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 focused on advocacy, integration, and external relations with affine Earth science disciplines and general stakeholders. The IAG charged GGOS 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 the measurement and consistent interpretation of 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 accomplish its mission, GGOS develops and maintains working relationships with the other IAG components and a variety of external groups and organizations.

GGOS Structure

The structure of GGOS is shown in Figure 1. The decision-making bodies are the Consortium and the Coordinating Board. The GGOS Executive Committee is responsible for the day-to-day activities necessary to carry out the mandate given by the decision-making bodies. 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. The GGOS Coordinating Office serves as the Secretariat of GGOS and carries out the administrative work as directed by the decision-making bodies and the Executive Committee. The work of the Coordinating Office includes communications, outreach, external relations and the maintenance and enhancement of the GGOS website and social media presence.

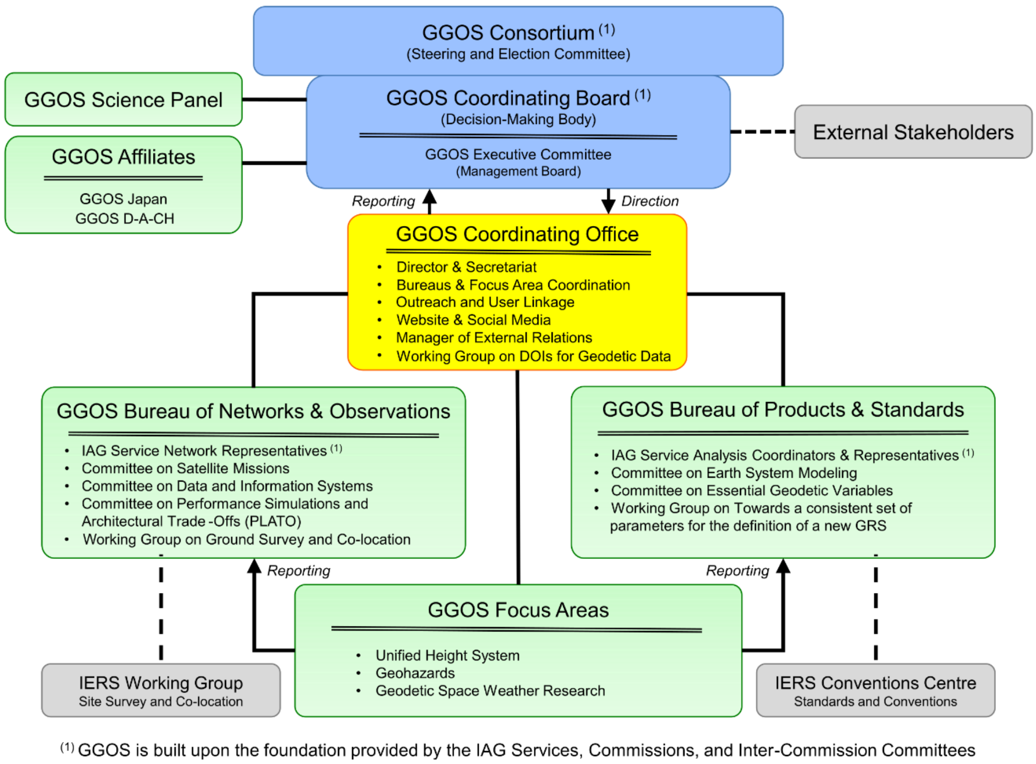


Figure 1. Organization chart of GGOS.

Overview

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 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 Geodetic Reference System (GRS). 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 a registry of 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 Frame (IHRF) and is currently working in the first computation of the IHRF. The IHRF operational coordination center will be launched in the coming year under the responsibility of the International Gravity Field Service (IGFS) and this Focus Area will be terminated at the IUGG2023 General Assembly. 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). This Focus Area has started to work in Oceania and established GTEWS Oceania as practical implementation of the system in the region. The Focus Area "Geodetic Space Weather Research" identified four central challenges and established four dedicated working groups. In addition to these three Focus Areas, a new Focus Area "Artificial Intelligence (AI) for Geodesy" has been established in May 2023 and will mainly work on three study areas: GNSS remote sensing, gravity field and mass changes, and Earth orientation parameter prediction.

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 the German-speaking countries: D (Germany), A (Austria) and CH (Switzerland). GGOS D-A-CH is the result of a strong cooperation between the national geodetic commissions of these countries and was developed on the basis of the strategic white paper "Geodesy 2030" (Müller, Pail et al., 2019, https://doi.org/10.12902/zfv-0243-2018). Its founding chair is Hansjörg Kutterer of the Karlsruhe Institute of Technology, a former GGOS President. GGOS D-A-CH has formulated its Terms of Reference with a clear focus on strategic topics in GGOS-related science. A next GGOS Affiliate is planned to be established by Spanish and Portuguese colleagues: GGOS Iberoatlantic. It aims to enhance participation in GGOS from counties around the Atlantic, including African and South American countries. GGOS Iberoatlantic has been officially adopted by the Spanish Geodetic Commission and is currently under discussion by Portuguese colleagues.

Web and Social Media Presenc*e*

One of the main focus of GGOS during the period 2019-2023 was devoted to outreach and communication. GGOS completely renewed its website (https://www.ggos.org). The new website highlights the dual roles of GGOS: one as an organization to foster collaboration within the IAG and among stakeholders, and the other as the IAG's geodetic observing system, supporting science and society as a fundamental infrastructure for monitoring the Earth. In the new website, the IAG Services are brought to the forefront to make them more visible and to provide easier access to their Internet portals. The new GGOS site also provides detailed descriptions and data registries of geodetic observations and products. These web components present the role and importance of geodesy, its observing techniques and products to non-geodesists with plain text and brief explanations, as well as eye-catching visual aids. This information is complemented by links to background articles on geodesy that can help non-geodesists to understand what geodesy is and why geodesy it is important to science and society.

Another new fundamental tool is the repository of key 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. Recently, GGOS has started to develop the GGOS-Portal. The GGOS-Portal aims to serve as a comprehensive search and access point for geodetic data and products (one-stop shop) by combining easy-to-understand descriptions of products and observation techniques with complete source descriptions and detailed metadata. To this end, GGOS conducted a survey the geodetic and affine communities from March to April 2023 to gauge the opinions of geodetic data users on data availability and visibility and to identify requirements for a comprehensive and user-friendly GGOS Portal. The results are being analyzed and will be utilized for the design of the Portal.

External relations and Digital Object Identifiers

GGOS also continued to strengthen and expand its external relations and stakeholder engagement. Continued participation in GEO included the establishment of a Geodesy Advocacy Community Activity within GEO entitled "Geodesy for the Sendai Framework", as well as continued 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 has extended this support to the UN Global Geodetic Centre of Excellence newly established on March 29, 2023 in the UN Campus in Bonn, Germany.

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 provided by the IAG and its Services. At the 2019 Unified Analysis Workshop, Digital Object Identifiers (DOIs) were discussed as a unique and unambiguous identifier for 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 and data providers. The Working Group on DOIs is chaired by Kirsten Elger of GFZ Potsdam and is composed of more than 20 colleagues, mainly from IAG Services. The WG analyzed use cases and best practices in geodesy and other scientific fields, and has been compiling recommendations directed to establish parameters and procedures for properly assigning DOIs to GNSS data, as the first example. Once the best procedure is identified, it will be extended to the other geodetic data sets.

Towards a new GGOS Strategic Plan

The current GGOS Strategic Plan was released in 2014. Given the advances in Geodesy and recent developments within the IAG, it became necessary to revise and update the GGOS Strategic Plan to meet new demands from the global geodetic community. With this purpose, GGOS conducted a Strategy Plan Survey between July 11 and Sep 30, 2022. This survey consisted of six closed questions (multiple choice of pre-given answers) and seven SWOT (Strengths, Weaknesses, Opportunities, Threats) questions. Seventy colleagues from 32 countries answered the GGOS survey. 71% of them are involved in IAG and 34% involved in the UN-GGIM's Subcommittee of Geodesy (SCoG). The outcomes of the survey were discussed at the GGOS Strategic Plan Workshop held in Munich, Germany in November 2022. From these discussions, four strategic goals and 16 objectives were identified as the core elements of the new GGOS Strategic Plan. This plan will be released after the IUGG2023 General Assembly after approval and endorsement by the GGOS Coordinating Board and consultation with the IAG Executive Committee, respectively.

Another key recommendation arising from the Strategic Plan survey is to merge the GGOS Consortium (steering and electoral committee) and the GGOS Coordinating Board (decision-making body) into one body as:

1) The functions of both bodies can be performed by only one body,
2) The involvement of all IAG components in the GGOS activities should be more visible, and
3) Having only one governing body would make decision-making within GGOS more efficient.

Accordingly, the GGOS Coordinating Board members were asked to vote for, against or abstain on the proposal to merge the current GGOS Coordinating Board and the GGOS Consortium into a single managing body called "GGOS Governing Board". This proposal was approved by 89% of the members. As following step, the proposal was presented to the IAG Executive Committee, whose members endorsed the decision of the GGOS Coordinating Board. Currently, the GGOS Executive Committee is aligning the GGOS Terms of Reference with the new Strategic Plan and governing body. Once the GGOS Coordinating Board and the IAG Executive Committee have approved the new GGOS Terms of Reference, both the new Strategic Plan and the new structure will come into effect.

Consortium

The GGOS Consortium acts 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 revised and renewed if necessary every four years, coinciding with the IUGG General Assemblies. The members of the GGOS Consortium for the term 2019–2023 are listed in Table 1.

The President of GGOS is the chair of the GGOS Consortium. The GGOS Consortium meets annually. The meetings corresponding to the 2019–2023 term were held as follows:

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
3. GGOS Days 2021, held virtually via Video Conference, 11-13 October 2021
4. GGOS Days 2022, Munich, Germany, 14-15 November 2022

Table 1. Members of the GGOS Consortium (term 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 in the term 2019–2023 are listed in Table 2.

The President of GGOS chairs the Coordinating Board. The Coordinating Board meets twice-per-year, usually during the GGOS Days and around the EGU. In the 2019-2023 term, following meetings were held:

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
5. GGOS Days 2021, held virtually via Video Conference, 11-13 October 2021
6. GGOS CB Meeting, held virtually via Video Conference, 16 May 2022
7. GGOS Days 2022, Munich, Germany, 14-15 November 2022
8. GGOS CB Meeting, Vienna, Austria, 22 April 2023

Table 2. Members of the GGOS Coordinating Board (term 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
FA Artificial Intelligence for Geodesy	No	Benedikt Soja (May-July 2023)
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 GGOS Executive Committee serves under the direction of the Coordinating Board to accomplish the day-to-day business 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 (term 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 the 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 Videos

In 2021 the idea was born to produce a short film about GGOS and Geodesy in General. It was produced within the GGOS Coordinating Office by the BEV (Federal Office of Metrology and Surveing of Austria) to explain the applications and importance of Geodesy to non-geodesists. The English version was published together with the Spanish, German and Japanese versions in February 2022. Now there are 12 language versions, created with the great help of volunteer geodesists who translated the text into their native language and made the sound recordings. This "Discover GGOS and Geodesy" film is available on YouTube: https://youtu.be/Jwqz097N2IY.

Due to the great success of the GGOS film by more than 11.000 views, the GGOS Coordinating will produce more short videos about geodetic observation techniques and products. All videos are available at the GGOS YouTube Channel www.youtube.com/@iag-ggos.

GGOS social media presence (Twitter, LinkedIn, YouTube, Facebook)

Nowadays it is very important for an organization to be active at Social Media to reach out to more people. The GGOS CO started with GGOS first Social Media presence in 2016 by setting up a Twitter account to be present in the social media and to speed up dissemination of GGOS-related information to the customers. In order to extend the audience, the GGOS CO set up further Social Media channels of GGOS at LinkedIn, YouTube and Facebook in 2021 (see table).

Platform	Set Up	Follower	Link

		(May 2023)	
Twitter	2016	1133	twitter.com/IAG_GGOS
LinkedIn	May 2021	782	linkedin.com/company/iag-ggos
YouTube	June 2021	410	youtube.com/@iag-ggos
Facebook	Dec. 2021	38	facebook.com/iagGGOS

GGOS Portal – A unique access point for geodetic data

The services of the International Association of Geodesy (IAG) provide very important and valuable geodetic data, information, and data products that are increasingly relevant for Earth system research, including monitoring of global change phenomena and a wide range of diverse applications such as satellite navigation, surveying, mapping, engineering, geospatial information systems, and so on.

Currently, it is difficult for many people to obtain an overview of all available geodetic products and data. The GGOS CO aims to fill this gap by developing the GGOS-Portal (ggos.org/portal), which will serve as a unique search and access point (one-stop shop) for geodetic data and products. Data and products will be described by rich metadata and remain physically located at their originating data centers of each contributing IAG service and other data providers. With this future platform, GGOS will contribute to increase the visibility of geodetic data for scientific research and to make other disciplines and the society aware of geodesy and its beneficial products.

To get an overview of the current availability of data products and their metadata, GGOS conducted a survey within the geodetic and geoscience community. This survey also inquired the opinions of geodetic data users on data availability and visibility, as well as desired requirements for a comprehensive and user-friendly GGOS-Portal.

Organized Conferences & Meetings

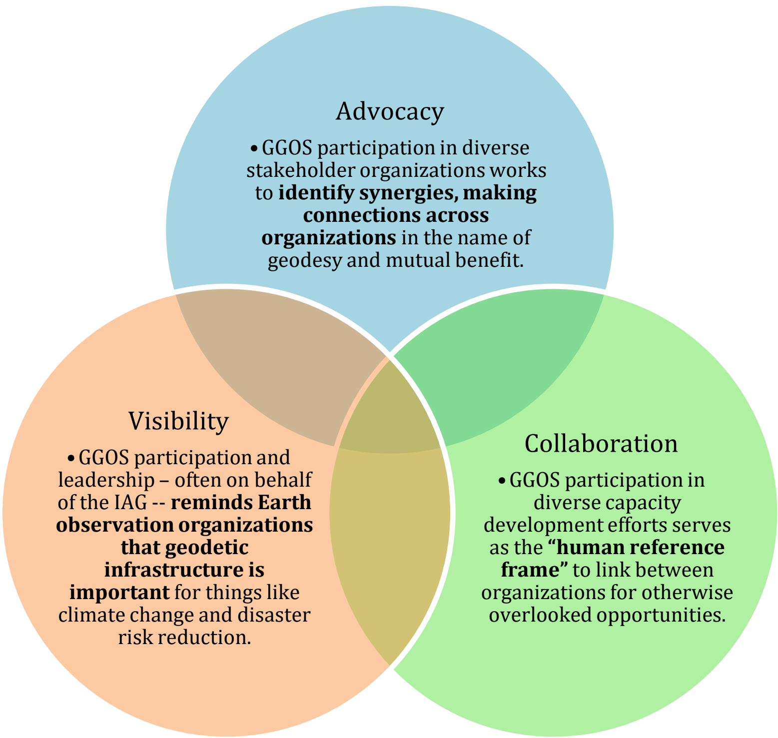
- Unified Analysis Workshop (UAW) – together with IERS
    - 2019 in Paris, France
    - 2022 in Thessaloniki, Greece
- GGOS Coordinating Board (CB) meetings (virtual: 2020, 2021, 2022, hybrid: 2023)
- GGOS Days 2019, Rio de Janeiro, Brasilia
- GGOS Days 2020 & 2021, virtual conference
- GGOS Days 2022, Munich, Germany

Conference attendance

- European Geosciences Union (EGU) (2020, 2021, 2022, 2023)
- American Geophysical Union (AGU) (2019, 2020, 2021, 2022)
- IAG Scientific Assembly 2021, virtual
- IUGG General Assembly 2023, Berlin, Germany

GGOS External Relations

To ensure geodesy is a visible, valued, and sustainable worldwide asset, GGOS external relations efforts within the GGOS Coordinating Office work toward proactive engagement with the broader Earth observations community. This is done by advocating for interoperable, discoverable, and openly available geospatial data, promoting infrastructure development, identifying tangible geodetic contributions to UN SDG and Sendai Framework targets and indicators, as well as working with external partners in capacity building and development initiatives.



Group on Earth Observations (GEO)

GGOS represents the IAG in the Group on Earth Observations (GEO), where it has represented the interests of the geodetic community by promoting visibility of geodesy within the broader Earth Observations community. IAG(GGOS) was first nominated as a member organization of the GEO Programme Board during 2018-2020. This representation on the GEO Programme Board was renewed for the 2020-2024 period, IAG(GGOS) continues to have a voice in steering the activities of GEO. In addition to participating on the Programme Board, IAG(GGOS) is also one of three participating organizations to serve on the GEO Executive Committee (2021-present). Richard Gross and Allison Craddock have served as the GGOS-appointed IAG representatives to the GEO Work Programme since 2018.

In the last four years, GGOS has ensured representation of the IAG and geodesy in the following GEO efforts:

- 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, later re-convened as the Working Group on Disaster Risk Reduction. This group 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).
- Capacity Development Working Group. IAG(GGOS) served as one of three co-chairs of the GEO Capacity Development Working Group, whose tasks included organizing virtual capacity development seminars, developing the GEO Statement on Open Knowledge. IAG also served in drafting and administering capacity development components of the over-arching "Mapping the Engagement of the 2020-2022 GEO Work Programme in Climate Action, Disaster Risk Reduction, and Capacity Development."
- Climate Change Working Group. IAG(GGOS) is a member of GEO's Climate Change Working Group that was established to develop and implement a strategy to advance the use of Earth observations for climate change adaptation and mitigation. The role of IAG(GGOS) in the Working Group is to ensure that geodetic observations are appropriately included in the strategy.
- Subgroup on Equality, Diversity, and Inclusion. IAG(GGOS) was a co-author of the GEO Statement on Equality, Diversity, and Inclusion (EDI).The GEO five-pillar EDI framework outlines a vision that equality, diversity, and inclusion are considered in every aspect of GEO, answering the mandate of the GEO mission to "*unlock the power of Earth observations by facilitating their accessibility and application to global decision making within and across many different domains."*
- Review Team for Digital Earth Africa proposal. IAG(GGOS) chaired the review team for the Digital Earth Africa proposal, reporting the process, criteria for a GEO Initiative, and the review team's assessment of the implementation plan against said criteria. This review ultimately led to Digital Earth Africa's accession as a GEO Initiative.

Participation at the Programme Board level ensures that IAG and 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 also plays a leadership role in a GEO Pilot Initiative within the GEO Work Programme, which is described below.

Group on Earth Observations: Geodesy for the Sendai Framework Pilot Initiative

GEODESY for the SENDAI FRAMEWORK

GGOS has led the establishment and administration of the first geodesy-centric component of the GEO Work Programme, initially as a Community Activity in the 2020-2022 GEO Work Programme, and extended as a Pilot Initiative in the 2022-204 GEO Work Programme. The overall objective of this group is to promote visibility for Geodetic observations and their role in helping to reduce the risk of disasters, as well as contribute to disaster preparedness with better mitigation and response.

Key goals of the Geodesy for the Sendai Framework Pilot Initiative include:

- Ministerial-level political support and funding for GNSS-enhanced tsunami early warning systems in the Circum-Pacific Belt (Pacific Ring of Fire) and Caribbean basin.
- Ministerial-level political support and funding for geodetic capacity building for disaster risk reduction and resilience.

Work led by GGOS on behalf of this group included:

- GGOS-Geohazards Working Group contributed content for the 2019 UN Global Assessment Report on Disaster Risk Reduction (GAR19)
- GGOS-IGS joint contribution to the 2022 UN Global Assessment Report on Disaster Risk Reduction (GAR22)
- Supporting geodetic development and capacity building for disaster risk reduction and resilience; identifying existing resources and stakeholder communities, and making connections
- Identifying geodetic elements of targets and indicators of the Sendai Framework for Disaster Risk Reduction
- Facilitating opportunity for other GEO efforts to interact with the international geodesy community
- Promoting integration of gedesy-enabled applications with UN Sustainable Development Goals and UN-GGIM World Bank Integrated Geospatial Information Framework

Joint collaborations with ITU, WMO, and UNEP supporting Artificial Intelligence for Geodetic Enhancements to Tsunami Monitoring and Detection.

AI for Natural Disaster Management
ITU Focus Group

GGOS also worked to identify and support innovations through participation in the Group on Earth Observations as well as joint initiative of the International Telecommunications Union (ITU), World Meteorological Organization (WMO), and UN Environment Programme (UNEP). The GEO Geodesy for the Sendai Framework Community Activity (later Pilot Initiative), represented by GEO participating organizations IAG and IUGG, led a new tsunami early warning collaboration with the recently established ITU Focus Group, organized jointly with WMO and UNEP to enhance the management of natural disasters, such as tsunami, by demonstrating the value of Earth Observations, namely GNSS data and infrastructure, in applications utilizing artificial intelligence (AI) and machine learning (ML).

The Topic Group "AI for Geodetic Enhancements to Tsunami Monitoring and Detection" has been set up this year under [ITU Focus Group on Artificial Intelligence for Natural Disaster Management (FG-AI4NDM)](). The topic group has worked on several deliverables, such as technical use-case reports with the relevant best practices in two uses of GNSS data: seismic/displacement observations, as well as ionospheric observations. Use cases will include descriptions of existing cutting-edge systems, such as: 1) Japanese real-time tsunami inundation forecast service that provides warning/forecast and estimated damage report to the Prime Minister's Office, and 2) NASA Jet Propulsion Laboratory's GNSS-based Upper Atmospheric Real-time Disaster Information and Alert Network (GUARDIAN system). The group will also contribute to a future ITU Recommendation on the topic of AI for disaster management.

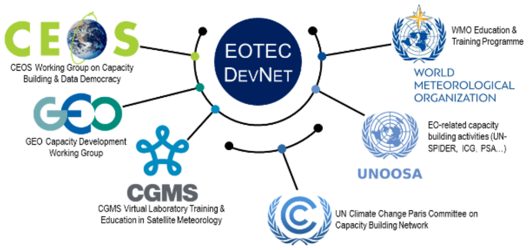
This new cooperation among the multiple international organizations aims to help lay the groundwork for the development and implementation of AI and ML applications expanding the use of geodetic Earth observations in places such as Small Island Developing States, which suffer from increasing tsunami threats in addition to other climate change impacts such as sea level rise.

Committee on Earth Observation Satellites (CEOS)

The Committee on Earth Observation Satellites

GGOS is an Associate Member of CEOS and regularly participates in its Plenary meetings, giving presentations and discussing the fundamental importance of the global geodetic reference frame to Earth observations. 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 also participates in the CEOS Working Group on Disasters, which supports the efforts of Disaster Risk Management authorities in protecting lives and safeguarding property by means of satellite-based Earth observations and science-based analyses. GGOS participation in this working group supports geodetic contributions to the group's objective to foster increased use of Earth observations in support of Disaster Risk Management and raise the awareness of politicians, decision-makers, and major stakeholders of the benefits of using geodetic Earth observations in all phases of Disaster Risk Management.



GGOS also participated in the initial establishment of the CEOS-led "EOTEC DevNet," a network of networks created to improve coordination and enhancement of Earth Observation asset and training providers in support of key global sustainable development outcomes. This is currently a deliverable in the CEOS 2021-2023 Work Plan. The goals of this effort include:

- **Improving coordination and cooperation among capacity building providers and users in order to meet existing needs and fill gaps**
- Fostering information sharing and exchange on capacity building resources
- Promoting effective assessment of capacity development needs at regional and national levels

GGOS also participated in the (now disbanded) CEOS Ad Hoc Team on the Sustainable Development Goals (AHT SDG), which worked toward highlighting the potential role for Earth observations in supporting the global indicator framework of the United Nations Sustainable Development Goals.

UN GGIM Subcommittee on Geodesy

United Nations

GGOS supports and, as needed, represents the IAG at the United Nations Committee of Experts on Global Geospatial Information Management (UN GGIM), as well as the meetings of the Sub-Committee on Geodesy (SCoG), to provide stability and long-term planning for the Global Geodetic Reference Frame (GGRF). GGOS supports IAG participation in major SCoG activities, including the following efforts to:

- provide an intergovernmental forum, with equitable international representation, for communication and cooperation on issues relating to **the maintenance and enhancement of a Global Geodetic Reference Frame (GGRF);**
- develop a roadmap for a **collaborative global geodetic observation network and the associated infrastructure**, with sustainable funding and investment, as well as strategic partnerships between mapping, space and other interested agencies;
- encourage **open sharing of geodetic data and information** that contribute to regional and global reference frames;
- advocate for guidelines and standards to **advance the interchangeability and interoperability** of geodetic systems and data; and
- **address various technical, institutional and policy issues** related to the implementation of a GGRF.

Numerous GGOS Consortium members were active in the UN GGIM SCoG on behalf of the IAG in the last four years, including Harald Schuh, Mike Pearlman, Detlef Angermann, Zuheir Altamimi, Laura Sanchez, and Martin Sehnal in key support and participation roles.

GGOS Consortium members also participate on behalf of their member state (country) and in consultation with GGOS External Relations, including: Richard Gross(USA), SCoG Working Group on Governance, and Allison Craddock (USA), SCoG Working Group on Communications and Outreach, Working Group on Education, Training and Capacity Building

GGOS has also served as a strong supporter of the recently-established United Nations Global Geodetic Centre of Excellence (UN-GGCE) with its goal to assist Member States and geodetic organizations to coordinate and collaborate to sustain, enhance, access and utilize an accurate, accessible and sustainable GGRF to support science, society and global development.

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 GGOS support of IAG enables the greatest use of geodetic data in support of these United Nations initiatives and beyond.

GGOS Working Group Digital Object Identifiers (DOIs) for Geodetic Data Sets

WG Kickoff: December 2019

Members

Chair: Kirsten Elger (GFZ, Germany), Detlef Angermann (TU Munich, Germany), Yehuda Bock (UCDC, US), Sylvain Bonvalot (GET, France), Markus Bradke (GFZ, Germany), Elisabeth 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 until 2021), 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 too. 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[1]) and the Enabling FAIR Data project[2], data with assigned DOIs are fully citable in scholarly literature and many journals require the data underlying a publication to be publicly available. 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

[1] https://copdess.org
[2] https://copdess.org/enabling-fair-data-project/

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. While this is easy for static data, like for global of regional gravitational models or GNSS campaign data, most geodetic data are large (mainly due to the large number of files with high temporal resolution), dynamic (real time data acquisition and provision), and highly granular. Geodetic services of the International Association for Geodesy (IAG) are international key player for geodetic data provision and distribution and their operating institutions and funding agencies increasingly require the provision of tangible data use and access statistics. Credit through citation was a major reason for the Global Geodetic Observing System (GGOS) to establish a 'Working Group on Digital Object Identifiers (DOIs) for Geodetic Data Sets'[3] (GGOS DOI WG) in October 2019. 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 to being able to discover, permanently cite and access data, and acknowledge the data providers;
(2) 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 (e.g. GeodesyML, Sitelogs).

Activities and Actions

- Physical kickoff meeting during AGU2019, 3-5 video conferences per year.
- Regular presentations of the group's activities during national and international conferences and workshops (AGU, EGU, GGOS Days, IAG GA, IVS GM, UAW, etc., see also the publications section below)
- Creation of a Zenodo Community where presentations and documents are collected and published with DOI[4]
- Collection of data products and already existing and planned DOI activities for IAG services and geodetic data centers (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.
- Introduction to different persistent identifiers (PID) and agreement on their importance for making data findable, accessible, interoperable and reusable (FAIR, Wilkinson et al., 2016). PIDs allow, e.g., to uniquely identify published data, scholarly literature and code (via DOIs), persons (via ORCID), institutions and funding agencies (via ROR – the registry of research organizations) via machine-actionable links that should be included in the metadata. PIDs

[3] https://ggos.org/about/org/co/dois-geodetic-data-sets/
[4] https://zenodo.org/communities/ggos-doi-wg/

within machine-actionable metadata (e.g. DataCite, GeodesyML) are key elements for connecting data with articles, software and other research outcome as well as to institutions, funding agencies, researchers, and instruments.
- Discussions on the objects, DOIs are assigned to, i.e. data products vs. data files or continuous time series from individual stations and development of recommendations for metadata properties.

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). As part of this collaboration, regional geoid models are successively assigned with DOI and collected in the dedicated 'IGS datacenter' of the catalogue of GFZ Data Services[5] with direct links to ISG's Geoid Repository[6] Recently also official models (e.g. Slovenia, Costa Rica, Austria) provided by federal agencies, have been assigned with DOI. This is a clear sign that DOI are increasingly attractive beyond the academics.
- **DOIs for data products or data files?** One of the first recommendation of the GGOS DOI WG is that DOIs for product 'types' (e.g. Precise Science Orbits, IAG final products) or observational networks (e.g., GNSS networks) are preferred to DOIs for individual data files. These DOIs for growing time series mainly serve for citation purposes and not for identifying individual data streams (similar to DOIs for seismic networks, e.g. Evans et al. 2015).
- **DOIs for rapid or ultra-rapid products?** These are existing for different geodetic techniques and are outdated very soon (precisely within days or few weeks when the next better product is available). However, they are occasionally used in research articles (and could be cited if assigned with a DOI). Due to the requirement that DOI-referenced data have to be available persistently, the group agrees to support DOIs for rapid and ultra-rapid products only if the data are archived for the long term by the datacenter. A datacenter that is not planning to archive rapid or ultra-rapid products should not assign DOIs to them (e.g. AIUB and GFZ have assigned DOIs to their rapid and ultra-rapid IGS products, while ESA is not using DOIs for these products, because of their 'rolling archive')
- Development of a **concept for assigning DOI to hierarchical products** and its implementation for the use case ICGEM/ COST-G (Combination Service for Time-variable Gravity Fields): monthly GRACE time series[7]: Individual monthly field solutions are produced by a number of International Analysis Centers and are later combined to the COST-G combination product which represents a „best fit model'. The connection between the original solutions and the combination product is done via the "related identifier" property of the DataCite Schema: the DOI metadata of the original solutions from the Analysis Center includes a reference (using the "related identifier" property) to the combination Product using the DataCite relation type „Is Part Of' (i.e., they have contributed to the COST-G combination product). The metadata of the combination product includes the citation of all original products from the Analysis Centers using the relation type „Is Derived From'. The adoption of this concept for ITRF2020 has been agreed by the IERS CB (May 2021) and in currently being implemented.

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[5] https://dataservices.gfz-potsdam.de/portal/?fq=datacentre_facet:%22DOIDB.ISG%20-%20ISG%20International%20Service%20for%20the%20Geoid%22
[6] https://www.isgeoid.polimi.it/Geoid/geoid_rep.html
[7] 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)

- **DOIs for GNSS data**: One task of the current project FAIR GNSS[8], funded by the Belgian Science Policy Office (BELSPO), is to apply the FAIR Principles (Wilkinson et al, 2016) to GNSS Data and to develop a DOI service for the European and Belgian GNSS data collections managed by the Royal Observatory Belgium. This was the opportunity begin with the development of metadata recommendations for the use case GNSS data. Moreover, GNSS data represents a good use case for geodetic data in general: DOIs for GNSS campaign data are examples for static products; IAG orbit and clock products are good examples for DOIs for dynamic data with new DOI versions only required when there are changes in the data processing routine; DOIs for GNSS networks are also already used (e.g. by UNAVCO, AIUB, GFZ, INGV), however: GNSS stations are not always organized as networks and some stations may be part of several networks. We have therefore accepted the necessity to assign DOI for the (ongoing) time series measured with one GNSS station. Tangible results of our discussions resulted in the:
- '**Metadata Recommendations for geodetic data: GNSS'**: a guide to recommended metadata properties and sub-properties relevant for GNSS data for DataCite and geodesyML schemas with examples on how to provide the information (e.g. separating first and last names, adding ORCID and ROR identifier whenever possible). This document is currently in discussion with the GGOS DOI WG and a first version expected to be released after IUGG2023. It includes a general introduction to DOIs and their application for geodetic data, followed by recommendations for the provision of specific metadata properties DataCite, GeodesyML metadata with examples. The document was developed for the GNSS use case, but already with a more general focus allowing an easily extension to apply for other geodetic datasets. Guiding principles for the recommendations were (1) maximum automatization: for metadata properties from GeodesyML/ Sitelogs mapped into DataCite metadata, (2) following the FAIR Principles and integration of PIDs in the metadata, (3) compliance with the General Data Protection Regulation (GDPR).
- **DOI assignment to GGOS Documents:** documents, like the GGOS Strategic Plan, GGOS implementation plan, IAG Travaux will be published with DOI from 2023 on (collaboration with GFZ).

Ongoing discussions and future plans

Ongoing discussions focus on the revision of the metadata recommendations and its extension to metadata s for other geodetic techniques. Our activities will further include recommendations of 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). These vocabularies should be registered via a vocabulary registration service (e.g. Research Vocabularies Australia[9]) and provided in machine-actionable format (RDF) following the SKOS[10] guidelines for the semantic web. Moreover, we will explore the potential implementation of the concept of the "Persistent Identification of Instruments Working Group[11]" of the Research Data Alliance (RDA[12]) for using PIDs for instruments and explore the required harmonization of DOI-related metadata from different data centers for similar products.

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[8] https://fair-gnss.oma.be/
[9] https://ardc.edu.au/services/research-vocabularies-australia/
[10] https://www.w3.org/2004/02/skos/
[11] Persistent Identification of Instruments Working Group: https://www.rd-alliance.org/groups/persistent-identification-instruments-wg
[12] RDA = Research Data Alliance (https://www.rd-alliance.org/)

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Wilkinson, M., Dumontier, M., Aalbersberg, I. et al. The FAIR Guiding Principles for scientific data management and stewardship. Sci Data 3, 160018 (2016). https://doi.org/10.1038/sdata.2016.18

Selected publications and conference presentations related to the WG

Journal Articles

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

Coetzer, G., Botha, R., Schollar, C., Elger, K. (2022): An Institutional Research Data Repository and Digital Object Identifiers for SARAO Radio Astronomy, Fundamental Astronomy, and Geodesy Datasets. - Bulletin of the American Astronomical Society, 54, 2. https://doi.org/10.3847/25c2cfeb.66ee866c

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

Presentations at conferences and workshops

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., De Bodt, S., Fabian, A., Legrand, J., Miglio, A., Moyaert, A., Oset Garcia, P., & Van Nieuwerburgh, I. (2022) Towards FAIR GNSS data. Splinter Meeting 3 at EUREF 2022 Symposium 02 June, 2022 (online) with invited talk by Elger, K. presenting the GGOS DOI WG(https://euref2022.eu/)

Bruyninx, C., De Bodt, S., Fabian, A., Legrand, J., Miglio, A., Oset Garcia, P., & Van Nieuwerburgh, I. (2022). FAIR-GNSS webinar - Putting the FAIR principles into practice: the journey of a GNSS data repository. Royal Observatory of Belgium (ROB). https://doi.org/10.24414/ROB-FAIRGNSS-PRESENTATION

Bruyninx, C., De Bodt, S., Legrand, J., Fabian, A., Miglio, A., Oset Garcia, P., Van Nieuwerburgh, I. (2022). Moving towards FAIR GNSS data: putting principles into practice" (poster) at BNCGG study day "Belgian contributions to Earth Sciences in a Changing World", Brussels, 4/11/2022

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

Bruyninx, C., Miglio, A., Fabian, A. Legrand, J. (2021) Introduction to FAIR data Towards FAIR GNSS data. Splinter meeting "Towards FAIR GNSS data" at EUREF 2021 Symposium, online, 27/05/2021

Coetzer, G., Botha, R., Elger, K. (2023) Digital Object Identifiers and Metadata for VLBI Datasets and Products. Poster presented at Bologna VLBI: Life begins at 40! (22-26 May 2023, Bologna), https://doi.org/10.5281/zenodo.8022888

Coetzer, G., Botha, R., Scholar, C., & Elger, K. (2021). Digital Object Identifiers for SARAO's Radio Astronomy, Fundamental Astronomy and Geodesy Datasets. Poster presented at the 9th conference on Library and Information Services in Astronomy (LISA IX),14 to 18 June 2021, https://doi.org/10.5281/Zenodo.4889095

Coetzer, G., Takagi, Y. Elger, K. (2021) Digital Object Identifiers for the IVS. Proceedings 12th IVS General Meeting 2021, URL: https://ivscc.gsfc.nasa.gov/publications/gm2022/44_coetzer_etal.pdf

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

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Elger, K. & GGOS DOI Working Group. (2022). Some backgrounds about DOI minting. GGOS Days 2022, Munich, Germany, 14-15 November 202,2 https://doi.org/10.5281/zenodo.7354892 (**Video**)

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, **Video**).

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

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

Elger, K., GGOS DOI WG (2021). News from the GGOS DOI Working Group - Abstracts, EGU General Assembly 2021 (Online 2021). https://doi.org/10.5194/egusphere-egu21-15081 (**PICO presentation**)

Elger, K., GGOS DOI WG (2023). The world of DOIs for geodetic data – metadata recommendations and status report of the GGOS DOI Working Group. EGU General Assembly 2023, Vienna, Austria, 23–28 April 2023. EGU23-6384, https://doi.org/10.5194/egusphere-egu23-6384

Elger, K., GGOS DOI Working Group (2022): News from the GGOS DOI Working Group - Abstracts, , EGU General Assembly 2022, Vienna, Austria, 23–27 May 2022, EGU22-10982, https://doi.org/10.5194/egusphere-egu22-10982 (**presentation slides**)

Elger, K., Miglio, A., & Bruyninx, C. (2023). Why do Geodetic Data need DOIs? An introduction to data publications and the GGOS DOI Working Group. Invited talk at the 335 Section Forum at the Jet Propulsory Laboratory (JPL), Pasadena, CA, US (March 9), https://doi.org/10.5281/Zenodo.8022958

Elger, K., Miglio, A., Bruyninx, C., Thaller, D., & GGOS DOI Working Group. (2022). Concepts for DOI minting for Geodetic Datasets. Unified Analysis Workshop 2022 (UAW 2022), Thessaloniki, Greece, 21-23 October 2022, https://doi.org/10.5281/zenodo.7239190

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

Miglio, A., Fabian, A., Bruyninx, C., De Bodt, S., Legrand, J., Oset Garcia, P., and Van Nieuwerburgh, I. (2022) Proposed metadata standards for FAIR access to GNSS data, EGU General Assembly 2022, Vienna, Austria, 23–27 May 2022, EGU22-11968, https://doi.org/10.5194/egusphere-egu22-11968

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

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. It is reaching the 10-year anniversary in 2023.

In recent years, GGOS Japan has constantly hosted its own annual meetings for broad range of space geodetic research and activities where additional English-spoken sessions were recently arranged with the DACH (2022) and Iberoatlantic (2023) colleagues. It also organises 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. GGOS Japan has updated 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 has adopted its logo in 2022, often shown in the presentation slides, the leaflets and the stickers.

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 2023, 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: Kensuke Kokado (Geospatial Information Authority of Japan)
- SLR: Yuto Nakamura (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 Affiliate: GGOS D-A-CH

Chair: Hansjörg Kutterer (Germany)

GGOS D-A-CH is the GGOS affiliate of the so-called D-A-CH region representing those countries in Central Europe with significant German-speaking populations: Germany (D), Austria (A), Switzerland (CH). GGOS D-A-CH is based on a joint initiative of the national geodetic commissions DGK, ÖGK and SGK in 2020. It was approved by GGOS CB on May 19, 2021, as the second regional GGOS affiliate after GGOS Japan.

GGOS D-A-CH was initiated by the members and guests of the Geodesy department of DGK and the respective members of ÖGK and SGK. There is a long-term and outstanding tradition of cooperation within these commissions both contributing to and benefitting from activities in mathematical, physical and space geodesy. GGOS D-A-CH was established as basis and forum for GGOS-related activities in the D-A-CH region and in particular as a stimulator and incubator for GGOS-related coordinated research. The publication "Geodesy 2023" by J. Müller and R. Pail (https://geodaesie.info/zfv/zfv-archiv/zfv-147-jahrgang/zfv-2022-4/geodesy-2030), with contributions from a multitude of scientists in the D-A-CH region, serves as scientific guideline. It addresses the grand challenges of Earth sciences and the respective contributions of Geodesy reflecting the scientific innovations and technological developments of the present decade and beyond.

GGOS D-A-CH comprises university members and members from the public sector. Qualification for membership is based on an expression of interest. As of June 2023, there are the following participations:

Coordination group: Johannes Böhm (Austria), Johannes Bouman (Germany), Susanne Glaser (Germany), Adrian Jäggi (Switzerland), Roland Pail (Germany), Markus Rothacher (Switzerland), Harald Schuh (Germany)

Group of member institutions:

- Universities: Technical University Berlin, University Bern, University Bonn, Technical University Dresden, Leibniz University Hannover, Karlsruhe Institute of Technology, Technical University Munich, University Stuttgart, Technical University Vienna, ETH Zurich
- Research institutions and national agencies: Federal Office of Metrology and Surveying (BEV, Austria), Federal Agency for Cartography and Geodesy (BKG, Germany), GFZ German Research Centre for Geosciences (GFZ, Germany)

Members of GGOS D-A-CH have actively been involved in the preparation of scientific meetings and conferences. In May 2022, a round-table discussion was organized under the umbrella of the German Research Foundation (DFG) in order to prepare a joint research proposal. Regular presentation and reporting is organized within the GGOS CB meetings, the annual GGOS Days and the annual gatherings of the national geodetic commission. In addition, regular meetings with GGOS Japan took place for mutual exchange. Finally, the IAG

Symposium G06 “Monitoring and Understanding the Dynamic Earth with Geodetic Observations” within the 28th General Assembly of the IUGG in Berlin 2023 was co-organized and co-convened.

GGOS Science Panel

Chair: Kosuke Heki (Japan) Comm. 2

Members:
Original members in this term 2019-2023

- *M. Rothacher (Switzerland) Comm.1*
- *G. Blewitt (USA) Comm. 1*
- *T. Gruber (Germany) Comm. 2*
- *J. Chen (USA) Comm. 3*
- *J. Ferrandiz (Spain) Comm. 3*
- *J. Wickert (Germany) Comm. 4*
- *P. Wielgosz (Poland) Comm. 4*
- *Y. Tanaka (Japan) ICCT*
- *M. Crespi (Italy) ICCT*
- *M. Sideris (Canada) FA (UHS)*
- *P. Lognonne (France) FA (Geohazards)*
- *D. Chambers (USA) FA(Sea level)**
- *E. Forootan (UK/Germany) FA (Geod. Space Weather)*

Members representing new organizations added in 2021

- *J. Muller (Germany) QuGe*
- *M. Van Camp (Belgium) QuGe*
- *P. Sakic (Germany) ICCM*
- *K. Tadokoro (Japan) ICCM*
- *A. Klos (Poland) ICCC*
- *C. Blackwood (USA) ICCC*

*FA dissolved

Two new members from each of the three newly organized organizations within IAG have been added in 2021. This made the number of members of the GGOS Science Panel increase from 14 to 20.

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 2019-2023 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 2019-2023 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)
- 2021 American Geophysical Union Fall Meeting (virtual conference)
- 2022 European Geosciences Union General Assembly (virtual conference)
- 2022 American Geophysical Union Fall Meeting (hybrid conference)
- 2023 European Geosciences Union General Assembly (hybrid conference)

Owing to the COVID19 pandemic, most international conferences from 2020 until 2022 spring were held as virtual (on-line) meetings. The 2022 December American Geophysical Union (AGU) and 2023 April European Geoscience Union (EGU) meetings were held as hybrid meetings. As a future session, the Science Panel proposed a GGOS session in the 2023 December AGU Fall Meeting (hybrid meeting in San Francisco). AGU and EGU intend to keep the meetings hybrid in future (2024-), but the on-site aspect will become major.

Starting 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. The pages are now complete and are visited frequently by researchers.

Unified Analysis Workshops (UAW) are co-organized by GGOS and International Earth Rotation and Reference Systems Service (IERS). The 2022 Workshop was the 6th in a series of workshops that are held every two years for the purpose of discussing issues that are common to all the space-geodetic measurement techniques. Attendance at the Workshops are by invitation only with each IAG Service nominating 5-6 experts to attend and participate in the discussion. The 2022 Workshop was held as a hybrid meeting in Thessaloniki, Greece, 21-23 October. There, the discussion focused on the data analysis especially on ITRF2020.

Objectives and Planned Efforts for 2023-2027 and Beyond

During the next four 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 (AGU), Fall Meetings
- Asia Oceania Geosciences Society (AOGS), Annual Meetings (optional)
- European Geosciences Union (EGU), General Assemblies
- International Association of Geodesy, General and Scientific Assemblies*
  *GGOS sessions in IUGG/IAG are mainly organized by GGOS-EC members rather than the Science Panel

The Strategic Plan Workshop was held in Munich, Germany during 16-17 November 2022 following the GGOS Days. There, future roles expected for the Science Panel were briefly discussed.

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, Sandra Blevins, 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, Markus Bradke/ GFZ Germany
  - ILRS (Frank Lemoine /NASA USA, Clement Courde/OCA, France)
  - IDS (Jérôme Saunier/IGN France, Guilhem Moreaux, CLS 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, Sandra Blevins/NASA/USA)
  - 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 and co-location 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; Unfortunately the current situation with Ukraine has put a significant hold on much of this activity;
- 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.
..
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 Net*works 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.

Pearlman, M., et al., "*GGOS Bureau of Networks and Observations: Network Status and Related Activities"* (poster), IAG Symposium 2021 Beijing, China, June 28 – July 2, 2021.

Pearlman, M., et al., "*An Update on the GGOS Bureau of Networks and Observations*", EGU General Assembly, Vienna, Austria, May 23 – 27, 2022.

Presentations on the BN&O at each annual GGOS Coordinating Board meeting and GGOS Days Meeting.

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 2023):
- AIUB, Switzerland: R. Dach, F. Andritsch (left AIUB)
- BKG, Germany: D. Thaller, H. Hellmers
- DGFI-TU Munich, Germany: M. Bloßfeld, A. Kehm
- ETH Zürich, Switzerland: M. Rothacher, B. Soja, M. Schartner, I. Herrera Pinzón (now at AIUB)
- GFZ/TU Berlin, Germany: B. Männel, S. Glaser
- IfE University Hannover, Germany: J. Müller, L. Biskupek
- IGN, France: D. Coulot, A. Pollet

- JPL, USA: R. Gross
- NASA GSFC/JCET, USA: E. Pavlis
- NMA, Norway: E. Mysen, G. Hjelle
- TU Vienna, Austria: J. Böhm, H. Wolf
- University Wrozlaw, Poland: K. Sosnica, J. Najder

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, the space ties, and potential atmospheric 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, GENESIS, 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, University Wrozlaw, IfE Hannover)
- Several geodetic software packages have been augmented by the capability to carry out realistic simulation scenarios (e.g., VieVS, DOGS, Bernese, Geodyn, EPOS-OC)
- 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.
- Studies on integration of VGOS and S/X-legacy network for VLBI were carried out.
- Optimized scheduling methods for VGOS were investigated.
- 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 (Huang et al., 2021; Huang et al., 2022).
- 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.
- Studies on the impact of adding the LLR data in infra-red to reference frame products were carried out by IfE, Uni Hannover.
- 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.
- Studies related to alternative parameterization of EOPs from 24-h VLBI sessions started, in order to be consistent with estimation intervals by the other space-geodetic techniques.
- PLATO members are involved in the GENESIS science team and supports the mission with realistic simulations and contributed to the GENESIS white paper (Delva et al., 2023)
- 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. The acceptance of the GENESIS mission by ESA's ministerial conference in November 2022 was a first achievement in this context.
- 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.
- Simulations of network projections will be carried out if new potential stations come up.

Publications

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- Delva, P., Altamimi, Z., Blazquez, A., Blossfeld, M., Böhm, J., Bonnefond, P., Boy, J.-P., Bruinsma, S., Bury, G., Chatzinikos, M., Couhert, A., Courde, C., Dach, R., Dehant, V., Dell'Agnello, S., Elgered, G., Enderle, W., Exertier, P., Glaser, S., Haas, R., Huang, W., Hugentobler, U., Jäggi, A., Karatekin, O., Lemoine, F. G., Le Poncin-Lafitte, C., Lunz, S., Männel, B., Mercier, F., Métivier, L., Meyssignac, B., Müller, J., Nothnagel, A., Perosanz, F., Rietbroek, R., Rothacher, M., Schuh, H., Sert, H., Sosnica, K., Testani, P., Ventura-Traveset, J., Wautelet, G., Zajdel, R. (2023): GENESIS: co-location of geodetic techniques in space. - Earth Planets and Space, 75, 5. https://doi.org/10.1186/s40623-022-01752-w
- Dill, R., H. Dobslaw, H. Hellmers, A. Kehm, M. Bloßfeld, M. Thomas, F. Seitz, D. Thaller, E. Schönemann, U. Hugentobler (2020): Evaluating Processing Choices for the Geodetic Estimation of Earth Orientation Parameters with Numerical Models of Global Geophysical Fluids. J Geophys Res Solid Earth 125(9):e2020JB02,002. https://doi.org/10.1029/2020JB020025
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- 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
- Huang W., Männel B., Brack A., Schuh H. (2021) Two methods to determine scale-independent GPS PCOs and GNSS-based terrestrial scale: comparison and cross-check. *GPS Solut* **25,** 4. https://doi.org/10.1007/s10291-020-01035-5
- Huang, W., Männel, B., Brack, A., Maorong, G., Schuh, H. (2022) Estimation of GPS transmitter antenna phase center offsets by integrating space-based GPS observations, Advances in Space Research, 69(7), https://doi.org/10.1016/j.asr.2022.01.004
- 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
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- Lengert, L., D. Thaller, C. Flohrer, H. Hellmers, A. Girdiuk (2022): On the improvement of combined EOP series by adding 24-hours VLBI to VLBI Intensive and GNSS data. In: Proceedings of the IAG

Scientific Assembly 2021, Beijing / virtual. IAG Symposia Series
- 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
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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.
- Advocate the realization of future gravity field missions: Future gravity satellite constellation MAGIC (double-pair mission). Decision on funding of polar pair (P1) by NASA/DLR; decision on Phase B of inclined pair (P2) at ESA Ministerial Conference in November 2022

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.
- Advocate and support national and international space agencies in their processes towards future gravity missions, by providing/exchange available technical information, and propose to support/participate in missions studies towards their realization;
- Communicate with Chinese IAG colleagues to seek advice and collaborations to advocate for possible availability of Chinese gravity mission data to the scientific community, Continue exchange with PLATO on joint interests and possible collaborations; 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.

Schlaak, M; Pail, R; Jensen, L; Eicker, A: Closed loop simulations on recoverability of climate trends in next generation gravity missions. Geophysical Journal International 232 (2), 2022, 1083-1098.

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Purkhauser, Anna F.; Pail, Roland: Triple-Pair Constellation Configurations for Temporal Gravity Field Retrieval. Remote Sensing 12 (5), 2020.

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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.

This work has been put on hold due to the unavailability of Nicholas Brown and Sandra Blevins departure from CDDIS. Sandra Blevins has been replaced by Taylor Yates from NASA/CDDIS; Discussion has been initiated with the IGS on a possible path forward in Nick’s activity.

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

JWG 1.2.2 : Methodology for surveying geodetic instrument reference points

Chair: *Ryan Hippenstiel (USA)*
Vice-chair : *Sten Bergstrand (Sweden)*

Members

- Zuheir Altamimi (IGN, France)
- Sten Bergstrand (BIPM, France)
- Steven Breidenbach (NOAA/NGS, USA)
- Benjamin Erickson (NOAA/NGS, USA)
- Cornelia Eschelbach (Frankfurt Univ. of Applied Sciences, Germany)
- Kendall Fancher (NOAA/NGS, USA)
- Charles Geoghegan (NOAA/NGS, USA)
- Dionne Hansen (LINZ, New Zealand)
- Ryan Hippenstiel (NOAA/NGS, USA)
- Christopher Holst (Technische Universität München, Germany)
- Michael Lösler (Frankfurt Univ. of Applied Sciences, Germany)
- Kevin Jordan (NOAA/NGS, USA)
- Saho Matsumoto (GSI, Japan)
- Jack McCubbine (GA, Australia)
- Damien Pesce (IGN, France)
- Anna Riddell (GA, Australia)
- Owen Smallfield (LINZ, New Zealand)
- Jerome Saunier (IGN, France)
- Elena Martínez Sánchez, (Observatorio de Yebes, Spain)
- Daniela Thaller, (BKG, Germany)
- Bart Thomas (GA, Australia)
- Agnes Weinhuber (Technische Universität München, Germany)

Correspondent Members

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

Overview

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 and publications during the period 2019–2023

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. In addition, a comparison of two approaches to quantifying deformation effects at Onsala will be undertaken. Members completed and documented work researching site-dependent GNSS antenna calibrations to account for systematic errors and biases. Personnel at Yebes are studying data collected from both a laser scanner and UAV, detailing differences in solutions at various temperatures and times of day.

Measurements were collected at the Zeppelin Observatory (Svalbard, Norway) and Hartebeesthoeck 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.

A tie survey at Yarragadee was completed in June of 2021, the results of which were developed into a presentation shared with working group members and participants of the Unified Analysis Workshop in 2022. In addition, Geoscience Australia (GA) recently completed a tie survey at Hobart with survey results and reporting forthcoming. GA continues to look at cooperation with universities to improve resources available and the efficiency of surveys.

Colleagues from Frankfurt Univ. of Applied Sciences, BKG and NLS submitted the results and further processing of tie surveys at Wettzell and Metsähovi for publication in the IAG 2021 conference proceedings.

IGN contributed local tie surveys at Malé, Crozet, Futuna, and Grasse, including new SAR reflectors and additional work processing with fully automated determination of the SLR telescope reference point at Côte d'Azur. This work (Barneoud, et al., 2023) was presented at REFAG2022. IGN also completed an updated of the COMP3D software which now includes full integration of axis determination and increased ability to input data. This software was used to process a 2021 survey of Ny-Ålesund (Brandal).

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 partially resumed in the fall of 2021. In addition, surveys investigating lines of sight and detailing the calibration piers for the SLR were performed at Goddard Geophysical and Astronomical Observatory (GGAO) in 2021 and 2022. A survey at KPGO - Kōke'e Park Geophysical Observatory was completed in May of 2023 and the final results and report will be released soon.

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 when developments are complete.

NGS has developed deflection of vertical (DoV) measurement capabilities utilizing a robotic total station and camera, and will continue testing equipment for deployment on upcoming local tie surveys. It is being called the TSACS (Total Station Astrogeodetic Control System), and the procedures and specifications were shared with researchers from Frankfurt who built and tested a similar system.

Collaboration among the group members has increased with information sharing leading to software, hardware, processing, and field protocols improvements. As an example, GSI Japan and Land Information New Zealand held a recent workshop with positioning staff. Saho presented about a local tie survey at Ishioka. In addition, GSI also released a video detailing the Ishioka site which highlighting co-location work.

Within the joint project GeoMetre, members determined the reference point of an SLR telescope at Wettzell, the Satellite Observing System Wettzell (SOS-W), using applied close-range photogrammetry instead of a polar measurement system.

Close range photogrammetry was also used to investigate on the deformation behaviour of the receiving unit of the Onsala Twin Telescope (OTT-N), as well as the 20 m Radio Telescope Wettzell (RTW) and the Twin Telescope Wettzell (TTW-2) in joint measurement campaigns of Frankfurt Univ. of Applied Sciences and Bochum Univ. of Applied Sciences. The signal path variations of these radio telescopes were derived using the common approach as well as spatial ray tracing. The results were reported to the IVS. Since VGOS-antennas are designed for broadband reception, the impact of frequency-dependent illumination functions onto the obtained signal path variations was studied in detail.

There is also a general interest from all members about moving towards locating InSAR targets and including them in tie surveys when co-located with other techniques. Some field results were captured in Collilieux et. al. 2022 as listed below.

Overall, the group has been active in this period, increasing the vectors used from ITRF2014 to ITRF2020, and decreasing the number of vectors with a discrepancy of greater than 5 mm. (Altamimi, 2023).

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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 Modeling**", 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 (TUM). The BPS staff members are Detlef Angermann, Thomas Gruber, Michael Gerstl, Urs Hugentobler and Laura Sánchez (all from TUM), 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 involved in standards and geodetic products. 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: June 2023)*

R. Heinkelmann, Germany	International Earth Rotation and Reference Systems Service (IERS)	
N. Stamatakos, USA	International Earth Rotation and Reference Systems Service (IERS)	geometry
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)	gravity
E. S. Ince, Germany	International Center 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. Kusche, Germany	Representative of gravity community	
J. Ferrandiz, Spain	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	other entities
S. Rózsa, Hungary	IAG Communication and Outreach Branch	
M. Sehnal, Austria	GGOS Coordinating Office	

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 as well as the temporal changes of these quantities in mm-accuracy. 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, ice melting, global water cycle) and for providing the metrological basis for an improved understanding of the Earth system. Figure **X.1** illustrates the integration of different observation types to determine consistent geodetic parameters as the basis for studies of the Earth system, the interactions among its sub-components and the connection to outer space.

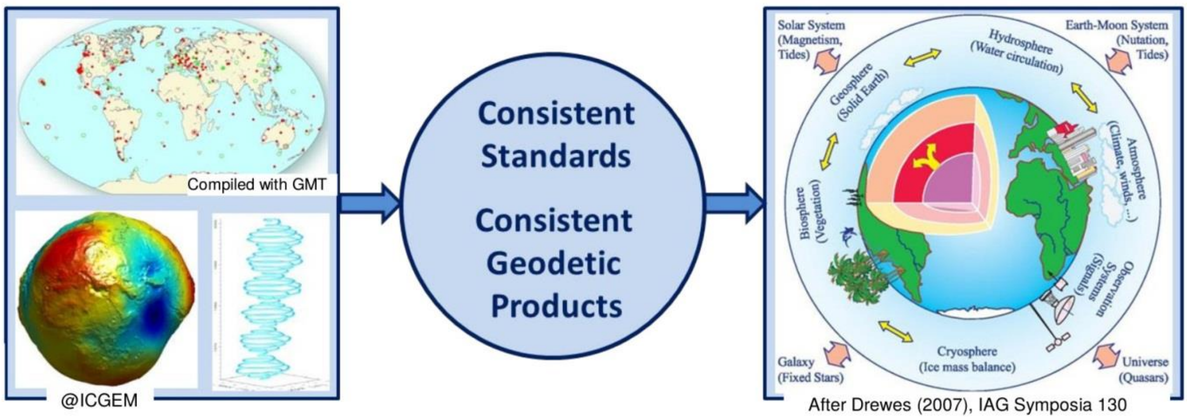

Fig. X.1*: The integration of the "three pillars" Earth's geometry, rotation and gravity field requires unified standards to obtain consistent geodetic products as the basis for Earth system research and for precisely quantifying global change phenomena.*

The mission of the BPS is:

- to serve as coordinating point for the homogenization of IAG standards and products;
- to keep track of the adopted geodetic standards and conventions across all components of the IAG;
- to motivate the development of new and integrated geodetic products, needed for Earth sciences and society;
- to describe and promote geodetic products (see GGOS website, www.ggos.org).

To accomplish these BPS tasks, a close interaction between the BPS and the IAG Services, the IERS Conventions Center and other entities involved in standards and conventions such as the IAU Commission A3 "Fundamental Standards", the International Organization for standardization (ISO/TC 211), the Committee on Data for Science and Technology (CODATA), the United Nation Global Geospatial Information Management (UN-GGIM) Subcommittee on Geodesy (SCoG) Working Group "Data Sharing and Development of Geodetic Standards", and the newly established UN Global Geodetic Centre of Excellence (UN-GGCE) has been established.

Objectives

The objectives of the BPS are 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

The BPS Implementation Plan 2020 – 2022 gives an overview and schedule of the BPS tasks (see Figure **X.2**). The activities of the BPS are divided into three main categories: Coordination activities, specific tasks of the BPS, and outreach activities. Currently, GGOS is developing a refined strategy and new implementation plans for its components for the term 2023 – 2026.

Updating 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".

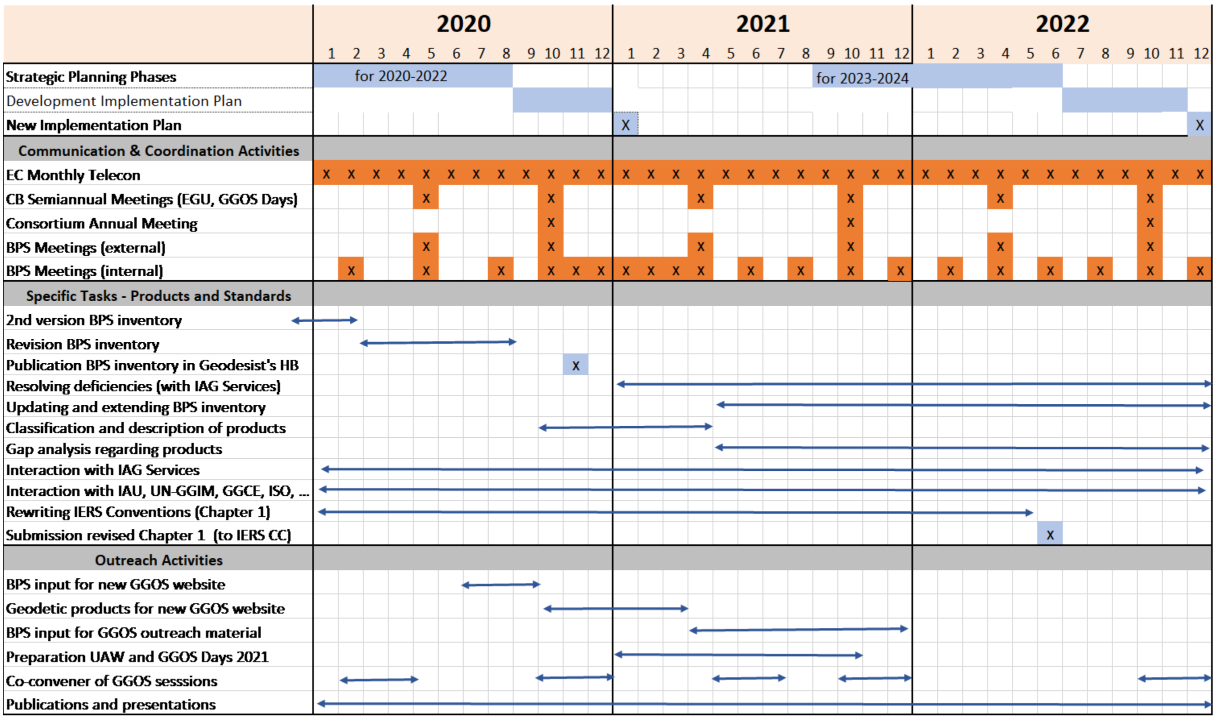

Fig. X.2: *Overview and schedule of BPS activities. Please note that some changes regarding the schedule of meetings and workshops were necessary due to the pandemic situation.*

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”).

Description and representation of geodetic products

In cooperation with the IAG Services, other data providers and contributing experts as well as the GGOS Coordinating Office and the members of the GGOS Science Panel, user-friendly product descriptions have been generated and implemented at the GGOS website (www.ggos.org).

The geodetic products are classified into two categories:

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

Until now, about 23 product descriptions are displayed at the GGOS website. Table **X.2** provides a list of these product descriptions along with so-called "appetizer questions" for each particular product. With such an information portal, GGOS contributes to advertise data science products to other disciplines and to make geodesy more visible in the geoscientific community and beyond (Angermann et al., 2022a). The product descriptions have been reviewed by the members of the GGOS Science Panel, coordinated by its chair Kosuke Heki, and 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.

Table X.2: *List of product descriptions that are currently displayed at the GGOS website (www.ggos.org), including an "appetizer question" for each particular product.*

Reference Frames		
	Terrestrial reference frame	How can we provide a stable reference for measuring changes of our planet?
	Celestial reference frame	How can we link Earth and space?
	Gravity reference frame	How to refer gravity measurements at the Earth surface to a uniform reference?
	Height reference frame	What is a height above sea level?
Geometry		
Land surface	Station positions & variations	Why do we need precise positioning and navigation on Earth and in space?
	Digital elevation model	How can the Earth's surface be represented?
	Surface deformation models	Why is the Earth's surface in constant change?
Ocean surface and lakes	Sea surface heights	How can the height of oceans be observed?
	Ocean topography models	What are dynamic ocean topography models and why are they needed?
	Sea level change	How fast is the sea level rising?
	Tide gauge records	What is the best sea level reference along the coasts?
Ice surface	Ice sheets and glaciers - variations	How fast is the ice being lost in Greenland and Antarctica?
Gravity field		
	Global gravity field models	How and why does the Earth's gravity change with location?
	Gravity field temporal variations	Why is the gravity field variable?
	Regional / local geoid models	What is a geoid and why is it needed?
	Terrestrial gravity data	What is the purpose of measuring gravity on the Earth's surface?
	Ice sheets and glaciers - variations	How fast is the ice being lost in Greenland and Antarctica?
	Height systems	Why are height systems so important?
Earth Orientation		
	Earth orientation parameters	Why are days getting longer and Earth is wobbling?
Positioning and Applications		
Atmosphere	Atmospheric products	How can space geodetic techniques observe the atmosphere?
	Lower neutral atmosphere	How can geodesy contribute to weather prediction?
	Ionosphere	How does electron density affect positioning and navigation?
	Thermosphere	How does the atmosphere influence low-flying satellites?
GNSS products	GNSS satellite orbits and clocks	How positioning benefits from precise satellite orbits and clocks?

BPS contributions to the updating of the IERS conventions

In the framework of the Unified Analysis Workshop (Thessaloniki, Greece, October 21-23, 2022), a dedicated session on standards, conventions, and formats has been organized by the BPS and the IERS Conventions Center. In this session, an overview about the status of the IERS Conventions update was given, followed by presentations on particular topics such as numerical standards, nutation issues, high-frequency EOPs, relativistic effects, etc.

In this context, the focus of the BPS is on the updating of Chapter 1 of the IERS Conventions "General definitions and numerical standards". One issue was the treatment of the permanent tide in heights as specified in the definition of the International Height Reference System (IHRS), which prescribes the IHRF coordinates in the mean-tide system to support oceanographic and hydrographic modeling. Section 1.1 "Permanent Tide" of the IERS Conventions will be updated accordingly to refer to these IHRS developments. Furthermore, the present status concerning numerical standards (Section 1.2 of the IERS Conventions) has been addressed. Several updates have been proposed that will be incorporated to reflect the latest changes in the field of standards and conventions (Angermann et al., 2022b). As outcome of the Unified Analysis Workshop 2022, two recommendations on numerical standards have been endorsed:

- **REC-1**: The BPS recommends that the used numerical standards including time and tide systems must be clearly and consistently documented for all geodetic products (IAG/GGOS)
- **REC-2**: The BPS recommends that the necessity of a new Geodetic Reference System (GRS) should be further clarified (WG: Urs Marti)

GGOS Days 2022 and Strategic Plan Workshop 2022 in Munich

The GGOS Days 2022 (Nov. 15-16) and the Strategic Plan Workshop (Nov. 16-17) took place in the city center of Munich, hosted at the representative facilities of the Bavarian Academy of Sciences and Humanities (BAdW).

Fig. X.3: *On-site participants of the GGOS Days 2022.*

The GGOS Days 2022 were organized by the German Geodetic Commission (DGK), the Technical University of Munich (TUM) and GGOS. In total 111 interested people from many countries around the world participated in this hybrid conference, 33 of them in-person and 78 virtually. Further information is available at the GGOS website (https://ggos.org/event/ggos-days-2022/). This website also provides links to download the presentations, videos and photos of the conference.

Directly after the GGOS Days 2022, the GGOS Strategic Plan Workshop was convened at the same venue. About 20 invited IAG representatives participated in this workshop to discuss the future direction and goals of GGOS. Besides about 15 in-person participants, a few colleagues attended remotely. The discussions were based on the results of a community survey to develop a new strategy for GGOS.

Selected publications:

- Angermann D, Gruber T, Gerstl M, Heinkelmann R, Hugentobler U, Sánchez L, Steigenberger P: GGOS Bureau of Products and Standards: Inventory of standards and conventions used for the generation of IAG products. 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, 2020.
- Angermann D., Gruber T., Gerstl M., Heinkelmann R., Hugentobler U., Sánchez L., Steigenberger P., Gross R., Heki K., Marti U., Schuh H., Sehnal M., Thomas M.: GGOS Bureau of Products and Standards: Description and promotion of geodetic products}. In: Freymueller J., Sánchez L. (Eds.), IAG Symposia, doi 10.1007/1345_2022_144, 2022a.
- Angermann D., Gruber T., Gerstl M., Heinkelmann R., Hugentobler U., Sánchez L., Steigenberger P.: GGOS of Products and Standards (BPS): BPS Activities on Standards}. Unified Analysis Workshop 2022, Thessaloniki, Greece, 10.5281/zenodo.7291721, 2022b.

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 further development and evaluation of model interfaces for dynamical coupling 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;
- Feasibility studies regarding the coupling of neural networks with traditional data assimilation techniques and application of the combined approach in stand-alone models. Application of neural networks for downscaling purposes.
- Discussion and estimation of consequences of upcoming hardware developments for CPU intensive model simulations (high-performance computing vs. exascale modeling).
- 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.

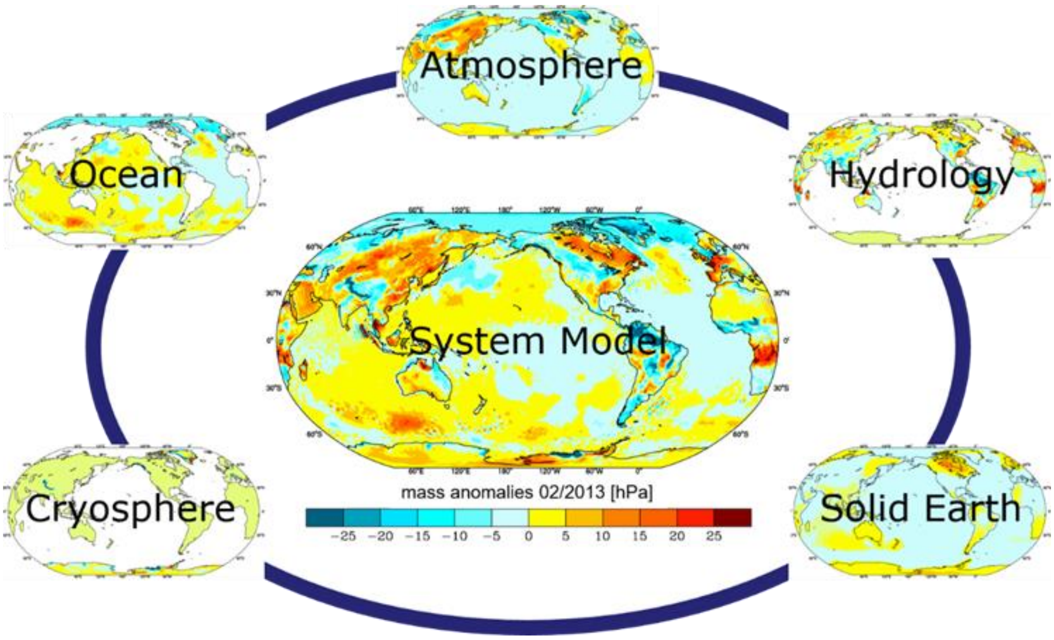

Fig. X.4: *Simulated mass anomalies in a modular system model approach.*

Selected publications:

- Bagge, M., Klemann, V., Steinberger, B., Latinovic, M., Thomas, M.: Glacial-isostatic adjustment models using geodynamically constrained 3D Earth structures. Geochemistry Geophysics Geosystems (G3), 22, 11, e2021GC009853, 2021.
- 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.
- Huang, P., Sulzbach, R., Tanaka, Y., Klemann, V., Dobslaw, H., Martinec, Z., Thomas, M.: Anelasticity and lateral heterogeneities in Earth's upper mantle: impact on surface displacements, self-attraction and loading and ocean tide dynamics. Journal of Geophysical Research: Solid Earth, 126, 9, e2021JB022332, 2021.
- 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.
- Irrgang, C., Boers, N., Sonnewald, M., Barnes, E. A., Kadow, C., Staneva, J., Saynisch-Wagner, J.: Towards neural Earth system modelling by integrating artificial intelligence in Earth system science. Nature Machine Intelligence, 3, 667-674, 2021.
- Schachtschneider, R., Saynisch-Wagner, J., Klemann, V., Bagge, M., Thomas, M.: An approach for constraining mantle viscosities through assimilation of palaeo sea level data into a glacial isostatic adjustment model. Nonlinear Processes in Geophysics, 29, 1, 53-75, 2022.

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.

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

Chair: Urs Marti (Switzerland)

Members: Detlef Angermann (Germany), Richard Gross (USA), Ilya Oshchepkov (Russia), Christopher Kotsakis (Greece), Jonas Ågren (Sweden), Ulrich Meyer (Switzerland), Riccardo Barzaghi (Italy), Jaakko Mäkinen (Finland), Pavel Novak (Czech Republic), Laura Sánchez (Germany), Hartmut Wziontek (Germany), John Nolton (USA), Robert Heinkelmann (Germany), Sergei Kopeikin (USA), Erricos Pavlis (USA), ILRS

Objectives and Activities

The main task of this WG is to define a consistent set of parameters and formulas for the definition of a new conventional Global Reference System (GRS). This includes the geometry (size and shape of a reference ellipsoid), the gravity field (normal gravity field of this ellipsoid), physical heights, terrestrial time and Earth rotation.

This new definition becomes necessary because since the introduction of GRS80 (Moritz, 1980) the knowledge in Geodesy has improved a lot (e.g. GNSS, gravity space missions) and the use of the parameters became inaccurate and inconsistent over time. The problem of the permanent Earth Tide was not yet a topic at the epoch of the definition of GRS80. A new set of parameters was published by Groten in 2004 but was not widely introduced in Geodesy. Another source of parameters are the IERS conventions, which do not strictly apply GRS80.

The acceptance of the IAG Resolution No. 1 in 2015 which defines the potential at sea level (W_0) even increases the inconsistency in the geodetic parameters of the conventional GRS (in GRS80, W_0 is a derived quantity).

The new set of parameters is based on the four fundamental parameters: W_0 (Potential at Reference Level), J2 (dynamic form factor, "flattening"), GM (geocentric gravitational constant) and ω (angular velocity of the Earth). All these quantities are well observed and monitored by various geodetic space techniques. (This implies that the semi major axis of the ellipsoid will be a derived parameter).

Most of the defining parameters change with time. This includes seasonal variations and long-term trends. These changes are important and must be considered for the consistency with the ITRF (e.g. ellipsoidal heights). Nevertheless, in order to keep things simple for the user, this time variability will not be treated in the published definition of a new GRS. All quantities will be fixed to the epoch 2010.0. This is the epoch at which the W_0 of the IAG resolution No. 1 is defined.

All calculations will be done in the zero-tide system. Only at the very end, conversion formulas to mean tide and tide-free will be given for all quantities. In order to keep things simple, some very minor terms in this conversion will be neglected.

Results

A draft of the paper with the calculation of the parameters is available. It follows more or less the structure of the papers by Moritz (1980) and Groten (2004). However, it is not ready to be published to a broader community, since it has not been thoroughly discussed yet and is not in a state of general agreement of the WG members. Therefore, this WG should be continued in some form.

The calculation of a new set of parameters is one thing. The main problem will be to convince the users to adopt such a system as a new global reference. Many users don't see the necessity to replace GRS80, as they just see it as a conventional model for the conversion of geocentric coordinates or for the calculation of gravity anomalies. Main concerns are the danger of confusion and the necessity to update many software packages. This discussion has still to be lead and arguments for and against such a change are still evaluated.

Another question to be answered is the necessity to define a conventional global gravity field model. For many applications (e.g. global height system, reference for local geoid determination), the assignment of such a standard model has some advantages. For different application we would need a low-resolution satellite-only model and a high-resolution combined model.

The progress of the work has been presented in October 2022 at the Unified Analysis Workshop (UAW) in Thessaloniki by D. Angermann and regularly at the GGOS days.

Focus Area "Unified Height System"

Lead: Laura Sánchez (Germany)

With contributions from: *H.A. Abd-Elmotaal (Egypt), J. Ågren (Sweden), H. Denker (Germany), R. Forsberg (Denmark), A. Gómez (Argentina), 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), 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), H. Teitsson (Faroes), 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(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 $\pm 3\times10^{-2}$ m^2s^{-2} (equivalent to ≈ ±3 mm in height) and $\pm 3\times10^{-3}$ $m^2s^{-2}a^{-1}$ (≈ ±0.3 mm a^{-1}), respectively. However, for the moment, the goal is to reach $\pm 1\times10^{-1}$ 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, see Fig. 1. 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.

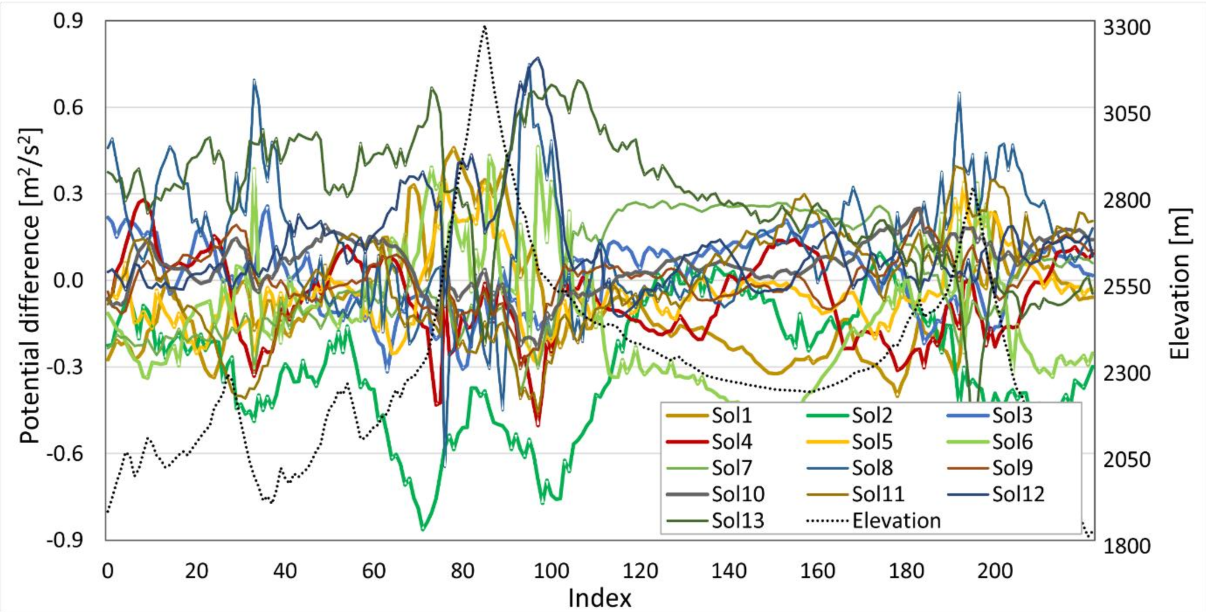

Fig. 1 Comparison of potential values obtained from different approaches using the same input gravity data: Standard deviation of the differences between C(P) from gravity field modelling and from levelling varies from 0.12 m2s-2 (~1.2 cm) to 0.78 m2s-2 (7.8 cm).

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. 2) and currently, it is regularly refined in agreement with changes/updates of other geodetic reference frames (ITRF and IGRF and their densifications).

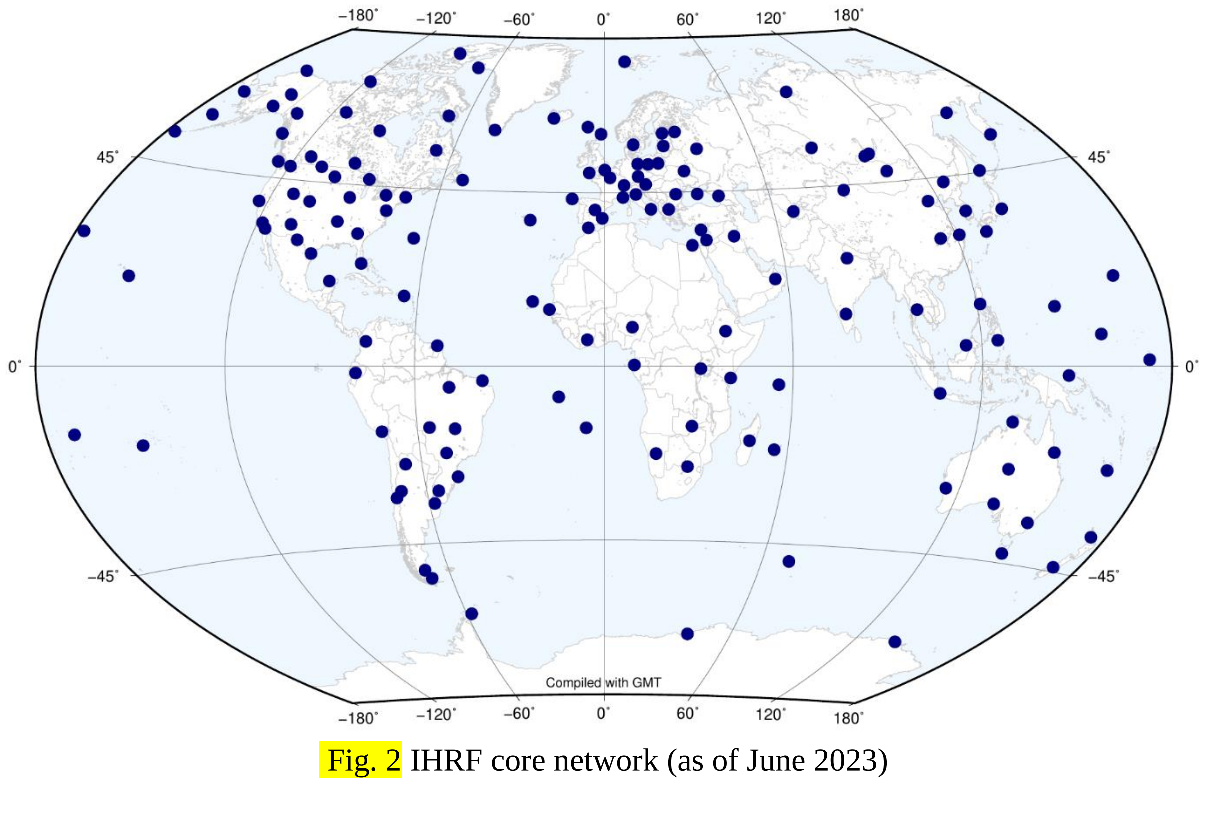

Fig. 2 IHRF core network (as of June 2023)

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).

The input gravity and topographic data, the GNSS/levelling validation data, and the 14 geoid and quasi-geoid models produced within the Colorado experiment are available from the International Service for the Geoid (https://www.isgeoid.polimi.it/Projects/colorado_experiment.html) and can be used as a basis to evaluate any geoid computation method or software anywhere.

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. 2) 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. The results of these computations will be presented at the next IUGG2023 General Assembly in Berlin, Germany.

Special Issue of the Journal of Geodesy on "*Reference System in Physical Geodesy*"

Based on the advances for the establishment of the IHSR/IHRF and the International Terrestrial Gravity Reference System and Frame (ITGRS/ITGRF), a special issue on *Reference Systems in Physical Geodesy* of the Journal of Geodesy has been completed. With the 18 papers in this special issue, important issues related to the establishment of the IHRF and ITGRF as well as to the improvement of accurate geoid modelling and the long-term stability of absolute gravity observations have been addressed. We are grateful to all authors for the efforts. A large number of international colleagues served as reviewers for the manuscripts, a laborious and time-consuming task. We thank them all for their important and diligent work. Finally, we would like to thank the Editor-in-Chief, Jürgen Kusche, for his generous and indispensable support in the editorial process, from the development of the special issue to its final publication. The papers included in this special issue are (papers contributing to this report are marked in fett):

Antokoletz ED, Wziontek H, Tocho CN *et al.* (2020) Gravity reference at the Argentinean–German Geodetic Observatory (AGGO) by co-location of superconducting and absolute gravity measurements, J Geod 94, 81, https://doi.org/10.1007/s00190-020-01402-7.

Bilker-Koivula M, Mäkinen J, Ruotsalainen H, *et al.* (2021) Forty-three years of absolute gravity observations of the Fennoscandian postglacial rebound in Finland, J Geod 95, 24, https://doi.org/10.1007/s00190-020-01470-9.

Claessens SJ, Filmer MS (2020) **Towards an International Height Reference System: insights from the Colorado experiment using AUSGeoid computation methods**, J Geod 94, 52, https://doi.org/10.1007/s00190-020-01379-3.

Grigoriadis VN, Vergos GS, Barzaghi R et al (2021) **Collocation and FFT-based geoid estimation within the Colorado 1 cm geoid experiment**, J Geod 9, 52, https://doi.org/10.1007/s00190-021-01507-7.

Işık MS, Erol B, Erol S, Sakil FF (2021) **High-resolution geoid modeling using least squares modification of stokes and hotine formulas in Colorado**, J Geod 95, 49, https://doi.org/10.1007/s00190-021-01501-z.

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, 10, https://doi.org/10.1007/s00190-020-01431-2.

Mäkinen J (2021) **The permanent tide and the International Height Reference Frame IHRF**, J Geod 95, 106, https://doi.org/10.1007/s00190-021-01541-5.

Oja T, Mäkinen J, Bilker-Koivula M, *et al.* (2021) Absolute gravity observations in Estonia from 1995 to 2017, J Geod 95, 131, https://doi.org/10.1007/s00190-021-01580-y.

Pálinkáš V, Wziontek H, Vaľko M, *et al.* (2021) Evaluation of comparisons of absolute gravimeters using correlated quantities: reprocessing and analyses of recent comparisons, J Geod 95, 21, https://doi.org/10.1007/s00190-020-01435-y.

Sánchez L, Ågren J, Huang J, Wang YM, Mäkinen J, Pail R, Barzaghi R, Vergos GS, Ahlgren K, Liu Q (2021) **Strategy for the realisation of the International Height Reference System (IHRS)**, J Geod, 95, 3, https://doi.org/10.1007/s00190-021-01481-0.

Scherneck HG, Rajner M, Engfeldt A (2020) Superconducting gravimeter and seismometer shedding light on FG5's offsets, trends and noise: what observations at Onsala Space Observatory can tell us, J Geod 94, 80, https://doi.org/10.1007/s00190-020-01409-0.

Schilling M, Wodey É, Timmen L. *et al.* (2020) Gravity field modelling for the Hannover 10 m atom interferometer, J Geod 94, 122, https://doi.org/10.1007/s00190-020-01451-y.

Van Westrum D, Ahlgren K, Hirt C, Guillaume S (2021) **A Geoid Slope Validation Survey (2017) in the rugged terrain of Colorado**, USA, J Geod 95, 9, https://doi.org/10.1007/s00190-020-01463-8.

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.

Wang YM, Sánchez L, Ågren J, Huang J, Forsberg R, Abd-Elmotaal HA, Barzaghi R, Bašić T, Carrion D, Claessens S, Erol B, Erol S, Filmer M, Grigoriadis VN, Isik MS, Jiang T, Koç Ö, Li X, Ahlgren K, Krcmaric J, Liu Q, Matsuo K, Natsiopoulos DA, Novák P, Pail R, Pitoňák M, Schmidt M, Varga M, Vergos GS, Véronneau M, Willberg M, Zingerle P (2021) **Colorado geoid computation experiment – Overview and summary**, J Geod, 95, 12, https://doi.org/10.1007/s00190-021-01567-9.

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.

Wziontek H, Bonvalot S, Falk R, Gabalda G, Mäkinen J, Pálinkáš V, Rülke A, Vitushkin L (2021) Status of the International Gravity Reference System and Frame, J Geod 95, 7, https://doi.org/10.1007/s00190-020-01438-9.

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

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. 3).
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. 3).
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. 3). 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. 3).

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. 3): 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. 3).

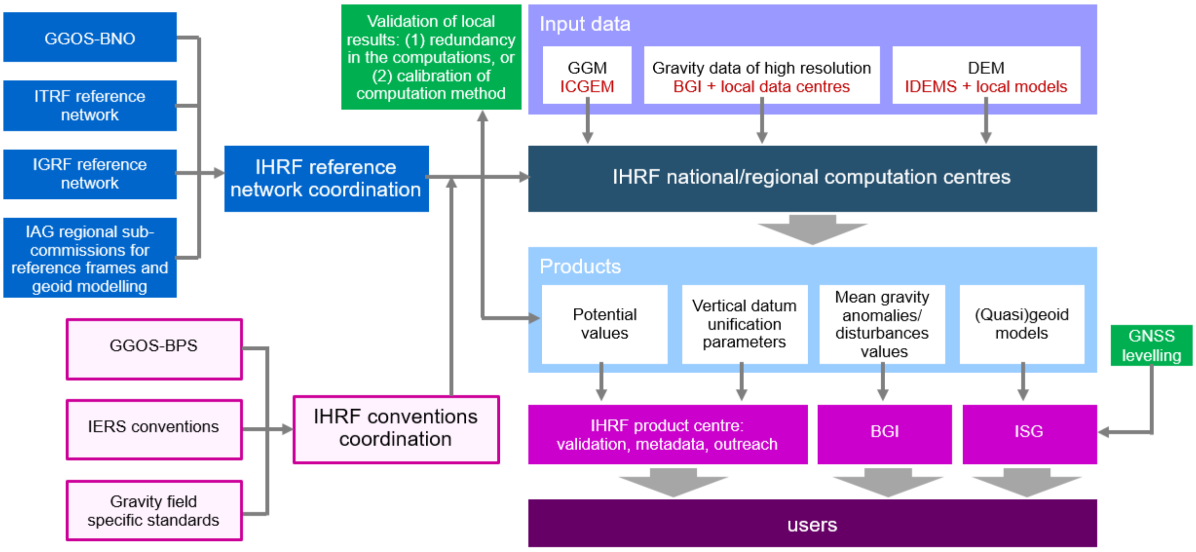

Fig. 3 Proposal for an IHRF operational infrastructure within the IGFS

The IHRF operational infrastructure within the IGFS will be managed by the *IHRF Coordination Centre*. Presently, we are preparing the terms of reference for this centre for approval by the IAG Executive Committee. With this centre established in the IGFS, we can declare the objectives of the GGOS-FA-UHS accomplished and this FA will be decommissioned at the IUGG2023 General Assembly.

GGOS Geohazards Focus Area

Focus Area Lead: John LaBrecque
Center for Space Research, U. Texas Austin
Austin, Texas
email: jlabrecq@mac.com

Activities, Actions, and Publications during 2019-2023:

Introduction: The concept of GNSS Tsunami Early Warning Systems (GTEWS) was borne of the societal suffering inflicted by the Great Indian Ocean Earthquake and Tsunami of Boxing Day 2004. We learned that the existing sparse regional IGS network of GPS receivers could have provided warning of the impending tsunami within 15 minutes of the initial fault zone rupture that produced the tsunami, many hours in advance of the seismological warning. GTEWS related research was further advanced by the Japanese GEONET realtime network measurements of the 2011 Tohoku Oki earthquake. Analysis of the GEONEt GNSS data demonstrated that an accurate tsunami prediction could be generated within 5 minutes of the initial fault rupture using the existing infrastructure. The GEONET data also demonstrated that ionospheric Total Electron Content measurements could also provide images of the development and propagation of the tsunami beginning within ten minutes of initial ocean uplift.

The 2019-2023 activities of GGOS Geohazards Focus Area (GGOS Geohazards) involve nearly a decade of continuous effort. Therefore, we will provide a brief recap of the integrated effort since 2015 to provide perspective on our efforts. GGOS Geohazards maintains a library containing relevant documents, presentations, newsletters, videos and other files of interest to the GATEW community at the following link https://www.dropbox.com/sh/fg20mtydg136vx6/AABNr2kSnMo429nCxEHhBDfoa?dl=0 .

Activities During 2015-2019: These significant demonstrations of GNSS based Tsunami Disaster Early Warning prompted the GGOS encourage the 2015 General Assembly adoption of Resolution #4 calling for the IUGG membership to support the development of a GNSS augmentation to Tsunami Warning Systems within the Indo-Pacific. On April, 2016 the GGOS issued its Call for Participation in the GNSS Augmentation for Tsunami Early Warning (GATEW) working group in support of Resolution #4. The GATEW working group now includes 18 institutions from 12 nations with substantial experience and roles in the development of geodetic applications to disaster risk reduction. The GGOS Geohazards collaborated with the Association of Pacific Rim Universities (APEC), NASA and the IUGG Commision on Geophysical Risk and Sustainability (GRC) to conduct the GTEWS 2017 workshop to explore the feasibility and utility of GTEWS.

Activities during 2019-2023: The GTEWS 2017 workshop report was published by the APRU in 2019 and subsequently UNDRR in 2020 as a contributing paper to its Global Assessment Report of 2019. The work shop report reviews the scientific and programmatic developments of GTEWS, endorses the development of an Indo-Pacific GTEWS and provides specific recommendations to insure a strong Indo-Pacific GTEWS program. The first recommendation was the formation of a "GNSS Shield Consortium" to apply the GTEWS 2017 recommendation for the establishment of an Indo-Pacific GTEWS program in support of the UNDRR Sendai Framework for Disaster Risk Reduction.

Scientific development of the GTEWS 2017 was significantly slowed by the COVID 19 pandemic that restricted international collaboration. Despite these restrictions the IGS, GRC and the GGOS/Geohazards FA worked with GEO to develop the Geodesy for Sendai framework to develop collaborations for the application of GNSS to goals of the Sendai Framework of the UNDRR. Geodesy4Sendai was codified in the GEO Work Programme of 2020-2022 and 2023 to 2O25. within the Geodesy for Sendai Framework. The GRC applied was granted $10K by the IUGG to support the organization of the GTEWS Coordinating Committee as recommended by the GTEWS 2017 workshop.

***Activities during* 2023:** The implementation of GTEWS continued as recommended by the IUGG Resolution #4 within the individual programs of Indian, Japanese, Chilean, and US agencies. Unfortunately, as noted by the GTEWS 2017 workshop report, a reticence persists among several Indo-Pacific nations to engage in the sharing of real time GNSS essential for the realization operation of an Indo-Pacific GTEWS. The GGOS Geohazards recognizes that GTEWS for the Indo-Pacific will require significant international collaboration between institutions and agencies. Our activities work to implement this important need for international collaboration.

The GGOS Geohazards. the IGS and the GRC have joined in support of the UN ICG Working Group task force on "Applications of GNSS for Disaster Risk Reduction" (Geodesy4DRR). The IGS published Stop 5 of the Tour de l'IGS that focussed upon GNSS Applications to the South Pacific Disaster Risk Reduction. Stop 5 included a report by the GRC/GGOS_Geohazards recommendation on the formulation of GTEWS_Oceania. The GTEWS_Oceania concept recognizes the need to develop a South Pacific real time GNSS network in support GTEWS as well as numerous other GNSS applications to environmental hazard risk reduction. The GRC and the GATEW working group members as well as the IGC Geodesy4DRR task force are engaging the member nations of the Oceania region in the formulation of GTEWS_Oceania. GTEWS_Oceania is holding monthly meetings to resolve a development plan for the GTEWS network.

Future Activities:

Following the GTEWS 2017 workshop report, the objective is to establish a governing council to determine data policy, identify resources, and establish a development plan to establish a GTEWS_Oceania network and analysis capability. It is too early to resolve the success of the GTEWS_Oceania Initiative but there is a growing participation by the nations of Oceania.

A draft Charter (Terms of Reference) is under review and implementation plans are being developed by a growing number of participating nations. The Oceania region has a significant number of GNSS receivers of varying quality and varying communications capability. Resources will be needed to upgrade these receiver stations and provide the regional broadband communications as well analysis systems. Discussions are underway to apply the $10K IUGG/GRC grant as a matching grant to further develop further resources for GTEWS_Oceania.

GGOS Focus Area 'Geodetic Space Weather Research'

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

Introduction

Space weather is 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 visualised now as a double tetrahedron.

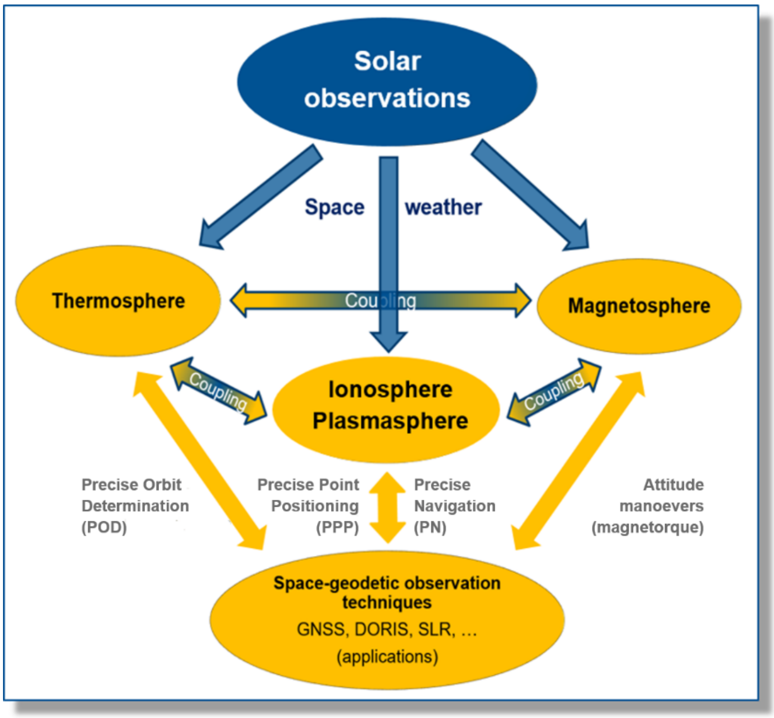

Fig. 1: Structure of the FA-GSWR including the plasmasphere and the magnetosphere: the yellow-coloured parts are related to geodetic applications such as Precise Orbit Determination (POD) and Precise Point Positioning (PPP); the blue-coloured parts are related to solar phenomena especially to space weather.

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 proposed 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 entitled 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 4 years will be presented in more details in what follows.

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

2nd IAG Commission 4 'Positioning and Applications' Symposium

Due to the Corona pandemic many of the planned activities at conferences and workshops did not work out during the reporting period and had to be postponed. One example is the 2nd IAG Commission 4 Symposium, which was originally scheduled for September 2020. It finally took place from September 5th to 8th, 2022, at Wissenschaftsetage Potsdam. The Symposium website (https://www.iag-commission4-symposium2022.net/) created by Copernicus GmbH will be available at least for a five-year timeframe. The scientific program of the symposium included altogether nine sessions. Some of them were arranged according to the IAG Commission 4 structure, and others were dedicated to the special topics of the FA-GSWR, namely (1) to Atmospheric Remote Sensing of the Ionosphere and (2) to the topics of the FA itself. The corresponding presentations and posters are part of the open access Symposium Proceedings and can be downloaded from https://zenodo.org/communities/iag-comm4-symp-2022/.

Apart from the scientific programme, a Joint Splinter Meeting of the IAG Sub-Commission 4.3 and the FA-GSWR took place; furthermore, an IAG, FA-GSWR and IAGA (International Association of Geomagnetism and Aeronomy) Splinter Meeting on the specific topic of "Space Weather Research" took place at the end of the symposium. During this meeting it was discussed how a joint inter-association study group on space weather topics within the IUGG can be established. Since there are already examples of this type of joint study group within the IAG, we planned to create a list of objectives for such a joint inter-association study group that would combine the activities of IAG and IAGA. A further discussion is now scheduled for the IUGG 2023 General Assembly, which will be held in Berlin from July 11 to 20, 2023. One of the goals of such a study group will be to develop a roadmap for the establishment of international space weather data centres and space weather services for scientific purposes. While space weather services, including warning systems for the public, must be installed by the governments of countries such as Germany, i.e., they are national institutions, the question here, for example, is how measurements from different scientific fields such as geodesy and solar physics can be combined to enable reliable prediction of space weather events. To solve these and other problems in space weather research, it is necessary to form an international team that brings together as much experience as possible.

Other issues

Many papers related to the scientific content of the JSG 1 and the JWG1 to JWG3 have been written in the last years. Significant progress has also been made in third-party funded national and international projects; the work within these projects is often strongly coupled with the objectives of individual groups of FA-GSWR.

On the next pages an overview of the scientific work of the JWGs of the FA-GSWR within the last four years, i.e. the reporting period 2019 to 2023, is provided.

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

Activities during the period 2019-2023

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. Figure 2 shows the main steps planned in the group. The steps were achieved through the realization of three main points:

- Development of a database, where the methods from the group members were evaluated using a common ground in terms of reference data. 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 (RO) were also included in the analysis, as well as TEC measurements from altimeters and other LEO satellites with receivers for precise orbit determination.
- Pragmatic assessment of established methods for 3D electron density was performed to define their accuracy related to specific parameters of high importance for Space Weather and Geodesy.
- Papers were published indicating the space weather conditions and expected errors of the methods.

The first two years (2019-2021) of the project development were devoted to establishing a fair database for our evaluations, selecting proper instruments and pre-processing techniques to the dataset. The remaining two years (2021-2023) were for the model developments and evaluations. A few campaigns were created to carry out a pragmatic model evaluation between the members. We have chosen 4 geomagnetic storms as basis for the analysis in case of disturbed days.

The following activities have been conducted based on the created dataset or within the group cooperation. A direct comparison between several models was investigated by Kodikara et al. (2021). We have conducted a few cross-validations between the electron density measurements provided by the instruments used in the dataset (Smirnov et al. 2021). We have also checked the feasibility of using ionosonde observations to evaluate established TEC models (Jerez et al. 2021). A high-resolution global-scale tomography was developed and evaluated by Prol et al. (2021b). A new climatological model was developed and evaluated by Hoque et al. (2022). Swarm in-situ measurements were used to improve ionospheric forecast of the Coupled Thermosphere Ionosphere Plasmasphere electrodynamics (CTIPe) (Fernandez-Gomez et al., 2022). A novel technique was developed to estimate differential code bias (DCB) based on receivers dedicated to LEO-POD (Hernández-Pajares et al., 2023). A new method was developed to extract electron density RO retrievals based on truncated measurements of the topside ionosphere (Hoque et al., 2023). A novel neural network model of Earth's topside ionosphere was developed (Smirnov et al., 2023).

A crucial problem identified in the current ionospheric models was the lack of a correct description of the topside ionosphere and plasmasphere. We understand now that 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. 2019), 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 characterise the upper part of the ionized atmosphere. Recent advances from Prol et al. (2021a) and Prol and Hoque (2021) have shown that great improvements on the topside ionosphere and plasmasphere can be obtained in comparison to typical models, especially during disturbed conditions of storm events. Prol and Hoque (2022) have also investigated the performance of tomography techniques to reconstruct the plasmasphere. Despite limited accuracy, it was feasible to propose a new method to develop further investigations of the region. Prol et al. (2022) have further discovered a way to combine the ionosphere and plasmasphere trough empirical relations.

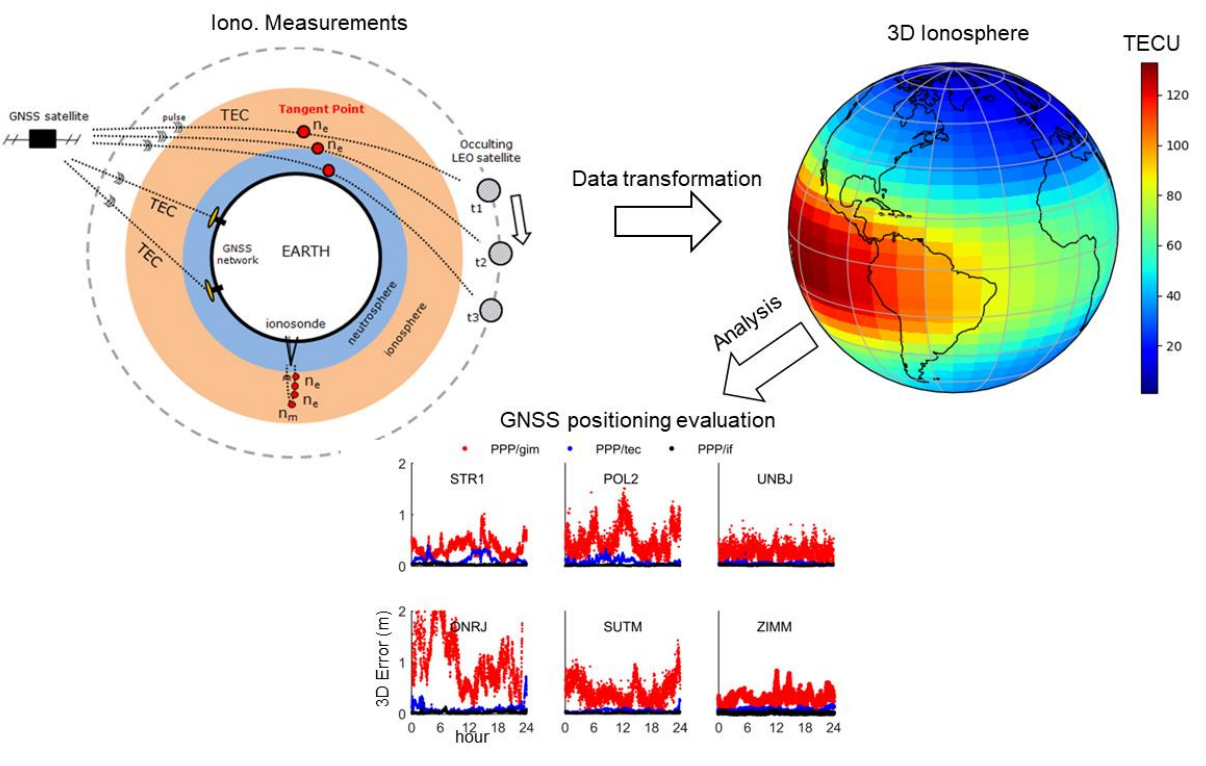

Fig. 2. Steps involved in the group of electron density modelling comprehend: 1) data gathering of electron density measurements; 2) data transformation into 3D grids; 3) evaluation of relevant parameters for the community, such as in terms of GNSS positioning. Positioning results are obtained by a high-accurate ionospheric model (see Prol et al., 2018 for details).

The activities of the group have been disseminated trough several conferences. A remarkable example is shown in Prol (2022), who addressed the current challenges and opportunities for 3D ionospheric imaging. In the future, it is expected to provide a simulated case scenario to be used as basis for a fair data evaluation. A first dataset, which is simulated considering the full environment of the ionosphere and plasmasphere, is complete. An upcoming publication will show details of the simulated dataset (Prol et al., 2023). This dataset not only incorporate TEC measurements from typical ground-based GNSS receivers and POD receivers, but also incorporate upcoming LEO-PNT mega-constellations. As we advance with the group goals, more complex dynamics are planned to be incorporated in the simulations of the ionosphere and plasmasphere.

Publications

Fernandez-Gomez, I., Kodikara, T., Borries, C., Forootan, E., Goss, A., Schmidt, M., Codrescu, M. V. (2022) Improving estimates of the ionosphere during geomagnetic storm conditions through assimilation of thermospheric mass density. Earth Planets Space 74, 121. https://doi.org/10.1186/s40623-022-01678-3

Hernández-Pajares, M.; Olivares-Pulido, G.; Hoque, M.M.; Prol, F.S.; Yuan, L.; Notarpietro, R.; Graffigna, V. (2023) Topside Ionospheric Tomography Exclusively Based on LEO POD GPS Carrier Phases: Application to Autonomous LEO DCB Estimation. Remote Sens. 15, 390. https://doi.org/10.3390/rs15020390

Hoque, M. M., Jakowski, N., Prol, F. S. (2022) A new climatological electron density model for supporting space weather services, J. Space Weather Space Clim., 12, 1. https://doi.org/10.1051/swsc/2021044

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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)
Natalia Hladczuk (The Netherlands)
Saniya Behzadpour (Austria)
Aleš Bezděk (Czech Republic)
Sean Bruinsma (France)
Michael Schmidt (Germany)
Barbara Süsser-Rechberger (Austria)
Peter Nagel (USA)
Andres Calabia (Spain)

Activities during the period 2019-2023

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.

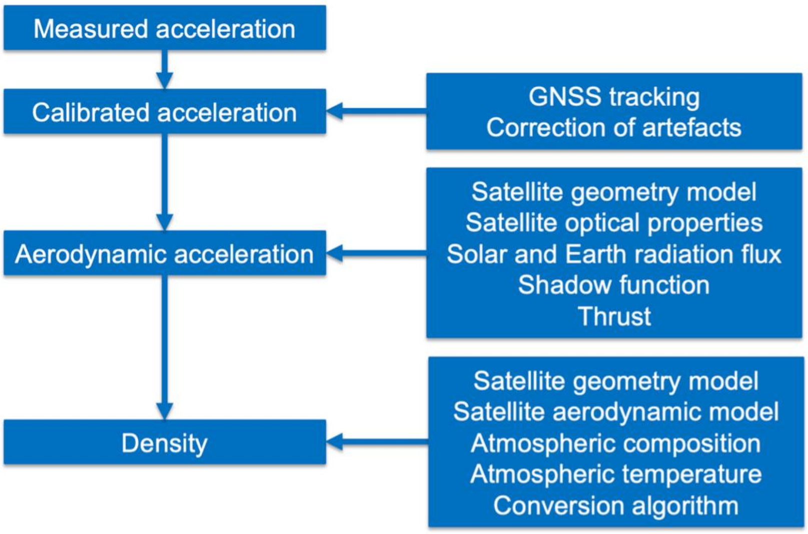

Fig. 3: Processing of measured accelerations to thermospheric mass density including required background models

Besides the theoretical model comparison, we initiated a data comparison. During our group meetings, we agreed on the comparison of GRACE A datasets because this covered all solar and geomagnetic activity and different eclipse conditions. The datasets used in the comparison are listed in **Error! Reference source not found.**. Initially, the Technical University of Graz, the University of Bonn, and the Delft University of Technology contributed their datasets. Later, also the Zentrum für angewandte Raumfahrttechnologie und Mikrogravitation (ZARM) of the Universität Bremen used the datasets for their comparisons.

A key result of the comparison was that the neutral density observations show scale differences of 10 – 60% as demonstrated in Figure 4. The differences need to be interpreted in light of the thermosphere model accuracy of 20 – 30% (Bruinsma et al., 2022). The selected approach of a thorough comparison of observational datasets is therefore a prerequisite for improving the thermosphere models. We identified significant differences in all processing steps, in particular the accelerometer data calibration, radiation pressure modelling, and the aerodynamic force coefficient modelling. Accurately modelling the aerodynamic force coefficient modelling is one of the hardest challenges (Mehta et al., 2022). Though the source of the differences between the datasets is presently not fully understood, identifying the differences was an important activity that provided valuable impulses to improve the modelling capabilities of the involved institutions. In addition to the accelerometer-derived datasets, we also performed a comparison of the Swarm C POD-derived density datasets for 2015 from TU Graz and TU Delft. It was found that the TU Graz density datasets show larger variations in comparison to the TU Delft ones. The TU Graz density dataset reaches low values, indicating that this dataset has some room for improvement. Finally, an overview of SLR-derived density observations was provided by guest speaker Mathis Bloßfeld from TU Munich.

Table 1: GRACE A datasets used for comparison

Dataset	TU Graz	Uni Bonn	TU Delft
Calibrated accelerations	✓	✓	✓
Observed aerodynamic accelerations	✓	✓	✓
Aerodynamic force coefficients	✓	✓	✓
Neutral density observations	✓	✓	✓
Modelled neutral density (along orbit)	✓	✓	✓
Orbit (position and velocity)	✓	✓	✓
Radiation pressure acceleration	✓	✓	✓
Shadow function	✓	✓	✓
F10.7 index	✓	✓	✓
Kp index	✓	✓	✓
ap index	✓	✓	✓
Period	2002-04-05 – 2017-06-29	2002-08-01 – 2009-12-31	2002-04-01 – 2009-12-31

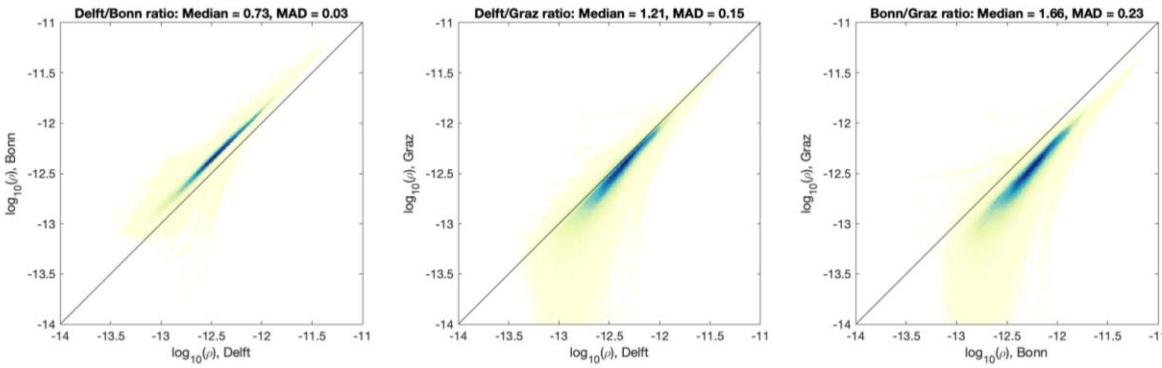

Fig. 4: Comparison of neutral density observations

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

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

Chair: Haixia Lyu (China, 2021 – 2023), Alberto Garcia-Rigo (Spain, 2019 – 2021)
Vice-Chair: Benedikt Soja (Switzerland)

(Joint with IAG Commission 4, Sub-Commission 4.3)

Members

Anna Belehaki (Greece)
Anthony J. Mannucci (USA)
Enric Monte-Monero (Spain)
Rami Qahwaji (UK)
Xiaoqing Pi (USA)
Denise Dettmering (Germany)
Consuelo Cid (Spain)
Jens Berdermann (Germany)
Pietro Zucca (The Netherlands)
Jinsil Lee (Republic of Korea)

Activities during the period 2019-2023

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 analysing 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, Traveling Ionospheric Disturbances (TIDs) and scintillations, solar flare detection/prediction, EUV flux-rate, CMEs and SEPs, solar corona electron density, dimming 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.

Particularly, 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 analysed adding a fourth case which was also considered by JWG 1. Thus, we will analyse 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.


GGOS
Global Geodetic Observing System

Joint Working Group 3 (JWG3) - Improved understanding of space weather events and their monitoring

JWG3 - Expertise in the field

What is your expertise on space weather events and their monitoring? You can either write a few sentences, paste an abstract or provide a link to a manuscript.

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. We have been 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.

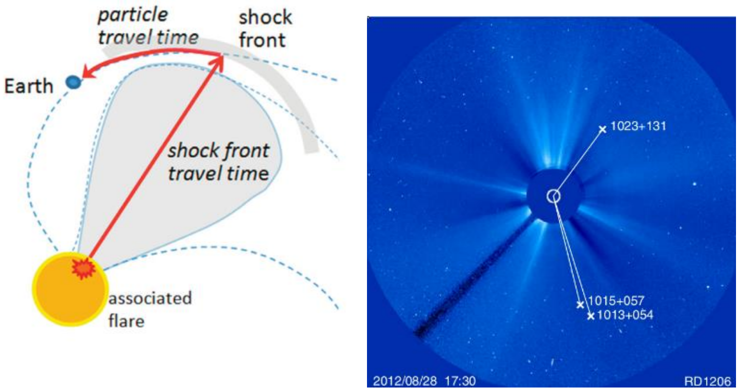

Fig. 5: Left: Shock interaction with the interplanetary magnetic field of SEP events associated to eastern events (Garcia-Rigo et al., 2016). Right: Radio source geometry and coronagraph images for VLBI experiment to assess the electron density of the solar corona (Soja et al., 2014)

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.

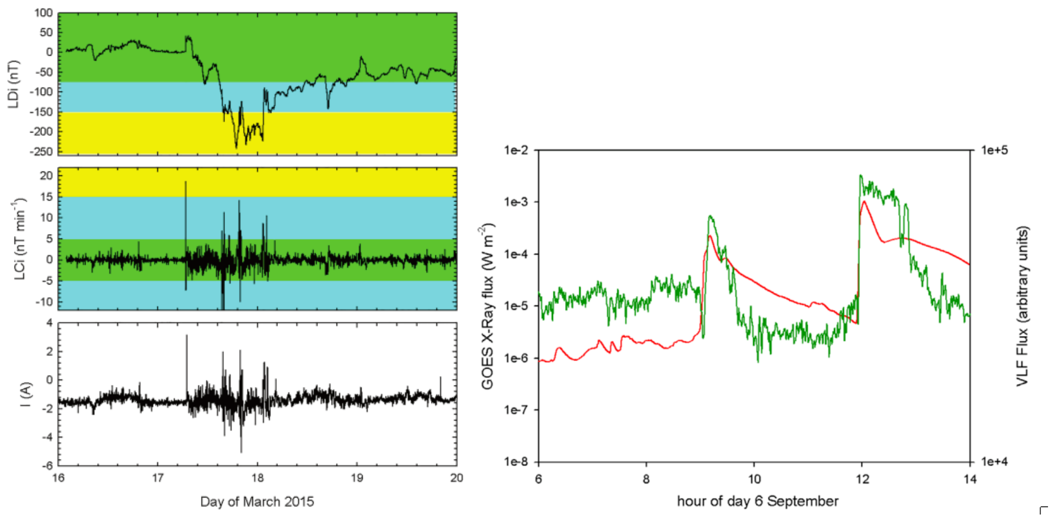

Fig. 6: Left: (from top to bottom) the LDi and LCi geomagnetic indices, and the geomagnetically induced current measured at a substation in the northwest of Spain by REE during the period from 16 to 20 March 2015. Colored areas in panels correspond to the five-level scale introduced to help decision 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).

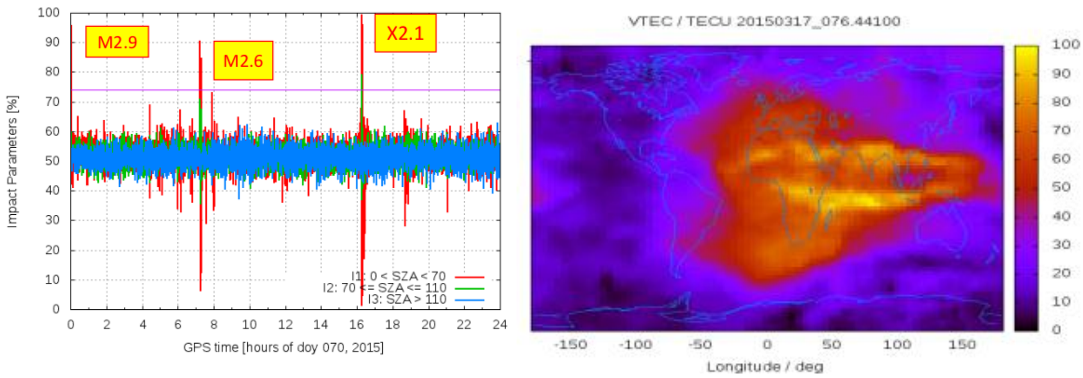

Fig. 7: Left: Detected solar flares prior to St. Patrick's day 2015 Geomagnetic Storm by means of SISTED detector, which relies on GNSS-based ionosphere monitoring (Garcia-Rigo et al., 2017; Borries et al. 2020). Right: UPC-IonSAT ionospheric TEC GIMs perturbed conditions during St. Patrick's day 2015.

To foster interdisciplinary cooperation, the Session AS52 "Ionospheric Space Weather Monitoring and Forecasting" at the Asia Oceania Geosciences Society (AOGS) 2023 from July 30 to August 4, 2023, was initiated and 19 abstracts were attracted; see Figure 8. Researchers from Geodesy and Space Physics will meet and exchange knowledge during this event.

AOGS 2023 20th Annual Meeting | Session AS52 "Ionospheric Space Weather Monitoring and Forecasting"

The Asia Oceania Geosciences Society (AOGS) 2023, the 20th annual meeting, will take place in **Singapore between 30 July and 04 August 2023**.

The following session is organized: **AS52 - Ionospheric Space Weather Monitoring and Forecasting**

Conveners:

- Haixia Lyu, Wuhan University, hxlyu@whu.edu.cn
- Sampad Kumar Panda, sampadpanda@gmail.com
- Punyawi Jamjareegulgarn, kjpunyaw@gmail.com

Session Description:

The Earth's ionosphere is highly variable due to the complex interaction in the solar wind-magnetosphere-ionosphere system, and the atmosphere-mesosphere-ionosphere coupling. It exhibits variation in different time scales and in different forms, e.g. gradients, disturbances, storms, etc. These abnormal or irregular behaviors of the ionosphere can adversely affect satellite navigation and communication systems on which nowadays human activities rely, thus the importance of ionosphere state monitoring and forecasting. Presently more and more observation instruments, networks, and satellite missions are built and launched for a better and deeper understanding of ionospheric climate features and space weather events. Benefiting from these observation plans, whether by state and/or commercial initiatives from different countries or by international collaboration, the impact of the ionosphere on GNSS positioning, telecommunication, and other techniques can be analyzed and evaluated. This session will cover the advancements in ionosphere modeling, forecasting, and validation, both globally and regionally. Analysis of the ionospheric space weather impact on the GNSS application and service is also welcome.

Please visit the conference website https://www.asiaoceania.org/aogs2023/public.asp?page=home.asp and submit your abstract to AS52 session by 14 February 2023.

Fig. 8: AOGS 2023 Session AS52 News released by the PITHIA-NRF project website

Among the fruitful research indicated in the publications, a new 3D ionosphere model based on characterizing shape function is constructed (Lyu et al. 2023), which deepens our understanding of the spatial variability of the ionosphere, thus with better prediction of the ionospheric state. This model will be further refined and shared with the JWG1 for assessment in order to facilitate the collaboration between JWG1 and JWG3.

It is worth mentioning that the newly built Chashan Broadband Solar millimeter spectrometer (CBS) has begun its routine observation from 35 to 40 GHz since 2020 and the first solar flare observation was reported by Yan et al. (2022). The CBS provides a new data source for space weather events and more synergy will be done in the future.

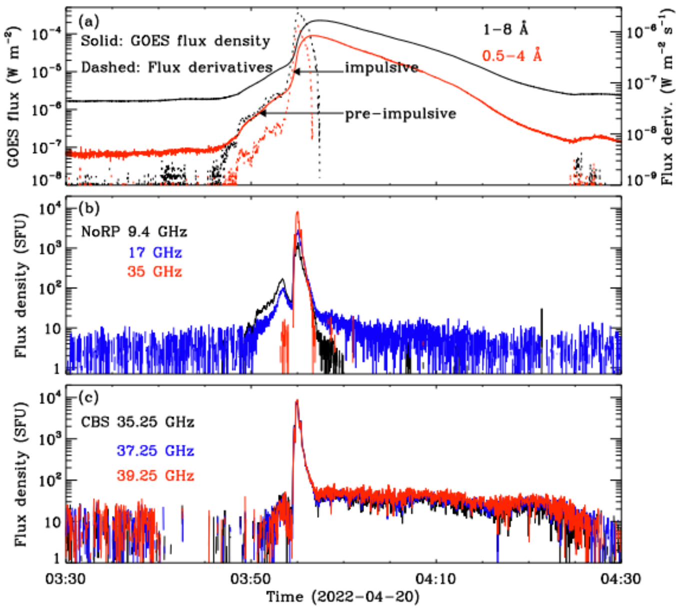

Fig. 9: Overview of the X2.2 flare observed by GOES, NoRP, and CBS on 2022 April 20 (Yan et al., 2022)

In a collaboration between IAG Sub-Commission 4.3 Working Group 4.3.2. "Ionosphere Prediction" and this FA-GSWR JWG 3, predictions of global ionospheric maps (GIMs) have been investigated. ETH Zurich provided predictions of one-day ahead forecasts that were then compared with those of other institutions. Three different types of predictions were computed, with one of them including data related to space weather and geomagnetic activity ("auxiliary data"). Comparisons of the results for quiet days in terms of ionospheric activity are given in Fig. 10, whereas the results for storm days are depicted in Fig. 11. The model that included auxiliary data did not result in improved predictive performance during quiet days, but delivered the best performance during the storm days.

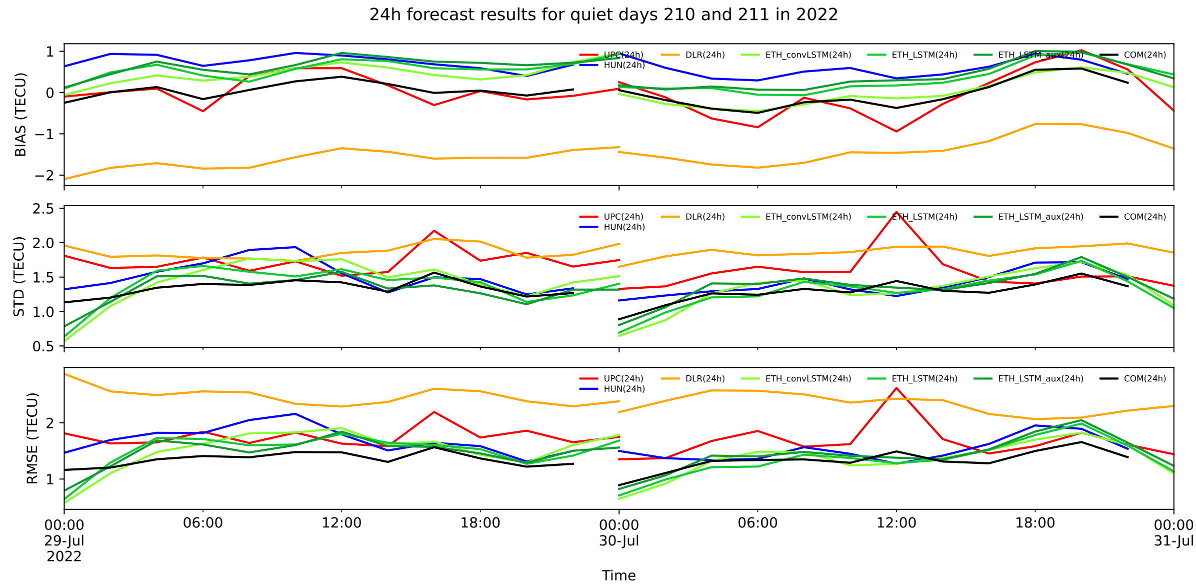

Fig. 10: One day ahead forecast errors of UPC (red), HUN (blue), DLR (orange), ETH models (shades of green; the model with space weather data is in dark green) and COM(black) with respect to IGS final maps on quiet days of 210 and 211 in 2022.

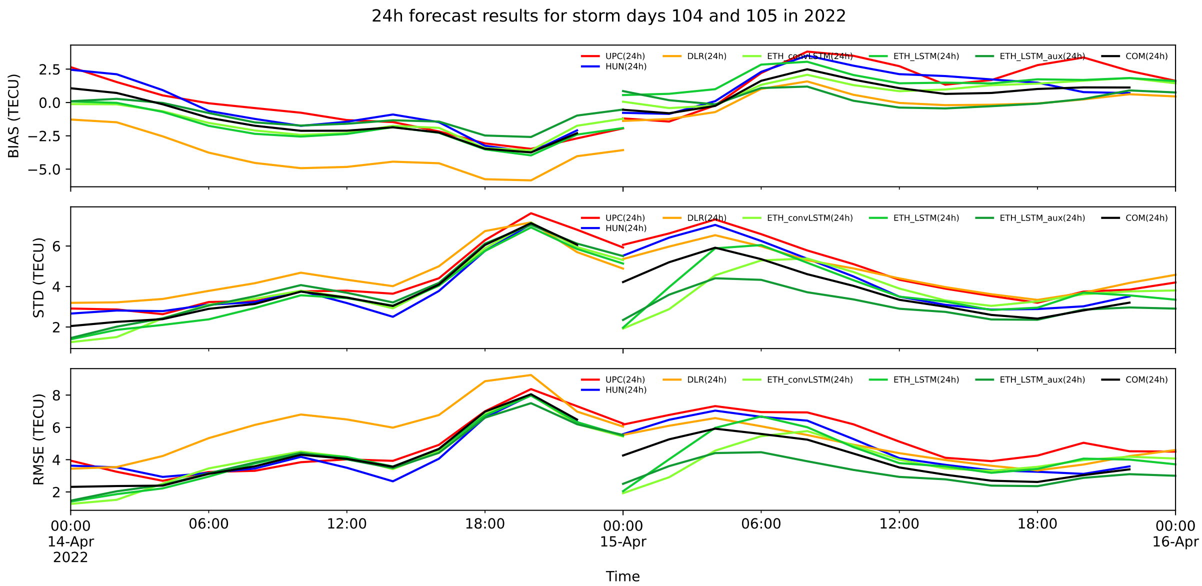

Fig. 11: One day ahead forecast errors of UPC (red), HUN (blue), DLR (orange), ETH models (shades of green; the model with space weather data is in dark green) and COM (black) and COM(black) with respect to IGS final maps on storm days of 104 and 105 in 2022.

In several publications and presentations by Natras et al. (2022a, b, c, d, e, f, 2023), space weather and geomagnetic data were used as input to machine learning models to predict VTEC at different latitudes. As shown in Fig. 12, in certain cases significant feature importance is attributed to the solar and geomagnetic data. This means that they have an impact on the prediction of VTEC. The physical relationship between VTEC and these parameters does not have to be exactly known as the machine learning algorithms learn the relationship between these variables.

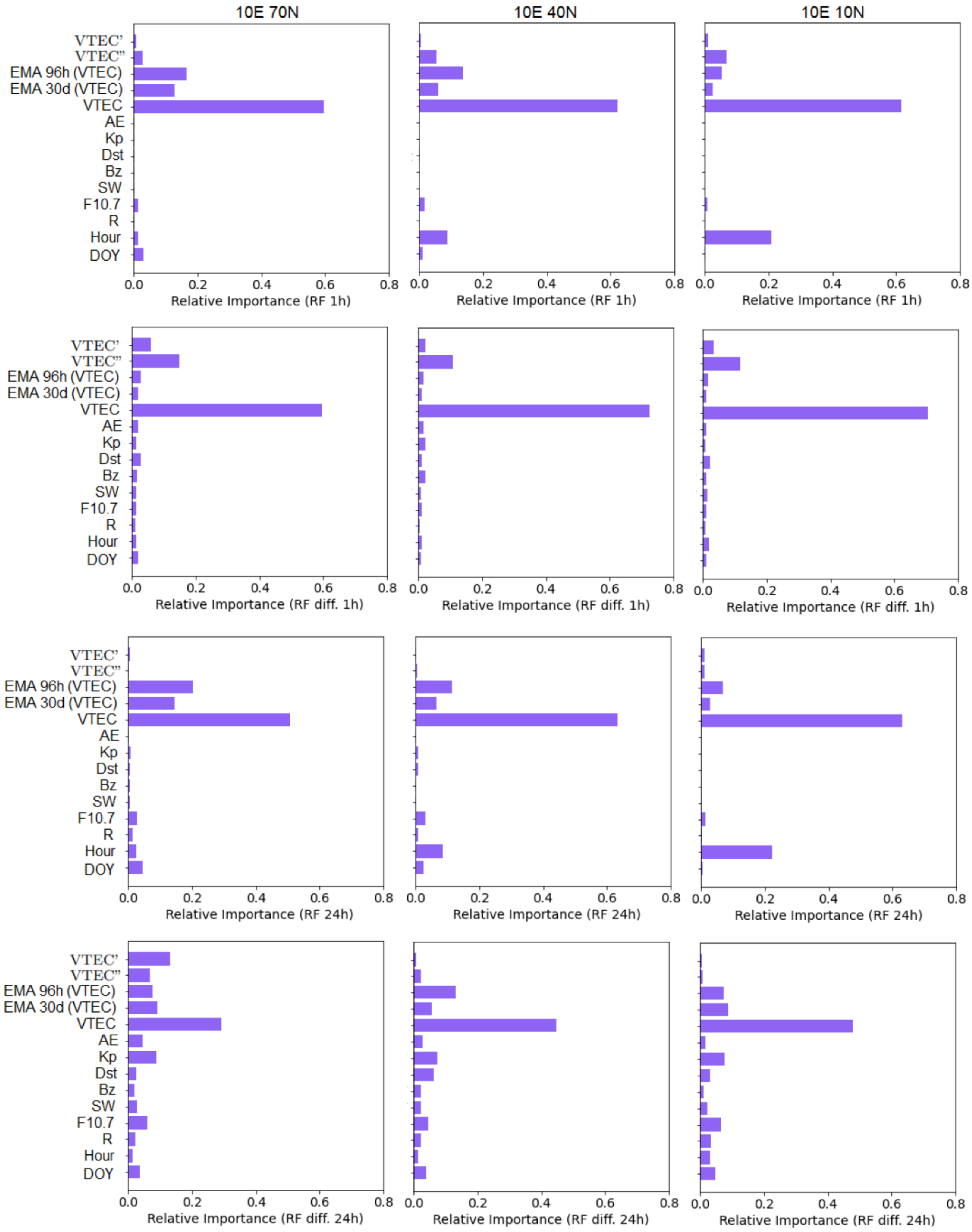

Fig. 12: Relative importance of input variables to VTEC forecast estimated from the Random Forest models. Results are presented for 1 h forecast with non-differenced data (first row) and differenced data (second row), and for 24 h forecast with non-differenced data (third row) and differenced data (fourth row) for high-latitude (left), mid-latitude (middle) and low-latitude (right) VTEC (Natras et al., 2022a).

In Awadaljeed et al. (2022), solar flux data from the Soil Moisture and Ocean Salinity (SMOS) mission was considered for improving predictions of ionospheric VTEC. The inclusion of the highly resolved solar flux data generally had a positive impact on the predictive performance, when included as input to most types of machine learning algorithms (Fig. 13). The work was presented at the "SMOS for Space Weather" workshop organised by ESA and shows how missions that were not originally intended for space weather monitoring can still make an important contribution.

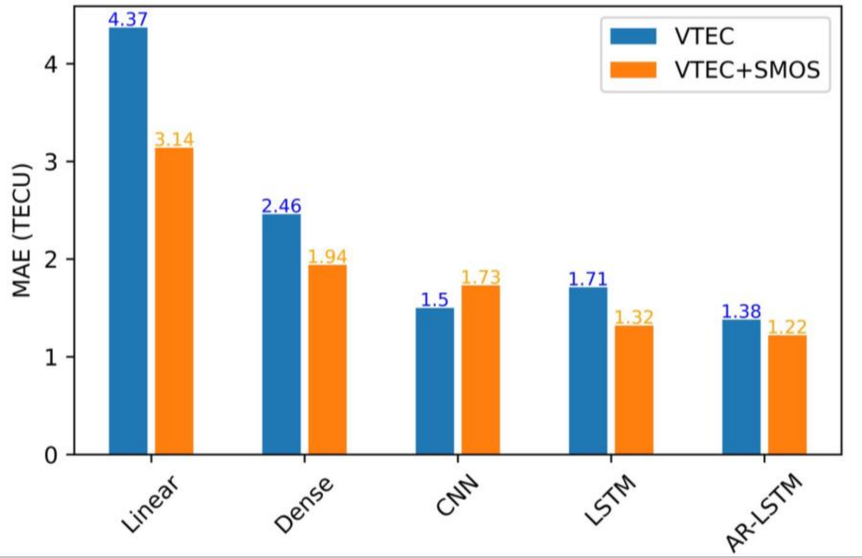

Fig. 13: VTEC prediction errors (in terms of Mean Absolute Error, MAE) of different machine learning algorithms. Blue bars indicate models that have only been trained on VTEC data. Orange bars represent models that include solar flux data from SMOS (Awadeljeed et al., 2022).

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.).

Publications

Abed, A. K., Qahwaji, R., Abed, A. (2021). The automated prediction of solar flares from SDO images using deep learning. Advances in Space Research, 67(8), 2544-2557.

Aroca-Farrerons, J., Hernández-Pajares, M., Lyu, H. (2022), Can the GEC be used as Space Weather index? Oral presentation in the 21st International Beacon Satellite Symposium, Boston, USA: 1-5 August 2022

Awadaljeed M., Kłopotek G., Soja B. (2022): "Exploring SMOS Solar Flux Data for Data Fusion with Machine Learning in the CAMALIOT Project"; Talk: 1st workshop on SMOS for Space Weather, ESA-ESRIN, Frascati, Italy; 2022-11-14.

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Focus Area "Artificial Intelligence for Geodesy" (AI4G)

Chair: *Prof. Dr. Benedikt Soja (ETH Zurich, Switzerland)*
Vice-Chair: *Dr. Maria Kaselimi (National Technical University of Athens, Greece)*

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Dr. Milad Asgarimehr (GFZ Potsdam, Germany)
Dr. Lei Liu (University of Colorado Boulder, USA)
Dr. Alexander Sun (University of Texas at Austin, USA)
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Dr. Justyna Śliwińska (Polish Academy of Sciences, Poland)

On May 12, 2023, the GGOS Coordinating Board accepted the proposal to establish a new GGOS Focus Area on Artificial Intelligence for Geodesy (AI4G). The establishment thus falls barely into the IAG period 2019-2023. As the Focus Area and its Joint Study Groups are currently in the phase of implementation, the report will not include a description of already completed activities, but rather on the goals, objectives, and planned activities of the Focus Area.

The Focus Area will utilize methods from the field of Artificial Intelligence (AI), including machine learning techniques, to improve geodetic observations and products.

Introduction

The field of artificial intelligence has seen rapid progress in recent years, with breakthroughs in areas such as natural language processing, computer vision, and deep learning. This progress has led to the development of new AI applications and technologies and has the potential to transform a wide range of industries and fields.

AI has become increasingly important in science, with applications in fields such as physics, biology, chemistry, and astronomy. It has become well-established in the neighboring disciplines of geodesy, including climate and weather prediction, space sciences, and remote sensing, helping to improve our understanding and prediction of complex natural phenomena. In general, AI can help scientists analyze complex data, identify patterns and relationships, and develop new hypotheses, ultimately accelerating the pace of scientific discovery.

Geodesy has seen a **significant increase in observational data in recent years**, for example in the case of Global Navigation Satellite Systems (GNSS) and InSAR missions. Furthermore, auxiliary data used in the analysis of space-geodetic data such as meteorological or environmental models have seen a significant increase in spatio-temporal resolution. Traditional data processing and analysis techniques that rely largely on human input are not well suited to harvest such rich data sets to their full potential.

Recent advances in the development of machine learning algorithms, in particular efficient implementations of deep neural networks, together with a significant increase in computing power, have the potential to facilitate:

- the automation of data processing,
- the detection of anomalies in time series and image data,
- their classification into different categories,
- modeling complex spatio-temporal data,
- and creating enhanced derivate products in geodesy.

For these reasons, there has been a strong increase in research related to AI and machine learning in geodesy, covering various problems, including those mentioned above in relation to geometric space-geodetic techniques, gravity field, and earth orientation parameters, among other topics.

Objectives

(1) Develop improved geodetic products based on AI and machine learning

The Focus Area aims to explore the potential of AI and machine learning methods in improving the quality and accuracy of geodetic observations and products. The objective is to develop new approaches and methods that can help extract valuable information from large and complex geodetic datasets and use this information to create more accurate and reliable products.

Depending on the application, improved geodetic products could have a higher accuracy, resolution, as well as better performance in in real-time or prediction scenarios. This will often involve assimilating data from different sources.

To achieve the above objective, it is important to **identify the most relevant and suitable geodetic and auxiliary datasets** that can be used for training and validating machine learning algorithms. This will involve selecting datasets that have the right spatio-temporal resolution, accuracy, and other relevant characteristics that can help improve geodetic products.

The Focus Area will also work on **designing appropriate machine learning methods** that can effectively improve the quality of geodetic data. This will involve exploring different machine learning algorithms, such as deep neural networks, and developing new techniques that can be used to analyze geodetic data.

(2) Evaluate improved geodetic products based on AI and machine learning:

Thorough quality assessment is essential for increasing trust in the products produced with the use of AI, especially considering the "black box" nature of deep learning algorithms.

The Focus Area will **compare the performance of different machine learning methods with traditional data analysis approaches**. This will involve identifying the strengths and limitations of each approach and determining the most appropriate method for a given application.

AI4G will pay particular attention to the accuracy, precision, and reliability of the results produced by machine learning algorithms. This will involve developing new techniques for **error assessment and uncertainty quantification**, and identifying potential sources of errors in the results.

Implementation

To achieve the objectives mentioned above, AI4G plans to implement at least three joint study groups, tackling specific topics related to the use of AI in geodetic observations and products. Concretely, we plan to establish study groups that will focus on GNSS remote sensing, gravity field and mass change determination, and Earth orientation parameter prediction.

JSG 1: AI for GNSS Remote Sensing

Chair: *Dr. Milad Asgarimehr (GFZ Potsdam, Germany)*
Vice-chair: *Dr. Lei Liu (University of Colorado Boulder, USA)*

The first study group will focus on GNSS remote sensing and will investigate topics such as ionosphere and troposphere modeling and prediction, as well as the retrieval of wind speed, soil moisture, and other environmental variables through GNSS reflectometry.

JSG 2: AI for Gravity Field and Mass Change

Chair: *Dr. Alexander Sun (University of Texas at Austin, USA)*
Vice-chair: *Dr. Saniya Behzadpour (ETH Zurich, Switzerland)*

The second study group will address the application of AI to improve the determination of the gravity field and the related mass change. The topics that will be covered include the fusion of gravity data with hydrological models, the downscaling of mass anomalies, bridging the gap between GRACE and GRACE-FO missions, and the improved processing of satellite gravimetry data.

JSG 3: AI for Earth Orientation Parameter Prediction
Chair: *Dr. Sadegh Modiri (BKG, Germany)*
Vice-chair: *Dr. Justyna Śliwińska (Polish Academy of Sciences, Poland)*

The third study group will explore the use of AI for predicting Earth orientation parameters. This group will build on the successful Second Earth Orientation Parameter Prediction Comparison Campaign organized by the International Earth Rotation and Reference Systems Service (IERS) and will continue to investigate machine learning for the prediction of Earth orientation parameters and effective angular momentum.

In addition to organizing joint study groups, AI4G also aims to facilitate collaboration beyond these study groups. The goal is to ensure that the methodological progress achieved in these study groups benefits the wider geodetic community. To this end, we plan to **organize events** such as workshops or summer schools in addition to sessions at scientific conferences to disseminate the findings of the joint study groups. The progress of the Focus Area will be documented on a **dedicated website** and advertised on social media.

The AI4G will **collaborate closely with existing components** of the International Association of Geodesy (IAG), in particular the working and study groups of its commissions and committees, as well as other relevant organizations, including the International Telecommunication Union (ITU) and its Focus Group on AI for Natural Disaster Management (FG-AI4NDM). In the case of IAG, the concrete ties will be defined when the working and study groups for the next four-year term are established following the IUGG General Assembly 2023 conference.