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version 1

Preamble

There is a growing demand for accurate and confident absolute gravity measurements. The technical basis for the determination of equivalence of metrological characteristics of absolute gravimeters is the system of the comparisons of their measurement results. The absolute gravimeters with the highest metrological characteristics determined in the comparisons become in some countries the primary measurement standards in gravimetry. The primary measurement standards in gravimetry can in principle provide the calibration of working absolute gravimeters through the comparison with the primary measurements standard. Currently the calibration service is not widely established over the world and tens of absolute gravimeters have to participate in the international comparisons organized by Consultative Committee of Mass and Related Quantities (CCM), CCM Working Group on Gravimetry, Joint Working Groups 1 and 2 of IAG Commission 2 "Gravity Field" to determine their metrological characteristics. The comparisons should be organized in such a way that the high requirements in gravity measurements in geosciences (e.g. Global Geodetic Observing System) and metrology (e.g. watt balance project) are fulfilled.

CCM and Regional Metrology Organizations (RMO) organize international Key Comparisons of the absolute gravimeters belonging to National Metrology Institutes and designated institutes (laboratories). Key Comparisons are organized according to the rules of CIPM Mutual Recognition Arrangement and usual practice is that CCM and RMO invite the absolute gravimeters which not belong to NMI or designated institutes to take part in the comparison. The CCM and RMO key comparisons of absolute gravimeters are organized in such a way that a large number of both designated (within the key comparison) and non-designated (within the pilot study) institutes are participating in so organized International Comparisons of Absolute Gravimeters. The presented list of site recommendations should be used as a guideline for preparation and selection of sites for hosting comparisons of absolute gravimeters.

Here then is the list of site recommendations that would help to address the concerns of the WGG. Some proposals may seem to cover the same subject matter but these items needed to be separated in order to describe in more detail specific aspects of the recommendations.

Site recommendations proposal

Proposals	Explanations and specifications	Priorities
(1) Stable electrical power	*Availability of stable electrical power supply (100/120/220/240 VAC; 50/60 Hz; grounding; at least 0.75 kVA per an absolute gravimeter). Voltage and frequency instabilities below 10% are required. Participants have to be informed about power system (voltage, frequency, sockets) at*	**1**

	comparison site. *Uninterruptible power supply (UPS) and voltage stabilizer are very helpful. If UPS is available, their capacity should be announced to comparison participants.*	**2**
(2) Seismically quiet site	*Seismically quiet site unaffected by excess noise. Large ground vibrations whether man-made or caused by e.g. ocean noise will normally introduce increased scatter in the observations and may cause aliasing effect in the measured gravity, thus creating greater uncertainties between instrumental results. The site should be quiet enough that a drop-to-drop scatter of 20 μgal or better can be achieved by a state-of-the-art absolute gravimeter in a good working condition.* *A spectrum of the noise level at comparison site could give useful information.* *It is recommended to use a relative gravimeter or a broadband seismometer to monitor the site conditions during comparisons. This should help participants identify seismic disturbances during measurements.*	**1** **3** **2 - 3**
(3) Location sufficiently removed from large hydrological variation	*Large variability in storage of surface water (lakes, rivers) or of subsurface water (soil moisture, groundwater) close to the site may increase the variability of gravity at the site. For example, if the area close to the pier has an effective porosity of 40%, a +0.05 m water table change due to rainfall may generate a* $8 \cdot 10^{-9}$ *m/s*^{2} *increase in gravity simply through direct attraction. Therefore, sites with large hydrological effects should be avoided and gravity variation during a comparison monitored, see issue (8).*	**2**
(4) Adequate number of stations and sufficient space for instruments	*Concrete pier(s) or basement with sufficient space for simultaneous operation of <u>3 or more</u> instruments is adequate to achieve appropriate results from comparisons.* <u>Explanation</u>: Increasing the number of stations with a fixed number of instruments decreases accuracy and reliability of the final results. On the other hand, in case of 3 stations only, the comparison may take even two months and increases the importance of using superconducting gravimeter for monitoring/applying gravity variations (see, issue (8)). It has been shown in ICAG-2009, that in case of a large number of participants (21) and three measurements for a particular gravimeter, an optimal comparison (redundancy vs. time consumption) can be achieved by using 5 stations. <u>Specifications concerning sufficient space for gravimeters</u>: As an example, an FG5 instrument has a stated “footprint” of about	**1**

	3 m^2. However, space is also needed to work around the instrument As a first estimate, each instrument should have an available total space of 5 m^2 including the pier. More space is required for cold-atom gravimeters. The laboratory should be able to provide a special access for this type of instrument.	
(5) Stable concrete pier(s)	*Instrument pier(s) preferably should be connected to competent bedrock. If bedrock is available, a good method usually is to have single-instrument piers for the sensor only, which minimizes the noise on the pier (electronic racks can be installed on the adjoining floor). For most commercial instruments a 1.1 m x 1.1 m pier is sufficient* *However, in sediments a large multi-instrument pier may be more advantageous than several smaller piers since a large pier will have more mass and will potentially minimize instrumental systematic effects due to self-induced vibrations. A larger square pier of 12 m^2 or more would be able to accommodate 4 or 5 instruments.* *The pier surface needs to be sufficiently smooth.*	**1**
	The pier should be flush with the floor or only a few centimeters above it.	**2**
	Materials used to build the pier(s) should not contain magnetic reinforcement bars (rebars). Non-metallic rebars or weakly magnetic stainless steel are suggested. <u>Explanation</u>: It is possible that a magnetic field would offset the wavelengths of lasers (it should not be a problem for an iodine-stabilized laser) if they are located close to the pillar surface. An example of such an instrument is the A-10 with its polarization-stabilized laser located at the bottom of the gravimeter. In addition, some relative gravimeters are susceptible to strong magnetic fields such as the LaCoste&Romberg. Moreover, falling test masses of absolute gravimeters can be sensitive on magnetic field gradient. It is especially important when a test mass is produced from magnetic materials and falls very close to a pier containing metallic rebars.	**2**
	Tilts are of concern: tests should be performed to see if piers are prone to tilts. Especially in the case if the piers are on an unconsolidated soil.	**2**
(6) Ability to host a large number of participants	*The organizer of the comparison should be able to host a large number of participating gravimeters. Note, in case of a three-pier site, the comparison may take more than one month.* *The organizer should then limit the number of participants for this technical reason only when the number exceeds 20. However, it is recommended to let comparisons open for as*	**1**

	wide community as possible. *A prolonged comparison may be significantly affected by gravity variations at the site. This point should be fixed according to the issue (8).*	
(7) Observed tidal parameters	*Tidal parameters should be determined on the base of at least half-yearly continuous record of a well calibrated tidal gravimeter. It should provide accurate tidal corrections for absolute gravity measurements.*	**1**
(8) Monitoring of the gravity variations	*Continuous gravity record before, during and after the comparison should be done to monitor gravity variations (mainly due to hydrological influences). It should be done with a superconducting gravimeter or a precise absolute gravimeter.*	**1**
	In case it is necessary to apply corrections (e.g. due to long duration of the comparison or significant influence of the local hydrology), a superconducting gravimeter (SG) is recommended to use. Only an SG with a drift-free signal enables corrections for environmental effects with a precision of 0.1 μGal. This approach was efficiently used in comparisons in Wettzell (2010) and Walferdange (2011). The SG drift should have been estimated using repeated absolute measurements with accuracy below 1 μGal/year.	**1-2**
(9) Accurate time	*An UTC clock with 1 s accuracy is needed to ensure that all instruments operate on the same time reference. A 5 s error on the time of the computer used to operate an AG causes an error (due to tidal corrections) below 0.1 μGal.*	**3**
(10) Accurate positions	*Each point comprised in the comparison site needs to be accurately indicated.*	**1**
	Each measurement site should have a surveyed reference marker and it should be clear that instrument heights are referred to the upper surface of the marker at a designated point. The site designation should be engraved on the marker and survey data should be available to link its position to that of other local sites and to give its position in global coordinates (accuracy at the level of 0.01 deg is sufficient).	**1**
	Orthometric or normal (not ellipsoidal) height at measurement site should be known at the 1-2 m accuracy level for the calculation of normal air pressure.	**1**
	To ensure the long-term monitoring of stability of a	**2**

	comparison site, it is recommended to provide connection to the reference systems of the country or to the next GPS reference station.	
(11) Adequate weather monitoring facilities to measure air pressure and other parameters such as ground water, precipitation, etc.	*Continuous air pressure monitoring is needed in order to provide barometric pressure corrections. The monitoring barometer should be calibrated with uncertainty below 1 hPa. A common source of information would be advantageous to all participants.* *Other parameters such as ground water levels or soil moisture monitoring can be helpful in context of monitoring gravity variations (see issue (8) above).*	**3** **3**
(12) Clock frequency and laser wavelength verification facilities	*The two principal references (length and time) of absolute gravimeters should be calibrated or verified. It is appreciated if the pilot lab can provide verification facilities during a comparison.*	**3**
(13) Stable environmental parameters such as temperature (and humidity if possible)	*Stable environmental conditions help to reduce external effects on the gravity observations. Stable temperatures and humidity are especially required for cold-atom gravimeters. An average temperature of 21°C is the norm. Also, relative humidity above 80% needs to be avoided due to possible electronic and optic problems. At the very least, the gravimeters should be maintained within the instrument specifications.* *A temperature is recommended to be 18 and 21 ^{o}C ± 2 ^{o}C.*	**2**
(14) Determining vertical and horizontal gravity differences	*Relative gravimeters and rigid multi-level tripods are necessary to determine:* *- gravity differences along the vertical for all the stations used in the comparison. It should allow to: 1) determine transfer corrections from the reference instrumental heights (0.5-1.3 m) to the reference level of the comparison with an uncertainty below 1 μGal, 2) determine the gravity differences along the drop trajectory of the instruments for the equation of motion in the processing by the participants* *- horizontal gravity differences at the reference level of the comparison for a possibility to use combined (AG+RG) solution in the least squares adjustment* Explanation: In order to determine relative gravity ties, very sensitive relative gravimeters are needed for this purpose. Three or more instruments are necessary to perform these observations as the systematic errors of these gravimeters are in the order of the absolute gravimeter sensitivities. Tripods or elevated platforms similar to the devices used at the last	 **1** **2**

	ICAG (2009) can be used as appropriate multi-level tripods. Uneven topography such as cliffs, large ground cavities, etc., will usually create inhomogeneities in the VGG, thus increasing the necessity to use more levels of measurements and describing gravity variations along the vertical using higher order polynomials.	
(15) General considerations	*Secure site* *Facilities for moving instruments* *- trolleys / dollies* *- elevators if stairs are unavoidable* *Infrastructure* *- site documentation* *- storage and preparation room for five AGs* *- internet facilities* *- assistance with customs clearance* *Availability of suitable turbo pump, tools, spares, plug adapters* *Facilities for the participants*	**1** **1** **1** **3** **2**
(16) Ease of access to major highways and/or airports	*Maps and driving Instructions* *List of accommodations*	**3**

Priorities

[**1**] Essential
[**2**] Desirable
[**3**] Useful