The International Gravity Reference System

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The International Gravity Standardization Net 1971

Adopted 1971, XXV. IUGG General Assembly (Moscow)

- Based upon the first 4 free fall absolute gravimeter measurements
- Relative measurements by spring gravimeters and pendulums

Objective: Worldwide reference (datum & scale) – Accuracy: ± 0.1 mGal

IGSN71 is still the official gravity reference

Morelli, IAG Bulletin n°4, Paris, 1971
Limited number of AG stations (<10)
Airborne and shipborne connections with relative meters
Network adjusted globally
Subject to densifications in all continents for decades
Diversity & Accuracy of gravity meters

Absolute gravity meters (corner cube, cold-atoms) → few µGal level

AG : independent measurements (no network adjustment required)

Super-conducting gravity meters → nGal level

Enables field AG surveys (10 µGal or better)
IAG Resolution N°2 (2015)

Establishment of a global absolute reference system

Key points

- **IGSN71 no longer fulfills the requirements and accuracy** for the understanding of the Earth’s System, metrology…
- **Measurement accuracy have improved** from the 100 µGal to « few µGal » level
- **Needs for consistent standards & conventions** of geometric and gravimetric observations (GGOS framework)

- Network of globally distributed stations where precise gravity reference is available at any time
- Link to ITRS
- Initiate the replacement of IGSN71 and IAGBN

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Definitions of System and Frame

Reference System

The fundamental principles

The definition of gravity must be stable over time

- Instantaneous acceleration of free fall traceable to the International System of Units (SI)
- Set of conventional corrections for the time independent components of gravity effects
  - Permanent tide (zero tide system)
  - Standard atmosphere (~ height)
  - Earth rotation axis IERS reference pole

Reference Frame

The realization of the system

Numbers actually obtained (subject to model improvements or updated requirements)

- Observations with absolute gravimeters (epoch, gravity, gravity as a function of height, ref. height)
- Comparisons of absolute gravimeters Common level, traceability, compatibility of the observations and processing, assessment of systematic effects
- Set of conventional models for correction of temporal changes (tides, ocean loading, atmosphere, polar motion)
- Compatible infrastructure (markers, points) and documentation (database)
Update of the IAGBN Processing Standards


- **Tides:**
  Zero-tide system for the permanent tide and Tide generating potential: Tamura (or higher development); Elastic response: Observed tidal parameters or Earth model of Dehant, Defraigne and Wahr (1999) (DDW)

- **Atmosphere:**
  Standard Atmosphere: DIN 5450 (ISO 2533:1975), Temporal variations: Single admittance of 0.3 µGal/hPa

- **Polar motion:**
  IERS reference pole with elastic gravimetric factor 1.164

- **Ocean tide loading:**
  FES2004 or best fitting model

- **Gravity as a function of height:**
  Linear approximation, measurement at 3 levels, Evaluation of equation of motion at effective height

Legend: fixed | improved | system | frame
Definition/Concept for a stable AG Reference

Gravity reference stations
- with continuous comparison reference function monitored by SG, QG or repeated AG

Absolute Gravimeters

Intercomparisons
- CCM-KC, RMO-KC Geodetic Comparisons with linked CRF

Standard correction models
Tides, Atmosphere, Polar Motion

Central Inventory (Database)
Long lasting cooperation between metrology and geosciences in Absolute Gravimetry (>30 years) between

- **BIPM**: Consultative Committee for Mass and Related Quantities (CCM)
- **IAG Commission 2 & IGFS (BGI, IGETS)**
  
  ✓ **Traceability to International System of Units (SI)**
  
  ✓ **International Keys Comparisons**
  (subset of AG)
  
  ✓ **Regional and Additional Comparisons**
  (to document agreement between different AG)

**Update 2014 (Strategy paper)**

Urs Marti, President of the International Association of Geodesy (IAG) Commission 2 «Gravity Field»
Philippe Richard, President of the Consultative Committee for Mass and Related Quantities (CCM)
Alessandro Germak, Chairman of the CCM working group on gravimetry (WGG)
Leonid Vitushkin, President of IAG SC 2.1
Vojtech Palinkas, Chairman of IAG JWG 2.1
Herbert Wilmes, Chairman of IAG JWG 2.2

11 March 2014

**CCM – IAG Strategy for Metrology in Absolute Gravimetry**
Role of CCM and IAG

and Travaux of IAG 2011 - 2015
Long term stability and traceability of Absolute Gravimeters

Comparisons of Absolute Gravimeters at different levels

CIPM Level
CCM.G-K2.2017
Key Comparison (KC) and Pilot Study (PS)
Beijing, China

RMO linked to CIPM by means of common participants:
Stability of mean absolute level!

RMO North America 2016
SIM.M.G-K1 KC and PS
Table Mountain, Boulder, CO, USA

RMO Europe 2018
EURAMET.M.G-K3 KC and PS
Wettzell, Germany
Gravimetric Reference and Comparison Station
Geodetic Observatory Wettzell
2018 EURAMET.M.G-K3 Key Comparison and Pilot Study of Absolute Gravimeters

- Regional Key Comparison and Pilot Study
- Organized by BKG and the pilot laboratory VÚGTK/RIGTC, Czech Republic at Geodetic Observatory Wettzell (V. Pálinkáš)
- 16 instruments from 12 countries including 5 instruments for KC
- 5 observation sessions between April 16th and June 15th 2018

Objectives:

- Validation of the Calibration and Measurement Capabilities (CMCs) published in the Key Comparison Database (KCDB)
- Link of European gravimeters to CCM.G-K2.2017, Changping, China
**2018 EURAMET.M.G-K3 Key Comparison and Pilot Study of Absolute Gravimeters**

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**Falk et. al:** The 2018 EURAMET.M.G-K3 Key Comparison and Pilot Study of Absolute Gravimeters in Wettzell, Germany. Poster presentation at 27th IUGG General Assembly, 8-18 July 2019, Montréal
AGGO
Argentine-German Geodetic Observatory

- Development of AGGO to a Gravimetric Reference Station for South America
- Gravimeter lab (5.3 x 7m) with 4 piers with 1.10 m side length, usable for all FG5
- Superconducting Gravimeter SG038: since Dec 2015
- Absolute gravimeter FG5-227: since Jan 2018

Residual Signal SG after drift correction
Combination of SG and AG observations
Example: AGGO

Central Inventory: AGrav database

www.agrav.bkg.bund.de

Operational since 2008
- Operated by BKG and BGI
- Increasing number of contributors
- DOI (Digital Object Identifiers)

Upgrade planned in 2019 (ex of new features)
- Time series plots in common reference height
- Documentation of comparison results
- Overview about IGETS observations

+ Joint collaboration with new IAG JWG 2.1.2
Unified file formats and processing software for high-precision gravimetry”
(Chair: Ilya Oshchepkov, Russia)
Present Status: AG observations (AGrav Database)

Over 1200 stations
- AG field measurements
- AG lab. & ref. measurements

Essential contribution from national agencies & AG contributors
Resolution 4: Establishment of the Infrastructure for the International Gravity Reference Frame

The International Association of Geodesy,

Considering,

- The IAG Resolution No. 2 for the establishment of a global absolute gravity reference system released at the 26th IUGG General Assembly in July 2015;

Acknowledging,

- The achievements of
  - JWG 2.1.1 “Establishment of a global absolute gravity reference system”,
  - Sub-Commission 2.1 “Gravimetry and Gravity Networks”,
  - International Gravity Field Service (IGFS)
- in realizing this resolution;

Noting,

- That the realization of the International Gravity Reference System (IGRS), the International Gravity Reference Frame (IGRF), is based on measurements with absolute gravimeters (AG) monitored at reference stations and during international comparisons, which needs the support of national and international institutions;

Urges,

- International and national institutions, agencies and governmental bodies in charge of geodetic infrastructure to
  - Establish a set of absolute gravity reference stations on the national level,
  - Perform regular absolute gravity observations at these stations,
  - Participate in comparisons of absolute gravimeters to ensure their compatibility,
  - Make the results available open access.
Potential Reference stations

Reference Station according to IGRS
- Continuous reference function by SG (relative) or Quantum gravimeter (absolute)
- Regular AG measurements (rep. rate: two years, less than two month (w/, w/o SG resp.))

Co-Location with other global reference networks
- Global Geodetic Observing System (GGOS)
- International Height Reference Frame
- IAG Joint Working Group 0.1.2.
- International Geodynamics and Earth Tides Service (IGETS)
National gravimetric networks
Argentina

Red Argentina de Gravedad Absoluta (RAGA)
- Collaboration between IGN, UNR, São Paulo University, IRD, UNSJ, UNLP
- Observations by A10#14, A10#32 in 2013 and 2014
National gravimetric networks
Brazil, Venezuela, Equador

Summary

- Transition from 100µGal range of IGSN71 to a new international gravity reference system/frame (IGRS/IGRF) in the few µGal range started

- System defined as *instantaneous acceleration of free fall* based on SI and a *set of constant corrections*

- Frame defined by observations with *validated absolute meters* and a set of models to correct for temporal gravity changes

- *Gravity reference stations* for quality assessment of absolute meters,

- *Comparisons of absolute meters* essential part of the concept, link to metrology,

- Link to GGOS, IGETS and IHRF,

- Update of *models for correcting temporal gravity variations*,

- *AGgrav database* as a central archive for absolute gravity observations (both, reference and infrastructure level) and comparison results, including referencing datasets with DOI

- New IGRS/IGRF will provide absolute, metrologically secured, homogeneous gravity values with on the accuracy level of (2..3)*10^-9, which also allows to document gravity changes with time