Structure, status and recent achievements of the International Association of Geodesy (IAG) and its Global Geodetic Observing System GGOS

Harald Schuh - IAG Immediate Past President
Helmholtz Centre Potsdam
GFZ German Research Centre for Geosciences

Hermann Drewes - IAG Immediate Past Secretary General
Deutsches Geodätisches Forschungsinstitut (DGFI-TUM)
of Technische Universität München

Rio de Janeiro, Nov. 12, 2019
Organisation of International Science

International Science Council (ISC) (2018: merger of ICSU and ISSC)

Sciences: IAU, ICA, IGA, ...

IUGG

Social Sciences

International Union of Geodesy and Geophysics (IUGG)

IACS  IAGA  IAHS  IAPSO  IAG  IAMAS  IASPEI  IAVCEI

International Association of Geodesy (IAG): 71 Member countries

Council: Representatives of the member countries

Executive Committee: 16 members (elected by the Council)

Bureau: Administrative work

Office: Management (Secretary General)
**Bureau**

- President: Zuheir Altamimi, France
- Vice-president: Richard Gross, USA
- Secretary General: Markku Poutanen, Finland

**Commissions**

<table>
<thead>
<tr>
<th>Commission</th>
<th>Chair</th>
<th>Representative(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Reference Frames</td>
<td>Ch. Kotsakis, GR</td>
<td>T. Herring, USA, T. Otsubo, JP, J. Böhm, AU</td>
</tr>
<tr>
<td>2 Gravity Field</td>
<td>A. Jäggi, CH</td>
<td></td>
</tr>
<tr>
<td>3 Geodynamics</td>
<td>J. Bogusz, PL</td>
<td></td>
</tr>
<tr>
<td>4 Applications</td>
<td>A. Kealy, AUS</td>
<td></td>
</tr>
</tbody>
</table>

**Inter-Commission Committee on Theory**

(P. Novák, CZ)

**Scientific Services**

- Geom.: IERS, IGS, IDS, ILRS, IVS
- Gravim.: IGFS, BGI, IDEMS, IGETS, ISG
- General: BIPM, PSMSL

(Representatives in the EC: T. Herring, USA, T. Otsubo, JP, J. Böhm, AU)

**Global Geodetic Observing System (GGOS)**

(R. Gross, USA)

**Communication and Outreach Branch (COB)**

(Sz. Rózsa, HU)

EC Members at Large: Y. Dang, CN, S. Costa, BR
Past President: H. Schuh, DE; Past Secretary General: H. Drewes, DE
The mission of the IAG is the advancement of geodesy by
- furthering geodetic theory through research and teaching,
- collecting, analysing, modelling and interpreting observational data,
- by stimulating technological development and
- providing a consistent representation of the figure, rotation, and gravity field of the Earth and planets, and their temporal variations.

The objectives of the IAG are to achieve the mission by studying all geodetic problems related to Earth observation and global change, i.e.:
- Definition, establishment, and maintenance of global and regional reference systems for interdisciplinary use;
- Gravity field of the Earth;
- Rotation and dynamics of the Earth and planets;
- Positioning and deformation;
- Ocean, ice and sea level.
- Atmosphere and hydrosphere.
1.1 Coordination of Space Techniques
- Co-location using clocks and new sensors: New site ties concepts
- Performance simulations and architectural trade-off (of the ITRF)

1.2 Global Reference Frames
- IERS Conventions (2010): update will come soon

1.3 Regional Reference Frames
- EUREF, SIRGAS, NAREF, AFREF, APREF, Antarctica
- Time-dependent transformations between reference frames

1.4 Interaction of Celestial and Terrestrial Reference Frames
- Consistent realization of ITRF, ICRF and EOP: new ICRF3 (only IAU)

WG1: Site survey and co-location
WG2: Modelling environmental loading effects
WG3: Troposphere ties
Commission 2 “Gravity Field” Activities

2.1 Gravimetry and Gravity Network
- Absolute and superconducting gravity measurements

2.2 Methodology for Geoid and Physical Height Systems
- Integration and validation of local geoid estimates

2.3 Satellite Gravity Missions
- GRACE Follow-On (GRACE FO) mission launched on May 22, 2018

2.4 Regional Geoid Determination
- Europe, South, N & Central America, Africa, Asia-Pacific, Antarctica

2.5 Satellite Altimetry
- New International Altimetry Service (under construction)

2.6 Gravity and Mass Transport in the Earth System
- Variation of groundwater, melting of ice, ...

WG: Relativistic Geodesy: Towards New Geodetic Techniques
3.1 Earth Tides and Geodynamics
- International Geodynamics and Earth Tide Service (IGETS), 2017

3.2 Crustal Deformation
- New SC3.2 Volcano Geodesy (jointly with IAVCEI), 2019

3.3 Earth Rotation and Geophysical Fluids
- Global mass transport, Earth rotation and low-degree gravity change

3.4 Cryospheric Deformations
- Glacial Isostatic Adjustment (GIA) research

3.5 Tectonics and Earthquake Geodesy
- Joint Sub-commission planned with IASPEI, 2019

JSG1 : Intercomparison of Gravity and Height Changes
JWG1: Theory of Earth Rotation and Validation
JWG2: Constraining Vertical Land Motion of Tide Gauges
Challenges of geodesy to rotation & geodynamics

- Prove consistency of the ICRF3 (released by IAU 2018) with ITRF;
- Model the effects of mass displacements (atmosphere, hydrosphere and solid Earth) on Earth rotation

NEW (established in 2019): Inter-Assoc. Sub-commissions, IAG Inter-Commission Committees (ICC), or IAG Project:

• With IASPEI (“Seismo-geodesy”)
• With IAVCEI (“Volcano-geodesy”)
• With IACS (“Cryosphere geodesy”)
• New ICC on “Marine geodesy“ (Chair: Yuangxi Yang)
• New ICC on “Geodesy for climate research” (Chair: Anette Eicker)
• New IAG Project on “Novel sensors and quantum technology in geodesy” (Chair: Jürgen Müller)
4.1 Emerging positioning technologies and GNSS augmentation
- Multi-sensor systems
- 3D point cloud monitoring
- Indoor positioning and navigation
- Robust positioning for urban traffic

4.2 Geo-spatial mapping and geodetic engineering
- Mobile mapping technologies
- Geodesy in mining engineering
- Mobile health monitoring
- Building information modelling

4.3 Atmosphere remote sensing
- Iono-atmosphere coupling
- Multi-dimens. Ionosphere
- Ionosphere scintillations
- Real-time iono-/atmosph. monitoring
- Impact on GNSS-positioning
- Troposphere tomography

4.4 Multi-constellation GNSS
- Integrity monitoring for PPP

WG1: Biases in multi-GNSS data processing
WG2: Integer ambiguity resolution for multi-GNSS PPP and PPP-RTK
Joint Study Groups with Commissions / Services

10: High-rate GNSS
11: Multi-resolution aspects of potential field theory
12: Methods for recovery of high-resolution gravity field models
13: Integral equations of potential theory for continuation and transformation of classical and new gravitational observables
14: Fusion of multi-technique satellite geodetic data
15: Regional geoid/quasi-geoid modelling for sub-centimetre accur.
16: Earth’s inner structure from geodetic and geophysical sources
17: Multi-GNSS theory and algorithms
18: High resolution harmonic analysis & synthesis of potential fields
19: Time series analysis in geodesy
20: Space weather and ionosphere
21: Geophysical modelling of time variations in deformation & gravity
22: Definition of next generation terrestrial reference frames
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Service Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>IERS</td>
<td>International Earth Rotation and Reference Systems Service</td>
</tr>
<tr>
<td>IDS</td>
<td>International DORIS Service</td>
</tr>
<tr>
<td>IGS</td>
<td>International GNSS Service</td>
</tr>
<tr>
<td>ILRS</td>
<td>International Laser Ranging Service</td>
</tr>
<tr>
<td>IVS</td>
<td>International VLBI Service</td>
</tr>
<tr>
<td>IGFS</td>
<td>International Gravity Field Service</td>
</tr>
<tr>
<td>BGI</td>
<td>Bureau Gravimetrique International</td>
</tr>
<tr>
<td>ICGEM</td>
<td>International Centre for Global Earth Models</td>
</tr>
<tr>
<td>IDEMS</td>
<td>International Digital Elevation Models Service</td>
</tr>
<tr>
<td>IGETS</td>
<td>International Geodynamics and Earth Tide Service</td>
</tr>
<tr>
<td>ISG</td>
<td>International Service for the Geoid</td>
</tr>
<tr>
<td>PSMSL</td>
<td>Permanent Service for Mean Sea Level</td>
</tr>
<tr>
<td>IAS</td>
<td>International Altimetry Service (under construction)</td>
</tr>
<tr>
<td>BIPM</td>
<td>Bureau International des Poids et Mésures</td>
</tr>
</tbody>
</table>
IAG Services on Gravimetry

**IGFS: International Gravity Field Service**
now with a new Product Center on “Combination for Time-variable Gravity field solutions (COST-G)”

**BGI: Bureau Gravimetricque International**

**ICGEM: International Centre for Global Earth Models**

**IDEMS: International Digital Elevation Model Service**

**IGETS: International Geodynamics and Earth Tide Service**
(in full operation since 2017)

**ISG: International Service for the Geoid**
(renamed and new agreement with IAG)
IAG Services on Geometry

**IERS: International Earth Rotation and Reference Systems’ Service**

**IGS: International GNSS Service**

**ILRS: International Laser Ranging Service**

**IVS: International Service for Geodesy and Astrometry**

**IDS: International DORIS**

All the techniques’ Services compute epoch station coordinates (weekly, monthly, session-wise) and provide them as free or loosely constrained networks to the ITRF processing centres of the IERS.
New challenges in geoscience

- Increase of natural disasters (e.g. typhoons, flooding, …)
  - Strong demand for prediction and warning
- Global climate change
The Global Geodetic Observing System works with the IAG components to provide the geodetic infrastructure necessary for monitoring the Earth system and global change research.

The vision of GGOS is

"Advancing our understanding of the dynamic Earth system by quantifying our planet’s changes in space and time.”
- combination and integration of all available observations, methods, ...
- combine physical measurements and geometric techniques
- improve our understanding of the interactions in "System Earth"
GGOS – general goals

- 1 mm position and 0.1 mm/yr velocity accuracy on global scales for the ITRF
- continuous measurements (time series of EOP, station positions and baselines)
- measurements in near real-time
- highest reliability and redundancy
- low cost for construction and operation of geodetic infrastructure
By its contribution to the GEO **Societal Benefit Areas (SBA)** GGOS shall benefit science and society by providing the foundations upon which advances in Earth science and applications are built.
GGOS shall benefit science and society by providing the foundations upon which advances in Earth science and applications are built.

Geodesy’s contribution to disaster research
M9.0 Tōhoku earthquake – March 11, 2011

Data source: GEONET, Geospatial Information Authority (GSI) Japan
processed by: Jet Propulsion Laboratory (JPL) und Caltech
M9.0 Tōhoku earthquake – March 11, 2011

ftp://sideshow.jpl.nasa.gov/pub/usrs/ARIA/
GGOS shall benefit science and society by providing the foundations upon which advances in Earth science and applications are built.

**Geodesy’s contribution to weather research**
GNSS atmospheric monitoring: ground-based

~ 400 GNSS stations, ~300 in NRT

SYNOP net of DWD

http://dwd.de/
Improvement of precipitation forecast by 20%

First GNSS processing center world-wide that operationally provides atmospheric slant data (humidity) to weather services (DWD, …).

*Zus (GFZ) et al., RS, 2015*
GGOS shall benefit science and society by providing the foundations upon which advances in Earth science and applications are built.

**Geodesy’s contribution to climate research**
Integrated water vapor (IWV) series, Greenbelt (U.S.)

trend: +0.94 mm/decade

GNSS processing center for the reference network of the Global Climate Observing System GCOS

Ning (GFZ) et al., Journal of Climate, 2016
GGOS shall benefit science and society by providing the foundations upon which advances in Earth science and applications are built.

Geodesy’s contribution to water research (global hydrology)
GRACE and GRACE-FO Twin Satellite Missions


GRACE-FO (NASA / GFZ, launched on May, 22\textsuperscript{nd}, 2018)

The twin Satellites are the Experiment!
GRACE Measurement Principle

\[ s = 220 \pm 50 \text{km} \]

Left: 1/rev separation change (primarily flattening of the Earth): \( \pm 2 \text{km} \)

Right: Observed mass change related distance variation: \( \pm 200 \mu \text{m} \)

\[ \sigma_s = \text{few } \mu \text{m} \]
(a tenth of the thickness of a human hair)

resp.

\[ \sigma_s / dt = 100 \text{nm/s} \]
Trends in Freshwater Availability from GRACE (2002-2015)

Antarctic ice sheet melting
Patagonia glaciers melting
Alaska glaciers melting
Greenland ice sheet melting
Southeastern U.S. drought
Central Valley, U.S. flooding
High Plains Aquifer groundwater depletion
Colombia glaciers melting
Peru glaciers melting
Orinoco and Amazon floods
Guarani Aquifer groundwater depletion
Patagonia glaciers melting

Midwest, U.S. flooding
Southwestern U.S. drought
North Africa groundwater depletion
North Africa Seas shrinking
North China Plain groundwater depletion
India/Bangladesh groundwater depletion
Indian monsoon
Mekong drought
NW Australia groundwater depletion

High latitude precipitation increase
Caspian/Aral Seas shrinking
Southwestern Africa groundwater depletion
Colombia glaciers melting
West Africa floods
Okavango floods
Ukraine drought

GGOS Days and SIRGAS Workshop 2019, Rio de Janeiro
GRACE-FO launch on May 22, 2018
Outlook and future perspectives

Maintain awareness of innovation and of technological developments relevant to geodesy

Example:
Using current developments in quantum technology, such as .... optical clocks for geodesy and geophysics, e.g. for height measurements
Future research tasks

Geodesy and metrology with transportable optical clocks

**Authors:** Jacopo Grotti, ..., Christian Voigt (GFZ), ...

*Nature Physics*, 12 Feb 2018, doi:10.1038/s41567-017-0042-3

Excellent agreement between height differences from clock and from conventional geodesy: 0.19 m, but clock accuracy still two orders of magnitude below geodesy
Observation/monitoring (ground-based, airborne, satellites)

Understanding & Prediction of the Earth System

New observation technologies

Processing

Improved observation

Monitoring products

Prediction

Integration, assimilation

Interpretation

Effect separation
Observation/monitoring (ground-based, airborne, satellites)

New observation technologies

Understanding & Prediction of the Earth System

Improved observation

Monitoring products

Processing

Integration, assimilation

Effect separation

Prediction

Interpretation

GGOS Days and SIRGAS Workshop 2019, Rio de Janeiro
Observation/monitoring (ground-based, airborne, satellites)

New observation technologies

Observation/monitoring (ground-based, airborne, satellites)

Improved observation

Monitoring products

Integration, assimilation

Effect separation

Prediction

Interpretation

Understanding & Prediction of the Earth System

GGOS Days and SIRGAS Workshop 2019, Rio de Janeiro
Observation/monitoring (ground-based, airborne, satellites)

Improved observation

Understanding & Prediction of the Earth System

New observation technologies

Processing

Monitoring products

Integration, assimilation

Effect separation

Prediction

Interpretation
Observation/monitoring (ground-based, airborne, satellites)

New observation technologies

Improved observation

Understanding & Prediction of the Earth System

Monitoring products

Integration, assimilation

Effect separation

Processing

Prediction

Interpretation

Quantification

Satellites

Big Data

Concepts/Methodology/Algorithm's

GGOS Days and SIRGAS Workshop 2019, Rio de Janeiro
Observation/monitoring (ground-based, airborne, satellites)

New observation technologies

Improved observation

Understanding & Prediction of the Earth System

Processing

Monitoring products

Integration, assimilation

Effect separation

Prediction

Interpretation
Observation/monitoring
(ground-based, airborne, satellites)

New observation technologies

Understanding & Prediction
of the Earth System

Processing

Monitoring products

Integration, assimilation

Improved observation

Effect separation

Interpretation

Prediction

Quantification

Big Data

Global phenomena

Geospatial information

Concepts/Methodology/Algorithms

Satellites
Observation/monitoring (ground-based, airborne, satellites)

Improved observation

New observation technologies

Understanding & Prediction of the Earth System

Processing

Monitoring products

Integration, assimilation

Effect separation

Prediction

Interpretation
Observation/monitoring (ground-based, airborne, satellites)

New observation technologies

Improved observation

Understanding & Prediction of the Earth System

Processing

Monitoring products

Integration, assimilation

Effect separation

Prediction

Interpretation
Welcome to the 28th IUGG General Assembly July 2023
Welcome to Berlin

City Cube Berlin – Venue for the 28th IUGG General Assembly
See You in Berlin in 2023, July 12-19
Thank you very much for your attention!
Conclusions

Most provoking challenges

- Reference Frames - Co- and post-seismic deformation models
- Gravity field - International Gravity Reference Frame (IGRF)
- Rotation & Geodyn. - Joint commissions with other associations
- Pos. & Applications - Atmosphere (iono- & troposphere) models
- Geodetic theory - Relativistic geodesy, new geodetic techniques
- GGOS - International Height Reference Frame (IHRS)
- - Essential geodetic variables
- - New GRS to replace GRS80
- Geometry Services - Reliable continuous ITRF
- Gravity Services - Recommended global gravity field model
- Combining Services - Adopt IAG resolutions ($W_0$)
- - Sea level variation model