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EUROPEAN GNSS (GALILEO) SERVICES

OPEN SERVICE

QUARTERLY PERFORMANCE REPORT

JULY - SEPTEMBER 2022

[1] This report is based on the OS-SDD v1.2, which was published in mid-December 2021, and is fully applicable during the quarter under consideration.

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1 INTRODUCTION

This document is the *Galileo Open Service (OS) Public Performance Report* for the period of **July, August and September 2022**. 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)[2].

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 the achieved 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 two subsections: "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 reported, given the ongoing "Public Observation Phase" announced by the Galileo Service Notice #09 [SvNOTE #09].

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

Section 8: all the cited reference documents are listed.

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

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

Satellite Code	SV ID (PRN)	CCSDS ID [hex]	Orbital Slot	Status
GSAT-0101	11	3A5	B05	Usable
GSAT-0102	12	3A6	B06	Usable
GSAT-0103	19	3A7	C04	Usable
GSAT-0201 [3]	18	261	non-nominal	Not usable since February 18th, 2021
GSAT-0202 [3]	14	262	non-nominal	
GSAT-0203	26	263	B08	Usable
GSAT-0205	24	265	A08	Usable
GSAT-0206	30	266	A05	Usable
GSAT-0207	7	267	C06	Usable
GSAT-0208	8	268	C07	Usable
GSAT-0209	9	269	C02	Usable
GSAT-0210	1	26A	A02	Usable
GSAT-0211	2	26B	A06	Usable
GSAT-0212	3	26C	C08	Usable
GSAT-0213	4	26D	C03	Usable
GSAT-0214	5	26E	C01	Usable
GSAT-0215	21	2C5	A03	Usable
GSAT-0216	25	2C6	A07	Usable
GSAT-0217	27	2C7	A04	Usable
GSAT-0218	31	2C8	A01	Usable
GSAT-0219	36	2C9	B04	Usable
GSAT-0220	13	2C0	B01	Usable
GSAT-0221	15	2C1	B02	Usable
GSAT-0222	33	2C2	B07	Usable
GSAT-0223 [4]	34	109	B03	Usable since 05/05/2022 @ 10:42
GSAT-0224 [5]	10	10B	B15	Auxiliary space vehicle Usable since 29/08/2022 @ 13:51

Table 1 : Galileo Reported Constellation Information

[3] The two Galileo Space Vehicles GSAT-0201 (E18) and GSAT-0202 (E14) have been temporarily removed from the provision of active service. This was notified with NAGU 2021008, and the reason is clarified by Galileo Service Notice #05 (SNGU 2021001, [SvNOTE #5]).

[4] Reference: NAGU 2022016

[5] Reference: NAGU 2022034

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:

GNSS Service Centre Web Resources	
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"

Table 2 : GSC main information web pages for Galileo status

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 **GSAT-0224** (**E10**), performance figures are provided only from the time an entire month of data has been collected after the satellite is declared available for service provision. Thus, its characterisation starts from September 2022. It should also be noted that this space vehicle is considered an "auxiliary" one 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 ≤ 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], in all cases. The following dashboards summarise the compliance with MPLs, using the colour coding defined in the successive legend:

OS MPLs		Target Value	Space Vehicle		July-22					August-22					September-22				
					E5a-E1	E5b-E1	E1	E5a	E5b	E5a-E1	E5b-E1	E1	E5a	E5b	E5a-E1	E5b-E1	E1	E5a	E5b
Signal In Space (SIS) Ranging	Accuracy, Any Satellite	≤ 7m [95%]	GSAT-0101	E11															
			GSAT-0102	E12															
			GSAT-0103	E19															
			GSAT-0203	E26															
			GSAT-0205	E24															
			GSAT-0206	E30															
			GSAT-0207	E07															
			GSAT-0208	E08															
			GSAT-0209	E09															
			GSAT-0210	E01															
			GSAT-0211	E02															
			GSAT-0212	E03															
			GSAT-0213	E04															
			GSAT-0214	E05															
			GSAT-0215	E21															
			GSAT-0216	E25															
			GSAT-0217	E27															
			GSAT-0218	E31															
			GSAT-0219	E36															
			GSAT-0220	E13															
			GSAT-0221	E15															
			GSAT-0222	E33															
			GSAT-0223	E34															
			GSAT-0224	E10															

Table 3 : MPL Fulfilment Status Dashboard (1/2)

Legend

- MPL measurement 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)

OS MPLs				Target Value	Jul-22	Aug-22	Sep-22
SIS Ranging	Accuracy, Over All Satellites	E1/E5a user		≤ 2m [95%]			
		E1/E5b user					
		E1 user					
		E5a user					
		E5b user					
	Availability	Per-slot	E1/E5a	≥ 92%			
			E1/E5b				
			E1				
			E5a				
			E5b				
Positioning and DOP	Availability	PDOP ≤ 6 – F/NAV (E5a)		≥ 90% @ AUL			
		PDOP ≤ 6 – I/NAV (E1-B and E5b)		≥ 90% @ AUL			
		PDOP ≤ 6 – F/NAV (E5a)		≥ 87% @ WUL			
		PDOP ≤ 6 – I/NAV (E1-B and E5b)		≥ 87% @ WUL			
		Dual Frequency E1-E5a, E1-E5b		≥ 90% @ AUL			
		Single Frequency E1-B, E5a, E5b		≥ 90%@ AUL			
		Dual Frequency E1-E5a, E1-E5b		≥ 87%@ WUL			
		Single Frequency E1-B, E5a, E5b		≥ 87%@ WUL			

OS MPLs			Target Value	Jul-22	Aug-22	Sep-22
Timing	Accuracy	UTC Time Dissemination	≤ 30ns [95%]			
		UTC Frequency Dissemination	< 3E-13 [95%]			
		GGTO Determination	≤ 20ns [95%]			
	Availability	UTC Dissemination	≥ 95%			
		UTC Determination Accuracy	≥ 95%			
		GGTO Determination	≥ 80%			
User Interface	NAGU	Planned Timeliness	≥ 2 days			
		Unplanned Timeliness	≤ 1.25 days			

Table 4 : MPL Fulfilment Status Dashboard (2/2)

The "per-slot" **Availability of a Healthy Signal** is well above the MPL threshold of 92%, with averaged monthly values at least equal to **96.80**% for every Single-Frequency (E1-B, E5a, E5b) and Dual--Frequency 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 12 months and excluding any auxiliary space vehicles, like it is the case of GSAT-0224 (E10).

The **Signal in Space Ranging Accuracy** shows a 95th percentile monthly accuracy between **0.21** [m] and **1.01** [m] for individual space vehicles ("Any Satellite") on Single Frequency observables [6]. For Dual Frequency signal combinations [7], 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 greater values (ref.: Figure 5) with respect to the previous quarter: monthly accuracy was between **0.33** [m] and **21.15** [m] for individual space vehicles ("Any Satellite") on Single Frequency observables [6]. For Dual Frequency signal combinations [7], the figure is in the range from **0.26** [m] to **21.26** [m]. Max values are driven by a single space vehicle: GSAT-0210 (E01), which underwent an on-board clock outage in August; excluding this satellite, highest ranging errors evaluated at 99.9% confidence level would be **2.63** [m] for Single frequency and **1.69** [m] for Dual Frequency, thus quite good. More details are provided in the dedicated section 3.2.

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

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

The average **Ranging Accuracy at constellation level** (over "All Satellites", ref. Figure 8) provides figures "per signal" that are better than or equal to **0.46** [m] for Single Frequency signals and **0.21** [m] for Dual Frequency signal combinations. The results achieved are almost 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** (≤ 31 [ns]) are characterised, as per Figure 9 and Figure 10. 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 **100%** during the whole quarter (ref.: Figure 11): "dummy" GGTO coefficients were never disseminated. Note, that the figures provided in §4.1 are no longer obtained by averaging over the last 12 months. 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 12) better than or equal to **4.6** [ns] during the reporting period), the **UTC Frequency Dissemination Service Accuracy** (offset ≤ 4.2×10^{-14}, as per Figure 13) and the **GGTO Determination Accuracy**, better than or equal to **4.2** [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. All figures related to time accuracy maintain the same targets in the new [OS-SDD], but they are now computed on measurement samples collected over 1 month and no longer referred to annual time series like in the past.

The [OS-SDD] includes commitments related to a full **3D Positioning Service** that are consistent with the achieved deployment status of the Galileo constellation, which includes 22 space vehicles actively contributing to the statistics until May, and 23 starting from June.

The associated metrics are as follows:

Regarding the **Availability of PDOP ≤ 6** (ref.: Figure 15), the [OS-SDD] in force raises the MPL target for the Average User Location (AUL) to **90%**, and introduces a new target, which did not exist before, of **87%** for the case of Worst User Location (WUL). In the case of WUL, the measured availability figure was better than or equal to **98.70%**, while for AUL it was at least **99.61%** (ref.: Figure 16).

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 Worst User Location (WUL, ref.: Figure 17) and at Average User Location (AUL, ref.: Figure 18) are as follows:

- in July: **99.97%** (DF) and **99.92%** (SF) at WUL; **100%** (DF) and **99.99%** (SF) at AUL;
- in August: **99.47%** (DF) and **99.44%** (SF) at WUL; **99.93%** (DF) and **99.91%** (SF) at AUL;
- in September: **99.81%** (DF) and **99.59%** (SF) at WUL; **99.97%** (DF) and **99.93%** (SF) at AUL.

The target MPL values appear increased in the new [OS-SDD] to **87%** at WUL and **90%** at AUL, respectively; these targets are thus 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 19 up to Figure 24).

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 **2.02** [m] and **3.42** [m] during the whole quarter. The corresponding RMS values, which are also not subject to an MPL assessment, are within respectively **1.38** [m] and **2.51** [m].

Regarding **Publication of NAGUs**, **11 NAGUs** have been issued in the reporting period, in all cases respecting the requirements for their timeliness. According to the new [OS-SDD], the minimum time for publishing a NAGU before the start of a scheduled event is increased to **48** hours (2 days), and reduced to not more than **30** hours (1.25 days) after the occurrence of an unscheduled one. Additional details about NAGU timeliness are presented in § 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 6, Figure 7), 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

With the new [OS-SDD] in force since December 2021:

- the MPL on the "Per-Slot" Availability of healthy SIS is increased to **92**%, for both SF and DF combinations.

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 Signal in Space "per slot" availability of Galileo HEALTHY Signals in Space, averaged over the entire constellation during the reporting period and normalised annually.[8] The [OS-SDD] Minimum Performance Level (MPL) specifies **92%** [9] as the target value for this constellation metric. The achieved performance is between **96.80%** (Single Frequency SIS E5a and Dual Frequency combination E1-E5a in September) and **97.59%** (Single Frequency SIS E1-B, E5B and Dual Frequency combination E1-E5B in July).

[8] The [OS-SDD] foresees an "annual normalisation", which is implemented with a moving average over 12 months. Monthly figures consider only those space vehicles that are declared active members of the constellation during the whole month.

[9] Ref.: [OS-SDD] §3.4.1 (Table 13)

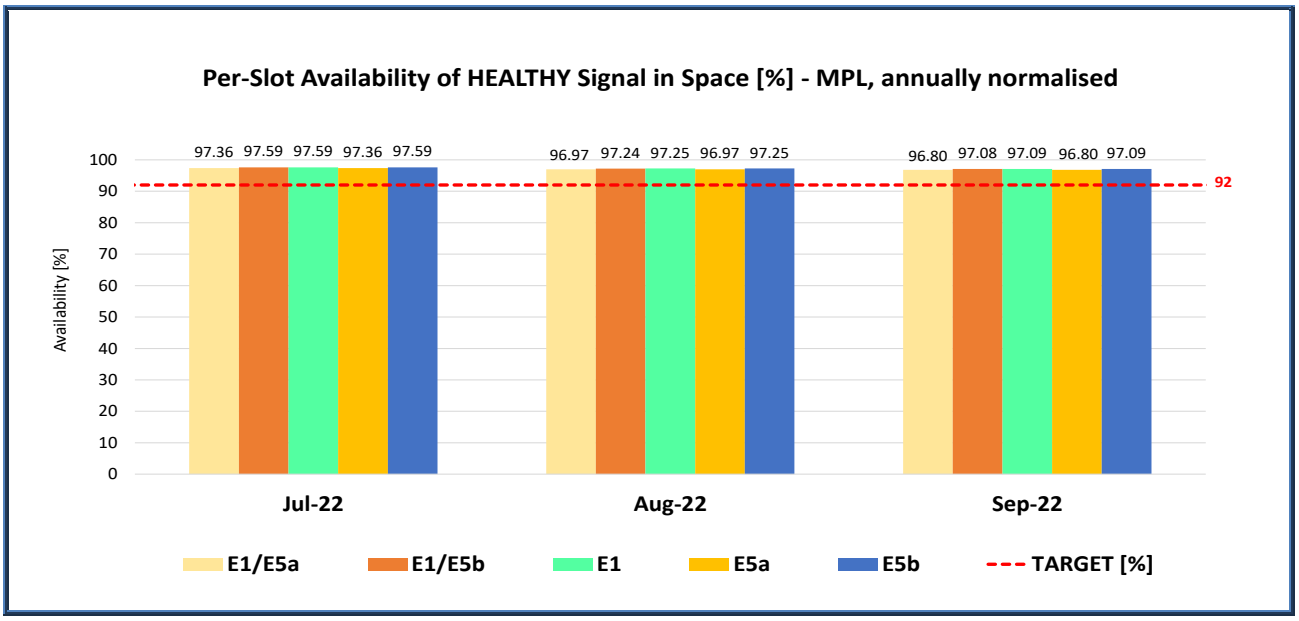


Figure 1 : "Per-Slot" availability of HEALTHY Signal in Space for the reporting period

Figure 2 provides the Signal in Space "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:

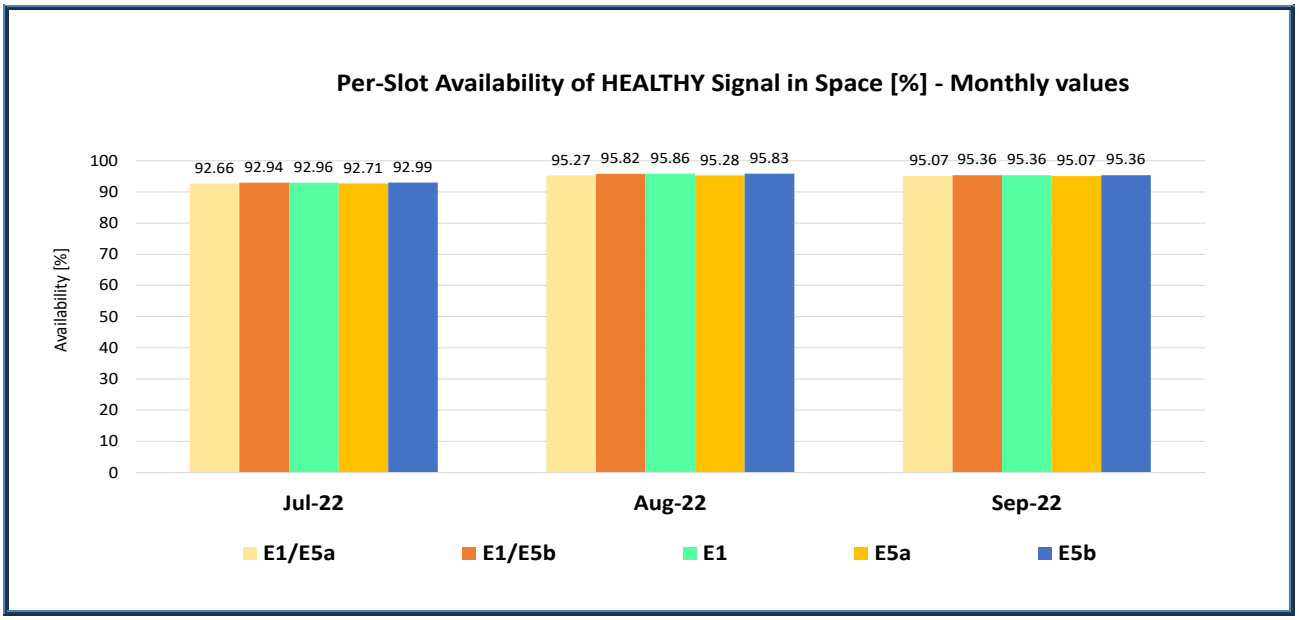


Figure 2 : "Per-Slot" availability of HEALTHY Signal in Space for the reporting period, not normalised

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

During the quarter, referring only to satellites occupying nominal orbit slots, such availability never achieved 100% simultaneously, for all space vehicles. Commenting Figure 3, looking at those monthly values for individual space vehicles:

- in July, **GSAT-0103** (**E19**) experienced low availability for service provision, down to **4.94**%. NAGU 2022029 extended the intended period of outage for this space vehicle up to the next month. The unavailability was already planned with NAGU 2022025, having started on 02/07/2022 @ 12:00. Furthermore, **GSAT-0223** (**E34**) was subject to a planned outage starting from 11/07/2022 @ 04:45 UTC, reducing its Service availability during the month to **32.92**%.
- in August, the availability of **GSAT-0223** (**E34**) for service provision was still low, down to **37.97**%. In fact, it was recovered on 01/08/2022 @ 16:00UTC (ref.: NAGU 2022030), but a new planned outage started on 11/08/2022 @ 00:00 UTC (ref.: NAGU 2022031), involving the satellite in the testing of new I/NAV message features until 29/08/2022 @ 13:51 UTC (ref.: NAGU 2022033).

  For the first time since its launch, **GSAT-0224** (**E10**) was declared usable for Navigation Services since 29/08/2022 @ 13:51 UTC (ref.: NAGU 2022034). However, its role is that of an active "auxiliary" space vehicle, which according to the applicable rules does not contribute to the Availability figures for healthy SIS. Nevertheless, users will benefit from the availability of this new space vehicle, for instance for obtaining better PDOP figures.
- In September, NAGU 2022035 announced the complete unavailability of **GSAT-0210** (**E01**) until further notice, starting already from 31/08/2022 @ 19:42 UTC. This was due to an unexpected outage of its on-board PHM clock [10]. For the rest, availability of individual space vehicles during the month was not lower than **93.29**%.

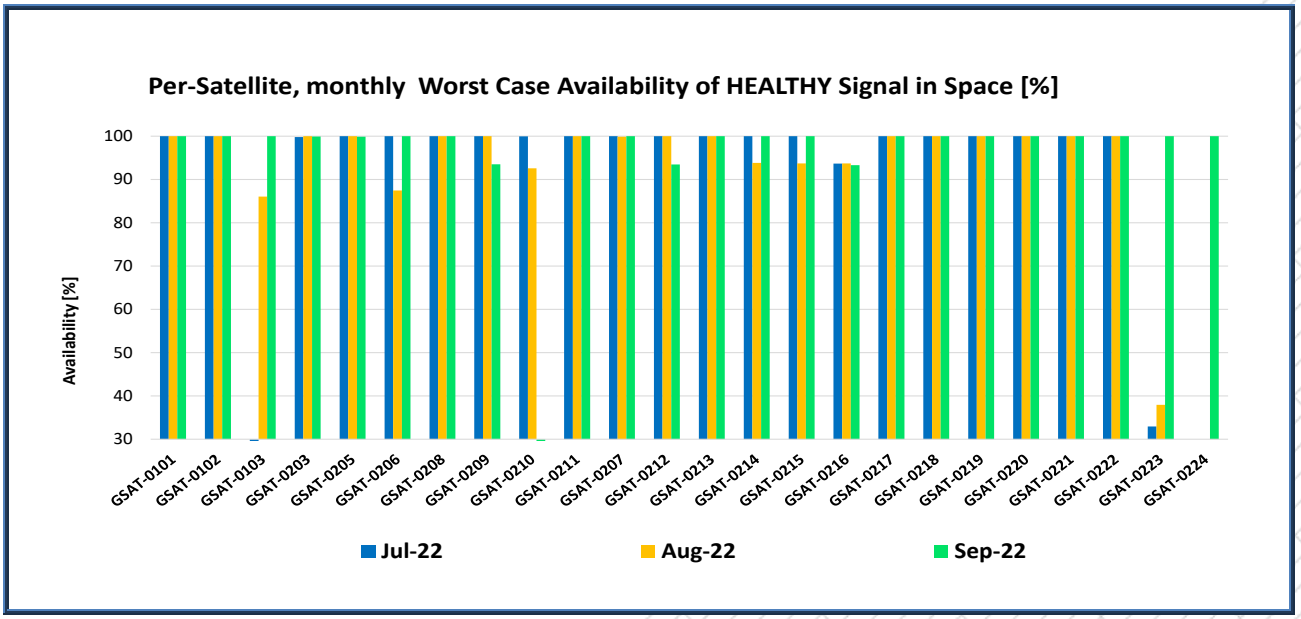


Figure 3 : Individual, "Per-Satellite" worst-case SIS availability of HEALTHY Signal in Space for the reporting period

[10] Satellite was returned to service on RAFS as of 19.12.2022 @ 15:36 UTC (re.f. NAGU 2022054)

Figure 4 provides the monthly percentage of availability of "N" Space Vehicles simultaneously transmitting a Healthy SIS, with Age of Ephemeris ≤ 4 [hours].

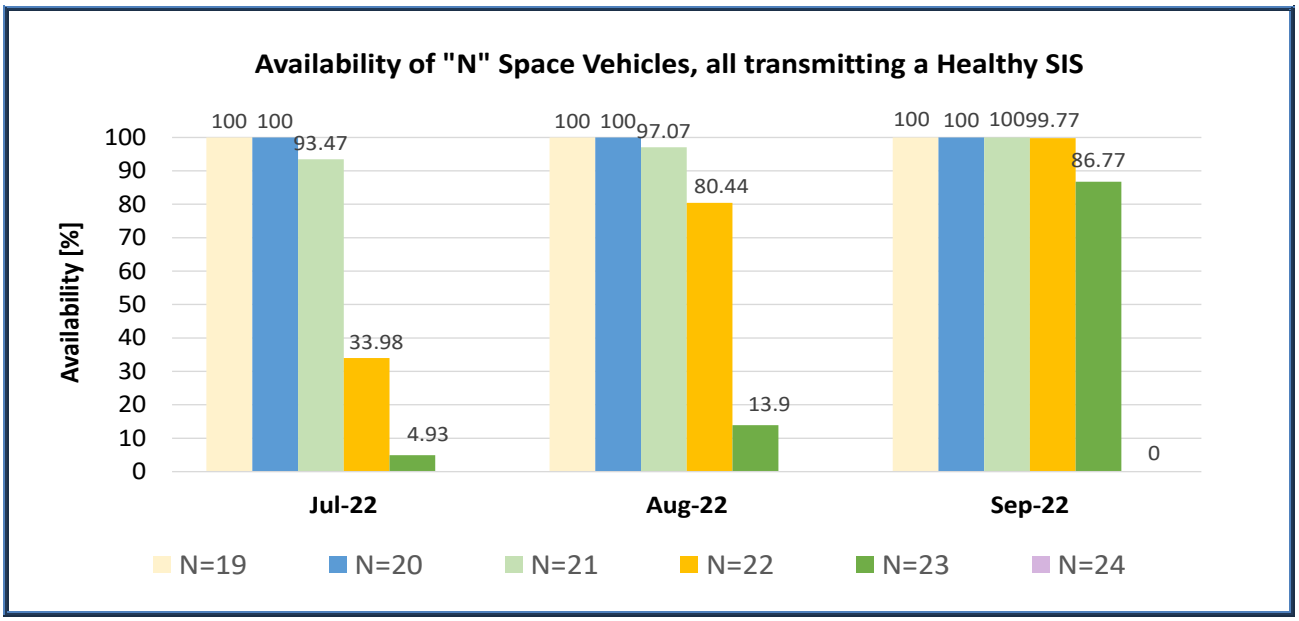


Figure 4 : Monthly percentage of availability of "N" Space Vehicles transmitting a Healthy SIS

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 Frequency/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 4 hours are filtered out, as per [OS-SDD] and explained in §5.3.

Figure 6 and Figure 7 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 [11] and frequency combinations [12], achieving the following results:

- for individual space vehicles in **July**, worst case values of **0.35** [m] for Dual Frequency and **1.01** [m] for Single Frequency. The best-case values over the month are **0.15** [m] and **0.22** [m], respectively.
- for individual space vehicles in **August**, worst case values of **0.35** [m] for Dual Frequency and **0.79** [m] for Single Frequency. The best-case values over the month are **0.16** [m] and **0.21** [m], respectively.
- for individual space vehicles in **September**, worst case values of **0.32** [m] for Dual Frequency and **1.11** [m] for Single Frequency. The best-case values over the month are **0.14** [m] and **0.22** [m], respectively.

In order to achieve a better view of Galileo ranging performance, Figure 5 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.

Performance at 99% confidence level needs to be commented, as the high offsets (up to **21.26** [m]) are only due to the abrupt and fast increase of ranging error impacting **GSAT-0210** (**E01**) by the end of August, due to an on-board clock outage. The event determined a sudden increase of

[11] Satellites in nominal slots plus Auxiliary Satellites.

[12] Graphics provide worst-case among all SIS (for Single Frequency) or between E1-E5a / E1-E5b for Dual-Frequency combinations

ranging error; even if DVS and SISA flags switched after a few minutes (respectively to “WWG” and “NAPA” states) indicating marginality of signals, the rump-up was very rapid and users experienced up to 51 [m] of ranging offset while SIS was still declared to be “healthy”.

GSAT-0210 (E01) is the only space vehicle degrading Ranging Accuracy evaluated at 99.9% confidence level in August.

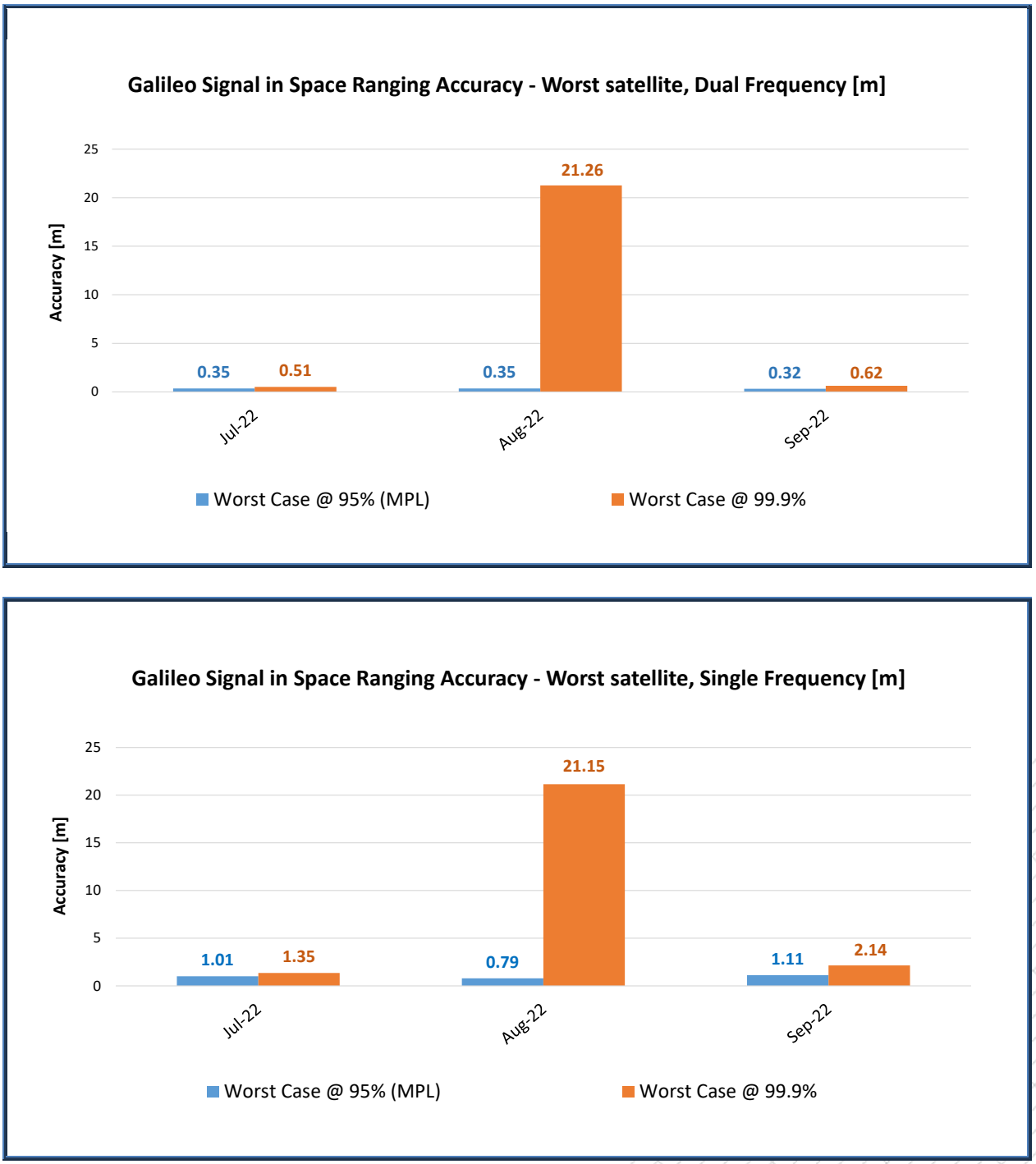
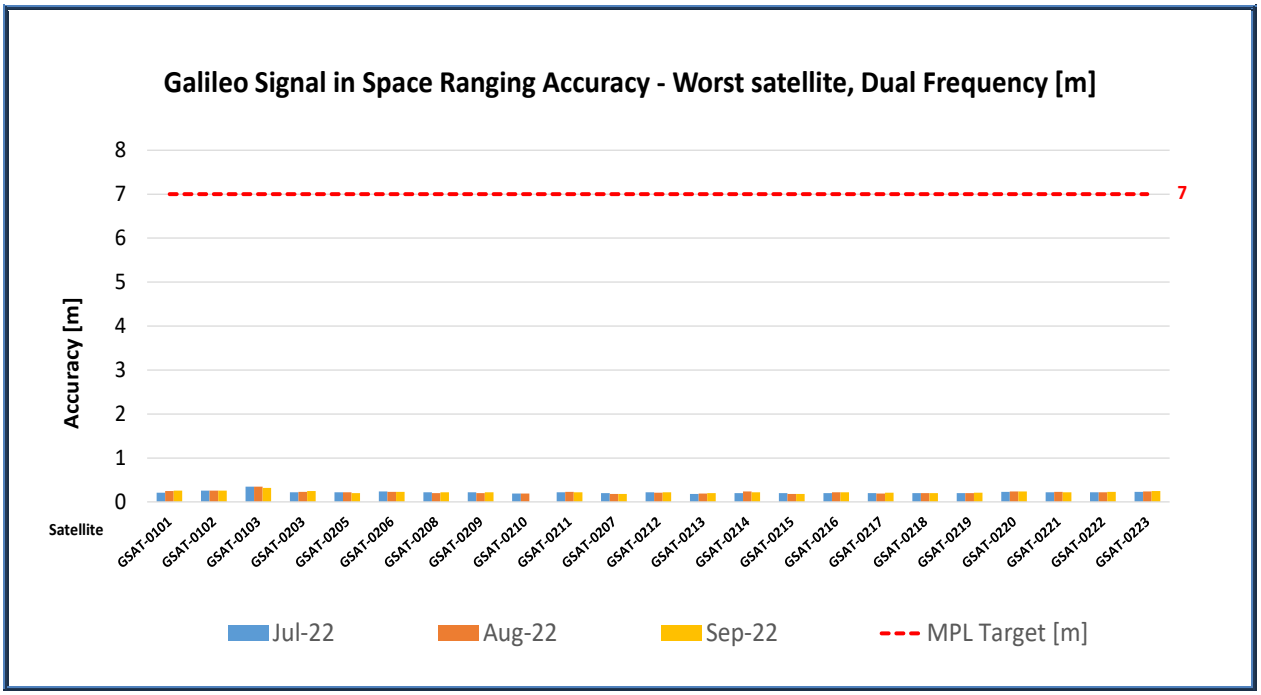


Figure 5 : Worst-case, monthly Galileo SIS Ranging Accuracy (at 95th and 99.9th confidence level percentiles) "for any satellite", any SIS (SF and DF combinations)



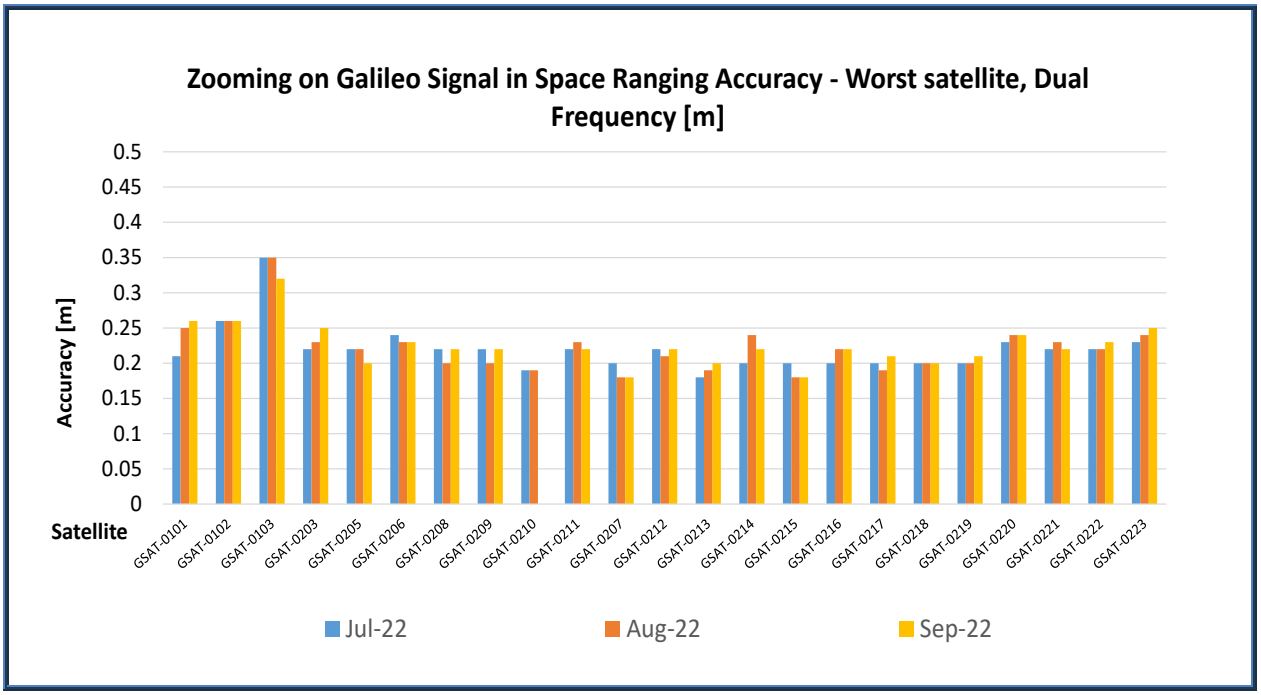
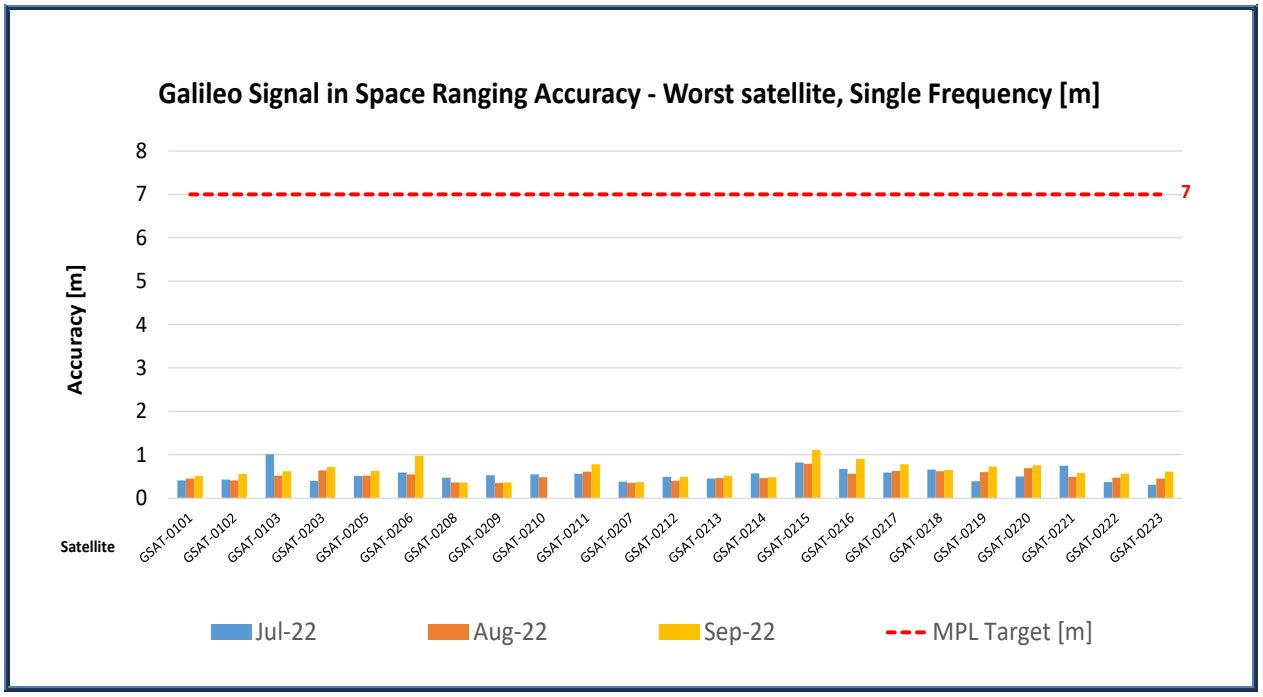


Figure 6 : Monthly Galileo SIS Ranging Accuracy (95th percentile) "for any satellite", measured during reporting period for worst-case, Dual-Frequency (DF)



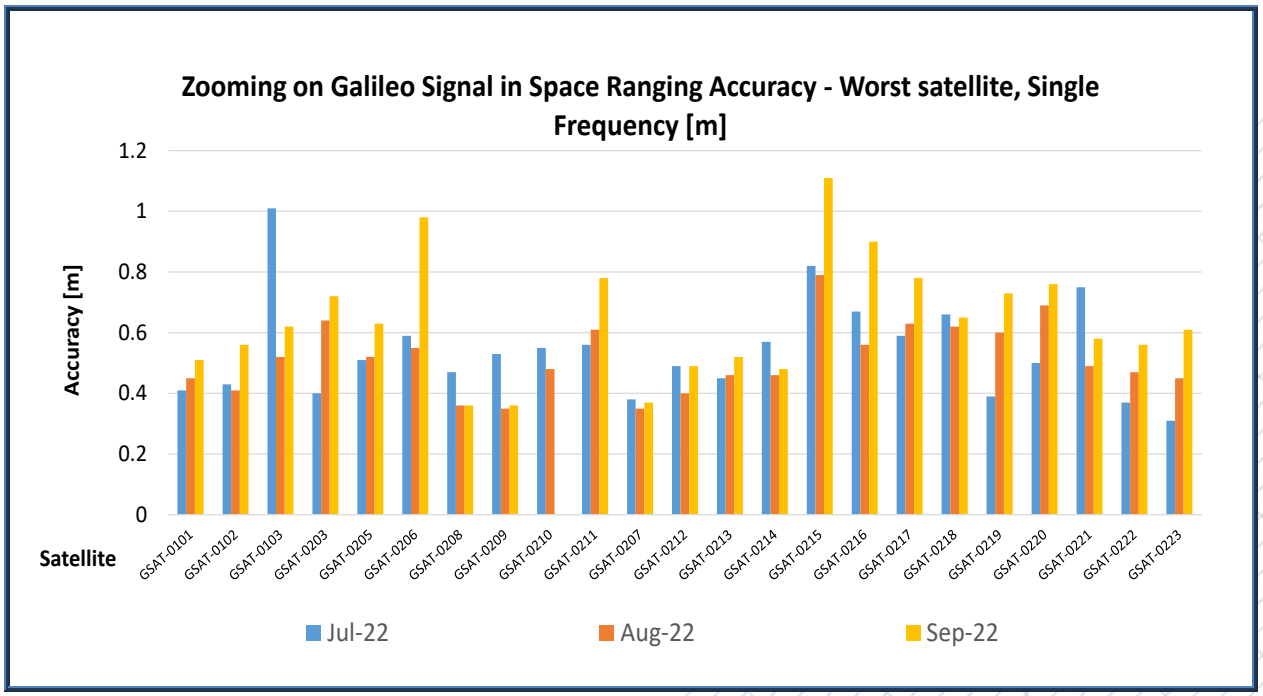


Figure 7 : Monthly Galileo SIS Ranging Accuracy (95th percentile) "for any satellite", measured during the reporting period for worst-case, Single-Frequency (SF)

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] [13] for the monthly performance of each individual satellite.

Figure 8 depicts the average "over all satellites" (constellation mean). Again, the [OS-SDD] MPL target of 2 [m] [14] is met by the Constellation average value.

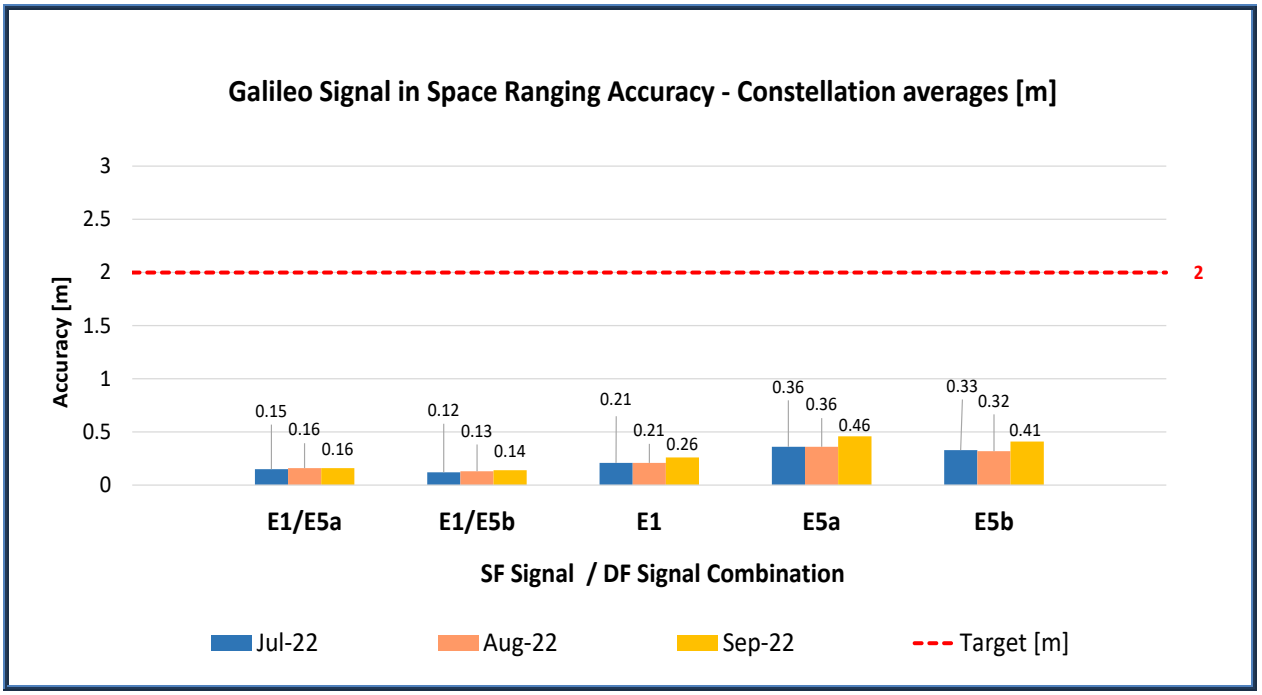


Figure 8 : Monthly Galileo SIS Ranging Accuracy (95th percentile) "over all satellites" (constellation average), measured during the reporting period

[13] Ref.: [OS-SDD] §3.3.1 (Table 9)

[14] 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

With the new [OS-SDD] in force since December 2021:

- the MPL on the Availability of the Galileo OS UTC Time Dissemination is increased to **95**%;
- the MPL on the Availability of UTC Time Determination accuracy better than 31 ns (95%) is increased to **95**%;
- the MPL on GGTO Determination Availability target remains 80%, and is **no longer normalised annually**.

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 9 provides the Worst User Location (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, increased to **95**% [15] in the new [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 10, with a required percentage of success increased to **95**% [16]. Those targets for Availability are also met with an availability of **100**% during the entire quarter.

[15] Ref.: [OS-SDD] §3.4.2 (Table 14)

[16] Ref.: [OS-SDD] §3.4.5 (Table 18)

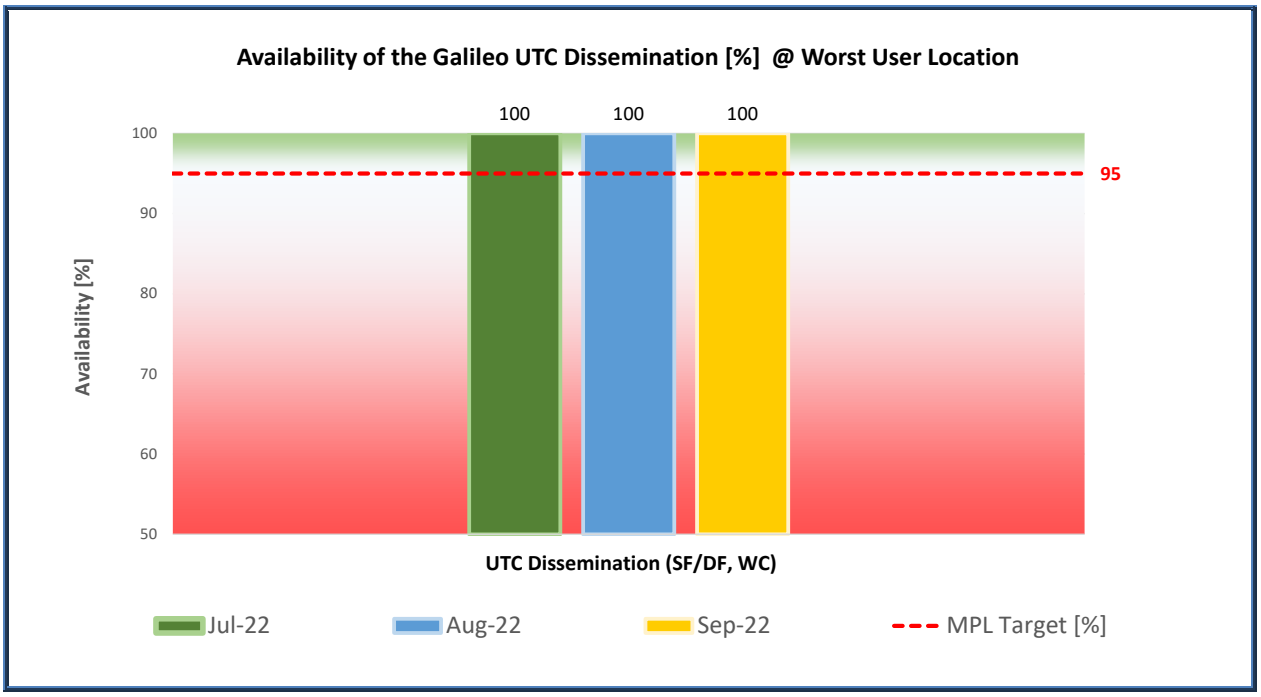


Figure 9 : Monthly availability of the UTC Dissemination Service during the reporting period

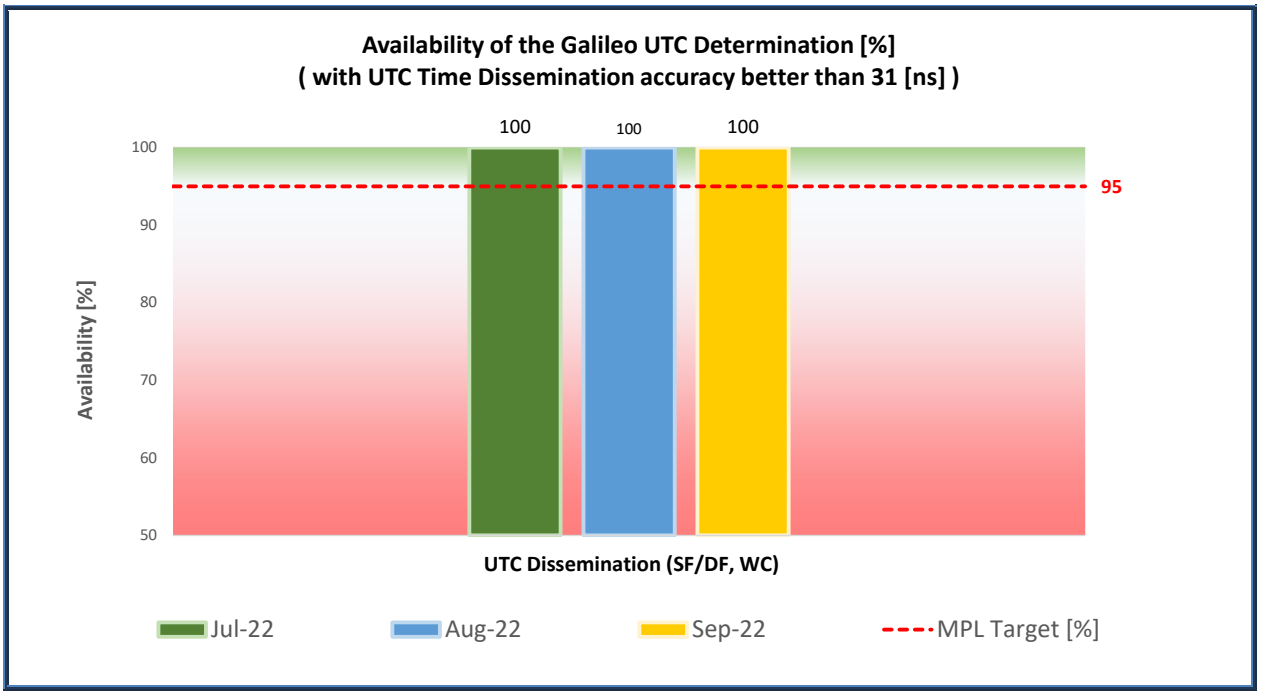


Figure 10 : Monthly availability of the UTC Determination ≤ 31 [ns] during the reporting period

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[17] set of coefficients within the Navigation message, acquiring SIS from a space vehicle seen above a minimum elevation angle of 5 degrees.

Figure 11 gives the availability of the GGTO Determination for Worst User Location (WUL), computed for a virtual grid of user positions over the service coverage area. Values are no longer normalised annually, as per new [OS-SDD] MPL definition.

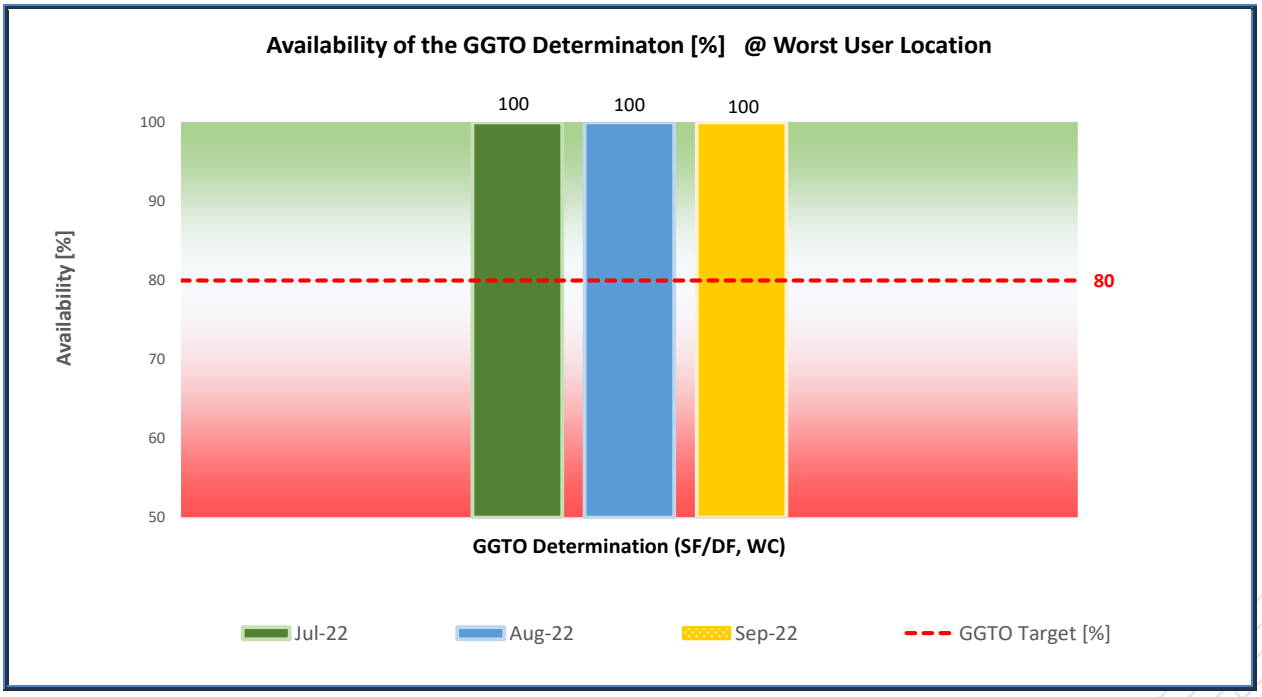


Figure 11 : Monthly Availability of the GGTO Determination, during the reporting period

The MPL of 80% [18] specified by [OS-SDD] for the monthly performance is fully achieved.

Note: the GGTO Determination capability was never reduced during the Quarter.

[17] "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.

[18] Ref.: [OS-SDD] §3.5.1.2 (Table 20)

4.2 ACCURACY OF GALILEO TIME CORRELATION PARAMETERS

With the new [OS-SDD] in force since December 2021:

- the MPLs on UTC Time and Frequency Dissemination Accuracy are **no longer normalised annually**; their targets remain unchanged (respectively 30 [ns] and 3E-13);
- the MPL on GGTO Determination Accuracy target remains 20 [ns] (95%), but is **no longer normalised annually**.

The Galileo Signal in Space Universal Time Coordinated (**UTC**) **Time Dissemination Accuracy** and the Galileo Signal in Space Universal Time Coordinated (**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 [19].

Figure 12 shows the 95th percentile of the daily average of the UTC Dissemination Accuracy, not further normalised [20], whilst observed over each period of 1 months.

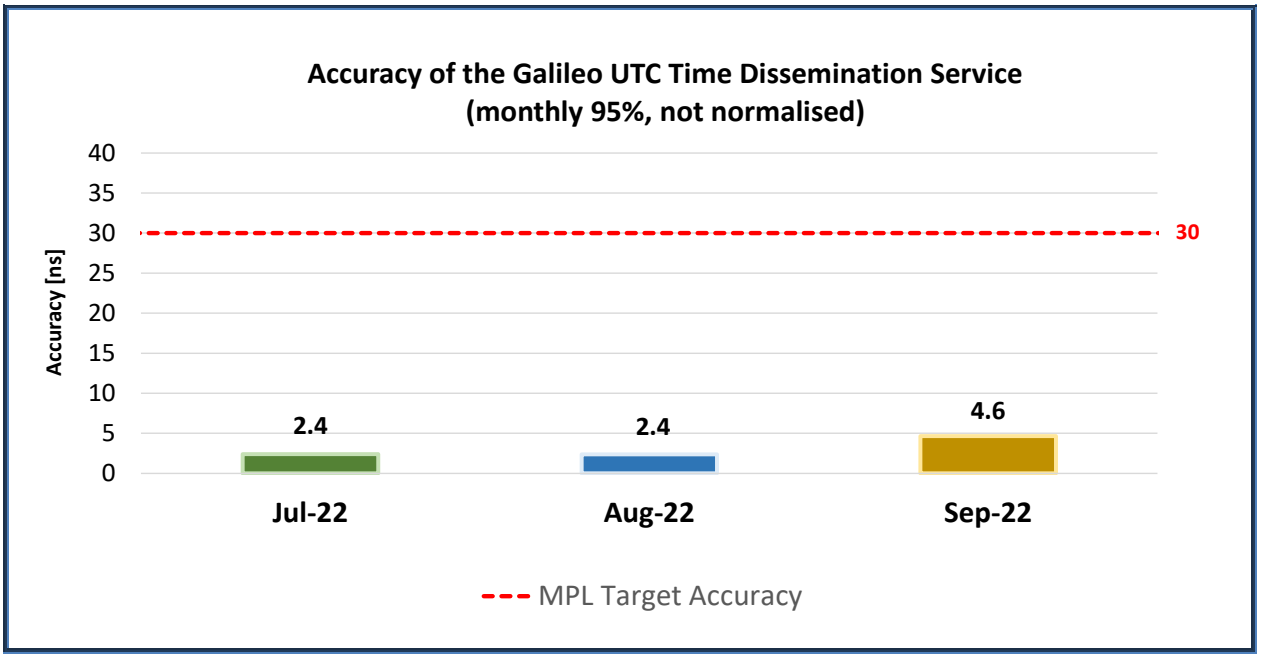


Figure 12 : Monthly UTC Time Dissemination Accuracy, 95% confidence level

[19] 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

[20] Ref.: [OS-SDD] §3.3.3 (Table 11)

Figure 13 shows the 95th percentile of the UTC Frequency Dissemination Accuracy, also in this case computed accumulating measurement data over a single month [21]. Figure 14 shows the 95th percentile of the daily average of the GGTO Determination Accuracy, also again not any longer normalised annually [22].

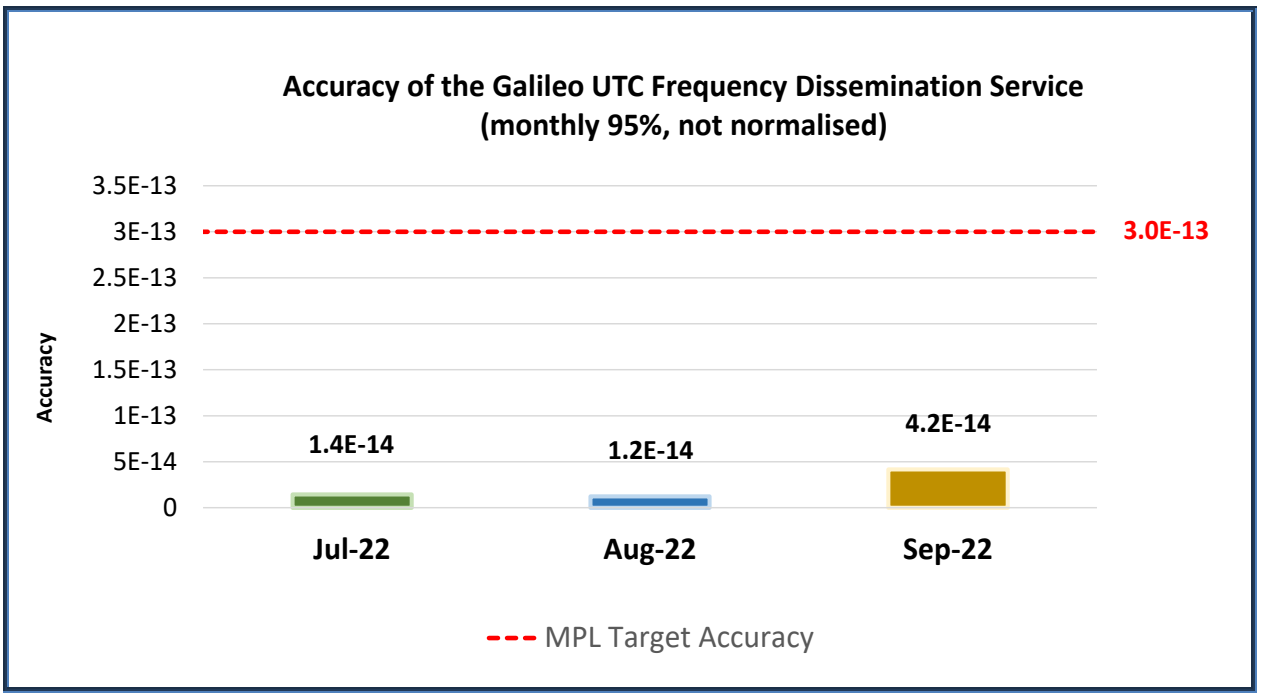


Figure 13 : Monthly UTC Frequency Dissemination Accuracy, 95% confidence level

As seen in Figure 12, the UTC (Time) Dissemination Accuracy achieves a very good performance level, with a maximum offset of 4.6 [ns], which is well below the [OS-SDD] Minimum Performance Level specification of 30 [ns] [20].

Regarding the UTC Frequency Dissemination accuracy, Figure 13 shows that the measured 95th percentile value is less than or equal to 4.2E–14, which is almost an order of magnitude better than the [OS-SDD] MPL normalised annual ceiling of 3.0E–13 [21].

The Galileo to GPS Time Offset (**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.

About the GGTO Determination Accuracy, shown in Figure 14, the measured values are constantly below 4.2 [ns] in the quarterly reporting period. These figures are within the [OS-SDD] MPL threshold of 20 [ns] [22], computed with a confidence level of 95%.

[21] Ref.: [OS-SDD] §3.3.3 (Table 12)

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

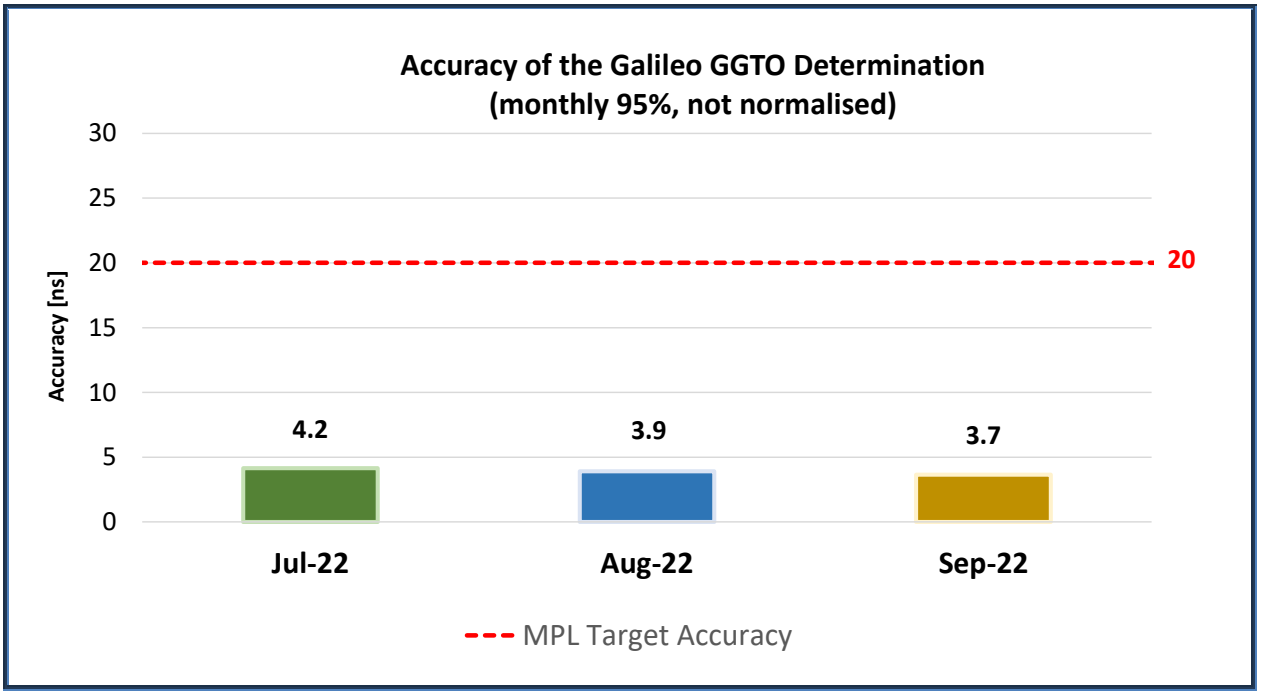


Figure 14 : Long-term 95th percentile of GGTO Determination Accuracy

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 parameters are reported considering only satellites in nominal slots.

5.1 AVAILABILITY OF THE GALILEO POSITION DILUTION OF PRECISION

With the new [OS-SDD] in force since December 2021:

- the MPL on availability of PDOP ≤ 6 is increased to **90**%;
- a new MPL is introduced for the **availability of the same metric at WUL**, with a **target of 87%.**

The applicable [OS-SDD] defines MPLs on the **Availability of a (3D) PDOP** (Position Dilution of Precision) less than or equal to **6**. As mentioned above, the target for AUL is increased to **90**% [23], while the target for WUL is newly introduced and set to **87**%[23] .

Results are presented in Figure 15 and Figure 16, distinguishing between the cases of SIS carrying I/NAV or F/NAV messages.

With figures all greater than **98.70**%, the target value is met for the Average User Location (AUL), and exceeded with significant margin for the Worst User Location (WUL).

[23] Ref.: [OS-SDD] §3.4.3 (Table 15)

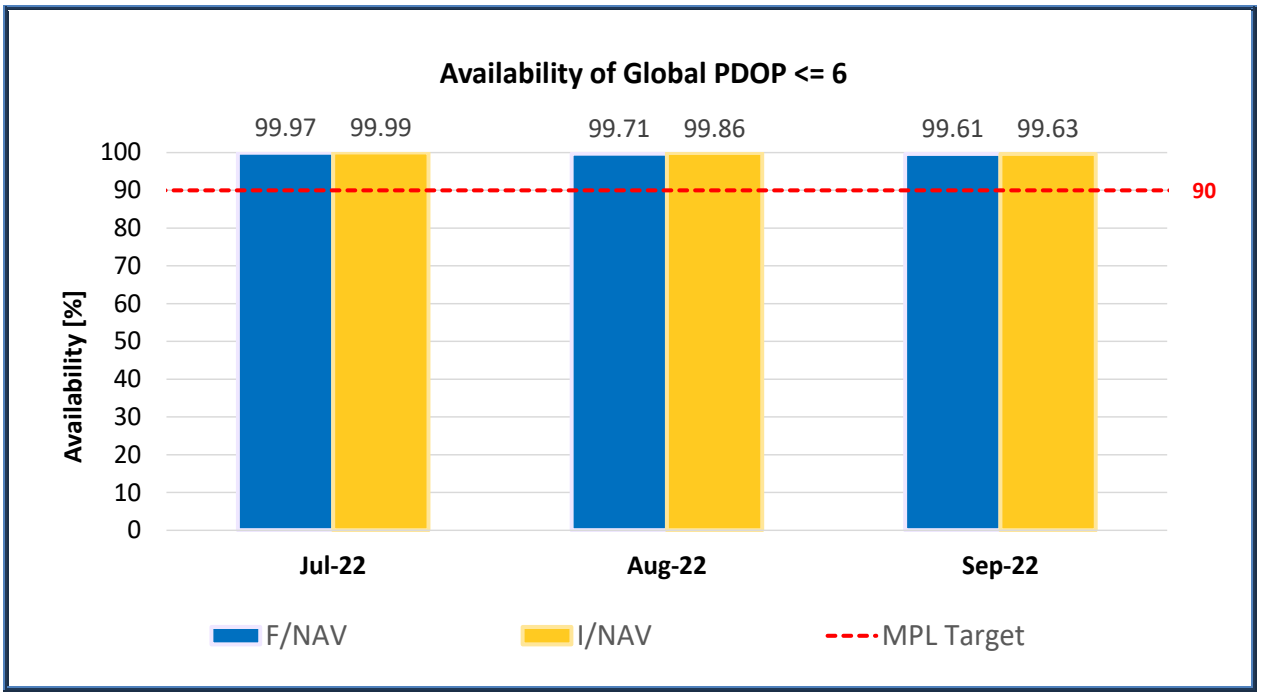


Figure 15 : Monthly Availability of PDOP ≤ 6 at Average User Location (AUL)

Figure 16 shows the Availability of a (3D) PDOP ≤6 at Worst User Location, which is now subject to an MPL target:

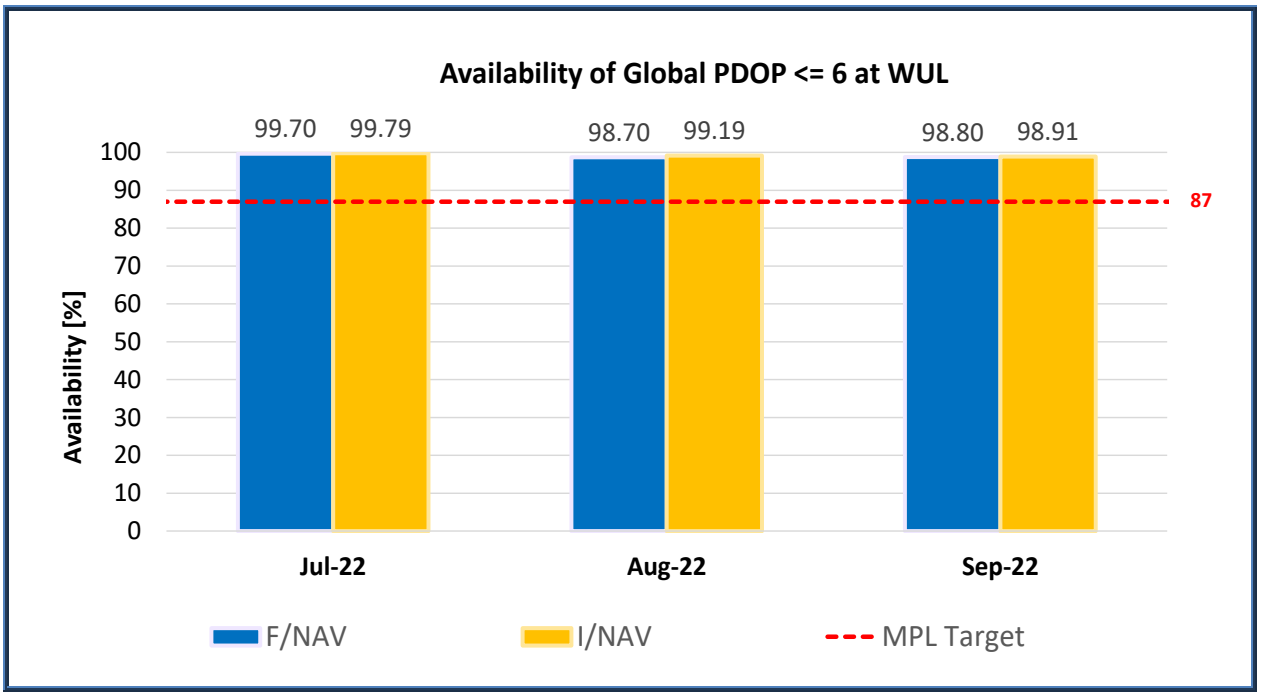


Figure 16 : Monthly Availability of PDOP ≤ 6 at Worst User Location (WUL)

5.2 AVAILABILITY OF THE GALILEO POSITIONING SERVICE

With the new [OS-SDD] in force since December 2021:

- the MPL on the Availability of Positioning with a Horizontal Positioning Accuracy better than 7.5 [m] and a Vertical Positioning Accuracy better than 15 [m] (95% confidence level) is increased to **90**% for both SF and DF at AUL and 87% at WUL (was 70%).

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 component (HPE), and not worse than **15** [m] for the vertical one (VPE), evaluated at 95%.

Different targets are assigned: increased to **87**% [24] at Worst User Location (WUL), and to **90**% [25] for the Average User Location (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 17 and Figure 18. The target values are met with large margins.

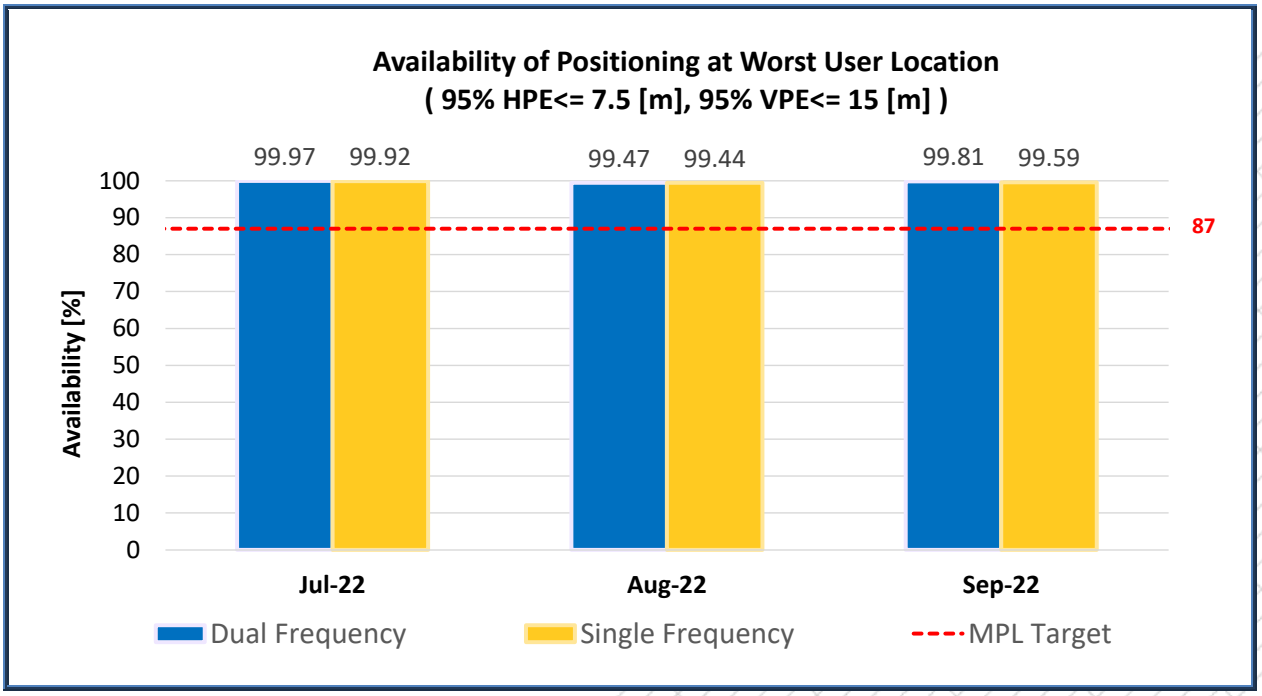


Figure 17 : Availability of Positioning at Worst User Location (WUL)

[24] Ref.: [OS-SDD] §3.4.4 (Table 17)

[25] Ref.: [OS-SDD] §3.4.4 (Table 16)

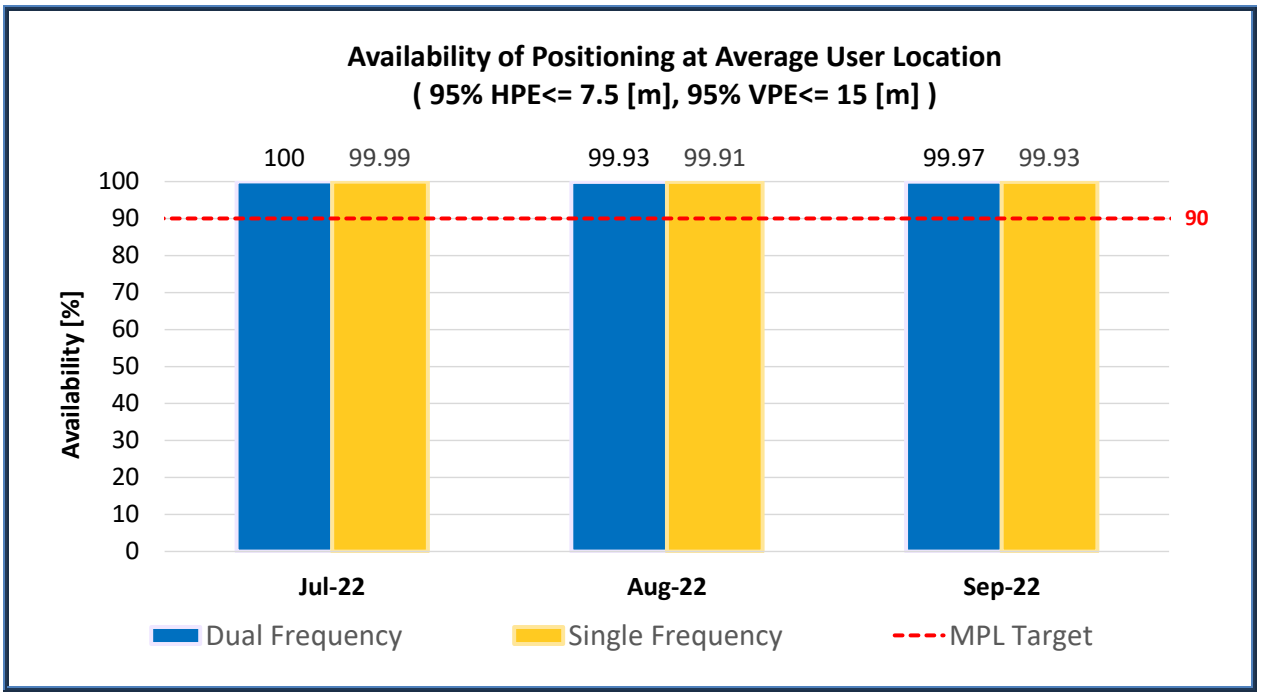


Figure 18 : Availability of Positioning at Average User Location (AUL)

5.3 GALILEO MEASURED POSITIONING PERFORMANCE

Although the Galileo 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" [26].

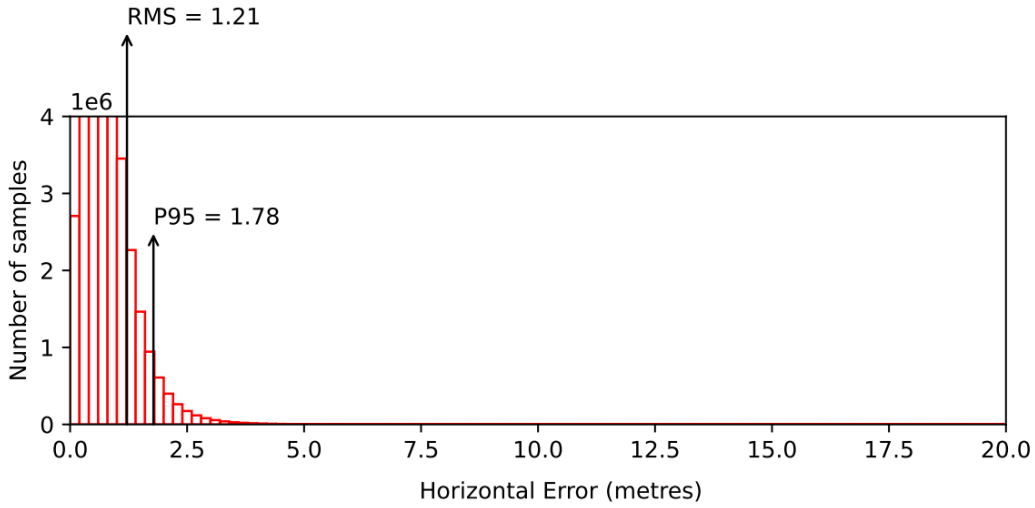
As specified in the [OS-SDD], Navigation message coefficients with an "Age of Ephemeris" beyond 4 hours are no longer considered valid, so that ranging observables from the corresponding satellite and signal should not be used for positioning and/or time measurement purposes.

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 [m].

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

[26] 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.

July 2022	
HPE 3D Positioning E1-E5a (DF) F/NAV	
Note: 20968 samples > 20 [m], around 0.058% of total	

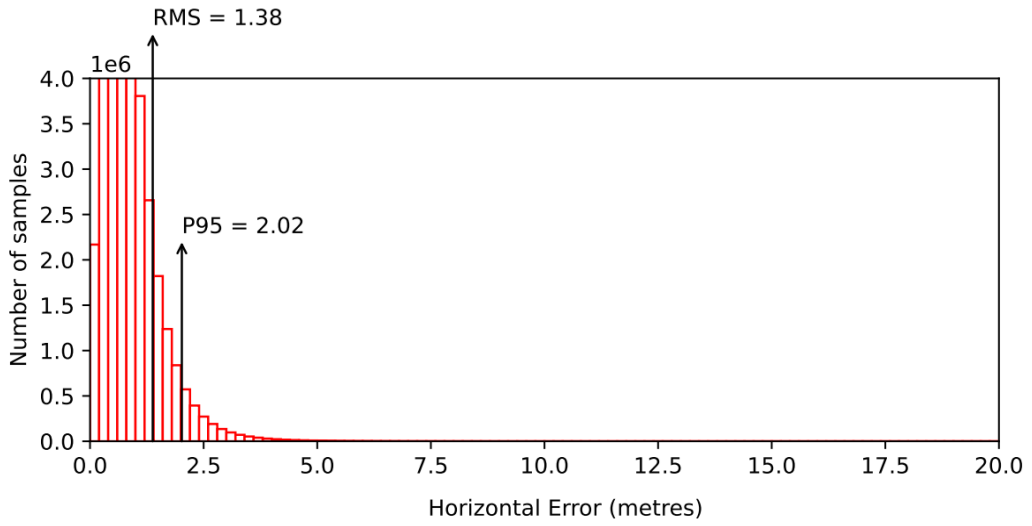
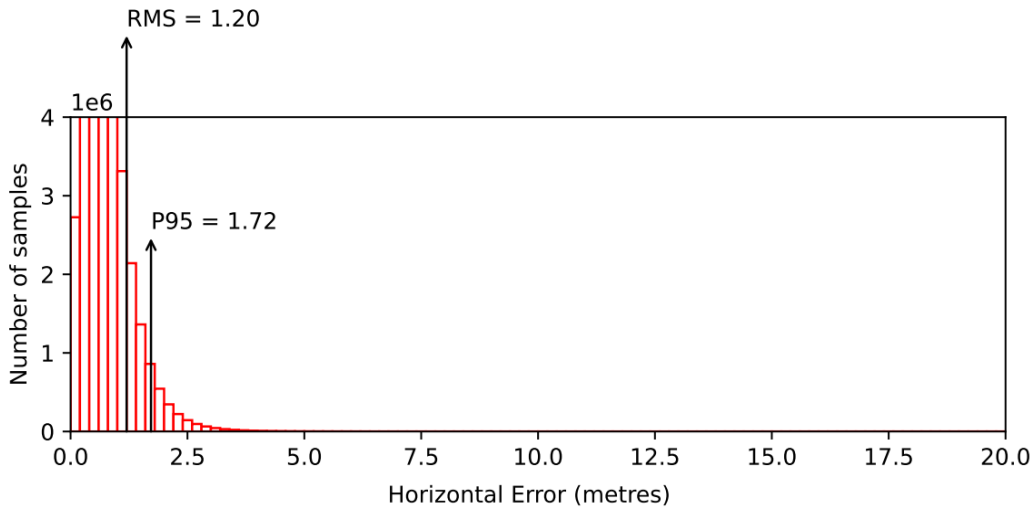
July 2022	
HPE 3D Positioning E1-E5b (DF) I/NAV	
Note: 23853 samples > 20 [m], around 0.065% of total	

Figure 19 : Horizontal Positioning Error (HPE) for "Galileo-only" users in July 2022

August 2022	
HPE **3D Positioning** **E1-E5a (DF)** **F/NAV**	
Note: 19865 samples > 20 [m], around 0.056% of total	

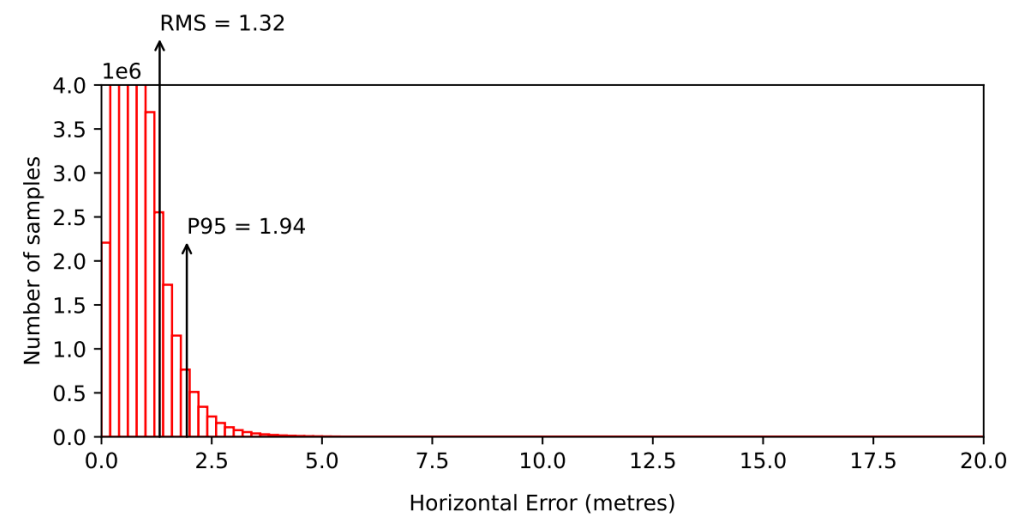
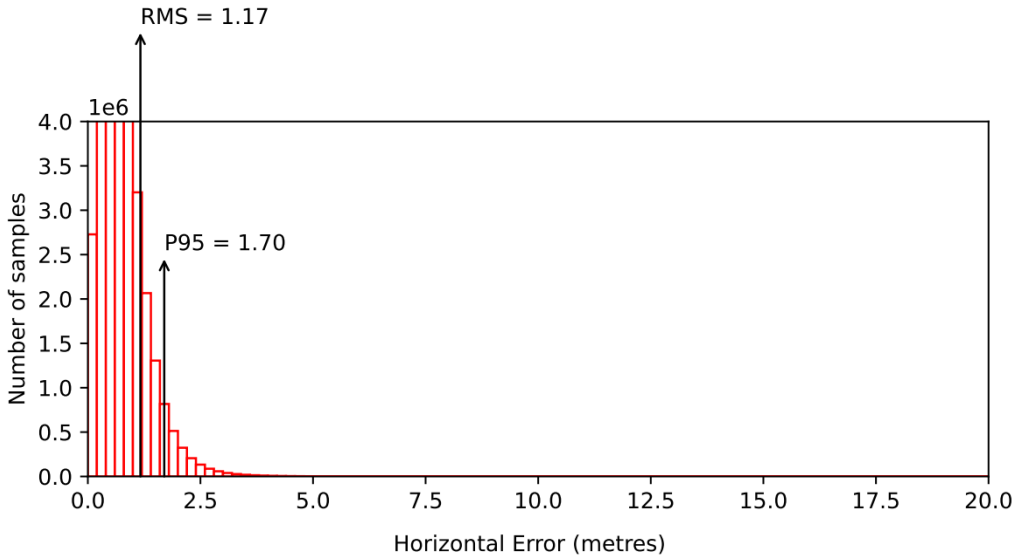
August 2022	
HPE **3D Positioning** **E1-E5b (DF)** **I/NAV**	
Note: 23760 samples > 20 [m], around 0.066% of total	

Figure 20 : Horizontal Positioning Error (HPE) for "Galileo-only" users in August 2022

September 2022	
HPE 3D Positioning E1-E5a (DF) F/NAV	
Note: 20849 samples > 20 [m], around 0.060% of total	

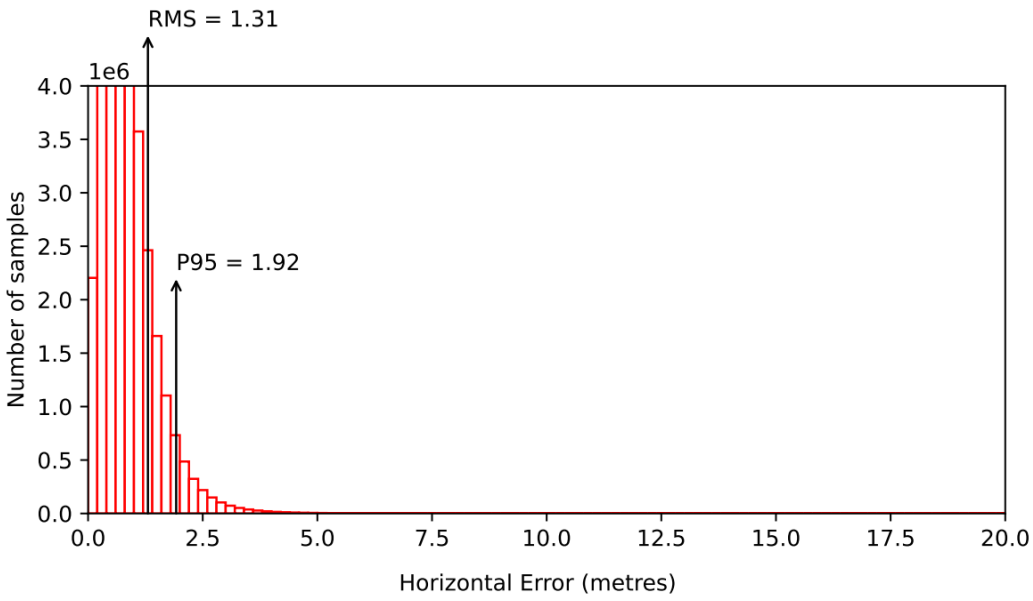
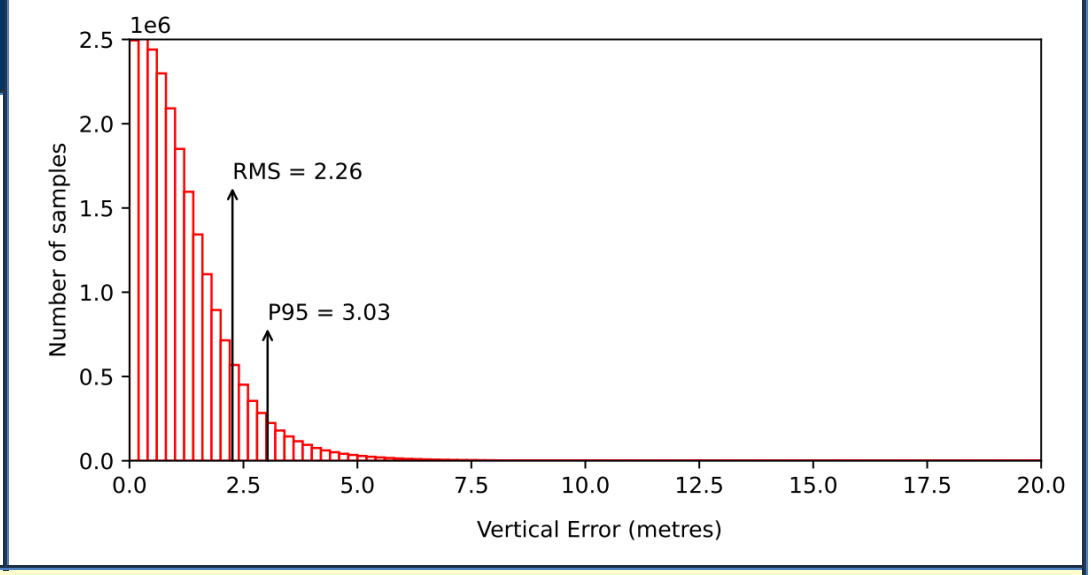
September 2022	
HPE 3D Positioning E1-E5b (DF) I/NAV	
Note: 24143 samples > 20 [m], around 0.069% of total	

Figure 21 : Horizontal Positioning Error (HPE) for "Galileo-only" users in September 2022

July 2022	
VPE 3D Positioning E1-E5a (DF) F/NAV	
Note: 24828 samples > 20 [m], around 0.068% of total	

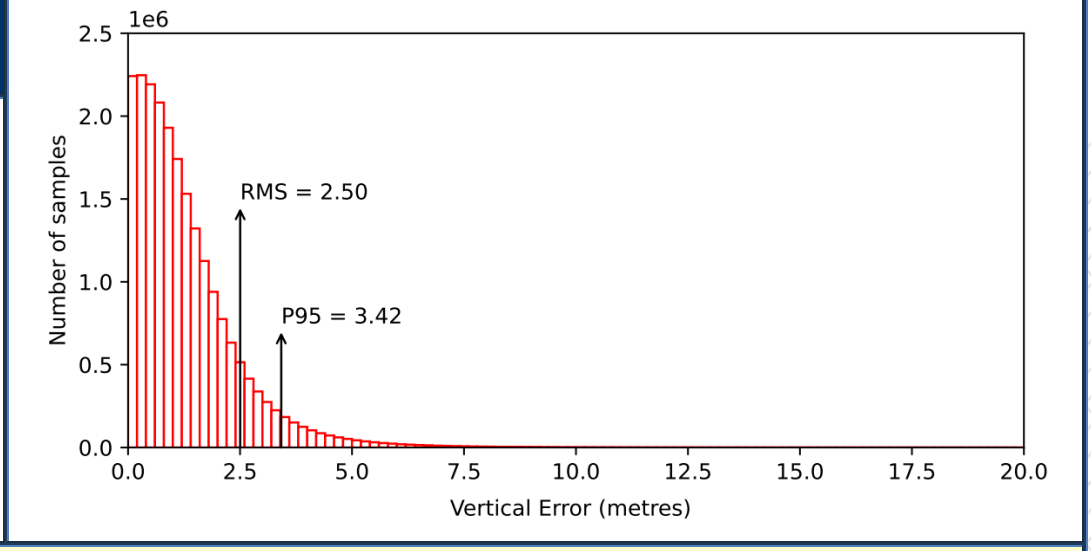
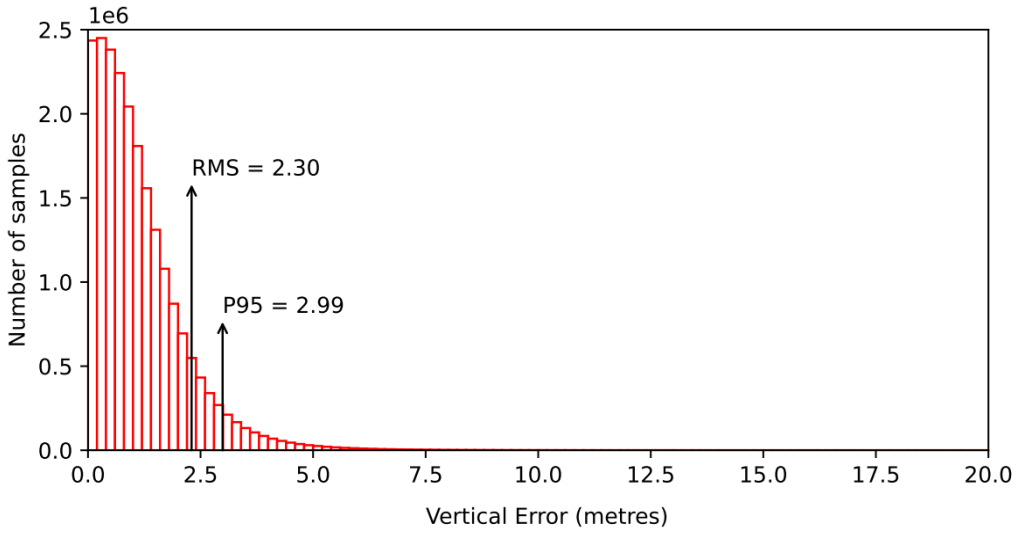
July 2022	
VPE 3D Positioning E1-E5b (DF) I/NAV	
Note: 25857 samples > 20 [m], around 0.071% of total	

Figure 22 : Vertical Positioning Error (VPE) for "Galileo-only" users in July 2022

August 2022	
VPE 3D Positioning E1-E5a (DF) F/NAV	
Note: 25850 samples > 20 [m], around 0.072% of total	

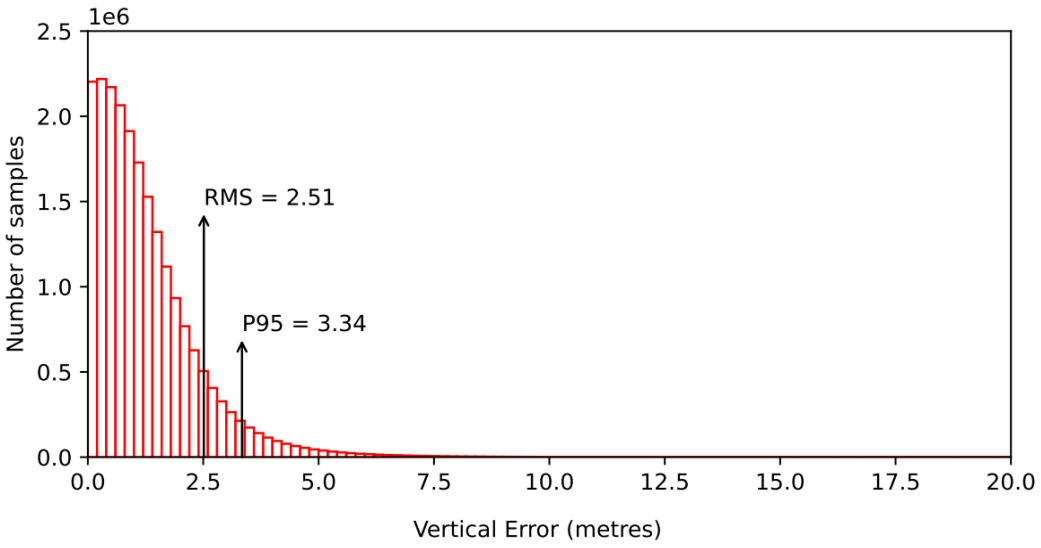
August 2022	
VPE 3D Positioning E1-E5b (DF) I/NAV	
Note: 27371 samples > 20 [m], around 0.076% of total	

Figure 23 : Vertical Positioning Error (VPE) for "Galileo-only" users in August 2022

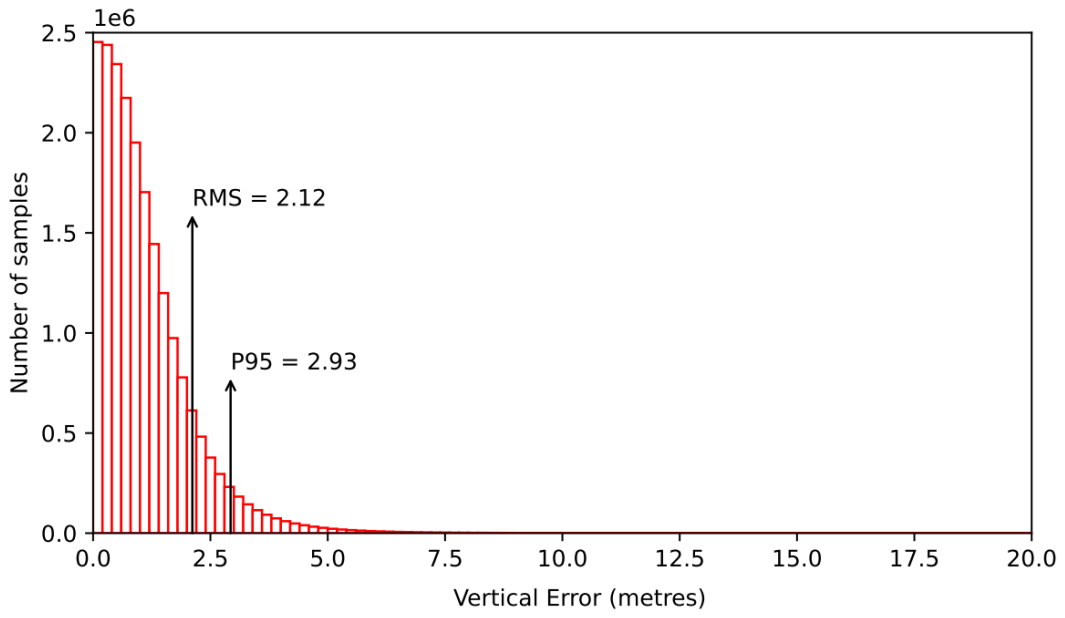
September 2022

VPE

3D Positioning

E1-E5a (DF)

F/NAV



Note: 26569 samples > 20 [m], around 0.076% of total

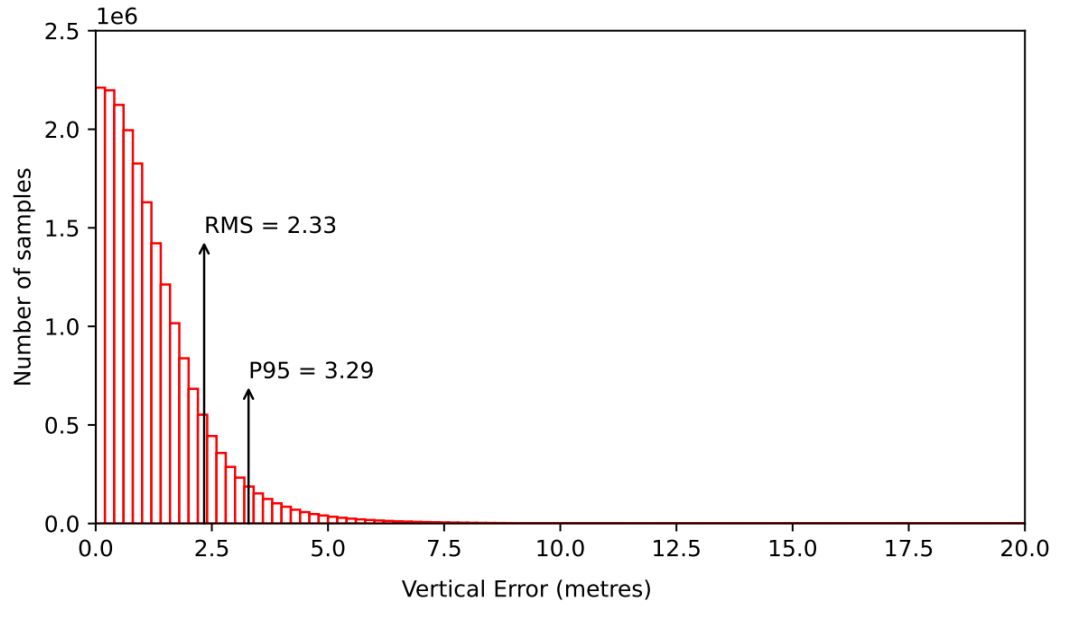
September 2022

VPE

3D Positioning

E1-E5b (DF)

I/NAV



Note: 28200 samples > 20 [m], around 0.080% of total

Figure 24 : Vertical Positioning Error (VPE) for "Galileo-only" users in September 2022

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:

GNSS Service Centre NAGU Publication Service Web Pages		
NAGUs Information	https://www.gsc-europa.eu/system-status/user-notifications	(Active user Notifications)
	https://www.gsc-europa.eu/system-status/user-notifications-archived	(Archived user Notifications)

Table 5 : GSC web pages for Galileo User Notifications (NAGUs)

With the new [OS-SDD] in force since December 2021:

- NAGUs related to Planned events need to be published at least **48** hours [27] (previously 24 hours) before the start of the event
- For Unplanned events, the [OS-SDD] specifies a delay of up to **30** hours [27] (previously 3 days) 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 6 . NAGU publication timeliness requirements were met with large margins, as per figures reported in the table.

During the quarter, **11** NAGUs have been published. In particular:

- in **July**, **4** NAGUs were issued; two of them "planned" and two of category "unplanned", the latter referred to GSAT-0203 (E26) (short-term outage lasting around 1.5 hours) and to GSAT-0103 (E19). In the case of E19, it was an extension for a previous planned outage;
- in **August**, **5** NAGUs were issued; 1 of category "planned", 4 "unplanned". The unplanned ones only refer to recovery of Service provision for GSAT-0223 (E34) and GSAT-0103 (E19) and to the initial availability for users of GSAT-0224 (E10);

[27] Ref.: [OS-SDD] §3.6.1 (Table 21)

- in **September**, 2 NAGUs have been published, both of category "unplanned". Most relevant is the one announcing the unavailability of GSAT-0210 (E01), until further notice.

Table 6 provides a summary of published NAGUs during the quarter.

Month	NAGU Type	Reason for publishing	Notice Advisory ID	NAGU Categ.	Timeliness
July	PLN_OUTAGE	Warning about the unavailability of GSAT-0223 (E34), starting from 2022-07-11 @ 04:45 UTC.	2022026	P	Timely published **3.56** days before the event.
	GENERAL (NOTICE)	Warning that GSAT-0224 will be involved in I/NAV message testing, with SIS health status flags alternating unhealthy/healthy status. Reminding that satellite should not be used until the relevant USABINIT NAGU is published.	2022027	P	Timely published **3.55** days before the event.
	UNP_SHTRCVR	Announcing the recovery of short-term outage affecting GSAT-0203 (all signals) since 19/07/2022 @ 09:10 UTC	2022028	U	Timely published **0.285** days after the event.
	EXTNS	Extending unavailability of GSAT-0103, with outage recovery estimated on 2022/08/06	2022029	U	Timely published **0.171** days after decision by SDM transferred to GSC OPS team.
August	USABLE	Announcing the recovered availability of GSAT-0223 (E34), starting from 01/08/2022 @ 16:00 UTC	2022030	U	Timely published **0.948 days** after the event
	PLN_OUTAGE	Warning about a planned outage scheduled for GSAT-0223 (E34), the unavailability of SIS starting from 11/08/2022 @ 00:00 UTC	2022031	P	Timely published **5.51 days** before the event

Month	NAGU Type	Reason for publishing	Notice Advisory ID	NAGU Categ.	Timeliness
	USABLE	Announcing the recovered availability of GSAT-0103 (E19), starting from 05/08/2022 @ 07:51 UTC	2022032	U	Timely published **0.183 days** after the event
	USABLE	Announcing the recovered availability of GSAT-0223 (E34), starting from 29/08/2022 @ 13:51 UTC	2022033	U	Timely published **0.100** days after the event
	USABINIT	Declaring the start of service provision by GSAT-0224 (E10) SIS, initiated on 29/08/2022 @ 13:51 UTC	2022034	U	Timely published **0.110** days after the event
September	UNP_UNUFN	Declaring GSAT-0210 (E01) unavailable for all Navigation Services, starting on 31.08.2022 @ 19:42 UTC until further notice	2022035	U	Timely published **0.867** days after the event
	UNP_SHTRCVR	Warning "*a -posteriori*" about the unavailability of GSAT-0203 (E26), starting on 19/09/2022 and lasting from 17:31 until 18:19 UTC. Published 0.770 days before the event.	2022036	U	Timely published **0.770** days after the event
NAGU Categorisation for timeliness evaluation: "P" = Planned, "U" = Unplanned					

Table 6 : NAGUs published during 3rd Quarter of 2022

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 verification failures will be corrected for the service provision phase.

7.1 AVAILABILITY OF AUTHENTICATION (MAC) TAGS

The following Navigation message Authentication types are considered:

- Type 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 4 space vehicles, within a period of 120 [s] (the latter computed since May).

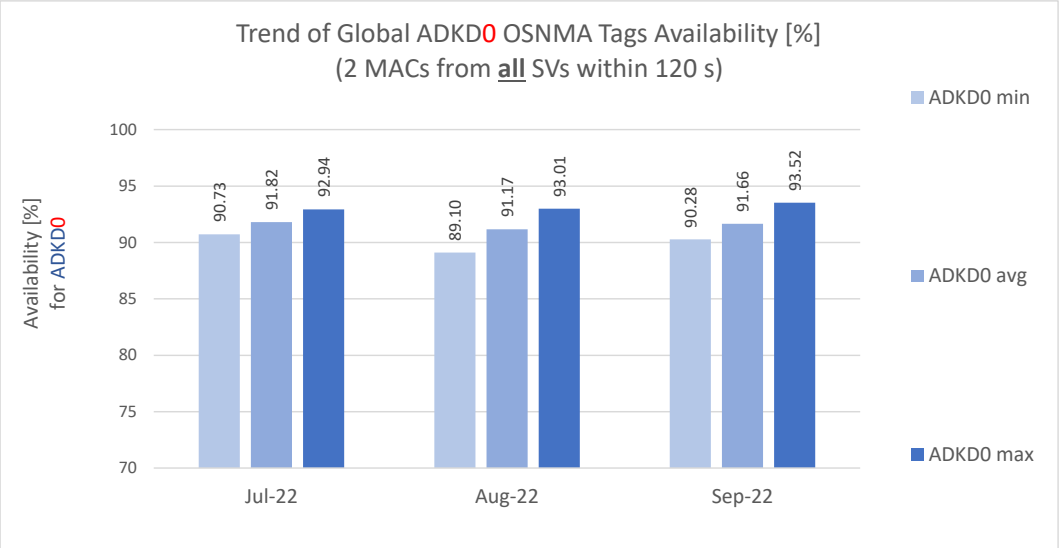
- Type ADKD4 → for the Galileo GST-UTC and GST-GPS conversion parameters.

  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].

- Type 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 4 satellites, within a period of 240 [s].

Results obtained during the Quarter are shown in the following:



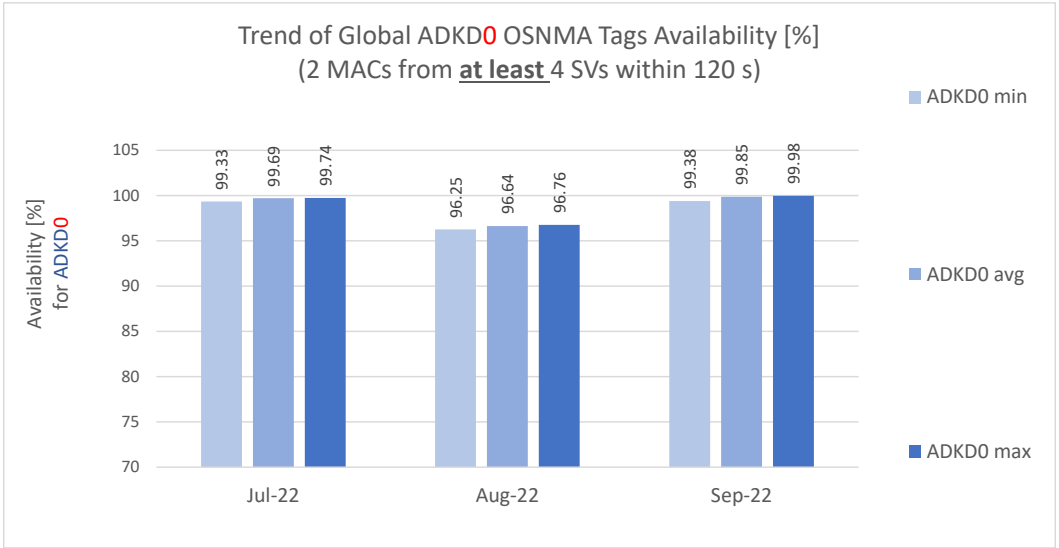


Figure 25 : Availability of Tags for Galileo I/NAV orbit & clock data (ADKD0)

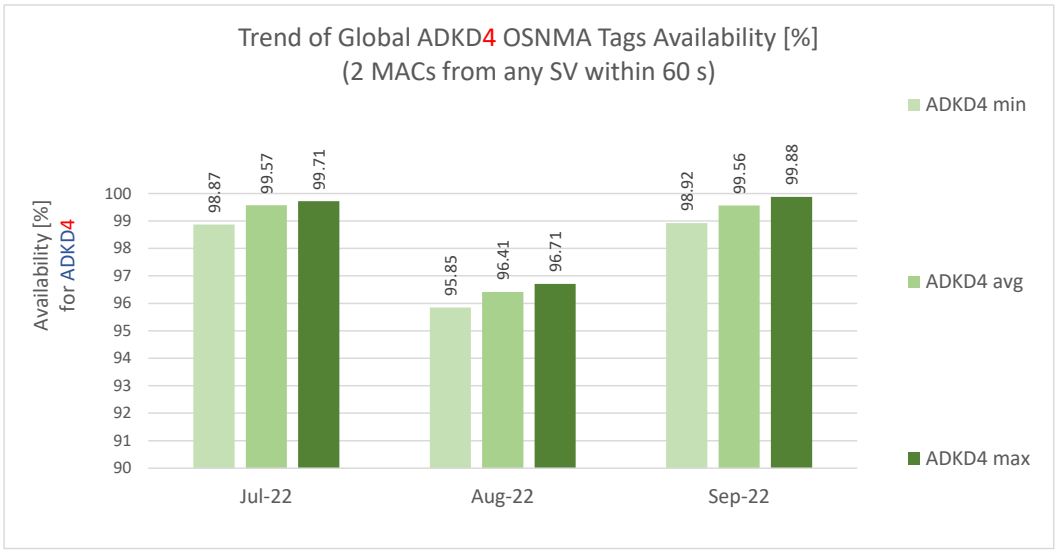


Figure 26 : Availability of Tags for the GST-UTC and GGTO Parameters (ADKD4)

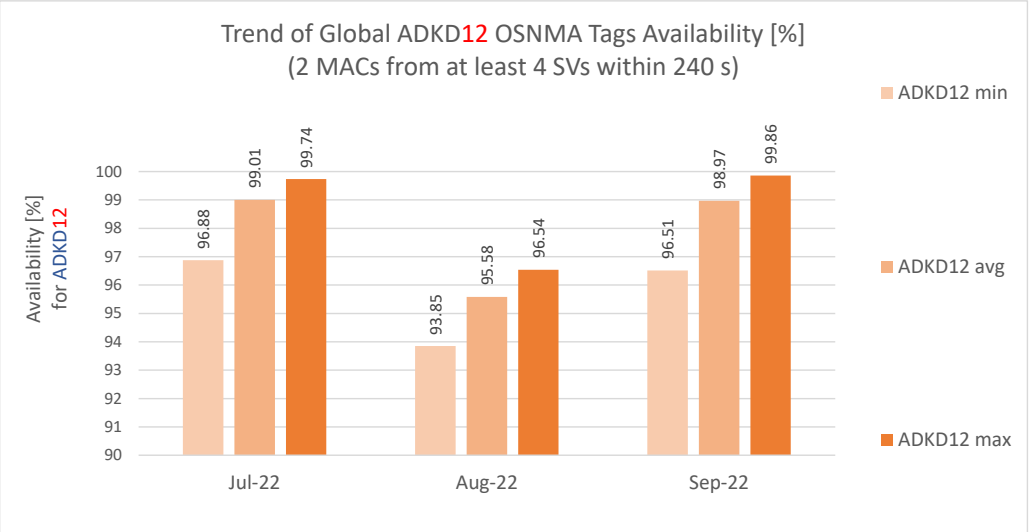


Figure 27 : Availability of Tags for Galileo I/NAV orbit & clock data (ADKD12)

Note:

in the case of ADKD0, with the entry into service of GSAT-0223 (E34), the availability "for all Space Vehicles" decreased, while the availability "for at least 4 Space Vehicles in view" was improved. Similarly, this happened with the addition of GSAT-0224 (E10) to the OSNMA module.

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):

			Jul-22	Aug-22	Sep-22
Successful OSNMA Tags [%]	Single Frequency	ADKD0	99.9996	99.9970	99.9849
		ADKD4	99.9960	99.9960	99.9860
		ADKD12	99.9993	99.9867	99.9889
	Dual Frequency	ADKD0	99.9999	99.9970	99.9850
		ADKD4	99.9960	99.9960	99.9860
		ADKD12	99.9997	99.9867	99.9889

Figure 28: Statistics for Dual Frequency – Successful OSNMA Tags

Percentages in Figure 28 do not account for space vehicles GSAT-0201 (E18) and GSAT-0202 (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.

[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 #4] Service Notice #04 - Use of the Galileo satellites GSAT-0201 and GSAT-0202

[SvNOTE #5] Service Notice #05 - Unavailability of the Galileo Auxiliary satellites GSAT-0201 and GSAT-0202

[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.

[OSNMA SIS-ICD] On November 18th 2020 @ 15:28 UTC, Galileo satellites started the transmission of authentication information, for testing purposes: first-ever signal-in-space (SIS) dissemination with OSNMA data, according to the OSNMA SIS-ICD applicable during this phase.

[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/), with the exception of Issue 1.0 of the OS-SDD.

IMPORTANT NOTE

Since mid-December 2021, the [OS-SDD] version in force is Issue 1.2, which is the version that is immediately accessible for download from the European GNSS Service Centre (GSC) website.

The quarterly reporting of metrics in this report is implemented in line with the [OS-SDD] Issue 1.2

Issue 2.0 of the [SIS-ICD] is available since January 2021.

For an exhaustive description of the Minimum Performance Levels (MPLs), the reader is referred to the [OS-SDD].

Individual sections of such document have been referenced throughout this report when referring to MPL target values and calculation methods, indicating explicitly any relevant changes with respect to past OS-SDD version (Issue 1.1).

9 LIST OF ACRONYMS

Acronym	Definition
AUL	Average User Location
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
GPS	Global Positioning System
G/S	Ground Segment
GSC	European GNSS Service Centre
GST	Galileo System Time
HDOP	Horizontal Dilution of Precision
HPE	Horizontal Positioning Error
ICD	Interface Control Document
I/NAV	Navigation message provided by the E1-B and E5b signals [SIS-ICD]
IS	(Galileo) Initial Services
MPL	Minimum Performance Level
NAGU	Notice Advisory to Galileo Users
OLTN	OSNMA Live Test Notification
OS	(Galileo Navigation) Open Service
OSNMA	Galileo Open Service Navigation data Authentication
PDOP	Position Dilution of Precision
SBDO	StandBy Duty Officer
SDD	Service Definition Document
SDM	Service Delivery Manager
SF	(Galileo OS) Single Frequency (E1, E5a, E5b)
SIS	Signal in Space
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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