Global Geodetic Observing System

http://www.ggos.org

Chair 2015–2017: Hansjörg Kutterer (Germany)
Chair 2017–2019: Richard Gross (USA)
Vice Chair: Ruth Neilan (USA))

As the observing system of the IAG, GGOS facilitates a unique and essential combination of roles centering upon advocacy, integration, and international relations. GGOS also promotes high-level outcomes, such as the realization of the International Terrestrial Reference Frame through developing and maintaining working relationships among a variety of internal and external groups and organizations.

GGOS Structure

The GGOS structure is illustrated in Figure 1. The decision-making entities are the Consortium, the Coordinating Board and its Executive Committee. Permanent Standing Committees and limited-term Working Groups are the thematic working bodies of GGOS and are distributed over two Bureaus, the Science Panel and the Focus Areas as well as affiliated organizations. In addition to being the Secretariat of GGOS, the Coordinating Office coordinates the activities of GGOS including communications and outreach and is responsible for the GGOS website and maintaining a presence on social media. The new position of Manager of External Relations resides within the Coordinating Office.

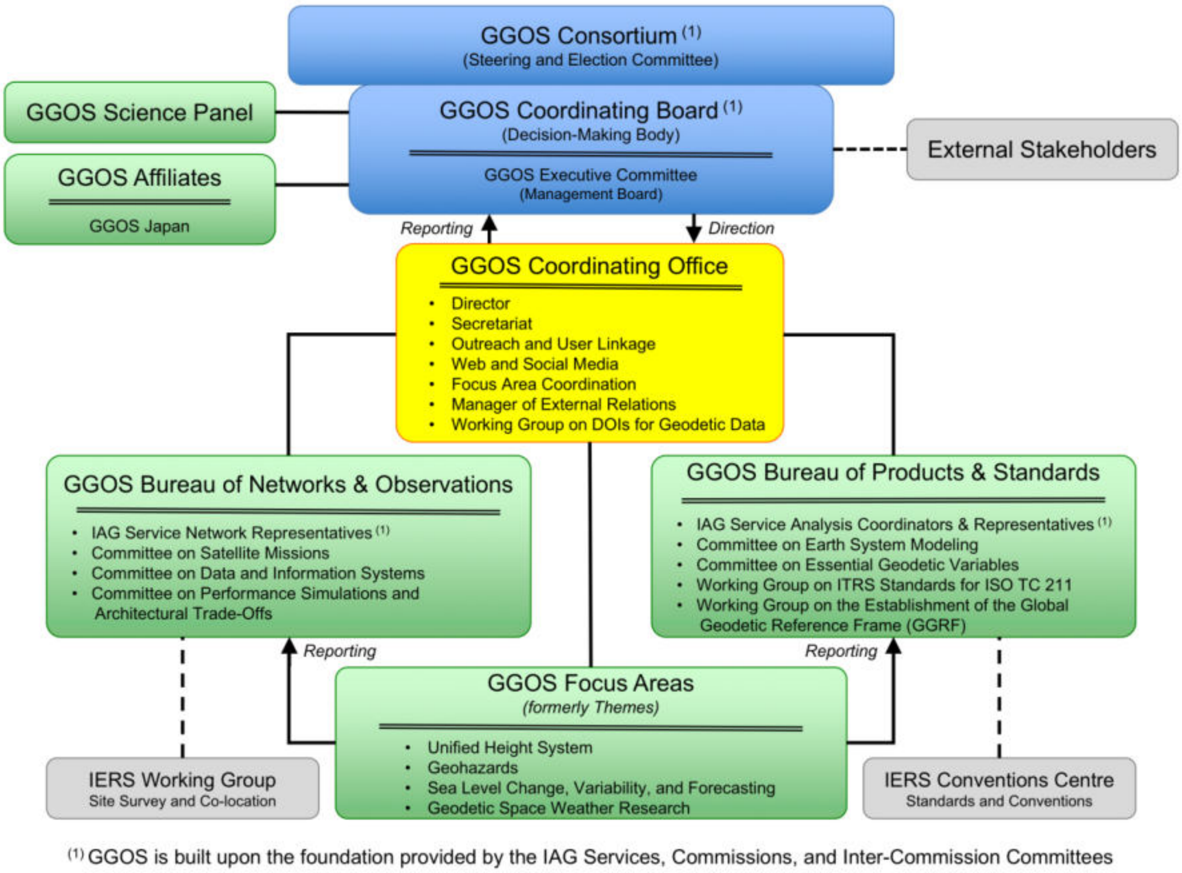

Figure 1. Organization chart of GGOS.

Overview

The 2015–2019 period was an active time of growth and organization within GGOS. A summary of the new activities that began during this time period is given below. A key activity touching on all elements of this overview was the revision and update of the GGOS Terms of Reference (ToR) in 2018 to reflect recent developments and strategic direction.

A new GGOS Focus Area on "Geodetic Space Weather Research" was established in 2017. The main objectives of the new Focus Area are to: (1) improve positioning and navigation by developing high-precision and high-resolution models of the electron density of the ionosphere, and to (2) improve satellite orbit determination by developing high-precision and high-resolution models of thermospheric drag.

As a mechanism to increase participation in GGOS, especially in the under-represented areas of Africa, Asia-Pacific, and South and Central America, a new component of GGOS, known as GGOS Affiliates, has been created. A GGOS Affiliate is a national or regional organization that coordinates geodetic activities in that nation or region. Once established, each GGOS Affiliate will have a representative to the GGOS Consortium and collectively they will have two representatives to the GGOS Coordinating Board. GGOS Japan, formerly known as the GGOS Working Group of Japan, became the first GGOS Affiliate in November 2017. GGOS Japan was established in 2013 and its current Chair is Prof. Toshi Otsubo of Hitotsubashi University. It provides a forum for multi-technique, space-geodetic discussions within Japan and works to improve the quality of its space-geodetic observations. GGOS Japan also encourages the different agencies in Japan that own, operate, and maintain the space-geodetic infrastructure there to collaborate with each other.

GGOS represents the IAG within the Group on Earth Observations (GEO) where it has been appointed to the GEO Programme Board for 2018–2020, GGOS participates in the Committee on Earth Observation Satellites (CEOS), and GGOS has a stake in the United Nations Global Geospatial Information Management (UN-GGIM) Subcommittee on Geodesy. Given the fundamental importance of GGOS participation in these external organizations and to better manage GGOS' involvement in them, the position of Manager of External Relations was created. Since the Manager of External Relations will coordinate GGOS engagement with external organizations, the position of Manager of External Relations resides within the Coordinating Office. The Manager of External Relations is a voting member of both the GGOS Coordinating Board and the GGOS Executive Committee. Allison Craddock became the first Manager of External Relations in January 2018.

Essential Geodetic Variables (EGVs) are observed variables that are crucial (essential) to characterizing the geodetic properties of the Earth and that are key to sustainable geodetic observations. Examples of EGVs might be the positions of reference objects (ground stations, radio sources), Earth orientation parameters, ground- and space-based gravity measurements, etc. Once a list of EGVs has been determined, requirements can be assigned to them. Examples of requirements might be accuracy, spatial and temporal resolution, latency, etc. These requirements on the EGVs can then be used to assign requirements to EGV-dependent products like the terrestrial and celestial reference frames. The EGV requirements can also be used to derive requirements on the systems that are used to observe the EGVs. A Committee within the Bureau of Products and Standards was established in order to define the list of Essential Geodetic Variables and to assign requirements to them. The Committee consists of representatives of the IAG Services, Commissions, Inter-Commission Committees, and GGOS Focus Areas. Richard Gross is the Chair of the Committee.

Consortium

The GGOS Consortium functions as the large steering committee and collective voice of GGOS, and is comprised of one representative from each GGOS Affiliate and up to two representatives from each IAG Service, Commission, and Inter-Commission Committee. According to the GGOS ToR, the Consortium membership is reviewed and refreshed every four years, which last took place coincident to the 2015 IUGG General Assembly. The members of the GGOS Consortium during 2015–2019 are given in Table 1.

The presiding chair of GGOS is also the chair of the GGOS Consortium. The GGOS Consortium meets annually, which during 2015–2019 took place during GGOS Days:

1. GGOS Days 2015, Frankfurt am Main, Germany, 21–23 October 2015
2. GGOS Days 2016, Boston, Massachusetts, USA, 24–27 October 2016
3. GGOS Days 2017, Vienna, Austria, 31 October to 02 November, 2017
4. GGOS Days 2018, Tsukuba, Japan, 02–05 October 2018

Table 1. Members of the GGOS Consortium During 2015–2019

Organization	**Name**	**Title**
GGOS	Hansjörg Kutterer Richard Gross	Chair (2015–2017) Chair (2017–2019)
GGOS Affiliate of Japan	Basara Miyahara	Designated GGOS Representative
International Gravimetric Bureau (BGI)	Sylvain Bonvalot	Director
International Gravimetric Bureau (BGI)	Sean Bruinsma	Designated GGOS Representative
Bureau international des poids et mesures, BIPM	Felicitas Arias	Director, BIPM Time Department
Bureau international des poids et mesures, BIPM	Gérard Petit	Principal Physicist, BIPM Time Department
International Centre for Global Earth Models (ICGEM)	Franz Barthelmes	Director
International DORIS Service (IDS)	Laurent Soudarin	Director, Central Bureau
International DORIS Service (IDS)	Pascal Willis	Chair, Governing Board
International Earth Rotation and Reference Systems Service (IERS)	Daniela Thaller	Director, Central Bureau
International Geoid Service (IGeS)	Mirko Reguzzoni	President
International Geoid Service (IGeS)	Giovanna Sona	Director
International Geoid Service (IGeS)	Urs Marti	Designated GGOS Representative
International Geoid Service (IGeS)	Jianliang Huang	Designated GGOS Representative
International Gravity Field Service (IGFS)	Riccardo Barzaghi	Chair
International Gravity Field Service (IGFS)	Georgios Vergos	Director, Central Bureau
International GNSS Service (IGS)	Ruth Neilan	Director, Central Bureau
International GNSS Service (IGS)	Gary Johnston	Chair, Governing Board
The International Laser Ranging Service (ILRS)	Giuseppe Bianco	Chair, Governing Board
The International Laser Ranging Service (ILRS)	Erricos Pavlis	Analysis Coordinator
International VLBI Service for Geodesy and Astrometry (IVS)	Axel Nothnagel	Chair, Directing Board

International VLBI Service for Geodesy and Astrometry (IVS)	Dirk Behrend	Director, Coordinating Center
Permanent Service for Mean Sea Level (PSMSL)	Lesley J. Rickards	Director
Permanent Service for Mean Sea Level (PSMSL)	Mark Tamisiea	Designated GGOS Representative
International Geodynamics and Earth Tides Service (IGETS)	Jean-Paul Boy	Director, Central Bureau
International Geodynamics and Earth Tides Service (IGETS)	Christoph Foerste	Designated GGOS Representative
International Geodynamics and Earth Tides Service (IGETS)	Alexander Kopaev	Designated GGOS Representative
Commission 1: Reference Frames	Geoff Blewitt	President
Commission 1: Reference Frames	Johannes Böhm	Vice President
Commission 1: Reference Frames	Tonie van Dam	Designated GGOS Representative
Commission 2: Gravity Field	Roland Pail	President
Commission 2: Gravity Field	Shuanggen Jin	Vice President
Commission 3: Earth Rotation and Geodynamics	Manabu Hashimoto	President
Commission 3: Earth Rotation and Geodynamics	Chengli Huang	Vice President
Commission 4: Positioning and Applications	Marcelo Santos	President
Commission 4: Positioning and Applications	Allison Kealy	Vice President
Inter-Commission Committee on Theory (ICCT)	Pavel Novák	President
Inter-Commission Committee on Theory (ICCT)	Mattia Crespi	Vice President
Inter-Commission Committee on Theory (ICCT)	Dimitrious Tsoulis	Designated GGOS Representative

Coordinating Board

The Coordinating Board is the decision-making body of GGOS. The members of the GGOS Coordinating Board during 2015–2019 are given in Table 2.

The Chair of GGOS is the Chair of the Coordinating Board. The Coordinating Board meets twice-per-year, which during 2015–2019 took place during GGOS Days and the Saturday before EGU:

1. GGOS Days 2015; Frankfurt am Main, Germany; 21–23 October 2015
2. EGU; Vienna, Austria; 16 April 2016
3. GGOS Days 2016; Boston, Massachusetts, USA; 24–27 October 2016
4. EGU; Vienna, Austria; 22 April 2017
5. GGOS Days 2017; Vienna, Austria; 31 October to 02 November, 2017
6. EGU; Vienna, Austria; 07 April 2018
7. GGOS Days 2018; Tsukuba, Japan; 02–05 October 2018
8. EGU; Vienna, Austria; 06 April 2019

Table 2. Members of the GGOS Coordinating Board During 2015–2019

Position	**Voting**	**Name**
Chair	Yes	Hansjörg Kutterer (2015–2017) Richard Gross (2017–2019)
Vice Chair	Yes	Ruth Neilan
Chair, Science Panel	Yes	Richard Gross (2015–2017) Kosuke Heki (2017–2019)
Director, Coordinating Office	Yes	Allison Craddock (2015–2016) Günter Stangl (2016–2017) Matthias Madzak (2017–2018) Helmut Titz (2018–2019)
Manager, External Relations	Yes	Allison Craddock
Director, Bureau of Networks & Observations	Yes	Mike Pearlman
Director, Bureau of Products & Standards	Yes	Detlef Angermann
Representative, GGOS Affiliates	Yes	Toshi Otsubo
Representative, IAG President	Yes	Richard Gross (2015–2017) Zuheir Altamimi (2017–2019)
Representative, IAG Services	Yes	Riccardo Barzaghi
Representative, IAG Services	Yes	Ruth Neilan
Representative, IAG Services	Yes	Christoph Foerste
Representative, IAG Services	Yes	Urs Marti
Representative, IAG Commissions and ICCT	Yes	Pavel Novák
Representative, IAG Commissions and ICCT	Yes	Roland Pail
Member-at-Large	Yes	Ludwig Combrinck
Member-at-Large	Yes	Luiz Paulo Fortes
Member-at-Large	Yes	Gary Johnston
Chair, Standing Committee on Satellite and Space Missions	No	Roland Pail
Chair, Standing Committee on Data and Information Systems	No	Allison Craddock (2015–2016) Günter Stangl (2016–2017) Matthias Madzak (2017–2018) Helmut Titz (2018–2019)
Chair, Standing Committee on Contribution to Earth System Modelling	No	Maik Thomas
Chair, GGOS Committee/IAG WG on PLATO	No	Daniela Thaller
Chair, JWG on Establishment of the GGRF	No	Urs Marti
Chair, WG on ITRS Standards	No	Claude Boucher
Lead, Focus Area on Unified Height System	No	Laura Sanchez
Lead, Focus Area on Geohazards	No	John LaBrecque
Lead, Focus Area on Sea Level	No	Tilo Schöne (2015–2018)
Lead, Focus Area on Geodetic Space Weather Research	No	Michael Schmidt
Manager, GGOS Web and Social Media	No	Allison Craddock (2015–2016) Günter Stangl (2016–2017) Matthias Madzak (2017–2018) Helmut Titz (2018–2019)
Immediate Past Chair of GGOS	No	Markus Rothacher (2015–2017) Hansjörg Kutterer (2017–2019)
Representative, GIAC/GIC*	No	Per Erik Opseth (2015–2016)

* Please note that GIAC was terminated at the end of 2016, so all references to GIAC or GIC are purely for historical purposes.

Executive Committee

The Executive Committee of the GGOS Coordinating Board serves at the direction of the Coordinating Board to accomplish the day-to-day activities of the tasks of GGOS. The members and guest observers of the Executive Committee during 2015–2019 are given in Table 3.

The Chair of GGOS is the Chair of the Executive Committee. The Executive Committee holds monthly conference calls and meets face-to-face during the meetings of the Coordinating Board (see above).

Table 3. Members of the GGOS Executive Committee During 2015–2019

Position	**Status**	**Name**
Chair	Member	Hansjörg Kutterer (2015–2017) Richard Gross (2017–2019)
Vice Chair	Member	Ruth Neilan
Director, Coordinating Office	Member	Allison Craddock (2015–2016) Günter Stangl (2016–2017) Matthias Madzak (2017–2018) Helmut Titz (2018–2019)
Manager, External Relations	Member	Allison Craddock
Director, Bureau of Networks & Observations	Member	Mike Pearlman
Director, Bureau of Products & Standards	Member	Detlef Angermann
Representative, IAG Services	Member	Riccardo Barzaghi
Representative, IAG Commissions	Member	Pavel Novák
Immediate Past Chair of GGOS	Guest	Markus Rothacher (2015–2017) Hansjörg Kutterer (2017–2019)
Chair, Science Panel	Guest	Richard Gross (2015–2017) Kosuke Heki (2017–2019)
Representative, IAG President	Guest	Richard Gross (2015–2017) Zuheir Altamimi (2017–2019)
Representative, GIAC/GIC*	Guest	Per Erik Opseth (2015–2016)

* Please note that GIAC was terminated at the end of 2016, so all references to GIAC or GIC are purely for historical purposes.

GGOS Coordinating Office

Director: *Helmut Titz (Austria)*
Manager of External Relations: *Allison Craddock (USA)*

Members: *Martin Sehnal (Austria)*

Purpose and Scope

The GGOS Coordinating Office (CO) serves as a centralized administrative and organisational entity and interacts with the GGOS Bureaus and Focus Areas for organisational matters. The CO performs the day-to-day activities and generates reports in support of the various components of GGOS especially the GGOS Executive Committee and the GGOS Coordinating Board. The CO ensures information flow, maintains and archives documentation and in its long-term coordination role ensures consistency and continuity in the contributions of the GGOS components. The CO implements and operates the GGOS website and outreach.

The Manager of External Relations connects GGOS with external organisations.

The Director of the CO and the Manager of External Relations are both ex-officio members of the GGOS Coordinating Board and GGOS Executive Committee.

History

The GGOS Coordinating Office has been transitioned twice in the period of 2015 – 2019 and there have been 5 directors of the CO.

- Until 04/2015: Giuseppe Bianco (ASI, Italy)
- 05/2015 – 04/2016: Allison Craddock (BKG, Germany)
- 05/2016 – 08/2017: Günter Stangl (BEV, Austria)
- 09/2017 – 11/2018: Matthias Madzak (BEV, Austria)
- 12/2018 onwards: Helmut Titz (BEV, Austria)

ASI: Agenzia Spaziale Italiana
BKG: Bundesamt für Kartographie und Geodäsie
BEV: Bundesamt für Eich- und Vermessungswesen

The position of the GGOS Manager of External Relations was officially approved at the Vienna GGOS Days in October 2017. Allison Craddock of the NASA Jet Propulsion Laboratory was elected to serve as the Manager of External Relations in January 2018.

Activities and Actions

Day-to-day activities and organisational matters

- Communicate with all entities of GGOS by sending and answering on emails
- Organizing GGOS Executive Committee Teleconferences
- Creating posters, brochures, logos, images and templates
- Collecting/Distributing reports
- Meeting preparation

GGOS website / GGOS.ORG Domain-Transfer

In September 2016 the BEV installed a server system for the implementation and operation of the new GGOS website. In Mai 2017 the official GGOS website www.ggos.org was shifted from ASI to BEV. Nevertheless it took another 2 years to finally complete the transfer of the ggos.org domain successfully to the BEV in February 2019. The new GGOS website was built from scratch while maintaining key items and historical resources. The webpages are maintained decentral by the different GGOS components using the DJANGO content management system. The CO is responsible for assigning usernames and access permissions for specific pages to the responsible persons and helps to set up the webpages and subpages. Links to the IAG Services, to metadata, datacentres and products have been established.

GGOS cloud server

An online cloud storage on the GGOS server has been installed and set operational on September 2017 temporary using the ggosdays.com domain name, as the official ggos.org domain was not accessible at that time. This cloud storage is based on the OwnCloud software. It is used for external (public) file distribution as well as internal file sharing. 28 personal user logins and 6 groups have been created and activated. Nevertheless the cloud storage has been rarely used.

Online Meetings Calendar

A Google Calendar was created to be able to view a timeline of the major internal and external meetings that may be interesting for GGOS. The calendar can be viewed on the GGOS website or be imported to other applications using iCal.

GGOS social media presence via Twitter

A GGOS Twitter account named @IAG_GGOS was created to be present in the social media and to speed up dissemination of GGOS-related information to the customers.

Online-Voting Tool

In order to use online voting possibilities more professionally, an account on surveymonkey.com was created and several GGOS internal elections were already performed online.

Conference attendance

- European Geosciences Union (EGU) (2015, 2016, 2017, 2018, 2019)
- American Geophysical Union (AGU) (2016, 2017)
- GGOS Days (2016, 2017, 2018)
- International Association for Geodesy (IAG/IASPEI) (2017)
- Group on Earth Observations (GEO) (2016, 2017)

GGOS External Relations

The position of GGOS Manager of External Relations was officially approved at the Vienna GGOS Days in October 2017.

Group on Earth Observations (GEO)

GROUP ON EARTH OBSERVATIONS

GGOS represents the IAG in the Group on Earth Observations (GEO), contributing to the GEO Foundational Task **GEOSS In-Situ Earth Observation Resources.** This task conducted a survey of existing in-situ Earth observing systems as a first step towards identifying gaps in the available observations. Gross participated in this survey by describing IAG's geodetic observing networks. In addition, IAG/GGOS has been selected to be a member of the **GEO Programme Board during 2018-2020**, with Gross being the Principal Representative and Craddock as Alternate Representative of IAG/GGOS to the Programme Board. IAG/GGOS is now one of 32 members of the Programme Board for the next 3 years and will have a voice in steering the activities of GEO.

Within the Programme Board, Gross has participated on behalf of IAG/GGOS in the **Subgroup on Sustainable Earth Observations**, which works in tandem with the GEOSS In-Situ Earth Observation Resources foundational task to assess the current Foundational Tasks focusing on both GEOSS Satellite and In-Situ Earth Observation Resources, and to evaluate strengths and weaknesses of observing systems for GEO's activities over the past decade, and to clarify the challenges in coordination of in-situ observations as well as in integrating in-situ and satellite observations toward coordinated observation systems in the future to implement GEOSS.

Also under the auspices of the Programme Board, Craddock has participated on behalf of IAG/GGOS in the **Subgroup on the Sendai Framework**. This subgroup supports GEO's strategic engagement priority area on the Sendai Framework for Disaster Risk Reduction, in the realm of championing and supporting the development of policy objectives that add value, drive efficiencies, and promote the uptake of Earth observations in alignment with Sendai and other disaster risk reduction initiatives. This is particularly relevant to supporting the **GGOS Geohazards Focus Area and its Global Navigation Satellite System to Enhance Tsunami Early Warning Systems (GTEWS)**.

GGOS also participates in the **GEO Communicators Network**, which was established in November 2017 as a means to connect communications professionals supporting earth observations, open data, and other initiatives such as UN SDGs. As a collaborative function of the Coordinating Office Director and Manager of External Relations, GGOS social media has interacted with GEO and other stakeholders through twitter posting, "liking" and re-posting. Through the GEO Communicators Network, GGOS supports relevant messages on social media with the GEO-led or supported hashtag campaigns

Participation at the Programme Board level ensures that IAG/GGOS efforts in alignment with GEO's global priorities (supporting the UN SDGs, Sendai Framework, as well as the Paris Agreement on Climate Change) are well supported and complimentary to other related work – as well as preventing unnecessary redundancy of work. Geodetic observations have a clear role in helping to reduce the risk of disasters, as well as contribute to disaster preparedness with better mitigation and response. Earth observations also play a major role in monitoring progress toward, and achieving, the SDGs.

Committee on Earth Observation Satellites (CEOS)

GGOS has participated in CEOS Plenaries, discussing what GGOS might need from participation in CEOS as an Agency/Partner Update. This is an opportunity for GGOS to speak about its plans and strategies in relation to CEOS, as well as the benefits and expectations of CEOS from the GGOS perspective.

GGOS has renewed its engagement with CEOS by appointing the Manager of External Relations as the GGOS representative to their **Ad Hoc Team on the Sustainable Development Goals** (AHT SDG), which highlights the potential role for Earth observations in supporting the global indicator framework of the United Nations Sustainable Development Goals. AHT SDG works closely with GEO (through the collaborative EO4SDG campaign) to highlight the numerous applications of Earth observations that provide data critical to monitoring progress toward the SDGs, and thereby further illustrate the immediate and secondary values of Earth observation data.

UN GGIM Subcommittee on Geodesy

GGOS supports and, as needed, represents the IAG at the United Nations Committee of Experts on Global Geospatial Information Management (UN GGIM). Harald Schuh, Mike Pearlman represented the IAG at the most recent session of the GGIM in New York (August 2018), and the meetings of the Sub-Committee on Geodesy (SCoG), to provide stability and long-term planning for the GGRF. As the work of the Subcommittee transitions from ideological to implementation-based, especially in the realm of member states making commitments for infrastructure or other contributions, IAG/GGOS participation within both the member state Delegations as well as IAG observers will be important to ensure best possible support of this initiative.

For more information, please visit the UN-GGIM website:
http://ggim.un.org/UN_GGIM_wg1.html.

Numerous GGOS Consortium members were active in the UN GGIM SCoG on behalf of the IAG this past year:

- Harald Schuh, IAG; SCoG Working Group on Governance
- Detlef Angermann, IAG; SCoG Working Group on Policy, Standards, and Conventions

GGOS Consortium members also participate on behalf of their member state (country) and in consultation with GGOS External Relations, including:

- Richard Gross, USA; SCoG Working Group on Governance
- Allison Craddock, USA; SCoG working Group on Communications and Outreach, Working Group on Education, Training and Capacity Building
- Gary Johnston, Australia; SCoG Co-chair

Pilot External Relations Project: Connecting GGOS with the United Nations Sustainable Development Goals and Sendai Framework for Disaster Risk Reduction

There is tremendous potential to increase the exposure and impact of GGOS by identifying potential contributions and connecting existing relevant work to efforts in support of both UN SDGs and the Sendai Framework. GGOS has the potential to facilitate linkages to agencies and other providers of geodetic data, make existing geodetic data discoverable and easily accessible, and to work toward standardization.

Connecting United Nations Initiatives with the GGOS Geohazards Focus Area through the GAR19 Report

The first External Relations Project, proposed in October 2017, sought to support the wide reach of the GATEW initiative by identifying numerous clear alignments with United Nations Sustainable Development Goals (SDGs) and Sendai Framework for Disaster Risk Reduction. The Manager of External Relations has worked with John LaBrecque, Lead of the Geohazards Monitoring Focus Area, to brainstorm strategies for aligning our work in natural hazards with the United Nations SDGs and Sendai Framework. These two prominent initiatives can clearly benefit from the focus group's involvement, will make GGOS more visible to organizations such as GEO, CEOS, and the UN, and could potentially lead to greater participation in GATEW/GTEWS and other GGOS efforts.

GATEW/GTEWS successfully submitted a chapter/paper for the 2019 UN Global Assessment Report on Disaster Risk Reduction (GAR19), which is a major UN report addressing disaster risk reduction that contributes to regional and global platforms for disaster risk reduction, as well as the high-level political forum on sustainable development.

> *The [2019] GAR will provide: a) an update on global progress made in implementing the outcome, goal, targets and priorities of the Sendai Framework and disaster-related Sustainable Development Goals (SDGs), b) current and future risk trends introducing systemic risk perspectives as represented in the forthcoming Global Risk Assessment Framework (GRAF), c) cutting edge, innovative research and practice in disaster risk management and good practice on how to manage and reduce disaster risks, and d) an introduction to the wider scope and systemic nature of hazards to be considered in implementing the Sendai Framework.*
>
> *Developed through an extensive set of partnerships with international organizations, governments, businesses, academic and research institutions, the GAR is both an ongoing process of evidence generation and policy engagement, and a product – in the form of a biennial report published by the UNISDR. The process contributes directly to greater access to risk information for decision-making, and identifies feasible practices that can be employed at the local, national, regional and international levels.*

The complete GAR19, published in May of 2019, is available to download here:
https://gar.unisdr.org/sites/default/files/reports/2019-05/full_gar_report.pdf

Future Connections

As GGOS connections with the SDGs and Sendai Framework mature, more opportunities to support these initiatives will become available. GGOS External Relations will pursue the most relevant and impactful avenues to ensure that IAG/GGOS enables the greatest use of geodetic data in support of these United Nations initiatives and beyond.

GGOS Affiliate
GGOS Japan

Chair: *Toshimichi Otsubo (Japan)*
Secretary: *Basara Miyahara (Japan)*

Background

The GGOS Working Group of Japan was established in 2013 under IAG Subcommittee of Science Council of Japan to strengthen the collaboration among space geodesy agencies in Japan and to get connected to international organizations. It was approved to become the first "GGOS Affiliate" in 2017 and renamed as "GGOS Japan" in 2019.

Activities 2015-2019

GGOS Japan has proposed or been involved in a number of science sessions on global geodesy in domestic meetings (Meetings of Geodetic Society of Japan, JpGU) and international meetings (IAG, AGU, IUGG etc). It regularly hosted its own meetings in Japan. In addition, here is the list of what it has achieved in the 2015-2019 period.

2014-2016: GSI's VLBI station modernization and relocation from Tsukuba to Ishioka.
May 2016: New Chair: T Otsubo (was S Matsuzaka), Secretary: B Miyahara (was T Otsubo).
August 2017: Updated the GGOS station list (7 stations of 6 institutes) of Japan whose first version was submitted in 2014.
October 2017: Became the first GGOS Affiliate. T Otsubo appointed as GGOS CB Member and B Miyahara as Consortium Member.
March-April 2018: Published the GGOS special issue in Journal of the Geodetic Society of Japan (written in Japanese); 14 papers in Issues 2 and 3, Volume 63.
May-July 2018: Issued and printed its leaflet.
June 2018: K Heki appointed as Science Panel Chair of GGOS.
October 2018: Cohosted GGOS Days 2018.
Summer-Autumn 2019 (planned): Set up its website under ggos.org.
May 2020 (planned): Propose a GGOS-related session in JpGU+AGU joint meeting.

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GGOS Science Panel

Chair: Kosuke Heki (Japan)

Members:
- *M. Rothacher (Switzerland)*
- *G. Blewitt (USA)*
- *T. Gruber (Germany)*
- *J. Chen (USA)*
- *J. Ferrandiz (Spain)*
- *J. Wickert (Germany)*
- *P. Wielgosz (Poland)*
- *Y. Tanaka (Japan)*
- *M. Crespi (Italy)*
- *B. Heck (Germany)*
- *D. Melgar (USA)*
- *D. Chambers (USA)*
- *E. Forootan (UK/Germany)*

Purpose and Scope

The GGOS Science Panel is a multi-disciplinary group of experts representing the geodetic and relevant geophysical communities that provides scientific advice to GGOS in order to help focus and prioritize its scientific goals. The Chair of the Science Panel is a member of the Coordinating Board and a permanent guest at meetings of the Executive Committee. This close working relationship between the Science Panel and the governance entities of GGOS ensures that the scientific expertise and advice required by GGOS is readily available.

Activities and Actions

The Science Panel provides scientific support to GGOS. During the 2015-2019 quadrennium this support included participation in Consortium, Coordinating Board, and Executive Committee meetings and conference calls.

The Science Panel has been actively promoting the goals of GGOS by helping to organize GGOS sessions at major scientific conferences. During the 2015-2019 quadrennium, GGOS sessions have been organized at:

- 2015 American Geophysical Union Fall Meeting in San Francisco
- 2016 American Geophysical Union Fall Meeting in San Francisco
- 2017 American Geophysical Union Fall Meeting in New Orleans
- 2018 American Geophysical Union Fall Meeting in Washington DC
- 2015 Asia Oceania Geosciences Society Annual Meeting in Singapore
- 2016 European Geosciences Union General Assembly in Vienna
- 2017 European Geosciences Union General Assembly in Vienna
- 2018 European Geosciences Union General Assembly in Vienna
- 2019 European Geosciences Union General Assembly in Vienna

- 2017 Japan Geophysical Union – American Geophysical Union Joint Meeting in Chiba, Japan
- 2018 Japan Geoscience Union Meeting in Chiba, Japan
- 2017 International Association of Geodesy – International Association of Seismology and Physics of the Earth's Interior Joint Scientific Assembly in Kobe, Japan

In addition to helping organize sessions at scientific conferences, the GGOS Science Panel also organizes topical science workshops in order to foster discussion about the geodetic observations and infrastructure required by different scientific disciplines. One such workshop was organized during 2015-2019 as the *IAU/IAG/IERS Joint Symposium on Geodesy, Astronomy, & Geophysics in Earth Rotation* held in Wuhan, China during 18-23 July 2016.:

International Symposium on Geodesy, Astronomy, and Geophysics in Earth Rotation (GAGER2016), Wuhan, China; 19-23 July 2016

The rotation of the Earth varies continuously, in both its rate of rotation and in the orientation of its axis with respect to either crust-fixed or space-fixed reference frames. Its study links together the fields of Geodesy, Astronomy and Geophysics. In this Symposium, over 50 participants from Asia, Europe, and the Americas met in Wuhan, China to assess our current ability to observe the Earth's time varying rotation, to assess our current understanding of the causes of the observed variations, to assess the consistency of Earth rotation observations with global gravity and shape observations, to explore methods of combining Earth rotation, gravity, and shape observations, and to identify improvements in the global geodetic observing system needed to further our understanding of the Earth's variable rotation. Peer-reviewed proceedings of the Symposium will be published as a special issue of *Geodesy and Geodynamics*.

Unified Analysis Workshops are co-organized by the International Association of Geodesy's Global Geodetic Observing System (GGOS) and International Earth Rotation and Reference Systems Service (IERS). The 2017 Workshop was the 5th in a series of workshops that are held every two years for the purpose of discussing issues that are common to all the space-geodetic measurement techniques. Attendance at the Workshops are by invitation only with each IAG Service nominating 5-6 experts to attend and participate in the discussion.

Unified Analysis Workshop, Paris, France; 10-12 July 2017

At the 2017 Workshop the discussion focused on (1) Systematic errors and biases in GNSS observations, (2) Systematic errors and biases in VLBI observations, (3) Systematic errors and biases in SLR observations, (4) Systematic errors and biases in DORIS observations, (5) Site survey and co-location, (6) Reference systems and frames, (7) Conventional mean pole, (8) Standards, conventions, and formats, and (9) Interoperability of portals and metadata.

Objectives and Planned Efforts for 2019-2023 and Beyond

During the next quadrennium the Science Panel will continue to participate in Consortium, Coordinating Board, and Executive Committee meetings and conference calls. In addition, the Science Panel will continue to help organize GGOS sessions at conferences and symposia including:

- American Geophysical Union Fall Meetings
- Asia Oceania Geosciences Society Annual Meetings
- European Geosciences Union General Assemblies
- International Association of Geodesy General and Scientific Assemblies

A GGOS session is also planned in the 2020 JPGU-AGU joint meeting in Chiba, Japan, as we did in 2017. The next Unified Analysis Workshop will be held in Paris, France during 02-04 October, 2019 (also planned in 2021, detail to be determined).
The Science Panel will also continue to organize topical science workshops in order to determine the requirements that different scientific disciplines have for geodetic data and products.

With the GGOS Bureau of Products and Standards, the Science Panel will help conduct a Gap Analysis to identify the gap between the data and products provided by the IAG and the needs of the user community. As part of this analysis, a list of Essential Geodetic Variables (EGVs) will be compiled along with observational requirements on those variables. This list of EGVs and their observational requirements can then be used to determine requirements on derived products like the terrestrial reference frame. The Science Panel convened sessions on EGV in the 2018 AGU Fall Meeting and the 2019 EGU General Assembly. Activities related to EGV will continue in the newly established committee on EGV, which includes the whole Science Panel members.

GGOS Bureau of Networks and Observations

Prepared by Michael Pearlman, Carey Noll, Erricos C. Pavlis, Frank Lemoine, Daniela Thaller, Guenter Stangl, Jürgen Müller, Benjamin Männel, and Sten Bergstrand

Membership

Standing Committees affiliated with this Bureau:

- GGOS Standing Committee on Satellite Missions
- GGOS Standing Committee on Data and Information Systems
- GGOS Standing Committee on Performance Simulations and Architectural Trade-Offs (PLATO)
- IERS Working Group on Survey and Co-location

Associated Members and Representatives:

- Director (Mike Pearlman/CfA USA)
- Secretary (Carey Noll/NASA USA)
- Analysis Specialist (Erricos Pavlis/UMBC USA)
- IERS Representative (Sten Bergstrand/BIPM France)
- Representatives from each of the member Services:
  - IGS (Allison Craddock/JPL USA, Gary Johnston/GA/Australia)
  - ILRS (Toshi Otsubo/Hitotsubashi U. Japan, Wu Bin/SHAO China)
  - IDS (Jérôme Saunier/IGN France, Pascale Ferrage/CNES France)
  - IVS (Hayo Hase/BKG Germany, Dirk Behrend/NASA USA)
  - IGFS (Riccardo Barzaghi/PM Italy, George Vergos/UT Greece)
  - PSMSL (Lesley Rickards/BODC UK, Tilo Schone/GFZ Germany)
- Representatives from each of the member Standing Committees:
  - PLATO (Daniela Thaller/BKG Germany, Benjamin Maennel/GFZ Germany)
  - Data and Information Systems (Guenter Stangl, Matthias Madzak/BEV Austria, Carey Noll/NASA USA)
  - Satellite Missions (Jürgen Müller/IfE Germany, Roland Pail/TUM Germany)
  - IERS Working Group on Survey Ties and Co-location (Sten Bergstrand/BIPM France)

Activities, Actions, and Publications during 2015-2019

Activities

The Bureau:

- Continued to provide a forum for the Services and Standing Committees/Working Groups to share and discuss plans, progress, and issues, and to develop and monitor multi-entity efforts to address GGOS requirements; meetings are held in conjunction with AGU and EGU each year; material from the meetings are posted on the GGOS website.
- Continued the Bureau's "Call for Participation in the Global Geodetic Core Network: Foundation for Monitoring the Earth System" and work with new potential groups interested in participating; a total of 19 submissions have been received covering 114 sites that included legacy core sites, legacy/new technology co-location sites, core and co-location sites under development, and sites offered for future participation; a summary of the CfP responses is available on the Bureau's website. A number of other new stations will join once they are operational.

Several new stations have joined or are in the process of joining the network during this period. Correspondence has been underway with ROSCOSMOS regarding their formal joining in the network, but their stations have been regular participants. Certificates of participation have been sent out to network sites.

- Continued to advocate for new and increased network participation, encouraging formation of new partnerships to develop new sites, monitored the status of the networks; held meetings and communications with representatives from Russia, Italy, Brazil, Japan, Spain, France, and Saudi Arabia to discuss implementation of new stations and upgrade of legacy stations.

  The BN&O has been advocating for enhanced network infrastructure for Latin America; participated in the UNGGIM Meeting on the Americas at the UN in August 2018; plans to participate in the SIRGAS meeting in Rio de Janeiro in November.

- Supported efforts for the integration of various ground observation networks within the GGOS affiliated Network; continued to maintain and update the "Site Requirements for GGOS Core Sites" document (with the IAG Services); the next major step will be to include the requirements for the gravity field once it is fully documented by the IGFS and the IGRF working group; work with the IGFS in the definition of its requirements.
- Continued to promote and advocate for GGOS and the GGOS integrated global geodetic ground-based infrastructure through talks and posters at AGU, EGU, AOGS, APSG (China), JpGU-AGU, IAG, etc. and meetings and special presentations at GSI (Japan), IMPE (Brazil), IAP (Russia), etc.; supported efforts to integrate relevant parameters from other ground networks (gravity field, tide gauges, etc.) into the GGOS network to support GGOS requirements.
- Continued to maintain and update the inventory/repository of current and near-future satellite missions, highlighting those of most interest to GGOS; continued advocating for new advocating new missions; wrote letters of support for the E-GRASP/Eratosthenes proposals; need to stress greater cooperation between the PLATO and Missions Standing Committees. More details are provided in the Missions Standing Committee section below .
- Provided simulations and analyses to estimate how the data products will improve over time as the infrastructure improves. The results from the periodic network surveys will be used to project network data quality capability 5 and 10 years ahead. Simulations on the e-GRASP/Eratosthenes mission and other co-location missions to strengthen the case for support and for network planning. More detail is provided in the Standing Committee on Performance Simulations & Architectural Trade-Offs (PLATO) section below.
- Continued development and implementation of a GGOS metadata system in two stages: a stage-one scheme (hosted by CDDIS) for GGOS and GGOS-relevant data and a longer term, stage-two implementation, for the full GGOS requirements including site and instrument information, based on an XML metadata scheme under development by the Geoscience Australia, UNAVCO, and the IAG. Additional details are provided in the Data and Information Standing Committee section below.
- Continued working on the establishment of a common terminology for all space geodesy techniques, a terminology which is also valid outside the space geodetic community; the DORIS community has adapted a common terminology, and improved its surveying procedures as well as communication of the results. The IGS terminology has done the same, but there are differences among the techniques; continued working on outreach to increase local survey participation and standardization. More details are provided in

the IERS Working Group on Survey Ties and Co-Location (see IERS Section of the Travaux Report).

Related Bureau Documentation:

As part of the network activity, the Bureau has facilitated the creation of several key documents; these documents will be made available on the GGOS website in the near future.

- “GGOS Site Requirements for Fundamental Stations” document.
- A guidelines document for site characterization of the GGOS network sites was developed, “The Global Geodetic Core Network: Foundation for Monitoring the Earth System”.
- A plan to define the process by which GGOS determines the extent of the needed infrastructure, including the scope and specification of the network, conditioned on the existing or plausible technology available, “GGOS Infrastructure Implementation Plan”.
- A plan to assess the current and future plans for a GGOS core network, including projections five to ten years in the future, “Space Geodesy Network Model”.
- Documents developed within the context of NASA’s Space Geodesy Project, evaluating several sites as potential core sites; these documents are available from the SGP website at:
  https://space-geodesy.nasa.gov/documentation/Project_Documentation.html
- A summary report issued from the TLS (Terrestrial Laser Scanner) Workshop that was held at NASA GSFC, September 08-10, 2008.

Websites: http://www.ggos.org/en/bureaus/bno/

Publications and Presentations

M. Pearlman, C. Ma, C. Noll, E. Pavlis, H. Schuh, T. Schoene, R. Barzaghi, S. Kenyon, “The GGOS Bureau of Networks and Observations and an Update on the Space Geodesy Networks”, Abstract EGU2015-7420, presented at EGU 2015 General Assembly, April 13-17, 2015, Vienna, Austria, April 12-17, 2015.

M. Pearlman, E. Pavlis, C. Ma, C. Noll, D. Thaller, B. Richter, R. Gross, R. Neilan, J. Mueller, R. Barzaghi, S. Bergstrand, J. Saunier, M. Tamisiea, “Update on the Activities of the GGOS Bureau of Networks and Observations”, Abstract No. 10095. Presented at European Geosciences Union General Assembly, April 17-22, 2016.

C. Noll, “GGOS: Global Geodetic Observing System”, presented at 2016 WDS Members’ Forum, Denver, Colorado, September 11, 2016.

G. Stangl, C. Noll, “GGOS: The Global Geodetic Observing System” (poster), presented at 2016 WDS Members’ Forum, Denver, Colorado, September 11, 2016.

M. Pearlman, C. Noll, C. Ma, E. Pavlis, R. Neilan, J. Saunier, T. Schoene, R. Barzaghi, D. Thaller, S. Bergstrand, J. Mueller, “The GGOS Bureau of Networks & Observations: An Update on the Space Geodesy Network & the New Implementation Plan for 2017-2018”, Abstract No. EGU2017-10698, presented at European Geosciences Union General Assembly 2017, Vienna, Austria, April 24-28, 2017.

M. Pearlman, H. Schuh, D. Angermann, C. Noll, “The Global Geodetic Observing System (GGOS) – Its Role and Its Activities”. JpGU-AGU Joint Meeting, Chiba, Japan, May 22-26, 2017.

M. Pearlman, C. Ma, R. Neilan, C. Noll, E. Pavlis, J. Saunier, T. Shoene, R. Barzaghi, D. Thaller, S. Bergstrand, J. Mueller, “The GGOS Bureau of Networks and Observations: Activities and Plans”. Presented at IAG-IASPEI, Kobe, Japan, July 30-August 04, 2017.

Merkowitz, S.M., Bolotin, S., Elosegui, P. et al., Modernizing and expanding the NASA Space Geodesy Network to meet future geodetic requirements, J Geod (2018), doi: https://doi.org/10.1007/s00190-018-1204-5

M. Pearlman, J. Gipson, G. Johnston, C. Noll, E. Pavlis, J. Saunier, A. Matthews, R. Barzaghi, D. Thaller, S. Bergstrand, J. Müller, “GGOS: Bureau of Networks and Observations”, Abstract No. EGU2018-5504, presented at the European Geosciences Union General Assembly, Vienna, Austria, April 08-13, 2018.

M. Pearlman, D. Behrend, A. Craddock, C. Noll, E. Pavlis, J. Saunier, A. Matthews, R. Barzaghi, D. Thaller, B. Maennel, S. Bergstrand, J. Müller, “GGOS: Current Activities and Plans of the Bureau of Networks and Observations”, Abstract No. EGU2019-6181, presented at the European Geosciences Union General Assembly, Vienna, Austria, April 07-12, 2019.

GGOS Standing Committee on Performance Simulations & Architectural Trade-Offs (PLATO)
(Joint WG with IAG Commission 1)

Chair: Daniela Thaller (Germany)
Vice-Chair: Benjamin Männel (Germany)

Contributing Institutions (as of April 2019):

- R. Dach, F. Andritsch (AIUB, Switzerland)
- D. Thaller, D. König (BKG, Germany)
- R. Biancale (CNES/IGN, France)
- M. Bloßfeld A. Kehm (DGFI-TU Munich, Germany)
- M. Rothacher, I. Herrera Pinzon (ETH Zürich, Switzerland)
- B. Männel, S. Glaser (GFZ/TU Berlin, Germany)
- J. Müller, F. Hofmann (IfE University Hannover, Germany))
- D. Coulot, A. Pollet (IGN, France)
- R. Gross (JPL, USA)
- E.C. Pavlis (NASA GSFC/JCET, USA)
- E. Mysen, G. Hjelle (NMA, Norway)
- J. Böhm (TU Vienna, Austria)

Purpose and Scope

- Develop optimal methods of deploying next generation stations, and estimate the dependence of reference frame products on ground station architectures
- Estimate improvement in the reference frame products as co-located and core stations are added to the network
- Estimate the dependence of the reference frame products on the quality and number of the site ties and the space ties
- Estimate the improvement in the reference frame products as other satellites are added, e.g., cannonball satellites, LEO, GNSS constellations
- Estimate the improvement in the reference frame products as co-locations in space are added, e.g., use co-locations on GNSS and LEO satellites, add special co-location satellites (GRASP, E-GRASP/Eratosthenes, NanoX, etc.)

Achievements over the past four years:

- Several projects related to simulation studies became funded and even extended to a second phase, like DIGERATI at DGFI-TUM, SORTS at TU Vienna, GGOS-SIM at GFZ, or KoKoRef at BKG
- Several geodetic software packages have been augmented by the capability to carry out realistic simulation scenarios (VieVS, DOGS, Bernese, Geodyn)
- Simulations for the planned E-GRASP/Eratosthenes which was a proposal for a dedicated co-location in space satellite mission within ESA Earth-Explorer-9 call. The proposal was submitted by a science team led by Richard Biancale (Biancale e al., 2017).
- Simulations for improved global SLR and VLBI station networks were carried out (Glaser e., 2017, Kehm et al., 2018, Anderson et al., 2018, Glaser et al. 2019).
- Simulations for improved SLR tracking of GNSS satellites were performed by AIUB (Andritsch et al., 2018).

- Simulations and analysis of VLBI tracking data of GNSS satellites and the Chinese APOD cube-satellite were carried out to assess the possibilities of VLBI satellite tracking (Hellerschmied e al., 2018).
- The impact of the local ties (LT) on the reference frame products were studied regarding different stochastic models of the LT, selection of the LT, and the impact of systematically wrong LT (Glaser et al., 2019).
- Local baselines were analyzed to identify technique-specific systematic error sources (Herrera Pinzón and Rothacher, 2018).
- The combined processing ground- and space-based GNSS observations was studied (Männel and Rothacher, 2017).
- Simulation for new laser ranging on the lunar surface were carried out by IfE, Uni Hannover (Hofmann, 2017, Hofmann et al, 2018).
- A PLATO status report was published in the International Symposium on Advancing Geodesy in a Changing World (Männel et al., 2018).
- Presentations were given at IAG Assembly (July 2017), COSPAR/REFAG (July 2018), annual conferences of EGU and AGU as well as meetings of IAG Services.

Outcomes and Future Plans

- A coordinated increase of ETALON observations should be further considered at the expense of LAGEOS observations, and specific studies based on the dedicated ETALON tracking campaigns by the ILRS will be carried out.
- In addition to building new SLR stations, existing laser telescopes should be encouraged and supported to increase their performance, if possible, to the proposed level of 20%.
- In terms of LLR additional stations capable to perform measurements to (new) lunar reflectors are highly important to achieve highest accuracy.
- Improved analysis methods for reference frame products will be developed with the focus of including all existing data (especially to satellites not yet included in standard TRF products) and all available co-locations
- Simulations performed by PLATO members showed impressively the benefits of a dedicated co-location in space satellite mission. Therefore, we recommend to strive by all means for a satellite mission dedicated to co-location in space.
- A coordinated analysis campaign with exchanged simulated observations was launched in 2018 and is still ongoing
- Status reports will be given at IUGG General Assembly (July 2019) and IAG Symposia (2021)
- Annual meetings are foreseen in conjunction with EGU General Assembly

Publications

Anderson, J.M., Beyerle, G., Glaser, S. et al., Simulations of VLBI observations of a geodetic satellite providing co-location in space, J Geod (2018) 92: 1023. https://doi.org/10.1007/s00190-018-1115-5

Andritsch, F., Dach R, Schildknecht T, Meyer U, Jäggi A (2018): The effect of SLR tracking scenraios to GNSS satellites in a combined GNSS/SLR solution. Presentation given at the 21st International Workshop on Laser Ranging, November 5, 2018. Available online at https://cddis.nasa.gov/lw21/docs/2018/presentations/Session2_Andritsch_presentation.pdf

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Herrera Pinzón, I. & Rothacher, M., Assessment of local GNSS baselines at co-location sites, J Geod (2018) 92: 1079. https://doi.org/10.1007/s00190-017-1108-9

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Kehm, A., Bloßfeld, M., Pavlis, E.C. et al., Future global SLR network evolution and its impact on the terrestrial reference frame, J Geod (2018) 92: 625. https://doi.org/10.1007/s00190-017-1083-1

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Männel B. et al. (2018) Recent Activities of the GGOS Standing Committee on Performance Simulations and Architectural Trade-Offs (PLATO). In: Freymueller J., Sánchez L. (eds) International Symposium on Advancing Geodesy in a Changing World. International Association of Geodesy Symposia, vol 149. Springer, Cham. https://doi.org/10.1007/1345_2018_30

Pavlis, E. C., S. M. Merkowitz, C. J. Beaudoin, M. Kuzmicz-Cieslak, D. D. Rowlands, and F. G. Lemoine (2019) GEOCON: Geodetic System Ties Using a CubeSat Constellation, EGU General Assembly 2019, Geophysical Research Abstracts, Vol. 21, EGU2019-6158-1

GGOS Standing Committee on Satellite Missions (CSM)

Chair: Jürgen Müller (Germany)
Co-Chair: Roland Pail (Germany)

Members

CSM has quite an open team of members, associate members and guests to work on the various CSM tasks and to provide material for the website, presentation material, and other documentation. CSM has about one meeting per year. The main work, however, is done via email exchange.

Purpose and Scope

The Committee on Satellite Missions (CSM) has been set-up as an international panel of experts, with consultants of national and international space agencies. CSM - formerly GGOS Satellite Mission Working Group - was established in December 2008, under the lead of C.K. Shum. In December 2010, Isabelle Panet became Chair, in December 2013 Roland Pail followed. Since December 2015, Jürgen Müller is the new Chair.

The purpose and scope of CSM is the information exchange with satellite missions as part of the GGOS space infrastructure, for a better ground-based network response to mission requirements and space-segment adequacy for the realization of the GGOS goals. New space missions shall be advocated and supported, if appropriate.

Satellite missions are a prerequisite for realizing a global reference for any kind of Earth observation. They are the key for monitoring change processes in the Earth system on a global scale with high temporal and spatial resolution. Therefore, beyond purely scientific objectives they meet a number of societal challenges, and they are an integral part of the GGOS infrastructure and essential to realize the GGOS goals. The role of CSM is to monitor the availability of satellite infrastructure, to propose and to advocate new missions or mission concepts, especially in case that a gap in the infrastructure is identified.

Activities

- An inventory/repository of the GGOS satellite infrastructure has been prepared.
- A list of satellite contributions to fulfill the GGOS 2020 goals has been prepared.
- Both lists have been published at the CSM section of the GGOS website.
- In 2018 (as in the years before), individual members of CSM have contributed to ESA's Earth Explorer 10 call by actively acting in the proposers' team of the planned future gravity satellite mission MOBILE – which finally has not been selected.
- Close cooperation exists with the Bureau of Products and Standards, and the Sub-Commissions 2.3 and 2.6 of IAG. Additionally, there are strong interfaces to national and international space agencies.
- Exchange with PLATO has been initiated by identifying joint interests and possible collaborations.

Objectives and Planned Efforts for 2019 and Beyond

1. The new CSM website will continuously be updated collaborating with the GGOS Coordinating Office.
2. The inventory/repository of current and near-future satellite missions will regularly be updated.

3. The list of satellite contributions to the GGOS 2020 goals will regularly be updated.
4. CSM will further support advocating new satellite missions.
5. The exchange with PLATO shall be expanded, e.g., to stimulate dedicated simulations to better understand and overcome shortcomings with respect to the GGOS 2020 goals.
6. CSM will continue to support GGOS positions in preparation to CEOS/GEO meetings.
7. CSM will further support the Executive Committee and the GGOS Science Panel in the GGOS Interface with space agencies.

Most of the CSM tasks are ongoing activities. These tasks require interfacing with other components of GGOS, especially with the ground networks component, the simulation activity (PLATO) as well as the Bureau of Products and Standards.

Website: http://www.ggos.org/en/bureaus/bno/committee-satellite-missions/

Publications and Presentations

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GGOS Standing Committee on Data and Information Systems

Chair: Guenter Stangl/Matthias Madzak (Austria)
Co-Chair: Carey Noll (USA)

Purpose and Scope

Develop a metadata strategy for all ground-based measurement techniques and data products that provides discoverability and interoperability, is easily transferable via web services, and is based on internationally recognized data exchange methods; the plan is to implement a metadata scheme in two stages: a stage-one scheme for GGOS and GGOS relevant data products and a longer term, stage-two scheme for the full GGOS requirements.

The current focus of the WG is on developing standards for metadata that can be utilized by the space geodesy community. Metadata typically encompass critical information about the measurements that are required to turn these measurements into usable scientific data. Metadata also includes information that supports data management and provides a foundation for data discovery. Data centers extract metadata from incoming data sources and also augment that metadata with information from other sources. It is typical for data centers to store the metadata in databases in order to manage the data in their archives and to distribute both data and metadata to data users. Metadata can further be utilized by data discovery applications to allow users to find datasets of interest. In order to be effective, metadata need to be simple to generate and maintain. They must be consistent and informative for the archivist and the user.

GGOS is seeking a metadata schema that can be used by all of its elements for standardized metadata communication, archiving, and retrieval. First applications would be automated distribution of up-to-date stations configuration and operational information, data archives and catalogues, and procedures and central bureau communication. Several schemas that show promise have been under development by SOPAC (Scripps), GML (Australia/NZ), etc. The intent is that data need be entered only from an initial source (a station, a Data Center, an Operations Center, data products, etc.) and would then flow to and be integrated into those metadata files where users would have access. The plan is to organize a meeting, probably in early August at UNAVCO in Boulder, for representatives from the Services, the Data Centers, the Science Community, etc. to give each of the schema developers an opportunity to preach his wears and allow discussion on the pros and cons of each.

The objective is to try to come to closure on a schema that we could as a community adopt for general implementation. Groups would not be obligated to a rapid implementation schedule, but would commit to the agreed schema when they are ready to begin the process.

Activities and Actions

- CDDIS continues to construct collection-level metadata records for implementation in NASA EOSDIS (CMR)
- Concepts and plans for implementation of a GGOS metadata scheme have been presented at Bureau meetings; status of the activities have also been presented
- IGS continues development of Site Log XML metadata (lead: UNAVCO)
    - Several IGS data centers and groups have worked with this schema and are implementing/refining
    - Use Cases are slowly being assembled
    - Software tools for text site log to XML site log conversion are being developed and will be available to all
- Geosciences Australia (GA) has released GeodesyML

- The GeodesyML project (http://www.geodesyml.org) has been created to facilitate the discoverability and availability of geodetic data and metadata to new (and existing) user communities in a standardized, discoverable, and interoperable way;
- Machine-to-machine communications are required to improve efficiency, robustness, and accuracy for sharing geodetic data and their metadata.
- Implements an application schema for the Site Log XML metadata;
- Nick Brown (GA) has been funded to do a scoping study that will build upon GeodesyML, SensorML, OGC and ISO and other international standards when possible to enabling machine-to-machine communication. International participation in the scoping study is invited. Results from the study are due at the end of 2019. Although the study is being carried out for GNSS, the efforts will benefit the IGS and GGOS.

Objectives and Planned Efforts for 2019 and Beyond

- Adopt and implement a metadata system to provide access to GGOS relevant data products.
- GA and groups participating in the GeodesyML activity are creating a scoping study to investigate and document the critical gaps in standards which restrict how to make geodetic data, in particular precise positioning data, accessible to user communities. Some activities to be covered by the study:
  - Improve and expand data standards for accessing geodetic data and enabling their combination with other data sets;
  - Review and document current standards and identify critical gaps in the proposed standards;
  - Review community use cases and document how they can be met by GeodesyML and international standards.
- Adopt and implement a full metadata system including site information and relevant tools and capability (e.g., the GeodesyML scheme)
  - Definition of the requirements; definition of Phase 1 (March 2020)
  - Resolve issues and applicability of the Australian GL scheme and recommend schema (EGU 2020)
  - Metadata implementation plan including definition of tasks, roles, and distribution of tasks, and plans for integration of components (June 2020)
  - Demonstration of Phase 1 prototype (December 2020)
  - Demonstration of Phase 1 first operational system (December 2021)

IERS Working Group on Site Survey and Co-location

Chair: Sten Bergstrand (France)
Co-Chair: John Dawson (Australia)

Members:

https://www.iers.org/IERS/EN/Organization/WorkingGroups/SiteSurvey/sitesurvey.html

Purpose and Scope

The working group was established in 2004 as part of the IERS to homogenize local surveying activities at different space geodetic sites. In 2014, it was agreed that the working group would act also for GGOS under the IERS name. The overall goal is to provide a base necessary for rigorous terrestrial reference frame realizations, and to highlight the presence of technique- and/or site-specific biases. The main effort aspires to provide the means of an uncertainty assessment that can be included in the next ITRF.

Activities and Actions

- Recent work has first been to establish a general and common terminology to all techniques, which is also valid outside the space geodetic community, and to fulfill the local tie requirements set out in the GGOS book. The DORIS community has adapted the common terminology, and improved its surveying procedure as well as communication of results.
- IGS terminology has been adapted without alterations; the concepts are there, but the technique specific terminologies vary. The main focus of the IGS component has been a reassessment of existing sites rather than surveying as such.
- The ILRS maintains a list of current and historical sites. A combined effort from several institutes involved a common application to the European EMPIR program. The application fulfilled the acceptance criteria, but was not granted funding due to limited resources.
- The VLBI terminology concerning site surveys has been consolidated, and an automated terrestrial monitoring system for telescopes called Heimdall has been developed, as well as a complete model for telescope deformation.
- A campaign to examine the short-term combination of VLBI, GNSS and automated terrestrial monitoring at two baseline ends has been performed, with some processing left to be finished.

Objectives and Planned Efforts for 2017-2019 and Beyond

- Assess the ground truth uncertainty of different techniques to include in the next ITRF;
- Evaluate the VLBI-GNSS-terrestrial campaign of the Onsala-Metsähovi baseline; additionally, more sites should be surveyed. However, this is an activity that the respective station managers need to allocate funding for. The working group does not have the means to do this, and would appreciate any help to create a pull in this direction.

Website

https://www.iers.org/IERS/EN/Organization/WorkingGroups/SiteSurvey/sitesurvey.html

GGOS Bureau of Products and Standards

Director: Detlef Angermann (Germany)
Vice Director: Thomas Gruber (Germany)

Members

- *Michael Gerstl (Germany)*
- *Robert Heinkelmann (Germany)*
- *Urs Hugentobler (Germany)*
- *Laura Sánchez (Germany)*
- *Peter Steigenberger (Germany)*

GGOS entities associated to the BPS:

- *Committee Contributions to Earth System Modelling, Chair: Maik Thomas (Germany)*
- *Committee Definition of Essential Geodetic Variables, Chair: Richard Gross (USA), (Remark: This component has been newly established, the TOR are under development)*
- *WG1 ITRS Standards for ISO TC211, Chair: C. Boucher (France)*
- *WG2 Establishment of the Global Geodetic Reference Frame (GGRF), Chair: Urs Marti (Switzerland)*

The Bureau comprises the staff members, the chairs of the associated GGOS components as well as representatives of the IAG Services and other entities. The present status of the associated members as BPS representatives is summarized in Table **X.1**.

Tab. **X.1**: Representatives of IAG Services and other entities involved in standards and geodetic products (status: May 2019)

Position (IAG Service, other entity)	Representatives	Affiliation, Country
IERS Conventions Center	Gérard Petit (until 2016)	BIPM (France)
	Nick Stamatakos (since 2017)	USNO (USA)
IERS Analysis Coordinator	Thomas Herring	MIT (USA)
	R. Heinkelmann (since 2019, BPS)	GFZ (Germany)
IGS Representative	Urs Hugentobler (BPS staff)	TUM (Germany)
ILRS Analysis Coordinator	Erricos Pavlis	UMBC/NASA (USA)
IVS Analysis Coordinator	John Gipson	GSFC/NASA (USA)
IDS Representatives	Frank Lemoine, John Ries,	GSFC/CSR (USA)
	Jean-M. Lemoine, H. Capdeville	CNES/GRGS (France)
IGFS Chair	Riccardo Barzaghi	Politec. Milano (Italy)
BGI Chair	Sylvain Bonvalot	IRD (France)
ISG President	Mirko Reguzzoni	Politec. Milano (Italy)
ICGEM Chair	Franz Barthelmes (until 2017)	GFZ (Germany)
	E. Sinem Ince (since 2018)	GFZ (Germany)
IDEMS Director	Kevin M. Kelly	ESRI (USA)
IGETS Chair	Hartmut Wziontek	BKG (Germany)
Gravity Comm. (corresp. Member)	Jürgen Kusche	Univ. Bonn (Germany)
IAG Representative to ISO	Johannes Ihde (until 2017)	BKG, GFZ (Germany)
	Detlef Angermann (since 2018)	TUM (Germany)
IAG Communication and Outreach	Josef Ádám	Univ. Budapest (Hungary)
IAU Commission A3 Representative	Catherine Hohenkerk (until 2018)	United Kingdom
	James L. Hilton (since 2018)	USNO (USA)
IAU Representative	Robert Heinkelmann (BPS staff)	GFZ (Germany)
Control Body for ISO Geodetic Registry	Michael Craymer (Chair)	NRCan (Canada)
	Larry Hothem (Vice Chair)	USA

Overview

The Bureau of Products and Standards (BPS) is a key component of IAG's Global Geodetic Observing System (GGOS). It supports IAG in its goal to obtain consistent products describing the geometry, rotation and gravity field of the Earth, along with its temporal variations. The BPS is built upon existing observing and processing systems of IAG.

Mission and overall objectives of the BPS:

- to serve as contact and coordinating point for the homogenization of IAG/GGOS standards and products;
- to keep track of the adopted geodetic standards and conventions across all IAG components, and to initiate steps to close gaps and deficiencies;
- to focus on the integration of geometric and gravimetric parameters and to develop new products needed for Earth sciences and society.

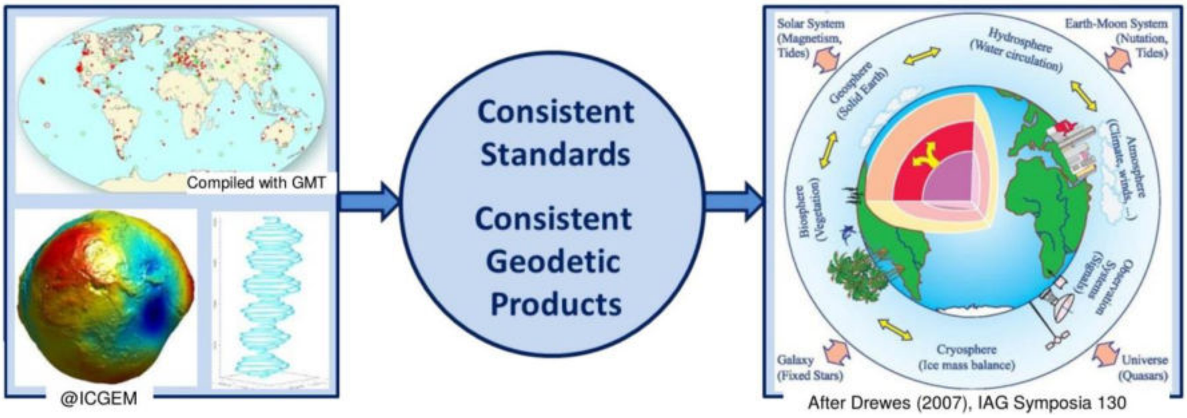

Fig. X.1*: The integration of the "three pillars" geometry, Earth rotation and gravity field requires consistent standards to obtain consistent geodetic products as the basis for Earth system research and for precisely quantifying global change phenomena.*

As regards the development of standards, there is a link with the IERS Conventions Center, the IAU Commission A3 "Fundamental Standards", the IAU Working Group "Numerical Standards for Fundamental Astronomy", the Bureau International des Poids et Mesures (BIPM), the Committee on Data for Science and Technology (CODATA), and the International Organization for Standardization (ISO) with its Technical Committee ISO/TC211.

Activities

According to its charter, the BPS has the task to keep track of adopted standards across all IAG components and to evaluate products of IAG with respect to the adequate use of standards and conventions. Based on this general task description, a major activity of the BPS was the compilation of an inventory regarding standards, constants, resolutions and conventions adopted and used by IAG and its components for the generation of IAG products (see Angermann et al., 2016 and 2018).

Summary and recommendations on numerical standards

As shown in Table **X.2**, different numerical standards are in use within the geodetic community. The values of the Geodetic Reference System 1980 (GRS80) are still used as official ellipsoid parameters, although it represents the scientific status of the 1970s. In the concept of GRS80, the tidal systems and relativistic theories are not considered (Ihde et al., 2017). The numerical standards of the IERS Conventions 2010 are commonly used for the processing of the geometric observations and for the generation of IERS products. The fact that the semi-major axis between GRS80 and IERS Conventions 2010 differs by 0.4 m is critical and has to be considered correctly for users of geodetic products. Table **X.2** also shows the numerical standards of the Earth Gravitational Model 2008 (EGM2008; Pavlis et al., 2012), which are partly different from the numerical standards given in the IERS Conventions. In cooperation between the IERS Conventions Center and the BPS, the conventional value W_0 = 62 636 853.4 m^2s^{-2} for the geopotential at mean sea level issued in the IAG (2015) Resolution No. 1 (Ihde et al., 2017; Sánchez and Sideris, 2017) has been updated in Chapter 1 of the IERS Conventions in 2017. Thus, the former difference between the IERS Conventions 2010 value and the IAG 2015 value of about -2.6 m^2s^{-2} (equivalent to a level difference of about 27 cm) has been resolved.

The current situation concerning numerical standards and the different use of time and tide systems is a potential source for inconsistencies and even errors of geodetic products. Thus, it is essential for a correct interpretation and application of geodetic results and products that the underlying numerical standards are clearly documented. Moreover, the combination of geodetic results referring to different time or tide systems, transformations have to be performed to get consistent results.

***Tab. X.2**: Numerical standards of conventional parameters presently in use within IAG. The defining parameters of the GRS80 are **a**, **GM**, **J₂** and **ω**. The IAG Resolution No. 1 (2015) recommends a conventional **W₀** value of 62 636 853.4m²s⁻². Note the consequential decoupling of **W₀** and **L_G**. This **W₀** value could be used as a defining parameter for a new GRS20XX, the semi-major axis **a** would then become a derived quantity. The advantage of **W₀** is that it does not depend on the tide system, which is not the case of the semi major axis **a**.*

	semi-major axis a [m]	Geocentric Grav. Constant GM [10^{12}m^{3}s^{-2}]	Dyn. form factor J_2 [10^{-6}]	Earth's rotation ω [rad s^{-1}]	Normal potential U_0 or W_0 [m^{2}s^{-2}]
GRS80 (1979)	6 378 137	398.600 5	1 082.63	7.292 115	62 636 860.850
EGM2008	6 378 136.3	398.600 4415$^{(1)}$	1 082.635 9	7.292 115	62 636 856.0 (1998)
IERS Conv. (2010)	6 378 136.6$^{(2)}$	398.600 4418$^{(3)}$	1 082.635 9	7.292 115	62 636 856.0 (1998)
IERS Conv. (update 2017)	6 378 136.6$^{(2)}$	398.600 4418$^{(3)}$	1 082.635 9	7.292 115	62 636 853.4 (2015)
IAG Resol. No. 1 (2015)					62 636 853.4 (2015)

$^{(1)}$TT-compatible value; $^{(2)}$value given in zero-tide system; $^{(3)}$TCG-compatible value

The following recommendations on numerical standards have been specified in the BPS inventory, also endorsed as recommendations of the Unified Analysis Workshop held in Paris 2017, which was co-organized by GGOS and the IERS:

- **Recommendation 1**: The used numerical standards including time and tide systems must be clearly documented for all geodetic products.
- **Recommendation 2**: The geopotential value W_0 = 62 636 853.4 m^2s^{-2} issued by the IAG resolution No. 1 (2015) should be used as the conventional reference value for geodetic work.
- **Recommendation 3**: The development of a new Geodetic Reference System GRS20XX based on best estimates of the major parameters related to a geocentric level ellipsoid is desired.

Product-based review of standards and conventions

The following major topics were addressed in the product-based evaluation of standards and conventions (see chapter 4 in the BPS inventory, Angermann et al., 2016):

- Celestial reference systems and frames
- Terrestrial reference systems and frames
- Earth orientation parameters
- GNSS satellite orbits
- Gravity and geoid
- Height systems and their realizations

IAG products exist for the celestial and terrestrial reference frames as well as for the EOP which are provided by the responsible Product Centers of the IERS (see www.iers.org). These products are derived from a combination of the contributing VLBI, SLR, GNSS and DORIS data. The IERS Conventions provide the basis for the work of the geometric IAG Services (IGS, ILRS, IVS and IDS), as well as for the definition and realization of geodetic reference systems and for the generation of IERS products. In addition to the IERS Conventions, several technique-specific standards are defined for the analysis of the individual geometric observations and technique-specific products (e.g., GNSS satellite orbits). The BPS inventory gives an overview about the present status concerning the IERS products, it identifies gaps and deficiencies and provides recommendations for future improvements for each product (Angermann et al., 2016). The work of the BPS should be considered as a supplement to the extensive activities performed within the IAG Services and the IERS. The present issues concerning the analysis and combination of the geometric space-techniques were discussed during the Unified Analysis Workshop 2017, which was co-organized by GGOS and the IERS.

Some general recommendations of the BPS inventory concerning the IERS products are given below:

- At present, the celestial and the terrestrial reference frames and their integral EOP solutions are not fully consistent with each other as they are computed independently by separate IERS Product Centers. The Resolution No.3 (2011) of the IUGG) recommends, that the highest consistency between the ICRF, the ITRF and the EOP as observed and realized by IAG and its components such as the IERS should be a primary goal in all future realizations of the ICRS.
- The processing standards and models should be consistently applied by all the analysis centers of the IAG Services providing data for the generation of the IERS products.
- The station networks and the spatial distribution of high quality co-location sites should be improved as a fundamental requirement to achieve the GGOS accuracy requirements as specified in the GGOS 2020 book.

The IGFS is responsible to coordinate the gravity-related IAG Services and its overall goal is to provide gravity field related data, software and information for the scientific community. In 2016, the new IGFS Central Bureau, hosted at the Aristotle University of Thessaloniki (Greece), started its activity, providing an updated IGFS website (igfs.topo.auth.gr), including a dedicated product portal for the download of data and results generated by the IGFS Services. As an example, about 170 models of the global gravity field of the Earth are made available to the public via the ICGEM website (icgem.gfz-potsdam.de). A recommendation is that a conventional global gravity field model might be useful as a reference model to be used for the generation of official IAG products, whereas scientific users should be free to use any preferred model for their particular purposes. The last topic of the product-based inventory focuses on height systems and their realizations (see Report of the GGOS Focus Area "Unified Height System"). More detailed information on the product-based evaluation are found in the BPS inventory (Angermann et al., 2016).

Summary of further BPS activities:

- The BPS is working on the update and revision of the inventory on standards and conventions. The 2nd version of this inventory will be published online on the GGOS website. The planned release date is June 30, 2019. The major changes are summarized as Document Change Record. These changes include updates on the organizational structure of GGOS and on numerical standards, as well as the replacement of the previous realizations (i.e., ICRF2, ITRF2008, EOP 08 C04) by the latest versions ICRF3, ITRF2014 and EOP 14 C04. Furthermore, the section on GNSS orbits, the activities of the IGFS and the developments towards the realization of the International Height Reference System have been updated and revised.
- In the field of standards and conventions the BPS closely interacts with the IERS Conventions Centers and IAU Commission A3 "Fundamental Standards". A topic of discussion during the GGOS Days 2018 in Tsukuba (Japan) was the interaction of the BPS and the IERS Conventions Center regarding the re-writing/revising of the IERS Conventions. As a result, the director of the BPS has been nominated as the Chapter Expert for the "General Definitions and Numerical Standards".
- The BPS also supports the development of new products derived from a combination of geometric and gravimetric observations. Towards this aim various activities have been initiated and dedicated GGOS entities have been established to focus on the development of integrated products, such as the Focus Area "Unified Height System", the Focus Area "Geodetic Space Weather Research" and the Joint IAG Working Group "Establishment of the Global Geodetic Reference Frame (GGRF)".
- The director of the BPS has been nominated by the IAG Executive Committee as the IAG Representative to the UN Global Geospatial Information Management (UN-GGIM) Subcommittee "Geodesy" (the former GGRF Working Group) for the Focus Group "Data Sharing and Development of Geodetic Standards". The BPS contributed to the GGRF Roadmap Implementation Plan to the UN-GGIM Committee of Experts, provided for the 8th session in New York (August, 2018). This Focus Group (which has been renamed in a UN GGIM Working Group) has formulated three main recommendations on data sharing and common standards along with a number of actions to be accomplished in these two fields.
- In 2018, the Committee on the definition of Essential Geodetic Variables (EGVs) has been established as a new GGOS component associated to the BPS. The members of the Committee on EGVs comprise the GGOS Science Panel, representing the IAG Commissions, the Inter-Commission Committee on Theory, and the four GGOS Focus Areas, as well as representatives of the IAG Services. The Committee on EGVs is chaired by R. Gross. It consists of 34 members in total. Examples of EGVs might be the position of reference objects (ground stations, radio sources), EOPs, ground- and space-based gravity measurements, etc. Such EGVs could then serve as a basis for a gap analysis to identify requirements concerning observational properties and networks, accuracy, spatial and temporal resolution and latency.

BPS board meetings during the period 2015-2019:

- IUGG General Assembly 2015, Prague, Czech Republic, June 27, 2015
- GGOS Days 2016, Frankfurt am Main, Germany, October 22, 2015
- EGU 2016, Vienna, Austria, April 19, 2016
- GGOS Days 2016, Cambridge, USA, October 26, 2016
- EGU 2017, Vienna, Austria, April 25, 2017
- GGOS Days 2017, Vienna, Austria, November 1, 2017
- EGU 2018, Vienna, Austria, April 10, 2018
- GGOS Days 2018, Tsukuba, Japan, October 3, 2018

Selected Publications:

Angermann D., Gruber T., Gerstl M., Heinkelmann R., Hugentobler, U., Sánchez L., Steigenberger P.: GGOS Bureau of Products and Standards: Inventory of Standards and Conventions used for the Generation of IAG Products. The IAG Geodesist's Handbook 2016, J Geod 90(10): 1095-1156, doi: 10.1007/s00190-016-0948-z, 2016

Angermann D., Gruber T., Gerstl M., Heinkelmann R., Hugentobler, U., Sánchez L., Steigenberger P.: GGOS Bureau of Products and Standards: Inventory of Standards and Conventions used for the Generation of IAG Products. In: Rizos C. Willis P. (Eds.) IAG 150 Years, IAG Symposia 143, 571-577, doi: 10.1007/1345_2015_165, 2016

Angermann D., Gruber T., Gerstl M., Heinkelmann R., Hugentobler U., Sánchez L., Steigenberger P.: GGOS Bureau of Products and Standards: Recent Activities and Future Plans. International Association of Geodesy Symposia, doi: 10.1007/1345_2018_28, 2018

Ihde J., Sánchez L., Barzaghi R., Drewes H., Foerste Ch., GruberT., Liebsch G., Marti U., Pail R., Sideris M.: Definition and proposed realization of the International Height Reference System (IHRS). Surveys in Geophysics 38(3), 549-570, doi: 10.1007/s10712-017-9409-3, 2017

Sánchez L., Čunderlík R., Dayoub N., Mikula K., Minarechová Z., Šíma Z., Vatrt V., Vojtíšková M.: A conventional value for the geoid reference potential W0. Journal of Geodesy 90(9), 815-835, doi: 10.1007/s00190-016-0913-x, 2016

Sánchez L., Sideris M. G.: Vertical datum unification for the International Height Reference System (IHRS). Geophys J Int 209(2), 570-586, doi: 10.1093/gji/ggx025, 2017

GGOS Committee on Earth System Modeling

Chair: Maik Thomas (Germany)

Activities

Recent activities of the committee mainly concentrated on systematic comparisons of different stand-alone and coupled model approaches as well as on the development of model interfaces and algorithms for data assimilation. In particular, the following progress could be achieved:

- A module for a realistic representation of the elastic response of the lithosphere to short-term variations of surface mass loading has been developed and implemented into various model approaches. Sensitivity of results to different numerical approaches (local, regional, global) for load-induced surface deformation as well as effects due to mantle inelasticity have been estimated.
- Several time series from system model simulations are operationally provided to the community via the GGFC/IERS Combination Center, e.g., time series of site displacements due to hydrological loading derived from model simulations applying the new loading module or effective angular momentum functions based on atmosphere-hydrosphere models.
- Kalman-based algorithms for the assimilation of (integral) geodetic observations have been generalized and implemented into stand-alone model components in order to improve numerical predictions of variations of surface deformation and Earth rotation parameters. Alternative techniques for the introduction of observational data into dynamically coupled models (e.g., particle filtering) have been intensively discussed; however, no generalized approach to constrain dynamically coupled models can be provided, so far.
- Feasibility studies for the provision of error estimates and uncertainties based on single- and multi-model ensembles have been performed.

Selected Publications

Dill, R., Klemann, V., Martinec, Z., Tesauro, M.: Applying local Green's functions to study the influence of the crustal structure on hydrological loading displacements. Journal of Geodynamics, 88, p. 14-22, 2015.

Dobslaw, H., Bergmann, I., Dill, R., Forootan, E., Klemann, V., Kusche, J., Sasgen, I.: The updated ESA Earth System Model for future gravity mission simulation studies. Journal of Geodesy, 89, 5, p. 505-513, 2015.

Irrgang, C., Saynisch, J., Thomas, M.: Ensemble simulations of the magnetic field induced by global ocean circulation: Estimating the uncertainty. Journal of Geophysical Research, 121, 3, p. 1866-1880, 2016.

Konrad, H., Sasgen, I., Klemann, V., Thoma, M., Grosfeld, K., Martinec, Z.: Sensitivity of Grounding-Line Dynamics to Viscoelastic Deformation of the Solid-Earth in an Idealized Scenario. Polarforschung, 85, 2, p. 89-99, 2016.

Martinec, Z., Klemann, V., van der Wal, W., Riva, R. E. M., Spada, G., Sun, Y., Melini, D., Kachuck, S. B., Barletta, V., Simon, K., James, T. S., G A.: A benchmark study of numerical implementations of the sea level equation in GIA modelling. Geophysical Journal International, 215, 1, pp. 389-414, 2018.

Saynisch, J., Bergmann, I., Thomas, M.: Assimilation of GRACE-derived oceanic mass distributions with a global ocean circulation model. Journal of Geodesy, 89, 2, p. 121-139, 2015.

Saynisch, J., Irrgang, C., Thomas, M.: Estimating ocean tide model uncertainties for electromagnetic inversion studies. - Annales Geophysicae, 36, pp. 1009-1014, 2018.

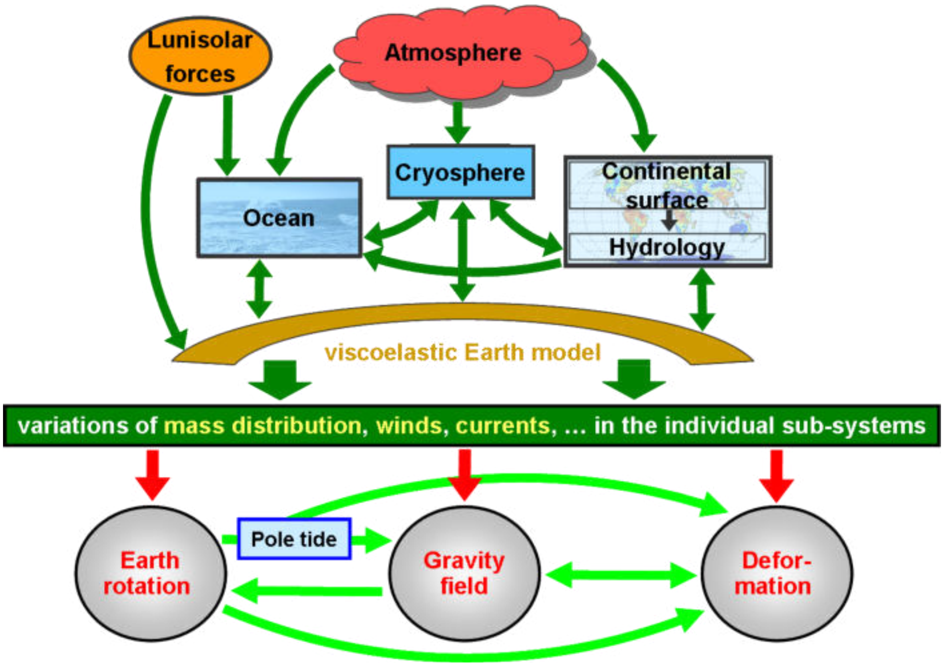

Fig. Y1: Concept of a modular Earth system model for geodetic applications.

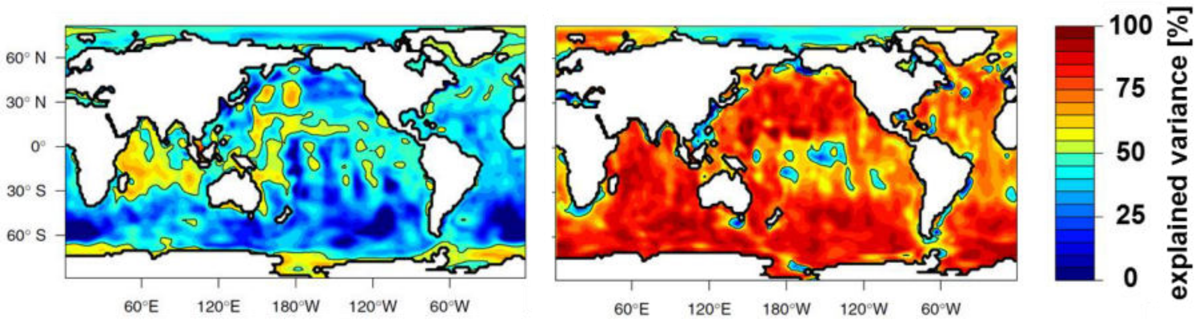

Fig. Y2: *Explained variance of GRACE ocean bottom pressure resulting from an unconstrained (left) and assimilated (right) ocean model simulation (Saynisch et al., 2015; updated).*

BPS WG1: ITRS Standards for ISO TC 211

Chair: Claude Boucher (France)

Members

- *Detlef Angermann (Germany)*
- *Sten Bergstrand (Sweden) chair IERS WG Site surveys and collocations*
- *Claude Boucher (France) chair WG, ISO project leader*
- *Xavier Collilieux (France) IAG SC1.2 chair*
- *Thierry Gattacceca (France) ISO project editor*
- *Larry Hothem (USA)*
- *Guy Woppelmann (France)*

Additional contributors via ISO group:

- *Zuheir Altamimi (France and IAG)*
- *Michael Craemer (Canada)*

Purpose and Scope

The mission of the WG is to coordinate the IAG community in the support of the development of the ISO standard on ITRS.

In order to ensure this support, some specific objectives has been identified (this list may be updated if needed):

1. To establish the list of IAG contributors to the work of the WG
2. To collect comments and proposals on any draft documents provided by the ISO TC211/19161-1
3. To establish a glossary of geodetic terms in relation with the scope of the WG

Activity report

1 IAG contributors

The present status of WG members is given at the beginning of this report. Additional contributors were provided through ISO 19161-1.

2 ISO TC211/19161-1

This group initially worked to establish a draft standard (versions 1 to 12)

In 2018, the ISO19161-1 Project Team consolidated and expanded the Working Draft, and successfully presented a Committee Draft (CD) to the TC211 on September 3. The CD was submitted in time to have the ballot completed before the TC211 plenary in Wuhan, in November 2018. Ballot results were: P-members in favour: 25; P-members against: 0; Abstentions: 11

A total of 130 comments (including 106 editorial ones) were received.

The first Editing Committee Meeting took place in Wuhan, China, on November 13, 2018, with 9 experts attending. All non-trivial editorial comments were processed.

The document was then edited to take into account the remaining comments (the trivial ones, and those less trivial or non-editorial that were discussed at the meeting and for which an answer was agreed on), thus producing the Draft International Standard (DIS). The DIS was circulated along with the updated table of comments to the EC members by the end of November, and submitted to ISO Central Secretariat in January 21, 2019.

The DIS ballot started on March 26, 2019 and will end June 18, 2019.

3 Glossary of terms

For information, here is the extract of the CD document related to the terminology part:

3.1 Coordinate system

Set of mathematical rules for specifying how coordinates are to be assigned to points

[SOURCE: ISO 19111:2018, 3.11]

3.2 Geocentric terrestrial reference system

GTRS

System of geocentric space-time coordinates within the framework of General Relativity, co-rotating with the Earth and related to the Geocentric Celestial Reference System by a spatial rotation which takes into account the Earth's orientation parameters

[SOURCE: IAG and IUGG resolutions of 1991 and 2007]

3.3 Positioning process

Computational process that determines directly from measurements the geodetic coordinates of points (absolute positioning), or that derives geodetic coordinates of points from previously determined geodetic coordinates (relative positioning)

3.4 Satellite ephemeris

Numerical representation of the trajectory of the centre of mass of an Earth orbiting artificial satellite expressed in an Earth centred terrestrial reference frame

3.5 Terrestrial reference frame

TRF
Realization of a TRS, by specifying its origin, orientation, scale, and its time evolution

[SOURCE: IERS Conventions 2010]

Note 1 to entry: The realization is achieved through a set of physical points with precisely determined coordinates in a specific coordinate system, which may include the rate of coordinate change.

Note 2 to entry: The realization is called static when no rates of coordinate change are defined, and kinematic when rates of coordinate change are defined without considering the underlying forces causing the motion. The realization may be called dynamic when these external forces are considered. “Dynamic” is also used colloquially to describe both the dynamic and kinematic cases without distinction.

3.6 Terrestrial reference system

TRS
Set of conventions defining the origin, scale, orientation and time evolution of a spatial reference system co-rotating with the Earth in its diurnal motion in space

Note 1 to entry: The abstract concept of a TRS is realized through a terrestrial reference frame.

Note 2 to entry: In such a system, positions of points attached to the solid surface of the Earth have coordinates which undergo only small variations with time, due to geophysical effects (tectonic or tidal deformations). In the Newtonian framework, the physical space is considered as a Euclidean affine space of dimension 3, with an origin, a scale and an orientation.

[SOURCE: IERS Conventions 2010]

BPS WG2: Establishment of the Global Geodetic Reference Frame (GGRF)

Chair: Urs Marti (Switzerland)

Members

Jonas Ågren (Sweden, Commission 2), Detlef Angermann (Germany, GGOS BPS, IERS), Riccardo Barzaghi (Italy, IGFS), Johannes Ihde (Germany, Working Group on Height Systems), Hansjörg Kutterer (Germany, GGOS), Jaakko Mäkinen (Finland, Tidal Systems), Pavel Novak (Czech Republic, ICCT), Roland Pail (Germany, Commission 2), Nikolaos Pavlis (USA, Global Gravity Field Models), Laura Sánchez (Germany, Working Group on Height Systems), Harald Schuh (Germany, IAG), Hartmut Wziontek (Germany, Global Gravity Reference Network)

Corresponding Members

Gary Johnston (Australia, Commission 1, UN GGIM), Johannes Böhm (Austria, Commission 1), Catherine Hohenkerk and Robert Heinkelmann (Representatives of the IAU)

Activities

This WG is a joint activity of IAG Commissions 1 and 2, the ICCT, the IERS and the IGFS.

The start-up meeting of this WG took place during the EGU Assembly 2016 in Vienna. In this meeting, the tasks of the WG were discussed and defined. A clear separation between this WG and the UN GGIM WG on the GGRF was reached. Thus, the IAG WG concentrates on the practical issues of the realisation of the GGRF and the setup of a consistent use of geometry and gravity field related quantities in the global reference frames. A key role in this discussion play the realisation of the International Height Reference System (IHRS) and the definition and realisation of a global Absolute Gravity Reference System (see corresponding reports of these WGs).

At the GGHS2016 conference in Thessaloniki a first official meeting of the WG was held. Some concrete tasks were defined there, such as:

- Work towards a conventional global reference gravity field model
- Develop or define a global, conventional combined gravity field model and a conventional Satellite only model
- Study the influence of permanent tide models on all kind of data (position, potential, gravity, gravity anomalies, heights) and develop transformation methods
- Study the redefinition of a global GRS based on actual values of W_0 / GM / ω and derived quantities
- Study the necessity to replace GRS80
- Study relativistic effects and their influence on the GRS
- Get an overview of parameters and models (e.g. tides, loading effects, atmosphere) used in products and conventions of IAG and other communities. (see BPS Inventory, Angermann et al., 2016)
- Intensify the contacts to IAU and IERS

Main discussions were the assignment of a conventional global gravity field model, where not all WG members agree that it is necessary. A second point of disagreement was, if it is really a good idea to replace GRS80 by a new model. A good summary of the main aspects can be found in 'Considerations on a Concept for future handling Geodetic Parameters/Numerical Standards in Conventions' by J. Ihde.

The concepts and activities of the WG were presented at the TGSMM conference in St. Petersburg in April 2016 , the GGOS days in Cambridge in October 2016, the IAG-IASPEI Scientific Assembly in Kobe (August 2017), the GGOS days in Vienna (November 2017) and the GGHS2018 conference in Copenhagen (September 2018).

Results

An overview of the parameters and models used by various groups in- and outside of Geodesy is available in the BPS inventory (Angermann et al. 2016 and 2018). Mäkinen presented in Kobe (2017) a study about the calculation of the permanent tide, the transformation and use of the various systems and their influence on the ellipsoid, the gravity potential and the physical heights. One main recommendation was to calculate all the influences in the zero tide system and to convert the corrections at the very end into other systems and to neglect very minor second order terms. In Copenhagen (2018), Oshchepkov presented a set of parameters of a reference system, consistent with the W_0 value, adopted in 2015 for the IHRS. All calculations are based on the zero tide system and terrestrial time (TT). As defining parameters W_0, GM, J_2 and ω were chosen. Values for the derived parameters (such as semi-major axis a, flattening f, normal gravity at the equator γ_E) were calculated as well. It was shown that a new set of parameters for a GRS has also small, but non-negligible influences on the gravity anomalies and normal heights. Kopeikin (et al.) published several papers on relativistic effects on a GRS, especially the effects on the reference ellipsoid, the gravity potential and the normal gravity (see list in the references).

Until now, no agreement about the definition of a "standard" global gravity field model was reached. There is even no agreement if such a "standard model" is needed at all. However, such a common reference model (satellite-only and combined) would be very useful for several purposes such as the realization of the International Height Reference System (IHRS) or for consistent regional geoid modelling. The newly installed IAG service COST-G (International Combination Service for Time-variable Gravity Field Solutions) of the IGFS could assist in finding such reference models, although their main focus is on the combination of time variable gravity field models.

One main task - the preparation of an IAG or IUGG resolution for the replacement of GRS80 by a new official GRS – could not be realized yet. Though we have a proposal for a new set of defining parameters (e.g. by Oshchepkov, alternative solutions are still calculated by other groups), we are not ready yet to present a broadly accepted new model. Many users do not see the necessity to change the conventional GRS80. This needs a broader discussion not only in IAG, but also in other related organisation such as the IAU and the IUGG. In the near future, this could become possible in the frame of the renewal of the IERS conventions and the newly established committee working on the definition of "Essential Geodetic Variables" (EGVs), associated with the GGOS Bureau of Products and Standards (BPS). Even if GRS80 will not be replaced as the conventional system, it is necessary to calculate a GRS based on today's knowledge and to propose a consistent set of parameters and formulas.

Presentations and Publications

Angermann D. et al (2016): Inventory of Standards and Conventions used for the Generation of IAG products.

Angermann D., Gruber T., Gerstl M., Heinkelmann R., Hugentobler U., Sánchez L., Steigenberger P.: GGOS Bureau of Products and Standards: Recent Activities and Future Plans. International Association of Geodesy Symposia, 10.1007/1345_2018_28, 2018

IAG Executive Committee (2016): Description of the Global Geodetic Reference Frame. Position Paper. April 2016.

Ihde J. (2016): The Role of Gravity and Height for the GGRF. Presentations at the EUREF Symposium May 2016. San Sebastian.

Ihde J. (2016): Future handling Geodetic Parameters/Numerical Standards in Conventions. Presentation at the GGOS Days October 2016. Cambridge.

Ihde J. (2016): Considerations on a Concept for future handling Geodetic Parameters/Numerical Standards in Conventions. November 2016.

Ihde J., Sánchez L., Barzaghi R., Drewes H., Foerste Ch., GruberT., Liebsch G., Marti U., Pail R., Sideris M.: Definition and proposed realization of the International Height Reference System (IHRS). Surveys in Geophysics, 38(3), 549-570, 10.1007/s10712-017-9409-3, 2017

Kopeikin S., E. Mazurova, A. Karpik (2015): Towards an exact relativistic theory of Earth's geoid undulation, Physics Letters A, 379, 1555.

Kopeikin S (2016): Reference ellipsoid and geoid in chronometric geodesy. Frontiers in Astronomy and Space Sciences, 3, 5

Kopeikin S., W.-B. Han, E. Mazurova (2016): Post-Newtonian reference-ellipsoid for relativistic geodesy, Physical Review D, 93, id. 044069

Kopeikin S. et al. (2018): Normal gravity field in relativistic geodesy. Physical Review D 97(4). DOI: 10.1103/PhysRevD.97.045020.

Mäkinen J. (2017): The permanent tide and the International Height Reference System IHRS. Presentation at the IAG-IASPEI Scientific Assembly, Kobe (Japan).

Marti U. (2016): GGRF. Presentation at the EGU General Assembly. April 2016, Vienna.

Marti U. (2016): GGRF. Presentation at the GGHS2016 Conference. September 2016, Thessaloniki.

Marti U. (2016): Presentation at the GGOS Days October 2016. Cambridge.

Marti U., L. Vitushkin, H. Wziontek (2016): The Role of a new Global Absolute Gravity Reference System in Relation to the GGRF. Presentation at the TGSMM Conference. April 2016. St.Petersburg.

Oshchepkov I. (2018): Geodetic reference system consistent with the IHRF W_0 value. Presentation at the GGHS2018 Conference in Copenhagen.

GGOS Focus Area "Unified Height System" and JWG 0.1.2 "Strategy for the Realization of the International Height Reference System (IHRS)"

Chair: Laura Sánchez (Germany)

Members: J. Ågren (Sweden), M. Amos (New Zealand), R. Barzaghi (Italy), S. De Freitas (Brazil), W. Featherstone (Australia), T. Gruber (Germany), J. Huang (Canada), J. Ihde (Germany), G. Liebsch (Germany), J. Mäkinen (Finland), U. Marti (Switzerland), P. Novák (Czech Republic), M. Poutanen (Finland), D. Roman (USA), D. Smith (USA), M. Véronneau (Canada), Y. Wang (USA), M. Blossfeld (Germany), J. Böhm (Austria), X. Collilieux (France), M. Filmer (Australia), B. Heck (Germany), R. Pail (Germany), M. Sideris (Canada), G. Vergos (Greece), C. Tocho (Argentina), H. Denker (Germany), D. Avalos (Mexico), H. Wziontek (Germany), M. Varga (Croatia), I. Oshchepkov (Russia), D. Blitzkow (Brazil), A.C.O.C. Matos (Brazil), J. Bouman (Germany), H.A. Abd-Elmotaal (Egypt), K. Matsuo (Japan), S. Claessens (Australia), R. Forsberg (Denmark), T. Jiang (China), V.N. Grigoriadis (Greece), D.A. Natsiopoulos (Greece), Q. Liu (Germany), M. Willberg (Germany), B. Erol (Turkey), M. Serkan Isik (Turkey), S. Erol (Turkey).

Activities

The objectives and planned activities of the GGOS-FA "Unified Height System" for the 2015-2019 period are described in the Geodesist's Handbook 2016 (Drewes H. et al., 2016). The main goal at present is the implementation of the International Height Reference System (IHRS) defined by the IAG 2015 Resolution No. 1 (ibid. page 981). The progress is summarized as follows:

- In Dec 2015, the joint working group (JWG) *Strategy for the Realization of the IHRS* was installed with the objective of developing a scheme for the realization of the IHRS; i.e., the establishment of the International Height Reference Frame (IHRF). This JWG is supported by *the International Gravity Field Service* (IGFS), the IAG Commissions 1 and 2 (*Reference Frames* and *Gravity field*), the *Inter-commission Committee on Theory* (ICCT), the *regional sub-commissions for reference frames and geoid modelling*, and both *GGOS Bureaus* (*Networks and Observations* and *Products and Standards*). In particular, there is a strong cooperation with
    - IAG JWG 2.2.2: *The 1 cm geoid experiment* (chair: Y.M. Wang, USA)
    - IAG SC 2.2: *Methodology for geoid and physical height systems* (chair: J. Ågren, Sweden)
    - ICCT JSG 0.15: *Regional geoid/quasi-geoid modelling - Theoretical framework for the sub-centimetre accuracy* (chair: J. Huang, Canada)
    - IAG JWG 2.1.1: *Establishment of a global absolute gravity reference system* (chair: H. Wziontek, Germany)
    - J. Mäkinen, *tide systems in the IHRS* (Finnland).

- A brainstorming and definition of action items took place at a JWG meeting carried out during the *International Symposium on Gravity, Geoid and Height Systems 2016* (GGHS2016) in Thessaloniki (Greece) in Sep 2016. This JWG meeting was attended by 70 colleagues and allowed us to identify the activities to be faced immediately (Sánchez, 2016a). A main output of this meeting are the criteria for the selection of IHRF reference stations:
    - GNSS continuously operating reference stations to detect deformations of the reference frame;

  - Co-location with fundamental geodetic observatories to ensure a consistent connection between geometric coordinates, potential and gravity values, and reference clocks (to support the implementation of the GGRF);
  - Co-location with reference stations of the *International Gravity Reference Frame* (IGRF): the IGRF and IHRF station selection for the co-location of this two reference frames is a contribution of IAG JWG 2.1.1;
  - Preference of stations belonging to the ITRF and the regional reference frames (like SIRGAS, EPN, APREF, etc.);
  - Co-location with reference tide gauges and connection to the national levelling networks to facilitate the vertical datum unification;
  - Availability of terrestrial gravity data around the IHRS reference stations as main requirement for high-resolution gravity field modelling (i.e., precise estimation of potential values).

- During the *GGOS Days 2016* (Boston (MA), USA, Oct 2016), a preliminary station selection for the IHRF was performed (Sánchez, 2016b). This selection was based on a global network with worldwide distribution, including a core network (to ensure sustainability and long-term stability of the reference frame) and regional/national densifications (to provide local accessibility to the global frame).

- Based on the conclusions of the meetings in Thessaloniki and Boston, regional and national experts were asked
  - to evaluate whether the preliminary selected sites are suitable to be included in the IHRF (availability of gravity data or possibilities to survey them), and
  - to propose additional geodetic sites to improve the density and distribution of the IHRF stations in their regions/countries.

- After the feedback from the regional/national experts (see Table 1), the first approximation to the IHRF is based on about 170 reference stations. This station selection is regularly refined in agreement with changes/updates of other geodetic reference frames (ITRF and IGRF and their densifications). Figure 1 shows the IHRF station distribution (as of Apr 2019) and the co-location with SLR, VLBI, DORIS, IGRF, tide gauges and levelling networks' stations.

- With the preliminary station selection, following efforts concentrated on the computation of station potential values and the assessment of their accuracy. Different approaches were evaluated (Sánchez et al., 2017):
  - As national/regional experts provided the JWG with terrestrial gravity data around some IHRF sites, a direct computation of potential values was performed using a combination of terrestrial gravity data and different global gravity models (GGM) as well as different mathematical formulations (least-squares collocation, FFT, radial basis functions, etc.).
  - Computation of potential values by national/regional experts responsible for the geoid modelling using their own data and methodologies.
  - Computation of potential values based on GGM of high-degree (like XGM2016, EIGEN-6C, EGM2008, etc.).
  - Recovering potential values from existing local (quasi-)geoid models.
  - Table 2 lists the colleagues contributing to this first experiment.

- The comparison of the results showed discrepancies up to the dm-level (Sánchez et al., 2017). The main conclusions of this experiment were:

- The use of only GGMs is (at present) not suitable for the estimation of precise potential values. GGMs may be used if there is *no other way* to determine potential values.
- A *standard* procedure for the computation of potential values may be not appropriate as
    - different data availability and different data quality exist around the world
    - regions with different characteristics require particular approaches (e.g. modification of kernel functions, size of integration caps, geophysical reductions like GIA, etc.)
- A *centralized* computation (like in the ITRF) is complicated due to the restricted accessibility to terrestrial gravity data

• To overcome these inconveniences, during the *IAG-IASPEI Joint Scientific Assembly* (Kobe, Japan, Aug 2017) was agreed to initiate a new experiment towards:
- the computation of IHRF coordinates using exactly the same input data and the own methodologies (software) of colleagues involved in the gravity field modelling, and
- the comparison of the results, to identify a set of standards that allow to get as similar and compatible results as possible.

• In the same IAG-IASPEI 2017 Assembly, J. Ågren (Chair of IAG SC 2.2) and J. Huang (Chair of ICCT JSG 0.15) proposed to establish an interaction with the JWG 2.2.2 (chaired by Y.M. Wang). Aim of JWG 2.2.2 is the computation and comparison of geoid undulations using the same input data and the own methodologies/software of colleagues involved in the geoid computation. The comparison of the results should highlight the differences caused by disparities in the computation methodologies. In this frame, it was decided to extend the "geoid experiment" to the computation of station potential values as IHRS coordinates. With this proposal, the US NGS/NOAA agreed to provide terrestrial gravity data, airborne gravity, and digital terrain model for an area of about 500 km x 800 km in Colorado, USA (Fig. 2). With these data, different groups working on the determination of IHRF coordinates should compute potential values for some virtual geodetic stations located in that region. Afterwards, the results individually obtained should be compared with the *Geoid Slope Validation Survey 2017* (GSVS17), which will provide potential differences inferred from first order levelling measurements and gravity corrections along a validation line (see red line in Fig. 2).

• The Colorado data were distributed in Feb. 2018, together with a document summarizing a minimum set of basic requirements (standards) for the computations. Ten different groups delivered solutions (Table 3) and the results were discussed during the *Gravity, Geoid and Height Systems (GGHS2018) Symposium* (Copenhagen, Denmark, Sep 2018). Main conclusions are (Wang et al., 2018; Sánchez et al. 2018a):
- Two solutions were declared as outliers. They present large discrepancies (at the 1.5 m level) in (quasi-)geoid heights as well in the potential numbers with respect to the other solutions.
- In the geoid comparison, six solutions agree within 3 cm to 10 cm in terms of standard deviation with respect to the mean value.
- In the quasi-geoid comparison, the same six solutions agree within 1 cm to 4 cm in terms of standard deviation with respect to the mean value.
- In the comparison of the potential values, four solutions agree within 1 cm to 2 cm in terms of standard deviation with respect to the mean value.
- The discrepancies present a high correlation with the topography.
- Possible sources of discrepancy:

- Different handling of terrain corrections/reductions
- Inconsistent use of the zero-degree term
- Precision degradation due to the conversion of quasi-geoid heights to geoid heights and vice versa
- Uncertainties in the processing of the airborne gravity data.

• To continue the Colorado experiment, following action items were formulated:
  - Participants in the experiment should provide a description with the main features of their computations in order to identify possible sources of discrepancies.
  - Participants should follow the basic standards/specifications distributed with the data, especially in the handling of corrections/reductions like the effect of the atmosphere, the consistent use of the zero-term, the global gravity models, etc.
  - The document with the standards/specifications was modified/extended to present more clearly some confusing issues like the handling of the zero degree term and the conversion from quasi-geoid to geoid (Sánchez et al., 2018b).
  - NGS/NOAA provided a pre-processed (cleaned) version of the GRAV-D data (down sampling 20 Hz data, de-biased data) by the end of 2018 in order to facilitate the use of these data in the individual solutions.

• Based on these action items, a second computation for the Colorado experiment was completed in Apr 2019. In total, 14 solutions were delivered (Table 4). At present, we are working on the comparison of geoid heights, height anomalies and potential values. The results will be discussed in the next *IUGG General Assembly* (Montreal, Canada, July 2019). It is expected to present all the results in a special issue of the *Journal of Geodesy*.

Outlook

To close the term 2015-2019, an executive report will be presented to the IAG and GGOS at the IUGG General Assembly 2019. It is expected to support this executive report with a peer-reviewed paper describing the strategy for the realization of the IHRS and a first solution for the IHRF. Aim of this first solution is to evaluate the achievable accuracy under the present conditions (data availability, computation methods, etc.) and to identify key actions to improve the determination of the IHRS/IHRF coordinates. These key actions should be faced in the next 2019-2023 period. For the same term, a joint working group of the GGOS FA-UHS, the IAG Commission 2 and the IGFS should investigate the best way to establish an *IHRS/IHRF element* within the IGFS to ensure the maintenance and availability of the IHRF. This implies regular updates of the IHRFyy to take account for new stations, coordinate changes with time, improvements in the estimation of coordinates (more observations, better standards, better models, better computation algorithms, etc.), geodetic products associated to the IHRF (description and metadata), and the organizational and operational infrastructure to ensure the IHRF sustainability.

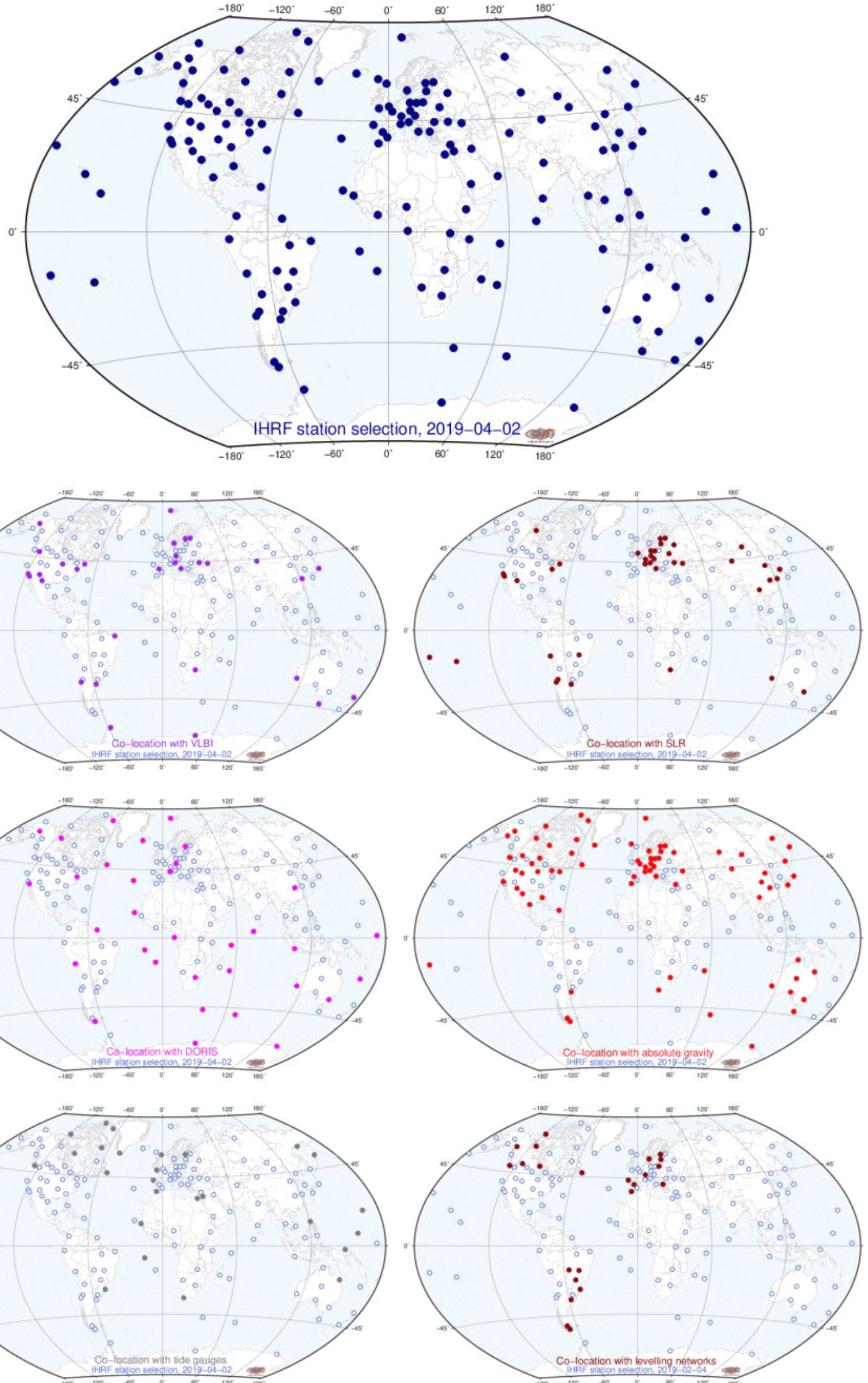

Fig. 1. IHRF stations as of April 2019 and the co-location with VLBI, SLR, DORIS, absolute gravity (IGRF), tide gauges and levelling networks' stations.

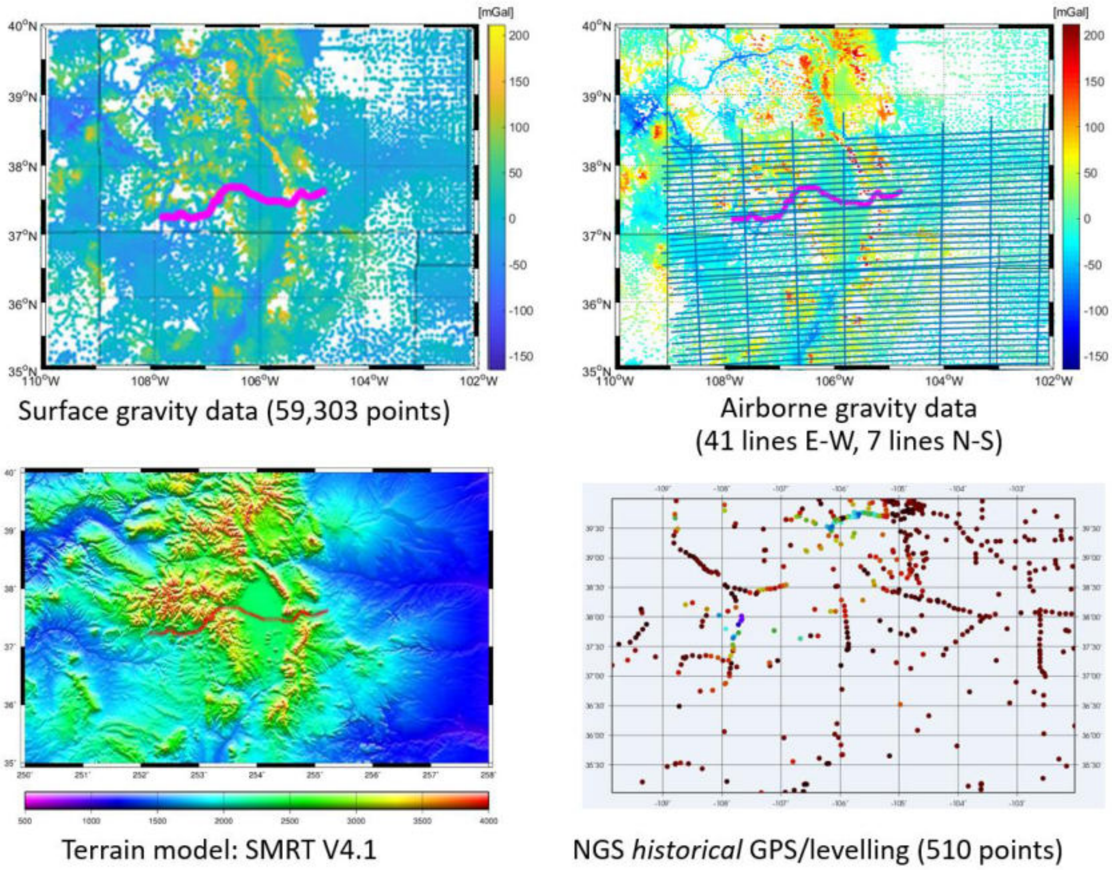

Fig. 2. Data provided by the US NGS/NOAA for the Colorado experiment. The red line represents the validation profile of the Geoid Slope Validation Survey 2017 (GSVS17). For validation, potential differences inferred from first order levelling and gravity corrections along this line will be compared with potential differences inferred from the different Colorado solutions (see Tables 2 and 3).

Table 1: Colleagues contributing to the station selection for the International Height Reference Frame (see Fig. 1)

- M Véronneau, J Huang - Natural Resources Canada, Canada
- I Oshchepkov - Center of Geodesy, Cartography and SDI, Russia
- D Roman, K Choi, K Ahlgren - US National Geodetic Service - NOAA, USA
- R Ruddick - Geoscience Australia, Australia
- M Amos - Land Information New Zealand, New Zealand
- SRC de Freitas - Universidade Federal do Parana, Brazil
- JR Chire Chira - Instituto Geográfico Nacional, Peru
- DA Piñón - Instituto Geográfico Nacional, Argentina
- C Estrella - Instituto Geográfico Militar, Ecuador
- A Álvarez - Instituto Geográfico Nacional, Costa Rica
- A Echalar Rivera - Instituto Geografico Militar, Bolivia
- D Avalos-Naranjo - Instituto Nacional de Estadística y Geografía, Mexico
- S Costa, R Luz - Instituto Brasileiro de Geografia e Estatística, Brazil
- D Blizkow, ACOC de Matos - Universidade de São Paulo, Brazil
- N Suárez - Servicio Geográfico Militar, Uruguay
- J Krynski - Institute of Geodesy and Cartography, Poland
- U Marti - Federal Office of Topography, swisstopo, Switzerland
- K Matsuo - Geospatial Information Authority of Japan, Japan
- H Abd-Elmotaal - Minia University, Egypt
- G Vergos - Aristotle University of Thessaloniki, Greece
- M Poutanen - Finnish Geospatial Research Institute, Finland

- PA Vaquero Fernández - Instituto Geográfico Nacional, Spain
- J Ågren - Lantmäteriet, Swedish mapping, cadastral and land registration authority, Sweden
- H Wziontek - Bundesamt für Kartographie und Geodäsie, Germany
- V Mackern, W Martínez - SIRGAS
- R Forsberg - National Space Institute, Denmark
- I Liepinš - Latvian Geospatial Information Agency, Latvia
- T Jiang - Chinese Academy of Surveying and Mapping, China

Table 2: Colleagues contributing to the first experiment for the determination of IHRS coordinates (Sánchez et al. 2017)

- M Véronneau, J Huang - Natural Resources Canada, Canada
- G Vergos - Aristotle University of Thessaloniki, Greece
- D Blizkow, ACOC de Matos - Universidade de São Paulo, Brazil
- JL Carrión-Sánchez, SRC de Freitas - Universidade Federal do Parana, Brazil
- H Denker - Leibniz Universität Hannover, Germany
- R Pail - Technische Universität München, Germany
- V Lieb - Technische Universität München, Germany
- L Sánchez - Technische Universität München, Germany

Table 3: Colleagues contributing to the first computation for the Colorado experiment (Wang et al., 2018; Sánchez et al., 2018b)

- VN Grigoriadis, GS Vergos, DA Natsiopoulos - Aristotle University of Thessaloniki, Greece
- H Abd-Elmotaal - Minia University, Egypt
- B Erol, M Serkan Isik - Istanbul Teknik Üniversitesi, Turkey
- YM Wang, X Li, K Ahlgren - US National Geodetic Survey - NOAA, USA
- M Véronneau, J Huang - Natural Resources Canada, Canada
- J Ågren - Lantmäteriet, Swedish mapping, cadastral and land registration authority, Sweden
- S Claessens, M Filmer - Curtin University, Australia
- EL Nicacio, JL Carrión, SRC de Freitas, R Dalazoana, VG Ferreira, Universidade Federal do Parana, Brazil
- D Blizkow, ACOC de Matos - Universidade de São Paulo, Brazil
- L Sánchez - Technische Universität München, Germany

Table 4: Colleagues contributing to the second computation for the Colorado experiment (results to be presented at the IUGG General Assembly 2019)

- VN Grigoriadis, GS Vergos, DA Natsiopoulos - Aristotle University of Thessaloniki, Greece and R Barzaghi, D Carrion - Politecnico de Milano, Italy
- T Jiang - Chinese Academy of Surveying and Mapping, China
- M Véronneau, J Huang - Natural Resources Canada, Canada
- S Claessens, M Filmer - Curtin University, Australia
- Q Liu, M Schmidt, L Sánchez - Technische Universität München, Germany
- R Forsberg - National Space Institute, Denmark
- K Matsuo - Geospatial Information Authority of Japan, Japan and R Forsberg - National Space Institute, Denmark
- M Willberg, R Pail - Technische Universität München, Germany
- B Erol, M Serkan Isik, S Erol - Istanbul Teknik Üniversitesi, Turkey
- J Ågren - Lantmäteriet, Swedish mapping, cadastral and land registration authority, Sweden

- YM Wang, X Li, K Ahlgren, US National Geodetic Survey - NOAA, USA
- M Varga, T Bašic - University of Zagreb, Republic of Croatia and M Pitonák, P Novák - University of West Bohemia, Czech Republic
- R Barzaghi, D Carrion - Politecnico de Milano, Italy
- D Blizkow, ACOC de Matos, Escola Politécnica da Universidade de São Paulo, Brazil

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Sánchez L: *International Height Reference System (IHRS): Required measurements and expected products*. GGOS Days 2016, Cambridge (MA), USA, https://ihrs.dgfi.tum.de/fileadmin/ JWG_2015/ Sanchez_IHRS_Obs_Prod_GGOS2016_2.pdf, 2016b.

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Further reading

Web site

A web site summarizing the main characteristics, achievements and challenges of the GGOS-FA "Unified Height System" is available at http://ihrs.dgfi.tum.de/. This information is mirrored at http://ggos.org/en/focus-areas/unified-height-system/.

Selected publications and presentations

Altiparmaki O.N., Vergos G.S.: *Potential determination at coastal stations from the synergy of SAR/SARin altimetry and local gravity data towards the IHRS*. International Symposium on Gravity, Geoid and Height Systems 2018 (GGHS2018), Copenhagen, Denmark, 2018.

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Ihde J., Sánchez L.: *Physical Height and the GGRF, Earth Gravity Field and the GGRF, GGRF an Integrated Approach*. GGOS Days 2015, Frankfurt a.M., Germany, 2015-10-22.

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Mäkinen J.: *The permanent tide and the International Height Reference System IHRS.* Joint Scientific Assembly of the International Association of Geodesy and the International Association of Seismology and Physics of the Earth's Interior (IAG-IASPEI 2017), Kobe, Japan, 2017.

Mäkinen J.: *Treatment of the permanent tide in the Global Geodetic Observing System.* EGU General Assembly 2018, Vienna, Austria. Geophysical Research Abstracts, Vol. 20, EGU2018-12672, 2018.

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Marti U., Sánchez L.: *Le système de référence altimétrique global*. Commission Géopositionnement, Conseil national de l'information géographique, Paris, France, 2017-03-15.

Nicacio E.L., Carrión J.L., de Freitas S.R.C., Dalazoana R., Ferreira V.G.: *Strategy for calculating local potential values as IHRS coordinates – a case study on the Colorado empirical experiment*. International Symposium on Gravity, Geoid and Height Systems 2018 (GGHS2018), Copenhagen, Denmark, 2018.

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Sánchez L.: *GGOS Focus Area 1: Unified Height System: Present activities*, GGOS Coordinating Board Meeting, TU Vienna, Vienna, Austria, 2016-04-16.
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Willberg M., Gruber Th., Vergos G.: *Height systems in Greece and its islands - some experimental results*. GGHS2016: International Symposium on Gravity, Geoid and Height Systems 2016, Thessaloniki, Greece, 2016-09-21.
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GGOS Focus Area "Geohazards"

Chair: John LaBrecque (USA)
Geohazards Focus Area Representative to GGOS Science Panel: Dr. Diego Melgar (USA)

The Geohazards Monitoring Focus Area (GFA) will apply geodetic science, technology, and infrastructure to mitigate natural hazards and improve disaster response. Following the devastating losses of the past two decades and the apparent short comings of available early warning systems the Geohazards Focus Area (GFA) determined that it would focus the application of geodetic techniques upon the improvement of tsunami warning. The publication of significant advances in real-time technology and analysis laid a compelling case for the implementation of this geodetic capability.

The GFA formally began its first initiative with the April 1, 2016 release of a Call for Participation (CfP) to the GNSS Augmentation to the Tsunami Early Warning Systems (GATEW) (http://kb.igs.org/hc/en-us/articles/218259648-Call-for-Participation-GNSS-Augmentation-to-the-Tsunami-Early-Warning-System). The GATEW CfP identifies the formal recommendations by the IGS, IUGG, IOC, and the APSG that support the CfP. The GATEW initiative will advance and implement the Resolution #4 of the IUGG 2015 General Assembly. The GATEW will build upon the benefits of the IGS Real Time Service (GPSRT) and the Multi-GNSS Experiment (MGEX) within the context of the UN-GGIM program.

Resolution 4: Real-Time GNSS Augmentation of the Tsunami Early Warning System (http://www.iugg.org/resolutions/IUGGResolutions2015.pdf):

The International Union of Geodesy and Geophysics

Considering

- That large populations may be impacted by tsunamis generated by megathrust earthquakes,
- That among existing global real-time observational infrastructure, the Global Navigation Satellite Systems (GNSS) can enhance the existing tsunami early warning systems,

Acknowledging

- The need to coordinate with the UNESCO Intergovernmental Oceanographic Commission (IOC) and the established intergovernmental coordination framework to define GNSS network requirements, data sharing agreements and a roadmap for the development and integration of the GNSS tsunami early warning augmentation.

Urges

- Operational agencies to exploit fully the real-time GNSS capability to augment and improve the accuracy and timeliness of their early warning systems,
- That the GNSS real-time infrastructure be strengthened,
- That appropriate agreements be established for the sharing of real-time GNSS data within the tsunami early warning systems,
- Continued support for analysis and production of operational warning products,

<u>Resolves</u>

- To engage with IUGG member states to promote a GNSS augmentation to the existing tsunami early warning systems.
- Initially to focus upon the Pacific region because the high frequency of tsunami events constitutes a large risk to the region's large populations and economies, by developing a prototype system, together with stakeholders, including scientific, operational, and emergency responders.

The GATEW CfP was distributed to the Earth science and disaster management agencies and institutions of more than 16 countries. The UN-GGIM-AP Secretariat distributed the GGOS GATEW CfP to the UN-GGIM membership. The GATEW working group currently comprises 17 agencies and institutions from 11 countries. The agencies and institutions of the GATEW working group are actively involved in the development of GNSS infrastructure, analysis, and disaster preparedness. The GATEW working group is a catalyst and motivating force for the definition of requirements, identification of resources, and for the encouragement of international cooperation in the establishment, advancement, and utilization of GNSS for Tsunami Early Warning. The GATEW CfP and registration to the GATEW working group remains open.

GATEW online library:

The GATEW maintains a library containing relevant documents, presentations, newsletters, videos and other files of interest to the GATEW community at the following link https://www.dropbox.com/sh/fg20mtydg136vx6/AABNr2kSnMo429nCxEHhBDfoa?dl=0 . The GFA will shift these files to the GGOS.org website when the appropriate GGOS web page is fully implemented.

The GFA initiated this first initiative with a program to inform influential organizations of the important contributions that real time GNSS analysis brings to effective and efficient tsunami warning systems. These efforts included presentations at significant scientific and governmental meetings.

The GATEW CfP called upon the community of agencies and institutions to join the GATEW working group to support and promote GNSS Augmentation to Tsunami Early Warning system as recommended by Resolution #4 of the 2015 IUGG General Assembly.

GGOS Working Group on GNSS Augmentation for Tsunami Warning

(As of January 13, 2018)

Country	Organization	Resources	Contact	Email
Australia	GeoScience Australia	Large National Real Time GNSS Network	John Dawson	John.Dawson@ga.gov.au
Chile	U.Chile, Department of Geophysics, CSN	Large National Real time Geodetic and Seismic Network	Sergio Barrientos, Sebastián Riquelme, Juan Baez	sbarrien@dgf.uchile.cl, sebastian@dgf.uchile.cl,jcbaez@csn.uchile.cl
China	GNSS Research Center, Wuhan University	First Real Time Asian Analysis Center	Jianghui Geng	jgeng@whu.edu.cn
China	Shanghai Observatory	Eminent geodetic research organization with strong experience in geodetic infrastructure, analysis and applications.	Shuanggen Jin	sgjin@shao.ac.cn
Colombia	Geological Survey Colombia	Large Real Time GNSS Network, Regional Data Sharing with Brazil, Peru, Panama, Venezuela, COCONet Data Center	Hector Mora	hmora@sgc.gov.co
France	Institut de Physique du Globe de Paris	Strong research in tsunami coupled ionospheric waves and tracking	Giovanni Occhipinti	ninto.a.paris@gmail.com
Germany	GeoForschung Zentrum, Department Geoservices	Strong research and development of GNSS Early Warning including Indonesia and Oman projects	Harald Shuh, Jörn Lauterjung	schuh@gfz-potsdam.de, lau@gfz-potsdam.de
Italy	University of Rome Geodesy and Geomatics	Initiating research in GNSS Tsunami Warning	Mattia Crespi, Augusto Mazzoni	mattia.crespi@uniroma1.it , augusto.mazzoni@uniroma1.it
Mexico	Instituto de Geofisica, UNAM	Large National GNSS network and analysis system, COCONet Data Center	Enrique Cabral	ecabral@geofisica.unam.mx
New Zealand	GNS Science	Large National Network	Elisabetta D'Anastasion	E.DAnastasio@gns.cri.nz
New Zealand	Land Information New Zealand	Large National Network	Dion Hansen	DHansen@linz.govt.nz
Sri Lanka	Survey Department of Sri Lanka	Strong interest in developing Tsunami Early Warning	P. Sangakkara,Mr A. Dissanayeke	sangakkara@yahoo.com, sg@sg@survey.gov.lk
USA	Georgia Tech	Significant focus on subduction zone activity and the generation of tsunamis	Andrew V. Newman	anewman@gatech.edu
USA	Jet Propulsion Laboratory	Real time expertise, Ionospheric mapping, global and operations, earthquake and tsunami warning	Attila Komjathy	attila.komjathy@jpl.nasa.gov
USA	UNAVCO	Global GNSS networks, real time data systems, Global GNSS support	Linda Rowan	rowan@unavco.org
USA	READI Working Group	NASA-NOAA working group developing GNSS Based Tsunami Warning	Yehuda Bock, Timothy Melbourne	ybock@ucsd.edu, tim@Geology.cwu.edu
USA	NASA	NASA Solid Earth Science. Provides funding from GNSS Tsunami Warning development. Cooperating with NOAA in this effort.	Gerald Bawden	gerald.w.bawden@nasa.gov

Presentations on GATEW were made at the following meetings:

2014, June 23-27, IGS Workshop 2014 , Pasadena, CA. http://kb.igs.org/hc/en-us/articles/204125433-2014-IGS Workshop-Summary-Recommendations
2015, June-22-July 2, IUGG-2015 Prague, Czech Republic
2015, August 10-15 , 9th ACES International Workshop, Chengdu, China
2015, August 24-28, Asia-Pacific Space Geodynamics Project-2015 Moscow, Russia, http://agora.guru.ru/display.php?conf=apsg-2015&page=program
2015, November 1-6, International Committee on GNSS-10, Boulder, US
2015, December 1-4, Asia-Pacific Regional Space Agency Forum (APRSAF 22) Bali, Indonesia
2015, December 14-18, AGU Fall Meeting, Session#8328 Global Naviga6on Satellite System for Natural Hazard Mitigation- Invited Talk, San Francisco, US
2016, February 8-12, International GNSS Service Workshop (IGS-2016) Sydney, NSW, Australia http://kb.igs.org/hc/en-us/articles/205944657-2016-IGS-Workshop-Information
2016, November 6-11, International Committee on GNSS-11, Sochi, Russia
2016, April 17-22, European Geosciences Union General Assembly-2016, Vienna, Austria
2016, May 3-5, COCONet Workshop, Punta Cana, Dominican Republic
2016, September 29 – October 1, Subduction Zone Observatory Workshop, Boise, US
2016, November 14-16, 8th Multi-GNSS Asia (MGA) Conference, Manila, Phillipines
2017, April 23-28, European Geosciences Union General Assembly-2017, Vienna, Austria
2017, July 3-7, 2017 IGS workshop 2017, Paris, http://kb.igs.org/hc/en-us/articles/216574478-2017-IGS-Workshop-Information
2017, July 25-26 GTEWS 2017 Workshop, Sendai, Japan
2017, July 29-30, UNGGIM TECHNICAL SEMINAR REFERENCE FRAME IN PRACTICE, Kobe, Japan
2017, July 30-Aug 4, IAG-IASPEI General Assembly and UN-GGIM-AP meeting in Kobe, Japan.
2017, August 15-18, Asia-Pacific Space Geodynamics Project-2017, Shanghai, China http://english.shao.cas.cn/rh/ca/201705/t20170502_176593.html
2017, December 11-15, AGU Fall Meeting, Gilbert F. White Distinguished Lecture, New Orleans, US
2018, June 18, IX Hotine-Marussi Symposium, LaBrecque J, Crespi M: GGOS Focus Area on Geohazards Monitoring – The role of real-time GNSS data processing, Rome, Italy
2018, December 10-14, AGU Fall Meeting, Washington, DC, US
2019, April 4-11, Institute of Navigation Pacific PNT Conference, Honolulu, Hawaii, US

GTEWS 2017: the 1st Meeting of the GATEW:

The GATEW Working Group held its first meeting in Sendai Japan as part of the GTEWS 2017 workshop July 25-27, 2017. The GGOS Geohazards Focus Area collaborated with NASA, the Association of Pacific Rim Universities (APRU) and the International Research Institute of Disaster Science (IRIDeS) of Tohoku University in support of the GTEWS 2017 workshop. 42 Participants reviewed the status and made recommendations on the development of a GNSS enhanced Tsunami Early Warning System as recommended by Resolution #4 of the IUGG 2015 General Assembly. Over 90% of the GATEW organizations registered for GTEWS2017 and GATEW provided a majority of the presentations.

GTEWS Publications:

The GFA assumed leadership in the assembly and publication of the findings of the GTEWS 2017. The GTEWS workshop report containing video and presentations of the proceedings and workshop recommendations is available on the website of the APRU (http://apru.org/resource/gnss-early-warning-report/) and within the GFA online library https://www.dropbox.com/s/zo4frdmsqis9scf/GTEWS2017.pdf?dl=0 .

The UNISDR has accepted an updated report of the GTEWS 2017 initiative for its GAR19 publication. The UN Global Assessment Report on Disaster Risk Reduction (GAR) is the flagship report of the United Nations on worldwide efforts to reduce disaster risk. The GAR is published biennially by the UN Office for Disaster Risk Reduction (UNISDR), and is the product of the contributions of nations, public and private disaster risk-related science and research, amongst others. GAR19 report is available at this site https://gar.unisdr.org/. A copy of the updated GTEWS report is also available at the GFA online library https://www.dropbox.com/s/15rnypek9vqacp4/Global%20Navigation%20Satellite%20System%20Enhancement%20for%20Tsunami%20Early%20Warning%20Systems.pdf?dl=0.

Recommendations of the GTEWS 2017 report

1. The GGOS/IUGG, APRU and the UN-GGIM are encouraged coordinate efforts to develop a GNSS Shield Consortium for the Indo-Pacific.
2. The GNSS Shield Consortium should work to encourage software, data exchange, and continued improvement of network design and performance.
3. Strengthen broadband communication to underserved regions of the GNSS Shield.
4. Work with national organizations including those mandated for natural hazards mitigation to develop agreements for inclusion of their GNSS receivers within the GNSS Shield.
5. Design an optimal GNSS Shield network for both crustal displacement and high-resolution TEC monitoring.
6. Understand the operational requirements of existing tsunami warning systems and determine the steps required to interface these tsunami warning systems.

Future Actions and Milestones:

- The GFA and the GATEW working group will work to develop the recommendations of the GTEWS 2017 workshop.
    - The READI Group has submitted a proposal to fund a cloud based GTEWS analysis system available to all national prototype GTEWS networks as proposed. (Action on Recommendation 2)
    - The GFA will undertake an effort to work with global Internet Service Providers to increase the participation of identified real-time GNSS stations with the GNSS Shield. (Action on Recommendation 3)
    - Wuhan University is in discussions to provide real-time GNSS distribution software to one or more of the national prototype networks to advance real-time data sharing. (Action on Recommendation 4)
- The Geohazards Focus Area recommends changing the status of GATEW to a Standing Committee for GNSS Enhancement of Tsunami Early Warning (GATEW). We expect that the GATEW standing committee will become increasingly important as the Indo-Pacific begins to integrate the several prototype GNSS early warning networks into an Indo-Pacific real time network.
- Expand the membership and influence of the GATEW standing committee.

GGOS Focus Area "Sea-Level Change, Variability and Forecasting"

Chair: *Tilo Schöne (Germany)*
Co-Chairs: *CK Shum (USA), Mark Tamisiea (UK), Phil Woodworth (UK)*

Purpose and Scope

Sea level rise and its impact on human habitats and economic well being have received considerable attention in recent years by the general public, engineers, and policy makers. A GGOS retreat in 2010 has identified sea level change as one of the cross-disciplinary themes for geodesy. Sea Level is also a major aspect in other observing systems, like e.g. GEO or GCOS. The primary focus of GGOS Focus Area 3 is to demonstrate and apply geodetic techniques, under the umbrella of GGOS, to the possible mitigation or adaption of sea level rise hazards including studies of the impacts of its change over the world's coastal and deltaic regions and islands, and to support practical applications such as sustainability. One major topic is the identification of gaps in geodetic observing techniques and to advocate enhancements to the GGOS monitoring network and Services where necessary.

Activities and Actions

Focus Area 3 has identified actions to be undertaken to advance geodetic techniques and technologies applied to sea level research. These are

- Identification or (re)-definition of the requirements for a proper understanding of global and regional/local sea-level rise and its variability especially in so far as they relate to geodetic monitoring provided by the GGOS infrastructure, and their current links to external organizations (e.g., GEO, CEOS, and other observing systems).
- Identification of organizations or individuals who can take forward each requirement, or act as points of contact for each requirement, where they are primarily the responsibility of bodies not related to GGOS.
- Identification of a preliminary set of practical or application (as opposed to scientific) pilot projects, which will demonstrate the viability, and the importance of geodetic measurements to mitigation of sea-level rise at a local or regional level. This identification will be followed by construction of proposals for pilot projects and their undertaking.

In the long-term, the aim is to support forecasting of global and regional sea level for the 21st century with an expected forecast period of 20 to 30 years or longer.
An open Call for Participation was issued in 2012. Special emphasis is given to local and regional projects which are relevant to coastal communities, and which depend on the global perspective of GGOS. Three projects have been accepted. Thus, GGOS Focus Area 3 now has approved "Landmark" projects:

The Use of Continuous GPS and Absolute Gravimetry for Sea Level Science in the UK (NERC British Isles continuous GNSS Facility (BIGF), University of Nottingham, UK), (NERC National Oceanography Centre (NOC), Liverpool, UK).

Revisiting the Threat of Southeast Asian Relative Sea Level Rise by Multi-Disciplinary Research (Delft University of Technology (DUT), Delft, Netherlands; University of Leeds, Leeds, United Kingdom; Ecole Normale Supérieure, Paris, France; Chulalongkorn University, Bangkok, Thailand; Royal Netherlands Meteorological Institute (KNMI), De Bilt, Netherlands)

Bangladesh Delta Relative Sea-Level Rise Hazard Assessment (Division of Geodetic Science, School of Earth Sciences, The Ohio State University, Columbus, Ohio, USA; University of Bonn, Bonn, Germany; GeoForschungsZentrum Potsdam (GFZ), Germany)

and additionally

Subsidence Monitoring in Urban Areas of the Republic of Indonesia with GNSS-controlled tide gauges and supporting methods (National Geospatial Agency (BIG) of Indonesia; Helmholtz Centre Potsdam GFZ, Germany; Institut Teknologi Bandung, Indonesia) together with the University of Cologne working on social aspects,

which is in preparation for submission.

All projects have their major focus on the combination of sea level and geodetic monitoring in an integrative approach. Also in the reporting period, Focus Area 3 continued communications with organizations, dealing with other than geodetic aspects of sea level monitoring. These are, e.g., the UNESCO International Oceanographic Commission Group of Experts (UNESCO/IOC GE) and the World Glacier Monitoring Service (WGMS). In Germany in 2016 a special research program (SPP 1889 - Regional Sea Level Change and Society, www.spp-sealevel.de) started and is dealing with many aspects relevant to GGOS Focus Area 3. Also cooperation with the IGS Tide Gauge Benchmark Monitoring Working is continued. A major step for GGOS Focus Area 3 was the alignment of its activities with the GGOS Bureau of Networks and Observations (B&O). The improvement of the observation network for sea level research is a major open topic. In 2015, the GLOSS Group of Experts (GLOSS-GE), the IGS TIGA-WG and the GGOS Focus Area 3 had submitted the Report "Priorities for installation of continuous Global Navigation Satellite System (GNSS) near to tide gauges" for consideration by GGOS. This report is now accepted by the GGOS CB and the GGOS B&O.
The GNSS-controlled tide gauges are an important monitoring component in climate and geodetic science. Over the years, the network of collocated stations has been growing, not at least through the constant effort of IOC/GLOSS Group of Experts, the IGS TIGA-WG, and GGOS. Focus Area 3 plays a significant role in improving the network coverage and the establishment of local ties between GNSS and tide gauges.

Objectives and Planned Efforts for 2017-2019 and Beyond

- Review and Refine current and future aspects of geodetic contributions for sea level research with groups identified in AS-SL-01/AS-SO-02
- Work on to identify and contact emerging Focus Area 3 pilot projects
- Support Focus Area 3 projects
- Establish/improve the outreach activities with the help of the GGOS-CO
- Work with IGS/TIGA on results of the TIGA reprocessing
- Work with GGOS CB and GGOS B&O on the findings of the report "Priorities for installation of continuous Global Navigation Satellite System (GNSS) near to tide gauges"
- Identify geodetic monitoring aspects relevant to Focus Area 3
- Maintain the GGOS web space for the Focus Area 3.

Website

http://www.ggos.org/en/focus-areas/sea-level-change-variability-and-forecasting/

Publications and Presentations

Woodworth, P., Aarup, T., Gaël, A., Donato, V., Enet, S., Edwing, R., Heitsenrether, R., Farre, R., Fierro, J., Gaete, J., Foden, P., Pugh, J., Perez, B., Rickards, L., Schöne, T. (Eds.)(2016):Manual on Sea-level Measurements and Interpretation, Volume V: Radar Gauges, (IOC Manuals and Guides ; 14) (JCOMM Technical Report ; No. 89), Paris : Intergovernmental Oceanographic Commission of UNESCO, 2016

Michael R. Pearlman, Chopo Ma, Ruth Neilan, Carey Noll, Erricos Pavlis, Jérôme Saunier, Tilo Schoene, Riccardo Barzaghi, Daniela Thaller, Sten Bergstrand, and Juergen Mueller: The GGOS Bureau of Networks and Observations: an update on the Space Geodesy Network and the New Implementation Plan for 2017 - 18,Geophysical Research Abstracts, Vol. XX, General Assembly European Geosciences Union (Vienna 2017), http://meetingorganizer.copernicus.org/EGU2017/EGU2017-10814.pdf

Schöne, T., Shum, C., Tamisiea, M., Woodworth, P. (2015): GGOS Theme 3: Understanding and Forecasting Sea-Level Rise and Variability - Scientific programme, 26th IUGG General Assembly (Prague 2015). http://gfzpublic.gfzpotsdam.de/pubman/item/escidoc:1437893:5/component/escidoc:1437892/GGOS_Theme3

Tilo Schöne, Ck Shum, Mark Tamisiea, and Philip Woodworth: GGOS Focus Area 3: Understanding and Forecasting Sea-Level Rise and Variability, Geophysical Research Abstracts, General Assembly European Geosciences Union (Vienna 2017), http://meetingorganizer.copernicus.org/EGU2017/EGU2017-8814.pdf

Tilo Schöne, Ck Shum, Mark Tamisiea, and Philip Woodworth: GGOS Focus Area 3: Understanding and Forecasting Sea-Level Rise and Variability, 10th GEO European Projects Workshop 2016, Berlin, 31.5.-2.6.2016, https://ec.europa.eu/easme/en/geo-european-projects-workshop-2016

GGOS Focus Area "Geodetic Space Weather Research"

Chair: Michael Schmidt (Germany)
Vice-Chair: Klaus Börger (Germany)

Members:
- *Andres Calabia Aibar (Spain)*
- *Fabricio dos Santos Prol (Bazil)*
- *Ehsan Forootan (Iran)*

Purpose and Scope

The issue "Space Weather" is an interdisciplinary field of research, where the subject geodesy contributes essentially by its expertise on ionosphere and thermosphere. The Focus Area on "Geodetic Space Weather Research" concentrates on the upper atmosphere, i.e. the compartments ionosphere and thermosphere, being original manifestations of space weather. Thus, in a nutshell, the main **objectives of the Focus Area** are (1) the development of improved ionosphere models and (2) the development of improved thermosphere models.

Objective (1) aims at the high-precision as well as the high-resolution (spatial and temporal) modeling of the electron density. This finally allows to compute a signal propagation delay, which can be used for different geodetic applications, in particular for "positioning, navigation and timing (PNT)". Moreover, it is also important for other techniques using electromagnetic waves, such as satellite- or radio-communications. Concerning objective (2), satellite geodesy will obviously benefit when working on "precise orbit determination (POD)", but there are further technical matters like the "collision analysis" or the "re-entry calculation", which will become more reliable when using high quality thermosphere models.

For a "Geodetic Space Weather Research", geodesy has to extend its traditional perspective on thermosphere and ionosphere, i.e. geodesy has to move away from the limited concept of regarding the atmosphere as only being a disturbing effect affecting electromagnetic waves. "Geodetic Space Weather Research" has to take into account the complete chain of cause and effect, which means it has to start with processes and events on the Sun. Next, it has to continue with the effects on the geosphere and finally it has to consider the impact on (geodetic) applications and systems. Besides this general chain of cause and effect interactions, the physics and especially coupling processes between thermosphere and ionosphere have to be regarded. Geodetic Space Weather Research is "fundamental research" too, particularly when intending to detect and to survey structures of the ionosphere, e.g. bubbles, or when proving special phenomena like electrojets. Summarized, geodetic space weather research has to be based on a) the use and combination of all space geodetic observation methods, b) the use of sun observations, c) real-time modeling, d) the development of deterministic and stochastic forecast approaches and e) assimilation strategies.

Finally, it should be mentioned that the work within the proposed Focus Area will be carried out in close relation to the International Association of Geomagnetism and Aeronomy (IAGA), since this organisation is also concerned with the understanding of properties related, e.g. to the ionosphere and magnetosphere as well as the Sun and the solar wind.

Activities during the period 2017-2019

Four new GGOS Joint Study Group (JSG) and Joint Working Groups (JWG) have to be installed into the IAG structure within the 4-year period 2019 to 2023. These are

- JSG 1: **Coupling processes between thermosphere and ionosphere** (implemented within the IAG ICCT and joint with GGOS)
- JWG 1: **Electron density modelling** (joint with IAG Commission 4)
- JWG 2: **Improvement of thermosphere models** (joint with IAG Commission 4)
- JWG 3: **Improved understanding of space weather events** and their monitoring by satellite missions (joint with IAG Commission 4).

The chair positions of JWG 2 and JWG 3 are still vacant. Appropriate candidates have been selected and approached, but they not yet confirmed their commitment. Ehsan Forootan (Institute of Physics and Meteorology, University of Hohenheim, Stuttgart, Germany) became member of the GGOS Science Panel.

During the last two years, the work and the activities of the Focus Area were presented at different meetings, see section “Presentations”.

Next actions of the Focus Area are:

- to find the chairs of JSG 1 and JWG 1
- to find the members of the JSG/JWGs and
- to set up the Terms of Reference of the JSG/JWGs.

In the following IAG four-year period the Focus Area will mainly work on the following three aspects:

- extensive simulation studies have to be performed in order to assess the impact of space weather on technical systems and to define – as a consequence – necessary actions in case of severe space weather events
- development of ionosphere and thermosphere models as stated above as GGOS products for direct application
- establishment of recommendations for applications of the models, e.g. in satellite orbit determination, collision analysis and re-entry computations.

Website

http://www.ggos.org/en/focus-areas/geodetic-space-weather-research

Presentations

- poster presentation at the GEO WEEK 2017 in Washington D.C., October 23 to 27, 2017
- poster presentation at the EGU 2018 in Vienna, GGOS Session, April 10, 2018
- poster presentation at the IX Hotine-Marussi Symposium in Rome in June 18 to 22, 2018
- poster presentation at the EGU 2019 in Vienna, GGOS Session, April 9, 2019
- poster presentation at the ESA Living Planet Symposium in Milan, May 13 to 17, 2019