Federal Agency for
Cartography and Geodesy

Towards a road map for the establishment of a global absolute gravity reference system

Meeting of IAG JWG 2.1.1 at

GGHS2016 “Gravity, Geoid and Height Systems 2016”September, 20th 2016 Thessaloniki, Greece

Chair: H. Wziontek (Germany)

IAG Commission 2: Gravity Field (2011-2015)

Joint Working Groups

JWG 2.1: Techniques and Metrology in Absolute Gravimetry
(joint with IGFS) Chair: Vojtech Palinkas (Czech Republic)

JWG 2.2: Absolute Gravimetry and Absolute Gravity Reference System
(joint with IGFS) Chair: Herbert Wilmes (Germany)

New Joint Working group JWG 2.1.1
Objectives

New direction since IUGG General Assembly in Prague 2015:

Focus on roadmap for the realization Resolution No. 2:

Establishment of a global absolute gravity reference system

- Repeated international comparisons of absolute gravimeters
  Guidance: CIPM and Regional Metrology organizations
- Operating a globally distributed set of gravity reference stations based on
  - Repeated absolute gravity measurements and
  - Continuous (residual) temporal gravity reference function (CRF) from superconducting gravimeters.
- Transfer of international comparison results to other absolute gravimeters and reference stations at regional stations with CRF
- Definition of standard models for the correction of absolute gravity data (in cooperation with the GGOS Bureau of Standards and Conventions).

New Joint Working group JWG 2.1.1: Linked IAG Services

IGFS: International Gravity Field Service

IGETS: International Geodynamics and Earth Tide Service
Times Series from Superconducting Gravimeters,
CRF from combination of SG / AG

ICCT: Intercommission Committee on Theory
Co-location with ITRF

- to link the reference stations to the International Terrestrial Reference System by co-location with space-geodetic techniques,
- to initiate the replacement of the International Gravity Standardization Net 1971 (IGSN71)

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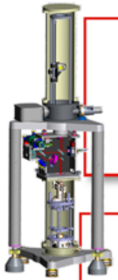
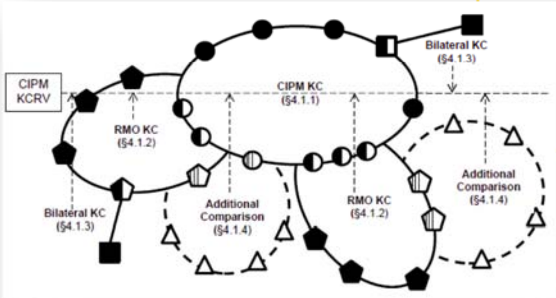
Proposed Components of a
Global Absolute Gravity Reference System

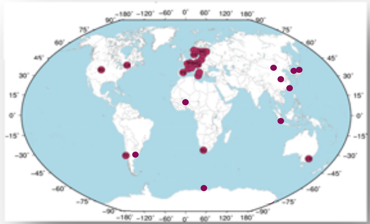


Absolute Gravimeters

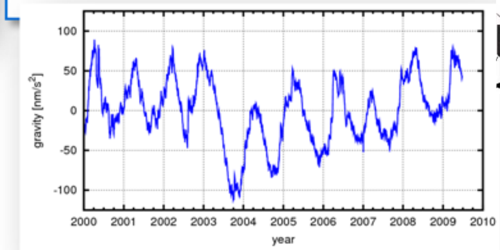
Intercomparisons:
CCM-KC, RMO-KC
Geodetic Comparisons
with linked CRF



Gravity reference stations
with continuous comparison reference function



Continuously operated most stable relative gravimeters (SG)



Definition of standard correction models (Tides, Atmosphere, Polar Motion, Hydro)

- to establish a gravity reference frame by globally distributed reference stations linked to the international comparisons of absolute gravimeters where precise gravity reference is available at any time,

International Comparisons and Link to Metrology

- Strategy paper of CCM and IAG in 2013/2014 confirms cooperation between metrology and geosciences in AG comparisons
- Link to Metrology ensures traceability to SI
- Only a subset of AG covered by Keys Comparisons
- Regional and Additional Comparisons necessary to keep common level of all instruments: AGrav database as inventory
  (see poster in session 4)

Urs Marti, President of the International Association of Geodesy (IAG) Commission 2
ity Field»
Philippe Richard, President of the Consultative Committee for Mass and related qua
(CCM)
Alessandro Germak, Chairman of the CCM working group on gravimetry (WGG)
Leonid Vitushkin, President of IAG SC 2.1
Vojtech Pálinkáš, 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

http://www.bipm.org/wg/CCM/CCM-WGG/Allowed/2015-meeting/CCM_IAG_Strategy.pdf
and in the Travaux of IAG 2011 - 2015

Work Packages

1. Selection of Reference Stations, update of station surveys from 2011
2. Homogenous processing of observations:
   Update of the IAGBN standards 1992
3. AG Comparisons: Further cooperation with CCM-WGG,
   Unique processing rules (e.g. evaluation at the gradient independent point),
   treatment of systematic effects (SAC, DC etc.);
   Reprocessing since 2005
4. Stability of the comparison reference level over time:
   Assessment of CRV deviations of different epochs, stabilization by the combination AG-SG
5. Regional / Additional Comparisons: Role of non-NMI/DI instruments
6. Evaluation of IGSN stations: Recommendation for the further use /re-observation of IGSN71 stations within the new reference system
7. Accessibility of the new system for practical work? Countries without AG?

Work package:
Selection of Reference Stations

- Circular Letter to the members of the IAG and CCM Working and Study Groups from 17.01.2011
- GGP Questionnaire on SG/AG Intercomparisons, 27 March 2011
- Positive response from many institutions operating AG and SG
- Good basis
- Update after 5 years?

17.01.2011

To the members of the IAG Working Group on Absolute Gravimetry (WGAG), IAG Study Group on Comparisons of Absolute Gravimeters (SGCAG) and Working Group on Gravimetry of CIPM Consultative Committee on Mass and Related Quantities (CCM WGG)

Dear colleagues,

You will probably have been informed that BIPM decided to close the International Comparisons of Absolute Gravimeters (ICAGs) at BIPM. As this is of high importance for almost all Absolute Ballistic Gravimeter (ABG) users the chairmen of IAG WGAG, CCM-WGG and SGCAG propose to discuss in the working groups the organization of future ICAGs and Regional Comparisons of Absolute Gravimeters (RICAG).

Until now four-yearly comparison campaigns have been carried out at BIPM to relate the instruments to SI standards and to determine the offset of each individual instrument with respect to the comparison reference values. The last ICAG in 2009 was subdivided into a CCM "Key Comparison" (KC) where the National Metrology Institutes (NMI) and designated national laboratories took part and a "Pilot Study" (PS) for all other institutions. Both parts of ICAG-2009 were organized following the Technical Protocol according to the rules of international comparisons specified in the documents of CIPM Mutual Recognition Arrangement (http://www.bipm.org/en/cipm-mra/) which now has been signed by the representatives of 79 NMI – from 48 Member States, 28 Associates of Metre Convention and 3 international organizations – and covers a further 134 institutes designated by the signatory bodies.

The results of CCM KC part of ICAG-2009 will be placed on the Key Comparison Data Base of BIPM and the results of both KC and PS will be published then in the journals and reported at the symposiums and conferences.

Additional intermediate comparisons were organized by the community of ABG users as Regional International Comparisons of Absolute Gravimeters. The connection between RICAG and ICAG was realized, in principle, by the participation of some instruments which took part in both comparisons.

Key comparisons reflect the importance for the National Metrology Institutes to maintain the national gravity measurement standards. For the geodetic and geophysical applications the emphasis is placed on establishing the worldwide System of Absolute Gravity Stations, consistent gravity networks and determining small temporal gravity variations with metrologically assured

Questionnaires 2011 to the international community with AG and SG instruments

WGAG (20)

Proposed RICAG stations, status 04/2011

Country	Institution	Site	Person
		Europe	
Austria	BEV/ZAMG/IMGW	Conrad Observatory	Diethardt Ruess, Norbert Höggerl, Roman Leonhard, Robert Edelmaier, Bruno Meurers, Christian Ulrich
Czech Republic	VUGTK	Pecny (GOPE)	Vojtech Palinkas
Finland	FGI	Metsähovi	Jaakko Mäkinen
France	SYRTE/CNRS	Paris	Franck Pereira, Sebastian Merlet
France	Univ. Montpellier	Larzac Observatory, Montpellier	Nicolas Le Moigne
Germany	BKG	Wettzell	Herbert Wilmes, Reinhard Falk
Italy	ASI	Matera	Domenico Iacovone
Italy	INRIM	Torino	Alessandro Germak
Italy	INGV	Catania (Sicily)	Filippo Greco
Latvia	LGIA	Riga	Janis Kaminskis
Luxembourg	ECGS	Walferdange	Olivier Francis
Poland	Institute of Geodesy and Cartography, Warsaw	Borowa Gora	Jan Krynski
Russia	VNIIM	St. Petersburg	Leonid Vitushkin
Spain	IGN	Yebes	Jose Manuel Serna Puente
Sweden / Scandinavia	Lantmäteriet / OSO Chalmers	*possibly:* Onsala (Sweden) Mårtsbo (Sweden) Metsähovi (Finland) Trysil (Norway)	Jonas Ågren, Hans-Georg Scherneck
		America	
Canada	NRCan	Cantley (CAGS)	Jacques Liard
USA	NGS/NOAA	Boulder / Table Mountain (TMGO)	Mark Eckl (NGS), Daniel Winester (NOAA)
Chile	BKG	TIGO Concepcion	Herbert Wilmes, Reinhard Falk
		Australia	
Australia	GeoscienceAustralia/ ANU	Mt Stromlo, Reynolds Dome	Nicholas Dando
		Africa	
South Africa	GFZ Potsdam	Sutherland (SAGOS)	Christoph Förste

GGP (16)

GGP Questionnaire on SG/AG Intercomparisons, 27 March 2011

Results of Survey of GGP Stations suitable for AG Intercomparisons
David Crossley, Saint Louis University

A questionnaire was sent to all SG stations (considered as the GGP Network) requesting information about the suitability of individual site for the intercomparison of AGs.

The following documents as supplied by H. Wilmes were circulated with the survey:

Meeting_Report_280211_final_110311.pdf,
ricag-sites_03_11.df

The assumption behind the questionnaire was to identify sites currently running SGs that have sufficient capacity to accommodate a reasonable number of AG instruments running in 'Intercomparison Mode'. This is to assist the decision of those in the AG community who are looking for new intercomparison sites. Although as Olivier Francis has stated, the presence of an SG is not mandatory, the continuous background gravity signal provided by an SG could be of quite useful in the intercomparisons, especially at any site with variable disturbances from hydrology, atmospheric, or coastal effects.

Our survey does not include every SG station, as some sites are unsuitable, or already identified as RICAG-sites.

Question 1: Give the number, and any details as appropriate, of Absolute Gravimeter piers (or pads, or pillars) in the near vicinity of the SG you represent.

The table lists sites alphabetically.

Station Code	Name	Institution / Location	Response to question
BF, Schiltach	Ruedi Widmer-Schnidrig, Stuttgart University	Black Forest Observatory	Site within tunnel has high humidity, limited space
BH, Bad Homburg	Herbert Wilmes	BKG, Frankfurt/Main, Germany	2 piers for AG measurements
BO, TMGO Boulder	Mark C. Eckl, Chief of Observation and Analysis Division of the National Geodetic Survey.	NOAA/National Geodetic Survey, 8600 N. 39th St. TMGO Bldg. F6, Longmont, CO. 80503	10 pads available
CA, Cantley	Jacques Liard, Geodetic Survey Division,	Natural Resources Canada, 615 Booth, Ottawa, ON, K1A 0E9, Canada	There is a large concrete pier poured directly on bedrock. We have the capacity to receive up to 4 instruments right now at CAGS (Cantley), and we can increase it to 8 or 9 if the need is felt.
CB, Canberra	Dr. Herb McQueen, Research School of Earth Sciences,	Australian National University, Canberra, Australia	Four isolated piers in the floor of a renovated telescope dome at Mount Stromlo Observatory adjacent to the building housing SG CT031
CI,	Yoichi Fukuda, Kyoto	National Coordinating	One nearby pier for an AG is available.

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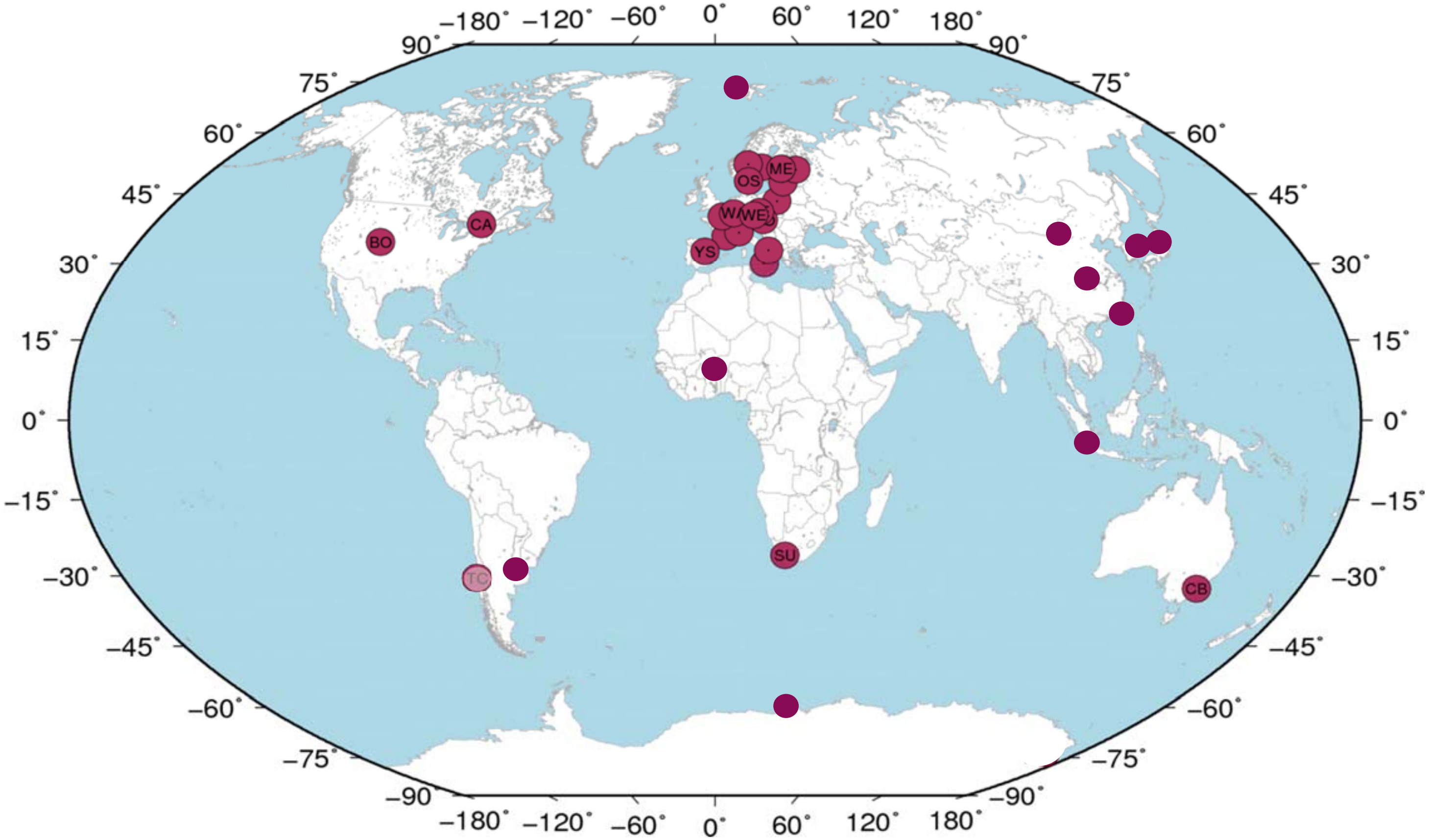
Possible gravity reference and comparison stations



Work package:
Update of the IAGBN Processing Standards

- Accommodation to IERS Conventions / Recommendations of the GGOS Bureau of Standards and Conventions
- Update of constants
- Update of tidal models, including permanent tide and elastic parameters
- Treatment of Ocean tide loading
- Atmospheric corrections, based on physical, not GNSS heights!

IAGBN: Absolute Observations Data Processing Standards

(1992 collection)

As far as possible the basis for the following recommendations were taken from IAG/IU(resolutions.

o Light travel time correction is based on c = 299 792 458 [ms^{-1}] (IAG 1983 resolution no. 1) Each individual time value should be corrected by

$$\delta t = -\frac{z}{c}$$

where z is the distance from the pre-drop resting position.

o Earth tides reduction: It is recommended to apply the Cartwright-Tayler-Edc development supplemented by the ICET to yield a total of 505 tidal constituents or anotl recognized development like Tamura, Büllesfeld or Xi. For the tidal parameters (amplitu factors and phase lags) values deduced from observations or from a recognized Ea model like Wahr-Dehant should be used, which seems better; else, an amplitude factor 1.164 may be applied. The details must be reported as part of the observation document.

The tidal reduction generally includes the M_0S_0 tide. Because the direct contribution of this tide, constant w time, should be attributed an amplitude factor of 1 instead of about 1.164 for the tides varying with time, difference can be corrected using

$$\delta g\ (M_0S_0) = -4.83 + 15.73 \cdot \sin^2\psi - 1.59 \cdot \sin^4\psi\ [10^{-8} ms^{-2}]$$

where

ψ geocentric latitude

(c.f. IAG 1983 resolution no. 9 and no. 16; details see Rapp 1983).

o Earth rotation changes: The geometric position of the Earth's body relative to its spin a: has to be referenced to mean position. It is recommended to use (e.g. Wahr 1985)

$$\delta g = -1.164 \cdot 10^8 \cdot \omega^2 \cdot a \cdot 2 \sin\phi \cdot \cos\phi\ (x \cdot \cos\lambda - y \cdot \sin\lambda)\ [10^{-8} ms^{-2}]$$

What's Next?

- Your opinion/ideas?
- Further discussion: Mailing List / Forum?
  http://agrav.bkg.bund.de/forum/
- Next meeting?
  - AGU 2016
  - EGU 2017
  - Workshop?