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EUROPEAN GNSS (GALILEO) SERVICES

OPEN SERVICE

QUARTERLY PERFORMANCE REPORT

APRIL – JUNE 2023

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1 INTRODUCTION

This document is the Galileo Open Service (OS) Public Performance Report for the period of April, May and June 2023. Since the declaration of Initial Services (IS) in December 2016, a new edition is published after each quarter, in order to provide the public with information about the Galileo Open Service measured performance statistics.

The document reports on the following performance parameters, with respect to their Minimum Performance Levels (MPLs) declared in the [OS-SDD]:

- ◊ Galileo Open Service Ranging Performance,
- ◊ Galileo UTC and GGTO Dissemination and Determination Performance,
- ◊ Galileo Positioning Performance,
- ◊ Timely Publication of Notice Advisory to Galileo Users (NAGUs)[1]

In addition, information is provided about measured values and metrics that are not subject to MPL targets, for example for the recently introduced reporting on the Galileo OSNMA "Public Observation" phase. The document comprises the following sections:

Section 1: introduces this report, including the status of the Galileo constellation over the quarterly reporting period.

Section 2: provides an executive summary describing main statistics about the achieved OS performance. Details are reported in the following chapters.

Section 3: the Open Service Ranging Performance comprises 2 subsections: "Per-slot Availability of HEALTHY Signal in Space" and "Galileo Signal in Space Ranging Accuracy".

Section 4: the "UTC and GGTO Dissemination and Determination Performance" is presented in two subsections: the "Availability of the Galileo Time Correlation Parameters and of UTC Determination" and the "Accuracy of Galileo Time Correlation Parameters". Performance is evaluated for the Universal Time Coordinated (UTC) Time & Frequency provision Service and the GST-GPS Time Offset (GGTO) Determination.

Section 5: the "Galileo Positioning Performance" is illustrated in three subsections: "Availability of the Galileo Position Dilution of Precision", "Availability of the Galileo Positioning Service" and "Galileo measured Positioning Performance".

Section 6: the "Timely Publication of Notice Advisory to Galileo Users (NAGUs)" is analysed.

Section 7: preliminary performance information about the new Galileo OSNMA Service is given, even if Service is not yet declared by the EU, according to the ongoing "Public Observation Phase" announced by the Galileo Service Notice #09 [SvNOTE #09]. In particular, "Availability of Authentication Tags" and "Statistics on Success of Tag Authentication" are reported.

Section 8: all the cited reference documents are listed.

Section 9: terms, acronyms and abbreviations used in the document are defined.

[1] NAGUs are issued publicly by the European GNSS Service Centre (GSC)

Table 1 provides the status of the Galileo constellation for which the performance data has been measured over the reporting period.

Table 1: Galileo reported constellation information

Satellite		CCSDS ID [hex]	orbital slot	status
ID	PRN			
GSAT0101	E11	3A5	B05	usable
GSAT0102	E12	3A6	B06	usable
GSAT0103	E19	3A7	C04	usable
GSAT0201	E18	261	non-nominal	not usable since 2021-02-18. This was notified with NAGU 2021008, and the reason is clarified by Galileo Service Notice #05 (SNGU 2021001, [SvNOTE #5]).
GSAT0202	E14	262	non-nominal	not usable since 2021-02-18, as GSAT0201
GSAT0203	E26	263	B08	usable
GSAT0205	E24	265	A08	usable, unless for a planned outage in June (ref.: NAGUs 2023035, 2023037)
GSAT0206	E30	266	A05	usable
GSAT0207	E07	267	C06	usable
GSAT0208	E08	268	C07	usable
GSAT0209	E09	269	C02	usable, unless for multiple planned operations in April (ref.: NAGUs 2023025, 2023026, 2023027, 2023028, 2023029, 2023030, 2023031)
GSAT0210	E01	26A	A02	usable only up to 2023-04-30; was in outage over the whole months of May and June (ref.: NAGU 2023032)
GSAT0211	E02	26B	A06	usable
GSAT0212	E03	26C	C08	usable, unless for a planned outage in May (ref.: ref.: NAGUs 2023033, 2023034);
GSAT0213	E04	26D	C03	usable
GSAT0214	E05	26E	C01	usable, unless for a planned operation in June (ref.: NAGUs 2023035, 2023037)
GSAT0215	E21	2C5	A03	usable
GSAT0216	E25	2C6	A07	usable
GSAT0217	E27	2C7	A04	usable
GSAT0218	E31	2C8	A01	usable, usable, unless for a planned outage in June (ref.: NAGUs 2023036, 2023039)
GSAT0219	E36	2C9	B04	usable
GSAT0220	E13	2C0	B01	usable
GSAT0221	E15	2C1	B02	usable
GSAT0222	E33	2C2	B07	usable
GSAT0223	E34	109	B03	usable
GSAT0224	E10	10B	B15	usable, however considered as auxiliary vehicle

For the most up-to-date information about the Galileo Constellation, please refer to the information published by the European GNSS Service Centre (GSC) on its website:

Table 2: Galileo Service Centre main information web pages for Galileo status

Constellation Status Information https://www.gsc-europa.eu/system-service-status/constellation-information
Reference Constellation Orbital and Technical Parameters https://www.gsc-europa.eu/system-service-status/orbital-and-technical-parameters
Incident Reporting (Galileo Incidents Report Form) http://www.gsc-europa.eu/helpdesk → "Report a Galileo Incident"
Interactive support to users (Galileo Help Desk) http://www.gsc-europa.eu/helpdesk → "Raise your questions"

The Galileo Helpdesk at GSC allows close interaction with users, both to support the exploitation of Galileo services and to collect relevant information on signal performance as observed by the users. The GSC is also responsible for providing the Notice Advisory to Galileo Users (NAGU) messages, as detailed in Section 6.

Note, that since January 2022, the reported metrics are based upon the [OS-SDD] edition v1.2, which is in force since mid-December 2021.

Regarding **GSAT0224** (**E10**), it should be noted that this space vehicle is considered as an "auxiliary" satellite and it is not located in a nominal orbit slot. Hence the constellation availability targets need to be achieved even without taking it into account, and the satellite contribution is neglected when computing MPLs such as "Availability of healthy SIS" and "Availability of PDOP $\leq$ 6". However, it is also a requirement that it shall not degrade the overall system performance, therefore, its ranging accuracy is monitored and reported and is included in the computation of the associated constellation average.

2 EXECUTIVE SUMMARY

During the quarterly reporting period under consideration, the measured Galileo Open Service performance figures exceed the Minimum Performance Level (MPL) targets specified in the [OS-SDD]. Table 3 and Table 4 summarise the compliance with MPLs as dashboards, using the colour coding defined in Table 5.

Table 3: OS MPL fulfilment status dashboard (1/2)

signal in space ranging					
accuracy, any satellite (95%), in m					
satellite			**2023**		
ID	**PRN**	**target value**	**April**	**May**	**June**
GSAT0101	E11	≤ 7	■■■■■	■■■■■	■■■■■
GSAT0102	E12		■■■■■	■■■■■	■■■■■
GSAT0103	E19		■■■■■	■■■■■	■■■■■
GSAT0203	E26		■■■■■	■■■■■	■■■■■
GSAT0205	E24		■■■■■	■■■■■	■■■■■
GSAT0206	E30		■■■■■	■■■■■	■■■■■
GSAT0207	E07		■■■■■	■■■■■	■■■■■
GSAT0208	E08		■■■■■	■■■■■	■■■■■
GSAT0209	E09		■■■■■	■■■■■	■■■■■
GSAT0210	E01		■■■■■		
GSAT0211	E02		■■■■■	■■■■■	■■■■■
GSAT0212	E03		■■■■■	■■■■■	■■■■■
GSAT0213	E04		■■■■■	■■■■■	■■■■■
GSAT0214	E05		■■■■■	■■■■■	■■■■■
GSAT0215	E21		■■■■■	■■■■■	■■■■■
GSAT0216	E25		■■■■■	■■■■■	■■■■■
GSAT0217	E27		■■■■■	■■■■■	■■■■■
GSAT0218	E31		■■■■■	■■■■■	■■■■■
GSAT0219	E36		■■■■■	■■■■■	■■■■■
GSAT0220	E13		■■■■■	■■■■■	■■■■■
GSAT0221	E15		■■■■■	■■■■■	■■■■■
GSAT0222	E33		■■■■■	■■■■■	■■■■■
GSAT0223	E34		■■■■■	■■■■■	■■■■■
GSAT0224	E10		■■■■■	■■■■■	■■■■■
accuracy, over all satellites (95%), in m					
		≤ 2	■■■■■	■■■■■	■■■■■
availability per slot, in %					
		≥ 92	■■■■■	■■■■■	■■■■■

■■■■■ E1/E5a | E1/E5b | E1 | E5a | E5b

Table 4: OS MPL fulfilment status dashboard (2/2)

OS MPL	target value	2023 April	2023 May	2023 June
positioning and dilution of precision (DOP)				
availability				
PDOP ≤ 6 at AUL, F/NAV, in %	≥ 90	■	■	■
PDOP ≤ 6 at AUL, I/NAV, in %	≥ 90	■	■	■
PDOP ≤ 6 at WUL, F/NAV, in %	≥ 87	■	■	■
PDOP ≤ 6 at WUL, I/NAV, in %	≥ 87	■	■	■
positioning @ AUL, DF, in %	≥ 90	■	■	■
positioning @ AUL, SF, in %	≥ 90	■	■	■
positioning @ WUL, DF, in %	≥ 87	■	■	■
positioning @ WUL, SF, in %	≥ 87	■	■	■
timing				
accuracy				
UTC time dissemination (95%), in ns	≤ 30	■	■	■
UTC frequency dissemination (95%), unitless	≤ 3E–13	■	■	■
GGTO determination (95%), in ns	≤ 20	■	■	■
availability				
UTC dissemination, in %	≥ 95	■	■	■
UTC determination accuracy, in %	≥ 95	■	■	■
GGTO determination, in %	≥ 80	■	■	■
user interface				
NAGU timeliness				
planned, in days	≥ 2	■	■	■
unplanned, in days	≤ 1.25	■	■	■

Table 5: legend of OS MPLs verification dashboard

legend colour	interpretation
none	MPL measurement is not available
■	target value for MPL is fulfilled
■	target value for MPL is not fulfilled (less than 10% away from the target value)
■	target value for MPL is not fulfilled (more than 10% away from the target value)

2.1 SUMMARY NOTES ABOUT OPEN SERVICE

The "per-slot" **availability of a healthy signal** is above the MPL threshold of 92%, with averaged monthly values at least equal to **94.98**% for every single-frequency – SF – (E1-B, E5a, E5b) and dual-frequency (DF) combination (E1/E5a, E1/E5b) during the quarter.

The monthly figures are normalised annually, according to the MPL definition, by a moving average applied over the most recent twelve months and excluding any auxiliary space vehicles, like it is the case of GSAT0224 (E10).

The **signal in space ranging accuracy** shows a 95th percentile monthly accuracy between **0.24 m** and **1.30 m** for individual space vehicles ("any satellite") on single-frequency observables [2]. For dual-frequency signal combinations [3], the figure is in the range from **0.14 m** to **0.35 m**. Compliance with the [OS-SDD] MPL, where the threshold is specified as **7 m**, is achieved with considerable margin by all satellites of the Galileo constellation.

The evaluation of worst-satellite ranging error at higher confidence level (99.9%, not subject to MPL) shows values which can be considered nominal (ref.: Figure 6): monthly accuracy was between **0.35 m** and **5.05 m** for individual space vehicles ("any satellite") on single-frequency observables [2]. For dual-frequency signal combinations [3], the figure is in the range from **0.23 m** to **4.82 m**. More details are provided in the dedicated section 3.2.

The average **ranging accuracy at constellation level** (over "all satellites", ref.: Figure 11) provides figures "per signal" that are better than or equal to **0.48 m** for single-frequency signals and **0.18 m** for dual-frequency signal combinations. The results achieved for DF are at least one order of magnitude better than the specified MPL threshold of **2 m**.

Concerning the **UTC time related service**, both **availability of the dissemination** and **availability of determination with a target accuracy** ($\leq$ 31 ns) are characterised, as per Figure 12 and Figure 13. In both cases, metrics had a monthly value of **100%** during the entire quarterly reporting period, while the [OS-SDD] MPL target is **95%** for both.

The **availability of GGTO determination** metric was also **100%** during the whole quarter (ref.: Figure 14): valid GGTO coefficients were always disseminated. The measured values are comfortably above the unchanged [OS-SDD] MPL target of **80%**.

Good values are also achieved for the **UTC time dissemination service accuracy** (ref.: Figure 15) equal to **3.42 ns** during the reporting period, the **UTC frequency dissemination service accuracy** (offset $\leq$ **6.8×10^{-14}**, as per Figure 13) and the **GGTO determination accuracy**, better than or equal to **2.76 ns** in the reporting quarter (ref.: Figure 14). The MPL targets, which are respectively **30 ns**, **3×10^{-13}** and **20 ns**, are all met.

The [OS-SDD] includes commitments related to a full **3D positioning service** that are consistent with the achieved deployment status of the Galileo constellation.

Regarding the **availability of PDOP $\leq$ 6** (ref.: Figure 18), the [OS-SDD] foresees a MPL target for the Average User Location (AUL) equal to **90%**, and **87%** for the case of Worst User Location (WUL). At WUL, the measured availability figure was better than or equal to **98.56%**, while for AUL it was at least **99.53%** (ref.: Figure 19).

[2] Ranging measurements on the OS signals E1, E5a, E5b.

[3] Ranging measurements on OS signal combinations E1/E5a, E1/E5b.

Under the conditions that HPE ≤ 7.5 m and VPE ≤ 15 m (95% confidence level), the **availability of positioning** figures for any single-frequency SIS or dual-frequency combination at WUL (ref.: Figure 21) and at AUL (ref.: Figure 22) are as follows:

- in April: **99.94%** (DF) and **99.83%** (SF) at WUL; **100%** (DF) and **99.99%** (SF) at AUL;
- in May: **99.80%** (DF) and **99.53%** (SF) at WUL; **99.97%** (DF) and **99.91%** (SF) at AUL;
- in June: **99.44%** (DF) and **99.27%** (SF) at WUL; **99.94%** (DF) and **99.89%** (SF) at AUL.

The target MPL values specified by the [OS-SDD] are **87%** at WUL and **90%** at AUL, respectively; these targets are met with large margin.

The availability figures are complemented with measured "Galileo-only" 3D positioning performance, attainable when PDOP ≤ 6. These metrics are not currently subject to an MPL target, but are reported because of their relevance, being obtained by processing data from a network of reference receivers (ref.: from Figure 24 up to Figure 29).

For dual-frequency combinations (E1/E5a and E1/E5b), the 95th percentile confidence level of **Horizontal and Vertical 3D Positioning Errors** (HPE and VPE, correspondingly) did not exceed **1.94 m** and **3.35 m** during the whole quarter. The corresponding root mean square (RMS) values, which are also not subject to an MPL assessment, are within respectively **1.35 m** and **2.55 m**.

Regarding **publication of NAGUs**, **15 NAGUs** have been issued in the reporting period, in all cases respecting the requirements for their timeliness. According to the [OS-SDD], the minimum time for publishing a NAGU before the start of a scheduled event is **48 hours** (two days), and **30 hours** (1.25 days) after the occurrence of an unscheduled one. Additional details about NAGU timeliness are presented in chapter 6.

3 OPEN SERVICE RANGING PERFORMANCE

In this section of the report, the following performance figures for the Galileo Open Service are provided:

- Per-slot Availability of HEALTHY Signal in Space: annually normalised MPL (ref.: Figure 1), as well as monthly average (ref.: Figure 2) and monthly values for individual space vehicles (ref.: Figure 3) which are provided for info, having no MPL target assigned;
- Galileo Signal in Space Ranging Accuracy: MPL at 95% confidence level (ref.: Figure 8, Figure 10), and metric at 99.9% confidence level, the latter delivered for info, being not subject to a target (ref.: Figure 5, where it is compared with the MPL at 95%).

3.1 PER-SLOT AVAILABILITY OF HEALTHY SIGNAL IN SPACE

The "availability of healthy signal in space" is defined, for each Galileo operational satellite in a nominal slot, as the percentage of time that the specific satellite broadcasts Galileo Open Service Signals in Space (SIS) that are considered "healthy". The SIS status is derived according to [OS-SDD] rules, regarding the configuration of specific L-band SIS status flags and the validity period of Navigation messages.

Figure 1 provides the SIS "per slot" availability of Galileo healthy signals in space, averaged over the entire constellation during the reporting period and normalised annually.[4] The [OS-SDD] MPL specifies **92%** [5] as the target value for this constellation metric. The achieved performance is between **94.98%** (single-frequency E5a in June) and **95.54%** (single-frequency SIS E1-B, E5b and dual-frequency combination E1-E5b in April).

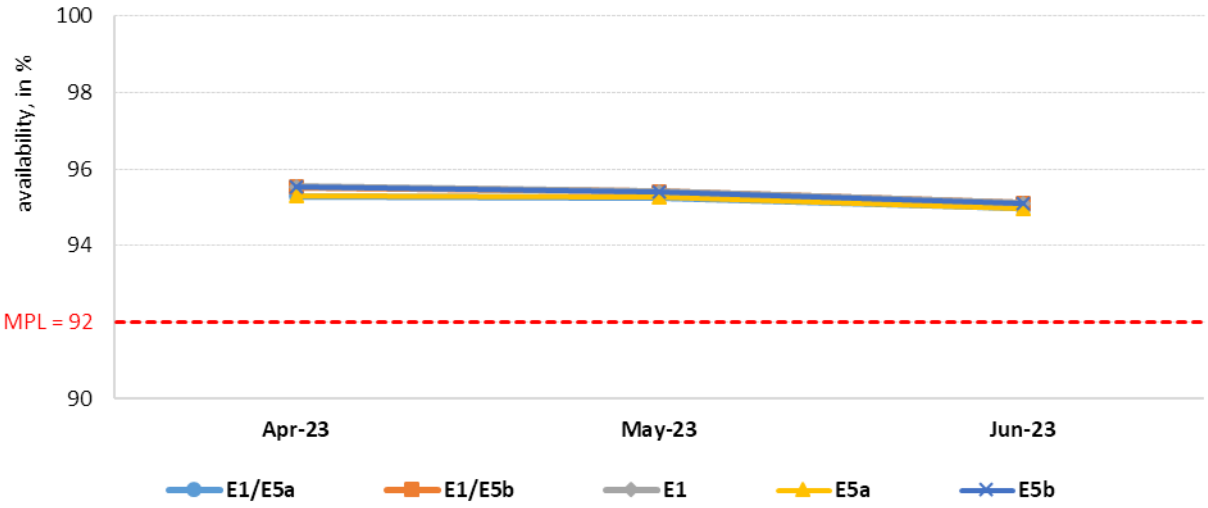


Figure 1: "per slot" availability of healthy signal in space for the reporting period (annually normalised)

Figure 2 provides the SIS "per slot" availability of Galileo healthy signals in space, averaged over the entire constellation during each month, but not normalised; as such, this performance measure is not subject to an MPL target and is provided for info:

[4] The [OS-SDD] foresees an "annual normalisation", which is implemented with a moving average over twelve months. Monthly figures consider only those space vehicles that are declared active members of the constellation during the whole month.

[5] Ref.: [OS-SDD] §3.4.1 (Table 13)

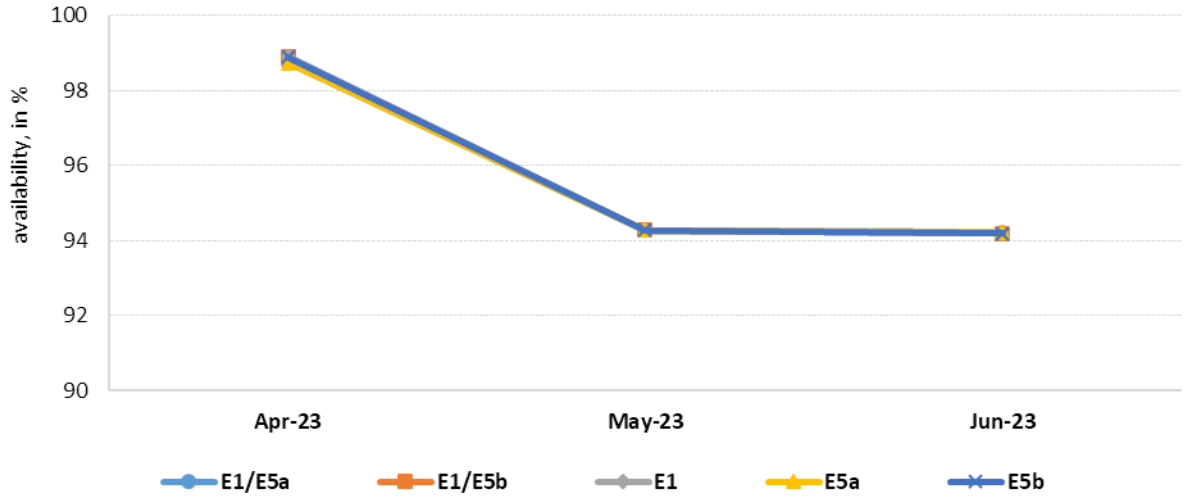


Figure 2: "per slot" availability of healthy signal in space for the reporting period, not normalised (monthly values)

The availability of Galileo healthy SIS, evaluated individually per frequency combination, satellite and month (without any averaging/normalisation), again not subject to an MPL target, is shown in Figure 3.

During the quarter, referring only to satellites occupying nominal orbit slots, such availability never achieved 100% simultaneously, for all space vehicles. General NAGU 2022037 warned users about the forth-coming update of the on board S/W of multiple Galileo space vehicles, according to Galileo service notice #11 [SvNOTE #11].

We can comment Figure 3, providing explanation for most relevant cases (healthy SIS availability lower than 90%):

April - GSAT0209 (E09), **80.08**%, all SIS

- **GSAT0209** (**E09**) was subject to multiple planned operations, being unavailable:
  - on 06/04/2023, from 14:00 until 15:05 UTC (ref.: NAGUs 2023025, 2023026);
  - on 11/04/2023 from 12:00 to 12:51 UTC (ref.: NAGUs 2023027, 2023028);
  - from 18/04/2023 @ 03:00 to 24/04/2023 @ 03:00 UTC (ref.: NAGUs 2023029, 2023030, 2023031).

May - GSAT0212 (E03): **68.39**%, all SIS; GSAT0210 (E01): **0**%, all SIS

- **GSAT0212** (**E03**), had a planned outage from 09/05/2023 @ 01:00 to 18/05/2023 @ 20:25 UTC (ref.: NAGUs 2023033, 2023034);
- **GSAT0210** (**E01**), not usable since 30/04/2023 @ 00:52 UTC (ref.: NAGU 2023032), was in outage over the whole month.

June - GSAT0214 (E05): **84.79**%, all SIS; GSAT0218 (E31): **87.19**%, all SIS; GSAT0210 (E01): **0**%, all SIS

- **GSAT0214** (**E05**), had planned outage from 20/06/2023 @ 04:38 to 24/06/2023 @ 18:21 UTC (ref.: NAGUs 2023035, 2023037);
- **GSAT0218** (**E31**), had planned outage: from 27/06/2023 @ 03:30 to 01/07/2023 @ 11:10 UTC (ref.: NAGUs 2023036, 2023039);
- **GSAT0210** (**E01**), continually not usable, over the whole month.

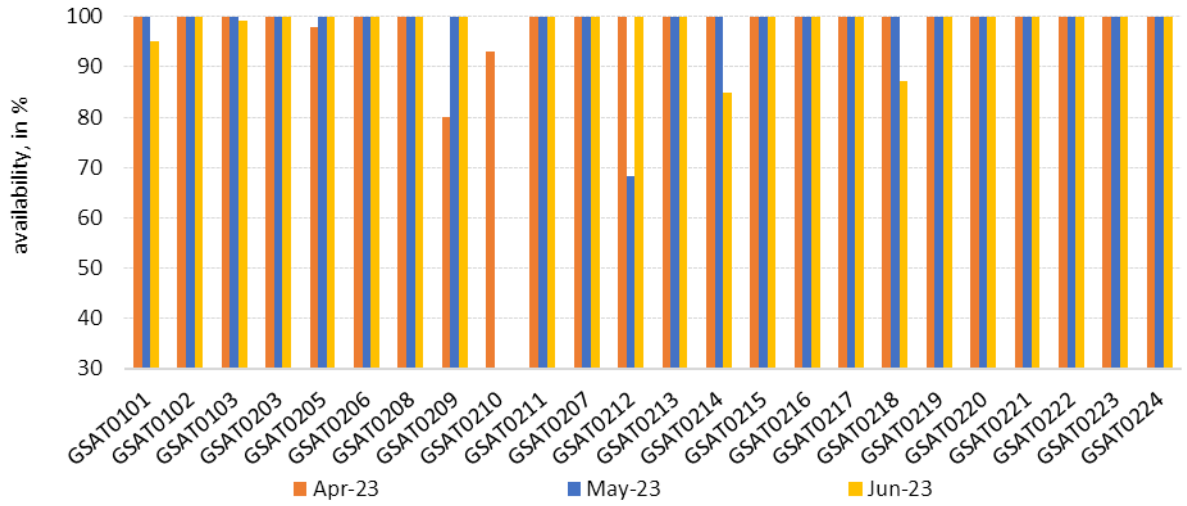


Figure 3: “per satellite” worst-case signal in space availability of healthy signal in space for the reporting period

Figure 4 provides the monthly percentage of availability of "N" space vehicles simultaneously transmitting a healthy SIS, with age of ephemeris less than or equal to four hours. Auxiliary satellites are included, in the case that they are declared available for service provision.

Please note that, in most cases, the unavailability of healthy SIS depends on planned operations, as described by NANUs in section 6. This involved multiple space vehicles during the quarter (E03, E05, E09, E31, E33). The only relevant unplanned outage concerns with GSAT0210 (E01), totalising over 60 days of Service unavailability.

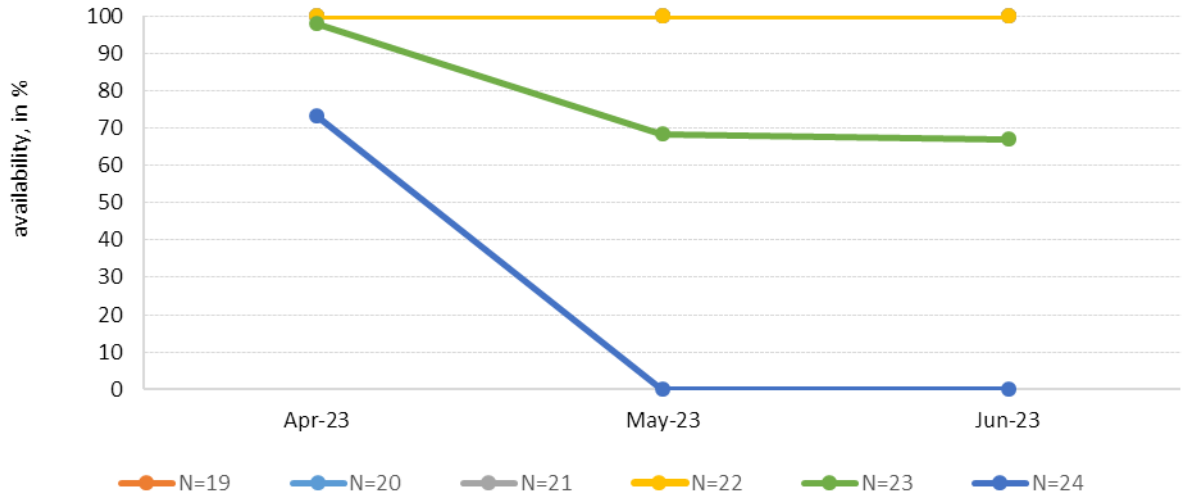


Figure 4: monthly percentage of availability of "N" space vehicles transmitting a healthy signal in space

3.2 GALILEO SIGNAL IN SPACE RANGING ACCURACY

The Galileo Signal In Space Error (SISE) vector provides the instantaneous difference between the Galileo satellite position/clock offset as obtained from the broadcast Navigation message, and the "true" satellite position/clock offset.

The true orbit path and clock performance are precisely reconstructed using sophisticated tools. When projecting SISE to the user location, the obtained scalar value is also named ranging accuracy and represents the ranging error affecting a user receiver.

The following figures show the 95th percentile of the monthly global average of the instantaneous ranging accuracy, achieved for each Galileo operational satellite and single-/dual-frequency combinations. Projection of SISE is implemented at the nodes of a virtual grid, representing all user locations within the navigation service coverage area.

Any signals carrying navigation message information with age of time of ephemeris beyond the validity period of four hours are filtered out, as per [OS-SDD] and explained in section 5.3.

Figure 8 and Figure 10 show the monthly 95% confidence level metric for Galileo signal in space ranging accuracy, to be compared against the MPL target levels. Computation is applied "for any space vehicle", over all satellites [6] and frequency combinations 7, achieving the following results:

- for individual space vehicles in **April**, worst case values of **0.35** m for dual-frequency and **1.30 m** for single-frequency. The best-case values over the month are **0.15** m and **0.30** m, respectively.
- for individual space vehicles in **May**, worst case values of **0.33** m for dual-frequency and **1.16** m for single-frequency. The best-case values over the month are **0.14** m and **0.30** m, respectively.
- for individual space vehicles in **June**, worst case values of **0.31** m for dual-frequency and **0.86** m for single-frequency. The best-case values over the month are **0.14 m** and **0.24** m, respectively.

In order to achieve a better view of Galileo ranging performance, Figure 6 provides the worst-case ranging accuracy values at both 95% confidence level (as per [OS-SDD] MPL) and at 99.9% confidence level, the latter value not being subject to any target and given for information only.

During the quarter, a slight degradation of ranging accuracy for single-frequency is observed, affecting multiple space vehicles. This is due to an increase of solar activity, determining a worsening in the quality of Broadcast Group Delays (BGDs).

[6] Satellites in nominal slots plus auxiliary satellites.

[7] Graphics provide worst-case among all SIS (for single-frequency) or between E1-E5a / E1-E5b for dual-frequency combinations

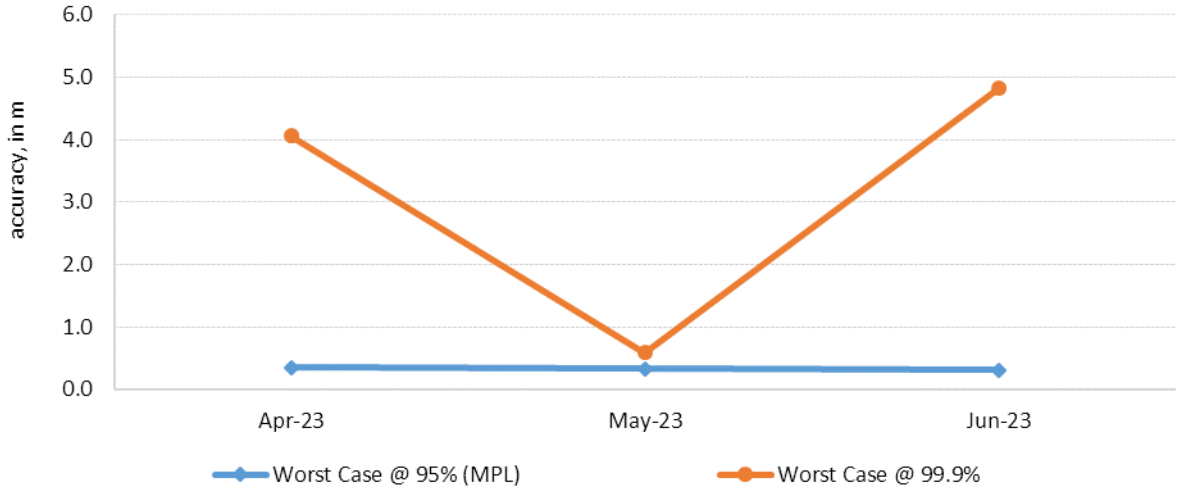


Figure 5: worst-case, monthly Galileo signal in space ranging accuracy (at 95th and 99.9th confidence level percentiles) for any satellite and any signal in space (dual frequency)

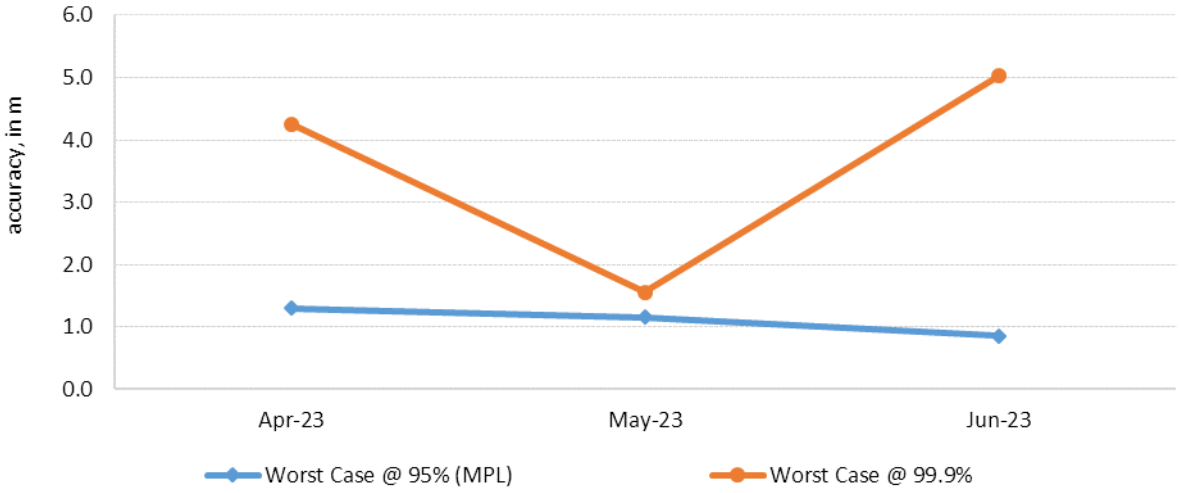


Figure 6: worst-case, monthly Galileo signal in space ranging accuracy (at 95th and 99.9th confidence level percentiles) for any satellite and any signal in space (single frequency)

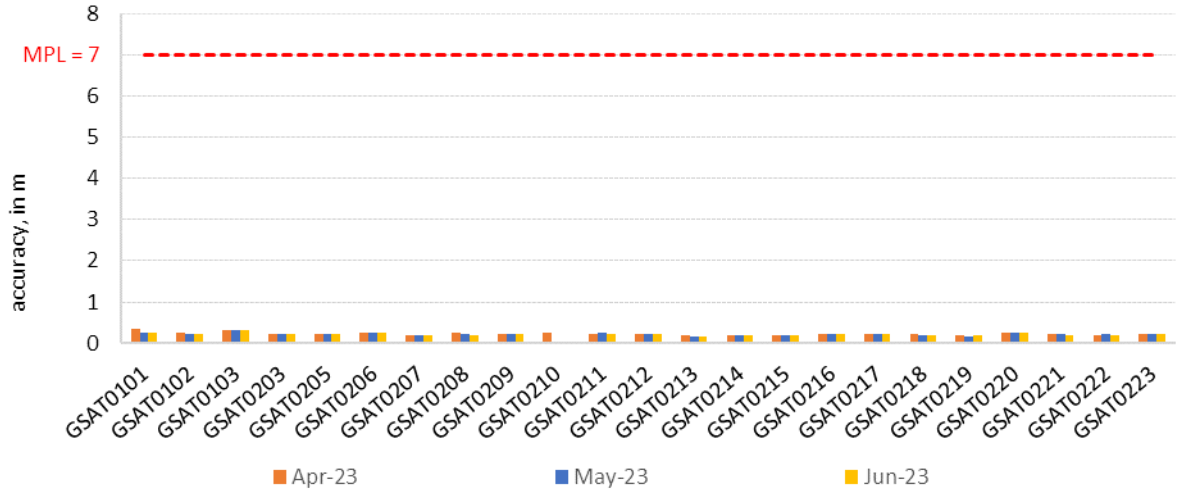


Figure 7: monthly Galileo signal in space ranging accuracy (95th percentile) for any satellite, measured during reporting period for worst-case (dual frequency) against MPL (minimum performance level)

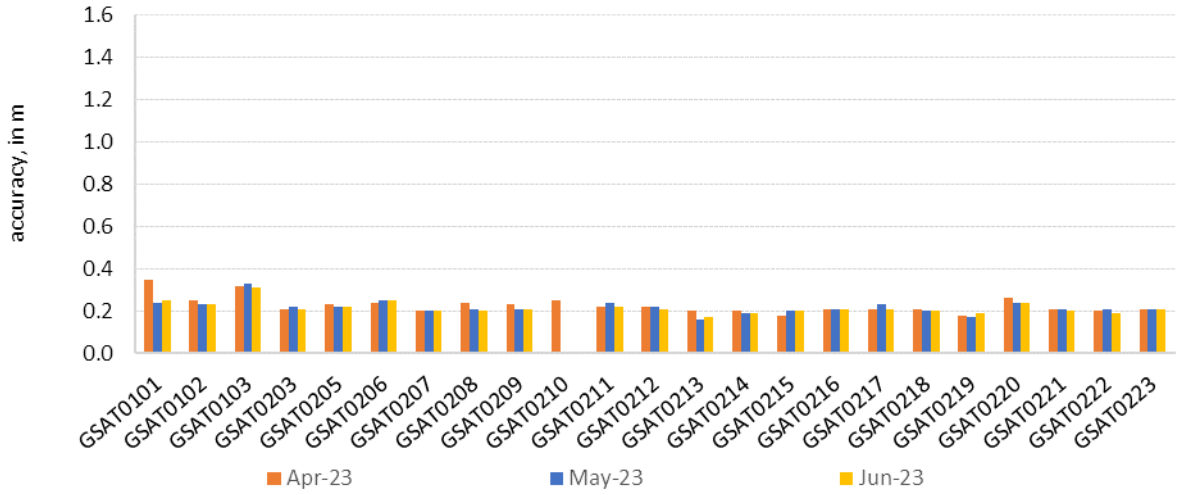


Figure 8: monthly Galileo signal in space ranging accuracy (95th percentile) for any satellite, measured during reporting period for worst-case (dual frequency) – zoom in

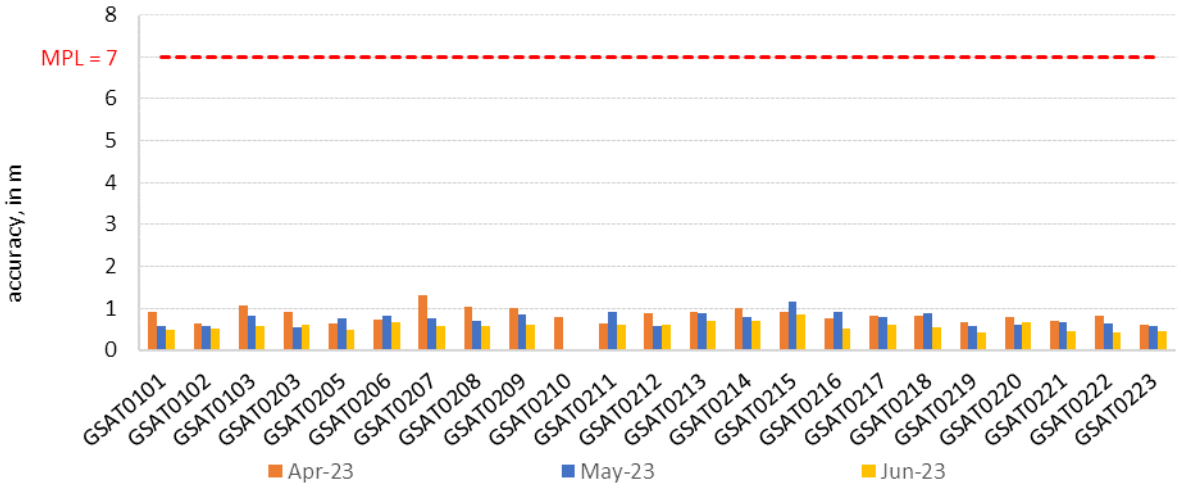


Figure 9: monthly Galileo signal in space ranging accuracy (95th percentile) for any satellite, measured during reporting period for worst-case (single frequency) against MPL (minimum performance level)

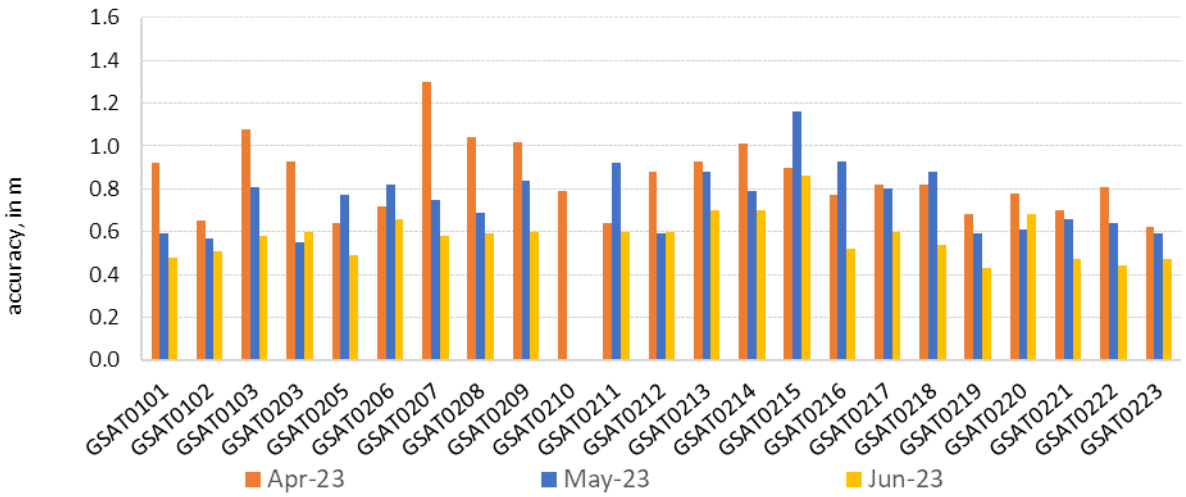


Figure 10: monthly Galileo signal in space ranging accuracy (95th percentile) for any satellite, measured during reporting period for worst-case (single frequency) – zoom in

Compliance with the MPL in [OS-SDD], referring to 95% confidence level, is achieved in all cases, with a specified maximum threshold of **7 m** [8] for the monthly performance of each individual satellite.

Figure 11 depicts the average "over all satellites" (constellation mean). Again, the [OS-SDD] MPL target of **2** m [9] is met by the constellation average value.

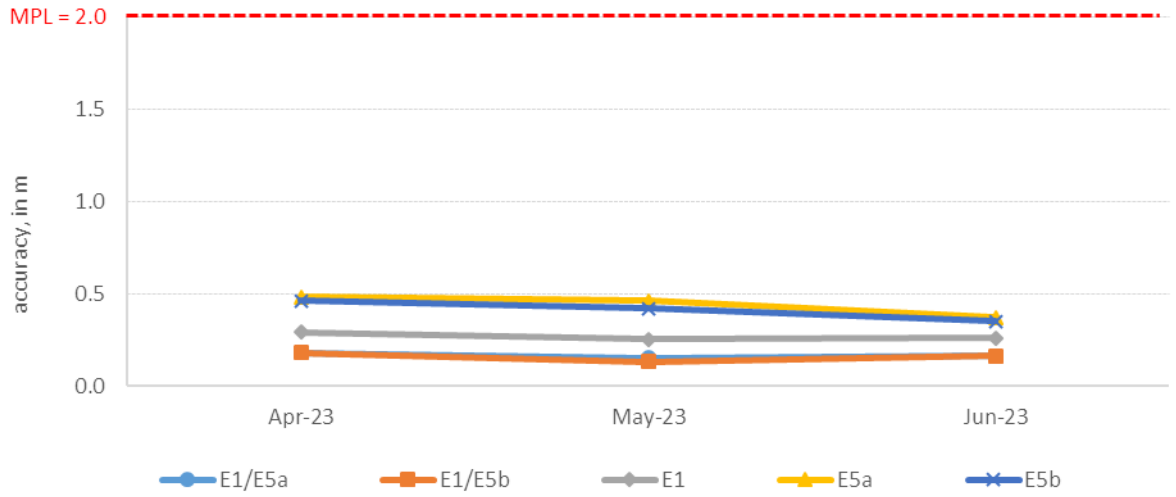


Figure 11: monthly Galileo signal in space ranging accuracy (95th percentile) over all satellites (constellation average), measured during the reporting period

[8] Ref.: [OS-SDD] §3.3.1 (Table 9)
[9] Ref.: [OS-SDD] §3.3.1 (Table 10)

4 UTC AND GGTO DISSEMINATION AND DETERMINATION PERFORMANCE

In this section of the report the following performance figures are provided:

- Availability of the Galileo Time Correlation Parameters and of UTC Determination;
- Accuracy of Galileo Time Correlation Parameters.

4.1 AVAILABILITY OF THE GALILEO TIME CORRELATION PARAMETERS AND OF UTC DETERMINATION

The **availability** of the Galileo Universal Time Coordinated (**UTC**) **time dissemination service** is defined as the percentage of time that the system provides at least one healthy ranging/timing signal in space above a minimum elevation angle of 5 degrees. Figure 12 provides the WUL availability of such service, computed for a virtual grid of user positions over the service coverage area.

As shown, the monthly (short-term) availability of the Galileo **UTC dissemination service** achieved **100**% during all three months of the reporting period. The MPL target of **95**% [10] prescribed by the [OS-SDD] is therefore fulfilled with the maximum margin.

Regarding the commitment concerning the **availability of UTC time determination service** with the assigned accuracy threshold of 31 ns, results for the observation period are given in Figure 13, with a required percentage of success increased to **95**% [11]. The target for availability is also met, with an availability of **100**% during the entire quarter.

The availability of Galileo to GPS Time Offset (GGTO) determination is the percentage of time that the system provides at least one non-dummy GGTO[12] set of coefficients within the navigation message, acquiring SIS from a space vehicle seen above a minimum elevation angle of five degrees.

Figure 14 gives the **availability of the GGTO determination** for WUL, computed for a virtual grid of user positions over the service coverage area. The MPL of **80%** [13] specified by [OS-SDD] for the monthly performance is fully achieved; the GGTO Determination capability was never reduced during the quarter, having an availability of **100**%. Please consider that, according to the [OS-SDD] in force, the computation of this figure does not foresee any longer an annual normalisation, opposite to the past.

[10] Ref.: [OS-SDD] §3.4.2 (Table 14)
[11] Ref.: [OS-SDD] §3.4.5 (Table 18)
[12] "Dummy" GGTO is defined in [OS-SDD] and in Galileo SIS ICD in terms of "all 1's" appearing in the GGTO parameters binary slot(s) carried by the navigation message.
[13] Ref.: [OS-SDD] §3.5.1.2 (Table 20)

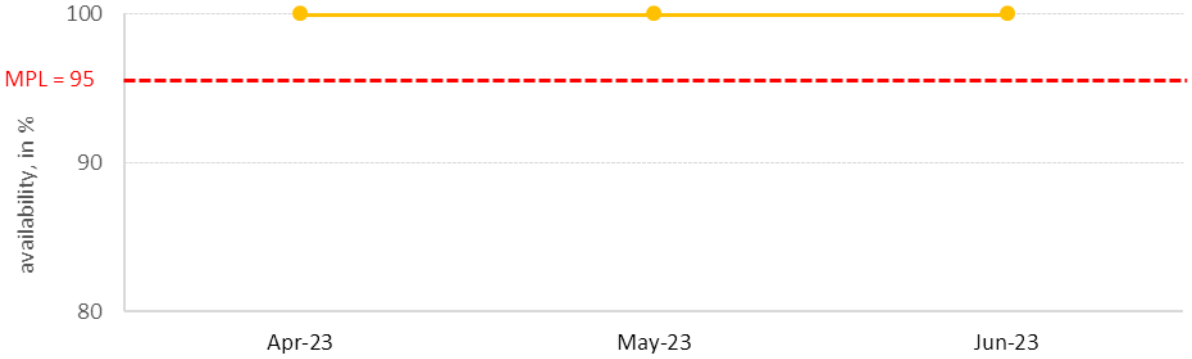


Figure 12: monthly availability of the UTC dissemination service during the reporting period

Figure 13: monthly availability of the UTC determination ≤ 31 ns during the reporting period

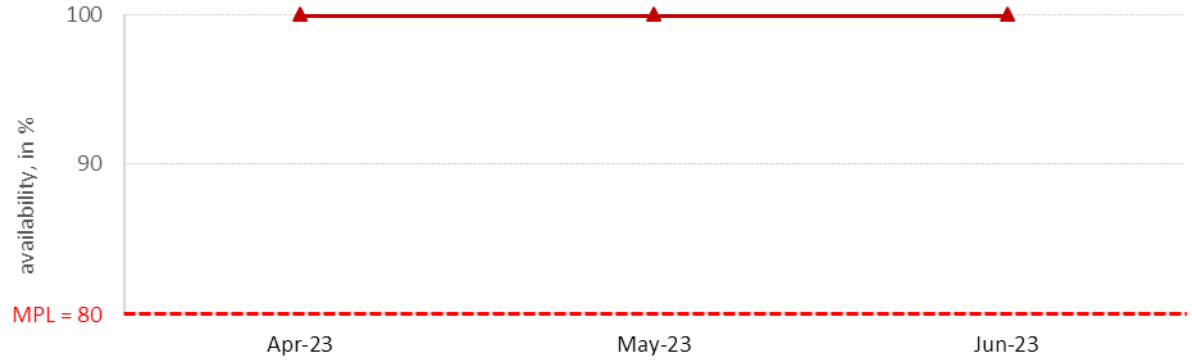


Figure 14: monthly availability of the GGTO determination, during the reporting period

4.2 ACCURACY OF GALILEO TIME CORRELATION PARAMETERS

The Galileo SIS **UTC time dissemination accuracy** and the Galileo SIS **UTC Frequency Dissemination Accuracy** are computed as the daily average error of the normalised time and frequency offset relative to UTC for a user equipped with a standard timing/calibration laboratory receiver [14].

According to the [OS-SDD] in force since December 2021, figures are not any more annually normalised.

Figure 15 shows the 95th percentile of the daily average of the UTC dissemination accuracy [15], observed over each period of one month.

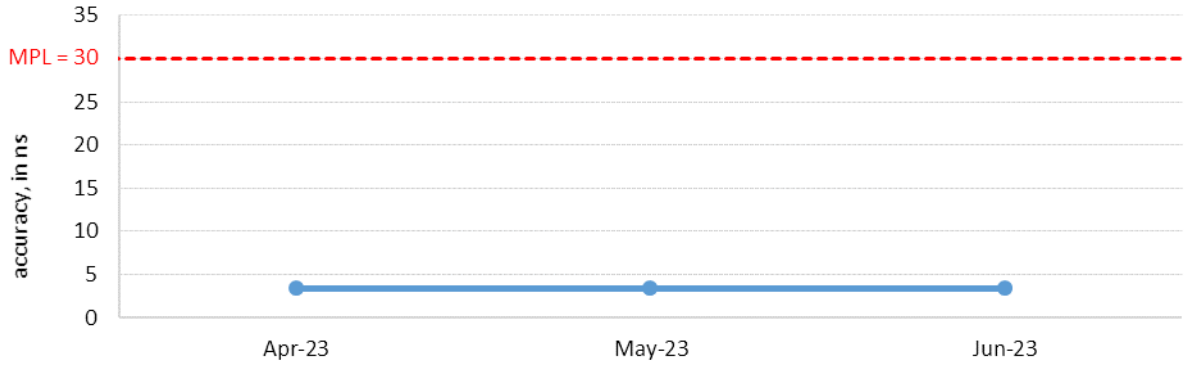


Figure 15: monthly UTC time dissemination accuracy (95th percentile) during the reporting period

As seen in Figure 15, the UTC dissemination accuracy achieves a very good performance level, with a constant offset of **3.42** ns, which is well below the [OS-SDD] MPL specification of **30** ns [15].

Figure 16 shows the 95th percentile of the UTC frequency dissemination accuracy, also in this case computed accumulating measurement data over a single month [16].

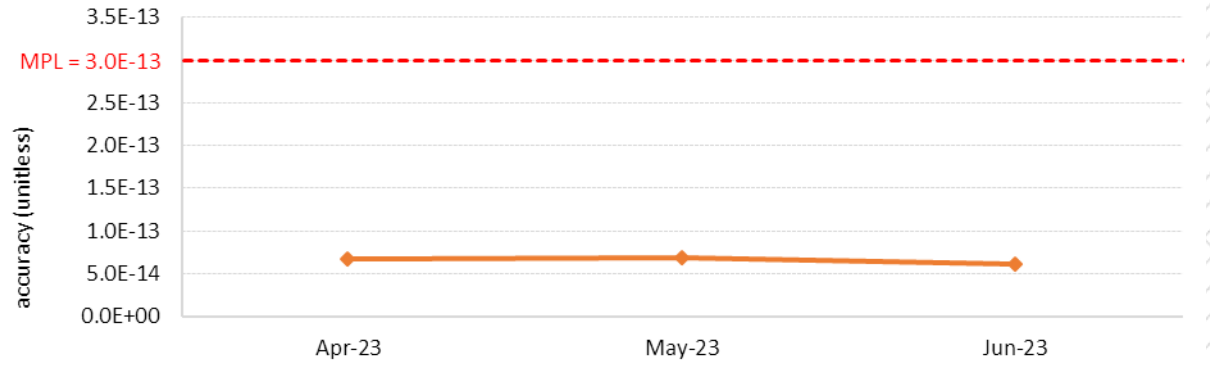


Figure 16: monthly UTC frequency dissemination accuracy (95th percentile) during the reporting period

[14] Note that the final UTC determination accuracy experienced by the user will also be affected by ranging errors, on top of the committed UTC dissemination accuracy

[15] Ref.: [OS-SDD] §3.3.3 (Table 11)

[16] Ref.: [OS-SDD] §3.3.3 (Table 12)

Regarding the UTC frequency dissemination accuracy, Figure 16 shows that the measured 95th percentile value is less than or equal to **6.8E−14**, which is almost an order of magnitude better than the [OS-SDD] MPL normalised annual ceiling of **3.0E−13** [16].

The **GGTO determination accuracy** is computed as the daily average of the difference between the GST-GPS time offset computed using the Galileo navigation message and the true GST-GPS time offset. Figure 17 shows the 95th percentile of the daily average of the GGTO determination accuracy, also again not any longer normalised annually [17]. The measured values are less than or equal to **2.76** ns in the whole quarterly reporting period. Figures are one order of magnitude better than the [OS-SDD] MPL threshold of **20** ns [17].

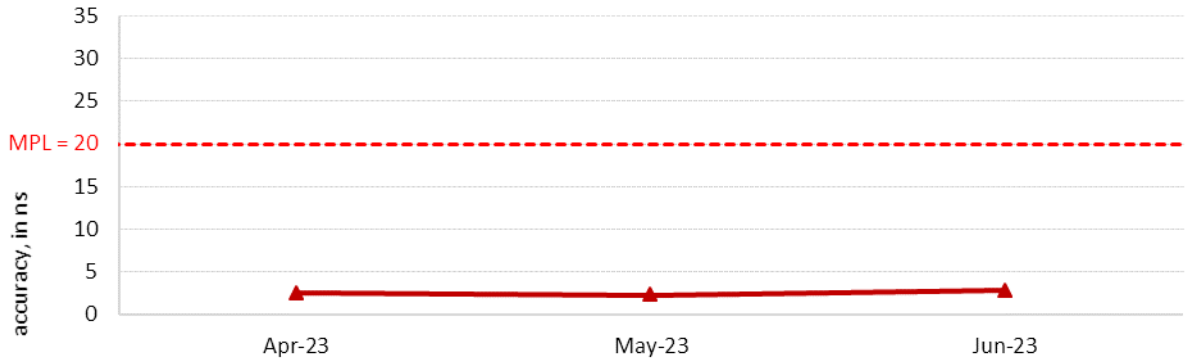


Figure 17: long-term 95th percentile of GGTO determination accuracy during the reporting period

[17] Ref.: [OS-SDD] §3.5.1.2 (Table 19)

5 GALILEO POSITIONING PERFORMANCE

In this section of the report, the following performance figures are provided:

- Availability of the Galileo Position Dilution of Precision;
- Availability of the Galileo Positioning Service;
- Galileo measured Positioning Performance.

These MPL parameters are reported considering only satellites in nominal slots; however, the improvement due to the usability of auxiliary space vehicles is also presented.

5.1 AVAILABILITY OF THE GALILEO POSITION DILUTION OF PRECISION

The applicable [OS-SDD] defines MPLs on the **availability of a (3D) PDOP** (Position Dilution of Precision) less than or equal to **six**. The target for AUL is **90**% [18], while the target for WUL is set to **87**%[18] .

Results are presented in Figure 18 and Figure 19, distinguishing between the cases of SIS carrying I/NAV or F/NAV messages.

With figures all greater than or equal to **98.56**%, the target value is met for the AUL, and exceeded with significant margin for the WUL.

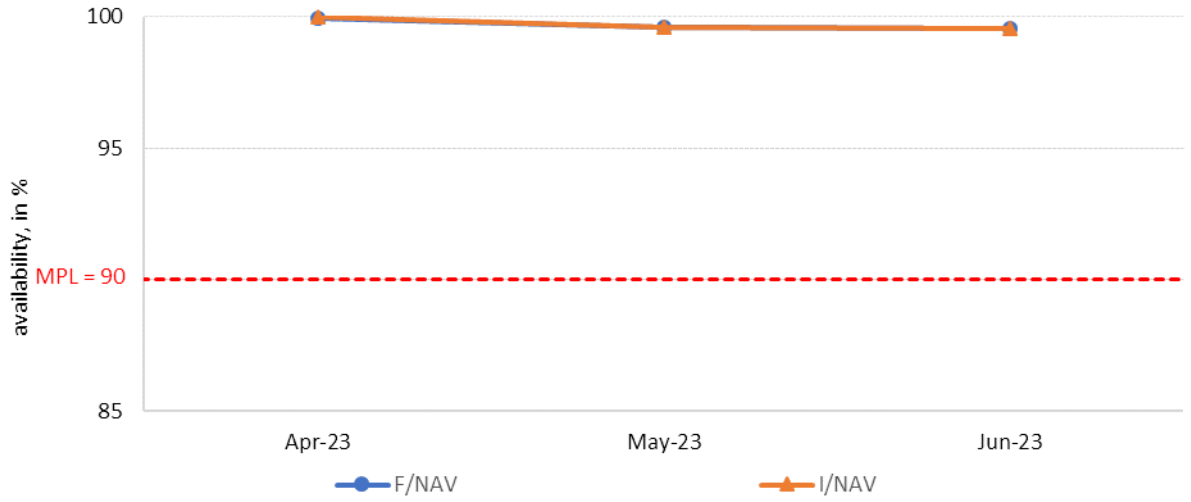


Figure 18: monthly availability of PDOP ≤ 6 at Average User Location (AUL) with F/NAV and I/NAV during the reporting period

[18] Ref.: [OS-SDD] §3.4.3 (Table 15)

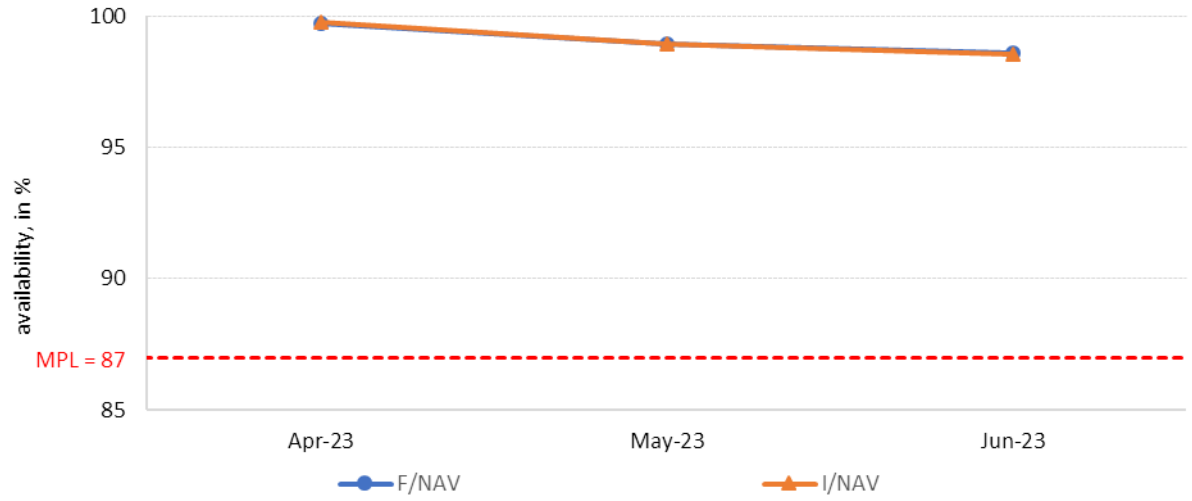


Figure 19: monthly availability of PDOP ≤ 6 at Worst User Location (WUL) with F/NAV and I/NAV during the reporting period

The usability of the auxiliary satellite GSAT0224 (E10) determines an increase in the availability percentages for PDOP ≤ 6, especially at the Worst User Location (WUL). The following figure depicts the achieved increments during the reporting quarter.

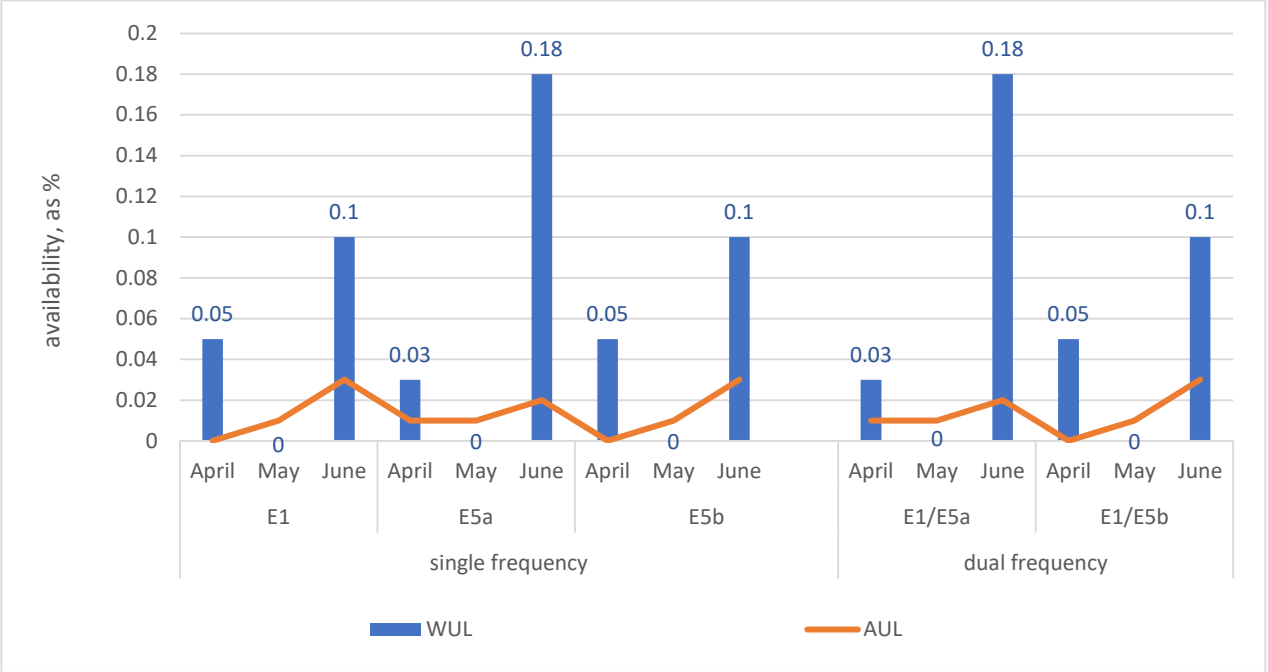


Figure 20: monthly availability of PDOP ≤ 6 – increment due to auxiliary satellite(s)

5.2 AVAILABILITY OF THE GALILEO POSITIONING SERVICE

The [OS-SDD] defines the **availability of positioning**, under the condition that location error due to system contribution is required to be not worse than **7.5** m for the horizontal positioning error (HPE), and not worse than **15** m for the vertical positioning error, evaluated at 95%.

Different targets are assigned: increased to **87**% [19] at WUL, and to **90**% [20] for the AUL.

The achieved results are shown separately for the case of worst single-frequency SIS (E1, E5a, E5b) and of worst dual-frequency combination (E1-E5a, E1-E5b) in the following Figure 21 and Figure 22. The target values are met with large margins, given that figures all greater than or equal to **99.27**%.

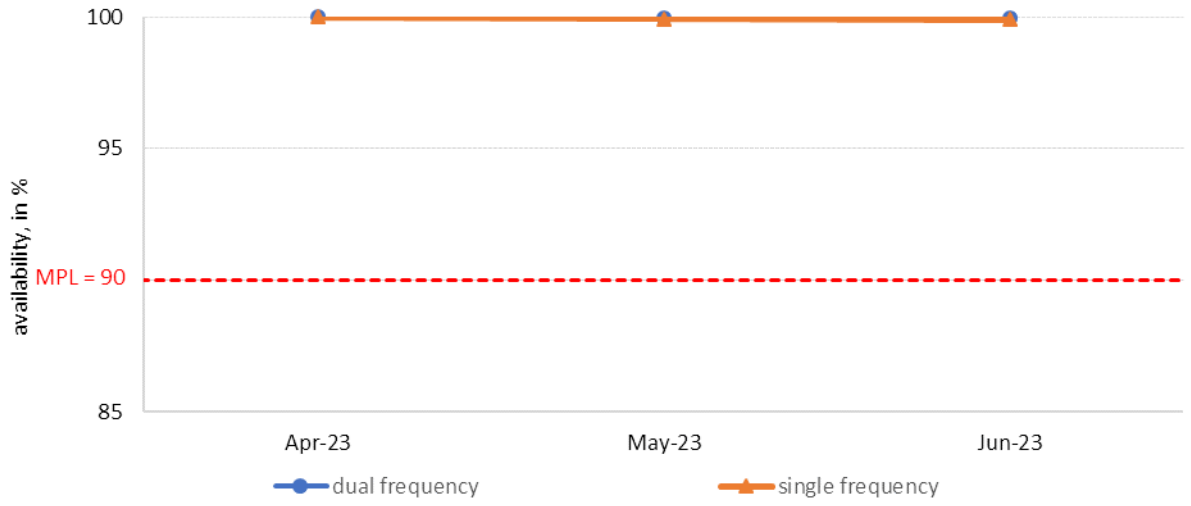


Figure 21: availability of positioning at Average User Location (AUL) for single and dual frequency during the reporting period

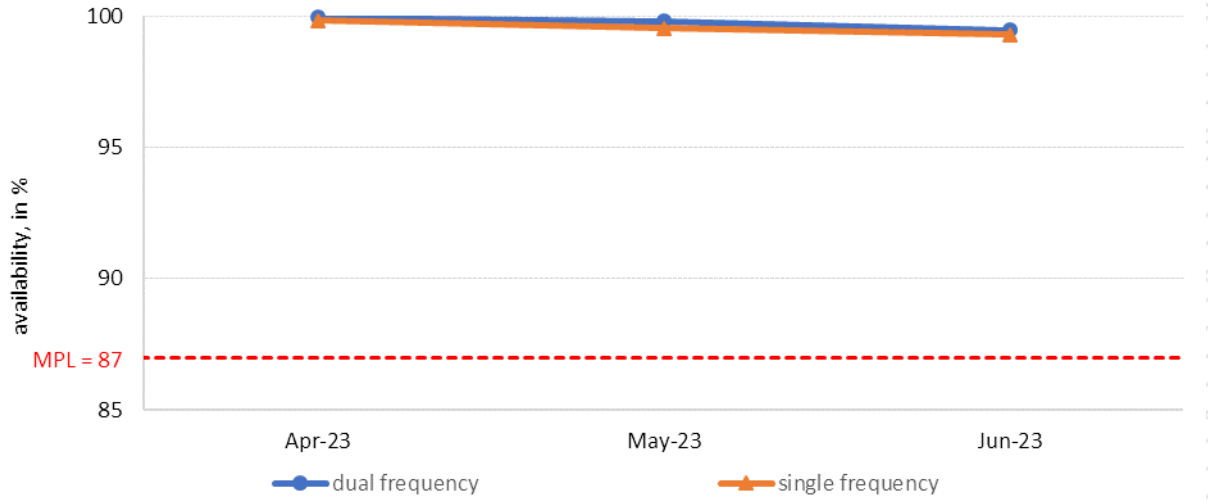


Figure 22: availability of positioning at Worst User Location (WUL) for single and dual frequency during the reporting period

[19] Ref.: [OS-SDD] §3.4.4 (Table 17)
[20] Ref.: [OS-SDD] §3.4.4 (Table 16)

As seen in the case of PDOP, the availability of the auxiliary satellite GSAT0224 (E10) determines as well an increase in the availability percentages for positioning with target thresholds on HPE and VPE. The effect is particularly evident for the Worst User Location (WUL), as shown in the following figure.

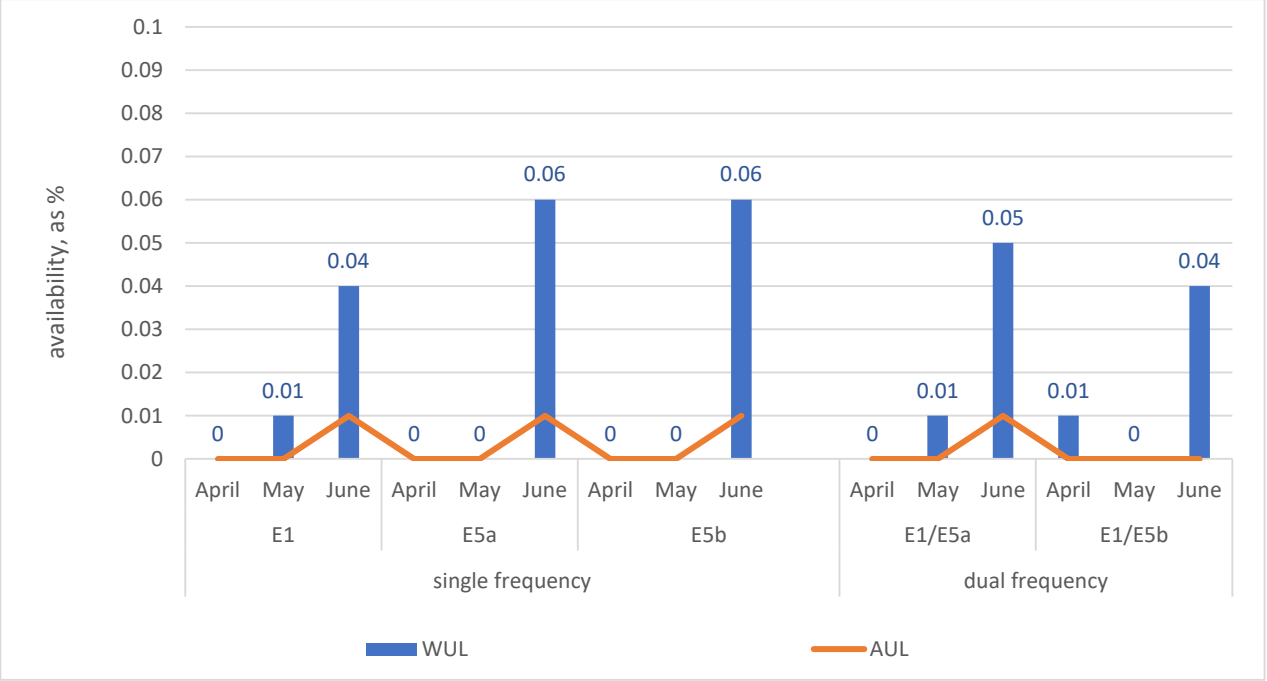


Figure 23: availability of positioning – increment due to auxiliary satellite(s)

5.3 GALILEO MEASURED POSITIONING PERFORMANCE

Although the Galileo Full Operational Capability (FOC) constellation is not yet completely deployed, since August 2019 the 3D positioning service achievable with the Galileo system is subject to a commitment regarding the availability for given positioning accuracy targets, as reported in the previous section 5.2.

In addition, this section provides navigation sensor error estimates for a full (3D) solution of navigation equations, i.e.: the horizontal and vertical positioning accuracy performance based on real measurements, collected over a number of test receivers, solving for user coordinates with a constraint of PDOP ≤ 6 and following [OS-SDD] recommendations regarding SIS health status and "age of ephemeris" [21].

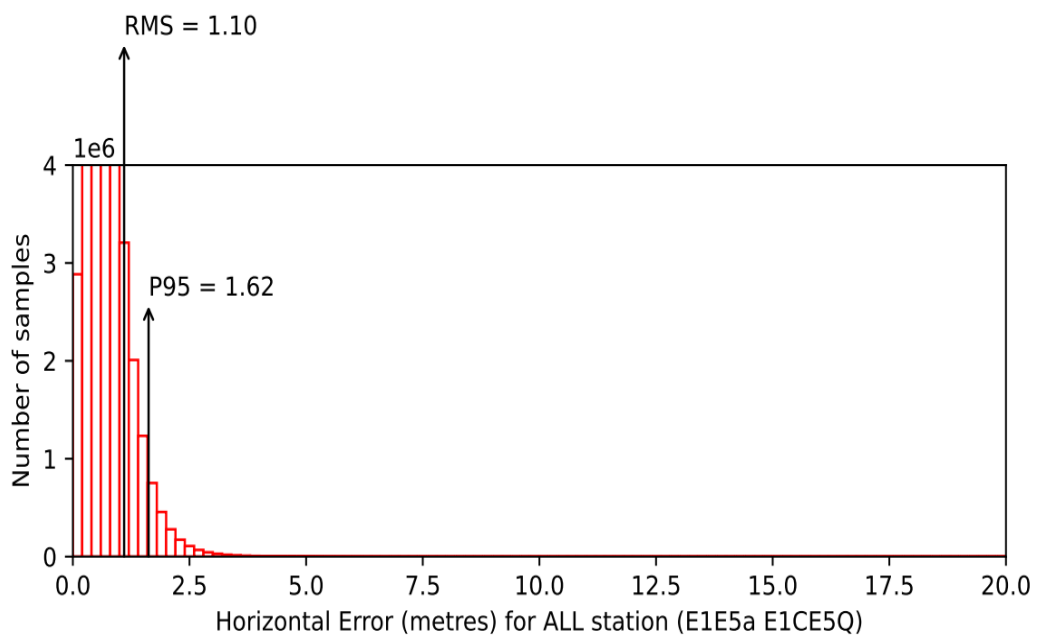
As specified in the [OS-SDD], navigation message coefficients with an "age of ephemeris" beyond four hours are no longer considered valid, so that ranging observables from the corresponding satellite and signal should not be used for positioning and/or time measurement purposes.

Samples affected by local issues, thus not attributable to Galileo SIS, are no longer included in the reported results, based on the adoption of an automatic outlier detection filtering, which was introduced in April 2020.

In the following figures, the horizontal axis is limited on each plot to a maximum error of 20 metres. Each figure also reports the number of samples exceeding a horizontal or vertical error larger than 20 metres.

Positioning performance is reported considering only satellites in the nominal slots.

[21] The Time of Ephemeris (toE in the [OS-SDD]), also called ephemeris reference time (t_{0E} in the [SIS-ICD], section 5.1.1.), is disseminated in the navigation message, as part of the precision ephemeris set. The terms "age of ephemeris" mentioned by the [OS-SDD] and "time from ephemeris reference epoch" appearing in the [SIS-ICD] are equivalent.

April 2023	
HPE **3D Positioning** **E1-E5a (DF)** **F/NAV**	
Note: 20912 samples > 20 m, around 0.06% of total	

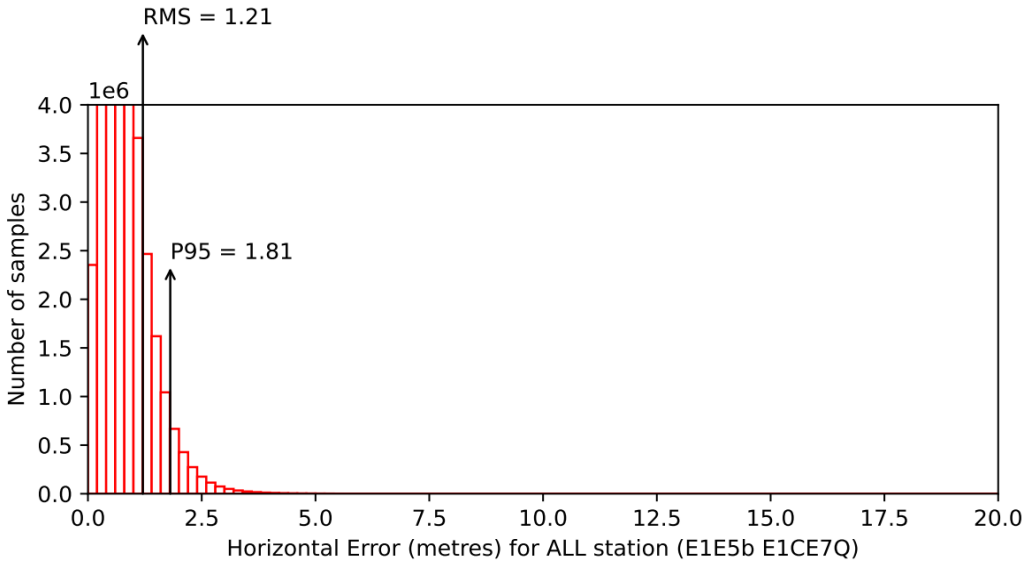
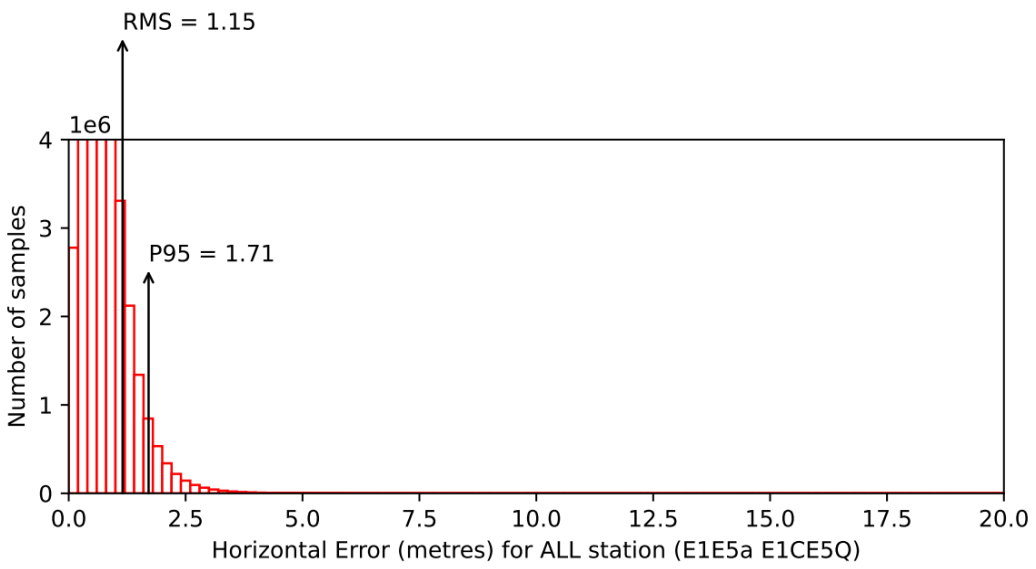
April 2023	
HPE **3D Positioning** **E1-E5b (DF)** **I/NAV**	
Note: 23339 samples > 20 m, around 0.07% of total	

Figure 24: Horizontal Positioning Error (HPE) for “Galileo-only” users in April 2023

May 2023	
HPE **3D Position-ing** **E1-E5a (DF)** **F/NAV**	
Note: 20042 samples > 20 m, around 0.06% of total	

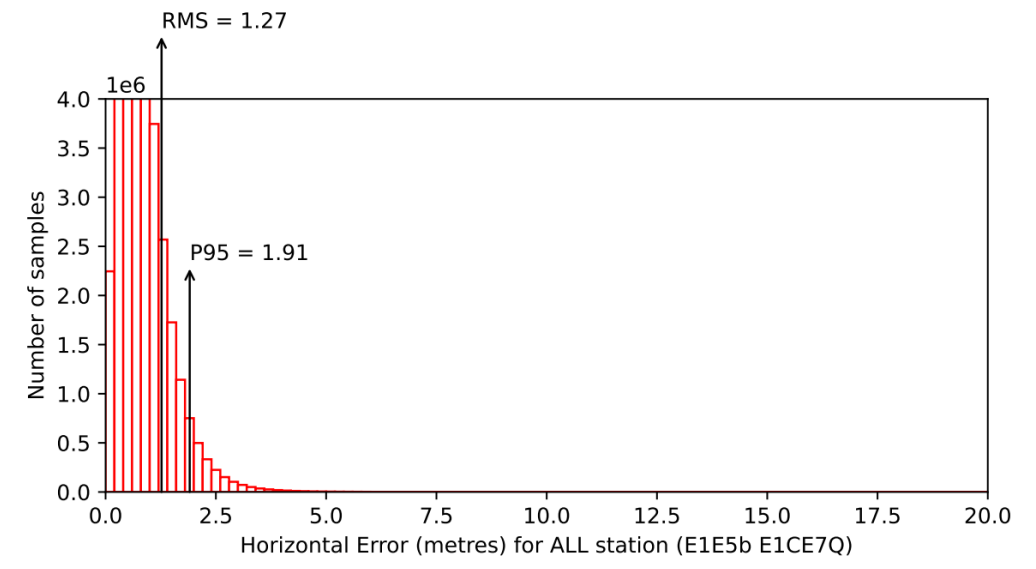
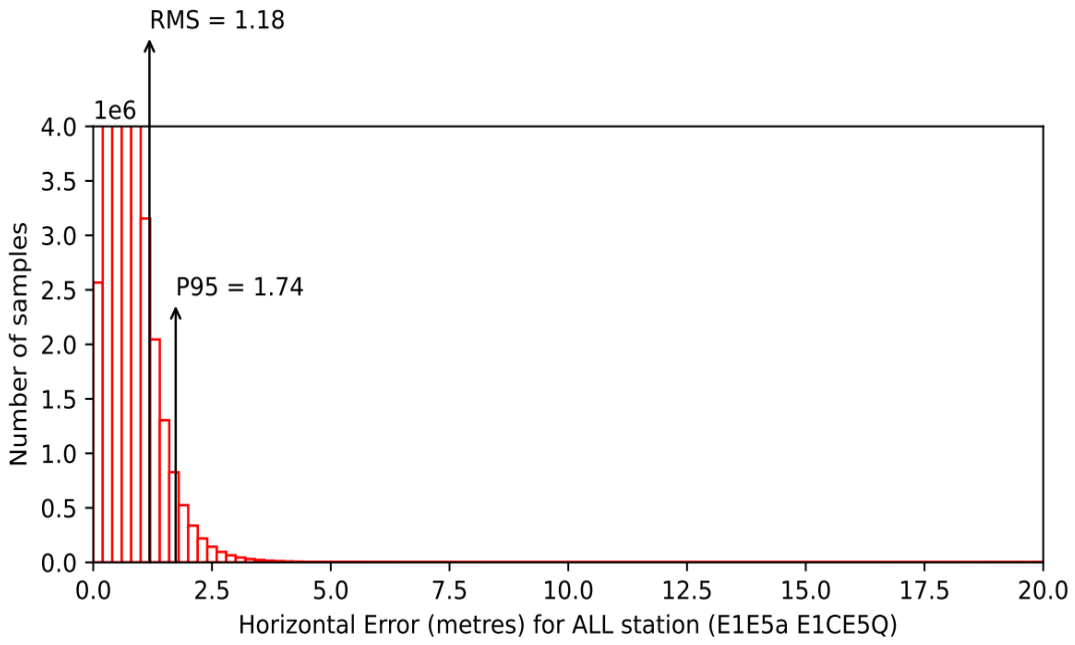
May 2023	
HPE **3D Positioning** **E1-E5b (DF)** **I/NAV**	
Note: 22168 samples > 20 m, around 0.06% of total	

Figure 25: Horizontal Positioning Error (HPE) for "Galileo-only" users in May 2023

June 2023	
HPE 3D Position-ing E1-E5a (DF) F/NAV	
Note: 22275 samples > 20 m, around 0.07% of total	

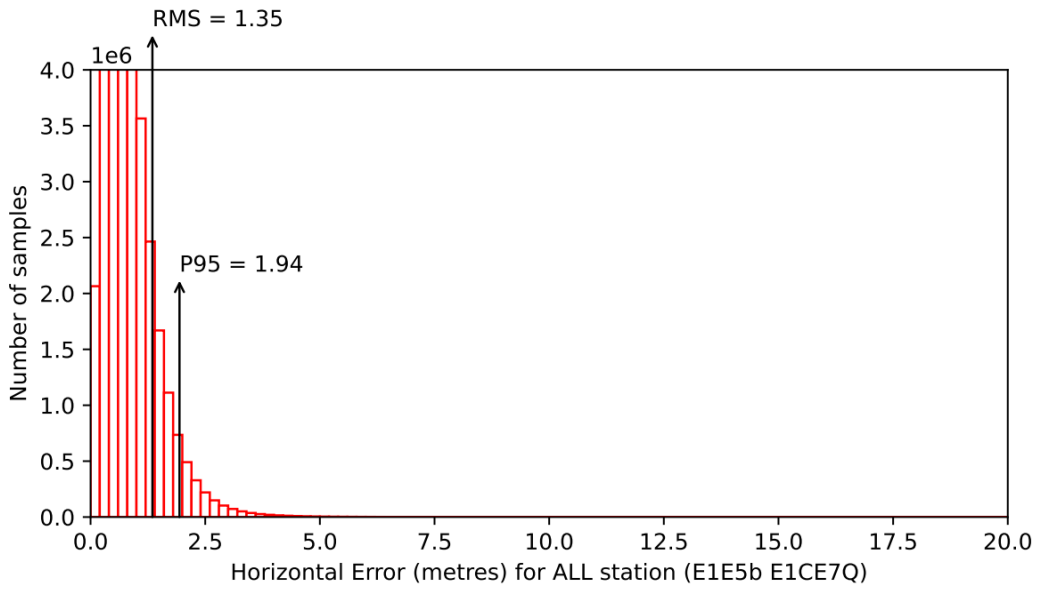
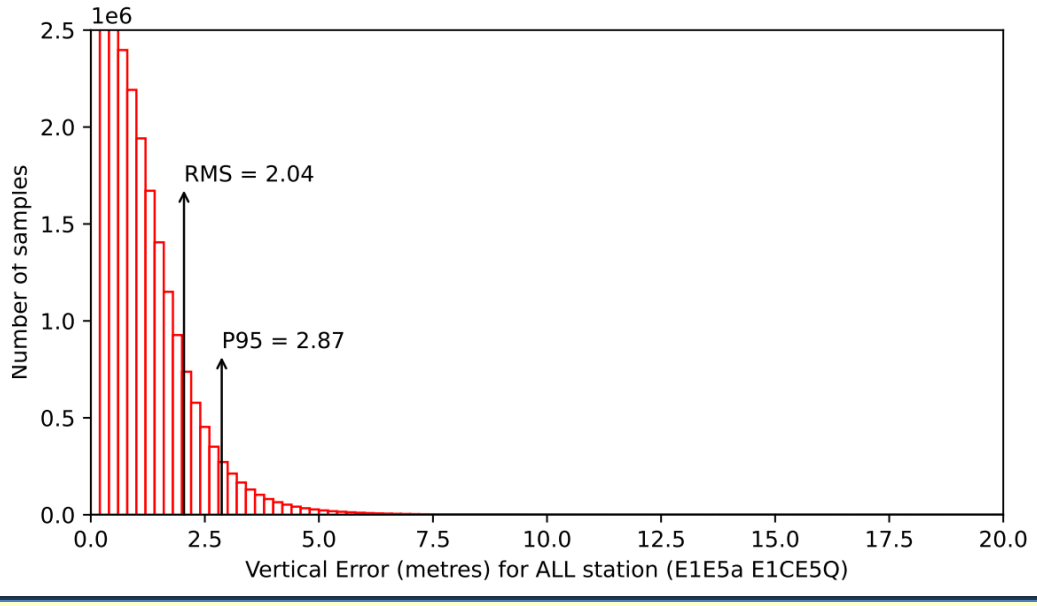
June 2023	
HPE 3D Positioning E1-E5b (DF) I/NAV	
Note: 28673 samples > 20 m, around 0.08% of total	

Figure 26: Horizontal Positioning Error (HPE) for "Galileo-only" users in June 2023

April 2023	
VPE 3D Positioning E1-E5a (DF) F/NAV	
Note: 29821 samples > 20 m, around 0.08% of total	

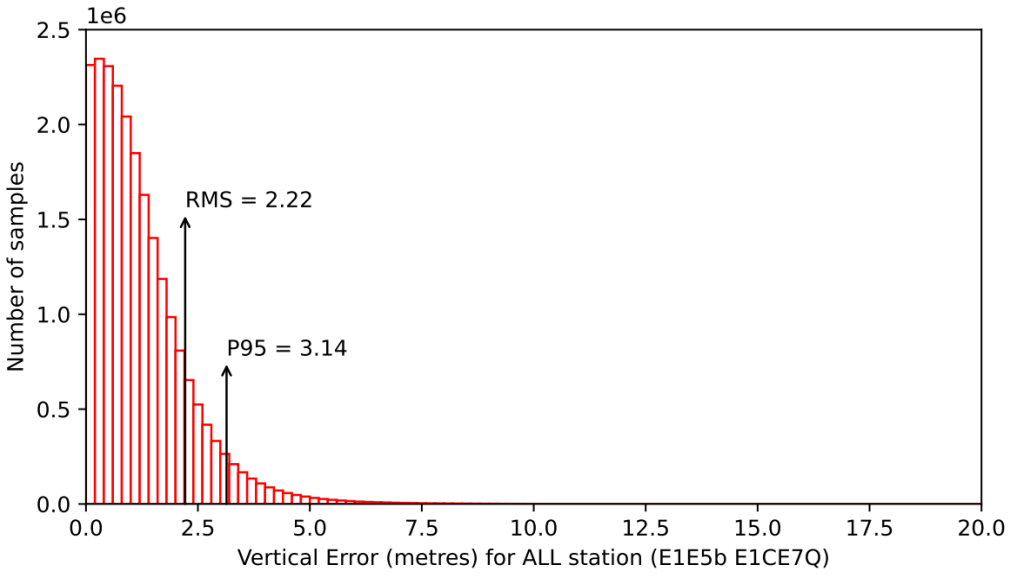
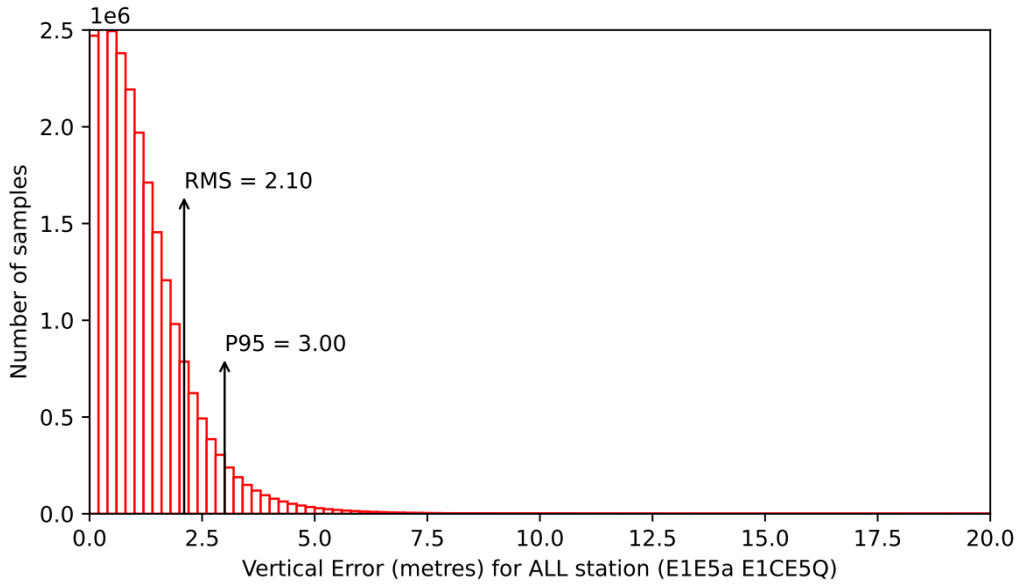
April 2023	
VPE 3D Positioning E1-E5b (DF) I/NAV	
Note: 31082 samples > 20 m, around 0.09% of total	

Figure 27: Vertical Positioning Error (VPE) for "Galileo-only" users in April 2023

May 2023	
VPE 3D Positioning E1-E5a (DF) F/NAV	
Note: 26696 samples > 20 m, around 0.07% of total	

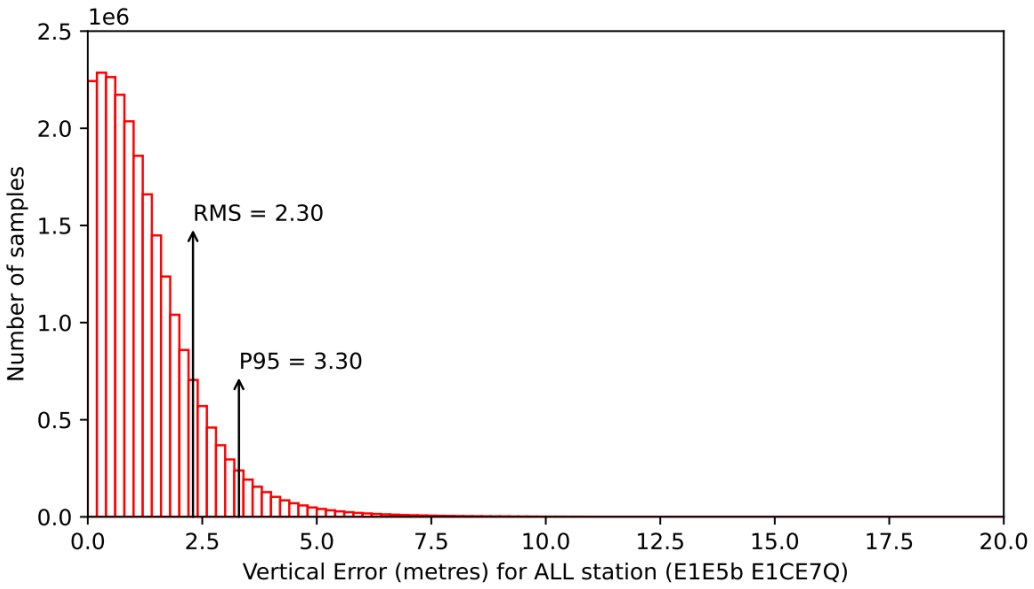
May 2023	
VPE 3D Positioning E1-E5b (DF) I/NAV	
Note: 28521 samples > 20 m, around 0.08% of total	

Figure 28: Vertical Positioning Error (VPE) for "Galileo-only" users in May 2023

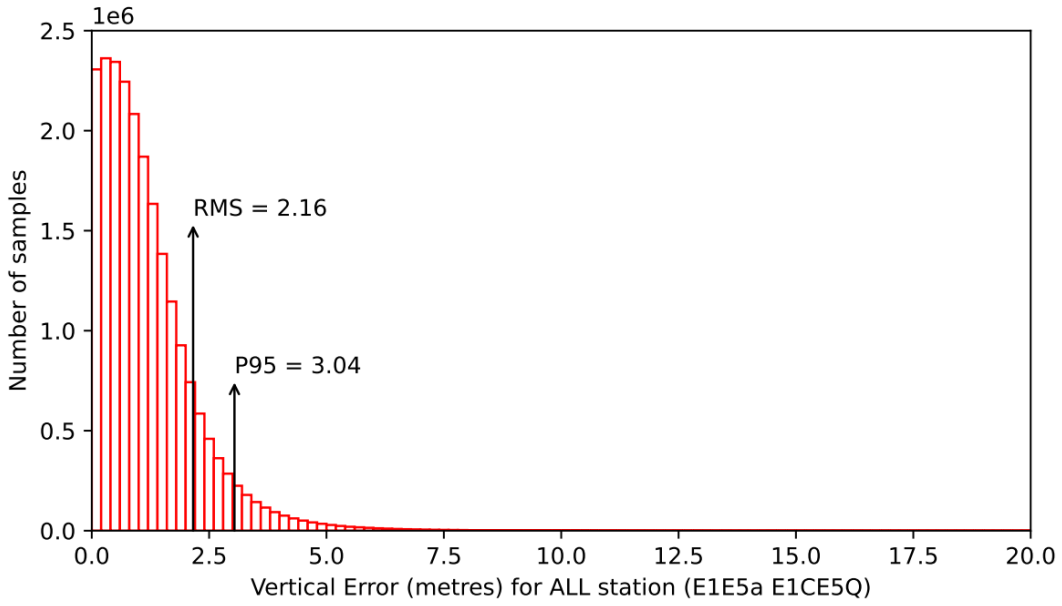
June 2023

VPE

3D Positioning

E1-E5a (DF)

F/NAV



Note: 30526 samples > 20 m, around 0.09% of total

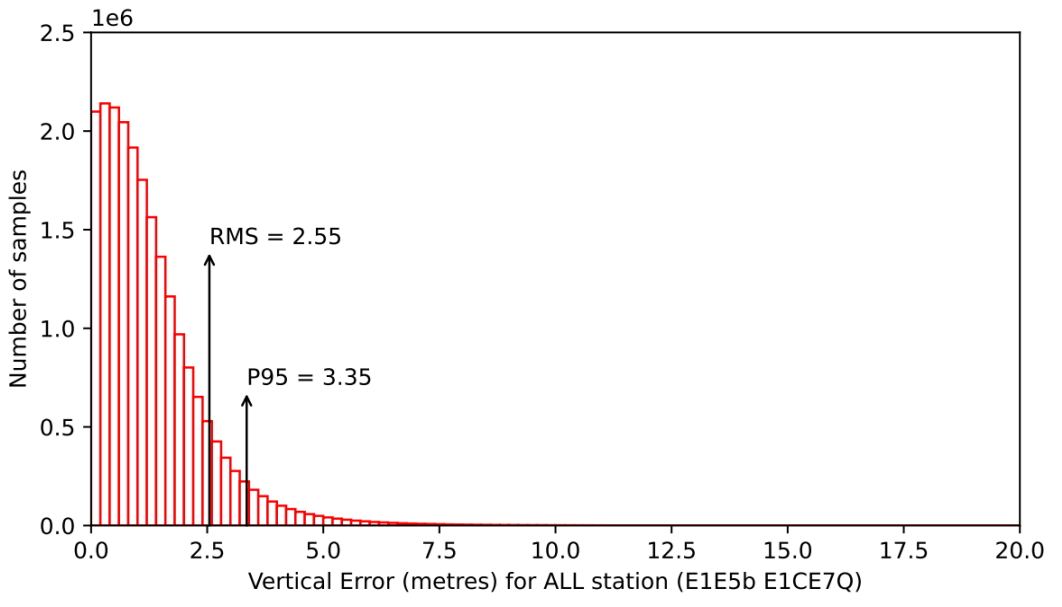
June 2023

VPE

3D Positioning

E1-E5b (DF)

I/NAV



Note: 41595 samples > 20 m, around 0.11% of total

Figure 29: Vertical Positioning Error (VPE) for "Galileo-only" users in June 2023

6 TIMELY PUBLICATION OF NOTICE ADVISORY TO GALILEO USERS (NAGUS)

The European GNSS Service Centre (GSC) is responsible for timely publication of Notice Advisory to Galileo Users (NAGU) messages on its web pages:

Table 6: Galileo Service Centre web pages for Notice Advisory to Galileo Users (NAGUs)

active NAGUs
https://www.gsc-europa.eu/system-status/user-notifications
archived NAGUs
https://www.gsc-europa.eu/system-status/user-notifications-archived

According to the [OS-SDD] in force, NAGUs related to planned events need to be published at least **48** hours [22] before the start of the event. For unplanned events, the [OS-SDD]specifies a delay of up to **30** hours [22] from the detection of the unplanned event until a corresponding NAGU is issued.

The summary of NAGUs that have been published during the reporting period is as per the following Table 7; NAGU publication timeliness requirements were met with large margins, as per figures reported in it.

During the quarter, **15** NAGUs have been published. In particular:

- in **April, 9 (nine)** NAGUs were issued. Three of them correspond to planned operations, all affecting GSAT0209 (E09). Five falling under category “unplanned”, announcing recovered usability for GSAT0205 (E24), GSAT0209 (E09), GSAT0210 (E01). One dealing with extension of a previous NAGU on unavailability of GSAT0209 (E09).
- in **May, 2 (two)** NAGUs were issued; one of category “planned” and affecting of GSAT0212 (E03), the other “unplanned”, dealing with the recovery of service provision by same space vehicle.
- in **June, 4 (four)** NAGUs have been published. 3 NAGUs have to do with “planned” outages, dealing with GSAT0214 (E05), GSAT0218 (E31), GSAT0222 (E33). One NAGU falls under category “unplanned”, announcing recovered usability for GSAT0214 (E05).

Table 7 provides a summary of published NAGUs during the quarter.

[22] Ref.: [OS-SDD] §3.6.1 (Table 21)

Table 7 : NAGUs published during the first quarter of 2023

month	NAGU type	reason for publishing	notice advisory ID	NAGU categ.*	timeliness
April					
	USABLE	Announcing the service recovery for GSAT0205 (E24), as of 01/04/2023 @ 15:26 UTC	2023024	**U**	Published **0.079** days (**01h:54m**) after the event
	PLN_OUTAGE	Warning about forthcoming unavailability of GSAT0209 (E09), as of 06/04/2023 @ 14:00 UTC	2023025	**P**	Published **2.94** days before the event
	USABLE	Announcing the service recovery for GSAT0209 (E09), as of 06/04/2023 @ 15:05 UTC	2023026	**U**	Published **0.080** days (**01h:55m**) after the event
	PLN_OUTAGE	Warning about forthcoming unavailability of GSAT0209 (E09), as of 11/04/2023 @ 12:00 UTC	2023027	**P**	Published **4.65** days before the event.
	USABLE	Announcing the service recovery for GSAT0209 (E09), as of 11/04/2023 @ 12:51 UTC	2023028	**U**	Published **0.090** days (**02h:09m**) after the event
	PLN_OUTAGE	Warning about forthcoming unavailability of GSAT0209 (E09), as of 18/04/2023 @ 03:00 UTC	2023029	**P**	Published **3.65** days before the event
	EXTNS	Announcing the extension of unavailability for GSAT0209 (E09)	2023030	**U**	Published **0.139** days (**03h:20**) after the decision taken by the SDM
	USABLE	Announcing the service recovery for GSAT0209 (E09), as of 24/04/2023 @ 03:00 UTC	2023031	**U**	Published **0.250** days (**06h:00m**) after the event
	USABLE	Announcing the service recovery for GSAT0210 (E01), as of 30/04/2023 @ 00:52 UTC	2023032	**U**	Published **0.318** days (**07h:38m**) after the event

month	NAGU type	reason for publishing	notice advisory ID	NAGU categ.*	timeliness
May					
	PLN_OUTAGE	Warning about forthcoming unavailability of GSAT0212 (E03), as of 09/05/2023 @ 01:00 UTC	2023033	**P**	Published **3.46** days before the event
	USABLE	Announcing the service recovery for GSAT0212 (E03), as of 18/05/2023 @ 20:25 UTC	2023034	**U**	Published **0.431** days (**10h:20m**) after the event
June					
	PLN_OUTAGE	Warning about forthcoming unavailability of GSAT0214 (E05), as of 20/06/2023 @ 04:38 UTC	2023035	**P**	Published **3.61** days before the event
	PLN_OUTAGE	Warning about forthcoming unavailability of GSAT0218 (E31), as of 27/06/2023 @ 03:30 UTC	2023036	**P**	Published **3.58** days before the event
	USABLE	Announcing the service recovery for GSAT0214 (E05), as of 24/06/2023 @ 18:21 UTC	2023037	**U**	Published **0.090** days (**02h:09m**) after the event
	PLN_OUTAGE	Warning about forthcoming unavailability of GSAT0222 (E33), as of 04/07/2023 @ 06:10 UTC	2023038	**P**	Published **3.55** days before the event

* NAGU categorisation for timeliness evaluation: **P** = planned, **U** = unplanned

7 GALILEO OSNMA PERFORMANCE

In November 2021, as per [SvNOTE #09], EUSPA officially initiated the OSNMA "Public Observation Test Phase", which involves the dissemination of a Test SIS and the active involvement of key stakeholders and interested parties. This allows receiver manufacturers, application developers and members of research institutions to access for the first time a real OSNMA data stream from the Galileo space segment.

EUSPA started a regular measurement of OSNMA key performance metrics applicable at this stage. Even if the parameters characterising the quality of delivered OSNMA Service are not currently subject to any MPL target, they are of interest and are reported starting with this quarterly report.

The main performance parameters currently detailed in the following are:

- OSNMA availability, measured as the percentage of time that the user is receiving OSNMA tags to perform a new authentication event, and this for the different navigation data types that are authenticated. Availability is measured for a Tag length of 80 bits. Please refer to the applicable Interface Control Document [OSNMA SIS-ICD] and the guidelines for the OSNMA implementation at user receiver [OSNMA Rx GL],
- percentage of OSNMA tag verification success. This characterisation is provided to allow developers to cross-check their observed authentication performance. Any root cause leading to MAC (Message Authentication Code) verification failures will be corrected for the service provision phase.

7.1 AVAILABILITY OF AUTHENTICATION TAGS

The following Navigation message authentication types are considered:

- **ADKD0** → for the Galileo I/NAV Orbit and Clock correction data of word types 1–5. Availability figure is measured as the percentage of time that at least 2×40 bit ADKD0 MACs can be accumulated for all space vehicles, within a period of 120 s and for at least four space vehicles, within a period of 120 s (the latter computed since May 2022).
- **ADKD4** → for the Galileo GST-UTC and GST-GPS conversion parameters. Availability figure is measured as the percentage of time that at least 2×ADKD4 MACs can be accumulated from at least one satellite, within a period of 60 s.
- **ADKD12** → for the Galileo I/NAV data of word types 1–5, targeting receivers with low synchronization requirements. Availability figure is measured as the percentage of time that at least 2×40 bit ADKD12 MACs can be accumulated from at least four satellites, within a period of 240 s.

Results obtained during the Quarter are shown in the following:

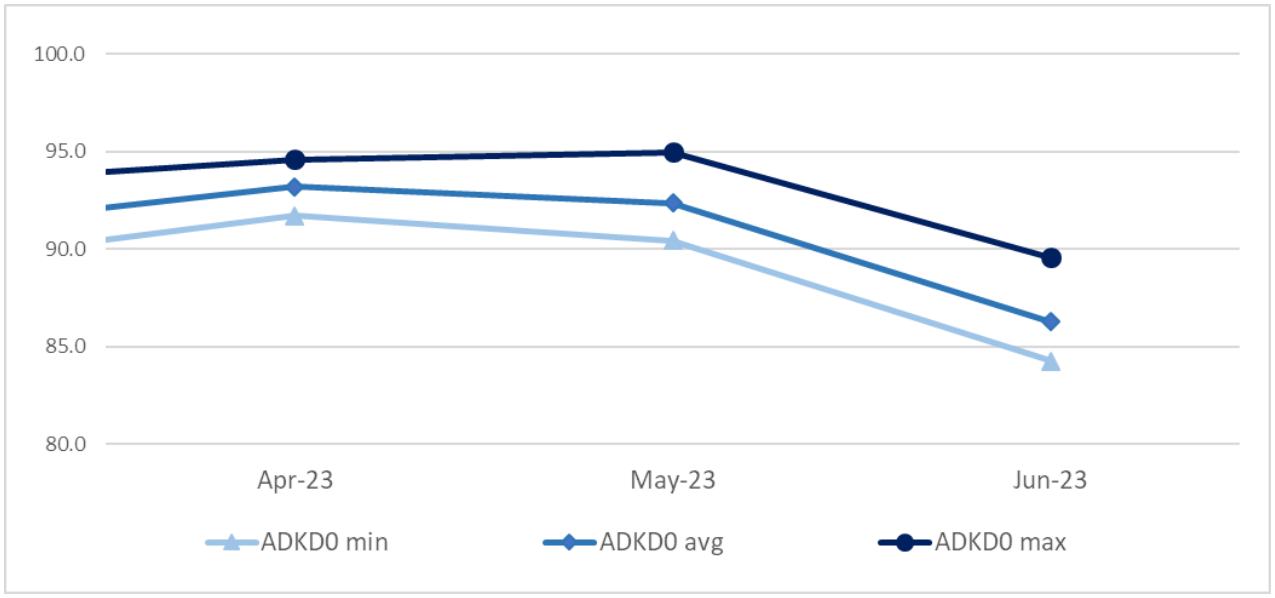


Figure 30: availability of tags for Galileo I/NAV orbit and clock data (ADKD0) – for all space vehicles, within 120 s

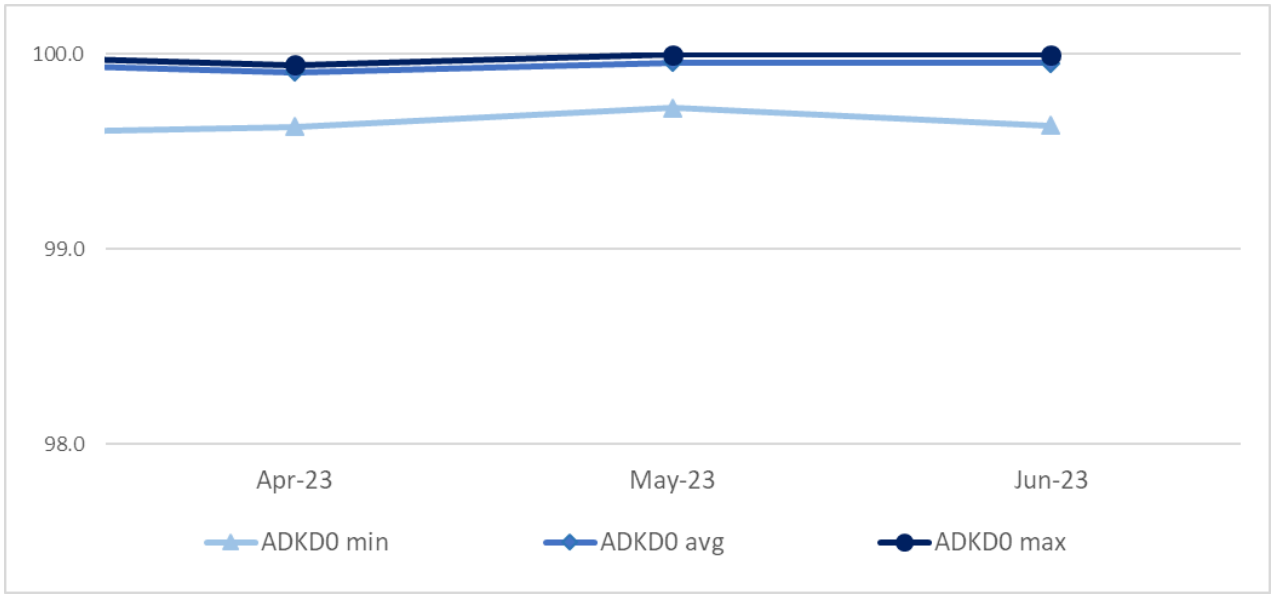


Figure 31: availability of tags for Galileo I/NAV orbit and clock data (ADKD0) – for four space vehicles, within 120 s

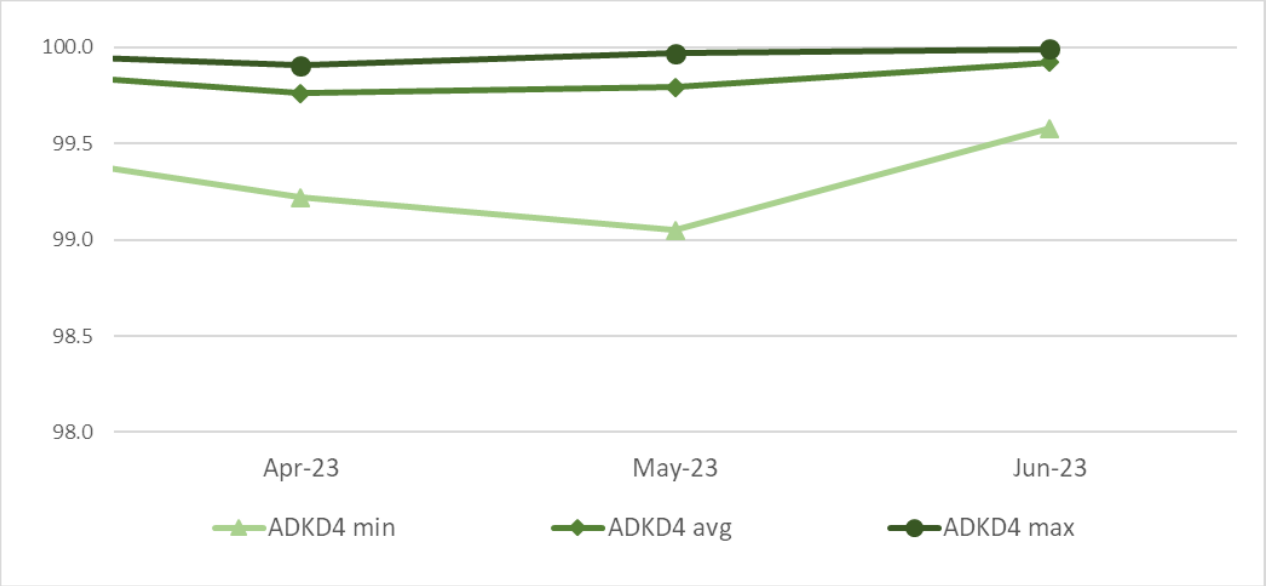


Figure 32: availability of tags for the GST-UTC and GGTO parameters (ADKD4)

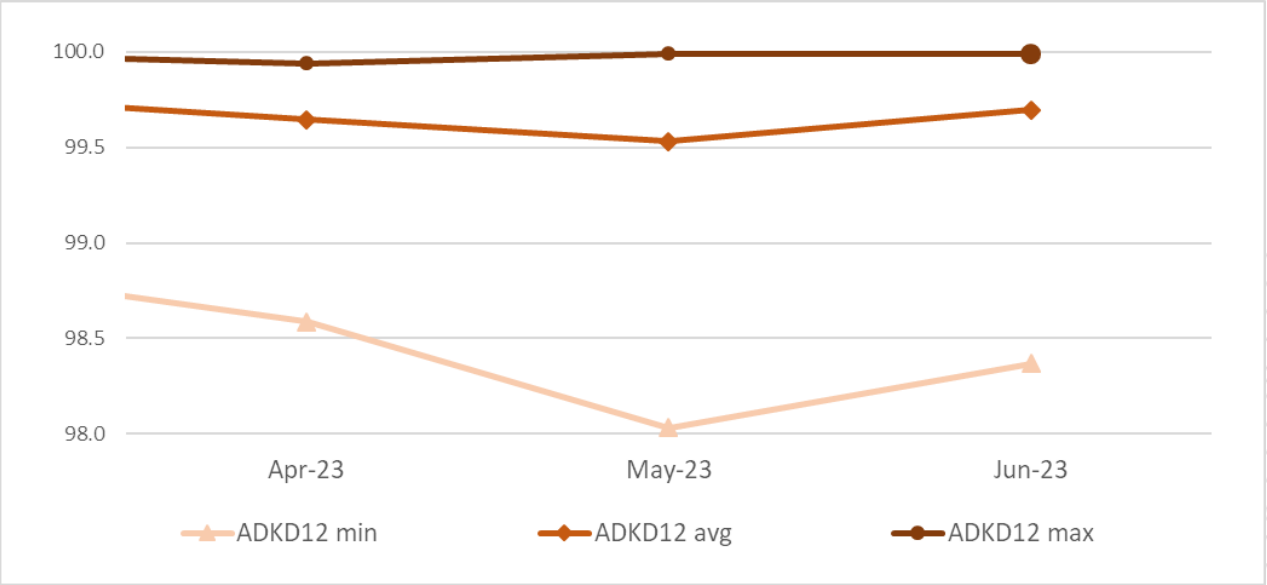


Figure 33: availability of tags for Galileo I/NAV orbit and clock data (ADKD12)

7.2 STATISTICS ON SUCCESS OF TAG AUTHENTICATION

The following table shows the percentage of OSNMA tag verification success depending on user receiver operation (single-frequency, dual-frequency) and on the kind of authentication performed (ADKD type):

Table 8: Statistics for successful OSNMA tags for single- and dual-frequency

	2023		
	April	**May**	**June**
single frequency, in %			
ADKD0	99.9580	99.9240	99.9690
ADKD4	99.9760	99.9700	99.9850
ADKD12	99.9740	99.9590	99.9900
dual frequency, in %			
ADKD0	99.9580	99.9240	99.9690
ADKD4	99.9760	99.9700	99.9850
ADKD12	99.9740	99.9590	99.9900

Percentages in Table 8 do not account for space vehicles GSAT0201 (E18) and GSAT0202 (E14), which are on elliptical orbits and declared not usable.

8 REFERENCES

This section identifies the documents explicitly referenced in this Galileo Open Service Public Performance Report. It also provides references to additional documents considered of interest for users.

[SIS-ICD] European GNSS (Galileo) Open Service Signal-In-Space Interface Control Document (OS-SIS-ICD), Issue 2.0, European Union, January 2021.

[IONO] Ionospheric Correction Algorithm for Galileo Single Frequency Users, Issue 1.2, European Union, September 2016.

[OS-SDD] European GNSS (Galileo) Open Service Definition Document (OS-SDD), Issue 1.2, European Union, November 2021.

[SvNOTE #5] Galileo Service Notice #05 - Unavailability of the Galileo Auxiliary satellites GSAT0201 and GSAT0202

[SvNOTE #09] Galileo Service Notice #09 - Officially announcing the beginning of Galileo OSNMA "Public Observation Phase", which implies the dissemination of a Test SIS and the active involvement of key stakeholders and parties interested in this new Service, devoted to the authentication of the engineering information carried by the Navigation signal.

[SvNOTE #11] Galileo Service Note #11 - Following the successful Testing activities for the enhanced I/NAV message on GSAT0223 (E34) and GSAT0224 (E10), Galileo users are notified that, until July 2023, the on-board S/W of all FOC satellites need to be upgraded, enabling the improvement.

[OSNMA SIS-ICD] On November 18th 2020 @ 15:28 UTC, Galileo satellites started the transmission of authentication information for testing purposes. The OSNMA Signal In space Interface Control Document (OSNMA SIS-ICD) Issue 1.0, released in December 2022 and applicable to the Service phase, is available.

[OSNMA Rx GL] Receiver Guidelines have been published to support the implementation of Galileo OSNMA at user receiver level.

Previous documents are available to users through the web portal of the European GNSS Service Centre (http://www.gsc-europa.eu/).

Individual sections of the Open Service – Service Definition Document [OS-SDD] have been referenced throughout this report when referring to MPL target values and calculation methods.

For an exhaustive description of the Open Service Minimum Performance Levels (MPLs), the reader is addressed to the [OS-SDD] in force.

9 LIST OF ACRONYMS

Acronym	Definition
AUL	Average User Location
BGD	Bias Group Delay (parameter delivered in the Navigation messages)
DF	(Galileo OS) dual-frequency combination (E1/E5a, E1/E5b)
DOP	Dilution of Precision
ECEF	Earth Centred, Earth Fixed frame coordinates
EUSPA	European Union Agency for the Space Programme
F/NAV	Navigation message provided by the E5a signal [SIS-ICD]
FOC	Full Operational Capability
GGTO	GST-GPS Time Offset
GMS	Galileo Mission Segment
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
G/S	Ground Segment
GSC	European GNSS Service Centre
GST	Galileo System Time
HAS	High Accuracy Service
HDOP	Horizontal Dilution of Precision
HPE	Horizontal Positioning Error
ICD	Interface Control Document
IDD	Internet Data Distribution (HAS)
I/NAV	Navigation message provided by the E1-B and E5b signals [SIS-ICD]
IS	(Galileo) Initial Services
MPL	Minimum Performance Level
MAC	Message Authentication Code
NAGU	Notice Advisory to Galileo Users
NAPA	No Accuracy Prediction Available
OLTN	OSNMA Live Test Notification
OS	(Galileo Navigation) Open Service
OSNMA	Galileo Open Service Navigation Message Authentication
PDOP	Position Dilution of Precision
SBDO	Stand-By Duty Officer

Acronym	Definition
SDD	Service Definition Document
SDM	Service Delivery Manager
SF	(Galileo OS) single-frequency (E1, E5a, E5b)
SIS	Signal in Space
SISA	Signal In Space Accuracy
SISE	Signal In Space Error vector (4-dimensional)
SNGU	Service Notice to Galileo Users
toE	Time of Ephemeris
UTC	Universal Time Coordinated
VPE	Vertical Positioning Error
WUL	Worst User Location

End of Document

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