1. uncertainty budget of the instrument that includes, at least, the following influence parameters:
   - Laser frequency
   - Rb-clock frequency
   - Gravity gradient measurement
   - Misalignments in the verticality of the laser beam correction
   - Imperfect collimation and cosine error effect
   - Verticality
   - Residual gas pressure
   - Diffraction effects
   - Glass wedges
   - Corner cube rotation
   - Air gap modulation
   - Inhomogeneous magnetic field
   - Apparatus gravity attraction effect
   - Electrostatics effect
   - Temperature changes
   - Beam divergence correction
   - Phase shifts in fringe counting and timing electronics
   - Choice of the initial and final scaled fringes effect
   - Reference height

   Other possible effects:
   - Laser frequency reproducibility/stability
   - Beam shear effect
   - Photodetection and fringe counting electronics effect
   - Finite speed of light effect
   - Optical effects
   - Radiation Pressure effect
   - Whichever other contribution characterized from the participant laboratory

2. measurement uncertainty in a specific site that includes, at least, the following influence parameters:

- Instrumental uncertainty (as results of the first step in the uncertainty calculation)
- Uncertainty in air pressure correction (admittance factor)
- Air pressure measurement effect
- Earth tide evaluation
- Ocean loading correction evaluation

- Polar motion correction evaluation
- Groundwater effect
- Coriolis acceleration effect
- Floor (instrument) recoil effect
- Gravity gradient (transfer to 1.3 m)
- Typical standard deviation of measurements

From the influencing quantities X_i , measurement deviations Δx_i and uncertainties in the form of standard deviation s_i (type A) and a_i (type B) are considered:

- standard uncertainty:
note: k_a depends on the type of statistical distribution (2 for U distribution, 3 for rectangular , 6 for triangular, etc.)

$$u^2(x_i) = s_i^2 \vee \frac{a_i^2}{k_a} \quad (1)$$

- sensitivity coefficients:

$$c_i \approx \left.\frac{\Delta g}{\Delta x_i}\right|_{X_1 = x_1, \ldots, X_N = x_N} \quad (2)$$

- single gravity deviation:

$$\Delta g_i = c_i \cdot \Delta x_i \quad (3)$$

- variances:

$$u^2(y_i) = c_i^2 u^2(x_i) \quad (4)$$

- combined standard uncertainty:

$$u(g) = \sqrt{\sum_{i=1}^{n} u^2(y_i)} \quad (5)$$

- sum of gravity deviations:

$$\Delta g = \sum_{i=1}^{n} \Delta g_i \quad (6)$$

- effective degrees of freedom, according to the Welch-Satterthwaite formula:

$$\nu_{eff} = \frac{u^4(y)}{\sum_{i=1}^{n} \frac{u_i^4(y)}{\nu_i}} \quad (7)$$

- coverage factor (p=level of confidence):

$$k = f(\nu_{eff}, p) \quad (8)$$

- expanded standard uncertainty:
note: $|\Delta g|$ is the calculated error. If it is not corrected, at least it should be included in the estimation of uncertainty. See F.2.4.5 in [2].

$$U(g) = k \cdot u(g) + |\Delta g| \quad (9)$$

- relative expanded standard uncertainty:

$$U_{rel}(g) = \frac{U(g)}{g} \quad (10)$$

An example of calculation of uncertainty is given in annex C. It contains the unified budget of uncertainty for FG5-type gravimeters, as result of the analysis done in previous ICAG comparisons.

8. Frequency measurements during ICAG-2013

The University of Luxembourg offers frequency measurements service during the ICAG-2013 both of stabilized lasers and the Rb clocks. Depending on the request from the participants, the traceability to national standard could be arranged. As these measurements are performed on the Campus of the University (15 minutes driving distance from the WULG), it is mandatory to make the request at least one week before the Comparison. It will be based on "first-come-first-served". A time table will be communicated to the operators during the comparison. The contact person is Olivier Francis.

9. Results elaboration

The results of ICAG-2013 will be the Comparison Reference Values with their uncertainties evaluated using all the measurements performed by all the gravimeters participating in ICAG-2013.

The data processing will be based on a weighted least square adjustment including the gravity differences measured by all gravimeters (PS and KC).

$$g_{ik} = g_k + \delta_i + \varepsilon_{ik}$$

with the condition

$$\sum_i \delta_i = 0$$

Two approaches will be compared. In the first approach, weights based on the uncertainty budget of the observations will be applied to the measured values g_{ik}. In a second approach, weights will be also applied on the biases δ_i. However, the participants should propose and justify the weights to be applied on the biases otherwise they will be decided by the Pilot Laboratory.

These two results will be presented to the participants in the Draft A.

Consequently, the participants will decide which will be the more appropriate method and it will be implemented in the Draft B report.

Since the comparison strive for a blind test type of measurement, **participants cannot communicate their results, neither to other participants nor officially on any other way before the issue of the Draft A.**

Once the draft B of the report on KC is published all the results of ICAG-2013 will be made public.

10. Transportation of the instrumentation and customs formalities

For the transportation of the instrumentation and customs formalities, the operators are invited to contact directly Olivier Francis if necessary. The name of a local shipping company or consignee who is used to deal with the customs formalities of this kind of equipment will be recommended on request.

11.References

[1] T. J. Quinn, *Guidelines for CIPM key comparisons carried out by Consultative Committees*, BIPM, Paris, 1 March 1999 with modifications by the CIPM in October 2003.
http://www.bipm.org/utils/en/pdf/guidelines.pdf

[2] BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML, *Guide to the Expression of Uncertainty in Measurement*; Edition 1993, corrected and reprinted 1995, ISO-GUM, International Organization for Standardization, Geneva, Switzerland,ISBN92-67-10188-9.
http://www.bipm.org/en/publications/guides/gum.html

[3] Petit G. and B. Luzum, IERS Conventions 2010, IERS Technical Note No. 36, 2010.
ftp://maia.usno.navy.mil/conv2010/tn36.pdf"

Annex A - Description of the absolute gravimeter

Manufacturer	
Model/Type	
s/n	
Method of the measurement of free-fall acceleration	
Approximated reference height	
vibration-isolation device	
interferometer type	
Laser type	
Throw/drop length used during measurement, number of fringes acquired and fringes used for g-evaluation	
Software	
Add other information	

Annex B - Report of measurement results

The g-values should be corrected for all known geophysical effects (tides, polar motion, atmospheric pressure, etc.) as well as for all instrumental effects (self-attraction, diffraction effects, etc.).
The g-value can be given for any desired height.

Date	Time (from÷to)	Gravimeter	Operator/s	Site	#sets, #drops	g@ measure-ment height /µGal	Measure-ment height / cm	std /µGal	u/ µGal	Degrees of freedom

Indicate the value of the applied self-attraction correction and diffraction correction with the associated uncertainty

Date	Time (from÷to)	Gravimeter	Operator/s	Site	Self-attraction /µGal	$u_{Self-attraction}$ /µGal	Diffraction /µGal	$u_{Diffraction}$ /µGal

Annex C - Example of calculation of uncertainty.

Example of instrumental uncertainty (unified for FG5s)

Note: table below is in MS-Excel® format. Double-click to open it. Light blue cells contain formulas that should not be modified

Example of instrumental uncertainty (unified for FG5s)

Influence parameters, x_i	Value	Unit	u_i or a_i	Type A, σ_i	Type B, a_i	Correction, Δg	Type of distribution	Equivalent variance	Sensitivity coefficients	Contribution to the variance	Degrees of freedom, ν_i	Equivalent standard uncertainty
Laser frequency		Hz	1,0E-01	1,0E-01			gaussian	1,0E-02	2,1E-08	4,4E-18	30	2,1E-09
Laser frequency reproducibility		Hz	1,0E-02	1,0E-02			gaussian	1,0E-04	2,1E-08	4,4E-20	30	2,1E-10
Rb-clock frequency		Hz	5,0E-04	5,0E-04			gaussian	2,5E-07	2,0E-06	1,0E-18	30	1,0E-09
Gravity gradient measurement		$m \cdot s^{-2} \cdot m^{-1}$	5,0E-12	5,0E-12			gaussian	2,5E-23	8,3E+02	1,7E-17	15	4,2E-09
Misalignments in the verticality of the laser beam correction	6,60E-09	$m \cdot s^{-2}$	±2,1E-09		2,1E-09	6,6E-09	rectangular	1,5E-18	1	1,5E-18	15	1,2E-09
Imperfect collimation and cosine error effect		$m \cdot s^{-2}$	1,0E-09	1,0E-09			gaussian	1,0E-18	1	1,0E-18	15	1,0E-09
Verticality		rad	4,8E-05		4,8E-05		rectangular	7,7E-10	1,41E-04	1,5E-17	15	3,9E-09
Residual gas pressure	2,0E-04	Pa	±2E-04		2E-04	3,6E-09	rectangular	1,3E-08	1,8E-05	4,3E-18	5	2,1E-09
Diffraction effects			±3,1E-10	3,1E-10			gaussian	9,6E-20	9,8E+00	9,2E-18	15	3,0E-09
Beam shear effect	unknown		unknown					0,0E+00		0,0E+00		0,0E+00
Glass wedges		rad		2,9E-05			gaussian	8,4E-10	-1,4E-04	1,6E-17	15	4,1E-09
Corner cube rotation		$rad \cdot s^{-1}$	±1E-02		1E-02		rectangular	3,3E-05	6,0E-07	1,2E-17	15	3,5E-09
Air gap modulation		mm	1,5E-07	1,5E-07			gaussian	2,3E-14	4,9E-02	5,4E-17	15	7,4E-09
Inhomogeneous magnetic field		T	±5E-05		5E-05		rectangular	8,3E-10	7,0E-05	4,1E-18	15	2,0E-09
Apparatus gravity attraction effect		$m \cdot s^{-2}$	±2E-09		2E-09		rectangular	1,3E-18	1	1,3E-18	10	1,2E-09
Electrostatics effect		$m \cdot s^{-2}$	1,0E-09	1,0E-09			gaussian	1,0E-18	1	1,0E-18	15	1,0E-09
Temperature changes		°C	±4E+00		4E+00		U	8,0E+00	7,0E-10	3,9E-18	10	2,0E-09
Diffraction effects	2E-08	$m \cdot s^{-2}$	1,10E-08	1,1E-08		2E-08	gaussian	1,2E-16	1	1,2E-16	10	1,1E-08
Index of refraction effect			negligible					0,0E+00		0,0E+00		0,0E+00
Phase shifts in fringe counting and timing electronics		s	±1E-08		1E-08		rectangular	3,3E-17	5,2E-01	9,0E-18	15	3,0E-09
Photodetection and fringe counting electronics effect			negligible					0,0E+00		0,0E+00		0,0E+00
Finite speed of light effect			negligible					0,0E+00		0,0E+00		0,0E+00
Choice of the initial and final scaled fringes effect		$m \cdot s^{-2}$	1,3E-08	1,3E-08			gaussian	1,7E-16	1	1,7E-16	15	1,3E-08
Optical effects			negligible					0,0E+00		0,0E+00		0,0E+00
Reference height		m	±1E-03		1E-03		rectangular	3,3E-07	3,0E-06	3,0E-18	30	1,7E-09
Radiation Pressure effect			negligible					0,0E+00		0,0E+00		0,0E+00
Others			negligible					0,0E+00		0,0E+00		0,0E+00
				Total correction		**3,02E-08**	**$m \cdot s^{-2}$**	Sum of variances		4,49E-16	$m^2 \cdot s^{-4}$	

Combined standard uncertainty, u	2,1E-08	$m \cdot s^{-2}$
Degrees of freedom, ν_{eff} (Welch-Satterthwaite formula)	55	
Confidence level, p	95%	
Coverage factor, k (calculated with t-Student)	2,00	
Expanded uncertainty (corrections applied), $U = ku$	**4,2E-08**	**$m \cdot s^{-2}$**
Relative expanded uncertainty (corrections applied), $U_{rel} = U/g$	**4,3E-09**	
Expanded uncertainty (corrections not applied), $U = ku + ABS(\Delta g)$	**7,3E-08**	**$m \cdot s^{-2}$**

Example of site dependent uncertainty (unified)

Note: table below is in MS-Excel® format. Double-click to open it. Light blue cells contain formulas that should not be modified

Influence parameters, x_i	Value	Unit	u_i or a_i	Type A, σ_i	Type B, a_i	Type of distribution	Equivalent variance	Sensitivity coefficients	Contribution to the variance	Degrees of freedom, ν_i	Equivalent standard uncertainty
Instrumental uncertainty	2,1E-08	$m \cdot s^{-2}$	2,1E-08	2,1E-08		gaussian	4,5E-16	1	4,5E-16	55	2,1E-08
Uncertainty in air pressure correction (admittance factor)	6,3E+00	hPa	6,0E-01		3,0E-01	rectangular	3,0E-02	3,2E-08	3,0E-17	15	5,5E-09
Air pressure measurement effect		$m \cdot s^{-2}$	±1E-09		1,0E-09	rectangular	3,3E-19	1	3,3E-19	30	5,8E-10
Earth tide evaluation		$m \cdot s^{-2}$	±1E-08		1,0E-08	rectangular	3,3E-17	1	3,3E-17	30	5,8E-09
Ocean loading correction evaluation		$m \cdot s^{-2}$	±0,5E-09		5,0E-09	rectangular	8,3E-18	1	8,3E-18	30	2,9E-09
Polar motion correction evaluation		$m \cdot s^{-2}$	±0,5E-11		5,0E-10	rectangular	8,3E-20	1	8,3E-20	30	2,9E-10
Groundwater effect	Unknown		Unknown				0,0E+00		0,0E+00		0,0E+00
Coriolis acceleration effect		$m \cdot s^{-2}$	±7,5E-09		7,5E-09	rectangular	1,9E-17	1	1,9E-17	15	4,3E-09
Floor (instrument) recoil effect		$m \cdot s^{-2}$	±2E-09		2,0E-09	rectangular	1,3E-18	1	1,3E-18	15	1,2E-09
Gravity gradient (transfer to 0.9 m)		$m \cdot s^{-2} \cdot m^{-1}$	5,0E-12	5,0E-12		gaussian	2,5E-23	8,3E+02	1,7E-17	30	4,2E-09
Typical standard deviation of measurements		$m \cdot s^{-2}$	5,0E-09	5,0E-09		gaussian	2,5E-17	1	2,5E-17	30	5,0E-09
		Sum of variances							5,83E-16	$m^2 \cdot s^{-4}$	
		Combined standard uncertainty, u							2,4E-08	$m \cdot s^{-2}$	
		Degrees of freedom, ν_{eff} (Welch-Satterthwaite formula)							89		
		Confidence level, p							95%		
		Coverage factor, k (calculated with t-Student)							1,99		
		Expanded uncertainty (corrections applied), $U = ku$							**4,8E-08**	$m \cdot s^{-2}$	
		Relative expanded uncertainty (corrections applied), $U_{rel} = U/g$							**4,9E-09**		
		Expanded uncertainty (corrections not applied), $U = ku + ABS(\Delta g)$							**7,8E-08**	$m \cdot s^{-2}$	
		Relative expanded uncertainty (corrections not applied), $U_{rel} = U/g$							**8,0E-09**		

Annex D - Parameters of the WULG site

The same geographical coordinates are used for all the sites:
Name of the station: Walferdange
Latitude: 49.6647 North
Longitude: 6.1528 East
Altitude: 295 m

Table D.1. Preliminary gradient values to be updated according to the new measurements

Site	Vertical gravity gradient /microGal/m
A1	-289.7±2.0
A2	-271.5±1.9
A3	-262.0±2.0
A4	-267.7±2.3
A5	-262.9±2.3
B1	-288.1±1.9
B2	-277.6±2.0
B3	-274.6±1.8
B4	-264.5±2.0
B5	-267.7±2.0
C1	-275.7±1.9
C2	-273.0±1.7
C3	-271.9±1.0
C4	-261.6±1.0
C5	-264.2±1.0

Table D2. Observed tidal parameters.

TIDALPARAM=	0.000000	0.000001	1.00000	0.0000	DC	#tidal param.
TIDALPARAM=	0.000002	0.249951	1.16000	0.0000	LONG	#tidal param.
TIDALPARAM=	0.721500	0.906315	1.14218	-1.4047	Q_1	#tidal param.
TIDALPARAM=	0.921941	0.940487	1.15001	0.1310	O_1	#tidal param.
TIDALPARAM=	0.958085	0.974188	1.16448	1.1522	M_1	#tidal param.
TIDALPARAM=	0.989049	1.011099	1.13628	0.3612	K_1	#tidal param.
TIDALPARAM=	1.013689	1.044800	1.17370	0.8380	J_1	#tidal param.
TIDALPARAM=	1.064841	1.216397	1.17638	4.7836	OO_1	#tidal param.
TIDALPARAM=	1.719381	1.872142	1.12839	3.3773	$2N_2$	#tidal param.
TIDALPARAM=	1.888387	1.906462	1.18419	3.5318	N_2	#tidal param.
TIDALPARAM=	1.923766	1.942754	1.19031	2.5519	M_2	#tidal param.
TIDALPARAM=	1.958233	1.976926	1.19620	2.7367	L_2	#tidal param.
TIDALPARAM=	1.991787	2.182843	1.19406	1.1885	S_2	#tidal param.
TIDALPARAM=	2.753244	3.081254	1.05599	0.0000	M_3	#tidal param.
TIDALPARAM=	3.791964	3.937897	1.05000	0.0000	M_4	#tidal param.