Satellite Navigation Branch, ANG-E66

GALILEO OPEN SERVICE PERFORMANCE ANALYSIS REPORT

October 2025

Report #16
Reporting Period: July 1, 2024 to September 30, 2024
http://www.nstb.tc.faa.gov

FAA William J. Hughes Technical Center
Atlantic City International Airport, New Jersey 08405

DOCUMENT VERSION CONTROL

VERSION	DESCRIPTION OF CHANGE	DATE
0.1	Initial Draft	04/25/2025
0.2	Internal Peer Review	06/30/2025
0.3	External Peer Review	08/19/2025
1.0	Final Report	10/15/2025

EXECUTIVE SUMMARY

In 2016, the European Union (EU) made available the Galileo Global Navigation Satellite System (GNSS) [1]. This system provides ranging, navigation, and timing services to properly equipped users. Galileo is currently in its initial operational capability phase. Galileo is a GNSS similar to the United States (U.S.) Global Positioning System (GPS). Galileo and GPS are interoperable and transmit signals on the same frequencies.

This report focuses exclusively on the Galileo performance. The Federal Aviation Administration (FAA) publishes a separate report on GPS performance and Advanced Receiver Autonomous Integrity Monitoring (ARAIM) performance. ARAIM is a dual-frequency/multi-constellation scheme that uses GPS and Galileo in an aviation application.

The Galileo performance assessment evaluates parameters in the Galileo Open Service (OS) Service Definition Document (SDD), version 1.3 [2]. The following parameters and high-level results for the quarter are included in this report or future reports.

Availability of Galileo Position Dilution of Precision (PDOP). The availability of PDOP less than or equal to 6 is calculated on an equally spaced grid across the world as a monthly statistic to coincide with Minimum Performance Level (MPL) in the OS SDD. Using Galileo navigation data (ephemerides and satellite health) provided by the International GNSS Service (IGS), coverage data was calculated for each month in the reporting period. Availability of PDOP was greater than 99% for July, August, and September.

Signal Health and Accuracy F/NAV. Using Galileo broadcast navigation data available from the IGS, Galileo E1b and E5a signals were tracked with the health assessed as per Figure 4 in the OS SDD v1.3 document [2]. The data was examined along with any available Notices Advisory to Galileo Users (NAGUs) relevant to each non-healthy event. Section 3.2 details data processing, cleansing, and modeling plans to assess SIS ranging accuracy (SISRA) as per OS SDD v1.3, Section 3.3, Tables 9, 10, and 11. This section includes SISRA results over 30-day and 1-year periods per the MPLs. The 95% SISRA for any satellite remained less than or equal to 1.098 m for July, August, and September. The 95% SISRA over all satellites remained less than or equal to 0.971 m for July, August, and September. The 99.9% SISRA for any satellite over a 1-year period remained less than or equal to 1.25 m.

Galileo Time Transfer Performance. Analysis of Galileo Time Transfer Performance will be incorporated in a future report. As is done with GPS time transfer analysis, a data product is needed from the U.S. Naval Observatory (USNO) comparing Galileo system time as computed by its users, with that of the Coordinated Universal Time (UTC) standard of time produced by the USNO and other labs. The evaluation of accuracy of Galileo’s time dissemination service will follow the descriptions in OS SDD v1.3, Section 3.3.3, and the evaluation of availability of Galileo’s time dissemination service will follow the descriptions in OS SDD v1.3 Sections 3.3.4, 3.42, and 3.45.

Availability of Galileo Positioning. In future reports this section will include data processing results assessing the availability of the Galileo positioning service at the worst user location and average user location as it relates to MPL commitments described in OS SDD v1.3, Section 3.4.4, Tables 16 and 17. The development of this section depends on the completed development of data processing, cleansing, and modeling detailed in Section 3.2. Using the dilution of precision modeled in Section 2 along with the signal-in-space ranging error, this section will present horizontal position error and vertical position error results modeled as described in OS SDD v1.3, Section C.4.5.3.

Galileo Position Accuracy. The Satellite Navigation Branch developed a Galileo dual frequency user position tool to measure position accuracy using Galileo. Galileo navigation measurement data is being collected using two G-III receivers located at the WJHTC, a GT7800 receiver located in Elko, Nevada, and a GT7800 receiver located in Arcata, California to process Galileo position accuracy. The 95% vertical and horizontal position accuracy was calculated as a monthly statistic. The 95% horizontal position accuracy remained less than 1.7 m for July, August, and September. The 95% vertical position accuracy remained less than 2.5 m for July, August, and September.

Timely Publication of NAGUs. The timeliness of NAGUs is determined based on the MPLs discussed in section 3.6.1 of the Galileo OS-SDD using NAGUs published to the European GNSS Service Center website [3]. This section has been updated to conform with the new MPLs published in version 1.3. There were 12 NAGUs published this quarter, 9 of which fell within the scope of this report.

- Two NAGUs announced planned outages for GSAT203 (NAGU 2024032) and GSAT213 (NAGU 2024036).
- One NAGU announced a planned maneuver for GSAT213 (NAGU 2024027).
- Three NAGUs announced the usability of satellites returning from maintenance, GSAT0213 (NAGUs 2024037 and 2024040) and GSAT0203 (NAGU 2024035).
- Two NAGUs announced the usability of two new satellites, GSAT0225 (NAGU 2024033) and GSAT0226 (NAGU 2024034).
- One NAGU announced the launch of two new satellites, GSAT0226 and GSAT0232 (NAGU 2024038).
- Three NAGUs regarded the High Accuracy Service (HAS) and are out of scope of this report.

Of the nine published Galileo Open Service NAGUs, all were published in a timely manner.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

In 2016, the EU made available the Galileo GNSS, providing ranging, navigation, and timing services to properly equipped users. Galileo is currently in its initial operational capability (IOC) phase. Galileo is a GNSS similar to the U.S. GPS. Galileo and GPS are interoperable and transmit signals on the same frequencies.

Galileo provides five services: OS, Safety-of-Life Service, Commercial Service, High Availability Service, and Public Regulated Service [4]. The scope of this report is limited to the OS, specifically the E1 and E5a signals. The Galileo signals applicable to the OS are E1 (1575.42 MHz, the same frequency as GPS L1), E5a (1176.45 MHz, the same frequency as GPS L5), and E5b (1207.14 MHz). The E1 and E5a frequencies and modulation scheme correspond to GPS L1 and L5 to simplify the combined use of both constellations.

The FAA will evaluate Galileo performance while it is still in its IOC phase. Internationally, standards organizations are preparing specifications for aviation use of Galileo. To prepare for the future use of Galileo in aviation, performance monitoring of Galileo is necessary to assess the performance and characteristics of the system. Note that the European Union Agency for the Space Programme (EUSPA) also publishes Galileo performance reports on their website [5].

This report focuses exclusively on Galileo performance. The FAA publishes a separate report on GPS performance and ARAIM performance. ARAIM is a dual-frequency/multi-constellation scheme that uses GPS and Galileo in an aviation application.

This report uses several sources of data for the evaluation. NovAtel G-III and GT7800 receivers located at the FAA WJHTC in Atlantic City, New Jersey; Elko, Nevada; and Arcata, California, collect the Galileo signals directly. Future reports will include data from other Galileo-capable receivers to expand the footprint of this report’s assessment of Galileo. Other sources of data include Galileo broadcast navigation data from the IGS and precise Galileo ephemeris and clock data from the Center for Orbit Determination in Europe (CODE). This report later explains the use of these offline data sources.

The Galileo performance assessment evaluates parameters in the Galileo OS SDD, version 1.3. The parameters included in this report or future reports are:

- Signal-in-Space (SIS) Ranging Accuracy
- SIS Ranging Rate Accuracy
- Galileo Time Transfer Accuracy and Availability (Future Report)
- Per Slot Availability
- Dilution of Precision (DOP) Availability
- Positioning Service Availability
- Timely Publication of NAGU
- User Position Error (this parameter is not in the OS SDD)

The MPLs for each of the parameters evaluated are in the applicable section of this report.

Note that two Galileo constellation "auxiliary" satellites, Space Vehicle Identification (SVID) numbers 14 and 18, were set unhealthy on February 18, 2021. An explanation for this is provided in Galileo Service Notice #05. This report does not include those two satellites in the performance assessment.

2. AVAILABILITY OF GALILEO PDOP

The availability of Galileo PDOP is the percentage of time the PDOP remains less than or equal to a threshold for any point in the Galileo service coverage. DOP is the effect on user position errors induced by the satellite geometry used in the position measurement solution. The Galileo OS SDD defines the availability of Galileo PDOP to be the percentage of time the PDOP remains less than or equal to 6 with a minimum of 4 Galileo satellites visible above a 5-degree elevation transmitting healthy SIS (satellite health described in OS SDD Section 2.3.1). On a global basis, the availability of PDOP is computed as the average over all user locations within the service coverage (service coverage described in OS SDD Annex C.3 [2]), provided as a monthly statistic.

Table 2-1 specifies the MPL for the availability of PDOP according to the OS SDD.

Table 2-1. Availability of PDOP Parameter

MPL of the Availability of PDOP	Conditions and Constraints
≥ 90% average user location	• PDOP <= 6 • At least 4 satellites in view with a minimum elevation angle of 5 degrees • Calculated for 30-day period • Includes planned and unplanned outages

The Satellite Navigation Branch at the FAA WJHTC developed a Galileo coverage area tool to calculate DOPs (horizontal dilutions of precision (HDOPs), vertical dilutions of precision (VDOPs), and PDOPs) using the Galileo constellation. Galileo ephemerides were obtained from broadcast Galileo data provided by IGS [9]. Galileo ephemerides were incorporated using the status of both E1b and E5a being healthy at the same time. Additionally, information provided in the NAGUs was incorporated to account for satellite maintenance and outages. Galileo auxiliary satellites E10 and E06 were not included in the calculations and data provided in this section. DOPs were calculated at every 2-degree grid between longitudes 180W to 180E and latitudes 74S to 74N at 1-minute time intervals. This resulted in 1440 samples for each of the 13,500 grid points over a 24-hour period. See APPENDIX A for a plot of the maximum PDOP computed at each timestep on this grid. Table 2-2 provides the results of the monthly Availability of PDOP (computed as an average of the 2-degree coverage area described above).

Table 2-2. Availability of PDOP

Month	Availability of PDOP (Galileo OS SDD MPL: ≥90%)
July 2024	99.0879%
August 2024	99.6448%
September 2024	99.7842%

Figure 2-1 through Figure 2-3 show a monthly contour plot of the availability of PDOP at each 2x2 degree grid point calculated for the Galileo coverage area. Inside each contour area, the availability of PDOP percentage is greater than or equal to the contour value shown in the legend for that color line. That area's value is also less than the next higher contour value unless another contour line lies within the current area. Please note the contour color values for Figure 2-1 through Figure 2-3 may vary for each plot.

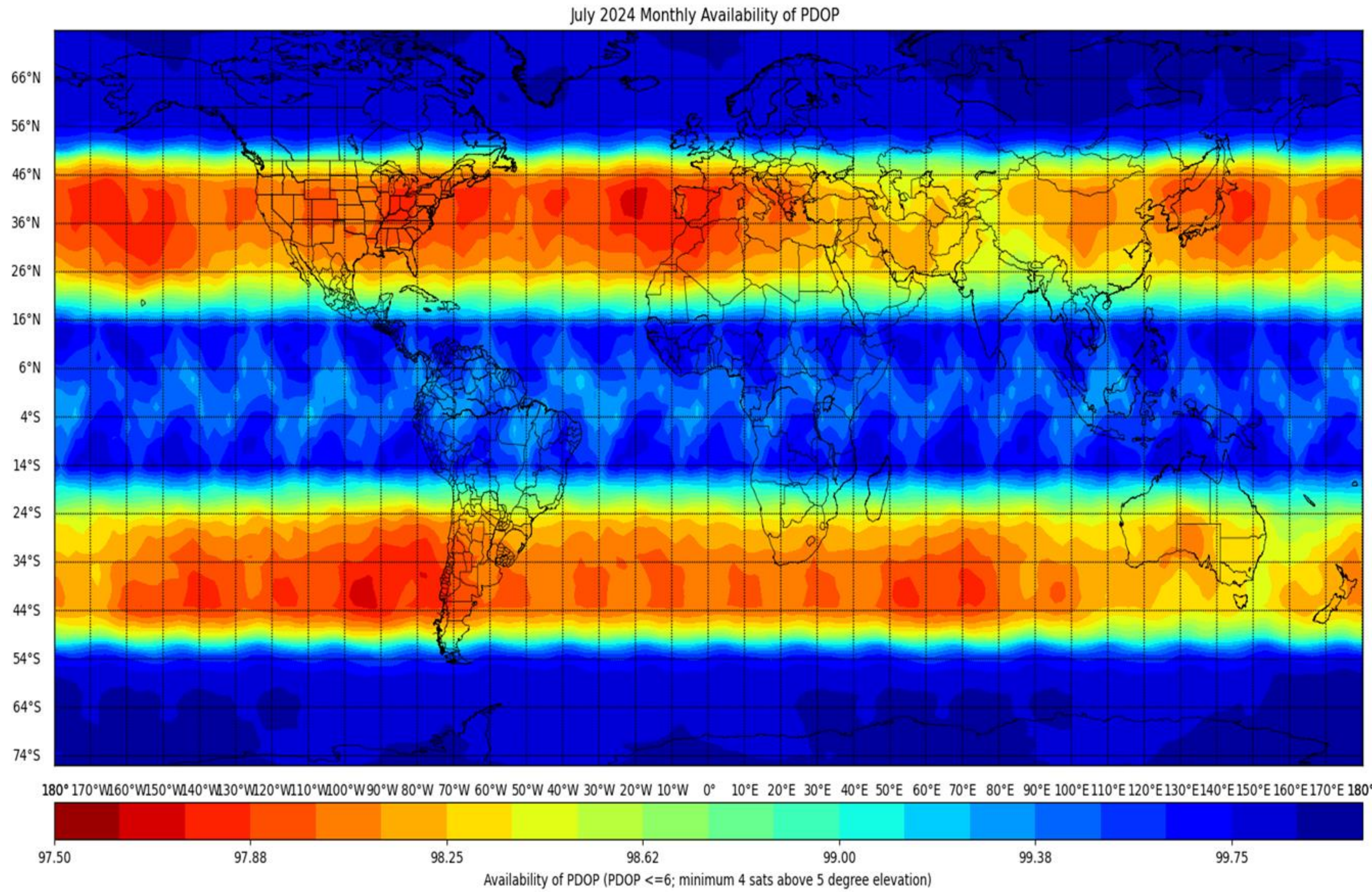


Figure 2-1. Availability of Galileo PDOP July 2024 (PDOP Availability Contour Color Bar: 97.5%–100%)

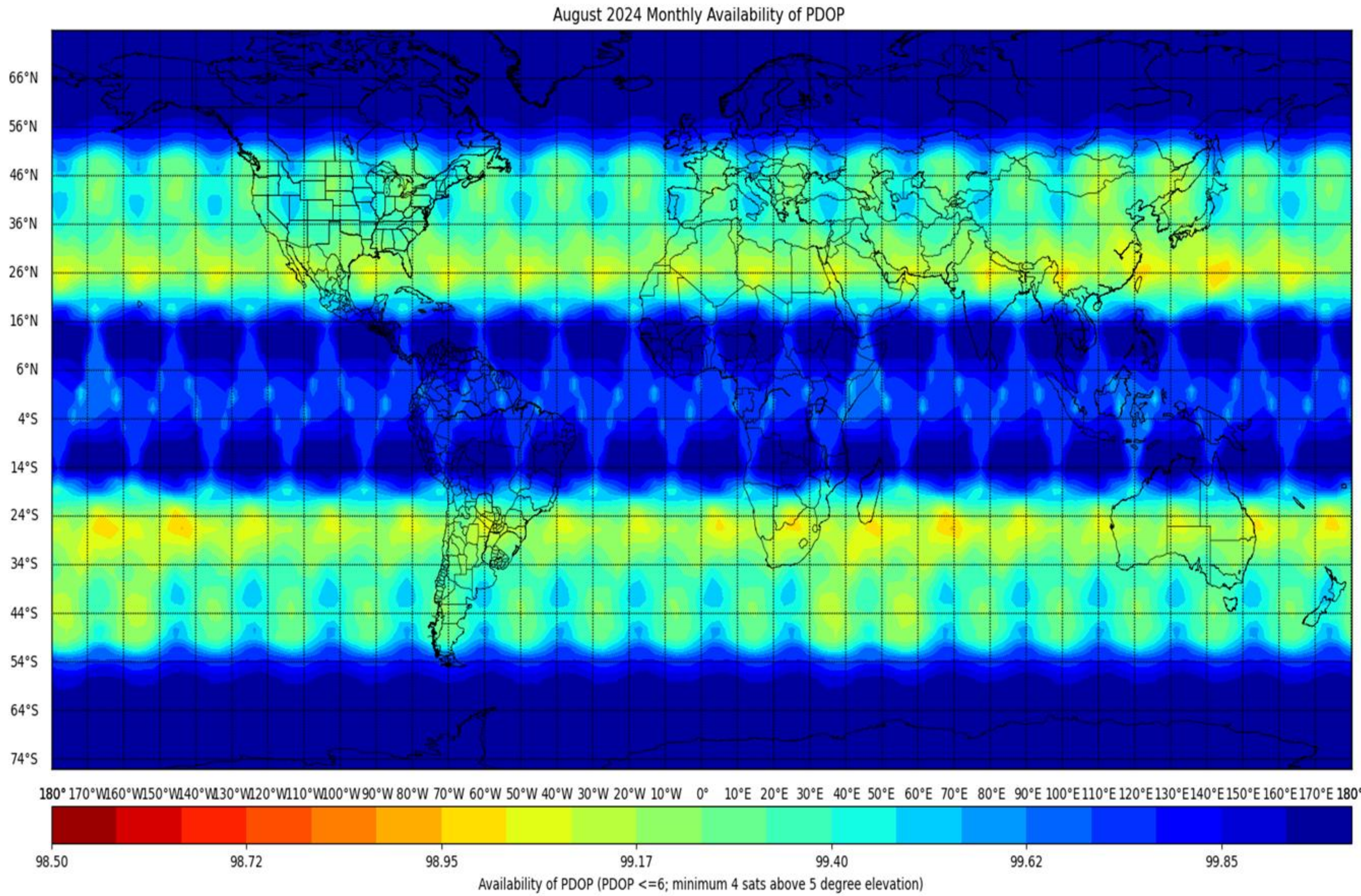


Figure 2-2. Availability of Galileo PDOP August 2024 (PDOP Availability Contour Color Bar: 98.5%–100%)

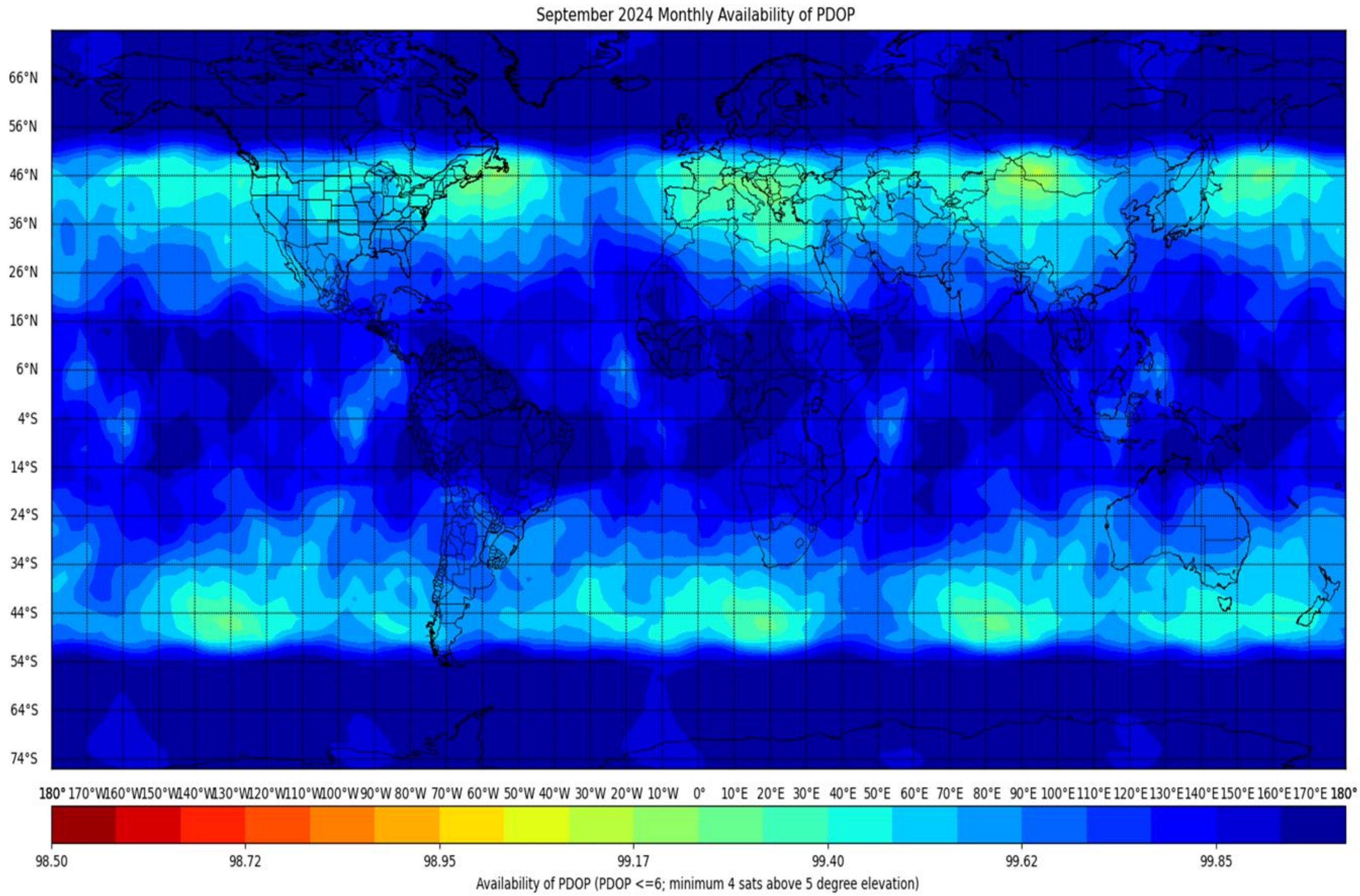
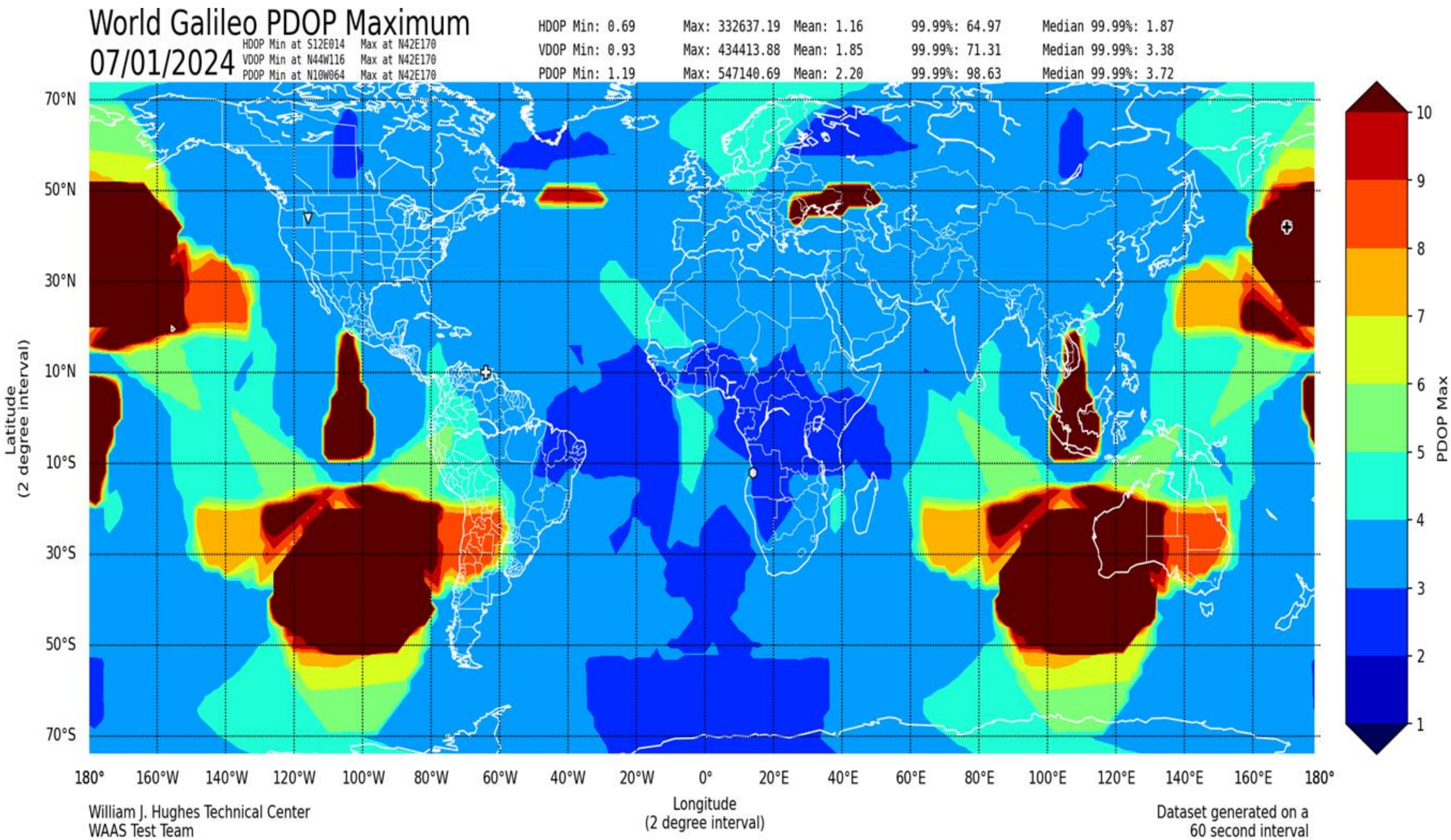


Figure 2-3. Availability of Galileo PDOP September 2024 (PDOP Availability Contour Color Bar: 98.5%–100%)

Figure 2-4 shows a contour plot of the maximum PDOP values at each 2-degree grid point for a 24-hour period. Figure 2-4 also shows PDOP performance using a day with no NAGUs or events affecting PDOP. Galileo constellation ground tracks have a 10-day repeatability cycle; therefore, consecutive 24-hour PDOP plots will not be repeatable day to day. APPENDIX B provides 10-day spatial PDOP plots to compare similar geometries.



+ ▼ ⬢ = location of maximum PDOP, VDOP, and HDOP, respectively

✙ ▽ ⬡ = location of minimum PDOP, VDOP, and HDOP, respectively

Figure 2-4. World Galileo Maximum PDOP (July 1, 2024)

2.1 NAGUs and Other Events Affecting PDOP

Events that affect Galileo PDOP are often due to satellite planned or unplanned outages. NAGUs provide information of forecasted satellite outages and summarize times satellites were unusable after the event. This quarter had three NAGU events and two other satellite events with no NAGUs that affected Galileo PDOP.

- SVID 04 was unusable from 04:40 UTC on July 10, 2024 until 15:34 UTC on July 19, 2024 (NAGUs 2024027 and 2024030). Figure 2-5 shows the maximum PDOP plot for July 11, 2024 (NAGU 2024030), and Figure 2-4 shows the maximum PDOP plot on July 1, 2024 with no events.

- SVID 26 was unusable from 01:31 UTC on September 3, 2024 until 02:38 UTC on September 6, 2024 (NAGUs 2024032 and 2024035). Figure 2-6 shows the maximum PDOP plot for September 3, 2024 (NAGU 2024035), and Figure 2-7 shows the maximum PDOP plot on August 24, 2024 with no events.

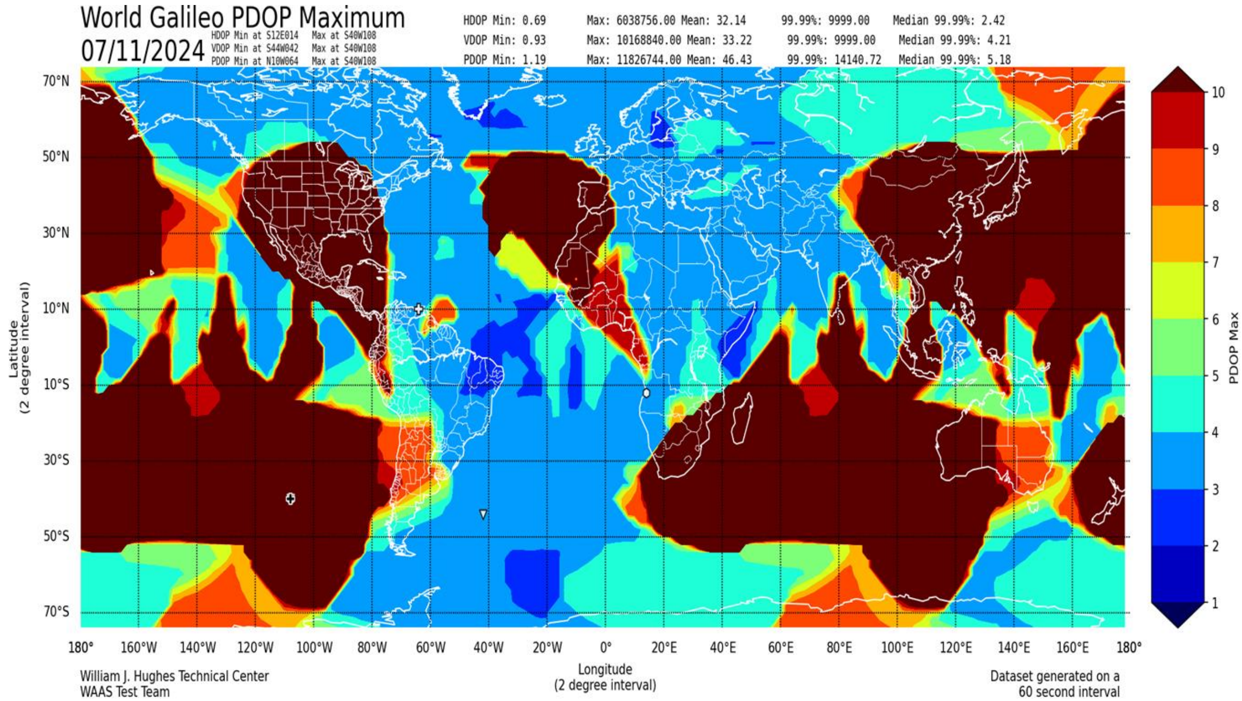
- SVID 29 was initially usable (Satellite First Time Usable) at 10:21 UTC on September 5, 2024 (NAGU 2024033). Figure 2-8 shows the maximum PDOP plot for September 7, 2024 (after NAGU 2024033), and Figure 2-7 shows the maximum PDOP plot on August 24, 2024 before SVID 29 became usable.

- SVID 06 was initially usable (Satellite First Time Usable) at 12:11 UTC on September 5, 2024 (NAGU 2024034). SVID 06 is an auxiliary satellite (occupies an orbital slot that is not part of the baseline constellation) and is not required to be processed by a receiver in order to meet the MPLs specified in the OS SDD. SVID 06 was not included in the calculation of Availability of PDOP in this report and not considered an event that affected Galileo PDOP.

- SVID 24 was marginal from 08:32 UTC until 10:19 UTC on July 20, 2024. Figure 2-9 shows the maximum PDOP plot for July 20, 2024 (with SVID 24 marginal), and Figure 2-4 shows the maximum PDOP plot on July 1, 2024 with no events.

- SVID 12 was marginal from 19:00 UTC on July 21, 2024 until 16:32 UTC on July 23, 2024. Figure 2-10 shows the maximum PDOP plot for July 22, 2024 (with SVID 12 marginal), and Figure 2-4 shows the maximum PDOP plot on July 1, 2024 with no events.

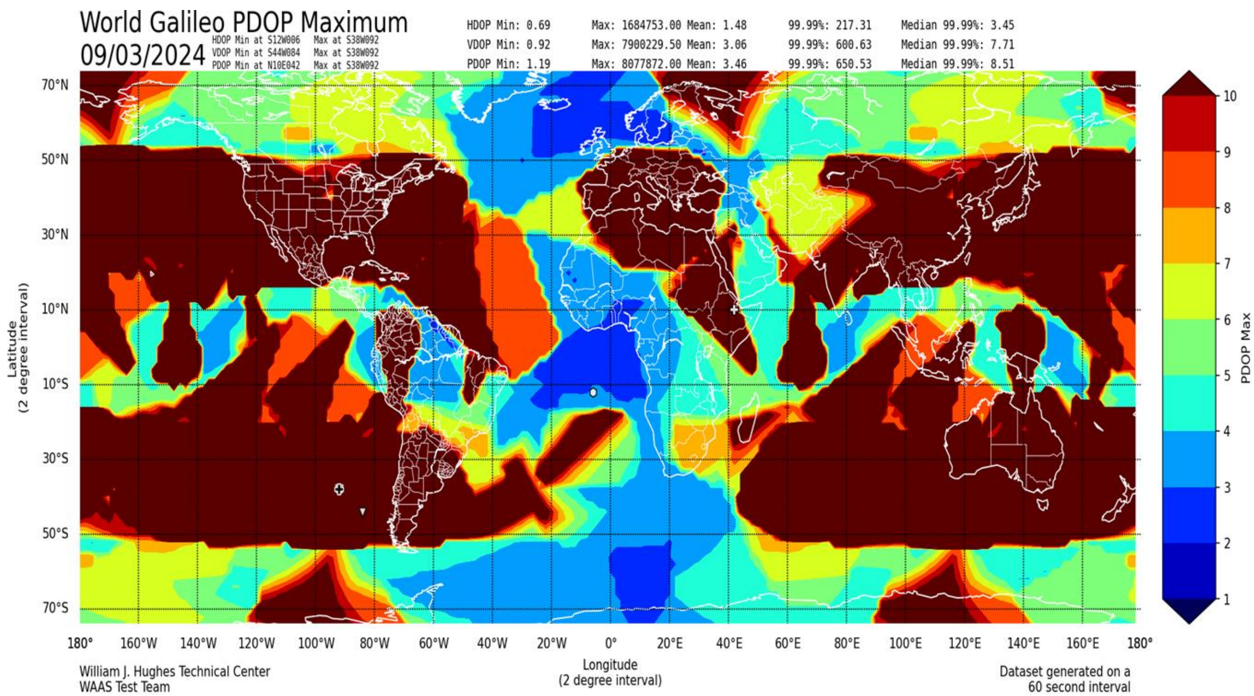
Section 3.1 details the satellite health during this time period, and Section 6 provides NAGU information.



+ ▼ ⬢ = location of maximum PDOP, VDOP, and HDOP, respectively

✚ ▽ ⬡ = location of minimum PDOP, VDOP, and HDOP, respectively

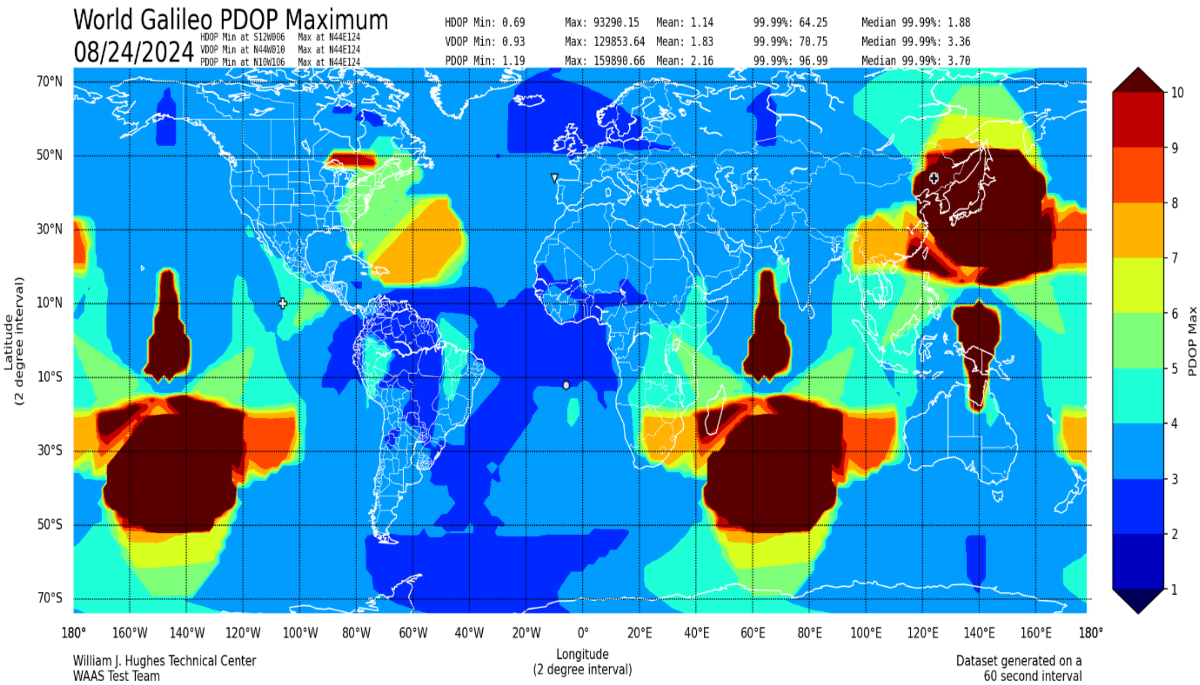
Figure 2-5. World Galileo Maximum PDOP (July 11, 2024) with SVID 04 Set Unusable



✚ ▼ ⬢ = location of maximum PDOP, VDOP, and HDOP, respectively

✜ ▽ ⬡ = location of minimum PDOP, VDOP, and HDOP, respectively

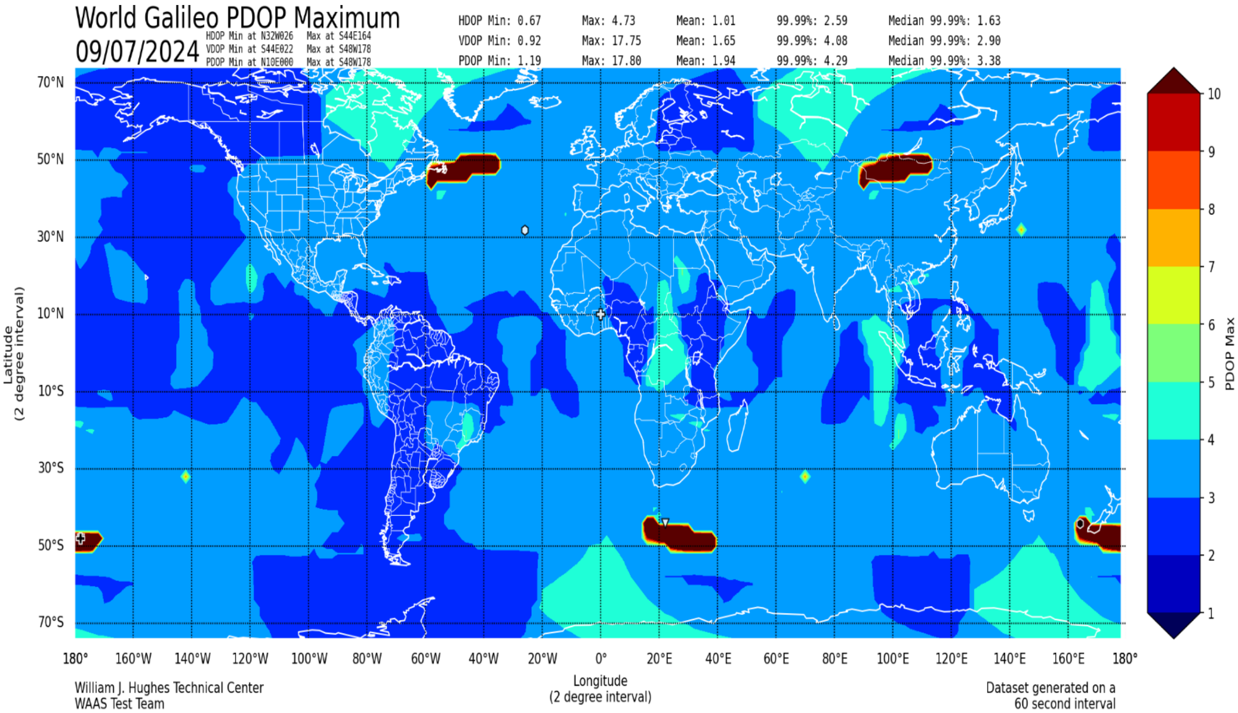
Figure 2-6. World Galileo Maximum PDOP (September 3, 2024) with SVID 26 Unusable



+ ▼ ⬣ = location of maximum PDOP, VDOP, and HDOP, respectively

✙ ▽ ⬡ = location of minimum PDOP, VDOP, and HDOP, respectively

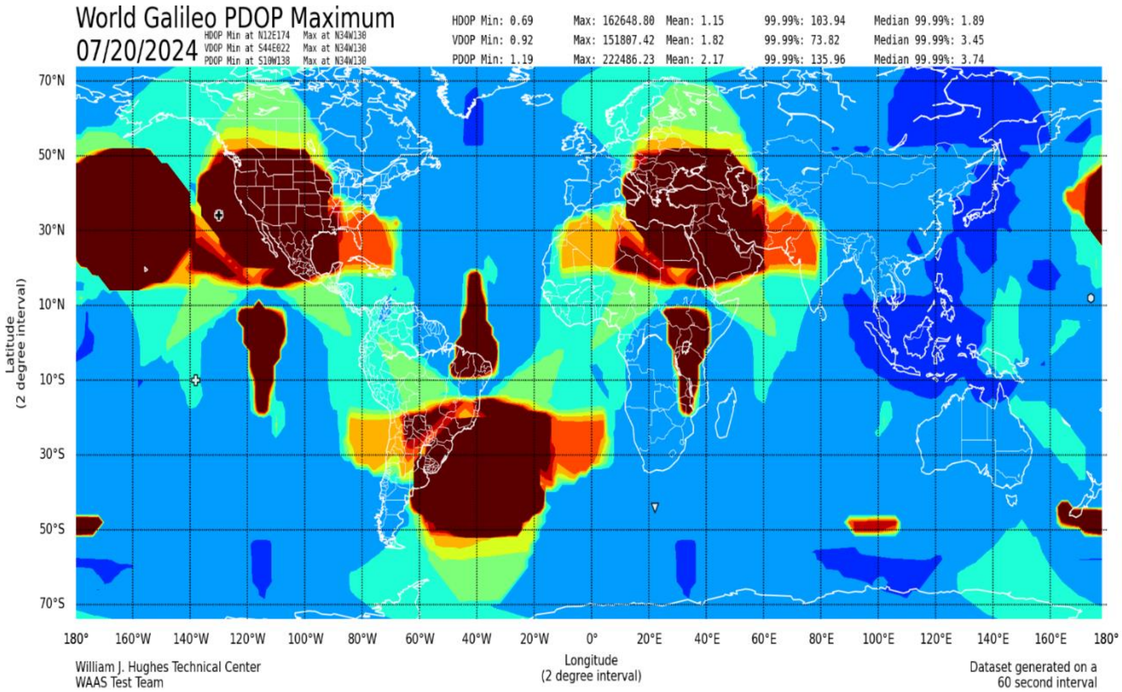
Figure 2-7. World Galileo Maximum PDOP (August 24, 2024) with No Events



+ ▼ ⬢ = location of maximum PDOP, VDOP, and HDOP, respectively

✚ ▽ ⬡ = location of minimum PDOP, VDOP, and HDOP, respectively

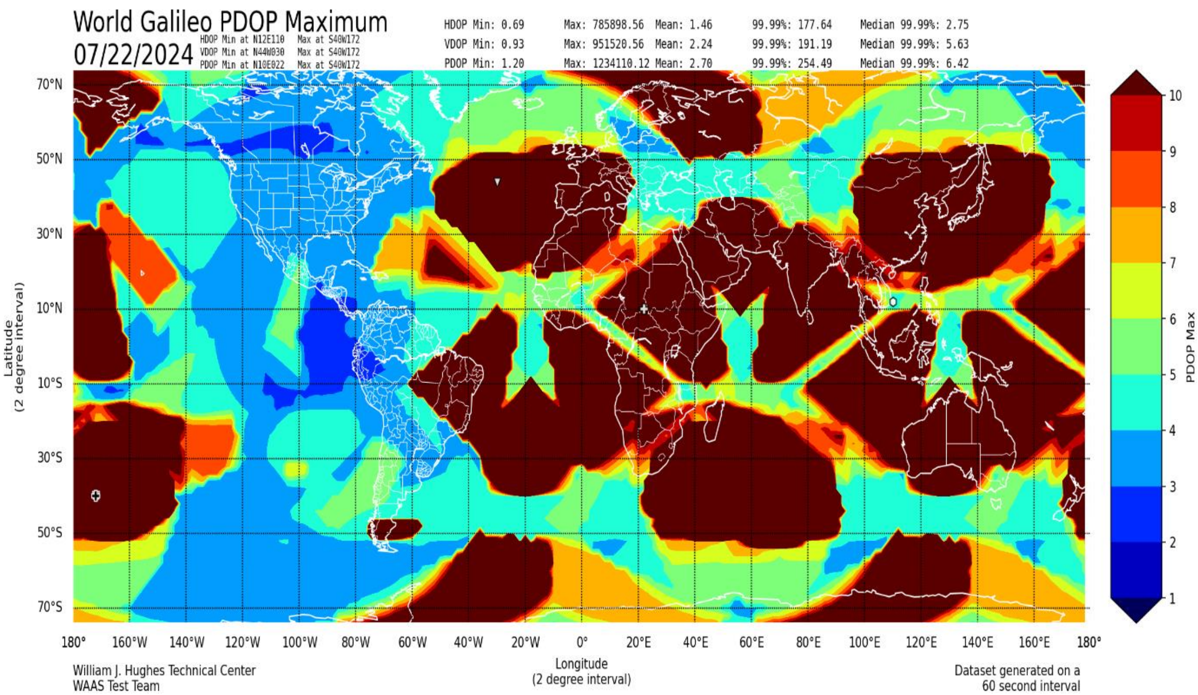
Figure 2-8. World Galileo Maximum PDOP (September 7, 2024) with SVID 29 Initially Usable



+ ▼ ⬣ = location of maximum PDOP, VDOP, and HDOP, respectively

✚ ▽ ⬡ = location of minimum PDOP, VDOP, and HDOP, respectively

Figure 2-9. World Galileo Maximum PDOP (July 20, 2024) with SVID 24 Marginal



+ ▼ ⬣ = location of maximum PDOP, VDOP, and HDOP, respectively

✜ ▽ ⬡ = location of minimum PDOP, VDOP, and HDOP, respectively

Figure 2-10. World Galileo Maximum PDOP (July 22, 2024) with SVID 12 Marginal

3. SIGNAL HEALTH AND ACCURACY (F/NAV)

3.1 Health Signal Summary

The Galileo OS SDD v1.3, Section 2.3.1.4 discusses the mapping of SIS status flags with the signal status. Figure 3-1 shows the percentage of time that the E1b and E5a signals would be classified as healthy following the decision tree described in Figure 4 of the OS SDD v1.3. The Figure 3-1 data source uses the Galileo broadcast navigation data available from the IGS as described in Section 3.2.1.1. Figure 3-1 does not evaluate a specific MPL since it is per SVID and not per-slot. Future reports will evaluate the MPL commitments in OS SDD, Section 3.4.1.

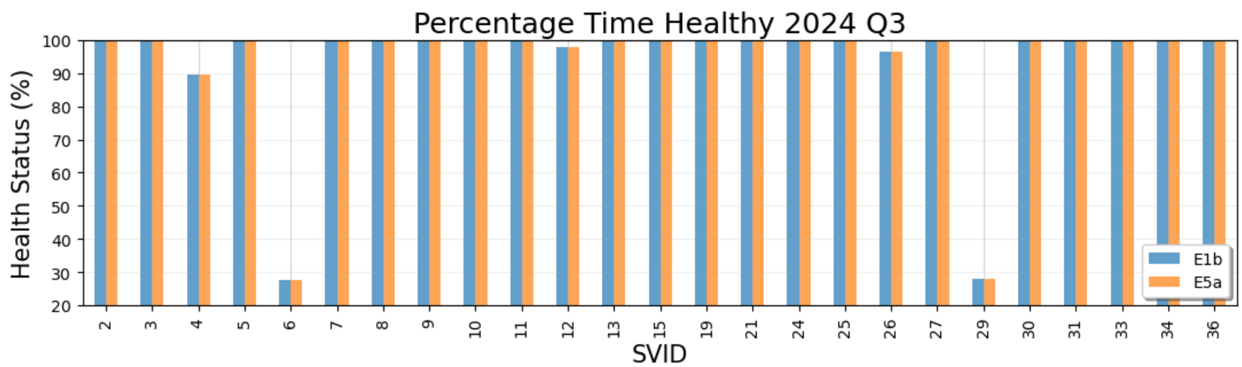


Figure 3-1. Percentage of Time for Healthy E1b and E5a Signals Per SVID

3.1.1 Health Signal Events

During Q3 2024, SVID health status for E1b and E5a remained healthy greater than 89% of the time. SVIDs 6 and 29 were healthy greater than 25% of the time due to being set healthy for the first time on September 5, 2024. The following is a list of events that indicate an unhealthy or marginal health status:

- On July 3 at 13:46 UTC SVID 9 was detected as marginal due to the SISA Index indicating NAPA in F/NAV and I/NAV with IODE 5. The signal was seen to return to a healthy state on July 3 at 14:31 UTC in F/NAV and I/NAV with IODE 10.

- On July 10 at 05:16 UTC SVID 4 was detected as unhealthy due to the E5a SHS flag set to Out of Service in F/NAV with IODE 81, and the signal was also seen as marginal due to the SISA Index indicating NAPA in F/NAV. The signal was seen to return to a healthy state on July 19 at 15:31 UTC in F/NAV with IODE 50.

- On July 20 at 08:31 UTC SVID 24 was detected as marginal due to the SISA Index indicating NAPA in F/NAV with IODE 25. The signal was seen to return to a healthy state on July 20 at 10:18 UTC in F/NAV with IODE 35.

- On July 21 at 18:59 UTC SVID 12 was detected as marginal due to the SISA Index indicating NAPA in F/NAV with IODE 112. The signal was seen to return to a healthy state on July 23 at 16:31 UTC in F/NAV with IODE 4.

- On August 30 at 10:51 UTC SVID 26 was detected as marginal due to the SISA Index indicating NAPA in F/NAV with IODE 22. The signal was seen to return to a healthy state on August 30 at 11:01 UTC in F/NAV with IODE 23.

- On September 3 at 01:31 UTC SVID 26 was detected as unhealthy due to the E5a SHS flag set to Out of Service in F/NAV with IODE 42, and the signal was also seen as marginal due to the SISA Index indicating NAPA in F/NAV. The signal was seen to return to a healthy state on September 6 at 02:37 UTC in F/NAV with IODE 99.

- On September 12 at 19:21 UTC SVID 4 was detected as marginal due to the E5a DVS flag set to Working Without Guarantee in F/NAV with IODE 56. The signal was seen to return to a healthy state on September 12 at 19:51 UTC with IODE 59.

- On September 28 at 08:51 UTC SVID 10 was detected as marginal due to the SISA Index indicating NAPA in F/NAV with IODE 27. The signal was seen to return to a healthy state on September 28 at 09:51 UTC with IODE 33.

3.1.2 Monthly E1b and E5a Signal Health

Figure 3-2, Figure 3-3, and Figure 3-4 show the health status of Galileo SVIDs using E1b and E5a data collected from the IGS described in Section 3.2.1.1. Healthy SIS status is determined based on a dual-frequency E1b/E5a user, incorporating E1b and E5a Signal Health Status (SHS) flag, E1b and E5a Data Validity Status flag (DVS), and FNAV Signal-In-Space Accuracy (SISA), as described in Table 7 of the OS SDD v1.3. In the following figures, healthy SIS statuses are marked with small green glyphs, marginal SIS statuses are magenta, unhealthy SIS statuses are red, and extended operation mode SIS statuses are blue.

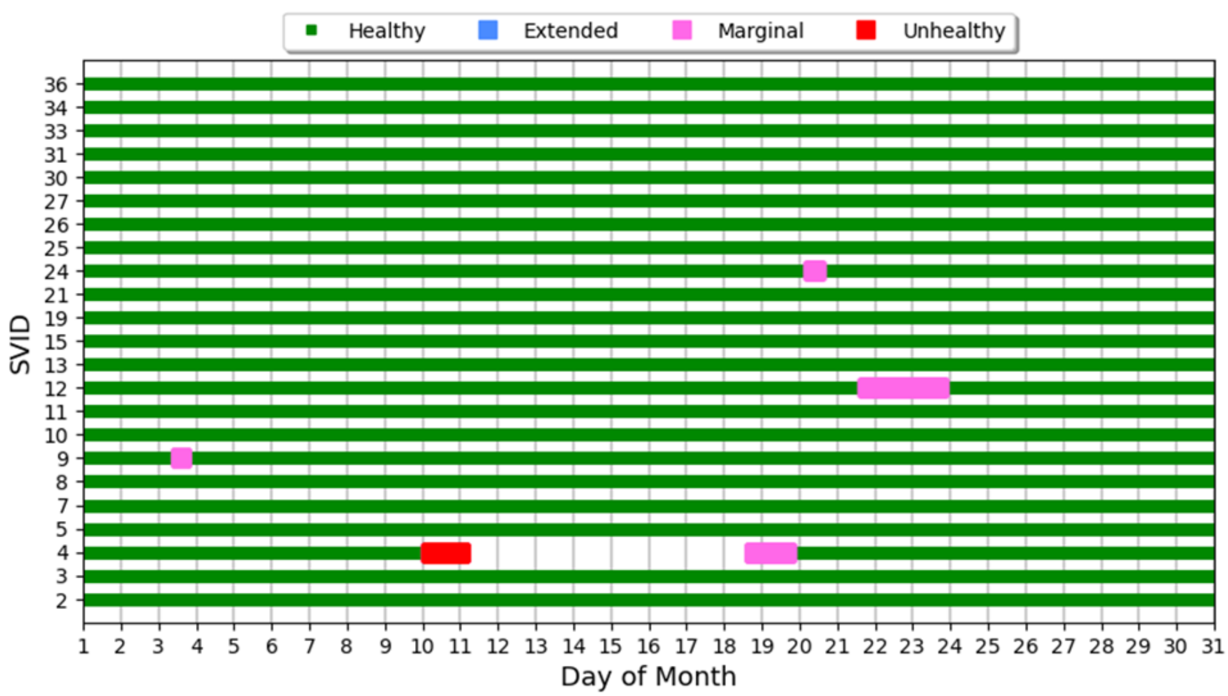


Figure 3-2. E1b/E5a July Signal Health by SVID

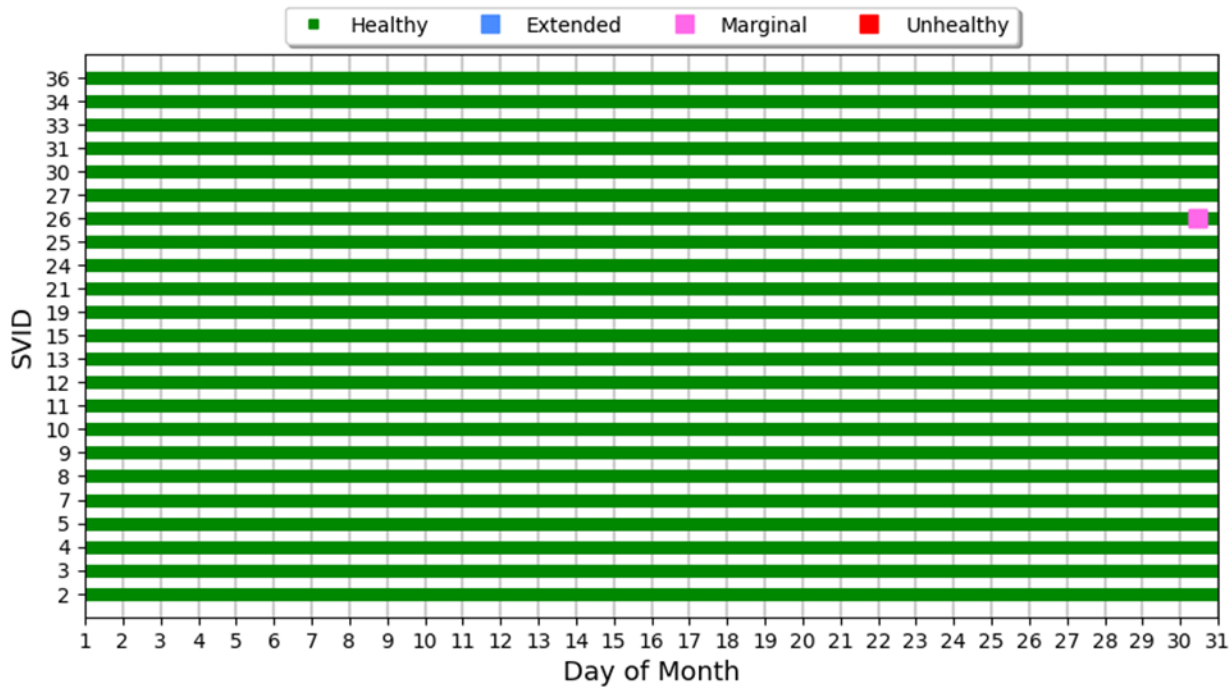


Figure 3-3. E1b/E5a August Signal Health by SVID

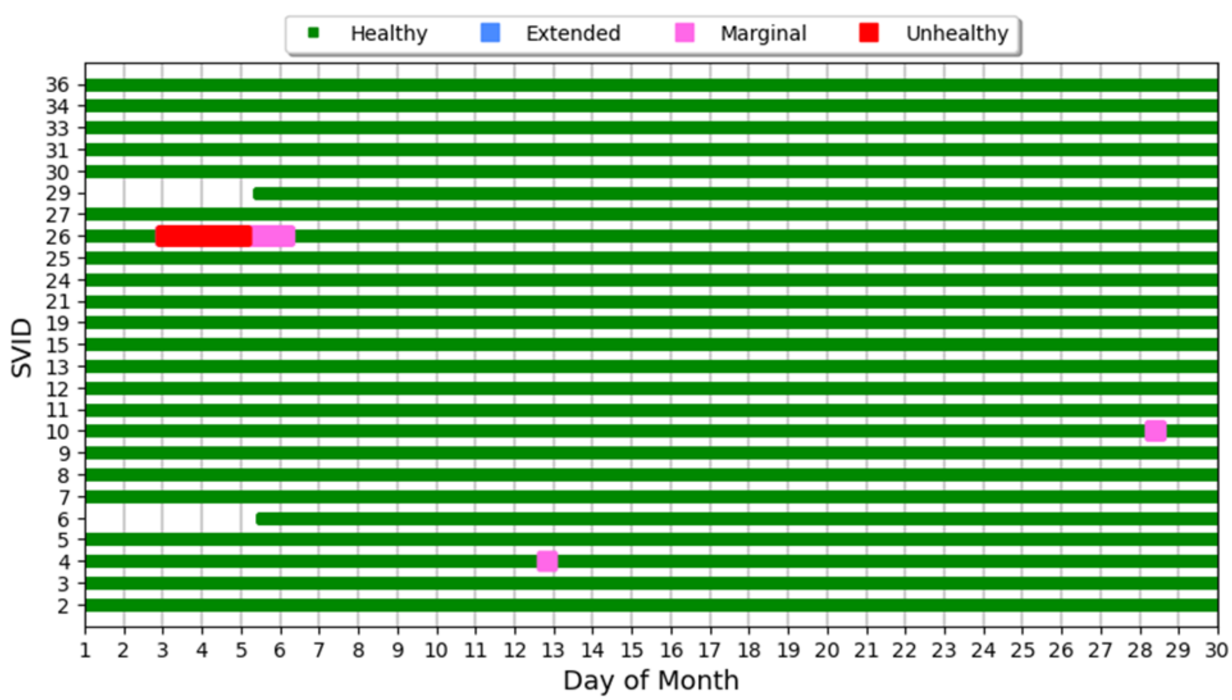


Figure 3-4. E1b/E5a September Signal Health by SVID

3.2 Satellite Position Errors

The Galileo OS SDD v1.3, Section 2.3.2.1 defines SIS Ranging Accuracy (SISRA) as a statistical measure of the Galileo SIS Ranging Error (SISE). SISE is the error contribution from the position and clock parameters for a satellite in the broadcast navigation message. Section 3.2.1 describes the data sources and error computation used to calculate SISRA. Section 3.2.2 presents the SISRA for each individual satellite as well as the SISRA over all satellites to evaluate the MPLs as described in OS SDD v1.3, Section 3.3, Tables 9, 10, and 11.

3.2.1 SISRA

3.2.1.1 Data Source and Rate

The offline analysis in this report uses two sources of input data: Galileo broadcast navigation data and post-processed precise data. The broadcast navigation data consists of satellite orbit and clock parameters from the Galileo F/NAV. The precise data consists of Galileo orbit and clock parameters, which is used as the truth reference.

A subset of the Galileo broadcast navigation data is available from the IGS in Receiver Independent Exchange (RINEX) navigation file format [6]. Precise Galileo ephemerides and clock are generated from CODE in the Standard Product #3 (SP3) format [7, 8]. The truth data from CODE is available at a 5-minute data rate. The broadcast navigation data compared to the truth data from CODE was used to compute SISRA at these 5-minute intervals.

3.2.1.2 Data Collection and Cleansing

A customized tool is used to automate the data downloads on a daily basis. All data are protected by checksums and other basic integrity checks. Galileo broadcast navigation data are downloaded from the Crustal Dynamics Data Information System (CDDIS) [9] archive site. Precise Multi-GNSS Experiment (MGEX) data are downloaded from the CDDIS archive server.

The broadcast navigation data, as received in RINEX format from IGS, sometimes contains defects such as duplications, inconsistencies, discrepancies, and errors that can cause false anomalies. A cleansing algorithm is applied to the IGS data to generate “validated” navigation messages, which have as many of these defects removed as possible. This process is based on the algorithm described by Heng [10].

3.2.1.3 Error Computation

For each timestep when precise data is available, all valid broadcast navigation data is used to propagate the satellite orbits and clocks. To account for clock offset in the precise product, at each epoch, the clock residuals between healthy precise and broadcast products are filtered for outliers, then a mean correction is applied onto the CODE precise clock estimate. At each data point for which both sources indicate a healthy signal and valid data within the fit interval, the satellite position error is determined by calculating the difference between the CODE-derived reference value and the calculated propagated satellite position, in Earth-Centered, Earth-Fixed (ECEF) coordinates. The errors are separated into radial, along-track, and cross-track (RAC) errors. The RAC and clock residuals from each satellite and epoch are used to produce signal-in-space range error (SISE) Global Average values (Figure 3-6 through Figure 3-9.)

The satellite position error is also computed geometrically at each epoch to produce the maximum projected error (MPE). The satellite position error is also projected along the lines of sight to individual user locations on Earth to produce User Projected Error (UPE). MPE and UPE are two forms of SISE that are used to evaluate the error distributions [10]. A mask angle of 5 degrees is used in both MPE and UPE computations. UPE is calculated using 200 evenly distributed user locations around the globe. This density has been determined to be sufficient such that a value within 2 cm of the unfaulted MPE will be observed at one or more of the user locations [11]. MPE is computed for each satellite, at each epoch. UPE is computed for each of the 200 user locations, for each satellite in view, for each epoch. Figure 3-5 shows the 200 user locations.

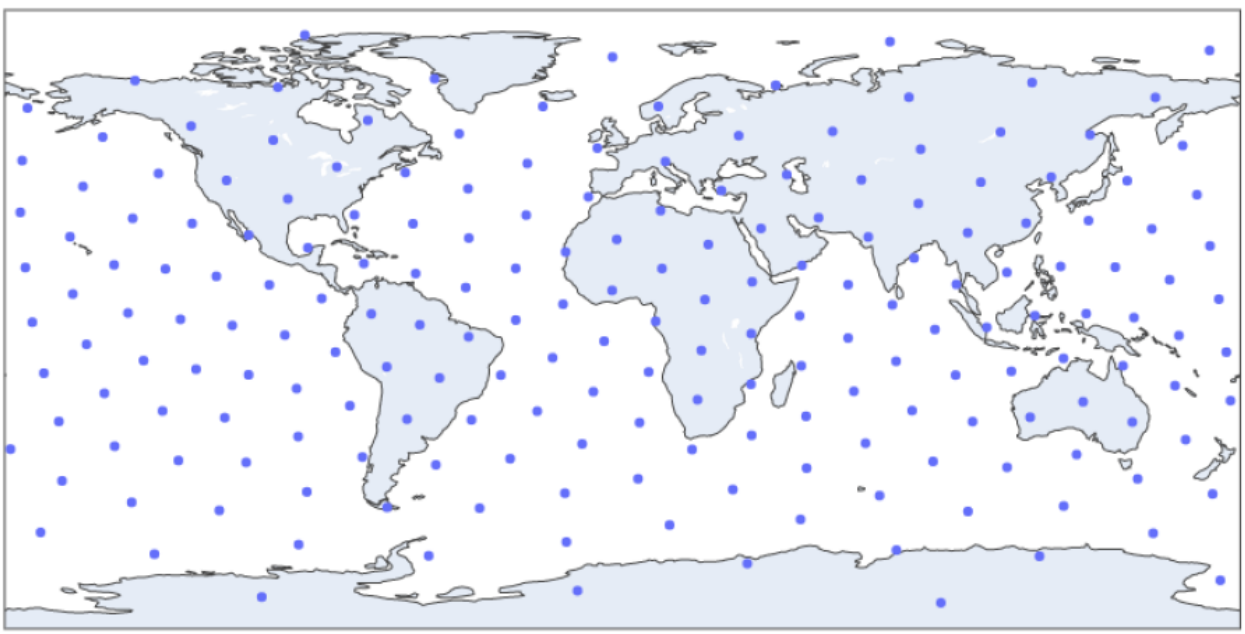


Figure 3-5. The 200 User Locations

Section 3.2.2 presents SISRA using SISE Global Average.

MPE and UPE will be used to evaluate the SIS ranging accuracy as described in OS SDD v1.3, Section 3.3, Tables 9, 10, and 11 in future reports.

3.2.2 SISRA Quarterly Results

Figure 3-6 through Figure 3-8 present the 95% and 99.9% SISRA for each individual satellite as well as the SISRA over all satellites ("All Satellites") per month. The 95% SISRA in these figures evaluate the MPLs in OS SDD v1.3 Tables 9 and 10 for a dual frequency (E1b/E5a) user. Figure 3-9 presents the 95% and 99.9% SISRA for each individual satellite as well as the SISRA overall satellites ("All Satellites") for the previous 1 year. The 99.9% SISRA for individual SVIDs in this figure evaluates the MPLs in OS SDD v1.3 Table 11 for a dual-frequency (E1b/E5a) user. Table 3-1 summarizes the MPLs evaluated in this section.

The SISRA results below were derived using the SISE global average calculation defined in Section C.4.3.2 of the OS SDD v1.3.

Table 3-1. SISRA MPLs for Each DF Combination

	MPL FOR SISRA	CONDITIONS AND CONSTRAINTS
SISRA MPL FOR ANY SATELLITE	For each DF combination: • ≤7 m (95%) global average, over all AODs	• Calculated over a period of 30 days • For any healthy OS SIS above a minimum elevation angle of 5 degrees • Propagation and user contributions excluded
SISRA MPL OVER ALL SATELLITES	For each DF combination: • ≤2 m (95%), over all AODs	• Calculated over a period of 30 days • 95th percentile of the time series of constellation average Galileo SIS Ranging Accuracy (computed as the rms of the instantaneous global average SISE)

SISRA AT 99.9th PERCENTILE FOR ANY SATELLITE	For E1-E5a DF combination: • ≤20 m (99.9%), Worst User Location • ≤10 m (99.9%), Global Average	• Calculated over a period of 1 year • Over all AOD • For any healthy OS SIS above a minimum elevation angle of 5 degrees • Propagation and user contributions excluded

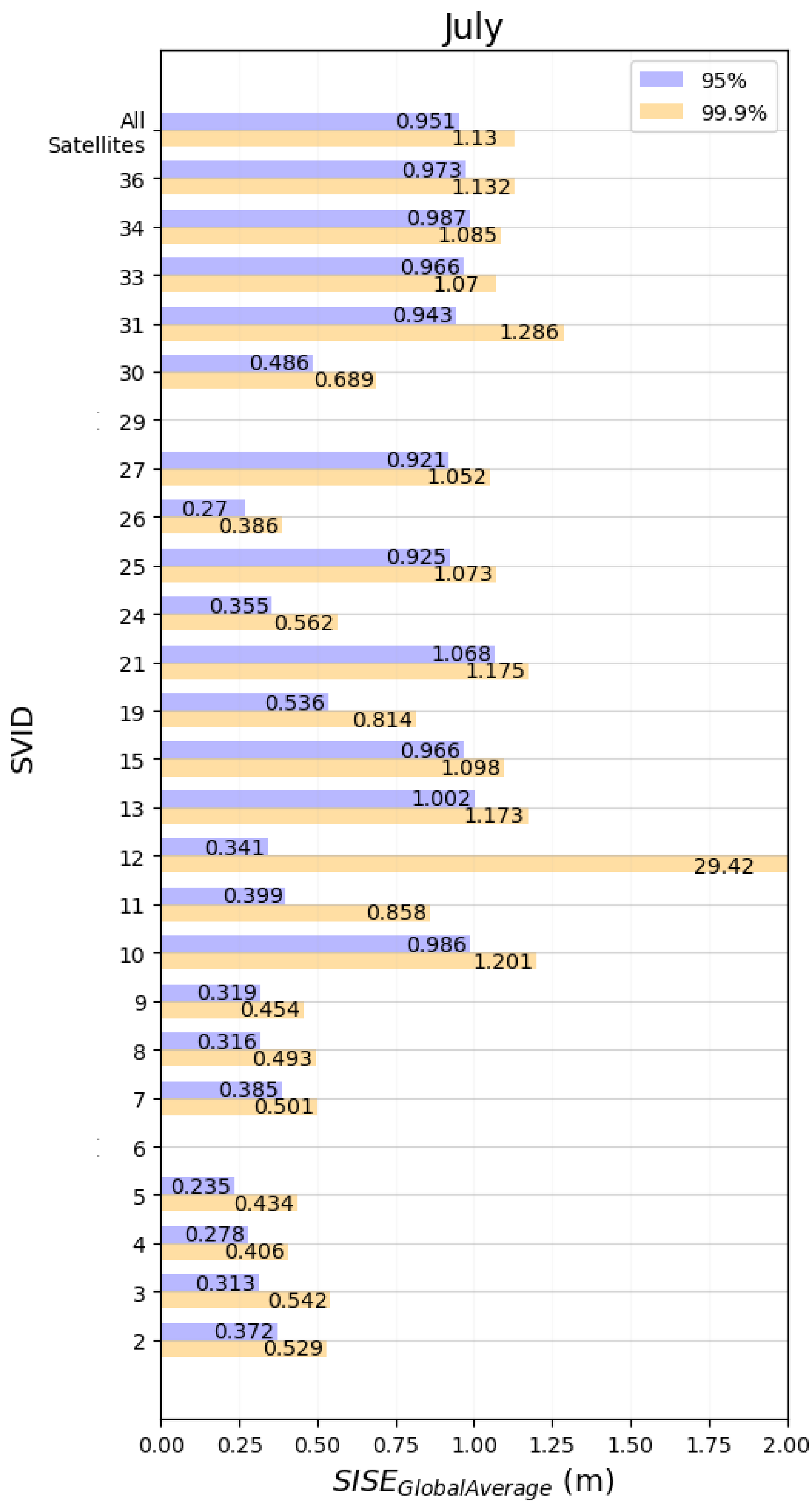


Figure 3-6. July SISRA

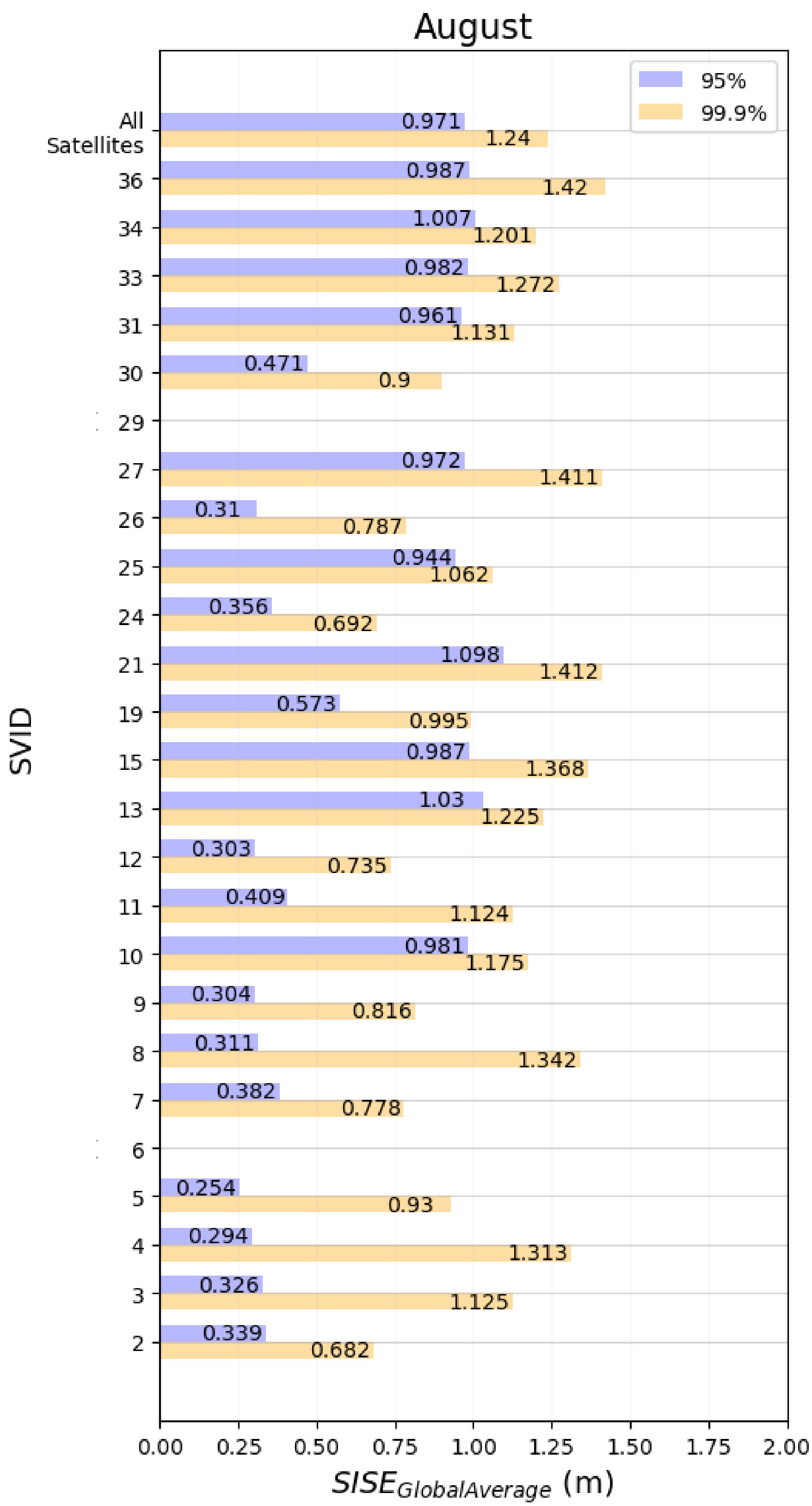


Figure 3-7. August SISRA

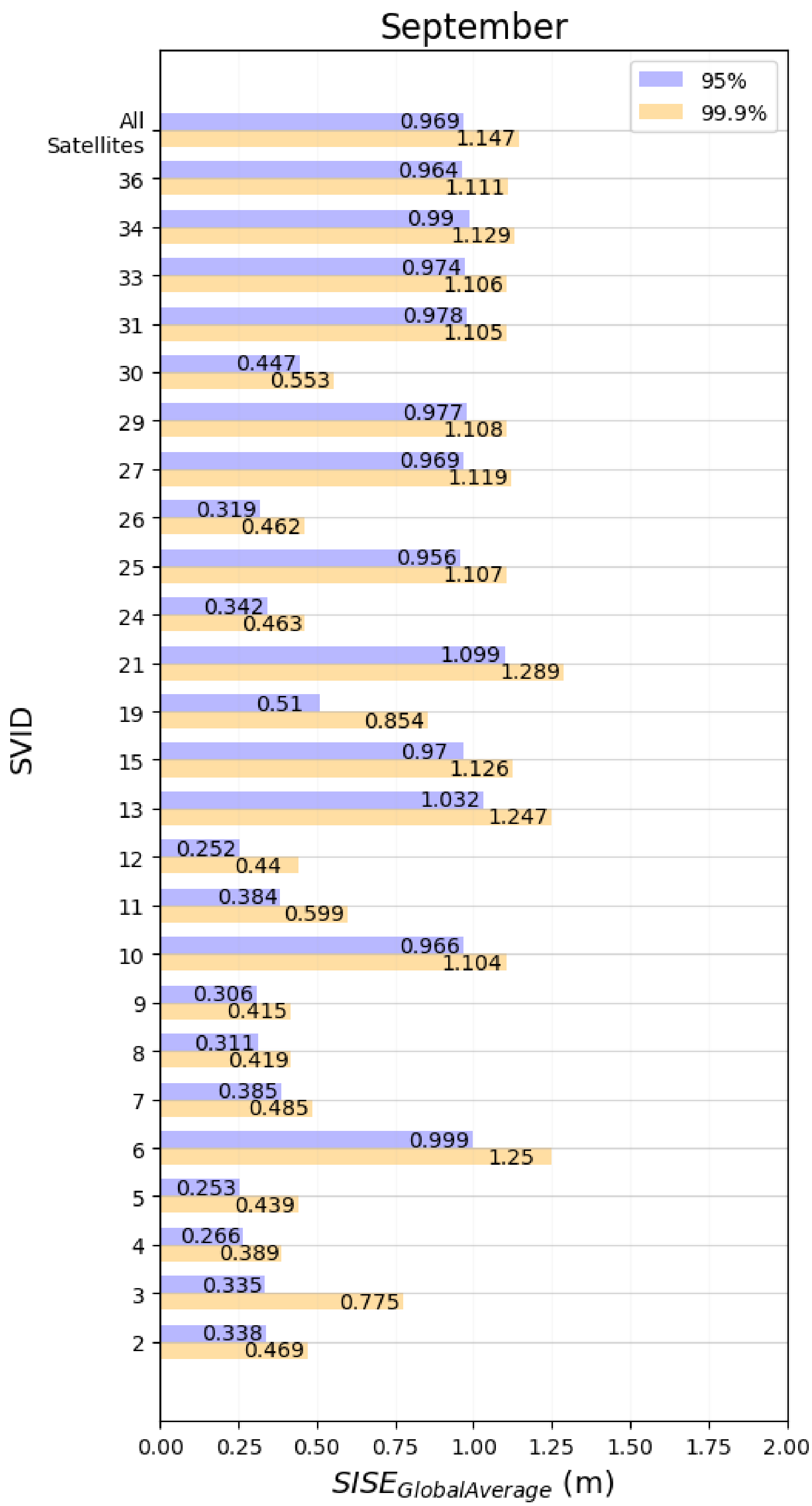


Figure 3-8. September SISRA

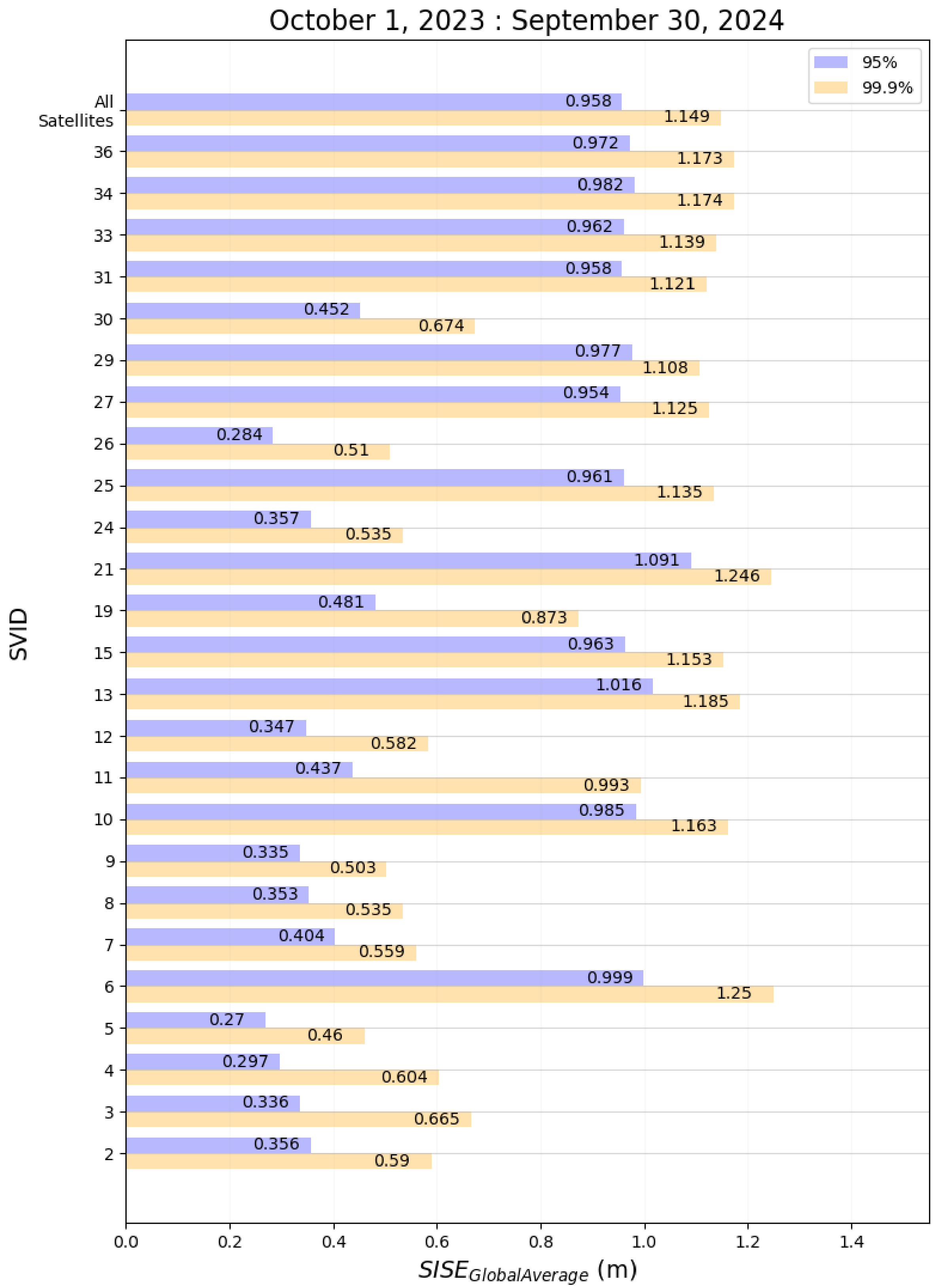


Figure 3-9. 1-Year SISRA (October 1, 2023–September 30, 2024)

4. GALILEO TIME TRANSFER PERFORMANCE

The Galileo time transfer error analysis will be provided in future reports.

4.1 Availability

The availability of the Galileo UTC Time Dissemination Service is defined as the percentage of time that the system provides at least one "healthy" ranging/timing SIS above a minimum elevation angle of 5 degrees.

4.2 Accuracy

The Galileo SIS UTC Time Dissemination Accuracy and the Galileo SIS UTC Frequency Dissemination Accuracy are computed as the daily average error of the normalized time and frequency offset relative to UTC for a user equipped with a Standard Timing/Calibration Laboratory Receiver.

The accuracy data is planned to be obtained from the U.S. Naval Observatory (USNO) website [12]. The data file will contain daily overall values for the entire constellation. They will be an estimate of the difference between the USNO Master Clock and Galileo System Time (GST). These values will represent a 2-day filtered linear solution and be computed for 0 hours Universal Time (UT) of the second day and published daily for the preceding day. To evaluate the Galileo time-transfer error, the data file will be used to create a histogram to represent the distribution of the Galileo time error. The histogram will be created by taking the absolute value of time difference between the USNO Master Clock and GST, then creating data bins with 1-nanosecond precision. The number of samples in each bin will then be plotted to form a histogram.

5. GALILEO POSITIONING PERFORMANCE

This section of the report provides information and performance for the availability of Galileo Position Service and Galileo Position Accuracy.

5.1 Availability of the Galileo Positioning Service

Figures in this section will show the availability of positioning at the worst user location (WUL) and average user location (AUL) to assess the commitments to the MPLs described in OS SDD v1.3, Section 3.4.4, Tables 21 and 22. Sections 3.2.1–3.2.2 describe the data source and processing followed to arrive at the SISE. The SISE, along with the DOP described in Section 2, are used to derive the position accuracy in this section as described in OS SDD v1.3, Section C.4.5.3.

5.2 Galileo Position Accuracy

Position Accuracy is the difference between the true user position and position solution calculated using measurement and navigation data obtained at the receiver. The Galileo OS SDD defines the Position Accuracy MPL to exclude errors not under the control of the Galileo system. Table 5-1 specifies the MPL for Galileo Position Accuracy according to the OS SDD v1.3 Table 16.

Galileo navigation measurement data is collected using NovAtel G-III and GT7800 receivers located at the FAA WJHTC; Elko, Nevada; and Arcata, California to process Galileo position accuracy. The Galileo user position tool uses a dual-frequency solution processing the E1b–E5a frequencies (F/NAV message). The user position is calculated once per second and compared to the surveyed position of the receiver to assess the position error when PDOP is less than or equal to 6. Galileo satellite measurement data is used in the position solution according to the ephemeris and SIS health status specifications in the OS SDD. The FAA Satellite Navigation Branch is currently working to incorporate and validate other test receivers processing Galileo navigation and measurement data into this report.

Navigation measurement data collected from the receivers was processed to determine position accuracy at each location using the user position tool described above. Position errors were analyzed, and statistics were generated to produce histogram data and daily 95% trends of the position errors. Figure 5-1 through Figure 5-6 show distribution of the calculated horizontal position error (HPE) and vertical position error (VPE) for the receivers over a 1-month period, highlighting the 95th percentile that evaluates the OS SDD MPL. Figure 5-7 shows the daily 95% horizontal and vertical position errors.

Table 5-1. Position Accuracy Parameter

MPL for Position Accuracy	Conditions and Constraints
For each DF combination: Average user location <= 5 m (95%) horizontal error <= 8 m (95%) vertical error	• Position solution is available • Calculated over a period of 30 days • Propagation and user contributions excluded

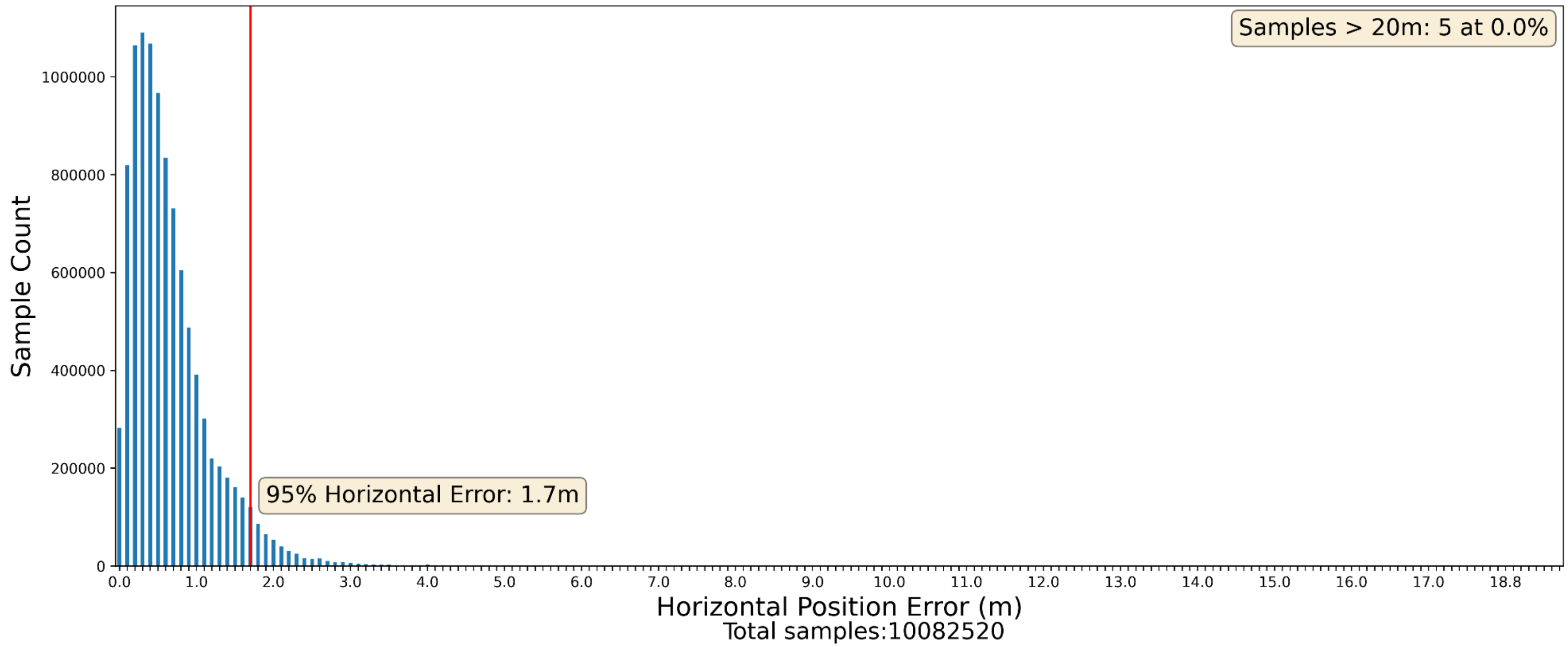


Figure 5-1. 95% Horizontal Error—July 2024

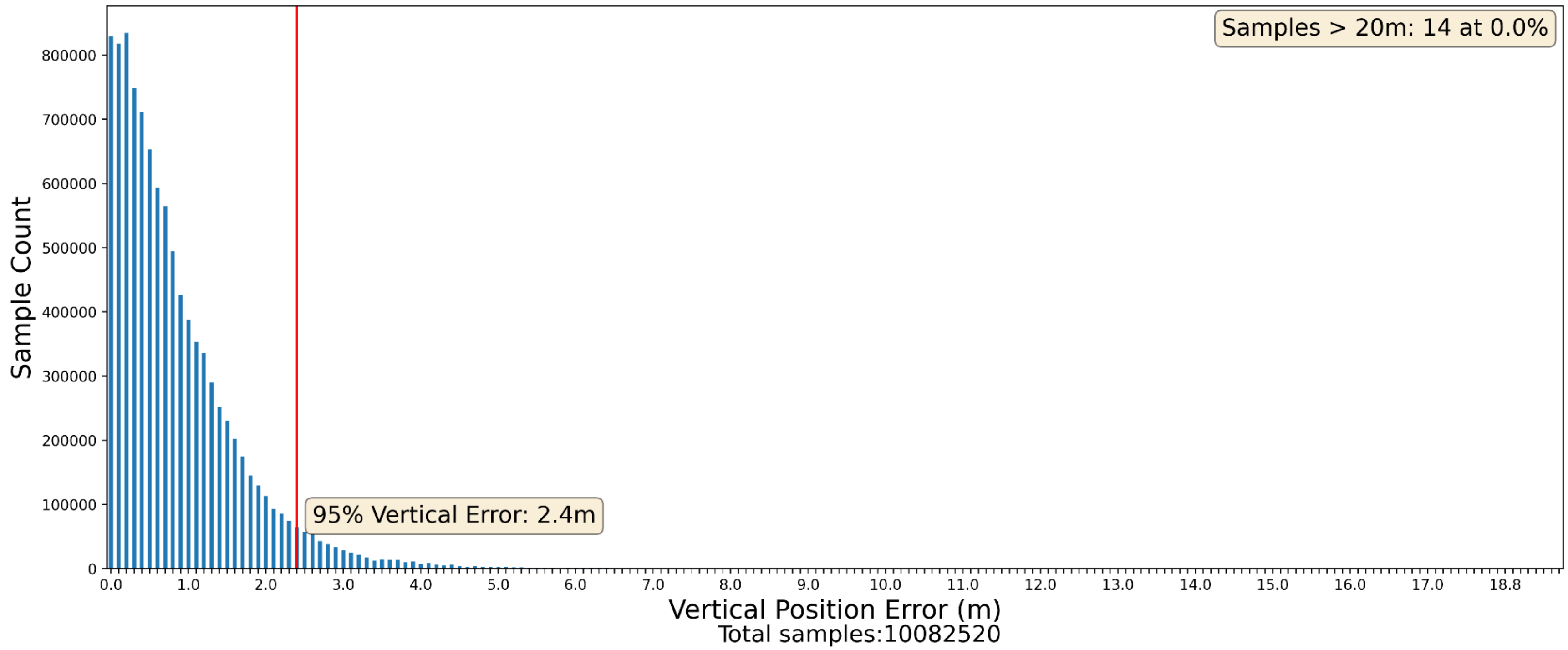


Figure 5-2. 95% Vertical Error—July 2024

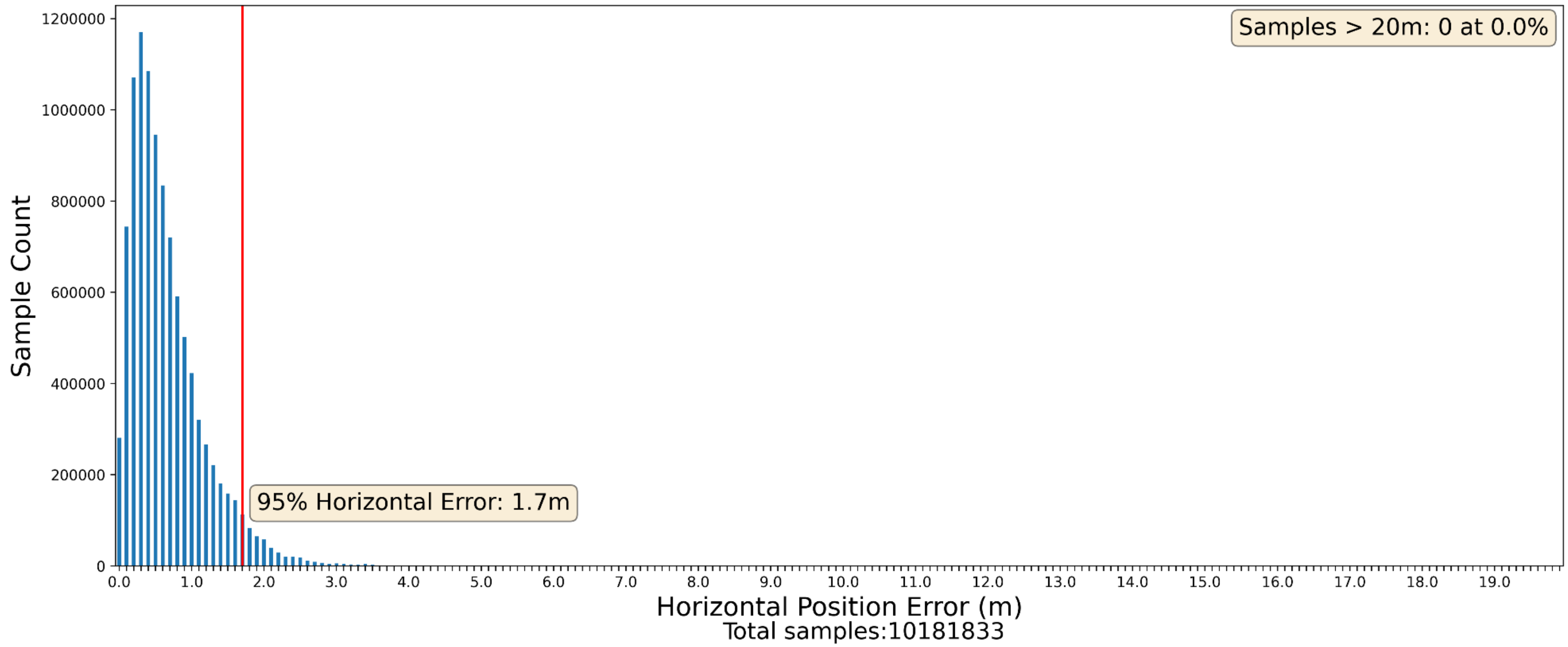


Figure 5-3. 95% Horizontal Error—August 2024

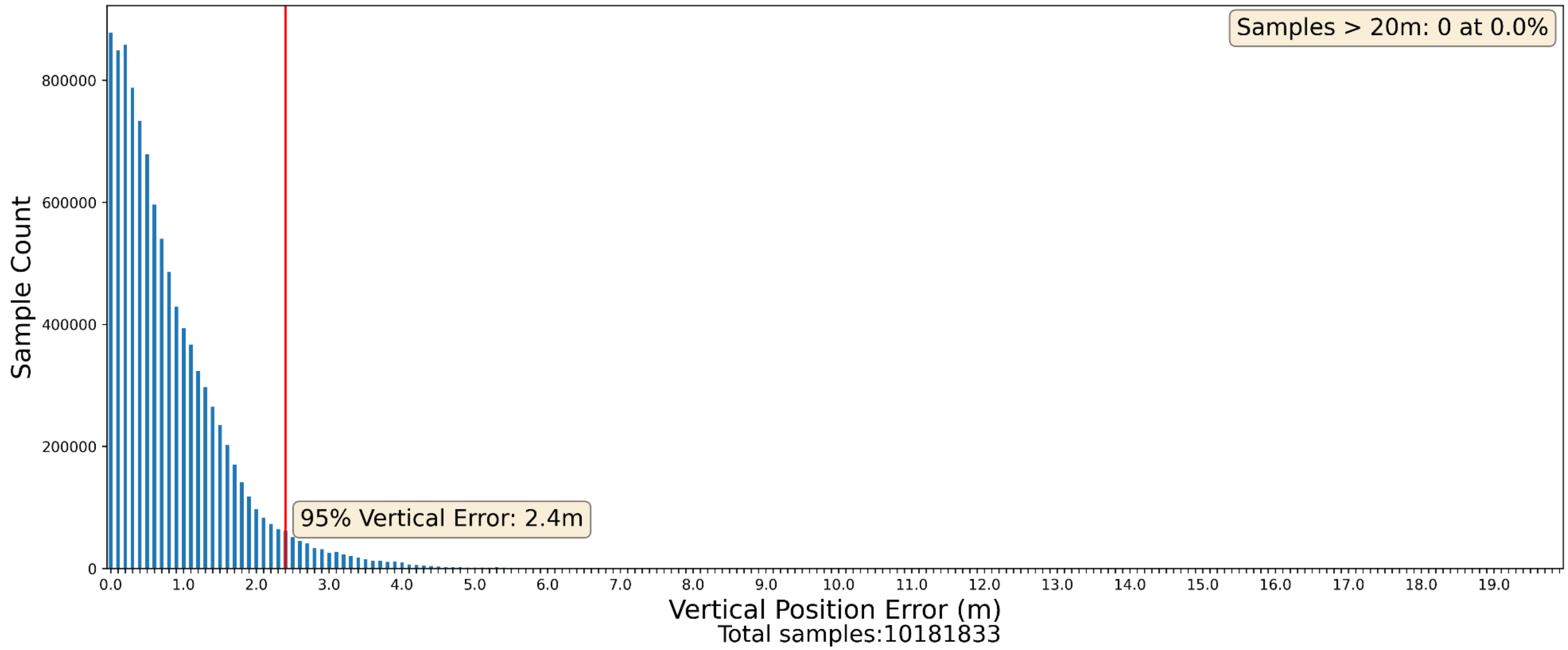


Figure 5-4. 95% Vertical Error—August 2024

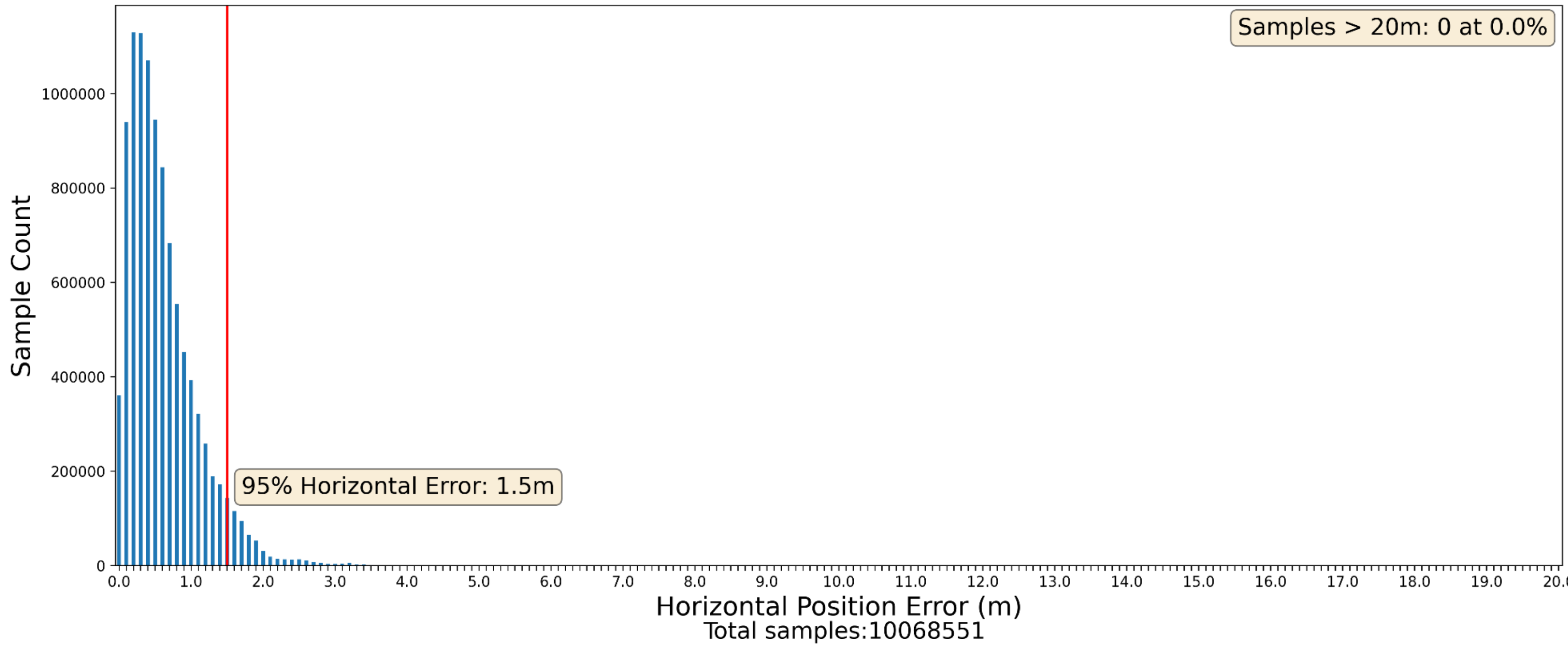


Figure 5-5. 95% Horizontal Error—September 2024

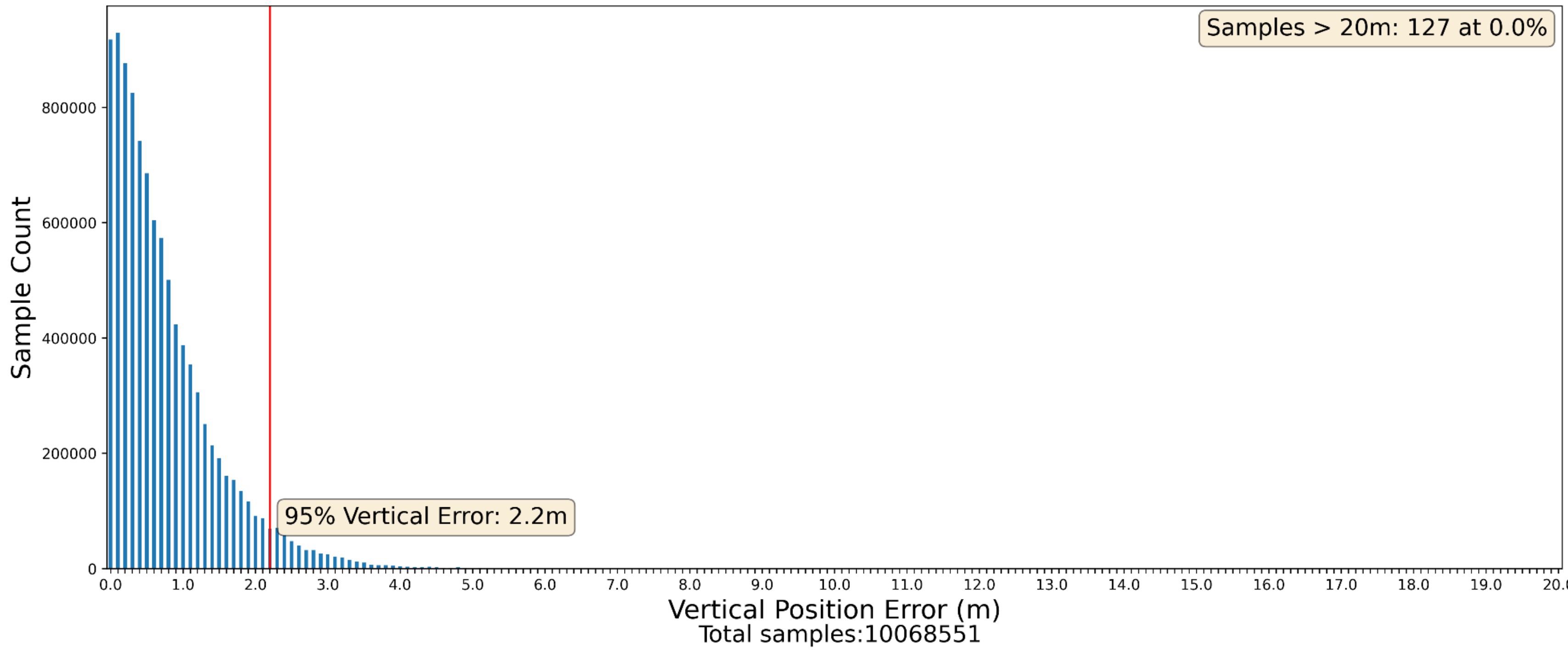


Figure 5-6. 95% Vertical Error—September 2024

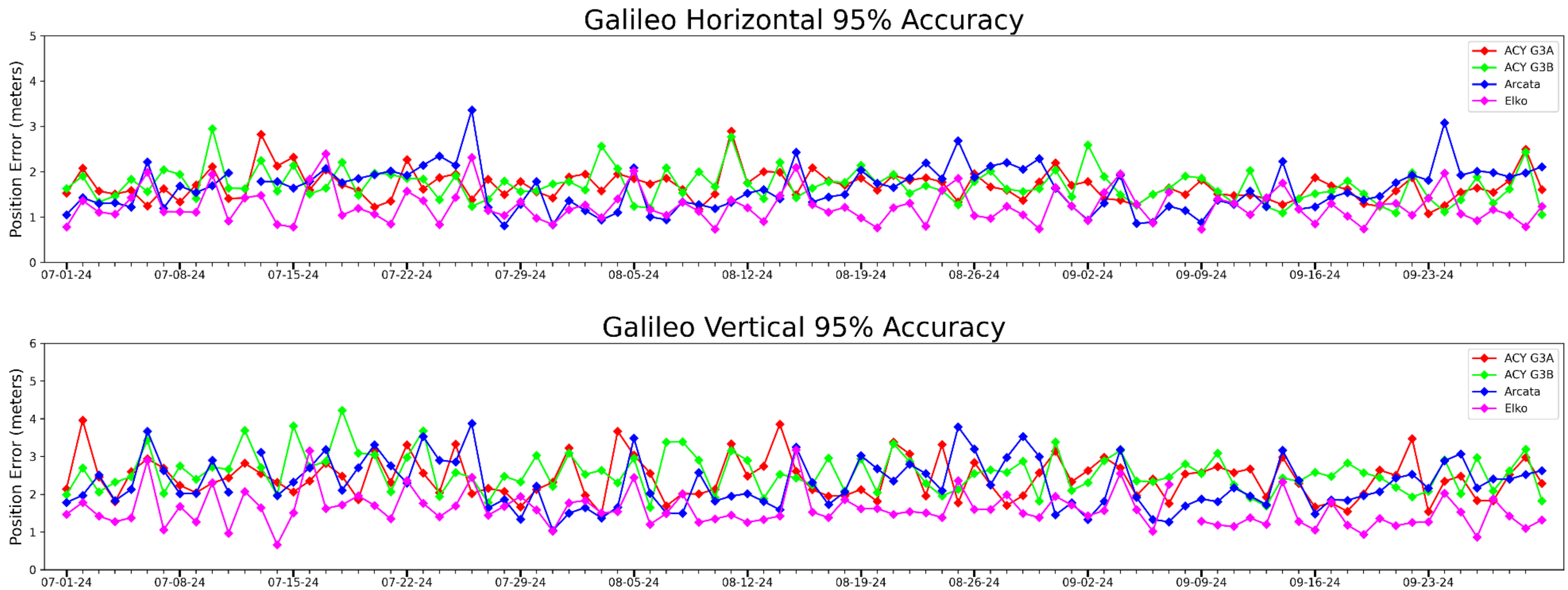


Figure 5-7. 95% Horizontal and Vertical Trends—2024 Q3

5.3 IGS Data (Position Errors)

This section will be included in future reports.

6. TIMELY PUBLICATION OF NAGUS

The Galileo OS-SDD Section 3.6.1 [2] discusses the timely publication of NAGUs. A published NAGU is considered timely if it fulfills the following criteria. If a NAGU is categorized as planned, it must be published over 48 hours before the event occurs. If a NAGU is categorized as unplanned or as an event impacting service availability, it must be published within 15 hours of the event that occurred. If it is a general UNP_UNUFN, UNP_SHTRCVR, or EOM_START NAGU, they should be published within 30 hours of the start of the event. All other general NAGUs should be published 48 hours before the event. Table 6-1 provides the categories and MPLs of the Timely Publication of NAGUs.

Table 6-1. MPL of the Timely Publication of NAGUs

MPL OF THE TIMELY PUBLICATION OF NAGUS	CONDITIONS AND CONSTRAINTS
For scheduled events affecting the service • ≥48 hours before the service is affected	
Unplanned events affecting the service • ≤15 hours after the event affecting the service is detected	
Service availability events • ≤15 hours after the event affecting the service is detected	
General events to be notified before their occurrence • ≥48 hours before the occurrence of the event to which they refer	Including GENERAL (NOTICE), GENERAL (LEAP SECOND), GENERAL (TIMING PLN_OUTAGE)
General events to be notified after their occurrence • ≤30 hours after the occurrence of the event to which they refer	All other types of GENERAL NAGUs, including also GENERAL (NOTICE), CANCEL, RESCH and EXTNS NAGUs

Satellite availability performance was analyzed based on published NAGUs. During this reporting period, July 1, 2024, through September 30, 2024, there were 12 NAGUs published.

- Two NAGUs announced planned outages for GSAT203 (NAGU 2024032) and GSAT213 (NAGU 2024036).
- One NAGU announced a planned maneuver for GSAT213 (NAGU 2024027).

- Three NAGUs announced the usability of satellites returning from maintenance, GSAT0213 (NAGUs 2024037 and 2024040) and GSAT0203 (NAGU 2024035).
- Two NAGUs announced the usability of two new satellites, GSAT0225 (NAGU 2024033) and GSAT0226 (NAGU 2024034).
- One NAGU announced the launch of two new satellites, GSAT0226 and GSAT0232 (NAGU 2024038).
- Three NAGUs regarded the High Accuracy Service (HAS) and are out of scope of this report.

Table 6-2 provides a summary of the time each NAGU affected positioning service. Total Unscheduled time is the amount of time in hours a NAGU indicated service outages without notifying Galileo users in advance or that fell outside the forecasted outage time. Total Scheduled time is the actual time in hours that satellite outages affected service according to the USABLE NAGU within the forecasted time indicated in the corresponding PLN_OUTAGE NAGU. The Total time is the amount of time, both Unscheduled and Scheduled, that a satellite outage affected service.

Table 6-2. NAGUs Affecting Satellite Positioning Availability

NAGU	SV ID	Type	Start	End	Total Unscheduled (hrs)	Total Scheduled (hrs)	Total (hrs)
2024030	04	USABLE	Jul 10, 2024, 04:30 UTC	Jul 19, 2024, 15:34 UTC	0.00	227.07	227.07
2024035	26	USABLE	Sep 03, 2024, 01:10 UTC	Sep 06, 2024, 02:38 UTC	0.00	73.47	73.47
2024037	04	USABLE	Sep 12, 2024, 19:00 UTC	Sep 12, 2024, 19:50 UTC	0.00	0.83	0.83
Totals of Unscheduled, Scheduled, and Total Downtime (hrs)					0.00	301.37	301.37

Table 6-3 provides a summary of published NAGUs that forecast satellite outages. “EXTNS” NAGUs are listed in the table, but they are not included in the Total Forecasted Downtime statistic.

Table 6-3. NAGUs Forecasted to Affect Satellite Positioning Availability

NAGU	SV ID	TYPE	Start	End	Total (hrs)	Comments
2024027	04	PLN_MANV	Jul 10, 2024, 04:30 UTC	Jul 19, 2024, 18:30 UTC	230.00	2024030

NAGU	SV ID	TYPE	Start	End	Total (hrs)	Comments
2024032	26	PLN_OUTAGE	Sep 03, 2024, 01:10 UTC	Sep 06, 2024, 05:00 UTC	75.83	2024035
2024036	04	PLN_OUTAGE	Sep 12, 2024, 19:00 UTC	Sep 12, 2024, 20:30 UTC	1.50	2024037
Total Hours					4.50	

Table 6-4 provides a summary of the time each NAGU affected GGTO service. Total Unscheduled time is the amount of time in hours that a NAGU indicated service outages without notifying Galileo users in advance or that fell outside the forecasted outage time. Total Scheduled time is the actual time in hours that satellite outages affected service according to the TIMING USABLE NAGU within the forecasted time indicated in the corresponding PLN_OUTAGE NAGU. The Total time is the amount of time, both Unscheduled and Scheduled, that a satellite outage affected service.

Table 6-4. NAGUs Affecting Satellite GGTO Availability

NAGU	SV ID	Type	Start	End	Total Unscheduled	Total Scheduled	Total
No GGTO Outages							

Table 6-5 provides a summary of published NAGUs that forecast satellite GGTO outages.

Table 6-5. NAGUs Forecasted to Affect Satellite GGTO Availability

NAGU	SV ID	TYPE	Start	End	Total	Comments
No Forecasted GGTO Outages						

Table 6-6 provides a summary of Satellite Reliability, Maintainability, and Availability data, which is collected based on published NAGUs. The Percent Operational was calculated based on the ratio of total actual operating hours to total available operating hours for every satellite according to published NAGUs.

Table 6-6. Galileo Satellite Maintenance Statistics

Satellite Availability Parameter	Positioning	GGTO
Total Forecasted Downtime (hrs)	307.33	0.00
Total Actual Downtime (hrs)	301.37	0.00
Total Actual Scheduled Downtime (hrs)	301.37	0.00
Total Actual Unscheduled Downtime (hrs)	0.00	0.00
Total Satellite Outages	3	0
Scheduled Satellite Outages	3	0
Unscheduled Satellite Outages	0	0
Percent Operational—Scheduled Downtime (%)	99.41	100
Percent Operational—All Downtime (%)	99.41	100

Table 6-7 provides the timeliness details of each NAGU that occurred during this quarter.

Table 6-7. Summary of 2024 Q3 Published NAGUs

Month	NAGU Type	NAGU Number	Published	Event Time	Category	Timeliness	Description
JUL	PLN_MANV	2024027	Jul 05, 2024, 11:30 UTC	Jul 10, 2024, 04:30 UTC	PLANNED	NAGU was published 113.00 hours before the event.	GALILEO SATELLITE GSAT0213 (ALL SIGNALS) WILL BE UNAVAILABLE FROM 2024-07-10 BEGINNING 04:30 UTC DUE TO MANOEUVRE. OUTAGE RECOVERY ESTIMATED ON 2024-07-19 18:30 UTC.
	GENERAL (HAS PLN_OUTAGE)	2024028	Jul 12, 2024, 10:50 UTC	Jul 16, 2024, 09:00 UTC	Out-of-scope	NAGU was published 94.17 hours before the event.	USERS ARE ADVISED THAT HAS SERVICE WILL BE UNAVAILABLE FROM 2024-07-16 BEGINNING 09:00 UTC. OUTAGE RECOVERY ESTIMATED ON 2024-07-16 15:00 UTC.
	GENERAL (HAS USABLE)	2024029	Jul 16, 2024, 18:35 UTC	Jul 16, 2024, 09:58 UTC	Out-of-scope	NAGU was published 8.62 after the event.	USERS ARE ADVISED THAT HAS SERVICE IS AVAILABLE SINCE/AS OF 2024-07-16 BEGINNING 09:58 UTC. HAS SERVICE WAS UNAVAILABLE FROM 2024-07-16 BEGINNING 09:03 UTC.
	USABLE	2024030	Jul 19, 2024, 18:30 UTC	Jul 19, 2024, 15:34 UTC	SERVICE AVAILABILITY	NAGU was published 2.93 after the event.	GALILEO SATELLITE GSAT0213 (ALL SIGNALS) IS USABLE SINCE/AS OF 2024-07-19 BEGINNING 15:34 UTC. PAYLOAD ON PHM CLOCK. GALILEO SATELLITE GSAT0213 (ALL SIGNALS) WAS UNAVAILABLE FROM 2024-07-10 BEGINNING 04:40 UTC.

AUG	GENERAL (HAS UNP_SHTRCVR)	2024031	Aug 02, 2024, 20:00 UTC	Aug 02, 2024, 07:09 UTC	UNCATEGORIZED	NAGU was published 12.85 after the event.	USERS ARE ADVISED OF HAS SERVICE UNAVAILABILITIES OCCURRED DURING THE PERIOD STARTING FROM 2024-08-02 BEGINNING 07:09 UTC UNTIL 2024-08-02 ENDING 08:22 UTC.
	PLN_OUTAGE	2024032	Aug 29, 2024, 14:00 UTC	Sep 03, 2024, 01:10 UTC	PLANNED	NAGU was published 107.17 hours before the event.	GALILEO SATELLITE GSAT0203 (ALL SIGNALS) WILL BE UNAVAILABLE FROM 2024-09-03 BEGINNING 01:10 UTC. OUTAGE RECOVERY ESTIMATED ON 2024-09-06 05:00 UTC.
SEP	USABINIT	2024033	Sep 05, 2024, 14:00 UTC	Sep 05, 2024, 10:21 UTC	SERVICE AVAILABILITY	NAGU was published 3.65 after the event.	GALILEO SATELLITE GSAT0225 (ALL SIGNALS) IS USABLE SINCE/AS OF 2024-09-05 BEGINNING 10:21 UTC. GSAT0225 IS POSITIONED IN SLOT C05 OF THE CONSTELLATION. PAYLOAD ON PHM CLOCK.
	USABINIT	2024034	Sep 05, 2024, 14:30 UTC	Sep 05, 2024, 12:11 UTC	SERVICE AVAILABILITY	NAGU was published 2.32 after the event.	GALILEO SATELLITE GSAT0227 (ALL SIGNALS) IS USABLE SINCE/AS OF 2024-09-05 BEGINNING 12:11 UTC. GSAT0227 IS POSITIONED IN SLOT C12 OF THE CONSTELLATION. PAYLOAD ON PHM CLOCK.

	USABLE	2024035	Sep 06, 2024, 09:00 UTC	Sep 06, 2024, 02:38 UTC	SERVICE AVAILABILITY	NAGU was published 6.37 after the event.	GALILEO SATELLITE GSAT0203 (ALL SIGNALS) IS USABLE SINCE/AS OF 2024-09-06 BEGINNING 02:38 UTC. PAYLOAD ON PHM CLOCK. GALILEO SATELLITE GSAT0203 (ALL SIGNALS) WAS UNAVAILABLE FROM 2024-09-03 BEGINNING 01:31 UTC.
	PLN_OUTAGE	2024036	Sep 09, 2024, 15:00 UTC	Sep 12, 2024, 19:00 UTC	PLANNED	NAGU was published 76.00 hours before the event.	GALILEO SATELLITE GSAT0213 (ALL SIGNALS) WILL BE UNAVAILABLE FROM 2024-09-12 BEGINNING 19:00 UTC. OUTAGE RECOVERY ESTIMATED ON 2024-09-12 20:30 UTC.
	USABLE	2024037	Sep 12, 2024, 21:50 UTC	Sep 12, 2024, 19:50 UTC	SERVICE AVAILABILITY	NAGU was published 2.00 after the event.	GALILEO SATELLITE GSAT0213 (ALL SIGNALS) IS USABLE SINCE/AS OF 2024-09-12 BEGINNING 19:50 UTC. PAYLOAD ON PHM CLOCK. GALILEO SATELLITE GSAT0213 (ALL SIGNALS) WAS UNAVAILABLE FROM 2024-09-12 BEGINNING 19:11 UTC.

	GENERAL (LAUNCH)	2024038	Sep 18, 2024, 06:30 UTC	Sep 17, 2024, 22:50 UTC	GENERAL UNPLANNED	NAGU was published 7.67 after the event.	GALILEO SATELLITES GSAT0226 (SVID 23) AND GSAT0232 (SVID 16) WERE LAUNCHED ON 2024-09-17 AT 22:50 UTC. GSAT0226 AND GSAT0232 ARE PLANNED TO BE POSITIONED IN SLOTS A02 AND A17 OF THE CONSTELLATION. USERS WILL BE ADVISED OF AVAILABILITY OF SIGNALS FOLLOWING COMPLETION OF COMMISSIONING ACTIVITIES.

7. ACRONYMS

AOD	Age of data
ARAIM	Advanced Receiver Autonomous Integrity Monitoring
AUL	Average user location
CDDIS	Crustal Dynamics Data Information System
CODE	Center for Orbit Determination in Europe
DOP	Dilution of precision
DVS	Data Validity Status
ECEF	Earth-Centered, Earth-Fixed
EU	European Union
EUSPA	European Union Agency for the Space Programme
FAA	Federal Aviation Administration
GGTO	GPS-Galileo Time Offset
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GST	Galileo System Time
HAS	High accuracy service
HDOP	Horizontal dilution of precision
HPE	Horizontal position error
HS	Healthy Status
IGS	International GNSS Service
IOC	Initial operational capability
IOD	Issue of Data
MGEX	Multi-GNSS Experiment
MPE	Maximum projected error
MPL	Minimum performance level
NAGU	Notice Advisory to Galileo Users
NAPA	No Accuracy Prediction Available
OS	Open Service
PDOP	Position dilution of precision
RAC	Radial, along-track, and cross-track
RINEX	Receiver Independent Exchange
SDD	Service Definition Document
SIS	Signal-in-Space
SISA	Signal-in-Space Accuracy
SISE	Signal-in-Space Ranging Error
SISRA	Signal-in-Space Ranging Accuracy
SP3	Standard Product #3
SPS	Standard Positioning Service
SVID	Space Vehicle Identification

UPE	User Projected Error
U.S.	United States
USNO	United States Naval Observatory
UTC	Coordinated Universal Time
UTCOE	UTC offset error
VDOP	Vertical dilution of precision
VPE	Vertical position error
WAAS	Wide Area Augmentation System
WJHTC	William J. Hughes Technical Center
WUL	Worst user location

8. REFERENCES

1. The European Space Agency, "What is Galileo?," ESA - What is Galileo?, last accessed March 12, 2025.

2. European GNSS (Galileo) Open Service Service Definition Document, Issue 1.3, available at https://www.gsc-europa.eu/sites/default/files/sites/all/files/Galileo-OS-SDD_v1.3.pdf, published November 2023, last accessed March 12, 2025.

3. European Global Navigation Satellite Systems Agency, European GNSS Service Center, "NAGUs (Notice Advisory to Galileo Users)," NAGUs (Notice Advisory to Galileo Users) | European GNSS Service Centre (gsc-europa.eu), last accessed March 12, 2025.

4. The European Space Agency, "Galileo Navigation Signals and Frequencies," https://www.esa.int/Applications/Navigation/Galileo/Galileo_navigation_signals_and_frequencies, last accessed March 12, 2025.

5. European Union Agency for the Space Programme (EUSPA), https://www.euspa.europa.eu/, last accessed March 12, 2025.

6. National Aeronautics and Space Administration, CDDIS, "GNSS MGEX Data," https://cddis.nasa.gov/Data_and_Derived_Products/GNSS/gnss_mgex.html, last accessed March 12, 2025.

7. International GNSS Service, "MGEX Pilot Project," https://www.igs.org/mgex#referencing, last accessed March 12, 2025.

8. International GNSS Service, "MGEX Data & Products," https://www.igs.org/mgex/data-products#products, last accessed March 12, 2025.

9. National Aeronautics and Space Administration, CDDIS, https://cddis.nasa.gov/, last accessed March 12, 2025.

10. L. Heng, "Safe Satellite Navigation with Multiple Constellations: Global Monitoring of GPS and GLONASS Signal-in-Space Anomalies," 2012.

11. Walter, T., Gunning, K., Phelts, E., and Blanch, J., "Validation of Unfaulted Error Bounds for ARAIM," NAVIGATION Journal of The Institute of Navigation, February 2018.

12. Naval Oceanography Portal, "The United States Naval Observatory," https://www.cnmoc.usff.navy.mil/USNO, last accessed March 12, 2025.

APPENDIX A: GLOBAL MAXIMUM PDOP TREND

Figure A-1 shows the max PDOP at each timestep from the grid described in Section 2.

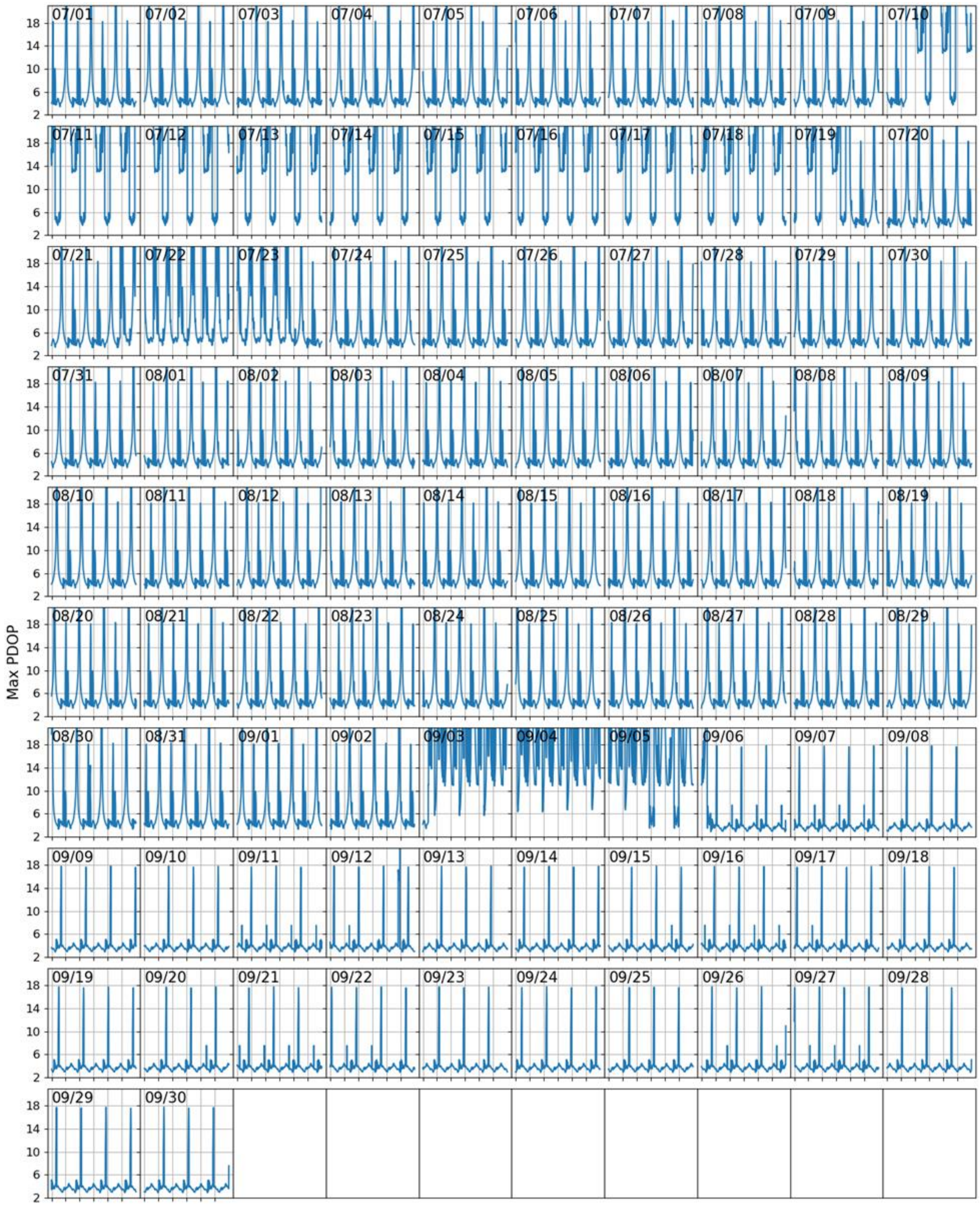


Figure A-1. Global Maximum PDOP Trend

APPENDIX B: GALILEO DAILY MAXIMUM PDOP 10-DAY GEOMETRY CYCLE COMPARISON

Figure B-1 through Figure B-10 are a group of plots that show the daily maximum PDOP on a 10-day cycle. The Galileo constellation repeats every 10 days, so each set of plots allows easy comparison of PDOP when the constellation geometry is the same. The colors on the plots denote the maximum PDOP seen on that day at that location. The scale for the colors runs from a PDOP of 1 (blue) to 10 (dark red).

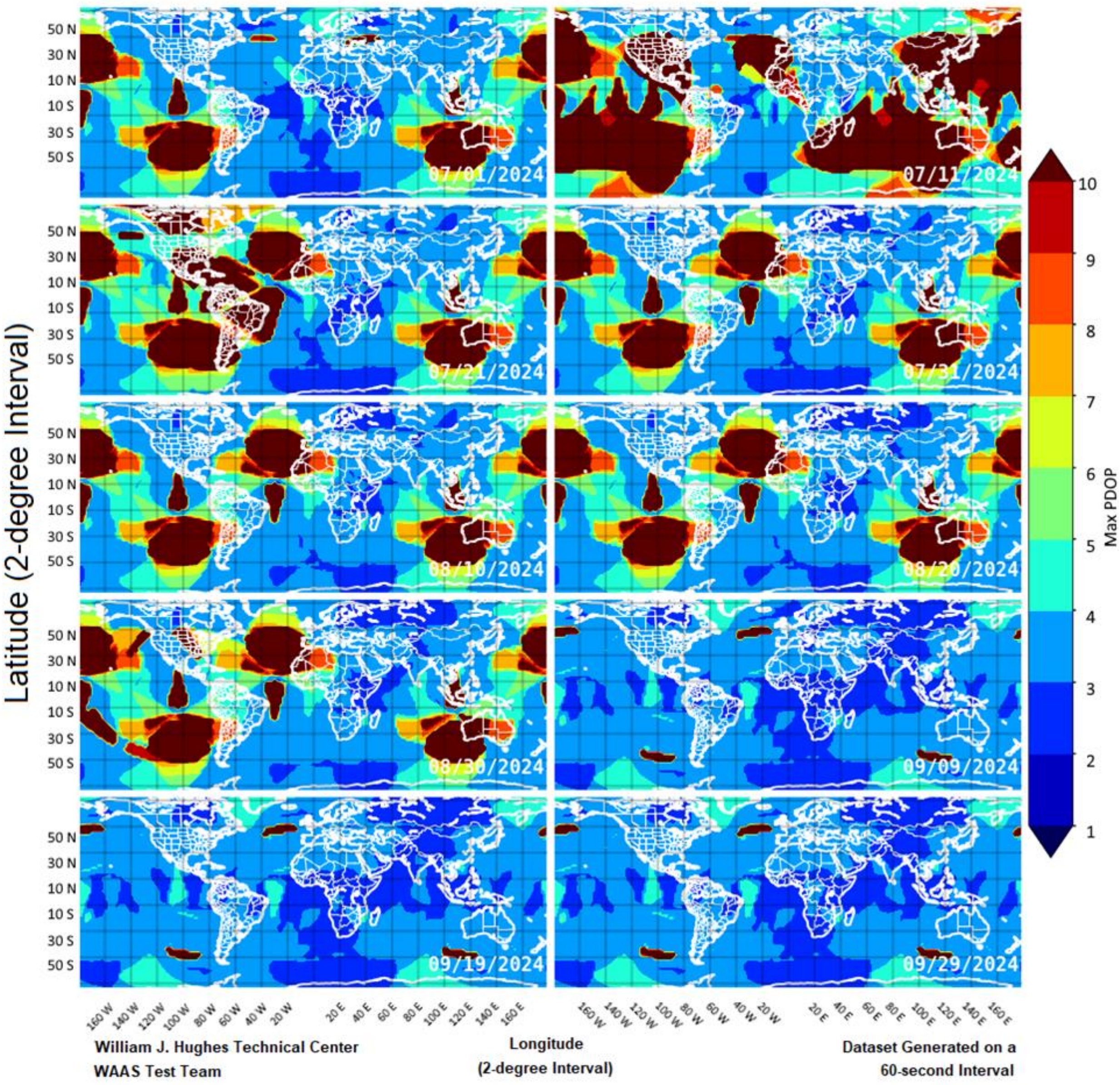


Figure B-1. Galileo Daily Maximum PDOP—Comparing 10-Day Geometry Cycle: July 1, 2024–September 29, 2024

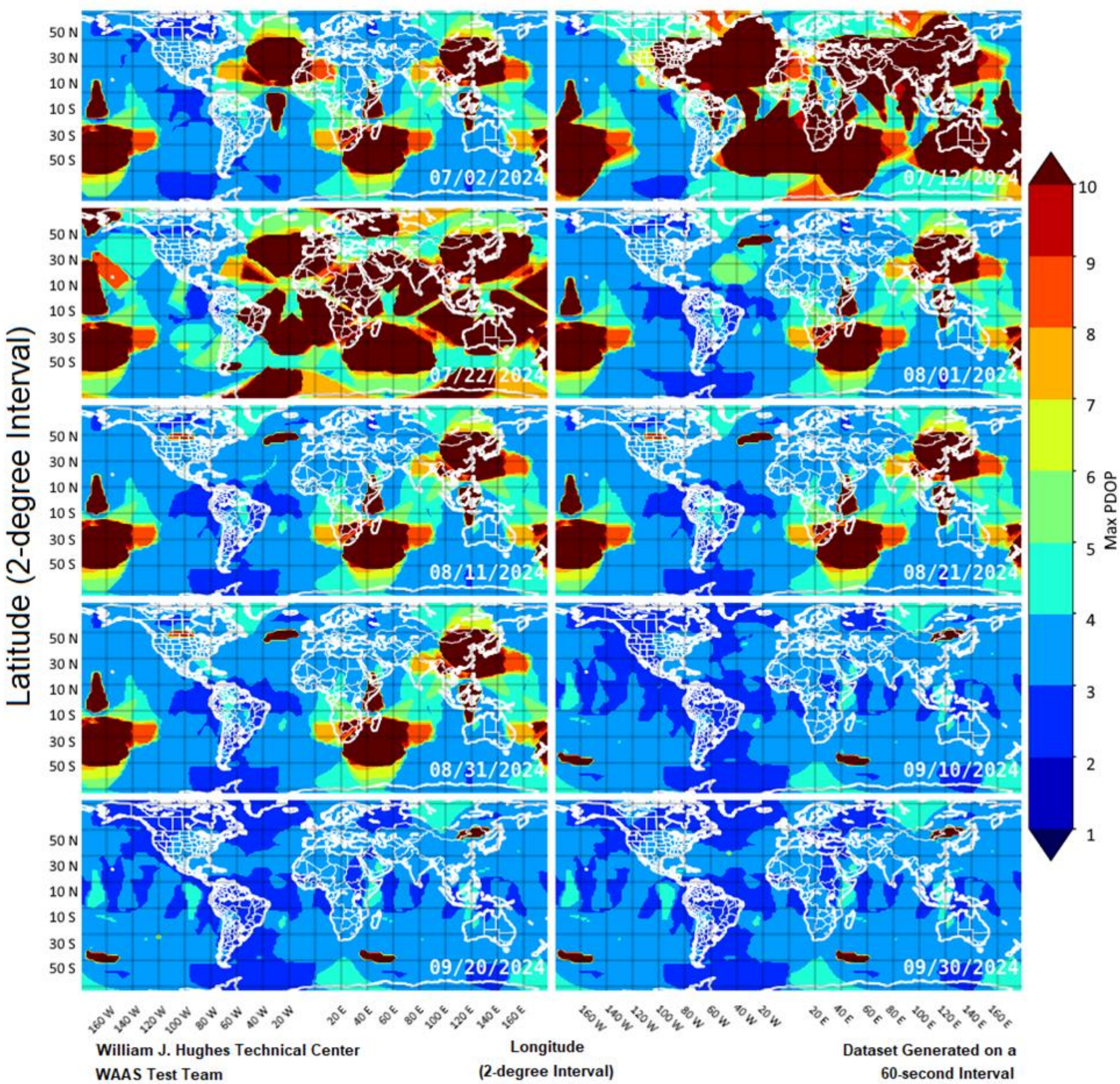


Figure B-2. Galileo Daily Maximum PDOP—Comparing 10-Day Geometry Cycle: July 2, 2024–September 30, 2024

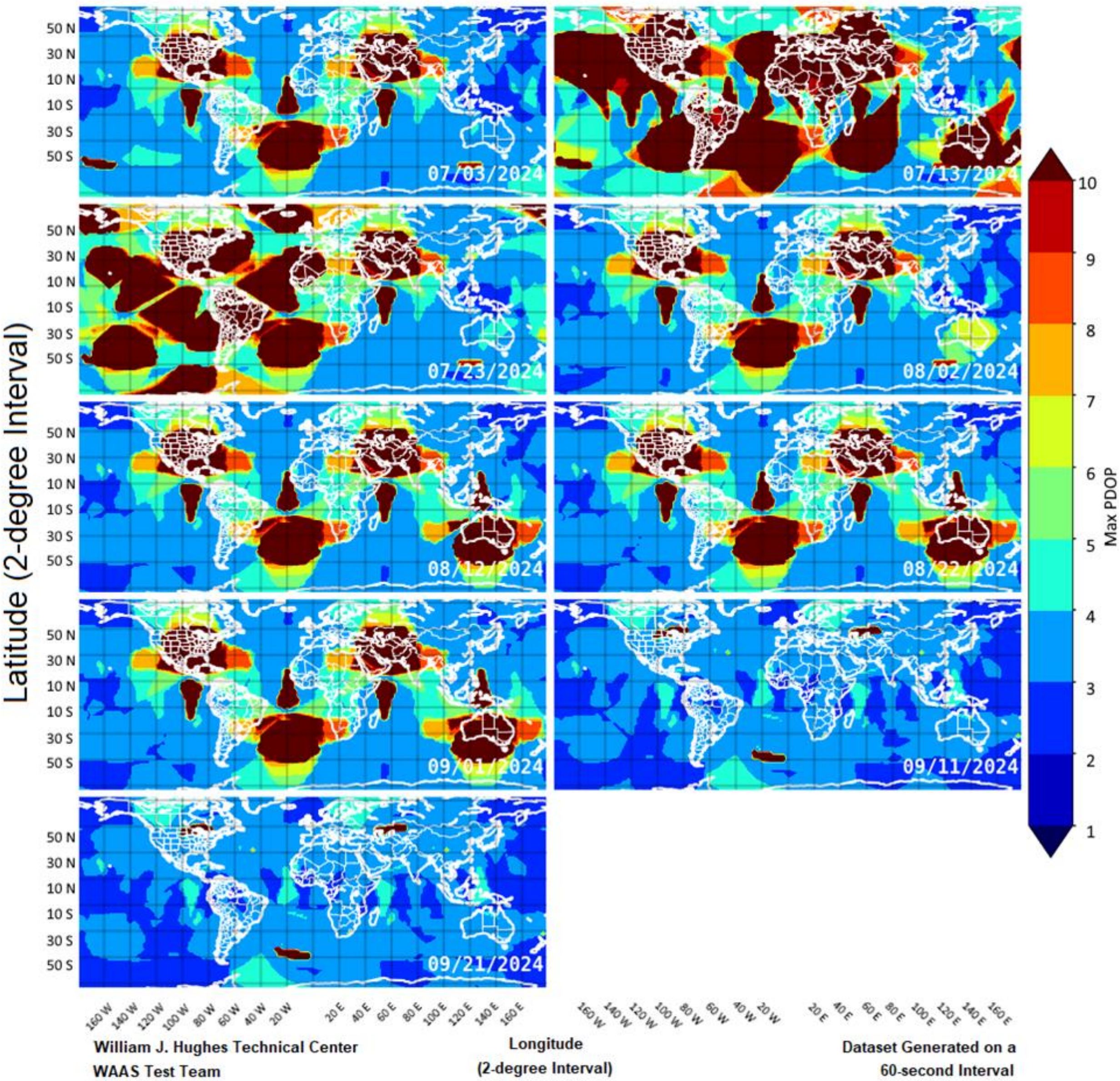


Figure B-3. Galileo Daily Maximum PDOP—Comparing 10-Day Geometry Cycle: July 3, 2024–September 21, 2024

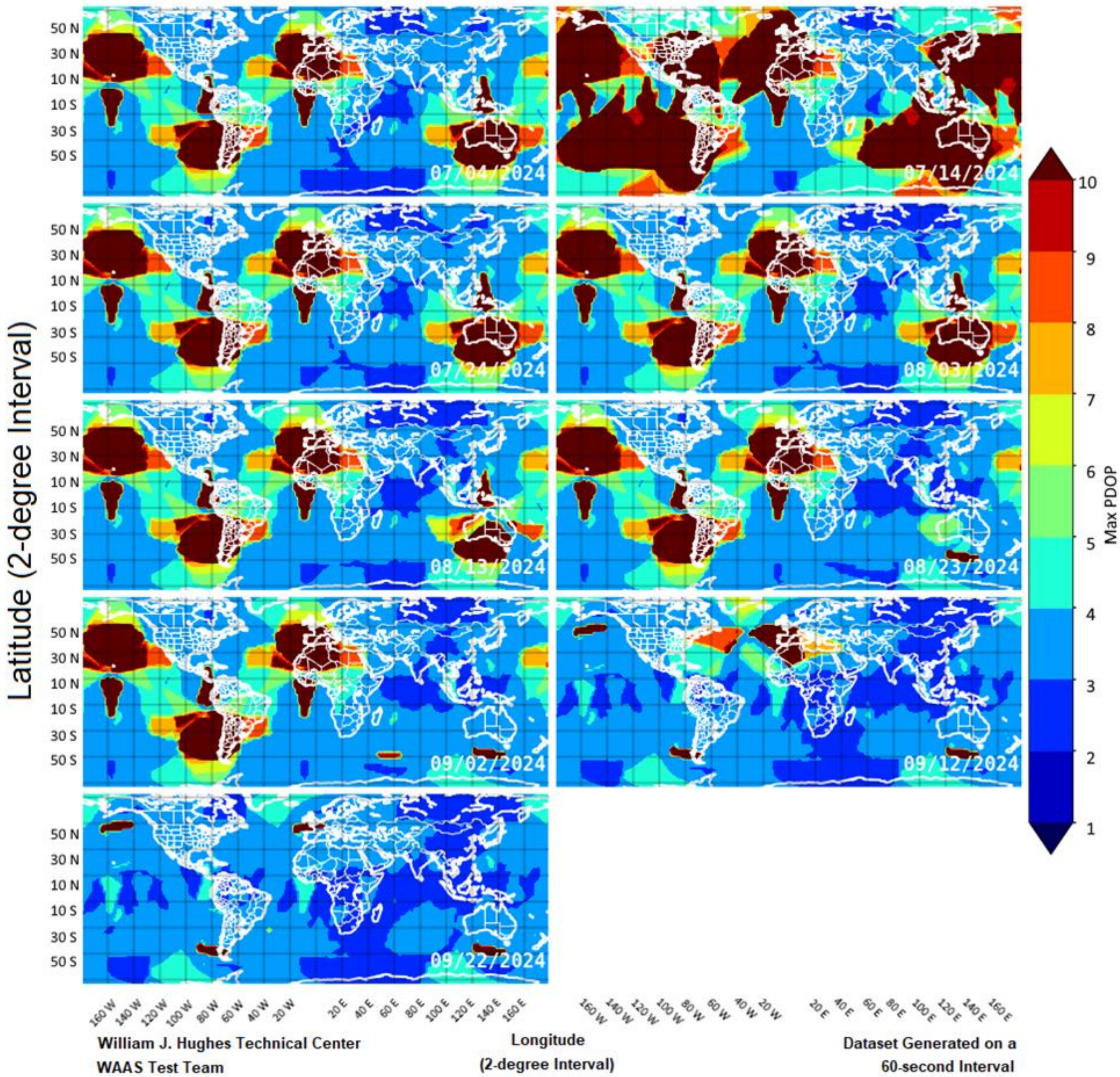


Figure B-4. Galileo Daily Maximum PDOP—Comparing 10-Day Geometry Cycle: July 4, 2024–September 22, 2024

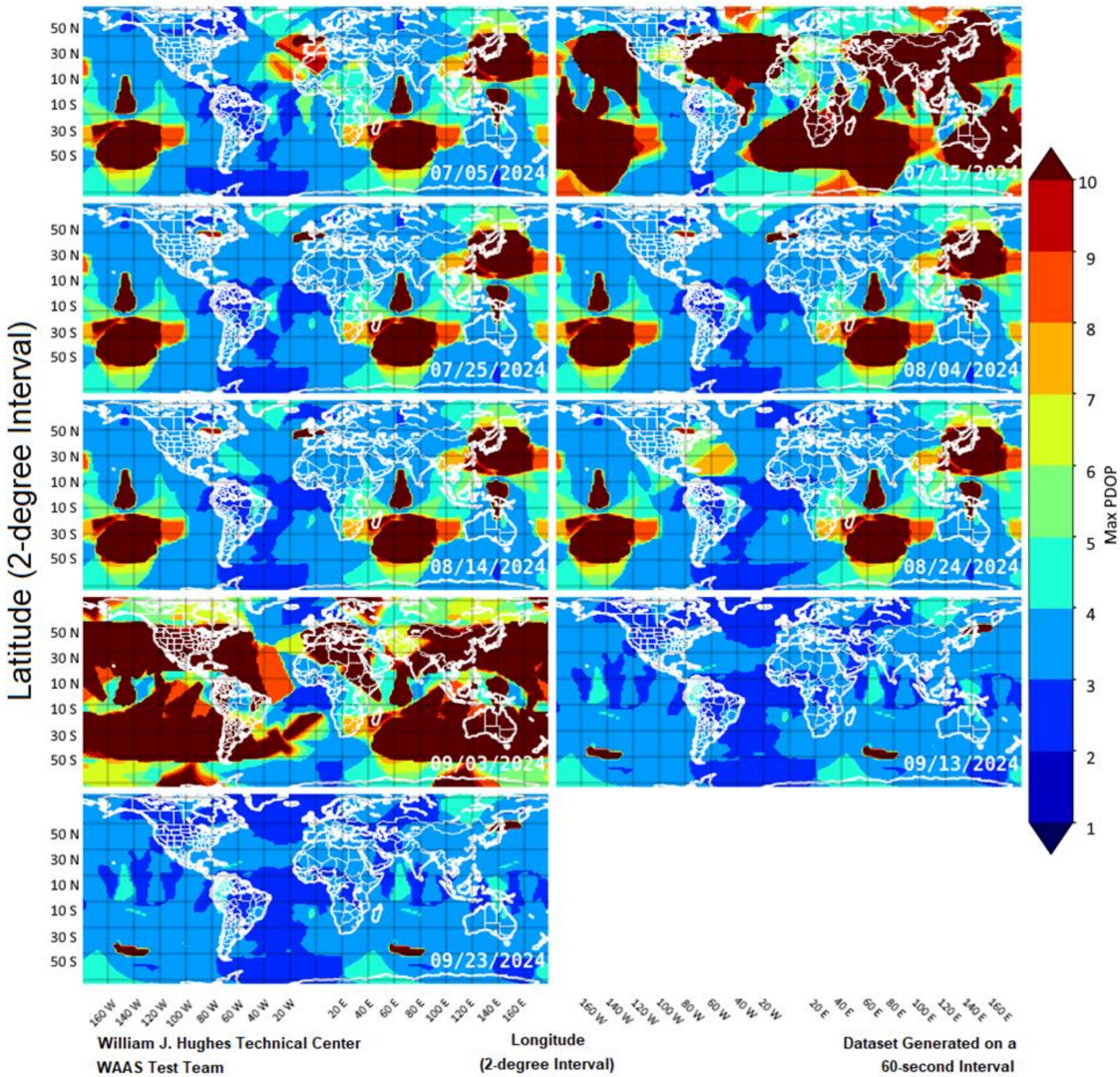


Figure B-5. Galileo Daily Maximum PDOP—Comparing 10-Day Geometry Cycle: July 5, 2024–September 23, 2024

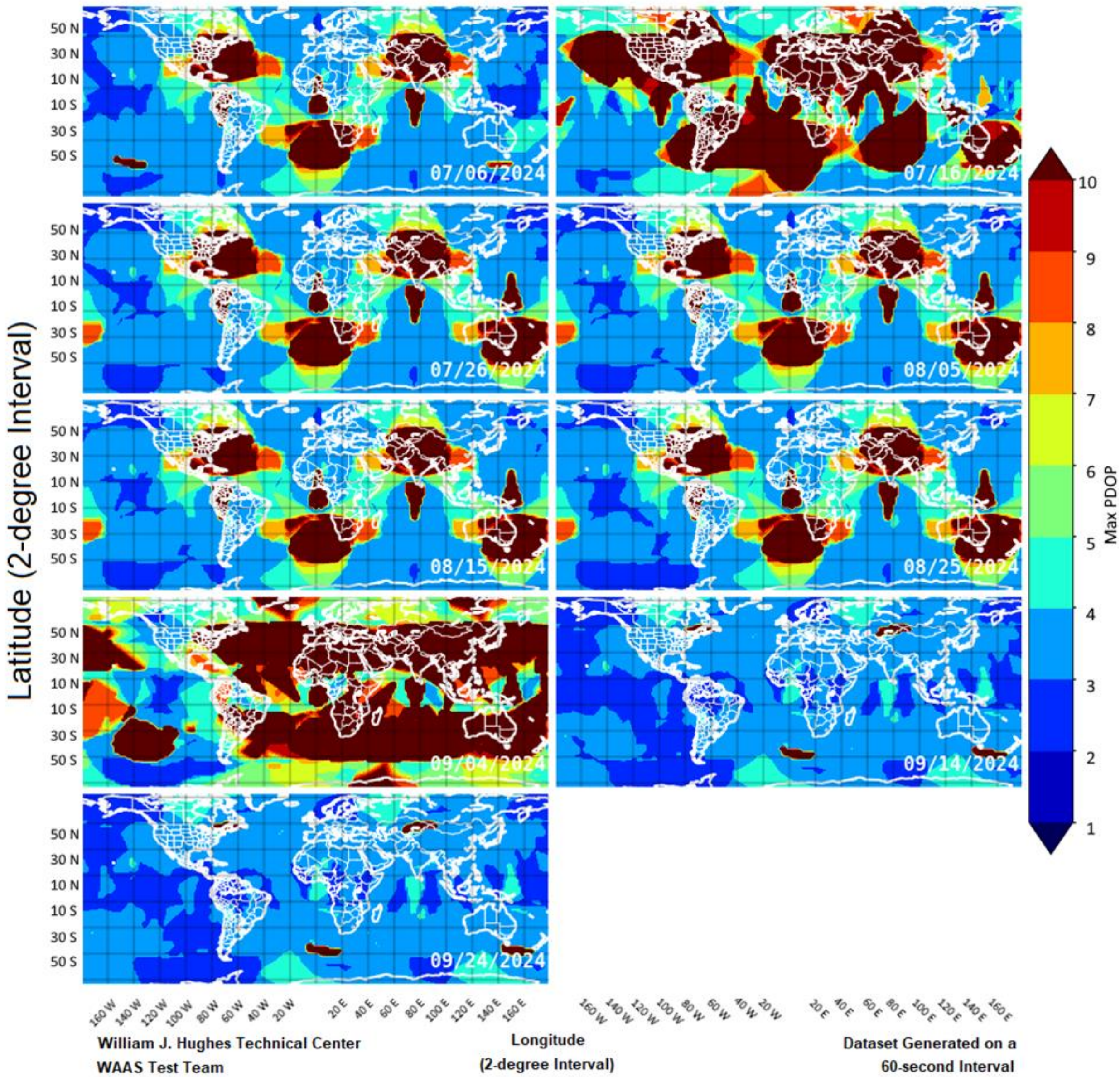


Figure B-6. Galileo Daily Maximum PDOP—Comparing 10-Day Geometry Cycle: July 6, 2024–September 24, 2024

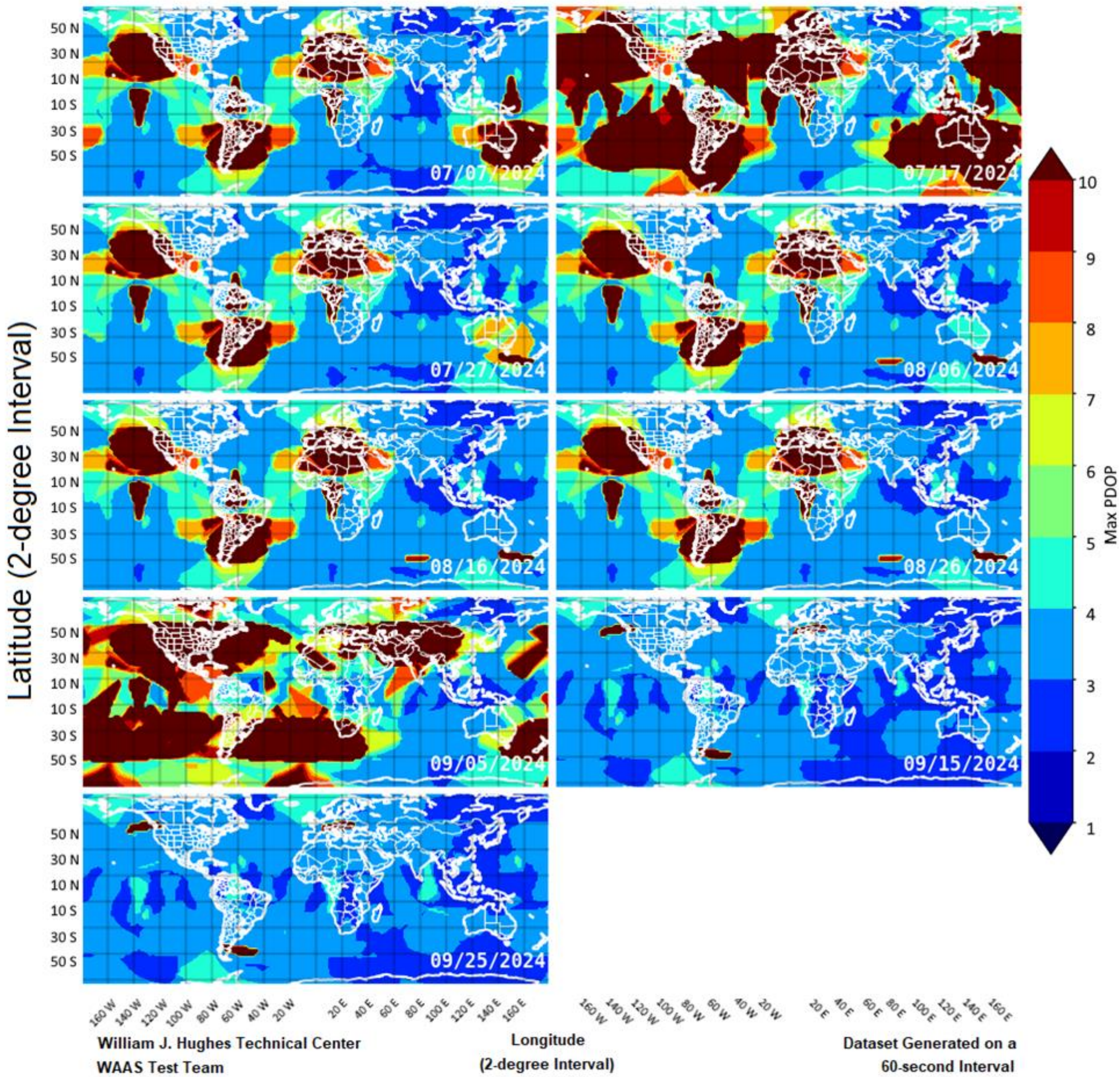


Figure B-7. Galileo Daily Maximum PDOP—Comparing 10-Day Geometry Cycle: July 7, 2024–September 25, 2024

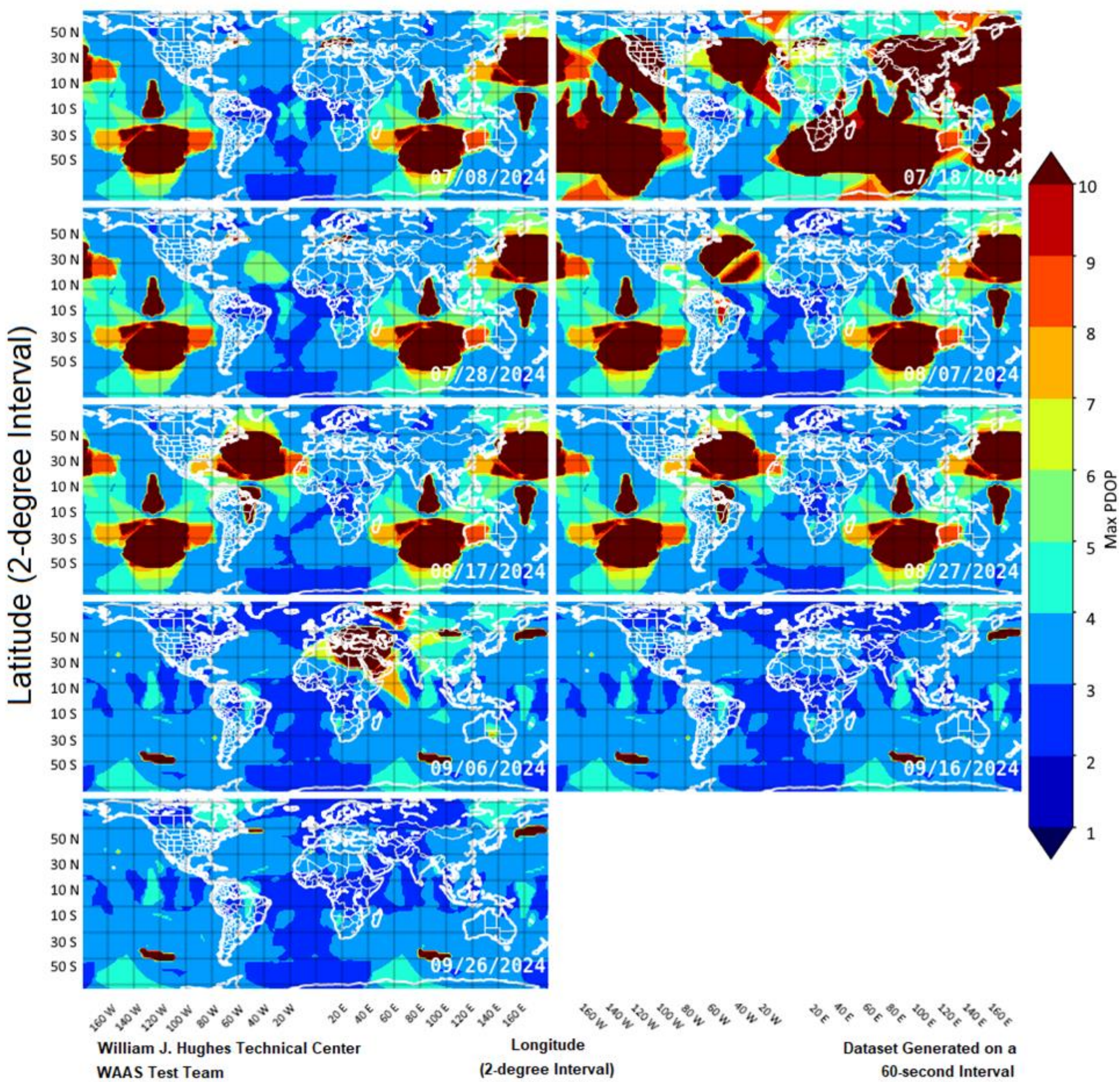


Figure B-8. Galileo Daily Maximum PDOP—Comparing 10-Day Geometry Cycle: July 8, 2024–September 26, 2024

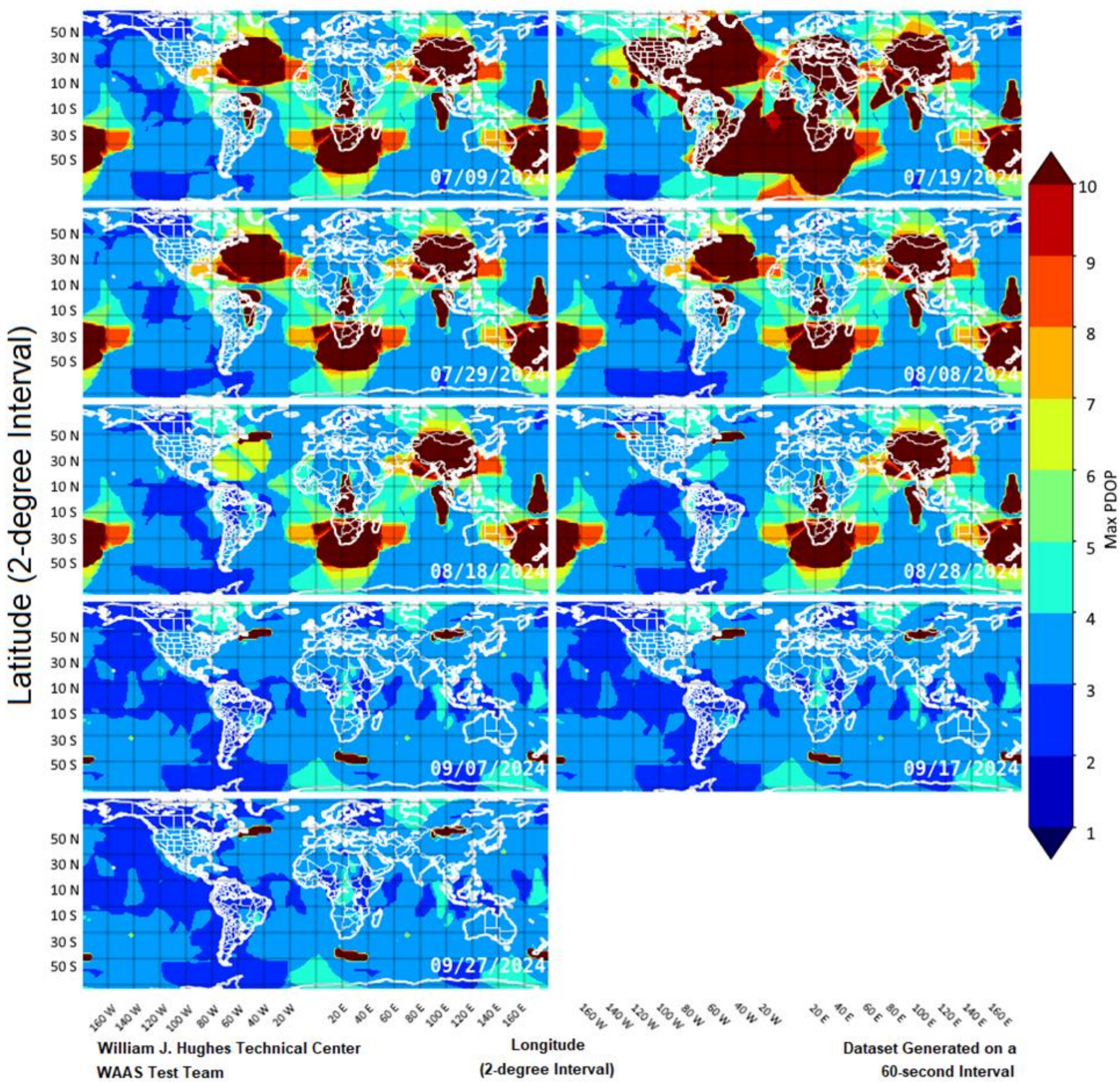


Figure B-9. Galileo Daily Maximum PDOP—Comparing 10-Day Geometry Cycle: July 9, 2024–September 27, 2024

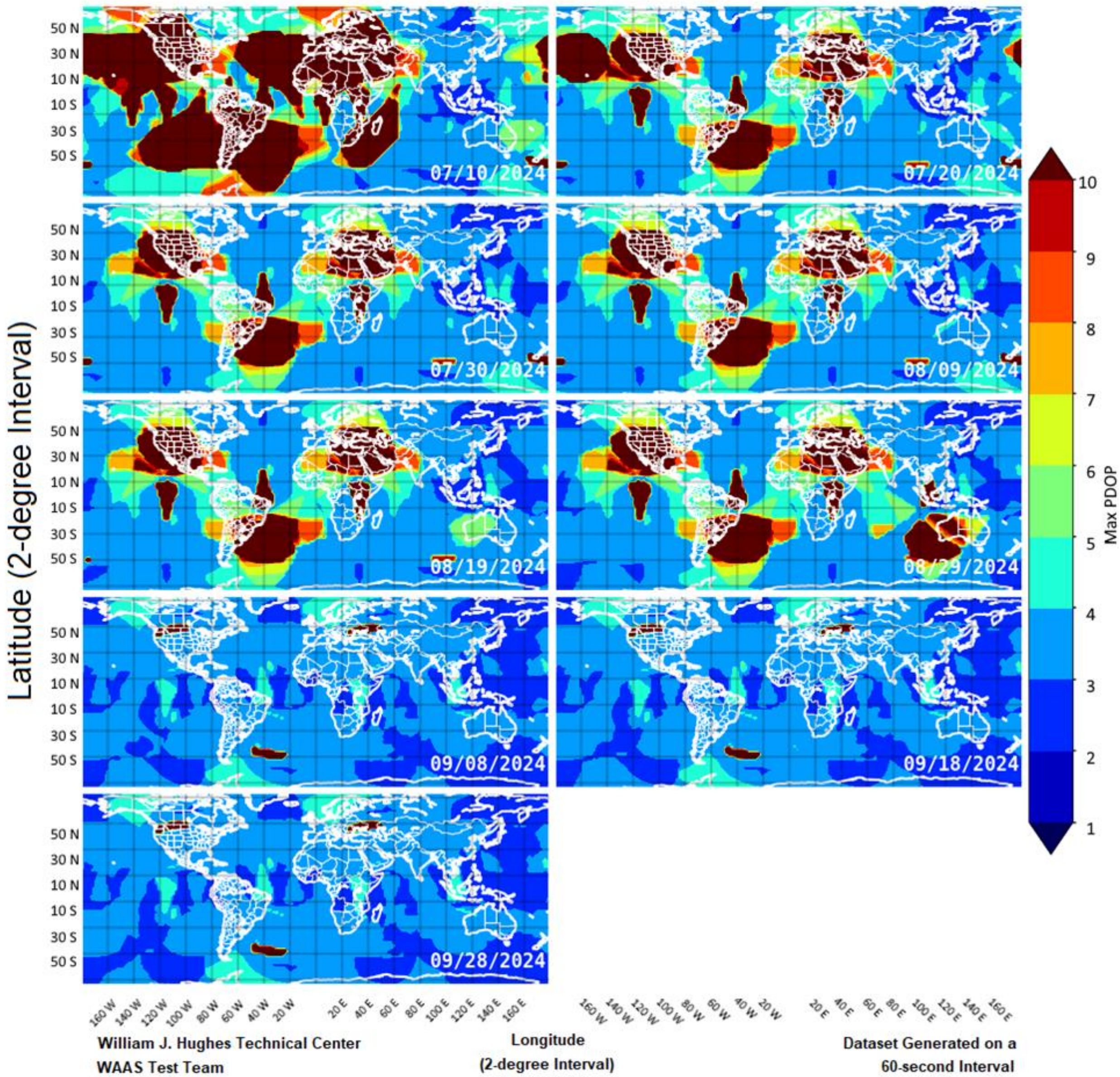


Figure B-10. Galileo Daily Maximum PDOP—Comparing 10-Day Geometry Cycle: July 10, 2024–September 28, 2024