IGS INTERNATIONAL GNSS SERVICE

TECHNICAL REPORT 2025

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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 2025* 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 2025.

This report is available in electronic version at https://files.igs.org/pub/resource/technical_reports/2025_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.

Contents

I **Executive Reports** 1

Governing Board
No report submitted

Central Bureau
No report submitted

II **Analysis Centers** 3

Analysis Center Coordinator 5
S. Masoumi, T. Herring, T. Yates

Wuhan Combination Center 21
J. Geng, Q. Wen, Y. Zhang, B. Wang

Center for Orbit Determination In Europe 39
R. Dach, D. Arnold, E. Brockmann, M. Kalarus, C. Kobel
M. Lasser, U. Meyer, S. Schaer, P. Stebler, A. Jäggi,
A. Villiger, D. Ineichen, S. Lutz, L. Prange,
D. Thaller, L. Klemm, S. Modiri, A. Rülke, W. Söhne, J. Bouman,
U. Hugentobler, B. Duan

ESA/ESOC IGS Analysis Centre 51

V. Mayer, T. Springer, M. van Kints,
B. Traiser, I. Romero, Iván Sermanoukian Molina,
F. Gini, F. Zimmermann, E. Schönemann

GeoForschungsZentrum 59

B. Männel, Z. Deng, A. Brack, T. Nischan, A. Brandt,
M. Bradke, M. Ramatschi

Centre National d'Etudes Spatiales/Collecte Localisation Satellites 65

S. Loyer, G. Katsigianni, A. Baños Garcia, A. Mezerette,
E. Saquet, A. Naouri, A. Santamaria Gomez, F. Perosanz,
F. Mercier, A. Couhert, J. C. Marty

GSI and JAXA 73

K. Akiyama, T. Miyazaki, S. Abe, K. Kawate,
Y. Igarashi, T. Sasaki, E. Imada, H. Takiguchi, T. Nagano, S. Kogure,
K. Yoshinaga, M. Yokokawa, B. Miyahara

Jet Propulsion Laboratory 81

P. Ries, W. Bertiger, D. Hemberger,
A. Komanduru, D. Murphy, A. Peidou, A. Sibthorpe

Massachusetts Institute of Technology 87

T. Herring

National Geodetic Survey 95

J. Jones, P. McFarland

Natural Resources Canada 101

S. Banville, S. Elson, R. Ghoddousi-Fard, O. Kamali,
P. Lamothe, E. Maia, Y. Mireault, T. Nikolaidou

Scripps Institution of Oceanography

No report submitted

United States Naval Observatory 113
S. Byram, J. Crefton, E. Lovegrove

Wuhan University 119
M. Li, N. Wei, L. Fan, Y. Zhou, Q. Zhao, C. Shi

EUREF Permanent Network Associate Analysis Centre 129
C. Bruyninx, A. Kenyeres, J. Legrand, T. Liwosz,
R. Pacione, W. Söhne, C. Völksen

III Data Centers 137

Infrastructure Committee 139
M. Bradke, R. Ruddick, D. Maggert, W. Söhne

Crustal Dynamics Data Information System
No report submitted

The GNSS Science Support Centre (GSSC) 145
J.C. Berton, S. del Rio García, N. Castrillo Merlán,
E. Schönemann, J. Ventura-Traveset, E. Montagnon

Institut National de l'Information Géographique et Forestière
No report submitted

Korean Astronomy and Space Science Institute
No report submitted

Scripps Institution of Oceanography
No report submitted

Wuhan University 157

M. Li, Q. Zhao

IV Committees, Pilot Projects 161

Antenna Product Committee
No report submitted

Bias and Ambiguity Resolution 163
J. Geng, Q. Wen, S. Banville, Q. Wu, Y. Wang, S. Lyu

Clock Products Committee
No report submitted

GNSS Monitoring Pilot Project
No report submitted

Ionosphere Product Committee 177
A. Krankowski, Z. Li, M. Hernández-Pajares,
A. Froń, K. Kotulak, P. Flisek

Multi-GNSS Pilot Project 183
P. Steigenberger, K. Akiyama, O. Montenbruck

Real-Time Product Committee
No report submitted

Reference Frame Product Committee 191
P. Rebischung, M. de La Serve

RINEX Committee 197
F. Gini, A. Hauschild

Tide Gauge Benchmark Monitoring Product Committee 199
M. Gravelle, G. Wöppelmann

Troposphere Product Committee 205
S. Byram

Inclusion, Diversity, Equity, and Accessibility Working Group
No report submitted

Part I

Executive Reports

Part II

Analysis Centers

Analysis Center Coordinator Technical Report 2025

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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 2025, a primary focus of the IGS Analysis Center Coordinators was the transitioning of the primary ACC operations from Geoscience Australia to NASA and multi-GNSS development (see Section 2). In addition to maintaining the quality of the IGS GPS-only products (Section 3), the ACC continued to provide demonstration multi-GNSS combined products and continued the contributions towards fully multi-GNSS combinations (Section 4).

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
GeoForschungsZentrum Potsdam (GFZ)	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 of primary operations and multi-GNSS development

During 2025, the work was progressed to transition the primary ACC operations from Geoscience Australia to NASA. On-site training and discussion between NASA, MIT and GA staff occurred in early 2025 at the GA office, and further online training and handover occurred during the year. There was a delay in handover of the operations compared to the initial planning of late 2025; however, the work is underway and the transition is expected to occur by July 2026.

A revised roadmap for the ACC transition, including transition to fully multi-GNSS combinations is shown in Figure 1. Testing of multi-GNSS combination software was progressed in 2025, in particular additional testing of clock and bias combinations. This was accompanied by the efforts of the IGS multi-GNSS task force, which provided options to the ACC to use for multi-GNSS product combinations. More details on the multi-GNSS combination efforts and prospects at the ACC are described in Section 4.

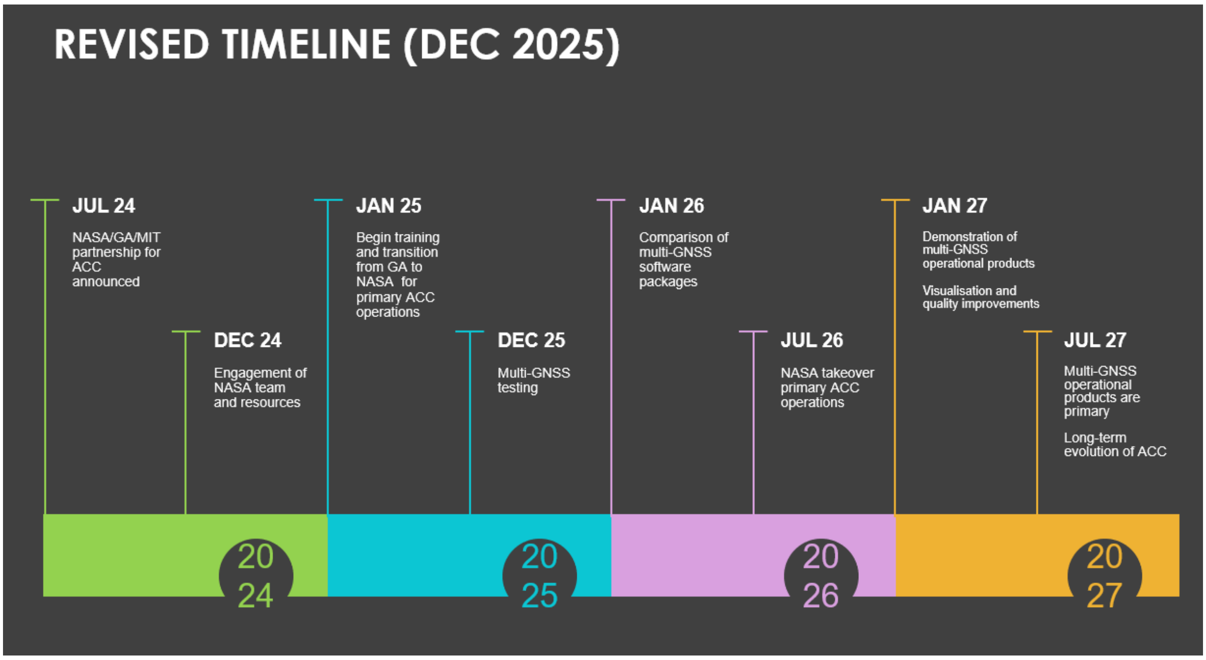

Figure 1: ACC revised transition roadmap as of December 2025.

3 Product Quality and Reliability

In 2025, the delivery of the ultra-rapid, rapid and final products was well within the expected latencies for most of the year (e.g. about 98.4% of the deliveries within the expected latency of 17-41 hours for the rapid products and about 99.9% within the expected latency of real time to 9 hours for the ultra-rapid products). In total, there were six instances of delayed rapid products (of up to 3-5 hours) and only one case of delayed ultra-rapid products (of 2 hours). Two of the delayed products were found to be due to an overflow of CPU or memory usage. There was also one case due to storage disk issue. Two cases of delays were due to issues reading and converting satellite broadcast navigation files, and one case was due to an error in one of the ACC scripts. Quality of the products and consistency of analysis center solutions remained as expected.

3.1 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 2025, IGS received submissions from nine different ACs which were combined to produce IGS ultra-rapid products (see Table 2 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.

Table 2: 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.

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

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 modeling 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.

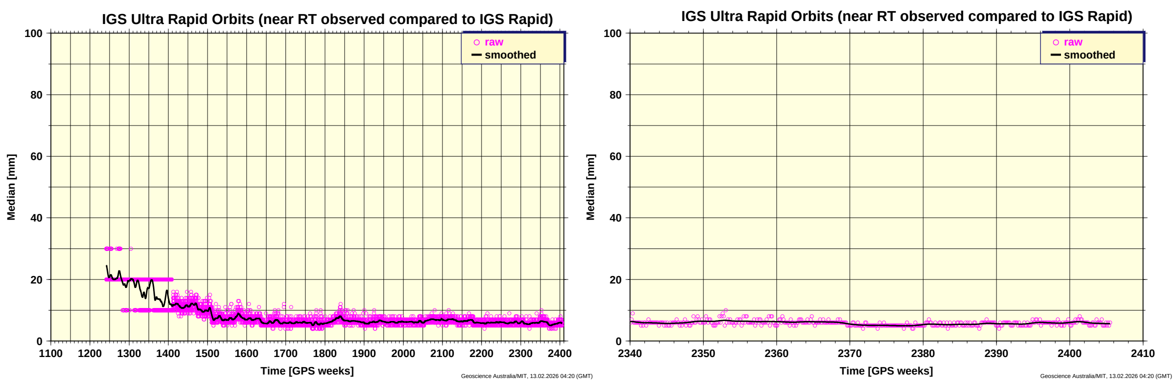

Figure 2: The median difference of the fitted component of the IGS ultra-rapid (IGU) combined orbits with respect to the IGS rapid (IGR) orbits. The historical time series of comparison results is shown on the left, and recent comparison results are shown on the right.

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 32 mm.

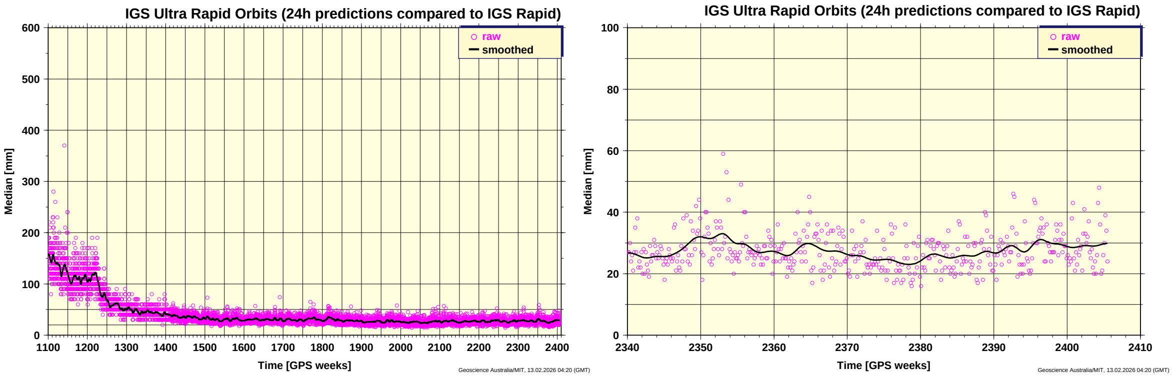

Figure 3: Median of IGU combined predicted orbits compared to IGR. The historical time series of comparison results is shown on the left, and recent comparison results are shown on the right. Note the change in scale of the Y axis.

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. GRG ultra-rapid orbits, currently unweighted, continued to compare well overall to the combined orbits after implementing increased duration of dynamic parameter estimation from 24 hours to 48 hours by the GRG team (Mezerette et al. , 2024). The ACC is still considering weighting the GRG ultra-rapid orbits to include one more AC contribution subject to improvement in modeling of eclipsing satellites.

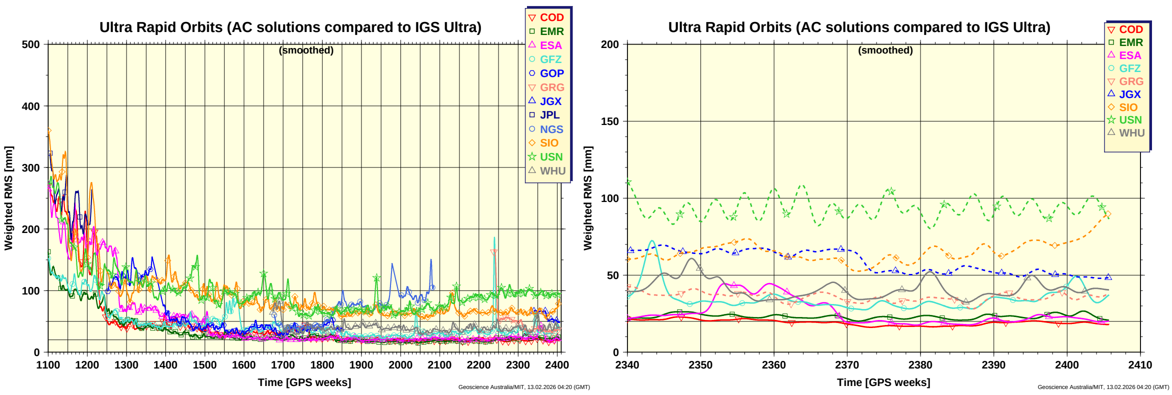

Figure 4: Weighted RMS of AC ultra-rapid orbit submissions (smoothed). The historical time series of comparison results is shown on the left, and recent comparison results are shown on the right. The dashed lines on the figure on the right are the solutions that are unweighted as of February 2026, while the solid lines are the weighted solutions. Note the change in scale of the Y axis.

Table 3: 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

3.2 Rapid

In total, eleven individual analysis centers contributed to the IGS rapid products in 2025 (see Table 3).

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). In addition, the standard deviation of the rapid satellite and station clock solutions was always below 25 picoseconds (ps) for the weighted centers (Figure 6).

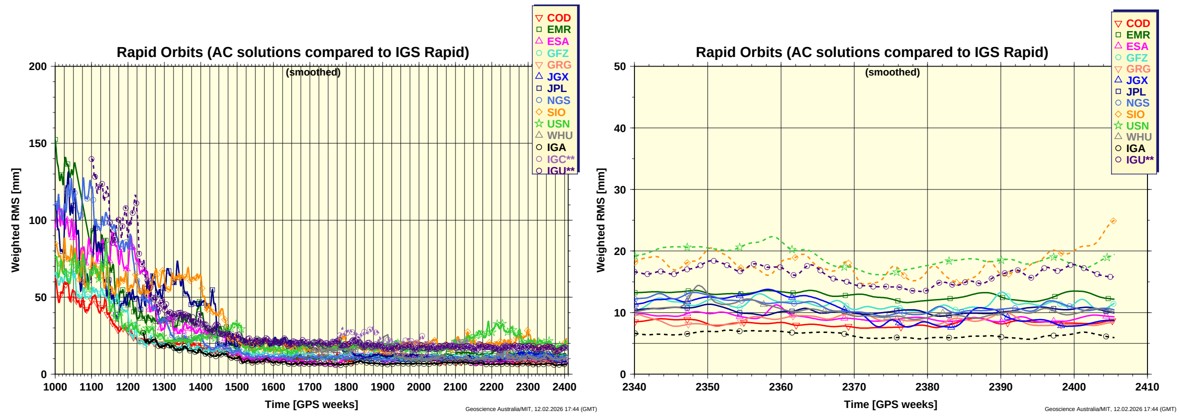

Figure 5: Weighted RMS of ACs rapid orbit submissions (smoothed). The historical time series of comparison results is shown on the left, and recent comparison results are shown on the right. IGC** are 24-hour products each containing four 6-hour segments from each update interval of the IGS real-time 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 2026, while the solid lines are the weighted solutions. Note the change in scale of the Y axis.

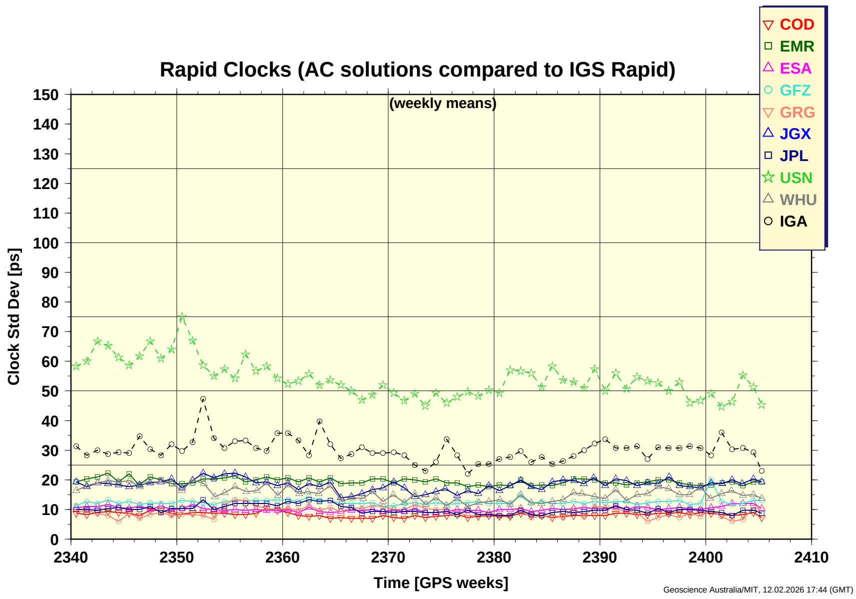

Figure 6: Standard deviation of ACs rapid clock submissions (smoothed). IGC** are 24-hour products each containing four 6-hour segments from each update interval of the IGS real-time stream. IGU** consists of four separate comparisons to IGR done each day over the first 6 hours of each IGS ultra-rapid product. The dashed lines are the solutions that are unweighted as of February 2026, while the solid lines are the weighted solutions.

3.3 Final

In total, there are ten individual ACs contributing to the IGS final products (see Table 4). EMR clocks started to be weighted in the combinations since the products of 04 May 2025 (GPS week 2365) after NRCan improved their clock solutions by including GPS phase biases and using the same software as in the repro3 campaign for their operational products. The significant drop in the standard deviation of the EMR clocks since GPS week 2365 is observed in Figure 8.

Table 4: ACs contributing to the IGS final products; W signifies a weighted contribution, C is comparison only. EMR clocks started to be weighted in the combinations since the products of 04 May 2025 (GPS week 2365).

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	C
JPL	W	W	W
MIT	W	W	C
NGS	W	W	C
SIO	W	C	-

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 standard deviations of the final clock solutions 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 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 5 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.

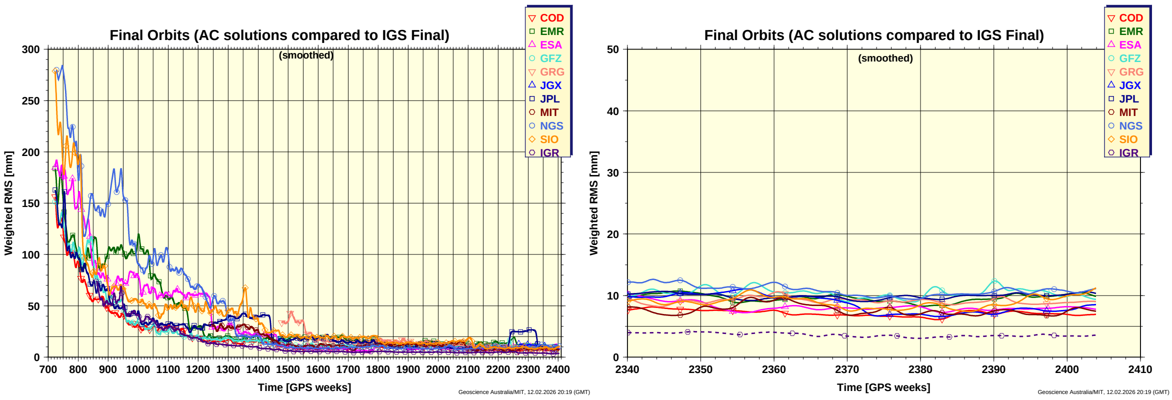

Figure 7: Weighted RMS of IGS final orbits (smoothed). The historical time series of comparison results is shown on the left, and recent comparison results are shown on the right. The dashed lines on the figure on the right are the IGS Rapid orbits that are plotted for comparison only. Note the change in scale of the Y axis.

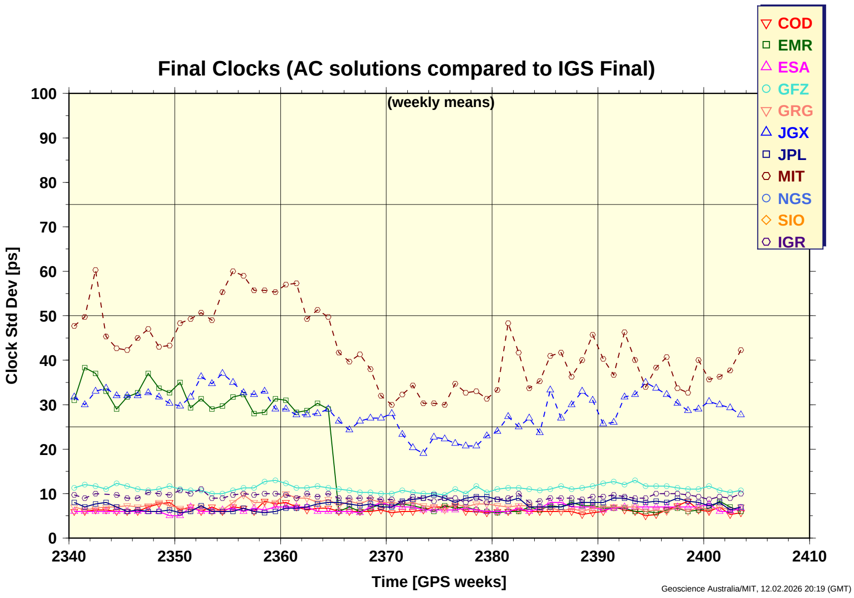

Figure 8: Standard deviation of IGS final clocks (smoothed). The dashed lines are the solutions that are unweighted as of February 2026, while the solid lines are the weighted solutions.

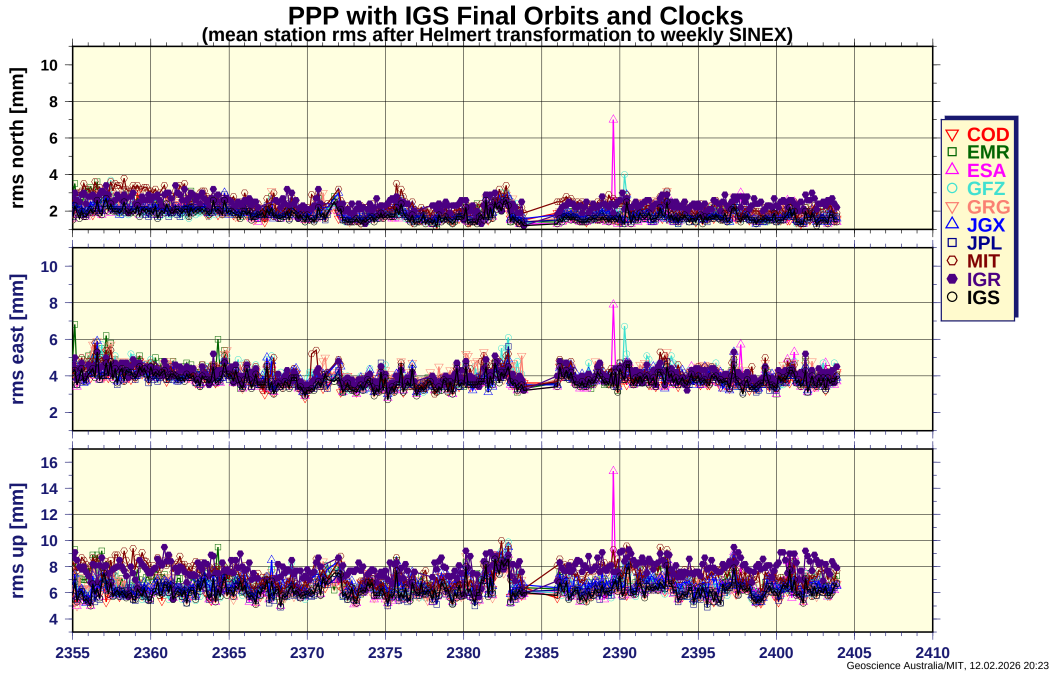

Figure 9: Station RMS residuals from the comparison of the PPP solutions using the final orbit and clock products of each of the analysis centers as well as IGS rapid and final products to the IGS weekly SINEX solution. All PPP solutions were estimated using the same network of IGb20 core sites and using Bernese v5.2 software.

Table 5: Median station coordinate residuals from comparison of PPP solutions using different sets of orbits and clocks compared with the IGS weekly SINEX solutions in 2025.

Products used in the PPP solution	North RMS [mm]	East RMS [mm]	Up RMS [mm]
COD	1.8	3.8	6.2
EMR	2.0	4.0	6.6
ESA	1.8	3.8	6.1
GFZ	1.9	4.0	6.3
GRG	2.0	4.0	6.3
JGX	1.9	3.9	6.5
JPL	1.8	3.8	6.1
MIT	2.4	4.1	7.5
IGR	2.4	4.0	7.8
IGS	1.7	3.7	6.0

4 Multi-GNSS combinations

As mentioned in Section 2, an important component of the ACC four-year roadmap has been the transition to multi-GNSS combined products. In 2025, the ACC started to test the different orbit and clock combination tools available for providing demonstration multi-GNSS combinations. These tools include GA's Robust Orbit Combination Software (ROCS) (Geoscience Australia, 2024), NRCan's clock and bias combination software (SPARKCombo) (Banville et al., 2020), and GFZ's Software for Precise Orbit and Clock Combination (SPOCC) (Mansur et al., 2022, 2024). The ACC also used the Gravity Recovery Object Oriented Programming System (GROOPS) developed by Graz University of Technology (Mayer-Guerr et al., 2021) for generating reference attitudes for multi-GNSS combined orbits. The IGS ACC also participated in the multi-GNSS Task Force, who completed the assessment of different combination software available for the multi-GNSS combinations, and concluded its mission.

In early 2026, the ACC will provide multi-GNSS demonstration Final orbits, clocks and biases along with reference attitudes for the period from the end of the Repro3 campaign to the current date, and will continue to provide the demonstration Final multi-GNSS products going forward. Following that, the ACC will consider creating multi-GNSS Rapid products as well. Early results will be presented at the IGS Workshop in June 2026 in Chile.

In addition to the Final demonstration products, 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 ultra-rapid orbits are published. The demonstration multi-GNSS orbit combinations use the GA's ROCS orbit combination software (Geoscience Australia, 2024).

Table 6 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-GNSS orbits are displayed in Figure 10. Figure 11 shows the RMS of the AC ultra-rapid orbit solutions per GNSS satellite in 2025.

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 weighted AC contributions for Galileo are consistent with each other at levels below 60 mm, which is very close to the consistencies observed for GPS satellites.

The consistency of the AC orbits for the GLONASS satellites is in the range 50-80 mm for the weighted ACs (Figure 10). The multi-GNSS combined orbits are consistent with the

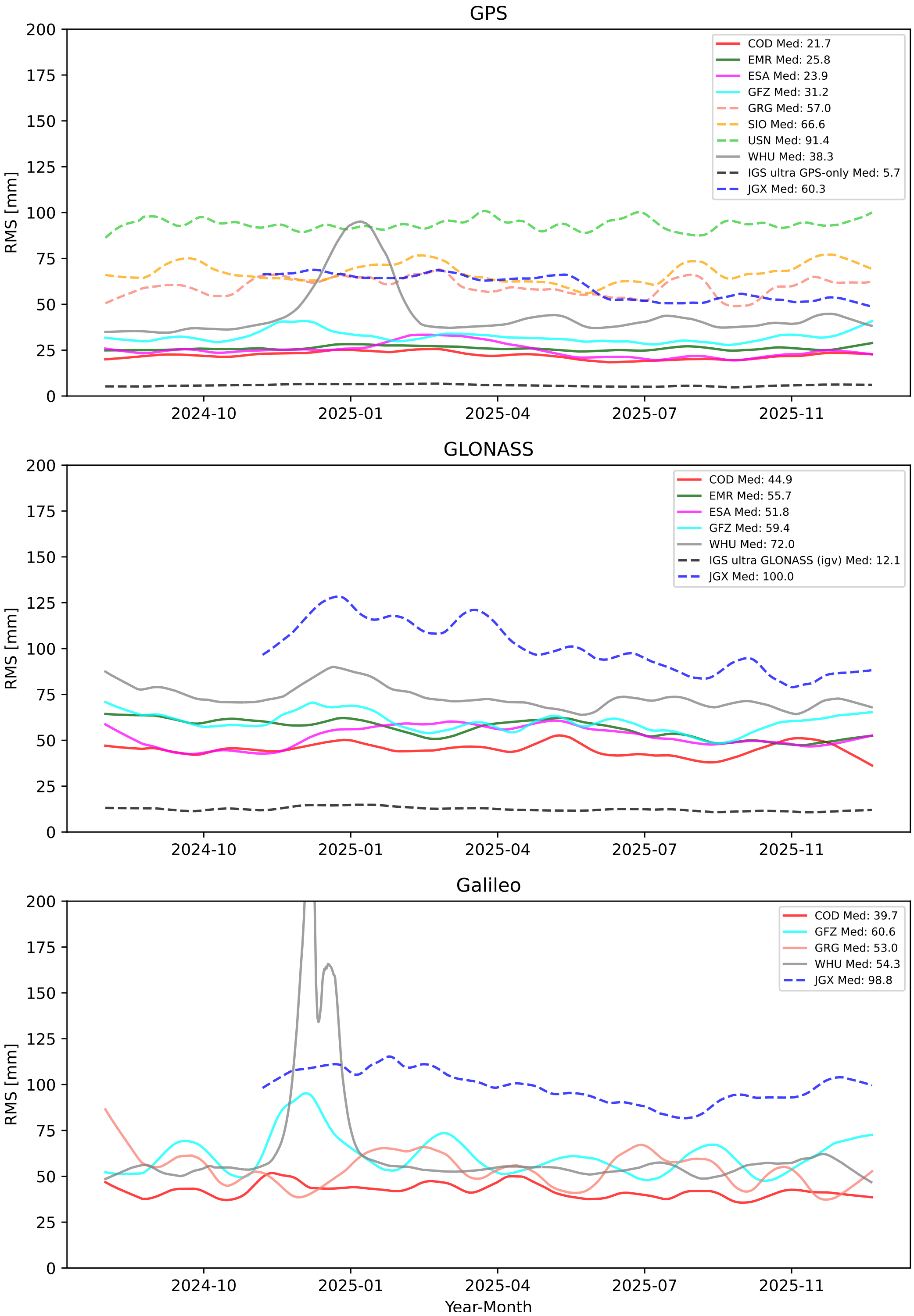

Figure 10: RMS of analysis center orbit solutions (smoothed) compared to the IGS combined orbits for the IGS multi-GNSS ultra-rapid demonstration products for GPS (top), GLONASS (middle) and GALILEO (bottom). The dashed lines are the AC solutions that are not weighted in the combinations, while the solid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

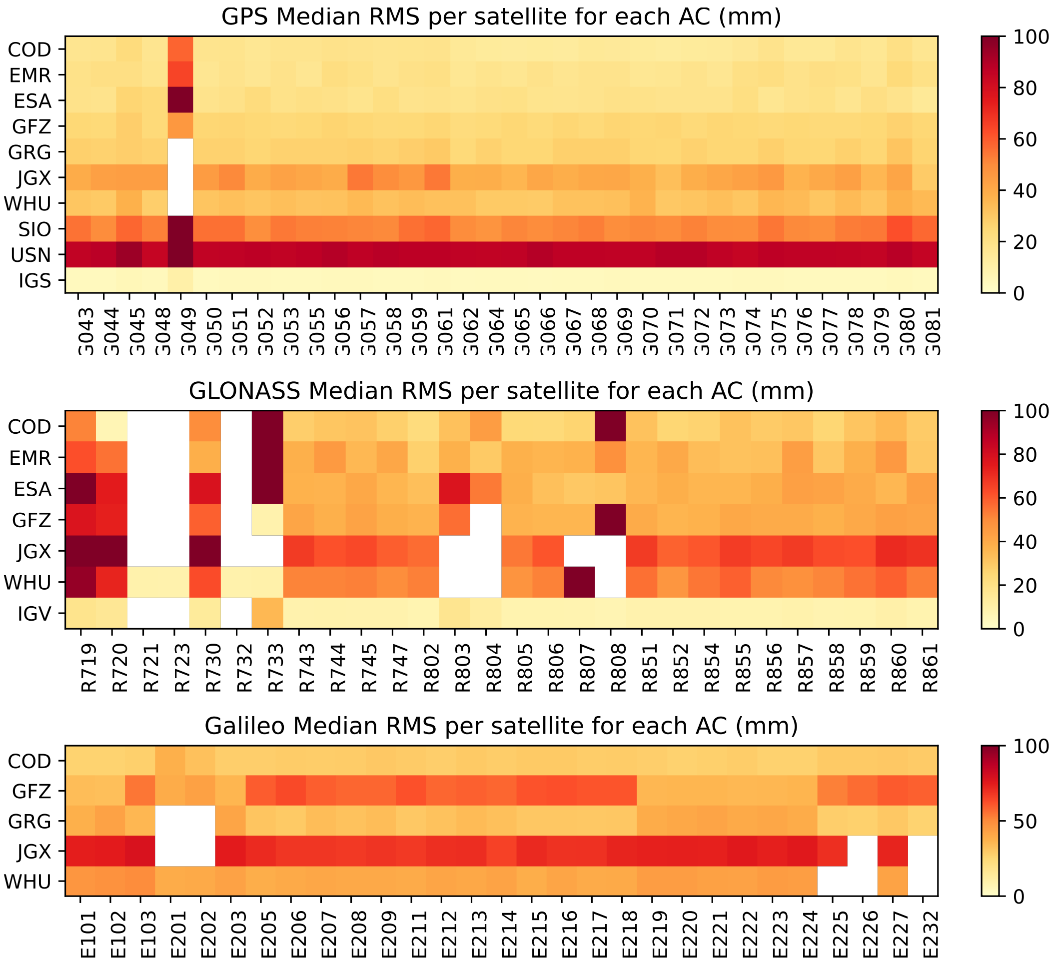

Figure 11: Median RMS of the individual satellites compared to the combined orbits for the multi-GNSS ultra-rapid solutions for GPS (top), GLONASS (middle), and Galileo (bottom) in 2025. IGS is the IGS ultra-rapid legacy GPS-only combined orbits, and IGV is the current experimental ultra-rapid GLONASS-only combined orbits.

Table 6: ACs contributing to the IGS demonstration multi-GNSS ultra-rapid orbits; W signifies a weighted contribution, C is comparison only.

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	-	-

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, R730, R731 and R733, while they have improved for the more recently launched satellites, e.g. R802 from the Block K1B or more recent launches in Block M such as R851. (see Figure 11).

5 Future Work

In 2026, the IGS ACC will complete the handover of the primary operations from GA to NASA, in accordance with the revised transition roadmap as in Section 2. Moreover, the ACC will progress the provision of combined multi-GNSS products. Final and Rapid set of multi-GNSS demonstration products will be made available in 2026, and will replace the current GLONASS experimental products. This will eventually lead to replacing the GPS-only operational products following the roadmap of Figure 1.

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Wuhan Combination Center Technical Report 2025

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1 Introduction

The Wuhan Combination Center (WCC) was formally approved by the Governing Board of the International GNSS Service on DThe Wuhan Combination Center (WCC) was formally approved by the IGS Governing Board (GB) as a Pilot Project (PP) in 2024. It aims at providing combined high-precision and highly-reliable multi-GNSS satellite orbits/clocks/biases and receiver clocks/biases. The priorities of the WCC include the development and exploitation of innovative combination efforts for orbits, clocks, and code/phase biases as an experimental alternative to the legacy combination procedure.

2 The one-year progress of WCC

The routine combination of both final and rapid products has been operational since GPS week 2357. The products are gathered and combined at a weekly basis. The combined products are released each Monday. The combined final products have two-week latency, while the combined rapid products have one-week latency.

The combination integrates contributions from multiple Analysis Centers (ACs) to generate robust and precise products. For the final product combination, the current input includes products from 11 ACs: COD, EMR, ESA, GFZ, GRG, HUS, JGX, JPL, MIT, NGS, and SIO. Among these, JGX is utilized primarily for comparison and validation purposes, while MIT, NGS, and SIO contribute exclusively to the orbit combination. While for rapid product combination, the inputs are also from 11 ACs: COD, EMR, ESA, GFZ, GRG, HUS, JGX, JPL, NGS, SIO, and WUM. Among these, JGX is utilized primarily for comparison and validation purposes, while NGS, and SIO contribute exclusively to the orbit combination.

Table 1: List of analysis center data used in the routine combination of final products

Final								
Label	system	orbit	clock	atti-tude	code OSB	phase OSB	24:00 epochs	Note
CODOOPSFIN	GRE	300 s	30 s	30 s	1 d (GE)	1 d (GE)	CLK&SP3	
EMROOPSFIN	G	300 s	30 s	30 s	1 d (G)	1 d (G)		
ESAOOPSFIN	GRE	300 s	30 s				SP3	
GFZOOPSFIN	GRE	300 s	30 s					
GRGOOPSFIN	GRE	300 s	30 s	30 s	1 d (GE)	1 d (GE)	CLK&SP3	
HUSOMGXFIN	GRE	300 s	30 s	30 s	1 d (GRE)	1 d (GE)	CLK&SP3	
IGSOOPSFIN	G	900 s	30 s					Comp. only
JGXOOPSFIN	GRE	300 s	30 s				SP3	Comp. only
JPLOOPSFIN	GE	300 s	30 s	30 s			CLK&SP3	
MITOOPSFIN	GE	300 s	30 s				CLK&SP3	
NGSOOPSFIN	G	300 s						
SIOOOPSFIN	G	900 s					SP3	

Table 2: List of analysis center data used in the routine combination of rapid products

Rapid							
Label	system	orbit	clock	atti-tude	code OSB	phase OSB	Note
CODOOPSRAP	GRE	300 s	30 s	30 s	1 d (GE)	1 d (GE)	
EMROOPSRAP	GR	300 s	300 s				
ESAOOPSRAP	GR	300 s	30 s				
GFZOOPSRAP	GRE	300 s	300 s				
GRGOOPSRAP	GE	300 s	30 s	30 s	1 d (GE)	1 d (GE)	
HUSOMGXRAP	GRE	300 s	30 s	30 s	1 d (GRE)	1 d (GE)	
IGSOOPSRAP	G	900 s	300 s				Comp. only
JGXOOPSRAP	GRE	300 s	30 s				Comp. only
JPLOOPSRAP	GE	300 s	30 s	30 s			
NGSOOPSRAP	G	300 s					
SIOOOPSRAP	G	900 s					
WUMOMGXRAP	GRE	300 s	30 s	30 s	1 d (GRE)	1 d (GE)	

2.1 Product combination method

The combination process is a multi-stage, iterative procedure designed to integrate inputs from multiple ACs into a single, robust set of precise products. The method can be summarized as follows:

1) Orbit and ERP Combination
The process begins with the ACs' individual orbit and Earth Rotation Parameter (ERP) products. An initial mean orbit is computed, followed by a Helmert transformation to align the solutions into a common reference frame. A weighted mean orbit is then calculated. This stage feeds directly into the generation of the final combined orbit and ERP product. Using the finalized combined orbit and ERP product, satellite attitude information is computed via external software (e.g., GROOPS) to generate the final attitude product.

2) Clock and Bias Combination
This stage processes clock and bias products. Prior corrections including radial orbit difference, phase wind-up effect, and antenna model difference are applied, and integer clocks are formed using narrow-lane UPDs. The solutions are aligned to a chosen reference, and statistical outlier detection is performed. An iterative loop (with a maximum of 10 iterations) ensures stability, continuing until the variation in assigned weights between iterations is less than 0.1 %. Once convergence is achieved, phase clocks and OSB estimates are extracted and aligned to GPST.

2.2 Combination strategy adjustment

To enhance the precision and robustness of the combined products, key adjustments have been implemented in the combination strategy

1) Expansion of orbit combination contributors
The orbit combination process has been strengthened by incorporating products from three additional ACs: NGS, SIO, and MIT. This inclusion leverages a broader set of independent solutions, improving the stability and reliability of the final combined orbit. The effectiveness of this expansion is validated by the Root Mean Square Error (RMSE) of individual AC orbits compared to the combined solution. For instance, in GPS week 2390, the combined orbit (IGS) serves as a stable reference with most ACs showing RMSE values within a close range (e.g., $7 - 11\,\mathrm{mm}$), confirming good overall agreement and a robust mean.

2) Enhancement of Galileo phase bias combination
A specific adjustment has been made to refine the combination approach for Galileo X/X channel phase biases. This enhancement explicitly considers the necessary alignment between code and phase biases across different Galileo signal channels (C/Q and X/X). The improvement is quantitatively demonstrated by an increase in the success rates for ambiguity resolution.

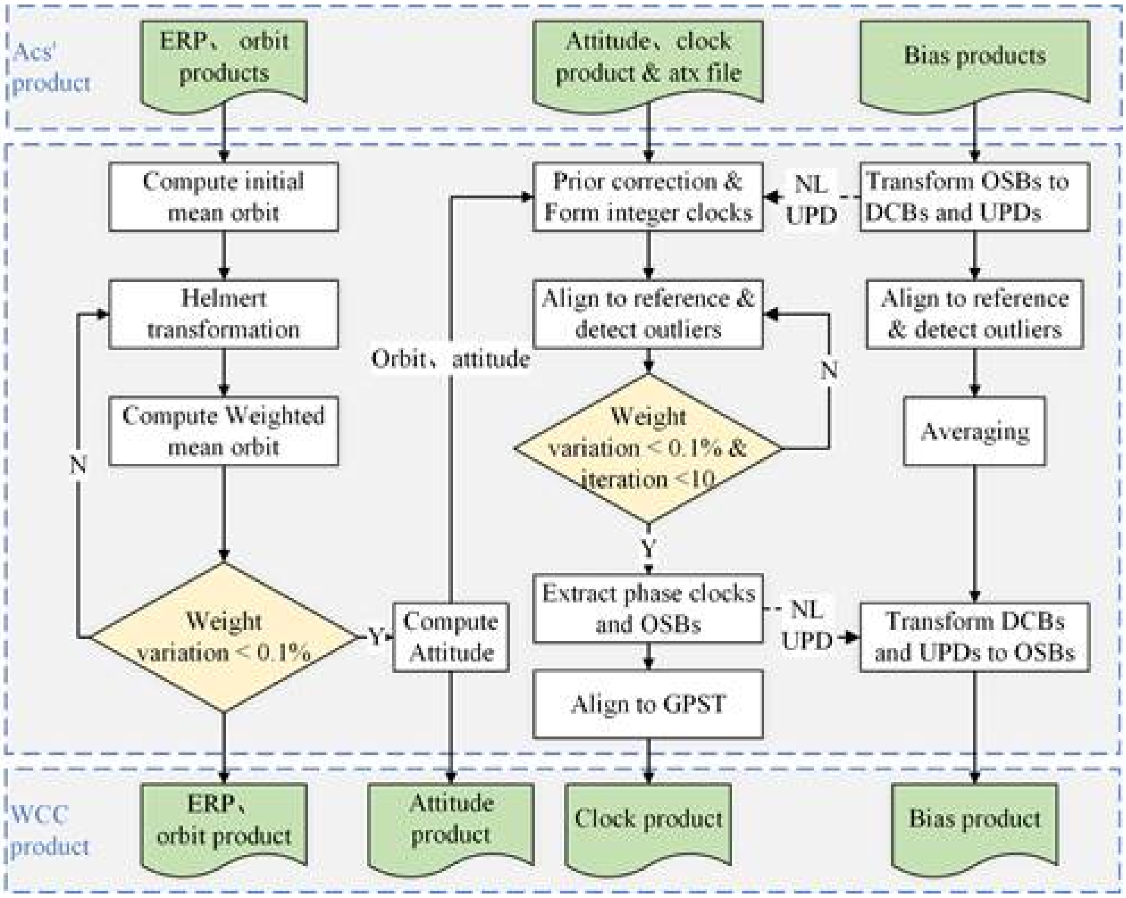

Figure 1: The combination flowchart

The updated WCC strategy (WCC_new) achieved an average success rate of 98.29 % over a 10-day period, a significant improvement over the previous strategy (WCC_old) at 97.28 %, and now performs comparably to other leading AC solutions. Furthermore, the positioning performance (North, East, Up components) remains consistent and on par with other solutions, confirming that the bias alignment adjustment enhances ambiguity resolution without compromising solution accuracy.

2.3 Main features of WCC combined products

1) Multi-GNSS Orbit, Clock, and Bias Product Combination
The WCC combined products integrates contributions from a global network of ACs, to generate a unified set of products for GPS, GLONASS, and Galileo systems, as well as BDS in the near future. This rigorous combination process does not merely average inputs but employs sophisticated weighted adjustment, outlier detection, and reference alignment

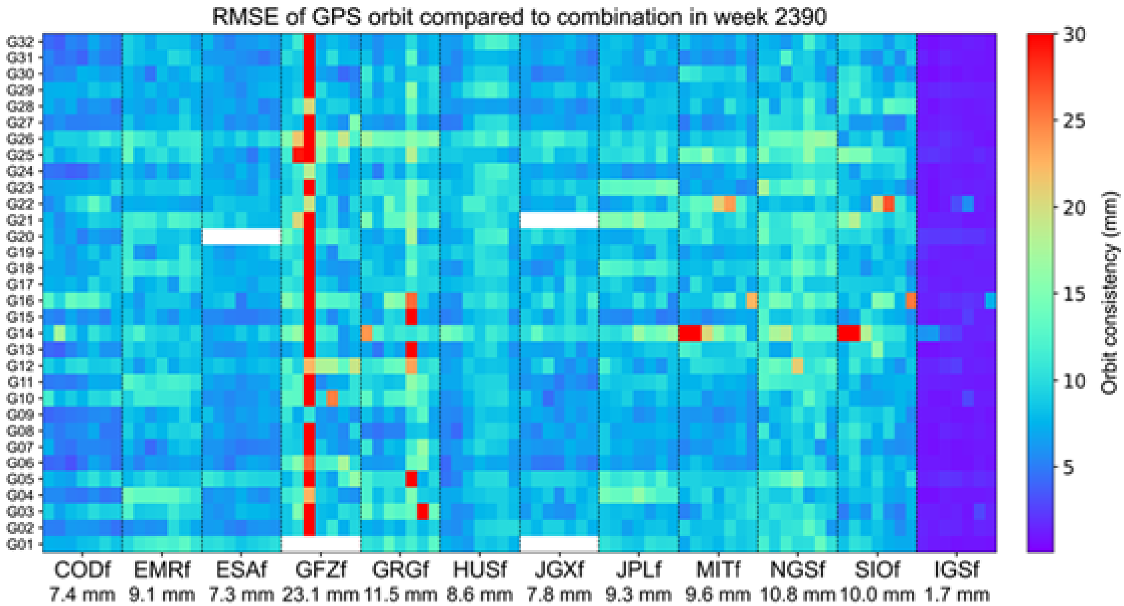

Figure 2: RMSE of GPS orbit compared to combination in week 2390

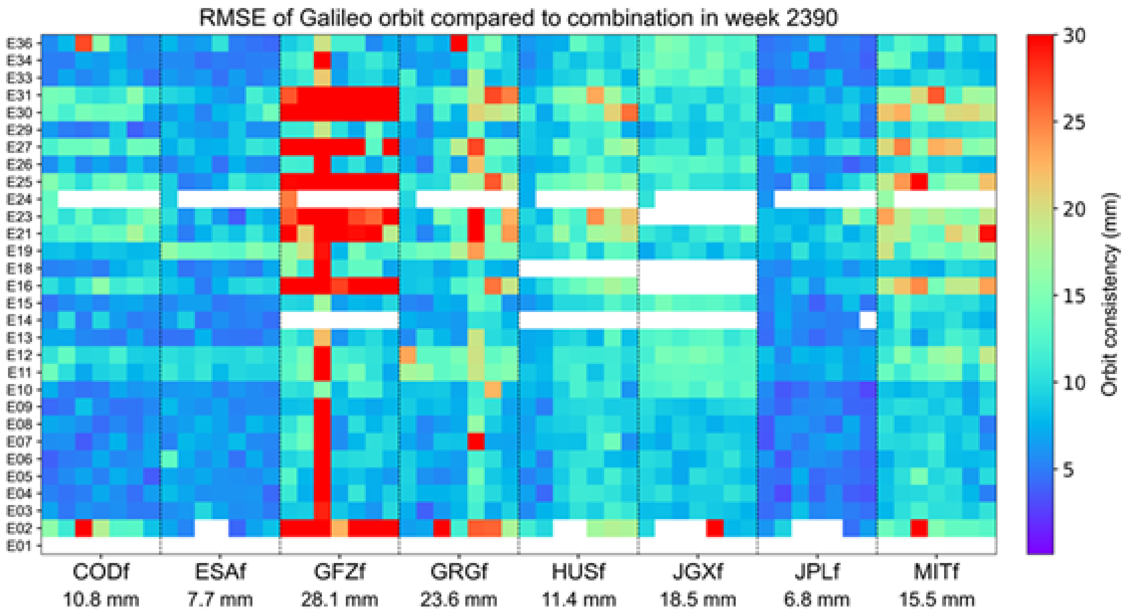

Figure 3: RMSE of Galileo orbit compared to combination in week 2390

strategies. By synthesizing diverse solutions, the final combined orbit, clock (satellite and station), and bias (code and phase) products achieve superior accuracy, robustness, and long-term stability compared to any single AC solution, providing a consistent and

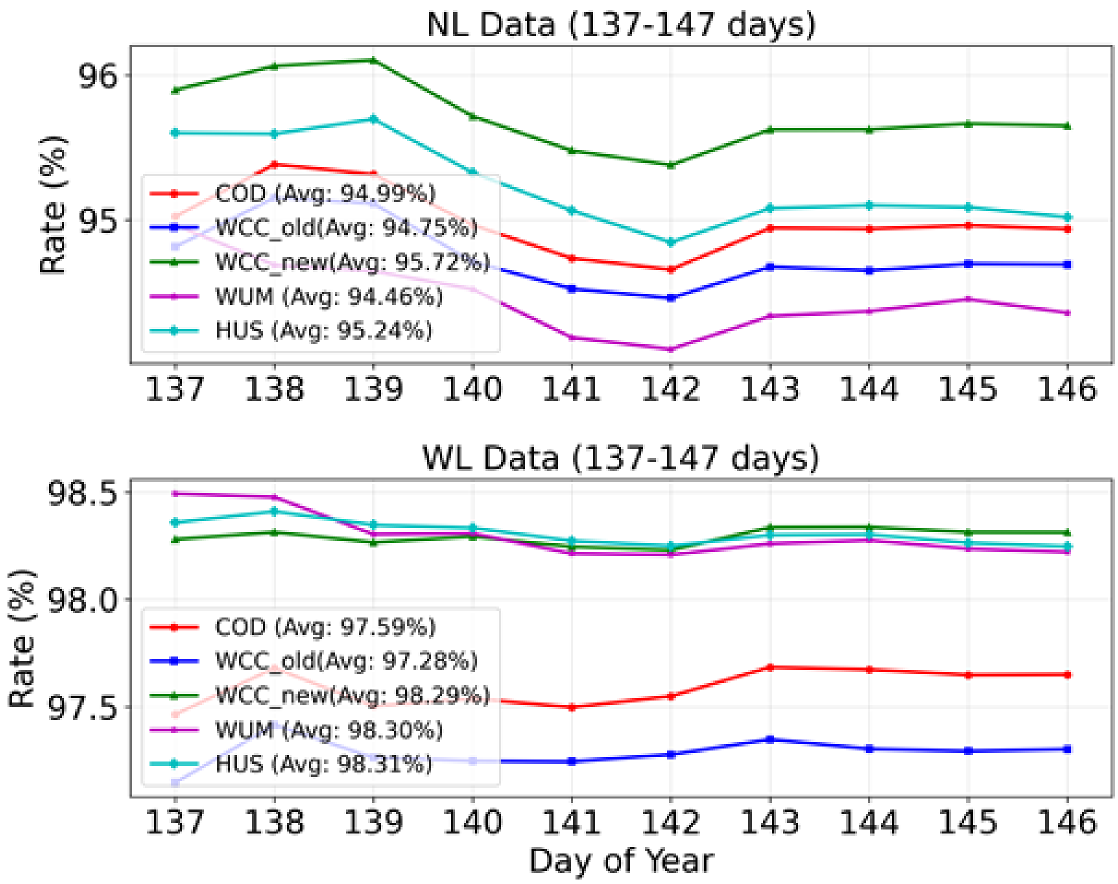

Figure 4: Ambiguity fixing rates with the updated WCC strategy and comparison with other AC

authoritative reference for the global user community.

2) Facilitation of PPP-AR at the user end
A defining feature of the WCC products is the direct integration of phase bias estimation into the combination. Unlike products that only provide code biases or require users to estimate phase biases independently, WCC generates and delivers consistent Observable-Specific Signal Bias (OSB) products. These products enable users to recover the integer nature of carrier-phase ambiguities in Precise Point Positioning (PPP) processing. This capability is critical for achieving centimeter-level positioning accuracy, significantly reducing convergence times, and enhancing the reliability of precise positioning services across geodetic, atmospheric, and navigation applications.

3) Ensured Day-Boundary Continuity of Combined Products
Recognizing that discontinuities at daily boundaries can degrade time-series analysis and long-term applications, the WCC processing strategy specifically addresses this issue. The

generated final products are continuous at the midnight epoch. This feature is particularly vital for time frequency transfer, long-term stability monitoring, and high-precision scientific studies that demand consistent data over extended periods.

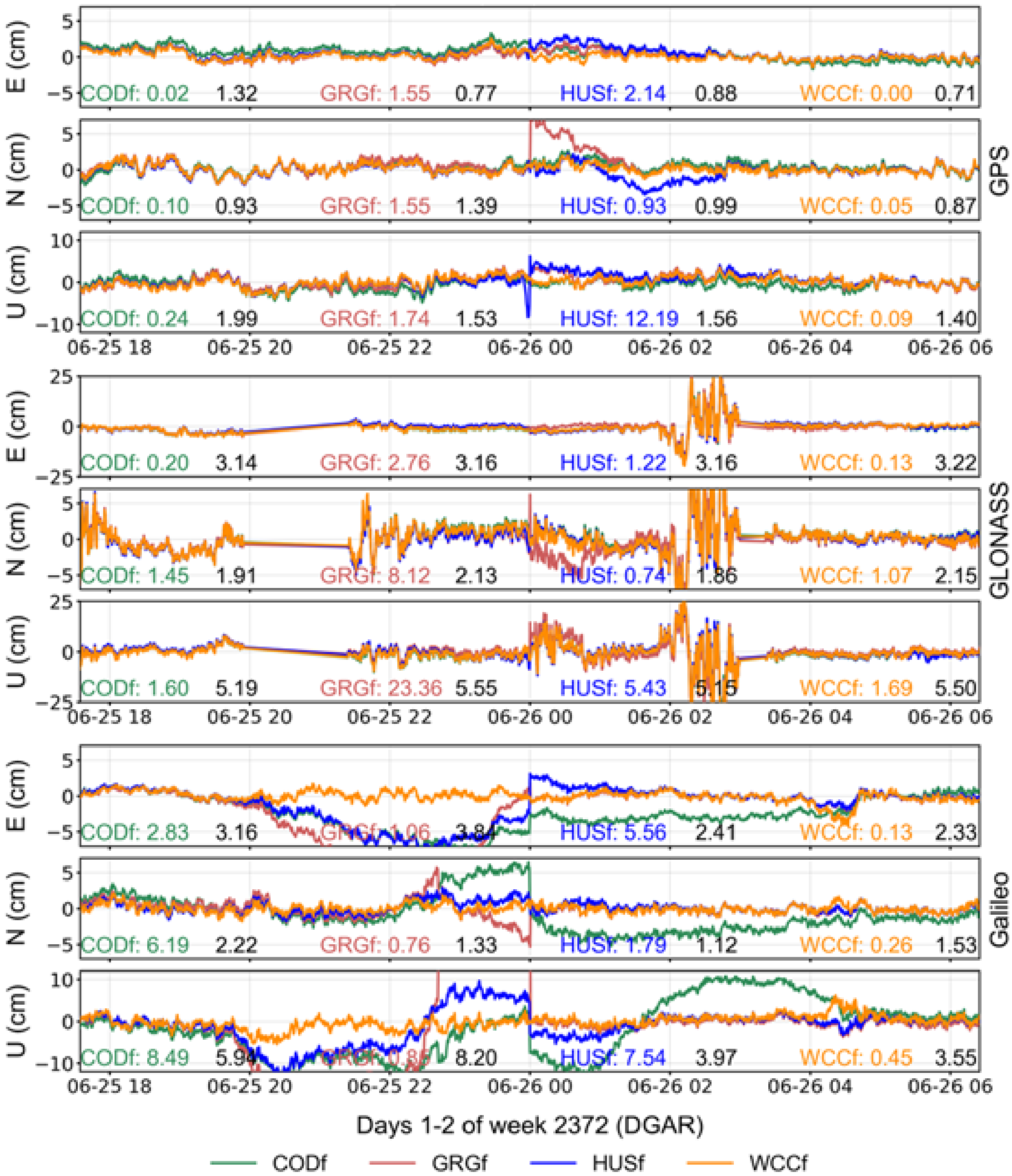

Figure 5: Across days PPP(-AR) results within different final products in week 2372

2.4 One-year combined solutions from WCC

1) Orbit combination weights and contributions

For the one-year period in 2025 (Days of Year 068–326), the weights assigned to different analysis centers for the combined orbit solution reveal distinct contributions across the GPS, GLONASS, and Galileo constellations. For GPS, COD holds the highest weight at 14.74 %. For GLONASS, COD again leads with a substantial 26.43 % contribution, followed by ESA. Notably, for Galileo, JPL receives the highest weight at 22.87 %. Examining the accumulated contributions up to GPS Week 2933 further details this distribution: for GPS, COD (14.74 %), JPL (7.71 %), and HUS (8.35 %) are key players; for GLONASS, COD dominates at 36.41 %, with ESA at 28.64 % and GRG at 23.91 %; for Galileo, the contributions are more distributed among COD (18.08 %), ESA (15.86 %), GRG (14.96 %), and HUS (11.32 %). These weights, derived from long-term performance evaluations, reflect the relative accuracy and reliability of each center's orbit products, which are then optimally averaged to create the final, higher-quality IGS combined orbits.

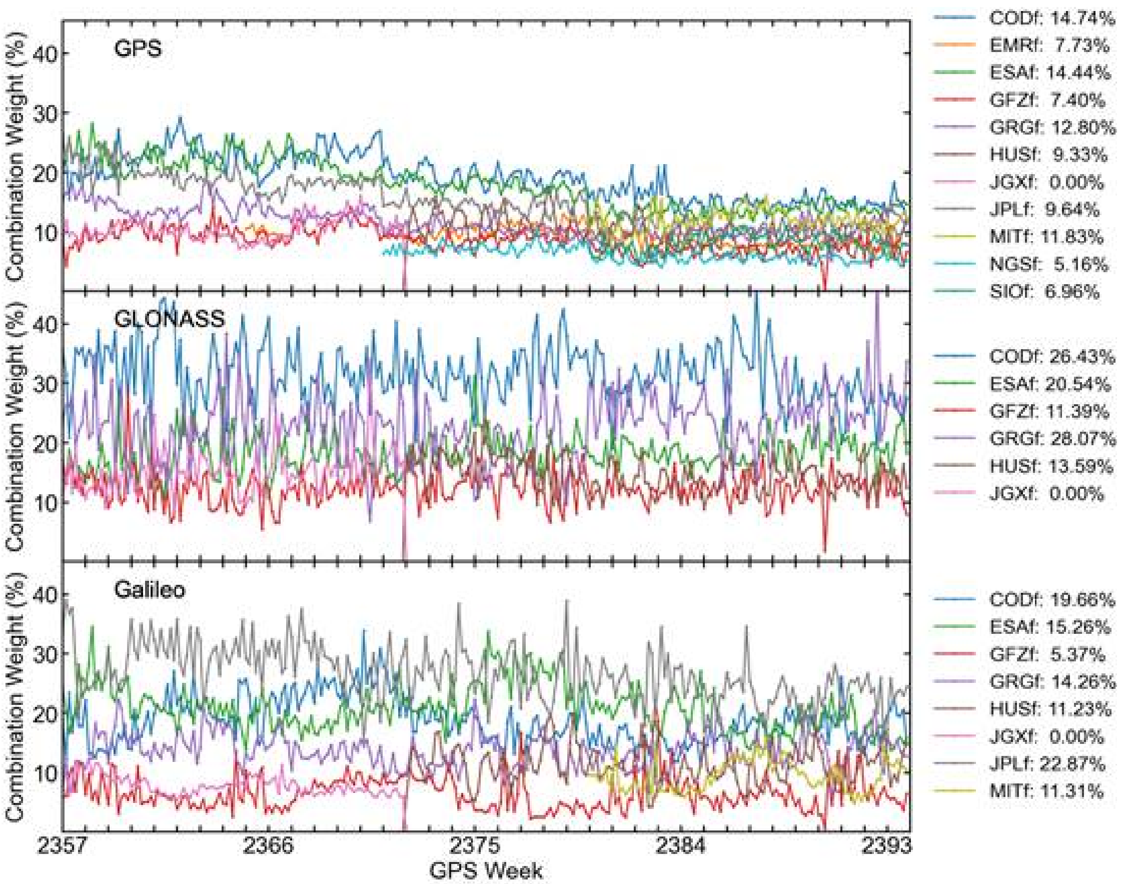

Figure 6: ACs' orbit contribution to the combination till week 2393

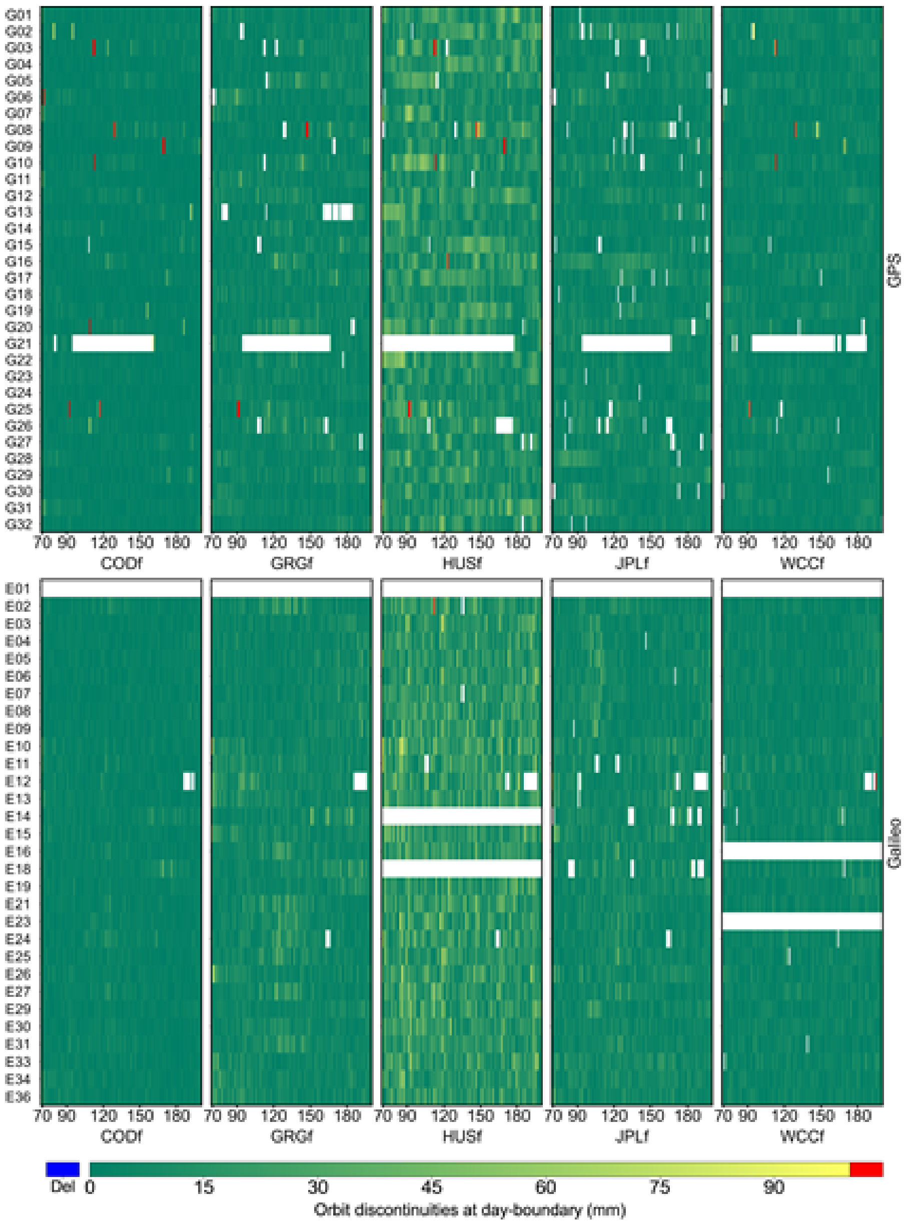

Figure 7: Stability of orbit products from different ACs at daily boundaries

2) Orbit day-boundary discontinuity analysis

The stability of orbit products at the boundary between processing days is a critical quality indicator. The analysis for 2025 (DOY 068–200) shows that COD's orbit products exhibit the smallest day-boundary discontinuities, representing the most stable continuity. Specifically, the radial discontinuity for GPS is lowest for COD at 2.94 mm, compared to 5.92 mm for GRG, 15.88 mm for HUS, 6.34 mm for JPL, and 4.67 mm for WCC. For

Galileo, COD again shows the best stability at 3.13 mm, followed by WCC at 5.01 mm, with GRG, JPL, and HUS showing larger jumps. This metric measures the consistency of orbit estimates at day boundary; smaller values indicate smoother orbits, which are vital for long-term data analysis and real-time applications. GPS orbits generally show smaller discontinuities than Galileo across all centers. WCC's combined product, while not the absolute best in this specific metric, maintains a very competitive performance close to the top.

3) Clock and bias combination weights

In the combination of satellite clock and bias estimates, the contributions from COD and GRG products are the most significant, ranking as the top two contributors. The detailed breakdown of accumulated contributions until GPS Week 2393 highlights the following weight distribution: COD leads with 22.42 %, followed by GRG at 15.78 %, HUS at 15.21 %, ESA at 14.47 %, EMR at 14.13 %, JPL at 9.27 %, and GFZ at 8.73 %. These weights are dynamically determined based on the long-term stability, accuracy, and consistency of each analysis center's clock solutions. A higher weight signifies that a center's clock product has consistently agreed well with the collective solution from other centers and has shown low noise and high reliability. The combination process leverages these strengths to generate a "best-estimate" clock product that is more accurate and stable than any single center's solution alone.

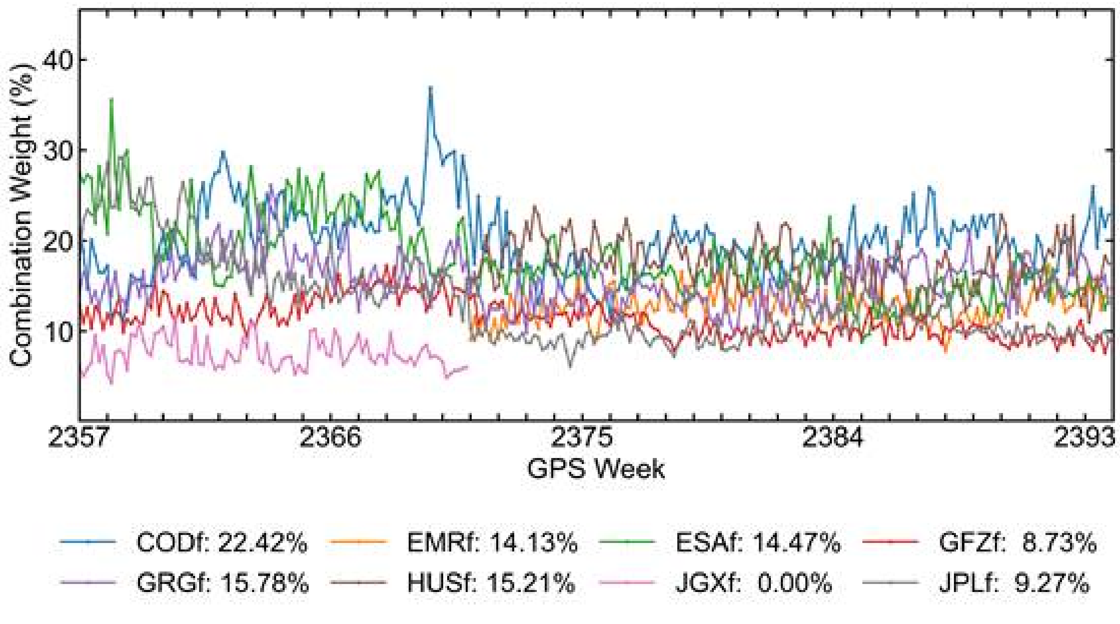

Figure 8: ACs' clock contribution to the combination till week 2393

4) Clock/Bias day-boundary discontinuity performance

A standout result from the 2025 evaluation is the exceptional stability of WCC's integer clock products at day boundaries. The discontinuity values for WCC are orders of magnitude smaller than those of other centers. For GPS, WCC's discontinuity is merely 5.35 picoseconds (ps), compared to 70.56 ps for JPL, 193.50 ps for HUS, 220.74 ps for GRG, and 352.43 ps for COD. For Galileo, WCC's performance is even better at 4.53 ps, while others range from 81.55 ps (JPL) to 200.98 ps (COD). This dramatically lower discontinuity is a direct benefit of using integer clock estimation, which aligns the clock parameters with the integer nature of carrier-phase ambiguities. This results in a much smoother and more consistent time series for satellite clocks, which is fundamentally important for enabling high-precision PPP-AR and for maintaining the coherence of timing applications.

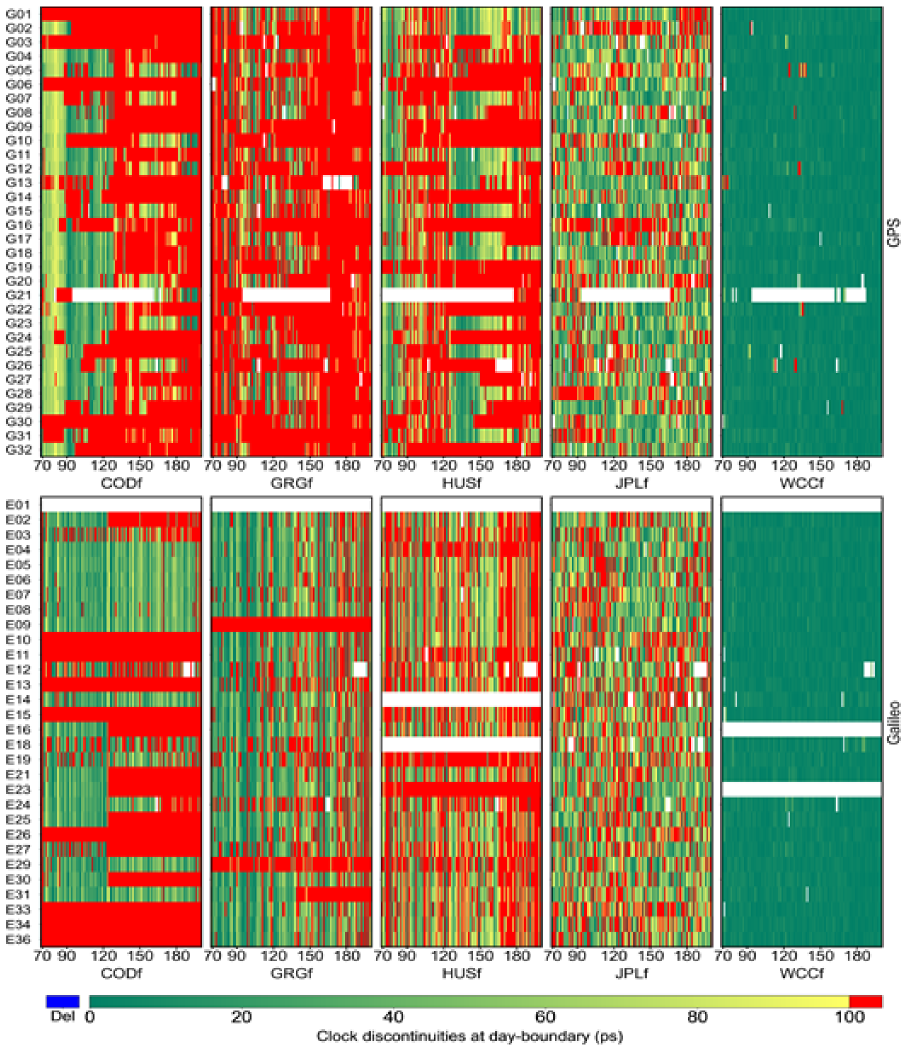

Figure 9: ACs' clock contribution to the combination till week 2393

5) Clock stability assessment
The long-term stability of satellite and receiver clocks is evaluated using a set of 9 satellites

from different GPS block types (IIIA, IIIF, etc.) and 6 ground stations equipped with highly stable hydrogen maser frequency standards. The assessment is based on analyzing 7-day arcs of accumulated clock estimates, which helps to characterize the noise and drift behavior over time. The results indicate that the satellite and receiver clock and bias stability is relatively consistent across the different analysis centers (ACs). This consistency implies that the fundamental quality of the estimated clock parameters is high and agreed upon by various independent processing lines. The Modified Allan Deviation or a similar stability measure is likely used to quantify this, showing that the core timing characteristics are reliably captured in the combined solution, ensuring dependable performance for time transfer and long-baseline positioning.

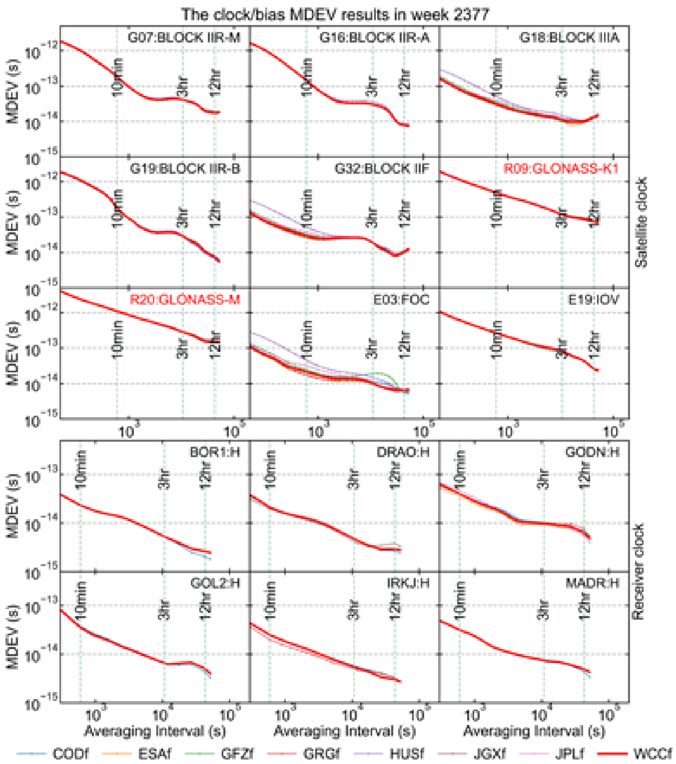

Figure 10: Assessment of long-term stability of satellite and receiver clocks

6) PPP-AR validation performance

The PPP-AR validation results clearly demonstrate that the positioning precision achieved using products from the WCC surpasses that of other leading ACs, namely COD, HUS, and GRG. This superior performance indicates that WCC's combined satellite orbit and clock solutions provide a more accurate and reliable foundation for PPP-AR. This enhancement is crucial for high-precision applications in geodesy, surveying, and scientific research, where millimeter-to-centimeter-level accuracy is required.

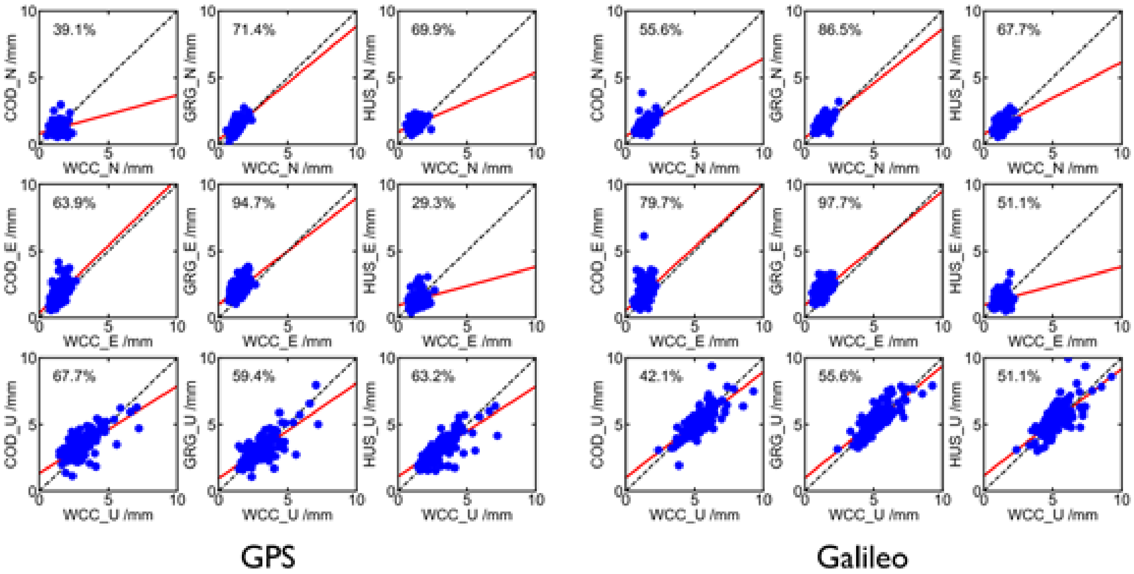

Figure 11: Positioning Accuracy Assessment: WCC vs. COD, HUS, and GRG

2.5 The introduction of WCC website and product storage FTP

The cornerstone for public information is the official WCC webpage hosted on the IGS portal at https://igs.org/wg/wcc. This site acts as the authoritative source for understanding the center's mission, scope, and activities. The site also offers news updates, technical descriptions of the combination methodology, and essential links for data access, making it an indispensable resource for researchers, collaborators, and users worldwide who seek to understand the foundation and output of the WCC's work.

The WCC combined products are accessible at ftps://bdspride.com. This FTPS server forms the technical backbone of the center's operations. It is the central hub where the combined products — categorized as rapid, and final — are stored and disseminated to the global user community.

3 The task force to draw out a new combination statistic format

3.1 The background to draw out the new format

Since 1994, the IGS Analysis Center Coordinator (ACC) has consistently executed product combination tasks, generated high-stability combined solutions and established feedback mechanisms to assess AC quality and drive technical advancements. As a core output, the

Figure 12: The official WCC webpage on the IGS portal

ACC publishes Summary files (e.g., `IGS0OPSRAP_20251850000_01D_01D_CLS.SUM`) covering satellite clock weights, Earth Rotation Parameters (ERP), orbit precision, and Helmert transformation parameters, supported by a web-based visualization system (http://acc.igs.org/). However, with the initiation of the third IGS data reprocessing campaign (Repro3), advancements in PPP-AR Working Group (WG), and the efforts of the Wuhan Combination Center (WCC) WG, multi-GNSS combination has become pervasive. Consequently, the traditional reporting architecture no longer satisfies the complex descriptive demands of multi-constellation, multi-frequency, and emerging signal characteristics. To address this, the Working Group on Standardization of Product Combination Statistics Formats was officially established on October 21, 2025, with the approval and support of the IGS Governing Board (GB) and Infrastructure Committee (IC). This group aims to develop comprehensive information standards to assist ACs and PPP users.

3.2 Motivation

For ACs, the architectural defects of existing summary files present severe challenges in diagnosing potential product quality issues. First, combination statistics lack a unified standardized format. Orbit (`*SUM.SUM`) and clock (`*CLS.SUM`) data are segregated into disparate files and lack critical combined bias information; this physical and logical separation significantly increases the complexity of data retrieval. Second, visualization capabilities are severely deficient. The absence of supporting plotting programs prevents ACs from intuitively transforming obscure text-based statistics into quality trends (e.g.,

```
cls-file Version 2.0
GPS week: 2373    Day: 5    MJD: 60860

RESULTS OF FINAL WEIGHTED COMBINATION
=====================================
```

CEN	NREPO	NBEPO	NRCLK	NRBAD	OFFSET (ps)	DRIFT (ps/d)	CLKSDV (ps)	SDVSAT (ps)	SDVSTA (ps)	CLKRMS (ps)	RMSSAT (ps)	RMSSTA (ps)	WEIGHT (%)
brd	96	0	3072	0	-28	50	545	545	0	1119	1119	0	0.00
cod	288	0	32491	266	-875	135	7	6	7	88	123	69	20.09
emr	288	0	21934	524	-1497	-762	19	19	18	89	92	86	5.20
esa	288	0	37225	3274	-4165	693	8	5	9	125	189	90	17.22
gfz	288	0	30567	1405	-376	322	12	12	12	96	130	78	9.71
grg	288	0	8919	567	-724	1414	8	8	0	106	106	0	15.60
iga	96	0	2976	0	10	-55	22	22	0	61	61	0	0.00
igu	96	0	2880	35	-63	333	1122	1122	0	2205	2205	0	0.00
jgx	288	0	33458	918	-70	130	15	20	12	77	71	79	6.20
jpl	288	0	36111	337	-3810	587	9	10	9	68	92	58	14.01
ngs	96	0	2976	4	-5	3	473	473	0	905	905	0	0.00
usn	288	0	32434	651	-2571	517	46	58	41	135	146	130	0.00
whu	288	0	8928	0	28	152	10	10	0	70	70	0	11.97

Figure 13: `IGS0OPSRAP_20251850000_01D_01D_CLS.SUM`

RMSE heatmaps), limiting the ability to rapidly identify anomaly patterns and assess stability. Finally, existing reports suffer from a critical lack of metadata support. The absence of contextual details — such as AC identifiers, satellite systems, and antenna models — reduces data interpretability and hinders the precise localization of observations.

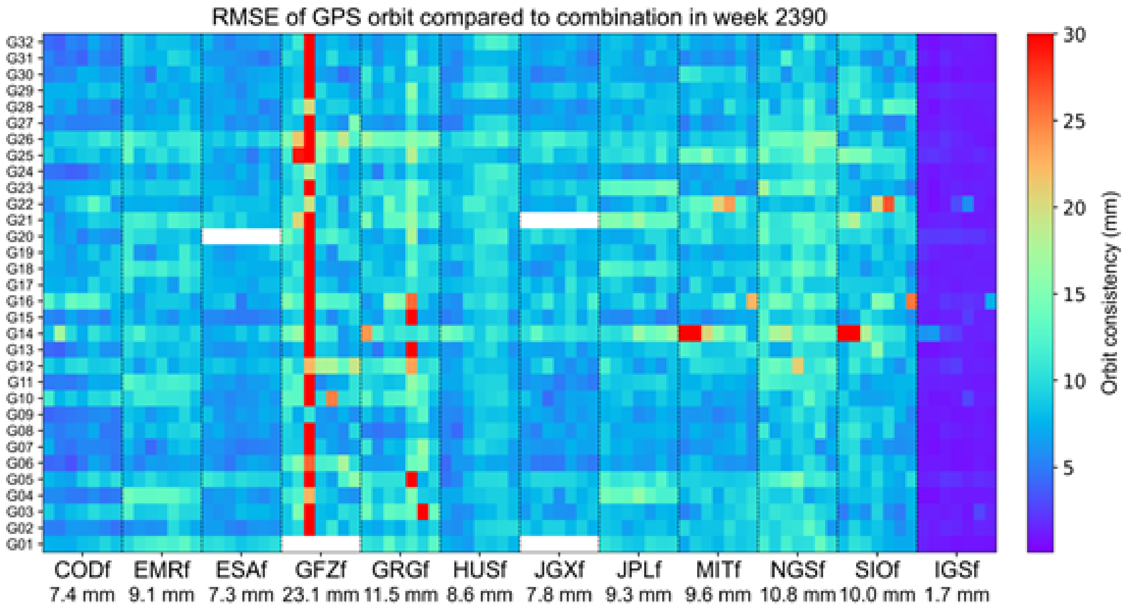

Figure 14: Orbit RMSE heatmaps

For PPP users, existing Summary files fail to provide key statistics, such as specific epochs for orbit and clock outliers, making it impossible to effectively identify faulty satellites and anomalous periods in AC products. This deficiency allows corrupted data to participate directly in PPP processing, severely compromising positioning convergence speed and final accuracy.

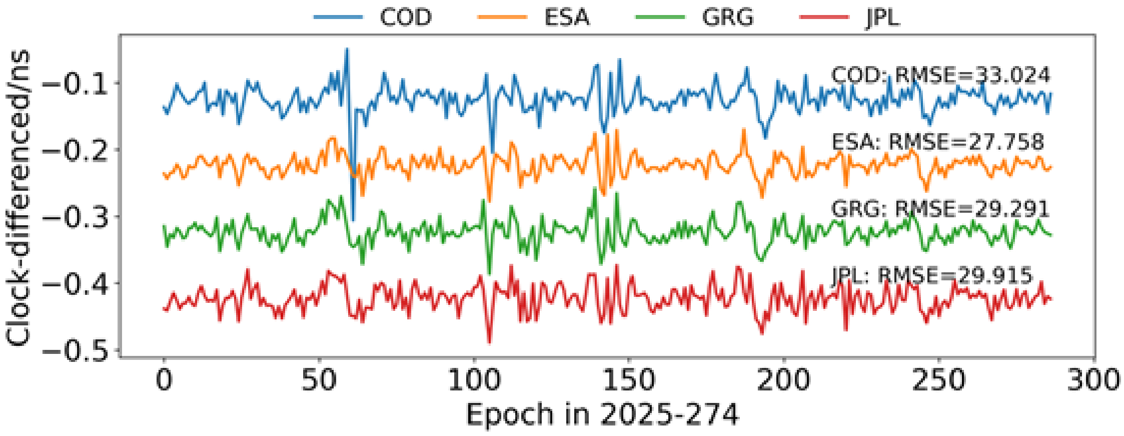

Figure 15: The difference between epochs of the station clock

3.3 Goals

This initiative aims to establish a standardized combination statistics format and associated toolset to fulfill three core functions: empowering ACs to efficiently conduct quality self-assessments and diagnostics via clear statistical indicators; providing PPP users with high-precision quality metrics to identify and exclude outliers in orbits, clocks, and biases for ensured positioning reliability; and developing auxiliary plotting tools to enable automated visualization, thereby comprehensively enhancing the efficiency of data analysis and application.

3.4 The KOM of the task force

On December 16, 2025, IGS Task Force for the format standard of the combination statistics held its Kick-off Meeting (KOM) to formally establish the strategic direction and outline the preliminary planning for the new generation of statistical standard formats. The meeting centered on the motivation and goals of the standardization, featuring in-depth discussions on four key technical topics: 1) the logical basis for the primary classification index (Analysis Center name vs. product type); 2) the technical selection of data interchange formats (comparison of JSON vs. SINEX adaptability); 3) the necessity of including multi-frequency signal biases in the statistical scope; and 4) the integration strategy for ERP combination information.

Specifically, the meeting first conducted an in-depth review of the historical limitations inherent in the traditional IGS summary file system (e.g., `*CLS.SUM` and `*SUM.SUM`). It was confirmed that the legacy system can no longer satisfy the urgent demands of ACs for refined quality monitoring, nor does it meet the requirements of PPP users for high-precision and high-reliability positioning. Consequently, the meeting formally established three core strategic goals for the new generation standard format: establishing a format for ACs to easily inspect their product problems, creating a format for PPP users to exclude outliers (e.g., orbits, clocks, and bias), and developing auxiliary tools to plot the relevant statistics of combination results. Building upon these defined objectives, the meeting further outlined the content architecture of the new format, preliminarily identifying four core modules: Introductory Information (to record context such as AC strategies, reference frames, and antenna models), followed by integrated statistics modules for clock, orbit, and bias. Furthermore, the meeting held an in-depth discussion regarding the technical selection of data interchange formats. To balance the scientific community's traditions with modern IT interoperability, three candidate formats were selected for subsequent testing and evaluation: SINEX (continuing the general standard in geodesy), JSON (adapted for efficient Web transmission and parsing), and YAML (balancing human readability with machine parsing). Finally, the meeting proposed a significant recommendation to include information related to coordinate combination in the new format, thereby ensuring a more comprehensive file system.

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Geng, J., Wen, Q., Chen, G., Dumitraschkewitz, P., and Zhang, Q. All-frequency IGS phase clock/bias product combination to improve PPP ambiguity resolution. *Journal of Geodesy*, 98(6), 48. doi: https://doi.org/10.1007/s00190-024-01865-y

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Wen, Q., Geng, J., Deng, Y., and Zhang, Y. Validating the IGS products in mitigating day-boundary discontinuities of kinematic positioning and time transfer. *GPS Solutions*, 29(4), 170.

Center for Orbit Determination in Europe (CODE) Analysis Center Technical Report 2025

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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 (?).

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 **?** . 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$^{\text{th}}$, 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$^{\text{th}}$, 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

CODOOPSRAP_yyyyddd0000_01D_05M_ORB.SP3 (old: CODwwwwd.EPH_R)
CODE early rapid GNSS orbits with 5 minutes sampling

CODOOPSRAP_yyyyddd0000_01D_01D_ERP.ERP (old: CODwwwwd.ERP_R)
CODE early rapid ERPs belonging to the early rapid orbits

CODOOPSRAP_yyyyddd0000_01D_30S_CLK.CLK (old: CODwwwwd.CLK_R)
CODOOPSRAP_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)

CODOOPSRAP_yyyyddd0000_01D_01H_TRO.TRO (old: CODwwwwd.TRO_R)
CODE rapid troposphere product, troposphere SINEX format

CODOOPSRAP_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

CODOOPSRAP_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

CODOOPSRAP_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)

CODOOPSRAP_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:
`COD0MGXFIN_yyyyddd0000_01D_05M_ORB.SP3.gz` CODE MGEX final GNSS orbits for GPS, GLONASS, Galileo, BeiDou, and QZSS satellites, SP3 format
`COD0MGXFIN_yyyyddd0000_01D_12H_ERP.ERP.gz` CODE MGEX final ERPs belonging to the MGEX final orbits
`COD0MGXFIN_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
`COD0MGXFIN_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
`COD0MGXFIN_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:

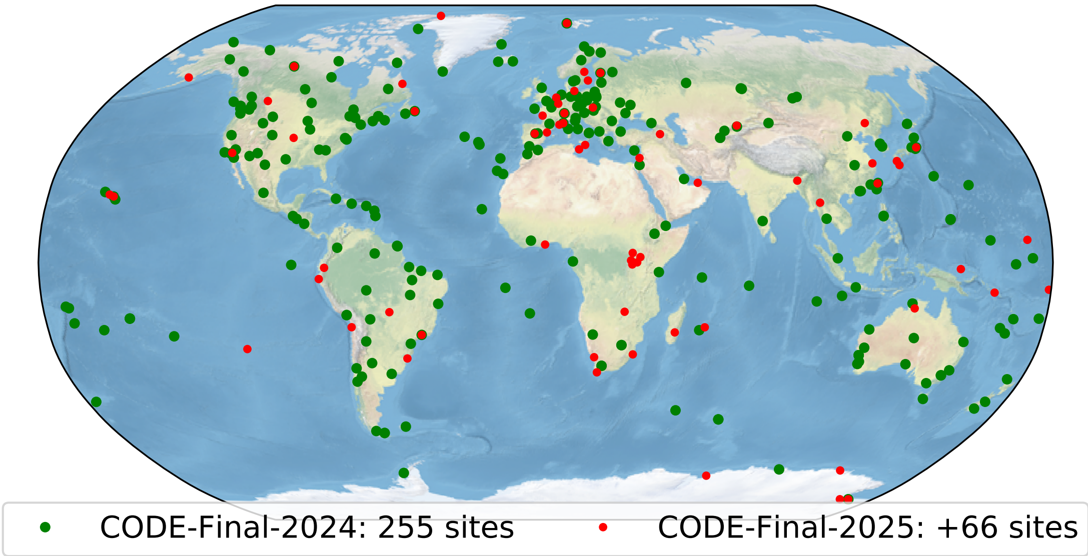
- Dach, R., S. Schaer, D. Arnold, E. Brockmann, M. Kalarus, M. Lasser, P. Stebler, A. Jaeggi (2024). *CODE final product series for the IGS*. Published by Astronomical Institute, University of Bern. URL: https://www.aiub.unibe.ch/download/CODE; DOI: 10.48350/197025.
- Dach, R., S. Schaer, D. Arnold,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

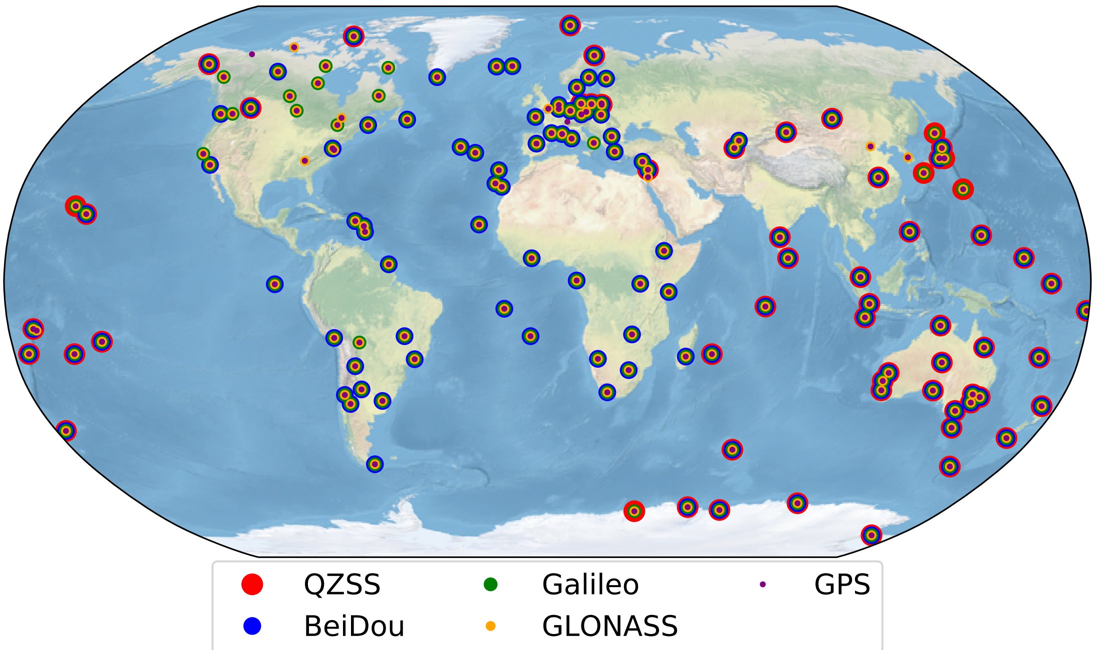
3.1 Selected general statistics

The network used by CODE for the final and MGEX processing is shown in Figure 1. In autumn 2025, 66 sites were added to the CODE final solution. Stations were selected by geometrical location, data availability and coordinate repeatability performance.

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 2025, the MGEX solution includes about 124 satellites of five satellite systems. Since Feb. 8, 2026 (week 2405) BDS-2 satellites are no longer processed (switching to L1/L5 instead of L2/L6). Therefore, the MGEX CODE orbit products contain in total 10 satellites less since then.



(a) Final solution: increased in autumn 2025 by 66 sites (from 255 to 321 sites)



(b) MGEX solution (more than 140 stations)

Figure 1: Network used for the processing at CODE by the end of 2025.

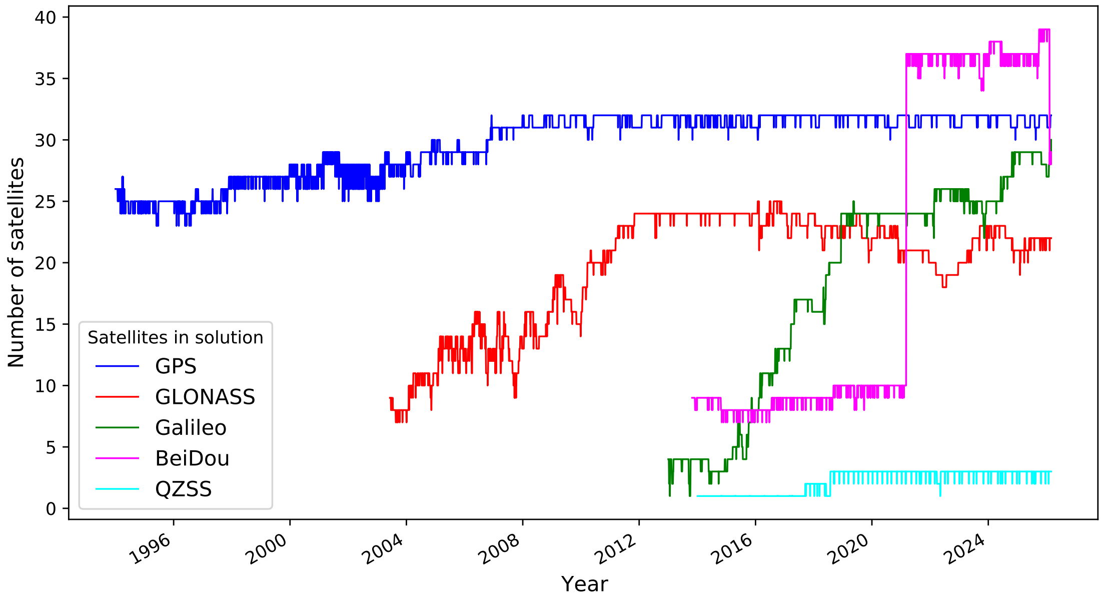


Figure 2: Development of the number of satellites in the CODE orbit products.

Table 7: Selected events and modifications of the CODE processing during 2025 (and beginning 2026).

Date	DoY/Year	Description
11-Jan-2025	011/2025	Gemoagnetic pole handling updated.
02-Feb-2025	033/2025	IGS20 -> IGb20 (week 2353).
06-Feb-2025	037/2025	MGEX-QZSS: L1C/L2L -> L1C/L5Q.
17-Feb-2025	048/2025	Activated IGRF14.
14-Nov-2025	318/2025	Addition of 66 stations to IGS final products.
02-Dec-2025	336/2025	`IGS20_2388.ATX`: SINEX code for G079, E225, E226, E227, E232 labled `IGS20_2353`.
12-Jan-2026	012/2025	IGb20 -> IGc20 (week 2401) and switch to `IGS20_2401.ATX`.
08-Feb-2026	039/2026	MGEX-BeiDou: L1/L5 instead of L2/L6, now w/o BeiDou-2.

4 Changes in the daily processing for the IGS

The CODE processing scheme for daily IGS analyses is constantly subject to updates and improvements.

In Section 4.1 we give an overview of important development steps in the year 2025.

4.1 Overview of changes in the processing scheme in 2025

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.

The CODE report is still under construction to include further contributions from the CODE partners.

ESA/ESOC IGS Analysis Centre Technical Report 2025

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1 Introduction

The IGS Analysis Center (AC) operated by the Navigation Support Office of the European Space Agency (ESA) is located at the European Space Operations Center (ESOC) in Darmstadt, Germany. Since joining the IGS at its establishment in 1992, the ESA/ESOC Analysis Centre (ESA AC) has played an integral role in its activities. This report provides an overview of key initiatives and contributions of the IGS Analysis Centre at ESOC. This includes routine generation of high-precision GNSS products, provision of GNSS ground station data, and its key roles in IGS committees and projects.

In 2025, the ESA AC adopted a new processing system, which significantly improved computational robustness, efficiency, and product quality (see Section 2.2), also in support of the upcoming GENESIS mission (see Section 4).

2 ESA IGS Contributions

2.1 Routine Products

The ESA AC GNSS product contribution to the IGS community:

- **Final:** GPS, Galileo, GLONASS, BeiDou, QZSS; weekly (Friday); 24h solutions with 200 stations and 110 satellites; includes Orbits, Clocks (30s), SINEX, ERPs, Troposphere; *NEW:* Long-term Differential Code Bias (DCB) (19 signal combinations) since 2017.

- **Rapid:** GPS, GLONASS; daily for previous day; available within 2h; 24h solutions with 150 stations and 55 satellites; includes Orbits, Clocks, ERPs, Troposphere.
- **Ultra-Rapid:** GPS, GLONASS; 4 times/day; available within 3h; 48h interval (24h estimated + 24h predicted); includes Orbits, Clocks (30s), SINEX, ERPs, Troposphere.
- **Global Ionosphere Maps:** GPS, GLONASS, Galileo, BeiDou, QZSS (final only); Final maps available within 4 days with 2h step-size. Rapid within 10h with 1 or 2 hours step-size
- **GNSS Sensor Stations:** Ten globally distributed EGON stations; Multi-GNSS, RINEX with 30s, real-time data with 1s 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 Product Changes

The Navigation Support Office 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). A modular design 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. On Feburary 3rd, 2025, ESA started to generate its AC contribution with CHAMP operationally. The changes most relevant to the users are summarized in Table 1.

2.3 Product Highlights

The ESA AC delivers comprehensive and high-quality products. A consistent set of GNSS orbit and clock products allows for multi-GNSS precise point positioning, with final clock products sampled at 30-second intervals to support this application.

A distinctive feature of ESA products is their basis on completely independent 24-hour solutions. While this approach does not necessarily yield the smoothest results – since real-world orbits and Earth Orientation Parameters (EOPs) are continuous – it offers

	2024	2025 (CHAMP)
Processing concept	Combined processing of all constellations	Constellation-wise processing + NEQ stacking
Constellations and Frequency Combinations	GPS (L1W-L2W) Galileo (E1C-E5Q) GLONASS (L1P-L2P)	GPS (L1W-L2W) Galileo (E1C-E5Q) GLONASS (L1P-L2P) BeiDou-3 (L1P-L5P) QZSS (L1L-L5Q)
Number of used stations	150	200
Ground antenna calibration required for used signals	No	Yes
Transmitter Antenna Calibrations	igs20.atx	esa23.atx [IGSMAIL-8394]
Zero-mean P1C1 correction based on	CODE.BIA	ESA0OPSFIN_DCB.BIA
UTC clock alignment	No	Yes

Table 1: Comparison of ESA AC Final solution: 2024 vs. 2025 (CHAMP)

significant scientific value by eliminating aliasing and smoothing between consecutive solutions. Another advantage is timeliness: ESA rapid products are typically available already within two hours after the end of the observation day.

ESA products are based on a box-wing model for GNSS satellites to account for solar radiation pressure, Earth albedo, and infrared effects. These block-type-specific models are regularly validated and refined, particularly for new satellites, which often include undocumented features that can significantly influence radiation pressure.

With the introduction of CHAMP, ESA has further enhanced product quality and consistency. By including BeiDou and QZSS in its IGS FINAL contribution, the ESA AC could demonstrate its capability to process multi-constellation solutions. Satellite and station clock products are now aligned to UTC via the UTC(ESOC) realisation, enabled by incorporating ground stations connected to ESOC timing facilities equipped with hydrogen masers.

The ESA AC has decided to adopt manufacturer-provided Phase Center Offset (PCO) calibrations for Galileo and GPS Block III satellites via `esa23.atx`, replacing `igs20.atx`. This is done to avoid inconsistencies in the processing. Furthermore, ESA now uses its own in-house DCB estimates for the P1C1 correction instead of the CODE values. The calibration differences introduce a scale offset and increase the RMS of station clocks, while the DCB differences raise the RMS of GPS satellite clocks. However, the standard deviation of the clocks, widely regarded as the more meaningful metric, remains very low. Both changes have been reviewed and approved by the IGS combination centers.

In 2025, ESOC introduced the Bias SINEX product `ESA0OPSFIN_DCB.BIA`, which defines a stable Bias Reference Frame (BREF) by providing long-term Differential Signal Bias (DSB) estimates for all signals from Galileo, GPS, BeiDou, and QZSS. ESA follows the PCO correction convention outlined in IGSMAIL-8113. Nineteen unique signal combinations are estimated daily – four for Galileo, five for GPS, five for BeiDou, and five for QZSS. Similar to the terrestrial reference frame generation, daily solutions are stacked, and discontinuities are introduced to account for jumps. BREF generation is implemented as a CHAMP subsystem and is based on the AC Final solution. The product is publicly available at the ESA Navigation Support Office website and is updated whenever bias values change or new satellites begin broadcasting. The ultimate goal is to enable full interoperability across all signals.

2.4 International GNSS Monitoring and Assessment Pilot Project

Since 2019, ESA is chairing the GNSS Monitoring Working Group, supporting development and leading coordination among the IGS Monitoring Analysis Centres (MACs). As part of the International GNSS Monitoring and Assessment (IGMA) Pilot Project, a monitoring system for all GNSS constellations is developed, implementing specialised processing systems to convert navigation messages, benchmark them against precise reference products, and assess compliance with ICD performance standards. To ensure comparability across centres, the IGMA Calculation Methodology was formalised. In 2025, the Pilot Project presented preliminary results for agreed evaluation periods (1–31 August 2022; for UTCOE: 1 September 2021–31 August 2022). The results cover PDOP, orbit and clock errors, SISRE, and UTCOE. Comparisons among the MACs and against the other participants in IGMA showed good agreements.

2.5 Governing Board and Committees

- Dr. Erik Schönemann is the Chairman of the GNSS Monitoring Working Group.
- Dr. Francesco Gini is the Chairman of the RINEX-RTCM committee to ensure format standardization to meet the needs of the IGS and of the the GNSS industry.

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. ESA's GNSS Observation Network (EGON) currently consist of 25 stations and will be further expanded.

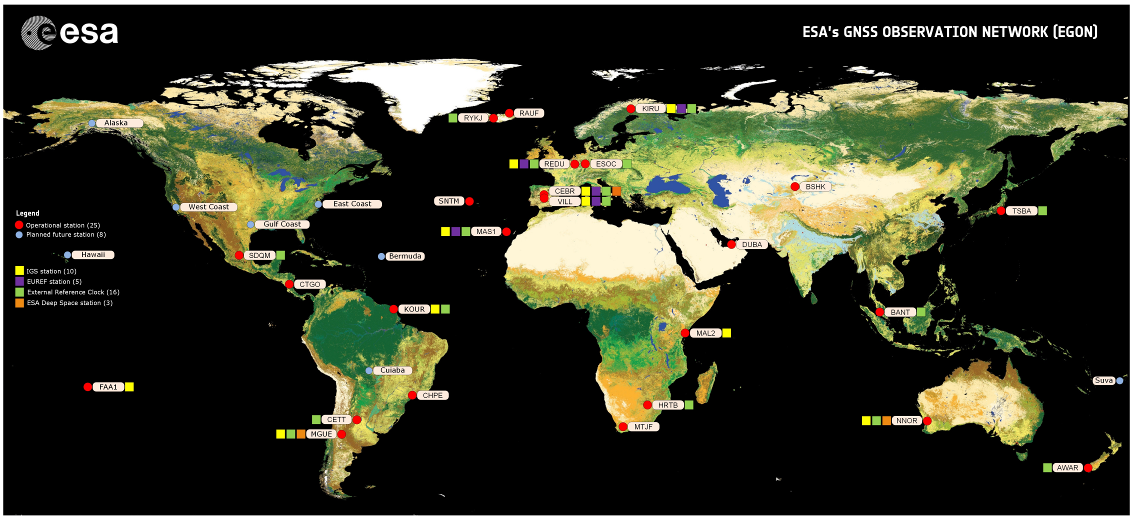

Figure 1: ESA/ESOC GNSS Station Network [http://navigation-office.esa.int/ESA's_GNSS_Observation_Network_(EGON).html]

Since 2023, EGON operates exclusively **Septentrio PolarRx5** receivers with the latest firmware installed (2025) to enable tracking of all GNSS global and regional satellite constellation signals (such as NavIC L1, QZSS C/B, etc.). The receivers are paired at all locations with **Septentrio PolaNt Choke Ring B3E6** antennas, except for MGUE, MAL2, MAS1 and FAA1, where **Leica AR25.R4** antennas are installed.

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 available for signal generation. Additionally, PolaRx5TR are also installed at 4 other ESA tracking locations (KIRU, KOUR, REDU, SNTM), which together make up the core of EGON. In addition, a PolaRx5TR timing receiver is operated at station ESOC in Darmstadt, for which data is now also publicly available, using the UTC(ESOC) realisation already mentioned above.

ESA/ESOC continues to contribute a full complement of RINEX 4 data – after migrating from RINEX 3 in mid-2025 – covering all signals and all satellites in view in daily, hourly and high-rate modes to the IGS from 10 of its public stations: VILL, CEBR, FAA1, KIRU, KOUR, MAS1, MAL2, NNOR, REDU and MGUE.

Additionally, in the next few years worldwide coverage is planned to be further enhanced.

4 GENESIS

The ESA Precise Navigation System (EPNS) can process data from the four space geodetic techniques, and the Navigation Support Office routinely computes and contributes products to the IGS, ILRS and IDS services of the IAG. In addition, the Navigation Support Office is currently an Associated AC for VLBI (IVS). To ensure that the software is fully prepared for GENESIS, activities to combine the observation of these four different techniques in one single solution were re-initiated. The activities focus on the GNSS and SLR data of the routine IGS and ILRS targets and include Sentinel-6A as a proxy for the upcoming GENESIS mission. The current results are already promising; however, substantial work still lies ahead. In addition to addressing shortcomings in the current solutions, DORIS and VLBI data will be included, and local site ties of stations that colocate multiple geodetic techniques will be incorporated. The current status was presented at the 2025 IAG Scientific Assembly (Sermanoukian, 2025).

5 Summary

Engagement in the IGS community remains a key priority for ESA. This is reflected in how the targets of the *IGS 2021+ Strategic Planning* align with ESA's contributions and technical developments.

By including BeiDou and QZSS in the IGS FINAL products, the ESA AC is supporting **IGS Goal 1: *Multi-GNSS Technical Excellence***. In addition, the new ESA0OPSFIN DCB product, which includes 19 signal combinations, makes the various GNSS signals more accessible to the community.

ESA's success in GNSS is built on close collaboration among researchers, scientists, navigation engineers, and operators, ensuring that operational products benefit from new concepts and methods in a timely manner. The ESA AC also works closely with other ESA experts, such as the GNSS Science Support Centre (GSSC), and GNSS specialists worldwide on a daily basis. ESA actively participates in IGS working groups and committees to improve exchange formats (e.g., RINEX-RTCM) and to strengthen links with system providers (e.g., IGMA). These activities support **IGS Goal 2: *Outreach and Engagement***.

In line with **IGS Goal 3: *Sustainability and Resilience***, the ESA AC has invested in infrastructure, personnel development and redundancy to ensure reliable operations and future growth. Minimising external dependencies is a key focus. Robustness was a central requirement in the development of CHAMP, which now includes improved logic to distinguish between healthy and faulty input data and automated anomaly detection.

After major successes in improving interoperability among individual GNSS systems, the next challenge is enhancing interoperability between GNSS and the other three Space

Geodesy techniques. The ESA AC has started prioritising this effort to prepare for the upcoming ESA GENESIS mission.

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Erik Schönemann, *Analysis of GNSS raw observations in PPP solutions*, Master Thesis, April, 2014, Faculty of Geodesie, TU Darmstadt, Darmstadt, Germany. ISBN 978-3-935631-31-0 Available at: https://tuprints.ulb.tu-darmstadt.de/3843/7/Schoenemann_Dissertation_TUD.pdf

Tim Springer, Rene Zandbergen, Alberto Águeda Maté, NAPEOS Mathematical Models and Algorithms, *DOPS-SYS-TN-0100-OPS-GN*, Issue 1.0, Nov 2009, Available at: http://navigation-office.esa.int/Publications.html

Iván Sermanoukian, Francesco Gini, Tim Springer, Michiel Otten, Florian Dilssner, Volker Mayer, Birgit Traiser, Sara Bruni, Jean-Christophe Berton, Frank Zimmermann, Werner Enderle, Sara Gidlund, Erik Schoenemann ESA's efforts towards a Combination on the Observation Level (COOL), Submitted for the proceedings of the IAG Scientific Assembly 2025

GFZ Analysis Center Technical Report 2025

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1 Summary

During 2025, 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 2025 including GPS, GLONASS, BeiDou, Galileo, and QZSS.

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

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

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)

- 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

- Männel, B., Brandt, A., Nischan, T., Brack, A., Sakic, P., Bradke, M. (2020): GFZ rapid product series for the International GNSS Service (IGS). GFZ Data Services. https://doi.org/10.5880/GFZ.1.1.2020.003

- Männel, B., Brandt, A., Nischan, T., Brack, A., Sakic, P., Bradke, M. (2020): GFZ ultra-rapid product series for the International GNSS Service (IGS). GFZ Data Services. https://doi.org/10.5880/GFZ.1.1.2020.004

Table 2: Recent processing changes

Date	**IGS**	**IGR**	**IGU**	Change
2025-01-09	w2347	w2348.4	w2347.3:12	administrative name change of GFZ to *GFZ Helmholtz Centre for Geosciences* reflected in products
2025-01-20	w2348	w2350.2	w2350.1:12	an inconsistency in LC checks during preprocessing was fixed
2025-02-03	w2351	w2352.2	w2352.1:09	switch to igs20_2350.atx
2025-02-05	w2351	w2352.4	w2352.3:15	incorrect COMARP values for E16 and E23 have been fixed
2025-03-04	w2356	w2356.3	w2356.2:18	switch to igs20_2356.atx
2025-03-20	w2358	w2358.5	w2358.4:12	switch from ITRF IGS20 to IGb20
2025-04-03	w2360	w2360.5	w2360.4:12	switch to igs20_2360.atx
2025-06-25	w2372	w2372.4	w2372.3:18	switch to igs20_2370.atx
2025-07-24	w2375	w2376.5	w2376.4:12	switch to igs20_2375.atx
2025-08-13	w2379	w2379.4	w2379.3:12	switch from igrf13 to igrf14

4 Multi-GNSS Data Processing

In 2025, the rapid multi-GNSS analysis product GFZMGX was routinely generated. The solution comprised observations from five GNSS constellations, including GPS, GLONASS, Galileo, BeiDou-2/3, and QZSS, with about 140 IGS ground stations and approximately 130 satellites processed (Fig. 1). Since GPS week 2352, the GFZMGX rapid product GFZ0MGXRAP has been provided in the IGb2020 reference frame. Furthermore, taking into account station data availability and global distribution, a minor optimization of the ground station network applied in the GFZMGX processing was activated at 2025/133. All GFZ MGEX products are available at CDDIS, IGN, and GFZ servers. The address of the GFZ server is 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

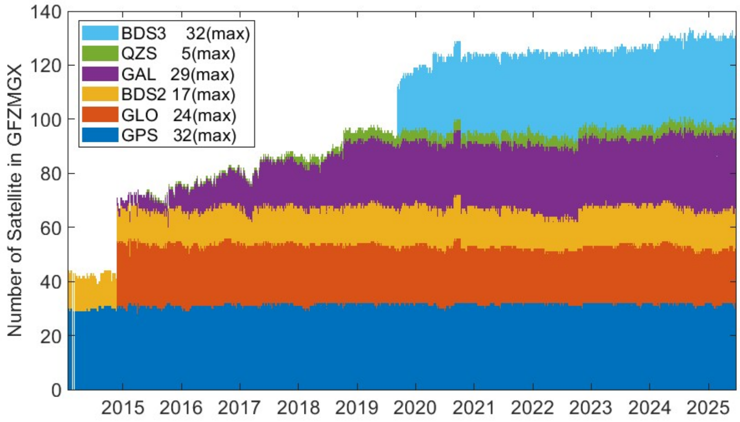

Figure 1: Total number of satellite per GNSS included in the daily multi-GNSS data processing GBM).

5 Real-time Products

Over the past years, GFZ has been developing a new real-time GNSS network processing software, which has been operationally used for the IGS Real-Time Service since October 2025. The new GPS, GLONASS, and Galileo orbit and clock solutions are provided with an update rate of five seconds, referring both to the satellite antenna phase centers as well as the centers of mass, respectively. The satellite orbits are fixed to the predicted part of the latest GFZ IGS ultra-rapid solution. The satellite clocks are estimated per epoch from real-time observation data of a global network of around 65 IGS tracking stations in a recursive least-squares adjustment using a sequential-scalar Kalman filter implementation. The new solution is provided via the mount points SSRA01GFZ* and SSRC01GFZ*. More details are available at:

- Brack, A.; He, S.; Wickert, J. (2026): Multi-GNSS real-time precise clock estimation at GFZ: Introduction and evaluation of new data product. International Association of Geodesy Symposia, *to be published*

6 Multi-GNSS Orbit and Clock Combination

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 framework, using variance component estimation (VCE) to determine the weights. 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 (Zajdel et al., 2025).

7 Operational Ionosphere Products

The rapid and final global ionosphere map (GIM) products were continued in 2025 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`

8 Clock Modeling

In 2025, the EPOS.P8 processing software was enhanced with new capabilities for clock estimation. In addition to the traditional epoch-wise clock solutions, the software now supports piece-wise linear clock modeling for satellite and receiver clocks. This approach has been implemented and successfully tested for several clock types, including the rubidium clocks onboard GPS IIF and IIIA satellites, the passive hydrogen maser clocks of the Galileo FOC satellites, and more than 50 highly stable hydrogen maser stations within the IGS network. The primary benefit of introducing clock models is the significant reduction in the number of estimated clock parameters. By constraining the behavior of the clocks through a piece-wise linear model, parameter correlations are reduced, leading to, e.g., more stable sub-daily height estimates.

- Widczisk, J; Männel, B; Wickert, J (2026): Investigations into highly stable GNSS ground and space clocks using a network of globally distributed H-maser stations. GPS Solutions, 30:21. https://doi.org/10.1007/s10291-025-01986-7

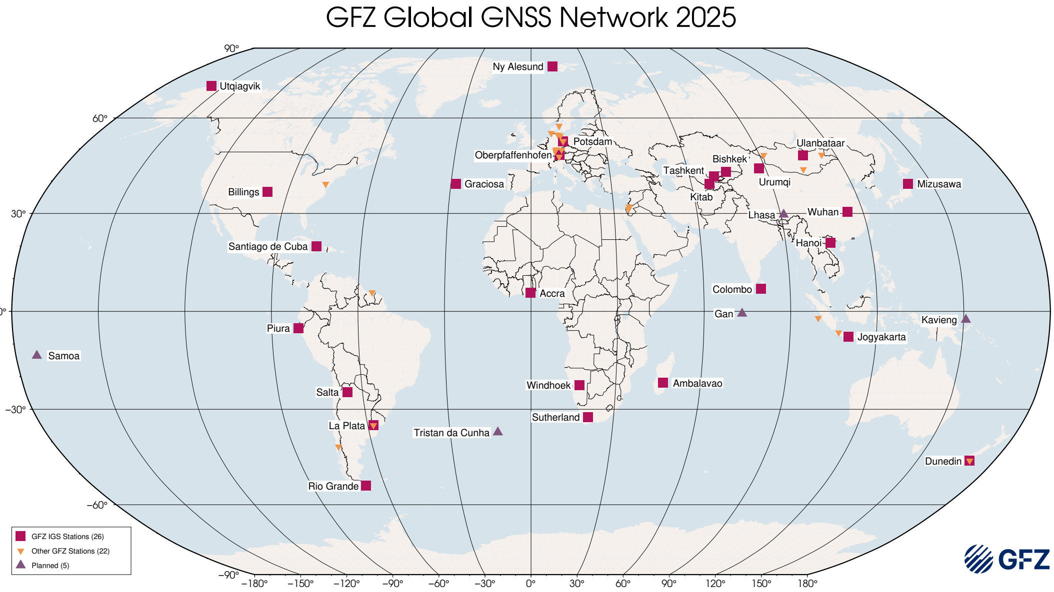

Figure 2: GNSS stations operated by GFZ (as of January 2026).

9 Operational GFZ Stations

The global GNSS station network operated by GFZ performed quite well in 2025 without major issues and without major hardware changes. Regular firmware updates have being performed to keep the existing receivers up to date. During 2025, our GNSS in Hanoi (HUMG, Viet Nam) und Piura (PIUR, Peru) became additional IGS sites. In total 25 sites operated by GFZ contribute their data to the IGS netork with 1 Hz /15 minute data files and 1 Hz data stream. 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

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Petit, G. and Luzum, B. (eds.) (2010). *IERS Conventions (2010)*. IERS Technical Note No. 36, Verlag des Bundesamtes für Kartographie und Geodäsie, Frankfurt am Main, Germany.

Zajdel, R., Mansur, G., Sakić, P., Rebischung, P., Brack, A., Männel, B., and Douša, J. (2025). Advancing multi-GNSS orbit combination in the variance component estimation framework. *Journal of Geodesy*, 99, 90. doi:10.1007/s00190-025-02005-w.

CNES-CLS Analysis Center Technical Report 2025

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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 2025 was focused on enhancing the quality of all our products; the rapid and ultra-rapid, the final and the MGEX solutions (now incorporating the BeiDou constellation alongside GPS, GLONASS and Galileo). Significant efforts have also been dedicated to refining the processing of satellite attitude data for all four constellations covered by our products. In addition, we have begun computing code measurements for signals not used in our main processing but required by certain users. These improvements are planned for deployment in our products in the near future.

The formal "GRG" products can be downloaded from the IGS data centers directory: `gps/products/wwww`. Any additional information and links to the CNES-CLS 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 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	
Ultra-rapid products GPS, Galileo & BeiDou (since week 2238) Updated four times a day		
GRG0OPSULT_YYYYDDD0000_02D_05M_ORB.SP3	Satellite orbits	5 min
GRG0OPSULT_YYYYDDD0000_01D_30S_ATT.OBX	Satellite attitude	5 min
GRG0OPSULT_YYYYDDD0000_02D_30S_CLK.CLK	Satellite & station clocks	5 min
GRG0OPSULT_YYYYDDD0000_02D_01D_ERP.ERP	Earth rotation parameters	every 6 h
GRG0OPSULT_YYYYDDD0000_02D_02D_SUM.SUM	Summary file	

The formal "GRG" pproducts can be downloaded from the IGS data centers directory: `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 CNES-CLS AC evolutions in 2024 and 2025

Date	GPS week	Change
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
02/02/2025	2352	Change to IGb20 reference frame

2 Rapid and Ultra-rapid products

Since May 2023, we have been providing rapid and ultra-rapid products for the GPS, Galileo, and BeiDou constellations with fixed phase ambiguities. These products contribute to the IGR and IGU combined products of the IGS (https://acc.igs.org) as well as to the BAR pilot project combined products (https://igs.org/wg/bias-and-ambiguity-resolution/), formerly associated with the PPP-AR working group (https://igs.org/wg/ppp-ar).

3 Final & MGEX products

Aside from the common transition to the IGb20 reference frame (see IGSMAIL #8543), no changes were introduced to our products this year. Their quality remains high and stable over time, as illustrated in Figure 1.

In 2025, we continued our participation in the evaluation campaign of BDS-3 phase center offset (PCO) estimates. The results indicate that the estimated values are stable and coherent with those from the other ACs participating in the campaign.

Figure 1: Sinex combination weight (top) and Orbit WRMS (bottom) with respect to IGS final solutions for the AC contributions, as computed by the IGS/ACC (GRG contribution highlighted in yellow). The corresponding plots are available via the IGS Plotter at https://igsac-cnes.cls.fr/html/links.html

As decided by the ACs, the new BeiDou antenna PCO values will be applied to our MGEX products starting from GPS week 2405.

4 Improvements in satellite attitude modeling

Significant changes have been implemented in the modelling of satellite attitudes for the GREC constellations. The applied mathematical models have been refined and corrected.

In addition, for the auxiliary attitude yaw law of the Galileo FOC satellites, we introduced an additional computation step to compensate for the attitude differences that occur when using different epoch intervals; for example 300 sec and 30 sec, as is the case for ORBEX files (Figure 2). A linear interpolation procedure has been incorporated to more precisely determine the entry time of the satellite in the collinearity region (and therefore the auxiliary law). In addition to the attitude law given by EUSPA, we introduced the equation 1:

$$t_{ref} = t_0 + (10^\circ - \epsilon_0)\frac{t_1 - t_0}{\epsilon_1 - \epsilon_0} \tag{1}$$

Where t_0 is referring to the "previous epoch" for time and collinearity angle and t_1 is referring to the current epoch after the entry to the collinearity region. The term t_{ref} is the exact time of entry to the auxiliary law where $\epsilon = 10°$. We apply the auxiliary law, not at the last epoch (t_0) of nominal law but the time exactly when the transition happens (t_{ref}), i.e. when the collinearity angle is exactly 10°.

This additional step optimized the transition to the auxiliary yaw law and demonstrated improvements in the overall orbit and clock overlap comparisons.

All these aforementioned corrections and additions will be incorporated into our Final, MGEX, Rapid and Ultra-rapid products in the near future.

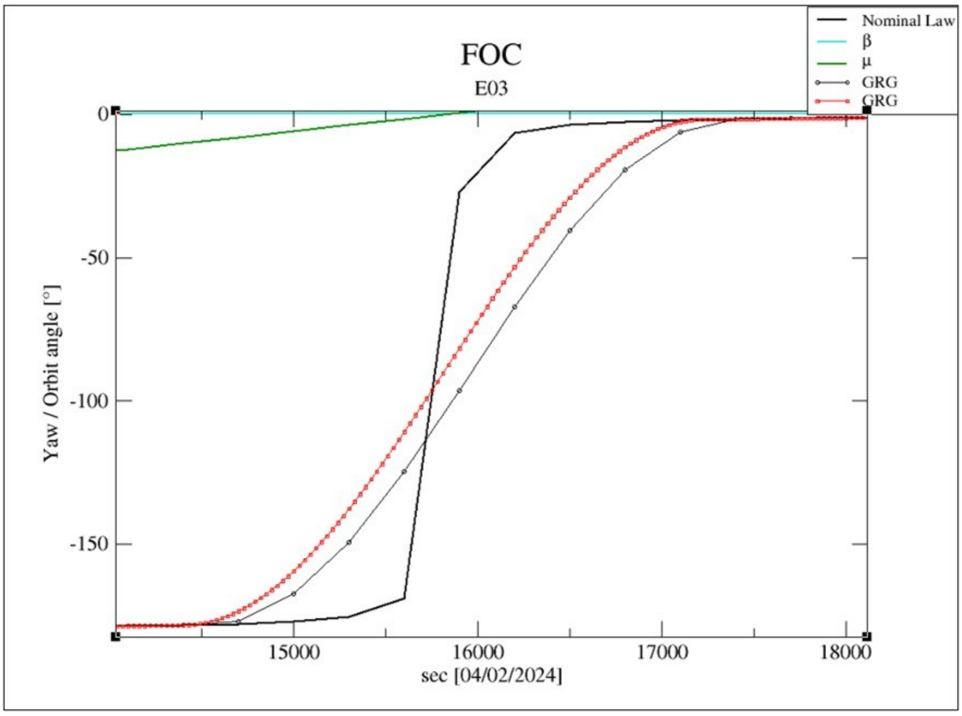

Figure 2: An example of FOC E33 satellite in eclipse season, showing the difference in yaw angle values when using 300sec step (in black) and 30sec step (in red) as calculated by GRG AC.

5 Other studies in progress

In 2025, the CNES-CLS Analysis Center also initiated the development of a processing chain for the generation of ionospheric products, including global Total Electron Content (TEC) maps. The processing scheme relies exclusively on GNSS measurements and estimates the global ionospheric parameters through a least squares adjustment combined with a spherical harmonics representation of the Vertical TEC (VTEC) field. The objective is to deliver IGS compliant ionospheric products and to contribute to the improvement of the IGS global combined ionosphere solution (e.g. Figure 3).

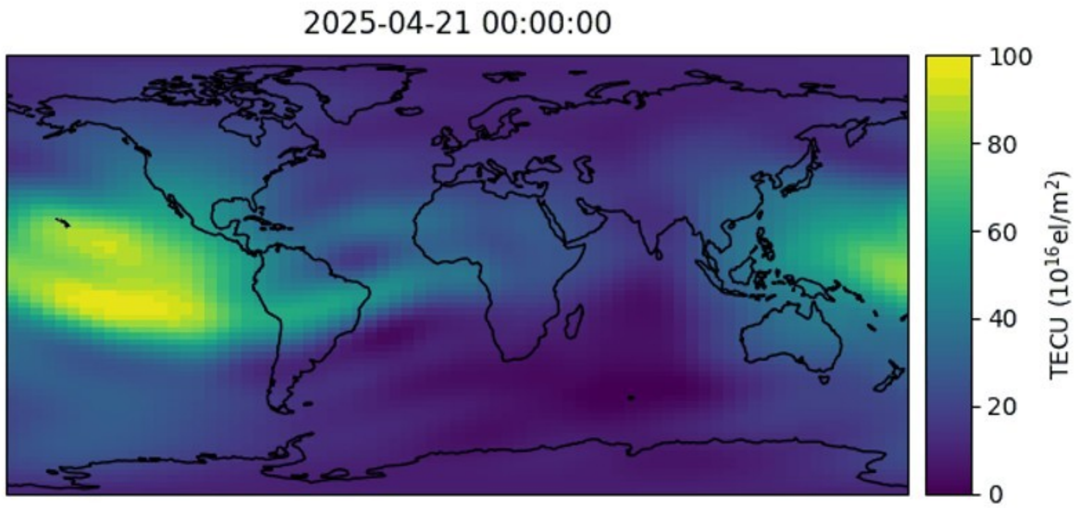

Figure 3: Example of an ionospheric map computed by the CNES CLS Analysis Center.

In parallel, we are developing new procedures for the estimation of Observable Specific Biases (OSB). The GRG OSB products currently distributed are limited to the signals used in our final and MGEX processing chains. However, some users require additional signals compatible with our orbit and clock estimates. To address this need, we currently employ four methods to derive these OSBs:

1. **Use of ionospheric maps**, adapted for the code biases between signals of different frequencies. This approach can be applied either during the ionospheric map generation process or by using external maps.
2. **Combination of phase and code measurements**, such as the wide lane (Melbourne-Wübbena) combination.
3. **Ionosphere free combinations**, for example, between code clocks and phase clocks.
4. **Direct differences of raw observations**, applicable to signals on the same fre-

quency. This method can be used to track code biases (directly) and phase biases (in the form of fractional biases). In both code and phase cases, a network processing is required to separate the satellite and the receiver contributions.

An example of the biases difference C2W-C2L derived using the fourth method is shown in Figure 4.

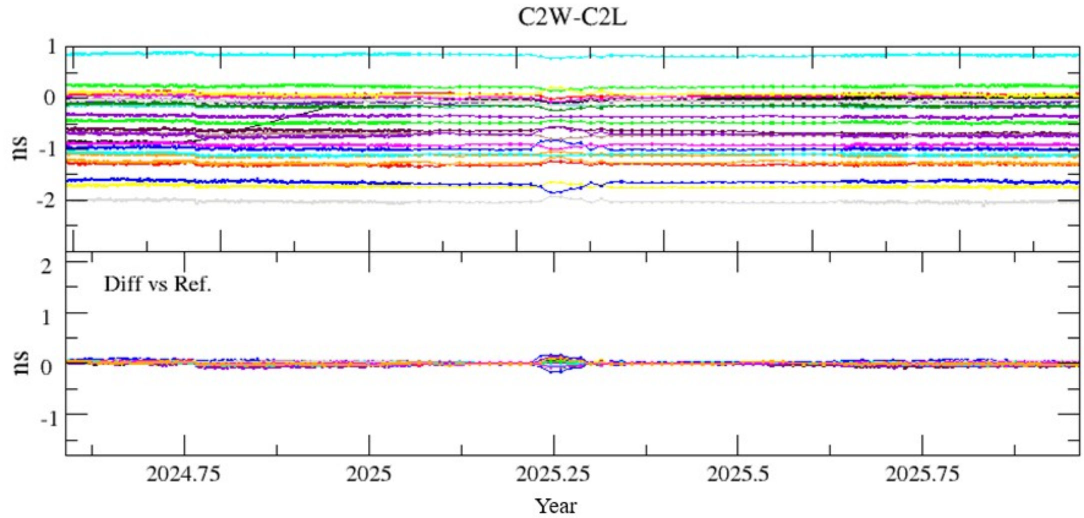

Figure 4: Top graph: C2L-C2W biases of GPS satellites. Bottom graph: Differences relative to the mean values (one curve per GPS satellite).

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Geospatial Information Authority of Japan (GSI) and Japan Aerospace Exploration Agency (JAXA) Analysis Center Technical Report 2025

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1 Introduction

The Geospatial Information Authority of Japan (GSI) and Japan Aerospace Exploration Agency (JAXA) jointly operate one of the IGS Analysis Centers (ACs) identified by the acronym "JGX" and generate GNSS orbits, clocks, ERPs, and SINEX products. The main processing engine of JGX is MADOCA software (Multi-GNSS Advanced Demonstration tool for Orbit and Clock Analysis), which is developed and maintained by JAXA (Kawate et al., 2023). JAXA is responsible for maintaining and improving the MADOCA software, while GSI is responsible for the processing of JGX operational products using the software, including quality control. Our contributions to the IGS community are summarized 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 11th November 2024; however, it has not yet been included in the IGS ultra-rapid combination.

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

JGX Final (weekly updates) GPS, GLONASS and Galileo	
JGX0OPSFIN_YYYYDDD0000_01D_05M_ORB.SP3	Daily GPS, GLONASS and Galileo orbits and clocks with 5 min intervals
JGX0OPSFIN_YYYYDDD0000_01D_30S_CLK.CLK	Daily GNSS satellite and station clocks with 30 sec intervals
JGX0OPSFIN_YYYYDDD0000_01D_01D_SOL.SNX	Daily station coordinates and ERPs in SINEX format
JGX0OPSFIN_YYYYDDD0000_01D_01D_ERP.ERP	Daily Earth rotation parameters
JGX0OPSFIN_YYYYDDD0000_01D_07D_DSC.SUM	Analysis summary for each processing
JGX0OPSFIN_YYYYDDD0000_01D_30S_ATT.OBX	Daily satellite attitude in OBX format
JGX Rapid (daily updates) GPS, GLONASS and Galileo	
JGX0OPSRAP_YYYYDDD0000_01D_05M_ORB.SP3	Daily GPS, GLONASS and Galileo orbits and clocks with 5 min intervals
JGX0OPSRAP_YYYYDDD0000_01D_30S_CLK.CLK	Daily GNSS satellite and station clocks with 30 sec intervals
JGX0OPSRAP_YYYYDDD0000_01D_01D_ERP.ERP	Daily Earth rotation parameters
JGX0OPSRAP_YYYYDDD0000_01D_01D_DSC.SUM	Analysis summary for each processing
JGX0OPSRAP_YYYYDDD0000_01D_05M_ATT.OBX	Daily satellite attitude in OBX format
JGX Ultra-Rapid (every 6 hours updates) GPS, GLONASS and Galileo	
JGX0OPSULT_YYYYDDDHH00_02D_05M_ORB.SP3	Daily GPS, GLONASS and Galileo orbits and clocks with 5 min intervals
JGX0OPSULT_YYYYDDDHH00_02D_01D_ERP.ERP	Daily Earth rotation parameters
JGX0OPSULT_YYYYDDDHH00_01D_01D_DSC.SUM	Analysis summary for each processing
JGX0OPSULT_YYYYDDDHH00_01D_05M_ATT.OBX	Daily satellite attitude in OBX format

Satellite attitude information in ORBEX format (Loyer et ãl., 2019) has been provided since 22th June 2025 for the final, rapid, and ultra-rapid products.

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, MADOCA, which has been developed and continuously updated by JAXA since 2011. MADOCA supports multi-GNSS constellations (GPS, GLONASS, Galileo, BDS, and QZSS) and incorporates force and measurement models compliant with the IERS conventions 2010 (IERS , 2010) and those applied in the IGS Repro3 campaign (IGS , 2019). The products are estimated both in post-processing using iterative weighted least squares and in real-time processing using extended Kalman filter (EKF) employing methods that reduce memory consumption and processing time while improving processing stability. JAXA has introduced new features to enhance performance, with recent efforts focusing on non-gravitational force modeling. Details of the POD algorithm are provided in our paper (Kawate et al., 2023).

The following changes have been implemented in version 2.2.1, which are currently used for the latest JGX products. This version corrects a bug in which the yaw-steering angles for GPS Block IIR and IIR-M were erroneously inverted by 180 degrees. JGX GPS orbit products incorporating this fix (since GPS week 2372) show improved consistency with IGS combined products. Additionally, regarding the third item below, the first Block III satellite of QZSS, J007 (QZS-6), began service in July 2025 (CAO , 2015). As an Analysis Center for the Multi-GNSS Pilot Project (MGPP), we are preparing to release products for this satellite.

1. Addition of a zonal tide model to mitigate the effects arising from the interpolation of UT1
2. Correction of the yaw-steering model for GPS Block IIR and IIR-M
3. Support for the new QZSS satellite block (Block III)
4. Inclusion of the prediction part of ERPs in the ERP files
5. Addition of constraint information to the SINEX files (to be activated when NNR+NNT constraints are applied)

Furthermore, we are currently implementing and conducting quality assessments of our phase bias products in both the observable-specific signal bias (OSB) and common clock (CC) representation (Schaer et al., 2021). These products are planned for release in 2026.

4 Operational Data Processing

The JGX operational final, rapid, and ultra-rapid products are currently generated using MADOCA software version 2.2.1a. The candidate IGS stations used for processing in 2025 are shown in Figure 1. Considering the quality, latency and availability of the daily data from IGS stations, we select approximately 150, 110, and 110 stations for the final, rapid, and ultra-rapid products, respectively. Approximately 50 fiducial sites are chosen for each daily solution to minimize inconsistencies between the Earth's center of mass (CoM) and the center of the network defined by the selected fiducial sites. The IGS20/igs20.atx reference frame is applied with no-net-rotation (NNR) minimum constraints, for the processing.

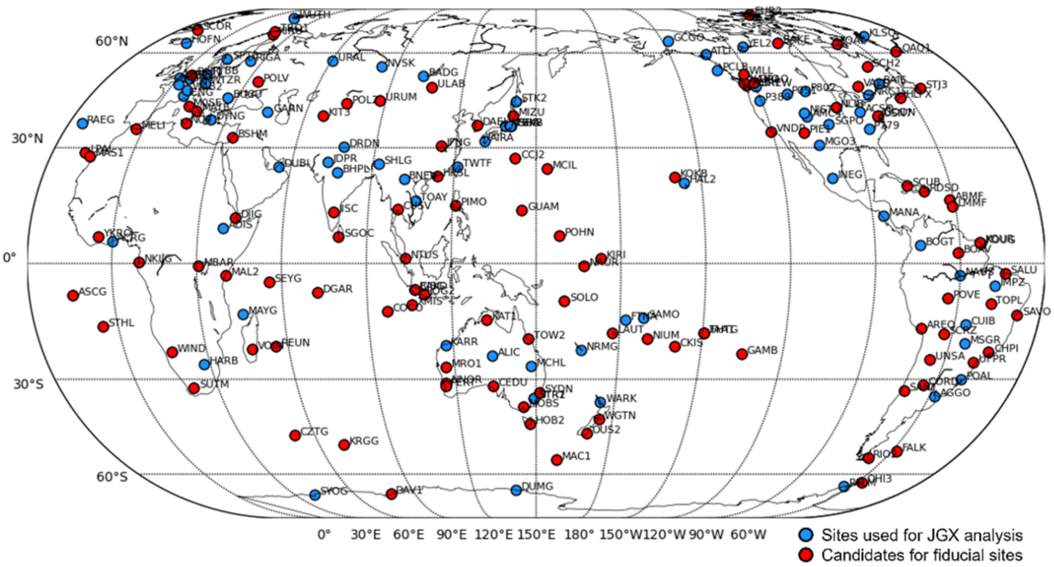

Figure 1: Station network for JGX processing in 2025.

The JGX final and rapid products for GPS, GLONASS, and Galileo have been routinely submitted to the IGS since GPS week 2269. The final products (SP3, CLK, SNX, ERP, SUM, OBX) are generated with a latency of five days and uploaded every Thursday. The rapid products (SP3, CLK, ERP, SUM, OBX) are generated with a latency of one day and uploaded on a daily basis. When unexpectedly large errors are detected in the final product, corrective measures are taken as far as possible prior to upload. The processing software was upgraded from version 2.2.0a to 2.2.1a at GPS week 2372. This newer version includes a bug fix on correcting the yaw steering angle for GPS Block IIR and IIR-M, and this update has improved the consistency between the JGX and IGS final products as shown in Figure 2.

The JGX ultra-rapid products (SP3, ERP, SUM, OBX) for GPS, GLONASS, and Galileo have been routinely submitted to IGS since GPS week 2340. However, they have not yet incorporated into the IGS combined products due to instability in satellite clock estimation.

Figure 2 shows the 3D RMS of satellite orbit differences among IGS ACs for the final products in 2025. No Helmert transformation has been applied. The quality of the JGX orbits is comparable to that of other ACs.

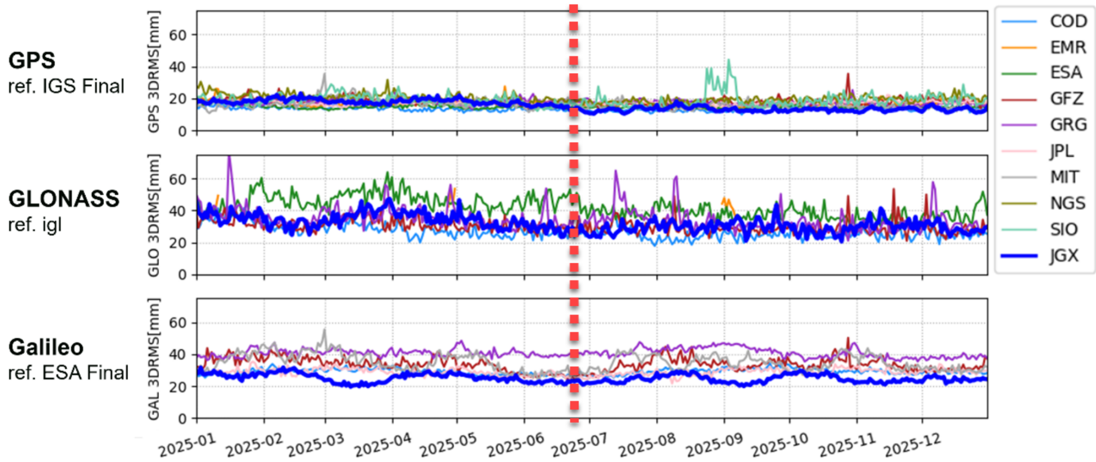

Figure 2: 3D RMS errors of the final products in 2025 with respect to the IGS final (GPS, GLONASS) and the ESA final products (Galileo). The red vertical dashed line (22 June) indicates the switch to the updated POD software version that includes the bug fix for the GPS yaw steering model.

The pressing issues for the JGX operational products are as follows.

- Product modification related to the center-of-network:
  To meet the convention requirement for the clock center-of-network (CLK:CoN), we plan to apply not only NNR constraints but also no-net-translation (NNT) constraints to our products. In addition, we plan to update our software to introduce the conversion from the Earth's CoM to the center of network (CoN) by applying the center of mass correction (CMC) for ocean tide loading (OTL) directly to the orbit. With the introduction of the NNR+NNT constraints, our preliminary PPP solutions processed with these modified products clearly showed improved repeatability in the temporal variation, which had been affected by the shift in the Earth's CoM. While the NNT constraint function has already been implemented in the current MADOCA software (version 2.2.1a), the implementation to output the minimum constraint information into SINEX file has not yet been completed. These changes will be applied to JGX operational products once validation by the IGS reference frame coordinator is completed.

- Improvement of the ultra-rapid products:
  The JGX ultra-rapid orbit products are not included in the IGS combination due to

insufficient accuracy in the prediction part of the orbits, and further improvement is required.

- Improvement of stability in the clock products:
  The stability issue was improved after March 2024 as a result of applying the following measures: selecting stable clock-reference sites and performing quality checks on reference clocks. In addition, we plan to introduce a more sophisticated iterative data-quality-control and screening procedure for satellite clock estimation in the future. We will continue to address operational issues as they arise.

5 Proposal for the IGS workshop 2028 in Japan

At the IGS governing board meeting in August 2025, it was decided that the JGX team will host the 2028 IGS workshop in Tsukuba, Japan. The 2028 workshop will be the first IGS workshop hold in Japan and will serve as an excellent opportunity to highlight the technological evolution and increasing diversity of the IGS community. The workshop will address key technical themes that are strongly connected to Japan, including multi-GNSS constellations such as QZSS, as well as the contribution of GNSS to disaster risk reduction, particularly in monitoring seismic deformations and crustal movements for geodetic applications. Furthermore, it will provide an opportunity for potential participants–such as university students, young professionals–in Japan and neighboring Asia-Pacific countries to engage with the IGS community.

The venue will be the Tsukuba International Congress Center (https://www.epochal.or.jp/en/). The main hall designated for the symposium can accommodate the expected number of IGS participants, with seating for up to 450 people. A dedicated space for the poster session is located adjacent to the main hall and can host up to 100 posters. Additionally, to support a hybrid format for the symposium and workshop, multiple meeting rooms will be available to facilitate concurrent sessions.

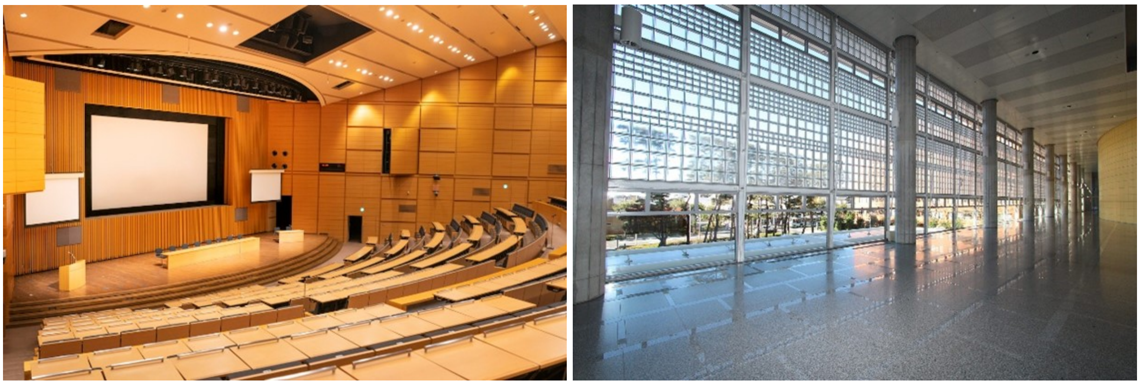

Figure 3: Main hall for symposium (left) and Large space for poster session (right).

Important facilities related to geodesy and Japan's space development - such as the Ishioka Geodetic Observing Station and the Tsukuba Space Center–are located near the conference venue. To make the workshop truly rewarding, the JGX team is planning to organize a variety of special events. We hope you look forward to the 2028 IGS Workshop.

Figure 4: Ishioka geodetic observing station (left) and Tsukuba space center (right).

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Jet Propulsion Laboratory Analysis Center Technical Report 2025

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1 Introduction

In 2025, 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 2025.

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 without applying any constraints between solutions. Before 2024-08-25, we produced

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

GPS-only Rapid and Final orbit and clock products and since that date 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 ((Bertiger et al., 2020)) 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 729:6 (1994-01-01).

The frame for Rapids and Finals was updated updated to IGb20 during week 2352 (2025-02-02).

Our IGS20 Rapid operations and our ongoing Final IGS20 reprocessing campaign continue to use several new models vs IGS14 processing, 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 et al., 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, DORIS, and VLBI data processing at the measurement level.
5. Multi-processor and multi-threaded capability.
6. Versatile PPP tool (gd2e).
7. Runs under Linux, Mac OS, post-processing, real-time environments, and embedded flight hardware.
8. GipsyX-1.0 released 2019-01-28.
9. Most recent release was GipsyX-2.5 on 2025-12-29.
10. Available for license, free to academia.

    (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 continued development of 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). VLBI was also incorporated using traditional site survey-derived ties.
- Added Doppler Orbitography by Radiopositioning Integrated on Satellite (DORIS) to the experimental reference frame solution (Peidou et al., 2025).
- 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).
- Add Beidou MEO to rapid and final products.
- Update empirical solar pressure modes for newer spacecraft (esp. Block III GPS).

6 Acknowledgments

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MIT Analysis Center Technical Report 2025

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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 use combined GPS and Galileo solutions and 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 ten 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 use a combined GPS+Galileo solution, with 5-minute tabular points in the SP3 orbit files to accommodate the high-eccentricity Galileo satellites. The 24:00 epoch has also been added to our orbit can clock files.

The network of stations processed by MIT in 2025 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 less than 10 times (14 stations in total) are not included in the plot. Only linear trends were removed from the time series. The median WRMS scatters of the 434 sites, measured more than five times, included in the statistics are 1.54, 1.51 mm in North and East and 5.46 mm in height. No annual signals were removed, nor are scale parameters estimated in the reference frame realization. The station selection criteria remain the same as previous years, except starting week 2360 (2025/03/30), we only include in the Galileo solutions those stations with antennas that have L5 phase calibrations.

The sites with high RMS in Figure 1 show anomalies for a variety of reasons. Table 3 describes what is known about the reasons for the high RMS of each site. Many of the sites with high RMS are IGS sites, but some sites are included in our analyzes to provide geographic coverage.

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
MIT0OPSFIN_YYYYDDE0000_01D_05M_ORB.SP3	Day 6 satellite orbits
MIT0OPSFIN_YYYYDDS0000_01D_05M_CLK.CLK	Day 0 satellite clocks
MIT0OPSFIN_YYYYDDE0000_01D_05M_CLK.CLK	Day 6 satellite clocks
MIT0OPSFIN_YYYYDDS0000_01D_01D_SOL.SNX	Day 0 coordinate and EOP SINEX file
MIT0OPSFIN_YYYYDDE0000_01D_01D_SOL.SNX	Day 6 coordinate and EOP SINEX file

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

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 2 we show the WRMS scatter

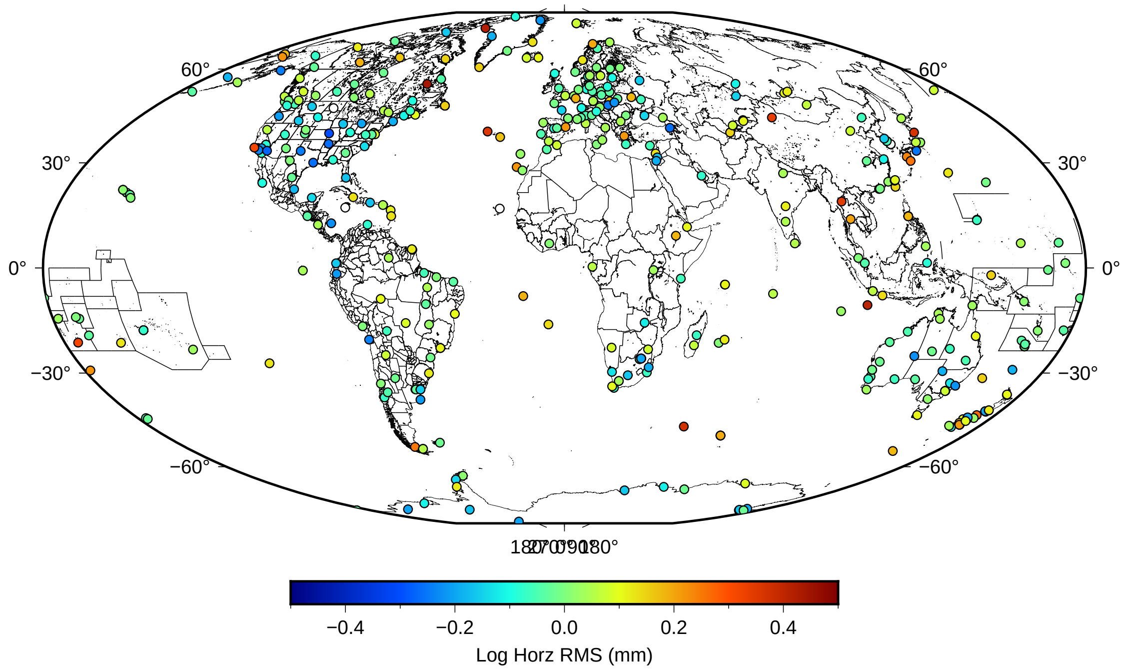

Figure 1: Log (base 10) of the WRMS scatter of the horizontal position estimates from the network of 442 stations. A total of 421 sites were processed by MIT in 2025, with 42 sites being used less than 5 times. Each daily network has 350 stations, and the networks evolve with time depending on data availability and geometry. Of the 440 stations, 223 have Galileo data with fully calibrated antennas.

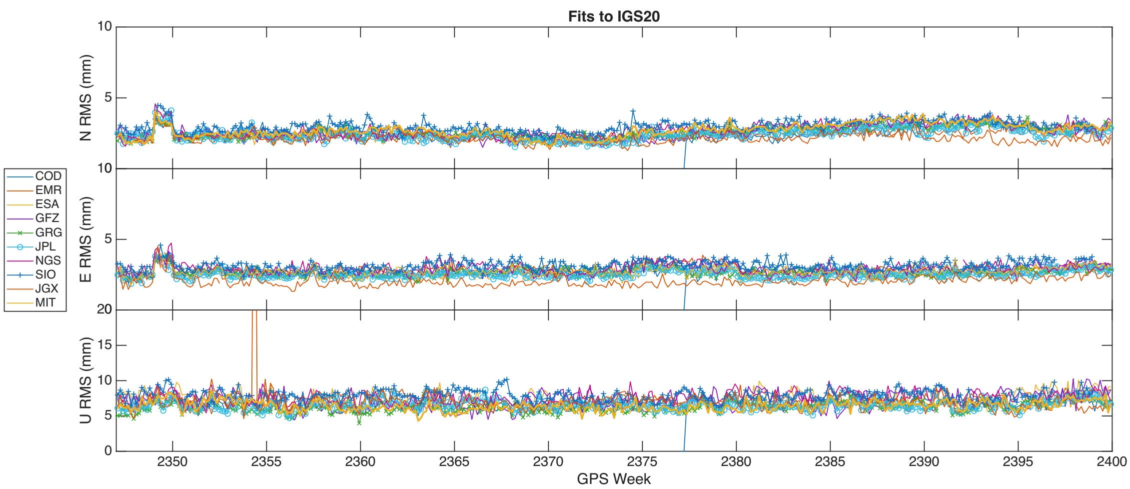

Figure 2: WRMS scatters of the fits of different IGS ACs to the IGS20 system using typically 45-50 stations. Note the scales here are twice those used in Figure 3

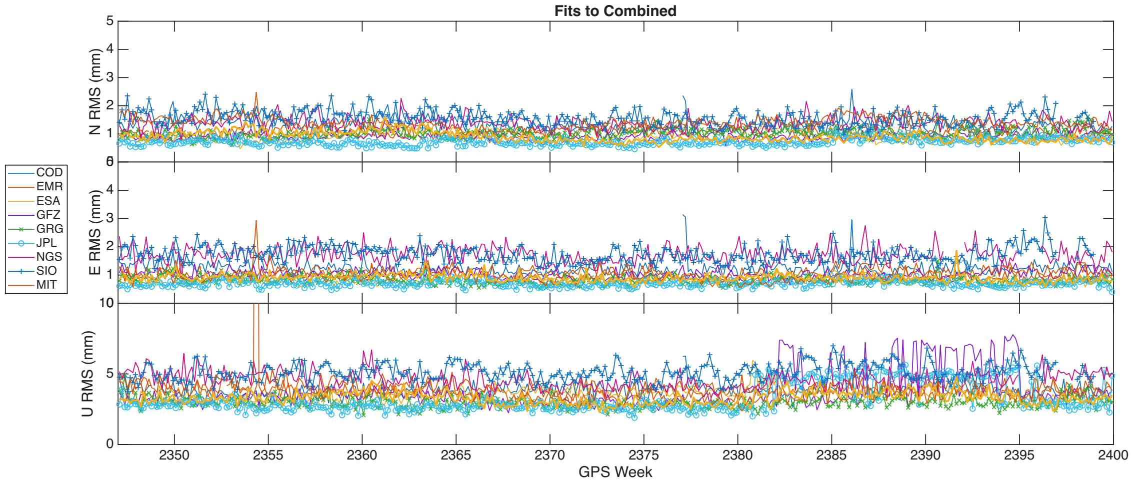

Figure 3: WRMS scatters of the fits of the different IGS ACs to the MIT0OPSSNX combined solution for 2025. The larger excursions were mostly due to non-detected outliers.

between the AC solutions and the IGS20 reference frame coordinates (IGb20 realization). While the AC results look similar, there are differences in the mean of the RMS differences. In Figure 3, we show the WRMS scatter of the daily fits to 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. A summary of the metrics for each AC is given in Table 4. This table gives the mean WRMS 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 3.39 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. Reweighting factors are computed for each center as part of the combination process and so the balance of the chi-squared values in not surprising.

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 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 Galileo processing is formed from the 350 sites used daily for the GPS network and includes all sites with fully calibrated antennas that have Galileo data. Generally, there are about 222 sites in the Galileo network. Of these sites, 211 sites were

Table 3: Explanations of high RMS sites

Site	Type	Explanation
CN11	NEU	Monument badly damaged during hurricane on 2025–10–29.
BSMK	NEU	Site in building that appears to be disturbed on 2025–06–17; data flow stops shortly afterwards.
URUM	NEU	IGS site with large annual signal in height, with outliers most likely due to snow.
TONG	NEU	IGS Tonga site with systematic noise and outliers in East seen by all ACs.
CMUM	NEU	IGS site in Thailand with systematic quasi-seasonal noise.
GAMG	N	IGS site in Korea with North offset of −19 mm on 2025–11–17, with no earthquake or metadata change in log.
CPVG	NE	IGS site in Cape Verde; non-secular motions possibly due to volcanic activity.
CZTG	NE	IGS site in French Southern and Antarctic Lands; very noisy, possibly due to atmospheric effects.
FLRS	E	IGS site on Ilha das Flores; highly skewed position residuals mostly in East.
SCH2	NEU	Northern Canadian IGS site affected by snow.
HYDE	NEU	Indian IGS site showing a large number of excursions persisting for multiple days; reasons are not obvious.
HORN	U	New Zealand site with an increasing number of outliers.
FLIN	U	Canadian IGS site with strong evidence for persistent snow effects.
INVK	U	Canadian IGS site affected by snow, similar to FLIN.
BOAV	U	Brazilian IGS site strongly affected by hydrologic loads, mostly in U but also N.
POVE	U	Brazilian IGS site affected by hydrology similar to BOAV.

used 10 or more times. There are about 40 other stations that track Galileo data but use antennas with only L1 and L2 phase calibrations.

Table 5 presents the median and 95% quantile WRMS scatter of position residuals in North, East, and Up after removing linear trends only for data collected in 2025 for sites common to all three solution types. It shows that Galileo-only solutions have higher WRMS scatter than GPS-only solutions, while the combined GPS and Galileo solution has the lowest WRMS scatter across all components for both the median and 95% quantile levels. When differences between GPS-only and Galileo-only solutions are analyzed, some sites show systematic mean differences, which affect the realization of the terrestrial reference frame as the IGS shifts from GPS to multi-GNSS solutions.

The differences between the L1/L2 and L1/L5 GPS and Galileo solutions with fully cal-

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.

	IGS20			Combined		
Center	N (mm)	E (mm)	U (mm)	N (mm)	E (mm)	U (mm)
MIT	2.71	2.74	6.42	0.90	0.90	3.29
COD	2.44	2.81	6.85	1.34	1.24	3.83
EMR	2.35	2.87	7.14	1.04	1.07	4.04
ESA	2.54	2.61	7.16	0.91	0.83	3.55
GFZ	2.60	2.79	7.02	0.91	1.02	3.70
GRG	2.58	2.64	6.22	1.02	0.81	2.98
JPL	2.44	2.54	6.60	0.72	0.70	3.25
NGS	2.68	2.92	7.60	1.39	1.72	4.61
SIO	2.99	3.14	7.88	1.57	1.74	5.12
JGX	2.15	2.03	7.02	1.40	0.99	3.85

ibrated 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 height differences for the 211 sites are shown in Figure 4 have a median difference of 0.3 mm, but the median WRMS scatter of these differences, 2.21 mm, is far greater than the typical standard deviation of the mean differences of 0.28 mm (although the latter, computed assuming white noise, is too small). Plots of the differences show that, for many sites, there are clear mean differences in height and horizontal coordinates. One specific case which seems to clearly show the impact of the environment of the antenna is for an antenna change at the IGS site JOG200IDN on 2023/10/23. On this day a fully calibrated JAV_RINGANT_G3T antenna was replaced with a SEPCHOKE_B3E6 antenna. Both antennas have E05 calibrations, and no radomes were installed. IGS photos of the site show a pillar mounted on a rooftop. The sloped roofs of other buildings are visible in the photos, but there is no nearby vegetation. Offsets in position are common when antennas are changed, but in this case, the position changes differ significantly between the GPS and Galileo solutions. The North-East differences (based on 30 days of data before and after the change) are 0.37±1.01 and 19.52±1.29 mm for GPS and 10.77±1.44 mm and 8.55 ±1.31 mm for Galileo, clearly showing a very different response to the antenna change. Other IGS analysis centers process this site as well, with those ACs submitting GPS-only solutions matching our GPS estimates (SIO NE 0.28±1.26, 17.41±1.50 mm), while ACs submitting multi-GNSS solutions vary. GFZ shows offsets similar to our combined solution offset (NE 9.59±0.70, 8.53±1.13 mm, the MITS combined solution submitted to the IGS shows offsets of NE 8.72±0.96, 11.17±1.09 mm), while CODE shows a result closer to GPS (NE 0.04±1.22. 18.44±1.12 mm). This latter result may be due to the relative weights assigned to Glonass, Galileo, and GPS in the CODE solution. There

Table 5: Median and 95% quantile WRMS scatters of the NEU position estimates from the 211 sites used more than nine times that are common to the GPS, Galileo, and combined solutions in 2025. All units are mm.

	Median			95% quantile		
Solution	N WRMS	E WRMS	U WRMS	N WRMS	E WRMS	U WRMS
GPS	1.67	1.63	5.68	2.67	2.94	9.19
Galileo	1.94	1.87	6.43	3.01	3.17	10.69
Combined	1.52	1.45	5.48	2.56	2.72	8.78

are other recent antenna changes that we are examining, but none of these generate the large horizontal coordinate difference seen at JOG200IDN. We are also starting analysis of short baseline data between close sites that track multi-GNSS signals and that have fully calibrated antennas.

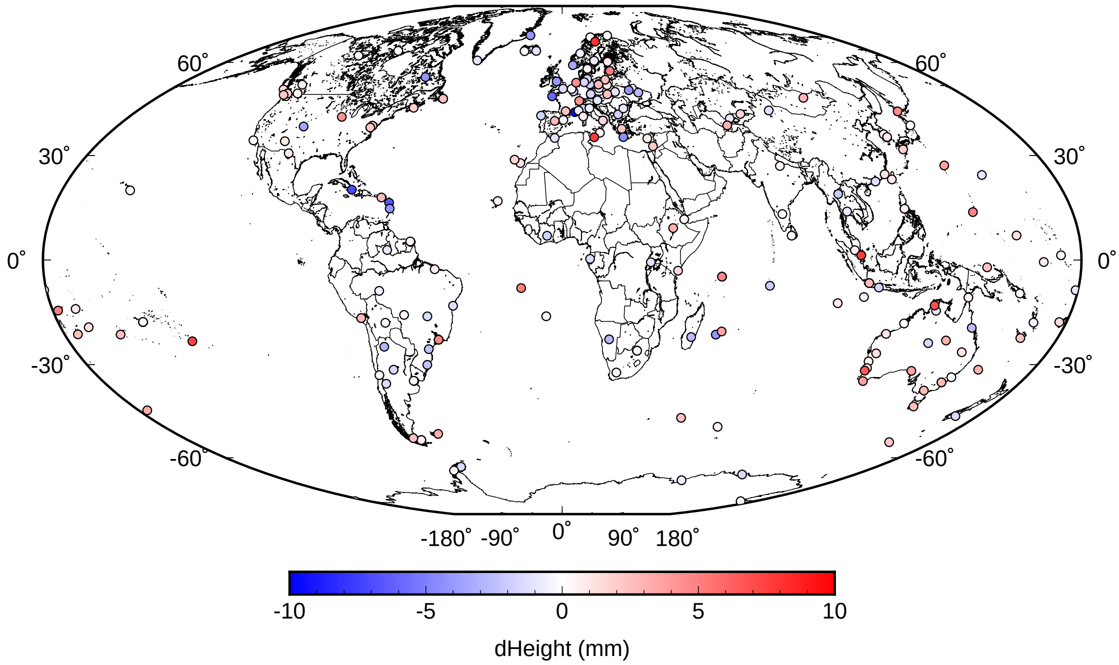

Figure 4: Differences between GPS-only and Galileo height estimates for sites that use fully calibrated antennas. For sites with high-quality data, the differences range from -9.96±0.21 (MARS00FRA) to +9.56±0.23 (DARW00AUS). There are large horizontal position differences as well. For North differences, the range is -2.61±0.08 (SG0C00LKA) to 4.21±0.06 (GRAS00FRA), and for East differences, the range is -7.64±0.11 (URUM00CHN) to 5.31±0.11 (CMUM00THA).

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NGS Analysis Center Technical Report 2025

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1 Introduction

In 2025, The National Geodetic Survey (NGS) continued to serve dual roles in the geodetic community as an analysis center and a regional data center for the International GNSS Service (IGS). This report summarizes the routine analysis and data center activities conducted at NGS; the products provided by NGS and their locations; plus the significant changes that occurred since the last contribution to the 2024 IGS Report.

2 Core Analysis Center Products

The NGS analysis center currently focuses on modeling the Global Positioning System (GPS) satellite orbits and providing the derived products presented in Table 1. We continue to use long file names accordingly, matching IGS standards. Solutions provided in 2025 were primarily aligned with the ITRF2020/IGS20 frame (initial date Nov 18, 2022). Starting GPS Week 2394 (Nov 23rd, 2025) we updated our provided solutions to the ITRF2020-u2023/IGb20 frame. These incremental updates are not new to IGS developed frames (i.e ITRF2014-u2020/IGb14), but the frequency has increased to streamline incorporating data from new IGS network sites. In 2026 to keep pace with fellow Analysis Centers we plan to update our solutions again to the ITRF2020-u2024/IGc20 frame update including 11 newly added IGS reference frame stations.

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

Table 1: Products provided by the NGS Analysis Center. DATE is in YYYYDDD format (ex. 2025230) for our currently provided products. This is an update from the GPS week-day format (wwwwd) used for older solutions on CDDIS before GPS Week 2237.

Current Products	
NGS0OPSRAP_**{DATE}**0000_01D_15M_ORB.SP3	Rapid GPS orbit solution
NGS0OPSRAP_**{DATE}**0000_01D_01D_ERP.ERP	Rapid Earth Rotation Parameters
NGS0OPSRAP_**{DATE}**0000_01D_01D_SUM.SUM	Rapid GPS combination summary
NGS0OPSFIN_**{DATE}**0000_01D_15M_ORB.SP3	Final GPS orbit solution
NGS0OPSFIN_**{DATE}**0000_01D_01D_SOL.SNX	Final PAGES position solution
NGS0OPSFIN_**{DATE}**0000_07D_01D_ERP.ERP	Final Earth Rotation Parameters
NGS0OPSFIN_**{DATE}**0000_07D_07D_SUM.SUM	Final GPS combination summary
Pre-Wk 2237 Products	
ngs**wwwwd**.sp3	GPS only orbit solution
ngs**wwwwd**.snx	PAGES position solution
ngs**wwww**7.erp	Earth Rotation Parameters

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 (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 positions, orbits, and EOPs from double-differenced GPS phase observables. NGS computes solutions from small regional clusters of stations through Delaunay triangulation. The last step 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).
- Gravity model used is the global Earth GRACE Gravity Model 05 (GGM05). Ries et al. (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 2025.

Site	Location	Lat.	Long.	Receiver Type	System
(1) 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
(2) 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
(3) 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

Table 3: Site Data facilitated by NGS during 2025

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

4 Regional Data Center Core Products

During 2025, NGS contributed data from the sites listed in Table 2 to the IGS Network. The sites are broken down into three tiers. Tier one sites are currently active and stable enough to be used in the development of the modern IGS20/IGb20 and previous frames. Tier two are active, but were left out of the IGS20/IGb20 defining sites. Tier three sites are inactive, but do have historical IGS data available. NGS also facilitated data flow for the sites given in Table 3 as a Regional Data Center. Please refer to the IGS Network website network.igs.org 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.

6 References

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NRCan Analysis Center Technical Report 2025

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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 2025 (products labelled 'EMR*'). Furthermore, it includes an outline of the changes to the stations and services managed by NRCan. Finally, NRCan's activities are presented with reference to the goals and objectives defined in the IGS Strategic Plan 2021+. Readers are referred to the Analysis Center Coordinator (ACC) 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

From the beginning of 2025 until GPS week 2361 (April 6th), the Final GPS products were generated using a hybrid Gipsy-X setup combining v1.3 and v2 together with in-house developments (gPOD) (Nikolaidou et al., 2024). Since then, processing has transitioned fully to Gipsy-X v2 and is running on upgraded workstations/VMs. Starting with GPS week 2365 (May 4th), the in-house software SPARKNet has been adopted for clock and bias estimation and attitude computation. While Gipsy-X provides a robust and high-quality processing framework, the use of SPARKNet allowed a more tailored tuning of the estimation strategy for the clocks, leading to further performance gains. As an example, a reduction in satellite clock standard deviations was observed (Fig. 1). Gipsy-X/gPOD is continued to be used for the orbits, ERPs and SINEX products. 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

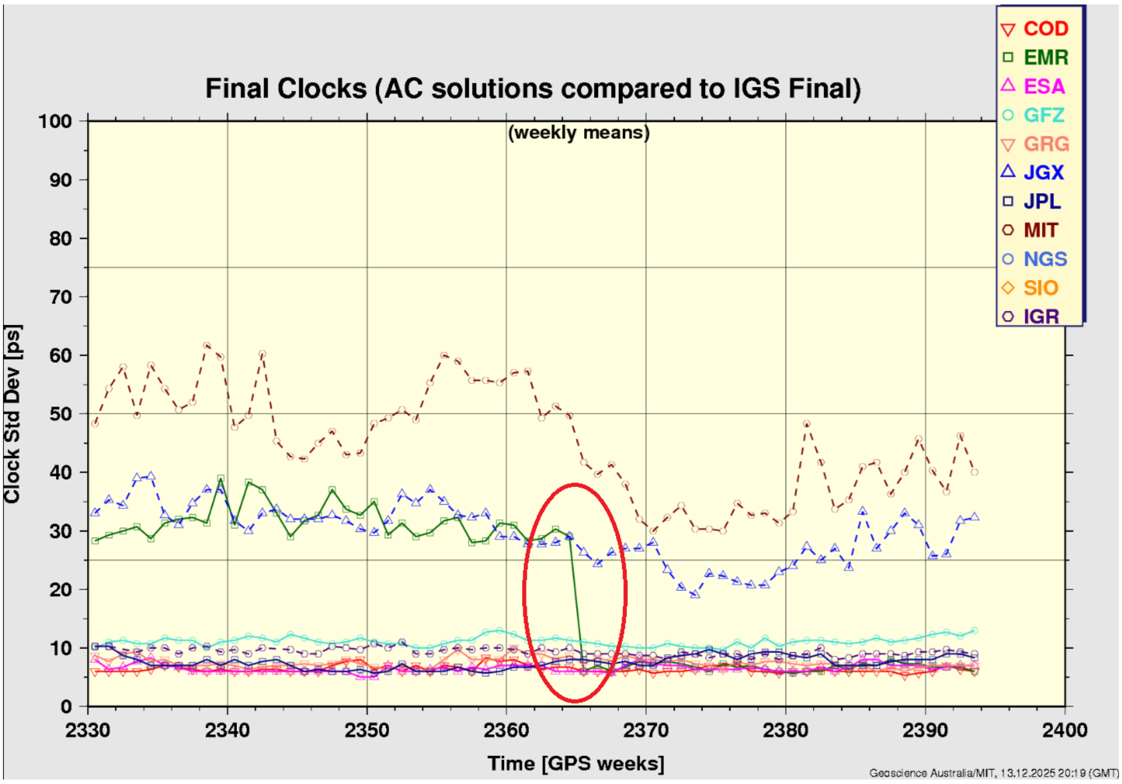

Figure 1: Standard deviations of the IGS final clock combination. The red ellipse signifies the EMR clock improvements resulting from the use of the in-house SPARKNet software.

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 and contributes to NRCan bias products. 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 (Krankowski et al., 2025) .

4 Real-time correction service

NRCan continues to generate and disseminate precise real-time correction streams to the IGS based on a Decoupled Clock Model (Collins et al., 2010) implementation. The service provides GPS real-time satellite orbits and clocks from network of about 90-120 real-time stations. The resulting SSR products include orbit corrections (RTCM 1060 at 5 s and 1057 at 60 s), clock corrections (RTCM 1060 at 5 s), and code bias corrections (RTCM 1059 at 5 s) for GPS signals C1C, C1W, C2W, and C2C, together with support for other wide set of RTCM messages (1019, 1057, 1058, 1059, 1060, 1061, 1062, 1264, 1265). During 2025, NRCan improved the stability and reliability of its IGS real-time mountpoint by troubleshooting and reconfiguring the real-time infrastructure and updating NTRIP casters resulting in a dedicated and more resilient IGS stream. Also, the IGS stream was migrated to the new in-house real-time rtCGS software platform, which removes previous internal architectural barriers and supports near future extension of NRCan's AR clock and orbit products to multi-GNSS. New rtCGS software facilitates future enhancements in line with IGS real-time combination requirements. In addition, in the coming months, NRCan adopts center-of-mass (CM) antenna phase center modeling for its dedicated IGS real-time stream, replacing the current L3 ionosphere-free convention, to ensure full compliance of its clocks and orbits with IGS standards and to enable better inclusion in the IGS real-time combination. NRCan also runs internal testbed to study performance of Galileo High Accuracy Service compared to other real-time correction streams over Canada (Ghoddousi-Fard R. , 2024, 2025) .

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 39 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 39 stations NRCan contributes to the IGS network, a further 30 GNSS stations are submitted to IGS data centers. Over the past three years, CGS has expanded their national network of GNSS stations. An additional 14 GNSS stations were made publicly available in 2025. Figure 2 shows a map of NRCan's publicly available

GNSS network as of January 2026 and Table 1 contains a list of new CGS-CACS stations. 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
ftp://cacsb.nrcan.gc.ca/gps

Table 1: NRCan-CGS New CACS Stations in 2025.

Station	Installation Date	Location
AUGO00CAN	2023-07-02	Athabasca, Alberta
CALV00CAN	2022-09-25	Calvert Island, British Columbia
CPAB00CAN	2022-07-03	Channel Port-aux-Basques, Newfoundland
IQLK00CAN	2023-06-10	Iqaluktuuttiaq, Nunaut
KAKA00CAN	2023-10-26	Kakabeka Falls, Ontario
KENO00CAN	2024-05-28	Keno City, Yukon
KLAT00CAN	2024-09-18	L'Anse aux Meadows, Newfoundland
PARQ00CAN	2024-07-05	Parent, Québec
PMNR00CAN	2024-10-19	Port-Menier, Québec
POWR00CAN	2023-07-30	Powell River, British Columbia
RIGO00CAN	2024-06-26	Rigolet, Labrador
SSMR00CAN	2023-05-03	Sault-Ste.-Marie, Ontario
WOLL00CAN	2024-10-22	Wollaston Lake, Saskatchewan
WRIT00CAN	2024-02-25	Writing-on-Stone, Alberta

6 NRCan Contribution to the IGS Strategic Plan 2021+

NRCan (then part of Energy, Mines and Resources, EMR) has been a contributor to the IGS since the 1992 IGS pilot phase and provided initial Analysis Centre coordination. NRCan's activities directly support the goals and objectives of the IGS Strategic Plan 2021+ through sustained delivery of high-quality GNSS products, methodological development, and long-term infrastructure stability.

Contribution to Goal 1: Achieve Multi-GNSS Technical Excellence

NRCan contributes to the IGS objective of multi-GNSS technical excellence through the routine generation of precise GNSS analysis products in compliance with IGS standards

Figure 2: NRCan Public GNSS Stations (CGS-CACS, CGS-RACS, CHIS-WCDA). Stations installed in 2025 are shown in green.

and performance requirements. In 2025, NRCan transitioned to exclusively use RINEX3 data for the generation of its products and expanded its Gipsy-X/gPOD capabilities to multi-GNSS including Galileo and GLONASS in testing mode, while maintaining its operational GPS Final and GPS+GLONASS Rapid and Ultra-Rapid products.

In 2025, migrating the IGS real time stream to the in house rtCGS platform marked an important step toward NRCan's multi GNSS capability by removing legacy architectural constraints and establishing a clear pathway to extend ambiguity resolved clocks/orbits and bias products to additional constellations. In parallel, NRCan maintained continuity and improved the stability of its operational GPS real time service dedicated to IGS. Within rtCGS, NRCan's real time computing engine implements the Decoupled Clock Model (DCM) estimation strategy (Collins et al., 2010), which is extendable to multi-

GNSS and supports high-rate PPP AR applications. Overall, NRCan's and the IGS real time approaches remain aligned in terms of workflows and emerging multi GNSS combination requirements.

A key contribution of NRCan to Goal 1 has been the development and validation of the clock and bias estimation software SPARKNet. SPARKNet was used to generate the clock and bias products for the IGS repro3 campaign (1996-2020) matching the performance of products from other IGS Analysis Centers (Geng et al., 2024).

Since May 2025, NRCan operationally uses SPARKnet for the generation of satellite phase and code bias products and the consistent dissemination of the satellite attitude model within its analysis workflow. These products contribute to the accurate modeling of GNSS observations and support advanced applications such as precise point positioning with ambiguity resolution (PPP-AR), thereby enhancing the overall quality and consistency of IGS products.

In addition, SPARKCombo, NRCan's clock and bias combination software is one of the two candidate software for next-generation multi-GNSS combined products generated by the IGS.

Overall, NRCan maintains and operates an independent analysis and validation chain based on in-house software developments, including its POD processing framework (gPOD), clock and bias estimation software (SPARKNet), clock combination software (SPARK-Combo) and monitoring system for daily assessment. This contributes to technical diversity and redundancy within the IGS, strengthening the robustness of combined products. Through consistent multi-GNSS processing and long-term solution stability, NRCan supports IGS monitoring, benchmarking, and coordination activities aimed at tracking progress toward full multi-GNSS capability.

Contribution to Goal 2: Strengthen Outreach and Engagement

Beyond its role as an Analysis Center, NRCan advances the IGS goal of outreach and engagement through the operation and continuous enhancement of the Canadian Spatial Reference System Precise Point Positioning (CSRS-PPP) service. CSRS-PPP is a free, publicly accessible GNSS post-processing service that enables users worldwide to derive highly precise static and kinematic coordinates from RINEX observation data without reliance on nearby reference stations, thereby giving access to precise positioning in both local (NAD83) and global (ITRF) frames. In 2025, a major upgrade introduced support for Galileo PPP with Ambiguity Resolution (PPP-AR), enabling more rapid convergence and improved accuracy by resolving integer carrier-phase ambiguities on multi-GNSS data, and expanding the range of supported GNSS signals. Over time the service has broadened satellite constellation support, adopted latest reference frame realizations, and increased its active users around the globe. Through these developments, CSRS-PPP enhances user access to high-precision GNSS positioning, exemplifies the utility of AC's products and IGS standards in real-world applications, and reinforces IGS advocacy for open, interoperable geodetic services.

Overall, NRCan supports IGS outreach and engagement objectives by ensuring that all contributed products are openly available to the global scientific and operational community, in accordance with IGS open-data principles. The NRCan AC participates in IGS coordination activities, technical exchanges, and reporting, contributing expert knowledge to the broader GNSS and geodetic community.

By adhering to IGS standards, formats, and conventions, NRCan facilitates interoperability and downstream use of IGS products in scientific research, positioning, navigation, timing, and Earth observation applications. These contributions help reinforce the role of IGS as a trusted provider of standardized, high-quality GNSS products.

Contribution to Goal 3: Build Sustainability and Resilience

NRCan supports IGS Goal 3 through the operation and long-term maintenance of the Canadian Active Control System (CACS) network. CACS is a national network of continuously operating GNSS reference stations that forms a core component of the Canadian Spatial Reference System. Through CACS, NRCan provides stable, high-quality GNSS tracking infrastructure that supports both national geodetic requirements and international services such as the IGS. The network contributes to the long-term continuity, reliability, and geographical diversity of the global GNSS tracking infrastructure.

The sustained operation of CACS strengthens IGS resilience by:

- Providing redundant, high-quality GNSS observations that support global product generation and validation.
- Ensuring long-term station stability and data continuity, which are essential for reference frame realization and geophysical applications.
- Supporting the integration of research and operational activities, as CACS data are used both for routine services and scientific investigations.

By maintaining a nationally funded, operationally robust GNSS network aligned with international standards, NRCan enhances the sustainability of the IGS observational infrastructure. This contribution directly supports IGS objectives related to infrastructural diversity, long-term resilience, and the provision of open-access geodetic data in support of global reference frames and Earth system monitoring.

Further NRCan provides continuous AC operations and maintains a complete processing strategy e.g., from data to products, over extended time periods. These efforts support IGS reprocessing activities and the long-term consistency of GNSS products used in terrestrial reference frame realizations.

The operation of independent software systems and analysis infrastructure enhances the diversity and resilience of IGS product generation. NRCan's integration of research-driven developments within an operational processing environment supports the dual role of the

IGS as both a collaborative research program and an operational service. Through its sustained commitment to open access GNSS products and international collaboration, NRCan supports IGS alignment with global geodetic and Earth observation frameworks.

7 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 • Use of SPARKNet since 2025-May-4 • Daily orbits, ERP and SINEX from GipsyX/gPOD • Satellite clocks, phase & code biases, attitude model from SPARKNet • Weekly submission for IGS Final combination
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).

<table>
<tr><th>Product</th><th>Description</th></tr>
<tr><td colspan="2">Ultra-Rapid (hourly):</td></tr>
<tr><td><code>emuwwwwd_hh.sp3</code>
<code>emuwwwwd_hh.clk</code>
<code>emuwwwwd_hh.erp</code></td><td>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.</td></tr>
<tr><td colspan="2">Real-Time:</td></tr>
<tr><td></td><td>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</td></tr>
</table>

USNO Analysis Center Technical Report 2025

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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.

The USNO AC is hosted in the GPS Analysis Division (GPSAD) of the USNO Earth Orientation Department. USNO AC activities, chairing the IGS Troposphere Committee, and serving on the IGS Governing Board are overseen by Dr. Sharyl Byram. All GPSAD members, including Mr. Jeffrey Crefton, and Dr. Elizabeth Lovegrove participate in the USNO 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 UT-GPS 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, 2025

Figures 1-4 show the 2025 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 18 mm with respect to (wrt) the IGS rapid combined orbits. The USNO Ultra-rapid orbits had median WRMSs of 20 mm (24-h post-processed segment) and 41 mm (6-h predict) wrt the IGS rapid combined orbits. USNO rapid (post-processed) and Ultra-rapid 6-h predicted clocks had median 137 ps and 671 ps RMSs wrt IGS combined rapid clocks.

USNO rapid polar motion estimates had (x, y) 26 and 21 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 152 and 274 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 356 and 364 microarcsec, respectively.

All USNO AC official products were generated with the Bernese GNSS Software in 2025 and were produced using the IGS20 or IGb20 reference frame as appropriate.

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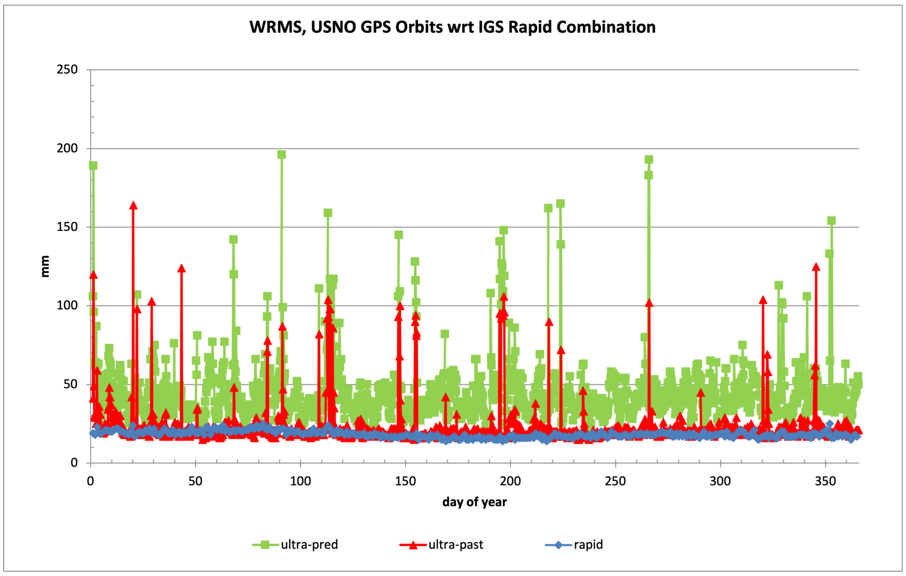

Figure 1: Weighted RMS of USNO GPS orbit estimates with respect to IGS Rapid Combination, 2025. "Ultra-past" refers to 24-hour post-processed section of USNO Ultra-rapid orbits. "Ultra-pred" refers to first six hours of Ultra-rapid orbit prediction.

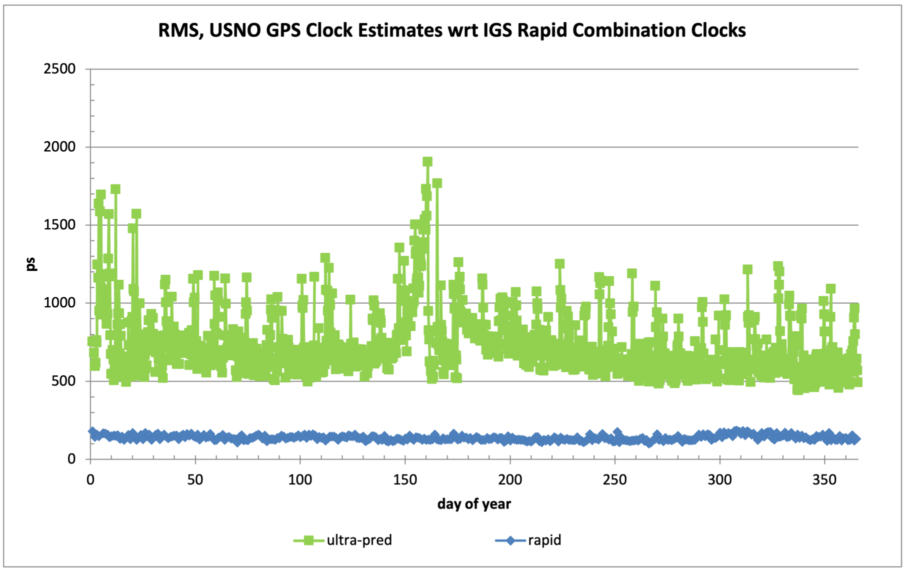

Figure 2: RMS of USNO GPS Rapid clock estimates and Ultra-rapid clock predictions with respect to IGS Rapid Combination, 2025.

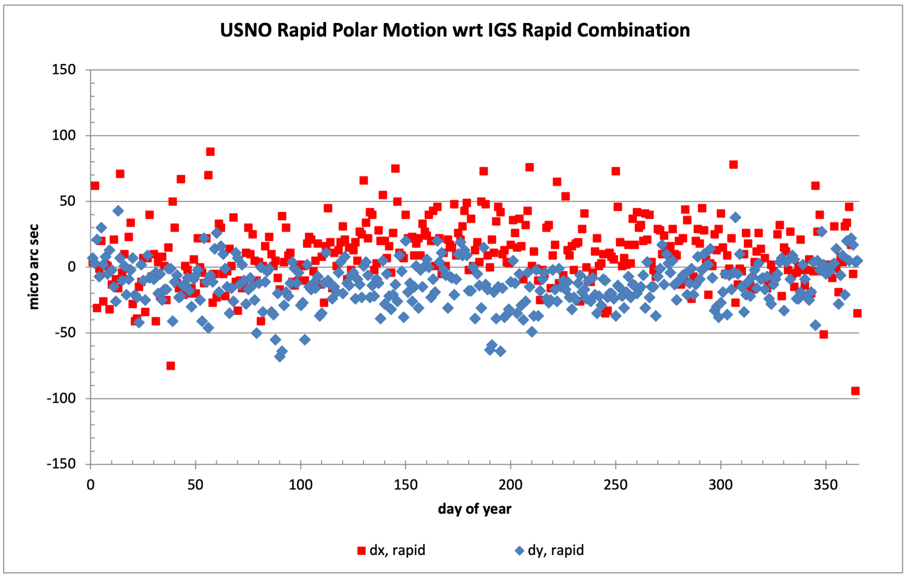

Figure 3: USNO Rapid Polar Motion estimates differenced with IGS Rapid Combination values, 2025.

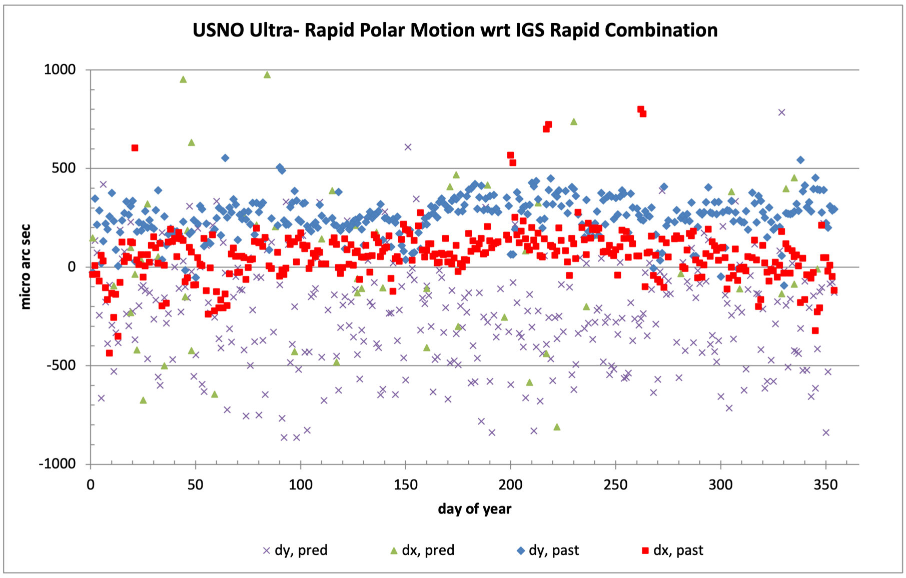

Figure 4: USNO Ultra-rapid Polar Motion estimates differenced IGS Rapid Combination values, 2025. “pred” denotes predicted and “past” denotes post processed.

Table 1: Precision of USNO Rapid and Ultra-Rapid Products, 2025. 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 past 24 h	ultra–rapid 6-h predict	rapid x	rapid y	ultra–rapid past 24 h x	ultra–rapid past 24 h y	ultra–rapid 24-h predict x	ultra–rapid 24-h predict y	rapid past 24 h	ultra–rapid 6-h predict
1/1/2025 – 12/31/2025	18	20	41	26	21	152	274	356	364	137	671

Wuhan University Analysis Center Technical Report 2025

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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 2025, besides the routine generation of precise GNSS products, efforts were devoted to improve the accuracy of geocenter motion parameters based on GNSS observations, including non-loading model improvements and the use of GPS–SLR space ties onboard LEO satellites.

2 WHU Analysis Products

The products provided by WHU are summarized in Table 1.

---

3 Refined Geocenter Motion derived from GNSS displacements

Geocenter motion (GCM) refers to the motion of the Earth's center of figure (CF) relative to its center of mass (CM). It is closely related to the definition of the reference

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
WUM0MGXNRT_YYYYDDDHH00_02D_30S_ATT.OBX	Satellite attitude, ORBEX 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

frame origin: the realization of the International Terrestrial Reference Frame (ITRF) corresponds to the CM on secular timescales but coincides with the CF on seasonal and shorter timescales before the release of ITRF2020 (Dong et al., 1997). GNSS, with its extensive global tracking network and continuous observations characterized by high spatial and temporal resolution, has proven to be a pivotal tool for estimating GCM with high precision.

With the GNSS technique, two methods can be employed for GCM estimation: the network shift approach and the degree-1 deformation approach. The accuracy of the GNSS-derived GCM model based on degree-1 deformation approach has improved in two aspects: the improvement of estimation methods and the update of GNSS data. First, in the degree-1 deformation approach to estimate GCM, the global degree-1 deformation is assumed to be primarily caused by surface mass redistribution Blewitt G. (2003). However, GNSS displacements include significant signals that are unrelated to surface mass loading, known as non-loading errors. Previous studies have shown that only about 40% of vertical and less than 20% of horizontal annual GNSS displacements can be explained by large-scale loading models (Dong et al., 2002; Niu et al., 2022). These errors can bias GCM estimates if not properly corrected.

To address this issue, we modeled and removed three types of non-loading errors, including bedrock thermoelastic deformation, GNSS draconitic errors, and background noise in GNSS residuals, with the purpose of improving GCM accuracy (Wei et al., 2025). Figure 1 shows the GCM derived from GNSS residuals before and after the removal of these three types of non-loading errors, together with independent reference GCM datasets from geophysical loading models. The results demonstrate that thermoelastic deformation is a significant contributor to the inconsistency between GNSS and other techniques in the annual variation of the Z component. It causes an annual variation with an amplitude of about 1.8 mm. Meanwhile, non-seasonal scatter in the GNSS-derived X and Y components is notably reduced after removing draconitic errors and filtering background noise. These corrections together significantly improve the consistency of GNSS-derived GCM with independent estimates.

Second, we found that the accuracy of GCM derived from GNSS using the degree-1 deformation approach has been greatly improved from the second to the third reprocessing campaigns (repro2 and repro3) (Zhou et al., 2025). We compared the GCM obtained from repro2 and repro3 station position residuals for the period 2003–2014, based on the same set of stations. The time series of obtained GCM are shown in Figure 2. In terms of the annual variations, the repro3-derived GCM outperforms the repro2-derived GCM, particularly in the Y component. The relatively poorer performance of repro2 in the Y component is mainly attributed to stronger draconitic errors, with the annual phase deviation reduced from 56° to 20° after mitigating these errors. For the intra-seasonal variations, repro2 is more scattered compared with repro3, while the correction of draconitic errors also improves their consistency. The improvement in GCM primarily results from the higher precision of station position time series in repro3 relative to repro2 (Rebischung et al., 2024). More specifically, the draconitic signals in repro3 station position residuals have been notably reduced compared with repro2, benefiting from refined GNSS satellite orbit modeling. In addition, the inclusion of Galileo observations in repro3 may also contribute.

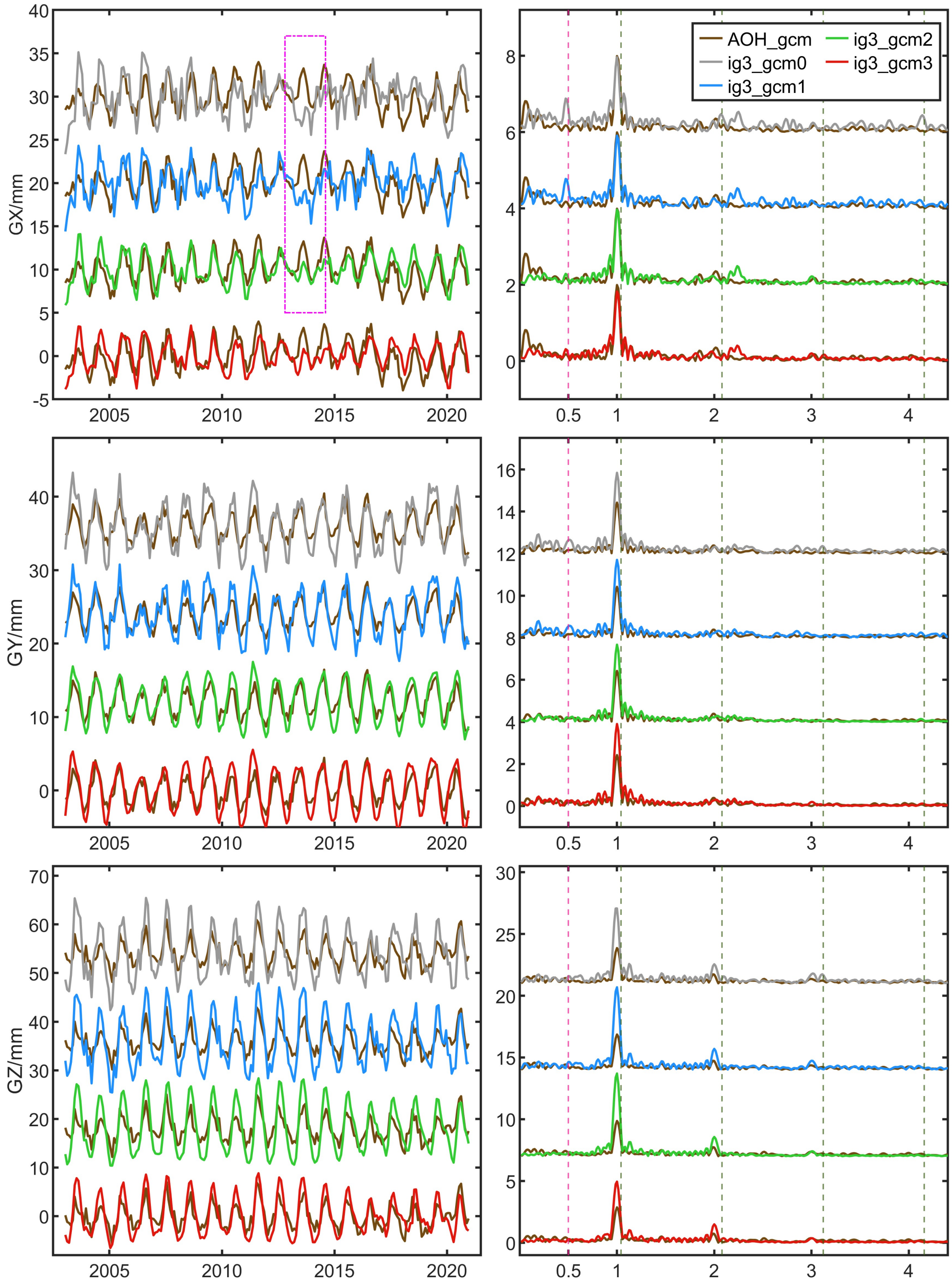

Figure 1: Time series and periodograms of the geocenter motion derived from four sets of GNSS residual time series (ig3_gcm0–ig3_gcm1) and the geophysical models (AOH_gcm). The magenta box highlights an abnormal fluctuation in GX. For ig3_gcm0–ig3_gcm3, the three solutions represent the results after sequentially removing draconitic errors, background noise, and thermoelastic deformation. The dashed lines denote the 0.5 cycles-per-year (cpy) harmonic (pink) and the first four draconitic harmonics (green). Offsets of 10, 12, and 18 mm have been added to the time series of GX, GY, and GZ, respectively. Offsets of 2, 4, and 7 mm have been added to the corresponding periodograms.

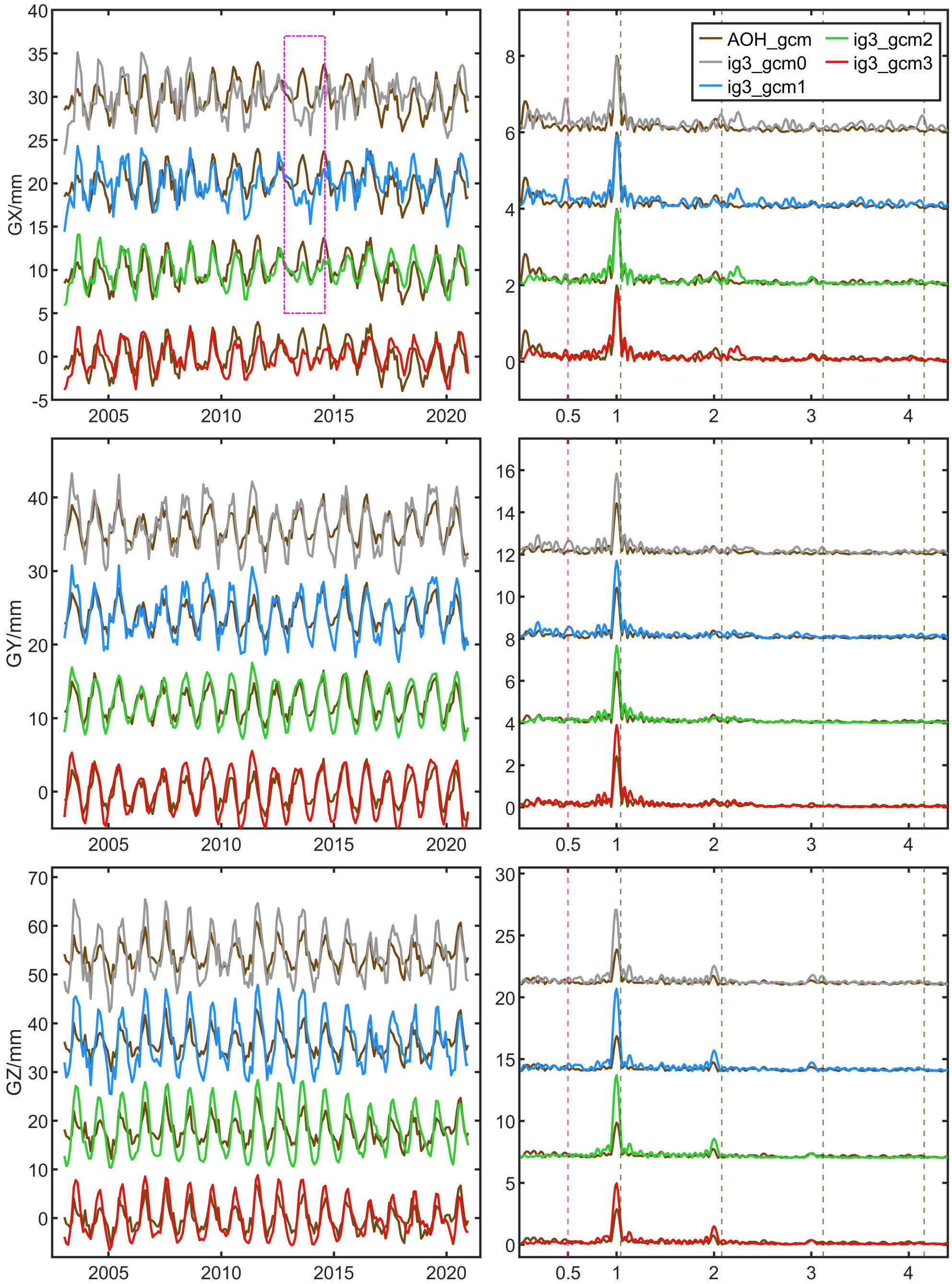

Figure 2: Time series and amplitude spectra of repro2 (ig2_gcm0–ig2_gcm2) and repro3 (ig3_gcm0–ig3_gcm2) GCM. The AOH_gcm is displayed as reference values, consistent with Figure 1. For both repro2 and repro3, gcm0 gcm2 represent the GCM estimates before correction, after removing draconitic errors, and after further removing thermoelastic deformation, respectively. Offsets of 14, 14, and 25 mm have been added to the time series of GX, GY, and GZ, respectively. Offsets of 4, 4, and 8 mm have been added to the corresponding periodograms. The dashed lines in the right panel denote annual and semi-annual harmonics (blue) and the first three draconitic harmonics (pink).

4 Global geodetic parameter determination using GPS-SLR space ties onboard LEO satellites

Global geodetic parameters, such as Geocenter Coordinates (GCCs) and Earth Rotation Parameters (ERPs), are critical for the definition of the International Terrestrial Reference Frame (ITRF) and geophysical studies. Traditional ITRF realization relies heavily on ground-based local ties to combine multiple space geodetic techniques, but these ties suffer from spatial unevenness, high maintenance costs, and infrequent updates. Low Earth Orbit (LEO) satellites equipped with multi-geodetic payloads have emerged as a transformative solution, offering "space ties" that enable inter-technique linkage independent of ground surveys. This co-location configuration compensates for the limitations of single GNSS technique, and provides advantages such as multi-payload compatibility, enhanced observation geometry, high temporal sampling, and improved geocenter sensitivity. In this case, the network shift approach is employed to calculate GCCs. Focusing on precise determination of global geodetic parameters using GPS-SLR space ties onboard three LEO satellites of the Swarm mission. To optimize performance, GPS and SLR techniques are directly combined at the observation level. Three sets of observations including ground-based GPS, Swarm-borne GPS, and SLR-to-Swarm data were processed using the self-developed GSTAR software over the period 2019–2023.

Figure 3 presents the daily formal errors of GCC estimates derived from the GPS-only, GPS+LEO, and GPS+LEO+SLR solutions. Overall, the formal errors of the GCC X and Y components are approximately half those of the GCC Z component. Compared to the GPS-only solution, the GPS+LEO solution reduces GCC formal errors by 46.5%, 48.4%, and 36.7% for the X, Y, and Z components, respectively, indicating that Swarm-borne GPS observations significantly enhance the reliability of GCC estimates. This improvement is primarily attributed to enhanced geocenter sensitivity and to rapidly varying observational geometry from LEO satellites. Compared to the GPS+LEO solution, GPS+LEO+SLR solution further improvements are achieved with formal errors reduced by 13.5%, 12.6%, and 0.5% for the X, Y, and Z components, respectively. Given the large discrepancy in observation volume (GPS vs. SLR), such improvement, particularly for X and Y components, is still substantial. This result confirms that unambiguous SLR range measurements outperform GNSS phase measurements for certain geodetic parameters. Additionally, incorporating SLR-to-Swarm observations further mitigated the β-angle dependence of the formal errors of GCC X/Y components (reducing errors by 12.6%–13.5%), and improved the consistency between GCC estimates and external SLR-based solutions.

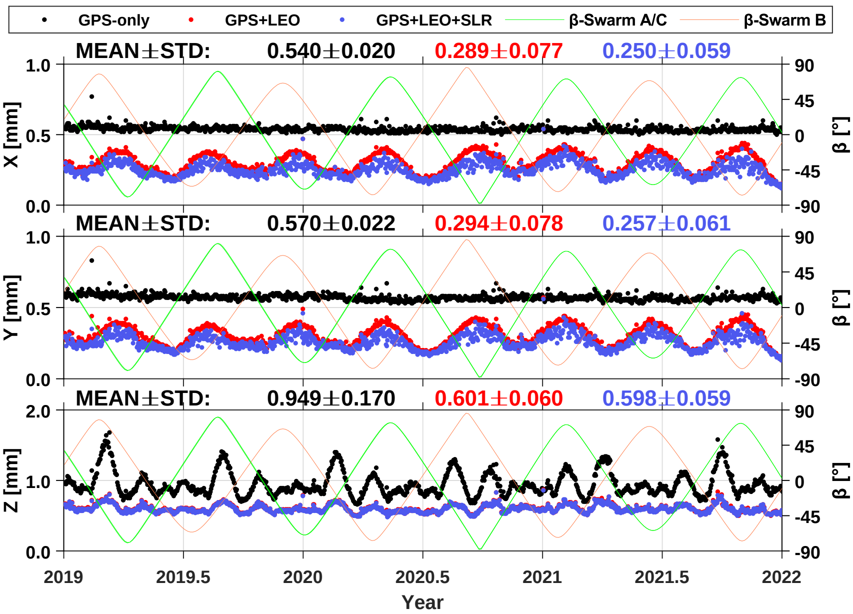

Figure 3: Formal errors of GCC estimates for the X (top), Y (middle), and Z (bottom) components. The green curve indicates the Sun elevation angles (β) for the orbital planes of Swarm A/C, and the red curve indicates that of Swarm B

Figure 4 presents the formal errors of pole coordinates and LOD estimates derived from the GPS-only, GPS+LEO, and GPS+LEO+SLR solutions. Compared to the GPS-only solution, the GPS+LEO solution reduced ERP formal errors by 31.5% (LOD) and 34.3%-40.2% (pole coordinates). Subsequent inclusion of SLR-to-Swarm observations yields only marginal improvements in ERP formal errors. This may be attributed to two factors: (1) Swarm-borne GPS observations already reduce ERP estimation errors to a low level; and (2) SLR-to-Swarm observations remain extremely sparse compared to continuous GPS data. In general, the impact Swarm-borne GPS observations on ERP estimates is mixed. Although Swarm-borne GPS observations improve the consistency with the IERS-20-C04 product for the Y-pole coordinate and LOD, they increase the differences for the X-pole coordinate. SLR-to-Swarm observations are one-way range measurements from individual SLR stations to Swarm satellites. Their absolute ranging capability and high geocenter sensitivity make them effective for direct and accurate estimation of geocenter motion. As a result, SLR-to-LEO observations have greatly improved GCC estimates. However, this absolute ranging property of SLR makes it insensitive to Earth rotation.

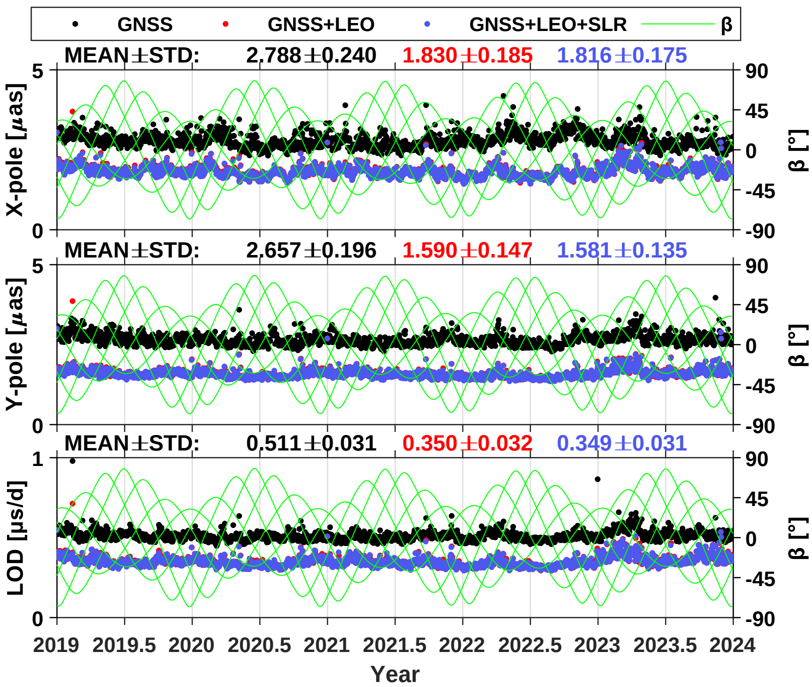

Figure 4: Formal errors of pole coordinates and LOD. The green curves denote the Sun elevation angles above GPS orbital planes ((β)

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EUREF Permanent Network Regional Network Associate Analysis Centre Technical Report 2025

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1 Introduction

The International Association of Geodesy (IAG) Regional Reference Frame Sub-commission for Europe, EUREF, defines, maintains, and provides access to the European Terrestrial Reference System (ETRS89; Altamimi and Collilieux , 2024). This is realized through the EUREF Permanent GNSS Network (EPN). EPN observation data, as well as precise station coordinates and zenith total delay (ZTD) parameters for all EPN stations, are publicly available.

EUREF also coordinates scientific activities related to the future evolution of ETRS89, including the ETRS89 Study Group, which investigates the strengths and weaknesses of alternatives to ETRS89.

EUREF cooperates closely with the International GNSS Service (IGS). EUREF members actively contribute to the IGS through participation in, for example, the IGS Governing Board, the Reference Frame Committee, the RINEX Committee, the Real-Time Committee, the Antenna Committee, the Troposphere Committee, the Infrastructure Committee, and the Multi-GNSS Pilot Project.

This paper provides an overview of the main changes in the EPN during the year 2025.

2 EPN Central Bureau

The EPN Central Bureau (CB, https://epncb.oma.be), managed by the Royal Observatory of Belgium (ROB), continued its operational oversight of the EPN network in 2025, with a focus on key station performance metrics such as data availability, metadata accuracy, and data quality (Bruyninx et al., 2019). Ten new GNSS stations were integrated into the EPN in 2025 (highlighted in green in Figure 1): two in France (INGP00FRA in Feb. and AAER00FRA in May), two in G.-D. Luxemburg (TROS00LUX and ECH200LUX in April), two in Romania (FOCS00ROU and MURE00ROU in Nov.), one in Andorra (PCAR00AND in Sept.), Cyprus (ASGA00CYP in April), Italy (PAD100ITA in July), and Germany (WT2100DUE in Nov.). Detailed information on all stations is available from the EPN CB. During the same period, three stations were decommissioned: BACA00ROU, IGNF00FRA, PADO00ITA.

Additionally, the Open Data Portal (https://gnss.be/opendataportal.php) built on top of the EPN Historical Data Centre transitioned from beta to full operational status in 2025. This transition included an update of the GNSS-DCAT-AP schema used by the portal (https://doi.org/10.5281/zenodo.7777568).

To further support EUREF's commitment to promoting FAIR (Findable, Accessible, Interoperable, Reusable) data practices, the number of EPN stations with assigned Digital Object Identifiers (DOI) increased significantly in 2025. Approximately 230 EPN stations now have DOI-referenced datasets, searchable via the M^{3}G system (https://gnss-metadata.eu), enhancing data visibility, citation, and recognition for data providers. This is an increase of more than 50% compared to 2024. To guarantee compliance with international standards, EUREF applied the recommendations from the GGOS Committee on Digital Object Identifiers (DOIs) for Geodetic Data Sets issued in 2025.

Following Resolution No. 1 of the 2025 EUREF Symposium in Covilhã (Portugal), the EPN station guidelines were updated in September 2025 to reflect that all EPN stations will, by default, be included in the GNSS network of the European Plate Observing System (EPOS). In practice, ROB will gradually make all EPN station metadata from M^{3}G and EPN RINEX data from the EPN Historical Data Centre discoverable within EPOS starting in 2026. The updated station guidelines also include revisited recommendations for the formats to be used when providing data to EUREF.

The number of EPN stations providing real-time data had a slight increase in 2025. By the end of 2025, 211 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, located at ASI, BKG and ROB. 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 220 data streams are

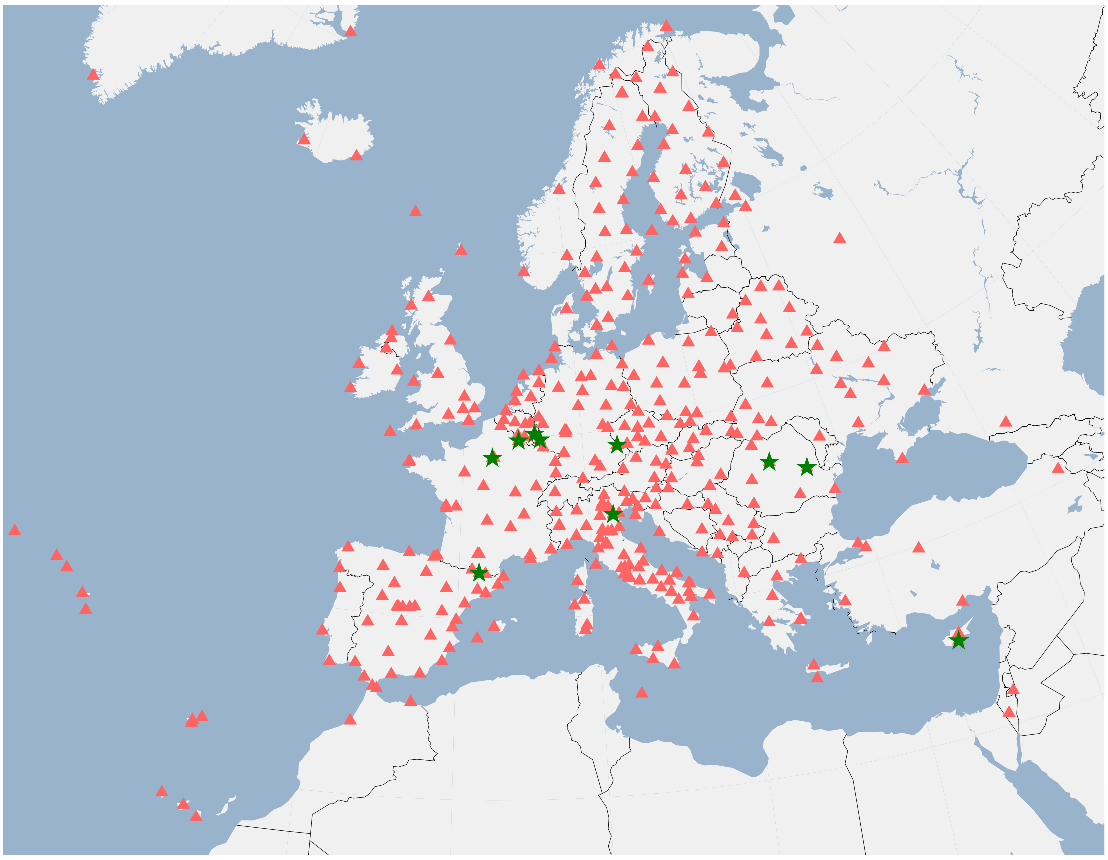

Figure 1: New GNSS stations (in green) integrated in the EPN in 2025.

monitored operationally, with 94% of the real-time data available across all three EPN casters.
Additionally, the EPN real-time products SSRA02IGS0_EUREF and SSRA03IGS0_EUREF, along with the broadcast ephemerides BCEP00BKG0, are accessible from the EPN casters.

3 Data Products

3.1 Positions

The EPN Analysis Centres (ACs) operationally process GNSS observations collected at EPN stations. In 2025, all 17 ACs (Table 1) were providing final daily coordinate solutions of their subnetworks. Twelve ACs were also providing rapid daily solutions, and three ACs were providing near-real-time solutions. All AC solutions were combined by the Analysis

Centre Coordinator (ACC). Details on the various combinations performed by the ACC are given on the ACC website (http://www.epnacc.wat.edu.pl/epnacc/final/). In 2025, 7 of 10 new EPN stations mentioned in section 2 (AAER00FRA, ASGA00CYP, ECH200LUX, IGNP00FRA, PAD100ITA, PCAR00AND, and TROS00LUX) were successfully included in the EPN combined coordinate solutions. The three remaining stations (FOCS00ROU, MURE00ROU, WT2100DEU) were incorporated into the EPN in November 2025, and the first EPN combined solutions in which these stations will be included will be released in January 2026.

On February 2, 2025 (start of GPS week 2352), the reference frame to which the EPN combined coordinate solutions are aligned was changed from IGS20 to IGb20. The new reference frame includes 24 additional EPN reference stations (62 in IGb20 vs. 38 in IGS20).

In October 2025, the EPN operational combined solutions for weeks 2238-2313 (27 November 2022 to 11 May 2024) were recombined to ensure better consistency with subsequent solutions. The new solutions are based on all 17 AC solutions (including previously missing solutions from two ACs) and incorporate updated solutions from several ACs.

3.2 Troposphere

The EPN ACs operationally submit to EUREF Zenith Total Delay (ZTD) parameters and horizontal gradients estimated for each EPN stations included in their subnetwork. In 2025, 17 ACs were providing final daily troposphere solutions. In addition, 10 ACs were providing rapid troposphere solutions. In 2025, 7 of the 10 new EPN stations (AAER00FRA, ASGA00CYP, ECH200LUX, IGNP00FRA, PAD100ITA, PCAR00AND, and TROS00LUX) have been successfully included in the individual and combined troposphere solutions.

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

The EPN CB shows on https://epncb.oma.be/_productsservices/troposphere/mean_zpd_biases.php for each AC the weekly mean bias (top) and the related standard deviation (bottom) of its solutions with respect to the combined solution. Gross errors (i.e. ZTD with formal standard deviation > 15 mm) and outliers, detected during the combination process, are removed thus not affecting the combined value. The time series is based on EPN-Repro2 solutions (GPS week 834 until 1824) and on operational solutions using IGS14 standards until GPS week 2237 and IGS20 standards afterwards. Due to these changes, the time series is not homogeneous, and it will be replaced by EPN-Repro3 products (January 1996 - November 2022). Thanks to the availability of the EPN Repro3 site coordinate combined product, the last months of 2025 have been devoted to the

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 (Dach et al., 2015), 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	122 (3/1)	GipsyX-2.1	GRE
BEK	Bavarian Academy of Sciences & Humanities, Germany	W,D,R,E03	144 (5/1)	BSW 5.4	GRE
BEV	Federal Office of Metrology and Surveying, Austria	W,D	172 (0/2)	BSW 5.4	GRE
BKG	Bundesamt für Kartographie und Geodäsie, Germany	W,D,R,E03	159 (4/1)	BSW 5.5	GRE
COD	Center for Orbit Determination in Europe, Switzerland	W,D	39 (0/0)	BSW 5.5	GRE
GFZ	GeoForschungsZentrum, Germany	W,D,E03	111 (1/0)	EPOS.P8	GRE
IGE	Instituto Geografico Nacional, Spain	W,D,R,E03	100 (3/1)	BSW 5.4	GRE
IGN	Institut Géographique National de L'information Geographique et Forestiére, France	W,D,E03	63 (4/1)	BSW 5.4	GRE
LPT	Federal Office of Topography swisstopo, Switzerland	W,D,R,N	60 (1/1)	BSW 5.5	GRE
MUT	Military University of Technology, Poland	D,R,E03	155 (0/1)	GG 10.71	GE
NKG	Nordic Geodetic Commission, Lantmäteriet, Sweden	W,D,R,N,E03	108 (0/0)	BSW 5.4	GRE
RGA	Republic Geodetic Authority, Serbia	W,D	71 (2/2)	BSW 5.4	GRE
ROB	Royal Observatory of Belgium, Belgium	D,R,E03	115 (5/1)	BSW 5.4	GRE
SGO	Lechner Knowledge Center, Hungary	W,D,R,E03	68 (2/1)	BSW 5.4	GRE
SUT	Slovak University of Technology, Slovakia	D,R,N,E03	96 (2/0)	BSW 5.4	GRE
UPA	University of Padova, Italy	W,D,R,E03	117 (3/2)	BSW 5.4	GRE
WUT	Warsaw University of Technology, Poland	W,D,R,E03	155 (1/0)	BSW 5.4	GRE

preparatory phase of EPN-Repro3 tropospheric combination.

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 of the analyzed day. Because of the distributed processing of the EPN stations, about 200 stations are included in the rapid combination disseminated 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.

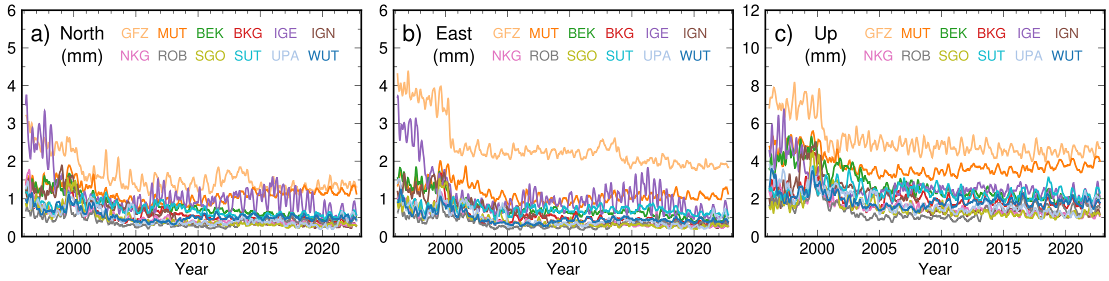

Figure 2: Mean RMS values of daily station position residuals between each AC solution and combined solution in EPN Reprocessing 3 project. RMS values presented for north (a), east (b) and vertical (c) components. The RMS values were smoothed in 14-day interval.

3.3 Third EPN reprocessing

The third EPN reprocessing (EPN-Repro3) reached a major milestone in 2025 with the completion of the analysis phase by twelve EPN ACs (see also Table 1). They successfully reprocessed GNSS data spanning from 1996 to 2022. To ensure the highest level of robustness and uniformity, the reprocessing followed a coordinated strategy aligned with IGS repro3 standards and utilized antenna calibrations consistent with the IGS20 reference frame. The processing design ensured that each station was analyzed independently by at least three different ACs, allowing for rigorous cross-validation. Beyond coordinates, the EPN-Repro3 ACs also estimated new troposphere parameters from 1996 onwards, which are currently being integrated for meteorological and climate applications.

In August 2025, based on the AC's Repro3 solutions, the EPN ACC completed the generation of combined Repro3 position solutions covering the period 1996-2022. The analysis and combination of the AC solutions were performed in two basic steps: (1) stacking and cleaning of individual AC solutions, and (2) combination of cleaned AC solutions into common daily solutions including all EPN stations. The mean daily RMS values of station position residuals between each AC daily solution and the combined solution are presented in Figure 2. The EPN-Repro3 combined products consist of daily and weekly coordinate solutions aligned to the IGS20 reference frame in SINEX format, along with accompanying combination reports in text format and new reports in YAML format. The products are available at the EPN data centers.

Based on these results, the final product, a new reference frame solution with the most accurate and up-to-date positions and velocities, is currently being finalized by the EUREF Reference Frame Coordinator and it is targeted for release at the beginning of 2026. It combines combined EPN-Repro3 daily position solutions (January 1996 – November 2022) with EPN operational daily solutions (November 2022 – June 2025). The multi-year solution is computed with CATREF (Altamimi et al., 2007) and expressed in IGc20 (IGSMAIL #8634) using minimal constraints on 50 reference stations. Outliers, position

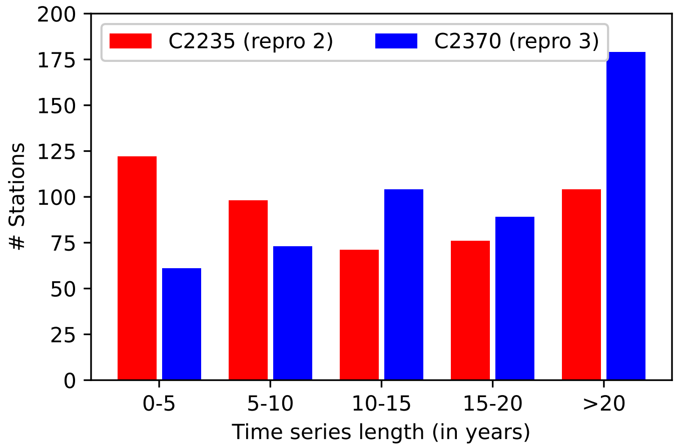

Figure 3: Comparison of time series length (in years) between the C2235 solution which was EPN-repro2 based and the C2370 which is EPN-repro3 based.

discontinuities, and velocity changes have been corrected, and harmonization with the global IGS solution ensures consistency with the global frame.

The retrieval of additional historical EPN data increased the dataset by 16% between 1996 and 2023, significantly extending many station time series and reducing by half the number of stations with fewer than five years of observations (see Figure 3). These improvements strengthen the reliability of the estimated velocities.

The carefully aligned analysis strategy ensured a smooth transition between EPN-Repro3 and operational products, with no visible discontinuities in residual RMS, transformation parameters, or station position time series. In addition, the new solution shows excellent agreement with IGc20, with 90% of stations matching within 4 mm horizontally and 10 mm vertically for positions, and within 0.25 mm/yr horizontally and 0.75 mm/yr vertically for velocities. These results highlight the robustness of the new solution and its suitability as the densification of ITRF2020 in Europe in order to maintain the ETRS89.

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Part III

Data Centers

Infrastructure Committee Technical Report 2025

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[4] BKG, Germany

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, committees, 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 Radio Technical Commission for Maritime Services (RTCM)) to synchronise with the global, multi-technique geodetic infrastructure.

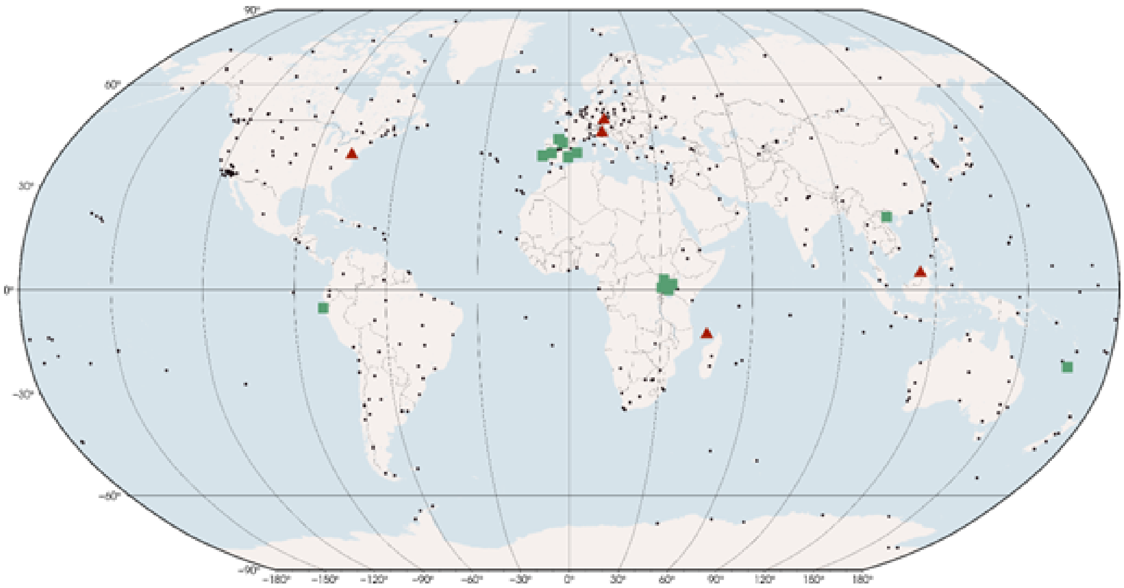

Figure 1: Map of the IGS Network in 2025; newly added stations highlighted in green, decommissioned stations highlighted in red

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, 2025, 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 2025

Throughout 2025, the IC actively assisted the Network Coordinator in responding to inquiries from IGS product and data users. The Station Proposal Committee (SPC) added 13 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 2025

Station	Location	Systems	Real-Time	Agency
Approved Stations (13):				
ALAC00ESP	Alicante, Spain	GREC	Yes	IGE
ARUA00UGA	Arua, Uganda	GREC		MLHUD-SMD
CACE00ESP	Caceres, Spain	GREC	Yes	IGE
CANT00ESP	Santander, Spain	GREC	Yes	IGE
CASC00PRT	Cascais, Portugal	GRECS	Yes	DGT
ENTB00UGA	Entebbe, Uganda	GREC		MLHUD-SMD
FPRT00UGA	Fort Portal, Uganda	GREC		MLHUD-SMD
HUMG00VNM	Hanoi, Vietnam	GRE	Yes	GFZ
MALL00ESP	Palma de Mallorca, Spain	GREC	Yes	IGE
NRMG00NCL	Noumea, New Caledonia	GRECIJS	Yes	CNES
PIUR00PER	Piura, Peru	GRECS	Yes	GFZ
RIO100ESP	Logrono, Spain	GRE	Yes	IGE
SRTI00UGA	Soroti, Uganda	GREC		MLHUD-SMD
Decommissioned Stations (5):				
BRUN00BRN	Gadong, Brunei	GRECJ		JAXA
GODZ00USA	Greenbelt, USA	GR		JPL
MAYG00MYT	Dzaoudzi, Mayotte	GRECIS		CNES
PADO00ITA	Padova, Italy	GRECIS		UPAD
WTZS00DEU	Bad Koetzting, Germany	GRECIS		BKG

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

4 2025 Activities: Review and Outlook

The IC is actively working towards implementing the recommendations derived from the 2024 IGS Workshop. A summary of these recommendations is provided in Table 2.

In 2023, we published the "Guidelines for Continuously Operating Reference Stations (CORS) in the IGS"[2] , 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. In 2025, the community added the following languages: Portuguese, Mandarin, Arabic, and Hindi. These translations are now available as web-based documentation on the official IGS GitHub repository[3].

In conjunction with the CORS Guidelines, we developed the "IGS CORS Management

[2] https://files.igs.org/pub/resource/guidelines/Guidelines_for_Continuously_Operating_Reference_Stations_in_the_IGS.pdf
[3] https://international-gnss-service.github.io/IGS_CORS_Guidelines

Table 2: List of recommendations from the IGS Workshop 2024 and their status

#	Description	Status
1	Encourage IGS station operators to track NavIC for stations within the footprint and analysis centers to analyze the data.	Ongoing
2	Develop a policy for the inclusion and exclusion of stations.	Completed
3	Contribute to the GGOS Data and Information System Committee to ensure the improvement of FAIR GNSS data and metadata.	Ongoing
4	Develop an extensible way to categorize stations by their use for the community.	Blocked
5	Harmonize the code lists within the IGS station metadata.	In Progress
6	Establish a task force on exploring cloud native storage formats.	In Progress
7	Develop a charter for IGS data centers.	Completed
8	Inclusion of more active members of the IC.	Ongoing

Policy”[4], a clear policy 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[5], 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, the IC developed a web-based application to maintain a Controlled Vocabulary for station metadata. The API can be integrated into existing station management platforms (e.g., IGS SLM[6], EPN M^{3}G[7]). The final implementation and deployment of the application is currently blocked due to resource limitations.

As part of our commitment to advancing the concept of a “Global GNSS Archive”, we developed the “Charter for the IGS Data Centres”[8], a comprehensive collection of mandatory and expected requirements that IGS data centres need to follow.

Additionally, members of the IC aim to explore cloud-based alternatives to RINEX as the storage and access format for GNSS data. This initiative reflects the ongoing efforts to enhance and optimise data storage and access methods in the GNSS community. A dedicated workshop is scheduled for February 2026 hosted in Coimbra, Portugal. The goals

[4] https://files.igs.org/pub/resource/guidelines/IGS_CORS_Management_Policy.pdf
[5] https://ggos.org/about/org/bureau/bno/cwg/data-information-systems/
[6] https://github.com/International-GNSS-Service/SLM
[7] https://gnss-metadata.eu/landing/m3g
[8] https://files.igs.org/pub/resource/working_groups/data_centers/Charter_for_International_GNSS_Service_Data_Centres.pdf

of the workshop are to prepare a draft schema and data model for a cloud-native GNSS format, build a shared understanding of applicable technologies, create a collaboration roadmap, and to draft a white paper to share with the broader community.

A dedicated task team is currently developing clear, community-aligned guidelines for the use of Digital Object Identifiers (DOI) and data licenses, respectively. The documents aim to promote consistent citation practices, improve the discoverability and reuse of research outputs, and clarify expectations around data sharing and licensing.

Acronyms

BKG	Bundesamt für Kartographie und Geodäsie
CDDIS	Crustal Dynamics Data Information System
CNES	Centre National d'Etudes Spatiales
CORS	Continuously Operating Reference Station(s)
DOI	Digital Object Identifier
ESA	European Space Agency
GA	Geoscience Australia
GFZ	GFZ Helmholtz Centre for Geosciences
GGOS	Global Geodetic Observing System
IERS	International Earth Rotation and Reference Systems Service
IGE	Instituto Geografico Nacional de Espana
IGN	Institut national de l'information géographique et forestière
JAXA	Japan Aerospace Exploration Agency
JPL	Jet Propulsion Laboratory
KASI	Korea Astronomy and Space Science Institute
MLHUD-SMD	Ministry of Lands, Housing and Urban Development Surveys and Mapping Department
RTCM	Radio Technical Commission for Maritime Services
SIO	Scripps Institution of Oceanography
SPC	Station Proposal Committee
UPAD	University of Padova
WHU	Wuhan University

The GNSS Science Support Centre (GSSC) - the ESA IGS Global Data Centre - Technical Report 2025

J.C. Berton[1], S. del Rio García[2], N. Castrillo Merlán[2], E. Schönemann[1], J. Ventura-Traveset[4], E. Montagnon[3]

[1] European Space Operations Centre, Darmstadt, Germany
[2] Starion España S.L.U., Madrid, Spain
[3] European Space Astronomy Centre, Villafranca, Spain
[4] European Space Agency Toulouse Office, Toulouse, France

1 Introduction

The GNSS Science Support Centre (GSSC) is the GNSS data preservation and exploitation environment provided by the ESA Science Navigation Operations Section in support to the IGS and the international geodetic scientific community.

The [GSSC] hosts:

- a large GNSS data repository, the **GSSC Archive**;
- a Digital Platform for GNSS data exploration, **GSSC Now**;
- data analysis features, **GSSC Now Datalabs**; and,
- ESA's online GNSS knowledge base, **Navipedia**.

As an IGS Global Data Centre (GDC), the GSSC contributes to GNSS data archiving and dissemination. Along the IGS Data Centres Charter, the GSSC collaborates with other IGS Data Centres and Analysis Centres to provide free and worldwide access to IGS data and products.

2 GSSC Archive

2.1 GSSC Archive Content

The GSSC Archive primarily consists of data collected from other geodetic Data Centres, ensuring data redundancy, long-term preservation and enhanced global accessibility. This redundancy strengthens the resilience of the global geodetic infrastructure by minimizing the risk of data loss and ensuring continuous access in case of network or server disruptions.

Currently, the GSSC implements a mirroring scheme to retrieve data from other geodetic Data Centres, ensuring that GSSC repository contains primarily GNSS data and products, but since October 2025, across all four geodetic techniques (GNSS, SLR, VLBI and DORIS). The files are sourced from the geodetic Data Centres indicated in Table 1.

Geodetic Technique	Data Source Repositories
GNSS	Crustal Dynamics Data Information System (CDDIS) Bundesamt für Kartographie und Geodäsie (BKG) Institut Géographique National (IGN)
SLR	Crustal Dynamics Data Information System (CDDIS)
DORIS	Crustal Dynamics Data Information System (CDDIS)
VLBI	Observatoire de Paris (OPAR)

Table 1: GSSC data sources for the four geodetic techniques

In most cases, the GSSC ingests assets by automatically pulling files directly from remote source repositories. Although this process runs through fully automated scheduled jobs, GSSC operators can manually trigger these jobs when necessary. Each download job is configured according to a pre-defined execution schedule and the time window it scans, as detailed in Table 2 (IGS Data) and Table 3 (IGS Products).

As shown in Figure 1 GSSC Storage Trend of IGS Data and Products below, the volume of the different IGS datasets hosted at GSSC keeps growing steadily.

The GSSC Archive provides access to more than 270 million of IGS assets (data and products files), as depicted in Table 4.

2.2 GSSC Archiving Concept

During ingestion, the GSSC Now software retrieves the list of files at the remote path, filters the list, downloads the selected files, moves them into the appropriate GSSC directory and submits each file for processing.

IGS data type	**Source**	**Schedule**	**Scans**	**GSSC DB**
Daily GNSS	CDDIS	Every hour	Last 24 hours	
		Sunday and Wednesday	Last 7 days	CDDIS CORS
		Twice a month on 1st and 15th	Previous month	
Daily GNSS	BKG	Every hour	Last 24 hours	BKG CORS
Daily GNSS	IGN	Every hour	Last 24 hours	IGN CORS
Merged site	CDDIS	Every hour	Last 24 hours	
navigation files		Sunday and Wednesday	Last 7 days	CDDIS CORS
		Twice a month on 1st and 15th	Previous month	
Hourly GNSS	CDDIS	Every hour	Last 24 hours	
		Sunday and Wednesday	Last 7 days	CDDIS CORS
		Twice a month on 1st and 15th	Previous month	
High rate	CDDIS	Every hour	Last 24 hours	
GNSS data		Sunday and Wednesday	Last 7 days	CDDIS CORS
		Twice a month on 1st and 15th	Previous month	
High rate	BGK	Every hour	Last 24 hours	
GNSS data		Sunday and Wednesday	Last 7 days	BKG CORS
		Twice a month on 1st and 15th	Previous month	

Table 2: IGS Data Storage in GSSC Archive and Ingestion Parameters

Furthermore, the system regularly checks for gaps between the source repository and the GSSC repository. If any discrepancy is detected, a dedicated downloader is launched to retrieve the missing data.

In addition to the mirroring functionalities, the GSSC has also the capability to get data

IGS product type	**Source**	**Schedule**	**Scans**	**GSSC DB**
Orbits, clocks, ERP	CDDIS	Twice a day at 11 and 23	Last 24 hours	
positions		Sunday and Wednesday	Last 7 days	CDDIS CORS
		Twice a month on 1^{st} and 15^{th}	Previous month	
MGEX products	CDDIS	Twice a day at 11 and 23	Last 24 hours	
		Sunday and Wednesday	Last 7 days	CDDIS CORS
		Twice a month on 1^{st} and 15^{th}	Previous month	
Ionosphere	CDDIS	Twice a day at 11 and 23	Last 24 hours	
		Sunday and Wednesday	Last 7 days	CDDIS CORS
		Twice a month on 1^{st} and 15^{th}	Previous month	
Differential Code	CDDIS	Twice a day at 11 and 23	Last 24 hours	
Biases		Sunday and Wednesday	Last 7 days	CDDIS CORS
		Twice a month on 1^{st} and 15^{th}	Previous month	
Troposphere	CDDIS	Last 24 hours		
		Sunday and Wednesday	Last 7 days	CDDIS CORS
		Twice a month on 1^{st} and 15^{th}	Previous month	

Table 3: IGS Data Products Storage in GSSC Archive and Ingestion Parameters

directly uploaded into the GSSC repository by accredited contributors. This ingestion mechanism is already in place for some GNSS datasets of different ESA space missions and projects, but also to get IGS products from IGS Analysis Centres such as the ESA

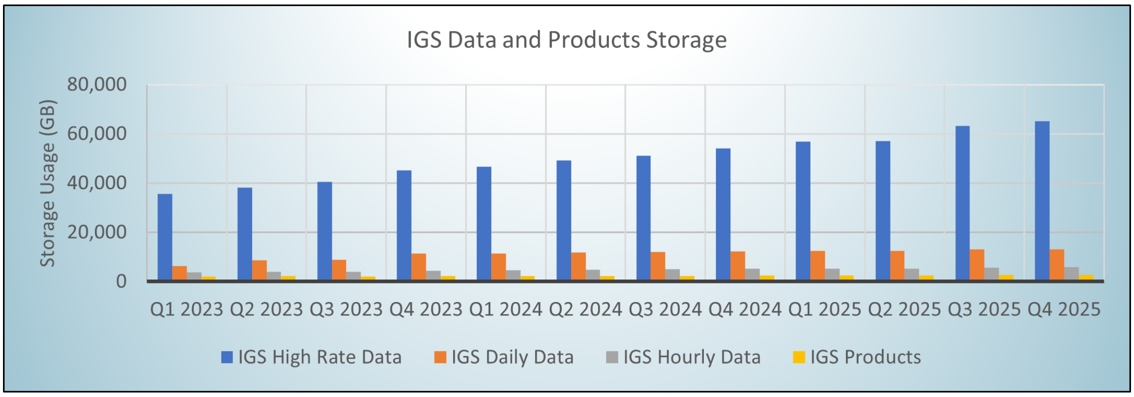

Figure 1: GSSC Storage Trend of IGS Data and Products

Data Format	**Nb. Files**
RINEX 2	>154 M
RINEX 3	>104 M
RINEX 4	>1 M
Data Type	**Nb. Files**
IGS Hourly Files	>135 M
IGS Daily Files	>73 M
IGS High-rate Files	>18 M
Products	**Nb. Files**
IGS Products	>4 M
Others	**Nb. Files**
IGS Stations logs, SINEX...	>38 M

Table 4: Number of IGS Assets in GSSC Archive

Navigation Support Office. In both cases, i.e. the data mirroring mechanism and the data upload by designated GSSC contributors, the GSSC Now Software handles metadata extraction. Each file added into the GSSC repository is processed to extract its metadata, which is then indexed and used to enable the users faceted search in GSSC Now.

Whereas the genuine IGS GDC repository still lies at the heart of the GSSC, its content has been expanded to include datasets from supplementary GNSS ground networks, relevant scientific services, GNSS receivers onboard spacecrafts and ESA experiments.

2.3 GSSC Archive Access

The GSSC offers various access methods to its [datasets] including FTP, SFTP, HTTPS, the NTRIP Caster and a REST API.

2.3.1 GSSC FTP/SFTP

The GSSC FTP and SFTP servers are both accessible using the hostname "gssc.esa.int". The FTP server operates on port 21, while the SFTP server uses port 2200. Public users can log in to either server by entering "anonymous" as the username and leaving the password field blank. These interfaces allow anonymous users to perform read operations.

Additionally, the GSSC provides an [FTP Web Client], where public users can also log in by entering 'anonymous' in the Account field and leaving the Password field empty.

2.3.2 GSSC FTP/SFTP Data Download

As shown in Figure 2 below, the volume of the different IGS datasets downloaded from GSSC benefits the worldwide scientific community.

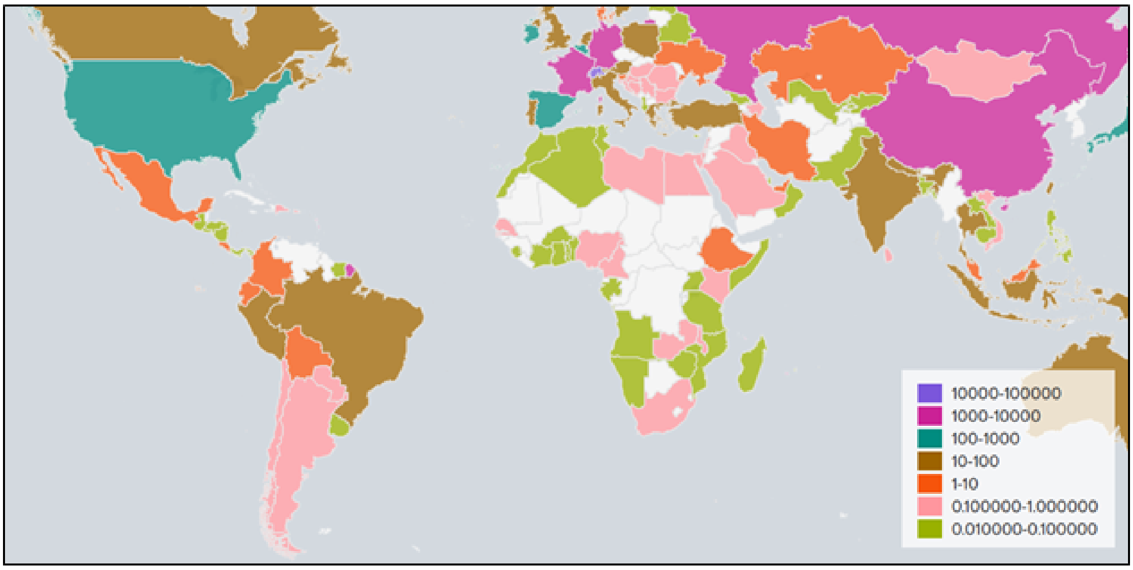

Figure 2: Download volumes of IGS files via GSSC FTP in 2025 (GB)

The volume of the different IGS datasets downloaded from GSSC, predominantly IGS Daily assets, has drastically increased over the last 2 years, as shown in Figure 3

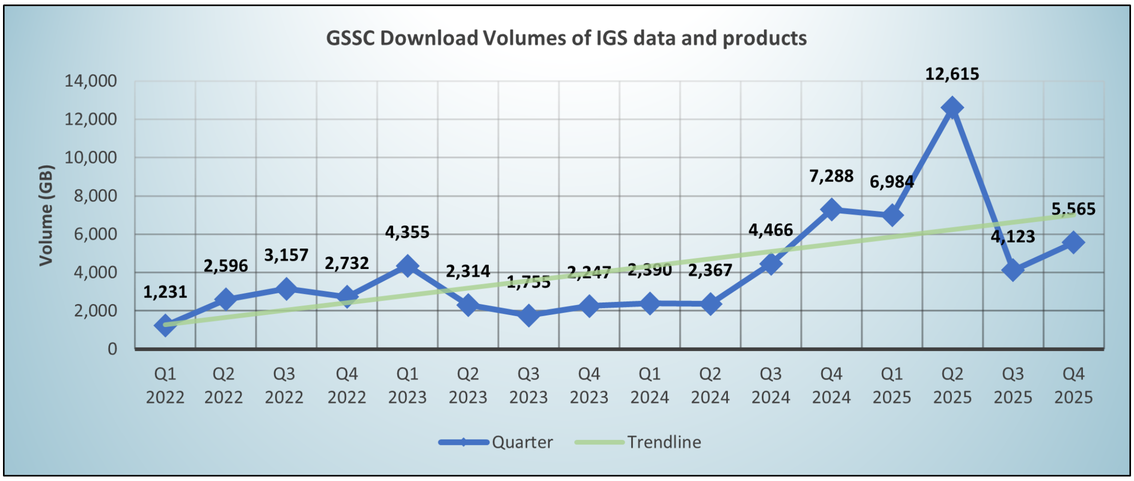

Figure 3: Number of downloads of IGS files via GSSC FTP since 2022

2.3.3 GSSC Now Portal (HTTPS)

The [ESA GSSC Portal] provides a secure HTTPS-based web interface through which registered GSSC users can access a variety of services and data tools.

2.4 GSSC CASTER

The GSSC provides real-time GNSS data streaming through the NTRIP protocol (Networked Transport of RTCM via Internet Protocol). At GSSC, users connect with an [NtripClient] to the caster at using credentials obtained from the [GSSC Helpdesk].

2.5 GSSC API

The GSSC Archive exposes a RESTful API for data access and management. The following sections provide the requirements, usage instructions, and example scripts to interact with GSSC services. The full [GSSC API documentation] is publicly available.

3 GSSC Now: ESA's GNSS Science Data Exploitation Platform

3.1 GSSC Now

[GSSC Now] is the digital platform that allows GSSC users to browse, download and analyse data from the GSSC data repositories. GSSC Now currently runs as a public fully operational version. Some GSSC Now features like multiple downloads or access to a private workspace area are only available upon [registration].

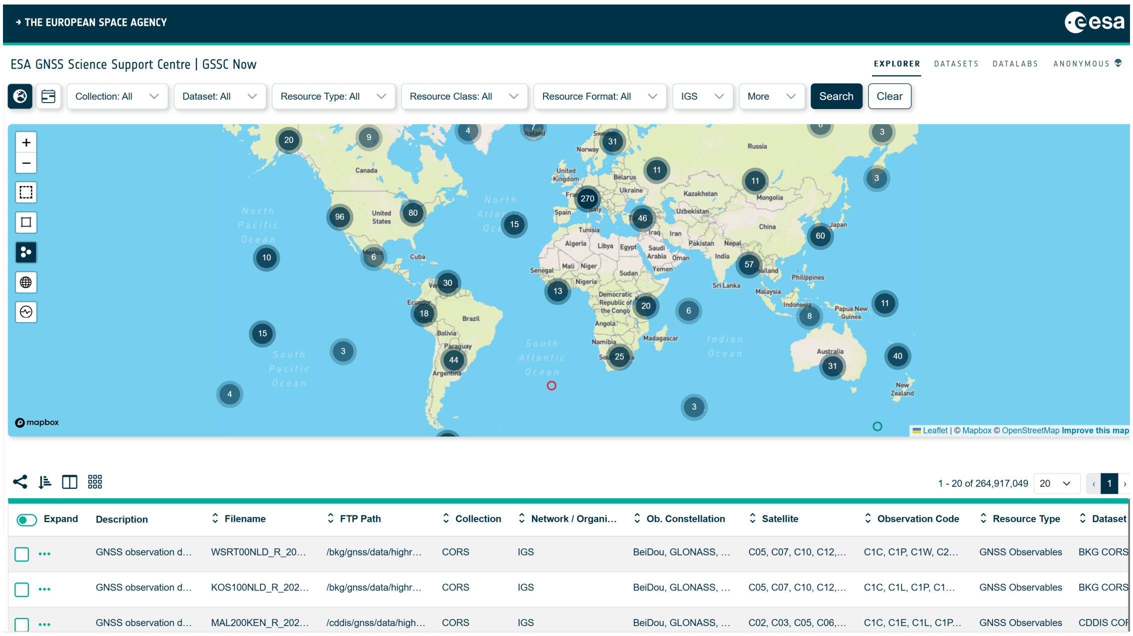

Figure 4: GSSC Now - Explorer View

The GSSC Now offers access to more than 270 million of IGS assets (data and products files). Most of the data is publicly available to scientific researchers and the overall GNSS community through the GSSC Now digital platform, whereas some datasets are under a moderated access policy. Users can browse and retrieve GNSS and related datasets directly through the portal, which provides metadata-based search with faceted filtering, allowing users to locate datasets using criteria such as time, satellite system, region or product type, among others.

3.2 GSSC Datalabs

From the same interface, users can also launch the GSSC Datalabs environment, which supports interactive analysis and visualization of selected datasets and offers tools for processing, plotting and exploring GNSS data. Results generated during Datalab sessions can be saved to a personal workspace that serves as persistent storage for analysis outputs, plots and processed files. In addition, users can upload their own assets to the GSSC Now platform, with storage capacity of up to 10 GB.

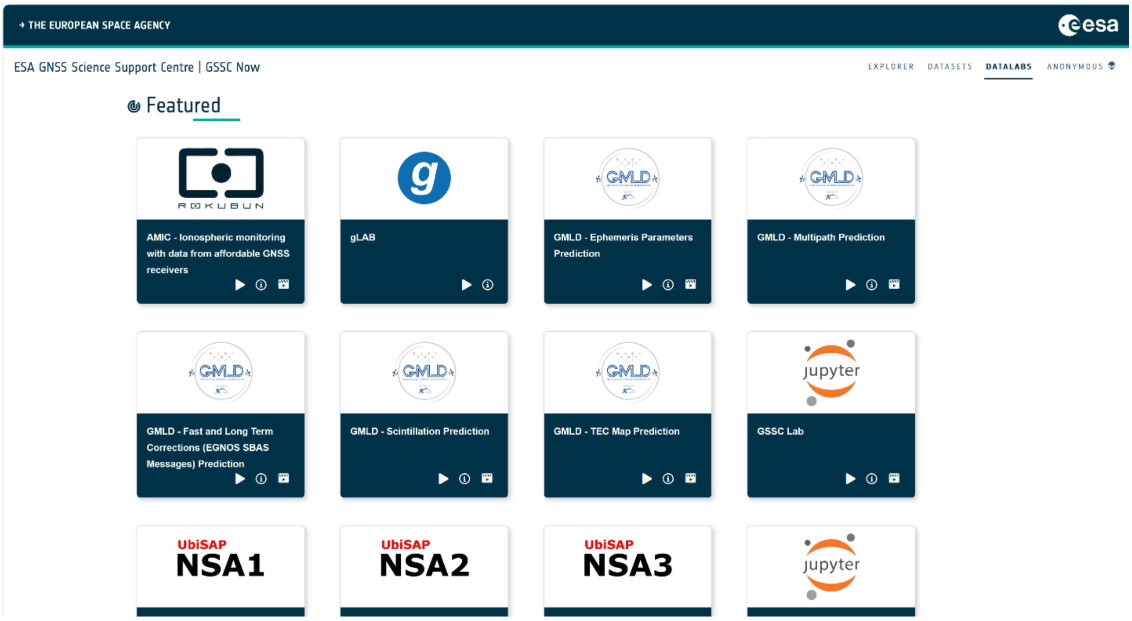

Figure 5: GSSC Datalabs Overview

4 GSSC Adoption of the IGS Data Centre Charter

The International GNSS Service (IGS) Infrastructure Committee (IC) issued the Charter for IGS Data Centres in May 2025, defining the roles and responsibilities of Data Centres and Regional Data Centres. As GSSC was designated as an official IGS Global Data Center in 2018, this Charter is considered an applicable document to GSSC.

Current GSSC efforts focus on fully meeting all IGS requirements by implementing the necessary changes and updating the GSSC Now software. The internal assessment of the current level of compliance with IGS needs is shown in Table 5.

Data Collection and Holding	**Status**
Data ingestion from Operational Data Centres	supported
Products ingestion from Analysis Centres	supported
Mirroring of other Data Centres	supported
Various latencies	supported
Various formats	supported
Various format versions	supported
Plain/compressed files	supported
Products/data	supported
Versioning	supported
Data Dissemination and Performance	**Status**
Scalability	supported
Redundant infrastructure and data replication	to be addressed
High availability	continuously improved
Low latency data dissemination	to be addressed
Data access control	supported
Intrusion detection control	on-going implementation
Traffic management	continuously improved
Data consistency	supported
Integrity	continuously improved
Monitoring and Analytics	supported
Data Archiving	**Status**
Long-Term Storage	supported
Metadata extraction	supported
Quality Control	**Status**
Quality assurance for incoming data	on-going implementation
Detect and flag metadata inconsistencies	on-going implementation
Quality checks on RINEX files	to be addressed
Security and Compliance	**Status**
Multi-Factor Authentication	to be addressed
Role-Based Access Control	supported
Data Encryption	to be addressed
Security Update/Patch Management	continuously improved
Monitoring and Analytics	on-going implementation
User Support	supported
Continuous Improvement	supported
Reporting	supported

Table 5: IGS Data Centre needs and implementation status at GSSC

5 GSSC 2025 Highlights

The GSSC continues to consolidate and operate its services to the international GNSS users' community through the expansion of its GNSS data archive and exploration platform.

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. GSSC currently hosts 270 million of IGS data and products, collected from IGS Regional Data Centres, other IGS Global Data Centres and from IGS Analysis Centres, such as the ESA Navigation Support Office, providing access to IGS assets all around the world.

In 2025, the GSSC adopted the IGS DC Charter as an applicable document and translated the IGS needs into the GSSC Now Software Requirements Baseline, identifying their implications in terms of e.g. data availability, scalability, storage, metadata handling, security, quality. Their implementation within GSSC is planned for 2026.

The GSSC data archiving and distribution functionalities keep supporting the ESA Navigation Support Office in its IGS data processing role and responsibilities: indeed, the year 2025 marked a milestone for GSSC with the ESA Navigation Support decision to fully rely on the GSSC for geodetic long-term data archiving. Therefore, since October 2025 the GSSC Archive has incorporated new datasets for the DORIS and VLBI geodetic techniques, while continuing to expand its GNSS and International Laser Ranging Service (ILRS) collections. DORIS and VLBI data are ingested into the GSSC Archive by mirroring Data Centres operated by the International Doppler Orbitography by Radiopositioning Integrated on Satellite Service (IDS) and International Very Long Baseline Interferometry Service (IVS), respectively.

Major progress was made on the GNSS Now Digital Platform, with three new versions throughout the year 2025. These updates brought reliability and performance optimizations, new features and stability improvements. These accomplishments were possible through the dedicated efforts and close collaboration of the teams from ESA, GMV and Starion.

The GSSC started its data archiving and distribution role in the ESA GENESIS mission, detailing its interface with the global scientific community, while exchanging with the ESA Navigation Support Office in its GENESIS science data processing role. After their approval at ESA Council at Ministerial level, this role will extend to other ESA Navigation missions like Novamoon.

Engagement with the GNSS community was strengthened through the release of the Navipedia contribution capabilities and regular news updates. Furthermore, the GSSC was represented in different prominent international forums, including the European Geosciences Union General Assembly 2025 and the United Nations International Committee on Global Navigation Satellite Systems, Korea. Finally, new collaborative ties were also pursued with educational institutions, industry stakeholders, and research organizations.

6 GSSC Evolution

The GSSC 2026 priorities aim at further adapting the infrastructure and processes to meet the requirements of the first version of the Charter for IGS Service Data Centres.

In support of the ESA Navigation Support Office analyse Centres role, the GSSC will also evolve its Archive to support Earth Orientations Parameters data and products.

The GSSC Now digital platform will further align with user needs to support the archiving and distribution of the ESA GENESIS mission data.

The GSSC will develop Quality Services in line with the requirements of the IGS Data Centre Charter and plans to implement them throughout 2026.

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Jean-Christophe Berton, Iván Sermanoukian Molina, Michiel Otten, Tim Springer, Sara Bruni, Florian Dilßner, Mark van Kints, Gaia Fusco, Sara Gidlund, Evelina Sakalauskaite, Pierre Waller, Erik Schönemann, Werner Enderle, *A New Combined Processing for Genesis*, presented at European Geoscience Union General Assembly 2025, April 29, Vienna, Austria. Available at: https://navigation-office.esa.int/attachments/125051657/1/EGU25_-_A_New_Combined_Processing_for_Genesis.pdf

Wuhan University Data Center Technical Report 2025

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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 addition to releasing routine IGS data and products like the CDDIS DC, the WHU DC also publishes specialized products computed by the Wuhan University Analysis Center, such as bias products, hourly orbit and clock products, real-time ionospheric products, and more.

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.

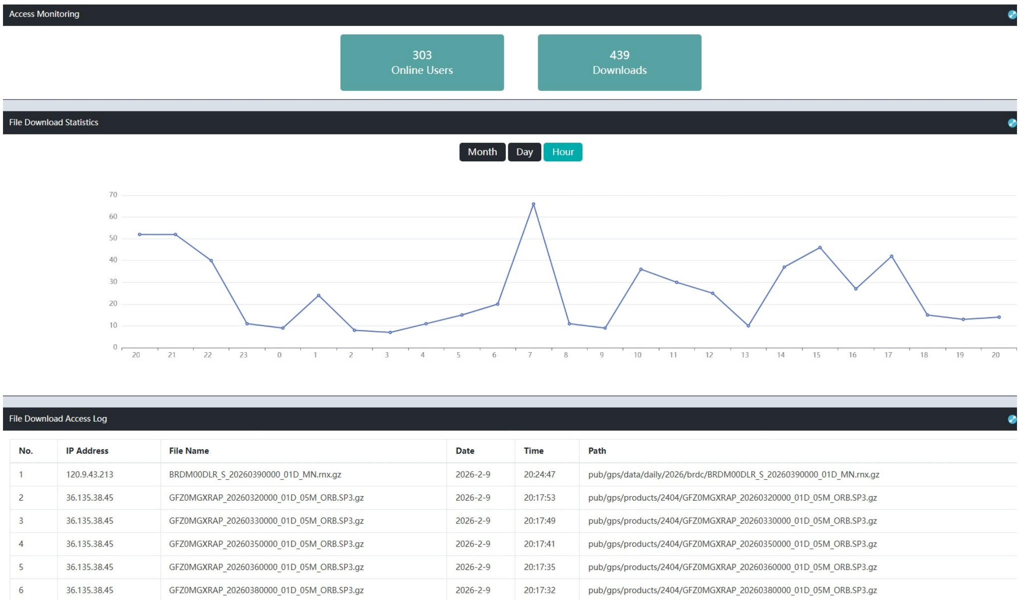
The WHU RT GIMs also are accessible via Wuhan Real Time Data Center (http://ntrip.gnsslab.cn) with Mountpoint IONO00WHU0 and Wuhan Data Center (ftp://igs.gnsswhu.cn/pub/whu/MGEX/realtime-ionex) in IONEX format.

4 Monitoring of WHU Data Center

Since 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.

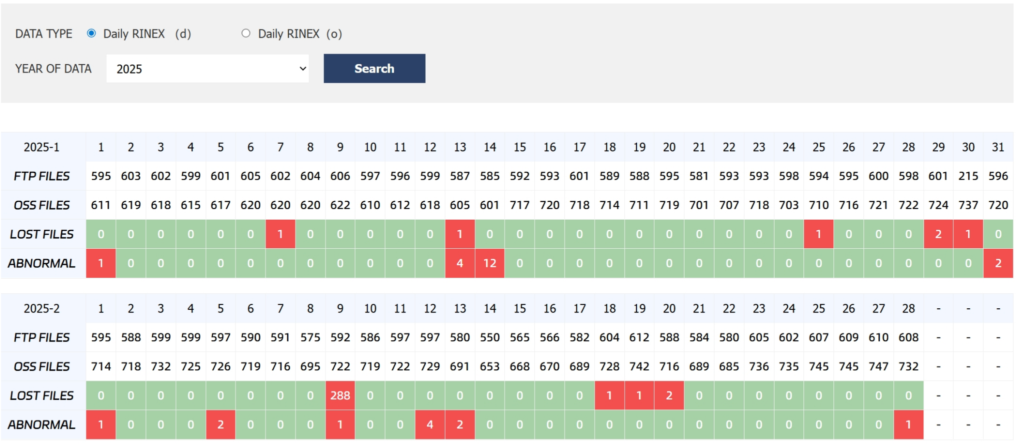
In order to ensure the integrity of the observation data and the products, we routinely compare the daily data, hourly data and products with those in CDDIS. If one data



No.	IP Address	File Name	Date	Time	Path
1	120.9.43.213	BRDM00DLR_S_20260390000_01D_MN.rnx.gz	2026-2-9	20:24:47	pub/gps/data/daily/2026/brdc/BRDM00DLR_S_20260390000_01D_MN.rnx.gz
2	36.135.38.45	GFZ0MGXRAP_20260320000_01D_05M_ORB.SP3.gz	2026-2-9	20:17:53	pub/gps/products/2404/GFZ0MGXRAP_20260320000_01D_05M_ORB.SP3.gz
3	36.135.38.45	GFZ0MGXRAP_20260330000_01D_05M_ORB.SP3.gz	2026-2-9	20:17:49	pub/gps/products/2404/GFZ0MGXRAP_20260330000_01D_05M_ORB.SP3.gz
4	36.135.38.45	GFZ0MGXRAP_20260350000_01D_05M_ORB.SP3.gz	2026-2-9	20:17:41	pub/gps/products/2404/GFZ0MGXRAP_20260350000_01D_05M_ORB.SP3.gz
5	36.135.38.45	GFZ0MGXRAP_20260360000_01D_05M_ORB.SP3.gz	2026-2-9	20:17:35	pub/gps/products/2404/GFZ0MGXRAP_20260360000_01D_05M_ORB.SP3.gz
6	36.135.38.45	GFZ0MGXRAP_20260380000_01D_05M_ORB.SP3.gz	2026-2-9	20:17:32	pub/gps/products/2404/GFZ0MGXRAP_20260380000_01D_05M_ORB.SP3.gz

Figure 1: Website download statistics.

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



2025-1	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	595	603	602	599	601	605	602	604	606	597	596	599	587	585	592	593	601	589	588	595	581	593	593	598	594	595	600	598	601	215	596
OSS FILES	611	619	618	615	617	620	620	620	622	610	612	618	605	601	717	720	718	714	711	719	701	707	718	703	710	716	721	722	724	737	720
LOST FILES	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	1	0
ABNORMAL	1	0	0	0	0	0	0	0	0	0	0	0	4	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2

2025-2	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	-	-	-
FTP FILES	595	588	599	599	597	590	591	575	592	586	597	597	580	550	565	566	582	604	612	588	584	580	605	602	607	609	610	608	-	-	-
OSS FILES	714	718	732	725	726	719	716	695	722	719	722	729	691	653	668	670	689	728	742	716	689	685	736	735	745	745	747	732	-	-	-
LOST FILES	0	0	0	0	0	0	0	0	288	0	0	0	0	0	0	0	0	1	1	2	0	0	0	0	0	0	0	0	-	-	-
ABNORMAL	1	0	0	0	2	0	0	0	1	0	0	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-	-	-

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

Part IV

Committees, Pilot Projects

Precise Point Positioning with Ambiguity Resolution Pilot Project Technical Report 2025

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1 Introduction to the BAR Committee

Currently, high-precision Global Navigation Satellite Systems (GNSS) positioning has reached a relatively high level of maturity. A variety of biases are integrated and presented in the form of Observable-Specific Biases (OSB), such as Differential Code Bias (DCB) and Uncalibrated Phase Delay (UPD). The core of high-precision positioning lies in the ambiguity resolution (AR). The most critical bias terms in this process are code and phase biases. In the past, the oversight of code and phase biases was carried out separately by the Bias and Calibration Committee and the Precise Point Positioning with Ambiguity Resolution (PPP-AR) Pilot Project. To further promote the research, development, and application of high-precision GNSS technologies, the International GNSS Service (IGS) established a specialized committee, the BAR Committee, to coordinate the research, standardization, validation, and dissemination of bias products relevant to current GNSS and future constellations.

2 The charter of BAR Committee

Over the last decades, GNSS have been deployed in support of positioning, navigation, and timing (PNT) users, as well as Earth-science applications. Originally, GPS receivers track a limited number of frequencies, whose observables are subject to different satellite biases such as well-known P1-P2 and P1-C1 differential code biases. However, with the introduction of multi-GNSS constellations and multi-frequency tracking receivers, the number of different biases has grown significantly, and their accurate estimation is crucial to future high-integrity and safety-critical applications.

The newly established BAR committee supersedes and consolidates the former PPP -AR Pilot Project and merges with the Bias and Calibration committee. The foreseen activities of the BAR committee have a strong relationship with the clock and ionosphere products. For this reason, it is expected to operate in close collaboration with the Analysis Centre Coordinator (ACC), Real Time Service (RTS), Clock committee, and other relevant IGS entities.

The objects of the BAR committee are divided into three parts. Tasks are defined in continuation of the PPP-AR Pilot Project, integrating fundamental activities carried out by the former Bias & Calibration Committee.

1. Harmonization and methodology consolidations
    - Survey existing bias definitions, network estimation strategies, and formats across individual ACs.
    - Consolidate existing observable-specific bias (OSB) conventions to accommodate all bias types, and update SINEX_Bias format if necessary.
    - Address issues with datum changes, e.g., at day boundaries, exploiting continuity of the integer carrier phase measurements.
    - Assessment of hardware stability, including intra-day variations and potential temperature-dependent effects.
    - Definition of a white paper describing the status of satellite and station bias products, which shall also provide clear recommendations in preparation of upcoming LEO-PNT systems and/or signals.
2. Product interoperability and bias combination
    - Address issues with availability of satellite products for specific signals and/or frequencies, encouraging and supporting more ACs to estimate multi-GNSS/all-frequency biases.
    - Evaluate consistency between code and phase biases, in particular since are often estimated in a cascade approach rather than in a single processing step.
    - Cross-validation quality assessment of clocks and biases, and standardize the specification of the product combination statistics in support of ACC and WCC.
    - Initiate testing campaigns, open to the community, to evaluate performances and to identify key issues in the combined products.
    - Potential development of a clock-bias combination free and open-source software toolbox that will be provide to the IGS community.

3. Ambiguity resolution and integrity monitoring

    - Provide best practices for a successful integer-cycle resolution of carrier-phase ambiguities, while defining common misconceptions in the statistical interpretation of ambiguity-fixed solutions.
    - Address issues with FDMA-signals, like in GLONASS, due to inter-frequency biases, or in future LEO-PNT systems working on alternative frequency bands, along with potentially accounting for intra-day variations currently neglected (or assumed slowly varying in current systems).
    - Establish an integrity monitoring system to detect unmodelled errors and degraded performance during the generation of satellite clock/bias corrections.

3 Latest progress of PPP-AR products from each existing AC

In 2025, an additional AC Natural Resources Canada (NRCan) now supports and releases OSB products. The GeoForschungsZentrum Potsdam (GFZ) and Wuhan University (WHU) ACs have also expanded their OSB coverage to include more satellites.

1. EMR include code/phase OSBs in its OPS final products, and its performance has been improved.

   During the IGS repro3 campaign, the EMR Analysis Center (AC) developed and validated the clock and bias estimation software SPARKNet. For the period 1996–2020, EMR generated satellite and station clock products, as well as satellite code and phase biases supporting PPP with ambiguity resolution (PPP-AR), based on NGS orbit and station position solutions. The resulting products exhibited performance comparable to those of other IGS Analysis Centers (Geng et al., 2024).

   Following an evaluation of clock product quality obtained with Gipsy-X under the EMR operational tuning and processing strategy, EMR implemented SPARKNet for the routine generation of its operational final clock and bias products. Starting with GPS week 2365, SPARKNet-based products have been used in operational processing. This transition led to reduced satellite clock standard deviation. In addition, EMR provides satellite attitude files in ORBEX format to support consistent satellite attitude modeling by users of the products.

```
OSB  G080 G01         C1C     2025:304:00000 2025:305:00000 ns        -6.3490      0.0000
OSB  G080 G01         C1W     2025:304:00000 2025:305:00000 ns        -5.2780      0.0000
OSB  G080 G01         C2W     2025:304:00000 2025:305:00000 ns        -8.6926      0.0000
OSB  G080 G01         L1W     2025:304:00000 2025:305:00000 ns        -0.2777      0.0000
OSB  G080 G01         L2W     2025:304:00000 2025:305:00000 ns        -0.0100      0.0000
OSB  G061 G02         C1C     2025:304:00000 2025:305:00000 ns        -9.2790      0.0000
OSB  G061 G02         C1W     2025:304:00000 2025:305:00000 ns       -11.0900      0.0000
OSB  G061 G02         C2W     2025:304:00000 2025:305:00000 ns       -18.2646      0.0000
OSB  G061 G02         L1W     2025:304:00000 2025:305:00000 ns        -0.1794      0.0000
OSB  G061 G02         L2W     2025:304:00000 2025:305:00000 ns        -0.0682      0.0000
OSB  G069 G03         C1C     2025:304:00000 2025:305:00000 ns         7.4987      0.0000
OSB  G069 G03         C1W     2025:304:00000 2025:305:00000 ns         8.1857      0.0000
OSB  G069 G03         C2W     2025:304:00000 2025:305:00000 ns        13.4814      0.0000
OSB  G069 G03         L1W     2025:304:00000 2025:305:00000 ns        -0.0061      0.0000
OSB  G069 G03         L2W     2025:304:00000 2025:305:00000 ns         0.1331      0.0000
```

Figure 1: Code/phase OSBs in EMR OPS final of NRCan

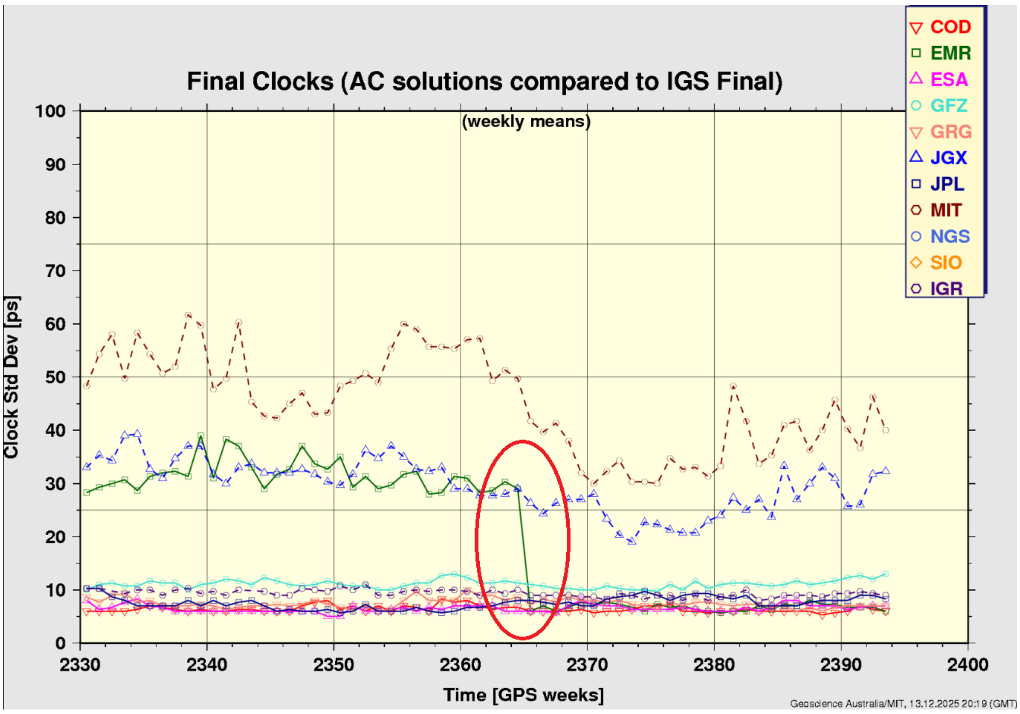

Figure 2: Standard deviations of the IGS final clock combination. The red ellipse at GPS week 2365 indicates the EMR clock improvements resulting from the use of the in-house SPARKNet software

2. WUM MGEX final include QZSS phase OSBs.

   The WUM MGEX (Multi-GNSS Experiment) final products now include phase OSBs for the QZSS. This enhancement is significant as it enables PPP-AR for QZSS signals, improving positioning accuracy and convergence time. Presently, WUM is one of only two IGS ACs, alongside CODE, that generate and provide these combined QZSS code and phase OSB products. The accompanying data tables detail the specific OSB values for various QZSS satellites and signals (e.g., C1C, C2X), referenced to a defined time period. The effectiveness of these products is demonstrated by performance metrics showing a 100% ambiguity fixing rate for both wide-lane and narrow-lane components at multiple monitoring stations, confirming the high quality and reliability of WUM's PPP-AR solution for QZSS.

```
OSB  JQS2 J02        C1X     2025:250:00000 2025:251:00000 ns      2.559900000000000    0.101300
OSB  JQS2 J02        C2L     2025:250:00000 2025:251:00000 ns      4.427600000000000    0.143900
OSB  JQS2 J02        C2X     2025:250:00000 2025:251:00000 ns      4.321800000000000    0.164800
OSB  JQS2 J02        C5Q     2025:250:00000 2025:251:00000 ns      3.029000000000000    0.114700
OSB  JQS2 J02        C5X     2025:250:00000 2025:251:00000 ns      2.389100000000000    0.125100
OSB  JQS2 J02        L1X     2025:250:00000 2025:251:00000 ns     -2.767264139528239    0.736214
OSB  JQS2 J02        L2X     2025:250:00000 2025:251:00000 ns     -4.557530300906368    0.722094
OSB  JQS4 J03        C1C     2025:250:00000 2025:251:00000 ns      0.759100000000000    0.091100
OSB  JQS4 J03        C1X     2025:250:00000 2025:251:00000 ns      0.529000000000000    0.101200
OSB  JQS4 J03        C2L     2025:250:00000 2025:251:00000 ns      1.160000000000000    0.144000
OSB  JQS4 J03        C2X     2025:250:00000 2025:251:00000 ns      0.961400000000000    0.164800
OSB  JQS4 J03        C5Q     2025:250:00000 2025:251:00000 ns      1.434000000000000    0.114700
OSB  JQS4 J03        C5X     2025:250:00000 2025:251:00000 ns      0.514100000000000    0.123900
OSB  JQS4 J03        L1X     2025:250:00000 2025:251:00000 ns     -1.031168151728678    0.736181
OSB  JQS4 J03        L2X     2025:250:00000 2025:251:00000 ns     -1.698276658777592    0.722003
OSB  JQS5 J04        C1C     2025:250:00000 2025:251:00000 ns     -1.518900000000000    0.120600
OSB  JQS5 J04        C1X     2025:250:00000 2025:251:00000 ns     -0.491700000000000    0.171500
OSB  JQS5 J04        C2X     2025:250:00000 2025:251:00000 ns     -0.841800000000000    0.277200
OSB  JQS5 J04        C5X     2025:250:00000 2025:251:00000 ns     -2.469500000000000    0.198600
OSB  JQS5 J04        L1X     2025:250:00000 2025:251:00000 ns      0.541159295835122    0.840516
OSB  JQS5 J04        L2X     2025:250:00000 2025:251:00000 ns      0.891259295835122    0.983614
OSB  JQS3 J07        C1C     2025:250:00000 2025:251:00000 ns     -2.690900000000000    0.099600
OSB  JQS3 J07        C1X     2025:250:00000 2025:251:00000 ns     -3.001500000000000    0.113700
OSB  JQS3 J07        C2L     2025:250:00000 2025:251:00000 ns     -4.531500000000000    0.158500
OSB  JQS3 J07        C2X     2025:250:00000 2025:251:00000 ns     -4.843700000000000    0.185700
OSB  JQS3 J07        C5Q     2025:250:00000 2025:251:00000 ns     -3.642300000000000    0.125800
OSB  JQS3 J07        C5X     2025:250:00000 2025:251:00000 ns     -4.658600000000000    0.136700
```

Figure 3: QZSS phase OSBs in WUM MGEX final of WHU

Table 1: Ambiguity fixing rates for QZSS

Station	Wide lane	Narrow lane
AIRA	100	100
GMSD	100	100
STK2	100	100

3. GFZ MGEX rapid and GRG MGEX final include phase OSBs for new BDS satellites C47-C50.

   GFZ MGEX rapid and GRG MGEX final products have incorporated code and phase OSBs for the newer BDS satellites with PRN numbers C47 through C50, which is a prerequisite for enabling PPP-AR for these satellites. This inclusion allows users to correct the observable-specific signal biases and attempt to fix integer ambiguities for the affected satellites. However, initial performance assessment using GFZ's products indicates that the narrow-lane ambiguity fixing rates for C47-C50 are relatively low at several global monitoring stations. For instance, at stations BRUX and TLSG, while wide-lane fixing rates are excellent (98-100%), the narrow-lane rates are 66% and 74%, respectively. At stations CEDU and KIRU, the rates are lower, at 59% and 57%. This suggests that while the necessary bias products are available, further refinement in the underlying orbit, clock, or bias estimation for these newer satellites may be required to achieve consistently high integer fix rates comparable to established constellations, highlighting an area for ongoing product improvement.

```
OSB  C232 C50         C2I      2025:282:00000 2025:283:03600 ns              -56.0418      0.9156
OSB  C232 C50         C6I      2025:282:00000 2025:283:03600 ns              -84.8746      1.3867
OSB  C232 C50         L2I      2025:282:00000 2025:283:03600 ns               57.0333      0.9163
OSB  C232 C50         L6I      2025:282:00000 2025:283:03600 ns               86.3762      0.9163
OSB  C233 C48         C2I      2025:282:00000 2025:283:03600 ns               -3.0051      0.9284
OSB  C233 C48         C6I      2025:282:00000 2025:283:03600 ns               -4.5512      1.4061
OSB  C233 C48         L2I      2025:282:00000 2025:283:03600 ns                3.2856      0.9291
OSB  C233 C48         L6I      2025:282:00000 2025:283:03600 ns                4.9761      0.9291
OSB  C234 C47         C2I      2025:282:00000 2025:283:03600 ns               -1.4354      0.8937
OSB  C234 C47         C6I      2025:282:00000 2025:283:03600 ns               -2.1739      1.3536
OSB  C234 C47         L2I      2025:282:00000 2025:283:03600 ns                0.9577      0.8945
OSB  C234 C47         L6I      2025:282:00000 2025:283:03600 ns                1.4504      0.8945
OSB  C235 C49         C2I      2025:282:00000 2025:283:03600 ns                3.3350      0.9562
OSB  C235 C49         C6I      2025:282:00000 2025:283:03600 ns                5.0509      1.4482
OSB  C235 C49         L2I      2025:282:00000 2025:283:03600 ns               -2.3269      0.9569
OSB  C235 C49         L6I      2025:282:00000 2025:283:03600 ns               -3.5240      0.9569
```

Figure 4: Code/phase OSBs for C47-C50 in GFZ MGEX rapid

```
OSB  C234 C47          C1P       2025:282:00000 2025:282:86399 ns               -17.6765       0.5573
OSB  C234 C47          C5P       2025:282:00000 2025:282:86399 ns               -31.6487       0.5841
OSB  C234 C47          C1X       2025:282:00000 2025:282:86399 ns               -25.9551       6.4662
OSB  C234 C47          C5X       2025:282:00000 2025:282:86399 ns               -46.4945      11.5672
OSB  C234 C47          L1P       2025:282:00000 2025:282:86399 ns                15.9148       0.4784
OSB  C234 C47          L5P       2025:282:00000 2025:282:86399 ns                28.5395       0.6996
OSB  C234 C47          L1X       2025:282:00000 2025:282:86399 ns                24.1934       6.4599
OSB  C234 C47          L5X       2025:282:00000 2025:282:86399 ns                43.3853      11.5736
OSB  C233 C48          C1P       2025:282:00000 2025:282:86399 ns                58.8819       0.5719
OSB  C233 C48          C5P       2025:282:00000 2025:282:86399 ns               105.7057       0.5983
OSB  C233 C48          C1X       2025:282:00000 2025:282:86399 ns                50.3572       6.4668
OSB  C233 C48          C5X       2025:282:00000 2025:282:86399 ns                90.4186      11.5668
OSB  C233 C48          L1P       2025:282:00000 2025:282:86399 ns               -62.7949       0.4880
OSB  C233 C48          L5P       2025:282:00000 2025:282:86399 ns              -112.6082       0.7205
OSB  C233 C48          L1X       2025:282:00000 2025:282:86399 ns               -54.2702       6.4599
OSB  C233 C48          L5X       2025:282:00000 2025:282:86399 ns               -97.3211      11.5738
OSB  C235 C49          C1P       2025:282:00000 2025:282:86399 ns               -16.2489       0.5608
OSB  C235 C49          C5P       2025:282:00000 2025:282:86399 ns               -29.1915       0.5851
OSB  C235 C49          C1X       2025:282:00000 2025:282:86399 ns               -24.4529       6.4660
OSB  C235 C49          C5X       2025:282:00000 2025:282:86399 ns               -43.9035      11.5663
OSB  C235 C49          L1P       2025:282:00000 2025:282:86399 ns                16.0548       0.4801
OSB  C235 C49          L5P       2025:282:00000 2025:282:86399 ns                28.7906       0.7033
OSB  C235 C49          L1X       2025:282:00000 2025:282:86399 ns                24.2588       6.4595
OSB  C235 C49          L5X       2025:282:00000 2025:282:86399 ns                43.5026      11.5729
OSB  C232 C50          C1P       2025:282:00000 2025:282:86399 ns                63.2448       0.6214
OSB  C232 C50          C5P       2025:282:00000 2025:282:86399 ns               113.3611       0.6419
OSB  C232 C50          C1X       2025:282:00000 2025:282:86399 ns                54.5828       6.4716
OSB  C232 C50          C5X       2025:282:00000 2025:282:86399 ns                97.8278      11.5695
OSB  C232 C50          L1P       2025:282:00000 2025:282:86399 ns               -66.6548       0.5197
OSB  C232 C50          L5P       2025:282:00000 2025:282:86399 ns              -119.5300       0.7886
OSB  C232 C50          L1X       2025:282:00000 2025:282:86399 ns               -57.9928       6.4626
OSB  C232 C50          L5X       2025:282:00000 2025:282:86399 ns              -103.9967      11.5785
```

Figure 5: Code/phase OSBs for C47-C50 in GRG MGEX rapid

Table 2: Ambiguity fixing rates for C47-C50 (GFZ/GRG)

Station	Wide lane	Narrow lane
BRUX	100/98	66/100
TLSG	100/98	74/100
CEDU	91/100	59/100
KIRU	89/89	57/88

4 The updates of product combination and validation in BAR committee

Products from a potential AC at HUS have been incorporated into the combination, and since this year, BDS-3 has also been included for the final PPP-AR product combination and validation. Besides, an inspection of the combination results has been carried out to identify and report any product issues.

1. A potential AC's products from HUS have been included into the combination since last year.

   During the past year, the BAR Committee continued the routine combination and validation of PPP-AR products, with several important updates focusing on AC participation, multi-GNSS capability, and product quality inspection.

   Products of HUS have been evaluated as a potential contribution to the routine combination. Following consistency checks and PPP-AR performance validation, HUS rapid and final products have been formally included in the combination. The HUS products provide GPS, Galileo, BDS-2, and BDS-3 clock and code/phase bias corrections, increasing the redundancy of contributing ACs, especially for BDS. Statistical analyses indicate that HUS products show consistency comparable to existing ACs and contribute stably to both rapid and final combined solutions.

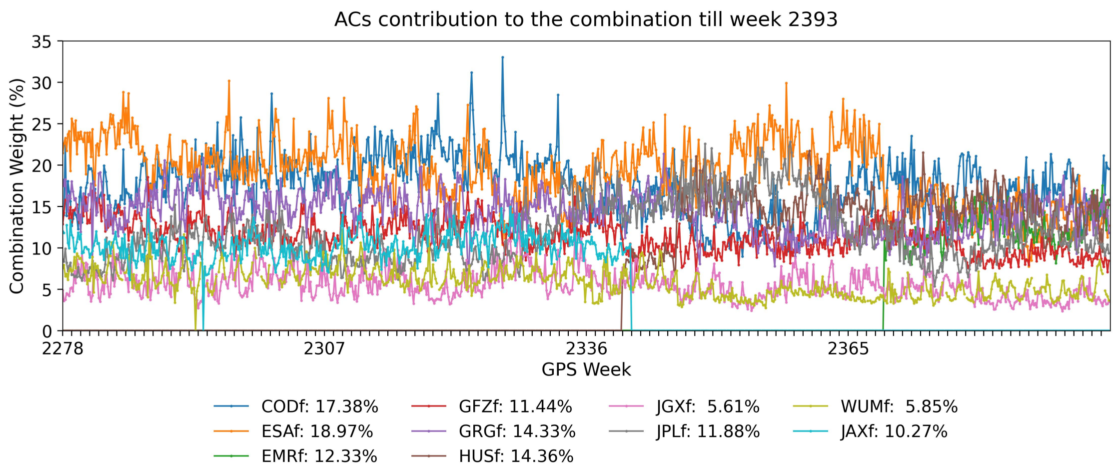

Figure 6: ACs contribution to the Final products combination from week 2278 to 2393

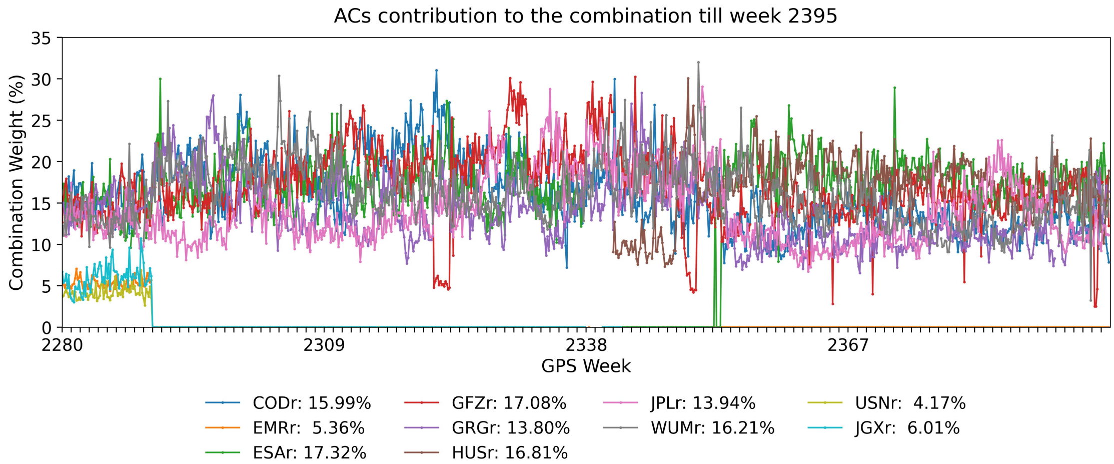

Figure 7: ACs contribution to the Final products combination from week 2278 to 2393

2. BDS-3 is included for the final PPP-AR product combination and validation since this year.

   Another major update is the inclusion of BDS-3 satellites in the final PPP-AR product combination and validation. With an increasing number of ACs providing high-quality BDS-3 clock and bias products, BDS-3 has been successfully integrated into the final combined products. The BDS consistency of the clock and bias combination for all products is shown below.

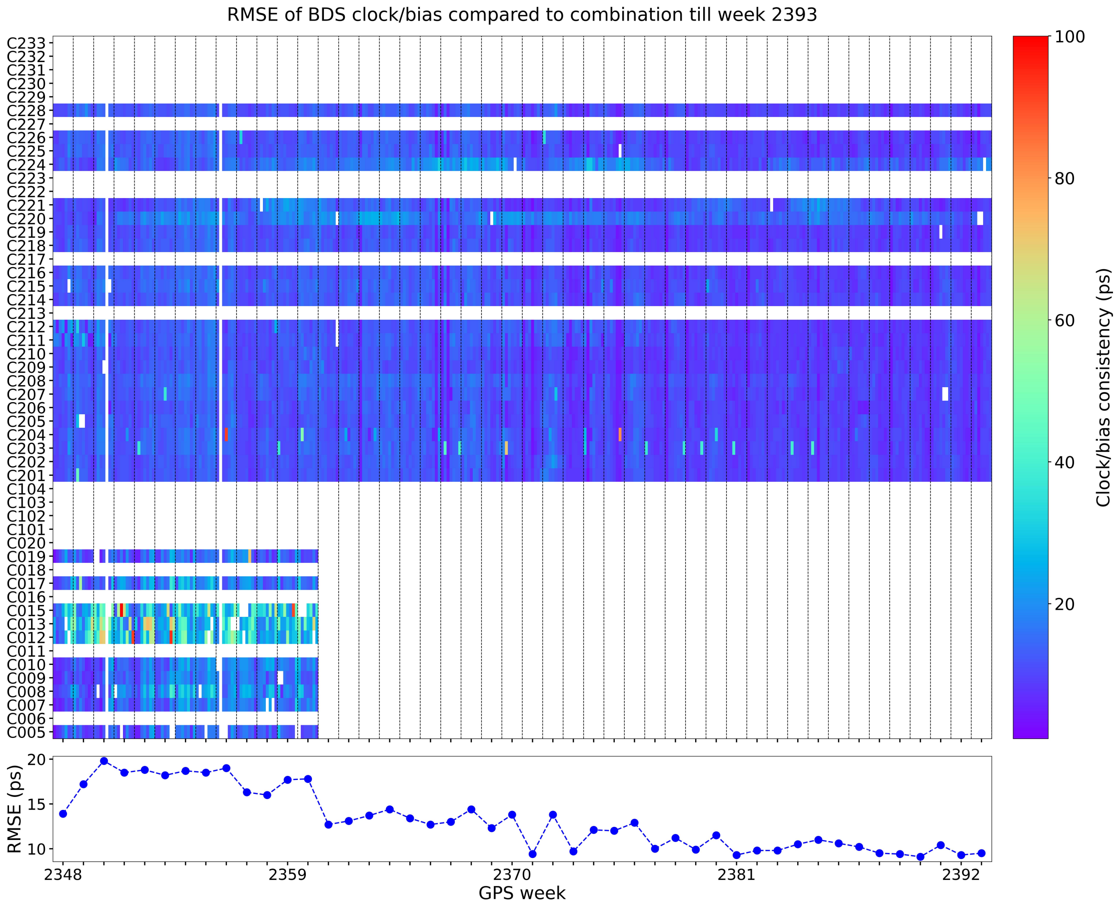

Figure 8: BDS clock/bias combination consistency of Final products over the year 2025

3. Inspection to the combination results to find and report some product issues.

   Routine inspections of the combination results have been carried out to identify potential product issues. The GPS/Galileo/BDS data with a sampling interval of 300 s from 10 globally distributed stations are processed for PPP-AR in a static mode. The fixing rate and position precision of each single constellation solution are presented in the Fig. 9. By analyzing residuals, weights, and satellite-dependent consistency patterns, several issues related to individual AC products were detected, such as the ANTEX indicator in CODE's products, where listing only "IGS20" instead of the exact ANTEX file version led to inaccurate positioning issues.

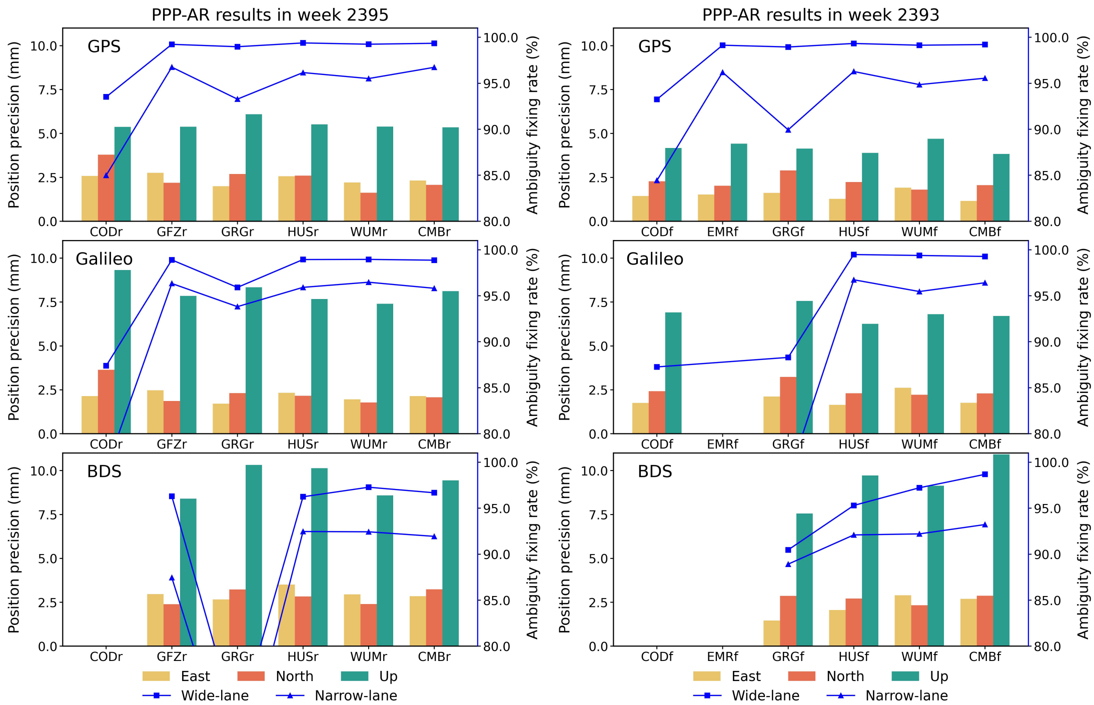

Figure 9: Ambiguity fixing rates and position precision for PPP-AR static solutions (Rapid products for the left panel, Final products for the right panel)

5 The kick-off meeting of BAR committee

On October 29, 2025 (UTC), the IGS BAR Committee convened its kick-off meeting. The BAR Committee, which integrates the former "Bias & Calibration Working Group" and "the PPP-AR Pilot Project", has its core objective of coordinating the research, standardization, validation, and dissemination of satellite bias products for existing GNSS and future LEO satellites. Researcher Jianghui Geng from the PRIDE Research Group chaired the kick-off meetings.

Dr. Wen Qiang from the PRIDE Research Group delivered a report titled Progress Report of the PPP-AR Pilot Project for 2024/2025, reviewing the work of the PPP-AR Pilot Project over the past year regarding orbit/clock/biases products. This year, BDS-3 PPP-AR product was included in the final combined product, thanks to the release of the HUS final BDS products. PPP-AR products from other Analysis Centers (ACs) of the IGS have also been updated. Specifically, EMR provides GPS code and phase OSBs in its OPS final products. WUM's MGEX final products include QZSS phase OSBs, while GFZ MGEX rapid and GRG MGEX final products include code and phase OSBs for BDS satellites with PRN numbers higher than C46 (C47-C50).

Additionally, during the meeting, Lotfi Massarweh from Delft University of Technology introduced the background, core objectives, work tasks, and charter of the newly established BAR Committee. Peter Steigenberger from the German Aerospace Center shared his research findings on the impact of GPS Flexible Power on the continuity of DCB estimation. Dr. Jiang Guo from the International Bureau of Weights and Measures presented his research on time transfer using continuous precise products.

In the final discussion session of the meeting, participants focused on the future core work directions, technical challenges, and user needs of the IGS-BAR Committee. Key topics included GNSS flexible power, day-boundary bias handling methods, phase biases quality, and the development of the BAR official website.

Over 60 experts, scholars, and researchers in the field of GNSS precise positioning from around the world attended the kick-off meeting. Through this meeting, all participants gained a clearer understanding of the BAR Committee's work directions, PPP-AR technology progress, and the application of biases products. This will provide important guidance for the subsequent upgrade of GNSS high-precision services and the support for the development of LEO system.

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Ionosphere Committee Technical Report 2025

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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. Qi Liu (Henan University)*
21. Haixia Lyu (Wuhan University)
22. Camille Martire (JPL)
23. Angelyn Moore (JPL)
24. Raul Orus (ESTEC)
25. Michiel Otten, PosiTim (SA/ESOC)
26. Ola Ovstedal (UMB)
27. Babatunde Rabiu (NSRDA, Nigeria)
28. Vergados Panagiotis (JPL)
29. Ignacio Romero, CSC (ESA/ESOC)
30. Stefan Schaer (CODE)
31. Michael Schmidt (DGFI-TUM)
32. Shuli Song (SHAO)*
33. Tim Springer, PosiTim (ESA/ESOC)
34. David R. Themens (University of Birmingham)
35. M. Sithartha Muthu Vijayan (CSIR 4PI)
36. Ningbo Wang (CAS)
37. Rene Warnant (ULiège)
38. Robert Weber (TU Wien)
39. Pawel Wielgosz (UWM)
40. Brian Wilson (JPL)
41. Chao Xiong (WHU)*
42. Junchen Xue (CAS)
43. Yunbin Yuan (CAS)
44. Qiang Zhang (WHU)*
45. Qile Zhao (WHU)

* elected in 2025

3 Key Issues

a Activities of eight IGS Ionosphere Associated Analysis Centres regarding GIMs: CODE, UPC, ESA, JPL, NRCan, CAS, WHU, OPTIMAP (GIMs) and works on inclusion of Shanghai Observatory (SHAO) as a new IAAC.

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 $\approx$ 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

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

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.

5 IGS 2024 Bern Workshop Recommendations and their implementation

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 Creation of two 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.

5.1 New Methodology for Combining IGS Ionospheric products

Activities of Study Group „New Methodology for Combining IGS Ionospheric products" resulted in proposition of a new methodology for developing a combined IGS ionospheric product (final and rapid variants), based on systematic validation using DORIS observations. The solution is currently in the implementation phase, with extensive comparative testing underway, including both the quality of results and operational stability. Ultimately, once the community accepts it, the methodology is intended to replace the currently used production pipelines. The proposed approach is distinguished by high computational efficiency, a modular architecture, and ease of expansion with additional components (e.g. ionospheric products of new IAACs). We see significant potential in it as a foundation for further development of production processes and the expansion of our group's expertise in the development and maintenance of IGS products. The proposal of a new methodology will be presented during IGS Workshop 2026 in Santiago, Chile.

5.2 Cooperation with IRI

Over the past year, the collaboration between the IGS Ionosphere Committee and the International Reference Ionosphere continued the regular delivery of ionospheric products supporting assimilation models. A key element was the stable, periodic release of dedicated climate VTEC maps, as well as development work aimed at improving the quality, consistency, and reliability of the entire production chain. Efforts focused on improving quality control, automating verification, and strengthening the pipeline's resilience to data gaps and operational disruptions. Solutions were also developed to facilitate product adaptation to model requirements and their subsequent integration into operational environments. This resulted in a more predictable delivery process and improved readiness for further service scaling and product expansion in subsequent stages of the collaboration.

Multi-GNSS Pilot Project Technical Report 2025

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1 Introduction

The IGS Multi-GNSS pilot project (MGPP) aims at the inclusion of all GNSS in all IGS products. An important step towards this goal was the completion of the BDS-3/QZSS satellite antenna calibration campaign which paves the way for the inclusion of BeiDou-3 and QZSS into the operational IGS products.

2 GNSS Evolution

Table 1 lists the GNSS satellite launches of the year 2025. NVS-02 is the second satellite of the second generation of the Indian regional navigation satellite system NavIC. It suffered from a launch failure and stranded in transfer orbit to its designated geostationary target destination. Nevertheless, it is transmitting navigation signals with PRN I11 (Steigenberger et al., 2025). Numerous IGS stations track the L5 signal of NVS-02, whereas the L1 and in particular S-band tracking is limited.

QZS-6 is the first QZSS Block III-G satellite. It transmits by default the L1C/B signal and is not able to transmit in the L2 frequency band, contrary to previous QZSS satellites. In the context of QZSS signal modernization, QZS-1R switched from L1C/A to L1C/B transmission in August 2025. Tracking of the L1C/B signal is supported only by a couple of Javad and Septentrio receivers with up-to-date firmware and proper configuration. Most receivers do not track L1C/B and some with outdated firmware or RINEX conversion software still report L1C/A observations for QZS-6. The launch of QZS-5 in December 2025 failed due to a malfunction of the 2nd stage of the H3 rocket.

The second GLONASS K2 satellite was launched in March 2025 and declared operational on day of year 358/2025. Tracking of the legacy frequency division multiple access (FDMA) signals is supported by most of the IGS stations. Although K2 satellites are able to transmit L1 and L2 code division multiple access (CDMA) signals, these are currently not tracked by the IGS stations. Despite its problems discussed in Steigenberger, P. and Montenbruck, O. (2024), the first GLONASS K1+ satellite R807 became part of the operational constellation on 136/2025. On 14 October 2025, R719 started the first transmission with slot number 28 (corresponding to PRN R28) in the history of GLONASS. However, this unhealthy satellite is currently only tracked by Javad receivers.

The Navigation Technology Satellite-3 (NTS-3) was launched in August 2025 into GEO (Davis, 2023). NTS-3 is expected to transmit PRN G34 but no such signals have been tracked by IGS receivers so far. The decommissioning of the Galileo FOC satellite E205 in December 2025 (European Commission, 2025) was followed by the first Galileo dual launch with Ariane 6 in the same month.

Table 1: GNSS satellite launches in 2025.

Date	Satellite	Type
29-Jan-2025	NVS-02	GTO
02-Feb-2025	QZS-6	GEO
02-Mar-2025	GLONASS K2	MEO
23-May-2025	GPS III	MEO
13-Aug-2025	NTS-3	GEO
13-Sep-2025	GLONASS K1B	MEO
17-Dec-2025	Galileo FOC E233/E234	MEO
23-Dec-2025	QZS-5	launch failure

For the Galileo Open Service Navigation Message Authentication (OSNMA), the European Union published the Service Definition Document (European Union, 2025c). The EU furthermore made available Issue 2.2 of the Galileo Open Service Signal-In-Space Interface Control Document (European Union, 2025a) including the definition of the new E5a Quasi Pilot signal. This signal is implemented on E216, E221, E223, and E226 since December 2025 (NAGU2025060, 2025). For the Galileo High Accuracy Service (HAS), a reference user algorithm was published (European Union, 2025b). Cabinet Office, Government of Japan, updated the QZSS Performance Standard (PS-QZSS, 2025) and the Centimeter Level Augmentation Service (CLAS) interface specification (IS-QZSS-L6-007, 2025)

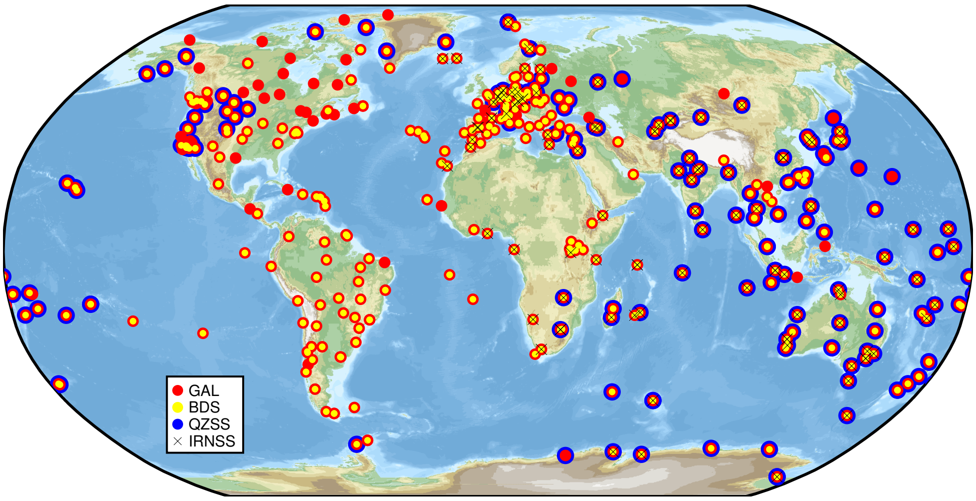

Figure 1: Distribution of IGS multi-GNSS stations supporting tracking of Galileo (red), BeiDou (yellow), QZSS (blue), and IRNSS (black crosses) as of January 2026.

3 Network

As of January 2026, the IGS multi-GNSS tracking network comprises 401 active stations, see Figs. 1 and 2. Compared to 2024, this is an increase of 16 stations. Six additional stations are completely dormant and did not provide any observations in 2025. Another 31 stations are only providing RINEX 2 files and are therefore only of limited value for multi-GNSS processing.

4 Products

Table 2 lists the analysis centers (ACs) contributing orbit and clock products to the IGS Multi-GNSS Pilot Project. The HUS joined as MGEX AC on 1 March 2025 providing ultra-rapid, rapid, and final products.

As already mentioned in Sec. 2, QZS-6 and all future QZSS satellites do not transmit signals in the L2 frequency band and transmit L1C/B instead of L1C/A. Therefore, the MGPP analysis centers decided to switch from the ionosphere-free linear combination of L1C/A and L2C to L1C and L5 starting with the products of GPS week 2352 (2 February 2025) as announced in Steigenberger P. (2025).

Several ACs and individual members of the MGPP contributed to the IGS BDS-3/QZSS satellite antenna calibration campaign. More details are given in the next section and 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

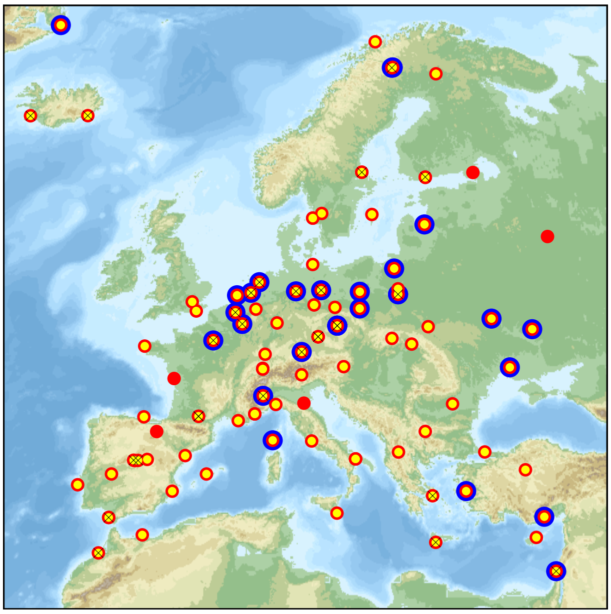

Figure 2: Distribution of European IGS multi-GNSS stations as of January 2026. See Fig. 1 for explanation of individual station labels.

Table 2: Analysis centers contributing to the IGS MGPP as of December 2025.

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
HUS	HUS0MGXFIN	GPS+GLO+GAL+BDS2+BDS3
IAC	IAC0MGXFIN	GPS+GLO+GAL+BDS2+BDS3+QZS
JAXA	JAX0MGXRAP	GPS+GLO+GAL+BDS2+BDS3+QZS
SHAO	SHA0MGXRAP	GPS+GLO+GAL+BDS2+BDS3
WU	WUM0MGXFIN	GPS+GLO+GAL+BDS2+BDS3+QZS

(quarterly final product). Details on the CAS products are given in the recent publication of Wang et al. (2025).

5 Satellite Antenna Calibration Campaign

The operational IGS products currently cover GPS, GLONASS and Galileo. BeiDou and QZSS are only included in the MGPP products discussed in the previous section. The inclusion of these constellations in the operational products is so far hampered by scale inconsistencies of the BDS and QZSS antenna models with the IGS20 reference frame scale.

In order to overcome these inconsistencies, the IGS Reference Frame Committee, the Antenna Committee, and the Multi-GNSS Pilot Project together with ten IGS/MGEX ACs have generated a new BDS-3/QZSS antenna model aligned to the IGS20 scale. The BeiDou-3 part includes block-specific estimated B1C/B2a phase patterns for BDS-3 CAST, SECM-A, and SECM-B MEO satellites as well as the BDS-3 IGSO satellites. The x-/y-PCOs and B1 z-PCOs are manufacturer calibrations provided by the Test and Assessment Research Center of the China Satellite Navigation Office (CSNO/TARC). Estimated satellite-specific B1C/B2a and B1I/B3I z-PCOs are used to derive a set of B1, B2, and B3 PCOs aligned to IGS20. Multiple intervals are considered for selected SECM satellites with time-varying PCOs. In this case, no PCOs are provided prior to January 1, 2021. PPP-AR validation of the new BDS-3 antenna model demonstrated a significantly improved scale consistency w.r.t. IGS20 of 0.1 - 0.2 ppb.

The QZSS model is limited to the L1 and L5 frequencies as the QZSS Block III satellites do not transmit L2 anymore. The satellite-specific phase patterns (except for J001) and the satellite-specific x-/y-PCOs provided by Cabinet Office are retained. The z-PCOs of J003, J005, and J007 provided by Cabinet Office are also retained whereas estimated L1/L5 z-PCOs are used for J001, J002, and J004.

6 Satellite Metadata

Cabinet Office, Government of Japan, published the satellite information for QZS-6 including the dimensions, optical properties, antenna phase center offsets and phase patterns for the main navigation antenna, SLR retro-reflector offsets, mass, center of mass position, and transmit power. Information on the satellite antenna phase center offsets of the most recent GPS III satellites G080 and G081 launched in 2024 and 2025, respectively, are still missing.

Starting with GPS week 2350, an additional `SATELLITE/PLANE` block has been added to the IGS satellite metadata file (Steigenberger P., 2025), which is a new feature of version 1.10 of the metadata file format (Steigenberger, P. and Montenbruck, O., 2024). In addition to the orbital plane, the slot within the plane is given. This information has been requested by the IGS Combination Task Force (see next section) to allow for a plane-specific grouping/weighting in the combination. The latest version of the IGS satellite metadata file is available at the IGS file server[1] as well as the IGS github repository[2].

[1] https://files.igs.org/pub/station/general/igs_satellite_metadata.snx

[2] https://github.com/International-GNSS-Service/IGS_Operational_Files/blob/main/operations/igs_satellite_metadata.snx

7 Combination Task Force

The IGS Combination Task Force (CTF) was established in 2022 as an initiative of the MGPP to support the build-up of a consolidated tool chain for multi-GNSS orbit and clock combination as well as the progressive build-up of a combined product portfolio within the IGS. In 2025, two new members from the Chinese Academy of Sciences and from NRCan joined the task force team and increased its capacity. The work of the task force focused on the validation and performance assessment of different orbit and combination techniques and software tools. In parallel to the task force, both GFZ and GA finalized their software packages for multi-GNSS orbit combination (SPOCC and ROCS) and made them publicly available to the GNSS community (https://gnss.gfz.de/services/spocc, https://github.com/GeoscienceAustralia/ROCS).

Extensive comparisons by the task force showed that both packages provide multi-GNSS orbit combinations of consistent quality despite the different approaches (variance component estimation vs. L1-norm weighting). Building on these results, initial multi-GNSS clock combinations were generated with the SPOCC clock combination module and the NRCan SPARKCombo software. Precise point positioning (PPP) solutions showed an excellent performance of the SPOCC combined orbits paired by NRCan's clock combinations. In particular the resulting multi-GNSS products were shown to be fully competitive with IGS GPS-only combinations and single-AC GPS+GLO+GAL products. Furthermore, a "no-harm" criterion was met for the combination including non-GPS constellations.

Initial problem with the SPOCC clock combination have been overcome by a revised reference clock handling and successfully verified in a PPP test. Thus, two independent orbit and clock combination packages have been validated and are available for the future generation of operational combined multi-GNSS products by the next analysis center coordinator. Given the current achievements, the CTF has essentially met its key goals and decided to terminate its work in early 2026.

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	Deutsches GeoForschungsZentrum
HUS	Huazhong University of Science and Technology

IAC Information and Analysis Center for Positioning, Navigation and Timing

JAXA Japan Aerospace Exploration Agency

MGPP Multi-GNSS Pilot Project

NRCan Natural Resources Canada

SHAO Shanghai Observatory

WU Wuhan University

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Reference Frame Committee Technical Report 2025

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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 2025 included:

- the definition of a new reference frame for the IGS products, IGc20, based on the second annual update of ITRF2020, ITRF2020-u2024 (Section 2),
- contributions to the IGS campaign for the calibration of the BDS-3 and QZSS satellite antennas (Section 3),
- the development of new services on the IGS terrestrial frame combination website, https://webigs-rf.ign.fr (Section 4).

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.

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 and IGS combined station positions once reference frame differences have been removed, since the beginning of 2025. These WRMS have remained in 2025 at similar stable levels as in the previous years.

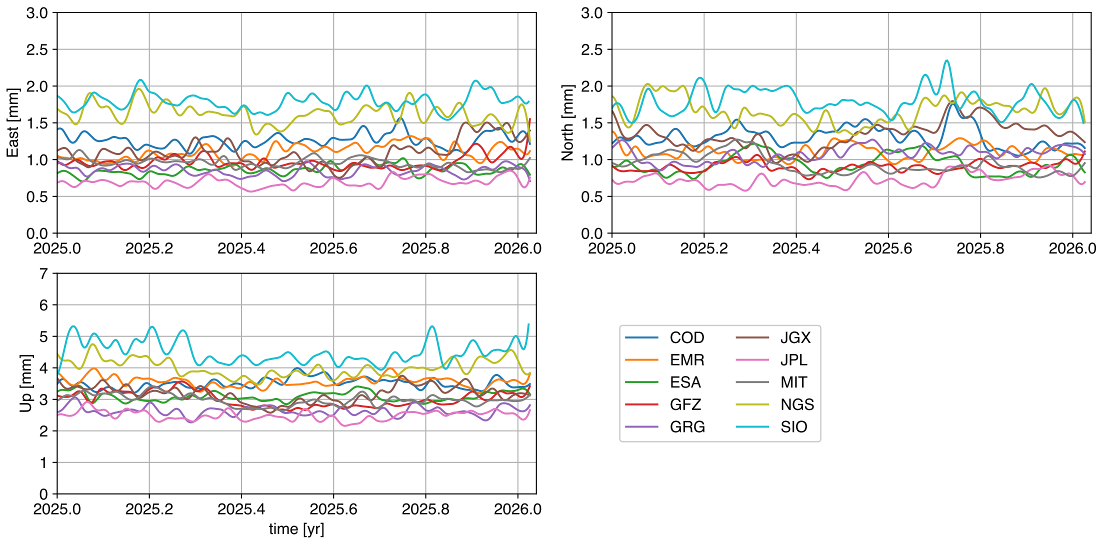

Figure 1: WRMS of AC station position residuals from the 2025 daily IGS SINEX combinations. All WRMS time series are low-pass filtered with a 20 cpy cutoff frequency.

2 IGc20 reference frame

To mitigate the progressive obsolescence of the International Terrestrial Reference Frame (ITRF) station coordinates due to extrapolation errors and to the occurrence of new station position discontinuities, 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 first annual update of ITRF2020, ITRF2020-u2023 (Altamimi et al., 2024), was adopted by the IGS on February 2, 2025 in the form of the so-called IGb20 reference frame (IGSMAIL #8543). Similarly, the second annual update of ITRF2020, ITRF2020-u2024 (Altamimi et al., 2025), has been adopted by the IGS since January 11, 2026 in the form of a new reference frame called IGc20.

IGc20 is a simple extract of ITRF2020-u2024 coordinates for 346 stable, well-performing, operational and historical IGS stations. The same 343 stations as in the previous IGS reference frame, IGb20, were retained, while 3 new stations were added in areas previously sparsely covered by IGS reference frame stations (see their distribution in Figure 2):

- CASC (Cascais, Portugal): historical EUREF station with 28-year long position time series, which recently joined the IGS network.
- MANA (Managua, Nicaragua): historical IGS station with 25-year long position time series. Although MANA was displaced by many earthquakes over its observation history, it was nevertheless selected in IGc20 because of its strategic location in Central America, where the only two other IGS reference frame stations are ei-

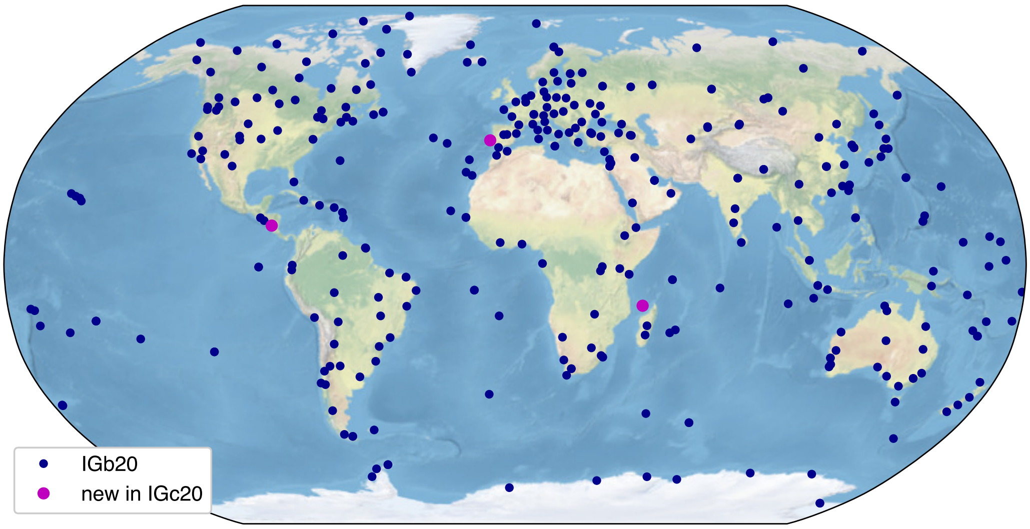

Figure 2: Distribution of the IGc20 reference frame stations.

ther dormant (GUAT) or without up-to-date ITRF2020-u2024 coordinates due to a recent earthquake (SSIA).

- MAYG (Dzaoudzi, Mayotte): the 11-year long position time series of the station features a large transient deformation pattern due to the 2018–2022 volcano-tectonic episode in Mayotte. While this pattern was roughly approximated by a piecewise linear model in previous ITRF releases, it is now accurately represented by a physics-based "double-exponential" model in ITRF2020-u2024.

More details on the IGc20 reference frame and its usage may be found in IGSMAIL #8634.

Since the ITRF2020 yearly updates are aligned in origin, scale and orientation to the original ITRF2020 solution, IGc20 should not be considered as a complete new reference frame, but rather as an update to individual IGb20 station coordinates. This alignment implies that the transformation parameters between ITRF2020 (IGS20), ITRF2020-u2023 (IGb20) and ITRF2020-u2024 (IGc20) are all zero. It also implies that the switches from IGS20 to IGb20, then IGc20 did not introduce any significant “datum” changes in the IGS products. On the other hand, the precision and accuracy of the alignment of the IGS products to the reference frame benefit from the adoption of regularly 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 BDS-3 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 BDS-3 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 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 BDS-3 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, the nadir component of phase center offsets (z-PCOs) have been estimated by eight ACs for the BDS-3 (B1C/B2a) and QZSS (L1C/L5) satellites, and the results were combined by the Reference Frame Committee (Steigenberger et al., 2025). Although the B1I/B3I frequency combination will not be used in the generation of future IGS operational products, updates to the BDS-3 (B1I/B3I) satellite z-PCOs were also estimated by the German Aerospace Center (DLR) and Wuhan University. The new BDS-3 satellite antenna phase center model was then tested and validated in the generation of orbit and clock products by Wuhan University and in PPP-AR by the Chinese Academy of Sciences. At the time of writing, the publication of a new version of igs20.atx including the new BDS-3 / QZSS satellite antenna phase center model is imminent, and a scientific paper is in preparation.

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.

4 New services on https://webigs-rf.ign.fr

4.1 Monitoring of satellite z-PCOs

One of the outcomes of the BDS-3 / QZSS satellite antenna calibration campaign was the finding of apparent jumps in the time series of z-PCO estimates of certain BDS-3 satellites (accounted for by means of piecewise constant z-PCOs in the new antenna model). To monitor possible future occurrences of similar jumps which may require future updates of igs20.atx, a new webpage was set up at https://webigs-rf.ign.fr/zpco. It displays weekly-updated time series of GPS, GLONASS, Galileo, BDS-3 and QZSS satellite z-PCO estimates derived from different series of AC SINEX solutions. Figure 3 shows an example of the z-PCO time series displayed for the BDS-3 satellite C215.

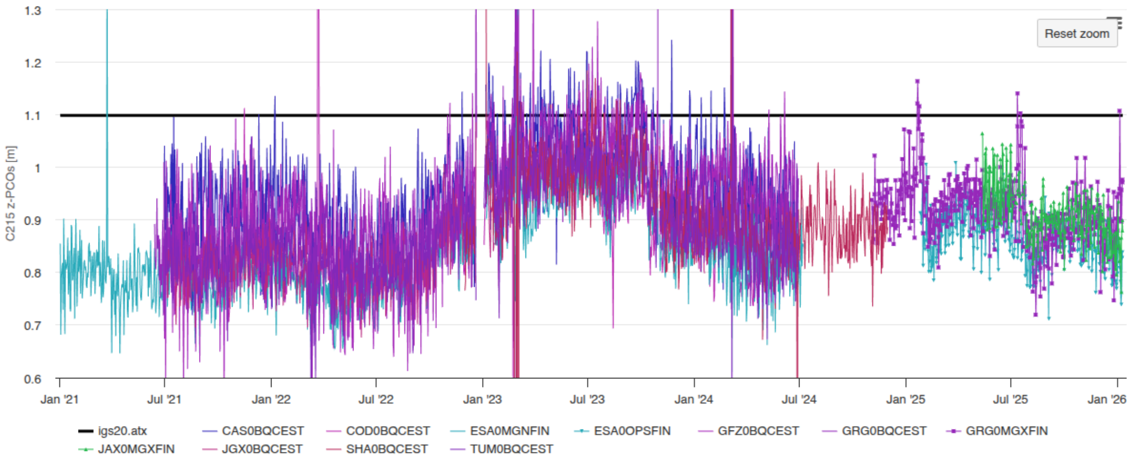

Figure 3: Example of satellite z-PCO time series displayed at https://webigs-rf.ign.fr/zpco.

4.2 Web service for the computation of possible co-seismic displacements

Back in 2023, an automatic procedure was set up to monitor and record the possible co-seismic displacements of IGS stations. The Global Centroid-Moment-Tensor (CMT; Ekström et al., 2012) catalog is scanned every day for new earthquakes. For every new earthquake, approximate co-seismic displacements are calculated for all IGS stations using a simple half-space dislocation model (see details at https://webigs-rf.ign.fr/coseismic). Whenever one or more calculated displacements exceed 1 mm, the information is distributed through the IGSSTATION and IGS-ACS mailing lists. The database of the possible co-seismic displacements recorded by IGS stations, available at ftp://igs-rf.ign.fr/pub/coseismic/IGS_coseismic.dat and https://webigs-rf.ign.fr/coseismic, is also updated.

In 2025, a new web service was set up which allows users to compute possible co-seismic displacements anywhere on Earth, based on the same CMT catalog and half-space dislocation model. Instructions on how to request this web service are given at https://webigs-rf.ign.fr/api/doc/#/Seismic/post_coseismic_request.

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1 Introduction

The IGS/RTCM RINEX committee was established in December 2011 to update and maintain the RINEX format to meet the needs of the IGS and the GNSS Industry. Since the RINEX format is widely used by the GNSS scientific community and industry it was decided that it should be jointly managed by the IGS and the Radio Technical Commission for Maritime Services – Special Committee 104 (RTCM-SC104). In this way the Committee consists of IGS scientific and institutional members and RTCM-SC104 industry members.

2 Membership

The committee has about 72 members at the current time and membership and subscription to the Mailing List can be requested here. In addition, at the end of the year 2024, André Hauschild from DLR was appointed as new vice-chair.

3 Summary of Activities in 2025

The RINEX Committee activities of the 2025 have been the following:

- RINEX 4.02, initially published in October 2024, has been revised to accommodate editorial changes and clarifications, to improve the ICD readability and clarity. A release update of the same format (still RINEX 4.02 version) has been published in September 2025. No format changes were introduced with this update.
- The committee received requests to support the standardization of additional GNSS navigation message data bits, such as Authentication messages (Galileo and QZSS) and the Galileo High Accuracy Service. The request has been accepted by the RINEX Committee and the IGS Governing Board and a dedicated Task Force to standardize these data has been approved. The creation and activities of this Task Force will be conducted in 2026.
- After the interest of the community, already raised during the 2024 IGS Workshop, in the LEO-PNT technologies, the committee received the request to support the standardization of the LEO-PNT Observation and Navigation Messages within the RINEX ICD. This hot topic has led to a broader discussion within the Governing Board to tackle the following question: “Shall the IGS embrace the LEO-PNT systems?”. A survey to the entire IGS community has been conducted to assess the general interest and understand, at least preliminary, the implications of such a step. Activities in this domain will be conducted in 2026.

4 Planned 2026 Activities

- Review of open request of changes for RINEX 4.02 (e.g., review of Galileo ICD released in November 2025)
- Formal creation and kick of the activities of the Task Force for the standardization of the Navigation message data bits.
- Continue to support the investigation in the LEO-PNT domain.

Tide Gauge Benchmark Monitoring Committee Technical Report 2025

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Cautionary note: TIGA was revived in 2025 after a pause of approximately three years, and its membership is currently being finalized. The text below reflects the understanding and views of the new co-chairs based on the discussions held so far and should not be interpreted as a finalized or formally agreed position of the group for 2025.

1 Historical perspective

The TIGA Committee (Pilot Project at that time) was established in 2001 to support GNSS tide gauge benchmark monitoring, that is, the geocentric determination of tide gauge datums and their vertical stability using permanent GNSS stations co-located with tide gauges.

The primary scientific objective of TIGA has been to provide GNSS-based estimates of vertical land motion at tide gauge sites, with uncertainties commensurate with those of long-term sea-level change derived from tide gauge records, i.e., at the sub-millimeter per year level. Additional applications were envisaged from the outset, including the unification of vertical datums (Sánchez and Bosch, 2009) and the calibration and validation of satellite radar altimetry sea-level data (Schöne et al., 2009).

To achieve these objectives, the following core components and activities were identified:

1. **GNSS at Tide Gauge stations:**
   - Promote the installation of GNSS stations at tide gauge locations.

- Provide training for tide gauge operators on GNSS installation, configuration, metadata management, and quality control (QC).
- Encourage the establishment of local leveling ties between the GNSS antenna reference point and the tide gauge datum (benchmarks).
- Offer advice on emerging applications.

2. **Thematic global Data Center:**
   - Develop a dedicated data center for assembling, quality-controlling, and distributing data and metadata from GNSS at tide gauge stations.
3. **Thematic global Data Center:**
   - Ensure consistent reprocessing of GNSS data at tide gauge stations, aligned with the latest IGS reprocessing standards.
   - Engage at least three individual analysis centers to allow for effective intercomparison of results.
4. **Thematic global Data Center:**
   - Establish a combination center to evaluate products (coordinate time series and velocities) from individual groups and produce official, combined TIGA products.

The implementation of these components followed the best-effort model typical of the IGS, with its associated strengths and limitations, depending on the level of engagement of contributing institutions and the resources available to them.

Figure 1 shows the distribution of GNSS stations located within 1 km of a tide gauge for which daily RINEX files are available through the SONEL data assembly center. SONEL has acted as the IGS thematic (TIGA) Global Data Center. In this role, it collects, performs quality control, archives, and distributes daily RINEX files for GNSS stations located within 15 km of a tide gauge. The 1-km distance shown in Figure 1 was considered a reasonable threshold to allow precise (1st-order) leveling between the GNSS antenna and the tide gauge benchmark defining the tide gauge datum. The total number of GNSS stations at tide gauges considered in SONEL can be viewed on the SONEL website (https://www.sonel.org/-GPS-.html).

The choice of a 15 km distance also allowed the inclusion of GNSS stations that are serendipitously located near tide gauges, with the aim of encouraging tide gauge operators either to establish geodetic ties or, where appropriate, to install GNSS stations closer to the tide gauge. The latter situation could arise, for example, if repeated leveling were considered unrealistic, or if existing leveling data revealed local land motion instability between the GNSS antenna and the tide gauge. In this sense, Figure 1 includes both TIGA-committed stations and a broader set of stations that could potentially fall within

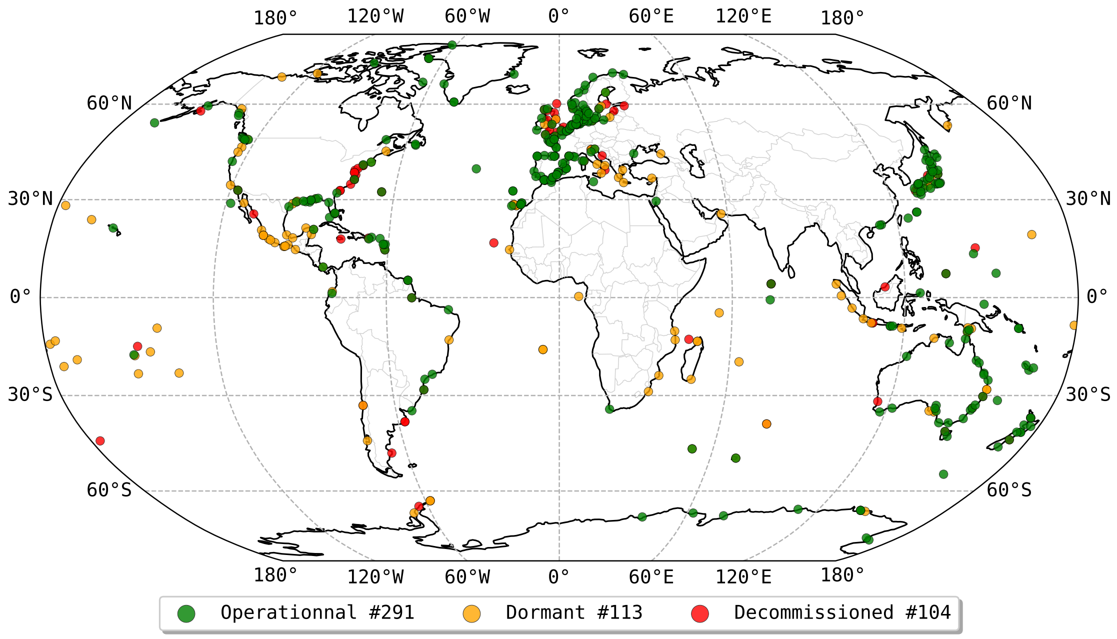

Figure 1: GNSS stations within 1 km of a tide gauge with daily RINEX files available at SONEL, acting as the IGS thematic (TIGA) global data center. Active stations are in green (291), stations without data for the past 30 days in orange (113), and decommissioned in red (104).

the scope of TIGA, as leveling over distances of up to 1-km was considered simple and realistic.

In addition to RINEX data, SONEL also collects and distributes products (position time series and velocities) from groups that follow the latest IGS standards associated with its reprocessing campaigns. Figure 2 presents GNSS velocity estimates produced by the two TIGA Analysis Centers that have contributed to IGS reprocessing efforts. Other groups have also processed GNSS data at tide gauge sites (e.g. Sánchez and Bosch, 2009) with the objective of contributing to combined TIGA solutions.

2 TIGA Renaissance in 2025

In 2025, the initial focus of the revived TIGA activities was on re-establishing the project and recruiting participants. The initial meetings discussed motivation of participants and original goals of TIGA and the associated components outlined above, while initiating discussions on their relevance and possible evolution. In particular:

- Identify what components of the original TIGA initiative were successful.

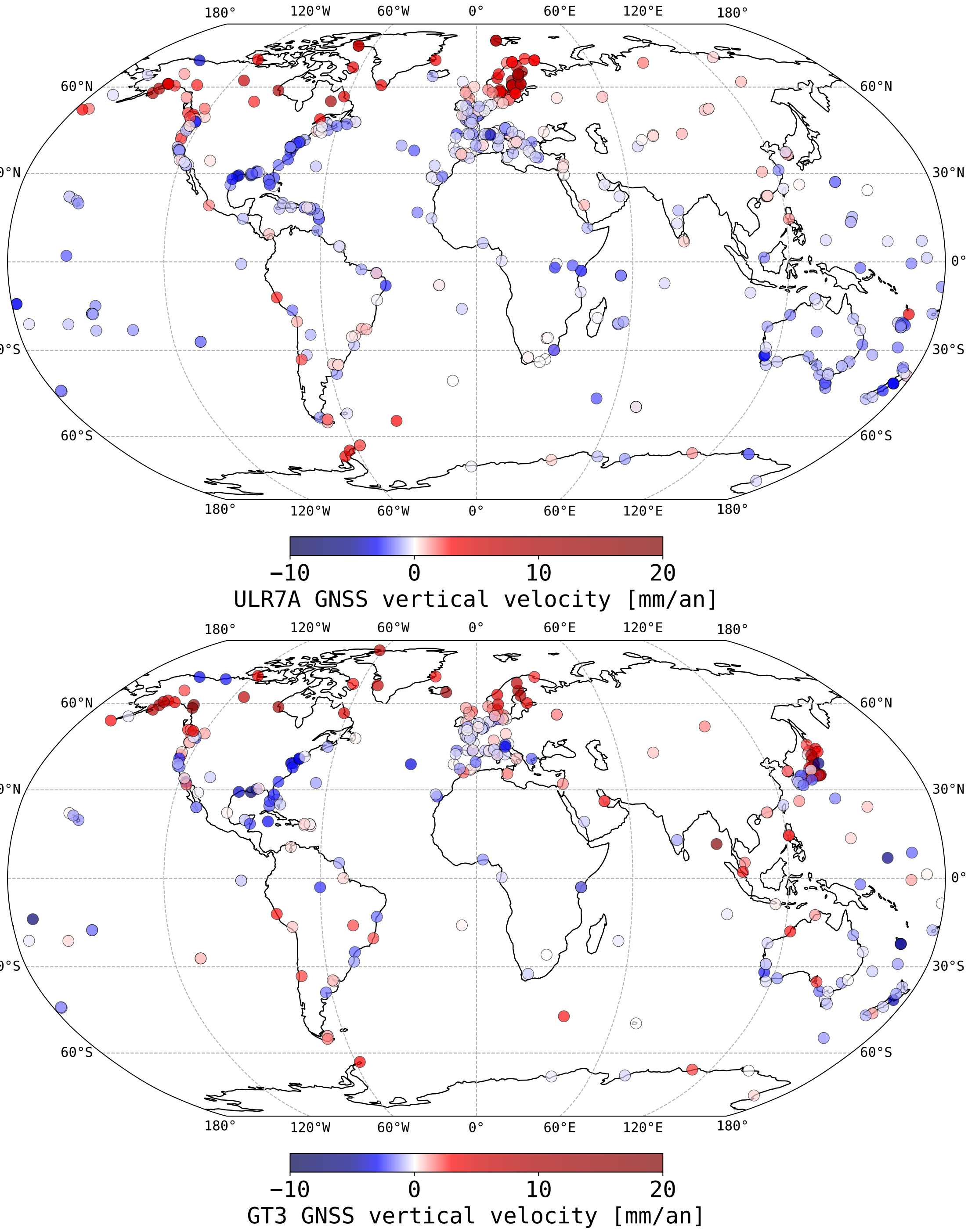

Figure 2: GNSS velocities estimated by ULR (top) and GFZ (bottom) from their contribution to IGS-repro3 (Gravelle et al. (2023); Männel et al. (2022), respectively).

- Assess which of these components should be maintained moving forward.
- Explore new opportunities and potential extensions of the TIGA framework.

These discussions emphasized the continued relevance of two core elements: the network of GNSS at tide gauge sites, and the maintenance of a thematic global data center. At the same time, participants recognized that new opportunities and challenges have emerged and should be considered in a renewed TIGA context.

2.1 Emerging opportunities

Two developments over the past decade appear particularly relevant for a TIGA renaissance. First, ground-based GNSS reflectometry (GNSS-IR; **?**) has emerged as a promising technique for measuring sea level directly using GNSS signals, complementing traditional tide gauge technologies. Demonstration studies (e.g. Larson et al., 2017) have shown the potential of GNSS-IR for mean sea level, stimulating the establishment of a dedicated portal at the PSMSL (`https://psmsl.org/data/gnssir/`). While this portal archives derived products (mean seal levels), the long-term value of GNSS-IR also requires appropriate archiving of raw GNSS data, often at higher sampling rates than the 30s considered within TIGA. Second, the long-recognized lack of repeated leveling data linking GNSS antennas and tide gauge reference points remain a critical limitation for many sites (Wöppelmann et al., 2016). In this context, InSAR has the potential to provide complementary information on relative ground motion in the vicinity of tide gauges (Filmer et al., 2020). While not a replacement for precise leveling, InSAR may help address questions relative to the applicability of GNSS-derived displacements to tide gauges or nearby coastal infrastructure, particularly where strict co-location or repeated leveling is difficult.

2.2 Lessons from past experience

The revival of TIGA-also provides an opportunity to step back and reflect on lessons learned from earlier phases. Questions raised include: What constitutes a TIGA station today? Is there still a need for independent analysis centers and a formal combination center? Which components worked well in the past, and which faced limitations? What new components or expertise may be required to address current and emerging applications? These questions are currently under discussion and will inform the future evolution of the TIGA Committee.

3 Acknowledgement

We would like to warmly thank our colleague and friend Tilo Schöne (GFZ Potsdam) for his long-standing commitment to TIGA and for his sustained efforts in advancing the

project over many years, always with enthusiasm and a positive spirit.

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IGS Troposphere Committee Technical Report 2025

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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. Rosa Pacione from e-GEOS in Italy is the Troposphere Committee's vice chair.

2 IGS Final Troposphere Product Generation 2025

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 and transitioned to the IGb20 reference frame in February 2025. The processing uses precise point positioning (PPP; Zumberge et al., 1997) and the GMF mapping function (Böhm et al., 2006) with

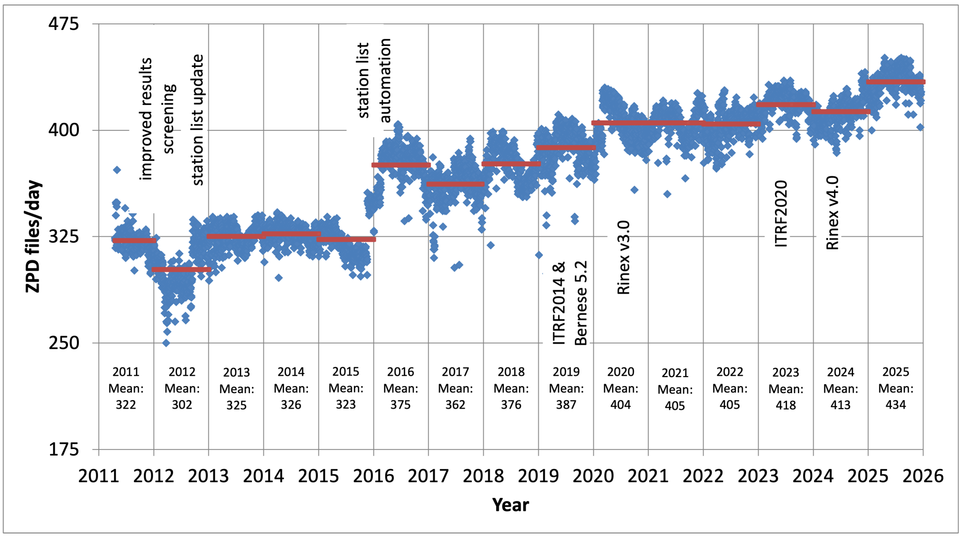

Figure 1: Number of IGS receivers for which USNO produced IGS Final Troposphere Estimates, 2011–2025. Red lines denote the mean for the year.

IGS Final satellite orbits/clocks and Earth orientation parameters (EOPs) as input. Each site-day's results are completed approximately three weeks 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 2011-2025. The average number of quality-checked station result files submitted per day in 2025 was 434. Fig. 1 is annotated with major changes in the processing of the IGS FTEs, most which result in an increase of produced IGS FTEs. All available station data is processed and quality checked. 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 2025

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 2025, the Troposphere Committee meeting continued to work on the recommendations from the 2024 IGS Workshop in Bern, Switzerland:

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.

Communications on news and activities were distributed via the committee's mailing list.

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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