



Towards the establishment of a global absolute gravity reference system

Meeting of IAG JWG 2.1.1 at EGU General Assembly 2017

Chair: H. Wziontek (Germany)

Vice-chair: Sylvain Bonvalot (France)

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 all 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).



Joint Working group JWG 2.1.1: Linked IAG Services



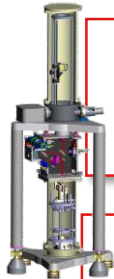
IGFS: International Gravity Field Service





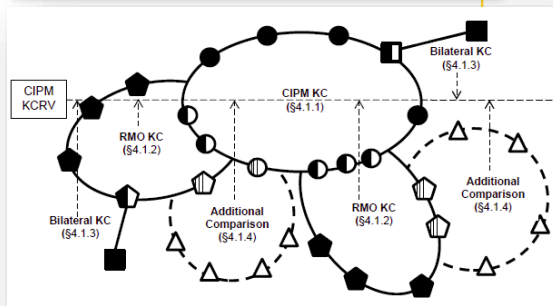
IGETS: International Geodynamics and Earth Tide Service
Times Series from Superconducting Gravimeters,
CRF from combination of SG / AG

Proposed Components of a Global Absolute Gravity Reference System

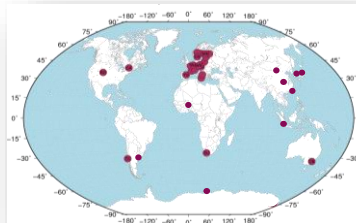


Absolute Gravimeters

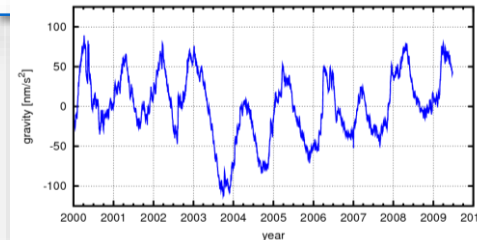
Intercomparisons:
CCM-KC, RMO-KC
Geodetic Comparisons
with linked CRF



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
Poster on Tuesday:

EGU 2017-15025



<http://agrav.bkg.bund.de/doc/EGU2017-15025-poster.pdf>

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](#)



Two Aspects of the Realization

Long term stable **Reference Level**:
Absolute gravimeters
monitored at reference stations

Infrastructure:
Accessibility of the system
by a global set of stations,
compatible with the reference level

- Repeated comparisons (monitoring of AG) at international/regional level
- Reference stations with continuous reference function (SG / IGETS) preferred but no exclusive
- Accuracy: A few μGal range
→ Resolution No. 2 (2015)



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



Questionnaire 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	Diethard Rues, Norbert Hoggarl, Roman Leonhard, Robert Edelmaier, Bruno Meurers, Christian Ulrich
Czech Republic	VUGTK	Pecny (GOPE)	Vojtech Palinkas
Finland	FGI	Metshovi	Jarkko Mäkinen
France	SYRTE/CNRS	Paris	Franck Pereira, Sebastian Marlet
France	Univ. Montpellier	Larzac Observatory, Montpellier	Nicolas Le Moigne
Germany	BKG	Wetzell	Herbert Wilmes, Reinhard Falk
Italy	ASI	Matera	Domenico Iacovone
Italy	INRIM	Torino	Alessandro Gennak
Italy	INGV	Catania (Sicily)	Filippo Greco
Latvia	LGIA	Riga	Janis Kaminskis
Luxembourg	ECGS	Walferdange	Olivier Francis
Poland	Institute of Geodesy and Cartography, Warsaw	Borowia Gora	Jan Krynski
Russia	VNIIM	St. Petersburg	Leonid Vinushkin
Spain	IGN	Yebes	Jose Manuel Serna Puente
Sweden / Scandinavia	Lantmätariet / OSO Chalmers	possibly: Ostala (Sweden) Mårbo (Sweden) Metshovi (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 Winster (NOAA)
Chile	BKG	TIGO Concepcion	Herbert Wilmes, Reinhard Falk
Australia			
Australia	Geoscience Australia/ 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.dcf

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-Schmidrig, 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. 39 th 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.

Survey of Reference Sites 2011

Europe

(status 27/06/2011)

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
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Italy	INGV	Catania (Sicily)	Filippo Greco
Latvia	LGIA	Riga	Janis Kaminskis
Luxembourg	ECGS	Walferdange	Olivier Francis
Poland	IgIK	Borowa Gora	Jan Krynski
Russia	VNIIM	St. Petersburg	Leonid Vitushkin
Spain	IGN	Yebes	José Manuel Serna Puente
Sweden / Scandinavia	Lantmäteriet / OSO Chalmers	possibly: Onsala (Sweden) Mårtsbo (Sweden) Metsähovi (Finland) Trysil (Norway)	Jonas Ågren, Hans-Georg Scherneck



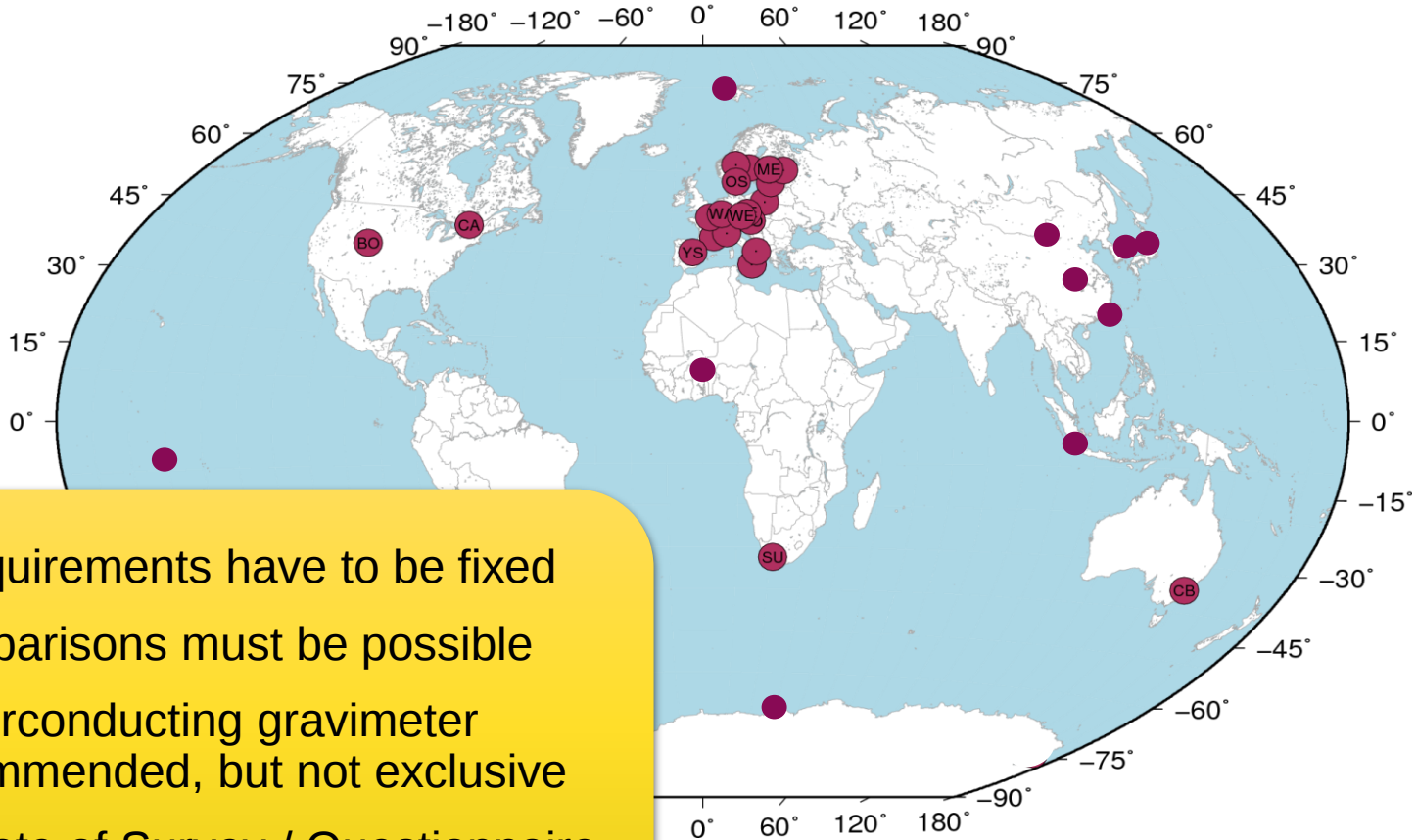
Survey of Reference Sites 2011

America/Asia/Australia/Africa/Antarctica

(status 27/06/2011)

Country	Institution	Site	Person
America			
Canada	NRCan	Cantley (CAGS)	Jacques Liard
USA	NGS/NOAA	Boulder / Table Mountain (TMGO)	Van Westrum (NGS), Daniel Winester (NOAA)
Argentina	BKG	AGGO / La Plata	Axel Rülke, Reinhard Falk
Asia			
China	NIM	Beijing's Changping Campus	Wu Shuqing
Australia			
Australia	GeoscienceAustralia/ ANU	Mt Stromlo, Reynolds Dome	Nicholas Dando
Africa			
South Africa	GFZ Potsdam	Sutherland (SAGOS)	Christoph Förste
Antarctica			
Antarctica	INRIM	Terra Nova Bay	Alessandro Germak

Potential Reference and Comparison (Core) stations



Site requirements have to be fixed

- Comparisons must be possible
- Superconducting gravimeter recommended, but not exclusive

→ Update of Survey / Questionnaire

Upcoming Regional Comparisons:

- Regional Comparison at Wettzell:
 - Three Weeks Mid April (after EGU) until Mid May
 - Will be registered as EURAMET comparison, with VUGTK / Pecny observatory as pilot (Vojtech Pálinkáš)
- Comparisons in South America:
 - in Brasil 2019 at MCTIC-Observatório Nacional (Mauro Andrade de Sousa)
 - Argentina at La Plata / AGGO after deployment of FG5-227 (BKG)



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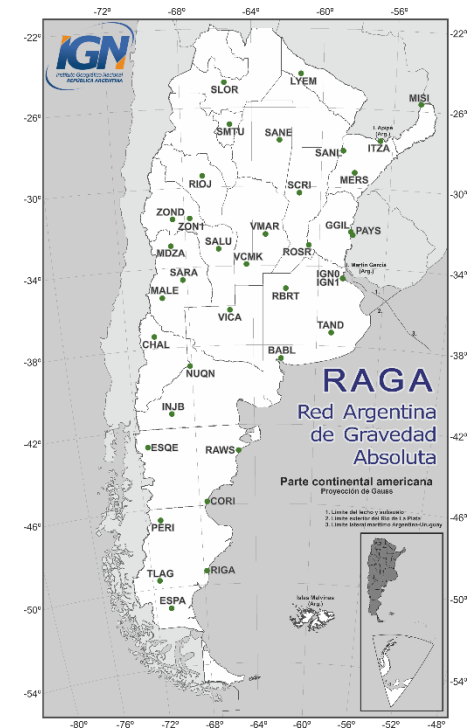
- to replace IGSN71, the system must be **accessible for any user**, including those not operating an AG!
- Compatibility: Comparisons (Additional comparisons) for all AG, e.g. A10, at reference stations (at any time → SG / IGETS)
- Relative surveys?
- Accuracy?



Establishing Infrastructure

- Evaluation of IGSN stations:
Recommendation for the further use /re-observation of IGSN71 stations within the new reference system
- Establishing new infrastructure in International Cooperation, e.g. by A10 field observations

IGSN71 ABSOLUTE GRAVITY VALUES						
IGB NUMBER	NAME	GRAVITY VALUE	STD ERROR	TIMES INT	TIED EXT	
00865 K	MEDELLIN	977 740.64	0.024	7	21	
00865 L	MEDELLIN	977 741.19	0.026	7	6	
00889 A	PANAMA	978 226.70	0.019	111	34	
00889 J	PANAMA	978 251.44	0.019	48	55	
00889 L	PANAMA	978 216.72	0.023	7	2	
00889 M	PANAMA	978 216.74	0.019	41	67	
00889 O	PANAMA	978 224.00	0.026	5	0	
00889 R	PANAMA	978 222.54	0.029	3	2	
00889 S	PANAMA	978 227.72	0.020	24	10	
00889 T	PANAMA	978 251.34	0.022	9	6	
00899 J	CRISTOBAL	978 238.56	0.034	0	4	
00994 K	SAN JOSE	977 964.36	0.023	4	36	
00994 L	SAN JOSE	977 963.59	0.026	4	4	
02087 J	KWAJALEIN	978 346.43	0.050	0	7	
02613 A	SINGAPORE	978 066.68	0.025	95	49	



Example:

Absolute gravity network of Argentina (RAGA):

- Based on 35 stations with A10 measurements.
- Cooperation of Instituto Geográfico Nacional (IGN) with Universidade de Sao Paulo (USP), Brazil and Institut de Recherche pour le Développement (IRD), France

<http://www.ign.gob.ar/NuestrasActividades/Geodesia/Gravimetria/RAGA>

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.

- Light travel time correction is based on $c = 299\,792\,458 \text{ [ms}^{-1}\text{]}$ (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.

- Earth tides reduction: It is recommended to apply the Cartwright-Tayler-Edden development supplemented by the ICET to yield a total of 505 tidal constituents or another recognized development like Tamura, Büllsfeld or Xi. For the tidal parameters (amplitude factors and phase lags) values deduced from observations or from a recognized Earth 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_2S_0 tide. Because the direct contribution of this tide, constant with time, should be attributed an amplitude factor of 1 instead of about 1.164 for the tides varying with time, the difference can be corrected using

$$\delta g (M_2S_0) = - 4.83 + 15.73 \cdot \sin^2\psi + 1.59 \cdot \sin^4\psi \text{ [10}^{-4}\text{ms}^{-2}\text{]}$$

where

ψ geocentric latitude

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

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

$$\delta g = -1.164 \cdot 10^8 \cdot \omega^2 \cdot a \cdot 2 \sin\phi \cdot \cos\phi (x \cdot \cos\lambda - y \cdot \sin\lambda) \text{ [10}^{-4}\text{ms}^{-2}\text{]}$$



Work Packages

1. Continuation of AG Comparisons at different Levels:

- Further cooperation with CCM-WGG
- Regional comparisons under guidance of Regional Metrology Organizations
- Include non-NMI/DI instruments by Additional Comparisons
→ Documentation in AGrav
- Stability of the comparison reference level over time:
CRV deviations of different epochs, combination AG-SG, definition of linking converter
- Unique processing rules (e.g. evaluation at the gradient independent point),
treatment of systematic effects (SAC, DC etc.);
- Reprocessing (since 2005)

2. Selection of Reference (Core) Stations:

- Fixing Site requirements
- Update of station surveys from 2011



Work Packages

3. Realization of Infrastructure:

- Evaluation of IGSN stations: Recommendation for the further use /re-observation of IGSN71 stations within the new reference system
- New observations with AG, including field stations with A10

4. Processing Standard for absolute gravity observations: Update of the IAGBN standards 1992



Discussion

- Your opinion/ideas?

- Forum

<http://agrav.bkg.bund.de/forum/>

- Next meeting?

- Workshop?



General Category		
	General Discussion Feel free to talk about anything and everything in this board.	4 Posts 2 Topics Last post by gravi in Re: AGrav forum opened on October 22, 2015, 10:06:32 AM
	AGrav database questions and suggestions concerning the AGrav database	0 Posts 0 Topics
	FG5 absolute gravimeter All issues related to the FG5 absolute gravimeter by Micro-g LaCoste	0 Posts 0 Topics
	A10 absolute gravimeter All issues related to the A10 absolute gravimeter by Micro-g LaCoste	5 Posts 1 Topics Last post by Jeff Kennedy in Re: Correcting A-10 data... on January 12, 2016, 10:39:12 PM
	Developments Exchange of ideas and news related to the development of new absolute gravimeters, e.g. atom interferometers	0 Posts 0 Topics
IAG SC 2.1 "Gravimetry and networks"		
	Study Group Techniques and metrology in terrestrial (land, marine, airborne) gravimetry Everything about IAG Study Group 2.1.1:	0 Posts 0 Topics
	Joint Working Group: Establishment of a global absolute gravity reference system Everything about IAG Joint Working Group 2.1.1	0 Posts 0 Topics

No New Posts Redirect Board

