Report of the CCM Working Group on Gravimetry (CCM-WGG)

Alessandro Germak (INRiM)
17th CCM meeting, 16 May 2019
Proposed changes to membership

No new member proposal

Actual members (22):

14 NMIs

3 DIs

4 personal

1 International

- BEV (Bundesamt für Eich- und Vermessungswesen)
- BGI (Bureau Gravimetric International)
- BIPM (Bureau International des Poids et Mesures)
- FGI (Finnish Geospatial Research Institute)
- INRIM (Istituto Nazionale di Ricerca Metrologica)
- KRISS (Korea Research Institute of Standards and Science)
- LGUL (Faculté des Sciences, de la Technologie et de la Communication)
- LNE-SYRTE (Observatoire de Paris/Systèmes de Référence Temps-Espace)
- METAS (Federal Institute of Metrology METAS)
- NIM (National Institute of Metrology)
- NIST (National Institute of Standards and Technology, United States Department of Commerce)
- NMIJ/AIST (National Metrology Institute of Japan, AIST)
- NPL (National Physical Laboratory)
- NRC (National Research Council of Canada)
- SASO-NMCC (Saudi Organization for Standardization, Metrology and Quality)
- UME (National Metrology Institute of Turkey)
- VNIIM (D.I. Mendeleyev Institute for Metrology)
- VUGTK (Research Institute of Geodesy, Topography and Cartography)
- Dr Reinhard Falk
- Prof. James Faller
- Prof. Dr Jan Krynski
- Dr Michel Van Camp
- RMO Technical Committee chairs in the field of Mass and Related Quantities or their representatives
Proposed changes to membership

- Proposed change in chairmanship:
  - **Chair:** Dr. WU Shuqing (NIM, China)
  - **Vice chair:** Dr. Vojtech Pálinkás (VUGTK, Czech Republic)
WG Meetings held since last CCM

- 13th may, 2019
  - BIPM
  - Sèvres, France

21 Participants (16 members, 5 invited/observers)
WG Meetings planned

- Next WGG meeting on 2021 in coincidence of IAG general assembly and meetings in Vienna (hosted by BEV)
Main actions taken and main achievements

- Organization and promotion of:
  - Key Comparisons (CCM and regionals)
  - CMCs submissions
  - Metrological issues
  - Liasons with geodetic/geophysicist community:
Main actions taken and main achievements

- **Different CMCs:**
  - **Absolute measurement** (on stable site)
  - **Calibration of AG:**
    - By direct comparison with other AG
    - By comparison with a reference station

"CCM – IAG Strategy for Metrology in Absolute Gravimetry": Scheme of the traceability chain

www.bipm.org
Main actions taken and main achievements

- **New CMCs:**
  - **NSC Ukraina**, (June 2017)

- **In progress:**
  - **VÚGTK, Czech Republic:** submitted for both absolute measurements and *calibration of absolute gravimeter* (first CMC submitted in this field): approved by EURAMET on Feb. 2019 and now under evaluation from the other RMOs
  - **CENAM, Mexico:** finished the preparation process (peer review and participation to a KC) for the CMC presentation and now they are under submission
  - **NIM, China:** under evaluation for both (measurement and calibration)
  - **NIMT, Thailand:** under evaluation (peer review on Feb. 2020)
Progressing the state of the art

- Better understanding on uncertainty in measurement (possible systematic errors on comparisons of FG5 type dominant AGs). *Agreed expanded uncertainty (95% confidence level) of FG5 type AGs: about $4.5 \times 10^{-8} \text{ m/s}^2$*

- Giving better possibilities in traceability for measurements (implementing all possible traceability paths described in the document «CCM – IAG Strategy for Metrology in Absolute Gravimetry”)

- Supporting emerging technologies of AGs (quantum...)

Progressing the state of the art

**Influence parameters:**

<table>
<thead>
<tr>
<th>Instrumental uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drag effect (residual gas)</td>
</tr>
<tr>
<td>Outgassing effect</td>
</tr>
<tr>
<td>Non-uniform magnetic field effect</td>
</tr>
<tr>
<td>Temperature gradient effect</td>
</tr>
<tr>
<td>Effect for electrostatics</td>
</tr>
<tr>
<td>Mass distribution effect (attraction of apparatus)</td>
</tr>
<tr>
<td>Laser beam verticality correction (glass wedges)</td>
</tr>
<tr>
<td>Trajectory verticality</td>
</tr>
<tr>
<td>Air gap modulation effect</td>
</tr>
<tr>
<td>Laser accuracy effect (distance measurement)</td>
</tr>
<tr>
<td>&quot;Beat-mode&quot; (inter-mode laser leak effects)</td>
</tr>
<tr>
<td>Index of refraction effect</td>
</tr>
<tr>
<td>Beam divergence correction (laser beam diameter, diffraction corr.)</td>
</tr>
<tr>
<td>Beam share effect</td>
</tr>
<tr>
<td>Clock effect (frequency standard)</td>
</tr>
<tr>
<td>Fringes timing effect (electronic phase shift, time interval asymmetry)</td>
</tr>
<tr>
<td>Finite value of speed of light effect</td>
</tr>
<tr>
<td>Retroreflector balancing (trihedron or test mass rotation)</td>
</tr>
<tr>
<td>Radiation pressure effect</td>
</tr>
<tr>
<td>Vertical gravity gradient</td>
</tr>
<tr>
<td>Data processing (start fringe and number of processed fringes)</td>
</tr>
<tr>
<td>Set up</td>
</tr>
<tr>
<td>Reference height (height measurement from a benchmark, effective height determination)</td>
</tr>
<tr>
<td>Air pressure measurement (air pressure correction - pressure sensor)</td>
</tr>
<tr>
<td>Seismic shocks</td>
</tr>
<tr>
<td>Reproducibility</td>
</tr>
<tr>
<td>Others</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Site-dependent uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coriolis effect</td>
</tr>
<tr>
<td>Floor recoil effect</td>
</tr>
<tr>
<td>Barometric pressure effect (diff. pressure, atmospheric attraction and loading correction, admittance factor)</td>
</tr>
<tr>
<td>Earth tides correction</td>
</tr>
<tr>
<td>Ocean loading correction</td>
</tr>
<tr>
<td>Polar motion correction</td>
</tr>
</tbody>
</table>
Liaison & stakeholders

- NMIs: for supporting their CMCs and for the new realization of the kilogram
- Liaisons with geodetic/geophysicist community:
  - IAG SC2.1 Gravimetry and Gravity Networks:
    - SG 2.1.1: Techniques and metrology in terrestrial (land, marine, airborne) gravimetry
    - JWG 2.1.1: Establishment of a global absolute gravity reference system
    - JWG 2.1.2: Unified file formats and processing software for high-precision gravimetry
KCs completed and underway

Key Comparisons:

- **SIM.M.G-K1, Pilot lab: NIST-USA, Oct. 2016, Approved for equivalence, Results available**
- **COOMET.M.G-S1, Pilot lab: NSC, Ukraine, Jan. 2016, Approved and published**
KC comparisons completed and underway

- **Key Comparisons:**
  
  **CCM.G-K2.2017**
  
  *Site*: Changping Campus of NIM, China
  
  *Pilot Lab*: NIM, China
  
  *Date*: Oct. to Nov. 2017
  
  **30 absolute gravimeters** (AGs):
  
  13 KC and 17 PS instruments
  
  (4+2 quantum/atomic gravimeters)
  
  **Draft B** circulated
KCs completed and underway

- **Key Comparisons:**
  - **CCM.G-K2.2017**
    - **Site:** Changping Campus of NIM, China
    - **Pilot Lab:** NIM, China
    - **Date:** Oct. to Nov. 2017
    - 30 absolute gravimeters (AGs):
      - **13 KC** and **17 PS** instruments
      - (4+2 quantum/atomic gravimeters)
    - **Draft B** circulated
**KCs completed and underway**

- **Key Comparisons:**
  - **CCM.G-K2.2017**
  - *Site:* Changping Campus of NIM, China
  - *Pilot Lab:* NIM, China
  - *Date:* Oct. to Nov. 2017
  - 30 absolute gravimeters (AGs):
    - **13 KC** and **17 PS** instruments
    - **(4+2 quantum/atomic gravimeters)**
  - *Draft B* circulated
KCs completed and underway

- **Key Comparisons:**
  
  **EURAMET.M.G-K3**
  
  *Site:* Geodetic Observatory Wettzell (GOW), BKG Bad Kötzting, Germany
  
  *Pilot Lab:* VÚGTK – Czech Rep.
  
  *Date:* Apr. to June 2018

  **16 absolute gravimeters (AGs):**
  
  5 KC and 11 PS instruments

  **Draft A circulated**
KCs completed and underway

- **Key Comparisons:**
  - **SIM.M.G-K1**
  - *Site:* Table Mountain Geophysical Observatory (TMGO)
    - Boulder, Colorado
  - *Pilot lab:* NIST-Gaithersburg
  - *Date:* Oct. 2016
  - **12 absolute gravimeters (AGs):**
    - 4 KC and 8 PS instruments
  - **Approved for equivalence,**
    - **Results available (2017)**
KCs completed and underway

- **Key Comparisons:**
  
  **SIM.M.G-K1**

  *Site:* Table Mountain Geophysical Observatory (TMGO)  
  Boulder, Colorado

  *Pilot lab:* NIST-Gaithersburg

  *Date:* Oct. 2016

  12 absolute gravimeters (AGs):

  - 4 **KC** and 8 PS instruments

  *Approved for equivalence, Results available (2017)*
KCs completed and underway

- **Key Comparisons:**
  
  **SIM.M.G-K1**

  **Site:** Table Mountain Geophysical Observatory (TMGO)  
  Boulder, Colorado

  **Pilot lab:** NIST-Gaithersburg

  **Date:** Oct. 2016

  12 absolute gravimeters (AGs):
  
  4 **KC** and 8 **PS** instruments

  **Approved for equivalence,**
  **Results available (2017)**
KCs completed and underway

- **Key Comparisons:**
  
  **COOMET.M.G-S1**
  
  *Site:* INRiM, Torino, Italy
  
  Pilot lab: NSC, Ukraine
  
  *Date:* Jan. 2016
  
  2 absolute gravimeters (AGs):
  
  Approved and published (2017)
  
  Agreement between the two participants
KCs planned

- Next CCM-KC in 2023
- Possible next RMO KC immediately after the CCM-KC
Program of work for the next 5 years

- Definition of the features of **reference sites**, improving the quality and the numbers in any Region
- Organization of technical **Seminar/Workshop** (in coincidence of WGG meetings)
- Improvement of **CMCs**
- Organization of **Key Comparisons** with periodicity of six years (next on 2023)
- Support the Global Absolute Gravity Reference System and the International Gravity Reference Frame - **IGRF** (Resolution No. 2 of the IAG at the XXVI General Assembly of the IUGG in 2015). The achieved uncertainty for measurement at reference stations should be better than 10 µGal, including systematic effects.
Thank you for your attention

a.germak@inrim.it