Global Geodetic Observing System

https://www.ggos.org

President: Basara Miyahara (Japan)
Vice President: Laura Sánchez (Germany)

As the observing system of the IAG, the Global Geodetic Observing System (GGOS) facilitates a unique and essential combination of roles centering upon advocacy, integration, and international relations. GGOS aims to provide the observations needed to monitor, map, and understand changes in the Earth's shape, rotation, and mass distribution, to provide the global geodetic frame of reference for measuring and consistently interpreting key global change processes and for many other scientific and societal applications, and to benefit science and society by providing the foundation upon which advances in Earth and planetary system science and applications are built. To complete its mission, GGOS develops and maintains 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, outreach, and external relations; as well as maintaining and developing the GGOS website and social media presence.

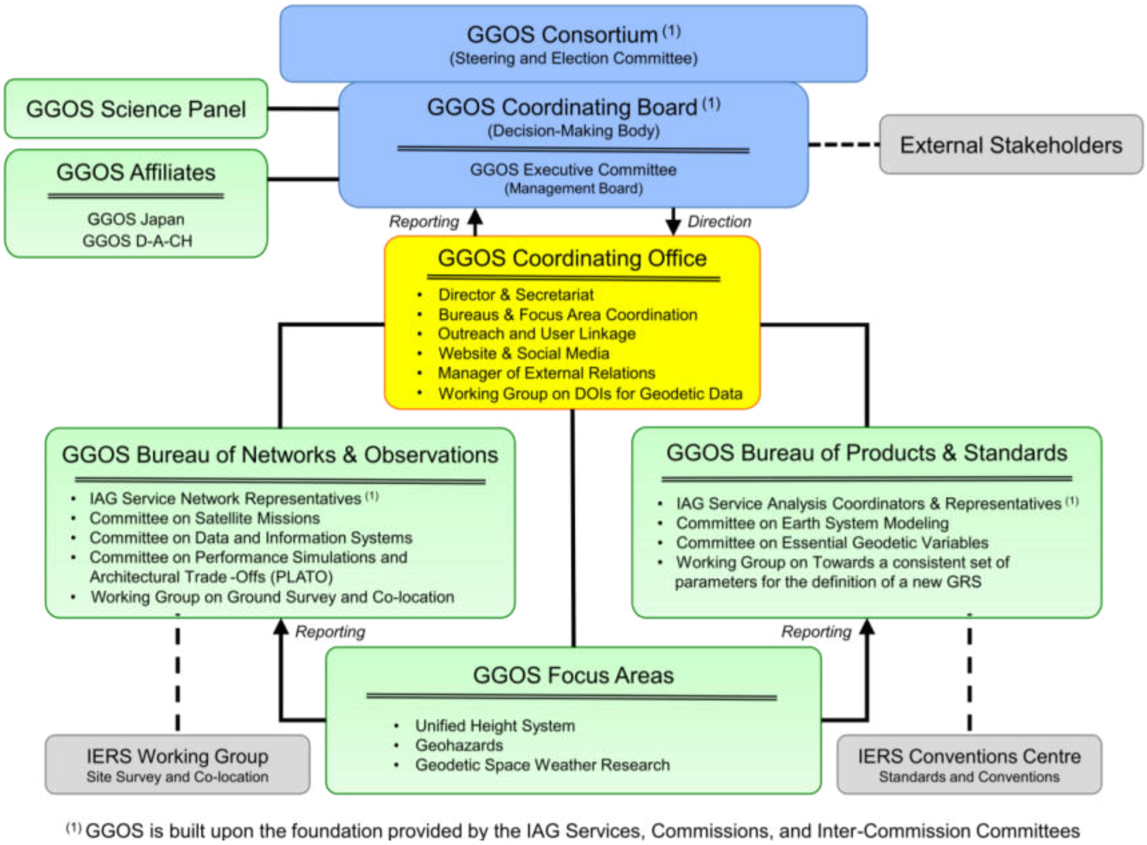

Figure 1. Organization chart of GGOS.

Overview

The GGOS renewed its structure in 2019 including the election of new President and Vice President and the restructuring of the GGOS Consortium and GGOS Coordinating Board. A Working Group on "DOIs for Geodetic Data Sets" was newly established within the GGOS Coordinating Office. The Working Group on "ITRS Standards for ISO TC 211" completed its work and was dissolved with successful contribution to ISO 19161-1. The Working Group on "Establishment of the Global Geodetic Reference Frame (GGRF)" was renewed and renamed to Working Group on "Towards a consistent set of parameters for the definition of a new GRS" and continues to work on the challenge to define a new GRS four more years. The GGOS Focus Area "Sea Level Change" was terminated in 2019.

The GGOS Bureau of Products and Standards (BPS) published a 2nd updated version of the BPS inventory in the Geodesist's Handbook 2020 to compile and refine an inventory on standards and conventions used for the generation of IAG products.

The GGOS Focus Area “Unified Height System” defined a strategy for the implementation of the International Height Reference System (IHRF) and is currently working in the first computation of the IHRF. The Focus Area “Geohazards” played a central role in the development of the initiative “GNSS enhancement to tsunami early warning systems (GTEWS)” and presently is supporting the creation of the GTEWS Consortium within the Community Activity “Geodesy for the Sendai Framework” of the Group on Earth Observations (GEO). The Focus Area “Geodetic Space Weather Research” identified four central challenges and established four dedicated working groups.

As a mechanism to increase participation in GGOS, the second of two GGOS Affiliates was established in 2021. GGOS D-A-CH is a regional affiliate group of German-speaking countries and its name is comprised of the country codes D (Germany), A (Austria) and CH (Switzerland). GGOS D-A-CH has been created by strong collaboration between the national geodetic commissions of these countries and developed based upon a strategic White Paper on “Geodesy 2030”. Its founding chair is Hansjörg Kutterer of Karlsruhe Institute of Technology. Moving forward, GGOS D-A-CH will formulate Terms of Reference with a clear focus on strategic topics in GGOS-related science. As a GGOS Affiliate, the group will have a representative to GGOS Consortium and GGOS Coordinating Board.

One of the main forces of GGOS during the period 2019-2021 is outreach and communication. GGOS renewed its website (https://www.ggos.org) to enhance outreach and communication to non-geodesists at the end of 2020. The new website focuses two faces of GGOS: one as an organization to foster collaboration between stakeholders mainly in IAG, and another as the geodetic observing system, which underpins science and society as fundamental infrastructure for monitoring the Earth. The new website put IAG Services in the front page to make them more visible and to provide easier access to their Internet portals. The new site also provides "products" and "observation" pages, which describe the role and importance of Geodesy, its observation techniques and products to non-geodesists with easy and brief explanations as well as eye-catching visual aids. The new site provides articles on Geodesy, which are also helpful for non-geodesists to understand what Geodesy is and why Geodesy is so important for science and society. Another new fundamental tool is the repository of main documents in the GGOS Cloud (https://cloud.ggos.org), which enables us to share the GGOS related materials such as Terms of Reference, reports, papers and presentations and ensures their long-term availability.

GGOS also further strengthened and expanded its external relations and stakeholder engagement. Continued participation in GEO included establishment of a geodesy advocacy Community Activity within GEO, titled “Geodesy for the Sendai Framework” as well as ongoing and diverse participation in the GEO Programme Board. GGOS also continues to strongly support the actions and initiatives of the UN GGIM Subcommittee on Geodesy, and intends to expand this support to the new UN Global Geodetic Centre of Excellence scheduled to commence operations in early 2022.

In addition to external advocacy, GGOS routinely looks inward to identify the best ways to cite and track the impact of the geodetic data, products, and other resources that the IAG and its services make freely and openly available to the general public. At the Unified Analysis Workshop in 2019, Digital Object Identifiers (DOIs) were discussed as unique identifiers of data as well as publications. DOIs are already widely used by publishers, and their implementation for data sets is expected to be beneficial for both users as well as data providers. Users can get easy access to data cited in journals, and use of DOIs improves traceability of published results and discoverability of data sets. This eliminates confusion about data used and enable wider distribution of data sets. Data providers can include information about data set on landing page (metadata), and DOIs easily allow number of data publications to be tracked and number of times data is used to be counted. Data providers can receive proper credit for their published data. Considering these benefits, the GGOS established a new Working Group on DOIs for Geodetic Data Sets in 2019. Its chair is Kirsten Elger of GFZ Potsdam and more than 20 members are participating in the WG, mainly from IAG Services. The WG has analyzed use cases and best practices both in geodesy as well as in other scientific fields, and is currently working on how to establish parameters and procedures for properly assigning DOIs to geodetic data set.

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 Terms of Reference, the Consortium membership is reviewed and refreshed every four years, which last one took place coincident to the 2019 IUGG General Assembly. The members of the GGOS Consortium during 2019–2023 are listed in Table 1.

The President of GGOS is also the chair of the GGOS Consortium. The GGOS Consortium meets annually, which during 2019–2021 took place during the GGOS Days:

1. GGOS Days 2019, Rio de Janeiro, Brazil, 12-14 November 2019
2. GGOS Days 2020, held virtually via Video Conference, 5-7 October 2020

Table 1. Members of the GGOS Consortium During 2019–2023

Organization	Name	Title
GGOS	Basara Miyahara	Chair
GGOS Affiliate: GGOS Japan	Yusuke Yokota	Designated GGOS Representative
GGOS Affiliate: GGOS D-A-CH	Markus Rothacher	Designated GGOS Representative (2021-2023)
IAG Service Representatives		
International Gravimetric Bureau (BGI)	Sylvain Bonvalot	Director
	Sean Bruinsma	Designated GGOS Representative
International Centre for Global Earth Models (ICGEM)	E. Sinem Ince	Designated GGOS Representative

International DORIS Service (IDS)	Laurent Soudarin	Director, Central Bureau
	Frank Lemoine	Chair, Governing Board
International Earth Rotation and Reference Systems Service (IERS)	Daniela Thaller	Director, Central Bureau
	Robert Heinkelmann	Analysis Coordinator
International Service for Geoid (ISG)	Urs Marti	Designated GGOS Representative
	Jianliang Huang	Designated GGOS Representative
International Gravity Field Service (IGFS)	Riccardo Barzaghi	Chair
	Georgios Vergos	Director, Central Bureau
International GNSS Service (IGS)	Nicholas Brown	Designated GGOS Representative
	Arturo Villiger	Designated GGOS Representative
The International Laser Ranging Service (ILRS)	Toshimichi Otsubo	Chair, Governing Board
	Erricos Pavlis	Chair, Analysis Working Group
International VLBI Service for Geodesy and Astrometry (IVS)	Axel Nothnagel	Chair, Directing Board
	Dirk Behrend	Director, Coordinating Center
Permanent Service for Mean Seal Level (PSMSL)	Elizabeth Bradshaw	Director
	Andy Matthews	Designated GGOS Representative
International Geodynamics and Earth Tides Service (IGETS)	Christoph Foerste	Designated GGOS Representative
	Hartmut Wziontek	Designated GGOS Representative
International Digital Elevation Model Service (IDEMS)	Kevin M. Kelly	Director
	Christian Hirt	Designated GGOS Representative
IAG Commissions Representatives		
Commission 1: Reference Frames	Christopher Kotsakis	President
	Tonie van Dam	Designated GGOS Representative
Commission 2: Gravity Field	Adrian Jäggi	President
	Mirko Reguzzoni	Vice President
Commission 3: Earth Rotation and Geodynamics	Janusz Bogusz	President
	Chengli Huang	Vice President
Commission 4: Positioning and Applications	Paweł Wielgosz	President
	Michael Schmidt	Vice President
IAG Inter Commission Committee (ICC) Representatives		
ICC on Theory (ICCT)	Pavel Novák	President
	Dimitrious Tsoulis	Designated GGOS Representative
ICC on Climate Research (ICCC)	Anette Eicker	President
	Carmen Boening	Vice President
ICC on Marine Research (ICCM)	Yuanxi YANG	President
	Heidrun Kopp	Designated GGOS Representative

Coordinating Board

The Coordinating Board is the decision-making body of GGOS. The members of the GGOS Coordinating Board during 2019–2023 are listed in Table 2.

The President of GGOS is the Chair of the Coordinating Board. The Coordinating Board meets twice-per-year, which during 2019–2021 took place during GGOS Days and around the EGU:

1. GGOS Days 2019, Rio de Janeiro, Brazil, 12-14 November 2019
2. GGOS CB Meeting, held virtually via Video Conference, 8 May 2020
3. GGOS Days 2020, held virtually via Video Conference, 5-7 October 2020
4. GGOS CB Meeting, held virtually via Video Conference, 7 May 2021

Table 2. Members of the GGOS Coordinating Board During 2019–2023

Position	Voting	Name
Chair	Yes	Basara Miyahara
Vice Chair	Yes	Laura Sánchez
Chair, Science Panel	Yes	Kosuke Heki
Director, Coordinating Office	Yes	Martin Sehnal
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	Toshimichi Otsubo
	Yes	Hansjörg Kutterer (2021-2023)
Representative, IAG President	Yes	Zuheir Altamimi
Representative, IAG Services	Yes	Riccardo Barzaghi
	Yes	Daniela Thaller
	Yes	Sean Bruinsma
	Yes	Robert Heinkelmann
Representative, IAG Commissions and ICC	Yes	Tonie Van Dam
	Yes	Adrian Jäggi
Member-at-Large	Yes	Maria Cristina Pacino (2019-2021) Claudia Tocho (2021-2023)
	Yes	Nicholas Brown
	Yes	Ludwig Combrinck
GGOS Focus Area (FA) Leads		
FA Unified Height System	No	Laura Sánchez
FA Geohazards	No	John LaBrecque
FA Geodetic Space Weather Research	No	Michael Schmidt
GGOS Committee Chairs		
Committee on Satellite and Space Missions	No	Roland Pail
Committee on Data and Information Systems	No	Martin Sehnal (2019) Nicholas Brown (2020-2023)
Committee on Contribution to Earth System Modelling	No	Maik Thomas
Committee on PLATO (IAG WG)	No	Daniela Thaller
Committee on Essential Geodetic Variables	No	Richard Gross
GGOS Working Group Chairs		
JWG: Ground Survey and Co-Location	No	Ryan Hippenstiel
JWG: Definition of a new GRS	No	Urs Marti
WG: DOIs for Geodetic Data Sets	No	Kirsten Elger
Others		
Manager, GGOS Web and Social Media	No	Martin Sehnal
Immediate Past Chair of GGOS	No	Richard Gross

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 2019–2023 are listed in Table 3.

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

Table 3. Members of the GGOS Executive Committee During 2019–2023

Position	Status	Name
Chair	Member	Basara Miyahara
Vice Chair	Member	Laura Sánchez
Director, Coordinating Office	Member	Martin Sehnal
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	Adrian Jäggi
Immediate Past Chair of GGOS	Guest	Richard Gross
Chair, Science Panel	Guest	Kosuke Heki
Representative, IAG President	Guest	Zuheir Altamimi

GGOS Coordinating Office

Director:	*Martin Sehnal (Austria)*
Manager of External Relations:	*Allison Craddock (USA)*
Chair of WG on DOIs:	*Kirsten Elger (Germany)*

Working Group (WG) affiliated with GGOS Coordinating Office:

- GGOS Working Group on "DOIs for Geodetic Data Sets"

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.

Activities and Actions

New Director of GGOS Coordinating Office

The director of the GGOS Coordinating Office changed in September 2019. Helmut Titz (BEV, Austria) stepped down due to health issues and Martin Sehnal (BEV, Austria) followed him interimistically and was finally approved by the BEV (Federal Office of Metrology and Surveying, Austria) as the new director of GGOS CO in July 2020.

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

New GGOS website – https://ggos.org

One major goal of GGOS is to communicate and advocate the benefits of Geodesy to scientists, user communities, policy makers, funding organizations and society. To reach this goal, it is essential to establish a strong online presence. The GGOS website serves as a source of information about GGOS, geodetic data, products, and services, as well as other non-technical resources for the IAG community.

After the transition of the GGOS CO from ASI (Agenzia Spaziale Italiana, Italy) to BKG (Bundesamt für Kartographie und Geodäsie, Germany) in 2015, it was transitioned again to

BEV (Federal Office of Metrology and Surveying, Austria) in 2016. BEV installed a completely new server system and launched a new designed GGOS website in 2017. In 2019 the GGOS Executive Committee decided to refresh and further develop it again to optimize the usability.

The new GGOS website (see image), which was published in December 2020, now emphasizes more on the "Observing System" than on the "GGOS organization" itself. Therefore, the website was enhanced to provide an extensive information platform to bring the IAG observations, products and services in the focus and to attract users from other disciplines. Visually attractive graphics navigate users to easy understandable introductions about geodetic products or observation techniques. Observation and product descriptions are complemented with a huge selection of web links containing scientific descriptions and data repositories provided by the IAG Services and additional data sources.

From 2019 to 2021, the GGOS Coordinating Office worked intensively together with all GGOS components and other important persons of the geodetic scientific community, to establish and launch this new information platform. Furthermore, the contributions of the IAG Services and other providers of geodetic products are gratefully acknowledged. The new GGOS website contributes to make geodesy more visible and to promote IAG and GGOS at global and multidisciplinary levels.

*New GGOS Cloud – https://*cloud.ggos.org

A first version of the GGOS Cloud service was installed in September 2017 and was based on the OwnCloud software. But due to several organizational and technical issues it was switched off. Together with the new GGOS Website, the GGOS Cloud was new developed and was published again in 2020. It is now based on the worldwide often used, regularly updated and free software Nextcloud. GGOS Cloud is fully integrated in the GGOS Website and is used as a file hosting platform for public files. Additionally, it is used to share files within the GGOS community.

*GGOS Blog & GGOS Newsletter – https://*blog.ggos.org

A blog was set up on the GGOS website, where users can find latest news and events of GGOS as well as short introductions into Geodesy and GGOS. Interested persons can subscribe to the GGOS mailing list to receive this news via the GGOS Newsletter https://ggos.org/newsletter/.

GGOS General Outreach Articles

In 2020 the idea was born to publish popular articles regularly (about 2-4 times a year) via email mailing list and also within the GGOS website. The aim of these articles is to strengthen the GGOS Outreach Activities by addressing readers with little or no knowledge of geodesy and its techniques or products. Therefore, the target audience consists of non-geodesists, geoscientists, geodesy students, politicians, etc. It is not the goal to offer updates to the geodetic scientific community. The first articles are planned to publish in 2021 or 2022.

GGOS social media presence via Twitter

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

Organized Conferences & Meetings

- Unified Analysis Workshop (UAW) (2019) - together with IERS
- Virtual GGOS Coordinating Board (CB) meetings (2020, 2021)
- GGOS Days 2019, Rio de Janeiro, Brasilia
- GGOS Days 2020, virtual conference

Conference attendance

- European Geosciences Union (EGU) (2020, 2021)
- American Geophysical Union (AGU) (2019, 2020)
- IAG Scientific Assembly (2021)

GGOS External Relations

Manager of External Relations: Allison Craddock (USA)

The position of GGOS Manager of External Relations was officially approved at the Vienna GGOS Days in October 2017. External Relations is based in the Coordinating Office, and works to ensure that GGOS, the IAG, and geodesy in general is represented and visibly contributing to stakeholder initiatives in service to science, Earth observation applications, and society.

Stakeholder Organization Participation

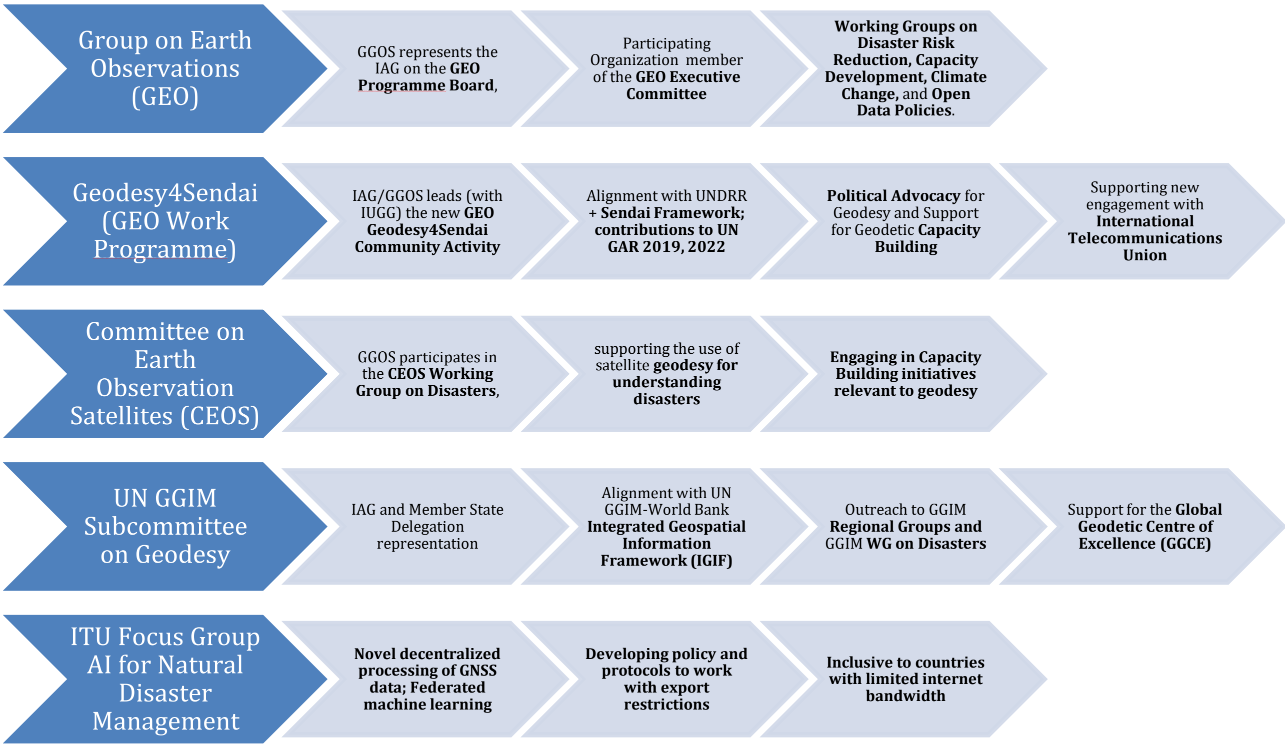

Figure: GGOS external relations with stakeholder organizations, as of December 2020.

Group on Earth Observations (GEO)

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.

GGOS has represented the IAG in the Group on Earth Observations (GEO) Programme Board since 2018, and was selected to serve on the GEO Executive Committee in 2021. GGOS Executive Committee members Richard Gross and Allison Craddock have served as IAG representatives to the GEO Programme Board since 2018. Within the Programme Board, IAG has been represented and contributed to the following Subgroups:

- **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.
- **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).
- **Subgroup on Equality, Diversity, and Inclusion:** This subgroup supports the strategic aim of developing GEO as an institution that provides a fair, supportive and encouraging networking environment with which a diverse set of participants engage responsibly. This subgroup aims to ensure that equality, diversity and inclusivity are fully considered, addressed, and embedded within GEO activities and decisions.

Additional IAG representation and participation at the Programme Board level included supporting **Work Programme Engagement Teams** on Climate Change, Cross-Cutting Applications, Sustainable Development Goals, and Disaster Risk Reduction/Hazards.

GGOS also represents IAG in leadership and participation in GEO Working Groups, which were established in 2020 and are open to participation from all GEO stakeholders. GGOS currently participates on behalf of IAG in the Working Groups on Disaster Risk Reduction, Capacity Development (co-chair), Climate Change, and Open Data Policies.

Group on Earth Observations Community Activity: Geodesy for the Sendai Framework

In late 2019 at the GEO Canberra Ministerial Summit, the IAG/GGOS proposal to form a GEO Community Activity dedicated to supporting applications of geodesy to disaster risk reduction was officially approved as a component of the GEO Work Programme 2020-2022. The activity, titled "Geodesy for the Sendai Framework" and often shortened to "Geodesy4Sendai", supports technical and scientific work of the GGOS Geohazards Focus Area with political advocacy for geodesy, and support for geodetic capacity building as a part of broader Earth observations for disaster risk reduction.

Geodesy4Sendai is jointly led by IUGG and IAG/GGOS, represented by John LaBrecque and John Rundle. The GGOS Manager of External Relations, Allison Craddock, serves as its executive secretary. To date, the work of Geodesy4Sendai has focused on the following objectives:

- Supporting geodetic development and capacity building for disaster risk reduction and resilience
- Identifies existing resources and stakeholder communities, and makes connections
- Identifies geodetic elements of targets and indicators of the Sendai Framework for Disaster Risk Reduction
- Provides opportunity for other GEO efforts to interact with geodesy community

- Integration with UN Sustainable Development Goals and UN-GGIM World Bank Integrated Geospatial Information Framework

Geodesy4Sendai strongly aligns with and contributes to implementation of the Sendai Framework for Disaster Risk Reduction, Targets F (Substantially enhance international cooperation to developing countries through adequate and sustainable support to complement their national actions for implementation of this framework by 2030) and G (Substantially increase the availability of and access to multi-hazard early warning systems and disaster risk information and assessments to the people by 2030), growing international cooperation and resilience – especially in small island developing states – by supporting access to early warning systems and other DRR information.

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 recently supported the contributions of geodesy to disaster risk reduction by taking an active role in the CEOS Working Group on Disasters, and Working Group on Capacity Development, especially where the work of these two groups overlaps with GEO and/or UN GGIM.

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). IAG works closely with the International Federation of Surveyors (FIG) as Observer participants 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.

Numerous GGOS 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
- Mike Pearlman, IAG

GGOS 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
- Basara Miyahara, Japan; SCoG Working Group on Education, Training and Capacity Building
- Gary Johnston, Australia; SCoG Co-chair (until end of 2019)

- Nicholas Brown, Australia; SCoG Co-chair (2020-present)

In the near future, GGOS will expand its involvement in GGIM as a component of strong IAG support for the proposed UN Global Geodetic Center of Excellence, scheduled to start operations in Bonn, Germany in early 2022.

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

International Telecommunications Union (ITU)
Focus Group on Artificial Intelligence for Natural Disaster Management (AI4NDM)

In early 2021, GGOS collaborated with GEO Geodesy4Sendai and IUGG GeoRisk Commission to propose a geodesy use case for the newly established ITU Focus Group "AI for Natural Disaster Management." The focus group, which is co-chaired by ITU, the World Meteorological Organization (WMO) and the UN Environment Program (UNEP), examines how Artificial intelligence (AI) and associated machine learning technologies and techniques can enhance our understanding of natural disasters and support disaster relief/early warning.

GGOS is a co-chair of a topic group examining the possible use of artificial intelligence and machine learning for "enabling Natural Hazards Risk Information Sharing Using Derived Products of Export-Restricted Real-Time GNSS Data for Detection of Ionospheric Total Electron Disturbances." This project seeks to explore the feasibility of using AI for novel decentralized domestic processing of GNSS data in countries where:

- Exporting of real-time GNSS data either prohibited by law, or;
- Participation/data sharing is restricted by limited internet bandwidth capacity (such as in small island developing states).

The project will establish guidelines for possible development and sharing of export-permitted data-derived products through artificial intelligence, federated machine learning, or a combination thereof. There is the potential for this to ultimately enable sharing of life-saving geodetic real-time tsunami risk information within the parameters of data export restrictions and/or constrained data transmission infrastructure.

External Relations Geodesy Advocacy Initiatives:
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.

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.

GAR
Global Assessment Report
on Disaster Risk Reduction

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

Following the success of advocating for geodetic contributions to tsunami early warning systems in the 2019 GAR, GGOS worked closely with the International GNSS Service to develop a second successful contribution to a GAR report, scheduled for publication in 2022. This contribution highlights the current and emerging geodetic contributions to complex disaster (wildfire) risk systems modelling, and is in strong support of recent work done by the IAG Inter-Commission Committee on Geodesy for Climate Research (ICCC) by highlighting and advocating the use of geodetic observations for climate studies. It further builds upon work to reinforce the utility of geodetic observations for disaster risk reduction and resilience, as well as introducing public health and wellbeing benefits.

The GAR22 paper, titled "Transdisciplinary application of Global Navigation Satellite System Radio Occultation (GNSS-RO) to characterize atmospheric hazards and model systemic risk," will also identify discrete geodetic contributions to UN Sustainable Development Goals for air quality, specifically Sustainable Development Goal 11: (Make cities and human settlements inclusive, safe, resilient, and sustainable); Indicator 11.6.2 specifically seeks to measure the annual mean levels of fine particulate matter (such as PM 2.5 and PM 10) in cities.

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 Working Group on DOIs for Geodetic Data Sets

Chair: Kirsten Elger (Germany)

Members

Chair: Kirsten Elger (GFZ, Germany), Detlef Angermann (TU Munich, Germany), Yehuda Bock (UCDC, US), Sylvain Bonvalot (GET, France), Markus Bradke (GFZ, Germany), Elizabeth Bradshaw (NOC, UK), Carine Bruyninx (ROB, Belgium), Daniela Carrion (Politecnico Milan, Italy), Glenda Coetzer (SARAO, South Africa), Pierre Fridez (CODE/ AIUB, Switzerland), Elmas Sinem Ince (GFZ, Germany), Philippe Lamothe (Geodetic Survey Canada), Vicente Navarro (ESA), Carey Noll (CDDIS/NASA, US), Mirko Reguzzoni (Politecnico Milan, Italy), Jim Riley (UNAVCO, US), Dan Roman (NGS, US), Laurent Soudarin (CLS, France), Daniela Thaller (BKG, Germany), Yusuke Yokota (GGOS Japan)

Associated Members

Godfred Amponsah (NGS, US), Sandra Blevins (CDDIS/NASA, US), Roelf Botha (SARAO, South Africa), Francine Coloma (NOAA CORS, US), Allison Craddock (JPL/NASA, US), Michael Craymer (Canadian Geodetic Networks, Canada), Theresa Damiani (NOAA CORS, US), Patrick Michael (CDDIS/NASA, US), Basara Miyahara (GGOS, Japan), Mike Pearlman (Harvard Smithsonian – Center for Astrophysics, US), Nacho Romero (ESA), Christian Schwatke (TU Munich, Germany), Martin Sehnal (GGOS, BEV, Austria), Lori Tyahla (CDDIS/NASA, US)

Motivation and purpose

Data publications with digital object identifiers (DOI) are best practice for FAIR sharing data. Originally developed with the purpose of providing permanent access to (static) datasets described in scholarly literature, DOI today are more and more assigned to dynamic data. These DOIs are providing a citable and traceable reference of various types of sources (data, software, samples, equipment) and means of rewarding the originators and institutions. As a result of international groups, like the Coalition on Publishing Data in the Earth, Space and Environmental Sciences (COPDESS) and the Enabling FAIR Data project, data with assigned DOIs are fully citable in scholarly literature and many journals require the data underlying a publication to be available – even before accepting an article. Initial metrics for data citation allows data providers to demonstrate the value of the data collected by institutes and individual scientists.
This is especially relevant for geodesy, because geodesy researchers are often much more involved in operational aspects and data provision than researchers in other fields might be. Therefore, compared to other scientific disciplines, geodesy researchers appear to be producing less “countable scientific” output. Consequently, geodesy data and equipment require a structured and well-documented mechanism which will enable citability, scientific recognition and reward that can be provided by assigning DOI to data and data products.
To address these challenges and to identify opportunities for improved coordination and advocacy within the geodetic community, the International Association of Geodesy’s (IAG) Global Geodetic Observing System (GGOS) has established a Working Group on “Digital Object Identifiers (DOIs) for Geodetic Data Sets”. This Working Group is designated to establish best practices and advocate for the consistent implementation of DOIs across all IAG Services and in the greater geodetic community.

Objectives

The main objectives and activities of this working group are

(1) to identify what the community needs from consistent usage of DOIs for data in terms of being able to discover data, permanently cite data, and acknowledge the data providers;
(2) to develop recommendations for DOI minting strategies for different geodetic data types and granularity across IAG Services (static, dynamic, observational data, data products, combination products, networks);
(3) to develop recommendations for a consistent method for data citation across all IAG Services, to support data providers, and to provide quantitative support detailing the use of geodetic datasets and other resources;
(4) to develop recommendations for connecting metadata standards for data discovery (e.g. DataCite, ISO19115) with community metadata standards (GeodesyML, Station Logs)

Activities and Actions

- physical kickoff meeting during AGU2019, monthly to bi-monthly video conferences.
- collection of data products and already existing and planned DOI activities for IAG services and geodetic data centres (living document).
- Outside the box: exploration of DOI minting and citation practices from other communities in the Earth sciences for potential adoption for geodetic data sets: e.g. network DOIs, persistent identifier for instruments, DOI citation recommendations for data compilations and hierarchical data products.

Outcomes

- support for the development of a DOI Service for the International Service for the International Service for the Geoid (IGS) in collaboration with GFZ Data Services (start July 2020).
- development of a concept for assigning DOI to hierarchical products (use case: ICGEM/ COST-G[1]), adoption for ITRF2020 products agreed by IERS CB (May 2021).
- DOIs for “fast living” products (rapid and ultra-rapid products) are supported only if the data are archived for the long term by the datacentre (e.g. AIUB and GFZ have assigned DOIs to their rapid and ultra-rapid IGS products, these DOIs are assigned on the product level and for individual datasets)

Ongoing discussions and future plans

Latest and future discussions explore geodetic metadata standards, like GeodesyML, and the possibility to include existing persistent identifier (PID), like ORCID for researchers, ROR for institutions, PID for instruments and other DOI-related discovery metadata in the geodetic metadata (for stations and data). These activities are aligned with current activities by the IGS infrastructure group to implement GeodesyML in GNSS station metadata. Early adopters are UNAVCO and ROB within M^3G[2], a common initiative between EPOS[3] and EUREF[4]. Our activities will include discussions with the developers of GeodesyML, the recommendation of

[1] Monthly GRACE series: https://doi.org/10.5880/ICGEM.COST-G.001, Monthly GRACE-FO series: https://doi.org/10.5880/ICGEM.COST-G.002)
[2] https://gnss-metadata.eu
[3] https://www.epos-eu.org/
[4] http://www.euref.eu/

controlled vocabularies describing geodetic datasets (to be used in metadata for stations and data, ideally the same vocabularies to facilitate cross-references between stations, sensory, data and networks). Moreover, we will explore the potential implementation of the new RDA[5]-derived concept for using PIDs for instruments[6] and include the harmonization of DOI-related metadata from different data centres in our recommendations.

Publications and conference presentations

Blevins, S. M., Tyahla, L., Michael, B. P., Noll, C. E. (2020) IN046-06 - DOIs for geodetic data and derived product collections at the NASA GSFC CDDIS. AGU 2020 Fall Meeting (Online 2020).

Bruyninx, C., Fabian, A., Legrand, J., & Miglio, A. (2020). GNSS Station Metadata Revisited in Re-sponse to Evolving Needs. Copernicus GmbH. https://doi.org/10.5194/egusphere-egu2020-18634

Craddoc, A., Elger, K., Sehnal, M., Fridez, P. (2019) DOIs for Geodetic Datasets. Unified Analysis Workshop, October 2-4, 2019, Paris, France.

Elger, K. (2020): G022-02 - What are the benefits for assigning DOI to Geodetic data? First ideas of the GGOS DOI Working Group - Abstracts, AGU 2020 Fall Meeting (Online 2020).

Elger, K. and the GGOS DOI WG (2020) Report from the GGOS Working Group on DOI for geo-detic data. Oral presentation during the GGOS Days 2020 (October 5-7, 2020, online)

Elger, K., Angermann, D., Bock, Y., Bonvalot, S., Botha, R., Bradke, M., Bradshaw, E., Bruyninx, C., Carrion, D., Coetzer, G., Elger, K., Fridez, P., Ince, E. S., Lamothe, P., Navarro, V., Noll, C., Reguzzoni, M., Riley, J., Roman, D., Soudarin, L., Thaller, D., Yokota, Y., Members, A., Amponsah, G., Blevins, S., Craddock, A., Craymer, M., Michael, P., Miyahara, B., Pearlman, M., Romero, N., Schwatke, C., Sehnal, M., Tyahla, L. (2021): News from the GGOS DOI Working Group - Abstracts, EGU General Assembly 2021 (Online 2021). https://doi.org/10.5194/egusphere-egu21-15081

Elger, K., Coetzer, G., Botha, R., GGOS DOI Working (2020): Why do Geodetic Data need DOIs? First ideas of the GGOS DOI Working Group - Abstracts, EGU General Assembly 2020 (Online 2020). https://doi.org/10.5194/egusphere-egu2020-17861

Ince, E. S., Barthelmes, F., Reißland, S., Elger, K., Förste, C., Flechtner, F., Schuh, H. (2019): ICGEM – 15 years of successful collection and distribution of global gravitational models, associated services and future plans. - Earth System Science Data, 11, 647-674. https://doi.org/10.5194/essd-11-647-2019

Miglio, A., Bruyninx, C., Fabian, A., Legrand, J., Pottiaux, E., Van Nieuwerburgh, I., & Moreels, D. (2020). Towards FAIR GNSS data: challenges and open problems. Copernicus GmbH. https://doi.org/10.5194/egusphere-egu2020-18398

Reguzzoni, M., Carrion, D., De Gaetani, C. I., Albertella, A., Rossi, L., Sona, G., Batsukh, K., Toro Herrera, J. F., Elger, K., Barzaghi, R., Sansó, F. (2021): Open access to regional geoid models: the International Service for the Geoid. - Earth System Science Data, 13, 4, 1653-1666. https://doi.org/10.5194/essd-13-1653-2021

Sehnal, M., Craddock, A. B., Elger, K. (2020): GGOS Coordinating Office – Recent Achievements and Activities. - Abstracts, AGU 2020 Fall Meeting (Online 2020).

Sehnal, M., Craddock, A., Elger, K. (2020): GGOS Coordinating Office – Recent Achievements and Activities - Abstracts, EGU General Assembly 2020 (Online 2020) https://doi.org/10.5194/egusphere-egu2020-6540

Yokota Y, Ishikawa T, Miyahara B, Otsubo M (2020): Issues and progress of Open Science in geodesy, JpGU-AGU meeting 2020, MGI36-11

Yokota Y, Miyahara B, Otsubo M, Murayama Y, Munekane H, Ishikawa T (2020): Activities of WG on DOIs in GGOS and Data DOI WG in GGOS Japan, JpGU-AGU meeting 2020, SGD01-05

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[5] RDA = Research Data Alliance (https://www.rd-alliance.org/)

[6] Persistent Identification of Instruments Working Group: https://www.rd-alliance.org/groups/persistent-identification-instruments-wg

GGOS Affiliate: GGOS Japan

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

This multi-institution entity was initially established as GGOS Working Group of Japan in 2013, later approved as GGOS Affiliate in 2017 and renamed as GGOS Japan in 2019. The purpose was to strengthen collaboration among Japan's geodetic stations and colleagues and to foster Japanese space geodetic activities internationally.

In recent years, GGOS Japan has constantly hosted its own annual meetings for broad range of space geodetic research and activities, and also organise smaller-size meetings on specific topics such as data DOI minting (2019) and co-location local tie (2020). It was remarkable that Japanese institutes were nicely collaborated to conduct local tie campaigns for the ITRF2020 project. A new aspect of GGOS Japan is to co-organise existing domestic meetings in the field of VLBI and SLR in 2020 where GGOS Japan core members are often given an opportunity of invited talks, and GGOS Japan is updating the terms of reference in 2021 so that co-hosting or supporting related meetings can be accommodated as one of its roles. It should be noted that in accordance with the renewal of GGOS website the webpages of GGOS Japan were largely updated, utilizing the GGOS Cloud function.

GGOS Japan is a loose organization of public sectors and university members. It does not have membership qualification, but its core members are selected. As of May 2021 they are:

Chair: Toshimichi Otsubo (Hitotsubashi University)
Secretary: Basara Miyahara (Geospatial Information Authority of Japan)
Outreach: Shinobu Kurihara (Geospatial Information Authority of Japan)
Data DOI WG Lead: Yusuke Yokota (University of Tokyo)
Technique Representatives:
- VLBI: Yu Takagi (Geospatial Information Authority of Japan)
- SLR: Shun-ichi Watanabe (Japan Coast Guard)
- GNSS: Hiroshi Takiguchi (Japan Aerospace Exploration Agency)
- DORIS: Yuichi Aoyama (National Institute of Polar Research)
- Gravity: Koji Matsuo (Geospatial Information Authority of Japan)

These members have actively involved in session planning of annual JpGU meetings and annual Geodetic Society of Japan meetings, where "GGOS" is always seen as (a part of) a session name. Likewise we should make every effort to utilize the "GGOS" keyword for budget hunting, aiming at future GGOS Core sites in Japan or Antarctica. Encouraging geodetic technology development is also in our scope - in addition to high precision and high operability, we are aware that we should significantly reduce costs per geodetic facility envisaging a denser global geodetic network in the future.

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 2019-2021 period, 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 2019-2021 period, GGOS sessions have been organized at:

- 2019 American Geophysical Union Fall Meeting in San Francisco
- 2020 American Geophysical Union Fall Meeting (virtual conference)
- 2020 European Geosciences Union General Assembly (virtual conference)
- 2021 European Geosciences Union General Assembly (virtual conference)
- 2020 Japan Geophysical Union – American Geophysical Union Joint Meeting in Chiba, Japan (virtual conference)

As a future session, the Science Panel proposed a GGOS session in the 2021 December American Geophysical Union Fall Meeting (hybrid meeting in New Orleans). Owing to the COVID19 pandemic, most international conferences in 2020 and 2021 were held as virtual online meetings. This situation is anticipated to continue until the condition recovers to the pre-2019 status.

In 2021, the Science Panel cooperated in the effort to renew the GGOS website, being led by the GGOS Coordinating Office and the GGOS Bureau of Products and Standards, specifically in reviewing the GGOS product page descriptions.

Objectives and Planned Efforts for 2021-2023 and Beyond

During the next two years 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

The next Unified Analysis Workshop is planned to be held in Munich, Germany during 05-08 October 2021, but the workshop may be postponed considering the COVID19 situation in Europe and the world. 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. Activities related to EGV will continue in the committee on EGV established in 2019, which includes the whole Science Panel members.

GGOS Bureau of Networks and Observations

Prepared by Michael Pearlman, Erricos C. Pavlis, Frank Lemoine, Daniela Thaller, Benjamin Männel, Roland Pail, C.K. Shum, Nick Brown, Ryan Hippenstiel

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 (Claudia Carabajal/SSAI NASA USA)
- Analysis Specialist (Erricos Pavlis/UMBC USA)
- IERS Representative (Ryan Hippenstiel/ NOAA USA)
- Representatives from each of the member Services:
  - IGS (Allison Craddock/JPL CalTech USA, Michael Moore/GA Australia)
  - ILRS (Toshi Otsubo/Hitotsubashi U. Japan, Jean-Marie Torre/ OCA France)
  - 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 (Elizabeth Bradshaw/BODC UK, Lesley Rickards/ BODC UK)
- Representatives from each of the member Standing Committees:
  - PLATO (Daniela Thaller/BKG Germany, Benjamin Maennel/GFZ Germany)
  - Data and Information Systems (Nick Brown/GA Australia)
  - Satellite Missions (Roland Pail/TUM Germany, C.K. Shum/OSU USA)
  - IERS WG on Survey Ties and Co-location (Ryan Hippenstiel/ NOAA USA)

Purpose and Scope

- Advocate for new and increased network participation, encouraging formation of new partnerships to develop new sites;
- Hold annual meetings of the Services and Standing Committees/Working Groups to share and discuss status plans, progress;
- Give talks and posters at public meetings to help familiarize the community with GGOS activities;
- Encourage integration of ground observation networks within the GGOS affiliated Network;
- Work with the UN GGIM and its affiliates to develop a plan for the implementation of the IAG geodetic network to satisfy the IAG requirement for the ITRF

Activities

- Participated and gave talks/posters on the BN&O and the ILRS at the AGU, EGU, IAG, JpGU-AGU, etc.
- The BN&O has been advocating for enhanced network infrastructure for Latin America, and participated and gave talks on the GGOS Bureau of Networks and Observations at;

- IUGG meeting "Implementation of the Global Reference Frame (GGRF) in Latin America" in in Buenos Aires, September 16 - 20, 2019;
- SIRGAS meeting in Rio de Janeiro, November 12 – 14, 2019;
- Unified Analysis Workshop in Paris, October 2 – 4, 2019;

- Met with representative from existing and planned stations in Latin America to discuss strategies, station details, equipment, etc.
- Supported new and vulnerable stations and analysis centers with letters of support and documentation;
- New SLR and VGOS stations have recently become active and others are scheduled to become active over the next few years; we have been disappointed by the schedule delays in many stations so we are now taking a closer look at deployment schedules to try to figure out what is realistic and what kind performance we can reasonably expect; from that we can estimate the expected quality of our data products including the Reference Frame.
- Worked with the IGFS define the gravity field measurement configuration at GGOS network core and co-location sites; encourage the cooperation of the IGS and DORIS with PSMSL to enhance the geodetic link of the tide gauges to the reference frame;
- A Memorandum of Cooperation had been established with ROSCOSMOS and the ILRS to enhance cooperation and data diagnosis issues: this may provide a vehicle for broader cooperation; the Russians have been regular participants in ILRS activities, we believe that are desirous of formally joining the GGOS network;
- The GGOS "Site Requirements for GGOS Core Sites" document (with the IAG Services) should be updated to include the requirements for the gravity field with the guidance of the IGFS;

Outcomes and Future Plans

- Continue the tasks above
- Bureau Call for Participation in the "Global Geodetic Core Network: Foundation for Monitoring the Earth System"; work with new potential groups interested in participating; discussions are underway with the Russian SLR network; they participate in ILRS and VLBI activities, but have yet to join the GGOS network; close with the Russians;
- Project network status 5 and 10 years ahead to anticipate data product quality especially the ITRF;
- Work with the IAG and the UN GGIM to develop a plan for the IAG Network to satisfy the ITRF requirements;
- The Standing Committees/Working Groups will each continue their tasks (see below)

Websites:

https://ggos.org/about/org/bureau/bno/

Presentations and Posters

Pearlman, et al., *Update on the Activities of the GGOS Bureau of Networks and Observation,* AGU Fall virtual meeting, December 14, 2018.

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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 Netw*orks and Observations", Abstract No. EGU2019-6181, presented at the European Geosciences Union General Assembly, Vienna, Austria, April 07-12, 2019.

Pearlman et al., *Status and Plans for the GGOS Bureau of Networks and Observations*, IUGG Meeting, Montreal Convention Center, July 15, 2019.

Pearlman, M., *GGOS Bureau of Networks and Observations,* presented at the IUGG, Implementation of the Global Reference Frame (GGRF) in Latin America, Buenos Aires, Argentina, September 16 – 20, 2019.

Pearlman, M., C. Noll, and E. Pavlis, *GGOS Bureau of networks and Observations*, GGOS Days 2019, October 5 – 7, 2019.

Pearlman, M. and Noll, C., *GGOS Bureau of Networks and Observations,* GGOS Days 2019 Meeting, Rio de Janiero, Brazil, November 13 – 14, 2019.

Pearlman, M., et al., "*Current Activities and Plans of the Bureau of Networks and Observations*" *(poster)*, AGU Fall virtual meeting, December 1 – 17, 2020.

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 May 2021):

- R. Dach, F. Andritsch (AIUB, Switzerland)
- D. Thaller (BKG, Germany)
- M. Bloßfeld, A. Kehm (DGFI-TU Munich, Germany)
- M. Rothacher, I. Herrera Pinzón (ETH Zürich, Switzerland)
- B. Männel, S. Glaser (GFZ/TU Berlin, Germany)
- J. Müller, L. Biskupek (IfE University Hannover, Germany))
- D. Coulot, A. Pollet (IGN, France)
- R. Gross (JPL, USA)
- E. 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.)
- Estimate the improvement in the reference frame products as new observation types and

concepts are added, e.g., inter-satellite links

Achievements during the reporting time span:

- Several projects related to simulation studies became funded and even extended to a second phase at various institutions (e.g., GFZ, DGFI-TUM, TU Vienna, BKG)s
- Several geodetic software packages have been augmented by the capability to carry out realistic simulation scenarios (VieVS, DOGS, Bernese, Geodyn, EPOS-OC)
- A concept for carrying out coordinated simulations and adjacent analysis tests was developed within the group. The start for this activity was delayed due to the pandemic situation.
- Simulations for improved global SLR station networks were carried out (Glaser et al. 2019, Kehm et al. 2019).
- Simulations of optimal locations for an additional VGOS station were carried out, with special focus on its contribution to EOP determination (Schartner et al., 2020). A location in South America is most beneficial.
- Simulations and analysis of VLBI tracking data of Galileo satellites are carried out to assess the possibilities for improving dUT (Wolf et al. 2021).
- The benefit of using a local time transfer system for short VLBI baseline analysis was demonstrated.
- Studies for combined GNSS-Rapid and VLBI Intensives showed that improved ERPs with low latency can be derived (Hellmers et al., 2019).
- Studies on the quality of GNSS-based scale by adding LEOs to an integrated processing or by using Galileo data were carried out. A correction to the satellite antenna phase center offset (PCO) in nadir direction of approx. -200mm was found for GPS.
- Studies on the potential of SLR Short baseline observations (e.g. at Wettzell) for monitoring the terrestrial local ties were carried out in order to identify technique-specific systematic error sources.
- 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).
- Studies on the impact of adding the LLR data in infra-red to reference frame products were carried out by IfE, Uni Hannover.
- Simulation capabilities for DORIS have been developed by GFZ.
- Studies on future GNSS constellations were carried out (Glaser et al., 2020).
- Consistent estimation of TRF+CRF+EOP started along with the VLBI reprocessing activities related to ITRF2020 generation.
- Presentations were given at IAG Assembly (July 2019), annual conferences of EGU and AGU as well as meetings of IAG Services.

Future Plans

- 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 satellite mission as co-location in space. 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 re-started in May 2021 in order to get an estimate about the comparability of the simulation studies.
- A consistently estimated IVS product for TRF+CRF+EOP will be generated for the first time along with the IVS activities related to ITRF2020.
- Simulations of network projections will be carried out if new potential stations come up.
- Status reports will be given at IUGG General Assembly (2023).
- A dedicated session covering the PLATO topics will be initiated for EGU General Assemblies.
- Annual meetings are foreseen in conjunction with EGU General Assembly or virtually.

Publications

- Glaser S, König R, Neumayer K H, Balidakis K, Schuh H (2019) Future SLR station networks in the framework of simulated multi-technique terrestrial reference frames, Journal of Geodesy doi:10.1007/s00190-019-01256-8
- Glaser S, König R, Neumayer K H, Nilsson T, Heinkelmann R, Flechtner F, Schuh H (2019) On the impact of local ties on the datum realization of global terrestrial reference frames, Journal of Geodesy, doi:10.1007/s00190-018-1189-0
- Glaser S, Michalak G, Männel B, König R, Neumayer K H, Schuh H (2020) Reference system origin and scale realization within the future GNSS constellation "Kepler", Journal of Geodesy, doi: 10.1007/s00190-020-01441-0
- Hellmers, H., D. Thaller, M. Bloßfeld, A. Kehm, A. Girdiuk (2019): Combination of VLBI Intensive Sessions with GNSS for generating Low-latency Earth Rotation Parameters. Advances in Geosciences, 50:49-56. Doi: 10.519/adgeo-50-49-2019
- Herrera Pinzón, I. & Rothacher, M. J Geod (2018) 92: 1079. https://doi.org/10.1007/s00190-017-1108-9
- Kehm A., Bloßfeld M., König P., Seitz F. (2019): Future TRFs and GGOS – where to put the next SLR station? Advances in Geosciences, 50, 17–25, DOI 10.5194/adgeo-50-17-2019
- 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, doi:10.1007/1345_2018_30
- Michalak G, Glaser S, Neumayer K H, König R (2021) Precise orbit and Earth parameter determination supported by LEO satellites, inter-satellite links and synchronized clocks of a future GNSS, Advances in Space Research, doi:10.1016/j.asr.2021.03.008
- M. Schartner, J. Böhm, A. Nothnagel (2020): Optimal antenna locations of the VLBI Global Observing System for the estimation of Earth orientation parameters. Earth Planets and Space, 72 (2020), 87; S. 1 – 14

GGOS Standing Committee on Satellite Missions (CSM)

Chair: Roland Pail (Germany)
Vice-Chair: C.K. Shum (USA)

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 traditionally has about one meeting per year, although the pandemic has precluded and will likely prohibit in the near future any such meetings. Therefore, the main work is and will accomplished via email exchanges. Additional members will be added in the near future.

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.

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

Improve coordination and information exchange with the missions for better ground-based network response to mission requirements and space-segment adequacy for the realization of GGOS goals, including:

- Advocate, coordinate, and exchange information 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;
- Assess current and near-future satellite mission infrastructures and their relevance towards achieving GGOS 2020 goals;
- Support proposals for new mission concepts and advocate for needed missions;
- Interfacing and outreach with other components of the Bureau; especially with the ground networks component, the GGOS Performance Simulations and Architectural Trade Offs (PLATO) activities, as well as with the Bureau of Standards and Products.

Future Activities and Objectives

- Continue the planned activities, i.e., updating the two central lists, supporting future satellite missions, etc.;
- Work with the Coordinating Office to set up and maintain a Satellite Missions Committee section on the GGOS website;
- Evaluate the contribution of current and near-term satellite missions to the GGOS 2020 goals;
- Work with GGOS Executive Committee, Focus Areas, and data product development activities (e.g., ITRF) to advocate for new missions to support GGOS goals;
- Support the Executive Committee and the Science Committee in the GGOS Interface with space agencies;
- Finalize and publish (outreach) of Science and User Requirements Documents for future gravity field missions.
- Increase the exchange and collaboration with PLATO; set up a more formal procedure of collaboration; discuss needs and run simulations to study the impact of future satellite missions, identify gaps for fulfilling the GGOS goals, etc.;
- Investigate possible collaborations with commercial satellite companies, e.g., Spire Global, Inc., PlanetIQ, GeoOptics, with launched Cubesat constellations, on GGOS research and applications including GNSS occultation, and bistatic radar reflectometry.

Website

Website will be built or improved.

Publications and Presentations

Pail, R.; IUGG, Writing Team: Observing Mass Transport to Understand Global Change and Benefit Society: Science and User Needs, An international multi-disciplinary initiative for IUGG; in: Pail, R. (eds.) Deutsche Geodätische Kommission der Bayerischen Akademie der Wissenschaften, Reihe B, Vol. 2015, Heft 320, Verlag der Bayerischen Akademie der Wissenschaften in Kommission beim Verlag C.H. Beck.

GGOS Standing Committee on Data and Information Systems

Chair: Nicholas Brown (GA Austria)
Vice-Chair: Sandra Blevins (NASA USA)

Purpose and Scope

The Committee on Data and Information had two GGOS objective areas:

- Development and implementation of a portal;
- Development and implementation of a metadata scheme

Near term Metadata activity (NASA CDDIS)

CDDIS continues to add new data and derived product collections and further populate collection-level metadata stored in the Earth Observation System Data and Information System (EOSDIS) Common Metadata Repository (CMR). CDDIS is an EOSDIS Distributed Active Archive Centers (DAACs) and thus utilizes the EOSDIS infrastructure to manage collection and granule level metadata describing CDDIS archive holdings; these metadata include 120 published DOIs representing DORIS, GNSS, and SLR data and derived product collections archived at the CDDIS archive. Since the AGU Fall Meeting 2019 the CDDIS actively participates in the GGOS DOI Working Group, sharing NASA Earth Science Data and Information System (ESDIS) DOI methods and best practices with the greater Geodesy community.

Longer-Term Metadata activity (Nick Brown/Geoscience Australia)

Development of a Geodesy Markup Language (GeodesyML), for the GNSS community; potential for expansion to the other space geodesy techniques and GGOS. The current study is identifying metadata standards and requirements, assessing critical gaps and the how these might be filled, what changes are needed in the current standards, and who are the key people who should work on it (more comprehensive scheme). The schema that would be used by its elements for standardized metadata communication, archiving, and retrieval. First applications would be the automated distribution of up-to-date station configuration and operational information, data archives and catalogues, and procedures and central bureau communication. One particular plan of great interest is a site metadata schema underway within the IGS Data Center Working Group. This work is being done in collaboration with the IGS, UNAVCO, SIO, CDDIS, and other GNSS data centers. The current activity is toward a means of exchange of IGS site log metadata utilizing machine-to-machine methods, such as XML and web services, but it is expected that this will be expanded to the other Services to help manage site related metadata and to other data related products and information. Schema for the metadata should follow international standards, like ISO 19xxx or DIF, but should be extendable for technique-specific information, which would then be accessible through the GGOS Portal.

Activities and Actions

Activities underway at CDDIS:

1. Complete collection level metadata related to CDDIS data and derived product holdings in the EOSDIS Common Metadata Repository (CMR)
2. Continue to re-ingest CDDIS data and derived product holdings in order to extract granule level metadata linked to these new collection level records

Activities underway in Geodesy Markup Language (GeodesyML) System

1. Review and document the metadata and standards requirements of precise positioning users in expected high use sectors (e.g. precision agriculture, intelligent transport, marine, location-based services etc.).

2. Assess and document the critical gaps in standards which restrict how Findable Accessible Interoperable and Reusable (FAIR) precise positioning data is for the expected high use sectors.
3. Record use cases of standards being applied well and the benefits it provides to users.
4. Review the "use cases" of geodetic data developed by Geoscience Australia and the IGS Data Center Working Group. (https://drive.google.com/drive/folders/1L792ImLktAiAbmhX9WZhvHrXB3BMD00G?usp=sharing) and document what work and time would be required to ensure these use cases can be met in international standards. This could be:
   - Identify which gaps can be filled by GeodesyML
   - Identify which components of GeodesyML would be better, handled by / integrated with, existing standards (such as TimeSeriesML, SensorML, Observations and Measurements) where possible.
   - Identify which components of already existing international geospatial infrastructure can be approached (such as the European Inspire initiative)
   - Advise on who we should engage with from the OGC/ISO community to facilitate a change to a standard to meet our requirements.
5. Work with Project Partners to develop and test other use cases (e.g. integration of geodetic data with geophysics data (e.g. tilt meters), Intelligent Transport Sector data, mobile applications). Then, document what work and time would be required to ensure these use cases can be met in international standards.
6. Provide advice on how to best engage with the right communities to learn from their experiences, test their tools and influence the development of required standards.

Future Activities and Objectives

1. Working with the IGS Infrastructure Committee, complete the development of the metadata system for GNSS (IAG) and then expand its role to the other IAG Services (IVS, ILRS, IDS, IGFS, etc.).

IERS Working Group on Site Survey and Co-location

Chair: Ryan Hippenstiel (NOAA USA)
Co-Chair: Sten Bergstrand (RISE Sweden)

Members: (Member list will be updated as WG develops and confirmation is received.)

- Zuheir Altamimi (IGN, France)
- Sten Bergstrand (BIPM, France)
- Steven Breidenbach (NOAA/NGS, USA)
- Benjamin Erickson (NOAA/NGS, USA)
- Cornelia Eschelbach (FRA UAS, Germany)
- Kendall Fancher (NOAA/NGS, USA)
- Charles Geoghegan (NOAA/NGS, USA)
- Rudiger Haas (Chalmers, Sweden)
- Ryan Hippenstiel (NOAA/NGS, USA)
- Christopher Holst (Technische Universität München, Germany)
- Kevin Jordan (NOAA/NGS, USA)
- Jack McCubbine (GA, Australia)
- Damien Pesce (IGN, France)
- Jerome Saunier (IGN, France)
- Elena Martínez Sánchez, (Observatorio de Yebes, Spain)
- Daniela Thaller, (BKG, Germany)

Correspondent Members
- Xavier Collilieux (IGN, France)
- Mike Pearlman (Harvard/GGOS, USA)
- Robert Heinkelmann, (GFZ, Germany)

Purpose and Scope

Areas of work of the Working Group on Site Survey and Co-location are standards and documentation (guidelines, survey reports, etc.), coordination (share know-how and join efforts between survey teams), research (investigate discrepancies between space geodesy and tie vectors, alignment of tie vectors into a global frame), and cooperation. Our group has a new set of terms and has received confirmation of new participants in the group. We would continue to encourage participation from any agency or community that is conducting research, improving protocols, or completing field surveys of local ties as sites with various space geodesy techniques present. Our group has continued to share improved protocols, technologies, and instrumentation to provide the most accurate tie measurements possible for all sites around the world. We reminded participants to share their contributions of local tie data for inclusion into ITRF2020 and many were submitted.

Activities during the period 2019 - 2021

Improvements have been made to standardize report and data submissions of local tie surveys to provide consistency across all agencies. Survey data has recently been reported with new standards in place.

The group is continuing to explore methodologies to measure and quantify antenna deformation. Research and continued field tests using laser scanning and terrestrial inSAR have been discussed. Members completed and documented work researching site-dependent GNSS antenna calibrations to account for systematic errors and biases.

Measurements were collected at the Zeppelin Observatory (Svalbard, Norway) and Hartebeesthoek has been reprocessed (Muller et al., 2020). The latter was assisted by updating of local software to allow estimating VLBI and SLR references points from raw survey data into one single processing.

The US National Geodetic Survey conducted an IERS local site survey at the National Radio Astronomy Observatory in Maui (GNSS and SLR), the Table Mountain Geophysical Observatory in Colorado (new GNSS, gravity), Midway Naval Research Laboratory's OTF in Virginia (GNSS and SLR), and the International Earth Rotation and Reference Systems Service (IERS) Mauna Kea site (VLBA). Surveys were paused in the spring of 2020 due to the COVID pandemic and have not yet resumed fully. It is hopeful that recon and survey efforts will begin again in the fall of 2021.

NGS fully implemented the use of an absolute laser tracking system (Leica AT402) into all completed tie surveys, enhancing precision of terrestrial observations. Progress was made on technical memorandum documenting current NGS procedures which will be released and reflect upon IERS TN39.

NGS has developed deflection of vertical (DoV) measurement capabilities utilizing a robotic total station and camera, and will continue testing equipment in 2021 for hopeful deployment on upcoming local tie surveys.

https://www.euramet.org/research-innovation/search-research-projects/details/project/large-scale-dimensional-measurements-for-geodesy/

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Eschelbach, C., Lösler, M., Haas, R., Greiwe (2020) A.: Untersuchung von Hauptreflektordeformationen an VGOS-Teleskopen mittels UAS. In: Wunderlich, T.A. (Eds.): Ingenieurvermessung 20: Beiträge zum 19. Internationalen Ingenieurvermessungskurs, Wichmann, pp. 411-424, ISBN: 978-3-87907-672-7

Eschelbach, C., Lösler, M., Haas, R., Fath, H. (2019) Extension and Optimization of the Local Geodetic Network at the Onsala Space Observatory. In: Proceedings of the 10th IVS General Meeting, Svalbard, pp. 27-31, NASA/CP-2019-219039.

Fancher, K., Hippenstiel, R. (2019) US National Geodetic Survey - Recent and Planned Local Site Survey Activites. Proceedings of the Unified Analysis Workshop 2019. http://ggos.org/media/filer_public/ff/67/ ff679767-62ec-4065-acfc-3394ae85d573/uaw_sitesurvey_1- hippenstiel_usnationalgeodeticsurvey.pdf

Lösler M., Eschelbach C., Riepl S., Schüler T. (2019) A Modified Approach for Process-Integrated Reference Point Determination. Proceedings of the 24th European VLBI Group for Geodesy and Astrometry Working Meeting, 17-19 March 2019, Las Palmas de Gran Canaria, Spain, Eds. R. Haas, S. Garcia-Espada, and J. A. López Fernández, :172-176 DOI: 10.7419/162.08.2019

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Pesce, D., Saunier J. (2019) IGN Recent and Planned Local Site Survey Activities & Contribution to the EURAMET GeoMetre Project. Proceedings of the Unified Analysis Workshop 2019. http://ggos.org/ media/filer_public/9f/b6/9fb60a43-3d60-4218-9f48-89ac81073b79/ uaw_sitesurvey_2-saunier_ignrecentactivities.pdf

Co-location survey online reports http://itrf.ign.fr/local_surveys.php and https://www.ngs.noaa.gov/corbin/iss/:

- Erickson, B., Breidenbach, S., Jordan, K. Maui co-location survey, June 2019
- Jordan, K., Hippenstiel, R., Erickson, B., Fancher, K. Stafford co-location survey, October 2019
- Jordan, K., Hippenstiel, R., Fancher, K. Table Mountain co-location survey, October 2019
- Jordan, K., Hippenstiel, R., May, J. Mauna Kea co-location survey, October 2019
- Muller J.-M., Pesce D., Collilieux X., 2014 Hartebeesthoek co-location survey reprocessing report, dec 2020

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 (EGV)**", Chair: Richard Gross (USA)*
- *Working Group "**Towards a consistent set of parameters for the definition of a new GRS**", Chair: Urs Marti (Switzerland)*

The Bureau of Products and Standards (BPS) is chaired and operated by the Technical University of Munich. The BPS staff members are Detlef Angermann, Thomas Gruber, Michael Gerstl, Urs Hugentobler and Laura Sánchez (all from Technical University Munich), as well as Robert Heinkelmann (GFZ German Research Centre for Geosciences Potsdam) and Peter Steigenberger (German Aerospace Centre (DLR), Oberpfaffenhofen). 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 2021)*

R. Heinkelmann, Germany	International Earth Rotation and Reference Systems Service (IERS)
N. Stamatakos, USA	International Earth Rotation and Reference Systems Service (IERS)
U. Hugentobler, Germany	International GNSS Service (IGS)
E. Pavlis, USA	International Laser Ranging Service (ILRS)
J. Gipson, USA	International VLBI Service for Geodesy and Astrometry (IVS)
P. Štěpánek, Czech Republic	International DORIS Service (IDS)
R. Barzaghi, Italy	International Gravity Field Service (IGFS)
S. Bonvalot, France	Bureau Gravimétrique International (BGI)
M. Reguzzoni, Italy	International Service for the Geoid (ISG)
E. S. Ince, Germany	International for Global Earth Models (ICGEM)
K. M. Kelly, Germany	International Digital Elevation Model Service (IDEMS)
H. Wzointek, Germany	International Geodynamics and Earth Tide Service (IGETS)
J. L. Hilton, USA	IAU Commission A3 Representative
M. Craymer, USA	Chair of Control Body for ISO Geodetic Registry Network
L. Hothem, USA	Vice-Chair of Control Body for ISO Geodetic Registry Network
S. Rózsa, Hungary	IAG Communication and Outreach Branch
D. Angermann, Germany	IAG Representative to ISO/TC211
J. Kusche, Germany	Representative of gravity community

Overview

The Bureau of Products and Standards (BPS) is a key component of IAG's Global Geodetic Observing System (GGOS). It supports GGOS in its goal to obtain consistent products describing the geometry, rotation and gravity field of the Earth. In order to fully benefit from the ongoing technological improvements of the geodetic observing systems, it is essential that the analysis of the precise observations is based on the definition and application of common standards and conventions. This is an important requirement for reliably monitoring global change phenomena (e.g., global sea level rise) and for providing the metrological basis for Earth system sciences (Fig. X.1).

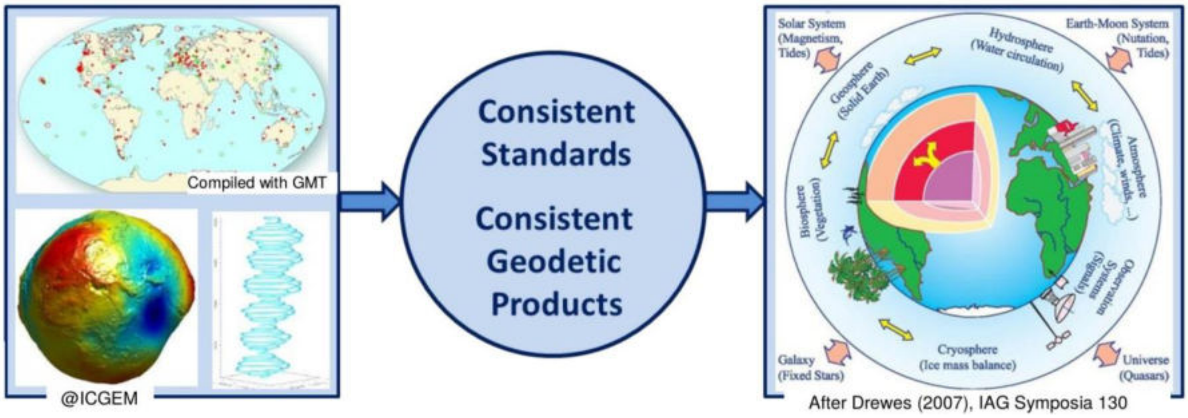

***Fig. X.1**: The integration of the "three pillars" Earth's geometry, rotation and gravity field requires unified standards to obtain consistent geodetic products as the basis for Earth system research and for precisely quantifying global change phenomena.*

Objectives

A key objective of the BPS is to keep track of adopted geodetic standards and conventions across all IAG components as a fundamental basis for the generation of consistent geometric and gravimetric products. The work is primarily build on the IAG Service activities in the field of data analysis and combinations. The BPS acts as contact and coordinating point regarding homogenization of standards and IAG products. Moreover, the BPS interacts with external stakeholders that are involved in standards and conventions, such as the International Organization for Standardization (ISO), the Committee on Data for Science and Technology (CODATA), the International Astronomical Union (IAU), the UN GGIM Subcommittee on Geodesy (SCoG) and the newly established Global Geodetic Centre of Excellence (GGCE).

The objectives of the BPS may be divided into two major topics:

- **Standards**: A key objective is the compilation of an inventory regarding standards, constants, resolutions and conventions adopted by IAG and its components. This includes an assessment of the present status, the identification of gaps and shortcomings concerning geodetic standards and the generation of the IAG products, as well as the provision of recommendations. It is obvious that such an inventory needs to be regularly updated, since the IAG standards and products are continuously evolving. The BPS shall also propose the adoption of new standards where necessary and propagate standards and conventions to the wider scientific community promoting their use. In this context, the BPS recommends the development of a new Geodetic Reference System GRS20XX based on the best estimates of the major parameters related to a geocentric level ellipsoid.

- **Products**: The BPS shall take over a coordinating role regarding the homogenization of standards and geodetic products. The present status regarding IAG Service products shall be evaluated, including analysis and combination procedures, accuracy assessment with respect to GGOS requirements, documentation and metadata information for IAG products. The Bureau shall initiate steps to identify user needs and requirements for geodetic products and shall contribute to develop new and integrated products. The BPS shall also contribute to the development of the GGOS Portal (as central access point for geodetic products), to ensure interoperability with IAG Service data products and external portals (e.g., GEO, EOSDIS, EPOS, GFZ Data Services).

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.

Updated version of the BPS inventory

In 2019 and 2020, the second version of the inventory has been prepared for publication in the Geodesist’s Handbook 2020 (Angermann et al., 2020). In this updated version of the inventory the general structure of the original document published in the Geodesist’s Handbook 2016 is largely kept, whereas the contents of the individual sections has been updated to take into account the latest developments.

The updates in the field of standards and conventions comprise the newly released ISO standards by ISO/TC211 covering geographic information and geomatics, the activities of the GGRF Working Group “Data Sharing and Development of Geodetic Standards” within the UN-GGIM Subcommittee on Geodesy, the update of the IERS Conventions initiated by the IERS Conventions Center, and the recently adopted resolutions by IAG, IUGG and IAU that are relevant for geodetic standards and products. In the framework of the update of the IERS Conventions, the director of the BPS has been nominated as Chapter Expert for Chapter 1 “General definitions and numerical standards”.

At the end of 2019, a new GGOS Working Group “Towards a consistent set of parameters for the definition of a new GRS” was established as a component of the BPS to solve open problems regarding numerical standards and open issues related to tide and time systems. The fact that various definitions are in use within the geodetic community is a potential source for inconsistencies and even errors of geodetic products. The BPS recommends to resolve these inconsistencies and to develop a new Geodetic Reference System.

Product-based review of standards and conventions

The second version of the inventory also provides an update regarding IAG products, addressing the following major topics (see Angermann et al., 2020):

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

New versions of IERS products have been released for the celestial and terrestrial reference frame as well as for the EOP, namely ICRF3, ITRF2014 and EOP 14C04. Although a significant progress has been achieved compared to previous realizations, there are still some deficiencies and open problems that are addressed in this inventory. Recommendations are provided for each product to further improve their accuracy and consistency. Concerning GNSS satellite orbits, the modelling has been improved and some missing information has been provided by the satellite operators, but there are still some remaining deficiencies. A remarkable progress has been achieved in the field of gravity and geoid related data and products, including the development of a dedicated data and products portal based on online applications for the creation of metadata for gravity and geoid data. Also the latest developments and achievements in the field of height systems and their realizations are reported (for details see the Report of the GGOS Focus Area "Unified Height System").

BPS contributions to the new GGOS website

The BPS representation at the GGOS website has been redesigned and updated, including the two Committees "Contributions to Earth System Modelling" and "Definition of Essential Geodetic Variables (EGVs)" and the Working Group "Towards a consistent set of parameters for the definition of a new GRS".

The BPS also contributed to the representation of geodetic products at the GGOS website. The GGOS website should serve as an "entrance door" to geodetic products to satisfy different user needs and communities (e.g., geodesists, geophysicists, other geosciences and further customers, …) in order to make geodesy more visible to other disciplines and to society.

Two classifications for the geodetic products have been implemented at the GGOS website:

- Option 1 "Geodetic themes": Reference frames, geometry, Earth orientation parameters, gravity field, positioning and applications.
- Option 2: "Earth system components and space": Outer and near space, atmosphere, hydrosphere, oceans, cryosphere, solid Earth.

Option 1 provides the classical geodetic view, whereas option 2 should also attract users from other disciplines. So far, about 25 product descriptions have been prepared by the BPS members, including valuable contributions from the IAG Services and several individual persons. The product descriptions provide an overview and easy understandable information on the products, including figures. Furthermore, the data sources (i.e., the links to the IAG Services and other data providers) are given for each product, including selected references. The products have been reviewed by the members of the GGOS Science Panel, coordinated by its chair Kosuke Heki. The product descriptions have been implemented at the GGOS website by Martin Sehnal, the Director of the GGOS Coordinating Office. All the above mentioned contributions are gratefully acknowledged by the BPS.

New BPS Implementation Plan 2020-2022

In 2020, the Implementation Plan for the Bureau of Products and Standards has been revised and updated for the years 2020 to 2022. The major changes were an update of the task descriptions of the BPS and the interactions with other entities involved in standards and conventions, such as the IAU, ISO and the UN-GGIM Subcommittee on Geodesy and its newly established Global Geodetic Centre of Excellence (GGCE).The activities of the BPS are divided into the three main categories: Coordination activities, specific tasks of the BPS and outreach activities. An overview and schedule of the BPS activities is provided in Fig. **X.2**.

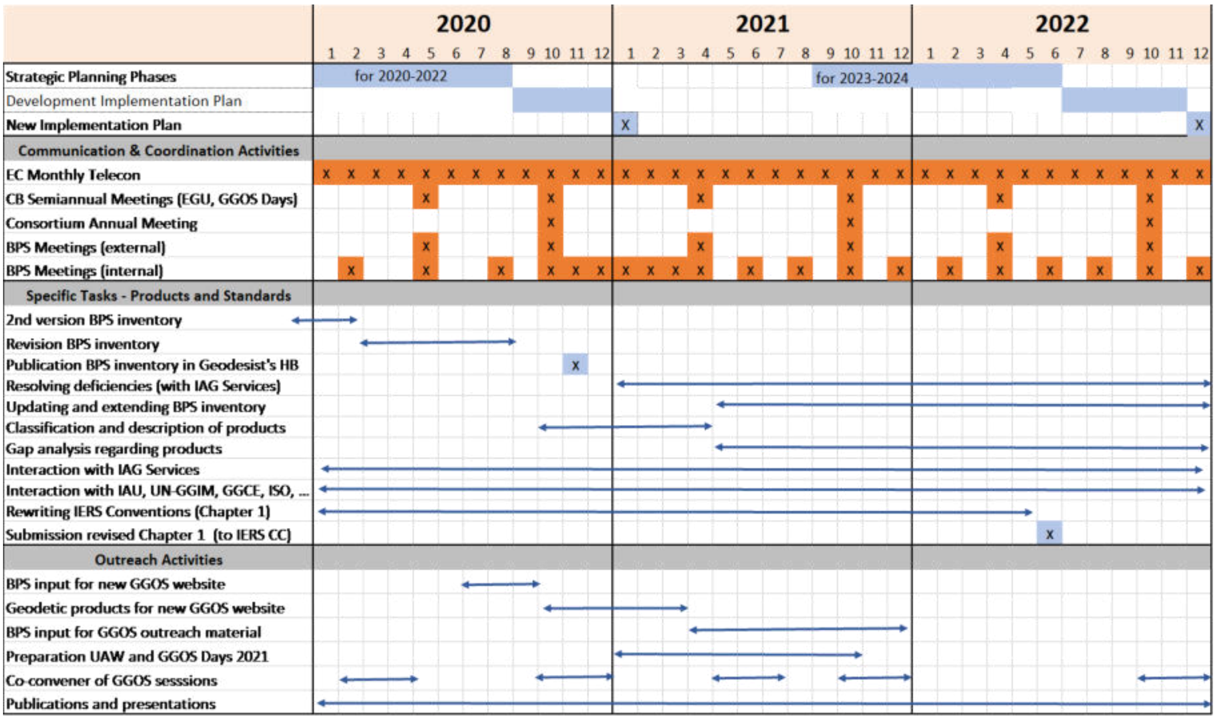

Fig. X.2: Overview and schedule of BPS activities

Selected publications:

- Angermann D, Gruber T, Gerstl M, Heinkelmann R, Hugentobler U, Sánchez L, Steigenberger P (2020): GGOS Bureau of Products and Standards: Inventory of standards and conventions used for the generation of IAG products. In: Drewes H, Kuglitsch F, Adám J, Rozsa S (Eds.) The Geodesist's Handbook 2020,Journal of Geodesy, https://doi.org/10.1007/s00190-020-01434-z.
- Angermann D., Gruber T., Gerstl M., Heinkelmann R., Hugentobler U., Sanchez L., Steigenberger P. (2019): GGOS Bureau of Products and Standards. In: Drewes H., Kuglitsch F. (Eds.), Report of the IAG Vol. 41 - Travaux de l'AIG 41, 2015-2019.

GGOS Committee on Earth System Modeling

Chair: Maik Thomas (Germany)

Role

The GGOS Committee on "Earth System Modeling" tends to promote the development of physically consistent modular Earth system modeling tools that are simultaneously applicable to all geodetic parameter types (i.e., Earth rotation, gravity field and surface geometry) and observation techniques. Hereby, the committee contributes to:

- The interpretation of geodetic monitoring data and, thus, to a deeper understanding of processes responsible for the observed variations;
- The establishment of a link between the geodetic products delivered by GGOS and numerical process models;
- A consistent combination and integration of observed geodetic parameters derived from various monitoring systems and techniques;
- The utilization of geodetic products for the interdisciplinary scientific community.

Objectives

The long-term goal is the development of a physically consistent modular numerical Earth system model for homogeneous processing, interpretation and prediction of geodetic parameters with interfaces allowing the introduction of constraints provided by geodetic time series of global surface processes, rotation parameters and gravity variations. This ultimate goal implicates the following objectives:

- Development of Earth system model components considering interactions and relationships between surface deformation, Earth rotation and gravity field variations as well as interactions and physical fluxes between relevant compartments of the Earth system;
- Promotion of homogeneous processing of geodetic monitoring data (de-aliasing, reduction) by process modeling to improve analyses of geodetic parameter sets;
- Contributions to the interpretation of geodetic parameters derived from different observation techniques by developing strategies to separate underlying physical processes;
- Contributions to the integration of geodetic observations based on different techniques in order to promote validation and consistency tests of various geodetic products.

Activities

The 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.

- Implementation of interfaces to geodetic monitoring data based on Kalman and particle filter approaches in order to constrain and improve stand-alone model approaches and to prove consistency of various geodetic monitoring products;

- Implementation and evaluation of various numerical approaches with different complexities for the consideration of self-attraction and loading in ocean general circulation models;
- Combination of neural network modules with stand-alone models as a basis for further studies on the applicability of artificial intelligence for downscaling purposes.
- Feasibility studies for the provision of error and uncertainty estimates of model predictions of geodetic parameters (Earth rotation, gravity field, surface deformation) due to imperfect model physics, initialization, and external forcing.

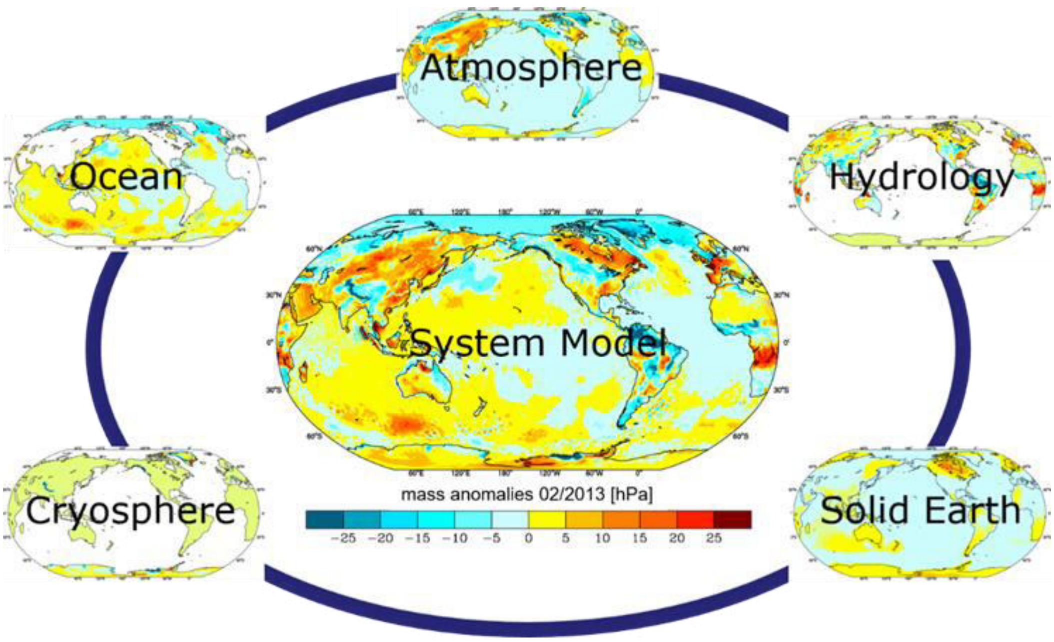

Fig. X.3: *Simulated mass anomalies in a modular system model approach.*

Selected publications:

- Boergens, E., Dobslaw, H., Dill, R., Thomas, M., Dahle, C., Flechtner, F.: Modelling spatial covariances for terrestrial water storage variations verified with synthetic GRACE-FO data. GEM - International Journal on Geomathematics, 11, 24, 2020.
- Irrgang, C., Dill, R., Boergens, E., Saynisch-Wagner, J., Thomas, M.: Self-validating deep learning for recovering terrestrial water storage from gravity and altimetry measurements. Geophysical Research Letters, 47, 17, e2020GL089258, 2020.

Committee on Essential Geodetic Variables

Chair: Richard Gross (USA)

The GGOS BPS Committee on Essential Geodetic Variables was established in 2018 in order to define a list of Essential Geodetic Variables and to assign requirements to them. 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 observing systems that are used to observe the EGVs. And the list of EGVs can serve as the basis for a gap analysis to identify observations needed to fully characterize the geodetic properties of the Earth. During GGOS Days 2017 it was agreed that a Committee within the GGOS Bureau of Products and Standards should be established in order to define the list of Essential Geodetic Variables and to assign requirements to them. This Committee was subsequently established in 2018 and consists of representatives of the IAG Services, Commissions, Inter-Commission Committees, and GGOS Focus Areas.

Tasks

The tasks of the Committee on Essential Geodetic Variables are to:

- Develop criteria for choosing from the set of all geodetic variables those that are considered essential
- Develop a scheme for classifying EGVs
- Within each class, define a list of EGVs
- Assign requirements to each EGV
- Document each EGV including its requirements, techniques by which it is observed, and point-of-contact for further information about the EGV
- Perform a gap analysis to identify potential new EGVs
- Define a list of geodetic products that depend on each EGV
- Assign requirements to the EGV-dependent products
- Hold workshops to engage the geodetic community in the process of defining EGVs, determining their dependent products, and assigning requirements to them

Activities

- A meeting of the Committee on Essential Geodetic Variables was held on 14 July 2019 in Montreal in conjunction with the 27th General Assembly of the IUGG. At the meeting, defining characteristics of essential geodetic variables were discussed.

Members

Committee on EGVs

GGOS
Detlef Angermann (Germany)
Richard Gross, Chair (USA)
Harald Schuh (Germany)

GGOS Focus Area
Unified Height System
Laura Sanchez (Germany)

GGOS Focus Area
Geohazards
Diego Melgar (USA)

GGOS Focus Area
Space Weather
Ehsan Forootan (UK)

IAG Commission 1
Markus Rothacher (Switzerland)
Geoffrey Blewitt (USA)

IAG Commission 2
Kosuke Heki (Japan)
Thomas Gruber (Germany)

IAG Commission 3
Jianli Chen (USA)
Jose Ferrandiz (Spain)

IAG Commission 4
Jens Wickert (Germany)
Pawel Wielgosz (Poland)

IAG ICC Theory
Yoshiyuki Tanaka (Japan)
Mattia Crespi (Italy)

IAG ICC Climate
Annette Eicker (Germany)

IAG Project Quantum
Jürgen Müller (Germany)

IERS
Tom Herring (USA)

IGS
Tom Herring (USA)
Michael Moore (Australia)

ILRS
Erricos Pavlis (USA)
Jürgen Müller (Germany)

IVS
John Gipson (USA)
Johannes Böhm (Austria)

IDS
Laurent Soudarin (France)
Jean-Michel Lemoine (France)

IGFS
Urs Marti (Switzerland)
Georgios Vergos (Greece)

BGI
Sylvain Bonvalot (France)

ICGEM
E. Sinem Ince (Germany)

ISG
Jianliang Huang (Canada)

IGETS
Hartmut Wziontek (Germany)
Jean-Paul Boy (France)

IDEMS
Christian Hirt (Germany)
Michael Kuhn (Australia)

PSMSL
Svetlana Jevrejeva (UK)

Other
Srinivas Bettadpur (UTCSR)
Johannes Bouman (BKG)
Don Chambers (USA)

Total: 38

Working Group "Towards a consistent set of parameters for the definition of a new GRS"

Chair: Urs Marti (Switzerland)

Terms of Reference

The Geodetic Reference System 1980 GRS80 is still the conventional system for most applications in Geodesy and other Earth sciences. It was defined through the four parameters a (semi-major axis), J2 (Dynamical Form Factor), GM (geocentric Gravitational Constant) and ω (Angular Rotation Velocity). It represents the scientific status of the 1970ies and in its concept, the tidal systems and relativistic theories are not considered. Since its adaptation, various inconsistencies have been introduced into geodetic standards and applications, such as new values for GM or a in the IERS conventions. In 2015, a conventional value for the gravitational potential at sea level W0 was adopted in an IAG resolution, which is in contradiction to the definition of GRS80.

This WG will publish a new set of defining parameters for a modern GRS based on todays knowledge and calculate all the necessary derived parameters in a consistent way. It will study the necessity to work towards an IAG resolution to replace GRS80 as the conventional system and provide transformation procedures between the two systems. It will study as well the necessity to define and adopt a conventional global gravity field model for standard applications in geodesy, navigation and related topics.

This JWG is assigned to the GGOS Bureau of Products and Standards (BPS) and works together with representatives of IAG Commissions 1 and 2, the Inter-Commission-Committee on Theory (ICCT), the International Gravity Field Service (IGFS), the International Earth Rotation and Reference Systems Service (IERS) and the Committee on Essential Geodetic Variables (EGV).

This JWG will focus its activities on the coordination of the geometric reference frame, the global height system, the global gravity network and their temporal changes. The application of Earth orientation parameters and tidal models and the underlying standard and reference models has to be brought into consistency.

Objectives and activities

The main objectives and activities of this working group are:

- Calculate consistent parameters of a new mean Earth ellipsoid and derived quantities
- Study the necessity to replace the global reference system GRS80 as the conventional system
- Advance the realization of a conventional global reference gravity field model (combined and satellite only)
- Assist the working group for establishing the International Height Reference System (IHRS) in the realization
- Integrating and combining the global gravity network with other techniques
- Study the influence of earth orientation parameters, tidal models and relativistic effects on the realization of a consistent global reference frame in geometry, height and gravity
- Foster the free exchange of geodetic data and products

Members

Urs Marti (Switzerland), Chair
Detlef Angermann (Germany), Chair of GGOS BPS, IERS
Richard Gross (USA) IAG Vice President, Committee on EGV
Ilya Oshchepkov (Russia), GRS, Gravity Networks and Height Systems
Christopher Kotsakis (Greece), Commission 1
Jonas Ågren (Sweden), Commission 2
Ulrich Meyer (Switzerland) COST-G
Riccardo Barzaghi (Italy), IGFS
Jaakko Mäkinen (Finland), Tidal Systems
Pavel Novak (Czech Republic), ICCT
Laura Sánchez (Germany), IHRF
Hartmut Wziontek (Germany), IGRF
John Nolton (USA), GRS
Robert Heinkelmann (Germany), IAU
Sergei Kopeikin (USA), relativistic effects
Erricos Pavlis (USA), ILRS

Focus Area "Unified Height System"

Lead: Laura Sánchez (Germany)

With contributions from: *H.A. Abd-Elmotaal (Egypt), J. Ågren (Sweden), H. Denker (Germany), W. Featherstone (Australia), R. Forsberg (Denmark), V.N. Grigoriadis (Greece), T. Gruber (Germany), G. Guimarães (Brazil), J. Huang (Canada), T. Jiang (China), Q. Liu (Germany), J. Mäkinnen (Finland), U. Marti (Switzerland), K. Matsuo (Japan), P. Novák (Czech Republic), I. Oshchepkov (Russia), D. Smith (USA), M. Varga (Croatia), G. Vergos (Greece), M. Véronneau (Canada), Y. Wang (USA), K. Ahlgren (USA), R. Winefield (New Zealand), M. Amos (New Zealand), D. Avalos (Mexico), M. Bilker-Koivula (Finnland), D. Blitzkow (Brazil), S. Claessens (Australia), X. Collilieux (France), M. Filmer (Australia), A.C.O.C. Matos (Brazil), J. McCubbine (Australia), R. Pail (Germany), D. Roman (USA), C. Tocho (Argentina), E. Antokoletz (Argentina), H. Wziontek (Germany).*

The GGOS Focus Area "Unified Height System" (GGOS-FA-UHS, formerly Theme 1) was established at the 2010 GGOS Planning Meeting (February 1 - 3, Miami, Florida, USA) to lead and coordinate the efforts required for the establishment of a global unified height system that serves as a basis for the standardisation of height systems worldwide. Starting point was the results delivered by the IAG Inter-Commission Project 1.2 Vertical Reference Frames (IAG-ICP1.2-VRF), which was operative from 2003 to 2011. During the 2011-2015 term, different discussions focussed on the best possible definition of a global unified vertical reference system resulted in the IAG resolution for the Definition and realisation of an International Height Reference System (IHRS) that was approved during the 2015 General Assembly of the International Union of Geodesy and Geophysics (IUGG) in Prague, Czech Republic. In the term 2015-2019, actions dedicated to investigate the best strategy for the realisation of the IHRS (i.e., the establishment of the International Height Reference Frame – IHRF) were undertaken. In particular, a preliminary station selection for the IHRF reference network was achieved and different computation procedures for the determination of potential values as IHRS coordinates were evaluated. For the present term, 2019-2023, the objectives of the GGOS-FA-UHS are (i) to compile detailed standards, conventions, and guidelines to support a consistent determination of the IHRF at global, regional and national levels; (ii) to coordinate with regional/national experts in gravity field modelling the computation of a first IHRF solution; and (iii) to design an operational infrastructure that ensures the long-term sustainability and reliability of the IHRS/IHRF. This infrastructure should operate under the responsibility of the International Gravity Field Service (IGFS).

Networking within the IAG

The implementation of a global reference system for physical heights as the IHRS is a big challenge and requires the support of a wide scientific community. Thus, the installation of the IHRS/IHRF is only possible within a global and structured organisation like the IAG. Presently, following entities are contributing to achieve the goals of the GGO-FA-UHS:

- GGOS-FA-UHS and IGFS working group *Implementation of the International Height Reference Frame (IHRF)*, chairs L Sánchez (Germany) and R Barzaghi (Italy).
- ICCT joint study group *Geoid/quasi-geoid modelling for realization of the geopotential height datum*, chairs: J Huang (Canada), YM Wang (USA).
- IAG SC 2.2: *Methodology for geoid and physical height systems*, chairs: G. Vergos (Greece), Rossen S. Grebenitcharsky (Saudi Arabia).
- IAG Commission 2.2 working group *Error assessment of the 1 cm geoid experiment*, chairs: T Jiang (China), V Grigoriadis (Greece).

- IAG Commission 2 joint working group *On the realization of the International Gravity Reference Frame*, chairs: H. Wziontek (Germany), S. Bonvalot (France)
- GGOS-BPS working group *Towards a consistent set of parameters for a new GRS*, chair U Martí (Switzerland)
- *International Gravity Field Service* – IGFS, chair: R, Barzaghi (Italy), vice-chair: G. Vergos (Greece).

Advances in the establishment of the IHRF

To move forwards in the realisation of the IHRS, we currently concentrate on four primary aspects: (1) specific standards and conventions that ensure consistency between the IHRS definition and the IHRF coordinates; (2) a global reference network for the IHRF; (3) the determination of IHRF coordinates at the reference stations; and (4) an operational infrastructure to guarantee a reliable and long-term sustainability of the IHRS/IHRF (see a detailed discussion of these four aspects in Sánchez et al. 2021).

Standards and conventions for the IHRS/IHRF

The IHRS is a gravity potential-based reference system: the vertical coordinates are geopotential numbers [$C(P) = W_0 - W(P)$] referring to an equipotential surface of the Earth's gravity field realised by the IAG conventional value W_0 = 62 636 853.4 m^2s^{-2}. The spatial reference of the position P for the potential $W(P) = W(\mathbf{X})$ is given by the coordinates **X** referring to the ITRS/ITRF. Geopotential numbers are defined as the primary vertical coordinate as they can be converted to any type of physical heights (orthometric or normal heights). As the reference value W_0 is constant and conventionally adopted, the IHRS essentially materialises the combination of a geometric component given by the coordinate vector **X** in the ITRS/ITRF and a physical component given by the determination of potential values W at **X**. To be compatible with the ITRF, the accuracy of the IHRF geopotential numbers and their variation with time should be at least $\pm 3\times 10^{-2}$ m^2s^{-2} (equivalent to ≈ ±3 mm in height) and $\pm 3\times 10^{-3}$ $m^2s^{-2}a^{-1}$ (≈ ±0.3 mm a^{-1}), respectively. However, for the moment, the goal is to reach $\pm 1\times 10^{-1}$ m^2s^{-2} (about 1 cm) in the static component.

The most pragmatic way to determine potential values W(P) would be to introduce the ITRF coordinates of any point into the harmonic expansion equation representing a global gravity model (GGM) of high degree (up to degree 2190 or higher). These models could provide potential values with accuracies of around ±0.2 m^2s^{-2} (equivalent to ±2 cm in height) in regions with flat and moderate terrains when dense and consistent gravity data are used in the computation of the GGM. If no regional gravity data are available to be included in the GGM, the best possible mean accuracy offered by these models would be around ±2.0 m^2s^{-2} (±0.2 m), or even worse (up to ±10 m^2s^{-2} or ±1 m) in regions with strong topography gradients. To increase this accuracy, the values W(P) could be determined from gravity field observables applying appropriate modelling strategies, which in general correspond to geoid or quasi-geoid computation methods. In the geoid/quasi-geoid computation, the primary functional to be determined is the disturbing potential $T = W - U$. If the disturbing potential T(P) is known, the determination of station potential values W(P) is straightforward. However, the determination of the disturbing potential relies not only on the available gravity data but also on the gravity field modelling approaches. This includes different methods for the handling of terrain effects, the filtering and combination of surface gravity data, the treatment of long-wavelength errors, the mathematical formulations to invert and to integrate gravity and terrain observations, etc. Since there are so many parameter choices when handling the gravity and terrain data, the obtained potential values inevitably vary from computation to computation. Thus, different groups can generate quite different results from the same input data. Nevertheless, to define only one standard procedure for the computation of potential values is unsuitable as different data availability and different data quality exist around the world, and additionally, regions with different characteristics require particular approaches (e.g. modification of kernel functions, size of integration caps, geophysical reductions like GIA, etc.). On the other hand, a centralised computation of the IHRF coordinates (like in the ITRF) also poses a problem due to the restricted accessibility to terrestrial gravity data.

In order to get as similar and compatible results as possible, we complied a set of basic standards covering general constants, reference ellipsoid, mass centre convention, zero-degree correction to realise the vertical datum defined by the conventional W_0 value, standardised formulas for the conversion of potential coordinates between different permanent tide systems, and a standardised procedure to recover potential values from existing regional/national geoid or quasi-geoid models. The latter is of particular importance as (1) the regional geoid/quasi-geoid models include surface gravity data sets that are not always available for the determination of GGM, (2) the regional models can assimilate new regional/local gravity surveys very quickly, and (3) national/regional experts on gravity field modelling have the best possible knowledge about the local conditions (topography, data distribution, geophysical corrections, validation data, etc.) to be considered in the computation of the geoid/quasi-geoid, or more precisely, in the determination of the disturbing potential T in their countries/regions.

Global reference network of the IHRF

The main criteria for the selection of IHRF reference stations were defined as:

- GNSS continuously operating reference stations to detect reference frame deformations (with preference for stations belonging to the ITRF and the regional reference frames like SIRGAS, EPN, APREF, etc.);
- Co-location with fundamental geodetic observatories to ensure a consistent connection between geometric coordinates, potential and gravity values, and reference clocks;
- Co-location with reference stations of the International Gravity Reference Frame (IGRF) to integrate the gravity and physical height reference frames;
- 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).

Based on this criteria, a preliminary station selection for the IHRF was initiated in 2016. 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). The core network includes fundamental geodetic observatories, ITRF sites with more than two space geodetic techniques, IGRF reference stations and selected IGS reference stations to ensure a global coverage as homogeneous as possible. During 2017-2018, 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, the first approximation to the IHRF reference network was completed in 2019. This network comprises about 170 stations (Fig. x1) and currently, it is regularly refined in agreement with changes/updates of other geodetic reference frames (ITRF and IGRF and their densifications).

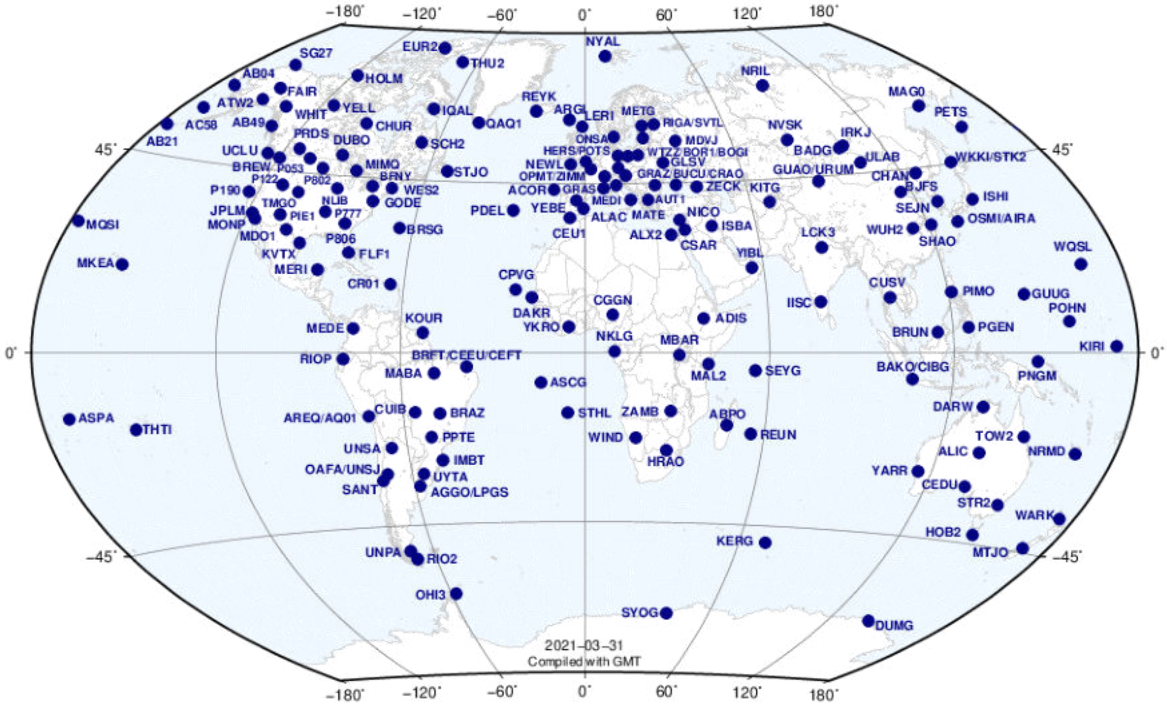

Fig. x1 IHRF reference network (latest update in March 2021)

Determination of IHRF coordinates

A key activity in this regard was the evaluation of different methodologies for the determination of potential values as IHRS/IHRF reference coordinates within the so-called Colorado experiment. This experiment aimed at computing geoid, quasi-geoid and potential values using the same input data and the own methodologies of colleagues involved in the gravity field modelling. About 40 colleagues grouped in fourteen international computation groups contributed to this initiative. The Colorado experiment started at the IAG/IASPEI Scientific Assembly (Aug 2017, Kobe). First results were discussed at the GGHS2018 Symposium (Sep 2018, Copenhagen). A second computation was ready for the EGU2019 (Apr 2019, Vienna) and some refinements (third computation) were delivered in Jun 2019. The results were extensively discussed at the IUGG2019, Symposium G02: Static Gravity Field and Height Systems (July 2019, Montreal). At present, a special issue on Reference Systems in Physical Geodesy to be published in the Journal of Geodesy is preparation. This special issue includes the scientific description of the individual solutions contributing to the Colorado experiment as well as key contributions for the establishment of the IHRS/IHRF and the IGRS/IGRF.

Based on the efforts of the previous term 2015-2019, in particular, the outcomes of the Colorado experiment, we classified the computation of potential values in three main scenarios:

a) Regions without (or with very few) surface gravity data,
   - The only option to determine potential values is the use of GGM of high resolution
   - Expected mean accuracy values around the ±4.0 m^2s^{-2} (±40.0 cm in terms of height) level or even worse in regions with strong topography gradients
   - It could be improved for instance to the ±1.0 m^2s^{-2} (±10.0 cm) level if new and better surface gravity data are included in the GGMs.
   - To avoid multiple potential values provided by different GGM-HRs at the same point, it is necessary to select one GGM-HR as reference model.

b) Regions with some surface gravity data, but with poor data coverage or unknown data quality,
   - The reliability of the existing (quasi-)geoid models is poor
   - Additional gravity surveys around the IHRF stations would help to increase the accuracy of the geopotential numbers computed at those specific stations.

c) Regions with good surface gravity data coverage and quality.
   - Potential values may be inferred from precise geoid/quasi-geoid regional models.

Using this classification, we started in the beginning of 2021 the computation of a first solution for the IHRF. As an initial action, a short description of the "step by step" to infer IHRF potential values from local/regional geoid/quasi-geoid models was prepared. It is based on the IHRS paper published by Sánchez et al. (2021) and was distributed to the members of the working group *Implementation of the International Height Reference Frame (IHRF)*, so that they can compute potential values at the IHRF stations located in their countries using their present/latest geoid/quasi-geoid models. This activity is supported by about 40 colleagues from Canada, Mexico, USA, Germany, Italy, Switzerland, Austria, Sweden, Finland, Australia, Japan, China, South America, Russia, and Africa. Complementary, the ISG and the IGFS are evaluating the quality and documentation of the different regional models available at the Geoid Repository of ISG in order to identify which models can be used to infer potential values. This action is useful for the IHRF computation in areas underrepresented in the working group.

Simultaneously, we are computing potential values for all the IHRF stations (Fig. x1) using GGM extended with topography-based synthetic gravity signals, reaching resolutions up to degree ~ 80000 … ~ 90000. As mentioned, this would be the only option available in those regions where no geoid/quasi-geoid models are available. At the end, we will have different potential values for the same points. The agreement of the different GGM and the models stored by ISG with the own computations performed by the colleagues of the working group will allow us to decide which GGM+topography models perform better. Our goal in this regard is to present the first results at the next IAG2021 Scientific Assembly in Beijing, China.

Operational infrastructure to ensure the long-term sustainability of the IHRS/IHRF

An IHRS/IHRF objective is to support the monitoring and analysis of Earth's system changes. The more accurate the IHRS/IHRF is, the more phenomena can be identified and modelled. Thus, the IHRS/IHRF must provide vertical coordinates and their changes with time as accurately as possible. As many global change phenomena occur at different scales, the global frame should be extended to regional and local levels to guarantee consistency in the observation, detection, and modelling of their effects. From this perspective, we are proposing the establishment of an operational infrastructure within the IGFS that takes care of (cf. Sánchez et al. 2021):

a) Maintenance of the IHRF reference network in accordance with the GGOS-BNO and the coordinators of the reference networks for the ITRF, IGRF and their regional densifications. This activity should be faced by the IHRF reference network coordination (see blue boxes in Fig. x2).
b) Maintenance of a catalogue with the conventions and standards needed for the IHRF. This should consider a harmonisation with the conventions and standards kept by the GGOS-BPO, the IERS Conventions (for the determination of the ITRF), and the standards applied in the IGRF and the global gravity field modelling. This task should be carried out by the IHRF conventions' coordination (see pink boxes in Fig. x2).
c) The national/regional agencies/entities contributing to the realisation of the IHRF in their regions may be declared as IHRF national/regional computation centres (dark blue

box in Fig. x2). The input data would then be provided by existing IAG gravity field services and local data centres; e.g., GGM are provided by ICGEM and surface gravity data are provided by the Bureau Gravimétrique International (BGI) and refined/complemented with gravity data available at local data centres. In a similar way, one can proceed with digital elevation models (see violet box in Fig. x2).

d) In an ideal data flow scheme, the national/regional IHRF computation centres would provide the IGFS with the following products (cyan box in Fig. x2): potential values at the IHRF reference stations; vertical datum unification parameters (to transform the existing local height systems to the IHRF); mean gravity anomalies or disturbances (without violating data confidentiality but contributing to the determination of improved GGMs); and regional geoid/quasi-geoid models of high resolution. The mean gravity anomalies (or disturbances) and the geoid/quasi-geoid models would be then managed by BGI and ISG. For the combination of the regional/national solutions, validation, storage, management, and servicing of potential values at IHRF stations and vertical datum parameters, the IGFS would have to establish a new element, which could be called IHRF product centre (see magenta boxes in Fig. x2).

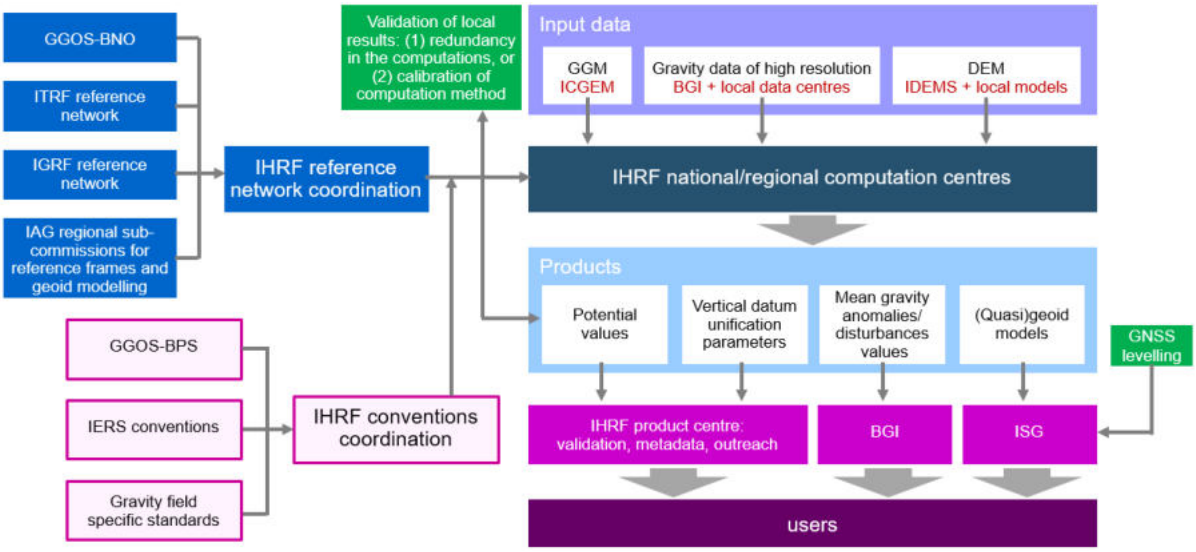

Fig. x2 Proposal for an IHRF operational infrastructure within the IGFS (taken from Sánchez et al., 2021)

Further activities

In addition to the actions oriented to the establishment of the IHRF, following activities are reported since July 2019:

a) Preparation of the Journal of Geodesy Special Issue *Reference Systems in Physical Geodesy* with
   - detailed description, comparison and evaluation of fourteen different approaches for the determination of the geoid/quasi-geoid within the Colorado experiment,
   - an initial strategy for the establishment of the IHRF, and
   - contributions about the establishment of the IGRS/IGRF.
   - Guest editors: L Sánchez, H Wziontek, YM Wang, G Vergos, L Timmen
   - Paper submission from Oct 25, 2019 to May 31, 2020
   - 23 papers submitted: 15 published, 2 rejected, 6 under revision/correction (as of May, 2021)

b) Contribution to the GGOS-BPS inventory with issues related to physical heights

c) Preparation of new texts and graphics for the new GGOS Website

d) Preparation of a joint session on Vertical Reference Systems for the IAG2021 Scientific Assembly together with the IAG Commissions 1 and 2, ICCT, and the project Quantum Geodesy (QuGe)
e) Presentations at: EGU2021 (virtual meeting, Apr 2021), Latin American Regional School on Geodesy (virtual meeting, March 2021), Symposium SIRGAS2020 (virtual meeting, Nov 2020), GGOS Days 2020 (virtual meeting, Oct 2020), SIRGAS webinar on the IHRF (virtual meeting, July 2020), EGU2020 (virtual meeting, May 2020), Symposium SIRGAS2019 (Rio de Janeiro – Brazil, Nov 2019), GGOS Days 2019 (Rio de Janeiro – Brazil, Nov 2019), GGOS-IERS Unified Analysis Workshop (Paris – France, Oct 2019), IUGG Workshop for the implementation the UN-GGRF in Latin America (Buenos Aires – Argentina, Sep 2019).

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Jiang T, Dang YM, Zhang CY (2020) Gravimetric geoid modeling from the combination of satellite gravity model, terrestrial and airborne gravity data: a case study in the mountainous area, Colorado. Earth Planets and Space 72, 189. https://doi.org/10.1186/s40623-020-01287-y.

Liu Q, Schmidt M, Sánchez L, Willberg M (2020) Regional gravity field refinement for (quasi-)geoid determination based on spherical radial basis functions in Colorado. J Geod 94-99, https://doi.org/10.1007/s00190-020-01431-2.

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Varga M, Pitoňák M, Novák P, Bašić T (2021) Contribution of GRAV-D airborne gravity to improvement of regional gravimetric geoid modelling in Colorado, USA, J Geod, 95, 53, https://doi.org/10.1007/s00190-021-01494-9.

Wang YM, Li X, Ahlgren K, Krcmaric J (2020) Colorado geoid modeling at the US National Geodetic Survey, J Geod 94, 106, https://doi.org/10.1007/s00190-020-01429-w.

Willberg M, Zingerle P, Pail R (2020) Integration of airborne gravimetry data filtering into residual least-squares collocation: example from the 1 cm geoid experiment. J Geod 94, 75 https://doi.org/10.1007/s00190-020-01396-2.

Willberg, M., Zingerle, P. & Pail, R. (2019) Residual least-squares collocation: use of covariance matrices from high-resolution global geopotential models. J Geod 93, 1739–1757. https://doi.org/10.1007/s00190-019-01279-1.

GGOS Geohazards Focus Area

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

Background:

The GGOS Geohazards Focus Area (GFA) is applying 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 to apply 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 (GTEWS) (http://kb.igs.org/hc/en-us/articles/218259648-Call-for-Participation-GNSS-Augmentation-to-the-Tsunami-Early-Warning-System). The GTEWS CfP identifies the formal recommendations by the IGS, IUGG, IOC, and the APSG that support the CfP. The GTEWS Initiative seeks to advance and implement the Resolution #4 of the IUGG 2015 General Assembly. The GTEWS Initiative builds upon the benefits of the IGS Real Time Service (GPSRT) and the Multi-GNSS Experiment (MGEX) within the context of the UN-GGIM program.

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. The membership has grown to 18 institutions from 12 nations with the recent addition of the Indian National Centre for Ocean Information Services (INCOIS),

The GTEWS 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 GTEWS CfP to the UN-GGIM membership. The GTEWS working group currently comprises 17 agencies and institutions from 11 countries. The agencies and institutions of the GTEWS working group are actively involved in the development of GNSS infrastructure, analysis, and disaster preparedness. The GTEWS 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 GTEWS CfP and registration to the GTEWS working group remains open and relevant organizations are encouraged to participate.

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,

Resolves

- 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.

GGOS Working Group on GNSS Augmentation for Tsunami Warning

12 nations - 18 organizations

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
India	Indian National Centre for Ocean Information Services (INCOIS)	INCOIS operates Tsunami Warning Center ESSO and a large array of seismic, tidal guages buoy, GNSS and strong motion accelerometers at sites including the Andaman and Nicobar Islands.	Mrs. Vijaya Sunanda Manneela	shenoi@incois.gov.in, sunanda@incois.gov.in
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, addsgc@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

The GTEWS Initiative:

The GGOS Geohazards Focus Area Website provides links to the foundational documents for the **G**NSS augmentation of **T**sunami **E**arly **W**arning **S**ystems (GTEWS) Initiative. Additional links to presentations, newsletters, videos and other files of interest to the GTEWS community are available at the GATEW online library. https://www.dropbox.com/sh/fg20mtydg136vx6/AABNr2kSnMo429nCxEHhBDfoa?dl=0 .

The GTEWS 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. Full recordings and presentations of the GTEWS 2017 workshop are available here.

The GTEWS 2017 Workshop Report:

Recommendations:

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.

Over 90% of the GTEWS organizations registered for GTEWS 2017 provided a majority of the presentations that are available on the GTEWS 2017 meeting recording.The GTEWS workshop report is available on numerous websites including the GGOS website, the APRU website and the UNDRR website for the 2019 Global Assessment Report (GAR19). These reports validate that GTEWS is effective and affordable providing tsunami risk reduction and broad economic benefits to both developing and developed nations. GTEWS 2017 workshop recommendations begin with the establishment of a GTEWS Consortium of Principals.

Unfortunately, the 2020 meeting GTEWS Principals Organizational Meeting planned to review and implement the GTEWS 2017 recommendations was postponed due to COVID-19 pandemic. The GTEWS Principals Meeting is postponed to Fall 2022 in Sendai, Japan. The following presents the current status of those plans and agreements for the 2022 GTEWS Principals Meeting.

Plans for the GTEWS Principals Meeting
Date and Venue: Fall 2022, Sendai, Japan
Forum: GEO Geodesy4Sendai Community Activity
Goal: Creation of the GTEWS Consortium per GTEWS 2017 recommendations

- The GTEWS initiative is supported by the 17 institutions of 12 nations that comprise the GTEWS working group of the GGOS Focus Area for Geohazards.
- APRU and Tohoku University IRIDeS pledged support
- The Group on Earth Observation has offered the Geodesy4Sendai community activity as a forum for the assembly of the GTEWS working group and other principal organizations for implementation of the GTEWS 2017 report.
- The GGOS and the IUGG have agreed to collaborate in support of the GTEWS initiative and the planned meeting of GTEWS Principals.
- The ITU Focus Group on AI for Natural Disaster Management (FG-AI4NDM-I-024) has initiated a topic group to advance the application of Artificial Intelligence to GTEWS. Leads: A. Craddock, A Komjathy, J. Rundle, B. Crowell
- Government agency participation is sought to advance sharing of real time data. The involvement of national emergency response agencies will help to solve funding issues and improve inter-agency and international collaborations
- Commercial and Non-government Organizations participation is sought to assist in the availability of international data networking, cloud computing resources, analysis and early warning software.

GGOS Focus Area 'Geodetic Space Weather Research'

Chair: Michael Schmidt (Germany)
Vice-Chair: Ehsan Forootan (Denmark)

Introduction

Space weather means a very up-to-date and interdisciplinary field of research. It describes physical processes in the near-Earth space mainly caused by the Sun's radiation of energy. The manifestations of space weather are multiple, e.g. variations of the Earth's magnetic field, variations of the upper atmosphere consisting of the compartments magnetosphere, ionosphere, plasmasphere, and thermosphere, also known as the MIPT system (due to coupling processes), as well as solar wind, i.e. the permanent emission of electrons and photons including the interplanetary magnetic field (IMF), i.e. the component of the solar magnetic field that is dragged out from the solar corona by the solar wind flow. The magnetosphere is the part of the near-Earth space in which the total magnetic field is dominated by the Earth's magnetic field and not by the IMF. It is well-known that the pressure of the solar wind compresses the magnetic field on the day side of the Earth and stretches it into a long tail on the night side.

Activities

The GGOS Focus Area on Geodetic Space Weather Research (FA-GSWR) has been installed in 2017. At the FA-GSWR splinter meeting during the IUGG 2019 General Assembly in Montreal, it was decided to extend the scientific content of the FA-GSWR by the magnetosphere and the plasmasphere such that it now deals with the complete MIPT system and the mutual couplings. As shown in Fig. 1 the scientific structure of the FA-GSWR can be visualized now as a double tetrahedron.

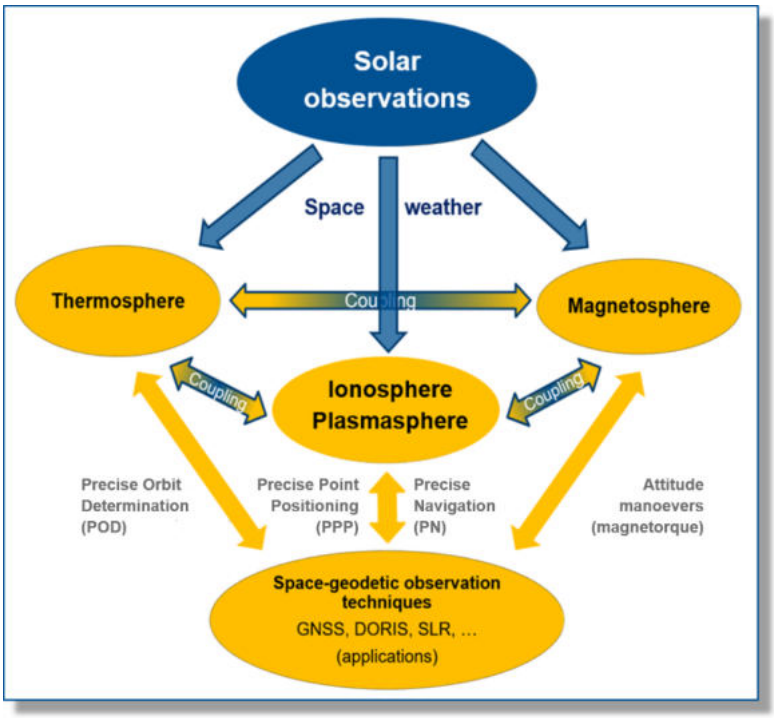

Fig. 1: Structure of the FA-GSWR including the plasmasphere and the magnetosphere: the yellow-colored parts are related to geodetic applications such as Precise Orbit Determination (POD) and Precise Point Positioning (PPP); the blue-colored parts are related to solar phenomena especially to space weather.

The most important task of the FA-GSWR is the development of a concept for the combined evaluation of measurements from solar and geodetic satellite missions as well as magnetic field information under the consideration of the physical coupling processes. Although rather challenging, this concept plays the most important role to reach the main objectives of the FA-GSWR, namely the development of an

(1) improved electron density model of the ionosphere including the plasmasphere and an

(2) improved model of the neutral density in the thermosphere.

In a study members of the FA-GSWR decided that both the electron density and the neutral density should be interpreted as so-called Essential Geodetic Variables (EGV); consequently, the developed improved models should finally be provided as GGOS products to potential users.

To approach these goals, an IAG GGOS Joint Study Group (JSG) and three IAG GGOS Joint Working Groups (JWG) have been established within the FA-GSWR. These IAG GGOS groups are titled as

JSG 1: Coupling processes between magnetosphere, 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).

Their achievements in the last two years will be presented in more detail below.

The special issue 'Observing and Modelling Ionosphere and Thermosphere using in situ and Remote Sensing Techniques' of the journal 'Remote Sensing' was initiated by members of the FA-GSWR. The deadline for manuscript submission was December 31, 2020.

Website

We have significantly updated the GGOS web pages about the FA-GSWR by including more information about space weather in general, but also more detailed information about the work in the JSG and the 3 JWGs. Furthermore, we added on the GGOS web page 'Geodetic Products' information about ionosphere and thermosphere products.

Planned activities for the period 2021-2023

In the final two years of the IAG four-year period 2019 – 2023 the FA-GSWR will concentrate on the aspects:

- extensive simulation studies 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
- continuation of the work on the definition and selection of the EGVs in the framework of the FA-GSWR
- organization of an own conference part for the FA-GSWR at the 2nd International

Symposium of the IAG Commission 4 'Positioning and Applications'. This conference was originally planned for September 2020 in Potsdam at GFZ, but due to the Corona pandemic postponed to September 2022.

Website

https://ggos.org/about/org/fa/geodetic-space-weather-research/

JSG 1 (JSG T.27): Coupling processes between magnetosphere, thermosphere and ionosphere

Chair: Andres Calabia (China)
Vice-Chair: Munawar Shah (Pakistan)
Research Coordinator: Binod Adhikari (Nepal)

(Led by ICCT; joint with GGOS, Focus Area on Geodetic Space Weather Research and Commission 4, Sub-Commission 4.3)

Members

Christine Amory-Mazaudier (France, Italy)
Astrid Maute (USA)
Yury Yasyukevich (Russia)
Gang Lu (USA)
Anoruo Chukwuma (Nigeria)
Oluwaseyi Emmanuel Jimoh (Nigeria)
Munawar Shah (Pakistan)
Binod Adhikari (Nepal)
Andres Calabia(China)
Piyush M. Mehta (USA)
LiangLiang Yuan (Germany)
Naomi Maruyama (USA)
Toyese Tunde Ayorinde (Brazil)
Charles Owolabi (Nigeria)
Emmanuel Abiodun Ariyibi (Nigeria)
Olawale S. Bolaji (Australia)

Since this study group is part of the Inter-Commission Committee on Theory (ICCT), the mid-term report of JSG 1 (JSG T.27) can be found in the ICCT Section of this report and is not repeated here.

JWG 1: Electron density modelling

Chair: Fabricio dos Santos Prol (Germany)
Vice-Chair: Alberto Garcia-Rigo (Spain)

(Led by GGOS; joint with Commission 4, Sub-Commission 4.3)

Members

A. Goss (Germany)
A. Smirnov (Germany)
B. Nava (Italy)
D. Themens (United Kingdom)
F. Arikan (Turkey)
G. Jerez (Brazil)
G. Seemala (India)
H. Lyu (Spain)
J. Norberg (Finland)
M. Hoque (Germany)
M. Muella (Brazil)
Mir-Reza Razin (Iran)
O. Arikan (Turkey)
S. Jin (China)
S. Karatay (Turkey)
S. Yildiz (Turkey)
T. Gerzen (Germany)
T. Kodikara (Germany)

K. Alazo (Italy) *Y. Migoya-Orue' (Italy)*

Activities during the period 2019-2021

The objective of JWG 1 Electron density modelling is to evaluate and improve established methods of 3D electron density estimation in terms of electron density, peak height, Total Electron Content (TEC), or other derived products that can be effectively used for GNSS positioning or studying perturbed conditions due to representative space weather events. This should be achieved through the realization of three main points:

- Development of a database, where the methods from the group members will be evaluated in terms of GNSS, radio-occultation, in-situ data, altimeters, among other electron density and TEC measurements.
- Pragmatic assessment of established methods for 3D electron density estimation in order to define their accuracy related to specific parameters of great importance for Space Weather and Geodesy.
- Generate products indicating the space weather conditions and expected errors of the methods.

The first two years of the project development were devoted to establish a group of experts and active members on the field in order to solve the project problems by means of a network of collaboration. So far, we have built a fair database for our evaluations, selecting proper instruments and pre-processing techniques to the dataset. A few campaigns were created to carry out a pragmatic model evaluation between the members. In future, the database is expected to be defined as a benchmark to other ionospheric modelling assessments.

Figure 2 shows an example of the global assessment that has been carried out by the group, where the Thermosphere-Ionosphere- Electrodynamics General Circulation Model (TIE-GCM) is evaluated in comparison to critical frequency values given by a global network of ionosondes. The same evaluation was already conducted by four models, including high-resolution global tomography techniques and empirical models. A direct comparison between the models is also being investigated (Prol et al. 2019a, Kodikara et al. 2021), in order to provide an overview of the quality of typical ionospheric models to the community interested in the GGOS focus area on Space Weather. Prol et al. (2018), for instance, have shown that high-resolution 3D ionospheric imaging can provide great improvements in the geodetic positioning when compared to the best VTEC models of the IGS products.

Besides ionosonde measurements, we have gathered in-situ data from C/NOFS, DMSP, GRACE and SWARM missions. Electron density profiles from Incoherent Scatter Radar and GNSS radio-occultation were also included in the analysis, as well as TEC measurements from altimeters and LEO-based satellites. In this regard, it is crucial to understand the quality of the ionospheric instruments used to collect the reference measurements. Therefore, we have conducted a few cross-validations between the electron density measurements provided by the instruments (Smirnov et al. 2021). We have also checked the feasibility of using ionosonde observations to evaluate established TEC models (Jerez et al. 2021).

It is relevant to notice that a main drawback of the 3D ionospheric models nowadays is to conduct a proper description of the topside ionosphere and plasmasphere. Empirical modelling of electron density needs to be essentially improved above the F2 layer peak (hmF2) for a better characterization of the topside TEC (Prol et al. 2019b), which can contribute from 10% to 60% to the ground-based TEC measurements. In this regard, a few studies of the group were devoted to better characterize the upper part of the ionized atmosphere. Recent advances from Prol et al. (2021) and Prol and Hoque (2020, 2021) have shown that great improvements on the topside ionosphere and plasmasphere can be obtained in comparison to typical models, in particular during disturbed conditions due to geomagnetic storm events.

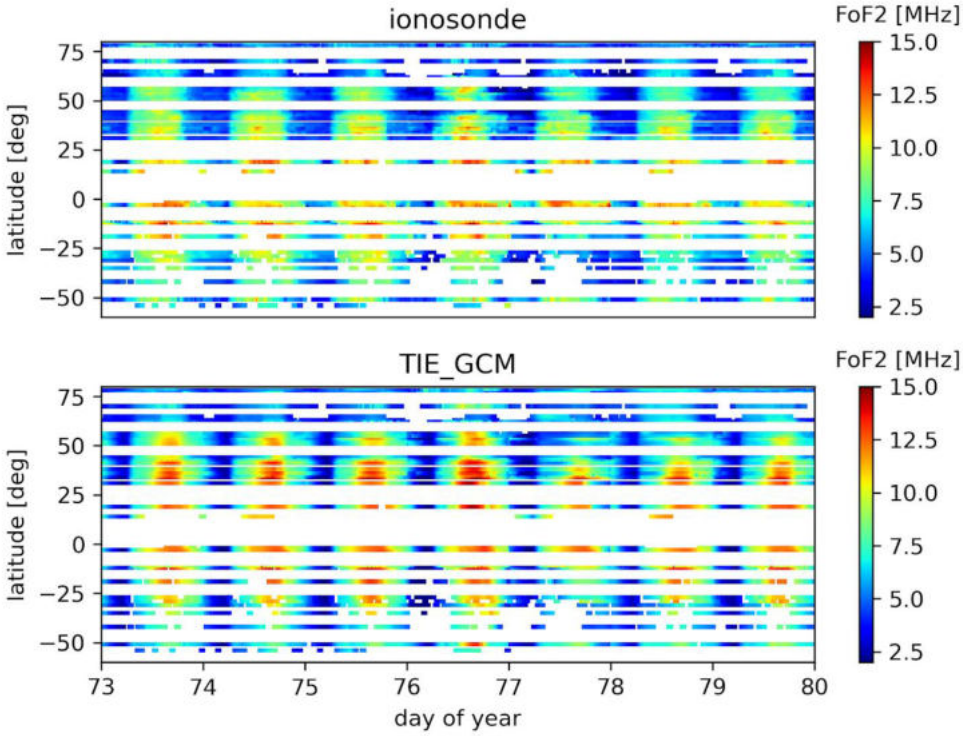

Fig. 2. Critical frequency (FoF2) evaluation during a campaign of 2013. The top panel shows the FoF2 values obtained by the ionosonde measurements. The bottom panel shows the corresponding FoF2 values computed using TIE-GCM model. y-axis is related to the geographical latitude. x-axis is related to the day of the year. The storm event main phase starts in the beginning of DOY 076.

In the next two years, it is expected to provide the final results of the current accuracy of ionospheric models using the best efforts to generate a fair evaluation between the models. Our investigation aims to provide a direct comparison of the accuracy of several models and techniques for ionospheric imaging, in which a simulated case scenario is also expected to be built. In principle, the simulations are planned to describe the electron density ionosphere during a quiet time. As we advance with the project goals, more complex dynamics are planned to be incorporated in the simulations.

Publications

Jerez G.O., Hernández-Pajares M., Prol F.S., Alves D.B.M., Monico J.F G. (2020) Assessment of Global Ionospheric Maps Performance by Means of Ionosonde Data. Remote Sens., 12, 3452. https://doi.org/10.3390/rs12203452

Kodikara T., Zhang K., Pedatella N.M., Borries C. (2021). The impact of solar activity on forecasting the upper atmosphere via assimilation of electron density data. Space Weather, 19, e2020SW002660. https://doi.org/10.1029/2020SW002660

Prol F.S., Camargo P.O., Hernández-Pajares M., Muella M.T.A.H. (2018). A new method for ionospheric tomography and its assessment by ionosonde electron density, GPS TEC, and single-frequency PPP. IEEE Transactions on Geoscience and Remote Sensing, 57, 2571-2582.

Prol F.S., Garcia-Rigo A., Hoque M.M., Schmidt M., Börger K. (2019a) Towards a global 3D ionospheric model for space weather monitoring and GNSS positioning. IUGG General Assembly, Montreal, Canada.

Prol F.S., Themens D.R., Hernández-Pajares M., Camargo P. O., Muella M. T. A. H. (2019b) Linear Vary-Chap Topside Electron Density Model with Topside Sounder and Radio-Occultation Data. Surv Geophys., 40, 277–293. https://doi.org/10.1007/s10712-019-09521-3

Prol F.S., Hoque M.M. (2020) Plasmaspheric electron density estimation based on COMISC/FORMOSAT-3 data, EGU General Assembly 2020, Online

Prol F.S., Hoque M.M. (2021) Topside Ionosphere and Plasmasphere Modelling Using GNSS Radio Occultation and POD Data. Remote Sens., 13, 1559. https://doi.org/10.3390/rs13081559

Prol F.S., Hoque, M.M., Ferreira A. A. (2021) Plasmasphere and topside ionosphere reconstruction using METOP satellite data during geomagnetic storms. J. Space Weather Space Clim., 11, 5. https://doi.org/10.1051/swsc/202007

Smirnov A., Shprits Y., Zhelavskaya I, Lühr H., Xiong C., Goss A., Prol F.S., Schmidt M., Hoque M.M., Pedatella N., Szabo-Roberts M. (2021) Intercalibration of the Plasma Density Measurements in Earth’s Topside Ionosphere. Submitted to JGR Space Physics.

Data & Software Products

Andres Calabia, & Shuanggen Jin. (2019, May 29). Supporting Information for "Solar-cycle, seasonal, and asymmetric dependencies of thermospheric mass density disturbances due to magnetospheric forcing". Zenodo. http://doi.org/10.5281/zenodo.3234582

Calabia, Andres, & Jin, Shuanggen. (2019, December 5). Supporting Information for "New modes and mechanisms of long-term ionospheric TEC variations from Global Ionosphere Maps". Zenodo. http://doi.org/10.5281/zenodo.3563463

Calabia, Andres, & Jin, Shuanggen. (2020). Supporting Information for "Short-term ionospheric TEC variations from Global Ionosphere Maps" [Data set]. Zenodo. http://doi.org/10.5281/zenodo.4280436

SIMuRG: System for Ionosphere Monitoring and Research from GNSS. https://simurg.iszf.irk.ru

Other Relevant Links

Community Coordinated Modeling Center: https://ccmc.gsfc.nasa.gov/models/models_at_glance.php

JWG 2: Improvement of thermosphere models

Chair: Christian Siemes (The Netherlands)
Vice-Chair: Kristin Vielberg (Germany)

(Led by GGOS; joint with IAG Commission 4, Sub-Commission 4.3 and ICCC)

Members

Armin Corbin (Germany)
Ehsan Forootan (Denkmark)
Mona Kosary (Iran)
Lea Zeitler (Germany)
Christopher McCullough (USA)
Sandro Krauss (Austria)
Saniya Behzadpour (Austria)
Aleš Bezděk (Czech Republic)
Sean Bruinsma (France)
Michael Schmidt (Germany)
Barbara Süsser-Rechberger (Austria)
Peter Nagel (USA)

Activities during the period 2019-2021

This working group was founded in November 2019. Since accurate observations of the thermospheric neutral density are the basis for thermosphere models, we formulate the objective to improve thermosphere models through providing relevant space geodetic observations and increasing consistency between datasets by advancing processing methods. Thus, we assembled a group of scientists with a focus on the processing of thermospheric neutral densities from accelerometers, GNSS and satellite laser ranging observations. Additionally, we attracted group members with expertise in data assimilation of mass densities into models.

Our first ongoing activity is the review of space geodetic observations and state-of-the-art processing methods. We started with a comparison of accelerometer-derived mass densities, since our working group has a large expertise in this area. Figure 3 provides an overview of the processing from accelerometer measurements to thermospheric mass densities including the variety of models used in the intermediate steps. In a living document, we assessed the models used by five different institutes in the processing of the densities, which paves the way to decide on a standard processing algorithm in the future.

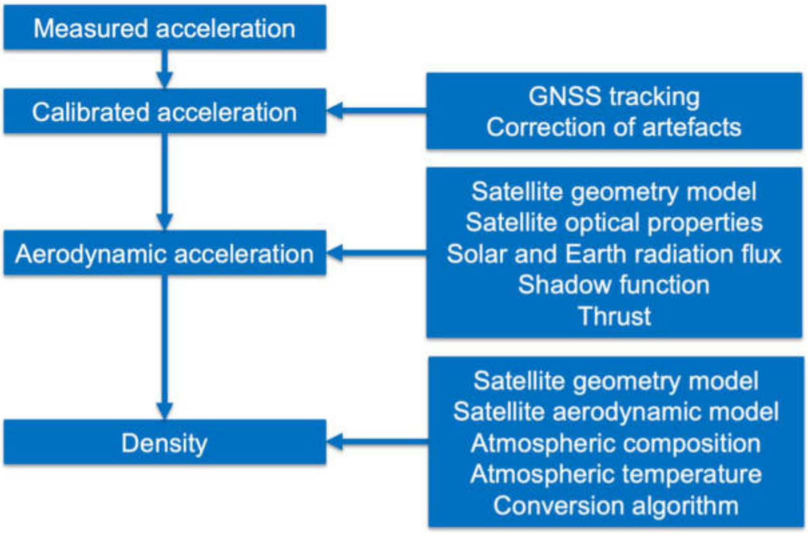

Fig. 3: Processing of measured accelerations to thermospheric mass density including required background models

Besides the theoretical model comparison, we initiated a data comparison. During our group meetings, we agreed on the comparison of GRACE data sets for selected periods with varying solar and geomagnetic activity and different eclipse conditions:

Table 1: Selected periods for the data and model comparison of accelerometer-derived mass densities from GRACE

Start date	Length of selected period	Characteristics
2002-11-20	10 days	high solar activity, includes some geomagnetic activity
2003-05-25	10 days	high solar activity, includes a geomagnetic storm
2008-03-01	5 days	low solar activity, geomagnetic quiet, no eclipses
2008-07-01	1 month	low solar activity, geomagnetic quiet, SRP large compared to aerodynamic acceleration
2015-03-15	5 days	high solar activity, St. Patrick's day storm

Already GRACE data sets from three processing centres are available for comparison. These include calibrated accelerometer data, orbits, modelled aerodynamic and radiation pressure accelerations and the final mass density. The ongoing comparison will provide insights into the major processing differences and will help to increase the consistency of accelerometer-derived densities in the future.

Beyond the joined activities of the working group, our group members published the following research papers relevant to improving thermospheric densities.

Publications

Bandikova, B., McCullough, C., Kruizinga, G. L., Save, H., and B. Christophe. "GRACE Accelerometer Data Transplant." Advances in Space Research. 2019, 64 (3), pages 623-644. doi: 10.1016/j.asr.2019.05.021

Behzadpour, S., Mayer-Gürr, T., and S. Krauss (2021). GRACE Follow-On accelerometer data recovery. Journal of Geophysical Research: Solid Earth, 126, e2020JB021297. https://doi.org/10.1029/2020JB021297

Farzaneh, S. and E. Forootan (2020), A least squares solution to regionalize VTEC estimates for positioning applications. MDPI Remote Sensing, 12 (21), pages 3545, doi.10.3390/rs12213545

Forootan, E., Farzaneh, S., Kosary, M., Schmidt, M., and M. Schumacher (2021), A simultaneous Calibration and Data Assimilation (C/DA) to improve NRLMSISE00 using Thermospheric Neutral Density (TND) from space-borne accelerometer measurements. Geophysical Journal International, 224 (2), pages 1096-1115, doi.10.1093/gji/ggaa507

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JWG 3: Improved understanding of space weather events and their monitoring by satellite missions

Chair: Alberto Garcia-Rigo (Spain)
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(Joint with IAG Commission 4, Sub-Commission 4.3)

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Activities during the period 2019-2021

JWG3 aims at gaining a better understanding of space weather events and their effect on Earth's atmosphere and near-Earth environment. In particular, by analyzing the correlation between Space Weather data from different sources (including observations from spacecraft and radio telescopes) and perturbed ionospheric/plasmaspheric conditions derived from different space geodetic techniques (e.g. GNSS, DORIS, RO, VLBI, satellite altimetry) and identifying the main parameters that could be useful to improve their real time determination and their forecasts in extreme conditions.

For this purpose, a multidisciplinary team has been assembled. In fact, the members of the WG provide access to complementary models as well as operational products/services linked to: ionospheric Total Electron Content determination, ionospheric electron density, geomagnetic disturbances from the Sun to Earth, DORIS ionospheric products, TIDs and scintillations, solar flares detection/prediction, EUV flux-rate, CMEs and SEPs, solar corona electron density, dimmings and coronal holes, solar wind, polar depletions, among others. Combination of such measurements and estimates can pave the way for a better understanding of space weather events.

At first, an online survey form to gather feedback from JWG 3 members was carried out to have a better understanding of the complementarity within the team, which was helpful to identify the existing background in both geodetic and space weather domains.

In particular, we identified potential useful data sources to broaden our analysis, as well as the existing models and operational products/services being provided or accessible by the members. Furthermore, applications that could impact positively to end users were listed, complementing the initial considered ones. In addition, it was a way to interchange ideas on the objectives and expectations of what the JWG should be.

At first, a set of three historical representative space weather events were selected. Given these were coincident with the ones selected within JWG 1, we have finally extended the events to be analyzed adding a fourth case which was also considered by JWG 1. Thus, we will analyze storm-related periods in 2013, 2015, 2017 and 2018. Also note that the connection between both joint working groups was considered a key objective from the beginning.

Fig 4: Capture of the online survey form

We are currently working on the correlation between SW products and perturbed ionospheric electron density/Total Electron Content, jointly with JWG 1. In particular, we are compiling and/or generating data and plots from different sources (see few plots below) that could be linked to the selected events useful to understand perturbed conditions and features found within JWG 1 analysis. The possibility to provide insights of these correlations could be helpful for JWG 1 and may also be highlighted through their website and database, as part of the coordination process we are conducting with them. We also keep in mind that for the monitoring and prediction of space weather events' and their impact on geodetic measurements, low latency data availability would be of great importance, ideally in real time (RT) or near real time (NRT), also to enable triggering alerts.

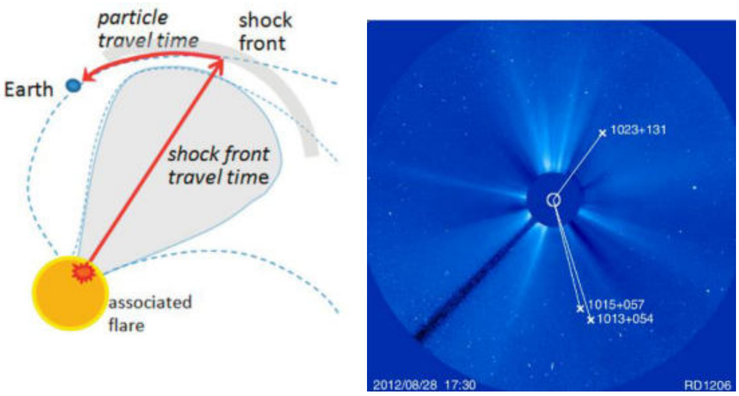

Fig. 5: Left: Shock interaction with the interplanetary magnetic field of SEP events associated to eastern events (Garcia-Rigo et al., 2016). Right: Radio source geometry and coronagraph images for VLBI experiment to assess the electron density of the solar corona (Soja et al., 2014)

The conducted analyses and the combination of measurements and estimates, derived from space geodetic techniques and from solar spacecraft missions, shall lead us to a better understanding of the main parameters that could be useful to improve real time determination as well as predictions derived from geodetic techniques, in case of extreme solar weather conditions. In fact, there is the interest within the team on how well models can reproduce changes during storms, understanding the interactions with the solar wind and magnetosphere, and how correlation of data from different available techniques could be key in this regard.

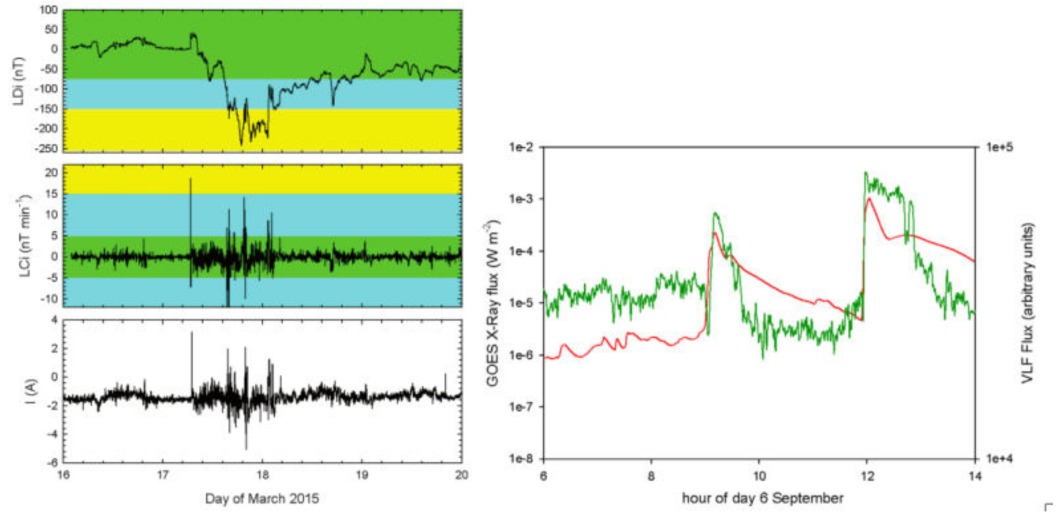

Fig. 6: Left: (from top to bottom) the LDi and LCi geomagnetic indices, and the geomagnetically induced current measured at a substation in the northwest of Spain by REE during the period from 16 to 20 March 2015. Colored areas in panels correspond to the five-level scale introduced to help decision makers in an operational environment (Cid et al., 2020). Right: Superposed plot of the GOES X-ray flux (red) and the amplitude of GQD recorded at UAH receiver (green) from 6 to 14 UT on 6 September 2017 (Guerrero, Cid et al., 2021).

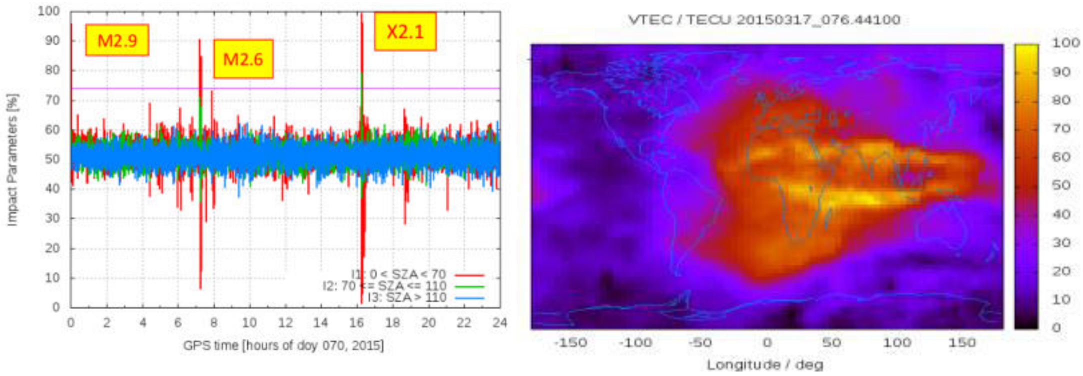

Fig. 7: Left: Detected solar flares prior to St. Patrick's day 2015 Geomagnetic Storm by means of SISTED detector, which relies on GNSS-based ionosphere monitoring (Garcia-Rigo et al., 2017; Borries et al. 2020). Right: UPC-IonSAT ionospheric TEC GIMs perturbed conditions during St. Patrick's day 2015.

Additional next steps include the possibility to conduct extensive simulations, combining different datasets and testing different algorithms, carry out comparisons and validation against external data, as well as deriving impact on end user' applications (such as in the case of HF communications, GNSS positioning and EGNOS performance degradation, influence on ground and space-based infrastructures, etc.).

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