Proposal for an IAG resolution on the International Terrestrial Gravity Reference System

Webmeeting of IAG Joint Working Group 2.1.1

Chair: **Hartmut Wziontek**, BKG (Germany)
Vice-chair: Sylvain Bonvalot, BGI (France)

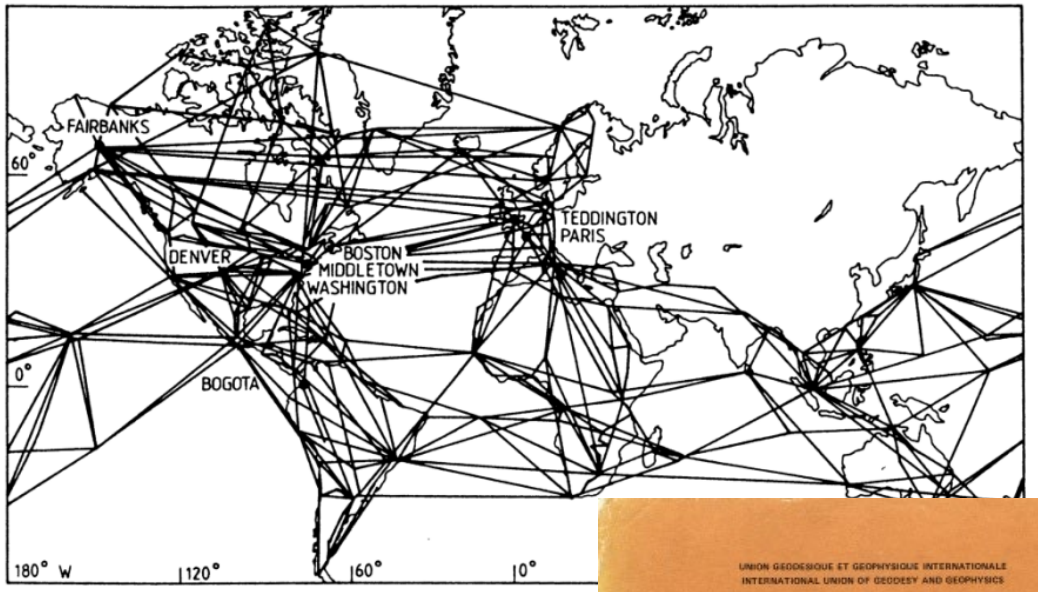
Gravity Reference System of IAG

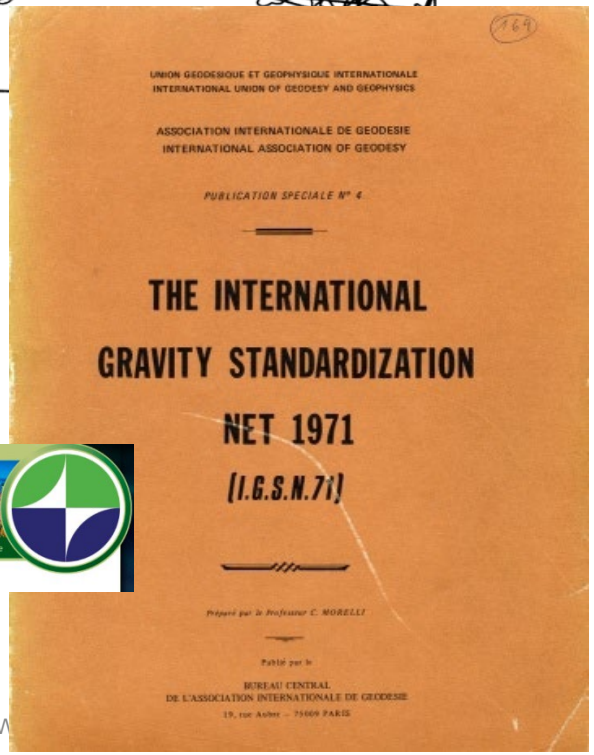
IGSN71 still official gravity reference system of IAG

- Accuracy of a single station:
  ±1 µm/s² (±100 µGal)
- Today, absolute gravity is observed at the µGal level

→ *IGSN71 doesn't fulfil todays requirements*

- **2015: IAG Resolution No. 2** for the establishment of a global absolute gravity reference system
- IAG Sub-Commission 2.1:
  JWG 2.1.1: Establishment of the International Gravity Reference Frame
- **2019: IAG Resolution No. 4**: Establishment of the Infrastructure for the International Gravity Reference Frame
- **2023**: IAG Resolution on the International *Terrestrial* Gravity Reference **System**





International *Terrestria*l Gravity Reference System and Frame (ITGRS / ITGRF)

Reference System:

The fundamental principles

Stable definition of gravity

- Measurand: **Instantaneous acceleration of free-fall**, expressed in the International System of Units (SI)
- Set of conventional models for the time dependent corrections, comprising **constant components**:
  - Zero-tide system for the tidal correction
  - Standard atmosphere ISO 2533:1975 (DIN 5450) for the correction for atmospheric gravity effects
  - Reference pole of the International Earth Rotation and Reference Systems Service (IERS) for the correction for polar motion.

→ **Conventional quantity „acceleration of gravity"**

Reference Frame:

The realization of the system

Compatibility of gravity measurements

The realization of the ITGRS, subject to model improvements or updated requirements and represented by

- **Absolute gravity measurements** traceable to the International System of Units (SI) (time and frequency)
- **Common reference level** and traceability to the SI: Absolute Gravimeters have to be checked at comparisons / by calibration
- Models for temporal gravity corrections: **IGRS 2020 Conventions**
- **Global set of reference stations** with reliable absolute gravity values (**relative accuracy of 10^{-8} and better**) and monitoring capabilities for temporal changes

Establishment of ITGRF infrastructure

IAG Resolution No. 4 of 2019

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.

27th IUGG General Assembly – Assemblée Générale de l'UGGI IUGG UGGI

July 8 – 18 2019, Montréal, Canada

- ITGRF is realized by measurements with absolute gravimeters at any time
- To make the ITGRF accessible to stakeholders and to finally replace IGSN71, an adequate infrastructure based on absolute gravity measurements needs to be built up.
- Support of international and national institutions, agencies and governmental bodies in charge of geodetic infrastructure is required to
  - ➢ Establish compatible first order gravity networks
  - ➢ Provide information about existing absolute gravity observations
  - ➢ Participate in AG comparisons

Proposal of an IAG resolution 2023 (a)

Reference System:

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→ **Conventional quantity „acceleration of gravity"**

IAG adopts,

- the ITGRS as the preferred gravity system based on the instantaneous acceleration of free-fall, expressed in SI and related to the zero-tide system, the reference atmosphere and the reference terrestrial pole.

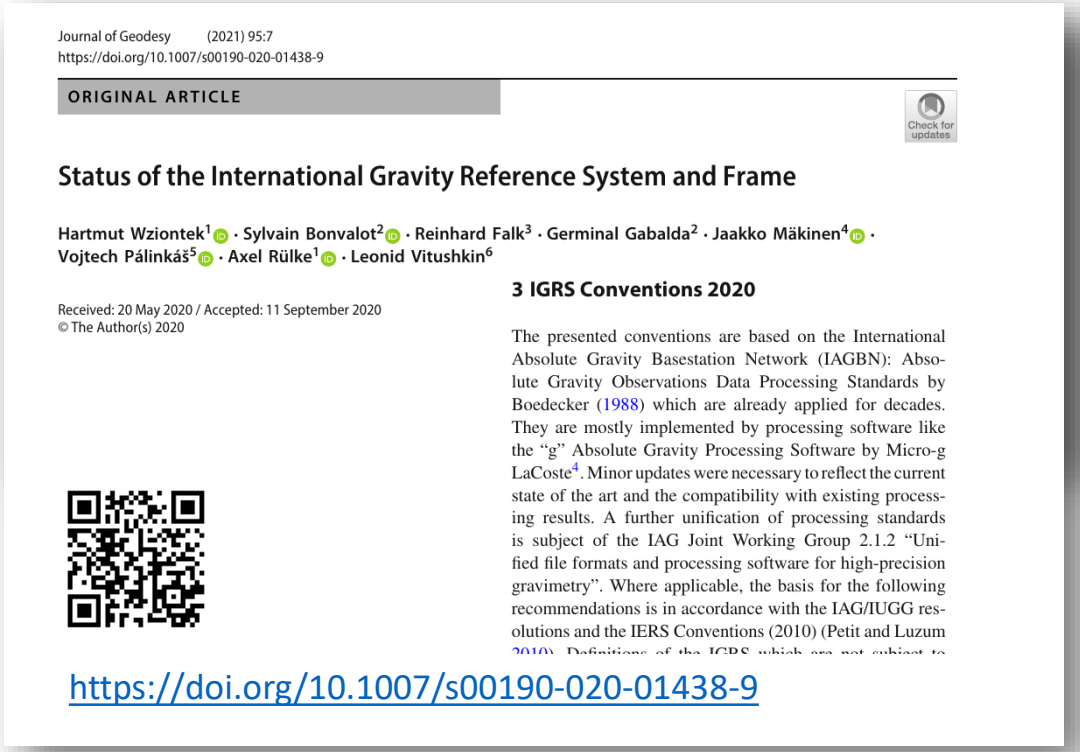
IGRS Conventions 2020 (1)

Conventional models (minimum requirements) for the correction of temporal gravity changes

Based on and compatible with International Absolute Gravimeter Base Network (IAGBN) Processing Standards, Boedecker (1988)

- Tides:
  Permanent tide: Zero-tide system
  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: *air pressure admittance: 3 nm/s²/hPa*
- Polar motion:
  IERS reference pole with *elastic gravimetric factor 1.164*
- Ocean tide loading:
  FES2004 or best fitting model

Legend: retained | improved | system | *frame*



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ORIGINAL ARTICLE

Check for updates

Status of the International Gravity Reference System and Frame

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3 IGRS Conventions 2020

The presented conventions are based on the International Absolute Gravity Basestation Network (IAGBN): Absolute Gravity Observations Data Processing Standards by Boedecker (1988) which are already applied for decades. They are mostly implemented by processing software like the "g" Absolute Gravity Processing Software by Micro-g LaCoste[4]. Minor updates were necessary to reflect the current state of the art and the compatibility with existing processing results. A further unification of processing standards is subject of the IAG Joint Working Group 2.1.2 "Unified file formats and processing software for high-precision gravimetry". Where applicable, the basis for the following recommendations is in accordance with the IAG/IUGG resolutions and the IERS Conventions (2010) (Petit and Luzum

https://doi.org/10.1007/s00190-020-01438-9

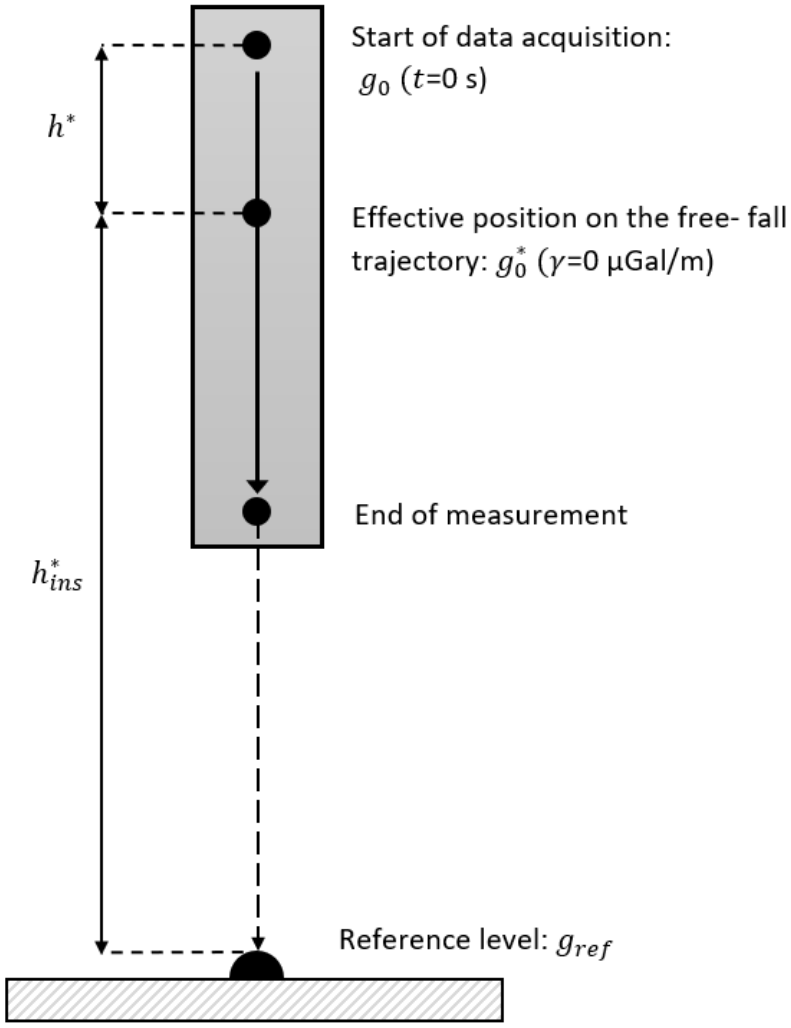
IGRS Conventions 2020 (2)

Absolute gravity height reference:

- Absolute gravity value should be referred to the effective position on the free-fall trajectory (invariant under changes of the constant vertical gravity gradient, VGG)
- Specify: Distance between the effective position on the free-fall trajectory and the marker: Effective instrumental height h^*_{ins}
- Information to be reported:
  1. Effective instrumental height
  2. VGG used in the observation equation.

Vertical gravity gradient (VGG):

- Transfer of absolute gravity value to a common reference height
- Determination from relative gravity measurements at three levels recommended



Proposal of an IAG resolution 2023 (b)

IAG adopts,

- the ITGRS as the preferred gravity system based on the instantaneous acceleration of free-fall, expressed in SI and related to the zero-tide system, the reference atmosphere and the reference terrestrial pole.

IAG recommends,

- that corrections for temporal gravity effects follow the *IGRS* Conventions 2020* as published by IAG JWG 2.1.1. in Journal of Geodesy (2021) 95:7 https://doi.org/10.1007/s00190-020-01438-9

Reference Frame:

The realization of the system

Compatibility of gravity measurements

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- **Absolute gravity measurements** traceable to the International System of Units (SI) (time and frequency)
- **Common reference level** and traceability to the SI: Absolute Gravimeters have to be checked at comparisons / by calibration
- Models for temporal gravity corrections: **IGRS* 2020 Conventions**
- **Global set of reference stations** with reliable absolute gravity values (relative accuracy of 10^{-8} and better) and monitoring capabilities for temporal changes

* published before the acronym was changed but not in conflict with IAGA

Comments/Suggestions to be discussed

GGOS UAW Oct 2022:

https://doi.org/10.5281/zenodo.7270482

https://doi.org/10.5281/zenodo.7270577

- include an accuracy requirement in the system definition and
- explain how it will be achieved (in the frame)
- include a gravity rate of change, in analogy to ITRF velocities.

IAG EC meeting Dec 2022

- EC is waiting for a draft formulation of the resolution
- check old resolutions to find the appropriate wording
- IUGG resolution?

Previous Resolutions

IUGG MOSCOW – 1971, IUGG Resolution N°16: **IGSN71**

https://iugg.org/wp-content/uploads/2022/03/moscow.pdf

The International Union of Geodesy and Geophysics

Recognising that the Potsdam datum adopted in London, 1909, has served its purpose in providing a reference for international gravity measurements;
Considering

a) that for scientific purposes a more accurate, system of gravity values is needed to provide both datum and scale;
b) that the IAG has adopted at the Lucerne meeting in 1967 a provisional correction of -14 mgal to the Potsdam value (Resolution no 22);
c) that the International Committee on Weights and Measures adopted in 1967 a resolution for a correction of - 14 mgal to the value of gravity in the Potsdam datum to be used for metrological purposes;
d) that recent absolute, and relative observations have provided a firm basis for the determination of datum and scale to the required accuracy;
e) that the above mentioned measurements have been adjusted to provide a homogeneous International Gravity Standardization Net (IGSN 71) which defines the datum and scale and gives
gravity values with the same order of accuracy throughout its extension;
f) that the establishment of such a system represents a major international effort and provision for maintenance and improvement must be made;
g) that the accuracy of the absolute determination of gravity is adequate for studies of variations in the distribution- and displacements of masses and possible variations of G;

Recommends

1. that the International Gravity Standardization Net 1971 (IGSN 71) be adopted and published in the Bulletin Géodésique,
2. that the Potsdam datum be corrected by the amount specified in the adjustment

IUGG MOSCOW – 1971, IAG RESOLUTION N° 12: **Maintenance of IGSN71**
[Section 5 of IGSN71 Documentation]

The International Association of Geodesy,

recommends that a *Permanent International Gravity Service,* coordinated with the *International Gravimetric Commission (IGC)* and the *International Gravimetric Bureau (IGB),* be formed with the following functions

1. to provide for expansion of the IGSN 71 to include areas where no stations now exist or values are not available.
2. the maintenance and reobservation of stations, and the replacement of any which may be destroyed,
3. to maintain the files in a computer-processable format and to incorporate new measurements into the existing files (one complete set of the values and descriptions to be deposited at the IGB),
4. to promote improvements in instrumentation, including the development of transportable absolute gravity meters, and their applicability to the standardization problem,
5. to establish in cooperation with the appropriate scientific institutions a net of permanent stations at which the absolute measurement of gravity, periodically repeated with an accuracy of the order of a few microgals, could be used as a geodetic reference and, in conjunction with other advanced geodetic methods, to monitor slowly varying parameters of the earth,
6. to carry out computations necessary for incorporating new stations into the system,
7. to maintain contact with agencies active in the field of gravity measurements or using gravity data, to ensure that the IGSN 71 satisfies current needs,
8. to provide advice, when requested, to agencies using the IGSN 71 in local standardization problems.

Previous Resolutions

***Hamburg 1983**: IAG RESOLUTION No. 9:* **Tides / Atmosphere**

https://office.iag-aig.org/doc/5d7b8fda34fe2.pdf

The International Association of Geodesy,

recognizing the high level of accuracy of both absolute and relative gravity measurements recently attained,

considering the necessity to adopt standard corrections to gravity observations in order to allow intercomparisons between measurements at different epochs of time,

recommends :

1. that the *tidal correction* applied to the gravity observations follow the final recommendations of the Standard Earth Tide Committee as presented at the XVIII IUGG General Assembly,
2. that the *atmospheric pressure corrections* refer to a common Standard Atmosphere, the sensitivity coefficient being $0.3 \cdot 10^{-10}$ m s^{-2}/Pa (0.3 microga]/mbar), unless it is determined by special investigations, in which case the value used must be published together with the results. The closed formula for the computation of this Standard Atmosphere will be published in a future issue of the Bulletin d'l nformation du Bureau Gravimétrique International with the corresponding numerical tables and the programming code.
3. that the gravity *gradient corrections* be published with the adopted local gradient and/or the adopted height difference so that the original values may be recovered.

***Hamburg 1983**: IAG RESOLUTION No. 16 1983:* **Permanent Tide**

The International Association of Geodesy,

recognizing the need for the uniform treatment of tidal corrections to various geodetic quantities such as gravity and station positions, and

considering the reports of the Standard Earth Tide Committee and S.S.G. 2.55 Predictive Methods for Space Techniques, presented at XVIII General Assembly,

recommends that :

1. the rigid Earth model be the Cartwright -- Tayler -- Edden model with additional constants specified by the International Centre for Earth Tides,
2. the elastic Earth model be that described by Wahr using the 1066 A model Earth of Gilbert and Dziewonski,
3. the indirect effect due to the permanent yielding of the Earth be not removed,

and

4. ocean loading effects be calculated using the tidal charts and data produced by Schwiderski as working standards.

Previous Resolutions

Vancouver 1987 *IAG RESOLUTION No. 2:* **AG Comparisons**

https://office.iag-aig.org/doc/5d7b8fda2abe1.pdf

The International Association of Geodesy,

recognizing the continuing need to investigate systematic errors in transportable absolute gravity instruments, and

considering the achievements to date of previous comparison campaigns at BIPM, Sévres,

recommends that such comparisons continue at Sévres and other major observatories, as well as in conjunction with the observations of the International Absolute Gravity Base Station Network, and

invites the institutions concerned to cooperate as requested by the International Gravity Commission.

Vancouver 1987 *RESOLUTION No. 4:* **Non-tidal loading**

The International Association of Geodesy,

recognizing the need to study non-tidal gravity changes on a global scale, and

considering the ability of both superconducting and absolute gravimeters to monitor variations of the gravity field at the microgal level, *endorses :*

1. Resolution No. 2 of the Permanent Commission on Earth Tides (Madrid 1985), and
2. Resolution No. 2 of the International Gravity Commission (Toulouse 1986),

and

recommends that the superconducting gravimeters be included in a network monitored by absolute gravity measurements, to fulfil this requirement, and

invites the institutions using absolute or superconducting gravimeters to participate in establishing this network.

Previous Resolutions

Vancouver 1987 *RESOLUTION No. 5:* **IAGBN**

The International Association of Geodesy,

recognizing the urgent need for a global absolute gravity reference network of high accuracy, particularly for monitoring variations with time and maintaining world gravity standards, and

considering the proposal of IAG SSG 3.87 for an International Absolute Gravity Base station Network (IAGBN) an appropriate basis,

- *recommends* this should be put in hand now, coordinated by the International Gravity Commission,

requests :

1. relevant agencies to give active support to station installation and gravity connections to existing base networks such as IGSN 71,
2. institutes using absolute gravitymeters to make the necessary observations, to cover the complete IAGBN in a reasonably short time interval, and

invites further groups to participate with other observations, e.g. positions as required.

Vancouver 1987 *RESOLUTION No. 6*

The International Association of Geodesy,

recognizing the highly efficient support of advanced space techniques and absolute gravimetry for terrestrial height systems when monitoring recent vertical crustal movements, and

considering that a number of scientific groups in Europe are operating sophisticated instruments of different types,

recommends that a fundamental network of space and absolute gravity stations should be established for investigating height variations, and

invites agencies and institutes using these advanced systems, as well as national survey agencies, to support these investigations.

Discussion

The IAG

Considering

IAG resolution No. 2 adopted 2015 in Prague and IAG resolutions No. 9.2 and No. 16.3 adopted 1983 in Hamburg and the importance of an International Terrestrial Gravity Reference System (ITGRS) for geodesy and geosciences

Adopts,

the ITGRS as the preferred gravity system based on the instantaneous acceleration of free-fall, expressed in SI and related to the zero-tide system, the reference atmosphere and the reference terrestrial pole.

Considering

accuracy achievable to few 1e-9