IGS INTERNATIONAL GNSS SERVICE

TECHNICAL REPORT 2024

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International GNSS Service

International Association of Geodesy
International Union of Geodesy and Geophysics

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Compiled in March 2024, by Rolf Dach and Elmar Brockmann (Eds.)

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Technical Report 2024

IGS Central Bureau

https://www.igs.org

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Published in May 2025

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IGS Technical Report 2024
ISSN: 2297-8526
ISBN: 978-3-03917-092-0 ; University of Bern, Bern Open Publishing.
DOI: 10.48350/191991

Cite as:
Dach, R., Bockmann, E. (eds.) (2025). *International GNSS Service Technical Report 2024 (IGS Annual Report).* IGS Central Bureau and University of Bern; Bern Open Publishing DOI 10.48350/191991

Abstract

Applications of the Global Navigation Satellite Systems (GNSS) to Earth Sciences are numerous. The International GNSS Service (IGS), a voluntary federation of government agencies, universities and research institutions, combines GNSS resources and expertise to provide the highest–quality GNSS data, products, and services in order to support high–precision applications for GNSS–related research and engineering activities.
This *IGS Technical Report 2024* includes contributions from the IGS Governing Board, the Central Bureau, Analysis Centers, Data Centers, station and network operators, committees, pilot projects, and others highlighting status and important activities, changes and results that took place and were achieved during 2024.

This report is available in electronic version at
https://files.igs.org/pub/resource/technical_reports/2024_techreport.pdf.

The IGS wants to thank all contributing institutions operating network stations, Data Centers, or Analysis Centers for supporting the IGS. All contributions are welcome. They guarantee the success of the IGS also in future.

IGS – Happy Birthday

Dear colleagues,

January 1st, 1994 did mark the official starting point of the IGS as an operational service of the IAG. So we can celebrate today the 30th anniversary of the IGS.

A lot of things have been achieved within the IGS (see for instance the plot on the GPS orbit combinations: http://acc.igs.org/media/Gmt_sum_final_all_orb_smooth_ALL.gif); we have not just a final but meanwhile a rapid, ultra-rapid and even a real-time product line. We have made progress in the inclusion of more and more systems into our operational product lines. With the regular reprocessing efforts the IGS strongly contributes to the ITRF solutions and allows the user community a direct access via the PPP approach. I know that this list of achievements is quite incomplete but I should resist to make the mail too long by listing all achievements of the last 30 years.

It is a good point to thank all people and their institutions supported the activities of the IGS in the past, present and in future for their contributions to the success story of this community. I had the pleasure to join many of the IGS workshops in the past and it was like a "come together event" of a big family in the scientific spirit of the "friendly competition".

All contributions to the community are important to keep the IGS a successful organization also in the future. Often only the big contributions like the central bureau, the data and analysis centers are very visible but each station or active participation in a working group (most of them became product committees with the most recent revision of the Terms of References) is important as well.

For the future I hope that we can continue our path of success with new groups and people getting involved (e.g., we are happy to welcome a new analysis center hosted by JAXA and GSI). This confirms that the IGS is still a field of interesting scientific work. We are seeking all the time for new people with new ideas to further develop the idea of the IGS and advance the quality of the products.

In this sense I'm looking forward to our next in person meeting at the IGS Symposium and workshop planned for the week from July 1st to 5th, 2024 (https://igs.org/workshop/2024/) where we are going to celebrate the IGS for Three Decades of Service to Science and Society.

I wish all the IGS contributors and friends of the IGS a good start into the new year 2024 – the 31st year of the IGS.

Best regards
Rolf Dach
(Chair of the IGS GB)

IGSMAIL-8411 sent from the IGS GB chair by January 1st, 2024

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Executive Reports

IGS Governing Board Annual Report 2024

Rolf Dach[1], Elisabetta D'Anastasio[2], Allison B. Craddock[3], Camille Martire[4]

[1] IGS Governing Board Chair
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1 Introduction

In 2024, the International GNSS Service (IGS) celebrated thirty years of operational service to science and society. The provision of free and openly available fundamental, high-quality geodetic products (GNSS satellite orbits, clock corrections, contributions to the terrestrial reference frame, and Earth rotation parameters) has been at the core of IGS activities since its inception. Over the past three decades, IGS has extended its activities to a significant number of applications based on GNSS data, supporting weather monitoring, ionosphere characterization, geodynamic or sea level change studies.

All these activities have been performed on a voluntary basis by contributing agencies and institutions around the world. The quality of IGS products has continuously improved over time, and is nowadays a demonstration of the tremendous effort invested by the many people worldwide who provide the necessary work for the IGS. A guiding principle since the beginning of IGS was - and still is - the free access to high-precision GNSS data and products and an open exchange of experience and knowledge. The IGS is currently on the path towards a full multi-GNSS Service with new multi-GNSS stations in the core network, extending the receiver antenna calibrations to new frequencies, and including all GNSS signals in the product generation. Several groups within the IGS community are currently working on developing a full multi-GNSS product combination for generating orbits and satellite clock products. This will be the last step of significant efforts towards a multi-GNSS service.

The IGS is led by the Governing Board (GB), elected by Associate Members who represent the IGS community as a whole (the largest set of contributing individuals providing a broad ensemble of inputs and efforts to the IGS). The GB discusses the activities of the various IGS components, sets policies, and monitors the progress with respect to the agreed strategic plan and annual implementation plan.

The GB continuously engages with our International User Community and their partner organisations, including the International Association of Geodesy (IAG), the Committee on GNSS (ICG), and the Global Geodetic Observing System (GGOS). Accordingly, some GB members also participate in the governance of IAG and GGOS bureaux, commissions, and Working Groups (WGs); this ensures that the IGS retains its strong level of international interconnectivity, significance, and sustainability. Importantly, GB members also participate in the United Nations Global Geospatial Information Management (UN-GGIM) and United Nations Global Geodetic Centre of Excellence (UN-GGCE) efforts on Geodesy, which aims to enhance the sustainability of the global geodetic reference frame through intergovernmental advocacy for geodesy.

After almost 5 years of virtual interaction and remote operations of IGS members as a response to the global pandemic, the IGS GB resumed in person meetings, now on an annual basis, and aligned with key IUGG, IAG, and/or IGS conferences and workshops. Furthermore, the GB was happy to return to in-person community workshops, especially on the occasion of celebrating 30 years of operations with an IGS Symposium and Workshop in July 2024 in Bern, Switzerland.

2 Membership and Governance

2.1 Membership Growth and Internal Engagement

The IGS membership consists of the Governing Board (GB) members, the Central Bureau (CB) members, and the Associate Members (AM). At the end of 2024, IGS counted over:

- 250 AMs (representing 46 countries/regions),
- 150+ contributing organizations participating within the IGS, including:
  - 100+ agencies operating GNSS Network Tracking Stations,
  - 6 Global Data Centers,
  - 13 Analysis Centers,
  - 31 Associate Analysis Centers,
  - 5 Product Coordinators,

- 22 Regional/Operational & Project Data Centers,
- 10 Committees
- 4 Pilot Projects, and
- 1 Working Group.

The Governing Board's 41 members guide the coordination of all of the aforementioned parties. The Central Bureau's 6 members function as the executive office of the Service holding all of the components of the IGS together by providing continuous management, technological support, and coordination of the IGS Information Systems, website, and outreach activities (see also the Central Bureau's Executive Report).

2.2 Current Status of the IGS Governing Board

The GB continues to be led by Rolf Dach (AIUB, Switzerland) in collaboration with GB Vice-Chair Elisabetta D'Anastasio (GNS Science Te Pū Ao, New Zealand). Allison Craddock (NASA JPL, USA) continues her appointment as CB Director in collaboration with CB Deputy Director Camille Martire [1] (NASA JPL, USA). Table 1 summarises the status of the Governing Board membership at the end of this year. Table 2 lists the IGS Component Vice-Chairs, who are de facto deputies to the corresponding IGS Component Chairs; they are not official members of the GB but play an important role in supporting it.

[1] Previously known as Léo Martire.

Table 1: Members of the IGS Governing Board as of January 2025.
Involvement is either of the following:
V if voting member, EC if member of the Executive Committee; observer otherwise.

Role	Name	Affiliation	Country	V	EC
Board Chair	Rolf Dach	Astronomical Institute, University of Bern	Switzerland	V	EC
Board Vice Chair	Elisabetta D'Anastasio	GNS Science Te Pū Ao	New Zealand	V	EC
CB Director	Allison Craddock	NASA Jet Propulsion Laboratory	USA	V	EC
CB Deputy Director	Camille Martire	NASA Jet Propulsion Laboratory	USA		EC
GB Executive Secretary	Camille Martire	NASA Jet Propulsion Laboratory	USA		EC
Network Coordinator	David Maggert	Earthscope Consortium	USA		
AC Coordinator	Thomas Herring	Massachusetts Institute of Technology (MIT)	USA	V	EC
AC Coordinator	Salim Masoumi	Geoscience Australia	Australia	*	
New ACC Representative**	***Taylor Yates***	NASA Goddard Space Flight Center (GSFC)	USA		
AC Representative	Sylvain Loyer	Collecte Localisation Satellites (CLS)	France	V	
AC Representative	Benjamin Männel	GFZ Helmholtz Centre for Geosciences	Germany	V	
AC Representative	Paul Ries	NASA Jet Propulsion Laboratory	USA	V	
DC Coordinator	***Ross Bagwell***	NASA Goddard Space Flight Center (GSFC)	USA		
DC Representative	Jianghui Geng	Wuhan University	China	V	
Network Representative	Rui Fernandes	University of Beira Interior (UBI); Institute Dom Luiz (IDL); SEGAL (UBI/IDL)	Portugal	V	
Network Representative	Ryan Ruddick	Geoscience Australia	Australia	V	EC
Network Representative	Wolfgang Söhne	Federal Agency for Cartography and Geodesy (BKG)	Germany	V	
Appointed Member	Fernand Balé	Bureau National d'Etudes Techniques et de Développement	Côte d'Ivoire	V	
Appointed Member	Werner Enderle	ESA/European Space Operations Centre (ESOC)	Germany	V	
Appointed Member	Satoshi Kogure	National Space Policy Secretariat (NSPS), Cabinet Office	Japan	V	
Appointed Member	José Antonio Tarrío Mosquera	University of Santiago de Chile (USACH)	Chile	V	
Appointed Member	***Neelu Kasat***	ISRO/ISTRAC - ISRO / Telemetry Tracking and Command Network	India	V	
Appointed Member	***Babatunde Rabiu***	NSRDA - National Space Research and Development Agency	Nigeria	V	

Changes since the last IGS Technical Report are font-coded: structural changes are in **bold**, new GB members are in ***bold italic***. The * denote specifics related to the ACC transition, see main text for explanations.

Table 1: Members of the IGS Governing Board, as of January 2025 (cont.)
Involvement is either of the following:
V if voting member, EC if member of the Executive Committee; observer otherwise.

Role	Name	Affiliation	Country	V	EC
Antenna Committee Chair	Arturo Villiger	Federal Office of Topography swisstopo	Switzerland	V	
Bias & Calibration Committee Chair	Stefan Schaer	Federal Office of Topography swisstopo	Switzerland	V	
Clock Products Committee Coordinator	Michael Coleman	Naval Research Laboratory (NRL)	USA	V	
Infrastructure Committee Coordinator	Markus Bradke	GFZ Helmholtz Centre for Geosciences	Germany	V	EC
Ionosphere Committee Chair	Andrzej Krankowski	University of Warmia and Mazury in Olsztyn	Poland	V	
Real-Time Committee Chair	Axel Rülke	Federal Agency for Cartography and Geodesy (BKG)	Germany	V	
Reference Frame Committee Chair	Paul Rebischung	Institut National de l'Information Géographique et Forestière (IGN)	France	V	
RINEX-RTCM Committee Chair	Francesco Gini	ESA/European Space Operations Centre (ESOC)	Germany	V	
SVOD Committee Chair	***Bingbing Duan***	TUM - Technische Universität München	Germany	V	
Troposphere Committee Chair	Sharyl Byram	United States Naval Observatory	USA	V	
IDEA Working Group Co-Chairs	***Elisabetta D'Anastasio & Camille Martire***	GNS Science Te Pū Ao & NASA Jet Propulsion Laboratory	New Zealand & USA		
GNSS Monitoring Pilot Project Chair	Erik Schönemann	European Space Agency / European Space Operations Centre	Germany	V	
Multi-GNSS Pilot Project Chair	***Peter Steigenberger***	Deutsches Zentrum für Luft- und Raumfahrt (DLR)	Germany	V	
PPP-AR Pilot Project Chair	Jianghui Geng	Wuhan University	China	V	
TIGA Pilot Project Chair	**DORMANT**			V	
Real-Time AC Coordinator	***Andrea Stürze***	Federal Agency for Cartography and Geodesy (BKG)	Germany	*	
IGS Representative to IERS	Elisabetta D'Anastasio	GNS Science Te Pū Ao	New Zealand	V	
IGS Representative to IERS	Rolf Dach	Astronomical Institute, University of Bern	Switzerland	V	
BIPM Representative to the IGS	Patrizia Tavella	Bureau International des Poids et Mesures (BIPM)	France		
FIG Representative to the IGS	Ryan Keenan	Positioning Insights	Australia		
GGOS President	Laura Sánchez	Deutsches Geodätisches Forschungsinstitut, Technische Universität München (DGFI-TUM)	Germany	V	
IAG President	Richard Gross	NASA Jet Propulsion Laboratory	USA	V	
IERS Representative to the IGS	Zuheir Altamimi	Institut National de l'Information Géographique et Forestière (IGN)	France	V	

Changes since the last IGS Technical Report are coded: structural changes are in **bold**, new GB members are in ***bold italic***. The * denote specifics related to the ACC transition, see main text for explanations.

Table 2: IGS Component Vice-Chairs as of January 2025.

IGS Component Vice Chair	Name	Affiliation	Country
Antenna Committee	***Tobias Kersten***	Leibniz Universität Hannover	Germany
Bias & Calibration Committee	vacant	n/a	n/a
Clock Products Committee	vacant	n/a	n/a
Infrastructure Committee	Ryan Ruddick	GA - Geoscience Australia	Australia
Ionosphere Committee	Zishen Li	CAS - Chinese Academy of Sciences	China
Real-Time Committee	***Ningbo Wang***	CAS - Chinese Academy of Sciences	China
Reference Frame Committee	Samuel Branchu	IGN - Institut National de l'Information Géographique et Forestière	France
RINEX-RTCM Committee	***André Hauschild***	DLR - Deutsches Zentrum für Luft- und Raumfahrt	Germany
SVOD Committee	vacant	n/a	n/a
Troposphere Committee	***Rosa Pacione***	e-GEOS - Agenzia Spaziale Italiana / Telespazio	Italy
IDEA Working Group	Not applicable: there are two co-Chairs.		
GNSS Monitoring	vacant	n/a	n/a
Multi-GNSS Pilot Project	***Kyohei Akiyama***	JAXA - Japan Aerospace Exploration Agency	Japan
PPP-AR Pilot Project	***Lotfi Massarweh***	DUT - Delft University of Technology	Netherlands

IGS Component Vice-Chairs as of January 2025. Changes since the last IGS Technical Report are font-coded: new Vice-Chairs are in ***bold italic***. Vice-Chairs are not official members of the GB but play an important role in supporting it.

The role of Analysis Centre Coordinator is currently jointly held by Geoscience Australia (Australia) and the Massachusetts Institute of Technology (MIT), but holds only one vote; for housekeeping purposes, we attribute it to MIT only, but note that the vote should reflect both institutions' positions. Taylor Yates (NASA Goddard Space Flight Center) joined the Governing Board as the representative of the new Analysis Centre Coordinator (see dedicated Section below) and will help coordinate the operational overlap period between the previous ACC and the new ACC.

Patrick Michael (NASA GSFC - Goddard Space Flight Center) was replaced by Ross Bagwell (NASA GSFC) in the position of Data Centre Coordinator. Oliver Montenbruck (DLR - Deutsches Zentrum für Luft- und Raumfahrt) stepped down from the voting role of Multi-GNSS Pilot Project Chair, and was replaced by Peter Steigenberger (DLR). Bingbing Duan (TUM - Technische Universität München) was elected as the new Chair for the Satellite Vehicle Orbit Dynamics Committee; this Committee had been discontinued in July 2023 (GB Decision 64-02), but the CB's final call for participation in December 2024 allowed to reignite interest in this important component. The IDEA (Inclusion, Diversity, Equity, and Accessibility) Working Group, created in November 2023 (GB Decision 65a-07), kicked off its activities in 2024, under the leadership of Elisabetta D'Anastasio (GNS Science Te Pū Ao) & Camille Martire (NASA Jet Propulsion Laboratory). Neelu Kasat (ISRO/ISTRAC - ISRO / Telemetry Tracking and Command Network) from India and Babatunde Rabiu (NSRDA - National Space Research and Development Agency) from Nigeria were elected as two new Appointed Members. Finally, José Antonio Tarrío Mosquera was renewed in his position of Appointed Member for another term.

In 2024, the Governing Board improved the overall sustainability of the Service by focusing on finding new Vice-Chairs for the many IGS Components. Out of 13 Components, only 3 (the Infrastructure, Ionosphere, and Reference Frame Committees) already had a Vice-Chair. Six new Vice-Chairs were identified, agreed to support the service as a deputy to the main Component Chair, and received support from the Governing Board. We recognise here their contribution to the IGS and welcome their help in safeguarding the future of these Components.

2.3 Diversity, Equity, Inclusion, and Accessibility

Following one of the goals set forth for 2023 in the 2022 Technical Report (GB Chapter, Section 8, page 14) and in alignment with Goal 2 and 3 of the IGS Strategic Plan 2021+, the IGS Governing Board created in early 2024 the IGS IDEA (Inclusivity, Diversity, Equity, and Accessibility) Working Group under co-leadership by Elisabetta D'Anastasio (GNS Science Te Pū Ao, New Zealand) and Camille Martire (NASA JPL, USA). Going forward, the report for this new Working Group will be included below in the "Committees, Pilot Projects, and Working Groups" Part of this Report.

3 Governing Board Meetings

The GB meets regularly to discuss the activities and plans of the various IGS components, sets policies, and monitors the progress with respect to the agreed strategic plan and annual implementation plan. For a summary of this year's Governing Board meetings, see the Central Bureau's Executive Report.

4 GB Accomplishments and Decisions in 2024

The past accomplishments and decisions can be found in the previous Technical Reports (https://igs.org/tech-report/). The accomplishments and decisions for 2024 are listed below:

- **GB 65b (February 2024)**

  Decision 65b-01: The CSWGG policy for sustainable governance was approved.
  Decision 65b-02: The CSWGG was dissolved after completing its mission.
  Decision 65b-03: The IGS Value White Paper shall be written from the IGS perspective only, at least at first.

- **GB 66 (June 2024)**

  Decision 66-01: When pertaining to IGS datasets and products, ESA shall not implement any DOI minting strategy before GB approval is acquired. The need for an organised IGS DOI linkage/reference policy was identified, as various IGS Components have been minting, and will continue to mint, DOIs containing data from other IGS Components.
  Decision 66-02: If IGS cannot be reclassified as an "institutional" contributor to the WDS, the IGS shall simply drop out of the WDS.
  Decision 66-03: The CB shall recommend RINEX4 as the only up-to-date standard for data provision, and pay particular attention to the operators only providing RINEX2 still.
  Decision 66-04: NASA shall take on the role of Analysis Centre Coordinator for the term 2024-2028.

- **GB 67 (September 2024)**

  No key decisions were made at this meeting.

- **GB 68 (December 2024)**

  Decision 68-01: The GB unanimously approved a 1-year extension for the previous ACC. The GB notes that this will allow for an overlap period between the previous and current ACC, which will maximise efficiency in the transition.
  Decision 68-02: The GB unanimously approved Ross Bagwell (NASA, USA) as the

new Data Centre Coordinator.

Decision 68-03: The GB approved Bingbing Duan (TUM, Germany) as the new Chair for the SVOD Committee.

Decision 68-04: The GB unanimously approved the renewal of José Antonio Tarrío Mosquera as Appointed Member.

Decision 68-05: The GB approved four (4) new Component Vice-Chairs ; André Hauschild (DLR, Germany) for the RINEX Committee, Rosa Pacione (e-GEOS, Italy) for the Troposphere Committee, Kyohei Akiyama (JAXA, Japan) for the Multi-GNSS Pilot Project, and Lotfi Massarweh (Delft University of Technology, Netherlands) for the PPP-AR Pilot Project. The SEC notes that all of them were first approved internally by the members of the corresponding Components.

Decision 68-06: The GB decided to open the two Appointed Member positions. The GB unanimously approved Neelu Kasat and approved Babatunde Rabiu as the two new Appointed Members.

Decision 68-07: The Wuhan Combination Centre Pilot Project was approved by the GB and thus created as a new Pilot Project.

Decision 68-08: In order to change a station name, the station shall have to be formally decommissioned and re-commissioned. This rule shall be added to the CORS Guidelines.

Decision 68-09: The Central Bureau will halt social media presence on X (formerly known as Twitter).

5 Operational Activities

5.1 Network Growth and Coordination

Daily network operations are the heart of the IGS – various components of the service ensure that data and products are made publicly available at least on a daily basis. Over 500 IGS Network sites (see Figure 1) are maintained and operated globally by a broad array of institutions and station operators. Data continues to be available to the public and the scientific community, with latencies ranging from daily to real-time.

During 2024, 14 new stations were added to the IGS network, and 5 stations were identified for decommissioning; the list can be found in the Infrastructure Committee's Report. The number of multi-GNSS stations increased from 374 to 388 (+14), while the number of real-time-capable stations increased from 308 to 327 (+19). The CB wishes to gratefully acknowledge the efforts of the institutions in charge of the stations, both new and decommissioned. Additionally, in 2024, there were 51 changes to the `rcvr_ant.tab`[2] file,

[2] https://files.igs.org/pub/station/general/rcvr_ant.tab, https://files.igs.org/pub/station/general/rcvr_ant.json

222 site log updates (≈18 per month), and 6 antenna changes at IGS20 reference frame stations.

5.2 Analysis Centre Coordinator Transition

The new Analysis Center Coordinator (ACC) was selected and announced at the IGS Workshop in July 2024. This new ACC team is a NASA/GA + MIT/GFZ partnership that combines the strengths of multiple organizations, including the experience of the current GA+MIT team, in service to the IGS. The primary focus for this new team in 2024 was the selection of Taylor Yates (NASA GSFC) to serve in the primary ACC role at NASA. Additionally, during this period, NASA established the cloud infrastructure that will be necessary for the transition of primary operations from GA to NASA. This concluded one of the most important objectives set forth for 2023 Technical Report.

The ACC transition for GA/MIT to NASA/GA started as planned in late 2024. The timeline for the transition will include Taylor Yates' in-person training and discussions at GA from February to March 2025. After this training, NASA staff will have access to a combination server and will be able to plan the transition to the installation of the legacy software in the NASA cloud environment. Between April and December 2025, the operational processing will run in parallel between NASA and GA. In late 2025 and

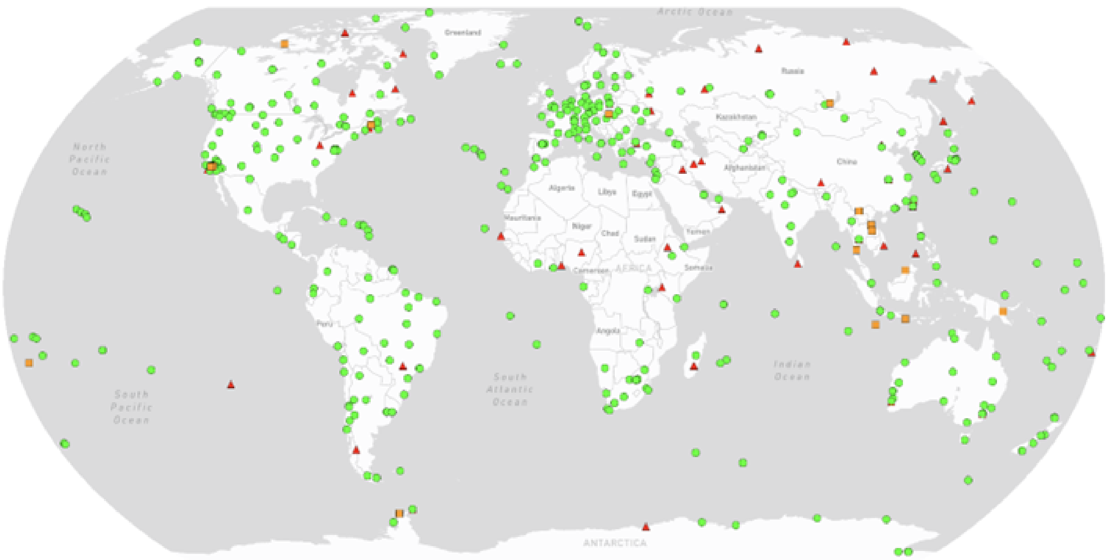

Figure 1: The IGS Network, as of the 1st of January 2025. The map showcases 522 stations in total, including 388 tracking multiple GNSS constellations and 327 having real-time caster capabilities. The IGS collects, archives, and freely distributes Global Navigation Satellite System (GNSS) observation data sets from a cooperatively operated global network of ground tracking stations. The live version of this map is available at `https://network.igs.org`.

possibly early 2026, NASA will take over the operational responsibility for generating the combined IGS products. GA and MIT will still be available to provide support as needed.

5.3 Analysis Centre Coordination and Product Generation

In parallel to the ACC Transition, the IGS Analysis Center Coordination (https://igs.org/acc) continued throughout 2024 to be jointly led by Salim Masoumi (Geoscience Australia, Australia) and Tom Herring (Massachusetts Institute of Technology, USA). The legacy operations remained based at Geoscience Australia in Canberra (Australia), while the combination software remained housed on cloud-based servers located in Australia and Europe; cloud operations ran smoothly throughout the year. The IGS product generation continued to be carried out solely by personnel at Geoscience Australia. MIT provides scientific guidance and suggestions on products. The IGS continues to maintain a very high level of product availability. For more details, see the Analysis Center Coordinator Report.

In 2024, the IGS ACC continued provision of multi-GNSS ultra-rapid orbit combinations as demonstration products. These ultra-rapid orbits are combinations of GPS, Galileo and GLONASS orbits provided by the IGS Analysis Centres, and are a step towards achieving a truly multi-GNSS IGS. IGS ACC is contributing to the IGS multi-GNSS Task Force in forming the future of the multi-GNSS combined products.

During 2024, the multi-GNSS orbit combination created at GA (ROCS, Robust Orbit Combination Software) was released as open-source (see IGSMAIL #8539). The multi-GNSS task force group are also leading tests running comparisons of different combinations using the GFZ's SPOCC and GA's ROCS software. In addition, a clock and bias combination software has been offered by Natural Resources Canada (NRCan), which the IGS ACC is planning to trial enabling the provision of multi-GNSS clock and bias combinations along with the orbits, supporting PPP with ambiguity resolution.

5.4 IGS Reference Frame Updates

The generation of the daily, weekly and long-term IGS terrestrial frame (SINEX) solutions continued to be carried out seamlessly by IGN throughout the year.

Following the release of the first annual update of ITRF2020, called ITRF2020-u2023, in December 2024 (IGSMAIL #8542), an update to the IGS20 reference frame was defined. It is called IGb20 and will be adopted for the alignment of the IGS products starting with the products of GPS week 2352 (February 2, 2025). More details on this new IGb20 reference frame and its usage may be found in IGSMAIL #8543.

A campaign for the calibration of the BDS-3 and QZSS satellite antennas was jointly coordinated by the IGS Reference Frame Committee, Multi-GNSS Pilot Project, and Antenna Committee. The IGS ANTEX file (igs20.atx) will shortly be updated with the BDS-3 satellite antenna phase variation patterns and phase center offsets, compatible with the IGS20 reference frame, determined during this campaign. The results for the QZSS satellites still need to be consolidated. This opens the way for a seamless incorporation of the BDS-3 (and later QZSS) constellations into the IGS operational processing, and completes another of the objectives set forth in the 2023 Technical Report.

5.5 Data Management

Thirteen (13) Analysis Centers and twenty-one (21) Associate Analysis Centers continue to utilise tracking data from between 70 to more than 500 stations to generate precision products up to four times per day. Product coordinators combine these products on a continuous basis and assure the quality of the products made available to the users. Collectively, the IGS produces more than 700 IGS final, rapid, ultra-rapid and GLONASS-only product files, as well as 133 ionosphere files weekly. Furthermore, troposphere files for more than 400 stations are produced on a daily basis. Delivery of the core reference frame, orbits, clocks, and atmospheric products continued. The IGS has also seen further refinement of the Real Time Service with considerable efforts being targeted towards development of standards.

The intense interest of users in IGS data and products is reflected in the user activity recorded by the various IGS Global and Regional Data Centres. The amount of IGS tracking data and products hosted by each of the six global Data Centers on permanently accessible servers increased from 2 TB in 2017 to 62 TB (over 453 million files) at the end of 2024, supported by significant additional storage capabilities provided by Regional Data Centers.

In particular, the Crustal Dynamics Data Information System (CDDIS) at NASA's Goddard Space Flight Center now totals 873 M files equating to 328 TB of GNSS data, and 67 M files equating to 23 TB of GNSS products. The average monthly download load in 2024 reached 48 M GNSS data files (equating to 16.1 TB) by 12 K unique users, and 3 M GNSS products files (equating to 1.5 TB) downloaded from 6 M unique users.

Furthermore, the Wuhan University Data Center has accumulated a total of 36.3 TB of GNSS data and products so far. The average monthly download load in 2024 reaches 37.2 M GNSS data and products files (equating to 23.8 TB) downloaded by 1.4 K unique users (an increase of 4.2 TB since last year).

6 External Engagement

At the direction of the Governing Board, the Central Bureau works with various components of the **International Association of Geodesy (IAG)** in order to promote communications and outreach, for instance with the IAG Communications and Outreach Branch and the **Global Geodetic Observing System (GGOS)**. IGS Associate Members (AMs) and GB members are also active participants in the **United Nations Initiative on Global Geospatial Information Management (UN GGIM)** Sub-Committee on Geodesy (`http://ggim.un.org/UN_GGIM_wg1.html`), and cover contributions to the five focus groups developed for the UN GGIM Global Geodetic Reference Frame Roadmap.

Additionally, IGS is an Associate Member of the **International Committee on GNSS (ICG)**, based under the aegis of the **United Nations Office for Outer Space Affairs (UN OOSA)**. Namely, IGS co-chairs the ICG's Working Group D (on "Reference Frames, Timing, and Applications") alongside BIPM, CNES, FIG, IAG, and IGN. The ICG also hosts the International GNSS Monitoring and Assessment (IGMA) Task Force (TF), in which the IGS' GNSS Monitoring Pilot Project holds a prime advisory role. Finally, the recently-created TF on "Applications of GNSS for Disaster Risk Reduction" (DRR TF) is led by IGS and co-chaired by China and Japan. In 2024, CB Director Allison Craddock represented IGS in person at the 18th meeting of the ICG (ICG-18) in October 2023, supported online by CB Deputy Director Camille Martire (NASA JPL, USA), while GNSS Monitoring Pilot Project Chair Erik Schönemann (ESA, Germany) represented the IGS in the IGMA TF. The WG-D, the IGMA TF, and the DRR TF all reported significant progress during ICG-18, with details reported in the ICG-18 Joint Statement. In particular, the IGS contributed to discussions around the creation of a new Working Group on Lunar PNT and secured the publication by ICG of a policy brief on the uses of GNSS for disaster risk reduction.

7 Future Steps for 2025

The IGS will continue to follow stakeholders' expectations for improved product timeliness, fidelity, and multi-GNSS compliance. The GB, CB, and Associate Members will continue their efforts towards enhancing advocacy for the IGS. Members of the IGS will continue giving presentations at a variety of forums within our discipline and outside of it, ensuring that the efforts of all contributors are acknowledged. In this way, the IGS will continue to build its user base, resulting in enhanced sustainability overall.

Among of important initiatives are considered for 2025. The licensing and citation of IGS data has become a very important topic for the sustainability of the Service. As such, the IGS as a whole will work towards establishing Service-wide policies to support the correct licensing and citation of our data and products, which will contribute to the sustainability of the IGS and to accurately acknowledging the contributions from its many international collaborators.

Finally, the GB thanks all participants within the IGS for the efforts, with particular thanks going to the Component Chairs who ended their current terms this year. Without the contributions of all, the IGS could not have achieved the significant outcomes detailed in this report.

8 Publications and Official IGS Citation

Official publications pertaining to the IGS are:

- previous Technical Reports:
  - IGS 2020 Technical Report
  - IGS 2021 Technical Report
  - IGS 2022 Technical Report
  - IGS 2023 Technical Report
- Terms of Reference:
  - IGS 2019 Terms of Reference
  - IGS 2023 Terms of Reference

It is expected that the IGS is properly acknowledged by referencing the IGS chapter found in the 2017 Springer Handbook of Global Navigation Satellite Systems:

> Johnston, G., Riddell, A., Hausler, G. (2017). The International GNSS Service. In Teunissen, Peter J. G., and Montenbruck, O. (Eds.), Springer Handbook of Global Navigation Satellite Systems (1st ed., pp. 967-982). Cham, Switzerland: Springer International Publishing. DOI: 10.1007/978-3-319-42928-1.

IGS Central Bureau
Annual Report 2024

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1 Introduction

In order to sustain the multifaceted efforts of the IGS, the Central Bureau (CB) works to support and realise the IGS strategic goals: achieving multi-GNSS technical excellence, strengthening public outreach and engagement, and building sustainability and resilience. The CB work program is shaped by the directives and decisions of the IGS Governing Board (GB) and IGS Executive Committee (EC), which often tasks members of the CB with representing the outward face of IGS to a diverse global user community and the general public.

The CB is funded by the United States National Aeronautics and Space Administration (NASA) and hosted at the Jet Propulsion Laboratory (JPL) in Pasadena, California, USA. This office is led by the CB Director Allison Craddock (NASA JPL, USA) with

Table 1: IGS Central Bureau staff and responsibilities. NASA is the National Aeronautics and Space Administration. JPL is the Jet Propulsion Laboratory (Pasadena, USA). JPL is managed by the California Institute of Technology (Caltech) for NASA.

Name	Affiliation	Role
Allison Craddock	NASA JPL	Director
Camille Martire	NASA JPL	Deputy Director
David Maggert	EarthScope Consortium	Network Coordinator
David Stowers	NASA JPL	CBIS Advisor
Robert Khachikyan	Raytheon Technologies	CBIS Manager
Brian Kohan	Raytheon Technologies	CBIS Engineer

support from Deputy Director Camille Martire (NASA JPL, USA). The CB also works as the command-and-control centre for tracking network operations, mostly overseen by the Network Coordinator, David Maggert (EarthScope Consortium, USA). Additionally, the CB manages the primary IGS Information System (CBIS), the principal information portal where the IGS web, data, and mail services are hosted; these tasks are led by Robert Khachikyan (Raytheon Technologies, USA). A list of the CB members along with their respective roles and responsibilities is given in Table 1 ; the full-time equivalent effort of CB staff is approximately 2.5 FTE.

2 Summary of Accomplishments

This Section highlights the progress made by the IGS CB in 2024. In general terms, the CB continues to strive for maximum efficiency in holding IGS activities and leading administrative operations, and continues to pay particular attention to equitably represent different regions of the world by adjusting the meeting times to various time zones and technology bandwidths. Aside from these important considerations, the CB has also achieved the following items:

1. Supported the timely delivery and dissemination of IGS Data and Products.
2. Maintained the public IGS GitHub Repository, in particular with respect to issues submitted by users.
3. Supported the dissemination of IGS Guidelines, Formats, and Standards; namely including the RINEX 4.02 format, the Procedure for Becoming an IGS Station, the IGS CORS Guidelines and their translations in various languages (DE, ES, FR), the IGS Guidelines for Long Product Filenames, the IGS Governing Board Elections Process, the Guidelines and Code of Conduct for IGS Events, Guidelines for IGS Analysis Centers, and the IGS Inclusivity, Diversity, Equity, and Accessibility Statement (see `https://geodesy.science/idea/working-groups/igs/`).

4. Successfully organised 4 Governing Board Meetings, 8 Executive Committee meetings, and 2 Associate Member Meetings (see next Section).

5. Coordinated, supported, and participated in the Standing Elections Committee (SEC) on the 2024 GB elections.

6. Provided administrative support to several IGS Components on an as-needed basis, including for instance meeting scheduling, voting form coordination, document hosting and publishing, etc..

7. Represented the IGS and its community interests at various stakeholder levels, including but not limited to: the United Nations Office for Outer Space Affairs' International Committee on GNSS (ICG), the Subcommittee on Geodesy of the United Nations Committee of Experts on Global Geospatial Information Management (UN GGIM), the World Data System (WDS), the International Association of Geodesy (IAG) Inter-Commission Committee on Climate, and the IAG Global Geodetic Observing System (GGOS).

8. Led the ACC Transition to a successful conclusion. This included, namely, coordinating meetings for establishing a timeline, distributing the calls for participation, collecting the various applications, and conceptualising a voting procedure for the very first time. See details in the corresponding Section in the GB Executive Report. This concluded one of the most important objectives set forth for 2024 in the 2023 Technical Report.

9. Continued and enhanced the IGS' social media presence.

3 Coordination of Meetings in 2024

The CB coordinated the necessary logistics and administrative organisation for four (4) Governing Board (GB) meetings (3 virtual and 1 hybrid), eight (8) Executive Committee (EC) virtual meetings, and two (2) Associate Member virtual meetings. A detailed list of these activities can be found in Table 2. In addition, the CB coordinated Standing Elections Committee meetings for the 2024 GB Elections.

Table 2: 2024 meetings led and/or coordinated by the Central Bureau. While topics of the various GB meetings are reported here, official GB decisions are reported in the GB Executive Report.

2024 IGS Workshop

01-05 July 2024 (partially hybrid)
See Section below.

GB Meetings

26 February 2024 (GB65b, virtual)
A final update from the Committee on Sustainable Working Group Governance and approval of the corresponding policy; the Multi-GNSS Transition; the ACC Transition; the IGS Value white paper; a report from the Inclusivity, Diversity, Equity, and Accessibility Working Group; the transition to Alpha-3 codes for countries and regions; and updates on the planning efforts for the 2024 IGS Workshop.

30 June 2024 (GB66, hybrid)
Data Licensing and Digital Object Identifiers for IGS Data and Products; numerous Central Bureau updates (RTCM dues, Technical Report, IGS Workshop, World Data System involvement, AM Database transition, network coordination, and opportunities for virtual secondments); updates on ESA's GENESIS project; the Multi-GNSS transition and the future of the MGEX Pilot Project; IGS Components' plans for the IGS Workshop; ACC Candidates' presentations and statements, the 2026 IGS Workshop (in Santiago de Chile, Chile); the call for proposals for the 2028 IGS Workshop; an introduction of the United Nations Global Geodetic Center of Excellence; and the IGS session at AGU2024.

30 September 2024 (GB67, virtual)
The ACC Transition (led by the new ACC, NASA/GA/GFZ/MIT); the v4.02 of the RINEX format; a review of the IGS Workshop Recommendations from all IGS Components; and the current status of the 2024 GB Elections.

03 December 2024 (GB68b, virtual)
The conclusion of the 2024 GB Elections; Data Licenses for IGS Data and Products; updates from the new ACC; updates from the Infrastructure Committee; and 2028 IGS Workshop proposals.

Table 2: 2024 meetings led and/or coordinated by the Central Bureau (cont.).

Associate Member Meeting

015 February 2024 (7th AM Meeting, virtual)
Special AM Meeting on the topic of the ACC Transition. Presentation of the call for participation and of the currently known candidate combination softwares.

03 December 2024 (GB68a, virtual)
Updates from IGS Components (Committees, Pilot Projects, and Working Groups). Updates from the new ACC (NASA/GA/GFZ/MIT) and from the newly-introduced Wuhan Combination Centre (WCC).

Executive Committee Meeting

09 January 2024

13 March 2024

09 April 2024

13 May 2024

18 June 2024

10 September 2024

21 October 2024

12 November 2024

3.1 2024 IGS Symposium and Workshop - 30th Anniversary of the IGS

After the IGS started its operational service on the 1st of January 1994, the first IGS Workshop was held at the premises of the University of Bern from the 25th to the 26th of March 1993 and focused on the Analysis Centres activities related to the pilot campaign started in 1992. The first decade of operational service was celebrated at an IGS Workshop hosted again in Bern Switzerland by the University of Bern in March 2004. In 2024, the IGS once again met in Bern to mark another milestone: 30 years of operational service.

The 2024 IGS Workshop took place from the 1st to the 5th of July, 2024, and was hosted by the Astronomical Institute of the University of Bern, together with the CODE Consortium (AIUB: Astronomical Institute of the University of Bern, Switzerland; swisstopo: Swiss Federal Office of Topography, Wabern, Switzerland; BKG: Federal Agency for Cartography and Geodesy, Frankfurt a. M., Germany; IAPG/TUM: Institute for Astronomical and Physical Geodesy, Technical University of Munich, Germany). The workshop was organized in two parts: 3.5 days of symposium-style presentations, keynotes, and poster sessions, and 1.5 days of in-depth Working Group sessions.

The Central Bureau supported the development of the event, agenda, website, and other planning efforts. We extend our thanks to the local and scientific organizers for their extensive efforts to ensure this workshop was a success, and look forward to assisting the organizers of our 2026 IGS Workshop. Ensuring successful workshops directly contributes to the goals and objectives of the IGS 2021+ Strategic Plan, providing facilitation, coordination, incubation, and advocacy for multi-GNSS technical excellence, community engagement, and organisational resilience.

3.2 Standing Elections Committee and Governing Board Elections Coordination

The SEC is responsible for the yearly GB Elections and is supported by the Central Bureau. This year, due to increased workforce needs to organise the 2024 Elections, the CB offered a more in-depth coordination role to the SEC. Together, the CB and SEC nominated and vetted the various candidates, contacted, and coordinated with people whose terms were up for renewal, worked with the EC for pre-approvals when relevant, and handled the end-of-term cases when applicable.

In 2024, the SEC was chaired by Elisabetta D'Anastasio (GNS Science | Te Pū Ao, New Zealand) and composed of Camille Martire (NASA JPL, USA), Ryan Keenan (Positioning Insights, Australia), Wolfgang Söhne (BKG, Germany), and Benjamin Männel (GFZ, Germany).

This year, the SEC handled all positions up for elections/reelections and provided significant work in reaching out to IGS Components without a Vice-Chair. Full details on the resulting GB composition changes are detailed in the "Current Status of the IGS Governing Board" section of the GB Executive Report.

The position of Analysis Center Coordinator was a special case due to the ACC Transition, and is beeing transferred to Taylor Yates (NASA GSFC, USA). The SVOD Committee and TIGA Pilot Project had been discontinued/vacant since July 2023 (GB Decision 64-02), but were reconsidered in 2024; for SVOD, candidates were found and the election could take place; for TIGA, interested parties were found but no Chair volunteered, so this item is still currently in progress.

Following the Governing Board desire to enhance outreach and engagement activities in Africa (a 2024 objective set forth in the 2023 Technical Report), the SEC researched potential collaborators on that continent and nominated Babatunde Rabiu (National Space Research and Development Agency, Nigeria) for the position of Appointed Member. Along the same ambition, the SEC also nominated Neelu Kasat (ISRO Telemetry Tracking and Command Network, India) for another Appointed Member position to improve our relations and engagement in the Republic of India and with its regional constellation "Navigation with Indian Constellation" (NavIC). Both Doctors Rabiu and Kasat were elected in these positions by the Governing Board, during the 68th GB meeting (Part B).

In addition to handling the various election items, the SEC also overhauled the documentation for the IGS Governing Board Elections Process for clarity and impartialness. The new document presents a streamlined process and workflow, ensuring IGS processes are as transparent as possible. It was published on the IGS website at https://files.igs.org/pub/resource/governance/GB_Elections_Process.pdf.

4 Central Bureau Information Systems (CBIS)

The CB continuously works toward maintaining and improving a number of critical public-facing web applications. The most important of them are the IGS Website, the Site Log Manager (SLM), the IGS Network Map, and the Associate Member (AM) Database. We describe in the following Sections the latest updates concerning these crucial systems.

4.1 IGS Website and Archives

The IGS Website (https://igs.org), meticulously curated by the CBIS team, stands as the prominent public interface of Service, and must therefore embody a commitment to excellence. As of today, it prioritises user satisfaction, accessibility, and effectiveness; namely through an intuitive and secure navigation structure adhering to web accessibility standards. Regular content updates, covering news, events, and institutional changes, reflect a dedication to keeping our users informed. A cohesive brand identity and interactive features (including feedback mechanisms and multimedia content) ensure consistent user engagement and create a dynamic online environment with which they can interact.

Practically speaking, the IGS Website is key for the CB to support all IGS events, and especially the virtual ones. Besides featuring the advertisement of events and registration information, the website also serves as an online catalogue of recorded presentations and other resources to the community after an event has been completed. It features the latest IGS workshops (https://igs.org/workshops), the Tour de l'IGS series (https://igs.org/tour-de-ligs/), important formats and standards (https://igs.org/formats-and-standards), reference documents (https://igs.org/documents/), and a variety of news relevant to the community (https://igs.org/news/, https://igs.org/tech-report/). This effort consolidated all current information in a more visible and easily accessible part of the CBIS.

In 2024, https://files.igs.org has served approximately 290 K users with approximately 22 TB of data. Roughly 120 K users were new users not previously known to our domain. https://slm.igs.org registered roughly 9 K visits by transferring about 150 GB of data. https://igs.org served approximately 620 K visitors with roughly 3 + TB of data.

4.2 Open-Source Site Log Manager and Network Map

Both the IGS Mission statement and IGS 2021+ Strategic Plan goals underline the importance of open access to data and products, which facilitates collaborations, standardisation, and inclusivity. Open access data enables scientists to visualise the geospatial coverage of the IGS Network, investigate the type of GNSS data from stations, view real time capabilities, and know the various data centres for sourcing GNSS data (CDDIS, etc.).

On one hand, the IGS Site Log Manager (SLM, https://slm.igs.org) is a web-based online application designed for the purpose of managing the metadata of IGS GNSS ground-based sites. On the other hand, the IGS Network Map (https://network.igs.org/) serves as the public interface for any user from all over the world to view station metadata from the IGS SLM through a comprehensive station list and interactive station map. The primary goal of the new SLM and Network Map is to maximise the reliability, accuracy, and searchability of site log metadata information.

Furthermore, IGS SLM 2.0 is open source and currently available on the public IGS GitHub Repository (https://github.com/International-GNSS-Service/SLM). By allowing users to access the SLM 2.0 codebase and documentation, other organisations can utilise this new and robust technology for their own needs and help the community move towards more consistent and seamless metadata editing.

4.3 Network Coordination

The CB Network Coordinator - with the help of the Infrastructure Committee - coordinates the monitoring of station logs and RINEX metadata, and evaluates all new IGS station proposals on a regular basis. Additionally, the CB Network Coordinator also collaborates with the Antenna Committee Chair and GNSS manufacturers to have their equipment added to the official IGS files (`rcvr_ant.tab` and `antenna.gra`). For the latest update on those fronts, see the Governing Board Executive Report. Finally, the CB Network Coordinator also ensured timely responses to all email inquiries received from users about data, products, or general IGS information.

4.4 Associate Membership Database

In 2022, the IGS CB developed and deployed a new Associate Member (AM) Database and registration system, available alongside the current and legacy lists at https://igs.org/am/.

From 2022 to 2024, the CB has worked to slowly transition all AMs from the previous, legacy database to this new one, proceeding in batches so that all transfers may be double-checked by the IGS Governance. This transition was completed in June 2024, concluding another of the main 2024 objectives set forth in the 2023 Technical Report.

In the revised AM Database system, community members apply through a simple form that gathers all relevant information to ensure they meet the minimum requirements for AM status. Once members are approved as AMs (by the IGS Executive Committee), the system automatically adds them to the comprehensive list of all AMs (https://igs.org/am/list/), which also provides access to individual profile pages. A secure login mechanism allows all AMs to manage, update, and/or edit their profiles on their own. Finally, the system also sends automated reminders for AMs to renew their membership at regular intervals; this allows the AM Database to remain as current as possible and to periodically remove members who retired from the IGS.

5 Communication Efforts

The CB strives to comprehensively address the diverse applications of IGS, fostering community engagement, disseminating IGS updates efficiently, and contributing appropriately to global initiatives. This commitment is exemplified through the implementation and sustained management of a multifaceted communication strategy, encompassing academic interactions, community outreach, social media presence, newsletter circulation, and collaborations with influential entities. The Tour de l'IGS virtual mini-workshop series namely makes up the academic side of IGS communications, allowing relevant interactions with / outreach to the community.

Furthermore, the CB fosters diverse community engagements and collaborations through a strong presence on social media, namely LinkedIn and YouTube. Numerous news pieces and social media posts covering IGS-related updates, activities, and other announcements were developed in collaboration with the Governing Board and relevant IGS Components.

Finally, the CB engages in ongoing efforts to develop new, impactful, and effective opportunities for IGS engagement. This includes active participation in international technical fora, coordinating with United Nations (UN) components, such as the UN International Committee on GNSS (ICG), UN Global Geospatial Information Management Subcommittee on Geodesy, and the newly-established UN Global Geodetic Center of Excellence. For more details, see the "External Engagement" Section in the GB chapter.

For social media in particular, the CB maintains a consistent cross-linking within the IGS website and across various social media platforms in order to enhance the clarity and utility of community resources. Beyond promoting IGS news and events, the CB actively engaged with followers by participating in trends relevant to geodesy and diversity in science. In terms of pure statistics, the IGS Social Media accounts grew as follows (as of 15 January 2025):

LinkedIn (https://www.linkedin.com/company/igsorg/):

- 2685 followers (+601 since last report, +50/month)

YouTube (https://www.youtube.com/igsorg):

- 546 subscribers (+108 since last report, +9/month)
- 23905 views (+5666 since last report, +472/month) - 2700 of which were obtained through the recordings of presentations given during the 30th-Anniversary IGS Workshop.

6 Future Steps for 2025

Moving forward, the IGS CB will continue working towards achieving substantial milestones towards sustainability and resilience for the IGS. As detailed in the GB Executive Report, the licensing and citation of IGS data has risen as a very important topic for the sustainability of the Service; the CB will help coordinate efforts to define IGS-wide policies in collaboration with the Data Licensing and DOI Working Groups, which were created in early 2025. The CB will also ensure that IGS Components operate in the most optimal fashion possible; in particular, the CB will (1) work with Component Chairs to identify missing Vice-Chairs, and (2) monitor and support the relaunching of the TIGA Pilot Project (under a new management as of early 2025). Finally, the CB will continue to fulfil all of its regular administrative tasks and duties, including event coordination, governance support, network coordination, and communications.

7 Acknowledgements

The Central Bureau gratefully acknowledges the contributions of our colleagues at the Astronomical Institute at the University of Bern, who edit, assemble, and publish the IGS Annual Technical Report as a service to the Central Bureau and IGS community. The Central Bureau also wishes to thank all Governing Board members who actively participated in committees, review panels, and other efforts that have contributed to the improvement and sustainability of this organisation and its administration.

Part II

Analysis Centers

Analysis Center Coordinator Technical Report 2024

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1 Introduction

The IGS Analysis Center Coordinator (ACC) is responsible for monitoring the quality of products submitted by individual analysis centers and combining them to produce the official IGS products. The IGS ACC also has the overall responsibility for coordinating the changes, developments and improvements within the contributing analysis centers to produce the IGS products using the latest models and standards. The IGS products continue to perform at a consistent level, and in general the solutions submitted by the analysis centers maintain a consistent level of performance. The combined IGS products by the ACC maintain the expected qualities and are the most consistent compared to any individual ACs. The different analysis centers contributing to the IGS operational products, are listed in Table 1. Table 1 also shows the abbreviations used across this report for the IGS products.

In 2024, the next IGS Analysis Center Coordinators were announced following a call for participation and a governing board vote, and the ACC started the work of transitioning to the new ACC (see Section 2). The evaluation of new ESA products using Galileo and GPS Block III antenna calibrations was carried out by the ACC (Section 3). In addition to maintaining the quality of the IGS GPS-only products (Section 4), the ACC continued to provide demonstration multi-GNSS combined products and continued the contributions towards fully multi-GNSS combinations (Section 5).

Table 1: The abbreviations used by the IGS ACC in this report for different analysis centers and IGS products.

Analysis center/IGS product	Description code
Center for Orbit Determination in Europe (CODE)	COD
Natural Resources Canada (NRCan)	EMR
European Space Agency (ESA)	ESA
GFZ Helmholtz Centre for Geosciences	GFZ
Centre National d'Etudes Spatiales (CNES/CLS)	GRG
Geospatial Information Authority of Japan (GSI) and the Japan Aerospace Exploration Agency (JAXA)	JGX
Jet Propulsion Laboratory (JPL)	JPL
Massachusetts Institute of Technology (MIT)	MIT
NOAA/National Geodetic Survey (NGS)	NGS
Scripps Institution of Oceanography (SIO)	SIO
The United States Naval Observatory (USNO)	USN
Wuhan University	WHU
IGS ultra-rapid adjusted part	IGA
IGS ultra-rapid predicted part	IGU
IGS ultra-rapid experimental GLONASS	IGV
IGS real-time	IGC
IGS rapid	IGR
IGS final	IGS

2 Transition to new ACC and multi-GNSS roadmap

During the IGS Symposium and Workshop in Bern, Switzerland in July 2024, new IGS analysis center coordinators were announced following an IGS governing board discussion and vote. The IGS welcomed NASA Goddard Space Flight Center and Geoscience Australia as the next analysis center coordinators in a joint partnership, supported by Massachusetts Institute of Technology (MIT) and GFZ Helmholtz Centre for Geosciences. Since then, the coordination work for the transition of the current MIT and GA partnership to NASA and GA has been progressing. This includes the transition of the majority of the operational combination capability to NASA by the end of 2025. On-site training and discussion between NASA, MIT and GA staff in the GA office started in early 2025, with further online training and hand-over planned to take place over 2025. Eventually in late 2025 or early 2026, NASA will take over as the primary ACC, and GA, MIT and GFZ will provide their support.

The roadmap for the ACC transition, including transition to fully multi-GNSS combinations is shown in Figure 1. More details on the multi-GNSS combination efforts are described in Section 5.

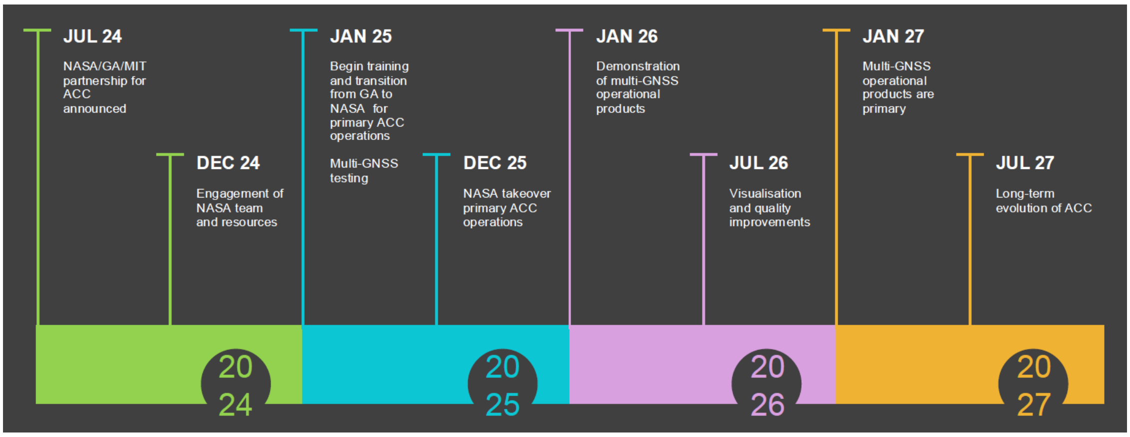

Figure 1: ACC transition roadmap.

3 ESA CHAMP products

At the IGS Symposium and Workshop in Bern, the analysis center at the European Space Agency (ESA) requested that their new Consolidated High Accuracy Multi-GNSS Processing (CHAMP) products are evaluated by the IGS ACC and the IGS Reference Frame Coordinator. A major difference between the ESA CHAMP products and their previously submitted products is that the CHAMP products use the calibrated Galileo (and GPS Block III) z-PCOs without any adjustment to align with the ITRF2020 scale (i.e. they used esa23.atx instead of igs20.atx). The request was to assess if the new CHAMP products would still provide access to ITRF2020, and more importantly if inclusion of them in the IGS combined products would negatively impact the combined products in providing access to ITRF2020.

The evaluation of the ESA CHAMP products was carried out by both the reference frame coordinator and the ACC. While the reference frame coordinator evaluations were based on the comparison of the ESA coordinate SINEX solutions, the IGS ACC assessments investigated whether Precise Point Positioning (PPP) solutions using ESA CHAMP orbits and clocks provide station coordinates that are aligned to ITRF2020. Based on one month of CHAMP orbit and clock products for January 2024 provided by ESA and a network of about 130 IGS20 core sites, the ACC carried out two sets of evaluations: (a) GPS-only PPP solutions using the Bernese software v5.2 (Dach and Walser, 2015); (b) multi-GNSS (GPS, Galileo and GLONASS) PPP solutions using the Ginan software (McClusky et al. , 2024). In both cases, both ESA conventional products and new CHAMP products were used to create PPP solutions. In the case of GPS-only, the combined IGS products as well as the combined products using the ESA CHAMP products instead of conventional ESA products were also used to create two additional PPP solutions. All of these PPP solutions were then compared against the IGS daily SINEX solutions published by the reference frame coordinator. The station residuals and the 7-parameter Helmert transformation parameters were calculated between each PPP solution and the IGS daily solution as a

Table 2: Median and standard deviation statistics for comparison of PPP solutions using the conventional ESA products and the new ESA CHAMP products against the IGS daily SINEX solutions. All solutions are based on final products of IGS or ESA, and based on a month of analysis in January 2024 over about 130 IGS20 core sites.

Products used in the PPP solution	North RMS [mm]	East RMS [mm]	Up RMS [mm]
ESA GPS-only	1.7±0.3	3.7±0.4	5.8±0.7
ESA CHAMP GPS-only	1.7±0.2	3.7±0.4	6.0±0.7
IGS Operational GPS-only	1.6±0.2	3.6±0.2	5.8±0.6
IGS combined GPS-only using ESA CHAMP instead of ESA	1.6±0.2	3.6±0.7	5.8±0.6
ESA GPS+GLONASS+Galileo	2.5±0.3	4.0±0.5	6.9±0.5
ESA CHAMP GPS+GLONASS+Galileo	2.3±0.3	3.8±0.5	6.9±0.6

measure of how well the PPP solutions provide access to the ITRF2020 reference frame.

The results from these comparisons demonstrated that the ESA CHAMP products are still able to provide access to ITRF2020 within reasonable uncertainties. Table 2 shows the total Root-Mean-Square (RMS) of each of the PPP solutions against the IGS daily solutions. There is no significant difference in the station RMS residuals compared to the IGS daily SINEX solutions between using the ESA CHAMP products and the ESA conventional products. This is evident in the PPP solutions using the ESA products as well the IGS combinations when using the new ESA CHAMP products instead of conventional ESA products. Notably for the multi-GNSS solutions, the ESA CHAMP products yield horizontal coordinates that are slightly more consistent with the IGS daily solutions than the coordinates estimated using conventional ESA products.

In addition to the station coordinate residuals, there was no significant difference in the seven Helmert transformation parameters between the solutions using new ESA CHAMP products and the conventional ESA products (figures not reported here but available in IGS ACC. (2024)).

Based on one week of products, a comparison was also made between the new ESA CHAMP clocks and the conventional ESA solutions. The comparison showed that the two clock products match each other after a re-alignment with typically less than 10 picoseconds difference. It was also revealed that they would receive similar weights (of about 11-14%) in a multi-GNSS clock combination involving GPS, Galileo and GLONASS

Table 3: Standard deviations of different final clock products and the weights received by each AC product based on a week of multi-GNSS clock combinations.

AC clock	Standard deviation [ps]	Weight
COD	12.4	9.4%
EMR	35.0	1.2%
ESA	10.1	14.4%
ESA CHAMP	11.4	11.3%
GFZ	10.3	13.9%
GRG	7.5	26.2%
JGX	23.8	2.6%
JPL	8.3	21.1%

clocks. These results are summarized in Table 3.

The detailed results of the above evaluations can be found in IGS ACC. (2024). Following these assessments and further evaluations carried out by the reference frame coordinator, it was agreed by the analysis centers during the analysis centers meeting of 27 November 2024 that ESA can switch to their new CHAMP products without negatively impacting the combined products. As a result, ESA started providing their new CHAMP products since the first week of February 2025.

4 Product Quality and Reliability

In 2024, the delivery of the ultra-rapid, rapid and final products was well within the expected latencies for most of the year (e.g. about 98.6% of the deliveries within the expected latency of 17-41 hours for the rapid products and about 99.8% within the expected latency of real time to 9 hours for the ultra-rapid products). However, there was an increased number of delayed combined products compared to the previous year, including five occurrences of delays in delivering the rapid products and three occasions of delayed ultra-rapid products. Upon investigating, most of the delayed rapid products were found to be due to an overflow of CPU usage when rapid and final PPP tests, as well as the conversion of RINEX version 3 files, were all being carried out at the same time, which slowed down all the processes and prevented the deposit of the products at the scheduled time of the day, requiring human intervention to deposit the products at a later time (with a delay of 3 to 6 hours due to the Australian timezone). This issue has now been resolved by forcing the PPP tests to run in the background while allowing the rest of combination steps and the deposit of the products to take place even if the PPP tests have not been completed. Two instances of the ultra-rapid product delays and one instance of the rapid product delays were due to an issue with the disk storage of the combination server. The

Table 4: ACs contributing to the IGS ultra-rapid products; *W* signifies a weighted contribution, *C* is comparison only. The SIO and WHU ERP solutions are by default weighted, with the exception of the length of day estimate which are excluded from the combination for these two ACs. JGX started providing ultra-rapid products since November 2024.

Analysis center	Orbit	ERP	Clock
COD	W	W	C
EMR	W	W	W
ESA	W	W	W
GFZ	W	W	C
GRG	C	C	C
JGX*	C	C	C
SIO	C	W (LoD C)	-
USN	C	C	W
WHU	W	W (LoD C)	C

remaining ultra-rapid product delay was due to missing predicted orbits for one of the AC products, which was left unnoticed by the combination software prior to the combination and failed the combination. The delay times for the ultra-rapid combinations were much lower than the rapid combination delays, ranging between 1 and 2.5 hours. In addition to the delays, there were three instances of re-submission of the combined rapid and/or final clocks due to issues in the alignment of the clocks to the IGS Timescale (IGST), which were all communicated to the users via the IGS mailing list.

4.1 Ultra-rapid

The ultra-rapid is one of the most widely utilized IGS products, often used for real-time and near-real-time applications. In 2024, IGS received submissions from nine different ACs which were combined to produce IGS ultra-rapid products (see Table 4 for a list of ACs that are currently included in the combined solutions). JGX started providing ultra-rapid products since November 2024 (GPS week 2340), which are included in the combination without weights.

The combined IGS ultra-rapid orbit can be split into two components, a fitted portion based on observations, and a predicted component reliant upon forward modelling of the satellite dynamics. The fitted portion of the ultra-rapid orbits continues to agree to the rapid orbits with a median value of 6 mm (see Figure 2) and has been consistently at this level since GPS week 1500.

In addition, over the past year there was little change in the agreement between the ultra-rapid predicted orbits compared to the IGS rapid orbits (see Figure 3) hovering around a median value of 27 mm.

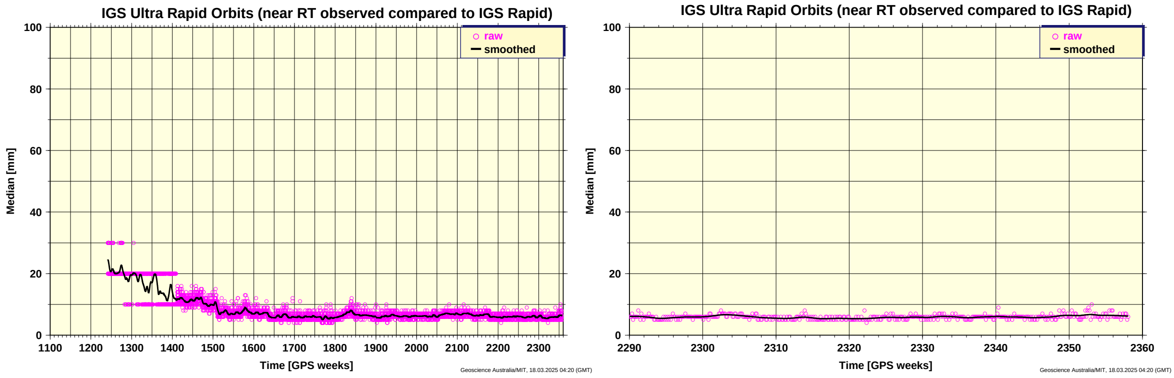

Figure 2: The median difference of the fitted component of the IGS ultra-rapid (IGU) combined orbits with respect to the IGS rapid (IGR) orbits. The historical time series of comparison results is shown on the left, and recent comparison results are shown on the right.

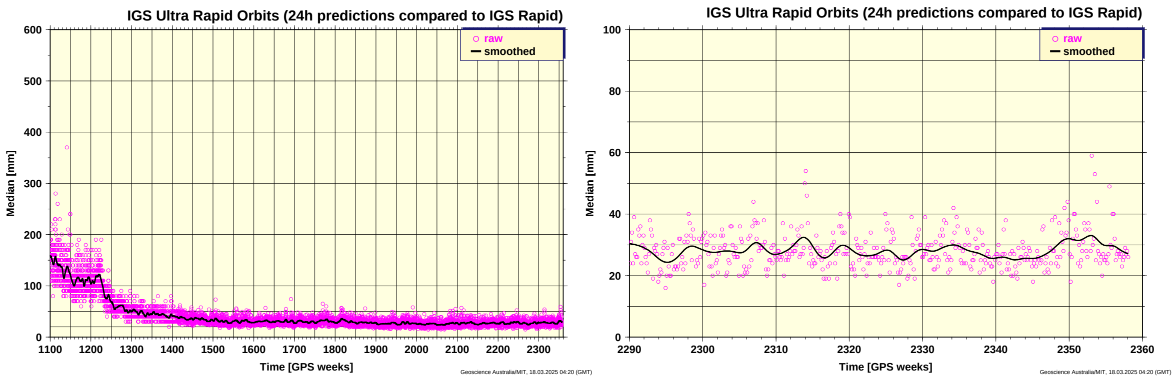

Figure 3: Median of IGU combined predicted orbits compared to IGR. The historical time series of comparison results is shown on the left, and recent comparison results are shown on the right. Note the change in scale of the Y axis.

The weighted RMS error of the individual orbit submissions from the analysis centers with respect to the combined ultra-rapid products are plotted in Figure 4. Since early 2025, ESA ultra-rapid orbits started to show higher discrepancies compared to the combined orbits, which is currently under investigation and has slightly improved in the most recent weeks. The consistency of GRG ultra-rapid orbits compared to the combined orbits started to improve from about mid-year 2024, which is likely attributed to their improved predicted orbits because of the increased duration of dynamic parameter estimation from 24 hours to 48 hours, although a number of eclipsing satellites are still poorly modeled (Mezerette et al. , 2024). The ACC is considering weighting the GRG ultra-rapid orbits upon successful evaluations.

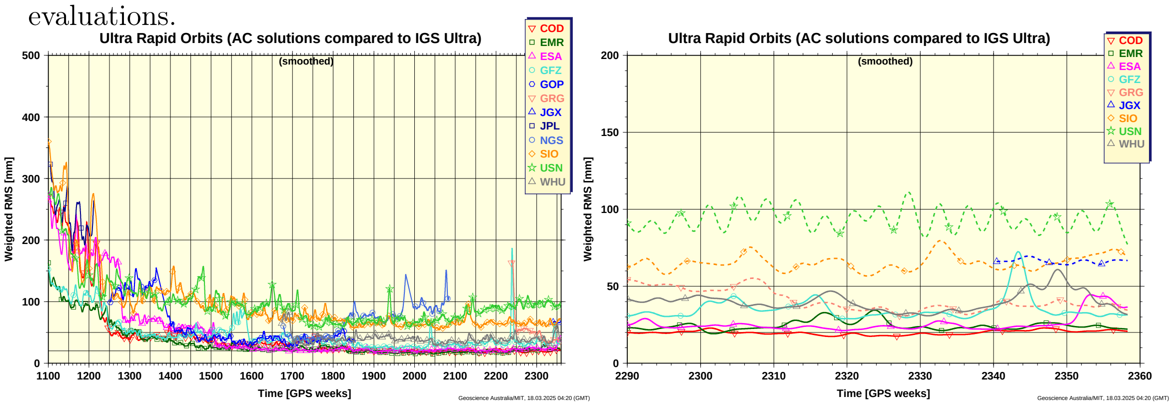

Figure 4: Weighted RMS of AC ultra-rapid orbit submissions (smoothed). The historical time series of comparison results is shown on the left, and recent comparison results are shown on the right. The dashed lines on the figure on the right are the solutions that are unweighted as of February 2025, while the solid lines are the weighted solutions. Note the change in scale of the Y axis.

4.2 Rapid

In total, eleven individual analysis centers contributed to the IGS rapid products in 2024 (see Table 5).

The rapid orbit products from the different analysis centers weighted in the combination remained at a consistent level of below 15 mm (Figure 5), and the difference between the combined IGS rapid orbits and the combined IGS final orbits was consistently below 5 mm (see Figure 7).

The standard deviation of the rapid satellite and station clock solutions was always below 25 picoseconds (ps) for the weighted centers (Figure 6). The clock RMS values of most of the weighted centers were also consistently below 150 ps at all times. The exception was GFZ rapid clocks which showed clock RMS's of up to about 170 ps for about 10 weeks during December 2024 to February 2025. This was confirmed to be due to an incorrect application of differential code biases (DCB) data resulting in satellite-specific

Table 5: ACs contributing to the IGS rapid products; *W* signifies a weighted contribution, *C* is comparison only. The USN ERP solutions are not weighted in the combination, with the exception of the length of day estimate, which is weighted.

Analysis center	Orbit	ERP	Clock
COD	W	W	W
EMR	W	W	W
ESA	W	W	W
GFZ	W	W	W
GRG	W	W	W
JGX	W	W	W
JPL	W	W	W
NGS	W	W	C
SIO	C	C	-
USN	C	C (LoD W)	C
WHU	W	W	W

clock offsets. This problem was identified and resolved by the GFZ team, and their clock solutions have bounced back to very low RMS's. It is important to note that an increased clock RMS does not normally impact the carrier phase positioning solutions where a phase ambiguity is resolved, as the clock biases are absorbed in the ambiguity parameters. The clock standard deviation is a more appropriate measure of the consistency of the clocks after removing a separate bias for each satellite/station clock.

4.3 Final

In total, there are ten individual ACs contributing to the IGS final products (see Table 6). JPL final products switched from the IGb14 frame to the IGS20 frame from the products of GPS week 2329 (25 August 2024). Since then, the JPL final products started to be weighted in the IGS combinations. The significant drop in the RMS/standard deviation of the JPL orbits and clocks from GPS week 2329, as observed in Figures 7 and 8, is a result of this switch in the reference frame.

The AC final orbit solutions that are weighted in the IGS combinations are comparable at around the 10 mm RMS level (see Figure 7). The final clock solutions from the weighted ACs are mostly below 150 ps level of RMS compared to the combined final clocks, with the exception of GFZ clocks which suffered from the same issue as in their rapid clocks (Figure 6) and have bounced back to small RMS's in their most recent solutions. The standard deviations of the final clock solutions, which have individual satellite/station biases removed, for the weighted centers were below 15 ps level for all of the weighted centers (Figure 8).

To assess the quality of the combined products, PPP solutions estimated using the orbit

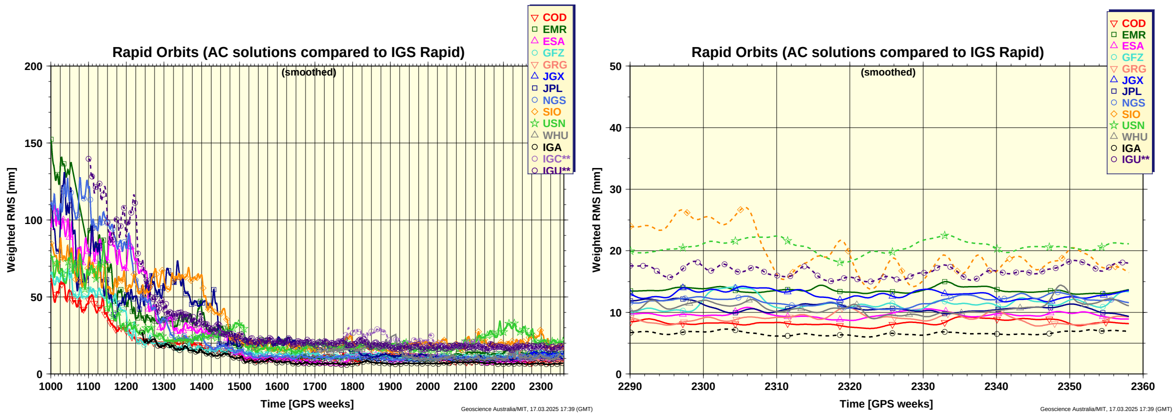

Figure 5: Weighted RMS of ACs rapid orbit submissions (smoothed). The historical time series of comparison results is shown on the left, and recent comparison results are shown on the right. IGC** are 24-hour products each containing four 6-hour segments from each update interval of the IGS real-time stream. IGU** consists of four separate comparisons to IGR done each day over the first 6 hours of each IGS ultra-rapid product. The dashed lines on the figure on the right are the solutions that are unweighted as of February 2025, while the solid lines are the weighted solutions. Note the change in scale of the Y axis.

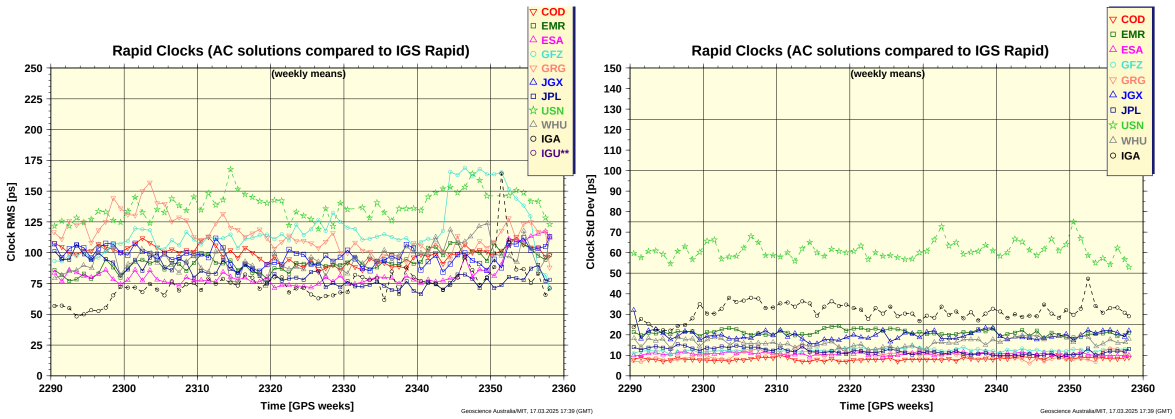

Figure 6: Weighted RMS (left) and standard deviation (right) of ACs rapid clock submissions (smoothed). IGC** are 24-hour products each containing four 6-hour segments from each update interval of the IGS real-time stream. IGU** consists of four separate comparisons to IGR done each day over the first 6 hours of each IGS ultra-rapid product. The dashed lines on the figure on the right are the solutions that are unweighted as of February 2025, while the solid lines are the weighted solutions. Note the change in scale of the Y axis.

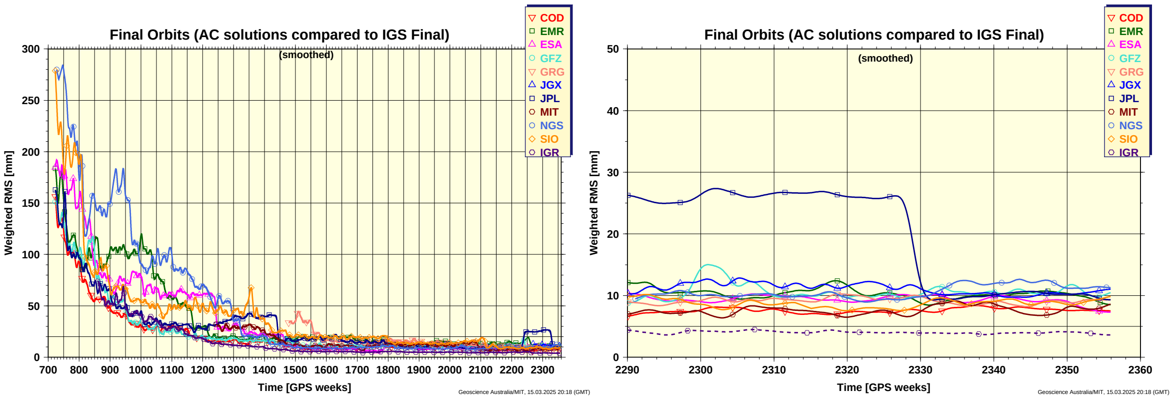

Figure 7: Weighted RMS of IGS final orbits (smoothed). The historical time series of comparison results is shown on the left, and recent comparison results are shown on the right. The dashed lines on the figure on the right are the solutions that are unweighted as of February 2025, while the solid lines are the weighted solutions. Note the change in scale of the Y axis.

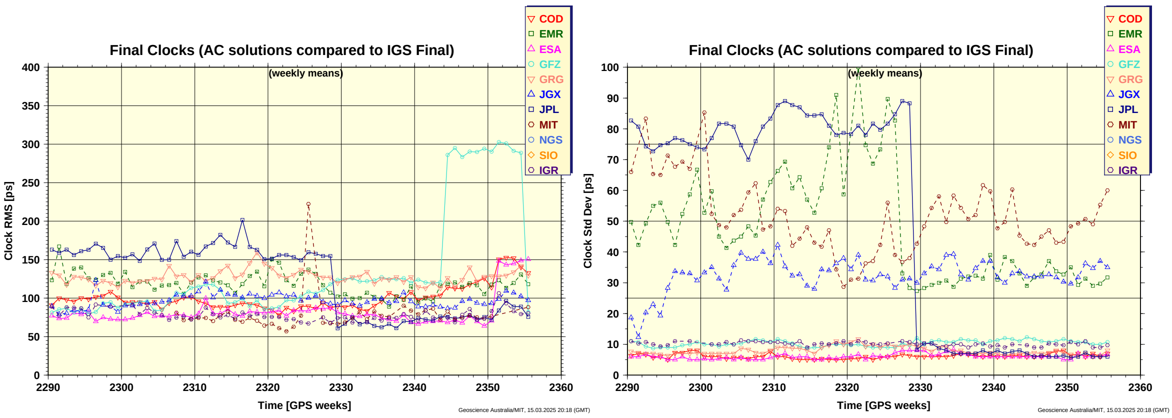

Figure 8: Weighted RMS (left) and standard deviation (right) of IGS final clocks (smoothed). The dashed lines on the figure on the right are the solutions that are unweighted as of February 2025, while the solid lines are the weighted solutions. Note the change in scale of the Y axis.

Table 6: ACs contributing to the IGS final products; W signifies a weighted contribution, C is comparison only. JPL solutions started to be weighted in the combinations since the products of 25 August 2024 (GPS week 2329) after they switched from the IGb14 to IGS20 frame.

Analysis center	Orbit	ERP	Clock
COD	W	W	W
EMR	W	W	C
ESA	W	W	W
GFZ	W	W	W
GRG	W	W	W
JGX	W	W	C
JPL*	W	W	W
MIT	W	W	C
NGS	W	W	C
SIO	W	C	-

Table 7: Median station coordinate residuals from comparison of PPP solutions using different sets of orbits and clocks compared with the IGS weekly SINEX solutions from January 2024 to Frbruary 2025.

Products used in the PPP solution	North RMS [mm]	East RMS [mm]	Up RMS [mm]
COD	1.9	3.7	5.9
EMR	2.4	4.2	6.7
ESA	1.9	3.6	5.8
GFZ	2.0	3.8	6.0
GRG	2.1	4.0	6.1
JGX	2.0	4.1	6.5
JPL	1.9	3.9	5.9
MIT	2.9	4.1	7.6
IGR	2.5	4.0	7.5
IGS	1.9	3.6	5.6

and clock products can be compared to the IGS daily SINEX solutions as a measure of how well the products provide access to the IGS reference frame. Figure 9 shows the station residual RMS of the PPP solutions using the IGS combined rapid and final products as well the PPP solutions using products of each of the contributing analysis centers. Table 7 lists the median RMS values for the past year. The IGS combined products are always one of the best solutions, and the IGS combined final products provide the best median consistency with the IGS SINEX solutions compared to every individual solution, making them the most suitable option to access the IGS reference frame, and consequently ITRF.

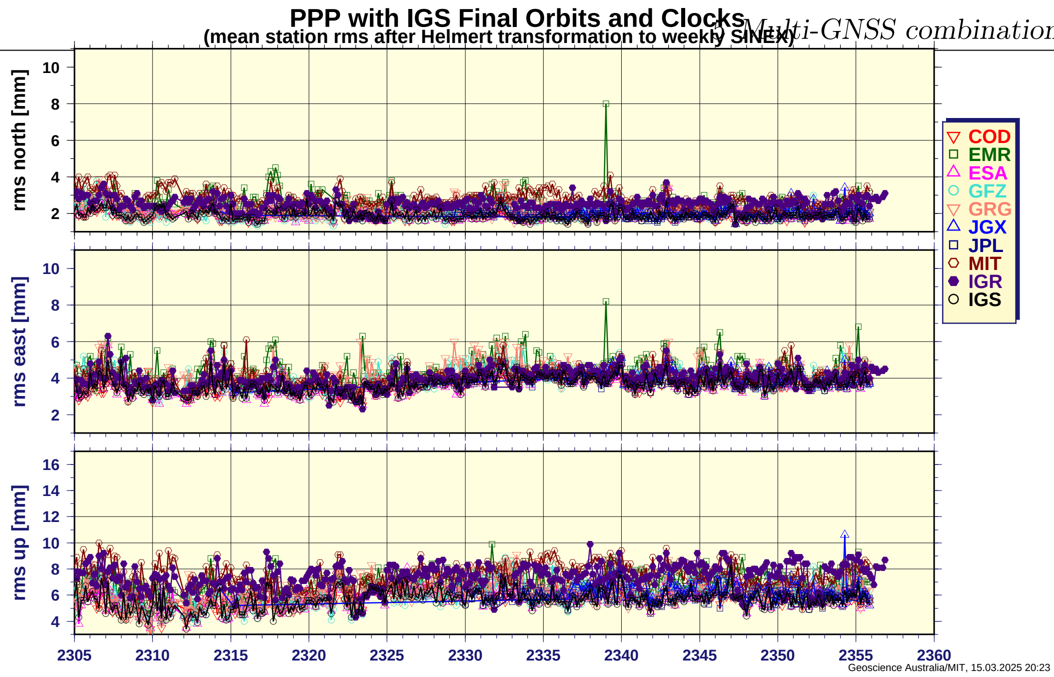

Figure 9: Station RMS residuals from the comparison of the PPP solutions using the final orbit and clock products of each of the analysis centers as well as IGS rapid and final products to the IGS weekly SINEX solution. All PPP solutions were estimated using the same network of IGS20 core sites and using Bernese v5.2 software.

5 Multi-GNSS combinations

As mentioned in Section 2, an important component of the ACC roadmap for the next four years is the transition to multi-GNSS combined products. In 2024, the GA's Robust Orbit Combination Software (ROCS) was released as open-source (Geoscience Australia, 2024). In addition, GFZ released the Software for Precise Orbit and Clock Combination (SPOCC) as another tool with the capability to produce combined orbits and clocks (Mansur et al. , 2024). Moreover, a clock and bias combination software has been offered by Natural Resources Canada (NRCan) (Banville et al., 2020). The IGS multi-GNSS Task Force has been progressing the assessment of different combination software available for the multi-GNSS combinations, and the IGS ACC has been contributing to the taskforce by providing test product combinations.

In 2024, the IGS ACC continued the provision of multi-GNSS (GPS, Galileo and GLONASS) ultra-rapid orbits on an operational basis as demonstration products. These multi-GNSS ultra-rapid products are currently made available four times a day approximately 20 minutes after the legacy GPS-only (and experimental GLONASS) ultra-rapid orbits are published. The demonstration multi-GNSS orbit combinations use the GA's ROCS orbit combination software (Geoscience Australia, 2024).

Table 8 lists the Analysis Centers currently contributing to the multi-GNSS ultra-rapid orbit combinations. The consistencies of the individual AC orbits with the combined multi-

Table 8: ACs contributing to the IGS demonstration multi-GNSS ultra-rapid orbits; W signifies a weighted contribution, C is comparison only.JGX started providing ultra-rapid orbits since November 2024.

Analysis center	GPS	GLONASS	Galileo
COD	W	W	W
EMR	W	W	-
ESA	W	W	-
GFZ	W	W	W
GRG	C	-	W
JGX*	C	C	C
WHU	W	W	C
SIO	C	-	-
USN	C	-	-

GNSS orbits are displayed in Figure 10. Figure 11 shows the RMS of the AC ultra-rapid orbit solutions per GNSS satellite.

From Figures 10 and 11, the RMS levels of the different AC solutions for GPS orbits are mostly very similar to those observed for the legacy GPS-only solutions (Figure 4) at below 50 mm for the weighted AC orbits. The comparison with the IGS ultra-rapid GPS-only legacy combinations (Figure 10, dashed black lines) also shows that the multi-GNSS combinations are generally very close to the GPS-only combinations for the GPS constellation, with the RMS level between the two at a median of about 6 mm.

The consistency of the AC orbits for the GLONASS satellites is in the range 50-80 mm for different ACs (Figure 10). The multi-GNSS combined orbits are consistent with the experimental legacy GLONASS-only combinations at about 14 mm level. The disparities between the different AC orbit solutions are the largest for the older Block M satellites, in particular R719, R720, R721 and R730, while they have improved for the more recent satellites, e.g. R802 from the Block K1B or more recent launches in Block M such as R851 (see Figure 11).

There are currently only three ACs (COD, GFZ and GRG) that are weighted in the multi-GNSS ultra-rapid Galileo combinations. The weighted AC contributions for Galileo are consistent with each other at the level of about 50-75 mm.

6 Future Work

In 2025, a major focus of the IGS ACC will be on the transition of the operational capability of the ACC to NASA, following the transition roadmap as in Section 2. The aim is for NASA to take over the primary role of the operational combinations by the

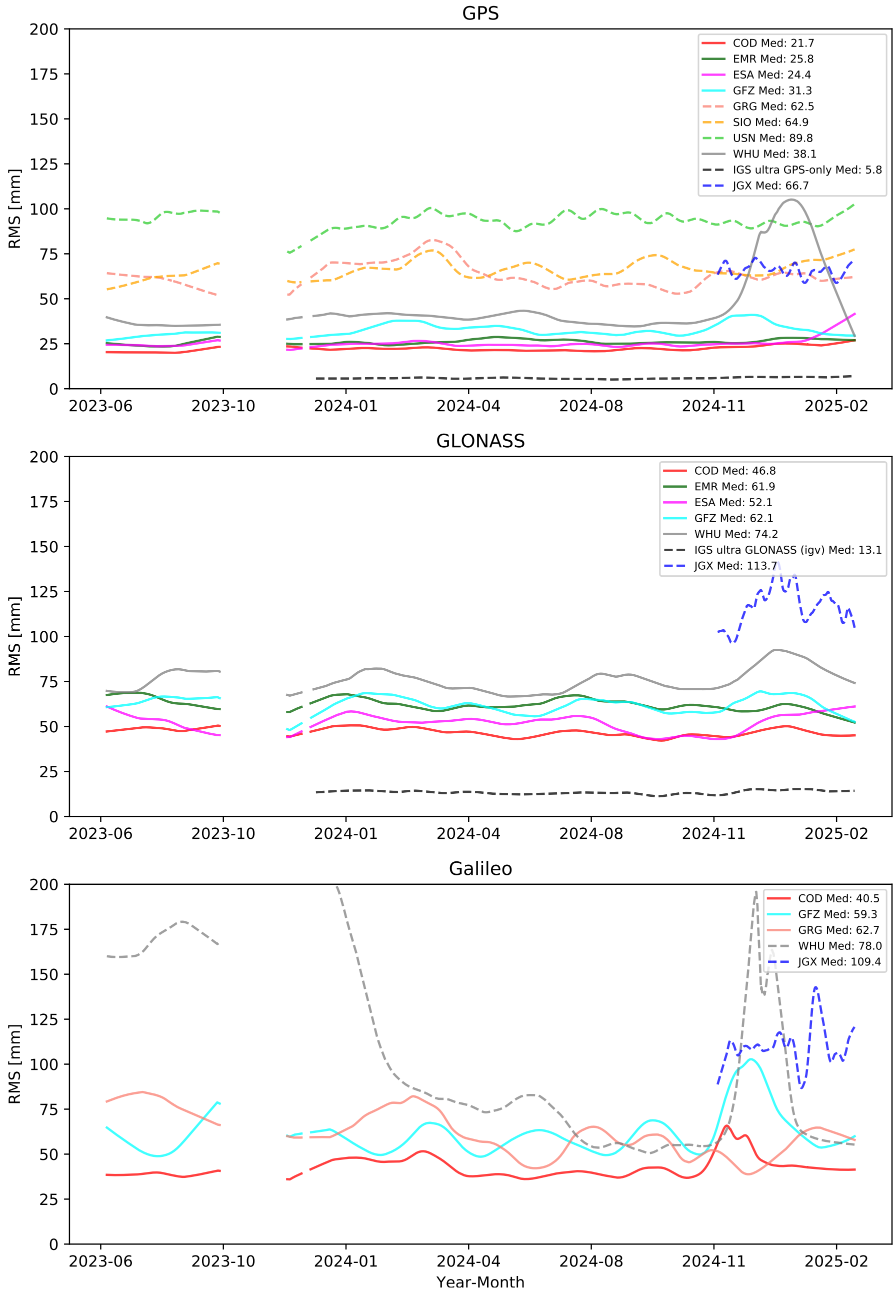

Figure 10: RMS of analysis center orbit solutions (smoothed) compared to the IGS combined orbits for the IGS multi-GNSS ultra-rapid demonstration products for GPS (top), GLONASS (middle) and GALILEO (bottom). The dashed lines are the AC solutions that are not weighted in the combinations, while the solid lines are the weighted ACs.

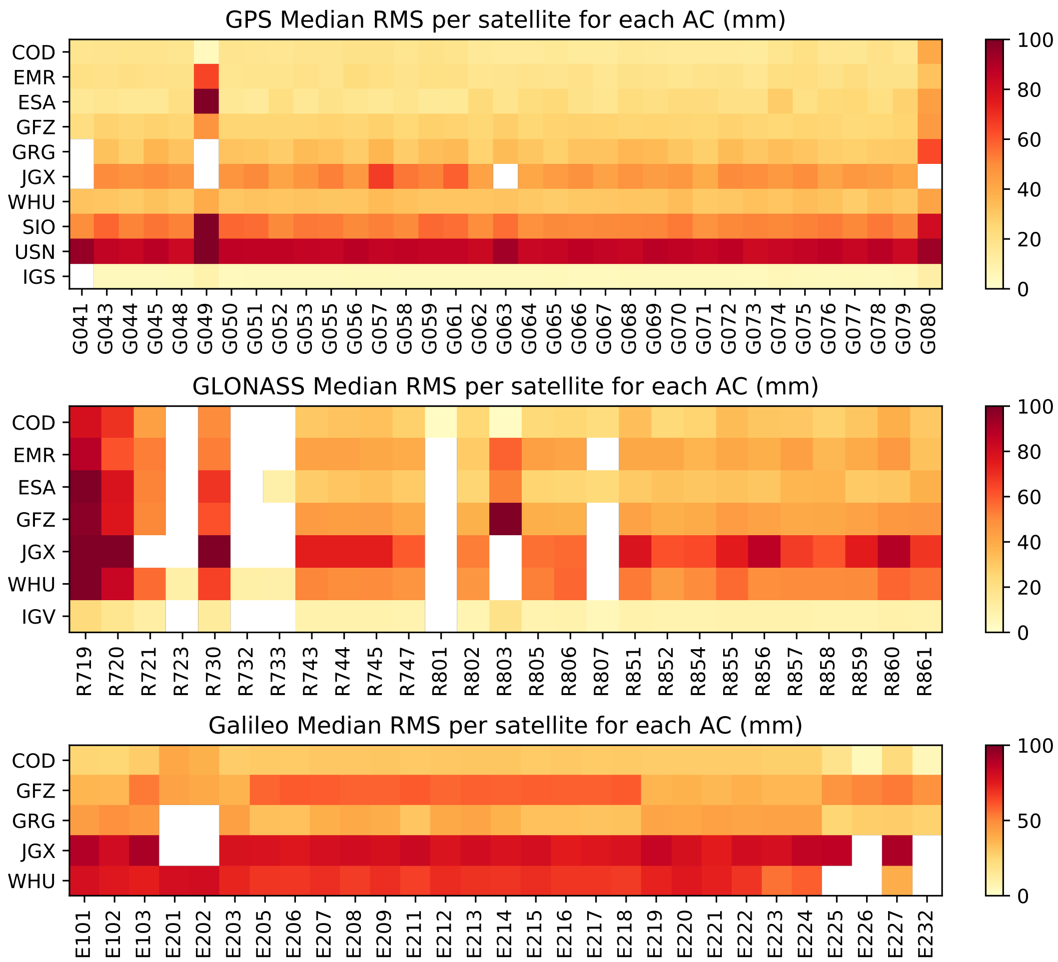

Figure 11: Median RMS of the individual satellites compared to the combined orbits for the multi-GNSS ultra-rapid solutions for GPS (top), GLONASS (middle), and Galileo (bottom). IGS is the IGS ultra-rapid legacy GPS-only combined orbits, and IGV is the current experimental ultra-rapid GLONASS-only combined orbits.

end of 2025 or early 2026, with GA still maintaining the contribution to the ACC beyond 2025.

As part of the transition to multi-GNSS, the IGS ACC continues to provide the multi-GNSS combinations and intends to trial a final multi-GNSS orbit combination paired with clock and bias combinations in collaboration with NRCan.

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Wuhan Combination Center Technical Report 2024

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1 Introduction

The Wuhan Combination Center (WCC) was formally approved by the Governing Board of the International GNSS Service on December 5, 2024. It aims at providing combined high-precision and highly-reliable multi-GNSS satellite products as backup to the ACC. It will officially operate in April, 2025. The WCC is a joint initiative by the State Key Laboratory of Precision Geodesy, Chinese Academy of Sciences and GNSS Research Center, Wuhan University. The key personnel are listed as follows,

Name	Affiliation	Role
Jianghui Geng	Chinese Academy of Sciences	Coordinator
Qiang Wen	Chinese Academy of Sciences	Lead of clock/bias combination
Guo Chen	Wuhan University	Lead of orbit combination

2 The role of WCC

The WCC will operate alongside the IGS Analysis Center Coordinator (ACC), led by NASA's Jet Propulsion Laboratory (JPL), as one of the two global combination centers for precise satellite products under IGS. The WCC has the priorities: 1) Back-up: The WCC serves as a backup combination center for the current IGS ACC. 2) Incorporating MGEX products: the WCC incorporates the MGEX products, which are otherwise excluded, into combination to offer a comprehensive evaluation. 3) Enhanced product features: The

WCC combined products contain all-frequency code/phase biases to avoid day-boundary discontinuity (Geng et al., 2024a).

The primary tasks of the IGS Wuhan Combination Center (WCC) are as follows: 1) Product combination: The WCC will focus on combining orbit, clock, and code/phase bias products, covering ultra-rapid, rapid, and final product types. 2) Multi-GNSS support: Initially, combined products for GPS, GLONASS, and Galileo will be released (Geng et al., 2024b). Combined products for BDS and other constellations will be introduced at an appropriate time once a sufficient number of ACs provide such data. 3) Day-boundary continuity: The WCC will ensure alignment of combined products across consecutive days to minimize day-boundary discontinuities. 4) Combined product validation: PPP-AR validation will be carried out for the combined products to ensure their quality and reliability.

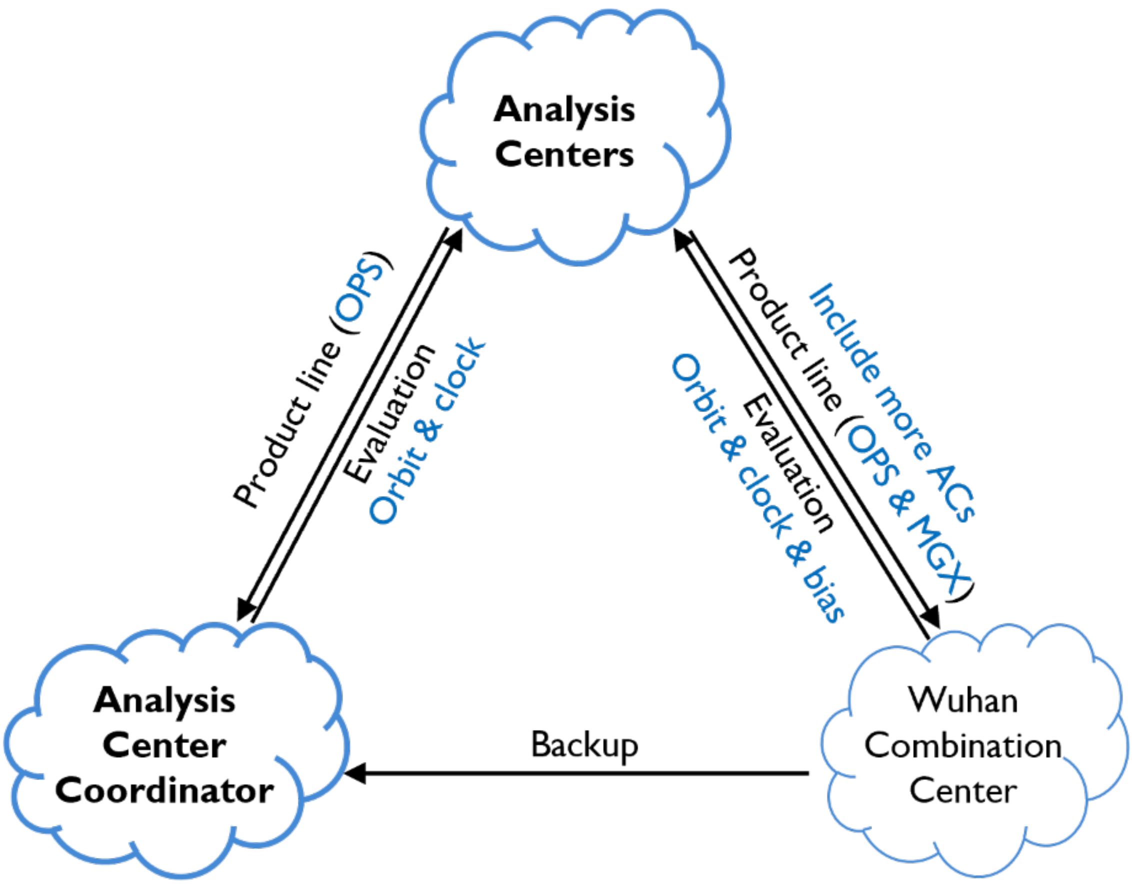

Figure 1: The relationship among WCC, ACC and ACs.

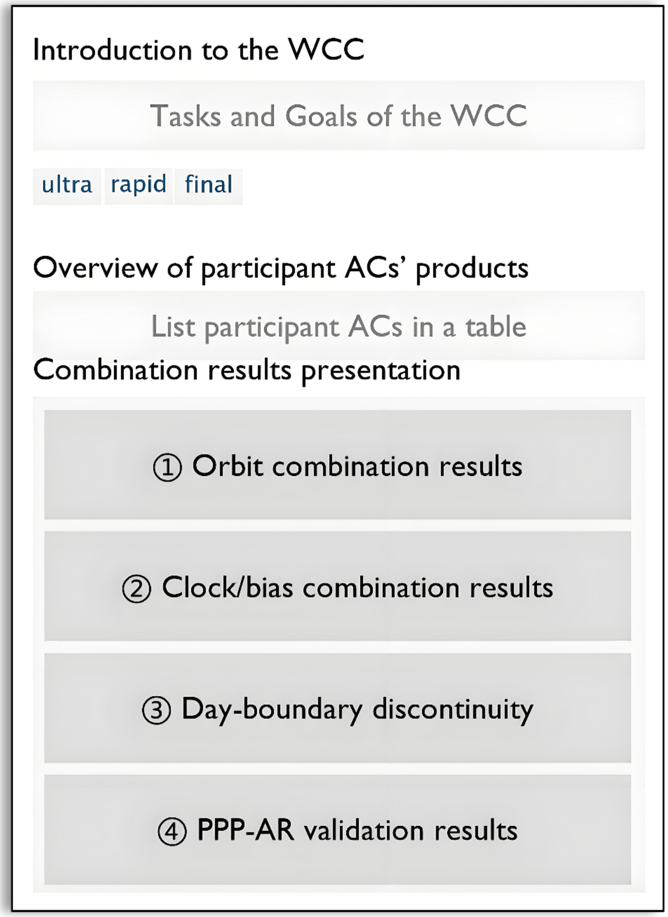

Figure 2: The sketch of WCC webpage on the IGS website.

3 The goals of WCC

Through multi-GNSS product combination, the WCC aims to enhance the consistency, interoperability, and reliability of GNSS products, addressing challenges in areas such as time and frequency transfer, global geodesy, and satellite positioning. Therefore, the goals of WCC include:

1. Introduction to the WCC
2. A detailed overview of the participant ACs and their products
3. The combination results updated every week
   a) The orbit combination results:
   In this column, the product integrity, AC-specific weights, inter-AC RMSE and

accumulated RMSE compared to combination, ACs' transformation parameters (Scale, translations, rotations) will be presented.

b) The clock/bias combination results:
In this column, the product integrity, AC-specific weights, inter-AC RMSE and accumulated RMSE compared to combination, Allan variance of combined clocks, satellite clock jumps will be presented.

c) Day-boundary discontinuity:
In this column, the comparison of day-boundary positioning discontinuities at IGS stations between AC-specific products and combined products will be presented.

d) PPP-AR validation results:
In this column, the wide-lane and narrow-lane ambiguity fixing rates, as well as positioning precision will be presented.

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Center for Orbit Determination in Europe (CODE) Analysis Center Technical Report 2024

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1 The CODE consortium

CODE, the Center for Orbit Determination in Europe, is a joint venture of the following four institutions:

- Astronomical Institute, University of Bern (AIUB), Bern, Switzerland
- Federal Office of Topography swisstopo, Wabern, Switzerland
- Federal Agency of Cartography and Geodesy (BKG), Frankfurt a. M., Germany
- Institute for Astronomical and Physical Geodesy, Technical University of Munich (IAPG, TUM), Munich, Germany

The operational computations are performed at AIUB, whereas IGS–related reprocessing activities are usually carried out at IAPG, TUM. All solutions and products are generated with the latest development version of the Bernese GNSS Software (Dach et al., 2015a).

2 CODE products available to the public

A wide range of GNSS solutions based on a rigorously combined GPS/GLONASS/Galileo data processing scheme is computed at CODE supporting the following IGS legacy product chains:

- **Ultra-rapid series** with several updates per day (GPS+GLONASS+Galileo). The ultra-rapid products contain also a prediction for near-real time applications. List of result files are provided in Table 1 .
- **Rapid series** is computed once per day (GPS+GLONASS+Galileo). Note that there is an update of the rapid solution, see Dach et al. (2015b) . List of result files are provided in Table 2 .
- **Final series** is submitted once per week (GPS+GLONASS+Galileo). Until GPS week 2037 (November 27$^{\mathrm{th}}$, 2022) the final solution did only consider GPS+GLONASS measurements. List of result files are provided in Table 3 .

The products are made available through anonymous ftp at:
`ftp://ftp.aiub.unibe.ch/CODE/` or
`http://ftp.aiub.unibe.ch/CODE/` or
`http://www.aiub.unibe.ch/download/CODE/`

With GPS week 2238, the IGS started to use a new product filenaming scheme. The tables provide both, the new and old product filenames.

Furthermore, CODE contributes to the IGS MGEX project with a five-system solution considering GPS, GLONASS, Galileo, BeiDou, and QZSS where the related products are published at:
`ftp://ftp.aiub.unibe.ch/CODE_MGEX/` or
`http://www.aiub.unibe.ch/download/CODE_MGEX/`

Up to the inclusion of Galileo into CODE's final solution in GPS week 2238 (November 28$^{\mathrm{th}}$, 2022), the triple-system solution (GPS, GLONASS, Galileo) from CODE's rapid processing is also kept accessible at:
`ftp://ftp.aiub.unibe.ch/CODE/yyyy_M` or
`http://www.aiub.unibe.ch/download/CODE/yyyy_M/`

An overview of the related product files is given in Table 4.

Tables 5 and 6 compile the product files submitted by CODE to the IGS data centers.

Within the table the following abbreviations are used:

`yyyy`	Year (four digits)	`ddd`	Day of Year (DOY) (three digits)
`yy`	Year (two digits)	`wwww`	GPS Week
`yymm`	Year, Month	`wwwwd`	GPS Week and Day of week

Table 1: CODE's ultra-rapid products available through anonymous ftp.

CODE *ultra-rapid* products available at ftp://ftp.aiub.unibe.ch/CODE

`COD0OPSULT.SP3` (old: `COD.EPH_U`)
: CODE ultra-rapid GNSS orbits (GPS+GLONASS+Galileo) with 5 minutes sampling

`COD0OPSULT.ERP` (old: `COD.ERP_U`)
: CODE ultra-rapid ERPs belonging to the ultra-rapid GNSS orbit product

`COD0OPSULT.TRO` (old: `COD.TRO_U`)
: CODE ultra-rapid troposphere product, troposphere SINEX format

`COD0OPSULT.SNX` (old: `COD.SNX_U.Z`)
: SINEX file from the CODE ultra-rapid solution containing station coordinates, ERPs, and satellite antenna Z-offsets

`COD0OPSULT_TRO.SNX` (old: `COD_TRO.SNX_U.Z`)
: CODE ultra-rapid solution, as above but with troposphere parameters for selected sites, SINEX format

`COD0OPSULT.SUM` (old: `COD.SUM_U`)
: Summary of stations used for the latest ultra-rapid orbit product

`COD0OPSULT.ION` (old: `COD.ION_U`)
: Last update of CODE rapid ionosphere product (1 day) complemented with ionosphere predictions (2 days), Bernese format

`COD0OPSULT_yyyyddd0000_01D_05M_ORB.SP3` (old:`CODwwwwd.EPH_U`)
: CODE ultra-rapid GNSS orbits from the 24UT solution available until the corresponding early rapid orbit is available (to ensure a complete coverage of orbits even if the early rapid solution is delayed after the first ultra-rapid solution of the day)

`COD0OPSULT_yyyyddd0000_01D_01D_ERP.ERP` (old: `CODwwwwd.ERP_U`)
: CODE ultra-rapid ERPs belonging to the above ultra-rapid GNSS orbits

The CODE ultra-rapid products are provided with static filenames containing the latest results.

Result files for CODE 5-day GNSS *orbit predictions*
available at ftp://ftp.aiub.unibe.ch/CODE

`COD0OPSPRD_05D.SP3` (old: `COD.EPH_5D`)
: CODE 5-day GNSS orbit predictions

`COD0OPSPRD_yyyyddd0000_05D_05M_ORB.SP3` (old: `CODwwwwd.EPH_5D`)
: CODE 5-day GNSS orbit predictions

`COD0OPSPRD_yyyyddd0000_21D_06H_ERP.ERP` (old: `CODwwwwd.ERP_5D`)
: CODE predicted ERPs belonging to the predicted orbits

Note, that as soon as a final product is available the corresponding rapid, ultra-rapid, or predicted products are removed from the anonymous FTP server.

Table 2: CODE's rapid products available through anonymous ftp.

CODE *early rapid* products: GPS+GLONASS+Galileo; third day of a 72-hour solution
available at `ftp://ftp.aiub.unibe.ch/CODE`

`COD0OPSRAP_yyyyddd0000_01D_05M_ORB.SP3` (old: `CODwwwwd.EPH_R`)
: CODE early rapid GNSS orbits with 5 minutes sampling

`COD0OPSRAP_yyyyddd0000_01D_01D_ERP.ERP` (old: `CODwwwwd.ERP_R`)
: CODE early rapid ERPs belonging to the early rapid orbits

`COD0OPSRAP_yyyyddd0000_01D_30S_CLK.CLK` (old: `CODwwwwd.CLK_R`)
`COD0OPSRAP_yyyyddd0000_01D_30S_CLK.CLK_V2`
: CODE GNSS clock product related to the early rapid orbit, clock RINEX format (versions 3.04 and 2.00)

`COD0OPSRAP_yyyyddd0000_01D_01H_TRO.TRO` (old: `CODwwwwd.TRO_R`)
: CODE rapid troposphere product, troposphere SINEX format

`COD0OPSRAP_yyyyddd0000_01D_01D_SOL.SNX` (old: `CODwwwwd.SNX_R.Z`)
: SINEX file from the CODE rapid solution containing station coordinates, ERPs, and satellite antenna Z-offsets, SINEX format

`COD0OPSRAP_yyyyddd0000_01D_02H_TRO.SNX` (old: `CODwwwwd_TRO.SNX_R.Z`)
: CODE rapid solution, as above but with troposphere parameters for selected sites, SINEX format

`COD0OPSRAP_yyyyddd0000_01D_01D_OSB.BIA`
: Code/phase biases related to the early rapid orbit and clock corrections, Bias-SINEX format
Note: Integer-cycle clocks in conjunction with accompanying code/phase biases enable PPP-AR (ftp://ftp.aiub.unibe.ch/CODE/IAR_README.TXT)

`COD0OPSRAP_yyyyddd0000_01D_30S_ATT.OBX`
: Satellite attitude, ORBEX format

CODE *final rapid* products: GPS+GLONASS+Galileo; middle day of a long-arc solution
where the rapid observations were completed by a subsequent ultra-rapid dataset
available at `ftp://ftp.aiub.unibe.ch/CODE`

`CODMOPSRAP_yyyyddd0000_01D_05M_ORB.SP3` (old: `CODwwwwd.EPH_M`)
: CODE final rapid GNSS orbits with 5 minutes sampling

`CODMOPSRAP_yyyyddd0000_01D_01D_ERP.ERP` (old: `CODwwwwd.ERP_M`)
: CODE final rapid ERPs belonging to the final rapid orbits

`CODMOPSRAP_yyyyddd0000_01D_30S_CLK.CLK` (old: `CODwwwwd.CLK_M`)
`CODMOPSRAP_yyyyddd0000_01D_30S_CLK.CLK_V2`
: CODE GNSS clock product related to the final rapid orbit, clock RINEX format (versions 3.04 and 2.00)

`CODMOPSRAP_yyyyddd0000_01D_01D_OSB.BIA`
: Code/phase biases related to the final rapid orbit and clock corrections, Bias-SINEX format
Note: Integer-cycle clocks in conjunction with accompanying code/phase biases enable PPP-AR (ftp://ftp.aiub.unibe.ch/CODE/IAR_README.TXT)

Note, that as soon as a final product is available the corresponding rapid, ultra-rapid, or predicted products are removed from the anonymous FTP server.

Table 2: CODE's rapid products available through anonymous ftp (continued).

Result files for CODE *rapid ionosphere* solution
available at ftp://ftp.aiub.unibe.ch/CODE

`COD0OPSRAP_yyyyddd0000_01D_01H_GIM.INX.gz` (old: `CORGddd0.yyI`)
CODE rapid ionosphere product, IONEX format
`COD0OPSRAP_yyyyddd0000_01D_01H_GIM.ION` (old: `CODwwwwd.ION_R`)
CODE rapid ionosphere product, Bernese format
`COD0OPSRAP_yyyyddd0000_01D_01D_GIM.RNX` (old: `CGIMddd0.yyN_R`)
Improved Klobuchar-style coefficients based on CODE rapid ionosphere product, RINEX format

`COD0OPSPRD_yyyyddd0000_01D_01H_GIM.INX.gz` (old: `COPGddd0.yyI`)
CODE ionosphere predictions, IONEX format
`COD0OPSPRD_yyyyddd0000_01D_01H_GIM.ION` (old: `CODwwwwd.ION_P`)
CODE ionosphere predictions, Bernese format
`COD0OPSPRD_yyyyddd0000_01D_01D_GIM.RNX` (old: `CGIMddd0.yyN_P`)
Predictions of improved Klobuchar-style coefficients, RINEX format

Result files for CODE *bias product* generation
available at ftp://ftp.aiub.unibe.ch/CODE

P1C1.DCB	CODE sliding 30-day P1−C1 DCB solution, Bernese format, containing only the GPS satellites
P1P2.DCB	CODE sliding 30-day P1−P2 DCB solution, Bernese format, containing the GPS and GLONASS satellites
P1P2_ALL.DCB	CODE sliding 30-day P1−P2 DCB solution, Bernese format, containing the GPS and GLONASS satellites and all stations used
P1P2_GPS.DCB	CODE sliding 30-day P1−P2 DCB solution, Bernese format, containing only the GPS satellites
P1C1_RINEX.DCB	CODE sliding 30-day P1−C1 DCB values directly extracted from RINEX observation files, Bernese format, containing the GPS and GLONASS satellites and all stations used
P2C2_RINEX.DCB	CODE sliding 30-day P2−C2 DCB values directly extracted from RINEX observation files, Bernese format, containing the GPS and GLONASS satellites and all stations used
CODE.DCB	Combination of P1P2.DCB and P1C1.DCB
CODE_FULL.DCB	Combination of P1P2.DCB, P1C1.DCB (GPS satellites), P1C1_RINEX.DCB (GLONASS satellites), and P2C2_RINEX.DCB
CODE.BIA	Same content but stored as OSBs in the Bias SINEX format
CODE_MONTHLY.BIA	Cumulative monthly OSB solution in Bias SINEX format

Note, that as soon as a final product is available the corresponding rapid, ultra-rapid, or predicted products are removed from the anonymous FTP server.

Table 3: CODE's final products available through anonymous ftp.

CODE *final* products available at ftp://ftp.aiub.unibe.ch/CODE/yyyy/

`COD0OPSFIN_yyyyddd0000_01D_05M_ORB.SP3.gz` (old: `CODwwwwd.EPH.Z`)
CODE final GPS+GLONASS+Galileo orbits
`COD0OPSFIN_yyyyddd0000_01D_01D_ERP.ERP.gz` (old: `CODwwwwd.ERP.Z`)
CODE final ERPs belonging to the final orbits
`COD0OPSFIN_yyyyddd0000_01D_30S_CLK.CLK.gz` (old: `CODwwwwd_v3.CLK.Z`)
`COD0OPSFIN_yyyyddd0000_01D_30S_CLK.CLK_V2.gz` (old: `CODwwwwd.CLK.Z`)
CODE final clock product, clock RINEX format (versions 3.04 and 2.00), with a sampling of 30 sec for the GNSS satellite and reference (station) clock corrections and 5 minutes for all other station clock corrections
`COD0OPSFIN_yyyyddd0000_01D_05S_CLK.CLK.gz` (old: `CODwwwwd_v3.CLK_05.Z`)
`COD0OPSFIN_yyyyddd0000_01D_05S_CLK.CLK_V2.gz` (old: `CODwwwwd.CLK_05S.Z`)
CODE final clock product, clock RINEX format (versions 3.04 and 2.00), with a sampling of 5 sec for the GNSS satellite and reference (station) clock corrections and 5 minutes for all other station clock corrections
`COD0OPSFIN_yyyyddd0000_01D_01D_OSB.BIA.gz` (old: `CODwwwwd.BIA.Z`)
CODE daily code and phase bias solution corresponding to the above mentioned clock products, bias SINEX format v1.00
See `ftp://ftp.aiub.unibe.ch/CODE/IAR_README.TXT` for the usage of the phase biases.
`COD0OPSFIN_yyyyddd0000_01D_30S_ATT.OBX.gz` (old: `CODwwwwd.OBX.Z`)
Satellite attitude information in ORBEX format
`COD0OPSFIN_yyyyddd0000_01D_01D_SOL.SNX.gz` (old: `CODwwwwd.SNX.Z`)
CODE daily final solution, SINEX format
`COD0OPSFIN_yyyyddd0000_01D_01H_TRO.TRO.gz` (old: `CODwwwwd.TRO.Z`)
CODE final troposphere product, troposphere SINEX format
`COD0OPSFIN_yyyyddd0000_01D_01H_GIM.INX.gz` (old: `CODGddd0.yyI.Z`)
CODE final ionosphere product, IONEX format
`COD0OPSFIN_yyyyddd0000_01D_01H_GIM.ION.gz` (old: `CODwwwwd.ION.Z`)
CODE final ionosphere product, Bernese format
`COD0OPSFIN_yyyyddd0000_01D_01D_GIM.RNX.gz` (also still available: `CGIMddd0.yyN.Z`)
Improved Klobuchar-style ionosphere coefficients, navigation RINEX format
`COD0OPSFIN_yyyyddd0000_07D_07D_SOL.SNX.gz` (old: `CODwwww7.SNX.Z`)
CODE weekly final solution, SINEX format (only for Sunday of the related week)
`COD0OPSFIN_yyyyddd0000_07D_01D_ERP.ERP.gz` (old: `CODwwww7.ERP.Z`)
Collection of the 7 daily CODE-ERP solutions of the week (only for Sunday of the related week)
`COD0OPSFIN_yyyyddd0000_07D_01D_SUM.SUM.gz` (old: `CODwwww7.SUM.Z`)
CODE weekly summary file (only for Sunday of the related week)

CODE *final bias* products available at ftp://ftp.aiub.unibe.ch/CODE/yyyy/

`P1C1yymm.DCB.Z`	CODE monthly P1−C1 DCB solution, Bernese format, containing only the GPS satellites
`P1P2yymm.DCB.Z`	CODE monthly P1−P2 DCB solution, Bernese format, containing the GPS and GLONASS satellites
`P1P2yymm_ALL.DCB.Z`	CODE monthly P1−P2 DCB solution, Bernese format, containing the GPS and GLONASS satellites and all stations used
`P1C1yymm_RINEX.DCB.Z`	CODE monthly P1−C1 DCB values directly extracted from RINEX observation files, Bernese format, containing the GPS and GLONASS satellites and all stations used
`P2C2yymm_RINEX.DCB.Z`	CODE monthly P2−C2 DCB values directly extracted from RINEX observation files, Bernese format, containing the GPS and GLONASS satellites and all stations used

Table 4: CODE's MGEX products available through anonymous ftp.

CODE *MGEX* products available at ftp://ftp.aiub.unibe.ch/CODE_MGEX/CODE/yyyy/

`CODOMGXFIN_yyyyddd0000_01D_05M_ORB.SP3.gz` (old: `COMwwwwd.EPH.Z`)
CODE MGEX final GNSS orbits for GPS, GLONASS, Galileo, BeiDou, and QZSS satellites, SP3 format

`CODOMGXFIN_yyyyddd0000_01D_12H_ERP.ERP.gz` (old: `COMwwwwd.ERP.Z`)
CODE MGEX final ERPs belonging to the MGEX final orbits

`CODOMGXFIN_yyyyddd0000_01D_30S_CLK.CLK.gz` (old: `COMwwwwd_v3.CLK.Z`)
(old: `COMwwwwd.CLK.Z` version 2.00)
CODE MGEX final clock product consistent to the MGEX final orbits, clock RINEX format (version 3.04), with a sampling of 30 sec for the GNSS satellite and reference (station) clock corrections and 5 minutes for all other station clock corrections

`CODOMGXFIN_yyyyddd0000_01D_01D_OSB.BIA.gz` (old: `COMwwwwd.BIA.Z`)
GNSS code and phase (GPS and Galileo only) biases related to the MGEX final clock correction product, bias SINEX format v1.00
See `ftp://ftp.aiub.unibe.ch/CODE/IAR_README.TXT` for the usage of the phase biases.

`CODOMGXFIN_yyyyddd0000_01D_30S_ATT.OBX.gz` (old: `COMwwwwd.OBX.Z`)
Satellite attitude information in ORBEX format

Table 5: CODE final products available in the product areas of the IGS data centers.

Files generated from three–day long–arc solutions:

`CODOOPSFIN_yyyyddd0000_01D_05M_ORB.SP3.gz` (old: `codwwwwd.eph.Z`)
GNSS ephemeris/clock data in daily files at 15–min intervals in SP3 format, including accuracy codes computed from a long–arc analysis

`CODOOPSFIN_yyyyddd0000_01D_01D_ERP.ERP.gz` (old: `codwwwwd.erp.Z`)
GNSS ERP (pole, UT1−UTC) solution belonging to the COD–orbit files in IGS IERS ERP format

`CODOOPSFIN_yyyyddd0000_01D_01D_SOL.SNX.gz` (old: `codwwwwd.snx.Z`)
GNSS daily coordinates/ERP/GCC from the long–arc solution in SINEX format

`CODOOPSFIN_yyyyddd0000_01D_30S_CLK.CLK.gz` (old: `codwwwwd_v3.clk.Z`)
`CODOOPSFIN_yyyyddd0000_01D_30S_CLK.CLK_V2.gz` (old: `codwwwwd.clk.Z`)
GNSS satellite and receiver clock corrections at 30–sec intervals referring to the COD–orbits from the long–arc analysis in clock RINEX format (versions 3.04 and 2.00)

`CODOOPSFIN_yyyyddd0000_01D_05S_CLK.CLK.gz` (old: `codwwwwd_v3.clk_05s.Z`)
`CODOOPSFIN_yyyyddd0000_01D_05S_CLK.CLK_V2.gz` (old: `codwwwwd.clk_05s.Z`)
GNSS satellite and receiver clock corrections at 5–sec intervals referring to the COD–orbits from the long–arc analysis in clock RINEX format (versions 3.04 and 2.00)

`CODOOPSFIN_yyyyddd0000_01D_01D_OSB.BIA.gz` (old: `codwwwwd.bia.Z`)
CODE daily code and phase bias solution corresponding to the above mentioned clock products

`CODOOPSFIN_yyyyddd0000_01D_30S_ATT.OBX.gz` (old: `codwwwwd.obx.Z`)
Satellite attitude information in ORBEX format

`CODOOPSFIN_yyyyddd0000_01D_01H_TRO.TRO.gz` (old: `codwwwwd.tro.Z`)
GNSS 2–hour troposphere delay estimates obtained from the long–arc solution in troposphere SINEX format

`CODOOPSFIN_yyyyddd0000_07D_01D_ERP.ERP.gz` (old: `codwwww7.erp.Z`)
GNSS ERP (pole, UT1−UTC) solution, collection of the 7 daily COD–ERP solutions of the week in IGS IERS ERP format

`CODOOPSFIN_yyyyddd0000_07D_01D_SUM.SUM.gz` (old: `codwwww7.sum`)
Analysis summary for 1 week

Note that the `COD`–series is identical with the files posted at the CODE's aftp server, see Table 3.

Table 5: CODE final products available in the product areas of the IGS data centers (continued).

Other product files (not available at all data centers):

`CODOOPSFIN_yyyyddd0000_01D_01H_GIM.INX.gz` (old: `CODGddd0.yyI.Z`)
GNSS hourly global ionosphere maps in IONEX format, including satellite and receiver P1−P2 code bias values

`CODNOPSFIN_yyyyddd0000_01D_01H_GIM.INX.gz` (old: `CKMGddd0.yyI.Z`)
GNSS daily Klobuchar-style ionospheric (alpha and beta) coefficients in IONEX format

`CODKOPSFIN_yyyyddd0000_01D_01H_GIM.INX.gz` (old: `GPSGddd0.yyI.Z`)
Klobuchar-style ionospheric (alpha and beta) coefficients from GPS navigation messages represented in IONEX format

Table 6: CODE MGEX products available in the product areas of the IGS data centers.

Files generated from three–day long–arc MGEX solutions:

`CODOMGXFIN_yyyyddd0000_01D_05M_ORB.SP3.gz`
CODE MGEX final GNSS orbits for GPS, GLONASS, Galileo, BeiDou, and QZSS satellites, SP3 format

`CODOMGXFIN_yyyyddd0000_01D_12H_ERP.ERP.gz`
CODE MGEX final ERPs belonging to the MGEX final orbits

`CODOMGXFIN_yyyyddd0000_01D_30S_CLK.CLK.gz`
CODE MGEX final clock product consistent to the MGEX final orbits, clock RINEX 3.04 format, with a sampling of 30 sec for the GNSS satellite and reference (station) clock corrections and 5 minutes for all other station clock corrections

`CODOMGXFIN_yyyyddd0000_01D_01D_OSB.BIA.gz`
GNSS code and phase (GPS and Galileo only) biases related to the MGEX final clock correction product, Bias SINEX format v1.00

`CODOMGXFIN_yyyyddd0000_01D_30S_ATT.OBX.gz`
Satellite attitude information in ORBEX format

Note that the `COD`-MGEX-series is identical with the files posted at the CODE's aftp server, see Table 4.

Referencing of the products

The products from CODE have been registered and should be referenced as:

- Dach, R., S. Schaer, D. Arnold, E. Brockmann, M. Kalarus, M. Lasser, P. Stebler, A. Jaeggi (2024). *CODE final product series for the IGS.* Published by Astronomical Institute, University of Bern. URL: https://www.aiub.unibe.ch/download/CODE; DOI: 10.48350/197025.
- Dach, R., S. Schaer, D. Arnold, E. Brockmann, M. Kalarus, M. Lasser, P. Stebler, A. Jaeggi (2024). *CODE rapid product series for the IGS.* Published by Astronomical Institute, University of Bern. URL: `https://www.aiub.unibe.ch/download/CODE`; DOI: 10.48350/197026.
- Dach, R., S. Schaer, D. Arnold, E. Brockmann, M. Kalarus, M. Lasser, P. Stebler, A. Jaeggi (2024). *CODE ultra-rapid product series for the IGS.* Published by Astronomical Institute, University of Bern. URL: `https://www.aiub.unibe.ch/download/CODE`; DOI: 10.48350/197027.
- Dach, R., S. Schaer, D. Arnold, E. Brockmann, M. Kalarus, M. Lasser, P. Stebler, A. Jaeggi (2024). *CODE product series for the IGS MGEX project.* Published by Astronomical Institute, University of Bern. URL: `https://www.aiub.unibe.ch/download/CODE_MGEX`; DOI: 10.48350/197028.

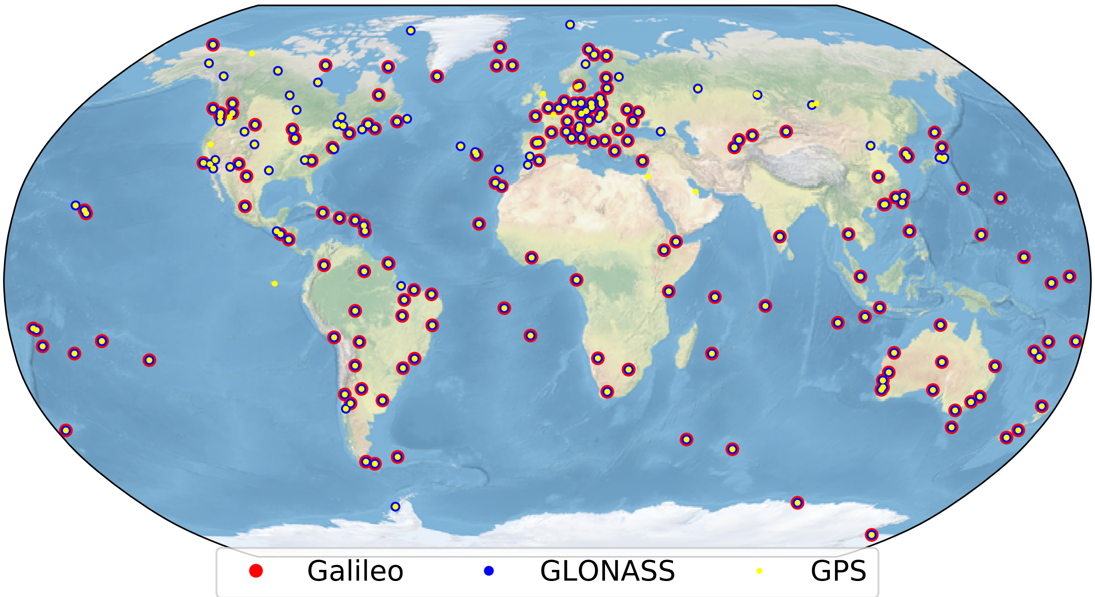
3 Statistics on the CODE solution

3.1 Selected general statistics

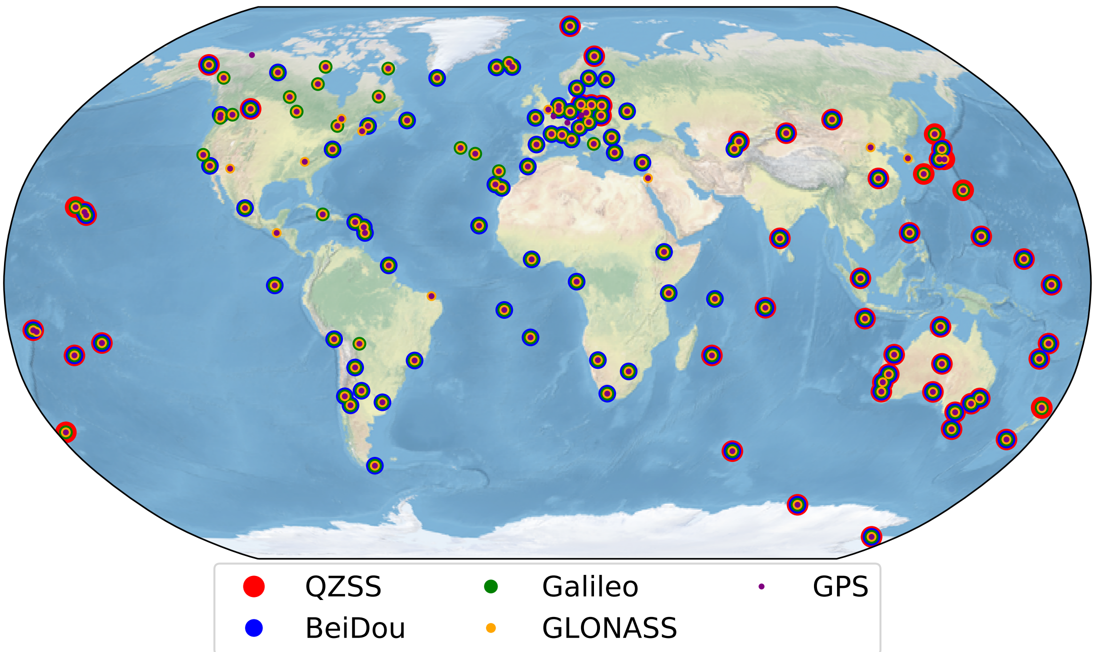
The network used by CODE for the final and MGEX processing is shown in Figure 1.

The development of the included satellite systems in the CODE solution is illustrated in Figure 2. Since May 2003 CODE is generating all its products for the IGS legacy series based on a combined GPS and GLONASS solution. Since 2012 the MGEX solution from CODE contains Galileo satellites and with beginning of 2014 also the satellites from the Asian systems BeiDou and QZSS. In March 2021, the BeiDou 3 constellation was added to the processing. For that reason a jump in the number of processed BeiDou satellites appears in the plot. End of 2024, the MGEX solution includes about 122 satellites of five satellite systems.

Figure 3 provides two key performance indicators for the CODE final products series: orbit misclosures at midnight (left panels) and the performance of the satellite clock (right panels) as the RMS of a linear fit through the values with a sampling of 30 s per day. Separate plots for the three constellations in the CODE solution (GPS, GLONASS, and Galileo) are provided.



(a) final solution (more than 250 stations)



(b) MGEX solution (more than 140 stations)

Figure 1: Network used for the processing at CODE by the end of 2024.

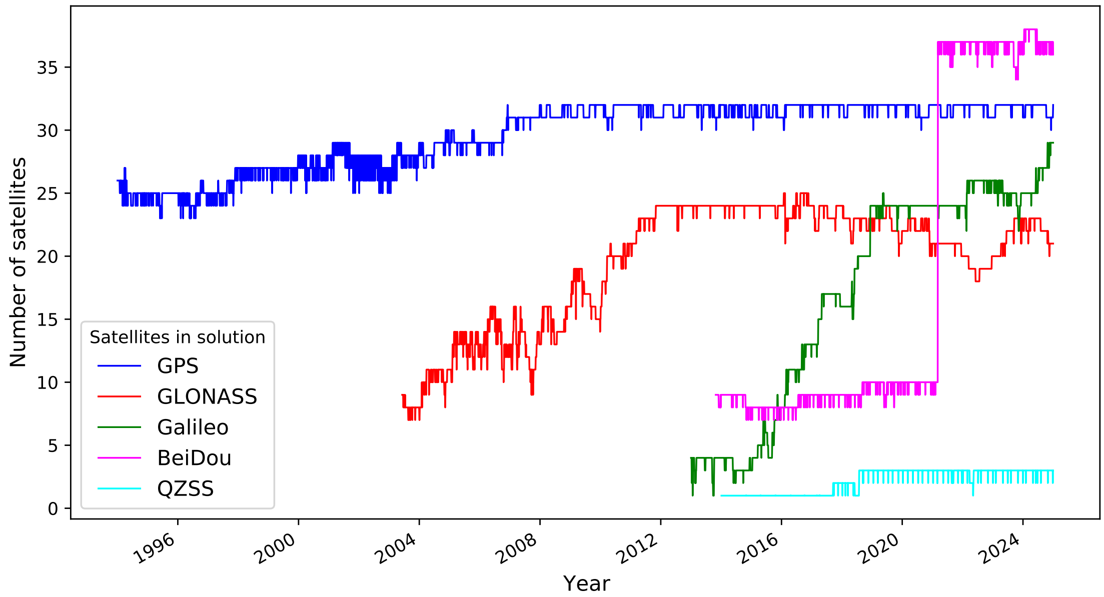
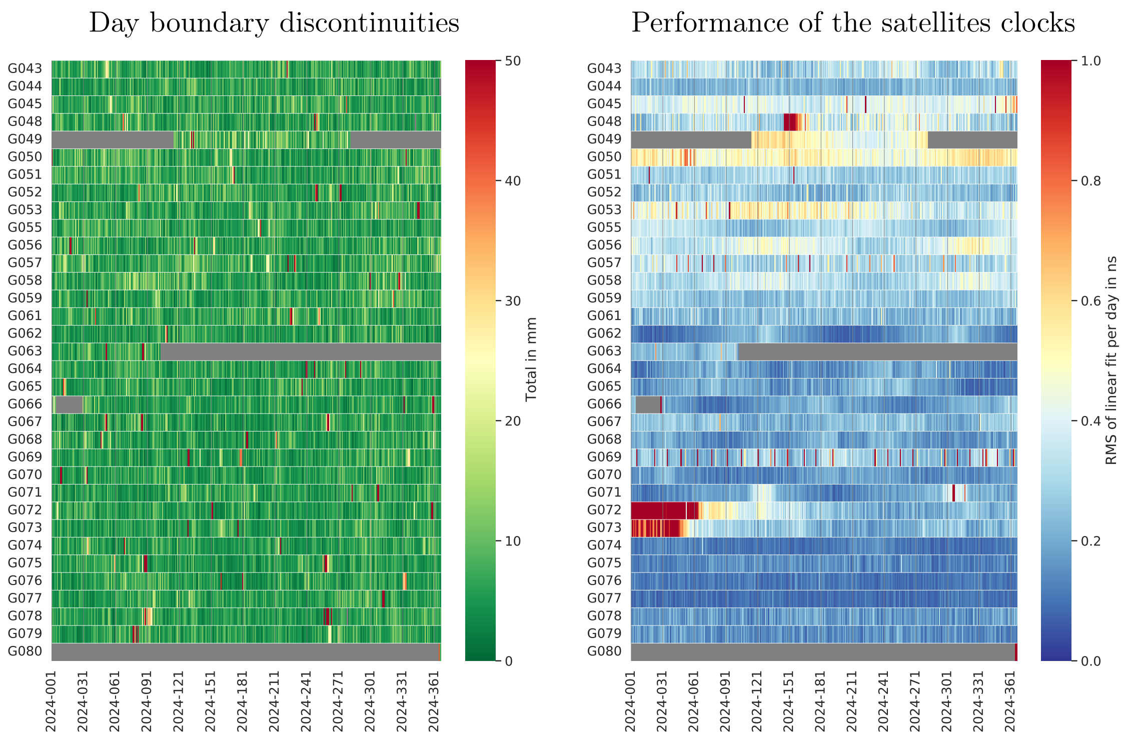


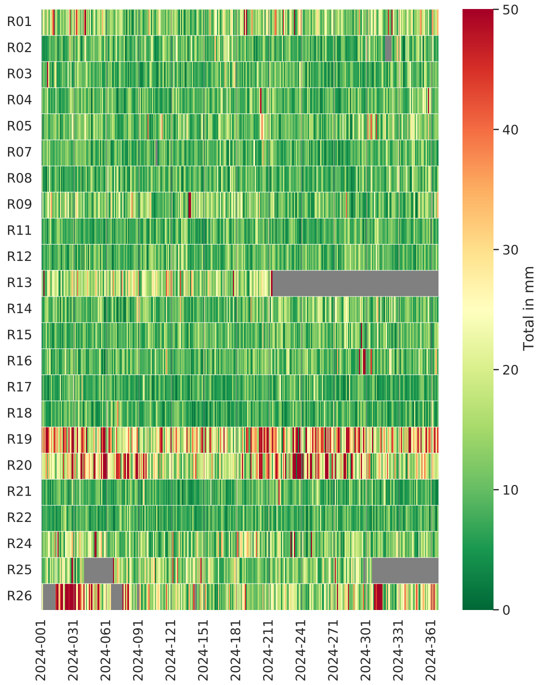
Figure 2: Development of the number of satellites in the CODE orbit products.



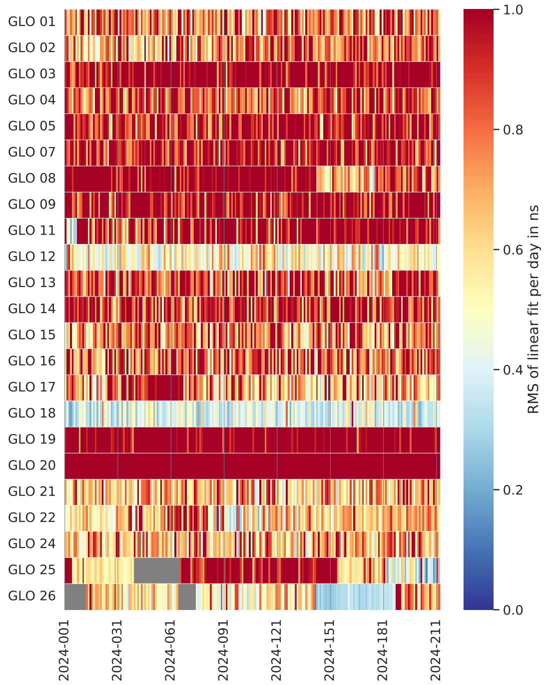
GPS constellation, sorted with respect to the SVN

Figure 3: Performance overview of the CODE three-day solution in 2024.

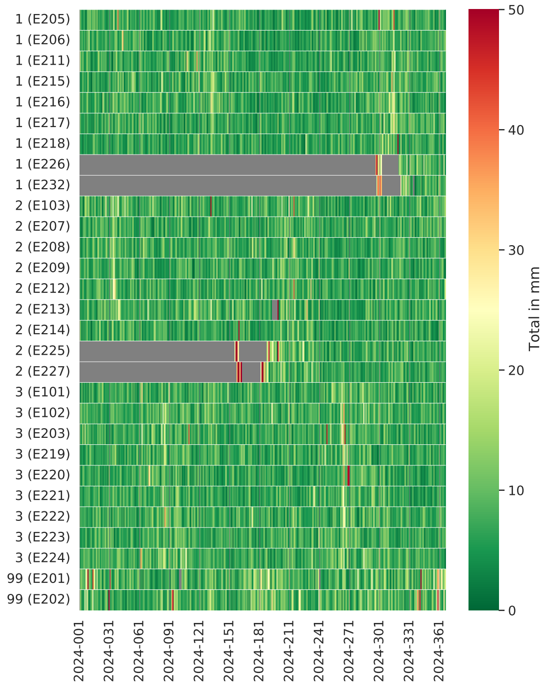
Day boundary discontinuities

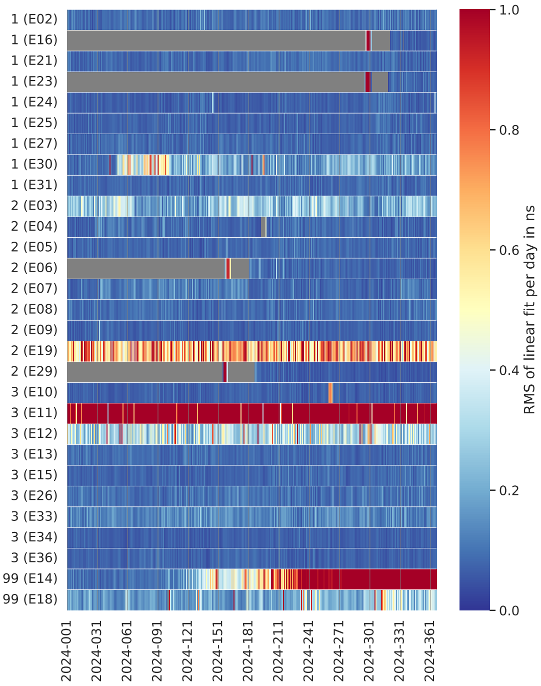


Performance of the satellites clocks



GLONASS constellation, sorted with respect to the slot numbers





Galileo constellation, sorted by PRN sorted by the orbital planes

Figure 3: Performance overview of the CODE three-day solution in 2024; continued.

The grey areas in the plots indicate periods where the related satellites are not active. The latest GPS satellite (SVN G80) became active within the last days of 2024 and was immediately included into the processing. Also the newly launched Galileo satellites emit first navigation signals for a few days before they are finally activated (e.g., E28 and E32 or E25 and E27). This is a characteristics of the CODE processing scheme that the satellites are included as soon as signals are tracked disregarding the health status.

The performance of the GPS satellite clocks is continuously increasing with the later satellite generations. On the other hand, the Galileo satellite clocks show in general an excellent performance. Nevertheless there are a number of satellites with a limited performance (e.g., the IOV satellites E11, E12, and E19). Also one of the two satellites in the elliptical orbit (E14) has a degraded performance since Summer 2024. The satellite orbit overlaps do not reflect the same development of performance which indicates that these are effects related to the performance of the satellite clock and not in the processing of the CODE analysis center. The discontinuities in the orbits between subsequent days is in general below 5 mm for GPS, at the level of 10 mm to 15 mm for GLONASS and below 10 mm for Galileo. In case of Galileo, the shadow periods show a slight degradation of the orbit quality parameter.

4 Changes in the daily processing for the IGS

The CODE processing scheme for daily IGS analyses is constantly subject to updates and improvements. The changes of the previous year 2023 were published in the last technical report in Dach et al. (2024).

In Section 4.1 we give an overview of important development steps in the year 2024.

4.1 Overview of changes in the processing scheme in 2024

Table 7 gives an overview of the major changes implemented during the year 2024. Details on the analysis strategy can be found in the IGS analysis questionnaire at the IGS Central Bureau (`https://files.igs.org/pub/center/analysis/code.acn`).

Several other improvements not listed in Table 7 were implemented, too. Those mainly concern data download and management, sophistication of CODE's analysis strategy, software changes (improvements), and many more. As these changes are virtually not relevant for users of CODE products, they will not be detailed on any further.

Table 7: Selected events and modifications of the CODE processing during 2024.

Date	DoY/Year	Description
26-Jan-2024	026/2024	Force a Galileo-only network prior the general network creation.
12-Apr-2024	103/2024	Disabled G01 after 13 yrs operation (SVN 63 and activated SVN 49 some days later).
01-May-2024	122/2024	CLK solution MGEX including widelane AR for BDS and QZSS.
14-May-2024	135/2024	Solutions strongly affected due to high geomagnatic activity.
10-Jun-2024	162/2024	Update of the Rocky Linux OS.
26-Aug-2024	239/2024	AU modified from 149597870691.D0 to 149597870700.D0 (impact < 0.1 mm on orbits).
21-Sep-2024	265/2024	Activation Gravity model derived from COST-G service COSTG_FSM_2309, where 2309 indicates that the coefficients have been fitted with data up to September 2023).
21-Oct-2024	295/2024	Activation Gravity model derived from COST-G service COSTG_FSM_2406, where 2406 indicates that the coefficients have been fitted with data up to June 2024).

4.2 BDS-3 / QZSS satellite antenna calibration campaign

In order to develop a fully multi-GNSS IGS product, several IGS ACs joined the activity to estimate improved BeiDou and QZSS antenna offsets and satellite antenna phase center corrections which are compatible with the IGS20 reference frame. In spring 2024, CODE participated in step 1 of this activity by deriving phase variation patterns for the BDS-3 satellites using the B1C/B2a frequency combination (and neglecting BDS-2 satellites). These values were derived from a one-year reprocessing using the MGEX processing chain. Daily solutions were accumulated to weekly solutions and an annual solution. The repeatability of the estimated antenna phase center variations with respect to the annual solution is shown for an arbitrary selected satellite in Figure 4, as well as the annual mean estimates for the CAST satellites.

Steigenberger et al. (2024) combined six AC contributions to an updated antenna model for each BeiDou satellite type (CAST, SECM-A, SECM-B, IGSO). This product was then used to derive in a second step the BeiDou and QZSS antenna offsets using frequencies B1C/B2a and L1C/L5, respectively. For the second step three years of data were reprocessed and results (daily SINEX file) were submitted mid of December 2024, again based on the MGEX processing chain.

The results of the combination of eight contributing ACs (Rebischung, 2024) are currently under discussion. CODE intends to integrate the BeiDou and QZSS system to the legacy products after analyzing the impact of such an enhancement in further detail.

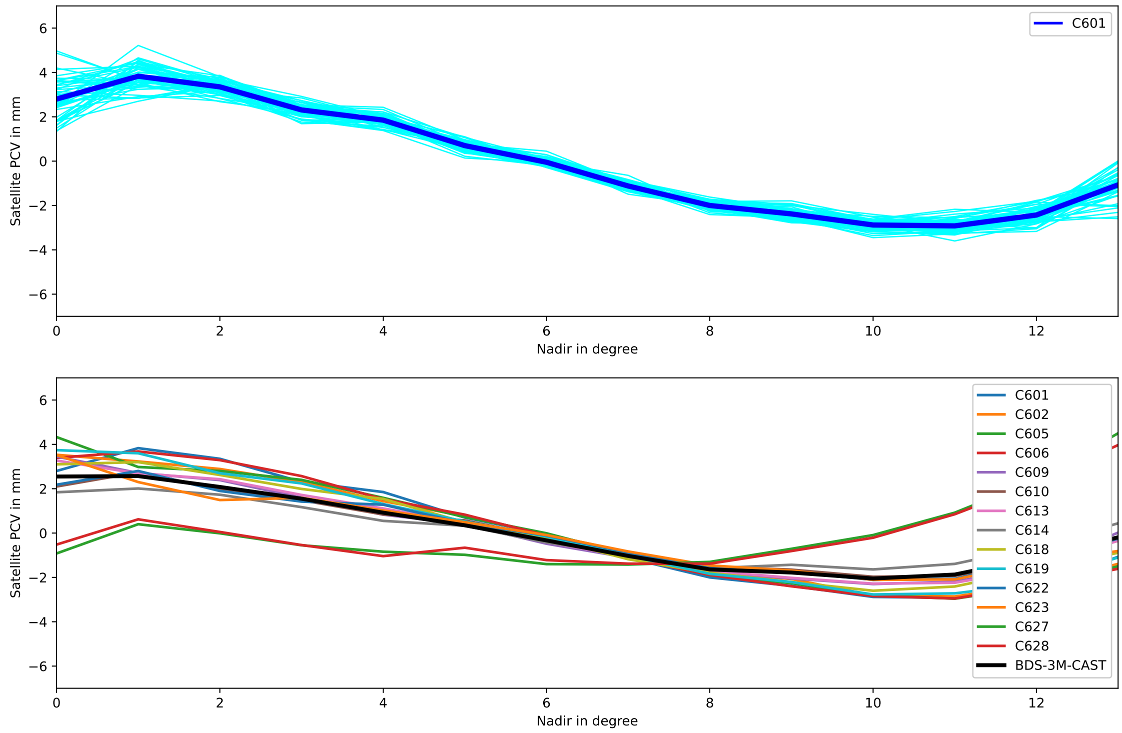


Figure 4: Antenna phase center variations derived from weekly solutions (in cyan) and the averaged value (in blue) for BeiDou satellite C19 (601, type CAST). Below, annual averages of the antenna phase center variations of the BeiDou CAST satellites.

4.3 Geocenter handling in global GNSS solutions

The recommendations for the "IGS Reference Frame Maintenance" from the IGS Workshop 2004 state:

- All IGS satellite clocks should be in ITRF center of network.
- Using IGS prodcuts for PPP shall provide coordinates in the ITRF realization.

The ITRF is a center-of-figure (CoF) based frame to obtain coordinates on the Earth surface that are not influenced by temporal changes of the origin of the reference frame. Nevertheless, the discussion on center-of-mass (CoM) based GNSS satellite clock solutions for IGS products came up, in particular for orbit determination purposes.

In order to implement the recommendations, the IGS solution at CODE Analysis Center is done by forcing the orbit and clock solution to the CoF – meaning to the current IGS/ITRF reference frame. This is of course not the perfect setup for orbit modelling because the satellites are flying around the instantaneous CoM. In order to assess the impact of this model deficiency, two solutions have been created based on CODE's rapid processing scheme for the days 180 to 189 in year 2023: once the solution was generated as usual, referring to the origin (CoF solution) and alternatively, the translation vector from the ITRF2020 geocenter motion model was considered when the coordinates are introduced for the datum definition (CoM solution). In both cases the datum definition was realized via an NNR and NNT condition on a verified list of stations with respect to the IGS20 frame.

A comparison of the two solutions shows:

- Station coordinates in IGS20 frame agree on an RMS level of < 0.5 mm without applying any transformation parameters
- Satellite positions agree in the IGS20 frame as well by < 1 mm RMS without the estimation of transformation parameters
- In the Earth centered inertial frame the satellite positions agree on the $5\ldots7$ mm level RMS with translations of about 2.2 mm in the Z-component and no translation in the X- and Y-components. They do not reflect the translation introduced into the datum definition.
- When comparing the satellite clock corrections between the CoF- and CoM-based solutions, systematic effects with the satellite revolution period appears (see Figure 5 showing the differences for selected Galileo satellites from the same orbital plane but with antipodal location in the constellation). The satellite clock differences can be translated into geocenter coordinates: $\mathrm{GCC}_X = 0.7$ mm, $\mathrm{GCC}_Y = 3.5$ mm, $\mathrm{GCC}_Z = 2.6$ mm. The introduced geocenter translation vector agrees well with $\mathrm{GCC}_X = 0.5$ mm, $\mathrm{GCC}_Y = 3.2$ mm, $\mathrm{GCC}_Z = 3.2$ mm (at least for the X and Y components).

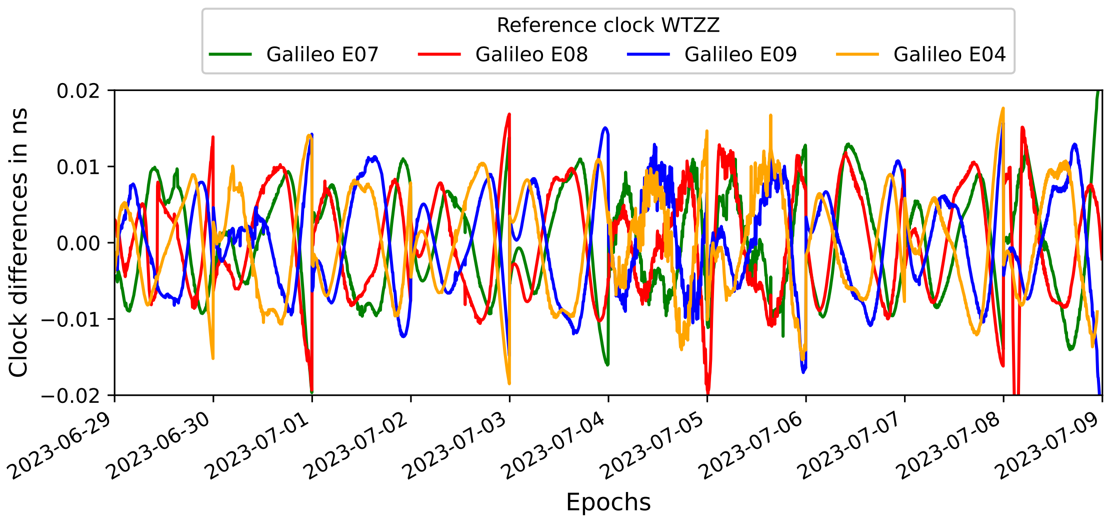


Figure 5: Differences between the satellite clock corrections between the CoF- and CoM-based solution for selected Galileo satellites.

This means that the satellite clock corrections do completely absorb the Geocenter corrections meaning that the satellite orbit modelling takes place in a CoM-based frame that is inherently realized by the GNSS solution – independent from the datum definition with respect to a CoF- or CoM-based frame.

Such a strong correlation between satellite clock corrections and the geocenter vector is only valid for an IGS-style estimation of GNSS satellite orbit and clock corrections. For instance, in the context of orbit determination for Low Earth Orbiting satellites (LEOs) the receiver clock cannot absorb the CoM variations because the observations are distributed down to the horizon (and not only to a nadir angle of 14° like for GNSS satellites).

The geocenter vector as it is established in the GNSS solution is typically degraded by orbit modelling effect – in particular the Z component. For that reason the inherent geocenter vector from the GNSS solution should be obtained and exchanged by a more realistic one for applications like LEO orbit determination. This can be done by estimating a geocenter translation vector in the orbit determination process. That also this vector is absorbed by the satellite clocks is demonstrated in Figure 6. The difference in the satellite clock correction between a solution with estimating the geocenter translation vector and without can be translated into a geocenter vector again, that agrees very well with the estimated one.

This allows for the following procedure to consider the CoM in a GNSS orbit solution assuming that the clock parameter are pre-eliminated if the geometry is computed.

1. The satellite positions are obtained in an inherent CoM-based frame. The corresponding geocenter translation vector can be estimated in the context of the orbit determination step.

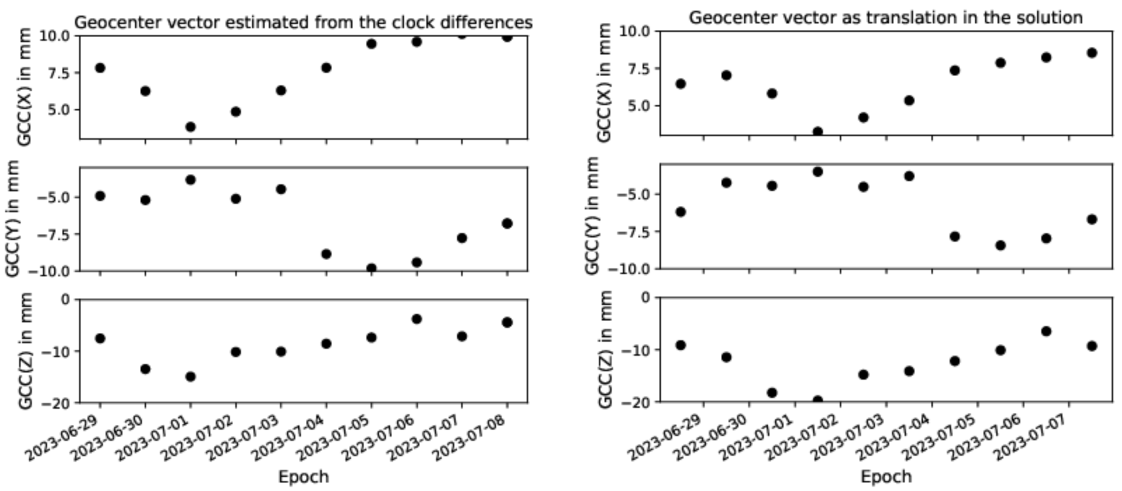


Figure 6: Comparison of the geocenter vector as obtained from the differences in the satellite clocks (left panel) and as estimated as translation parameter (right panel).

2. The satellite positions can be transformed into the CoF-based frame when correcting them by the estimated geocenter translation vector.
3. If a certain CoM modell shall be implemented to realize a CoM-based frame (e.g., for LEO orbit determination), the satellite positions can now be corrected by the related CoM vector.

After each of these operations the GNSS satellite positions can be used for the backsubstitution of the satellite and receiver clock corrections. The frame of the station coordinates defines whether a PPP application will end in a CoF- or CoM-based frame. Looking at the variations of the satellite clock parameters options 2. or 3. are minimizing the variations when applying CoF- or CoM-based station coordinates, which might for instance be interesting for modelling the satellite clocks instead of estimating them independently epoch by epoch.

5 Development of a combined Earth Orientation Parameters product at BKG

5.1 Extension of the combined Earth Rotation Parameters with SLR data

The Earth Rotation Parameters (ERPs) describe the rotation between the Terrestrial Reference Frame (TRF) and the Celestial Reference Frame (CRF) and represent an essential component of the Global Geodetic Reference Frame (GGRF).

The publicly available ERP series provided by the International Earth Rotation and Reference Systems Service (IERS), such as Bulletin A and the C04 series, are generated by combining individual technique-specific ERP solutions at the parameter level. This approach represents the least rigorous combination method, as each parameter type is combined independently and correlations between the different parameters are not taken into account.

To address these limitations, the BKG is developing a multi-technique combination strategy at the level of datum-free normal equations (NEQs). The core objective is to improve the estimation of ERPs through the use of consistent input data from multiple geodetic space techniques, currently GNSS, VLBI, and SLR. This combination ensures a homogeneous reference frame and a consistent set of estimated parameters. The NEQs of seven consecutive days are combined into one NEQ system before the datum constraints are applied, and the parameters, in particular ERPs and station coordinates, are estimated (see Figure 7). Repeating this procedure on a daily basis results in a continuous ERP series with a daily resolution and short latency of one day, which is particularly important for the highly variable parameter dUT1.

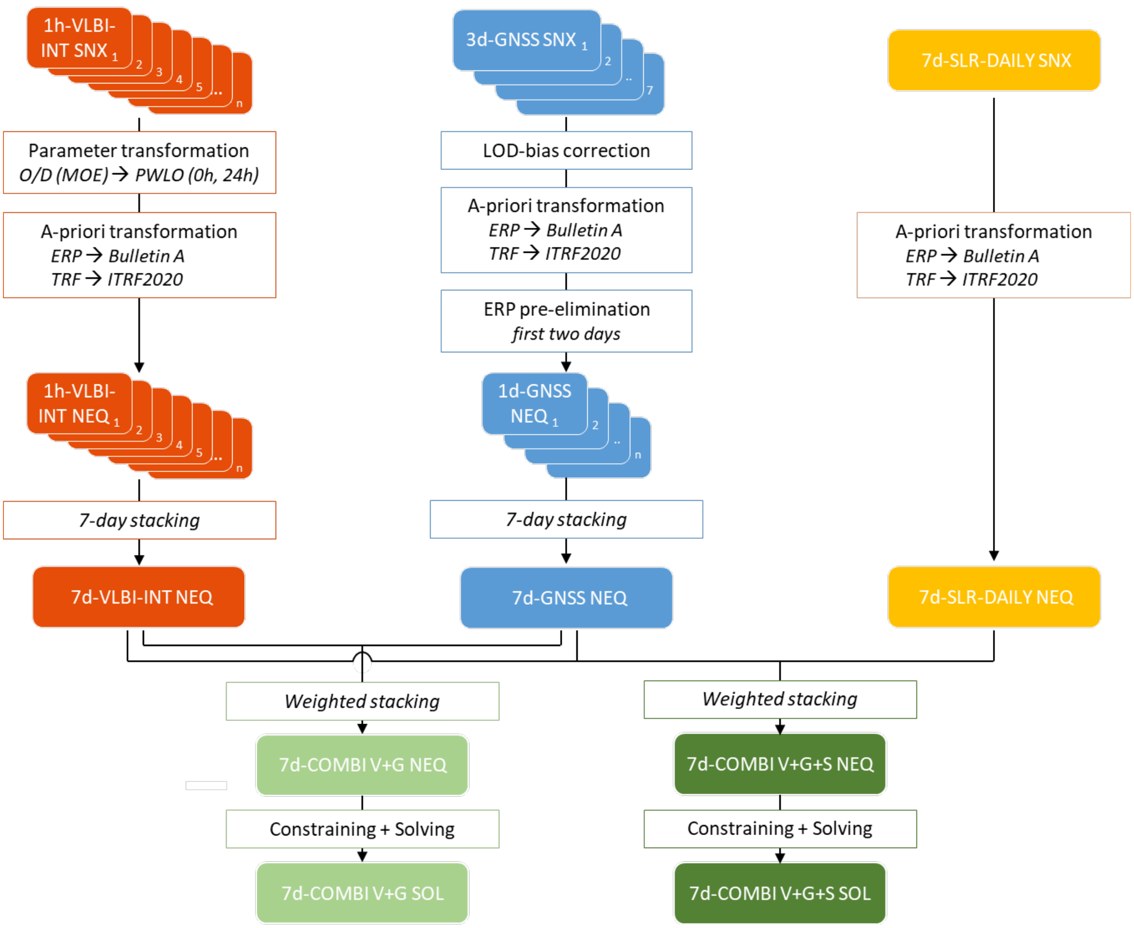


Figure 7: Flow chart of the multi-technique combinations for rapid ERP estimation including an overview of the different solutions.

Initial developments focused on the combination of GNSS and VLBI data using SINEX files from the CODE IGS Analysis Center and the BKG IVS Analysis Center. This combination led to a significant improvement in the accuracy of the resulting ERP series, particularly for dUT1, compared to individual technique-specific solutions. Detailed methodology and results are described in Lengert et al. (2021, 2022) and Klemm et al. (2024a,a).

To further enhance the combined solution, Satellite Laser Ranging (SLR) data has recently been integrated into the processing. SLR provides high-quality LOD estimates with short latency, complementing the strengths of GNSS and VLBI. With a latency of approximately one day, the SLR-DAILY product is, in principle, suitable for expanding the data basis of the short-latency ERP series, which currently relies on GNSS Rapid and VLBI Intensives data.

However, the official SLR-DAILY product of the ILRS is a 7-day solution that explicitly contains polar motion (only as constant offsets over 24 hours) and LOD, but no dUT1 parameters. Therefore, this solution is not optimal for our combination approach because the parameterization of the ERPs is not identical to that of the other techniques. To address this, BKG's in-house ILRS Analysis Center developed a tailored SLR solution that includes all required ERP components and their rates in a consistent format.

For a comprehensive validation of the combined ERP series, both internal and external comparison analyses were conducted. For the internal validation, the impact of including SLR data in the combination was evaluated by analyzing the differences between the GNSS+VLBI+SLR and GNSS+VLBI-only ERP solutions. The root mean square (RMS) values of the resulting difference time series (i.e., GNSS+VLBI minus GNSS+VLBI+SLR) serve as quantitative indicators of the contribution of SLR. For dUT1, RMS values range from 4 to 6 μs. The pole coordinates show RMS variations of 13 to 28 μs for the x-pole and 11 to 27 μs for the y-pole, depending on the day within the 7-day arc. These variations highlight the contribution of SLR data to the combined ERP solution and demonstrate its internal consistency. For external validation, the consistency of the GNSS+VLBI+SLR combined solution was evaluated by comparing it to independent reference series provided by the IERS, specifically C04 20 and Bulletin A. The comparisons were made at the midpoints of the 7-day arcs, and the weighted root mean square (WRMS) values were used as indicators of agreement. For dUT1, WRMS values of 23 μs (C04) and 11 μs (Bulletin A) were obtained. For the pole coordinates, WRMS values are 61 μs and 60 μs for the x-pole, and 42 μs and 41 μs for the y-pole, respectively. These WRMS values are similar in magnitude to those ERP series obtained from the GNSS+VLBI combination without the inclusion of SLR data.

Future work includes detailed investigations into the datum definition and weighting strategies within the combination, as well as a transition toward the fully automated operational production.

5.2 ERP prediction using GNSS products from the CODE analysis center

Accurate prediction of ERPs is vital for real-time applications in satellite orbit determination, GNSS positioning, deep space navigation, and Earth system monitoring (Śliwińska-Bronowicz et al. , 2024). While the IERS provides multi-technique combined ERP series (e.g., IERS C04, Bulletin A (finals.daily)), the operational latency and the combination strategy, based on parameter-level integration can limit both timeliness and internal consistency. To address these challenges, GNSS-derived ERP series, particularly those from the CODE Analysis Center, offer a reliable and low-latency alternative for operational ERP prediction (Modiri et al., 2024). CODE provides high-quality daily ERP solutions based solely on GNSS data, characterized by a dense temporal resolution, a consistent estimation strategy, and robust modeling using the Bernese GNSS Software. The rapid series is publicly available with a latency of only 1–2 days, making it particularly suitable for short-term ERP forecasting, especially for highly dynamic parameters such as LOD.

To evaluate the potential of CODE GNSS products specifically for LOD prediction, we applied a hybrid approach combining Singular Spectrum Analysis (SSA) to extract deterministic trends and Copula-based modeling to capture and forecast stochastic residuals (Modiri et al., 2018, 2020). Using CODE LOD data from January 2014 to December 2019 as training input, we performed sliding window forecasts across a three-year evaluation period (2020–2022), generating daily 30-day predictions.

As shown in Figure 8 (upper panel), the CODE LOD series exhibits clear seasonal and interannual variability. The lower panel presents the mean absolute errors (MAE) of the predicted LOD values. The yellow curve shows the MAE between predictions and the

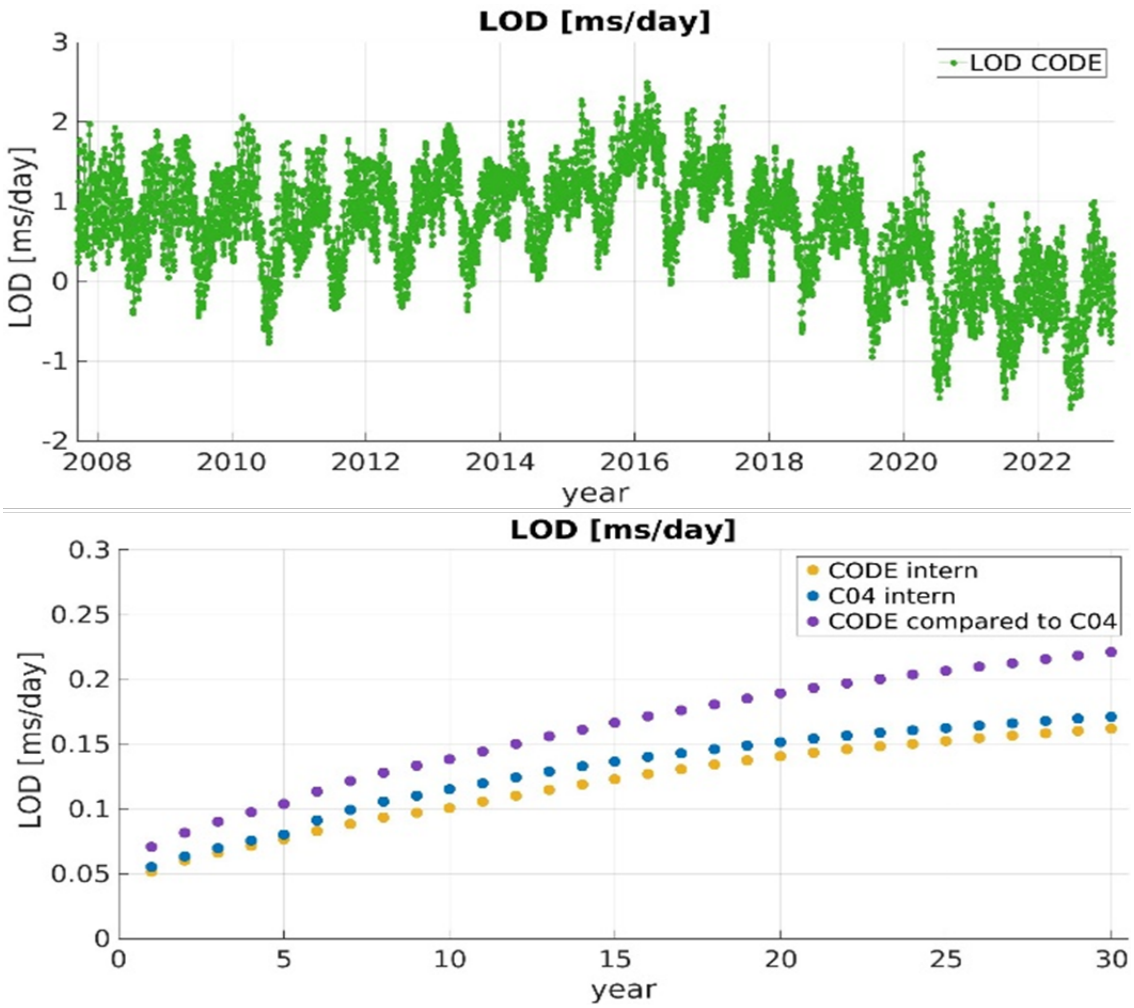


Figure 8: Top: CODE GNSS-derived LOD time series (2008–2022). Bottom: MAE of 30-day LOD predictions using CODE and IERS C04 as input and reference. CODE-based predictions show comparable or better accuracy.

original CODE time series, while the light blue curve represents the MAE for predictions based on IERS C04 data compared to its original time series. The purple curve indicates the MAE when CODE-based predictions are compared against the IERS C04 reference. These results demonstrate that CODE-based predictions offer similar or better internal consistency than IERS C04. Notably, the forecast error remains below 0.1 ms/day during the first 10 days and increases gradually, staying under 0.2 ms/day even for the longest 30-day prediction horizon.

The results confirm that CODE GNSS-derived products, when appropriately modeled, are capable of providing highly accurate short-term predictions of LOD, meeting or surpassing current international benchmarks. Their high temporal resolution, low latency, and internal consistency make them particularly suitable for operational Earth Orientation Parameter (EOP) prediction, addressing the limitations associated with delayed multi-technique solutions. As prediction frameworks continue to advance, particularly through the incorporation of data-driven and machine learning approaches, the CODE GNSS-based EOP series is expected to remain a fundamental resource within the global geodetic infrastructure.

6 IGS Symposium and Workshop

As we all know, IGS started its operational service of the IAG by January 1$^{\text{st}}$, 1994. Nevertheless, the first workshop of the IGS took place in March 1993 and was hosted by the University of Bern. So we are proud that the 30$^{\text{th}}$ anniversary of successful activities of the IGS was celebrated in Bern as well. Overall we welcomed 230 attendees from 37 countries all over the world.

The event was held for the week from 1 to 5 July in 2024. This in-person event took place in two parts: symposium (1-4 July) and workshop (4-5 July).

The symposium was covering 12 oral and 3 poster sessions related to the topics:

- GNSS Standards and Infrastructure (8 oral/21 poster)
- Building Global GNSS-Based Reference Frames (22 oral/23 poster)
- Giving Access To The Reference Frame Through GNSS (12 oral/14 poster)
- GNSS for Climate (12 oral/17 poster)
- GNSS-Enabled Applications (12 oral/14 poster)

In addition two keynote presentations have been included into the program:

- **Marco Falcone**: Galileo and the Future of European Navigation
- **Heike Peter**: Copernicus POD Service – What is the Connection to the IGS?

Disregarding the scientific program, a dedicated session for celebrating the anniversary was organized. Six out of seven IGS Governing Board chairs were presenting the highlights from their period which provided a nice overview on the developments and achievements of the IGS within the three decades.

In the second part (starting in the afternoon, July 4th and covering the complete July 5th) overall 13 sessions for discussions within the IGS committee, pilot project and working group components were held in a workshop format. In these sessions, actual developments and future plans have been discussed. Conclusions and a number of action items have been derived from these discussions. About 80% of the registered participants also attended this workshop part which reflects a strong interest in the activities of the IGS also outside from the core components.

Most of the presentations and posters can be inspected at `https://igs.org/workshop/2024/`. The Figures 9 to 11 may provide some impressions.

The members of the CODE consortium have also been involved in the scientific program. Arturo Villiger chaired the scientific organizing committee; four of the members of the CODE consortium helped organizing two of the sessions during the symposium as well as two of the workshop sessions. There have been significant number of contributions presented by CODE consortium members as well:

- Session 2: Building Global GNSS-Based Reference Frames
  - Pascal Stebler et al.: How Do Errors in Box-Wing Model Propagate in a Global GNSS Solution
  - Rolf Dach et al.: Earth's Center of Mass Handling for GNSS Orbit Determination and PPP
  - Daniel Arnold et al.: Genesis Orbit And Geodetic Parameter Estimation Based On GNSS: Impact Of Trasmit Antenna Phase Pattern Errors
  - Rolf Dach et al.: Activities at the CODE Analysis Center
  - Rolf Dach et al.: Evaluating Combined IGS Orbit Products
  - Bingbing Duan et al: Estimating GNSS Satellite Antenna Phase Center Offsets And Various Simultaneously With Flatness Constraints
- Session 3: Giving Access To The Reference Frame Through GNSS
  - Andrea Stürze et al.: IGS Real-Time ACC at BKG: First Experiences
- Session 5: GNSS-Enabled Applications
  - Ulrich Meyer et al.: Products of the Combination Service for Time-variable Gravity fields for GNSS POD
  - Daniel Arnold et al.: LEO Activities at AIUB

Figure 9: From left: Felix Perosanz (IGS Governing Board chair: 2020-2023), Rolf Dach (GB chair since 2023), Allison Craddock (director of the IGS central Bureau), Gerhard Beutler (GB chair: 1994-1998), Christoph Reigber (GB chair: 1998-2002), John M. Dow (GB chair: 2002-2010), Urs Hugentobler (GB chair: 2011-2014); Gary Johnston (GB chair: 2015-2020) was not present. Photo: Vanessa Mercea.

Figure 10: We would like to thank everyone for attending. Photo: Vanessa Mercea.

Figure 11: Rolf Dach, the head of the Local Organizing Committee thanks all the people from AIUB, the student assistants, the staff from the ExWi building, and everyone else that supported the event. Photo: Vanessa Mercea.

The Local Organizing Committee from AIUB wants to take the opportunity to thank the CODE partners (in particular BKG and swisstopo) for supporting this event together with the other sponsors: Leica Geosystems, GMV, and u-blox. There was a great support from the administrative and informatics groups from AIUB and the University, the logistics team (Hausdienst) from the Exact Science building, that has to be acknowledged as well. We are thankful to the students support team for helping with the technical environment during the Symposium. Last but not least we thank the Central Bureau for their help in preparing the event and the Scientific Organizing Committee for compiling the program. The time keeping tool was generously offered by Shingo Yonezawa from Kyoto University.

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All publications, posters, and presentations of the *Satellite Geodesy* research group at AIUB are available at http://www.bernese.unibe.ch/publist .

ESA/ESOC IGS Analysis Centre Technical Report 2024

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1 Introduction

The IGS Analysis Centre of the European Space Agency (ESA) is located at the European Space Operations Centre (ESOC) in Darmstadt, Germany. The ESA/ESOC Analysis Centre has been involved in the IGS since its inception in 1992. In this report we give a summary of the IGS Analysis Center related activities at ESOC in 2024. ESA also provides a global data center, the GSSC, from which a report may be found in the data center section of this annual report.

2 ESA IGS Contributions

2.1 Routine Products

The ESA/ESOC IGS Analysis centre contributes to all the core IGS analysis centre products, being:

- Final GNSS products
  - Constellations included: GPS, Galileo, GLONASS
    - From February 2025 is also includes: BeiDou, QZSS (February 2025)

  - Provided weekly, normally on Friday after the end of the observation week
  - Based on 24hour solutions using 150 stations
  - True multi-GNSS solutions obtained by simultaneously and fully consistently processing of the GNSS measurements, using a total of around 80 GNSS satellites
  - Consisting of Orbits, Clocks (30s), daily SINEX with station coordinates and EOPs, and Global Ionosphere Maps
- Rapid GNSS products
  - Constellations included: GPS, GLONASS
  - Provided daily for the previous day
  - Available within 3 hours after the end of the observation day
  - Based on 24hour solutions using 110 stations
  - True GNSS solutions obtained by simultaneously and fully consistently processing of the GNSS measurements, using a total of around 55 GNSS satellites
  - Consisting of Orbits, Clocks and ERPs
- Ultra-Rapid GNSS products
  - Constellations included: GPS, GLONASS
  - Provided 4 times per day covering a 48 hour interval; 24 hours of estimated plus 24 hours of predicted products
  - Available within 3 hours after the end of the observation interval ending at 0, 6, 12, and 18 hours UTC
  - Based on 24 hours of observations using 110 stations
  - True GNSS solutions obtained by simultaneously and fully consistently processing of the measurements, using a total of around 55 GNSS satellites
  - Consisting of Orbits, Clocks, and ERPs
- Global Ionsphere Maps
  - Constellations included: GPS, GLONASS, Galileo, BeiDou, QZSS (finals only)
  - Provided as final and rapid products
  - Final products are 2 hourly maps available 4 days after the end of the observation day
  - Rapid products are 1 and 2 hourly maps available 10 hours after the end of

the observation day

- Real-Time GNSS services
  - Generation of two independent real-time solution streams
  - Generation and dissemination of the IGS Real Time Combined product stream
  - Discontinued in first quater 2024
- GNSS Sensor Stations
  - A set of 11 globally distributed GNSS sensor stations, which are a part of ESOC's global GNSS Sensor Station network, called EGON
  - Station data available in real-time with 1 second data sampling

A general overview of all the different ESA GNSS products may be found at:
http://navigation-office.esa.int/GNSS_based_products.html

An up to date description of the ESA IGS Analysis strategy may always be found at:
http://navigation-office.esa.int/products/gnss-products/esa.acn

2.2 Multi-GNSS Products

In 2017 ESOC has started to routinely publish its experimental multi-GNSS products on a best effort basis using the normal IGS products and naming convention. Meanwhile, these products have matured to a standalone product in the ESOC portfolio. Starting in 2024, these multi-GNSS products are generated by ESOC's new Consolidated High Accuracy Multi-GNSS Processing (CHAMP) processing system Gini (2024b) and published as ESA0MGNFIN on our ESA web site. These products will become our official IGS products in 2025. For more information see section 4. The key differences between the curent ESOC IGS AC products and the new CHAMP based products are the station selection and the fact that the constellations are processed independently and combined on the NEQ level. The daily processing includes a network of 200 stations and over 120 satellites: Galileo, GPS, GLONASS, BDS-3 and QZSS. The homogenous reprocessed time series starts in 2017 and is continuously advanced. The products we provide on our web-site are:

- Daily SP3 orbits (5 min sampling to accommodate for eccentric orbits).
- Daily ERP file in normal IGS format
- Daily Clock-RINEX files with 30 second sampling of the clocks
- Daily SINEX file
- Daily summary file
- Troposphere SINEX

The ESA/ESOC multi-GNSS products (ESA0MGNFIN) are publicly available from our web-site under:
http://navigation-office.esa.int/products/gnss-products/

An up-to-date description of the ESA Multi-GNSS Analysis strategy may be found at:
http://navigation-office.esa.int/products/gnss-products/esm.acn

2.3 Product Changes

As we were setting up our new CHAMP processing system there were a limited amount of processing changes during 2024.

- Contineous improvements in and tuning of our GNSS box-wing and attitude models
  - Our understanding of the Galileo satellites keeps improving
  - BeiDou satellites seem to have significant differences between the two manufacturers but also significant differences from launch to launch
  - Initial models for NavIC

2.4 Product Highlights

The ESA/ESOC Analysis Centre products are among the best and most complete products available from the individual IGS analysis centres. We provide a consistent set of GNSS orbit *and* clock products that can be used for multi-GNSS precise point positioning. In particular for this purpose, the sampling rate of our final clock products is 30 seconds. A special feature of the ESA products is that they are based on completely independent 24 hour solutions. Although this does not necessarily lead to the best products, as in the real world the orbits and EOPs are continuous, it does provide a very interesting set of products for scientific investigations as there is no aliasing and no smoothing between subsequent solutions. Another unique feature is that our rapid products are one of the most timely available products. Normally our rapid GNSS products are available within 2 hours after the end of the observation day whereas the official GPS-only IGS products become available only 17 hours after the end of the observation day, a very significant difference. Another important feature of the ESA products is that we use a box-wing model for the GNSS satellites to a priori model the Solar- and Earth Albedo and IR radiation pressure. The GNSS block type specific models are regularely tested and improved where needed. In particular new satellites have to be reviewed carefully as many GNSS satellites carry unspecified *extras* which in many occasions significantly affect the radiation pressure on the satellite.

2.5 Additional ESA IGS Contributions

- Dr Werner Enderle is a voting member of the IGS Governing Board since 2015
- Dr Francesco Gini is the Chairman of the RINEX committee to ensure format standardization to meet the needs of the IGS and of the the GNSS industry
- Dr Erik Schönemann is the Chairman of IGMA pilot project
- Dr Florian Dilßner is involved in the committee for the estimation and validation of the GNSS PCO and PCVs. Also contributes significantly to the estimation and validation of the GNSS attitude modes, in particular during the eclipse phases

3 GNSS Sensor Station Network Upgrade

ESA/ESOC continues to provide worldwide data for all GNSS constellations to the IGS via 10 of its 11 public stations, and to expand its total station network EGON (ESA's GNSS Observation Network), currently operating 25 stations, Figure 1. This expansion is accomplished by focusing on the establishment of collaborations with third parties to install new stations at geographically varied locations around the world such as in South Africa, Mexico, Argentina, Brazil, Malaysia, Kyrgyzstan, New Zealand, Iceland, etc. The most recent addition to the network is in Cartago, Costa Rica (2022). No data is publicly available for the time being for any of the newly installed stations.

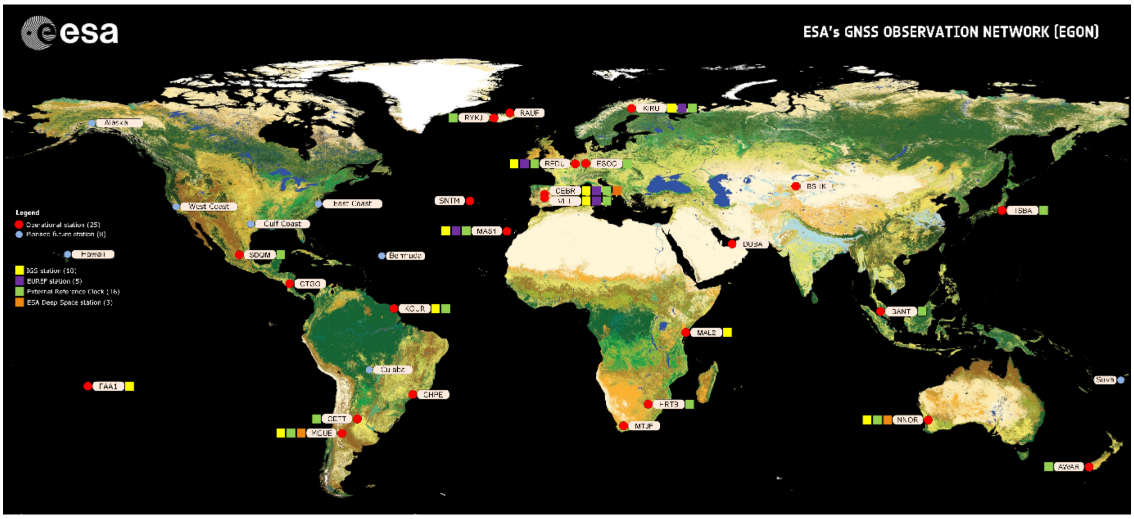

Figure 1: ESA/ESOC GNSS Station Network

Since 2023, the ESA GNSS network operates exclusively Septentrio PolarRx5(TR) receivers, and Septentrio PolaNt Choke Ring B3E6 antennas, with the exception of MGUE, MAL2, MAS1 and FAA1 where Leica AR25.R4 antennas are installed. The Septentrio PolaRx5 receivers were chosen as the next step in the station evolution as they can track the new signals at B3/E6 from QZSS, Beidou and Galileo plus all the GNSS legacy signals.

The ESOC GNSS Reference Station network operates Septentrio PolaRx5TR timing receivers at all 3 ESA Deep Space sites (CEBR, MGUE, and NNOR) where high quality H-masers are installed for signal generation. Additionally, PolaRx5TR are also installed at 4 other ESA tracking locations (KIRU, KOUR, REDU, SNTM) which together make up the core ESA network. In addition, a PolaRx5TR timing receiver is operated at station ESOC, for which data is now also publicly available.

ESA/ESOC continues to contribute a full complement of RINEX 3 data covering all signals and all satellites in view in daily, hourly and high-rate modes, plus real-time data streams, to the IGS from 10 of its public stations; VILL, CEBR, FAA1, KIRU, KOUR, MAS1, MAL2, NNOR, REDU and MGUE. Station ESOC is contributed to EUREF and available for IGS processing as well.

Ongoing activities include migrating towards RINEX 4 data, as well as FW upgrades that enable tracking of the new L1 NAViC frequency, which in turn will allow dual frequency NAViC POD activities. Additionally, in the next few years worldwide coverage is planned to be further enhanced, with on-going negotiations with third parties in the US, Fiji, Brazil and Bermuda as well as establishing a local tie with ESA's SLR station in Tenerife.

http://navigation-office.esa.int/ESA's_GNSS_Observation_Network_(EGON).html

4 CHAMP

The Navigation Support Office at the European Space Agency (ESA) has developed a novel GNSS processing concept called CHAMP which stands for Consolidated High Accuracy Multi-GNSS Processing (Gini, 2024b). Based on constellation-wise data processing and normal equation stacking, the method is used to efficiently generate GNSS products for all five global navigation systems (GPS, Galileo, GLONASS, BeiDou, QZSS). CHAMP's modular design, conseptionally shown in Figure 2, allows the different projects within the Navigation Support Office to combine the necessary constellation results, leading to substantial savings in CPU power and storage requirements. Datum consistency is ensured by aligning satellite orbits and station coordinates to IGN's latest cumulative IGS2020 realization of the ITRF2020-u2023. CHAMP uses ESA's multi-GNSS ANTEX for all satellites, which was presented in [IGSMAIL-8394]. ESA operates its own UTC realization. A number of calibrated receivers are connected, allowing CHAMP to align all GPS and Galileo clock products to UTC(ESA). ESA's data processing for the IGS is among the activities benefiting from CHAMP. The future ESA AC Final products will include Galileo (E1A-E5Q), GPS (L1W-L2W), GLONASS (L1P-L2P), BeiDou-3 (C1P-C5P) and QZSS (L1-L2). The ESA AC Ionosphere final and rapid products have already transitioned to

CHAMP. Four years of reprocessed ESA Finals using CHAMP have been provided to the IGS for validation. The results were presented at the IGS Analysis Centres Meeting on Wednesday, 27 November 2024. No concerns were raised by the validators or any of the participants, which opens the door for the transition in 2025. For future developments, ESA is considering switching QZSS frequencies to L1C-L5 and making Galileo, rather than GPS, the reference system for all clock estimations.

Tree	Levels	Description	Example
	Leaves	Product generation and advanced processes (orchids).	IONO, DCBIAS
	Branches	NEQ-Stacking of individual constellation solutions, No-net rotation, BAHN (Code+Phase, 30s-clock solution).	MGNSS
	Trunk	Core processing: Broadcast Fit, GnssObs (Code-only solution), BAHN (Code+Phase, float solution), AmbFix (Ambiguity fixing), BAHN (Code+Phase, fixed solution).	DAILY
	Roots	Input data from ESOC NAVOPS Navigation Data archive.	dcd, brdc, ATX, EOP

Figure 2: ESA/ESOC CHAMP Concept

The CHAMP setup was used for reprocessing all multi-GNSS data since 2014 several times to do an indepth analysis of the results, fine tune the processing and thus further improve the quality of the resulting products (Sermanoukian, 2024). The efficiency of the CHAMP constellation-wise processing approach thus enabled us to discover and resolve various anomalies. Many stations record corrupt tracking data for particular satellites or constellations, while others function correctly. Instead of rejecting the station entirely, CHAMP was modified to identify and filter only the problematic station-satellite links. Additionally, ESA was able to trace differences in the station clocks of the individual single-constellation solutions back to undetected cycle slips.

4.1 Observation Specific Signal Bias SINEX product

ESOC is developing a new Bias SINEX product aimed at providing long-term Differential Signal Bias (DSB) and Observable Signal Bias (OSB) estimates for all signals from Galileo, GPS, BeiDou, and QZSS within a stable Bias Reference Frame (BREF). ESA will follow the PCO correction convention communicated in [IGSMAIL-8113]. A total of 19 signal combinations with unique DSBs have been identified and are estimated daily (4 for Galileo, 5 for GPS, 5 for BeiDou, and 5 for QZSS). Similar to the generation of a terrestrial reference frame, the daily solutions are stacked, and jumps are accounted for by introducing discontinuities. This product will be made available on the ESA Navigation Support

Office's webpage and will be updated whenever a bias value changes or a new satellite begins broadcasting. The ultimate goal is to enable interoperability between all signal. The BREF generation is a subsystem of CHAMP and uses the ESA Final OPS orbit, clock and ionosphere products. The same products that are soon submitted as ESA AC contribution.

5 New GNSS Transmit Antenna Phase Center Model

In March 2024, the ESA Analysis Center released its new GNSS transmit antenna phase center model, *esa23.atx* (Schönemann, 2024). Motivation for ESA to derive its own satellite ANTEX file was the IGS decision to align the GNSS terrestrial scale to the ITRF2020 scale by applying constellation-specific biases to the original *repro3* satellite antenna z-offsets. As a result, Galileo z-offsets in the current IGS antenna model (*igs20.atx*) differ by about 16 cm from the original Galileo calibration values derived from anechoic measurements. For ESA in general and Galileo services such as the Galileo Open Service (OS), the High Accuracy Service (HAS) or the Galileo Geodetic Service Provider (GRSP) in particular, changing the carefully calibrated Galileo antenna parameters was neither scientifically acceptable nor physically justified. Uncertainties in the calculation of the ITRF2020 argue against adjusting the GNSS z-offsets to its scale. Notable reasons to question the ITRF scale are 1) the fact that the SLR range biases in the ILRS contribution to the ITRF have been treated as error-free and 2) that a large number of VLBI solutions, including those from recent years, have been discarded. Main feature of the

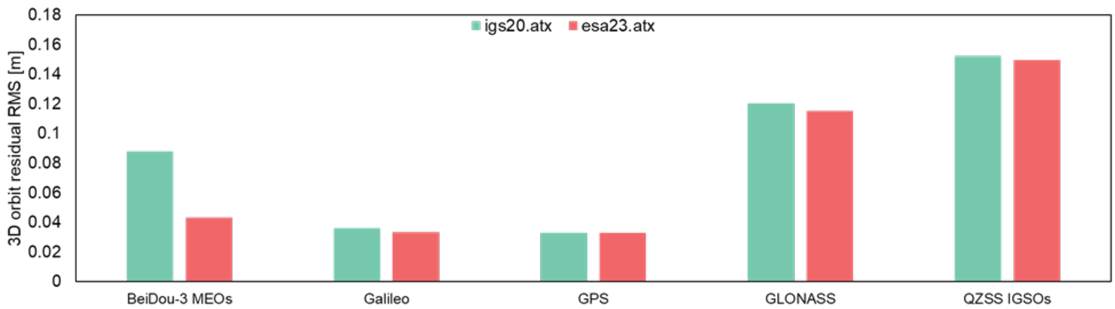

Figure 3: Comparison of day-boundary orbit residual RMS when using igs20.atx and esa23.atx satellite antenna phase center corrections

ESA antenna model is its scale-alignment with the latest reference frame realization from DGFI-TUM ("DTRF2020"), and its full consistency across all GNSS satellite constellations. Z-offset parameters for GPS, GLONASS and BeiDou have been estimated as part of a comprehensive reprocessing of IGS tracking data spanning 2014-2023, while retaining the manufacturer calibration values for the Galileo, QZSS and GPS Block III antenna offsets and phase center variations (PCVs). Processing of the data was carried out in daily batches using ESA's Navigation Package for Earth Observing Satellites (NAPEOS) software, now called EPNS (ESA Precise Navigation System). The daily antenna offset solutions were rigorously combined on normal equation (NEQ) level. Further processing details are given in the ESA ANTEX file header. Using the esa23.atx model leads to measurable improvements in GNSS orbit precision, especially for BeiDou. Computation of day-boundary orbit residuals shows reduction in 3D RMS for the BeiDou MEO satellite constellation by a factor two, from 89 mm with igs20.atx to 43 mm with esa23.atx. Satellite orbits of the Galileo system improve by about 3 mm. Figure 3. In addition to carrier phase corrections, esa23.atx includes group delay variation (GDV) parameters for BeiDou-2 satellites, which are essential for reliable BeiDou-2 integer ambiguity resolution.

The ESA ANTEX file is publicly available and updated regularly at:
https://navigation-office.esa.int/products/metadata/esa23.atx.

6 Summary

The Navigation Support Office at the European Space Operations Centre (ESOC) of the European Space Agency (ESA) is continuously improving its capabilities and associated services and products. As a consequence, the Analysis Center continues to produce *best in class* products for the IGS. All products are generated using the Navigation Package for Earth Orbiting Satellites (NAPEOS) software, (Springer, 2009). With the switch to our CHAMP based processing we will switch to the new ESA Precise Navigation System (EPNS). EPNS is the further development of the NAPEOS software which includes enhanced GNSS processing capabilities, in particular our *RAW* GNSS processing method, (Schönemann, 2014). EPNS is a state of the art software package that is accurate, very efficient, robust and reliable. EPNS enables ESA/ESOC to deliver the high quality products as required for the IGS but also for the other space geodetic techniques DORIS, SLR and VLBI and any combination of these techniques. This is important as, because besides being an IGS Analysis Centre, ESA/ESOC is also an Analysis Centre of the IDS and the ILRS and soon the IVS.

In the coming year our main focus will be on further improving the orbit modelling for the different GNSS constellations and making combined solutions based on GNSS and SLR observations including LEO satellites like Sentinel-3, Sentinel-6 and Jason-3

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ESA ANTEX DOI: https://doi.org/10.57780/esa-q8jgzrf

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GFZ Analysis Center Technical Report 2024

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1 Summary

During 2024, the standard IGS product generation was continued with minor changes in the processing software EPOS.P8. The GNSS observation modeling follows the repro3 (3rd IGS Reprocessing campaign) settings. Operational products cover GPS, GLONASS, and Galileo. The multi-GNSS processing was continued routinely during 2024 including GPS, GLONASS, BeiDou, Galileo, and QZSS.

Please note, that GFZ changed name as of Jan 1, 2025. We are now the GFZ Helmholtz Centre for Geosciences. Accordingly, email addresses and domain changes to gfz.de. This will affect also the access to our ftp directories, we will inform about these changes via igsmail.

2 Products

The list of products provided to the IGS by GFZ is summarized in Table 1. The long naming scheme was introduced for the IGS products in week 2238.

3 Operational Data Processing and Latest Changes

Our EPOS.P8 processing software is following the IERS Conventions 2010 (Petit and Luzum, 2010) and the repro3 standards, changes in the processing lines are reported in

Table 1: List of products provided by GFZ AC to IGS and MGEX; YD = YYYYDDD0000. The long naming scheme was introduced for the IGS products in week 2238.

IGS Final (GLONASS since week 1579, Galileo since week 2238)	
GFZ0OPSFIN_YD_01D_05M_ORB.SP3	Daily orbits for GPS/GLONASS satellites
GFZ0OPSFIN_YD_01D_30S_CLK.CLK	Clocks for stations (5min) and satellites (30sec)
GFZ0OPSFIN_YD_01D_01D_SOL.SNX	Daily SINEX files
GFZ0OPSFIN_YD_07D_01D_ERP.ERP	Earth rotation parameters
GFZ0OPSFIN_YD_07D_07D_DSC.SUM	Summary file including Inter-Frequency Code Biases (IFB) for GLONASS
GFZ0OPSFIN_YD_01D_01H_TRO.TRO	Troposphere estimates (1h ZPD, 24h gradients)
GFZ0OPSFIN_YD_01D_02H_ION.IOX	Ionosphere product, IONEX format
IGS Rapid (GLONASS since week 1579, Galileo since week 2159)	
GFZ0OPSRAP_YD_01D_05M_ORB.SP3	Daily orbits for GPS, GLONASS, Galileo satellites
GFZ0OPSRAP_YD_01D_30S_CLK.CLK	Clocks for stations (5min) and satellites (30sec)
GFZ0OPSRAP_YD_01D_01D_ERP.ERP	Daily Earth rotation parameters
GFZ0OPSRAP_YD_01D_01D_DSC.SUM	Summary file
GFZ0OPSRAP_YD_01D_02H_ION.IOX	Ionosphere product, IONEX format
IGS Ultra-Rapid (every 3 hours; provided to IGS every 6 hours; GLONASS since week 1603, Galileo since week 2159, YDH = YYYYDDDHH00)	
GFZ0OPSULT_YDH_02D_05M_ORB.SP3	Adjusted and predicted orbits for GPS, GLONASS, Galileo satellites
GFZ0OPSULT_YDH_02D_01D_ERP.ERP	Earth rotation parameters
GFZ0OPSULT_YDH_01D_01D_DSC.SUM	Summary file
MGEX Rapid containing GPS, GLONASS, Galileo, BeiDou, and QZSS	
GBM0MGXRAP_YD_01D_05M_ORB.SP3	Daily satellite orbits
GBM0MGXRAP_YD_01D_30S_CLK.CLK	Clocks for stations (5min) and satellites (30sec)
GBM0MGXRAP_YD_01D_01D_ERP.ERP	Daily Earth rotation parameters
GBM0MGXRAP_YD_01D_01D_OSB.BIA	Bias file: observable-specific signal bias
GBM0MGXRAP_YD_01D_01D_DCB.BSX	Bias file: differential code and inter-system biases
GBM0MGXRAP_YD_01D_01D_SOL.SNX	Daily SINEX file
GBM0MGXRAP_YD_01D_30S_ATT.OBX	Attitude quaternions (30sec)

Table 2. Operational processing lines cover approximately 140, 120, and 70 sites for IGS final, rapid and ultra-rapid chains, respectively. Since 2020 the ultra-rapid, rapid, and final products are available via GFZ Information System and Data Center (ISDC,

Table 2: Recent processing changes

Date	IGS	IGR	IGU	Change
2024-02-06	w2299	w2329.4	w2329.3:18	switch from igrf12 to igrf13
2024-02-29	w2303	w2303.4	w2303.3:18	switch to igs20_2303.atx
2024-04-22	w2310	w2311.1	w2311.1:18	switch to igs20_2309.atx
2024-06-05	w2316	w2317.4	w2317.3:12	corrected inconsistencies in orbit modelling
2024-06-05	w2316	w2317.5	w2317.4:12	switch to igs20_2317.atx
2024-10-10	w2335	w2335.6	w2335.6:00	switch to igs20_2335.atx
2024-11-26	-	w2342.1	w2342.1:18	changed internal brdc orbit format from Rinex 3 to Rinex 4
2024-12-05	w2394	w2395.6	w2395.6:00	system upgrade of processing server and switch from ifort v20 to gfortran v13 compiler

https://isdc.gfz-potsdam.de/gnss-products/) and referenced under DOIs:

- Männel, B., Brandt, A., Nischan, T., Brack, A., Sakic, P., Bradke, M. (2020): GFZ final product series for the International GNSS Service (IGS). GFZ Data Services. https://doi.org/10.5880/GFZ.1.1.2020.002

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An inconsistency in our orbit modeling caused an increased RMS for the difference between GFZ and the IGS combined product observed in spring 2024. The issue was solved in June 2024.

4 Multi-GNSS Data Processing

The rapid multi-GNSS product GFZMGX was continued in 2024. The GFZMGX solution cover five GNSS constellations, namely GPS, GLONASS, Galileo, BeiDou2/3, and QZSS. The number of processed stations and satellites are about 140 and 130, respectively. Since GPS week 2337 the GFZ MGX product GFZ0MGXRAP SP3 includes the midnight epoch. The first hourly RINEX files from the successive day are analyzed in our MGEX Precise Orbit Determination processing. In 2024 GFZMGX participated the BDS/QZSS satellite antenna calibration campaign which is linked to Goal 1 of the IGS 2021+ Strategic Plan.

All GFZ MGEX products are available at DC CDDIS, IGN and GFZ own ftp server: ftp://ftp.gfz.de/GNSS/products/mgnss/.

- Deng, Z., Nischan, T., Bradke, M. (2017): Multi-GNSS Rapid Orbit-, Clock- & EOP-Product Series. https://doi.org/10.5880/GFZ.1.1.2017.002

5 Multi-GNSS Obrit and Clock Combination

In 2024, we continued our efforts in developing a multi-GNSS orbit and clock combination, leading to the Satellite Precise Orbit and Clock Combination (SPOCC) software. The main focus was on extending the functionality and facilitating its usability. As announced at Jan 24, 2025, SPOCC is now available for external usage. Further details are given at https://gnss.gfz.de/services/spocc. With the publication of the software we contribute to Goal 1 and 3 of the IGS 2021+ Strategic Plan.

SPOCC can handle all available constellations and is based on a well-defined unified least-squares framework, using variance component estimation (VCE) to determine the weights. A main objective is to support multi-GNSS precise point positioning (PPP) users. The combination workflow consists of quality checks such as outlier detection, alignments harmonizing the AC products, and a weighted averaging. For the orbit combination, the optional alignments consist of Helmert transformations. The clock alignments consist of radial corrections and a removal of the impact of different reference clocks and reference inter-system biases (ISB) in the AC solutions. The combination can be configured for different weighting schemes, ranging from AC specific to satellite type or even satellite specific weights, and the alignments can be based on different sets of satellite orbits. A dedicated manuscript prepared by Zajdel et al. is under review. SPOCC's combination strategies and results were discussed in the IGS Combination Task Force, which aims at providing the next ACC software.

More information is availabe at:

- Mansur, G., Sakic, P., Brack, A., Männel, B., Schuh, H. (2022) Combination of GNSS orbits using least-squares variance component estimation. Journal of Geodesy, 96(11):92. https://doi.org/10.1007/s00190-022-01685-y
- Mansur, G., Sakic, P., Brack, A., Männel, B., Schuh, H. (2024) Utilizing Least Squares Variance Component Estimation to Combine Multi-GNSS Clock Offsets. GPS Solutions, https://doi.org/10.1007/s10291-023-01604-4.

6 Operational ionosphere products

The rapid and final global ionosphere map (GIM) products were continued in 2024 without changes. Global VTEC maps with a temporal resolution of two hours are computed from GPS, GLONASS, and Galileo observation data from around 250 IGS tracking stations. The final solutions contain the middle day of a combination of three consecutive daily solutions on the normal equation level. The processing is based on a rigorous least-squares approach using uncombined code and phase observations, and does not entail leveling techniques. A single-layer ionospheric model with a spherical harmonic VTEC representation is applied. The products are provided via https://isdc.gfz-potsdam.de/gnss-products as daily IONEX files following the IGS long-name definition. The products are referenced under the DOI:

- Brack, A.; Männel, B.; Bradke, M.; Brandt, A.; Nischan, T. (2021): GFZ Global Ionosphere Maps. GFZ Data Services. https://doi.org/10.5880/GFZ.1.1.2021.006

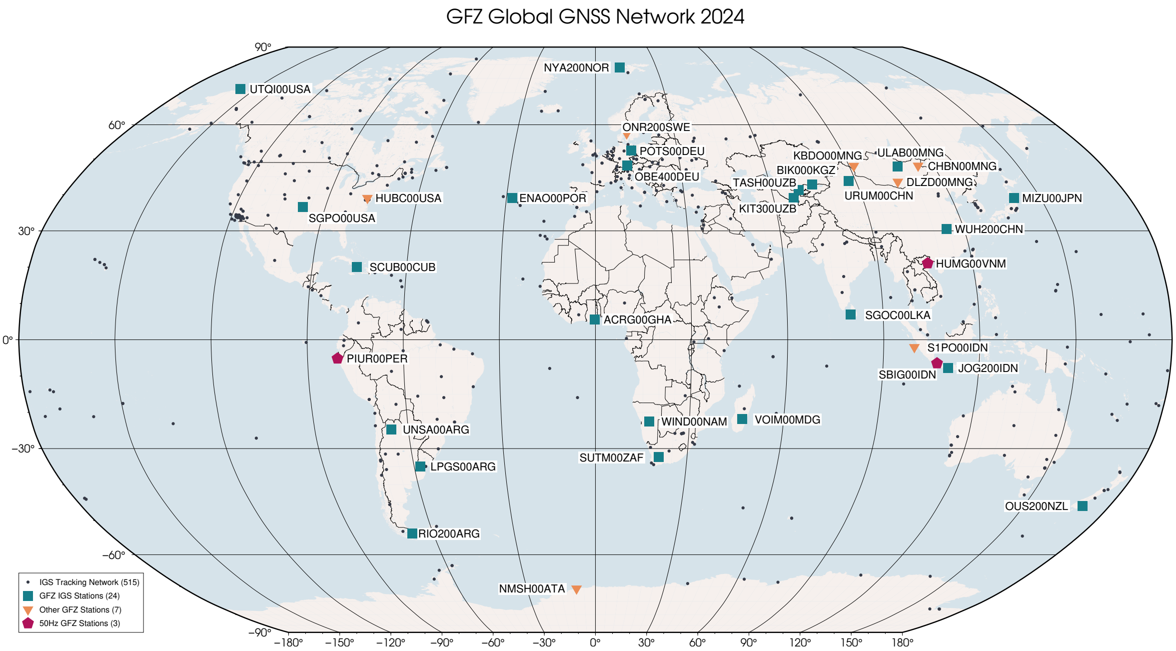

Figure 1: GNSS stations operated by GFZ (as of January 2025).

7 Operational GFZ Stations

The global GNSS station network operated by GFZ performed quite well in 2024 without major issues and without major hardware changes. During 2024, we installed a new GNSS station at the Paramaribo Atmospheric Observatory (Suriname) with the main focus of atmospheric monitoring. Our GNSS station network is referenced under the DOI:

- Ramatschi, M; Bradke, M; Nischan, T; Männel, B (2019): GNSS data of the global GFZ tracking network. V. 1. GFZ Data Services. http://doi.org/10.5880/GFZ.1.1.2020.001

Additional information and quality indicators (e.g., data availability, latency, completeness) can be accessed through our GNSS portal gnss.gfz.de. This portal also serves as the landing page for our RINEX toolbox **gfzrnx**.

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1 Introduction

The CNES-CLS Analysis Center is providing openly available final, rapid and ultra-rapid products (according to the Goals 1 and 2 of the IGS 2021+ Strategic Plan (IGS Central Bureau, 2021)) on behalf of the "Groupe de Recherches de Géodésie Spatiale" (GRGS) using the GINS CNES software package.

The year 2023 was partially dedicated, on the one hand, to the enhancement of the rapid/ultra-rapid products and, on the other hand, to the delivery of our 4-constellation (GREC) MGEX products.

The year 2024 has been driven by improving the quality/operationality of all our products; the rapid and ultra-rapid, the final and the MGEX (with inclusion of BeiDou constellation). Furthermore, we started focusing on a multi-technique Precise Orbit Determination (POD) approach for LEO altimetry satellites that will prepare our group for the future ESA GENESIS mission.

The formal "GRG" pproducts can be downloaded from the IGS data centers directory:

Table 1: GRGS publicly available products

File	Type	Sampling
GRG final products GPS, GLONASS & GALILEO (since week 2238) Updated weekly		
GRG0OPSFIN_YYYYDDD0000_01D_05M_ORB.SP3	Satellite orbits	5 min
GRG0OPSFIN_YYYYDDD0000_01D_01D_OSB.BIA	Observable specific biases	1/day
GRG0OPSFIN_YYYYDDD0000_01D_01D_SOL.SNX	SINEX files	1/day
GRG0OPSFIN_YYYYDDD0000_01D_02H_TRO.TRO	Tropospheric estimation	2 hr
GRG0OPSFIN_YYYYDDD0000_01D_30S_ATT.OBX	Satellite attitude	30 sec
GRG0OPSFIN_YYYYDDD0000_01D_30S_CLK.CLK	Satellite & station clocks	30 sec
GRG0OPSFIN_YYYYDDD0000_07D_01D_ERP.ERP	Earth rotation parameters	1/day
GRG0OPSFIN_YYYYDDD0000_07D_01D_SUM.SUM	Summary file	
MGEX products: GPS, GLONASS, GALILEO & BEIDOU (since week 2288) Updated weekly		
GRG0MGXFIN_YYYYDDD0000_01D_05M_ORB.SP3	Satellite orbits	5 min
GRG0MGXFIN_YYYYDDD0000_01D_01D_OSB.BIA	Observable specific biases	1/day
GRG0MGXFIN_YYYYDDD0000_01D_30S_ATT.OBX	Satellite attitude	30 sec
GRG0MGXFIN_YYYYDDD0000_01D_30S_CLK.CLK	Satellite & station clocks	30 sec
GRG0MGXFIN_YYYYDDD0000_07D_01D_ERP.ERP	Earth rotation parameters	1/day
Rapid products GPS, GALILEO & BEIDOU (since week 2238) Updated daily		
GRG0OPSRAP_YYYYDDD0000_01D_05M_ORB.SP3	Satellite orbits	5 min
GRG0OPSRAP_YYYYDDD0000_01D_01D_OSB.BIA	Observable specific biases	1/day
GRG0OPSRAP_YYYYDDD0000_01D_30S_ATT.OBX	Satellite attitude	30 sec
GRG0OPSRAP_YYYYDDD0000_01D_30S_CLK.CLK	Satellite & station clocks	30 sec
GRG0OPSRAP_YYYYDDD0000_01D_01D_ERP.ERP	Earth rotation parameters	1/day
GRG0OPSRAP_YYYYDDD0000_01D_01D_SUM.SUM	Summary file	
Rapid products GPS, GALILEO & BEIDOU (since week 2238) Updated four times a day		
GRG0OPSULT_YYYYDDD0000_01D_05M_ORB.SP3	Satellite orbits	5 min
GRG0OPSULT_YYYYDDD0000_01D_30S_ATT.OBX	Satellite attitude	5 min
GRG0OPSULT_YYYYDDD0000_01D_30S_CLK.CLK	Satellite & station clocks	5 min
GRG0OPSULT_YYYYDDD0000_01D_01D_ERP.ERP	Earth rotation parameters	every 6 h
GRG0OPSULT_YYYYDDD0000_01D_01D_SUM.SUM	Summary file	

`gps/products/wwww`. Any additional information and links to the AC publications can be found at https://igsac-cnes.cls.fr/.

The list of all the GRG products delivered is given in Table 1 (for more information refer to: https://igs.org/products/). The main evolutions during the last two years are summarized in Table 2 .

Table 2: Main GRG-AC evolutions in 2023 and 2024

Date	GPS week	Change
12/11/2023	2288	Start of delivery of 4-constellation MGEX products (GREC)
28/11/2023	2290	Inclusion of BDS-3 in the Rapid and Ultra-rapid products
04/03/2024	2304	Change of the gravity field model from RL04 to RL05 (without degree 1)
	2310	Addition of 24h prediction for the ultra-rapid products
02/06/2024	2317	Change to format 2.00 for the `GRG0OPSFIN_YD_01D_02H_TRO.TRO` files
14/07/2024	2323	Inclusion of midnight epochs in the SP3/CLK/OBX final and MGX products
22/12/2024	2340	Change from frequencies 26 to frequencies 15 for BeiDou constellation in MGX products

2 Rapid and Ultra-rapid products

From May 2023, we deliver rapid and ultra-rapid products for GPS, Galileo and BeiDou constellations with fixed phase ambiguities. As the ambiguities of the BDS-2 generation satellites cannot be fixed, we have decided to process only the BDS-3 satellites. Only the MEO satellites are fixed (Mezerette et al., 2024).

2.1 Rapid products

The processing of the rapid products consists of 4 stages: floating solution, ambiguity resolution, fixed solution and finally clock densification to 30 s. This processing is executed on a dedicated 8-core virtual machine and lasts approximately 2 hours from the end of the data retrieval to the delivery of products (nearly 3h40 for rapid processing). Several modifications have been made, compared to the final products processing to speed up the processing (data sampling, modelling, number of stations etc.)

Our rapid products participate in the combined multi-constellation solution as part of the "PPP-AR" working group (contribution to the Objectives 1.1 and 2.3 of the IGS 2021+ Strategic Plan). The quality of our rapid products is shown in Figure 1 .

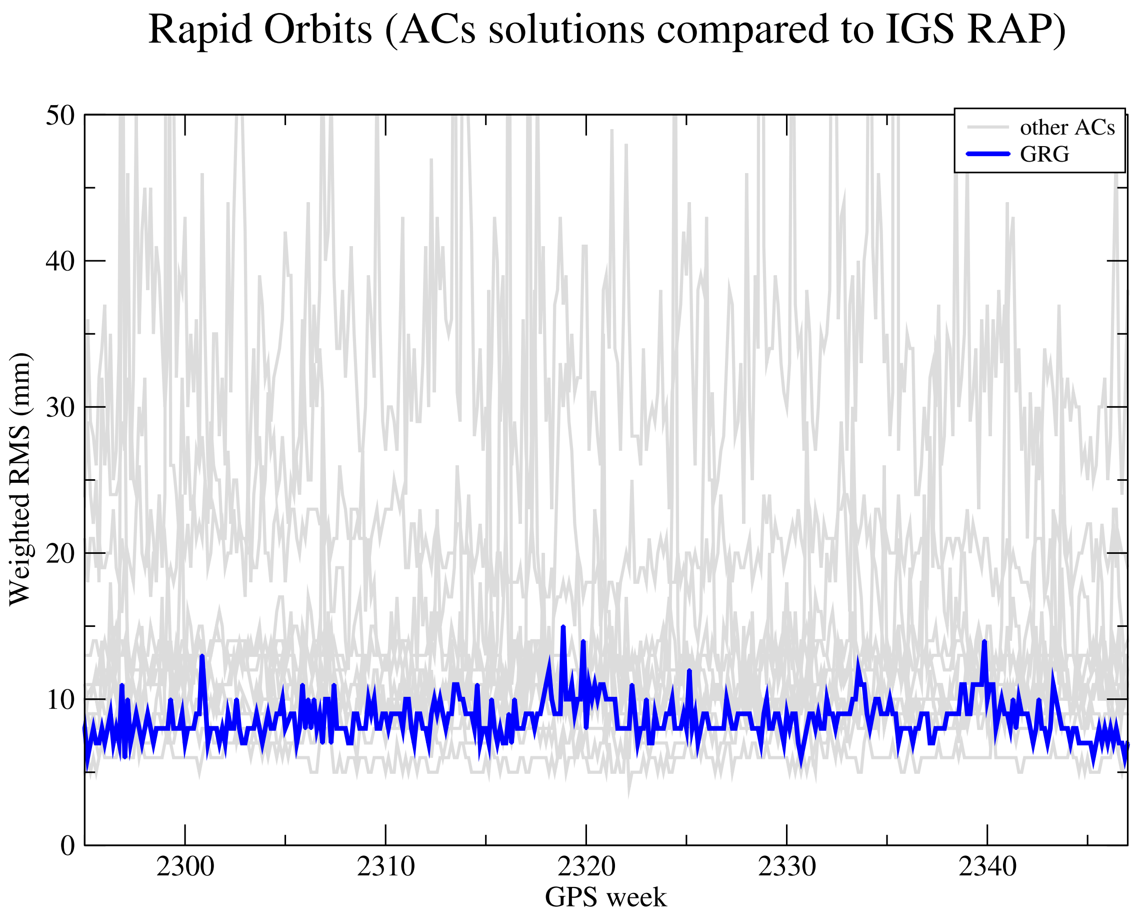

Figure 1: Combination weighted RMS values of the rapid products

2.2 Ultra-rapid products

The processing of the ultra-rapid products consists of 3 stages: floating solution, ambiguity resolution and fixed solution. In 2024 (week 2310) we added a supplementary 24h prediction for the ultra-rapid products. This prediction is calculated by propagating the dynamic parameters of the 24h restituted products. This addition allowed us to improve the quality of the ultra-rapid products and to include them in the combination of IGS Ultra. The difference between before and after week 2310 when this change took place can be seen in Figure 2 .

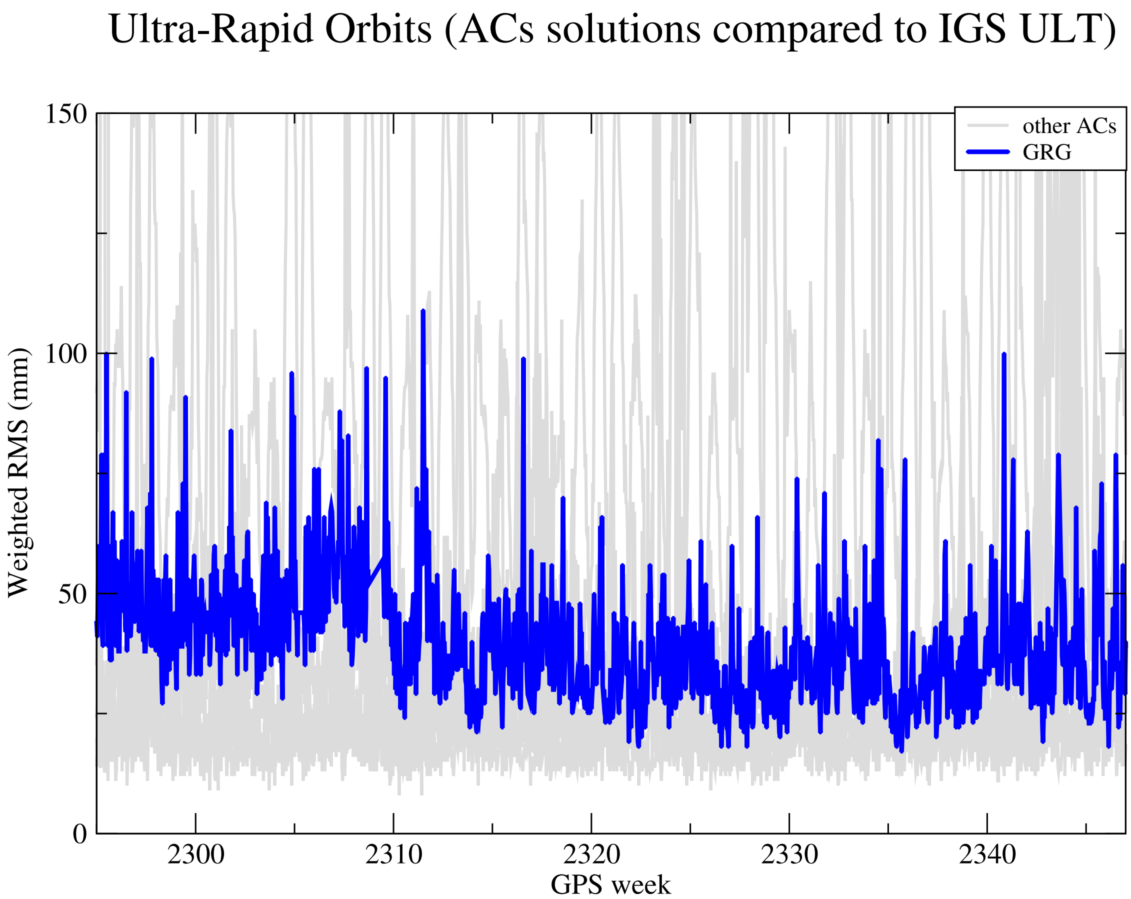

Figure 2: Combination weighted RMS values of the ultra-rapid products

3 Final & MGEX products

Following the IGS recommendations, we added the midnight epochs to our orbit, clock and attitude products (for both GRG0OPSFIN & GRG0MGXFIN). This change will allow an overlap between two consecutive days and better detection of any cycle slips.

From 11/2023 we started delivering BeiDou ephemeris as new MGEX products. We improved our processing software to include BDS-3 signals. We use the igs20 reference frame and igs20.atx. The ambiguity resolution is done using the undifferenced ionosphere-free linear combination (Saquet et al., 2024). From November 2024 we changed the processing of BeiDou products from frequencies 26 to frequencies 15 (according to the guidelines in Mail IGS-ACS 1662) and the phase ambiguities of the IGSO satellites are now fixed.

All satellites and constellations are processed at the same time. However, BeiDou is slightly downweighted relative to GPS and Galileo. The reason is that there are around

70 stations tracking BeiDou in comparison to 125 stations tracking GPS and Galileo.

In addition, our AC participates in the PCO evaluation campaign of BDS-3 estimates. The first results showed that the values are stable and coherent with the other AC that participated in the campaign.

4 GNSS-LEO project studies

Our analysis center can perform DORIS, GNSS and ILRS studies using GINS software. From 2024, we initiated a multi-technique project called GEOD-ESIS, with the goals of preparing for the forthcoming ESA GENESIS mission and of assessing the benefits of a

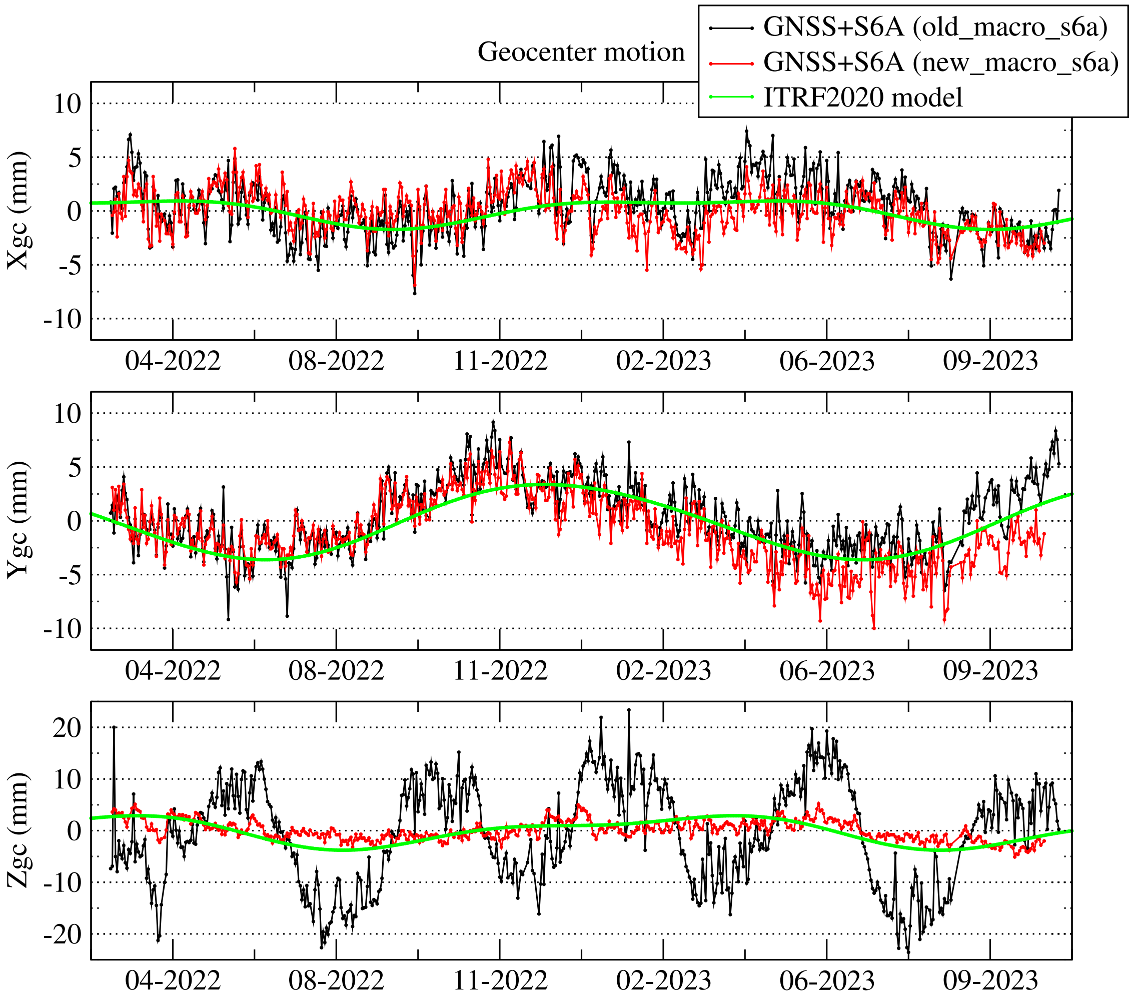

Figure 3: Geocenter motion values as calculated from the GNSS+S6A processings and ITRF2020

multi-technique space tie to TRF realizations (Goal 2 of the IGS 2021+ Strategic Plan). The benefit of this joint processing is that it uses the same software, force models and displacement models (Loyer et al., 2024).

We have done a GPS+Galileo+Sentinel-6 POD computing. The results showed that for Sentinel-6 the orbit is very similar to the Copernicus POD solutions. In addition, the GNSS orbits were not significantly affected by the inclusion of Sentinel-6. As far as the station network is concerned, the addition of Sentinal-6 does not affect the station network geometry, relatively to IGS solutions (Loyer et al., 2024).

Figure 3 is an example that shows the solutions of a GNSS+Sentinel-6 geocenter motion coordinates as calculated from the GEOD-ESIS project. There is an improvement when using the new Sentinel-6 macromodel from (Conrad et al., 2022). Overall, we observe a consistency between the GNSS+S6A solution (red line) and the official ITRF2020.

Future work will include all three space geodesy techniques (DORIS, GNSS and ILRS) and more than one LEO satellite.

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Geospatial Information Authority of Japan (GSI) and Japan Aerospace Exploration Agency (JAXA) Analysis Center Technical Report 2024

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1 Introduction

The Geospatial Information Authority of Japan (GSI) and Japan Aerospace Exploration Agency (JAXA) is jointly working as a IGS analysis center to provide the GNSS orbit, clock, ERP, and SINEX products identified with the acronym "JGX". The JGX products are generated using our original software MADOCA (Multi-GNSS Advanced Demonstration tool for Orbit and Clock Analysis) developed by JAXA (Kawate et al., 2023). JAXA is responsible for improving the software and the GSI uses the software to generate the JGX products and manages the quality of the products. Our contributions to IGS community are as follows.

Our contributions

1. Provide independent results from other ACs via our original analysis software MADOCA.
2. Provide precise multi-GNSS products, e.g., GPS, GLONASS, Galileo, BDS and QZSS.

3. Provide more detailed information regarding the POD for QZSS.
4. Provide a stable supply of products through years of experience in product generation.

2 JGX Core Products

The JGX products provided by GSI and JAXA to IGS are listed in Table 1. The ultra-rapid product has been provided since 12th November 2024, but has not been included in the combination of the IGS ultra-rapid product so far.

Table 1: List of JGX products provided by GSI and JAXA to IGS.

JGX Final (weekly updates) GPS, GLONASS and Galileo	
`JGX0OPSFIN_YD_01D_05M_ORB.SP3`	Daily GPS, GLONASS and Galileo orbits and clocks with 5 min intervals
`JGX0OPSFIN_YD_01D_30S_CLK.CLK`	Daily GNSS satellite and station clocks with 30 sec intervals
`JGX0OPSFIN_YD_01D_01D_SOL.SNX`	Daily station coordinates and ERPs in SINEX format
`JGX0OPSFIN_YD_01D_01D_ERP.ERP`	Daily Earth rotation parameters
`JGX0OPSFIN_YD_01D_07D_DSC.SUM`	Analysis summary for each processing
JGX Rapid (daily updates) GPS, GLONASS and Galileo	
`JGX0OPSRAP_YD_01D_05M_ORB.SP3`	Daily GPS, GLONASS and Galileo orbits and clocks with 5 min intervals
`JGX0OPSRAP_YD_01D_30S_CLK.CLK`	Daily GNSS satellite and station clocks with 30 sec intervals
`JGX0OPSRAP_YD_01D_01D_ERP.ERP`	Daily Earth rotation parameters
`JGX0OPSRAP_YD_01D_01D_DSC.SUM`	Analysis summary for each processing
JGX Ultra-Rapid (every 6 hours updates) GPS, GLONASS and Galileo	
`JGX0OPSULT_YD_01D_05M_ORB.SP3`	Daily GPS, GLONASS and Galileo orbits and clocks with 5 min intervals
`JGX0OPSULT_YD_01D_01D_ERP.ERP`	Daily Earth rotation parameters
`JGX0OPSULT_YD_01D_01D_DSC.SUM`	Analysis summary for each processing

The JGX products are also available at the following URL after completing the registration:
https://jgxnet.gsi.go.jp/en/top/

3 Software and the Latest Changes

The JGX products are generated using our POD software named "MADOCA" which has been developed by JAXA since 2011. MADOCA supports Multi-GNSS (GPS, GLONASS, Galileo, BDS, and QZSS) and has adopted force and measurement models compliant with the International Earth Rotation and Reference Systems Service (IERS) conventions 2010 (Petit et al., 2010). The estimations could be made in both post-processing with iterative weighted least squares and real-time processing with extended Kalman filter (EKF) using the methods to reduce memory usage and processing time and to improve process stabilization. JAXA continues to improve the performance mainly focusing on non-gravitational force models. The details of POD algorithm are shown in our paper Kawate et al. (2023).

The following are the changes that have been made since the last IGS technical report.

1. Support BeiDou-3.
2. Application of box-wing model for Galileo, BDS, and QZSS including shadow model for QZS-3. (see references)
3. Support ORBEX satellite orbit/attitude output (Loyer , 2019).
4. Support satellite PCO estimation with constraint.
5. Add zonal tide model to remove the effect from interpolation of UT1 (Petit et al., 2010).

4 Operational Data Processing

The JGX operational final, rapid, and ultra-rapid products are currently generated using MADOCA software version 2.1.1. The candidate IGS stations for processing in 2024 are shown in Figure 1. Considering the daily data delivery status of each station, we selected approximately 150, 110, and 110 stations for final, rapid, and ultra-rapid processing respectively. The fiducial sites were adjusted to about 50 stations daily so that the center of the network did not deviate from the origin of the reference coordinate system. The IGS20/igs20.atx framework was applied as a reference frame for processing using minimum constraints with no-net-rotation (NNR).

The JGX final and rapid products for GPS, GLONASS, and Galileo have been routinely submitted to IGS since GPS week 2269. The final products (SP3, CLK, SNX, ERP, SUM) have a latency of 5 days and are uploaded every Thursday. The rapid products (SP3, CLK, ERP, SUM) have a latency of 1 day and are uploaded on a daily basis. For the final product, unreasonable estimates in parameters are addressed as much as possible before uploading. The version of the analysis software upgraded from version 2.1.0 to 2.1.1

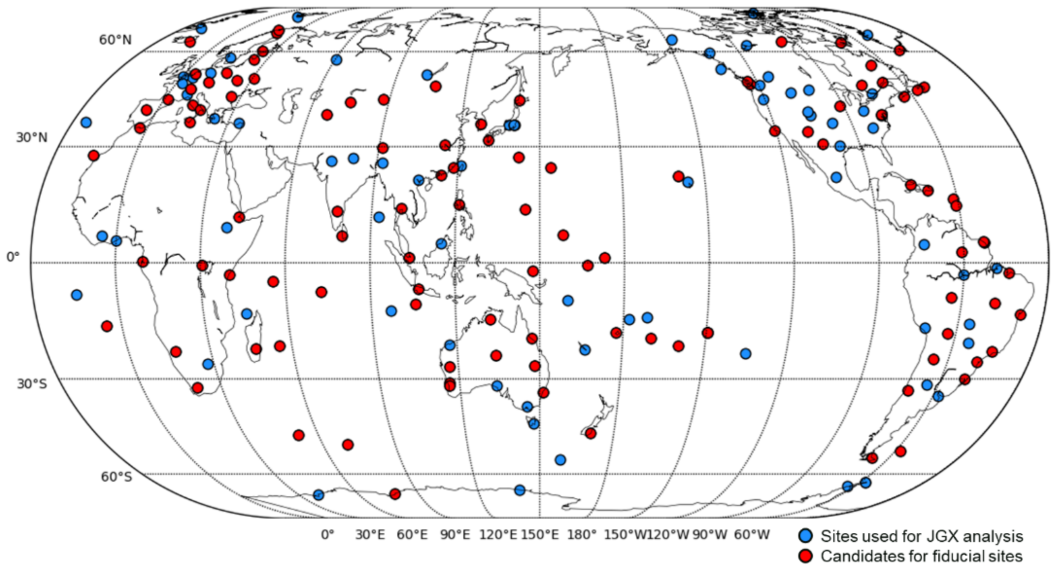

Figure 1: Station network used for JGX processing in 2024.

at GPS week 2331. In the newer version, the box-wing model is applied to Galileo and the zonal tidal model is adopted.

The JGX ultra-rapid products (SP3, ERP, SUM) for GPS, GLONASS, and Galileo have been routinely submitted to IGS since GPS week 2339. However, it is not incorporated into IGS products so far due to challenges of orbit prediction accuracy.

The 3D RMS of satellite orbit differences of the final products in 2024 is shown in Figure 2. No Helmert transformation is adopted in the plot. The quality is comparable with other ACs.

The pressing issues for JGX operational products are as follows.

- Product modification on center-of-network:
  To satisfy the clock center-of-network (CLK:CoN) convention, we plan to impose not only NNR but also no-net-translation (NNT) as minimum constraints. In addition, to convert the CoM reference orbit to a CoN reference orbit, we plan to modify the software to apply the center of mass correction (CMC) of ocean tide loading directly to the orbit. Our preliminary PPP analysis using these modified products is consistent with the origin of the ITRF coordinate system.

- Improvement of the ultra-rapid products:
  The JGX ultra-rapid orbit products are not included in the IGS combination due to issues with low accuracy in the prediction part, so it needs to be improved. In addition, we are making effort to add a function to output prediction part of ultra-rapid EOP.

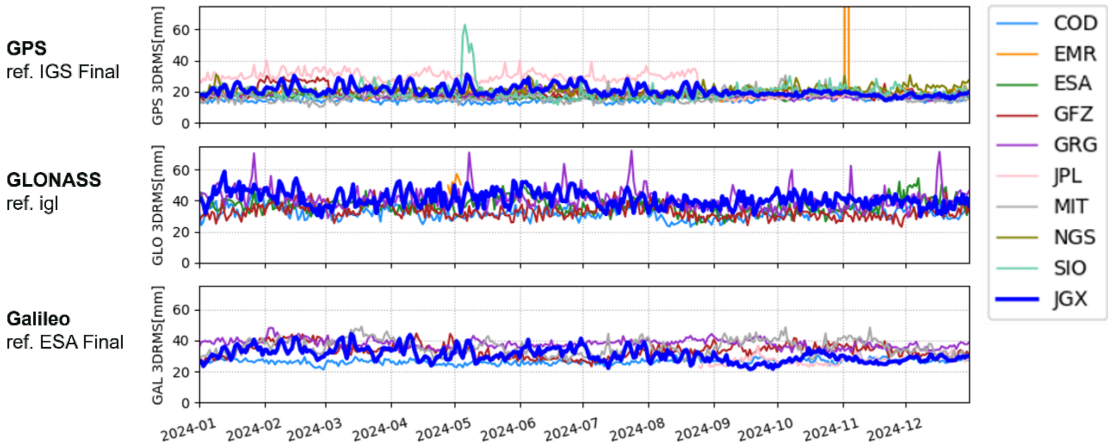

Figure 2: 3D RMS error of final products w.r.t. IGS final (GPS, GLONASS) and ESA final (Galileo) in 2024.

- Improvement of stability in clock products:
  The stability issue was improved after March 2024 due to the revision of the selected clock reference sites and quality check process. We will continue to address flexibly the issues identified in operations.

5 Contribution to the BDS/QZSS satellite antenna calibration campaign

We have provided satellite PCO estimates for both BDS-3 and QZSS. The BDS-3 PCO estimates are in good agreement with those from the other ACs. Sharing of the QZSS PCO estimates has enabled us to conduct a comparative analysis with those from the other ACs. The evaluation is currently underway.

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Jet Propulsion Laboratory Analysis Center Technical Report 2024

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1 Introduction

In 2024, the Jet Propulsion Laboratory (JPL) continued to serve as an Analysis Center (AC) for the International GNSS Service (IGS). We contributed operational orbit and clock solutions for the GPS satellites; position, clock and troposphere solutions for the ground stations used to determine the satellite orbit and clock states; and estimates of Earth rotation parameters (length-of-day, polar motion, and polar motion rates). This report summarizes the activities at the JPL IGS AC in 2024.

Table 1 summarizes our contributions to the IGS Rapid and Final products. All of our contributions are based upon daily solutions centered at noon and spanning 30 hours. Each of our daily solutions is determined independently from neighboring solutions, namely

Table 1: JPL AC Contributions to IGS Rapid and Final Products.
(Galileo products available from 2024-08-25 onwards)

Product	Description	Rapid/Final
JPL0OPSFIN_YYYYJJJHHMM_01D_05M_ORB.SP3	GPS (+Galileo) orbits and clocks	Rapid & Final
JPL0OPSFIN_YYYYJJJHHMM_01D_30S_CLK.CLK	GPS (+Galileo) satellite and station clocks	Rapid & Final
JPL0OPSFIN_YYYYJJJHHMM_01D_30S_TRO.TRO	Tropospheric estimates	Rapid & Final
JPL0OPSFIN_YYYYJJJHHMM_01D_01D_ERP.ERP	Earth rotation parameters	Rapid & Final
JPL0OPSFIN_YYYYJJJHHMM_01D_30S_ATT.OBX	Satellite attitude quaternions	Rapid & Final
JPL0OPSFIN_YYYYJJJHHMM_01D_01D_SOL.SNX	Daily SINEX file	Final
JPL0OPSFIN_YYYYJJJHHMM_01W_00U_SUM.SUM	Weekly solution summary	Final

without applying any constraints between solutions. Before 2024-08-25 we produced GPS-only Rapid and Final orbit and clock products and since that data we have produced GPS+Galileo Rapid and Final orbit and clock products. Note that both high-rate (30-second) Final and Rapid clock products are created.

The JPL IGS AC also generates Ultra-Rapid orbit and clock products for the GPS constellation. These products are generated with a latency of less than 2.5 hours and are updated hourly (Bertiger et al., 2020). Although not submitted to the IGS, our Ultra-Rapid products are available in native GipsyX formats at:

- https://sideshow.jpl.nasa.gov/pub/JPL_GNSS_Products/Ultra

2 Processing Software and Standards

On 29 Jan 2017 (start of GPS week 1934) we switched from using GIPSY (version 6.4) to GipsyX to create all our orbit and clock products. As of week 2329 (2024-08-24), all IGS Finals were submitted in the IGS20 frame, and furthermore a reprocessing in the IGS20 frame has also been released back through week:day 1146:2 (2002-01-01).

The frame for Rapids was updated to IGb14 during week 2107 on 2020-05-26 and updated to IGS20 during week 2238 (2022-11-28).

Our IGS20 Rapid operations and our ongoing Final IGS20 reprocessing campaign adopted several new models, some from repro3 and some from our own choices:

1. Use of center of mass seasonals for reference site positions.
2. Data weighting based on optimization testing.
3. Troposphere randomwalk parameter optimized based on external (Young et al., 2022) and internal research.
4. VMF1 (Boehm etal., 2006) troposphere models and mapping functions instead of GPT2 for better station positioning (Martens and Simons , 2023).
5. Sub-daily EOP model (Desai and Sibois , 2016).
6. Time varying-gravity model.
7. Antenna thrust models per IGS recommendations.
8. Modern ocean tide loading, using GOT4.8 (Ray, 2013).
9. IGS20 antenna calibrations.

We continue to use empirical GPS solar radiation pressure models developed at JPL instead of the DYB-based strategies that are commonly used by other IGS analysis centers. This choice is based upon an extensive evaluation of various internal and external metrics after testing both approaches with the GIPSY/OASIS software (Sibthorpe et al., 2011).

3 GipsyX Overview

GipsyX has been the sole operational software at the JPL IGS Analysis center, replacing GIPSY-OASIS since January 2017.

GipsyX has the following features:

1. GipsyX is the C++/Python3 replacement for both GIPSY and Real-Time GIPSY (RTG).
2. Driven by need to support both post-processing and real-time processing of multiple GNSS constellations.
3. Can already process data from GPS, GLONASS, Beidou, and Galileo.
4. Supports simultaneous GNSS, SLR, and VLBI data processing at the measurement level.
5. DORIS data processing is also supported.
6. Multi-processor and multi-threaded capability.
7. Single rtgx executable replaces multiple GIPSY executables: model/oi, filter, smoother, ambiguity resolution.
8. Versatile PPP tool (gd2e) to replace GIPSY's gd2p.
9. Similar but not identical file formats to current GIPSY.
10. Runs under Linux and Mac OS.
11. First GipsyX beta-version released to the GIPSY user community in December 2016.
12. GipsyX-1.0 released 2019-01-28.
13. Most recent release was GipsyX-2.3 on 2024-08-27.
14. Available under similar license to GIPSY license.

    (see `https://gipsy-oasis.jpl.nasa.gov/index.php?page=software` for more details)

Further details can be be found in the GipsyX/RTGx paper (Bertiger et al., 2020).

In parallel with the GipsyX development we have also developed new Python3 operational software that uses GipsyX to generate the rapid and final products that we deliver to the IGS as well as generating our ultra-rapid products that are available on our https site.

4 Recent Activities

- Released a reprocessing campaign in IGS20 from 2002-2024 (Peidou et al. (2023),Ries et al. (2024)) that will go back to 1992 (to be released in 2025).
- Contributed to research into creating an experimental reference frame using combined SLR and GNSS data at the observation level tied together using spacecraft with both GNSS receivers and SLR reflectors which showed good agreement with ITRF2020 (Haines et al., 2024).
- On 2024-08-25 switched to creating high-rate (30s) GPS+Galileo orbit and clock products in IGS format and delivering these products to IGS data centers.
- Increased ground network used to create Rapid and Final products from 80 stations to 120 stations.
- Gave a GipsyX class at University of Beira Interior, Covilhã, Portugal, Sept 4-6, 2024.
- Continued Multi-GNSS and multi-technique development. Efforts included substantial code refinement, all based around our GipsyX software.

5 Future Work

Continue Multi-GNSS and multi-technique development and operational support incorporating lesson learned from reference frame at the observational level work (Haines et al., 2024).

6 Acknowledgments

The work described in this report was performed at the Jet Propulsion Laboratory, California Institute of Technology under a contract with the National Aeronautics and Space Administration.

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MIT Analysis Center Technical Report 2024

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1 Introduction

In this report, we discuss the results generated by the MIT Analysis Center (AC) for submissions of weekly final IGS solutions, as well as our weekly combination of SINEX files from MIT and the other eight IGS analysis centers that submit final SINEX files. We present an analysis of the networks we process and a comparison between our position estimates and those from other IGS analysis centers. For repro3 and our IGS20 submissions, we utilize combined GPS and Galileo solutions, and we also examine the differences between GPS-only and Galileo-only solutions.

2 Overview of MIT processing

The MIT analysis for IGS final orbits, clocks, and terrestrial reference frame uses the GAMIT/GLOBK software versions 10.71 and 5.34 (Herring et al., 2019). The processing methods remain unchanged from those discussed in the 2022 MIT Analysis Center report (see Dach and Brockmann , 2023).

In addition to weekly final processing, we also generate combined SINEX processing from the combination of up to nine IGS ACs contributing to the IGS finals. We do this in our role as an associate analysis center (AAC). In Tables 1 and 2, we list the products submitted by MIT in our AC and AAC roles. Our operational processing continues to be a combined GPS+Galileo solution with 5-minute tabular points in the SP3 orbit files to accommodate the high eccentricity Galileo satellites. We have also added the 24:00 epoch to our orbit and clock files starting week 2325 (2024/07/28, DOY 210) for SP3 files and one week later for clock files.

Table 1: MIT products submitted for weekly finals analysis.

Long File Name	Description
MIT0OPSFIN_YYYYDDS0000_07D_01D_SUM.SUM	Summary file
MIT0OPSFIN_YYYYDDS0000_07D_01D_ERP.ERP	Earth rotation parameters for 7-days
MIT0OPSFIN_YYYYDDS0000_01D_05M_ORB.SP3	Day 0 satellite orbits to
MIT0OPSFIN_YYYYDDE0000_01D_05M_ORB.SP3	Day 6 satellite orbits
MIT0OPSFIN_YYYYDDS0000_01D_05M_CLK.CLK	Day 0 satellite clocks to
MIT0OPSFIN_YYYYDDE0000_01D_05M_CLK.CLK	Day 6 satellite clocks
MIT0OPSFIN_YYYYDDS0000_01D_01D_SOL.SNX	Day 0 coordinate and EOP sinex file to
MIT0OPSFIN_YYYYDDE0000_01D_01D_SOL.SNX	Day 6 coordinate and EOP sinex file

YYYY year, DDS DOY Start, DOE DOY End.

Table 2: MIT products submitted for daily combinations of IGS final AC SINEX files.

Long File Name	Description
MIT0OPSSNX_YYYYDDD0000_01D_01D_SUM.SUM	Summary file
MIT0OPSSNX_YYYYDDD0000_01D_01D_SOL.SNX	Combined SINEX file from all available analysis centers
MIT0OPSSNX_YYYYDDD0000_01D_01D_RES.SUM	File of the individual AC position estimates residuals to the combined solution for the week

YYYY year, DDD DOY for each day of week.

The network of stations processed by MIT in 2024 is shown in Figure 1. The figure shows the weighted root-mean-square (WRMS) scatter of the horizontal coordinates of nearly all of the stations included in the MIT finals processing. Stations that were used just a few times (6 stations in all) are not included in the plot. Only linear trends were removed from the time series. Figure 2 shows histograms of the WRMS in all three topocentric coordinates after removing linear trends from the time series. The median WRMS scatters of the 439 sites, measured more than five times, included in the statistics are 1.5, 1.5 mm in North and East and 5.6 mm in height. No annual signals were removed. The station selection in 2024 was based on the station selection list for the third reprocessing campaign (Repro3). This list was based on the priority order list for Repro3. (http://acc.igs.org/repro3/repro3_station_priority_list.pdf).

The sites with high RMS in Figure 2 show anomalies for a variety of reasons. Table 3 describes what is known about the reasons for each site's high RMS.

Table 3: Explanations of high RMS sites.

Site	Type	Explanation
BRUN	NE	Horizontal offsets of −40 mm N and 37 mm E occur on 24/09/17. All ACs see this jump but there are no meta changes or any local earthquakes.
TNML	NE	Horizontal offsets of −41 mm N and 35 mm E occur on 24/02/02 seen by all ACs due to local earthquake.
CPVG	NE	Site on Sal Island in Canary Islands. Most likely volcanic transient motions.
AB11	NE	Snow most likely reasons for outliers.
XMIS	NE	Data quality degrades after installation Trimble Alloy receiver with JAVRINGANT_DM antenna.
CMUM	NEU	Site in Thailand with systematic quasi-seasonal noise.
SCH2	NE	Canadian site most likely affected by snow.
DRBA	NE	Site in South Africa with noisy data; maybe be due to local RFI?
TONG	NEU	Tonga site with systematic noise and outliers in East seen by all ACs.
ULAB	NE	Mongolian site with possible snow effects. Antenna also mounted on a tall pole.
PTVL	NEU	Earthquake offset on 24/12/17 with −25, −40 and −50 mm co-seismic offsets.
DUNT	U	Problem with MIT metadata update not being applied in a timely fashion. Fixed 24/08/25.
WGTT	U	Problem with MIT metadata update not being applied in a timely fashion (24/07/18−24/08/04)
FAIR	U	Systematic height changes seen in earlier years as well. Could be snow effect.
URUM	U	Mostly likely snow effects.
KZN2	U	System is failing. Stopped processing data in early 2025 due to poor quality.
MDVJ	U	Data quality degrades with noisy results.

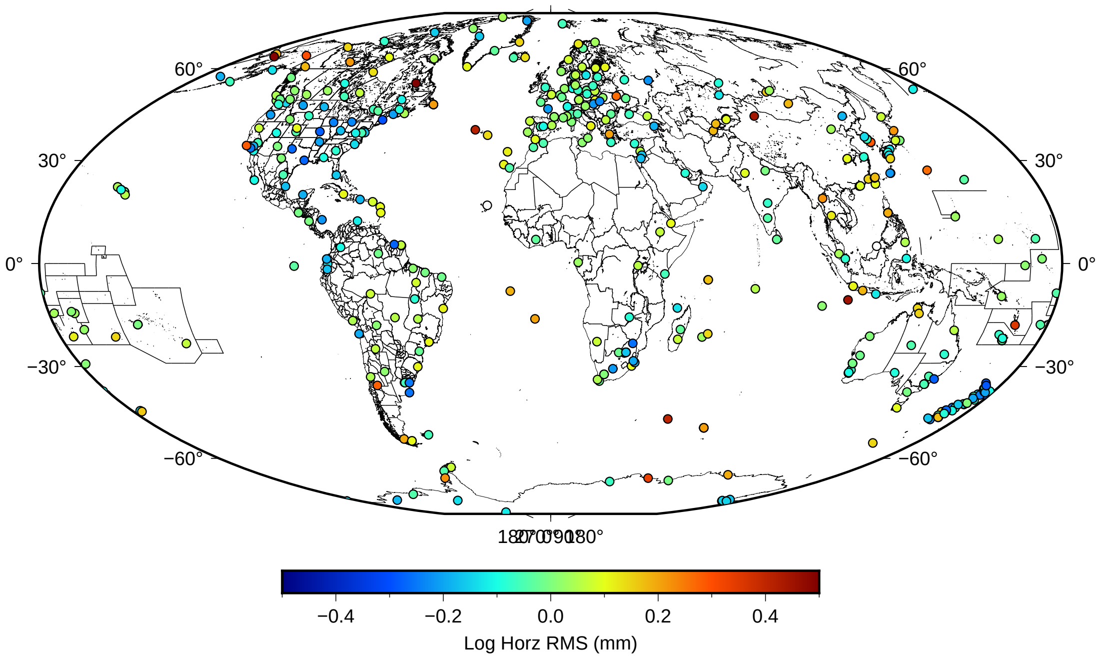

Figure 1: Log (base 10) of the WRMS scatter of the horizontal position estimates from the network of 440 stations. A total of 482 sites were processed by MIT in 2024, with 42 sites being used less than 5 times. Each daily network has ≈ 350 stations, and the networks evolve with time depending on data availability and geometry. Of the 440 stations, 295 have Galileo data (262 have more than 5 days of solutions). The cooler colors are all less than 1 mm WRMS scatter, while the warmer colors are greater than 1 mm scatter. The sites with the highest horizontal WRMS scatters (sum square of N and E RMS scatters, mm) are BRUN (17.39), TNML (9.98), CPVG (9.09), AB11 (7.47), XMIS (6.05), CMUM (5.72), SCH2 (5.67), DRBA (5.62), TONG (5.44), and PTVL (5.22) mm. The sites with the largest height RMS scatters (mm) are DUNT (28.51), WGTT (24.68), FAIR (17.65), URUM (15.31), KZN2 (14.24), PTVL (10.97), CMUM (10.68), TONG (10.64), ULAB (10.59), and MDVJ (10.54) mm. Possible reasons for the high RMS values are given in Table 3.

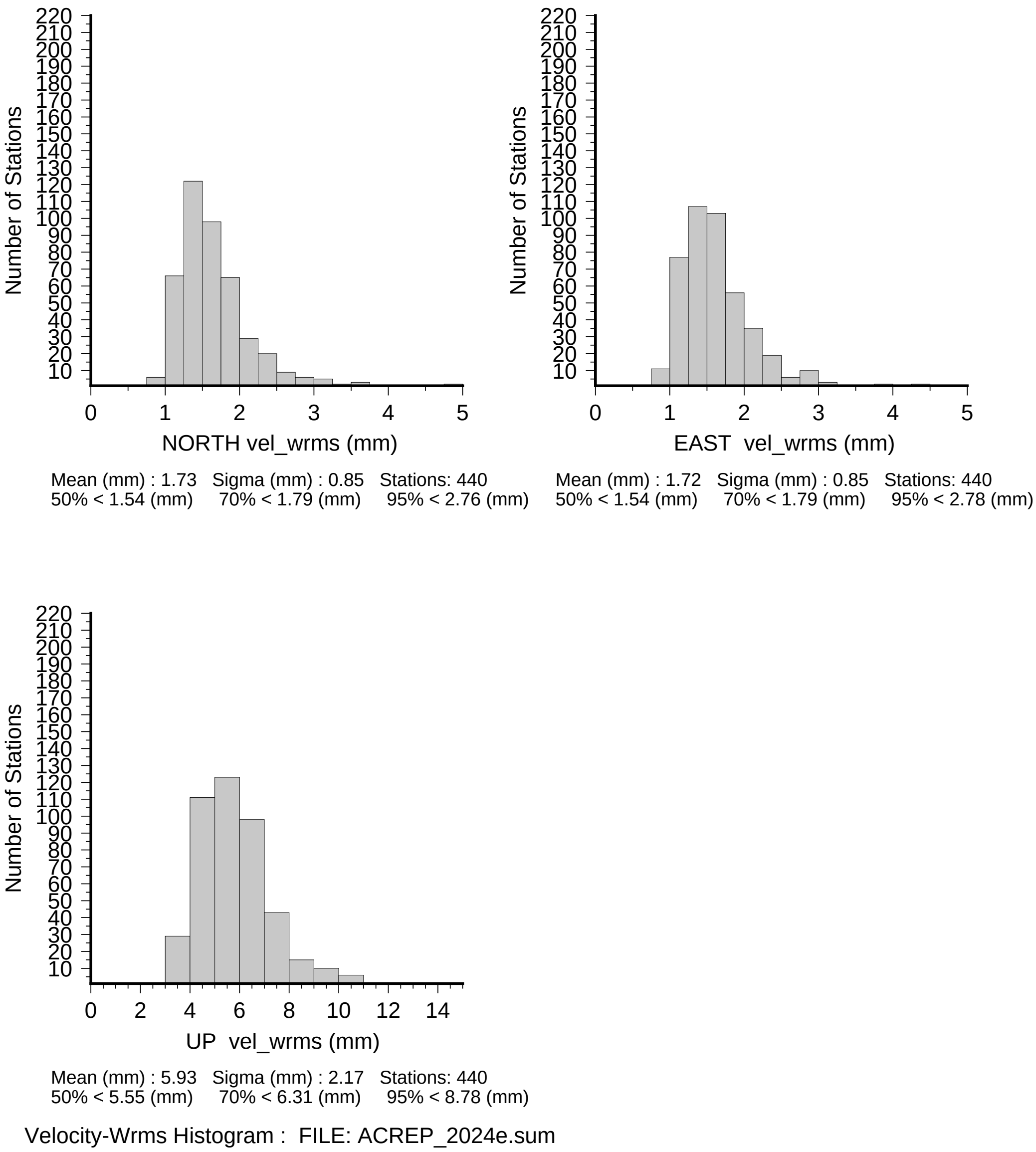

Figure 2: Histogram of the weighted root-mean-square (WRMS) scatter of daily position estimates of sites used more than five times for 2024 after removing linear trends and eliminating gross outliers (5 times WRMS scatter). The median scatters are similar to last year, with 1.5, 1.5 mm horizontal, and 5.6 mm vertical.

3 Position repeatability and comparison to other ACs

We can also compare the MIT daily position estimates with those of other analysis centers based on the AAC combinations performed at MIT. In Figure 3, we show the WRMS scatter of the daily fits to $\approx$ 50 IGS20 reference frame sites from each of the IGS ACs from the combined SINEX solution with the weights assigned to each AC consistent with the fit of the AC to the combination of the other ACs. There is good consistency between the ACs. Figure 4 shows the WRMS scatter between the AC solution IGS20 reference frame coordinates. While the AC results look similar, there are differences in the mean of the RMS differences. Table 4 gives the mean RMS differences for each AC with respect to IGS20 coordinates and the combination solution coordinates. This table shows that, on average, the MIT solution provides a very good match to the combined solution with millimeter horizontal WRMS and 3.34 mm WRMS in height. We also compute the chi-squared per degree of the fits, and all ACs have similar chi-squared values, indicating that no one center dominates the combination.

4 Comparison between GPS-only, Galileo-only, and combined solutions

The MIT contribution to the final IGS20 orbit and reference frame products is a combination of the GPS and Galileo solutions. We also process each system separately so that we

Table 4: Comparison of the fits to the IGS20 reference frame (RF) and daily combined solutions for RF sites in the MIT and other AC daily final SINEX files. Typically, 50 sites are used in the comparison to IGS20. The JPL statistics also include the period when they were down-weighted in the combination because they were not using the IGS20 system.

Center	IGS20			Combined		
	N (mm)	E (mm)	U (mm)	N (mm)	E (mm)	U (mm)
MIT	3.13	3.45	7.88	1.02	1.07	3.34
COD	2.89	3.53	7.37	1.44	1.45	4.08
EMR	2.94	3.16	7.14	1.13	1.24	3.92
ESA	3.15	3.39	7.26	1.00	0.92	3.72
GFZ	2.86	3.26	7.81	0.93	1.21	3.97
GRG	2.58	2.86	6.43	1.00	0.95	2.93
JPL	3.16	3.48	7.72	1.20	1.46	4.06
NGS	3.02	3.92	7.98	1.45	1.88	4.60
SIO	3.65	3.55	8.29	1.60	1.90	4.54
JGX	3.11	3.33	7.46	1.72	1.24	4.30

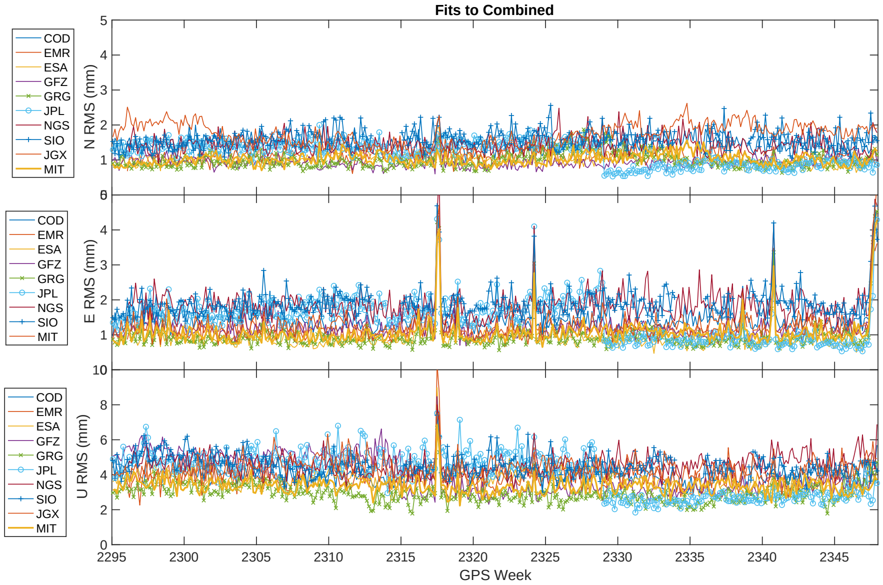

Figure 3: WRMS scatters of the fits of the different IGS ACs to the MIT0OPSSNX combined solution for 2024. Not all centers have adopted the IGS20 system for the whole year. Specifically, JPL was weighted only after its adoption of IGS20 models for their finals processing. After this adoption, their performance compared to the other centers was excellent. The outlier points were due to non-detected outliers.

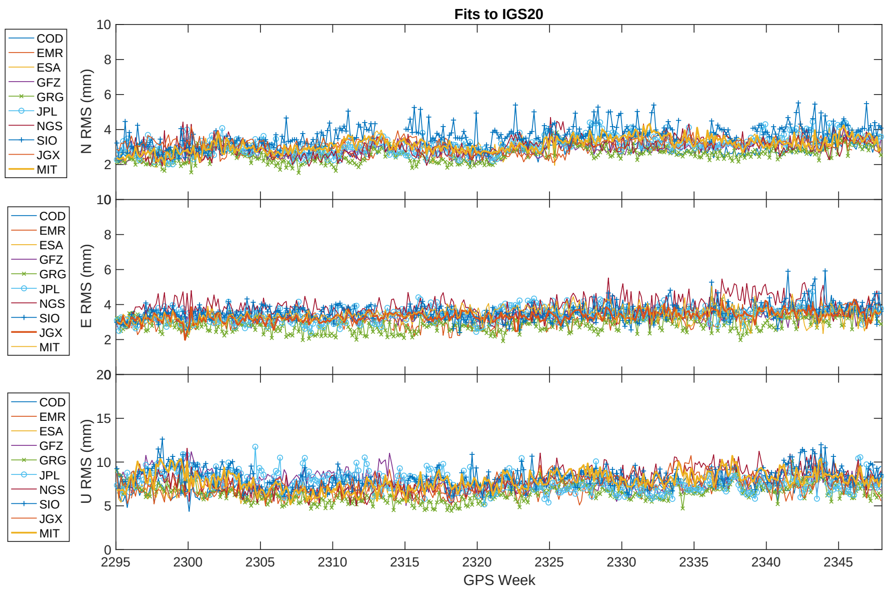

Figure 4: WRMS scatters of the fits to the IGS20 system using typically 45−50 stations. Not all centers used the IGS20 system for the whole year. Note the scales here are twice those used in Figure 3.

can compare the mean differences between the solutions and the RMS differences of the time series of each system and the combination after removing linear trends. The network of sites used for the Galileo processing is formed from the 350 sites used daily for the GPS network and includes all sites with Galileo data that don't have AOA DM antennas. Generally, there are about 260 sites in the Galileo network.

Table 5 gives the median and worst WRMS scatters of the sites common to all three solution types. This table shows that Galileo-alone solutions have higher WRMS scatter than GPS-only solutions but that the combined GPS+Galileo solution has the lowest WRMS scatter in all components for both median and worst values. When the differences between the GPS-only and Galileo-only solutions are analyzed, some sites have systematic mean differences. The ten largest positive and negative differences for each component are given in Table 6. The table has three blocks for Height, North, and East differences. Not all of the antennas analyzed have full Galileo calibrations, but the lack of L5 calibration does not seem to introduce systematic differences except for the AOAD/M_T and B antennas, where the height differences are all positive and range from 4.8 to 22 mm (from repro3 results). Large positive height differences occur most commonly with antennas with only G01 and G02 calibrations. However, large negative differences (about half the size of the positive differences) occur with fully calibrated antennas. Both large positive and negative differences are associated with fully calibrated antennas for North and East differences, with only one entry for north and east that has only G01/G02 antenna calibrations. (When L5 calibrations are not available, the L2 calibration is used).

The differences between the L1/L2 and L1/L5 GPS and Galileo solutions with fully calibrated antennas indicate that the phase center model to be used at individual sites is likely to depend critically on the in-situ environment in which the antenna is installed. The histogram of the differences for all sites, shown in Figure 5, shows very small mean and median differences in north and east and a positive difference in height, which is related to G01/G02 only calibrated antennas.

Table 5: Median and Worst WRMS scatters of the 262 sites used more than 5 times common to the GPS, Galileo, and combined solutions. All units are mm.

Solution	Median N WRMS	Median E WRMS	Median U WRMS	Worse N WRMS	Worse E WRMS	Worse U WRMS
Galileo	2.09	2.09	6.75	11.77	12.54	38.66
GPS	1.64	1.72	6.08	12.80	12.46	17.93
Combined	1.55	1.53	5.88	12.27	12.33	17.65

Table 6: Sites with the largest differences between GPS-only and Galileo-only solutions. In this table, # is the number of days of data used; ΔP is the difference in position, either height, north or east, depending on the block in the table; ± is the standard deviation of the mean difference assuming white noise; WRMS is the weighted RMS scatter about the mean; χ is a shorthand notation for the square-root of chi-squared per degrees of freedom and it would be close to one if the standard deviation of the differences were consistent with the scatter; Receiver is the receiver type; Antenna is the antenna and radome type; and F is the GPS (G) and Galileo (E) frequency calibrations available (other available calibration frequencies are not shown).

Site	#	ΔP	± (mm)	WRMS (mm)	χ	Receiver	Antenna	F
Height								
THTI	581	−12.52	1.71	41.20	0.50	TRIMBLE NETR9	ASH701945E_M NONE	G01 E01 G02 G05 E05
PGEN	426	−10.47	0.40	8.32	0.70	LEICA GR50	LEIAR25 LEIT	G01 G02
MARS	773	−9.95	0.24	6.54	0.50	LEICA GR50	TRM57971.00 NONE	G01 E01 G02 G05 E05 E06 E07 E08
ABMF	771	−6.91	0.31	8.54	0.60	SEPT POLARX5	TRM57971.00 NONE	G01 E01 G02 G05 E05 E06 E07 E08
SCUB	677	−5.95	0.34	8.78	0.70	JAVAD TRE_G3TH DELTA	JAV_RINGANT_G3T NONE	E01 E05 E06 E07 E08 G01 G02 G05
BRST	774	−5.65	0.15	4.28	0.50	TRIMBLE ALLOY	TRM57971.00 NONE	G01 E01 G02 G05 E05 E06 E07 E08
LMMF	777	−5.13	0.32	9.01	0.60	TRIMBLE ALLOY	TRM57971.00 NONE	G01 E01 G02 G05 E05 E06 E07 E08
CHTI	52	−4.63	0.60	4.31	0.50	TRIMBLE ALLOY	TRM115000.00 NONE	G01 E01 G02 G05 E05 E06 E07 E08
AMC4	768	−4.50	0.16	4.56	0.50	SEPT POLARX5TR	TPSCR.G5C NONE	G01 E01 G02 G05 E05
THTG	776	−4.38	0.29	8.08	0.70	SEPT POLARX5TR	LEIAR25.R3 LEIT	G01 E01 G02 G05 E05 E06 E07 E08
FAIR	751	12.21	0.22	6.00	0.60	SEPT POLARX5	ASH701945G_M JPLA	G01 G02
BADG	769	12.40	0.13	3.69	0.60	JAVAD TRE_3 DELTA	JAVRINGANT_DM JVDM	G01 G02
PARK	732	12.63	0.16	4.31	0.40	SEPT POLARX5TR	LEIAR25 NONE	G01 G02
ABPO	583	13.61	0.29	7.04	0.50	SEPT POLARX5	ASH701945G_M SCIT	G01 G02
NYA1	767	14.79	0.26	7.15	0.60	TRIMBLE NETR9	ASH701073.1 SNOW	G01 G02
KOKB	643	15.04	0.28	7.18	0.60	SEPT POLARX5TR	ASH701945G_M NONE	G01 G02
SYDN	574	15.38	1.00	24.01	0.50	SEPT POLARX5TR	ASH701945C_M NONE	G01 E01 G02 G05 E05 E06 E07 E08
BREW	767	17.43	0.32	8.78	0.40	SEPT POLARX5TR	ASH701945C_M SCIT	G01 G02
ANTC	110	22.62	0.77	8.08	0.30	SEPT POLARX5	ASH700936D_M SNOW	G01 G02
KERG	767	29.09	0.38	10.56	0.60	TRIMBLE ALLOY	ASH701945E_M SNOW	G01 G02

Table 6: Continuation.

North

Site	#	ΔP	± (mm)	WRMS (mm)	χ	Receiver	Antenna	F
SGOC	700	−2.50	0.09	2.41	0.60	SEPT POLARX5	JAVRINGANT_G5T NONE	G01 E01 G02 G05 E05
SEYG	774	−2.46	0.09	2.58	0.70	SEPT POLARX5	TRM59800.00 NONE	G01 E01 G02 G05 E05 E06 E07 E08
FTNA	395	−2.41	0.13	2.68	0.60	TRIMBLE ALLOY	TRM59800.00 NONE	G01 E01 G02 G05 E05 E06 E07 E08
NAUS	7	−2.22	1.30	2.48	0.70	TRIMBLE NETR9	TRM33429.20+GP NONE	G01 G02
WUH2	19	−2.01	0.66	2.90	0.70	JAVAD TRE_3	JAVRINGANT_G5T NONE	G01 E01 G02 G05 E05
MAYG	28	−1.97	0.36	1.90	0.50	TRIMBLE ALLOY	TRM59800.00 NONE	G01 E01 G02 G05 E05 E06 E07 E08
MEDI	768	−1.97	0.07	1.99	0.60	LEICA GR10	LEIAR20 LEIM	G01 E01 G02 G05 E05 E06 E07 E08
KOKV	642	−1.69	0.07	1.83	0.60	JAVAD TRE_G3TH DELTA	ASH701945G_M NONE	G01 G02
DJIG	740	−1.62	0.07	1.83	0.70	SEPT POLARX5	TRM59800.00 NONE	G01 E01 G02 G05 E05 E06 E07 E08
GAMB	757	−1.58	0.07	1.99	0.70	TRIMBLE ALLOY	TRM59800.00 NONE	G01 E01 G02 G05 E05 E06 E07 E08
QAQ1	774	1.92	0.06	1.70	0.60	SEPT POLARX5	ASH701945E_M SCIS	G01 E01 G02 G05 E05 E06 E07 E08
GODS	756	1.95	0.06	1.65	0.50	JAVAD TRE_3 DELTA	JAVRINGANT_DM SCIS	G01 E01 G02 G05 E05 E06 E07
YKRO	745	1.97	0.07	1.92	0.60	JAVAD TRE_3 DELTA	ASH701945C_M NONE	G01 E01 G02 G05 E05 E06 E07 E08
FALK	771	2.02	0.08	2.25	0.60	SEPT POLARX5	ASH701945E_M SCIT	G01 E01 G02 G05 E05 E06 E07 E08
URUM	773	2.86	0.16	4.46	1.50	JAVAD TRE_3	JAVRINGANT_G5T NONE	G01 E01 G02 G05 E05
SCH2	766	3.35	0.08	2.12	0.70	JAVAD TRE_3N DELTA	ASH701945E_M NONE	G01 E01 G02 G05 E05
CMUM	767	4.19	0.10	2.83	0.60	TRIMBLE NETR9	JAV_GRANT-G3T NONE	G01 E01 G02 G05 E05 E06 E07 E08
GRAS	743	4.26	0.07	1.97	0.60	TRIMBLE NETR9	ASH701945E_M NONE	G01 E01 G02 G05 E05
THTI	758	4.29	0.12	3.44	0.50	TRIMBLE NETR9	ASH701945E_M NONE	G01 E01 G02 G05 E05
JOG2	776	5.16	0.21	5.96	1.90	SEPT POLARX5	SEPCHOKE_B3E6 NONE	G01 E01 G02 G05 E05

Table 6: Continuation.

East								
Site	#	ΔP	± (mm)	WRMS (mm)	χ	Receiver	Antenna	F
URUM	774	−7.79	0.13	3.58	1.20	JAVAD TRE_3	JAVRINGANT_G5T NONE	G01 E01 G02 G05 E05
JOG2	776	−4.46	0.22	6.05	1.60	SEPT POLARX5	SEPCHOKE_B3E6 NONE	G01 E01 G02 G05 E05
SGOC	700	−3.46	0.12	3.13	0.70	SEPT POLARX5	JAVRINGANT_G5T NONE	G01 E01 G02 G05 E05
FAIR	751	−2.34	0.07	1.98	0.60	SEPT POLARX5	ASH701945G_M JPLA	G01 G02
LCK4	753	−2.32	0.14	3.91	1.00	TRIMBLE ALLOY	JAVGRANT_G5TLBI NONE	G01 E01 G02 G05 E05 E06 E07 E08
GODN	756	−2.21	0.07	1.80	0.60	JAVAD TRE_3 DELTA	TPSCR.G3 SCIS	G01 E01 G02 G05 E05 E06 E07 E08
PALM	240	−2.17	0.22	3.48	0.70	SEPT POLARX5	ASH700936D_M SCIS	G01 E01 G02 G05 E05 E06 E07 E08
PIE1	765	−2.14	0.07	2.01	0.70	JAVAD TRE_3 DELTA	ASH701945E_M NONE	G01 E01 G02 G05 E05
IMPZ	357	−1.81	0.14	2.61	0.70	LEICA GR50	LEIAR10 NONE	G01 E01 G02 G05 E05
SYOG	696	−1.71	0.07	1.87	0.60	TRIMBLE ALLOY	TRM159900.00 SCIS	G01 G02
NRMG	65	2.22	0.22	1.80	0.50	SEPT POLARX5	TRM57971.00 TZGD	G01 E01 G02 G05 E05
HERS	774	2.24	0.08	2.35	0.80	SEPT POLARX5TR	LEIAR25.R3 NONE	G01 E01 G02 G05 E05 E06 E07
YARR	757	2.26	0.07	1.88	0.70	SEPT POLARX5	LEIAT504 NONE	G01 E01 G02 G05 E05
VARS	739	2.34	0.07	1.77	0.50	TRIMBLE NETR9	TRM59800.00 SCIS	G01 E01 G02 G05 E05 E06 E07 E08
BSHM	511	2.42	0.09	1.99	0.60	SEPT POLARX5	TRM59800.00 SCIS	G01 E01 G02 G05 E05 E06 E07 E08
SAMO	733	2.61	0.12	3.19	0.60	SEPT POLARX5	JAVRINGANT_DM NONE	G01 E01 G02 G05 E05 E06 E07 E08
WUH2	19	3.16	0.83	3.61	0.80	JAVAD TRE_3	JAVRINGANT_G5T NONE	G01 E01 G02 G05 E05
HRAO	766	4.43	0.08	2.13	0.60	SEPT POLARX5TR	ASH701945E_M NONE	G01 E01 G02 G05 E05
ULAB	740	5.41	0.09	2.45	0.90	JAVAD TRE_3	JAVRINGANT_G5T NONE	G01 E01 G02 G05 E05
CMUM	767	5.44	0.13	3.64	0.60	TRIMBLE NETR9	JAV_GRANT-G3T NONE	G01 E01 G02 G05 E05 E06 E07 E08

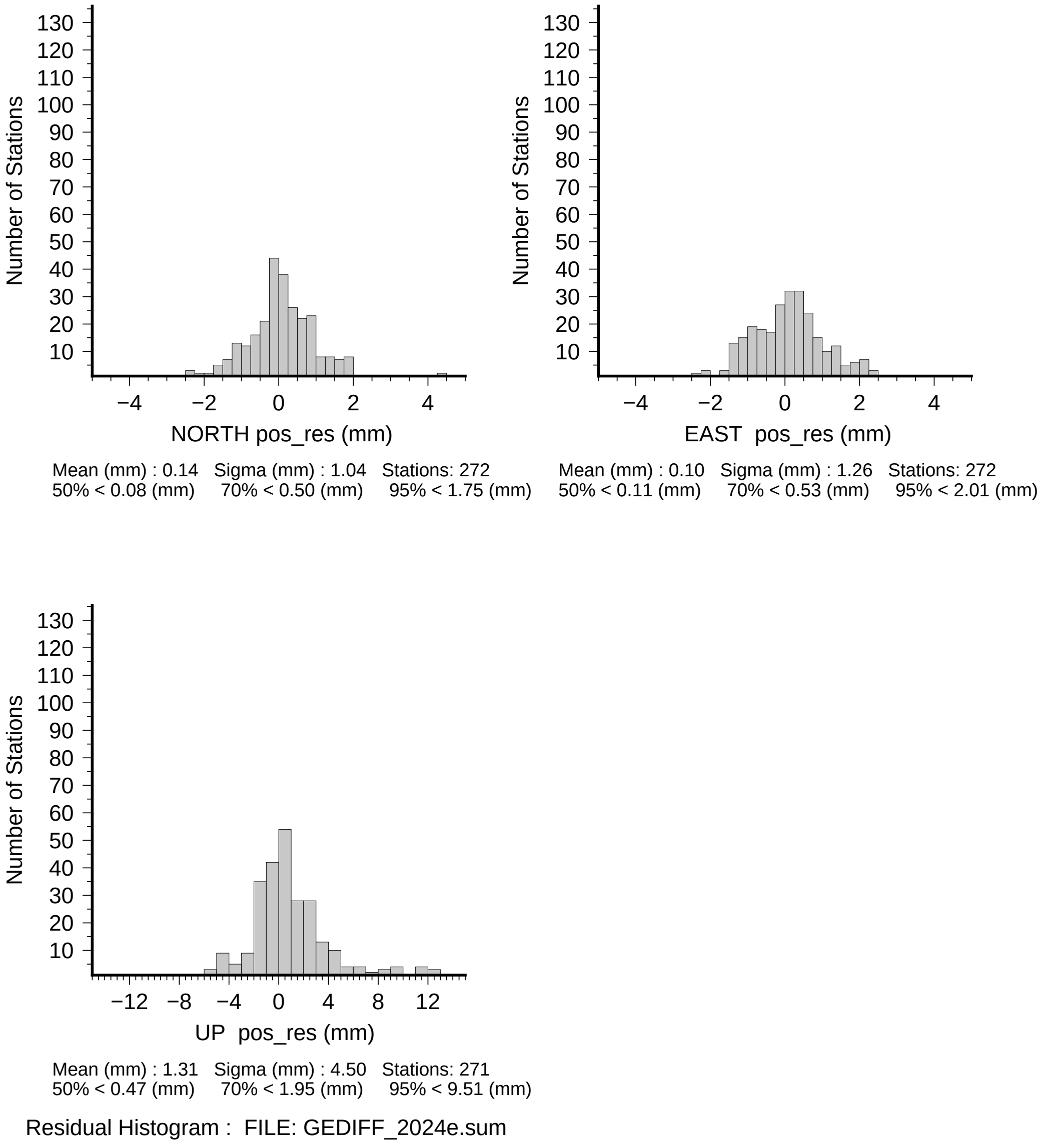

Figure 5: Histograms of the mean differences in North, East, and Height between GPS-only and Galileo-only analyses. The mean differences are small, and the slight positive mean difference in the height component is due to positive height differences for sites with only G01 and G02 antenna calibrations (see Table 6). Large negative height differences occur with fully calibrated antennas in general. Large negative and positive differences in horizontal components occur for fully calibrated antennas.

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NGS Analysis Center Technical Report 2024

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1 Introduction

In 2024, The National Geodetic Survey (NGS) continued to serve as an IGS analysis center and a regional data center. This report summarizes the routine analysis and data center activities conducted at NGS, and the significant changes that occurred since the last contribution to the IGS Report (Jones et al., 2024).

2 Core Analysis Center Products

The NGS analysis center currently focuses on producing the rapid and final products presented in Table 1. We continue to provide updated solutions to the IGS, aligning with the ITRF2020/IGS20 frame (initial date Nov 18, 2022). Updates are also underway to stay current with a shift to the ITRF2020-u2023/IGb20 update including the newly added 11 IGS reference frame stations. We continue to use the updated long file names accordingly, matching IGS standards.

We have also updated our Final submission products to include the midnight epoch value, at the end of the arc, starting with our GPS week 2334 submission. The second midnight epoch value will also be added to our daily Rapid submissions in the near future. With these changes, we continue to provide rapid products on a daily basis and include a daily ERP file. We are still working internally on the implementation of ultra-rapid products for the IGU combinations. New software under development at NGS should include the additional capabilities necessary to create this additional product. Combination statistics for NGS submissions can be found at the IGS Analysis Coordinator website

Table 1: NGS Analysis Center Products

Pre-Wk 2237 Products	
ngswwwd.sp3	GPS only orbit solution
ngswwwd.snx	PAGES software position/velocity solution
ngswww7.erp	Earth Rotation Parameters
Current Products	
NGS0OPSRAP_YYYYDDD0000_01D_15M_ORB.SP3.gz	Rapid GPS orbit solution
NGS0OPSRAP_YYYYDDD0000_01D_01D_ERP.ERP.gz	Rapid Earth Rotation Parameters
NGS0OPSRAP_YYYYDDD0000_01D_01D_SUM.SUM.gz	Rapid GPS combination summary
NGS0OPSFIN_YYYYDDD0000_01D_15M_ORB.SP3.gz	Final GPS orbit solution
NGS0OPSFIN_YYYYDDD0000_01D_01D_ERP.ERP.gz	Final Earth Rotation Parameters
NGS0OPSFIN_YYYYDDD0000_01D_07D_SUM.SUM.gz	Final GPS combination summary
NGS0OPSFIN_YYYYDDD0000_01D_01D_SOL.SNX.gz	Final PAGES position solution

(http://acc.igs.org). We are also in the process of developing the capacity to provide Final and Rapid products for GLONASS and GALILEO constellations.

3 Analysis Center Processing Software and Strategies

The NGS Analysis Center uses an in-house software package, Program for the Adjustment of GPS Ephemerides (PAGES), to estimate station baselines, orbits, and EOPs from double-differenced GPS phase observables. NGS computes solutions from small regional clusters of stations and combines the regions, at the normal equation level, into a global solution using the software package GPSCOM with no-net-rotation constraints.

For details about the models and strategies used, please refer to the IGS contributions to ITRF2020 and Altamimi et al. (2023). Important distinctions in the models and strategies to the processing software include:

- High-frequency pole model from Desai and Sibbois (2016).
- Solar radiation pressure model in use is ECOM2 for GPS satellites except Block IIF which uses ECOM1.
- Ocean loading model in use is FES2014.
- Interconnection of the Inertial and Terrestrial reference frame using the initial IAU 1976 Precession and 1980 Nutation Theory.

Table 2: Sites contributed to the IGS network during 2024

Site	Location	Lat.	Long.	Receiver Type	System
ASPA00USA	Pago Pago, American Samoa	-14.33	-170.72	SEPT-POLARX5	GPS+GLO+GAL
BARH00USA	Bar Harbor, ME, USA	44.39	-68.22	LEICA GR30	GPS+GLO
BRFT00BRA	Eusebio, Brazil	-3.88	-38.43	SEPT-POLARX5	GPS+GLO+GAL
EPRT00USA	Eastport, ME, USA	44.91	-66.99	LEICA GR50	GPS+GLO+GAL
GUUG00USA	Mangilao, Guam, USA	13.433	144.80	TRIMBLE-ALLOY	GPS+GLO+GAL
HNPT00USA	Cambridge, MD, USA	38.59	-76.13	LEICA GR50	GPS+GLO+GAL
WES200USA	Westford, MA, USA	42.61	-71.49	TRIMBLE-ALLOY	GPS+GLO+GAL

4 Regional Data Center Core Products

During 2024, NGS contributed data from the sites listed in Table 2 to the IGS Network. NGS also facilitated data flow for the sites given in Table 3 as a Regional Data Center. Please refer to the IGS Network website http://igs.org/network for site logs, photos, and data statistics for the sites serviced and facilitated by NGS.

5 Acknowledgements

The analysis and data center teams wish to express our gratitude to NGS and NOAA management for their support of this work as fundamental activities of NGS. For information about how these activities fit into NGS plans, see the National Geodetic Survey Strategic Plan - 2024.

Table 3: Site Data facilitated by NGS during 2024

Site	Location	Lat.	Long.	Receiver Type	System
BJCO00BEN	Cotonou, Benin	6.38	2.45	TRIMBLE NETR5	GPS+GLO
GUAT00GTM	Guatemala City, Guatemala	14.59	-90.52	LEICA GRX1200GGPRO	GPS+GLO

6 References

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NRCan Analysis Center Technical Report 2024

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1 Introduction

This report provides an overview of the major activities conducted at the NRCan Analysis Center (NRCan-AC) and product changes during the year 2024 (products labelled 'EMR*'). Furthermore, it includes an outline of the changes to the stations and services managed by NRCan. Readers are referred to the Analysis Coordinator web site at http://acc.igs.org for historical combination statistics of the NRCan-AC products. The NRCan-AC is located at the Canadian Geodetic Survey (CGS).

2 NRCan Core Products

The Final GPS products are being generated using GipsyX using v2 with in-house developments (Nikolaidou et al., 2024). The GNSS Rapid and Ultra-Rapid products continued to be generated using the Bernese software version 5.2 (Dach et al., 2015). IGS20/Repro3 standards have been implemented for all products. The products available from the NRCan-AC are summarized in Table 2. The Rapid products are available from the following anonymous ftp sites:

ftp://cacsa.nrcan.gc.ca/gps/products
ftp://cacsb.nrcan.gc.ca/gps/products

3 Ionosphere and DCB monitoring

NRCan's global ionosphere Total Electron Content (TEC) maps continued to be produced at 1 hour intervals (`EMR0OPSFIN_[yyyy][ddd]0000_01D_01H_GIM.INX.gz`), and include GPS and GLONASS differential code biases (DCBs). They are available at CDDIS with a latency of less than 2 days. Apart from near-real-time maps that are being generated internally using Real-Time IGS stations, a daily 3-constellation (GPS, GLONASS, and Galileo) global TEC mapping and DCB estimation process continued to run internally as their performance was being monitored. Station and satellite specific GLONASS DCB estimation using about 250 IGS stations collecting GLONASS measurements continued to be monitored. Ionospheric irregularities as sensed by 1Hz GPS, GLONASS and Galileo phase rate measurements continued to be monitored in near-real-time from Real-Time IGS stations in a development platform to enhance studies on ionospheric irregularities. NRCan continues to contribute to joint collaborations on ionospheric studies within IGS (Hernández-Pajares et al., 2024; Lyu et al., 2024; Krankowski et al., 2024) .

4 Real-time correction service

NRCan is moving towards cloud-computing to host its real-time platform. The goal remains to maximise flexibility when generating multiple constellation corrections in real-time.

5 Operational NRCan stations

In addition to routinely generating all core IGS products, NRCan also provides public access to GNSS data for more than 100 Canadian stations. This includes 36 stations currently contributing to the IGS network through the CGS's Canadian Active Control System (CGS-CACS), the CGS's Regional Active Control System (CGS-RACS), and the Canadian Hazards Information Service's Western Canada Deformation Array (CHIS-WCDA). In addition to the 37 stations NRCan contributes to the IGS network, a further 30 GNSS stations are submitted to IGS data centers. Several upgrades/changes to NRCan's IGS stations were completed in 2024 and these are listed in Table 1. Figure 1 shows a map of the NRCan's publicly available GNSS network as of January 2025. Further details about NRCan stations and access to NRCan public GNSS data and site logs can be found at:
https://webapp.csrs-scrs.nrcan-rncan.gc.ca/geod/data-donnees/cacs-scca.php

or from the following anonymous ftp sites:
ftp://cacsa.nrcan.gc.ca/gps and ftp://cacsb.nrcan.gc.ca/gps

Figure 1: NRCan Public GNSS Stations (CGS-CACS, CGS-RACS, CHIS-WCDA).

Table 1: NRCan-IGS Station Upgrades in 2024.

Station	Date	Remarks
EUR200CAN	2024-11-07	Station officially adopted as IGS station
CHUR00CAN	2024-10-23	Antenna replaced with TWIVC6150
QIKI00CAN	2024-07-12	Antenna replaced with TWIVC6150
IQAL00CAN	2024-07-11	Station receiver upgraded to SEPT POLARX5S
RESO00CAN	2024-06-14	Antenna replaced with TWIVC6150

6 Acknowledgement

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Table 2: NRCan-AC products.

Product	Description
Repro2:	
em2wwwwd.sp3 em2wwwwd.clk em2wwwwd.snx em2wwww7.erp	GPS only • Time Span 1994-Nov-02 to 2014-Mar-29 • Use of JPL's GIPSY-OASIS II v6.3 • Daily orbits, ERP and SINEX • 5-min clocks • Submission for IGS repro2 combination
Repro3:	
EMR0R03FIN_yyyydoy0000_01D_01D_OSB.BIA EMR0R03FIN_yyyydoy0000_01D_30S_CLK.CLK EMR0R03FIN_yyyydoy0000_01D_30S_ATT.OBX	GPS only • Time Span 1996-Jan-01 to 2020-Dec-31 • In-house software (SPARKNet) • 30-sec clocks • Based on NGS repro3 solution (ERP, SP3 and SNX) • Submission for IGS repro3 combination

Table 2: NRCan-AC products (continued).

Product	Description
Final (weekly):	

`EMR0OPSFIN_yyyydoy0000_01D_15M_ORB.SP3`
`EMR0OPSFIN_yyyydoy0000_01D_01D_SOL.SNX`
`EMR0OPSFIN_yyyydoy0000_01D_30S_CLK.CLK`
`EMR0OPSFIN_yyyydoy0000_07D_01D_ERP.ERP`
`EMR0OPSFIN_yyyydoy0000_07D_01D_SUM.SUM`
	GPS only
	• Since 1994 and ongoing
	• Use of JPL's GIPSY-OASIS II v6.4 from 2016-Feb-01to 2022-Nov-26
	• Use of JPL's GipsyX (mix of v1.3 and 2.0) since 2022-Nov-27
	• Daily orbits, ERP and SINEX
	• 30-sec clocks
	• Weekly submission for IGS Final combination
	
	GPS+GLONASS
	• Since 2011-Sep-11 and ongoing
	• Use of Bernese 5.0 until 2015-Jan-31
	• Use of Bernese 5.2 since 2015-Feb-01
	• Daily orbits and ERP
	• 30-sec clocks
	• Weekly submission for IGLOS Final combination
	• Station XYZ are constrained, similar to our Rapid solutions

Rapid (daily):	

`emrwwwwd.sp3`
`emrwwwwd.clk`
`emrwwwwd.erp`
	GPS only
	• From July 1996 to 2011-05-21
	• Use of JPL's GIPSY-OASIS (various versions)
	• Orbits, 5-min clocks and ERP (30-sec clocks from 2006-Aug-27)
	• Daily submission for IGR combination
	
	GPS+GLONASS
	• Since 2011-Sep-06 and ongoing
	• Use of Bernese 5.0 until 2015-Feb-11
	• Use of Bernese 5.2 from 2015-Feb-12
	• Daily orbits and ERP
	• 30-sec GNSS clocks

Table 2: NRCan-AC products (continued).

Product	Description
Ultra-Rapid (hourly):	

`emuwwwwd_hh.sp3`
`emuwwwwd_hh.clk`
`emuwwwwd_hh.erp`
	GPS only
	• From early 2000 to 2013-09-13, hour 06
	• Use of Bernese 5.0
	• Orbits, 30-sec clocks and ERP (hourly)
	• Submission for IGU combination (4 times daily)

	GPS+GLONASS • Since 2013-09-13, hour 12 • Use of Bernese 5.0 until 2015-Feb-12 • Use of Bernese 5.2 since 2015-Feb-13 • Orbits and ERP (hourly) • 30-sec GNSS clocks (every 3 hours) • 30-sec GPS-only clocks (every other hours) • Submission for IGU/IGV combination (4 times daily) • From 2020-10-20, hourly 30-sec GLONASS clocks produced (used to be every 3h) in addition to orbits and ERP with a delay of less than one hour.
Real-Time:	

	GPS only
	• Since 2011-11-10 until 2018-05-07
	• In-house software (HPGPS.C)
	• RTCM messages:
	  – orbits and clocks:1060
	    positions at Antenna Reference Point
	    float ambiguity clocks
	  – pseudorange biases: 1059
	  – phase biases: 1265
	• Interval: 5 sec

	GPS only
	• Since 2018-05-08
	• In-house software (HPGPS.C)
	• RTCM messages:
	  – orbits and clocks:1060
	    positions at Antenna Reference Point
	    phase clocks
	  – pseudorange biases: 1059
	  – phase biases: 1265 (proposed)
	• Interval: 5 sec

USNO Analysis Center Technical Report 2024

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1 Introduction

The United States Naval Observatory (USNO), located in Washington, DC, USA has served as an IGS Analysis Center (AC) since 1997, contributing to the IGS Rapid and Ultra-rapid Combinations since 1997 and 2000, respectively. USNO contributes a full suite of rapid products (orbit and clock estimates for the GPS satellites, Earth rotation parameters (ERPs), and receiver clock estimates) once per day to the IGS by the 1600 UTC deadline, and contributes the full suite of Ultra-rapid products (post-processed and predicted orbit/clock estimates for the GPS satellites; ERPs) four times per day by the pertinent IGS deadlines.

USNO has also coordinated IGS troposphere activities since 2011, producing the IGS Final Troposphere Estimates and chairing the IGS Troposphere Working Group (IGS TWG).

The USNO AC is hosted in the GPS Analysis Division (GPSAD) of the USNO Earth Orientation Department. USNO AC activities, chairing the IGS TWG, and serving on the IGS Governing Board are overseen by Dr. Sharyl Byram who also oversees production of the IGS Final Troposphere Estimates. All GPSAD members, including Mr. Jeffrey Crefton, Dr. Elizabeth Lovegrove, and contractor Mr. James Rohde, participate in AC efforts.

USNO AC products are computed using Bernese GNSS Software (Dach et al., 2015). Rapid products are generated using a combination of network solutions and precise point positioning (PPP; Zumberge et al. , 1997). Ultra-rapid products are generated using network solutions. IGS Final Troposphere Estimates are generated using Precise Point Positioning (PPP).

GPSAD also generates a UT1-UTC-like value, UTGPS, four times per day. UTGPS is a GPS-based extrapolation of UT1-UTC measurements. The IERS (International Earth Rotation and Reference Systems Service) Rapid Combination/Prediction Service uses UTGPS in their combined daily processing of UT1-UTC. Mr. Crefton oversees UTGPS.

More information about USNO Rapid, Ultra-rapid, Troposphere, and UTGPS products can be found at the USNO website: https://maia.usno.navy.mil/products/gps-analysis. The IGS Final Troposphere Estimates can also be downloaded at https://cddis.nasa.gov/archive/gnss/products/troposphere/zpd/.

2 Product Performance, 2024

Figures 1-4 show the 2024 performance of USNO Rapid and Ultra-rapid GPS products, with summary statistics given in Table 1. USNO rapid orbits had a median weighted RMS (WRMS) of 20 mm with respect to (wrt) the IGS rapid combined orbits. The USNO Ultra-rapid orbits had median WRMSs of 24 mm (24-h post-processed segment) and 44 mm (6-h predict) wrt the IGS rapid combined orbits. USNO rapid (post-processed) and Ultra-rapid 6-h predicted clocks had median 135 ps and 613 ps RMSs wrt IGS combined rapid clocks.

USNO rapid polar motion estimates had (x, y) 23 and 33 microarcsec RMS differences wrt IGS rapid combined values, respectively. USNO Ultra-rapid polar motion estimates differed (RMS of x, y) from IGS rapid combined values by 162 and 296 microarcsec for the 24-h post-processed segment, respectively. The USNO Ultra-rapid 24-h predict-segment values differed (RMS of x, y) from the IGS rapid combined values by 366 and 399 microarcsec, respectively.

All USNO AC official products were generated with the Bernese GNSS Software, Version 5.2 in 2024 and were produced using the IGS20 reference frame.

References

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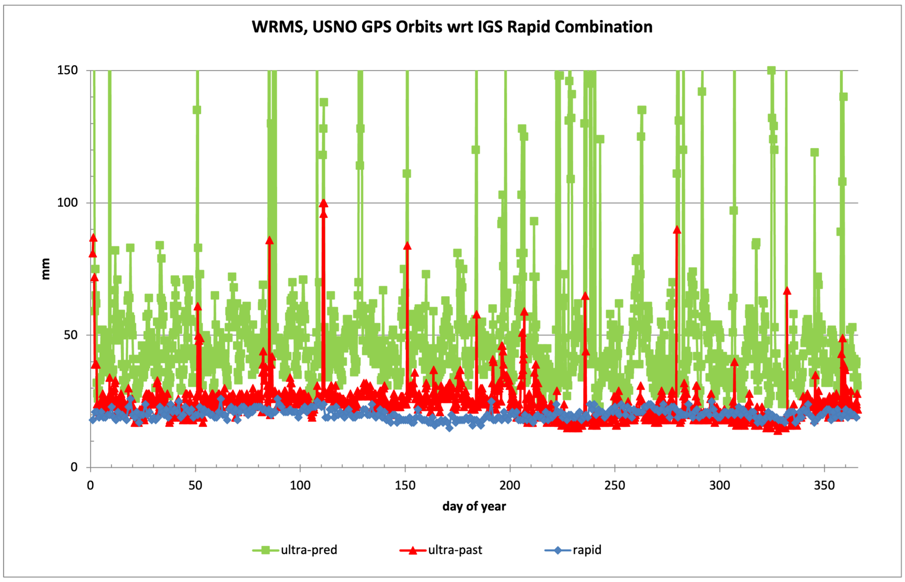

Figure 1: Weighted RMS of USNO GPS orbit estimates with respect to IGS Rapid Combination, 2024. "Ultra-past" refers to 24-hour post-processed section of USNO Ultra-rapid orbits. "Ultra-pred" refers to first six hours of Ultra-rapid orbit prediction.

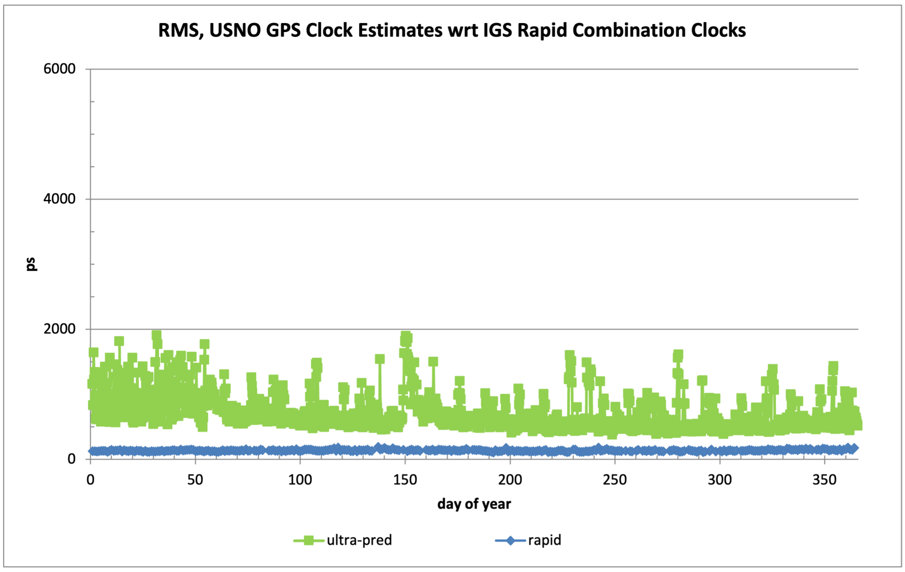

Figure 2: RMS of USNO GPS Rapid clock estimates and Ultra-rapid clock predictions with respect to IGS Rapid Combination, 2024.

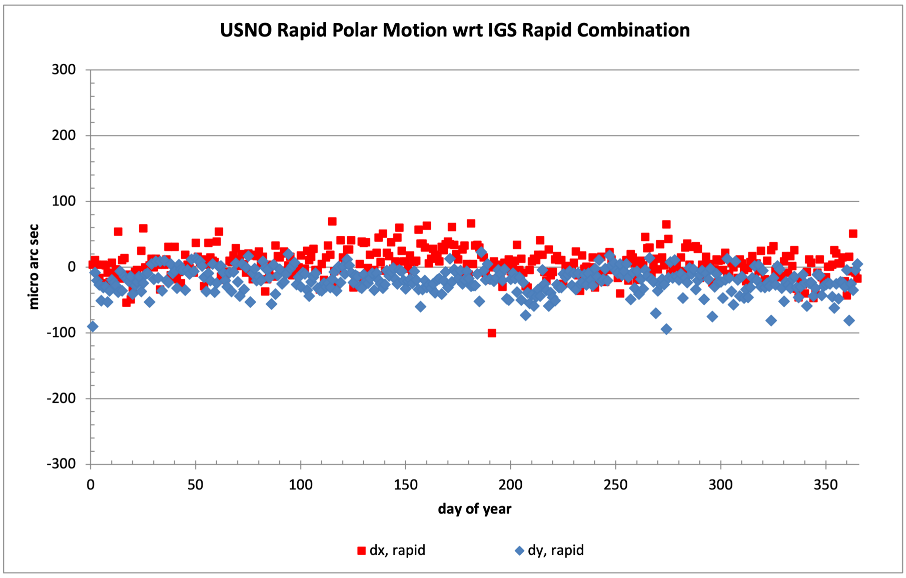

Figure 3: USNO Rapid Polar Motion estimates differenced with IGS Rapid Combination values, 2024.

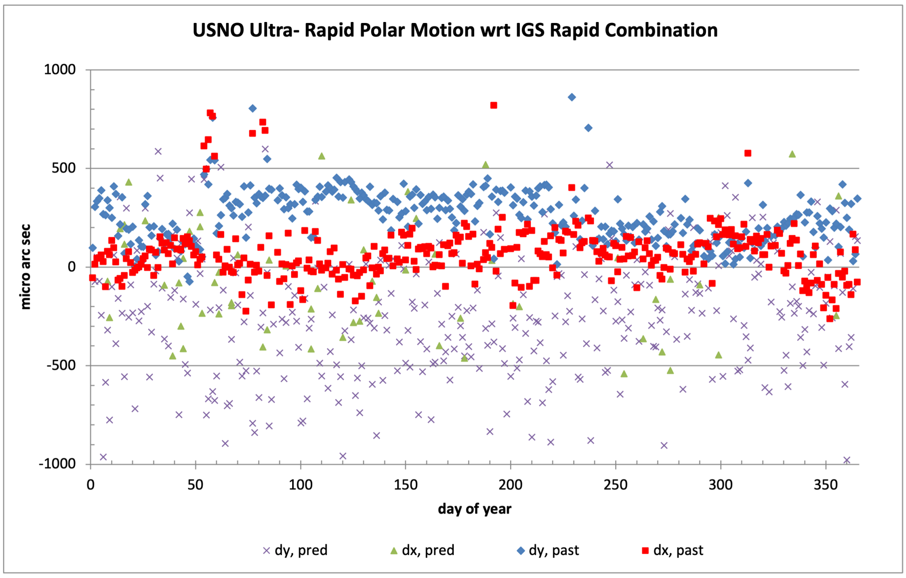

Figure 4: USNO Ultra-rapid Polar Motion estimates differenced IGS Rapid Combination values, 2024. “pred” denotes predicted and “past” denotes post processed.

Table 1: Precision of USNO Rapid and Ultra-Rapid Products, 2024. All statistics computed with respect to IGS Combined Rapid Products.

USNO GPS satellite orbits				USNO GPS–based polar motion estimates						USNO GPS–based clock estimates	
Statistic: median weighted RMS difference units: mm				Statistic: RMS difference units: 10^{-6} arc sec						Statistic: median RMS difference units: ps	
dates	rapid	ultra–rapid		rapid		ultra–rapid				rapid	ultra–rapid
		past 24 h	6-h predict			past 24 h		24-h predict		past 24 h	6-h predict
				x	y	x	y	x	y		
1/1/2024 – 12/31/2024	20	24	44	23	33	162	296	366	399	135	613

Wuhan University Analysis Center Technical Report 2024

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1 Introduction

Since 2012, the IGS Analysis Center at Wuhan University (WHU) has been a key contributor to the International GNSS Service (IGS), providing precise ultra-rapid, rapid, and MGEX products on a regular basis. These products are generated using the latest version of the Positioning and Navigation Data Analyst (PANDA) software (Liu and Ge, 2003; Shi et al., 2008).

In 2024, WHU made several significant advancements. The strategy for near real-time hourly Multi-GNSS products was updated, enhancing accuracy and efficiency. Additionally, in-depth investigations were conducted into the reference time of Multi-GNSS precise clock products and the determination of geocenter motion considering GNSS satellite clock modeling.

2 WHU Analysis Products

The products provided by WHU are summarized in Table 1.

3 Near real-time Multi-GNSS products updates

The hourly observations from approximately 120 stations provided by the IGS, the International GNSS Monitoring and Assessment System (iGMAS) and BDS Experimental Tracking Stations (BETS) established by the WHU are utilized.

Table 1: List of products provided by WHU.

WHU rapid GNSS products	
WHU00PSRAP_YYYYDDDHH00_01D_15M_ORB.SP3	Orbits for GPS/GLONASS/Galileo satellites
WHU00PSRAP_YYYYDDDHH00_01D_05M_CLK.CLK	5-min clocks for stations and GPS/GLONASS/Galileo satellites
WHU00PSRAP_YYYYDDDHH00_01D_01D_ERP.ERP	ERPs
WHU ultra-rapid GNSS products	
WHU00PSULT_YYYYDDDHH00_02D_15M_ORB.SP3	Orbits for GPS/GLONASS/Galileo satellites, provided to IGS every 6 hours
WHU00PSULT_YYYYDDDHH00_02D_01D_ERP.ERP	observed and predicted ERPs provided to IGS every 6 hours
WHU Hourly GNSS products	
WUM0MGXNRT_YYYYDDDHH00_02D_05M_ORB.SP3 WUM0MGXNRT_YYYYDDDHH00_02D_05M_CLK.CLK WUM0MGXNRT_YYYYDDDHH00_02D_30S_CLK.CLK	Orbits and clock for GPS/ GLONASS/ Galileo/ BDS/ QZSS satellites provided to IGS-MGEX every 1 hours
WUM0MGXNRT_YYYYDDDHH00_02D_01D_ERP.ERP	Observed and predicted ERPs provided to IGS-MGEX every 1 hours
WUM0MGXNRT_YYYYDDDHH00_01D_01D_OSB.BIA	code/phase biases related to the NRT orbit and clock corrections, Bias-SINEX format
WHU Ionosphere products	
whugDDD0.YYi	Final GIM with 3-d GPS/GLONASS observations
whrgDDD0.YYi	Rapid GIM with 1-d GPS/GLONASS observations
WUM0MGXRAP_YYYYDDD0000_01D_01D_ABS.BIA	Rapid OSB with 1-d multi-GNSS observations
IONO00WHU0	Real time GIM with 5-min GPS observations

To further reduce computational time, multi-threading processing are applied to station- or satellite- independent computations. Figure 1 shows the current workflow for the generation of NRT products at Wuhan University, where the parallel steps are marked in blue. The resolution of double difference (DD) ambiguity fixing is necessary for better estimation of IF ambiguity. Furthermore, the phase OSB is extracted by introducing the WUM code OSB. Subsequently, the between-satellite single-difference ambiguities are constrained in the normal equations (NEQ) to improve the orbit. Three threads are used for GPS/GLONASSS, GPS/Galileo/QZSS and GPS/BDS combined data analysis to generate the orbit, clock bias, OSB, EOP, and attitude file in orbit exchange format (ORBEX) format (Loyer et al., 2019). To mitigate the discrepancy among each product, identical stations are employed for the processing. The Galileo, BDS and QZSS orbit, clock, phase OSB, and attitude products from the GPS/Galileo and GPS/BDS combined solutions are

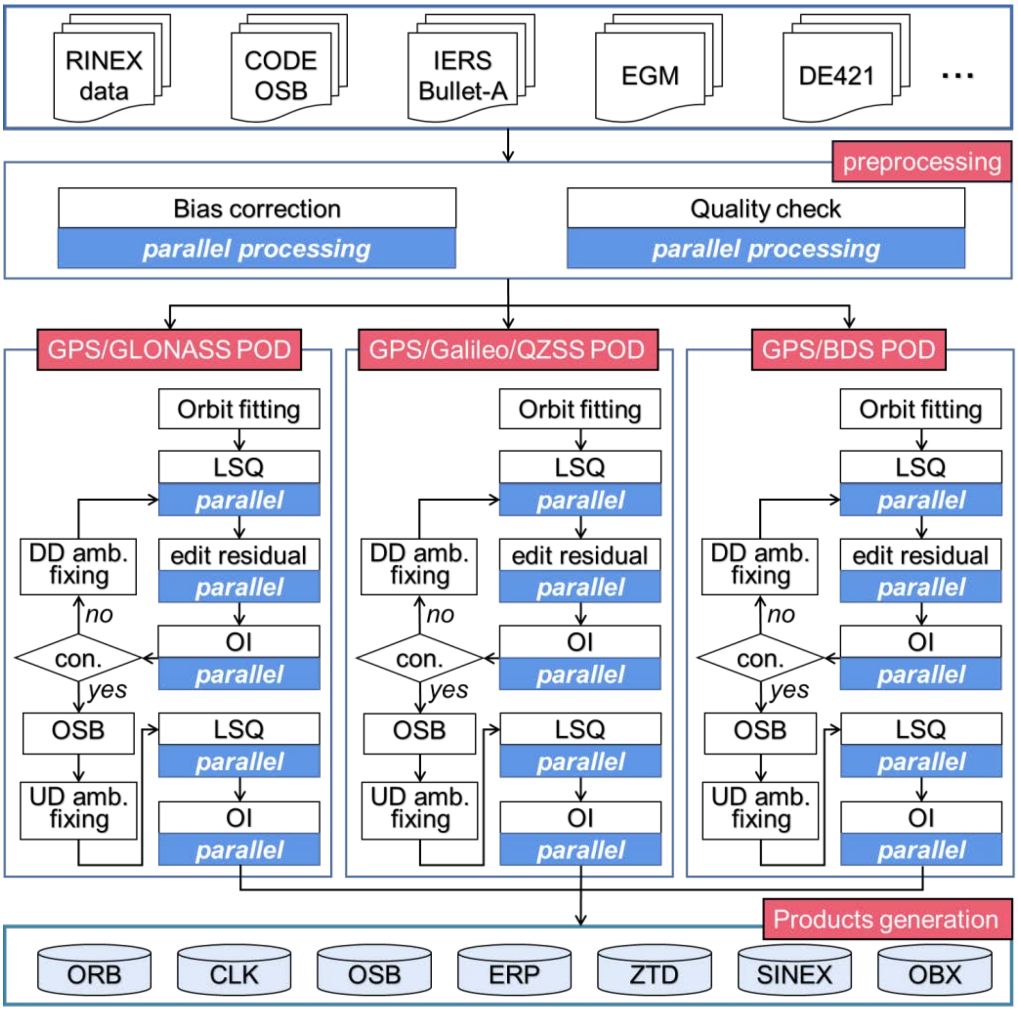

Figure 1: The workflow for the determination of the WUM NRT products.

extracted and combined with those of the GPS/GLONASS solution to obtain the final products. To enhance the orbit prediction precision, a 48-hour arc with a sampling rate of 600 s is employed, and the orbit can be predicted for the following 24 h to serve as the real-time orbit. The quadratic polynomial model is applied for the clock fitting and predicting.

Figure 2 depicts the cumulative distribution function (CDF) of real-time orbit errors. The CDFs of MEO and IGSO orbits for GPS, Galileo, and QZSS exhibit similar patterns. The 95th-percentile values for the along-track, cross-track and radial components are listed as follows: (5.8, 3.2, 3.0) cm for GPS, (9.7, 4.5, 4.2) cm for Galileo and (16.1, 14.4, 21.4) cm for QZSS. Regarding GLONASS, the 95th-percentile values are (11.8, 6.6, 4.7) cm, excluding two satellites, possibly due to the aging of satellite payload (R19 and R20). For

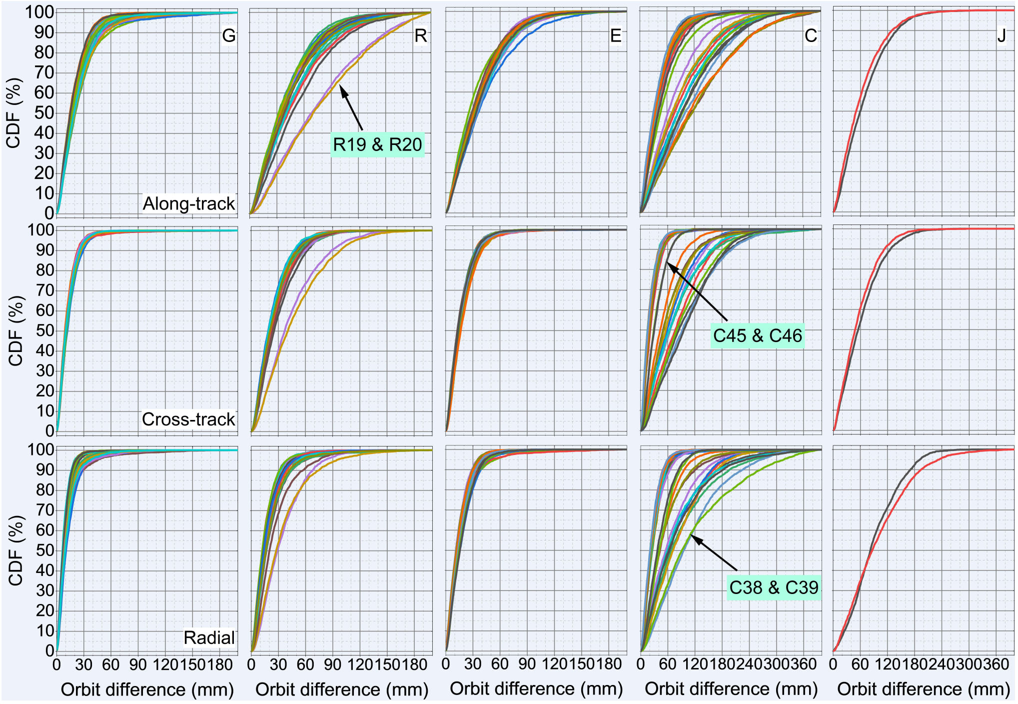

Figure 2: CDFs of real-time orbit precision for GPS, GLONASS, Galileo, BDS and QZSS IGSO and MEO satellites.

BDS, three distinct patterns emerge. BDS3-MEO exhibits superior performance, with values of (11.2, 5.6, 6.7) cm, followed by BDS2-MEO (33.8, 14.7, 13.9) cm and IGSO satellites(24.4, 19.0, 21.7) cm, respectively. BDS-3 IGSO exhibits the worst performance, with values at the 95th-percentile of (25.4, 22.1, 27.4) cm. For the BDS3-MEO satellites, notable degradation occurs in C45 and C46, potentially attributed to an inadequate a priori SRP model, which is equipped with Search and Rescue (SAR) payload, and further refinement is needed (Guo et al., 2024).

The PPP-AR results with WUM NRT products for east, north, and up direction of the static positioning solutions with respect to IGS weekly solutions are presented in Figure 3. The mean Root Mean Square (RMS) values measuring 1.6 mm, 1.7 mm, and 5.0 mm for the east, north and up directions, respectively. In addition, the mean wide-lane fixing rate is 91.3%, 96.8%, 84.5% and 91.5% for GPS, Galileo, BDS2 and BDS3. And the narrow-lane fixing rate is 99.4% for GPS, 99.1% for Galileo, 91.3% for BDS2 and 98.1% for BDS3.

Besides the near real-time orbit, clock, as well as Multi-GNSS dual-frequency OSB products with 1h latency, we also have provided the hourly-updated 30s high-rate clock products, but the latency is about 1.5 hour. Hopefully, those products can meet the GNSS applications with low latency requirement, and can be downloaded in public via IGS data

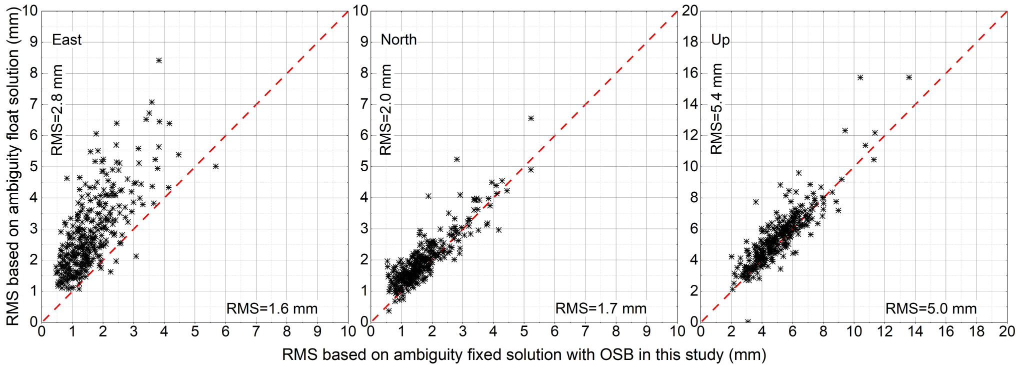

Figure 3: RMS of static PPP solutions with respect to IGS weekly solutions.

center at Wuhan or IGN. The details can be referred to Xu et al. (2024).

4 Reference Time of multi-GNSS precise clock products

Through the collaborative efforts of the IGS and the Bureau International des Poids et Mesures (BIPM), the IGS/BIPM Pilot Project has significantly advanced the field of precise time and frequency comparison using the Precise Point Positioning (PPP) technique. Studies have demonstrated that time and frequency comparisons achieved through this approach can attain an accuracy of 1 ns and a fractional frequency uncertainty of 10^{-16} over an averaging period of one day (Defraigne et al., 2022). Coordinated Universal Time (UTC), as the globally recognized reference timescale, plays a pivotal role in scientific research and industrial applications. The IGS clock products, aligned with specific timescales such as IGRT (IGS Rapid Timescale) and IGST (IGS Final Timescale), are daily adjusted to their optimal internal realizations of UTC.

Using data from multiple timing laboratories, Santra et al. (2022) analyzed the temporal deviations of IGRT relative to UTC. Their findings revealed that the time deviation between IGRT and UTC remained within $\mp 15\,\mathrm{ns}$ during the period from 2020 to 2022. However, it is important to note that IGST and IGRT currently incorporate only GPS satellites, leaving the offsets of GPS, Galileo, and BDS reference times in multi-GNSS precise clock products uncharacterized. Furthermore, investigating the offsets of real-time clock products relative to UTC would provide valuable insights for enhancing the accuracy of one-way timing in PPP applications.

By utilizing GNSS observations from UTC(k) stations, the combined effects of local clock offsets and hardware delays can be readily derived through PPP techniques. The hardware calibrations for GPS, Galileo, and BDS at UTC(k) stations are publicly accessible via the BIPM database (https://webtai.bipm.org/database), enabling the calculation of the offsets between GPS, Galileo, and BDS reference times and UTC. For this analysis, four UTC(k) stations within the IGS network—BRUX, PTBB, ROAG, and USN8—were selected to evaluate the offsets of IGST and multi-GNSS products relative to UTC. It is important to note that while BDS precise clock estimations rely on B1I/B3I observations, the BIPM provides calibrations exclusively for B1C/B2a signals. Consequently, only the variations in the offsets of the BDS reference time relative to UTC can be analyzed. The dataset for the entire year of 2023 was processed using the Geodetic SpatioTemporal data Analysis and Research software (Shi et al., 2023), ensuring robust and consistent computational results.

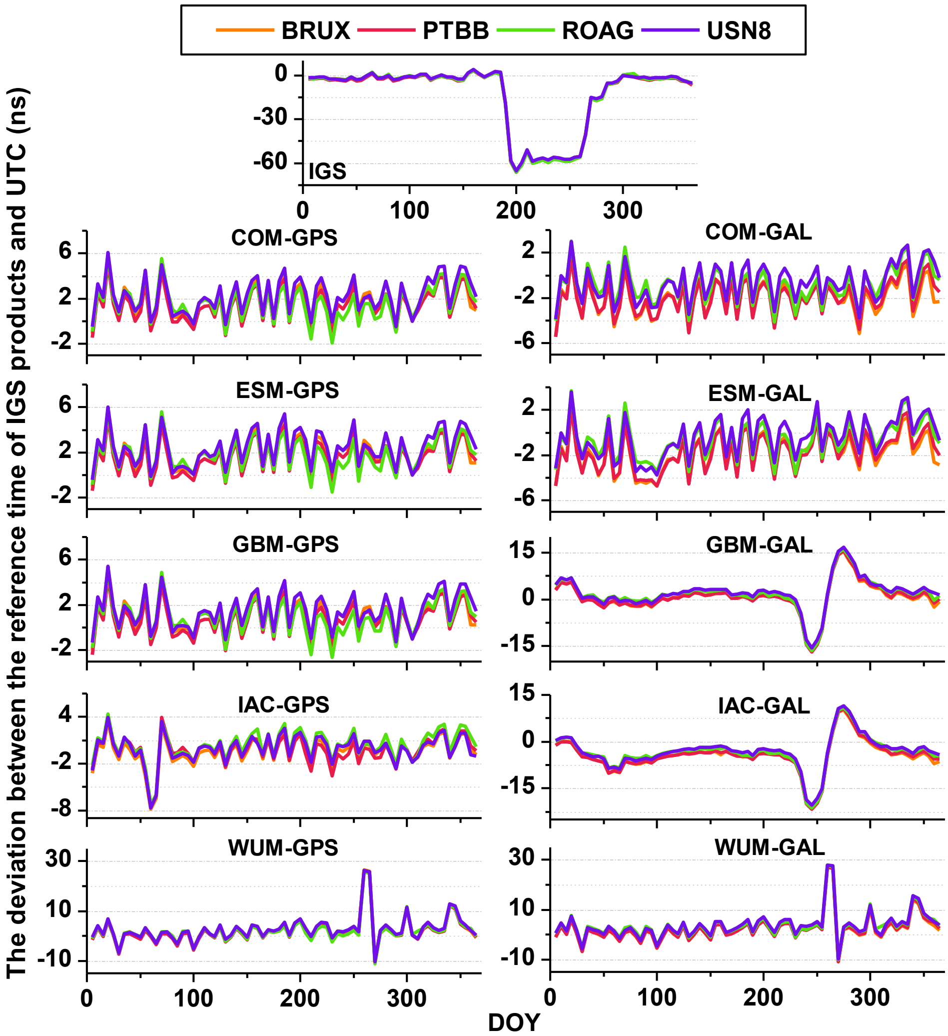

Figure 4: Estimated offset of GPS and Galileo reference time from UTC using a subset of UTC(k) stations, the top panel shows the offset of the IGST timescale with resepct to UTC.

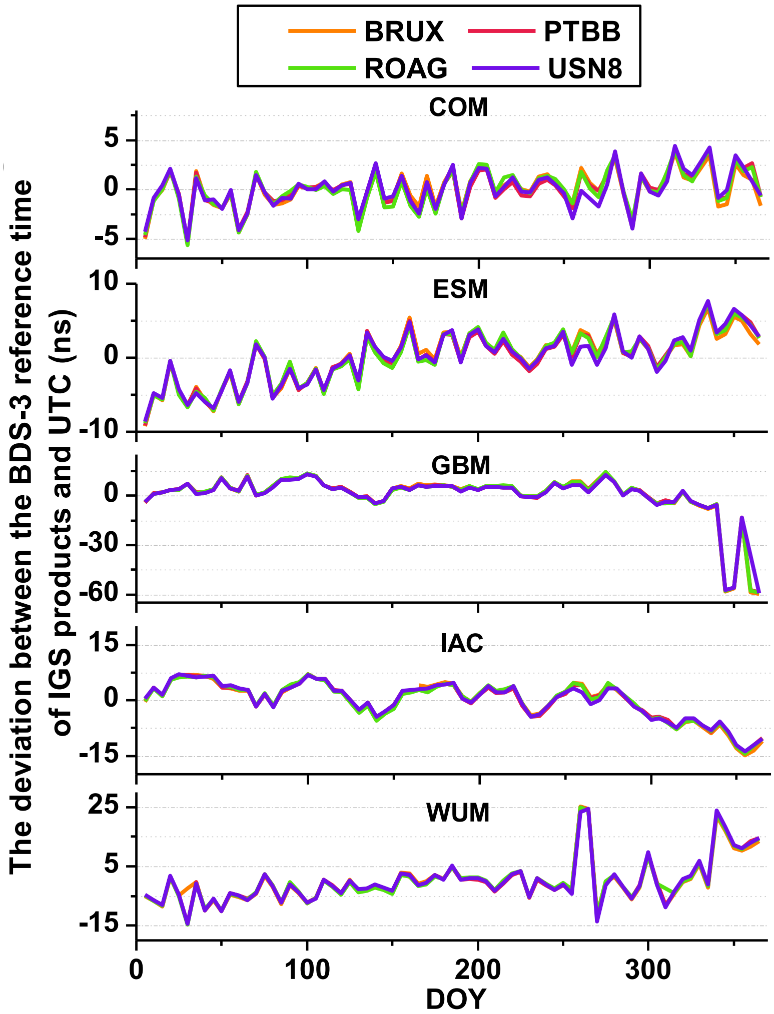

Figure 5: Estimated offset of BDS reference time from UTC using a subset of UTC(k) stations.

Figures 4 illustrate the offsets of the GPS and Galileo reference times relative to UTC. Notably, the estimated offset of the IGST from UTC reaches up to −66 ns in 2023, which is a significant deviation. In contrast, most MGEX ACs, including COM, ESM, GBM, and IAC, demonstrate better consistency with UTC, with offsets remaining below 8 ns. However, the GPS reference time offset for WUM exceeds 25 ns. The GPS and Galileo reference time offsets exhibit strong consistency for COM, ESM, and WUM. In contrast, the estimated Galileo reference time offsets for GBM and IAC display considerable variability, with peak-to-peak values reaching up to 30 ns.

Figure 5 presents the estimated offsets of the BDS reference time relative to UTC. Due to the lack of BDS B1I/B3I calibrations, only the variations in the offsets could be analyzed.

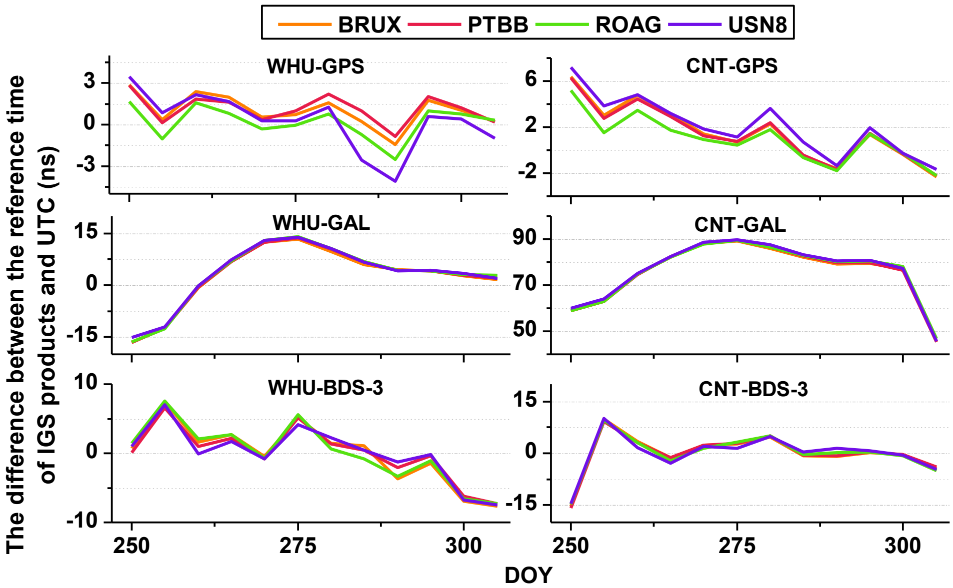

Figure 6: Estimated offset of GPS, Galileo and BDS real-time reference time from UTC using a subset of UTC(k).

The offset variations are relatively stable for COM, ESM, and IAC, whereas the peak-to-peak values exceed 30 ns for GBM and WUM.

Furthermore, Figure 6 depicts the estimated offsets of the GPS, Galileo, and BDS reference times in the IGS real-time Analysis Centers (ACs), specifically WHU and CNES. The GPS reference time offsets remain within 7 ns of UTC, while the peak-to-peak values of the time deviations for BDS-3 and Galileo exceed 15 ns and 30 ns, respectively, over a period of nearly two months.

5 Geocenter motion determination considering GNSS satellite clock modeling

The realization of the International Terrestrial Reference Frame (ITRF) aligns with the center of mass (CM) on secular time scales but coincides with the center of figure (CF) on shorter time scales. Geocenter motion, defined as the displacement of the CM relative to the CF, represents a critical parameter in modern geodesy. The GNSS, with their extensive global tracking networks and continuous observations characterized by high spatial and temporal resolution, have proven to be a pivotal tool for estimating geocenter motion with precision.

In the determination of geocenter motion using the GNSS, satellite clock offsets are typ-

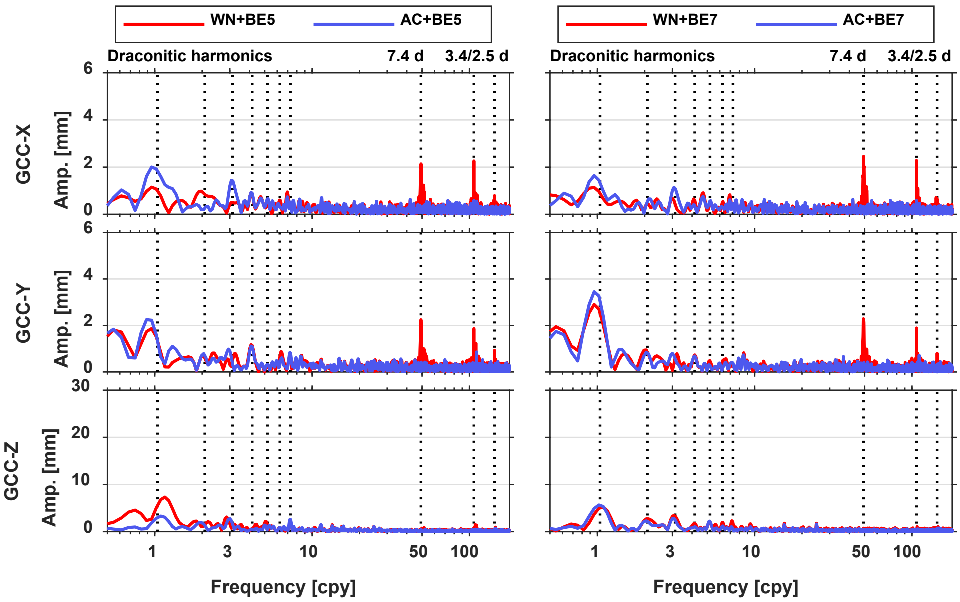

Figure 7: Amplitude spectra of multi-GNSS-derived geocenter coordinates (WN: white noise clock; AC: proposed clock model). BE5 and BE7 represent 5- and 7-parameter ECOM2 models with the a priori box-wing model. The vertical black lines denote the harmonics of a draconitic year and several signals around the 7.4, 3.4 and 2.5-day period.

ically modeled as a white noise process or eliminated through inter-station differencing. However, the inherent correlation between geocenter coordinates (GCC) and epoch-wise satellite clock errors can degrade the accuracy of GCC estimates. To address this issue, a more robust modeling approach for satellite clock offsets is proposed, wherein the offsets are represented by a polynomial model instead of being treated as a white noise process. The deviation of this model from the true clock behavior is characterized as a random parameter, with its process noise described by a variogram.

Based on 3.7 years of BDS, Galileo and GPS observations from 98 global stations, we investigate the impact of the satellite clock model on GCC estimates using the GSTAR software (Shi et al., 2023). Figure 7 illustrates the amplitude spectra of the GCC time series derived from the combined observations of the BDS, Galileo, and GPS systems using different solar radiation pressure models. Notably, the figure shows that the application of the proposed satellite clock modeling approach results in a substantial reduction of GNSS draconitic signals, nearly eliminating them from the GCC time series. However, in the solutions where satellite clock offsets are modeled as white noise, distinct spectral peaks are observed at approximately 7.4, 3.4, and 2.5 days in the X and Y components

To investigate the origin of these peaks, various system combinations were analyzed, including BDS+Galileo, BDS+GPS, and Galileo+GPS. The results reveal that the 7.4-day peak is predominantly present in the BDS+Galileo and BDS+GPS solutions, while the 3.4-day and 2.5-day peaks are exclusively identified in the BDS+Galileo and Galileo+GPS solutions. The 7.4-day peak is attributed to the beat frequency between the Earth's rotation and the orbital period of BDS satellites. A similar mechanism is observed for Galileo, with a calculated beat period of 3.3 days, closely matching the observed 3.4-day peak. The 2.5-day peak is likely associated with the fourth harmonic of Galileo's 10-day orbital repeat period.

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EUREF Permanent Network Regional Network Associate Analysis Centre Technical Report 2024

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1 Introduction

The International Association of Geodesy Regional Reference Frame sub-commission for Europe, EUREF, defines, maintains, and provides access to the European Terrestrial Reference System (ETRS89). This is done through the EUREF Permanent GNSS Network (EPN). EPN observation data as well as the precise coordinates and the zenith total delay (ZTD) parameters of all EPN stations are publicly available. The EPN cooperates closely with the International GNSS Service (IGS); EUREF members are e.g. involved in the IGS Governing Board, the IGS Reference Frame Working Group, the RINEX Working Group, the IGS Real-Time Working Group, the IGS Antenna Working Group, the IGS Troposphere Working Group, the IGS Infrastructure Committee, and the IGS Multi-GNSS Working Group and Multi-GNSS Extension Pilot Project (MGEX).

This paper provides an overview of the main changes in the EPN during the year 2024.

2 EPN Central Bureau

The EPN Central Bureau (CB, https://epncb.oma.be), managed by the Royal Observatory of Belgium, continued its operational oversight of the EPN network in 2024, focusing on station performance metrics such as data availability, metadata accuracy, and data quality (Bruyninx et al., 2019). During the year, 11 new GNSS stations were integrated into the EPN (highlighted in green in Figure 1): six in Italy, one in Greenland (not shown on the map), one in Greece, and three in Serbia. Concurrently, six stations were decommissioned: three in Ukraine, two in Great Britain, and one in Finland. Additionally, on December 4, the EPN CB transitioned to the IGS site log format v2.0, aligning the network with updated IGS standards.

In response to Resolution No. 1 of the 2024 EUREF Symposium in Barcelona, significant progress was made in promoting FAIR (Findable, Accessible, Interoperable, Reusable) data practices. A key milestone was the initiation of Digital Object Identifier (DOI) assignments to datasets from EPN stations in 2024. Over 150 EPN stations now have DOIs, accessible via the M3G platform (https://gnss-metadata.eu). This initiative will continue in the coming years to ensure more stations benefit from enhanced data discoverability and proper citation, providing appropriate recognition for data providers. To guarantee compliance with international standards, EUREF collaborates closely with the GGOS Committee on DOIs for Geodetic Data.

Furthermore, historical EPN data is now accessible through a new open data portal (https://gnss.be/opendataportal/). Currently in beta, this platform offers a GUI as well as web services to provide access to RINEX data enriched with standardized metadata compliant with the GNSS-DCAT-AP schema (Bruyninx et al., 2024). These advancements significantly enhance the accessibility and reusability of GNSS data.

EUREF also strengthened its ties with the European Plate Observing System (EPOS). Notably, all new stations added to the EPN in 2024 also joined EPOS, and 87% of all EPN stations now share data with EPOS.

Following the release of ETRF2020 (Altamimi and Collilieux , 2024), the online ETRF/ITRF Coordinate Transformation Tool (ECTT, https://epncb.oma.be/_productsservices/coord_trans/) was updated to include transformations to and from ETRF2020.

The number of EPN stations providing real-time data decreased in 2024. During the last quarter of 2024, the majority of Finish EPN stations stopped providing real-time data to the EPN due to a change in national data policy. By the end of 2024, 208 EPN stations were providing real-time data, with an additional nine stations experiencing extended outages in the past. The EPN Central Bureau monitors the availability and latency of the real-time data streams at the three EPN broadcasters. Detailed status updates are available from https://epncb.oma.be/_networkdata/data_access/real_time/status.php while metadata monitoring can be accessed at https://epncb.oma.be/_networkdata/data_access/real_time/metadata_monitoring.php. A total of 217 data streams are monitored operationally, with 93% of the real-time data available across all three EPN casters: ASI, BKG, and ROB. Additionally, the EPN real-time products SSRA02IGS0_EUREF and SSRA03IGS0_EUREF, along with the broadcast ephemerides BCEP00BKG0, are accessible from the EPN casters.

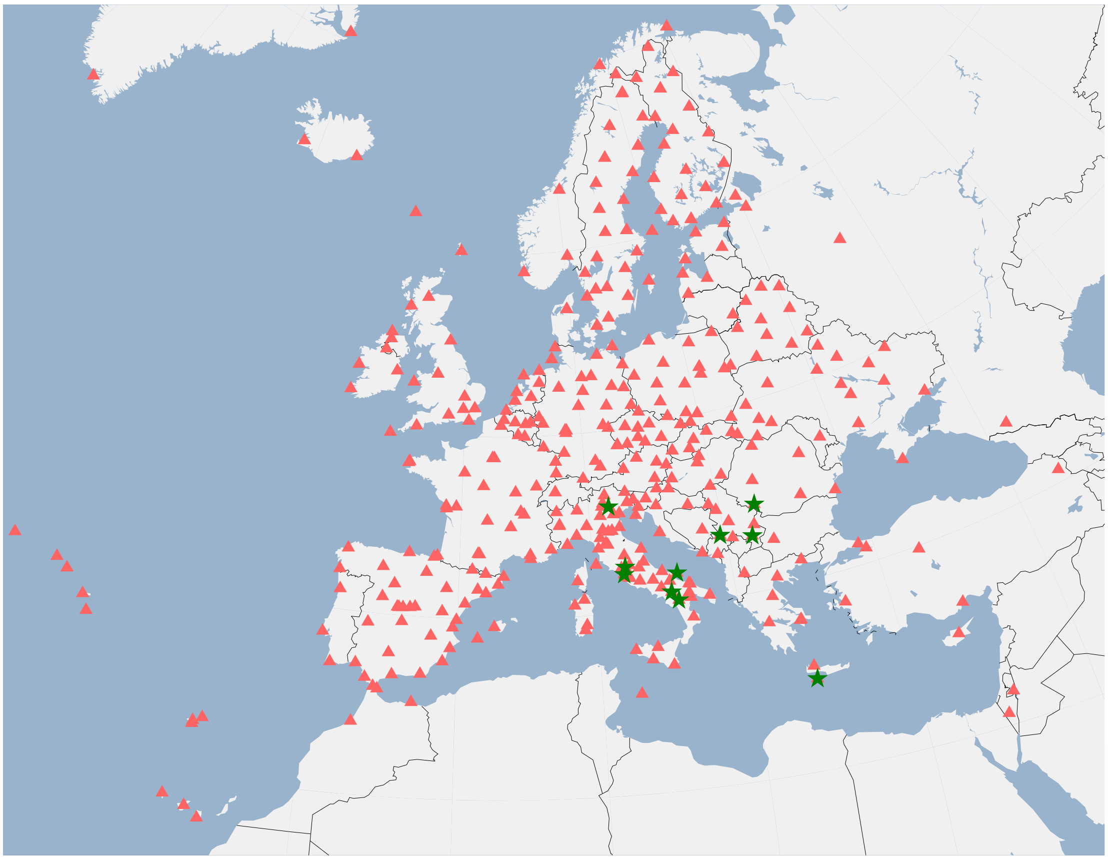

Figure 1: New GNSS stations (in green) integrated in the EPN in 2024.

3 Data Products

3.1 Positions

The EPN Analysis Centres (ACs) operationally process GNSS observations collected at EPN stations. In 2024, all 17 ACs (Table 1) were providing final daily coordinate solutions of their subnetworks. Thirteen ACs were providing also rapid daily solutions, and three ACs were providing near real-time solutions. All AC solutions are combined by the Analysis Centre Coordinator (ACC). Details on the various combinations done by the ACC are given on http://www.epnacc.wat.edu.pl/epnacc/final/. In 2024, all 11 new EPN stations mentioned in section 2 have been included in AC and combined coordinate solutions.

Since June 2024, the EPN combined operational solutions have been based on contributions from all 17 ACs. Previous solutions, from November 2022 to May 2024, were based on 15 AC solutions. The additional operational solutions started to be provided regularly by the RGA AC since March and by the IGN AC since June. Both ACs provided also all their solutions since November 2022. To improve the consistency of the combined solutions, the ACC decided to recombine the earlier AC solutions to include the previously missing solutions. The new combined solutions will also include the updated AC solutions which were provided after the operational combined solutions were released. The updated combined solutions (from November 2022 to May 2024) will be released at the beginning of 2025.

In 2024, the EPN ACC also reviewed the AC solutions submitted for the EPN Reprocessing 3 project (EPN-Repro3). A total of 12 EPN ACs are participating in this project (see Table 1). As of December 2024, 10 ACs have provided solutions covering the entire period from 1996 to 2022. Currently, the ACC is analysing the AC solutions individually. The analysis strategy is the same as in case of operational solutions.

The analysis begins with verifying the correctness of metadata provided in SINEX files. Next, the daily solutions from each AC are stacked in CATREF software (Altamimi et al., 2007) into a multi-year solution to evaluate the quality of station position time series. During this step, residual station position time series are inspected, and outliers are removed. Based on the cleaned AC daily solutions, the EPN-Repro3 combined solutions will be generated and are expected to be released in the first half of 2025.

3.2 Troposphere

The EPN Analysis Centres (ACs) operationally submit Zenith Total Delay (ZTD) parameters and horizontal gradients in SINEX_TRO v2.0 format collected at EPN stations. In 2024, 17 ACs were providing final daily troposphere solutions of their subnetworks. Ten ACs were providing also rapid troposphere solutions. In 2024, 7 new EPN stations have been included in individual and combined troposphere solutions.

For each combined EPN station Integrated Water Vapour (IWV) is provided along with ZTD. Tropospheric products are disseminated only in SINEX_TRO v2.0 format and are available in the EUREF product directory at the BKG and BEV data centres.

https://epncb.oma.be/_productsservices/troposphere/mean_zpd_biases.php shows for each AC the weekly mean bias (top) and the related standard deviation (bottom) of its solutions with respect to the combined solution. The time series are based on EPN-Repro2 solutions (GPS week 834 until 1824) and on operational solutions in IGS14 standards until GPS week 2237 and IGS20 standards afterwards. Gross errors (i.e. ZPD with formal standard deviation > 15 mm) and outliers, detected during the combination process, are removed thus not affecting the combined value.

Ten EPN ACs are delivering rapid troposphere estimates obtained as a by-product of the rapid site position processing. These rapid solutions are the input for a rapid operational troposphere combination available with a latency of 22 hours after the end of observations

Table 1: EPN Analysis Centres characteristics: provided solutions (W – final weekly, D – final daily, R – rapid daily, N – near real-time, E03 – repro3), the number of analysed GNSS stations (in brackets: number of stations added/excluded in 2024), used software (BSW – Bernese GNSS Software, GG – GAMIT/GLOBK), used GNSS observations (G – GPS, R – GLONASS, E – Galileo).

AC	Analysis Centre Description	Solutions	# sites	Software	GNSS
ASI	Centro di Geodesia Spaziale G. Colombo, Italy	W,D,R,N,	120 (10/1)	GipsyX-2.1	GRE
BEK	Bavarian Academy of Sciences & Humanities, Germany	W,D,R,E03	141 (7/1)	BSW 5.4	GRE
BEV	Federal Office of Metrology and Surveying, Austria	W,D	174 (0/3)	BSW 5.4	GRE
BKG	Bundesamt für Kartographie und Geodäsie, Germany	W,D,R,E03	156 (2/1)	BSW 5.4	GRE
COD	Center for Orbit Determination in Europe, Switzerland	W,D	39 (0/0)	BSW 5.5	GRE
GFZ	GeoForschungsZentrum, Germany	W,D,E03	112 (0/2)	EPOS.P8	GRE
IGE	Instituto Geografico Nacional, Spain	W,D,R,E03	98 (0/2)	BSW 5.4	GRE
IGN	Institut Géographique National de L'information Geographique et Forestiére, France	W,D,E03	61 (0/1)	BSW 5.4	GRE
LPT	Federal Office of Topography swisstopo, Switzerland	W,D,R,N	60 (1/0)	BSW 5.5	GRE
MUT	Military University of Technology, Poland	D,R,E03	157 (0/2)	GG 10.71	GE
NKG	Nordic Geodetic Commission, Lantmateriet, Sweden	W,D,R,E03	108 (1/0)	BSW 5.4	GRE
RGA	Republic Geodetic Authority, Serbia	W,D	71 (3/0)	BSW 5.4	GRE
ROB	Royal Observatory of Belgium, Belgium	D,R,E03	112 (0/2)	BSW 5.4	GRE
SGO	Lechner Knowledge Center, Hungary	W,D,R,E03	67 (3/0)	BSW 5.4	GRE
SUT	Slovak University of Technology, Slovakia	D,R,N,E03	94 (0/0)	BSW 5.4	GRE
UPA	University of Padova, Italy	W,D,R,E03	116 (6/4)	BSW 5.4	GRE
WUT	Warsaw University of Technology, Poland	W,D,R,E03	154 (1/3)	BSW 5.4	GRE

of the analysed day. Because of the distributed processing of the EPN stations, about 200 stations are included in the rapid combination available in SINEX_TRO v2.0 format in the EUREF product directory at the BKG and BEV data centres. On a weekly basis the agreement between the final and rapid combination is in the range of $[1; 2\,]mm$ for the standard deviation and $[-3; 0\,]mm$ for the bias.

The EPN multi-year tropospheric solution has been updated up to GPS week 2295 and covers the period 1996-12/2023. For each EPN station, ZTD time series, ZTD monthly mean and inter-technique comparison with radiosonde data (if collocated) plots are available at the EPN CB from https://www.epncb.oma.be/_productsservices/troposphere/. The radiosonde data used are provided by EUMETNET in the framework of the MoU in place between EUMETNET and EUREF. Being based on EPN-Repro2 and operational products and due to the transition to IGS20 standards occurred on November 27$^{\text{th}}$, 2022 this time series is not homogeneous and it will be replaced in the near future by EPN-Repro3 products.

3.3 Reference Frame

To maintain the ETRS89, EUREF updates the multi-year positions/velocities of the EPN stations every 15 weeks in the latest ITRS/ETRS89 realizations. These EPN multi-year solutions are computed by the Reference Frame Coordinator (RFC) using the CATREF software (Altamimi et al., 2007). Exceptionally since the transition to IGS20, the last official EUREF Reference Frame Product was not updated anymore since January 2024 (C2235, `https://doi.org/10.24414/ROB-EUREF-C2235`).

To bridge the gap while awaiting the EPN-Repro3 daily SINEX files needed for generating a new official reference frame product in IGS20, a temporary hybrid reference frame solution was developed. This hybrid solution, aligned with IGS20, provides only updated station positions from November 2022 onward.

The hybrid solution combines daily solutions from EPN-Repro2 (`IGS14/igs14.atx`) and operational EPN solutions (`IGS20/igs20.atx`). It includes revised position and velocity discontinuities aligned with the IGS/ITRF list and incorporates ITRF2020 post-seismic deformation models for ISTA00TUR, REYK00ISL, and TUBI00TUR (ITRF2020 PSD models `https://itrf.ign.fr/ftp/pub/itrf/itrf2020/ITRF2020-psd-gnss.snx`).

Presented at the EUREF Symposium in June 2024, the hybrid solution covers 492 stations, adding velocities for 47 stations and positions for 37 new stations compared to C2235. For 101 stations, a discontinuity was introduced at GPS week 2238 due to the switch to `IGS20/epn20.atx`. 21 stations were affected by an additional discontinuity after the switch.

The temporary hybrid solution and the updated time series, generated daily with 2-day delay, are available online: `https://epncb.oma.be/_productsservices/coordinates/hybrid.php` and `https://epncb.oma.be/_productsservices/timeseries/hybrid.php?station=ACOR00ESP`. Together with the quality checks provided by the EPN CB, these quick updates enable monitoring the behaviour of the EPN stations and facilitate prompt responses to any problems.

4 Working Groups

4.1 EPN reprocessing

The EPN-Repro3 project achieved significant progress in the past year, with 12 ACs reprocessing EPN data from EPN dating back to 1996. The project ensures all EPN products are aligned with the IGS20 reference frame, complementing current operational solutions. This uniformity will create consistent position time series that improve the realization of the ETRS89. Each AC is responsible for processing a subnetwork of EPN stations, which vary in size from 60 to 150 stations, contributing to the reprocessing of 27 years of data. Although mostly automated, final checks are required to address outliers and recalculations. By late 2024, over 80% of the data had been processed, with the remaining tasks close to completion. Further steps include the daily combination of sub-networks by the EUREF ACC and finally, based on this work, a multi-year position and velocity solution will be computed by EUREF RFC. This final product is expected in the course of 2025. Additionally, the EUREF Troposphere Coordinator will integrate recalculated tropospheric data starting from 1996, offering valuable resources for meteorological validation. Despite its complexity and being conducted alongside routine operations, EPN-Repro3 will significantly enhance ETRS realization and tropospheric data utility.

4.2 EPN Densification

EPN Densification (EPND) is a collaborative effort involving 30 European GNSS Analysis Centres. These centres provide daily or weekly station position estimates for dense national and regional GNSS networks in SINEX format (Kenyeres et al, 2019). The estimates are cross-checked and combined into one homogenized set of weekly SINEX series, which are subsequently adjusted using the CATREF software to produce a European-scale station position and velocity product. The most recent combination, D2237, was published in 2023. It is expressed in the IGS14 reference frame and includes weekly SINEX solutions spanning GPS weeks 1500 to 2237. Detailed information about this combination can be found at the EPN Densification product portal (https://epnd.sgo-penc.hu). Since the release of D2237, no new combinations have been performed. The continuation of EPND is closely tied to the progress of EPN-Repro3 reprocessing effort, both at the EPN and national levels. This reprocessing represents a monumental task, unprecedented in its scope, and its completion is not anticipated before Q3 2025. In the meantime, work is underway on an additional combination based on the last IGS14 solution. This effort integrates the network of 1900 EPOS stations processed by UGA (Université Grenobles Alpes) with EPND national networks, resulting in a more comprehensive and extended solution. Notably, the extension incorporates the UK network included in the EPOS solution. The new combination, encompassing over 3,600 stations, will also be expressed in ETRF2020. A new EPND combination will not be expected before Q4 2025.

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Part III

Data Centers

Infrastructure Committee Technical Report 2024

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1 Introduction

The IGS Infrastructure Committee (IC) is a permanent body established to ensure that the data requirements for the highest quality GNSS products are fully satisfied while also anticipating future needs and evolving circumstances. Its principal objective is to ensure that the IGS infrastructure components which collect and distribute the IGS tracking data and information are sustained to meet the needs of main stakeholders, in particular the IGS Analysis Centres, fundamental product coordinators, pilot projects, and working groups.

The IC fulfils this objective by coordinating and overseeing facets of the IGS organisation involved in the collection and distribution of GNSS observational data and information, including network stations and their configurations (instrumentation, monumentation, communications, etc.), and data flow. The IC establishes policies and guidelines, where appropriate, working in close collaboration with all IGS components, as well as with the various agencies that operate GNSS tracking networks. The IC interacts with International Association of Geodesy (IAG) sister services and projects — including the International Earth Rotation and Reference Systems Service (IERS) and the Global Geodetic Observing System (GGOS) -– and with other external groups (such as the RTCM) to synchronise with the global, multi-technique geodetic infrastructure.

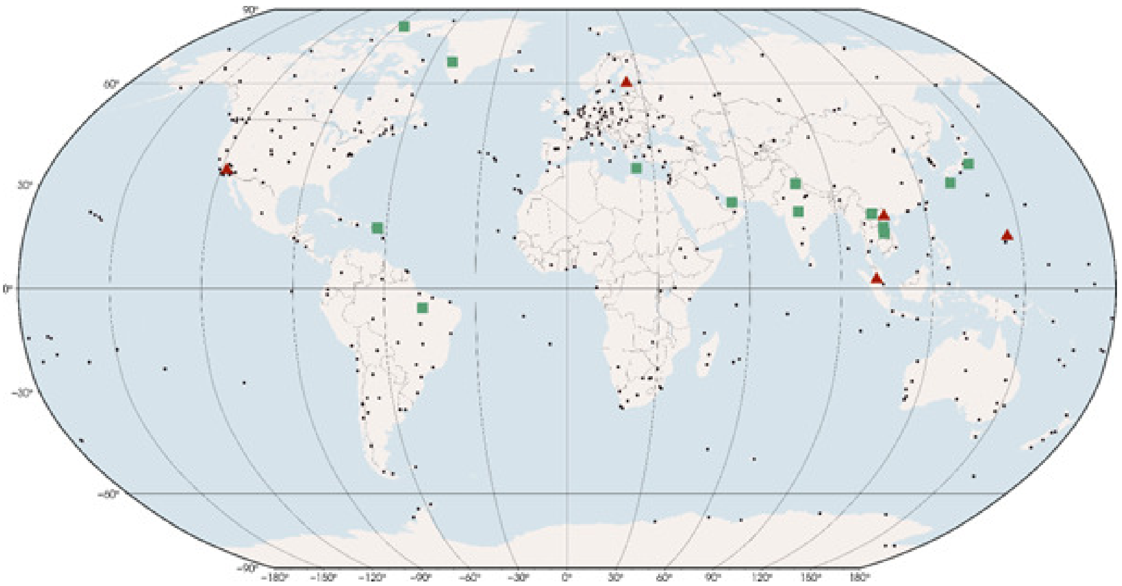

Figure 1: Map of the IGS Network in 2024; newly added stations highlighted in green, decommissioned stations highlighted in red

2 Members

The Committee is composed of the leadership (2), ex-officio members (11), who hold active roles in other IGS Working Groups, representative members nominated and accepted by ex-officio members (3), and a representative from each of the active global data centres[1] (6).

As of December 31, 2024, the Committee has a total of 22 active members. The IGS Infrastructure Committee is open to all Associate Members who have an interest in the sustainment and enhancement of the IGS Infrastructure. Non-Appointed members do not have voting rights but are encouraged to actively participate in the Committee.

3 Advancements to the IGS Network in 2024

Throughout 2024, the IC actively assisted the Network Coordinator in responding to inquiries from IGS product and data users. The Station Proposal Committee added 14 multi-GNSS stations to the network and removed 5 stations by request of the station operators. Figure 1 highlights the newly added and decommissioned stations in a global map, details for each station can be found in Table 1.

[1] CDDIS, IGN, ESA, WHU, KASI, SIO

Table 1: List of approved and decommissioned Stations in the IGS Network in 2024

Station	Location	Systems	Real-Time	Agency
Approved Stations (14):				
BHPL00IND	Bhopal, India	GRECJIS	No	ISRO
BNEU00LAO	Booneua, Laos	GREC	No	DOL
DRND00IND	Dehradun, India	GRECJIS	No	ISRO
DUBI00ARE	Dubai, United Arab Emirates	GREC	Yes	DM
EUR200CAN	Eureka, Canada	GREC	Yes	NRCan
GMSD00JPN	Nakatane Town, Japan	GRECJ	Yes	JAXA
GVDG00GRC	Gavdos Island, Greece	GRECIS	No	CNES
IMPZ00BRA	Imperatriz, Brazil	GRECS	Yes	IBGE
KLSQ00GRL	Kangerlussuaq, Greenland	GRECJ	No	DTU
NKAY00LAO	Nakai, Laos	GREC	No	DOL
SABY00BES	Zions Hill, Saba	GRECS	Yes	KNMI
SEUS00BES	Oranjestad, Sint Eustatius	GRECS	Yes	KNMI
TKBG00JPN	Tsukuba, Japan	GRECJS	Yes	JAXA
TOAY00LAO	Ta Oy, Laos	GREC	No	DOL
Decommissioned Stations (5):				
ANMG00MYS	Putrajaya, Malaysia	GRECJ	-	JAXA
CHIL00USA	San Gabriel Mountains, USA	GR	-	USGS
CNMR00USA	Saipan, USA	GRE	-	NGS
JNAV00VNM	Hanoi, Vietnam	GRECJ	-	JAXA
METS00FIN	Kirkkonummi, Finland	G	-	FGI

Legend for system IDs
G: GPS, R: GLONASS, E: Galileo, C: BeiDou, J: QZSS, I: IRNSS/NavIC, S: SBAS

4 2024 Activities: Review and Outlook

The Infrastructure Committee (IC) has developed a comprehensive program for the 2024 IGS Workshop, held in Bern, Switzerland. As part of this program, Session 1: “GNSS Standards and Infrastructure” featured eight oral presentations covering a diverse range of topics. These included FAIR GNSS metadata principles, Low Earth Orbit Positioning, Navigation, and Timing (LEO-PNT), advancements in digital platforms, as well as innovative software tools for RINEX pre-processing and quality assessment. During the accompanying splinter session, IC members engaged in in-depth discussions on emerging topics and key challenges in GNSS standardization and infrastructure. These discussions fostered collaboration and set the stage for future developments in the field.

Building on the outcomes of the workshop, the IC is actively working towards implementing the recommendations derived from the 2024 IGS Workshop. A summary of these recommendations is provided below.

1. Encourage IGS station operators to track NavIC for stations within the footprint and analysis centers to analyze the data.

2. Develop a policy for the inclusion and exclusion of stations.
3. Contribute to the GGOS Data and Information System Committee to ensure the improvement of FAIR GNSS data and metadata.
4. Develop an extensible way to categorize stations by their use for the community.
5. Harmonize the code lists within the IGS station metadata.
6. Establish a task force on exploring cloud native storage formats.
7. Develop a charter for IGS data centers.
8. Inclusion of more active members of the IC.

The Infrastructure Committee (IC) is committed to expanding the global reach of the IGS by increasing the number of Multi-GNSS and Real-Time stations through targeted outreach efforts. To address existing gaps in coverage, we are prioritizing regions with limited representation, such as Africa, Oceania, and the Middle East. Our strategy involves building partnerships with local station operators and providing tailored support to enhance their capacity and capabilities. As part of this initiative, we will be participating in the upcoming FIG Working Week [2] in Brisbane, Australia, where we aim to forge connections with regional stakeholders, promote the benefits of IGS infrastructure, and encourage new collaborations.

In 2023, we published the "Guidelines for Continuously Operating Reference Stations in the IGS"[3] , a comprehensive resource designed to support station owners and operators in planning, establishing, and maintaining CORS. As part of our commitment to inclusion, diversity, equity, and accessibility (IDEA), we have made these Guidelines accessible to a broader audience by translating them into multiple languages, including French, Spanish, and German. These translations are now available as web-based documentation on a dedicated server, currently hosted by GFZ. Additionally, a Chinese translation is currently in progress, further expanding the reach of this valuable resource. Building on this effort, our next step is to develop clear policies governing the inclusion and exclusion process for stations in the IGS network, aiming to enhance quality, consistency, and user experience.

The GeodesyML task team has transitioned to its new home within the GGOS Committee on Data and Information Systems[4] , marking an exciting new chapter in its evolution. This strategic move enables the team to broaden its scope, supporting multiple geodetic techniques and driving innovation through the development of a next-generation, JSON-LD based schema that will ultimately replace the current XML-based framework. Furthermore, task team members are also lending their expertise to the GGOS Working Group

[2] https://www.fig.net/fig2025/
[3] https://files.igs.org/pub/resource/guidelines/Guidelines_for_Continuously_Operating_Reference_Stations_in_the_IGS_v1.0.pdf
[4] https://ggos.org/about/org/bureau/bno/cwg/data-information-systems/

on Digital Object Identifiers (DOIs) for Geodetic Data Sets[5], fostering collaboration and advancing data management best practices across the geodetic community.

In 2024, the committee successfully finalized the migration to IGS Site Log Version 2.0. This upgrade enabled the integration of ISO-3166 Alpha-3 codes for more precise geographic descriptions. Additionally, it allowed us to retire the outdated 4-character station IDs and adopt more unique and descriptive 9-character station IDs.

Additionally, members of the IC aim to explore cloud-based alternatives to RINEX as the storage and access format for GNSS data. Several prototypes utilising TileDB[6] have been developed. However, further feasibility studies and benchmark tests are required to evaluate the practicality and performance of TileDB in an operational environment. This initiative reflects the ongoing efforts to enhance and optimise data storage and access methods in the GNSS community. A dedicated task force will provide further guidance.

Building on our efforts to standardize naming conventions, we published the "Guidelines for Long Product Filenames in the IGS v2.1"[7] in 2024. We are already working on the next iteration, with Version 2.2 currently in development. This upcoming release will introduce an important enhancement: an expanded solution type identifier that includes support for predicted products.

We are committed to advancing the concept of a "Global Archive" by developing a comprehensive framework that addresses key challenges and opportunities. Our approach will involve three main stages:

1. Formulating a detailed concept for the Global Archive
2. Compiling requirements from various stakeholders
3. Conducting a thorough feasibility analysis

Our primary focus will be on tackling critical aspects such as:

- Data storage and access
- Metadata collection and management
- Quality checks and assurance
- Security standards and protocols
- Synchronization methods between data centres (or the lack thereof)

However, our scope extends beyond data centres to encompass Information Security in its entirety. We recognize that this crucial aspect is often underappreciated, despite its

[5] https://ggos.org/about/org/co/dois-geodetic-data-sets
[6] https://tiledb.com/
[7] https://files.igs.org/pub/resource/guidelines/Guidelines_For_Long_Product_Filenames_in_the_IGS_v2.1.pdf

far-reaching implications for every component of the IGS, from receiver infrastructure to analysis and data centres. To address this knowledge gap, we plan to create promotional materials that highlight the importance of Information Security across all facets of the IGS. By raising awareness and promoting best practices, we aim to foster a culture of security and resilience within our community.

Acronyms

BKG	Bundesamt für Kartographie und Geodäsie
CDDIS	Crustal Dynamics Data Information System
CNES	Centre National d'Etudes Spatiales
DM	Dubai Municipality
DOL	Department of Lands of Laos
DTU	DTU Space Denmark
ESA	European Space Agency
FGI	National Land Survey of Finland
GA	Geoscience Australia
GFZ	GFZ Helmholtz Centre for Geosciences
GNS	GNS Science New Zealand
IBGE	Instituto Brasileiro de Geografia e Estatística
IGN	Institut national de l'information géographique et forestière
ISRO	Indian Space Research Organisation
JAXA	Japan Aerospace Exploration Agency
KASI	Korea Astronomy and Space Science Institute
KNMI	Kadaster and Royal Netherlands Meteorological Institute
NGS	NOAA-National Geodetic Survey
NRCan	Natural Resources Canada
SIO	Scripps Institution of Oceanography
USGS	United States Geological Survey
WHU	Wuhan University

CDDIS Global Data Center Technical Report 2024

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1 Introduction

The Crustal Dynamics Data Information System (CDDIS) is one of NASA's Earth Observing System Data and Information System (EOSDIS) Distributed Active Archive Centers (DAACs) (see https://earthdata.nasa.gov). CDDIS supports the international space geodesy community. For over 40 years, CDDIS has provided continuous, long-term, public access to Global Navigation Satellite System (GNSS), Satellite Laser Ranging (SLR), Very Long Baseline Interferometry (VLBI), and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) data and derived products required for a diverse variety of scientific studies, including the determination of a global terrestrial reference frame, and geodetic studies in plate tectonics, earthquake displacements, volcano monitoring, Earth orientation, and atmospheric angular momentum, among others. EOSDIS DAACs serve a diverse user community and are tasked to provide facilities that enable the discovery and access of science data and products. CDDIS is also a regular member of the International Council for Science (ICSU) World Data System (WDS, https://www.icsu-wds.org) and the Earth Science Information Partners (ESIP, https://www.esipfed.org).

CDDIS is funded by NASA but cooperates extensively with the international community in support of Earth science research. CDDIS serves as one of the primary data centers and core components for the geodetic services established under the International Association of Geodesy (IAG). In particular, the system has supported the International GNSS Service (IGS) as a global data center since 1992. CDDIS activities within the IGS during 2024 are summarized below. This report also includes any recent changes or enhancements made to CDDIS.

2 Archive Contents

As a global data center for the IGS, CDDIS is responsible for archiving and providing access to GNSS data from the global IGS network, as well as the products derived from the analyses of these data in support of both operational and working group/pilot project activities. CDDIS archive is approximately 106 TBytes in size (over 417 million files) of which nearly 90 % (88 TBytes) is devoted to GNSS data and GNSS products. All these GNSS data and derived products are accessible through subdirectories at https://cddis.nasa.gov/archive/gnss.

CDDIS archive of IGS data and products are globally accessible through secure ftp (FTPS/FTP-SSL, address: ftp://gdc.cddis.eosdis.nasa.gov) and through web-based archive access (https://cddis.nasa.gov/archive). CDDIS is located at NASA's Goddard Space Flight Center in Greenbelt, Maryland, and is available to users 24 hours per day, seven days per week.

2.1 GNSS Data

2.1.1 Main Data Archive

The user community has access to GNSS data and derived products available through the on-line global data center archives of the IGS. Nearly 50 operational and regional IGS data centers and station operators make data available in RINEX format to CDDIS from receivers on a daily, hourly, and sub-hourly basis. CDDIS also accesses the archives of other IGS global data centers (GDCs) to retrieve (or receive) data holdings not routinely transmitted to CDDIS by an operational or regional data center. However, this is not a formal mirroring of the other GDCs, and as such it is possible that GDCs are not in a one-for-one agreement on holdings. Table 1 summarizes the types of IGS GNSS data sets available at CDDIS in the operational, non-campaign directories of the GNSS archive.

The main GNSS data archive (https://cddis.nasa.gov/archive/gnss/data) at CDDIS contains GPS and GPS+GLONASS data in RINEX V2 format and multi-GNSS data in RINEX V3 and RINEX V4 formats. Since January 2016, RINEX V3 data, and since May 2022, RINEX V4 data, using the V3 "long" filename specification, have been made available here along with the RINEX V2 data. The availability of RINEX V3 data into the operational, main archives at the IGS GDCs (and detailed in the "RINEX V3 Transition Plan") addressed a key recommendation from the IGS 2014 Workshop: "one network one archive" and provided for the better integration of multi-GNSS data into the entire IGS infrastructure. Starting in 2015, stations began submitting RINEX V3 data using the format's "long" filename specification. The transition plan specified that RINEX V3 data from IGS network sites using the V3 filename structure should be archived in the same directories as the RINEX V2 data. Therefore, starting on January 1, 2016, all daily, hourly, and high-rate data submitted to CDDIS in RINEX V3 format and using the long,

Table 1: GNSS Data Type Summary

Data type	Sampling Rate	Data Format	Available On-line
Daily GNSS	30 sec.	RINEX V2	Since 1992
Daily GNSS	30 sec.	RINEX V3	Since 2016
Daily GNSS	30 sec.	RINEX V4	Since 2022
Hourly GNSS	30 sec.	RINEX V2	Since 2005
Hourly GNSS	30 sec.	RINEX V3	Since 2016
Hourly GNSS	30 sec.	RINEX V4	Since 2022
High-rate GNSS	1 sec.	RINEX V2	Since 2001
High-rate GNSS	1 sec.	RINEX V3	Since 2016
High-rate GNSS	1 sec.	RINEX V4	Since 2022
Satellite GPS	10 sec.	RINEX V2	2002-2012

V3 filename specification have been archived in the same directories as the RINEX V2 data (which use the 8.3.Z filename for daily and hourly files and the 10.3.Z filename format for high-rate files). In late 2021, the RINEX 4.00 format, which follows the V3 “long” filename specification, was officially accepted by the IGS Governing Board. The Infrastructure Committee developed a transition plan for the new format. More information on this transition plan is available in IGSMAIL #8207 sent in May 2022. In addition, these RINEX V3 and RINEX V4 files are compressed in gzip (.gz) format; files in RINEX V2 format now use gzip (.gz) as of 1 December 2020. These data in RINEX V3 and RINEX V4 formats include all available multi-GNSS signals (e.g., Galileo, QZSS, SBAS, BeiDou, and IRNSS) in addition to GPS and GLONASS.

CDDIS archives three major types/formats of GNSS data, daily, hourly, and high-rate sub-hourly, all in RINEX format, as described in Table 1. Nearly 234K daily station days from 563 distinct GNSS receivers were archived at CDDIS during 2024 of these sites, 155 sites supplied both RINEX V2 and V3 data (see Table 2), and 5.5K daily station days from 5 GNSS receivers were archived in RINEX V4 format. A complete list of daily, hourly, and high-rate sites archived in CDDIS can be found in the yearly summary reports at URL `https://cddis.nasa.gov/archive/reports/gnss`. All incoming files for CDDIS archive are now checked for conformance to basic rules, such as valid file type, non-empty file, correct compression usage, consistency between filename and contents, correct file naming convention usage, and other logic checks. After incoming files pass these initial checks, content metadata are extracted and the files undergo further processing based on data type and format.

Daily RINEX V2 data are quality-checked, summarized (using UNAVCO’s teqc software), and archived to public disk areas in subdirectories by year, day, and file type; the summary and inventory information are also loaded into an on-line database. However, this data quality information, generated for data holdings in RINEX V2 format, is not available

Table 2: GNSS Data Archive Summary for 2024

Data Type	Number of sites					Vol.	# files	Directory
	V2	V3	V2+V3	V4	Unique			
Daily	275	445	155	5	563	1813 GB	1.1 M	`/gnss/data/daily`
Hourly	166	368	131	3	410	734 GB	14.2 M	`/gnss/data/hourly`
High-rate	117	318	108	4	328	21.3 TB	34.7 M	`/gnss/data/highrate`

through the software used by CDDIS to summarize data in RINEX V3 or RINEX V4 format. CDDIS continues to investigate and evaluate software capable of providing data summary/quality control (QC) information for RINEX V3 and RINEX V4 data.

Within minutes of receipt (typically less than 30 seconds), the hourly GNSS files are archived to subdirectories by year, day, and hour. Although these data are retained on-line, the daily files delivered at the end of the UTC day contain all data from these hourly files and thus can be used in lieu of the individual hourly files.

2.1.2 Broadcast Navigation Files

CDDIS generates global RINEX V2 broadcast ephemeris files (for both GPS and GLONASS) on a daily and hourly basis. The hourly concatenated broadcast ephemeris files are derived from the site-specific ephemeris data files for each hour and are appended to a single file that contains the orbit information for all GPS and GLONASS satellites for the day up through that hour. The merged ephemeris data files, named `hourDDD0.YYn.gz`, are then copied to the day's subdirectory within the hourly data file system. Within 1-2 hours after the end of the UTC day, after sufficient station-specific navigation files have been submitted, this concatenation procedure is repeated to create the daily broadcast ephemeris files (both GPS and GLONASS), using daily site-specific navigation files as input. These daily RINEX V2 broadcast ephemeris files, named `brdcDDD0.YYn.gz` and `brdcDDD0.YYg.gz`, are then copied to the corresponding year/day nav file subdirectory as well as the yearly brdc subdirectory (`/gnss/data/daily/YYYY/brdc`).

CDDIS also generates daily RINEX V3 concatenated broadcast ephemeris files. The files are archived in the yearly brdc subdirectory (https://cddis.nasa.gov/archive/gnss/data/daily/YYYY/brdc) with a filename of the form `BRDC00IGS_R_YYYYDDDHHMM_01D_MN.rnx.gz`. The procedure for generating these files, using the software provided by the chair of the IGS Infrastructure Committee, is similar to the V2 procedure in that site-specific, mixed V3 ephemeris data files are merged into to a single file that contains the orbit information for all GNSS satellites for the day. Users can thus download these single, daily (or hourly) files (in both RINEX V2 and V3 formats) to obtain unique navigation messages, rather than downloading multiple broadcast ephemeris files from the individual stations.

Beginning in 2022, the TUM/DLR team began providing to CDDIS a daily RINEX V4 broadcast ephemeris file. These files are archived in the yearly brdc subdirectory (https://cddis.nasa.gov/archive/gnss/data/daily/YYYY/brdc) with a filename of the form `BRD400DLR_S_YYYYDDHHMM_01D_MN.rnx.gz`.

CDDIS also archives a merged, multi-GNSS broadcast ephemeris file containing GPS, GLONASS, Galileo, BeiDou, QZSS, and SBAS ephemerides. This file, generate by colleagues at the Technical University in Munich (TUM) and Deutsches Zentrum für Luft- und Raumfahrt (DLR) from real-time streams, contains all the unique broadcast navigation messages for the day. The file, named `BRDM00DLR_S_YYYYDDD0000_01D_MN.rnx.gz`, is stored in daily subdirectories within the archive (`/gnss/data//daily/YYYY/DDD/YYp`) and in a yearly top level subdirectory (`/gnss/data/daily/YYYY/brdc`).

Creation of the merged GPS/QZSS LNAV and CNAV navigation file generated from real-time streams with the naming convention `BRDX00DLR_S_YYYYDDDHHMM_01D_MN.rnx.gz` ceased at the end of 2021. Archival of these files using the RINEX V2 naming convention which were stored in the MGEX campaign directories ended in the summer of 2020.

2.1.3 Supporting Information

CDDIS generates and updates "status" files, (`/gnss/data/daily/YYYY/DDD/YYDDD.status` for RINEX V2 data and `YYDDD.V3status` for RINEX V3 data) that summarize the holdings of daily GNSS data. These status files of CDDIS GNSS data holdings reflect timeliness of the data delivered, as well as statistics on number of data points, cycle slips, and multipath (for RINEX V2 data). The user community can thus view a snapshot of data availability and quality by checking the contents of such a summary file.

2.2 IGS Products

CDDIS routinely archives IGS operational products (daily, rapid, and ultra-rapid orbits and clocks, ERP, and station positions) as well as products generated by IGS working groups and pilot projects (ionosphere, troposphere, real-time, MGEX). Table 3 below summarizes the GNSS products available through CDDIS. CDDIS currently provides online access to all IGS products generated since the start of the IGS Test Campaign in June 1992 in the file system `/gnss/products`; products from GPS+GLONASS data are available through this filesystem. Products derived from GLONASS data only continue to be archived at CDDIS in a directory structure within the file system `/glonass/products`.

CDDIS also continues to archive combined troposphere estimates in directories by year and day of year. Global ionosphere maps of total electron content (TEC) from the IONosphere Map Exchange (IONEX) Associate Analysis Centers (AACs) are also archived in

Table 3: GNSS Product Summary for 2024

Product Type	Number of ACs/AACs	Volume	Directory
Orbits, clocks, ERP positions	14+Combinations	1.9 GB/week	`/gnss/products/WWWW` (GPS, GPS+GLONASS) `/glonass/products/WWWW` (GLONASS only)
Troposphere	Combination	2 MB/day, 735 MB/year	`/gnss/products/troposphere/YYYY`
Ionosphere	7+Combination	15.7 MB/day, 5.8 GB/year	`/gnss/products/ionosphere/YYYY`
MGEX	8	3.1 GB/week	`/gnss/products/WWWW`

Note: `WWWW`=4-digit GPS week number; `YYYY`=4-digit year

subdirectories by year and day of year. Real-time clock comparison products have been archived at CDDIS in support of the IGS Real-Time Pilot Project, and current IGS Real-Time Service, since 2009.

Seven AACs – Center for Orbit Determination in Europe (CODE), GFZ Helmholtz Centre for Geosciences (GFZ), Space Geodesy Team of CNES (GRG), Japanese Aerospace Exploration Agency (JAXA), Shanghai Astronomical Observatory (SHAO), GLONASS Information and Analysis Center (IAC), and International GNSS Monitoring and Assessment System (iGMAS at Wuhan) generated weekly products (orbits, ERP, clocks, and others) in support of MGEX; these AACs now utilize the "long" filename convention for their products. These files are archived at CDDIS by GPS week (`/gnss/products/WWWW`).

Colleagues at DLR and the Chinese Academy of Sciences (CAS) provide a differential code bias (DCB) product for the MGEX campaign. This product is derived from GPS, GLONASS, Galileo, and BeiDou ionosphere-corrected pseudorange differences and is available in the bias Solution Independent Exchange (SINEX) format. DLR has provided quarterly DCB files containing daily and weekly satellite and station biases since 2013 in CDDIS directory `/gnss/products/biases`; CAS provides files on a daily basis. Additional details on the DCB product are available in IGSMail message 6868 sent in February 2015 and message 7173 sent in October 2015. Both products use the RINEX V3 file naming convention.

In late summer 2022, the IGS and the ACs began creating their GNSS products using the RINEX V3 file naming convention. From GPS week 2222 through GPS week 2237, these products were archived in the directory structure `/gnss/products/WWWW/igs20` for testing purposes. Starting with GPS week 2238 (November 27, 2022), CDDIS began archiving these files in the operational subdirectories (`/gnss/products/WWWW`). More information on this file name transition is available in IGSMail messages 8238 sent in July 2022 and 8274 sent in November 2022.

2.3 Real-Time Activities

CDDIS real-time caster has been operational since early 2015 in support of the IGS Real-Time Service (IGS RTS). By the end of 2022, CDDIS caster broadcasts 36 GNSS product and 375 data streams in real-time. The caster runs the NTRIP (Network Transport of RTCM via Internet Protocol) format. A full updated listing of all the streams CDDIS provides can be found at this URL - https://cddis.nasa.gov/Data_and_Derived_Products/Data_caster_streams.html.

CDDIS caster serves as the third primary caster for the IGS RTS, thus providing a more robust topology with redundancy and increased reliability for the service. User registration, however, for all three casters is unique; therefore, current users of the casters located at the IGS/UCAR and BKG are required to register through CDDIS registration process in order to use CDDIS caster. More information about CDDIS caster is available at https://cddis.nasa.gov/Data_and_Derived_Products/Data_caster_description.html.

CDDIS staff updated the caster to provide new 10-character mount point names for both data and derived product streams, as per direction of the IGS Real-Time Working Group (RTWG). The expanded mount point names align with the RINEX V3 naming convention utilized within the IGS to accommodate multi-constellation data. CDDIS caster configuration was also updated to relay data streams from upgraded hardware and improved BKG and Geoscience Australia casters. CDDIS staff also developed scripts to monitor and report GNSS data streams with unusually high mean latencies (greater than 10 seconds).

As stated previously, CDDIS utilizes the EOSDIS Earthdata Login, for authenticating file uploads to its incoming file server. Since the NTRIP-native registration/access software was not compatible with NASA policies, CDDIS developed software to interface the caster and the Earthdata Login within a generic Lightweight Directory Access Protocol (LDAP) framework. Access to CDDIS caster requires that new users complete two actions: 1) an Earthdata Login registration and 2) a CDDIS caster information form, providing the user's email, institution, and details on their planned use of the real-time data. Following completion, the information is submitted to CDDIS staff for the final steps to authorize access to CDDIS caster; this access is typically available to the user within 24 hours.

2.4 Supporting Information

Daily status files of GNSS data holdings, show timeliness of data receipt and statistics on number of data points, cycle slips, and multipath, continue to be generated by CDDIS for RINEX V2 data; status files, with limited information, summarizing RINEX V3 data holdings are also available. These files are archived in the daily GNSS data directories and available through at URL https://cddis.nasa.gov/reports/gnss/status.

Other available ancillary information at CDDIS include daily, weekly, and yearly summaries of IGS tracking data (daily, hourly, and high-rate, in both RINEX V2 and V2

Table 4: GNSS Data Retrieval Summary

Data Type	# of Files	Volume
Daily	131.0 M	187 TB
Highrate	263 M	127 TB
Hourly	624 M	41 TB
Products	59 M	30 GB

formats) archived at CDDIS are generated on a routine basis. These summaries are accessible through the web at URL https://cddis.nasa.gov/reports/gnss. CDDIS also maintains an archive of and indices to IGS Mail, Report, Station, and other IGS-related messages.

3 System Usage

Summarizing the retrieval of GNSS data and products from the online archive in 2024, Table 4 illustrates the number and volume of GNSS files retrieved by the user community during the past year, categorized by type (daily, hourly, high-rate, products). Over 1.5 billion files (over 350 TBytes) were transferred in 2024.

4 Recent Developments

4.1 Updates to Archive Access

CDDIS has a large international user community; over 143K unique hosts accessed the GNSS files in the system in 2024. Today, users access CDDIS archive through encrypted anonymous ftp and https. On 1 November 2020, unencrypted anonymous ftp was terminated at CDDIS as per US government regulations.

Archive access through the https protocol utilizes the same NASA single sign-on system, the EOSDIS Earthdata Login utility, as is used for the file upload and real-time caster user authentication. Before using the https protocol to access CDDIS archive, new users must initially access the webpage, https://cddis.nasa.gov/archive, to establish an account and authorize access; this page will then redirect the user to the Earthdata Login page. Earthdata Login allows users to easily search and access the full breadth of all twelve EOSDIS DAAC archives. Earthdata Login also allows CDDIS staff to know our users better, which will then allow us to improve CDDIS capabilities.

Once an account is established, the user has all permissions required to access CDDIS archive using the https protocol, via a web browser or via a command line interface (e.g., through cURL or Wget) to script and automate file retrieval.

In addition, ftp-ssl access, an extension of ftp using TLS (transport layer security), can be used for scripting downloads from CDDIS archive. The ftp-ssl is the option most similar to standard anonymous ftp. As with https, ftp-ssl will satisfy U.S. Government/NASA requirements for encryption.

Examples on using these protocols, including help with the cURL and Wget commands, are available on CDDIS website; users are encouraged to consult the available documentation at: https://cddis.nasa.gov/About/CDDIS_File_Download_Documentation.html and examples documentation at: https://cddis.nasa.gov/Data_and_Derived_Products/CDDIS_Archive_Access.html. Various presentations on these updates to CDDIS archive access are also available (see Section 6 below and https://cddis.nasa.gov/Publications/Presentations.html).

4.2 Metadata Improvements

CDDIS continues to make modifications to the metadata extracted from incoming data and product files pushed to its archive and implemented these changes in the new file ingest software system. These enhancements have facilitated cross-discipline data discovery by providing information about CDDIS archive holdings to other data portals such as the EOSDIS Earthdata Search client and future integration into the GGOS portal. The staff continues work on a metadata evolution effort, re-designing the metadata extracted from incoming data and adding information that will better support EOSDIS applications such as its search client and the metrics collection effort. CDDIS is also participating in GGOS metadata efforts within the Bureau of Networks and Observations.

CDDIS continues to create and register Digital Object Identifiers (DOIs) to select IGS collections (GNSS data and derived products). DOIs can provide easier access to CDDIS data holdings and allow researchers to cite these data holdings in publications. Landing pages are generated for each of the DOIs created for CDDIS data products and linked to description pages on CDDIS website; an example of a typical DOI description (or landing) page, for daily Hatanaka-compressed GNSS data files, can be viewed at: https:/cddis.nasa.gov/Data_and_Derived_Products/GNSS/daily_gnss_d.html. DOIs have now been assigned to the majority of GNSS data and product sets archived at CDDIS.

4.3 High-rate Archive Modifications

CDDIS staff put forward a recommendation at the 2018 IGS Workshop to consolidate the sub-hourly high-rate data files into a tar archive, one file per site per day. At this time, each site supplies up to 96 files per day; the bundling of the files into a single daily site-specific tar file simplifies downloads for the user as well as streamlines the directory structure at the data centers. In mid-2022, CDDIS enacted these modifications to the high-rate data archive starting with 2001 and working toward the present; the data from the past 6 months will remain in the standard, submitted 15-minute file format.

4.4 Repro3 Support

CDDIS provided support through the upload of files from the ACs and online archive of the IGS repro1 and repro2 campaigns (`/gnss/products/WWWW/repro[1,2]` and `/gnss/products/repro[1,2]/WWWW`). As such, repro3 will be archived similarly. Acceptance of repro3 data up through the end of 2023 concluded in early 2023.

5 Future Plans

5.1 Website Migration

In response to requirements outlined in the 21st Century Integrated Digital Experience Act (IDEA), NASA launched the Web Modernization Project to consolidate the agency's multitude of websites into `nasa.gov` or `science.nasa.gov`. NASA's Earth Science Data Systems (ESDS) Program followed suit and launched the Web Unification Project in December 2021 to migrate all ESDS-funded web properties to earthdata.nasa.gov by the end of 2026.

Beginning in March 2025, updates will take place on the public-facing CDDIS website. These changes will include the migration of the CDDIS website (including `cddis.nasa.gov`) to the Earthdata website (`earthdata.nasa.gov`). By July 2025, all content from the CDDIS website will be migrated over to the Earthdata website.

These changes will only affect the user interface that accessed CDDIS information and web content. The paths for finding and downloading data within the CDDIS archive will not change (located at `https://cddis.nasa.gov/archive`; Earthdata Login required to access). CDDIS will do everything possible to ensure that users have a seamless transition during this migration.

This effort is NASA's approach to improve data discoverability and data findability and build efficient pathways for data users to access data and information from all of NASA's DAACs.

5.2 Real-Time Activities

CDDIS will continue to add real-time data and product streams to its operational caster in support of the IGS RTS. CDDIS continues to review the implementation of software to capture real-time streams for generation of 15-minute high-rate files for archive. This capability requires further testing and coordination with the IGS Infrastructure Committee. CDDIS staff is also performing extensive testing to ensure the newest BKG Professional Caster configuration offers optimal performance given increasing volumes of new NTRIP caster user accounts (248 new user requests in 2024, an increase of 40% from 2022, the most requests CDDIS has had in a single year).

CDDIS staff members continue to investigate the use of DLR's ntripchecker software for updating the caster source table in real-time, maintaining stream record consistency among CDDIS and regional casters.

6 Publications

CDDIS staff attended the 2024 Fall American Geophysical Union (AGU) meeting and presented the following:

J. Woo, T. Yates, C. McLaughlin, and R. Limbacher. Crustal Dynamics Data Information System (CDDIS) contributions to the Global Geodetic Observing System (GGOS), presented at the *2024 Fall AGU Meeting*, Washington, DC, USA, December 2024.

N. Pollack. T41B-3243NASA/CDDIS NTRIP Caster Realtime Differential Global Positioning System, presented at the *2024 Fall AGU Meeting*, Washington, DC, USA, December 2024.

Electronic versions of this and other publications can be accessed through CDDIS online documentation page on the web at URL https:/cddis.nasa.gov/Publications/Presentations.html.

7 Contact Information

To obtain more information about CDDIS IGS archive of data and products, contact:

Rivers Lamb, Email: Rivers.Lamb@nasa.gov
Manager (Interim), CDDIS

Ross Bagwell, Email: Ross.Bagwell@nasa.gov
Deputy Manager, CDDIS

web: https://cddis.nasa.gov
Code 61A
NASA GSFC
Greenbelt, MD 20771
Phone: (301) 614-5370
Fax: (301) 614-6015

General questions on CDDIS, archive contents, and/or help using the system, should be directed to the user support staff at: support-cddis@earthdata.nasa.gov.

8 Acknowledgments

Funding for CDDIS, and its support of the IAG, IGS, and other services, is provided by NASA through the Earth Science Data and Information System (ESDIS) project, which manages the EOSDIS science systems and DAACs. The authors would like to acknowledge the entire CDDIS staff. The success of CDDIS and its recognition in the many international programs supported by the system can be directly attributed to the continued dedicated, consistent, professional, and timely support of its staff.

9 Additional Resources

C. Noll, The Crustal Dynamics Data Information System: A resource to support scientific analysis using space geodesy, *Advances in Space Research*, Volume 45, Issue 12, 15 June 2010, Pages 1421-1440, ISSN 0273-1177, DOI: 10.1016/j.asr.2010.01.018.

C. Noll, Y. Bock, H. Habrich and A. Moore, Development of data infrastructure to support scientific analysis for the International GNSS Service, *Journal of Geodesy*, Feb 2009, pages 309-325, DOI 10.1007/s00190-008-0245-6.

"Access NASA Earth Science Data", from Earthdata website, https://earthdata.nasa.gov.

GSSC Global Data Center Technical Report 2024

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1 Introduction

The GNSS Science Support Centre (GSSC[1]) is the GNSS Science Exploitation Platform provided by ESA's Navigation Science Office to consolidate a GNSS data preservation and exploitation environment in support of IGS and the overall GNSS scientific community.

As an IGS Global Data Center (GDC), the GSSC contributes to GNSS data storage and dissemination, and collaborates with other GDCs such as CDDIS to make lGS data and products available in a free, worldwide manner.

2 GSSC Overview

The GSSC hosts ESA's innovative Digital Platform for GNSS, GSSC Now[2] (see Figure 1), which integrates a large GNSS repository with cutting-edge features for data exploration and analysis. GSSC Now currently runs as a public beta version.

Whereas the original IGS GDC repository still lies at the heart of the GSSC, the content has been expanded to include datasets from supplementary ground networks, relevant scientific services, GNSS receivers on-board spacecrafts and ESA experiments. Public data and products in GSSC archive can be accessed through a traditional approach via anonymous SFTP and HTTPS[3]; nevertheless, the GSSC Now provides powerful features to navigate and refine searches through its vast array of GNSS Datasets[4].

[1] https://gssc.esa.int/
[2] https://gssc.esa.int/portal/
[3] https://gssc.esa.int/activities/ftp-and-web-access-to-gnss-repository/
[4] https://gssc.esa.int/portal/datasets

Furthermore, GSSC Now Datalabs[5] (see Figure 2) provide web-based access to on-demand data analysis and visualisation tools, referred as Datalabs. A Datalab is a software component available for execution on GSSC Now's cloud infrastructure from the user's web browser. Beyond applications natively designed to run on a browser, GSSC Now Datalabs offer the possibility to containerise desktop-based applications as web-based ones. This capability, for example, enables the expansion of GSSC Now Datalabs catalogue with legacy data processing systems, ensuring their long-term preservation.

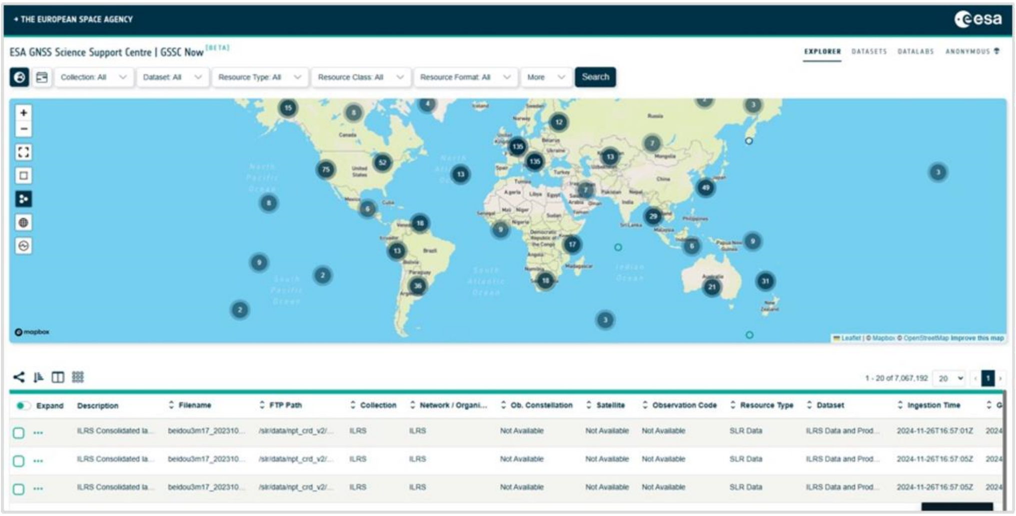

Figure 1: GSSC Now - Explorer View

3 GSSC an Open Door to IGS data: 2024 statistics

The GSSC Archive kept growing in 2024, reaching more than 225 million of IGS assets (data and products) collected not only from other GNSS Global and Regional Data Centers but also from IGS Analysis Centers such as the European Space Agency/ESOC. Most of the data is publicly available to scientific researchers and the overall GNSS community through GSSC Now digital platform, whereas some datasets are under a moderated access policy.

As shown in Figures 3 - 9, the number of accesses to the IGS datasets hosted at GSSC, as well as the download volumes of IGS data and products, keeps growing steadily.

[5] https://gssc.esa.int/portal/datalabs

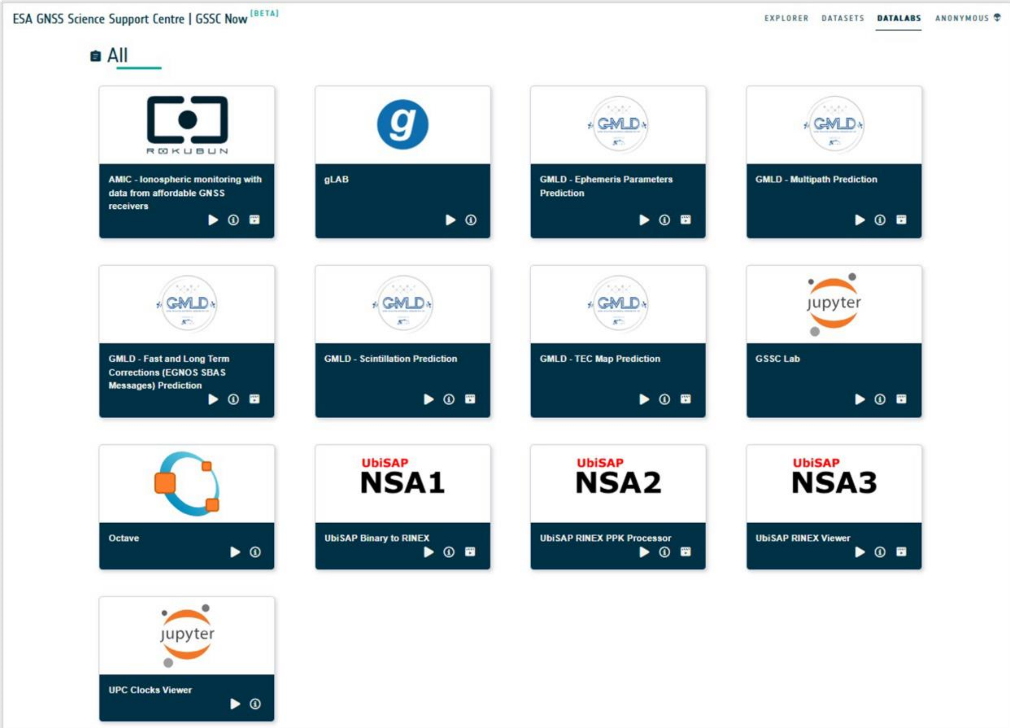

Figure 2: GSSC Now - Datalabs

4 GSSC Key 2024 Highlights

In addition to expanding the GSSC archive, the year 2024 marked significant milestones for the GSSC. Major progress was made on ESA's GNSS Now Digital Platform, highlighted by the release of four new versions of GSSC Now throughout the year. These updates introduced additional datasets, on-data processing tools, performance optimizations, new features, and stability improvements. These accomplishments were made possible through the dedicated efforts and close collaboration of the teams from ESA, GMV, Ideorum, and Starion.

The GSSC also published a featured paper in the *Journal of Advances in Space Research*, contributing valuable insights to the field. Engagement with the GNSS community was strengthened through webinars showcasing GSSC processing capabilities and regular news updates. Furthermore, the GSSC had a strong presence at prominent international forums, including the 30th International GNSS Service (IGS) Workshop in Bern, Switzerland, and the 9th GNSS Science Colloquium in Wroclaw, Poland.

Finally, new collaborative ties were also initiated with educational institutions, industry stakeholders, and research organizations.

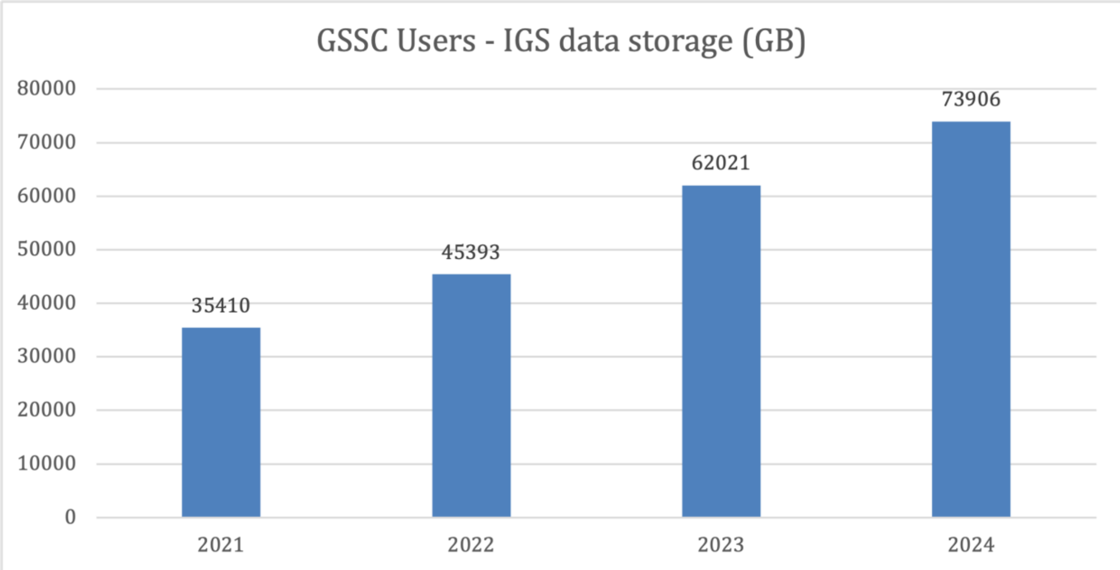

Figure 3: IGS data storage per year

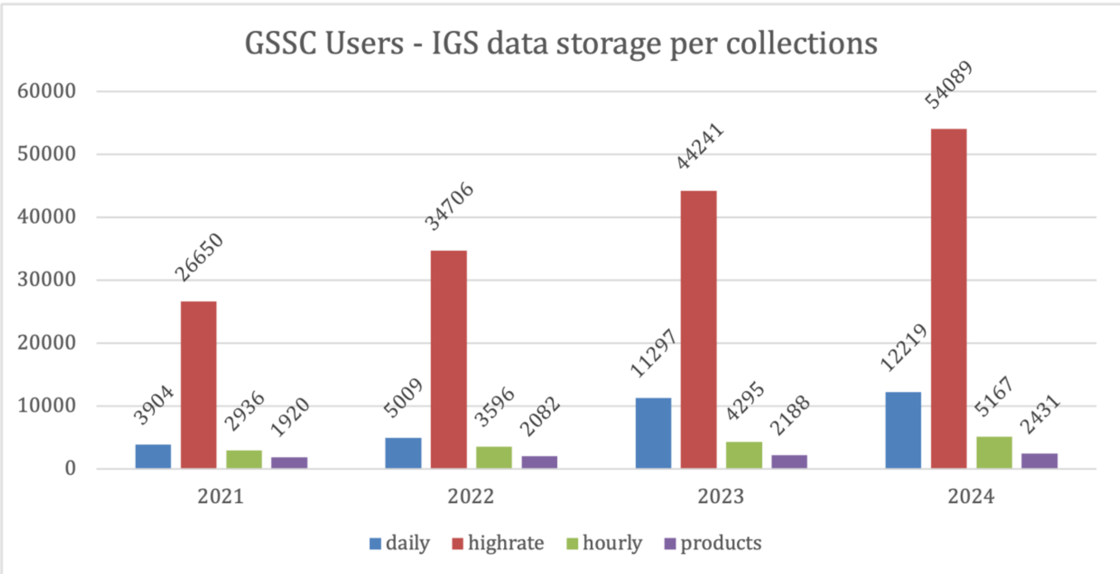

Figure 4: NIGS Data storage per collections

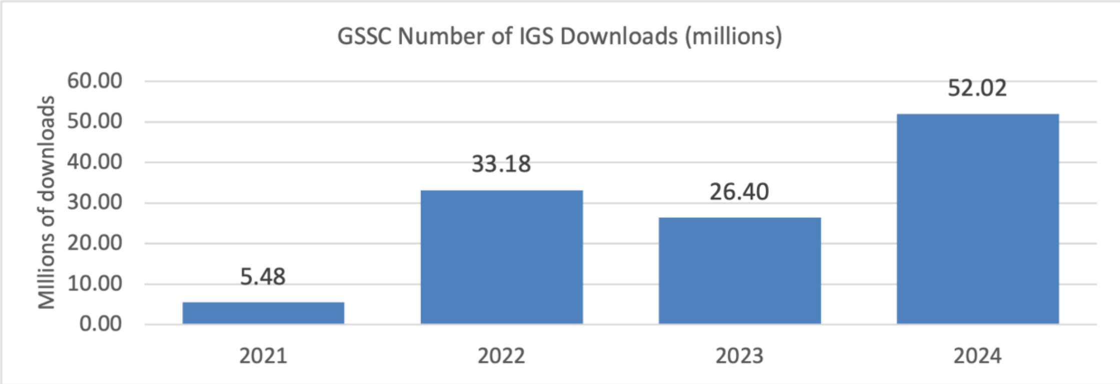

Figure 5: GSSC Number of Downloads of IGS assets in millions

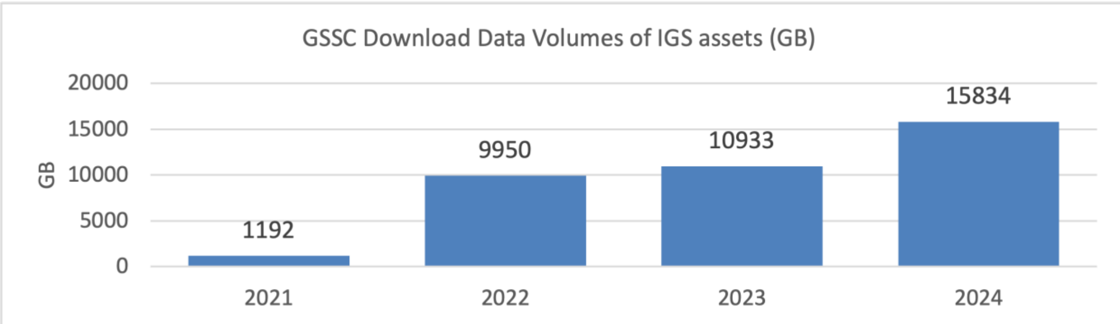

Figure 6: Download volumes of IGS assets via GSSC

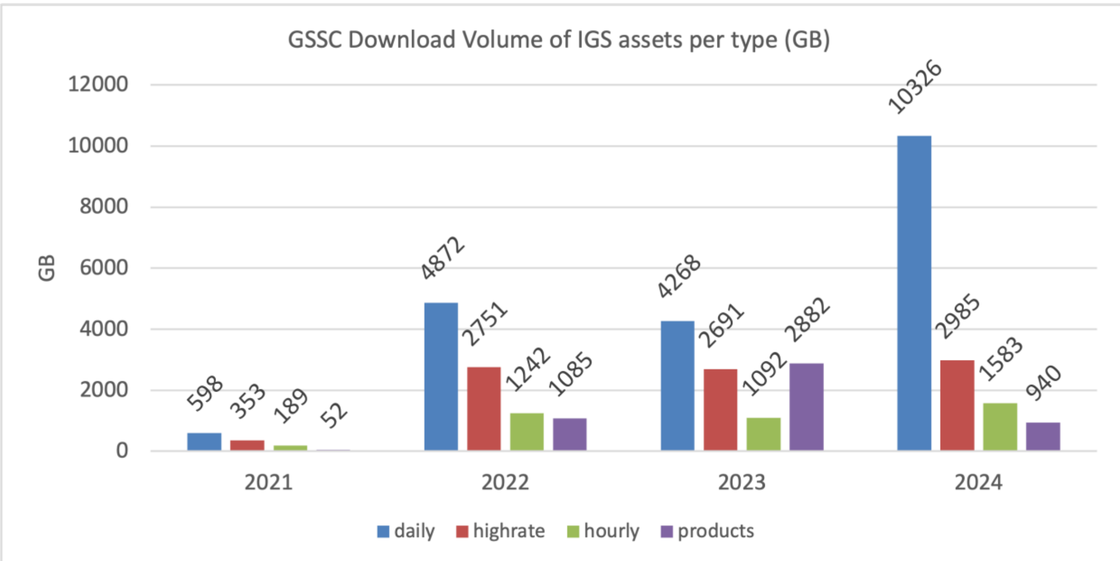

Figure 7: Download volumes of IGS assets via GSSC per type

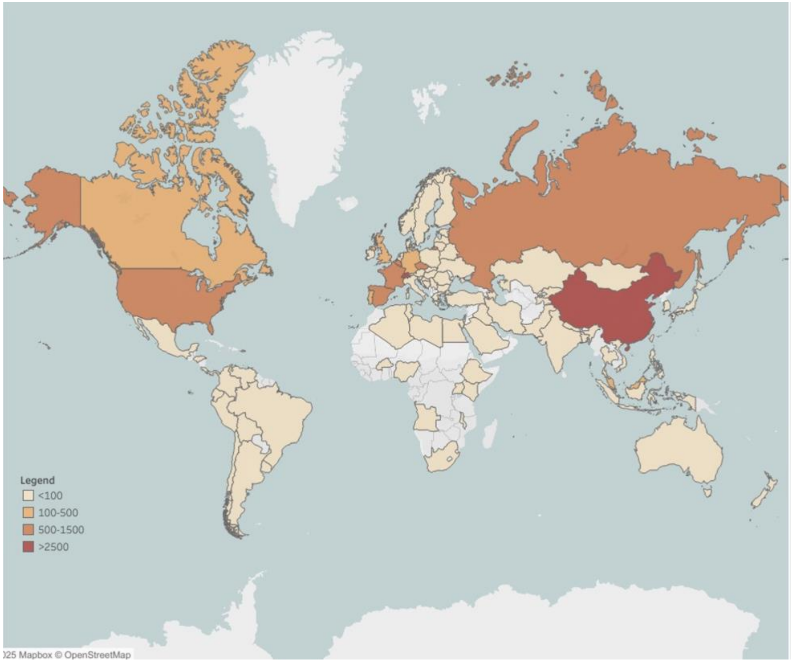

Figure 8: Downloads Data Volume (GB) per Country - IGS

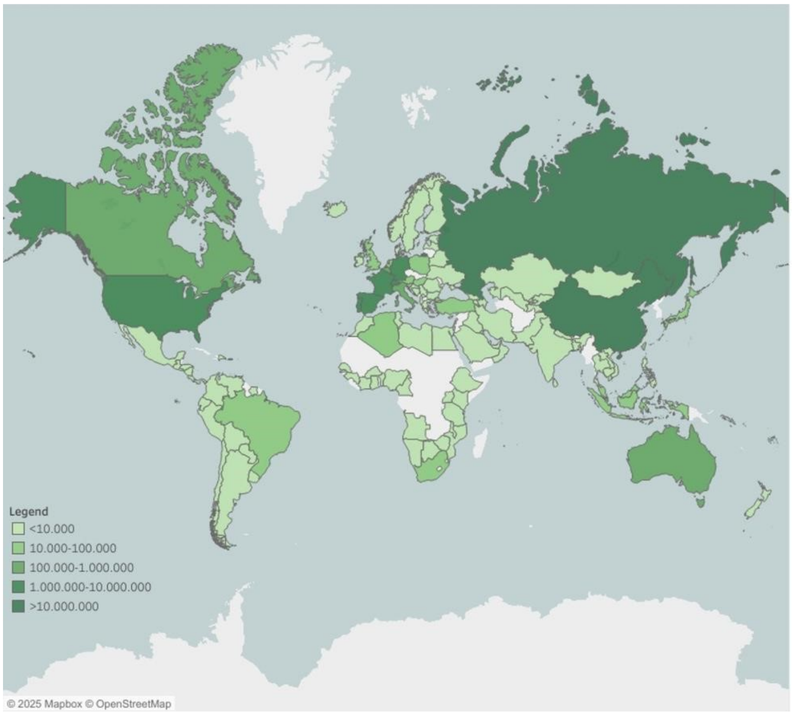

Figure 9: Number of Downloads per Country – IGS

5 What´s Next?

In 2025, the GSSC will prioritize the adaptive and evolutionary maintenance of the GSSC Now digital platform, ensuring alignment with user needs and compliance with IGS standards. A key objective will be the development and integration of new features and enhancements to support the ESA GENESIS mission's Processing, Archive, and Distribution System (PROAD). The mission aims to establish a highly refined reference frame for Earth, achieving an unprecedented accuracy of 1 mm and a long-term stability of 0.1 mm per year. This advanced coordinate system will serve as a foundation for the most demanding navigation applications worldwide.

Wuhan University Data Center Technical Report 2024

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1 Introduction

Since 2015, Wuhan University has served as an IGS Global Data Center, dedicated to supporting global users, with a particular focus on the Chinese community, for both post-processing and real-time applications. The WHU Data Center (WHU DC) archives and provides access to GNSS observations from all IGS and MGEX network stations, along with various IGS products.

In 2024, the new version of the WHU DC website was launched, offering data monitoring and data management services. The DC has accumulated a total of 36.3 terabytes of GNSS data and products so far. The average monthly download in 2024 reaches 37.2M GNSS data and products files (equating to 23.8 terabytes) downloaded by 1.4K unique users (an increase of 4.2 terabytes since last year).

2 Access of WHU Data Center

In order to ensure a more reliable data flow and a better availability of the service, two identical configurations with the same data structure have been setup in Alibaba cloud and Data Server of Wuhan University. Each configuration has:

- FTP access to the GNSS observations and products (ftp://igs.gnsswhu.cn/).
- HTTP access to the GNSS observations and products (http://www.igs.gnsswhu.cn/).

3 GNSS Data & Products of WHU Data Center

The WHU Data Center contains all the regular GNSS data and products, such as navigational data, meteorological data, observational data, and products.

- Navigational data: daily and hourly data
  (ftp://igs.gnsswhu.cn/pub/gps/data)
- Observational data: daily and hourly data
  (ftp://igs.gnsswhu.cn/pub/gps/data)
- Products: orbits, clocks, Earth Rotation Parameters (ERP), and station positions, ionosphere, troposphere
  (ftp://igs.gnsswhu.cn/pub/gps/products)

In addition to the IGS operational products, WHU data center has released ultra-rapid products updated every 1 hour and every 3 hours (ftp://igs.gnsswhu.cn/pub/whu/MGEX/) from the beginning of June 2017. The ultra-rapid products include GPS / GLONASS / BDS / Galileo satellite orbits, satellite clocks, and ERP for a sliding 48-hr period, and the beginning/ending epochs are continuously shifted by 1 hour or 3 hours with each update. The faster updates and shorter latency should enable significant improvement of orbit predictions and error reduction for user applications.

WHU data center started to provide multi-GNSS rapid phase bias products in the bias-SINEX format along with self-consistent orbit, phase clock, code biases and attitude quaternion products since September 2021, and the products are traced back to the beginning of 2020 (ftp://igs.gnsswhu.cn/pub/whu/phasebias/). Five GNSS are included in our products: GPS, GLONASS, Galileo, BDS and QZSS.

The WHU RT GIMs also are accessible via Wuhan Real Time Data Center (http://ntrip.gnsslab.cn) with Mountpoint IONO00WHU0 and Wuhan Data Center (ftp://igs.gnsswhu.cn/pub/whu/MGEX/realtime-ionex) in IONEX format.

4 Monitoring of WHU Data Center

In 2024, we have revamped and upgraded our data center's FTP and service websites, with data storage and FTP services both deployed on Alibaba Cloud Storage.

WHU Data Center provides data monitoring function to display log information such as online user status, the arrival status of data and products, and the status of user downloading in real time. It can display real-time data downloading and data analysis related products graphically, with real-time information on online user status and product accuracy.

In order to ensure the integrity of the observation data and the products, we routinely compare the daily data, hourly data and products with those in CDDIS. If one data

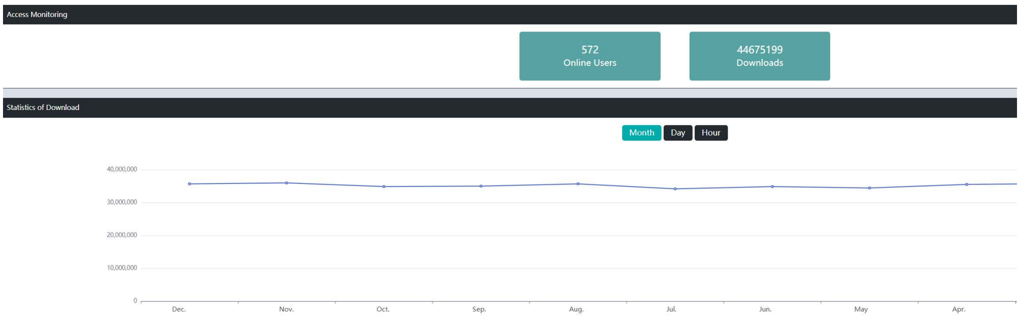

Figure 1: FTP download statistics.

file is missing, we will redownload it from CDDISs. Figure 2 shows the status of daily observation.

DATA TYPE ◉ Daily RINEX (d) ○ Daily RINEX (o)

YEAR OF DATA 2024 Search

2024-1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
FTP FILES	580	583	584	577	577	585	579	568	571	565	557	556	557	466	638	628	644	639	638	630	638	636	631	637	635	636	632	640	637	643	636
OSS FILES	704	709	706	694	691	712	704	681	687	679	660	672	671	637	808	793	806	811	801	795	810	803	799	808	807	797	795	813	805	814	803
LOST FILES	0	0	0	0	1	0	0	2	1	1	3	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ABNORMAL	0	1	0	0	0	1	0	0	0	1	1	3	6	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

2024-2	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	-	-
FTP FILES	635	631	619	627	628	630	632	629	623	620	627	628	625	618	630	630	628	634	632	629	635	630	629	630	631	630	636	633	636	-	-
OSS FILES	809	793	771	785	785	799	803	792	780	775	788	790	788	777	790	791	786	795	799	786	802	797	786	785	797	793	799	800	806	-	-
LOST FILES	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-
ABNORMAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-

2024-3	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
FTP FILES	638	633	638	634	636	635	640	636	639	638	643	638	642	636	634	638	634	632	625	628	633	618	625	634	629	636	635	627	635	628	637
OSS FILES	804	796	808	802	810	807	811	795	797	813	816	808	810	810	801	803	803	803	794	797	797	771	782	799	798	805	801	796	800	794	812
LOST FILES	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ABNORMAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 2: Data and products monitoring of WHU data center.

BKG Regional Data Center Technical Report 2024

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1 Introduction

Since more than 25 years BKG is contributing to the IGS data center infrastructure operating a regional GNSS Data Center (GDC). BKG's GDC is also serving as a data center for the regional infrastructure of EUREF as well as for national infrastructure or for specific projects. Two types of data and products are handled in the GDC: file-based (section 2) and real-time (section 3) data and products. Since 2004, BKG is operating various entities for the global, regional and national real-time GNSS infrastructure. The development of the basic real-time components has been done independently from the existing file-based data center. The techniques behind, the user access etc. were completely different from the existing file-based structure. Moreover, operation of a real-time GNSS service demands a much higher level of monitoring than it is necessary in the post-processing world, where for example RINEX files can be reprocessed the next day in case of an error. The core real-time infrastructure is running independently from the file-based infrastructure. However, there are several common features and interfaces like site log files, skeleton files, and high-rate files. Therefore, the BKG GDC serves as the single point of access to the public and merges all kind of GNSS data and products, e.g. via one web interface.

2 GDC File Archive

2.1 Infrastructure

Since many years, BKG's GDC is running on several virtual machines placed at BKG's premises. It consists of a file server, a database server and an application server dedicated to data processing and web access. All relevant parts of BKG's GDC are backed-up on a daily basis.

2.2 Access

Access to the file-based data center is possible via FTP, HTTPS and web interface. The web interface allows the following activities:

- Full "Station List" with many filtering options and links to meta data
- File browser
- Search forms for RINEX files as well as for any file
- Availability of daily, hourly and, to a limited extent, high-rate (i.e. 1 Hz) RINEX files
- Interactive map allowing condensed information about each station

A processing monitor informs about the average time needed to process a single RINEX file and the amount of RINEX files stored daily or hourly. Changes in the processing software or system hardware are indicated as well.

As the FTP protocol has security weaknesses, users are encouraged to use the HTTPS protocol for downloading files. Support for FTP uploads has already been switched off at an earlier stage. Support for downloading files via FTP will be turned off by the end of 2025 or in 2026 at the latest.

2.3 GNSS Data & Products

The BKG GDC contains all the regular GNSS data, as there are navigational data, meteorological data, observational data, in RINEX v2 (Rx2), RINEX v3 (Rx3) and RINEX v4 (Rx4), daily, hourly and high-rate data of approximately 923 (with national stations 1.347) globally distributed stations, roughly half of them belonging to the IGS network.

The directory structure applied by BKG is related to projects, i.e. within the "Data Access" a user will see IGS, EUREF, GREF, MGEX directories plus some other or historic completed projects. The main sub-directories for the projects are

- `BRDC` for navigational data,
- `highrate` for sub-hourly 1Hz data,
- `nrt` (near real-time) for 30 seconds hourly data,
- `obs` for daily data.

Since at the beginning of storing Rx3 files the standard short file names were identical to those containing Rx2, BKG decided to introduce parallel sub-directories with the extension `_v3` for storing files with the short names. After the introduction of the long file names in the IGS for the Rx3 files, Rx2 and Rx3 files could be stored both in the `obs` sub-directory and sub-directories with extensions were obsolete.

In 2022, BKG started to store RINEX v4 (Rx4) files. For the test phase, the files were stored in a separate directory, `obs_v4`. The files were mainly coming from DLR and GFZ. In 2023, BKG followed the IGS guidelines for finally storing the Rx4 files in the legacy directories. Since then, only a few numbers of stations started providing Rx4 files. The majority of them coming from conversion, not directly from the receiver.

Additionally, BKG is providing some IGS products by mirroring from other IGS data centers, mainly from the CDDIS. Each project has some additional sub-directories: products, reports, and stations. For specific projects, more sub-directories might have been introduced.

2.4 Monitoring

Routinely data-checks are performed for all incoming files. The files are processed through several steps, see Goltz et al. (2017) for details. An “Error Log” page on the web interface gives valuable information especially to the data providers how often and for what reasons a file was excluded from archiving, see https://igs.bkg.bund.de/file/errors.

On the “Station List” page https://igs.bkg.bund.de/stations a user or a data provider can see the completeness of the most recent data. You can also see some simple positioning time series for each station which is part of the EUREF or GREF network.

2.5 Usage Statistics

22.6 million files are stored in the GDC at the end of 2024, with an overall archive size of 33.0 TB. We are facing with approx. 80.000 uploads and 700.000 downloads per day. There was no noteworthy difference in the number of downloaded files with respect to 2023. Approximately 1.000 different users did visit the GDC websites per day.

In 2024, the GDC experienced only few short-term outages, usually due to interruptions in the IT.

2.6 Policy

BKG GDC has to strictly follow the European Union’s General Data Protection Regulation (GDPR). As a consequence, it was agreed in the wider GNSS community to introduce, if not already applied, generic names and emails in the publicly available files. These changes are ongoing in cooperation with, e.g. the EPN Central Bureau.

3 GDC Real-Time Streaming

3.1 Infrastructure

The development of the broadcaster technology and its usage for GNSS was mainly driven by BKG. It is originally based on the ICECAST technology and adapted for GNSS data (Weber et al., 2005). Information on the use of real-time data, such as registration and software, can also be found on the GDC homepage. Since 2008, BKG is offering the so-called Professional Ntrip Caster which is used by many organizations and companies around the globe and which is updated and continuously improved. BKG is maintaining various broadcasters for global, regional and national purposes (IGS, EUREF, GREF). BKG's casters are still hosted by an external service provider and maintained by BKG staff. Similar to the file-based infrastructure – or even more important – is the aspect of redundancy. The redundancy concept for real-time streaming on the data center's side is realized in different ways. For example, the various casters are installed on different virtual machines at the service provider, so if one machine fails not all real-time streams are interrupted at the same time.

In 2021, a separate virtual machine had been setup for each caster. The corresponding IPv4 addresses have changed as a result. The prefix "www" of the URL is no longer needed.

3.2 Access

The access to the GDC broadcasters is possible with many commercial or individual tools. One software tool for easy access to the various IGS resources is the BKG Ntrip Client (BNC, Weber et al., 2016). Since BNC has been developed in parallel and close connection to the Professional broadcaster development, it is perfectly suited to the open IGS infrastructure.

3.3 GNSS Data & Products

As mentioned before, BKG is maintaining different casters (status end of 2023):

- On the IGS caster (`http://igs-ip.net`) approx. 367 data streams in `RTCM3.0/1/2/3` format are provided. The majority is in `3.2/3.3` Multiple Signal Message (MSM) format. There are still two streams available in the old RTCM 2.3 format (BOR100POL0, DAEJ00KOR0). All streams are provided with long mount-point names.
- On the EUREF caster (`http://euref-ip.net`) approx. 227 data streams in `RTCM3.0/1/2/3` format provided. There are still four streams available in the old RTCM 2.3

format (BOR100POL0, ROVE00ITA0, UNPG00ITA0, UNTR00ITA0).

- On the PRODUCTS caster (http://products.igs-ip.net) approx. 90 data streams in RTCM3.0/1/2 format as well as in the IGS-SSR format, provided from various organizations. Most of these streams are containing satellite clock & orbit corrections. Some of them are providing in addition Observable-specific Signal Biases (OSB) as well as VTEC information. Furthermore, there is a low number of product data streams containing ionosphere information only, and two product streams containing OSB information only. To provide real-time access to broadcast ephemeris, there are various streams available, which carry only ephemerides data sets. Therefore, incoming ephemerides are checked for errors and inconsistencies and then merged, encoded and uploaded to Ntrip broadcasters with a high repetition rate.
- Beside the national GREF caster, one other global caster (http://mgex.igs-ip.net) is still running with real-time data of approx. 60 streams provided, mostly received in raw data format. Seven ephemeris data streams are generated with EuroNet software from raw data streams: one multi-GNSS and one each exclusively for BeiDou, Galileo, GLONASS, GPS, QZSS, and SBAS.

The information on the meta-data (e.g. format, message types, sampling rates, receiver type) can be found in the source-table of each caster. More information can be found at https://software.rtcm-ntrip.org/wiki/Sourcetable.

3.4 Monitoring

BKG is monitoring the availability of the data streams of its casters using a dedicated web page (https://bkgmonitor.gnssonline.eu). Color-coded, the monitor shows the availability of each data stream, the duration since the last interruption, the percentage of outages per day and month as well as the number of connections per day and month. In addition, one can investigate a table for each data stream showing the history of outages, interesting for users looking for data streams with as much as possible un-interrupted availability.

The IGS RTS provides access to real-time precise products such as orbits, clocks, code and phase biases, which can be used as a substitute for ultra-rapid products in real-time applications. The true performance of these products can be monitored by the daily statistics derived from the comparison with IGS rapid products. The current RTS product monitoring is based on comparisons performed by the RTACC at BKG. In order to satisfy high demands on availability and reliability, the RTACC also provides two combined multi-GNSS product data streams: SSRA02IGS/SSRC02IGS (GPS, GLONASS, Galileo) and SSRA03IGS/SSRC03IGS (GPS, GLONASS, Galileo, BeiDou). As part of the Center for Orbit Determination in Europe (CODE) BKG has access to high resolution CODE rapid products, which can be processed to perform such comparisons. Hence, the IGS Analysis Center CODE rapid products for GPS, Galileo and GLONASS with a time resolution of

30 seconds are used for monitoring and comparison purposes. Several monitoring results are delivered for the official RTS Web page https://igs.org/rts/monitoring/.

An indirect verification of the individual RT AC results as well as of the combination results is performed by their application to various precise point positioning strategies in real-time (https://igs.bkg.bund.de/ntrip/ppp). This is done e.g. using the GPS+GLONASS+Galileo+BDS observations of our GREF station FFMJ01DEU but with IGS stations as well.

3.5 Usage Statistics

While there is still anonymous download for the file-based data, a registration is necessary for accessing real-time data (https://register.rtcm-ntrip.org/cgi-bin/registration.cgi). Since 2008, when starting with the registration on an operational basis, the request for registration for BKG' casters has been stable on a high level of more than 600 requests per year (see Figure 2) but increasing since the last years to more than 1200 per year. However, many of such registrations show up for a small amount of time only. Nevertheless, the number of so-called listeners, i.e. the requested data streams in parallel, reaches more than 6800 from approx. 200 different users during a typical day. Figure 1 shows the requests to the caster visualized by the daily bandwidth which is constantly increasing over the last decade, in particular for the operational IGS caster after 2019. To balance between the various IGS broadcasters and to keep the increase of the number of listeners and the amount of downloading at BKG small, requests for registration coming from a region where other IGS casters are running, are redirected to the respective providers.

After BKG's casters moved to the new virtual servers in June, a discontinuity in the workload became apparent. This was caused by a caster software bug, that had no effect on the old servers. Meanwhile, this bug has been fixed and a new release of the caster software has been created.

3.6 Caster Software

Since July 2024, BKG as the provider and publisher of the Professional Ntrip Caster changed its policy and started offering the caster software without fee. Since then, the number of requests for the Caster software significantly increased, see Figure 3.

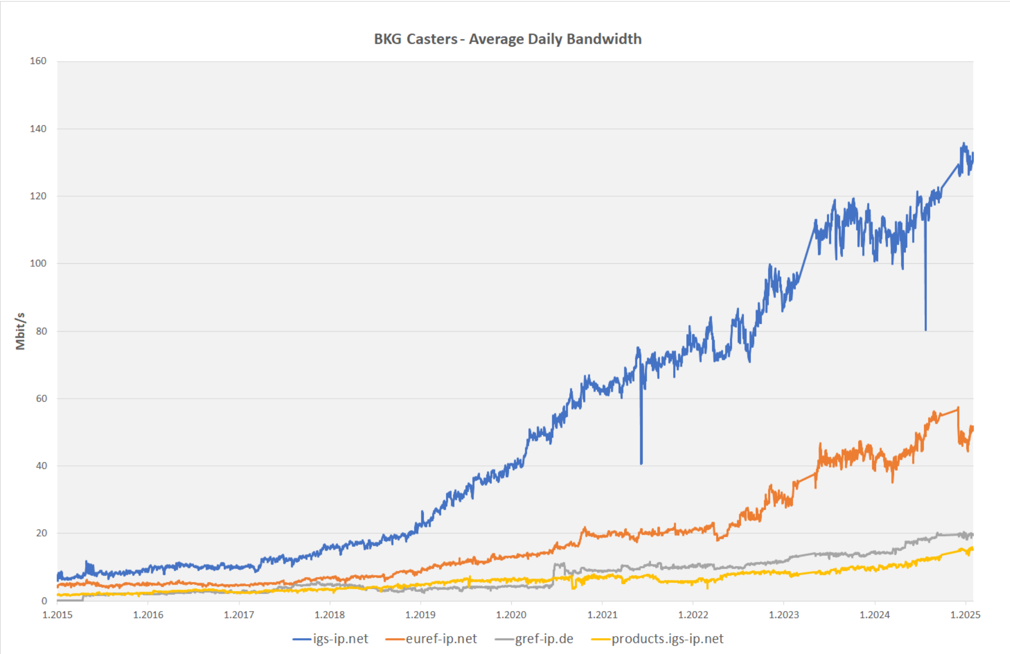

Figure 1: Average daily bandwidth of the BKG Broadcasters from 2015 to the end of 2024

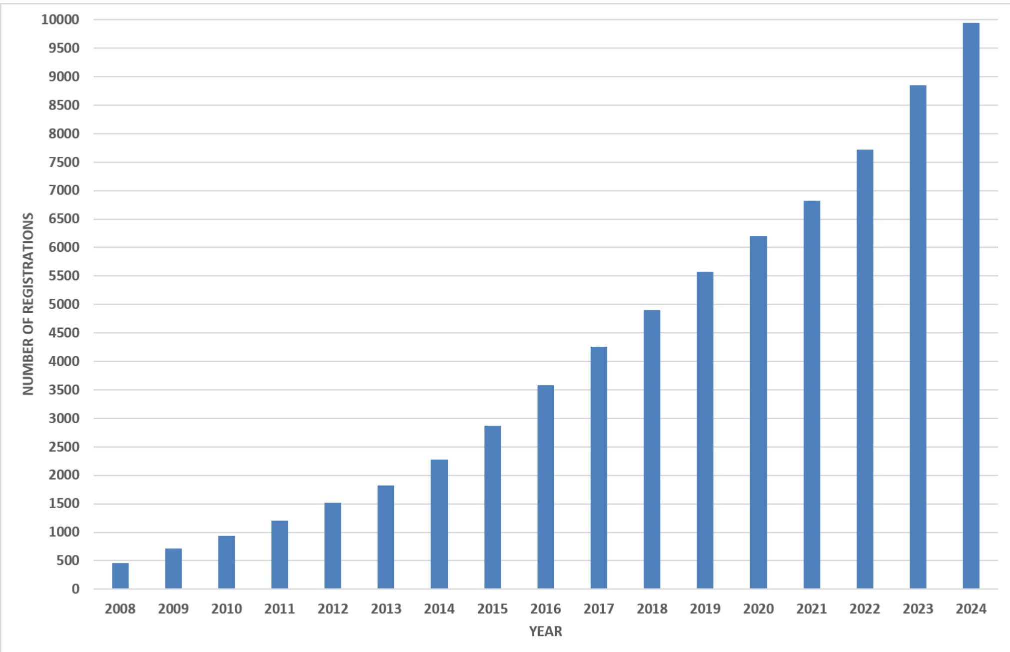

Figure 2: Number of user registrations for usage of the BKG Broadcasters from 2008 to the end of 2024

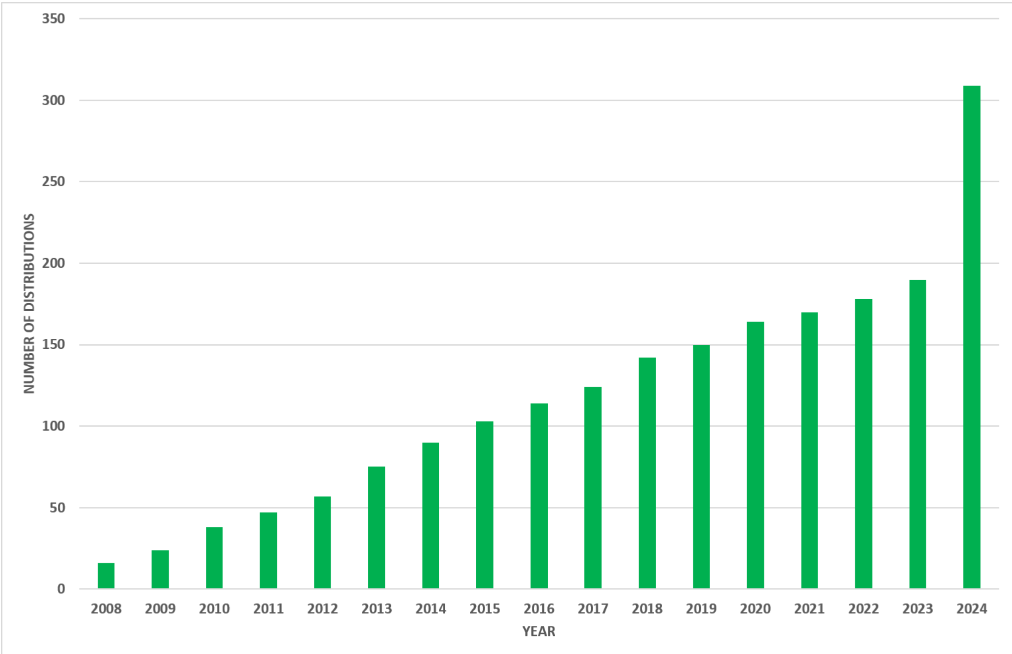

Figure 3: Number of delivered Professional Caster software from 2008 to the end of 2024

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Goltz M.. E. Wiesensarter, W. Söhne, and P. Neumaier Screening, Monitoring and Processing GNSS Data and Products at BKG Poster presented at the IGS Workshop 2017 in Paris (http://www.igs.org/assets/pdf/W2017-PS05-08%20-%20Goltz.pdf)

Weber, G., D. Dettmering, H. Gebhard, and R. Kalafus Networked Transport of RTCM via Internet Protocol (Ntrip) – IP-Streaming for Real-Time GNSS Applications ION GNSS, 2005, pp. 2243-2247

Weber, G., L. Mervart, A. Stürze, A. Rülke, and D. Stöcker BKG Ntrip Client (BNC) Version 2.12 Mitteilungen des Bundesamtes für Kartographie und Geodäsie, Band 49, 2016, ISBN 978-3-86482-083-0

RTCM Standard 10410.1 Networked Transport of RTCM via Internet Protocol (Ntrip) – Version 2.0 RTCM Paper 111-2009-SC-STD

RTCM Standard 10403.3 Differential GNSS (Global Navigation Satellite Systems) Services – Version 3 RTCM Paper 141-2016-SC104-STD

Part IV

Committees, Pilot Projects

Antenna Committee Technical Report 2024

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1 Introduction

The IGS Antenna Committee establishes a contact point to users of IGS products, providing guidance for antenna calibration issues and for a consistent use of IGS products. It maintains the IGS files related to receiver and antenna information, namely the IGS ANTEX file including satellite antenna and receiver type-mean calibrations.

Antenna phase center issues are related to topics such as reference frame, clock products, calibration, monumentation. The Antenna Committee therefore closely cooperates with the respective working committees (Reference Frame Committee, Clock Product Committee, Bias and Calibration Committee), with the Analysis Center Coordinator and the Analysis Centers for analysis related issues, and with the Network Coordinator concerning maintenance of relevant files.

2 Updates and content of the antenna phase center model

Table 1 lists all updates of the igs20_wwww.atx in 2024. 8 new antenna/radom combinations have been added.

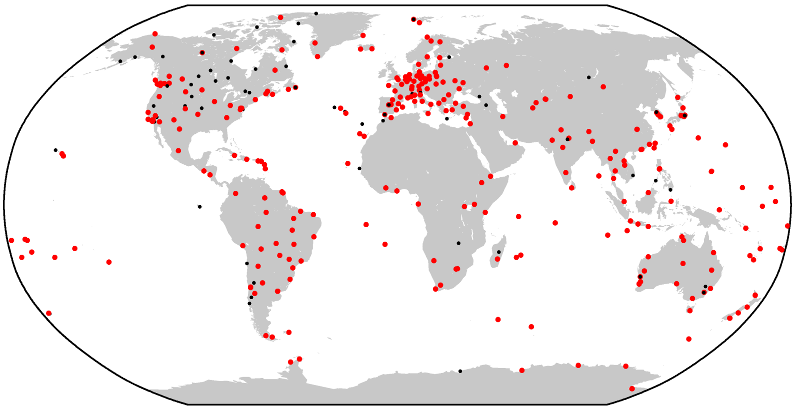

Figure 1: IGS stations tracking Galileo. Red dots: antennas with Galileo calibrations; Black dots: antennas without Galileo calibrations.

Table 1: Updates of the phase center model `igs20_wwww.atx` in 2024 (`wwww`: GPS week of the release date; model updates restricted to additional receiver antenna types are only announced via the *IGS Equipment Files* mailing list)

Week	Date	Change
2335	10. Oct 2024	`Added E226 (E23) and E232 (E16)`
		`TRMR980 NONE`
2317	05. Jun 2024	`Added E225 (E29) and E227 (E06)`
		`GPPVC6050 NONE`
		`GPPVC6050 GPP1`
		`SPPSP100 NONE`
		`TRMR780-2 NONE`
2315	24. May 2024	`Added GMXZENITH60PRO NONE`
		`JAVTRIUMPH_3A1 NONE`
		`JAVTRIUMPH_LSPA NONE`
2309	22. Apr 2024	`Added G049 (G01)`
		`Decommission date G063 (G01)`
2303	29. Feb 2024	`Added R803(R25,R26), R807 (R26,R25)`
		`C232(C50), C233(C48)`
		`Decommission date R803 (R26,R25), R807 (R25,R26)`
		`Added GING40 NONE`

3 Calibration status of the IGS network

Table 2 shows the percentage of IGS tracking stations with respect to certain calibration types. For this analysis, 525 IGS stations as contained in the file `IGSNetwork.json` (available at `https://files.igs.org/pub/station/general/`) were considered. At that time,

Table 2: Calibration status of 5133 stations in the IGS network (`logsum.txt` vs. `igs20_wwww.atx`) compared to former years

Date	Absolute calibration (azimuthal corrections down to 0° elevation)		Converted field calibration (purely elevation-dependent PCVs above 10° elevation)	Uncalibrated radome (or unmodeled antenna subtype)
DEC 2009		61.4%	18.3%	20.2%
MAY 2012		74.6%	8.2%	17.2%
JAN 2013		76.8%	7.7%	15.5%
JAN 2014		78.7%	7.8%	13.5%
JAN 2015		80.1%	7.5%	12.4%
JAN 2016		83.0%	6.5%	10.5%
JAN 2017	igs08.atx:	84.9%	6.2%	8.9%
	igs14.atx:	90.7%	2.2%	7.1%
JAN 2018	igs14.atx:	92.1%	2.2%	5.7%
JAN 2019	igs14.atx:	92.6%	1.8%	5.6%
JAN 2020	igs14.atx:	93.5%	1.8%	4.7%
JAN 2021	igs14.atx:	93.5%	1.8%	4.7%
JAN 2022	igs14.atx:	93.5%	0.2%	4.6%
JAN 2023	igs20.atx:	93.8%	1.0%	4.3%
JAN 2024	igs20.atx:	94.7%	1.0%	4.3%
JAN 2025	**igs20.atx:**	**95.0%**	**1.0%**	**4.0%**

105 different antenna/radome combinations were in use within the IGS network. The calibration status of these antenna types was assessed with respect to the phase center model `igs20_wwww.atx` that were released in December 2024. The overall situation regarding the stations with state-of-the-art robot- and chamber-based calibrations is similar to the one from 2023. While for the igs08 84.9% and for the igs14 93.5% of the IGS stations are covered by robot calibration the situation is slightly better of the new igs20 with a coverage of 95.0%.

The IGS20 is based on three GNSS systems (GPS, GLONASS, Galileo) while the predecessor IGS14 relied on GPS and GLONASS only. The inclusion of Galileo in the IGS20 was possible due to the release of updated receiver antenna calibrations covering the corresponding frequencies. Currently the `igs20.atx` covers 410 out of 525 sites with antennas for which multi-GNSS calibrations are available. 410 IGS sites are currently tracking Galileo out of which 82.7% are antennas with available mutli-GNSS calibrations. Figure 1 shows stations which are tracking Galileo (according to `https://network.igs.org/`). Stations using antennas with according Galileo antenna pattern are represented as red dots while the black dots are antennas without Galileo calibration patterns.

Bias and Calibration Committee Technical Report 2024

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1 Introduction

The IGS Bias and Calibration Committee coordinates research in the field of GNSS bias retrieval and monitoring. It defines rules for appropriate, consistent handling of biases which are crucial for a "model-mixed" GNSS receiver network and satellite constellation, respectively. At present, we consider: GPS C1W–C1C, C2W–C2C, and C1W–C2W differential code biases (DCB). Potential quarter-cycle biases between different GPS phase observables (specifically L2P and L2C) are another issue to be dealt with. In the face of GPS and GLONASS modernization programs and other meanwhile fully occupied GNSS, such as the European Galileo and the Chinese BeiDou, careful treatment of measurement biases in legacy and new signals becomes more and more crucial for combined analysis of multiple GNSS.

The IGS Bias and Calibration Committee (formerly Working Group, shortly BCWG) was established in 2008. More helpful information and related Internet links may be found at https://igs.org/wg/bias-and-calibration. For an overview of relevant GNSS biases, the interested reader is referred to (Schaer , 2012).

2 Activities in 2024

- Regular generation of C1W–C1C (P1–C1) bias values for the GPS constellation (based on *indirect* estimation) was continued at CODE/AIUB.
- At CODE, a refined GNSS bias handling to cope with all available GNSS systems and signals has been implemented and activated (in May 2016) in all IGS analysis lines (Villiger et al. , 2019a). As part of this major revision, processing steps relevant

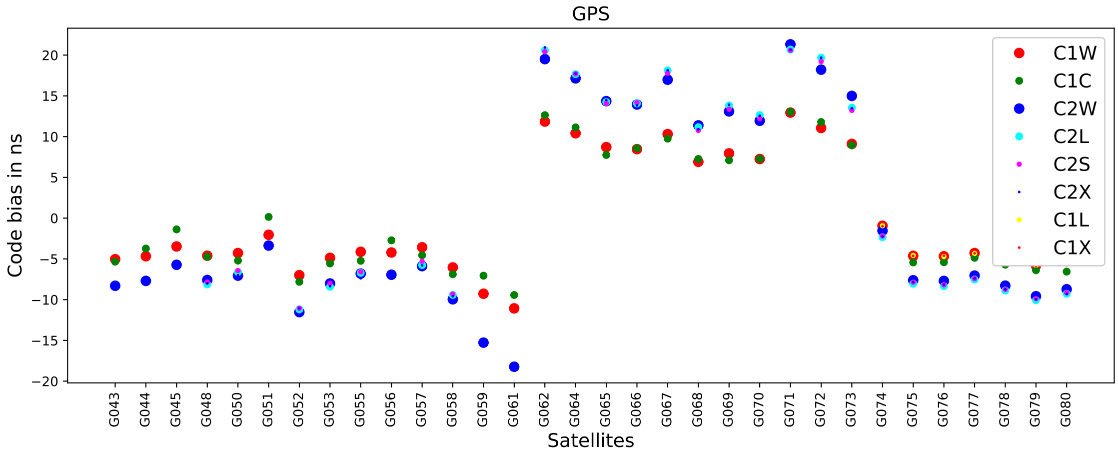

Figure 1: Observable-specific code bias (OSB) estimates for GPS code observable types (using the RINEX3 nomenclature) and GPS SV numbers, computed at CODE, for January 2025. Note that G043–G061 correspond to Block IIR, IIR-M; G062–G073 correspond to Block IIF satellite generations and G074–G080 corresponds to Block IIIA.

to bias handling and retrieval were reviewed and completely redesigned. In 2017, further refinements could be achieved concerning bias processing and combination of the daily bias results at NEQ level. Daily updated 30-day sliding averages for GPS and GLONASS code bias (OSB) values coming from a rigorous combination of ionosphere and clock analysis are made available in Bias-SINEX V1.00 at
`http://ftp.aiub.unibe.ch/CODE/CODE.BIA`
`https://cddis.nasa.gov/archive/gnss/products/bias/code.bia`

- Starting with GPS week 2072, CODE has extended its rapid and ultra-rapid solutions from a two-system to a three-system processing: GPS, GLONASS, and Galileo (as announced in (Villiger et al. , 2019b)). Galileo is also considered in the rapid clock analysis (with fixed ambiguities for GPS and Galileo) as well as in the rapid ionosphere analysis at CODE. As a consequence of this, corresponding Galileo bias results (combined OSB results from clock and ionosphere analysis) could be incorporated into to the CODE.BIA product. Starting with GPS week 2238, an identical extension (to three GNSS) was made in the CODE final analysis line. From the latter point in time, the results of the rapid analysis line are no longer included in the long-term history of the CODE.BIA product.
- CODE monthly OSB values for GPS C1W and C1C (that are recommended to be used for repro-3) are made available in Bias-SINEX V1.00 at
`http://ftp.aiub.unibe.ch/CODE/CODE_MONTHLY.BIA`
`https://cddis.nasa.gov/archive/gnss/products/bias/code_monthly.bia`
Note that the 1994-1999 period is not yet covered in this file.

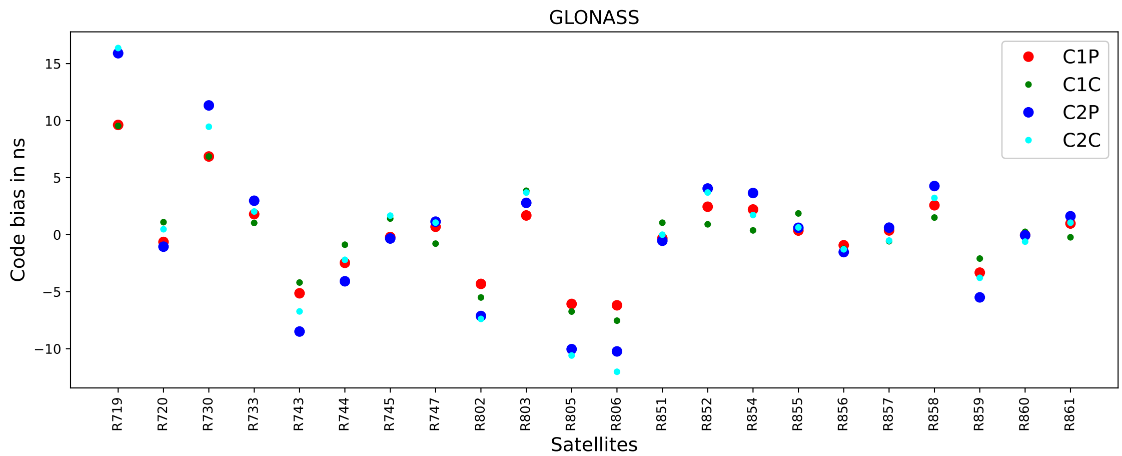

Figure 2: Observable-specific code bias (OSB) estimates for GLONASS code observable types (using the RINEX3 nomenclature) and GLONASS SV numbers, computed at CODE, for January 2025. Note that R719–R747 and R851–R861 correspond to GLONASS-M; R802,R805, R806 correspond to GLONASS-K1 satellite generations; R803 represents the first GLONASS-K2 satellite.

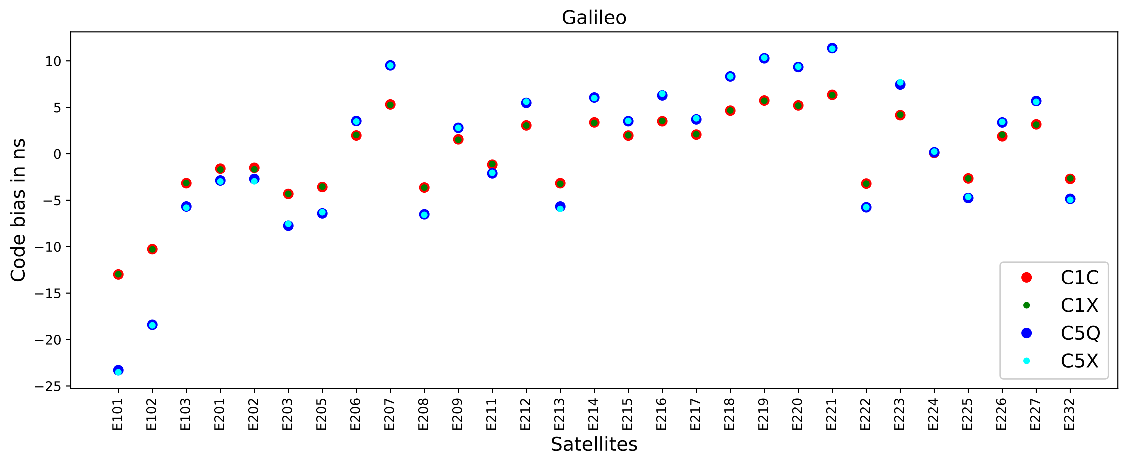

Figure 3: Observable-specific code bias (OSB) estimates for Galileo code observable types (using the RINEX3 nomenclature) and Galileo SV numbers, computed at CODE, for January 2025.

- It should be mentioned that the current GPS C1W–C1C DSB (P1–C1 DCB) product provided by CODE (specifically in the Bernese DCB format) corresponds to a converted extract from our new OSB final/rapid product line.
- Our new bias implementation allows to combine bias results at normal-equation (NEQ) level. We are thus able to combine bias results obtained from both clock and ionosphere analysis, and, moreover, to compute coherent long-term OSB solutions. This could be already achieved for the period starting with epoch 2016:136 up to now. Corresponding long-term OSB solutions are updated daily.
- The use of the RINEX2-based tool for *direct* estimation of GPS and GLONASS P1–C1 and P2–C2 DCB values has been discontinued in February 2022. In its place, a newly developed, RINEX3-driven tool for *direct* estimation of all determinable intra-frequency code biases is now applied. This tool is declared to be multi-GNSS capable, treats the generated information at OSB level and further allows to export this information (at NEQ level) for later parameter stacking operations. It is intended that corresponding bias estimates will eventually be used to complement the CODE.BIA 30-day and long-term product. They are currently being substituted (down-converted) for the GPS/GLONASS DCB legacy product files and are already being used to augment CODE'a daily bias product files, in particular with regard to the GPS satellit constellation, now covering all sampled code signals of L1 and L2 (specifically since GPS week 2210). It should be noted that the GPS DCB values declared as P1–C1 and P2–C2 are now strictly equivalent to C1W–C1C and C1W–C2L.
- The new bias convention concerning satellite antenna corrections was implemented according to the IGS guidelines, both in relation to the Melbourne-Wübbena LC and in relation to the geometry-free LC (see also section 4). This means that inter-frequency code bias determinations generated by CODE are also affected by this model change (effective from start of GPS week 2238). However, it should be pointed out that this only affects all bias products in the OSB representation. **Caution:** Inter-frequency DCB legacy products in the Bernese DCB format are explicitly corrected to the old, simplifying bias convention. This means that this particular legacy product (which will be obsolete in the foreseeable future) will no longer experience this model change (also to allow long-standing users to make this model change when switching to a contemporary OSB product).
- The ambiguity resolution scheme at CODE was extended (in 2011) to GLONASS for three resolution strategies. It is essential that *self-calibrating* ambiguity resolution procedures are used. Resulting GLONASS DCPB(differential code-phase bias) results are collected and archived daily.
- CODE's enhanced RINEX2/RINEX3 observation data monitoring was continued (and expanded to RINEX4). Examples may be found at:
http://ftp.aiub.unibe.ch/igsdata/odata2_day.txt

http://ftp.aiub.unibe.ch/igsdata/odata2_receiver.txt
http://ftp.aiub.unibe.ch/igsdata/odata3_gnss_day.txt
http://ftp.aiub.unibe.ch/igsdata/odata3_gnss_receiver.txt
http://ftp.aiub.unibe.ch/igsdata/y2024/odata2_d335.txt
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http://ftp.aiub.unibe.ch/igsdata/y2024/odata3_beidou_d335.txt
http://ftp.aiub.unibe.ch/igsdata/y2024/odata3_qzss_d335.txt
http://ftp.aiub.unibe.ch/igsdata/y2024/odata3_sbas_d335.txt
Internally, the corresponding information is extracted and produced using metadata stored in an xml database (established in December 2014).

3 Last Reprocessing Activities

In 2012: A complete GPS/GLONASS DCB reprocessing was carried out at CODE on the basis of 1990–2011 RINEX data. The outcome of this P1–C1 and P2–C2 DCB reprocessing effort is: daily sets, a multitude of daily subsets, and in addition monthly sets.

In 2016/2017: A GNSS bias reprocessing (for GPS/GLONASS) using the recently implemented observable-specific code bias (OSB) parameterization was initiated at CODE for 1994-2016 RINEX data. The outcome of this reprocessing effort are daily NEQs for GPS and GLONASS OSB parameters from both global ionosphere and clock estimation. A consistent time series of global ionosphere maps (GIMs) with a time resolution of 1 hour is an essential by-product of this bias reprocessing effort.

In 2017: 3-day combined ionosphere solutions were computed for the entire reprocessing period (back to 1994). The ionosphere (IONEX) results (for the middle day) of this computation effort were not yet made available to the public.

In 2022: RINEX3 observation data covering well over one calendar year (back to January 1, 2021) was reprocessed for testing and validation purposes using the newly developed multi-GNSS-capable tool for direct code bias estimation. Corresponding intra-frequency biases could be retrieved between:

GPS C1C/C1L/C1W/C1X and C2L/C2S/C2W/C2X,
GLONASS C1C/C1P and C2C/C2P,
BeiDou C2D/C2I/C2P/C2X,
QZSS C1C/C1L/C1X/C1Z and C5P/C5Q.

With regard to Galileo, the available tracking data does not allow a direct determination of intra-frequency differential code biases.

4 New Bias Convention for Melbourne-Wübbena LC and Geometry-Free LC

It was agreed in the IGS that, at the same time as the model switch to IGS20 (specifically from the start of GPS week 2238), a new bias convention for the Melbourne-Wübbena LC should also be applied. Satellite antenna corrections (especially concerning antenna phase center offsets), which were usually ignored until now, shall now be taken into account. This change of convention affects in particular phase biases as they are needed in the PPP-AR application.

An analogous adjustment is in principle also necessary withn respect to the geometry-free LC as used for ionosphere analysis. In this application, one expects different estimates for inter-frequency code biases, namely for all satellites with deviating L1 and L2 PCO values, i.e., in particular for all Block IIIA satellites of the GPS constellation (currently G01/G080, G04/G074, G11/G078, G14/G077, G18/G075, G23/G076, G28/G079). Such GPS C1W–C2W DCB values conforming with the new convention are about 0.492 m or 1.64 ns larger than those following the old convention (where until recently it was not necessary to consider satellite PCO). Conversely, this means that new GPS Block III DCB estimates would have to be corrected by −1.64 ns in order to obtain old determinations.

It is therefore important to clearly state the bias convention to be applied in Bias-SINEX product files. The `BIAS/DESCRIPTION` sequence is suitable for this. We apply the following declaration when relying on the new bias convention:

```
 APC_MODEL                                IGS20
*SATELLITE_ANTENNA_PCC_APPLIED_TO_MW_LC  YES
*SATELLITE_ANTENNA_PCC_APPLIED_TO_GF_LC  YES
```

If none of the above records or one of the following records can be found, then the old convention is assumed:

```
*SATELLITE_ANTENNA_PCC_APPLIED_TO_MW_LC  NO
*SATELLITE_ANTENNA_PCC_APPLIED_TO_GF_LC  NO
```

Note that MW and GF denote the respective linear combinations (where exactly this bias convention is supposed to apply).

5 CODE's Main Bias Product Files

It is strongly advised to consider bias files of the following list:
http://ftp.aiub.unibe.ch/CODE/CODE.BIA
http://ftp.aiub.unibe.ch/CODE/CODE_MONTHLY.BIA
https://cddis.nasa.gov/archive/gnss/products/bias/code.bia
https://cddis.nasa.gov/archive/gnss/products/bias/code_monthly.bia
These are in Bias-SINEX format, contain OSB values, labeled with RINEX3 observation codes, and time windows for validity. The first bias file contains values averaged over the

last 30 days; the second file contains a time series of monthly averages. It is extremely important that this bias product line is consistent with the corrections addressed in Section 4. Although OSB values are provided here, these may and should of course also be used for differential (DCB) applications. Any differentiation is permitted, for intra-frequency as well as inter-frequency observation combinations.

The use of existing DCB product files should be avoided. The end of production is foreseeable for corresponding product lines, such as:
http://ftp.aiub.unibe.ch/CODE/P1C1.DCB
http://ftp.aiub.unibe.ch/CODE/P1P2.DCB
http://ftp.aiub.unibe.ch/CODE/CODE.DCB
It must be clearly stated that these old bias products do not contain the correction required in Section 4. The influence of this particular correction is undone (effectively back-corrected), also to avoid problems for old application areas. This specifically applies to the P1P2.DCB output (also included in CODE.DCB).

6 Bias-SINEX Format Version 1.00

The latest Bias-SINEX format description document (Schaer , 2018) may be found at:

https://files.igs.org/pub/data/format/sinex_bias_100.pdf

The following addendum from (Schaer et al. , 2021) should help to clarify any uncertainty regarding the sign rule for phase biases in Bias-SINEX. Finally, it contains some elementary rules that we consider useful within the scope of PPP-AR:

https://doi.org/10.1007/s00190-021-01521-9#appendices

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GNSS Monitoring Pilot Project Technical Report 2024

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1 Introduction

The International Committee on GNSS (ICG) established the International GNSS Monitoring and Assessment (IGMA) Task Force at the ICG-6 meeting in Tokyo in 2011, tasked to facilitate cooperation and information between providers and scientific organizations that engage in open service signal quality monitoring. The International GNSS Service (IGS) is coordinating the operation of a global multi-GNSS network and is playing a key role in generating precise GNSS products since its inception in 1994.

The ICG recommended at the ICG-10 meeting in Boulder in 2015 that the IGMA Task Force and the IGS initiate a joint Trial Project to demonstrate a global GNSS Monitoring and Assessment capability, utilizing existing resources and infrastructure and avoiding duplication. Participation from non-IGS analysis groups, networks, and data centers is invited to develop benchmarking between groups and to generate analysis products, cross-sharing between existing IGS functional streams and IGMA activities. Initially, it is proposed to initiate the activity with the monitoring of a limited number of parameters to demonstrate the service and exercise it operationally. This will be followed by a broader set of parameters to be monitored as the system approaches permanent operations.

The IGS Monitoring Working Group has been established to install, operate, and further develop the GNSS Monitoring and Assessment Trial Project jointly with ICG's IGMA Task Force, considering the Terms of Reference of the IGMA Task Force for the IGMA-IGS Joint Trial Project, utilizing existing resources and infrastructure, and creating publicly available, useful data products.

2 Membership

A second Call for Participation has been released at the beginning of 2024 to enlist the participants of the new IGS Monitoring Pilot Project and to solicit the participation of new institutions. 13 organizations responded, of which 5 applied as Monitoring Analysis Center (MAC) and 3 as active participants. One expressed interest in becoming a data center and 4 registered for information only.

3 Summary of Activities in 2024

During the 64$^{\text{th}}$ IGS Governing Board Meeting, it was decided to restart the activities of the former IGS Monitoring Working Group in the form of a new Pilot Project, called the IGS Monitoring Pilot Project.

In the following months, a review of the ICG IGMA ToR has been performed.

In the 65$^{\text{th}}$ IGS Governing Board Meeting, the IGS GB endorsed the updated ICG IGMA ToR and agreed to issue a second Call for Participation in the IGS Monitoring Pilot Project. This was followed by an IGS pilot project meeting and an IGS Pilot Project technical meeting, where a first test campaign was defined. The first results of the test campaign were evaluated. This was followed by an IGS Pilot Project meeting and an IGS Pilot Project technical meeting, where a first test campaign was defined. The first results of the test campaign were evaluated and presented at the IGS 66$^{\text{th}}$ GB Meeting and at GS-ICG IGS workshop in Bern.

4 Planned 2025 Activities

In 2025 the IGS Monitoring Analysis Centres (MAC) continue the consolidation of its performance calculation methodology. It is planned to validate the implementation at the different MACs, ensuring consistent results within the IGS MAC. In a second step it will be decided how the available and validated MAC solutions can be combined and provided to the International GNSS Monitoring and Assessment (IGMA) Task Force of the International Committee on GNSS (ICG) as IGS contribution to the currently ongoing 2$^{\text{nd}}$ trial run.

It is further planned to review and update the IGS Monitoring Pilot Project Charter. The working group chair will represent the IGS Monitoring Pilot Project in the ICG IGMA.

Ionosphere Committee Technical Report 2024

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2 Aerospace Information Research Institute,
Chinese Academy of Sciences (AIR/CAS), Beijing, China
3 UPC–IonSAT, Barcelona, Spain

1 General goals

The Ionosphere Committee started the routine generation of the combine Ionosphere Vertical Total Electron Content (TEC) maps in June 1998. This has been the main activity so far performed by the eight IGS Ionosphere Associate Analysis Centers (IAACs): CODE/Switzerland, ESOC/Germany, JPL/ U.S.A, UPC/Spain, CAS/China, WHU/China, NRCan/Canada and OPTIMAP/Germany. Independent computation of rapid and final VTEC maps is used by each analysis center: Each IAAC computes the rapid and final TEC maps independently and with different approaches. Their GIMs are used by the UWM/Poland, since 2007, to generate the IGS combined GIMs. Since 2015 UWM/Poland generate also IGS TEC fluctuations maps.

[*]Chair of Ionosphere Committee
[†]Vice-Chair of Ionosphere Committee

2 Membership

1. Mahdi Alizadeh (TU Berlin and K.N.Toosi University of Technology Tehran)
2. Dieter Bilitza (GSFC/NASA)
3. Claudio Cesaroni (INGV)
4. M. Codrescu (SEC)
5. Anthea Coster (MIT)
6. Joachim Feltens, Telespazio (ESA/ESOC)
7. Mariusz Figurski (TU Gdansk)
8. Pawel Flisek (UWM)
9. Adam Froń (UWM)
10. Alberto Garcia-Rigo (UPC)
11. Reza Ghoddousi-Fard (NRCan)
12. Manuel Hernandez-Pajares (UPC)
13. Pierre Heroux (NRCan)
14. Norbert Jakowski (DLR)
15. Attila Komjathy (JPL)
16. Andrzej Krankowski (UWM)
17. Kacper Kotulak (UWM)
18. Richard B. Langley (UNB)
19. Zishen Li (CAS)
20. Haixia Lyu (Wuhan University)
21. Camille Martire (JPL)
22. Angelyn Moore (JPL)
23. Raul Orus (ESTEC)
24. Michiel Otten, PosiTim (SA/ESOC)
25. Ola Ovstedal (UMB)
26. Vergados Panagiotis (JPL)
27. Ignacio Romero, CSC (ESA/ESOC)
28. Stefan Schaer (CODE)
29. Michael Schmidt (DGFI-TUM)
30. Tim Springer, PosiTim (ESA/ESOC)
31. David R. Themens (University of Birmingham)
32. M. Sithartha Muthu Vijayan (CSIR 4PI)
33. Ningbo Wang (CAS)
34. Rene Warnant (ULiège)
35. Robert Weber (TU Wien)
36. Pawel Wielgosz (UWM)
37. Brian Wilson (JPL)
38. Junchen Xue (CAS)
39. Yunbin Yuan (CAS)
40. Qile Zhao (WHU)

3 Key Issues

a Activities of eight IGS Ionosphere Associated Analysis Centres regarding GIMs: CODE, UPC, ESA, JPL, NRCan, CAS, WHU, OPTIMAP (GIMs)

b Activities of UWM IAAC regarding ROTI maps.

c IGS real-time service for global ionospheric total electron content modeling.

d IGS ROTI Maps: Current Status and Its Extension towards Equatorial Region and Southern Hemisphere.

e Towards Cooperative Global Mapping of the Ionosphere: Fusion Feasibility for IGS and IRI with Global Climate VTEC Maps.

f Cooperation with International LOFAR Telescope (ILT) for potential synergies.

g Creation of 2 new Study Groups: "Ionospheric Mapping Function" and "New Methodology for Combining IGS Ionospheric products"

h Moving towards real-time multi-constellation ionosphere products including VTEC maps, ROTI maps, scintillation products.

4 Current IGS ionosphere products

4.1 IGS combined global ionospheric maps (GIM)

Currently the VTEC combined maps in the IONEX format include:

- Final solution with ≈ 11 days latency and weekly updates
- Rapid solution with less than $24-$hour latency and daily updates

Both products are arranged in grid maps with resolution of 5 deg (longitude) by 2.5 deg (latitude) and 2 hours in time. However the products elaborated by different IAACs may have different temporal resolution – from 15 minutes up to 2 hours.

The draft Real-Time combined product based on the four IAACs (prepared in cooperation with the Real-Time IGS WG) is also provided.

All information about validation, evaluation and combination of the products can be found at the Ionosphere Committee webpage (`https://igsiono.uwm.edu.pl/`).

4.2 IGS ROTI fluctuation maps for the Northern hemisphere

Since 2014 UWM provides the IGS diurnal ROTI maps to characterize ionospheric irregularities occurrence over the Northern hemisphere.

Currently the ROTI fluctuation product is being expanded to cover also the Southern hemisphere and equatorial region with use of over 1200 ground-based GNSS permanent stations.

4.3 Ionospheric products

Ionospheric products are available through CDDIS:

`https://cddis.nasa.gov/archive/gnss/products/ionex/YYYY/DDD/`

where `YYYY` is the year and `DDD` – the day of the year identification

The ionospheric products since GPS week 2238 (November 26, 2022), are in transition to the IGS long product filename convention. The available products are listed in Table 1 together with their previous short names and new long names.

Table 1: Available products with their old and new filenames.

File type	Old short name	New long name
Final combined IONEX	`igsgddd0.yyi.Z`	`IGS0OPSFIN_yyyyddd0000_01D_02H_GIM.INX.gz`
Rapid combined IONEX	`igrgddd0.yyi.Z`	`IGS0OPSRAP_yyyyddd0000_01D_02H_GIM.INX.gz`
ROTI (Northern hemisphere)	`rotiddd0.yyf.Z`	`IGS0OPSFIN_yyyyddd0000_01D_01D_ROT.INX.gz`

`ddd`: day of year [001...366] `yy`: 2-digit year `yyyy`: 4-digit

5 Discussion highlights during IGS 2024 Bern Workshop

a Celebration of 25th Anniversary of IGS ionospheric activity.

b Progress towards the final real-time global ionospheric maps have been discussed – performance of the two independent IGS combined real-time products has been presented.

c The final ROTI ionospheric fluctuation product development towards covering the southern hemisphere and equatorial region has been presented.

d Creation of 2 new Study Groups: “Ionospheric Mapping Function” and “New Methodology for Combining IGS Ionospheric products”.

e Establishment of long file naming convention expansion for different predicted ionospheric products.

f Progress within the cooperation between IGS and IRI groups regarding the development of the VTEC maps as an input for the GIRO GAMBIT system.

g Progress within simultaneous ionospheric observations with GNSS and LOFAR systems have been presented.

6 IGS 2024 Bern Workshop Recommendations

a Preparation of final version of IGS RT-GIMs.

b Preparation of final version of IGS ROTI maps extension towards low latitudes and Southern Hemisphere.

c Continuation of works of new Study Groups: “Ionospheric Mapping Function” and “New Methodology for Combining IGS Ionospheric products”.

d Close cooperation with the Real-Time Committee in order to elaborate full real-time VTEC and ROTI products.

e Continuation of cooperation with IRI, LOFAR-ERIC and ICG communities

Multi-GNSS Pilot Project Technical Report 2024

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1 Introduction

All activities of the IGS Multi-GNSS Pilot Project (MGPP) contribute to the number one goal of the IGS Strategic Plan 2021+: "Achieve Multi-GNSS Technical Excellence". In July 2024, Peter Steigenberger took over the chair of the MGPP from Oliver Montenbruck who continues to lead the IGS Combination Task Force (CTF). Kyohei Akiyama from JAXA fills the new position of the MGPP vice-chair. During the IGS Workshop in July 2024, the following recommendations have been proposed by the MGPP:

1. Request GB approval for Satellite Metadata SINEX File Format 1.10.
2. Station owners are requested to transition to RINEX 4 subject to support by the receiver/conversion software.
3. Include 24:00 epoch in all IGS orbit products.
4. OPS ACs are encouraged to participate in step 3 of the BDS-3/QZSS satellite antenna calibration campaign (impact on OPS products) to include these constellations in their operational products.
5. Suggest parallel testing of the GA orbit combination software and the SPOCC orbit/clock combination software by the new ACC to consolidate multi-GNSS combination and decide on final software.
6. Establish an IGS component addressing LEO PNT.

2 GNSS Evolution

Table 1 lists the GNSS satellite launches of the year 2024. After a break of more than two years, launches of Galileo satellites resumed. Two pairs of Galileo FOC satellites have been launched by SpaceX with its Falcon-9 rocket. The two BeiDou MEO satellites launched in September 2024 are the last spacecraft of the BeiDou-3 system. They serve as backup and for testing technologies of the next-generation BeiDou-4. The 7th GPS III satellite was launched in December 2024 and started signal transmission with PRN G01 on 28 December 2024.

Table 1: GNSS satellite launches in 2023.

Date	Satellite	Type
28-Apr-2024	Galileo FOC 25 and 27	MEO
17-Sep-2024	Galileo FOC 26 and 32	MEO
19-Sep-2024	BeiDou-3 M-25 and M-27	MEO
17-Dec-2024	GPS III-7	MEO

The European Union published updated receiver guidelines (European Union, 2024) for the Open Service Navigation Message Authentication (OSNMA) as well as the interface control document for OSNMA internet data distribution (European Union, 2024). Cabinet Office, Government of Japan, published the interface specification of the QZSS Navigation Message Authentication (NMA, Cabinet Office, 2024).

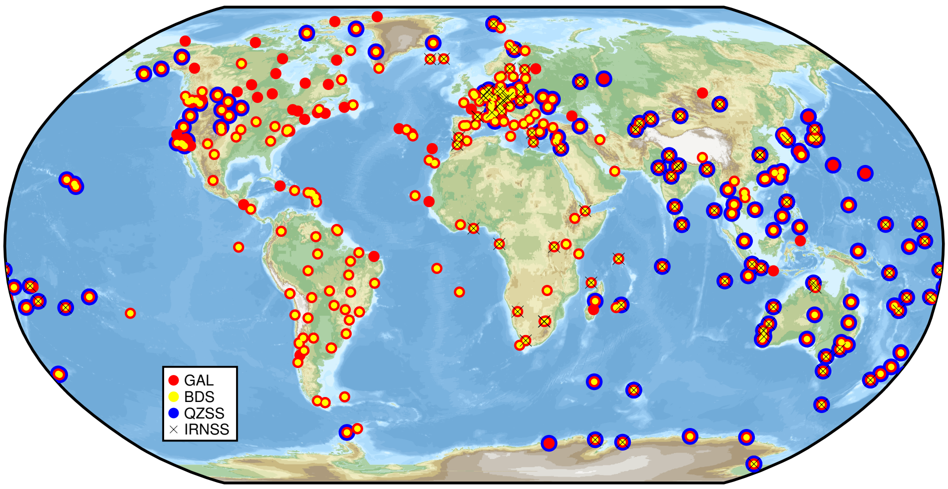

Figure 1: Distribution of IGS multi-GNSS stations supporting tracking of Galileo (red), BeiDou (yellow), QZSS (blue), and IRNSS (black crosses) as of January 2025.

3 Network

As of January 2025, the IGS multi-GNSS tracking network comprises 385 active stations, see Figs. 1 and 2. For the first time, this is a reduction compared to the previous year (−18 stations). Unfortunately, another two stations are completely dormant and did not provide any observations in 2024.

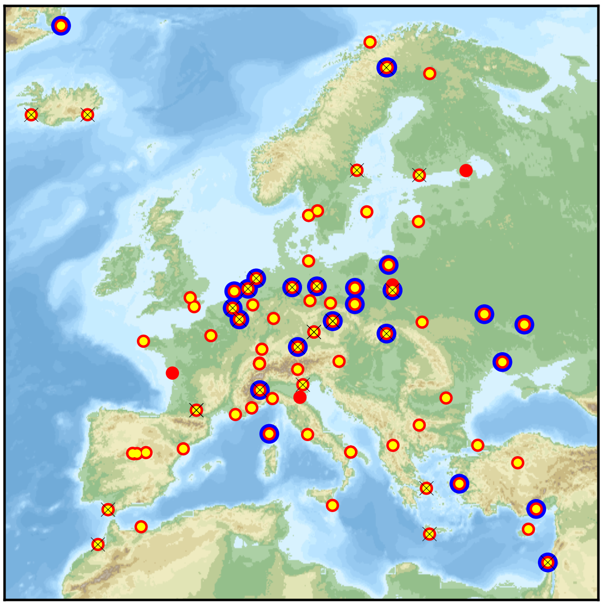

Figure 2: Distribution of European IGS multi-GNSS stations as of January 2025. See Fig. 1 for explanation of individual station labels.

4 Products

Table 2 lists the analysis centers (ACs) contributing orbit and clock products to the IGS Multi-GNSS Pilot Project. Changes in the MGPP products cover additional constellations and the inclusion of the midnight (24:00) epoch in orbit and clock product files. All ACs now cover the global systems GPS, GLONASS, Galileo, and BeiDou.

- Inclusion of the midnight epoch:
  - SHAO: 56/2024
  - GFZ: 186/2024
  - CNES/CLS: 196/2024 (Loyer , 2024)
- JAXA covers BDS-2 and BDS-3 in their products starting with GPS week 2334, (29-Sep-2024).

Table 2: Analysis centers contributing to the IGS MGPP as of December 2024.

Institution	Abbr.	GNSS
CNES/CLS	GRG0MGXFIN	GPS+GLO+GAL+BDS2+BDS3
CODE	COD0MGXFIN	GPS+GLO+GAL+BDS2+BDS3+QZS
GFZ	GFZ0MGXRAP	GPS+GLO+GAL+BDS2+BDS3+QZS
IAC	IAC0MGXFIN	GPS+GLO+GAL+BDS2+BDS3+QZS
JAXA	JAX0MGXRAP	GPS+GLO+GAL+BDS2+BDS3+QZS
SHAO	SHA0MGXRAP	GPS+GLO+GAL+BDS2+BDS3
Wuhan University	WUM0MGXFIN	GPS+GLO+GAL+BDS2+BDS3+QZS

Several ACs and individual members of the MGPP contribute to IGS BDS-3/QZSS satellite antenna calibration campaign. The aim of that campaign is to provide a set of BDS-3 and QZSS satellite antenna phase patterns and phase center offsets consistent with the IGS20/IGb20 reference frame in order to include these systems also in the operational IGS products. More details are given in the report of the Reference Frame Product Committee.

Multi-GNSS differential code bias (DCB) products are generated by CAS and GFZ (daily rapid products) as well as DLR (quarterly final product). The transition of the MGEX DCB products to operational (OPS) IGS products officially took place on 23 January 2024 but both ACs generating daily products provided their files in both flavors for a transition period of about eight weeks.

5 Satellite Metadata

A new version 1.10 of the IGS satellite metadata format has been published (Steigenberger and Montenbruck, 2024) and approved by the IGS Governing Board. The major change of this version is an additional `SATELLITE/PLANE` block. In addition to the orbital plane, the slot within the plane is given. This information has been requested by the IGS Combination Task Force to allow for a plane-specific grouping/weighting in the combination. The latest version of the IGS satellite metadata file is available at https://files.igs.org/pub/station/general/igs_satellite_metadata.snx.

Lockheed Martin published the phase center offsets of the 6th GPS III satellite G079 (GSC, 2024). Antenna patterns for G079 are currently still missing. Antenna calibrations, spacecraft mass, center of mass, and laser retro reflector location for the first pair of Galileo FOC satellites launched in 2024 have been published by the European GNSS Service Center (GSC, 2024).

6 Combination Task Force

The Combination Task Force (CTF) established in the context of the MGPP continued its efforts to advance, implement, and validate concepts for combination of multi-GNSS products. Several online meetings were held in the reporting period and intermediate results were presented at the IGS Workshop in the middle of 2024. The CTF presently comprises a total of 19 members including recent additions from the Chinese Academy of Sciences. Work in 2024 included the study of algorithmic improvements and the validation of variance component estimation (VCE) based orbit combination schemes, with specific attention to the newly proposed sequential formulation. This promises more robust weighting in case of satellite-specific weight determination.

Geoscience Australia (GA) released their newly developed Robust Orbit Combination Software (ROCS) with mean absolute deviation (MAD) based weighting for public use (Geoscience Australia, 2024), and GFZ Helmholtz Centre for Geosciences (GFZ) is likewise preparing a public release of its VCE-based Satellite Precise Orbit and Clock Combination (SPOCC) software (Mansur et al., 2024). A dedicated campaign has been setup to systematically compare VCE and MAD based combination results from the two software packages using a one-year data set of multi-GNSS products from the current OPS and MGX chains of various IGS analysis centers. Based on the findings of this campaign, a recommendation for the new analysis center coordinator (ACC) can be developed concerning the software package which appears most suitable for the implementation of an operational multi-GNSS orbit and clock combination within the IGS.

Acronyms

CAS	Chinese Academy of Sciences
CLS	Collecte Localisation Satellites
CTF	Combination Task Force
CNES	Centre National d'Etudes Spatiales
CODE	Center for Orbit Determination in Europe
DLR	Deutsches Zentrum für Luft- und Raumfahrt
GA	Geoscience Australia
GFZ	GFZ Helmholtz Centre for Geosciences
IAC	Information and Analysis Center for Positioning, Navigation and Timing
JAXA	Japan Aerospace Exploration Agency
MGPP	Multi-GNSS Pilot Project
SHAO	Shanghai Observatory
WU	Wuhan University

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Precise Point Positioning with Ambiguity Resolution Pilot Project Technical Report 2024

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1 Introduction

The precise point positioning with ambiguity resolution (PPP-AR) Working Group (WG) was established in 2018, and after the 65$^{\text{th}}$ Governing Board Meeting in 2023, the PPP-AR working group was renamed to the PPP-AR Pilot Project (PP). The aim of the PPP-AR PP is to analyze the feasibility and benefits of adopting a modernized combination process considering the consistency of the satellite clock and code/phase bias products. Based on the achievements before 2023, the goal of the IGS PPP-AR PP for the next stage is to routinely cross-validate each contributing AC's phase clock/bias products and encourage their continuing efforts in improving phase bias qualities and developing multi-frequency phase clock/bias products.

2 Latest progress of phase bias products from each existing AC

In 2024, some enhancements were witnessed on products from some ACs, and products from Huazhong University of Science and Technology (HUS) are included in the product combination and assessment, especially for BDS products.

1. CODE MGEX products have incorporated QZSS phase OSBs (Fig. 1), and the code OSBs on baseline frequencies have ceased being zero values (Fig. 2).

```
OSB  J004 J03           L1C      2024:302:00000 2024:303:00000 ns                  0.37913     0.00000
OSB  J004 J03           L1L      2024:302:00000 2024:303:00000 ns                  0.37913     0.00000
OSB  J004 J03           L1X      2024:302:00000 2024:303:00000 ns                  0.37913     0.00000
OSB  J004 J03           L1Z      2024:302:00000 2024:303:00000 ns                  0.37913     0.00000
OSB  J004 J03           L2L      2024:302:00000 2024:303:00000 ns                  0.66087     0.00000
OSB  J004 J03           L2S      2024:302:00000 2024:303:00000 ns                  0.66087     0.00000
OSB  J004 J03           L2X      2024:302:00000 2024:303:00000 ns                  0.66087     0.00000
OSB  J005 J04           L1C      2024:302:00000 2024:303:00000 ns                 -0.37688     0.00000
OSB  J005 J04           L1L      2024:302:00000 2024:303:00000 ns                 -0.37688     0.00000
OSB  J005 J04           L1X      2024:302:00000 2024:303:00000 ns                 -0.37688     0.00000
OSB  J005 J04           L1Z      2024:302:00000 2024:303:00000 ns                 -0.37688     0.00000
OSB  J005 J04           L2L      2024:302:00000 2024:303:00000 ns                 -0.65723     0.00000
OSB  J005 J04           L2S      2024:302:00000 2024:303:00000 ns                 -0.65723     0.00000
OSB  J005 J04           L2X      2024:302:00000 2024:303:00000 ns                 -0.65723     0.00000
```

Figure 1: QZSS phase OSBs in CODE MGEX products

```
OSB  G061 G02           C1C      2024:302:00000 2024:303:00000 ns                 -9.3819      0.0064
OSB  G061 G02           C1W      2024:302:00000 2024:303:00000 ns                -11.1419      0.0000
OSB  G061 G02           C2W      2024:302:00000 2024:303:00000 ns                -18.3501      0.0000
OSB  G069 G03           C1C      2024:302:00000 2024:303:00000 ns                  7.0522      0.0065
OSB  G069 G03           C1W      2024:302:00000 2024:303:00000 ns                  7.7727      0.0000
OSB  G069 G03           C2L      2024:302:00000 2024:303:00000 ns                 13.5046      0.0176
OSB  G069 G03           C2S      2024:302:00000 2024:303:00000 ns                 13.0199      0.0138
OSB  G069 G03           C2X      2024:302:00000 2024:303:00000 ns                 13.5708      0.0168
OSB  G069 G03           C2W      2024:302:00000 2024:303:00000 ns                 12.8011      0.0000
```

Figure 2: Non-zero value code OSBs on baseline frequencies

2. GRG has introduced the MGEX Final products, during which their OPS Rapid bias products have transitioned to the standard Bias-SINEX format. Both the GRG MGEX Final and OPS Rapid products now encompass BDS phase OSBs (Fig. 3).

```
OSB  C219 C37           C2I      2024:301:00000 2024:301:86399 ns                  1.4476      0.8055
OSB  C219 C37           C6I      2024:301:00000 2024:301:86399 ns                  2.4182      0.8423
OSB  C219 C37           L2I      2024:301:00000 2024:301:86399 ns                 -4.3887      0.6944
OSB  C219 C37           L6I      2024:301:00000 2024:301:86399 ns                 -6.6467      0.9808
OSB  C227 C41           C2I      2024:301:00000 2024:301:86399 ns                 14.5187      0.8215
OSB  C227 C41           C6I      2024:301:00000 2024:301:86399 ns                 21.8454      0.8609
OSB  C227 C41           L2I      2024:301:00000 2024:301:86399 ns                -18.5062      0.7077
OSB  C227 C41           L6I      2024:301:00000 2024:301:86399 ns                -28.0275      1.0024
OSB  C226 C43           C2I      2024:301:00000 2024:301:86399 ns                -26.9496      1.0107
OSB  C226 C43           C6I      2024:301:00000 2024:301:86399 ns                -41.0475      1.0444
OSB  C226 C43           L2I      2024:301:00000 2024:301:86399 ns                 27.0744      0.8547
OSB  C226 C43           L6I      2024:301:00000 2024:301:86399 ns                 41.0038      1.2376
```

Figure 3: BDS phase OSBs in GRG OPS Rapid products

3. GFZ MGEX products have resolved the problems in phase OSBs, shown as Fig. 4, and released GPS/Galileo/BDS phase OSBs in standard Bias-SINEX format.

4. The WUM MGEX Rapid and Final products feature all-frequency GPS/Gelileo/BDS phase OSBs, with the Rapid products addressing day-boundary discontinuity issues. In addition, WUM rapid products have incorporated a section dedicated to the Discontinuity of Orbits, Clocks, and Biases (DOCB) within their bias products (Geng et al., 2024).

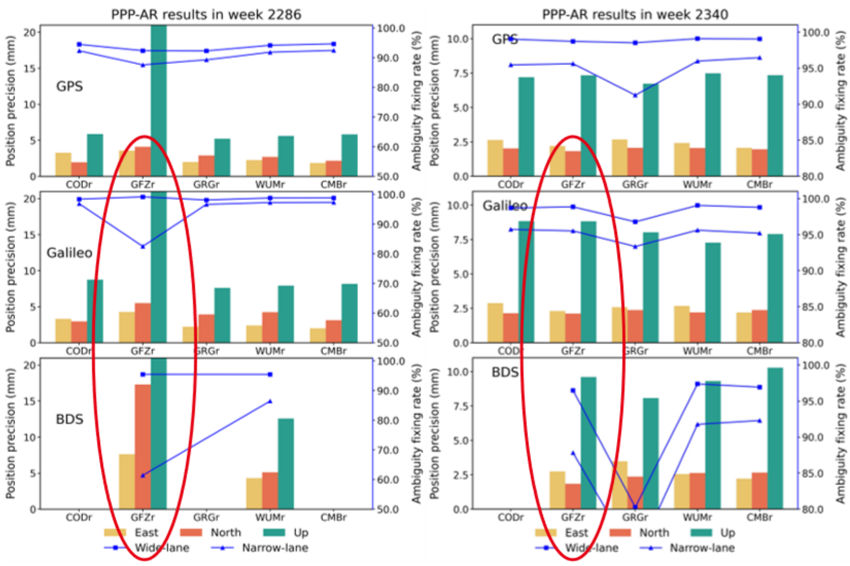

Figure 4: A comparison of GFZ MGEX PPP-AR performance between week 2286 and 2340

3 A new contributing AC since 2024 — HUS

Since Day Of Year (DOY) 285, HUS has been offering GPS/Galileo/BDS-2/BDS-3 MGEX products, accessible via `ftp://ggda.ac.cn/pub/mgex/products`. These products are generated using the Gravity and Orbit Determination Software (GODS), developed by HUS. A special characteristic of this software is that the noise variances for each observation group (categorized by station and GNSS system) are derived from the variance component estimation and are subsequently used for data weighting. The Differential Code Biases (DCBs) are computed using pseudo Slant Total Electron Content (STECs) derived from an uncombined Precise Orbit Determination (POD) process. High-order ionosphere delays in the observations are corrected with the STECs derived from the DCBs computation. The wide-lane UPDs are derived from a Hatch–Melbourne–Wübbena (HMW) analysis, while the narrow-lane UPDs are computed based on the Ionosphere-Free (IF) ambiguities from the POD process and wide-lane ambiguities from the HMW analysis. The wide-lane and narrow-lane UPDs are then converted into OSBs and integrated to the POD process to obtain ambiguity-fixed clocks.

The IGS PPP-AR PP has incorporated their products in the weekly combination since DOY 329, 2024. By the end of 2024, their contribution to the combination amounted to 8.42% for Final products and 9.56% for Rapid products. We conducted an analysis of the PPP-AR performance of HUS, and according to Fig.5, HUS demonstrated comparable ambiguity fixing rates and positioning accuracy to WMC products. Specifically, both the Final (HUSf) and Rapid (HUSr) products successfully supported single-receiver integer ambiguity resolution, with an ambiguity fixing rate exceeding 90% for GPS/Galileo/BDS systems. In terms of position precision, the HUS products performed similarly to the combined products (WMC, accessible at ftp://igs.gnsswhu.cn/pub/whu/phasebias/).

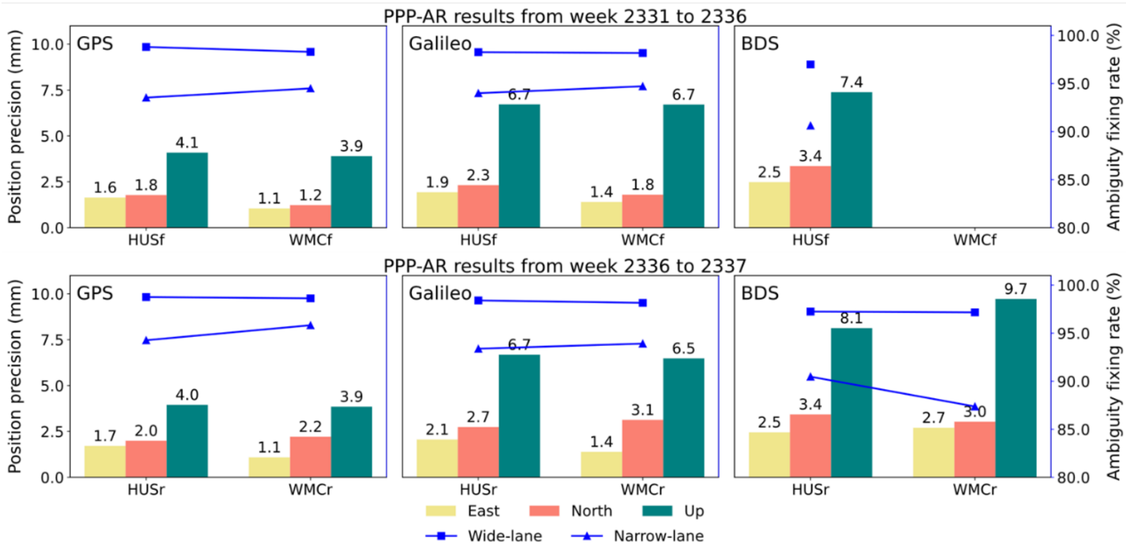

Figure 5: PPP-AR examination of HUS Final and Rapid products.

4 One-year results of the routine PPP-AR product combination

In order to encourage more ACs to provide phase bias products and improve their product quality based on the feedback from the combination, the IGS PPP-AR PP completed the deployment of the daily products combination, and set up the web page to objectively present the results of the product combination and assessment in the form of figures (https://igs.org/wg/ppp-ar/#rapid and https://igs.org/wg/ppp-ar/#final). To date, the routine PPP-AR product combination have been operating and maintaining for one year. The statistics for the relevant results in the one-year period are shown below.

The clock combination employs an iterative weighting method in which the weight assigned to a specific product depends on its residuals in relation to the combined clock. The distribution of weights for each product in the satellite clock and bias combination for a full year in 2024 is shown in Figures 6 and 7.

Meanwhile, the consistency of the clock and bias combination for all products is shown in Figures 8-10, which reflects the precision of clock and bias combination and the consistency between individual ACs. Each grid represents a satellite on a particular day.

In addition, the PPP-AR static solutions with a sampling interval of 300 s from 10 globally

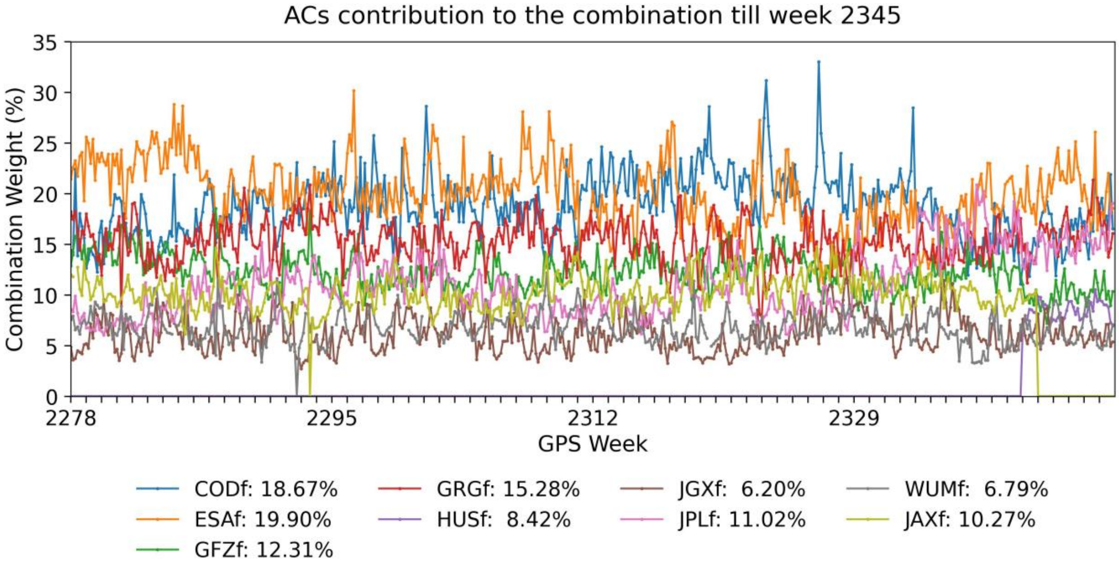

Figure 6: ACs contribution to the Final products combination from week 2278 to 2345

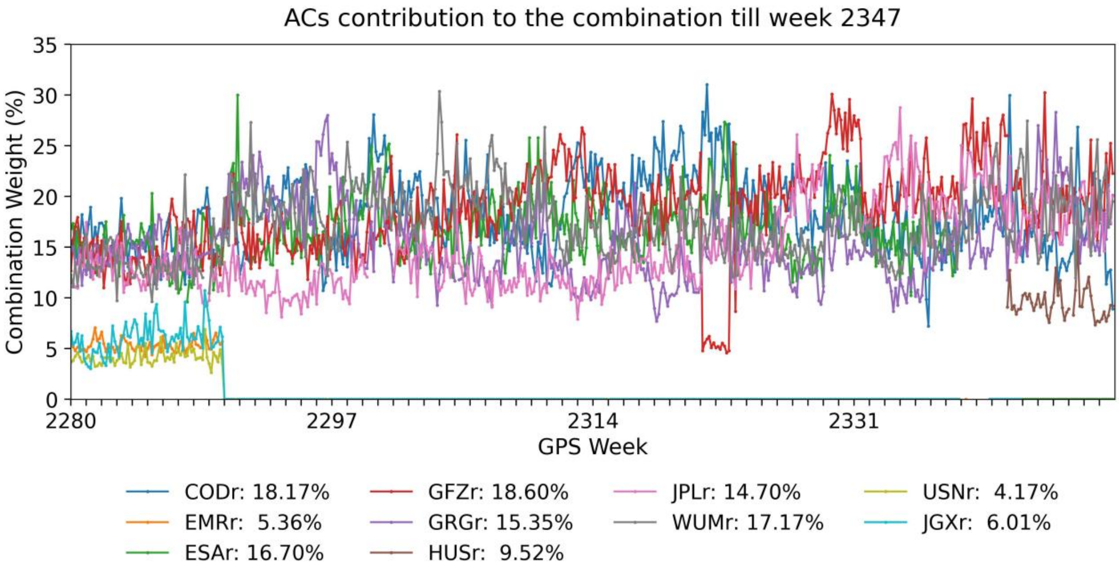

Figure 7: ACs contribution to the Rapid products combination from week 2278 to 2347

distributed stations until the DOY 300 of 2024 are shown in Figure 11, GPS and Galileo wide-lane and narrow-lane ambiguity fixing rate are as follows, where the BDS are not included here, as it was added into the combination in the mid-2024.

In conclusion, the PPP-AR PP will continue to maintain this work, contribute to the

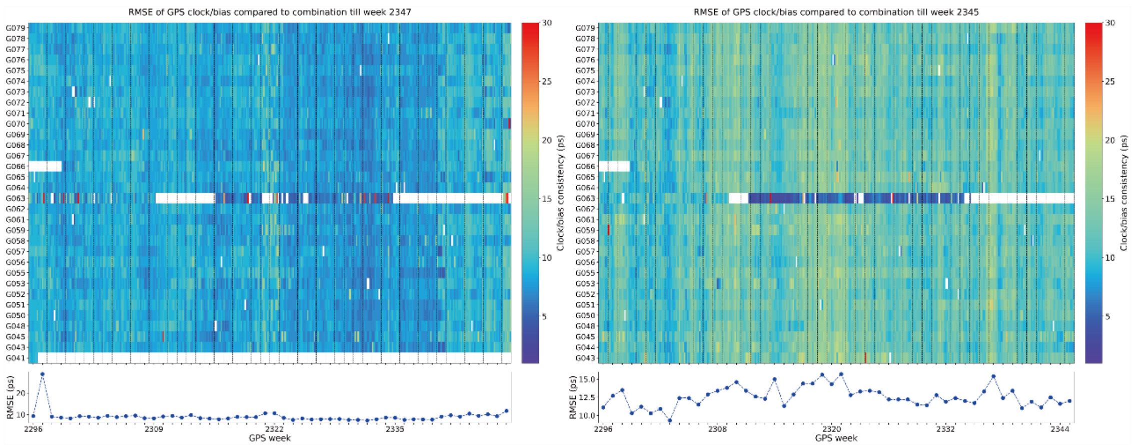

Figure 8: GPS satellite clock/bias combination consistency over the year 2024 (Rapid products for the left panel, Final products for the right panel)

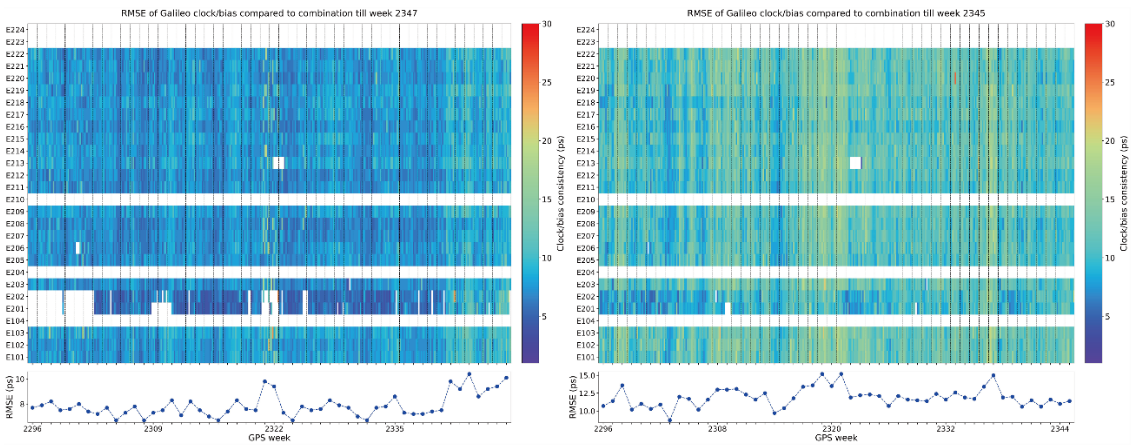

Figure 9: Galileo satellite clock/bias combination consistency over the year 2024 (Rapid products for the left panel, Final products for the right panel)

improvement of the accuracy of PPP-AR products, and provide users with better PPP-AR services.

5 The day-boundary discontinuity mitigation from WUM products

A method for aligning satellite clock and phase bias products at day boundaries has been applied to the WUM Rapid products for the sake of resolving discontinuities in GNSS-based time/frequency transfer. The aligned products allow for the continuity of position

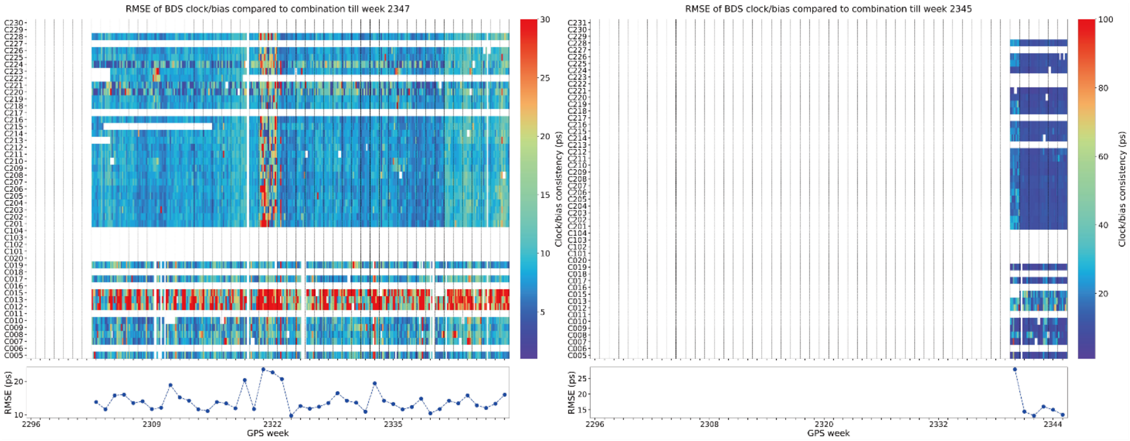

Figure 10: BDS satellite clock/bias combination consistency over the year 2024 (Rapid products for the left panel, Final products for the right panel)

and receiver clock time series in consecutive multi-day PPP-AR processing by holding the continuous and constant ambiguities without resetting at day boundaries. Compared to conventional IGS products, the WUM0MGXRAP product offers additional orbit and clock estimates for each GPS, Galileo, and BDS satellite at the second midnight epoch (24:00:00) in both SP3 and CLK files.
The continuity index at day boundaries, termed as DOCB, is added to the newly defined section “`SOLUTION/DAY_BOUNDARY_DISCONTINUITY`” of the Bias-SINEX file. Though this new block has not been official and is still tentative, it is taken as an attempt to facilitate end PPP users (Lin et al., 2024).

On April 2, 2024, at 23:58:12 UTC, an M 7.4 earthquake occurred off the eastern coast of Hualien. The time of the earthquake occurred near the day-boundary, which made the day-boundary discontinuity issues critical for the products. In order to precisely analyze the effect of the earthquake and obtain its characteristics, precise alignment for PPP-AR products is necessary. We compare the impact of different products by applying them to PPP/PPP-AR using the software PRIDE PPP-AR, and find that providing orbit and clock estimates at the 24:00 epoch may not be sufficient to resolve the day-boundary issues, the alignment of clock and bias products across day boundaries are further required (Figure 12).

In order to further assess the magnitude of day-boundary discontinuity in products from different ACs, we analyze data from over 70 stations, spanning from 2024 DOY 310 to 2024 DOY 333. We compute the DBD values for the east, north and up components, then convert them into 3D coordinates. The heat map of the statistical results is shown below, with each grid representing the average for that day. The total average values are shown in Table 1. Note that all of these products from different ACs provide 24:00 epoch orbit/clock estimates, but WUM0MGXRAP, which performs precise alignment, exhibits

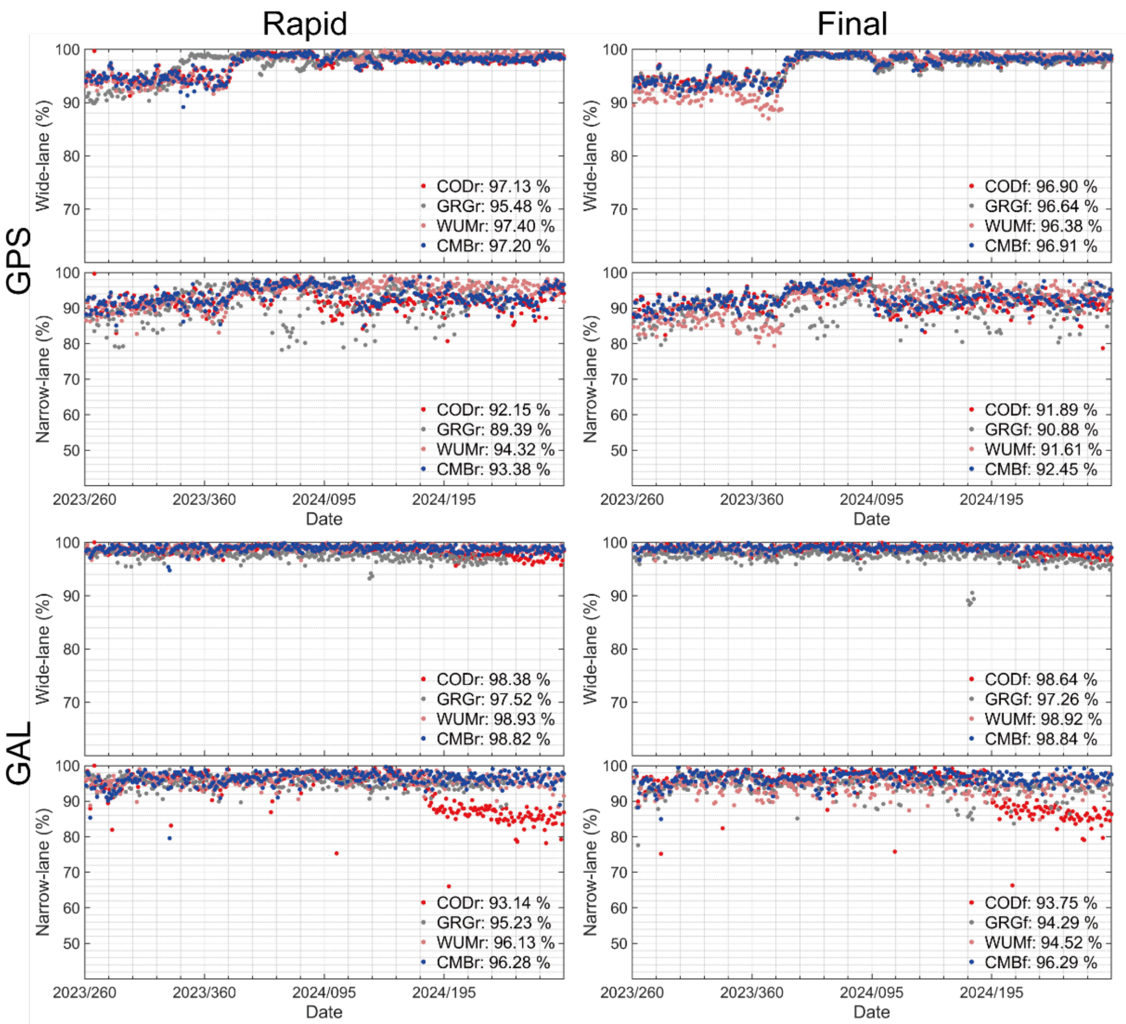

Figure 11: Ambiguity fixing rates for PPP-AR static solutions

the lowest DBD. Therefore, we recommend that ACs perform precise alignment for PPP-AR products, particularly for clock and bias corrections between consecutive days, to reduce the DBD value.

6 Annual virtual meeting

On November 27, 2024, the IGS PPP-AR PP held a virtual meeting to review the progress made over the past year and address some of the technical challenges related to the PPP-AR products. The meeting focused on the contributions of the IGS ACs' PPP-AR products

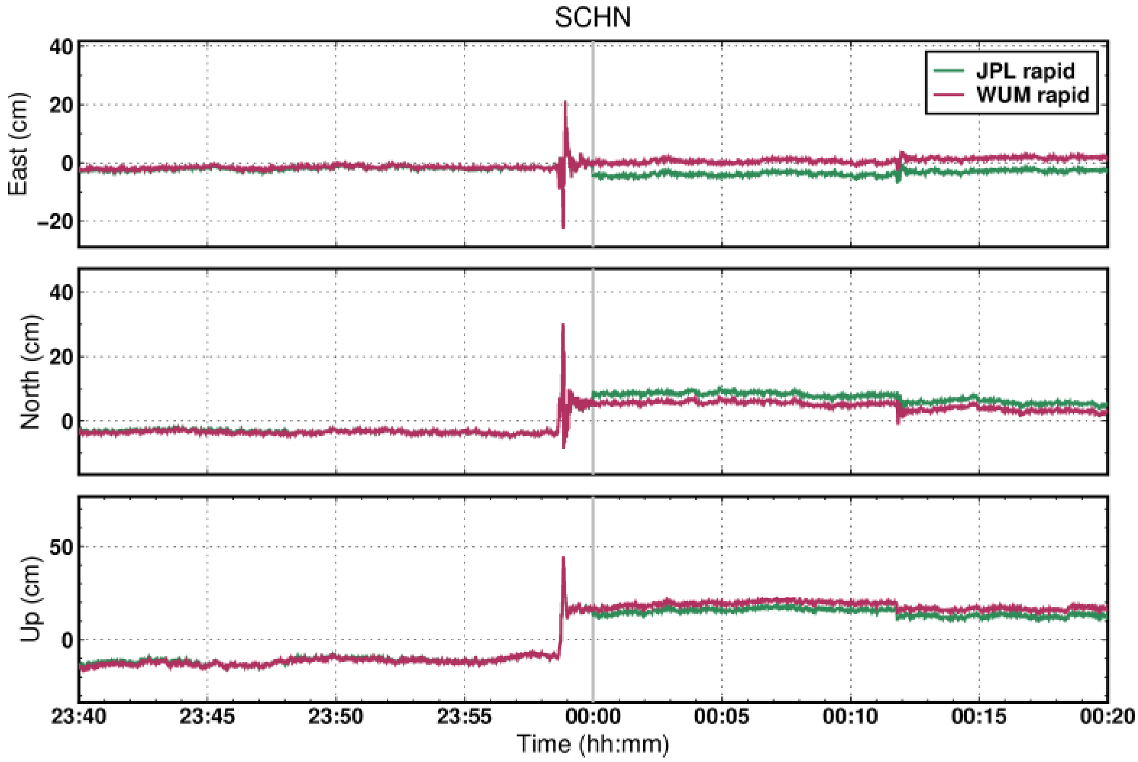

Figure 12: Positioning time series near the earthquake using JPL0OPSRAP and WUM0MGXRAP products (Only GPS used).

and improving interoperability among the products. Key discussions included an overview of the one-year routine combination results for orbit/clock/bias products, the effectiveness of these products in addressing day-boundary discontinuity issues, and the introduction of potential new contributions from HUS. The meeting also examined the need for further improvements and alignment in PPP-AR products to enhance overall performance and consistency for PPP-AR.

In more detail, the meeting began with a review of the progress made by the IGS ACs

Table 1: Total average values of ENU components for different products

Produtcs	East (cm)	North (cm)	Up (cm)	3D (cm)
COD0OPSFIN	0.51	0.57	1.17	1.40
GFZ0MGXRAP	0.69	0.57	1.32	1.60
JPL0OPSRAP	1.21	0.90	1.86	2.39
WUM0MGXRAP	0.51	0.46	1.16	1.35

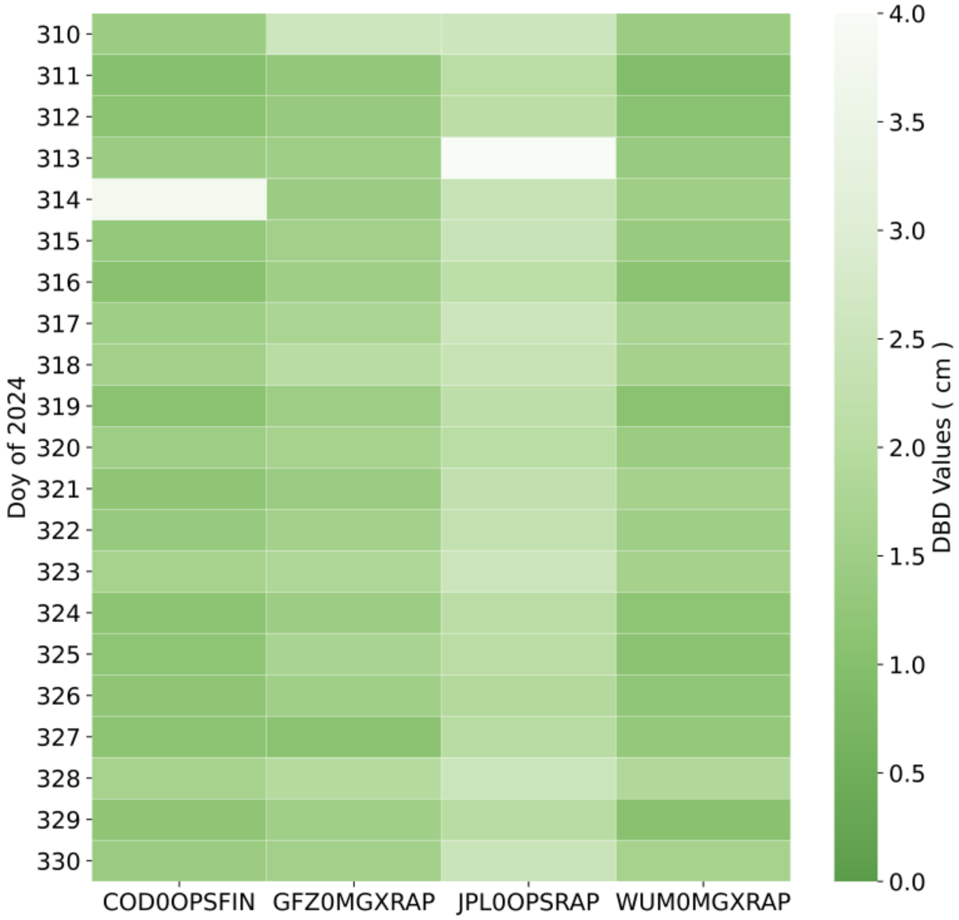

Figure 13: Day-boundary discontinuity values of 3D in one month

in producing PPP-AR products, which have played a critical role in advancing multi-GNSS capabilities. These products have significantly improved the interoperability of orbit/clock/bias data among the IGS ACs. The routine product combination, which has been ongoing for a year, was assessed, and several AC-specific issues were identified through cross-validation. Researchers from GRG, GFZ, and WHU provided explanations for these discrepancies and promised further investigations to implement improvements. The combination process itself was praised for offering an objective evaluation of AC products, resulting in increased interest from additional ACs to participate in the routine

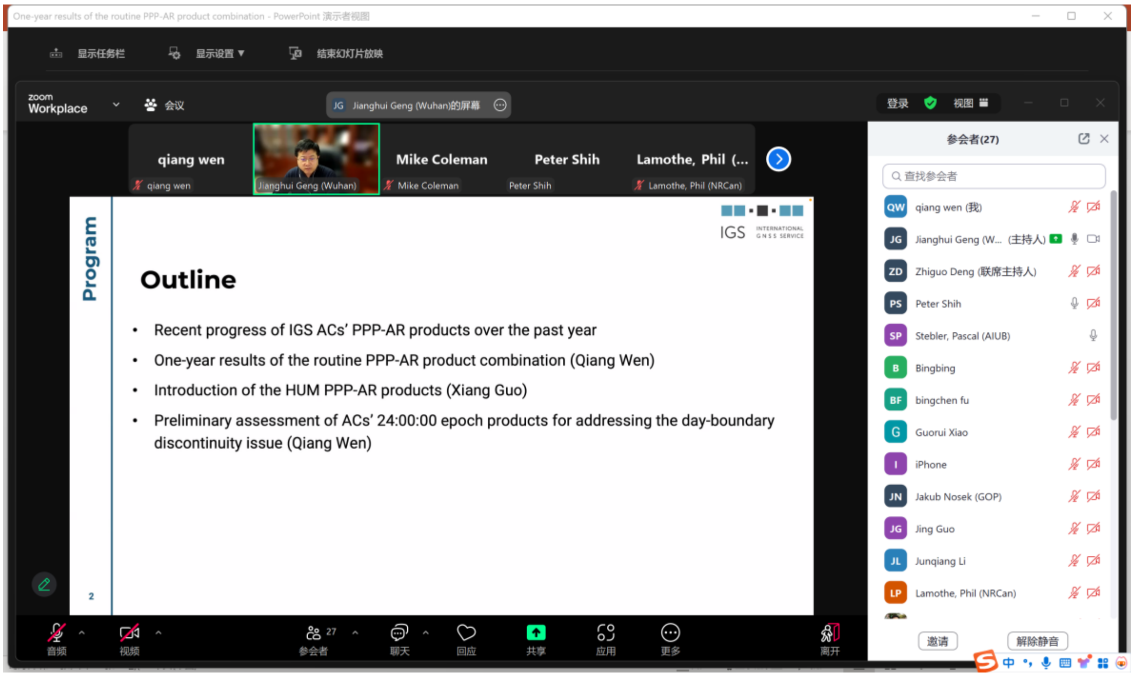

Figure 14: IGS PPP-AR PP Virtual Meeting (November 27, 2024)

combination. Moreover, the products from HUS, including phase bias data for GPS, Galileo, and BDS, were discussed for potential integration into the routine combination, pending quality assurance. The inclusion of HUS products would be particularly beneficial for improving interoperability with BDS. Finally, the issue of day-boundary discontinuity was addressed, with the recommendation that more precise alignment of clock and bias products across consecutive days is needed to resolve the problem effectively.

References

Geng J, Lin J, Zhang Q, Wen Q, Zeng J, Jin B (2024). Phase clock/bias estimation for GNSS all-frequency undifferenced ambiguity resolution. *Acta Geodaetica et Cartographica Sinica*. 53(12):2254-2267.

Lin J, Geng J, Zhang Q (2024). Aligning GPS/Galileo/BDS satellite integer clock products across day boundaries for continuous time and frequency transfer. *(under review)*

IGS Real-Time Committee Technical Report 2024

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1 Introduction

The IGS Real-Time Committee organizes the operation of the IGS Real-Time Service (IGS RTS) and coordinates the handling of real-time GNSS data and products through its data centers. The IGS RTS is providing access to IGS real-time products, such as satellite orbits, satellite clocks, biases and models of the ionosphere. These products are computed by a number of Real-Time Analysis Centers (RT-ACs). The Real-Time Analysis Coordinator (RT-ACC) performs quality control checks tests to these individual products and computes a combined IGS Real-Time product.

The data centers provide access to the real-time observation data streams of the global IGS network and to the IGS RTS products, the products by the individual RT-ACs and the combined IGS products.

2 Committee Activities in 2024

In 2024, the IGS Real-Time Committee had organized a virtual committee meeting in April and a splinter meeting at the occasion of the IGS Workshop in Bern in July.

The IGS Real-Time committee gave presentations at the 18th Meeting of the United Nations International Committee on GNSS (ICG) in October 2024 (Rülke A., 2024; Rülke et al., 2024).

BKG and IGS are members of the Radio Technical Commission for Maritime Services. Andrea Stürze is representing BKG in Special Committee 104 of RTCM. The chairman of the IGS RINEX Committee Francesco Gini is representing the IGS in RTCM.

3 Collaborating IGS Committees

The IGS Real Time Committee collaborates with a number of other IGS Committees. In detail this includes the Infrastructure Committee on the station network, data centres and casters and observation and product data streams, the ionosphere committee on the development of real-time ionosphere products and the PPP-AR committee on biases. The IGS Real-Time committee benefits significantly from this cooperation and it is highly appreciated.

4 Standards and Formats

4.1 RTCM-SSR

An open standard for providing complete sets of State Space Representation (SSR) messages suitable for PPP-RTK with centimeter accuracy is under development in RTCM. Within SC104 a task force was created to push the development. While only very little progress has been made in 2024, the task force has resumed in early 2025.

4.2 IGS-SSR

The IGS-SSR format has been released in October 2020 and is widely used by the GNSS community. The propriety messages are assigned to Message Type 4076 of the RTCM standard 10403.4. Due to the slow progress in the RTCM-SSR format development it was agreed to keep and enhance the IGS-SSR format at the virtual IGS Workshop in 2022. New proposals for this format deal with satellite attitude, satellite offset satellite PCV/GDV and accuracy information associated to RT-VTEC products. In addition to that, new proposals on metadata, ionosphere and troposphere messages need to be discussed.

4.3 RTCM Transformation Messages

New coordinate transformation message standards have been released by RTCM. This covers message types 1300, 1301 and 1302 and allows to provide Helmert transformation parameters for the transformation between different coordinate reference systems.

5 IGS RT Data Centers

The BKG GNSS Data Center (GDC, https://igs.bkg.bund.de/) provides access to the real time observation data streams of the global IGS network and products of the IGS RTS (Söhne et al., 2024).

The NASA's Archive of Space Geodesy Data provides real time data observation data streams and products. In 2025, CDDIS plans to migrate their website from https://cddis.nasa.gov/ to https://www.earthdata.nasa.gov/. For data access, please check the registration routine at CDDIS and Earthdata websites respectively.

While BKG and CDDIS act as the primary data centers for real time data, there are relay data centers supplying users in specific regions of the Earth: The Global Navigation Satellite System Data Center at Geoscience Australia (GA, https://gnss.ga.gov.au/) supplies user in Australia and the Pacific, the Data Center at the GNSS Research Center in Wuhan (ntrip.gnsslab.cn) supplies the user community in China. Since 2024, the newly established data center at the Chinese Academy of Sciences (CAS, https://igs.bdsmart.cn/) has been delivering additional real-time observation data streams to IGS users. The transmitted data streams, replayed from BKG and GA, are supported by an updated version of the BKG caster software (Wang, N., 2024).

Regional real time data centers hold real time observation data for specific regions, such as the Royal Observatory of Belgium (https://www.euref-ip.be/), the Geodetic Data Archiving Facility of the Italian Space Agency (http://geodaf.mt.asi.it/gps_caster_access.php) and BKG's GDC for EUREF.

6 IGS RTS Analysis Centers and Products

In total, twelve IGS Real-Time Analysis Centers provide individual products to the IGS RTS. These products include satellite orbits and clocks for up to four GNSS, code and phase biases and ionosphere information. The satellite orbits are referenced to Satellite Antenna Phase Center (APC) and Center of Satellite Mass (CoM), respectively. Detailed information on the used data, correction models and parameter modeling of each individual AC's products are being collected. This effort is expected to further enhance the IGS Real Time Service product descriptions on the IGS website.

The full list of IGS Real-Time analysis centers and their products is given at https://igs.org/rts/contributors/#real-time-analysis-centers.

7 Real-Time Analysis Coordinator (RT-ACC)

The Real Time Analysis Coordinator (RT-ACC) monitors the product data streams of the RT-ACs and combines the individual products to the final IGS RT products. The RT-ACC at BKG uses BKG's open source software BKG Ntrip Client (BNC). BNC is an open source multi-stream tool box for a variety of real-time GNSS applications. It can be used to decode, convert and monitor RTCM 2.x and RTCM 3.x data streams and supports real-time PPP, high rate RINEX data centers, real-time GNSS engines and real-time combination. The latest BNC version can be downloaded for a variety of operating systems at https://igs.bkg.bund.de/ntrip/bnc.

8 IGS RTS Products

8.1 IGS RTS broadcast ephemeris data streams

The IGS RT receiver network is used to create a complete set of broadcast ephemeris information for GPS, GLONASS, Galileo (F/NAV and I/NAV), BDS, QZSS and SBAS satellites.

BKG's provides BNC software package and encoded as RTCM V3 messages. The complete and combined data set is provided through BKGs RT caster on mountpoints `BCEP00BKG0`. A number of mountpoints `BCEP0[1-7]BKG0` have been set up at the same caster to provide broadcast ephemerides for each GNSS individually in separate data streams.

Chinese Academy of Sciences (CAS) is providing broadcast ephemeris streams derived from the global IGS network and created by its software BDSMART. There is one data stream available at mountpoint `BCEP00CAS0` including GPS, GLONASS, Galileo and BDS broadcast ephemeris.

GMV is also providing a compiled broadcast ephemeris stream for GPS, GLONASS, Galileo and BDS. The data stream is created by GMV's software magicGNSS and available through mountpoint `BCEP00GMV0`.

JPL provides combined broadcast ephemeris data streams for GPS, GLONASS and Galileo ephemeris. The two data streams at mountpoints `BCEP01JPL0` and `BCEP02JPL0` are created by two GDGPS operations centers.

The complete list of Broadcast Ephemeris products is given at https://igs.org/rts/products/.

8.2 IGS RTS Combined products

The RT-ACC combines the individual AC contributions for orbit and clock corrections to the IGS combined product. The `SSR[A,C]02IGS1` product contains orbit and clock corrections for GPS, GLONASS and Galileo, the `SSR[A,C]03IGS1` provides also BDS corrections. For each product, one data stream refers to the Satellite Antenna Phase Center (APC), another stream refers to the Center of Mass of the satellites (CoM).

There are also three Ionosphere products provided by University of Catalunya (UPC) and Chinese Academy of Sciences (CAS). The ionosphere products contain VTEC spherical harmonic coefficients.

All products are combined in Table 1. There are SSR products using the RTCM-SSR messages (message types 1057 – 1302). The messages type 4076 is a proprietary message type of the IGS and wraps sub-messages for orbit and clock corrections, biases and ionosphere models. A list of IGS sub-message numbers is given at https://igs.org/rts/formats/.

9 IGS RTS product monitoring

A selection of results of the IGS RTS product monitoring can be found at https://igs.org/rts/monitoring/. This includes analyses on the agreement of orbit and clock estimates of the individual RT ACs (cf. Figure 1) or time series of RT precise point positioning (PPP) estimates for selected stations (cf. Figure 2). The monitoring also gives information on the bias and standard deviation of the ionospheric delay correction products. The current validation of ionospheric products is based on GNSS-dSTEC analysis at selected IGS stations. This approach will be extended to a fully independent assessment using DORIS-dSTEC analysis (cf. Figure 3).

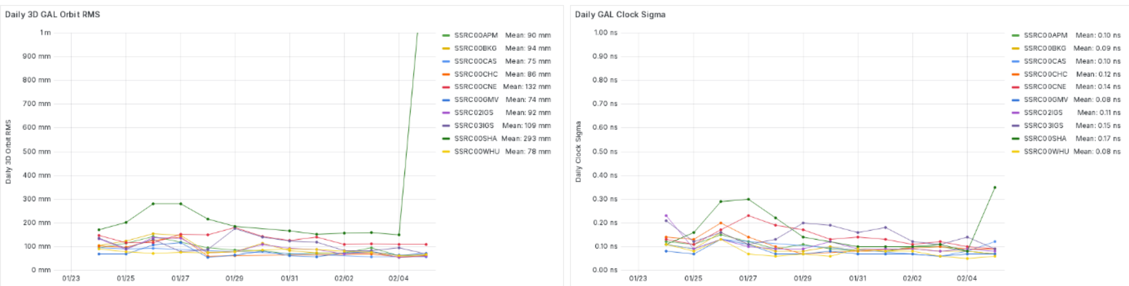

Figure 1: Agreement of real time Galileo orbits (left) and clock (right) products provided by different RT ACs.

Table 1: IGS Real-Time Service combination products.

Stream Name	Description	Ref. Point	IGS-SSR Messages and sampling [s]	Soft-ware
SSRA02IGS0	Orbit/Clock Correction, Kalman Filter Combination RTCM-SSR: G, R, E	APC	1057(10), 1058(10), 1063(10), 1064(10), 1240(10), 1241(10), 1300(60), 1302(60)	BKG
SSRC02IGS0	Orbit/Clock Correction, Kalman Filter Combination RTCM-SSR: G, R, E	CoM	1057(10), 1058(10), 1063(10), 1064(10), 1240(10), 1241(10), 1300(60), 1302(60)	BKG
SSRA02IGS1	Orbit/Clock Correction, Kalman Filter Combination IGS-SSR: G, R, E	APC	4076_021(10), 4076_022(10), 4076_041(10), 4076_042(10), 4076_061(10), 4076_062(10)	BKG
SSRC02IGS1	Orbit/Clock Correction, Kalman Filter Combination IGS-SSR: G, R, E	CoM	4076_021(10), 4076_022(10), 4076_041(10), 4076_042(10), 4076_061(10), 4076_062(10)	BKG
SSRA03IGS0	Orbit/Clock Correction, Kalman Filter Combination RTCM-SSR: G, R, E, C	APC	1057(10), 1058(10), 1063(10), 1064(10), 1240(10), 1241(10), 1258(10), 1259(10), 1300(60), 1302(60)	BKG
SSRC03IGS0	Orbit/Clock Correction, Kalman Filter Combination RTCM-SSR: G, R, E, C	CoM	1057(10), 1058(10), 1063(10), 1064(10), 1240(10), 1241(10), 1258(10), 1259(10), 1300(60), 1302(60)	BKG
SSRA03IGS1	Orbit/Clock Correction, Kalman Filter Combination IGS-SSR: G, R, E, C	APC	4076_021(10), 4076_022(10), 4076_041(10), 4076_042(10), 4076_061(10), 4076_062(10), 4076_101(10), 4076_102(10)	BKG
SSRC03IGS1	Orbit/Clock Correction, Kalman Filter Combination RTCM-SSR: G, R, E, C	CoM	4076_021(10), 4076_022(10), 4076_041(10), 4076_042(10), 4076_061(10), 4076_062(10), 4076_101(10), 4076_102(10)	BKG
IONO00IGS1	Global Ionospheric Model		4076_201(15)	UPC
IONO01IGS0	Global Ionospheric Model		1264(30)	CAS
IONO01IGS1	Global Ionospheric Model		4076_201(30), 4076_202(30)	CAS

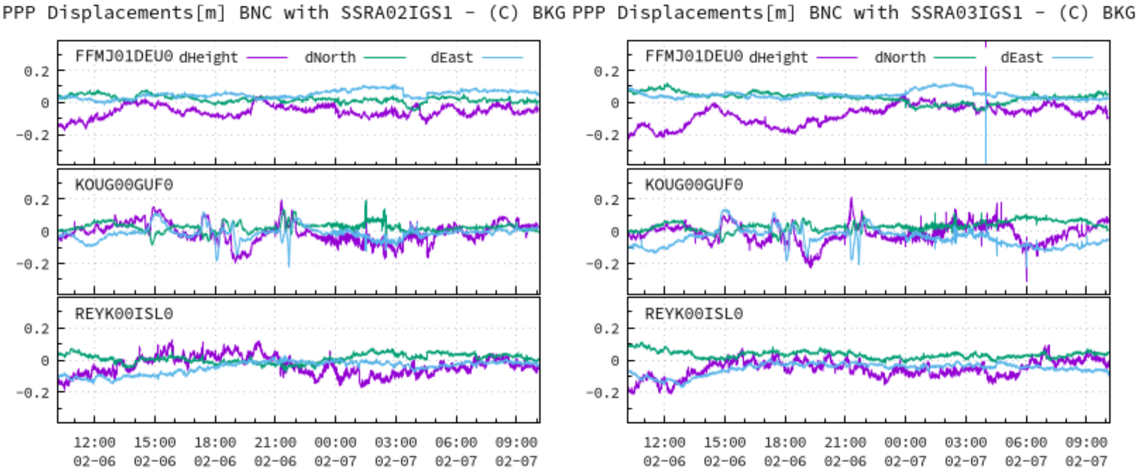

Figure 2: Real Time Positioning estimates of PPP solutions using IGS RTS products `SSRA02IGS1` (left) and `SSRA03IGS1` (right). The PPP client Software BNC is used to estimate for positions of stations FFMJ (Frankfurt, Germany), KOUG (Kourou, French Guinea) and REYK (Reykjavik, Iceland) at February 6$^{\text{th}}$ and 7$^{\text{th}}$ 2025. In this example, the position estimates are significantly influenced by an active ionosphere.

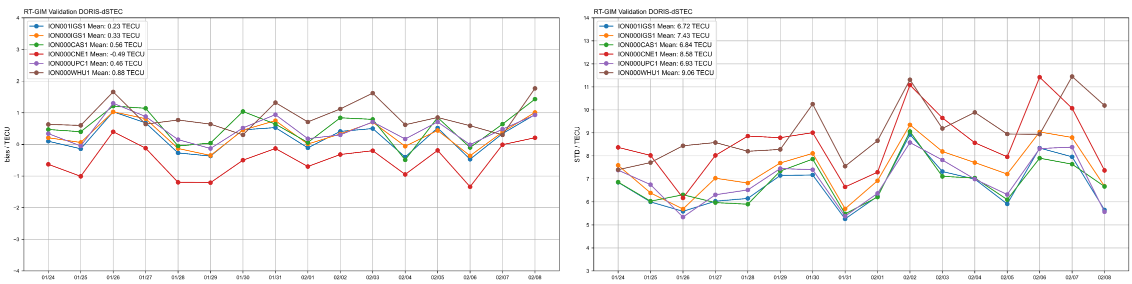

Figure 3: Performance assessment of global ionospheric products provided by different RT ACs using independent DORIS observation data (January 24$^{\text{th}}$ to February 8$^{\text{th}}$ 2025).

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Reference Frame Committee Technical Report 2024

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Besides operational combinations of the daily terrestrial frame (SINEX) solutions provided by the IGS Analysis Centers as part of their final products (Section 1), the Reference Frame Committee activities in 2024 included:

- the publication of an article on an "Analysis of the IGS contribution to ITRF2020" in Journal of Geodesy (Rebischung et al., 2024),
- the definition of a new reference frame for the IGS products, IGb20, based on the first annual update of ITRF2020, ITRF2020-u2023 (Section 2),
- contributions to the IGS campaign for the calibration of the BDS-3 and QZSS satellite antennas (Section 3).

1 Operational SINEX combinations

The main operational task of the Reference Frame Committee is to combine the daily terrestrial frame (SINEX) solutions provided by the IGS Analysis Centers (ACs) as part of their final products. The daily combined SINEX solutions thus obtained contain the official daily IGS station position and Earth Rotation Parameter (ERP) estimates. The residuals from the daily SINEX combinations additionally allow evaluating the consistency and quality of the SINEX solutions provided by the different ACs. Since GPS week 2238 (November 27, 2022), the daily IGS combined SINEX solutions have been, like the other IGS products, aligned to the IGS20 reference frame and consistent with the igs20.atx set of antenna phase center corrections (see Rebischung, 2023a; Villiger, 2023, for more details on the IGS20/igs20.atx framework).

Figure 1 shows the WRMS of the Analysis Center (AC) station position residuals from the daily IGS SINEX combinations, i.e., the global level of agreement between the AC

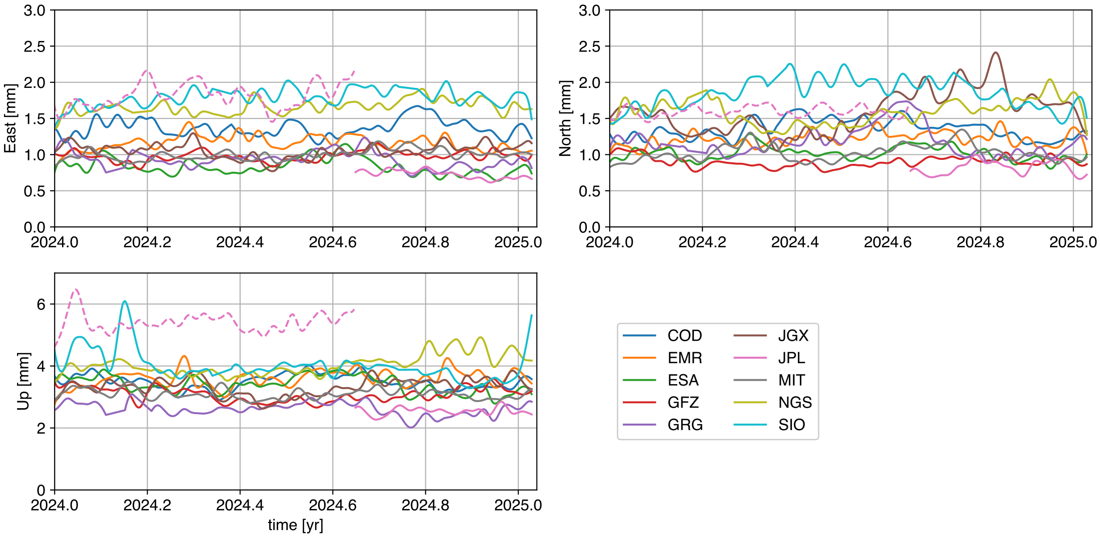

Figure 1: WRMS of AC station position residuals from the 2024 daily IGS SINEX combinations. All WRMS time series are low-pass filtered with a 20 cpy cutoff frequency.

and IGS combined station positions once reference frame differences have been removed, since the beginning of 2024.

The WRMS of the AC station position residuals have remained at similar stable levels as in the previous years, with just one notable exception: on GPS week 2329 (August 25, 2024), JPL switched from the IGb14/igs14.atx to the new IGS20/igs20.atx framework, as well as to a new processing strategy, which brought the WRMS of their residuals among the lowest. JPL solutions have been included back with weight in the IGS SINEX combinations since then.

2 IGb20 reference frame

The successive IGS reference frames, to which IGS products are aligned, are essentially extracts of stable IGS station coordinates from the successive realizations of the International Terrestrial Reference Frame (ITRF). However, station coordinates from a given ITRF realization are known to progressively degrade with time (Rebischung, 2023b). Two different effects contribute to this progressive degradation. First, random errors in the ITRF station trajectory models, which are determined from data up to a certain point in time, naturally grow as these models are extrapolated beyond that point. Second, GNSS stations are occasionally affected by position discontinuities due to earthquakes, equipment changes, or other unidentified causes. Discontinuities posterior to the end of the input data of a given ITRF are obviously not represented in the station trajectory models of that ITRF. More and more ITRF station trajectory models thus become outdated as new discontinuities occur, and more and more IGS reference frame stations therefore become unusable for operational alignment of the IGS products.

This progressive obsolescence of ITRF coordinates is the reason why intermediate updates of the IGS reference frame had previously been made in between ITRF releases. The last such intermediate frame was IGb14 (IGSMAIL #7921), which succeeded the ITRF2014-based IGS14 frame (IGSMAIL #7399) and preceded the current ITRF2020-based IGS20 frame (IGSMAIL #8238). The progressive obsolescence of the ITRF coordinates is also one of the reasons why the International Earth Rotation and Reference Systems Service (IERS) committed to provide yearly updates of ITRF2020 until a full new version of the ITRF becomes necessary. The IGS Analysis Centers agreed on implementing the ITRF2020 updates as they become available, in the form of updates to the IGS20 reference frame.

The first ITRF2020 update, called ITRF2020-u2023, was recently released (IGSMAIL #8542). A first update to the IGS20 reference frame, called IGb20, was subsequently defined. It is a simple extract of ITRF2020-u2023 coordinates for 343 stable, well-performing, operational and historical IGS stations. The same 332 stations as in the current IGS reference frame, IGS20, were retained, while 11 new stations were added in areas currently sparsely covered by IGS reference frame stations – see their distribution in Figure 2. More details on the IGb20 reference frame and its usage may be found in IGSMAIL #8543.

IGb20 will be adopted for the alignment of the IGS products starting with the products of GPS week 2352 (February 2, 2025).

Since ITRF2020-u2023 is aligned in origin, scale and orientation to ITRF2020, IGb20 should not be considered as a complete new reference frame, but rather as an update to individual IGS20 station coordinates. This alignment implies that the transformation parameters between ITRF2020 (IGS20) and ITRF2020-u2023 (IGb20) are all zero. It also implies that the switch from IGS20 to IGb20 will not introduce any significant "datum" change in the IGS products. On the other hand, the precision and accuracy of the alignment of the IGS products to the reference frame will benefit from the adoption of updated reference station coordinates.

3 BDS-3 / QZSS satellite antenna calibration campaign

In the perspective of developing fully multi-GNSS IGS products, a campaign for an empirical calibration of the BeiDou and QZSS satellite antennas was initiated by the IGS Reference Frame Committee, Multi-GNSS Pilot Project and Antenna Committee in the end of 2023. The overall aim of the campaign is to incorporate the BeiDou and QZSS constellations into the IGS operational processing, while minimizing any possible adverse impact on the IGS terrestrial frame products, as well as on the access to the ITRF by

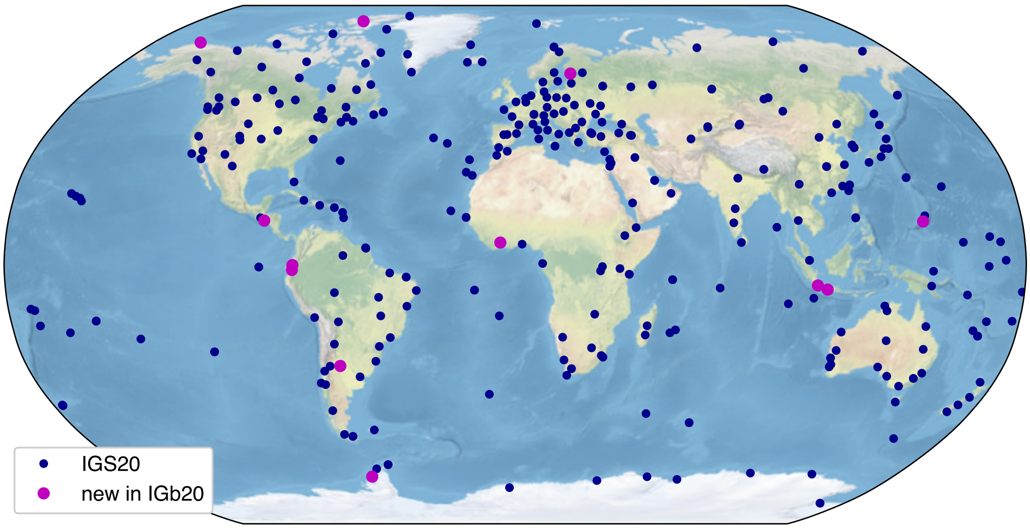

Figure 2: Distribution of the IGb20 reference frame stations.

users of the IGS orbit and clock products. Given the differences observed between the manufacturer calibrations and empirical calibrations of the BDS-3 satellite antennas in particular (e.g., Zajdel et al., 2022), a necessary preparatory step for that purpose is to incorporate into the current IGS ANTEX file (igs20.atx) empirical phase variation patterns and phase center offsets for the BeiDou and QZSS satellites compatible with the IGS20 reference frame.

In the first step of the campaign, phase variation patterns were estimated for the BDS-3 satellites and the B1C/B2a frequency combination. Contributions from six ACs were combined and compiled by Steigenberger et al. (2024) into an intermediate ANTEX file. In the second step of the campaign, phase center offsets (PCOs) have been estimated by eight ACs for the BDS-3 (B1C/B2a) and QZSS (L1C/L5) satellites. At the time of writing, the PCO estimation results are still being discussed, but the incorporation of combined empirical BDS-3 and QZSS satellite antenna calibrations into igs20.atx is expected in the near future. A journal article presenting the phase variation and PCO estimation results will also be written.

Afterwards, the impact of adding the BDS-3 and/or QZSS constellations into the operational processings of individual ACs willing to do so will be assessed on a case-by-case basis. The impact on the terrestrial frame products (resp. GPS, GLONASS, Galileo orbit and clock products) will be assessed by the Reference Frame Committee (resp. Analysis Center Coordinator) from parallel series of test solutions, after which decisions will be taken on the incorporation of the new systems in the AC operational products.

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IGS Troposphere Committee Technical Report 2024

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1 Introduction

The IGS Troposphere Working Group (IGS TWG) was founded in 1998. The United States Naval Observatory (USNO) assumed chairmanship of the WG as well as responsibility for producing IGS Final Troposphere Estimates (IGS FTE) in 2011. In 2023, the current working groups of the IGS were transitioned to committees, thus making the former Troposphere Working Group now the Troposphere Committee.

Dr. Sharyl Byram has chaired the working group/committee since December 2015 and also oversees production of the IGS FTEs. IGS FTEs are produced within the USNO Earth Orientation Department GPS Analysis Division, which also hosts the USNO IGS Analysis Center.

2 IGS Final Troposphere Product Generation 2024

USNO produces IGS Final Troposphere Estimates for nearly all of the stations of the IGS network subject to data availability. Each 24-hr site result file provides five-minute-spaced estimates of total troposphere zenith path delay (ZPD), north, and east gradient components, with the gradient components used to compensate for tropospheric asymmetry.

Since January 2017, the IGS Final Troposphere estimates have been generated with Bernese GNSS Software 5.2 (Dach et al., 2015) and in 2023 started using the IGS20 reference frame, the IGS realization of the ITRF2020 reference frame. The processing uses precise point positioning (PPP; Zumberge et al., 1997) and the GMF mapping function (Böhm et al., 2006) with IGS Final satellite orbits/clocks and Earth orientation parameters (EOPs) as input. Each site-day's results are completed approximately three weeks

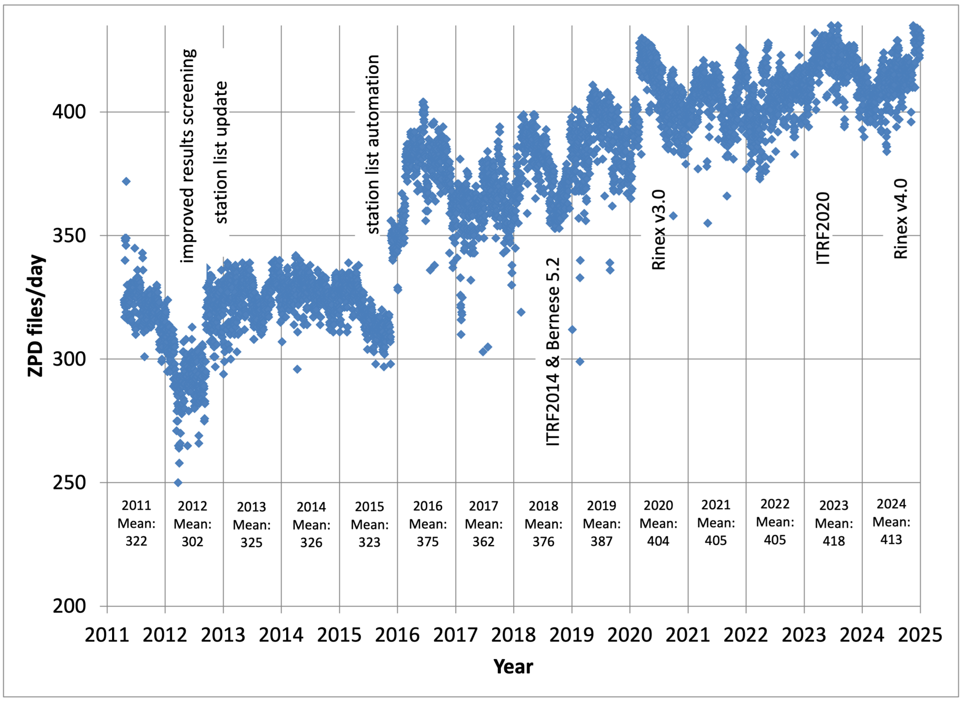

Figure 1: Number of IGS receivers for which USNO produced IGS Final Troposphere Estimates, 2011–2024.

after measurement collection as the requisite IGS Final orbit products become available. Further processing details can be obtained from Byram and Hackman (2012).

Fig. 1 shows the number of receivers for which USNO computed IGS FTEs 2011-2024. The average number of quality-checked station result files submitted per day in 2024 was 413. Fig. 1 is annotated with major changes in the processing of the IGS FTEs, most which result in an increase of produced IGS FTEs. In 2024, the inclusion of Rinex v4.0 files was added resulting in an additional few stations being processed. The result files are available for download from the CDDIS data server at: https://cddis.nasa.gov/archive/gnss/products/troposphere/zpd/.

3 IGS Troposphere Committee Activities 2024

The goal of the IGS Troposphere Committee is to improve the accuracy and usability of GNSS-derived troposphere estimates. It does this by coordinating (a) committee projects and (b) technical sessions at the IGS Analysis Workshops.

The group usually meets once or twice per year: the fall in conjunction with the American Geophysical Union (AGU) Fall Meeting (USA), in the spring/summer, either in conjunction with the European Geosciences Union (EGU) General Assembly (Vienna, Austria), and/or at the IGS Workshop (location varies). Meetings are simulcast online so that members unable to attend in person can participate. Members can also communicate and coordinate activities using the IGS TWG email list.

In 2024, a Troposphere Committee meeting was held in person during the 2024 IGS Workshop in Bern, Switzerland producing the following recommendations which direct committee activities. Communications on news and activities were distributed via the TWG mailing list.

Recommendations from the 2024 Committee Meeting:

1. **Test newer troposphere models in final troposphere estimates**
   GMF is currently being used in the IGS Final Troposphere estimates. The recommendation of the committee is to test new troposphere models including the VMF model. However, there is concern about the 6-hour release discontinuities with the VMF model. Analysis of the effect of these discontinuities will be conducted. Other models will also be investigated as well.

2. **Repro3 reprocessing and comparison**
   The committee recommends that the Repro3 combination products suitability for troposphere reprocessing is investigated. If determined to be a suitable time series for PPP reprocessing, the committee recommends creating a reprocessed troposphere estimate time series consistent with the Repro3 combination products. The committee also recommended to provide comparisons to the AC contributions if available to provide the ACs feedback.

3. **Multi-GNSS investigation**
   The final recommendation from the committee meeting was to begin testing production and analysis quality of a multi-GNSS final troposphere product including other fully operational constellations. The quality analysis of these multi-GNSS estimates should be of combined observations as well as evaluating individual constellation inclusion into the estimates.

4 How to Obtain Further Information

IGS Final Troposphere Estimates can be downloaded from: https://cddis.nasa.gov/archive/gnss/products/troposphere/zpd .

For technical questions regarding the estimates, please contact the Troposphere Committee Chair, Dr. Sharyl Byram, at sharyl.m.byram.civ@us.navy.mil .

To learn more about the IGS Troposphere Committee, you may:

- contact Dr. Sharyl Byram at sharyl.m.byram.civ@us.navy.mil

- visit the IGS Troposphere Committee website: https://twg.igs.org
- subscribe to the IGS Troposphere Committee email list: https://lists.igs.org/mailman/listinfo/igs-twg

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Inclusion, Diversity, Equity, and Accessibility Working Group Technical Report 2024

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1 Introduction

The IGS has made significant strides in improving geographic diversity over the past five years by adjusting its approach to regional representation, strategically recruiting members from underrepresented areas, embracing virtual meetings to accommodate its global workforce, and hosting capacity-building workshops. To ensure long-term sustainability, the IGS must continue fostering inclusive participation and inspiring future leaders.

Supporting this effort, the IGS Governing Board recommended the creation of the IGS Inclusion, Diversity, Equity, and Accessibility Working Group (IDEA WG). This action aligns with Goal 3 of the IGS 2021+ Strategic Plan, which seeks to improve the Service's long-term sustainability and strength.

Building on prior governance initiatives and led by Elisabetta d'Anastasio and Camille Martire, the IDEA WG is dedicated to embedding inclusivity, diversity, equity, and accessibility in all IGS activities and decisions. Its initial focus was to develop a formal statement to communicate IGS' commitment to these important topics (see below). The IDEA Working Group (WG) will assess and enhance these efforts, developing guidelines and metrics to track improvements. Prioritising these efforts will allow the IGS to enhance trust, innovation, and global engagement, all the while reinforcing its position as a leader in the scientific community and supporting an ever-expanding global network.

Unlike most IGS components, which must limit membership to IGS Associate Members and actively engaged individuals, the IDEA WG deliberately maintains an open membership policy. This approach ensures a broad range of perspectives, fostering inclusivity and minimising biases in its efforts. As of December 2024, the IDEA WG has members from Australia, China, India, New Zealand, Philippines, South Africa, Sweden, Switzerland and the United States. The Chair of the International Association of Geodesy DEI Working Group Rebekka Steffen is also a valued member of the working group.

To stay engaged, interested individuals can reach out to the co-Chairs, Elisabetta D'Anastasio and Camille Martire. Additionally, the WG has established a mailing list (https://lists.igs.org/mailman/listinfo/inclusion) to keep members informed and encourage participation. Please feel free to reach out to us, your input is invaluable in shaping a more inclusive and diverse IGS community!

2 Accomplishments in 2024

The IDEA WG created the official IGS Statement on Inclusion, Diversity, Equity, and Accessibility (see https://geodesy.science/idea/working-groups/igs/). It outlines the organisation's commitment to fostering a collaborative, fair, and globally representative environment, and highlights the importance of these topics for the benefit of the Service as a whole. These principles are essential for strengthening the IGS community, improving the quality of GNSS data and services, and supporting a wide range of scientific and societal applications. The IDEA statement was approved by the IGS Governing Board in June 2024, and was made available to the IGS community through the IGS IDEA working group website dedicated page.

Furthermore, the IDEA WG also overhauled the IGS Guidelines and Code of Conduct for IGS Events, which establishes clear expectations for respectful and inclusive participation to all IGS-organised and -sponsored events, while ensuring a professional and welcoming environment. This code of conduct encourages respectful behavior, including valuing diverse perspectives, fostering collaboration, and providing constructive feedback; it strictly prohibits harassment, discrimination, aggression, and disruptive behavior, with examples provided to maintain a safe and professional atmosphere. This document also outlines guidelines on recordings, photographs, and availability of presentations online. Developing this explicit document allows the IGS to ensure its events remain inclusive, productive, and aligned with its mission of global scientific collaboration. These guidelines were namely applied for and used during the 2024 IGS workshop in Bern, Switzerland.

The IDEA Working Group recognises the importance of improving the accessibility of the IGS Guidelines for Continuously Operating Reference Stations, originally published in English by the Infrastructure Committee. With the release of the updated guidelines in English, the IDEA WG coordinated efforts to translate the guidelines into additional languages to better serve the broader IGS community. By the end of 2024, the IGS CORS guidelines were made available in English, German (thanks to Markus Bradke), French (thanks to Camille Martire, Paul Rebischung, and Fernand Balé), and Spanish (thanks to María Virginia Mackern, José Antonio Tarrío Mosquera, Catalina Noelia Cáceres Venegas, and Miguel Marten). The IDEA WG is deeply thankful to all those who contributed to this important effort.

3 Plan Going Forward

The IDEA working group will continue to support and promote the translation of IGS CORS Guidelines into several more languages, as this has been recognised as an important step towards global knowledge sharing and cooperation. IDEA WG members will work towards the CORS guidelines translation in Chinese (Junchen Xue, Haobo Li and Jianghui Geng), Hindi (Chiranjeevi Vivek G and Neelu Kasat) and potentially Arabic and Portuguese. The IDEA WG will be available to promote and support translation efforts and, as required, to coordinate with the Infrastructure Committee to ensure long-term sustainability of translated guidelines.

During the 2024 IDEA WG Splinter session, the IGS ACC guidelines were identified as an important document that, if translated, could better support underrepresented regions and members. During 2025, the IDEA WG will continue to support and encourage the translation of those documents and seek for contribution within the IGS community.

Furthermore, the IDEA WG will review the IDEA statement to include cultural awareness considerations and will update the IGS Guidelines and Code of Conducts for IGS Events to reflect the recommendations and suggestions gathered during the June 2024 IDEA Splinter Session.

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