CCM.G-K2.2017：

CIPM Key Comparison of Absolute Gravimeters

Final Report

Pilot

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Abstract:

The CCM.G-K2.2017 comparison was organised for the purpose of determination of the degree of equivalence of the national standards for free-fall acceleration measurement. The comparison was held in the Changping Campus of National Institute of Metrology China (NIM), from October to November in 2017. This is the first time that such a comparison is organized outside of the Europe continent and establishes a new global comparison sites in China [1, 2]. This comparison is also the largest ever organized with the participation of 13 instruments.

Dr. Shuqing Wu, Dr. Jinyang Feng and Mrs. Chunjian Li from the NIM were in charge of the local organization of the comparison and of the elaboration of the results. NIM was the Pilot Laboratory under the leadership of Dr. Shuqing Wu. The comparison steering committee (SC) is composed of Prof. Olivier Francis (LU), Dr. Vojtech Pálinkáš (VÚGTK/RIGTC), Dr. Derek van Westrum (NOAA-NGS), Dr. Reinhard Falk (BKG) and Dr. Shuqing Wu (NIM). The SC is supported and consulted by the CCM-WGG Chair, Prof. Alessandro Germak (INRIM). The comparison was organized in accordance with the CIPM MRA-D-05 of the Consultative Committee on Mass and Related Quantities (CCM).

Before the comparison, the Technical Protocol (TP) was approved by all the participants and CCM-WGG. This TP includes the list of the registered participants, a description of the comparison site, the timetable of the measurements, and an example to express the uncertainty of the gravimeters. It also specifies the data processing as well as the reporting of the results.

We give the list of the participants who actually performed measurements during the comparison, the data (raw absolute gravity measurements and their uncertainties) submitted by the participants as well as the results of the vertical gravity gradient at the comparison sites. The measurement strategy is briefly discussed and the data elaboration is presented. Finally, the results of the data adjustment are presented including the degrees of equivalence (DoE) of the absolute gravimeters and the key comparison reference values (KCRVs). Overall, the measurements of KC instruments are all consistent given the declared uncertainties.

In this report, the microgal (μGal) is used as unit of gravity acceleration, 1 μGal is equal to 1×10^{-8}m/s^2.

Graphical Summary of Results:

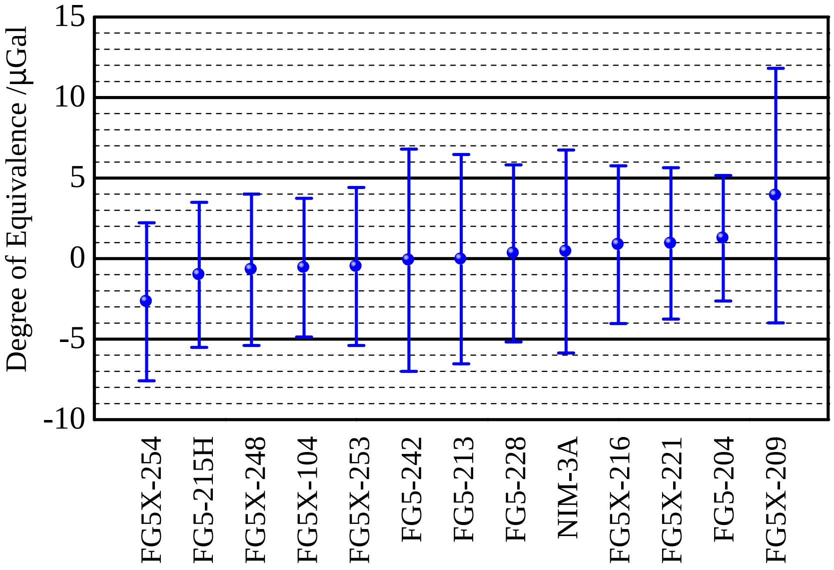


Figure 1. Degrees of equivalence expressed as the deviation of the key comparison reference value. The error bars refer to expanded uncertainties of the deviations at a 95 % level of confidence.

Contents

1. Introduction

In 2013, CCM-WGG decided to recommend NIM China as the pilot lab to host the International Comparison of Absolute Gravimeters in 2017.In 2015, 15th CCM meeting approved this propose from CCM-WGG and agreed this comparison is registered as the CCM.G-K2.2017 in the frame of CIPM-MRA.

2.List of Participants, Facilities Used

The list of the participants is given in Table 1. In total, 13 absolute gravimeters were compared including several different types of instruments. The number of FG5 or FG5X free-fall absolute gravimeters was dominant.

Table 1. Participants to CCM.G-K2.2017.

#	Country	Institution	Gravimeter	Participant(s)
1	Austria	Federal Office of Metrology and Surveying and Surveying (BEV)	FG5#242	Christian Ullrich
2	China	National Institute of Metrology (NIM)	NIM-3A	Jinyang Feng Chunjian Li Qiyu Wang
3	Czech Republic	VÚGTK/RIGTC Geodetic Observatory Pecný	FG5#215H ("H" is related to the modified measurement and evaluation system of the FG5#215 gravimeter according to [3]	Vojtech Pálinkáš Jakub Kostelecký
4	Finland	Geospatial Research Institute (FGI), National Land Survey of Finland	FG5X#221	Mirjam Bilker-Koivula Jyri Näränen
5	France	LNE-SYRTE - Géosciences Montpellier - France	FG5#228	Sébastien Merlet Nicolas Le Moigne
6	Japan	National Metrology Institute of Japan, National Institute of Advanced Industrial Science and Technology (NMIJ/AIST)	FG5#213	Shigeki Mizushima
7	Luxembourg	University of Luxembourg (LU)	FG5X#216	Olivier Francis
8	Republic of Korea	Korea Research Institute of Standards and Science (KRISS)	FG5X#104	In-Mook Choi Min-Seok Kim
9	Saudi Arabia	Saudi Standards, Metrology &Quality Org. (SASO-NMCC)	FG5X#253	HomoodM. Alotaibi Ahmed Aljuwayr

10	Switzerland	Federal Institute of Metrology METAS	FG5X#209	Henri Baumann
11	Thailand	National Institute of Metrology,Thailand (NIMT)	FG5X#248	Tasanee Priruenrom Nattanan Woradet
12	Turkey	Ulusal Metroloji Enstitüsü (UME/TÜBİTAK)	FG5X#254	Cafer KIRBAŞ İlkcan Coşkun
13	USA	National Institute of Standard Technology (NIST)	FG5#204	David Newel

3. Transfer Standard:

There was no transfer standard. All the instruments were transfered to NIM China for comparison together according to the comparison protocol.The reference standard is the local free-fall acceleration of NIM's comparison station.

The comparison was carried out in the Changping Campus of NIM. The Campus is located in the famous Nature Reserve for Ming Tombs, which are the world cultural heritages and far away from the city and industry noise. It is about 40 km north from Beijing city. The comparison station is sited in an individual building at the foot of a mountain in the campus, as shown in Figure 2. The 9 measured sites 1~9 are located on two pillars with each a size of 9 m×5 m, 4 m in depth and weighs about 400 ton. The pillar has concrete feet of 12 m in length connecting directly to the stable bedrock of mountain. The pillar B is 0.3 m higher than the pillar A which can generate about 80 μGal gravity difference for comparison. The station is very "quiet", the overall vibration is within the required criterion of 1×10^{-6} m/s^2 RMS (<10 Hz). The comparison location provides a perfect environment with very low vibration noise and ±0.5℃ temperature variation.

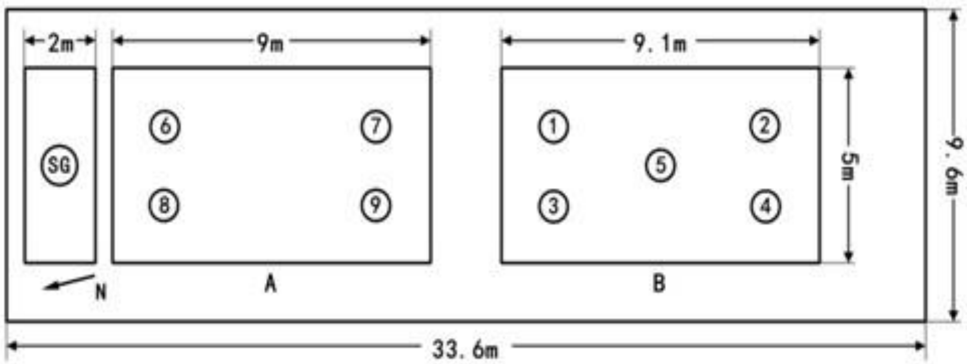


Figure 2. Top: Gravimetric building at Changping Campus of NIM, where the CCM.G-K2.2017 was held. Bottom: Scheme of pillars and sites at the underground comparison station.

Vertical gravity gradients (VGGs) were calculated from gravity differences measured with Scintrex CG-6#S032, ZLS Burris#B095 and ZLS Burris#B101 gravimeters at 4 different vertical levels above all the sites, as shown in Figure 3. This same procedure was adopted from the ICAG-2009 in BIPM [3]. Based on the results obtained from three relative gravimeters, we approximated gravity changes with height at all sites by second order polynomial fitting $g(h) = a + bh + ch^2$, the coefficients are presented in Table 2. The gravity difference δg between heights h1 and h2 can be written as:

$$\delta g = g(h_2) - g(h_1) = b(h_2 - h_1) + c(h_2^2 - h_1^2) \tag{1}$$

and the associated uncertainty：

$$\sigma_{\delta g}^2 = (h_2^2 - h_1^2)^2 \times \sigma_c^2 + (h_2 - h_1)^2 \times \sigma_b^2 + 2 \times (h_2^2 - h_1^2) \times (h_2 - h_1) \times \sigma_{bc} \tag{2}$$

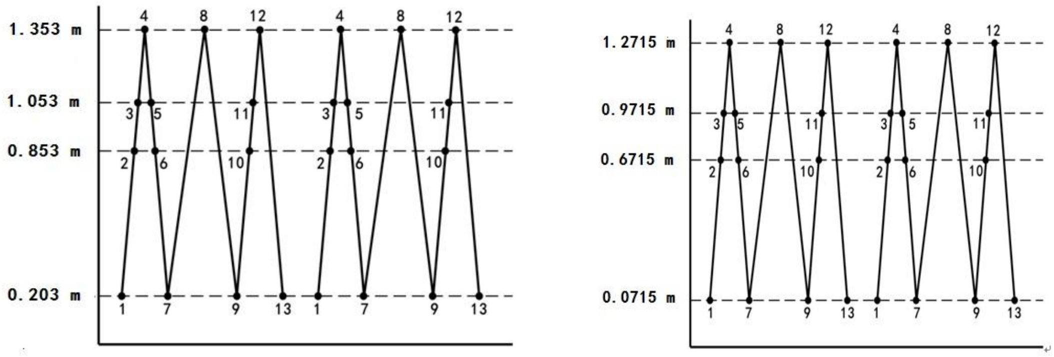


Figure 3. Left: VGG measurements by CG-6#S032 with 26 occupations at 4 levels. Right: VGG measurements by Burris#B095 and Burris#B101 with 26 occupations at 4 levels.

Table 2. Coefficients of second order polynomials for vertical gravity changes at the 9 sites used for the comparison. A least-squares fit provides with the coefficients a, b and c as well as the standard deviation σ_b, σ_c and the covariance σ_{bc}.

Site	**b** /µGal m^{-1}	σ_b /µGal m^{-1}	*c* /µGal m^{-2}	σ_c /µGal m^{-2}	σ_{bc} //µGal^2 m^{-3}
1	-273.76	3.91	5.87	2.83	-10.71
2	-257.18	3.77	0.34	2.74	-10.00
3	-271.49	3.46	4.43	2.51	-8.41
4	-265.57	3.64	7.54	2.64	-9.30
5	-261.22	3.76	-1.80	2.72	-9.90
6	-275.57	4.01	7.49	2.91	-11.30
7	-275.16	4.72	5.14	3.42	-15.63
8	-278.93	5.22	7.97	3.77	-19.06
9	-275.69	3.52	8.40	2.56	-8.73

The observed tidal parameters (Table 3) were estimated from more than one year of continuous observations of the superconducting gravimeter (SG) GWR-iGrav#012K installed in the same laboratory on a neighbouring pillar.

Table 3. Observed tidal parameters for the Changping Campus from more than one year of continuous observations with the (SG) GWR-iGrav#012K

Wave	Start freq. /cpd	End freq. /cpd	Amplitude factor	Phase lag /deg
M_0+S_0	0.000000	0.000001	1.00000	0.0000
Long Period	0.000002	0.249951	1.16000	0.0000
Q_1	0.878676	0.896968	1.16950	0.3584
O_1	0.911391	0.931206	1.16869	0.2095
M_1	0.958085	0.974188	1.16448	1.1522
K_1	1.001370	1.004107	1.14838	0.0327
J_1	1.035380	1.057485	1.16676	-0.1923
OO_1	1.071834	1.090052	1.16703	-0.2887
$2N_2$	1.845945	1.863026	1.17782	-0.1237
N_2	1.880265	1.897351	1.17090	-0.1369
M_2	1.914129	1.950419	1.16901	0.0524
L_2	1.964768	1.984282	1.16623	0.1456
S_2	1.998997	2.002736	1.16829	-0.2347
M_3	2.881177	3.381378	1.07648	0.1850
M_4	3.381379	4.347615	1.03900	0.0000

Gravity variations during the comparison were monitored by the SG GWR-iGrav#012K.

Figure 4 shows the gravity variations after applying corrections for tides, polar motion and atmospheric effect（-0.3μGal /hPa）. The instrumental drift of SG iGrav#012K was calculated by linear fitting of the differences between SG and AG data [4]. We used one year SG iGrav#012K data corresponding to 24 AG measurements (every two weeks one absolute measurement) by FG5X#249 and we obtained the linear drift of -1.75 μGal/year for the iGrav#012K. Consequently, we have applied the SG drift correction to the SG gravity time series.

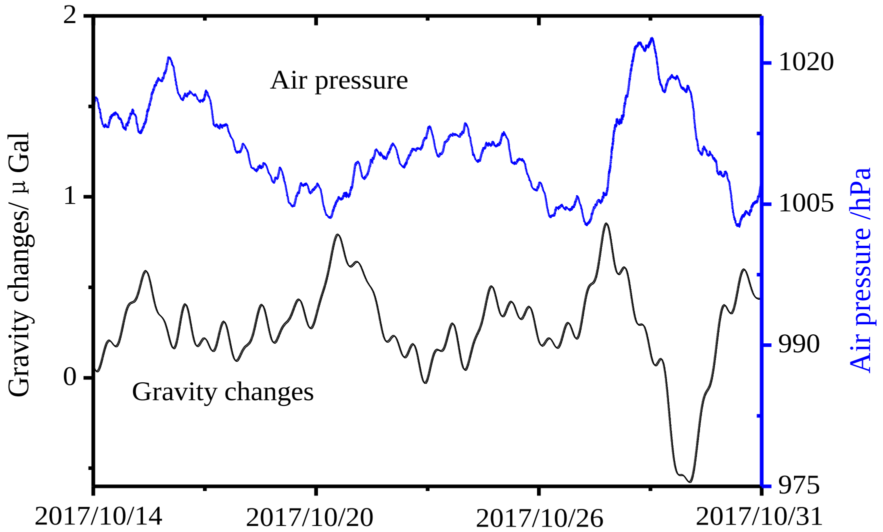


Figure 4. Gravity variation (after the corrections of tides, polar motion, atmospheric effect and drift of SG) and air pressure observed by GWR-iGrav#012K during CCM.G-K2.2017.

4. Comparison Protocol:

Before the comparison, the Technical Protocol (TP) was approved by all the participants and CCM-WGG. This TP includes:

- the list of the registered participants
- a description of the comparison site
- the timetable of the measurements
- an example to express the uncertainty of the gravimeters
- the data processing as well as the reporting of the results. etc.

5. Methods of Measurement and Range of Conditions:

The raw absolute gravity measurement is the mean free-fall acceleration at the specified measurement corrected by:

- the gravimetric Earth tides to obtain "zero-tide" values for gravity;
- the atmospheric attraction and loading effects using an admittance factor of -0.3μGal/hPa on the difference between the normal air pressure [5] and measured air pressure at the station.
- the polar motion effect, estimated from the coordinates of the Celestial Ephemeris Pole relative to the IERS Reference Pole.
- the vertical gravity gradient to obtain gravity at the specified measurement height;
- and all known instrumental effects (e.g. self-attraction, laser beam diffraction, etc…).

The corrections for tides, polar motion and atmospheric mass redistributions are in compliance with the International Earth Rotation and Reference Systems Service (IERS) conventions 2010 [6] and IAGBN (International Absolute Gravity Base-station Network) processing standards [7].

The participants were responsible for processing their gravity data. They submitted the final g-values and the combined uncertainties for all the measured sites preferably at the instrument's reference height [8, 9] (distance between a bench mark and the effective position of free-fall [10], the reference height is instrument dependent: around 1.21 m, 1.27 m and 0.68 m for the FG5s, FG5Xs, A-10s, respectively), where g is in variant of the VGG used in the equation of motion.

According to the TP, 9 gravity sites were used during the comparison organized in four consecutive sessions. Each gravimeter was planned to measure at 4 gravity sites. The schedule was arranged in such a way that two instruments did not measure twice at the same site. In addition, the program has been optimized in such a way that each gravity site was measured by 4 to 7 KC instruments (Table4).

Table 4. Site occupations for the KC absolute gravimeters

Site / Instrument	1	2	3	4	5	6	7	8	9	Total
FG5#242		×	×			×	×			4
NIM-3A		×			×		×		×	4
FG5#215H			×	×			×	×		4
FG5X#221		×		×			×		×	4
FG5#228	×						×	×	×	4
FG5#213	×		×			×		×		4
FG5X#216			×	×				×	×	4
FG5X#104	×		×		×	×				4
FG5X#253	×			×		×	×			4
FG5X#209	×		×		×				×	4
FG5X#248		×			×	×			×	4
FG5X#254	×	×		×		×				4
FG5#204		×		×				×	×	4
Total	6	6	6	6	4	6	6	5	7	

6.Uncertainty due to the Transfer Standard

There was no transfer standard. The uncertainty due to the reference standard of free-fall acceleration of NIM's comparison station were as below:

Table 5. The official KCRVs of g . The constant value 980 122 000.0 μGal is subtracted from the KCRVs. The uncertainty $U_{site}=2\sigma$ (σ is the standard deviation of reference value from the adjustment) is the expanded uncertainty at 95% confidence. All gravity values refer to 1.25 m above the marker.

Site	KCRV /μGal	U_{site}(k=2) /μGal
1	575.1	1.3
2	568.9	1.3
3	579.0	1.4

4	575.6	1.3
5	581.1	1.4
6	649.6	1.4
7	641.9	1.3
8	653.9	1.3
9	647.3	1.3

7.Corrections to the Transfer Standard

There was no transfer standard. The corrections due to the reference standard of free-fall acceleration of NIM's comparison station were shown in Table 2 and Figure 4.

The new determinations of the vertical gravity gradient (see Table 2) are used to transfer the g-values from the instrumental reference heights for the FG5s and A-10s to the comparison reference height of 1.25 m (average of all KC instrumental reference heights) which minimized the contribution of uncertainty from VGGs to the uncertainty of KCRV. For the other types of gravimeters, their g-values were transferred from the given height to the comparison reference height of 1.25 m.

Each absolute gravimeter measured at four sites exactly. The reported start and end time are used to determine the average measurement time of each observation. The SG gravity time series were obtained by applying corrections for tides, atmosphere and polar motion using the same models as for the absolute gravity measurements. The corrections that account for gravity variations during the comparison (SG corrections) have been obtained by averaging the SG observations over the same time window as each AG measurement session(see Figure 4). This correction implies that one needs to define an official comparison time which was chosen to be at 00:00 on October 23, 2017 (UTC). In other words, all the observations have been transferred to this time when the SG correction is zero.

8.Data Processing and Computation of the KCRV

As each gravimeter measured at only 4 of the 9 gravity sites, the g-values cannot be directly compared. A global weighted least-square adjustment (LSA) is performed using as inputs the g-values transferred to the comparison reference height of 1.25 m and their associated uncertainties. The uncertainties are used to weight the gravity observations as a weight of $w_{ik} = u_0^2 / u_{ik}^2$ in the LSA, where u_0^2 is the unit weight. The observation equation made by the gravimeter "i" (with the systematic error δ_i) at the site "k" (the adjusted g-value of which is g_k) is described as

$$g_{ik} = g_k + \delta_i + \varepsilon_{ik}, \tag{3}$$

with the weighted constraint:

$$\sum_i w_i \delta_i = 0, \tag{4}$$

Where ε_{ik} is the random error. The outputs are the adjusted g-values g_k at all sites (representing Key Comparison Reference Values (KCRV)) and biases δi (numerically equal as Degree of Equivalence (DoE), in case all the measurements of i-th gravimeter were used for determination of KCRV, which is assumed to be constant during the comparison) for each instrument. This additional constraint condition allows us regularizing the ill-posed problem. Without it, there would be indeed an infinite number of solutions by adding the same constant at all the biases.

The final adjustment includes the data of all the gravimeters that participated in the Key Comparison. All the g-values are corrected for the observed geophysical gravity changes with the SG.

9.Results

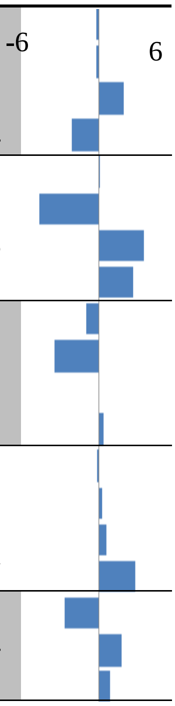
The official solution proposed in this report is based on the mathematical model described above. Here all the KC instrument measurements presented by the participants were used in the least-square adjustment with the weighted condition for absolute observations.

The g-values of the KC gravimeters are compared to the official KCRVs in Table 5. The differences between the gravimeters measurements and the corresponding official KCRVs are calculated along their uncertainties. Those are given by the square root of the sum of the square of the expanded uncertainty (k=2) of the g-value and of the official KCRV. In addition, we also calculated the compatibility index En defined by:

$$E_n = \frac{|x_i - x_j|}{\sqrt{U^2(x_i) + U^2(x_j)}} \tag{5}$$

In other words, this is the ratio between the difference of two estimated values and the expanded uncertainty (k=2) of the difference. The En factor lager than 1 indicates that the two values are incompatible as their difference cannot be covered by their uncertainties. It means that either one of the two values is corrupted or the declared uncertainties are too small. The distributions of 52 measurements from 13 KC gravimeters which are versus official KCRVs are listed in Table 6.

Table 6. Comparison between the gravimeter measurements from NMI/DIs and the official KCRVs. E_n is the compatibility index. The uncertainty U_D is combined of U_i and U_{site}, represents the expanded uncertainties at 95% confidence. The constant value 980 122 000.0 µGal is subtracted from the gravimeter g-value and official KCRVs.

Gravimeter	Site	g after all corrections /µGal	U_i (k=2) /µGal	KCRV /µGal	U_{site} (k=2)/ µGal	g-KCRV /µGal	U_D (k=2)/ µGal	E_n	g-KCRV plot/µGal
FG5-242	6	649.4	6.8	649.6	0.80	-0.2	6.9	0.1	
	7	641.7	6.8	641.9	0.70	-0.2	6.9	0.1	
	3	581.0	6.8	579.0	0.70	2.0	6.9	0.3	
	2	566.8	6.8	568.9	0.70	-2.1	6.9	0.4	
NIM-3A	2	569.0	6.2	568.9	0.70	0.1	6.3	0.1	
	5	576.4	6.2	581.1	0.80	-4.7	6.3	0.8	
	7	645.5	6.2	641.9	0.70	3.6	6.3	0.6	
	9	650.0	6.2	647.3	0.70	2.7	6.3	0.5	
FG5-215H	3	578.0	4.4	579.0	0.70	-1.0	4.5	0.3	
	4	572.1	4.4	575.6	0.70	-3.5	4.5	0.8	
	7	641.9	4.4	641.9	0.70	0.0	4.5	0.1	
	8	654.3	4.4	653.9	0.70	0.4	4.5	0.1	
FG5X-221	2	568.8	4.6	568.9	0.70	-0.1	4.7	0.1	
	4	575.9	4.6	575.6	0.70	0.3	4.7	0.1	
	7	642.5	4.6	641.9	0.70	0.6	4.7	0.2	
	9	650.2	4.6	647.3	0.70	2.9	4.7	0.7	
FG5-228	8	651.2	5.4	653.9	0.70	-2.7	5.5	0.5	
	9	649.1	5.4	647.3	0.70	1.8	5.5	0.4	
	7	642.8	5.4	641.9	0.70	0.9	5.5	0.2	

	1	576.3	5.4	575.1	0.70	1.2	5.5	0.3
FG5-213	1	573.3	6.4	575.1	0.70	-1.8	6.5	0.3
	6	648.1	6.4	649.6	0.80	-1.5	6.5	0.3
	8	655.0	6.4	653.9	0.70	1.1	6.5	0.2
	3	580.9	6.4	579.0	0.70	1.9	6.5	0.3
FG5X-216	3	577.9	4.8	579.0	0.70	-1.1	4.9	0.3
	4	578.1	4.8	575.6	0.70	2.5	4.9	0.6
	8	654.5	4.8	653.9	0.70	0.6	4.9	0.2
	9	648.6	4.8	647.3	0.70	1.3	4.9	0.3
FG5X-104	1	575.3	4.2	575.1	0.70	0.2	4.3	0.1
	3	576.4	4.2	579.0	0.70	-2.6	4.3	0.6
	5	581.5	4.2	581.1	0.80	0.4	4.3	0.2
	6	649.2	4.2	649.6	0.80	-0.4	4.3	0.1
FG5X-253	1	573.9	4.8	575.1	0.70	-1.2	4.9	0.3
	4	574.9	4.8	575.6	0.70	-0.7	4.9	0.2
	6	648.7	4.8	649.6	0.80	-0.9	4.9	0.2
	7	642.7	4.8	641.9	0.70	0.8	4.9	0.2
FG5X-209	9	651.7	7.8	647.3	0.70	4.4	7.9	0.6
	1	578.5	7.8	575.1	0.70	3.4	7.9	0.5
	3	583.6	7.8	579.0	0.70	4.6	7.9	0.6
	5	584.2	7.8	581.1	0.80	3.1	7.9	0.4
FG5X-248	5	580.1	4.6	581.1	0.80	-1.0	4.7	0.3
	2	569.1	4.6	568.9	0.70	0.2	4.7	0.1
	9	644.8	4.6	647.3	0.70	-2.5	4.7	0.6
	6	650.1	4.8	649.6	0.80	0.5	4.9	0.2
FG5X-254	1	572.5	4.8	575.1	0.70	-2.6	4.9	0.6
	2	564.8	4.8	568.9	0.70	-4.1	4.9	0.9
	4	573.9	4.8	575.6	0.70	-1.7	4.9	0.4
	6	647.2	4.8	649.6	0.80	-2.4	4.9	0.5
FG5-204	4	576.7	3.8	575.6	0.70	1.1	3.9	0.3
	9	647.7	4.2	647.3	0.70	0.4	4.3	0.2
	8	655.0	3.6	653.9	0.70	1.1	3.7	0.4
	2	571.0	3.6	568.9	0.70	2.1	3.7	0.6

We can conclude from Table 6 that the compatibility indexes En of 13 KC gravimeters measurements are all less than 1, showing compatibility at 95% confidence.

10. The Key Comparison Reference Value and Its Uncertainty

See in Table 5.

11. Degrees of Equivalence

The DoEs of 13 KC gravimeters are presented in Table 7 and Figure 1.

Table 7. The official DoEs of the gravimeters from the NMI/DIs corresponding to the KCRVs in Table 7. U_i represents the expanded uncertainties at 95% confidence. $U_i=2u_i$, where u_i represents the weighted root mean square of u_{ik} of each instrument.

Gravimeters	**DoE /µGal**	**U_i (k=2) /µGal**
FG5-242	-0.1	6.9
NIM-3A	0.4	6.3
FG5-215H	-1.0	4.5
FG5X-221	0.9	4.7
FG5-228	0.3	5.5

FG5-213	0.0	6.5
FG5X-216	0.9	4.9
FG5X-104	-0.6	4.3
FG5X-253	-0.5	4.9
FG5X-209	3.9	7.9
FG5X-248	-0.7	4.7
FG5X-254	-2.7	4.9
FG5-204	1.3	3.9

12.Summary and Conclusions

For the comparison of CCM.G-K2.2017,there were 13 absolute gravimeters were compared in accordance of the TP established and accepted by all the participants.

The proposed official KCRVs and DoEs have been estimated by a least-square adjustment with weighted condition of the g-values of the NMI/DI's gravimeters. The uncertainties are estimated and provided by the participants, taking into account of the uncertainties in transferring the g to the comparison reference height of 1.25 m.

In conclusion, the DoEs of the 13 KC gravimeters are between -2.7 μGal and +3.9 μGal with a RMS of 1.5 μGal. They are all in equivalence with declared uncertainties at 95% confidence.

13. Appendices

All the raw measurement datas are displayed in Table 8.

Table 8. List of all the raw AG measurements from 13 KC instruments corrected for all the known geophysical (tides, atmospheric pressure and polar motion) effects, vertical gravity gradient and instrumental effects (speed-of light correction, laser beam diffraction, self-attraction etc.). The constant value 980 122 000.0 µGal has been subtracted from the gravity measurements. u_{decl} is the uncertainty declared by the participants, u_{trans} is the transfer uncertainty from the measurement or the instrumental reference height to the comparison reference height of 1.25 m using final VGG coefficients and u_{ik} is the uncertainty of the g value measured by the "i"th gravimeter at the "k"th site including the contribution of the uncertainty in the vertical gravity gradient transfer. The SG corrections are given (all the observations are related to the time UTC at 00:00 on October 23, 2017 when the SG correction was chosen to be zero). k is the coverage factor. The data marked (a) at the upper right corner of measurement height are those a little far away from the instrumental reference height, so we use the VGGs from TP to re-calculate the g value to the instrumental reference height (FG5 and FG-5X fixed to 1.2 m and 1.27 m, respectively) and then transfer the g value to the comparison reference height 1.25 m using the VGGs updated in this paper (see Table 2).

Time(UTC)		**Instrument**	**Site**	**Measurement height /m**	***g* at measurement height /µGal**	**u_{decl}** (k=1) /µGal	**VGG from TP** /µGal/m	**Coefficients for final VGG**		***g* transfer to 1.25m** /µGal	**u_{trans}** /µGal	***g* at 1.25 m** /µGal	**u_{ik}** (k=1) /µGal	SG corrections /µGal	***g* after all corrections** /µGal
start	**end**							*b* µGal/m	*c* µGal/m²						
10-14-01:56	10-15-00:57	Austria FG5#242	6	1.21	659.9	3.4	-268.7	-275.57	7.49	-10.3	0.1	649.6	3.4	-0.2	649.4
10-15-08:32	10-16-01:32	Austria FG5#242	7	1.21	652.6	3.4	-264.5	-275.16	5.14	-10.5	0.2	642.1	3.4	-0.4	641.7
10-16-09:05	10-17-01:35	Austria FG5#242	3	1.21	591.7	3.4	-261.3	-271.49	4.43	-10.4	0.1	581.3	3.4	-0.3	581.0
10-17-03:58	10-17-22:54	Austria FG5#242	2	1.21	577.2	3.4	-260.9	-257.18	0.34	-10.3	0.1	566.9	3.4	-0.2	566.7
10-29-12:02	10-30-00:25	China NIM-3A	2	1.034	623.9	3.0	-260.9	-257.18	0.34	-55.4	0.6	568.5	3.1	0.5	569.0
10-18-12:02	10-19-00:39	China NIM-3A	5	1.034	634.0	3.0	-264.9	-261.22	-1.80	-57.4	0.6	576.6	3.1	-0.3	576.3
10-30-12:02	10-30-23:55	China NIM-3A	7	1.034	702.6	3.0	-264.5	-275.16	5.14	-56.9	0.7	645.7	3.1	-0.2	645.5
10-31-12:02	10-31-23:53	China NIM-3A	9	1.034	705.9	3.0	-264.2	-275.69	8.40	-55.4	0.6	650.5	3.1	-0.5	650.0
10-17-08:47	10-18-00:50	Czech FG5#215H	3	1.2248	584.8	2.2	-261.3	-271.49	4.43	-6.6	0.1	578.2	2.2	-0.2	578.0
10-18-06:56	10-19-00:50	Czech FG5#215H	4	1.2253	578.5	2.2	-254.6	-265.57	7.54	-6.1	0.1	572.4	2.2	-0.3	572.1
10-19-05:37	10-20-00:49	Czech FG5#215H	7	1.2251	648.8	2.2	-264.5	-275.16	5.14	-6.5	0.1	642.3	2.2	-0.4	641.9
10-20-05:25	10-21-00:39	Czech FG5#215H	8	1.2245	661.6	2.2	-265.5	-278.93	7.97	-6.6	0.1	655.0	2.2	-0.7	654.3
10-25-05:25	10-26-00:53	Finland FG5X#221	2	1.265	565.3	2.3	-260.9	-257.18	0.34	3.8	0.1	569.1	2.3	-0.3	568.8
10-26-05:30	10-27-00:38	Finland FG5X#221	4	1.267	571.9	2.3	-254.6	-265.57	7.54	4.2	0.1	576.1	2.3	-0.2	575.9
10-27-05:15	10-28-00:53	Finland FG5X#221	7	1.266	639.0	2.3	-264.5	-275.16	5.14	4.2	0.1	643.2	2.3	-0.7	642.5
10-28-02:20	10-29-00:58	Finland FG5X#221	9	1.268	646.0	2.3	-264.2	-275.69	8.40	4.6	0.1	650.6	2.3	-0.4	650.2

10-16-06:53 10-17-01:40	France FG5#228	8	1.296[a]	639.0	2.7	-265.5	-278.93	7.97	12.5	0.2	651.5	2.7	-0.3	651.2
10-17-07:46 10-18-01:03	France FG5#228	9	1.2955 [a]	636.8	2.7	-264.2	-275.69	8.40	12.5	0.1	649.3	2.7	-0.2	649.1
10-18-05:28 10-19-01:14	France FG5#228	7	1.296[a]	630.8	2.7	-264.5	-275.16	5.14	12.3	0.2	643.1	2.7	-0.3	642.8
10-19-04:06 10-20-01:53	France FG5#228	1	1.2955[a]	564.1	2.7	-267	-273.76	5.87	12.5	0.2	576.6	2.7	-0.4	576.2
10-16-08:10 10-17-01:15	Japan FG5#213	1	1.2093	584.1	3.2	-267.0	-273.76	5.87	-10.6	0.1	573.5	3.2	-0.3	573.2
10-17-09:00 10-18-01:00	Japan FG5#213	6	1.2088	658.9	3.2	-268.7	-275.57	7.49	-10.6	0.1	648.3	3.2	-0.2	648.1
10-18-03:56 10-19-00:56	Japan FG5#213	8	1.2087	666.0	3.2	-265.5	-278.93	7.97	-10.8	0.2	655.2	3.2	-0.3	654.9
10-19-05:30 10-20-01:00	Japan FG5#213	3	1.2077	592.3	3.2	-261.3	-271.49	4.43	-11.0	0.1	581.3	3.2	-0.4	580.9
10-18-03:00 10-19-00:30	Luxembourg FG5X#216	3	1.27	572.9	2.4	-261.3	-271.49	4.43	5.2	0.1	578.1	2.4	-0.3	577.8
10-15-05:40 10-16-01:30	Luxembourg FG5X#216	4	1.27	573.6	2.4	-254.6	-265.57	7.54	4.9	0.1	578.5	2.4	-0.4	578.1
10-17-05:30 10-18-00:40	Luxembourg FG5X#216	8	1.27	649.5	2.4	-265.5	-278.93	7.97	5.2	0.1	654.7	2.4	-0.2	654.5
10-16-07:45 10-17-01:00	Luxembourg FG5X#216	9	1.27	643.8	2.4	-264.2	-275.69	8.40	5.1	0.1	648.9	2.4	-0.3	648.6
10-26-06:10 10-27-00:40	Republic of Korea FG5X#104	1	1.3853 [a]	539.6	2.0	-267.0	-273.76	5.87	36.0	0.5	575.6	2.1	-0.2	575.4
10-27-01:50 10-28-00:50	Republic of Korea FG5X#104	3	1.3853 [a]	541.7	2.0	-261.3	-271.49	4.43	35.3	0.5	577.0	2.1	-0.6	576.4
10-28-01:40 10-29-00:10	Republic of Korea FG5X#104	5	1.3863 [a]	545.8	2.0	-264.9	-261.22	-1.80	36.1	0.5	581.9	2.1	-0.4	581.5
10-25-05:20 10-26-00:20	Republic of Korea FG5X#104	6	1.3843[a]	613.7	2.0	-268.7	-275.57	7.49	35.8	0.5	649.5	2.1	-0.3	649.2
10-29-01:40 10-30-08:10	Saudi Arabia FG5X#253	1	1.27	568.4	2.4	-267.0	-273.76	5.87	5.2	0.1	573.6	2.4	0.3	573.9
10-27-08:40 10-27-21:10	Saudi Arabia FG5X#253	4	1.27	570.7	2.4	-254.6	-265.57	7.54	4.9	0.1	575.6	2.4	-0.7	574.9
10-24-08:00 10-24-19:30	Saudi Arabia FG5X#253	6	1.27	643.9	2.4	-268.7	-275.57	7.49	5.1	0.1	649.1	2.4	-0.4	648.7
10-26-08:40 10-26-21:10	Saudi Arabia FG5X#253	7	1.27	637.7	2.4	-264.5	-275.16	5.14	5.2	0.1	642.9	2.4	-0.2	642.7
10-24-07:17 10-24-22:17	Switzerland FG5X#209	9	1.3 [a]	639.1	3.9	-264.2	-275.69	8.40	13.0	0.2	652.1	3.9	-0.4	651.7
10-25-05:27 10-25-22:32	Switzerland FG5X#209	1	1.3[a]	565.6	3.9	-267.0	-273.76	5.87	13.2	0.2	578.8	3.9	-0.4	578.4
10-26-05:44 10-26-23:10	Switzerland FG5X#209	3	1.3[a]	570.8	3.9	-261.3	-271.49	4.43	13.1	0.2	583.9	3.9	-0.2	583.7
10-27-01:30 10-27-22:02	Switzerland FG5X#209	5	1.3 [a]	571.5	3.9	-264.9	-261.22	-1.80	13.2	0.2	584.7	3.9	-0.6	584.1
10-25-09:00 10-26-00:00	Thailand FG5X#248	5	1.3[a]	567.2	2.3	-264.9	-261.22	-1.80	13.3	0.2	580.5	2.3	-0.3	580.2
10-26-09:00 10-27-00:00	Thailand FG5X#248	2	1.3[a]	556.4	2.3	-260.9	-257.18	0.34	12.9	0.2	569.3	2.3	-0.2	569.1
10-27-09:00 10-28-00:00	Thailand FG5X#248	9	1.3[a]	632.4	2.3	-264.2	-275.69	8.40	13.0	0.2	645.4	2.3	-0.7	644.7
10-28-07:00 10-29-00:00	Thailand FG5X#248	6	1.3 [a]	637.2	2.4	-268.7	-275.57	7.49	13.2	0.2	650.4	2.4	-0.4	650.0
10-18-09:46 10-19-00:32	Turkey FG5X#254	1	1.27	567.6	2.4	-267.0	-273.76	5.87	5.2	0.1	572.8	2.4	-0.3	572.5
10-22-04:33 10-22-22:19	Turkey FG5X#254	2	1.27	559.8	2.4	-260.9	-257.18	0.34	5.1	0.1	564.9	2.4	-0.1	564.8

10-19-06:46	10-20-00:32	Turkey FG5X#254	4	1.27	569.3	2.4	-254.6	-265.57	7.54	4.9	0.1	574.3	2.4	-0.4	573.9
10-27-05:56	10-27-23:28	Turkey FG5X#254	6	1.27	642.8	2.4	-268.7	-275.57	7.49	5.1	0.1	647.9	2.4	-0.7	647.2
10-24-07:30	10-24-22:45	USA FG5#204	4	1.2508[a]	576.5	1.9	-254.6	-265.57	7.54	0.6	0.0	577.1	1.9	-0.4	576.7
10-25-10:00	10-25-22:45	USA FG5#204	9	1.2532[a]	646.8	2.1	-264.2	-275.69	8.40	1.3	0.0	648.1	2.1	-0.3	647.8
10-26-07:30	10-27-00:45	USA FG5#204	8	1.2514 [a]	654.5	1.8	-265.5	-278.93	7.97	0.7	0.0	655.2	1.8	-0.2	655.0
10-28-02:45	10-28-22:45	USA FG5#204	2	1.2519[a]	570.7	1.8	-260.9	-257.18	0.34	0.7	0.0	571.4	1.8	-0.4	571.0

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