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EUROPEAN GNSS (GALILEO) SERVICES

OPEN SERVICE

QUARTERLY PERFORMANCE REPORT

OCTOBER - DECEMBER 2021

[1] However, as the OS-SDD v1.2 was published by mid-December 2021, this report is based on OS-SDD v1.1, applicable version for the quarter under consideration

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

This document is the *Galileo Open Service (OS) Public Performance Report* for the period of **October, November and December 2021**. Following 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 magnitudes and metrics which are not subject to MPL target, like it is also the case of the newly introduced reporting on Galileo OSNMA "Public Observation" phase. The document then 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 info about 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: the adopted terms, acronyms and abbreviations 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	18	261	not-nominal	Not usable since February 18th, 2021
GSAT-0202	14	262	not-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 [3]	34	109	B03	Not yet declared usable
GSAT-0224 [3]	10	10B	B15	Not yet declared usable

Table 1 : Galileo Reported Constellation Information

[3] Launched on 05.12.2021; actually, undergoing In Orbit Test

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]).

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.

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	October-21					November-21					December-21				
			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															

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	Oct-21	Nov-21	Dec-21
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	≥ 87%			
			E1/E5b				
			E1				
			E5a				
			E5b				
Positioning and DOP	Availability	PDOP – F/NAV (E5a SIS)		≤ 6			
		PDOP – I/NAV (E1-B and E5b SIS)		≤ 6			
		DF, at Average User Location		≥ 77%			
		SF, at Average User Location		≥ 77%			
		DF, at Worst User Location		≥ 70%			
		SF, at Worst User Location		≥ 70%			

OS MPLs			Target Value	Oct-21	Nov-21	Dec-21
Timing	Accuracy	UTC Time Dissemination	≤ 30ns [95%]			
		UTC Frequency Dissemination	< 3E-13 [95%]			
		GGTO Determination	≤ 20ns [95%]			
	Availability	UTC Dissemination	≥ 87%			
		UTC Determination Accuracy	≥ 87%			
		GGTO Determination	≥ 80%			
User Interface	NAGU	Planned Timeliness	≥ 1 day			
		Unplanned Timeliness	≤ 3 days			

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

The "per-slot" **Availability of a Healthy Signal** is considerably above the MPL threshold of **87%**, with averaged monthly values at least equal to **99.04**% for every Single-Frequency (E1-B, E5a, E5b) and Dual-Frequency combination (E1/E5a, E1/E5b) during the quarter.

The monthly figures are annually normalised, according to the MPL definition, by a moving average applied over the most recent 12 months.

Looking instead at the monthly values for individual space vehicles, and without implementing annual averaging (as reported in Figure 3):

- in October and November GSAT-0206 (E30) exhibited low availability figures, down to 79.04%, due to a planned orbit correction manoeuvre (ref.: NAGUs 202116 and 202117);
- similarly, in November GSAT-0203 (E26) had healthy SIS availability as low as 62.57%, again caused by a planned orbit adjustment (ref.: NAGUs 202118 , 202119 , 2021022).

The **Signal in Space Ranging Accuracy** shows a 95th percentile monthly accuracy between **0.20** [m] and **0.62** [m] for individual space vehicles ("Any Satellite") on Single Frequency observables [4]. For Dual Frequency signal combinations [5], the figure is in the range from **0.15** [m] to **0.28** [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.

Also, the evaluation of worst-satellite ranging error at higher confidence level (99.9%, not subject to MPL) shows good values (ref.: Figure 5): monthly accuracy between **0.31** [m] and **1.85** [m] for

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

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

individual space vehicles ("Any Satellite") on Single Frequency observables [4] . For Dual Frequency signal combinations [5], the figure is in the range from **0.26** [m] to **0.83** [m].

The average **Ranging Accuracy at constellation level** (over "All Satellites", ref. Figure 8) provides figures "per signal" that are better than or equal to **0.34** [m] for Single Frequency signals and **0.16** [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 given Accuracy** (i.e.: better than 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 targets are **87%**.

The **Availability of GGTO Determination** metric was **99.40%** in October, **98.29%** in November and **98.36%** in December (ref.: Figure 11). We recall that "dummy" GGTO coefficients have been disseminated in November over 4 days (ref.: NAGUs 2021021 and 2021023). The figures provided in §4.1 are obtained by averaging over the last 12 months. The measured values are comfortably above the [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** (normalised offset $\leq 1.5\times10^{-14}$, as per Figure 13) and the **GGTO Determination Accuracy**, constantly around **3.2** [ns] in the reporting quarter (ref.: Figure 14). The [OS-SDD] MPL targets, which are respectively 30 [ns], 3×10^{-13} and 20 [ns], are all met. All figures related to time accuracy are computed by accumulating daily measurement samples over 12 months.

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 currently includes 22 space vehicles actively contributing to the provision of navigation services. Associated metrics are as follows:

For both F/NAV and I/NAV, the **Availability of Global PDOP ≤ 6** (ref.: Figure 15) was better than or equal to **99.52%** during the first two months, then raising to **99.99%** in December, against a target MPL of **77%**. At Worst User Location (not subject to MPL), availability figure was better than or equal to **99.29%** during the quarter (ref.: Figure 16).

Under the conditions that 95% HPE ≤ 7.5 [m] and, at the same time, 95% VPE ≤ 15 [m], the **Availability of Positioning** totals for any Single-Frequency SIS or Dual-Frequency combination at Worst User Location (WUL, ref.: Figure 17) and at Average Uer Location (AUL, ref.: Figure 18):

- in October: **99.43%** (DF) and **99.34%** (SF) at WUL; **99.91%** (DF) and **99.87%** (SF) at AUL;
- in November: **99.72%** (DF) and **99.58%** (SF) at WUL; **99.96%** (DF) and **99.92%** (SF) at AUL;
- in December, **100%** even at WUL.

The target MPL values are **70%** at WUL and **77%** at AUL, 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, and obtained by processing data from a network of real reference receivers (ref.: from Figure 19 up to Figure 24).

For Dual-Frequency combinations (E1/E5a and E1/E5b), the 95th percentile of **Horizontal and Vertical 3D Positioning Errors** (HPE and VPE, correspondingly) did not exceed **1.93** [m] and **2.74** [m] during the whole quarter. The corresponding RMS values, which are also not subject to an MPL assessment, are not trespassing respectively **1.32** [m] and **2.52** [m].

Regarding **Publication of NAGUs**, **9 NAGUs** have been issued in the reporting period, in all cases respecting the requirements for their timeliness. The target is to issue a NAGU at least **24** hours before the start of a scheduled event, as well as not more than **72** hours after 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

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.

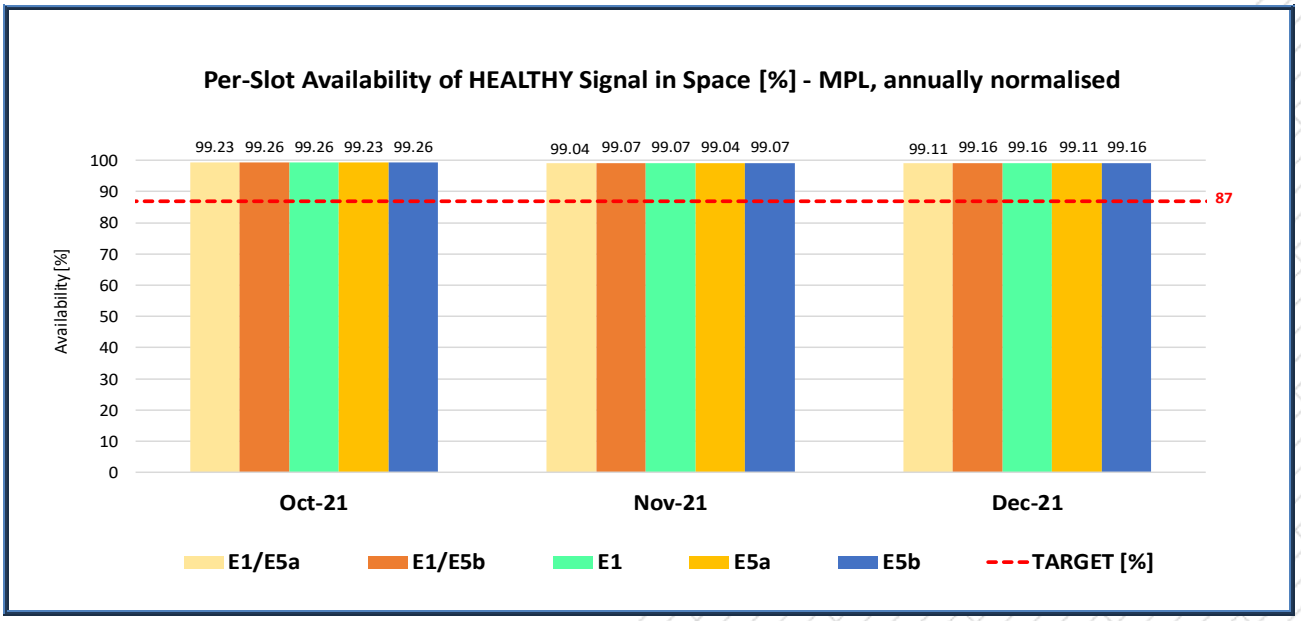

Figure 1 : "Per-Slot" availability of HEALTHY Signal in Space for the reporting period

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.[6] The [OS-SDD] Minimum Performance Level (MPL) specifies 87% [7] as the target value for this constellation metric. The achieved performance is between 99.04% (Single Frequency SIS E5a and Dual Frequency combination E1-E5a in November) and 99.26% (Single Frequency SIS E1, E5b and Dual Frequency combination E1-E5b in October).

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:

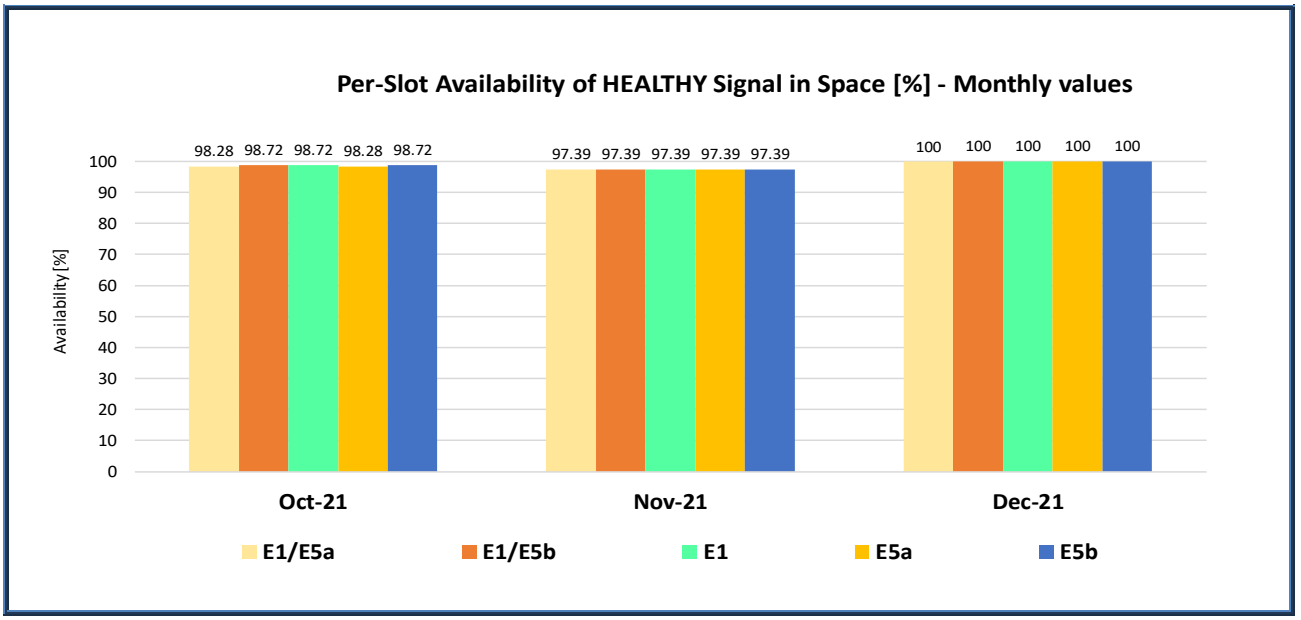

Figure 2 : "Per-Slot" availability of HEALTHY Signal in Space for the reporting period, not normalised

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, the availability achieved 100% in December. Lower values were observed during the first two months, mainly due to the planned orbit correction manoeuvres of GSAT-0206 (E30) and GSAT-0203 (E26), as mentioned in the executive summary and also visible in Figure 3 .

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6 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.

7 Ref.: [OS-SDD] issue 1.1, §3.4.1 (Table 13)

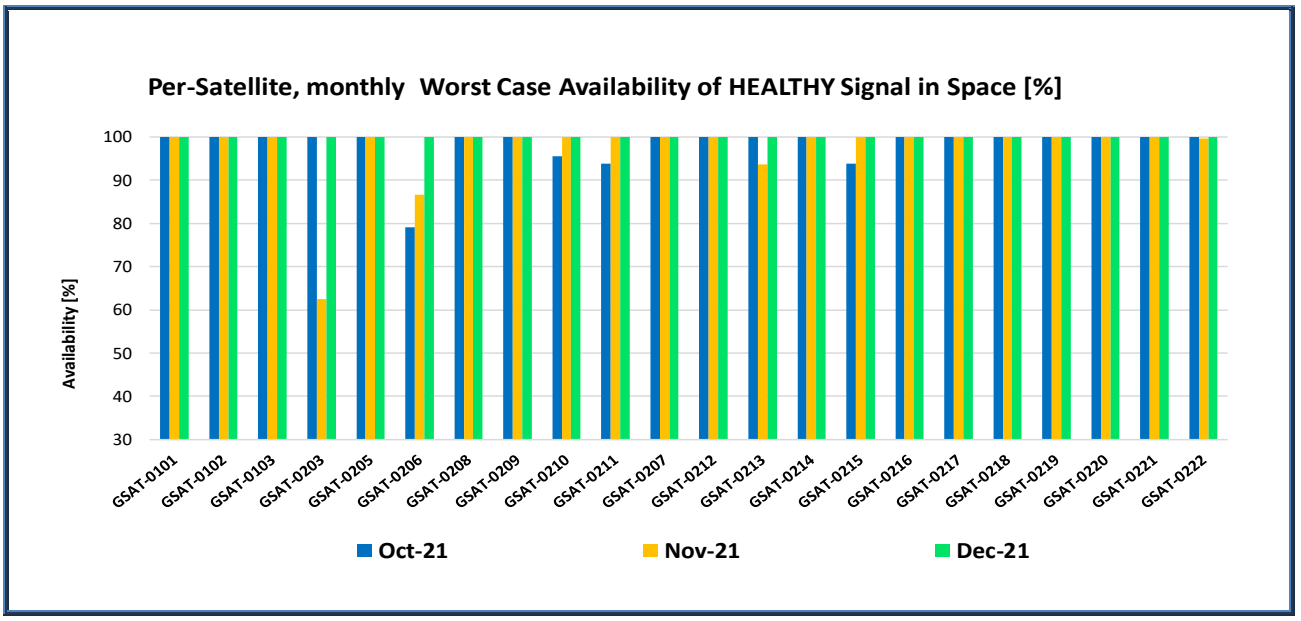


Figure 3 : Individual, "Per-Satellite" worst-case SIS availability of HEALTHY Signal in Space for the reporting period

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

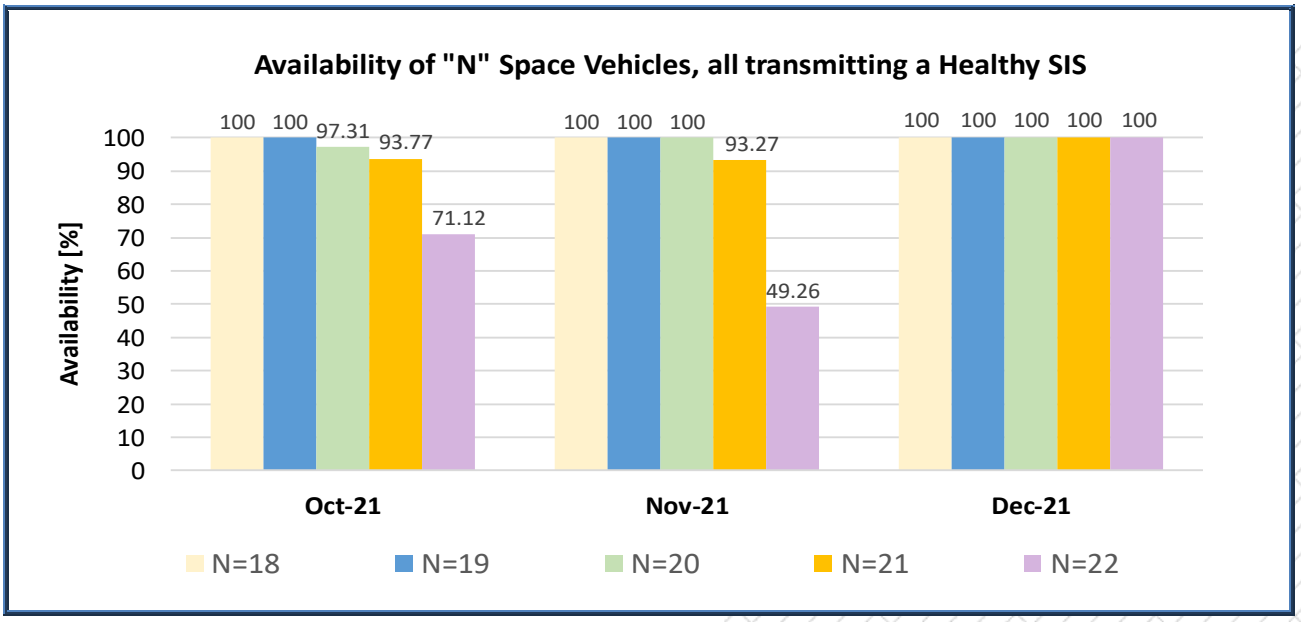


Figure 4 : Monthly percentage of availability of "N" Space Vehicles transmitting a Healthy SIS

In the case of N=22, the low percentage values of 71.12% and 49.26% are mainly due to the unavailability of GSAT-0203 (E26), which lasted around 11.24 days, and the one of GSAT-0206 (E30), about 10.5 days, due to planned orbital correction manoeuvers.

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.

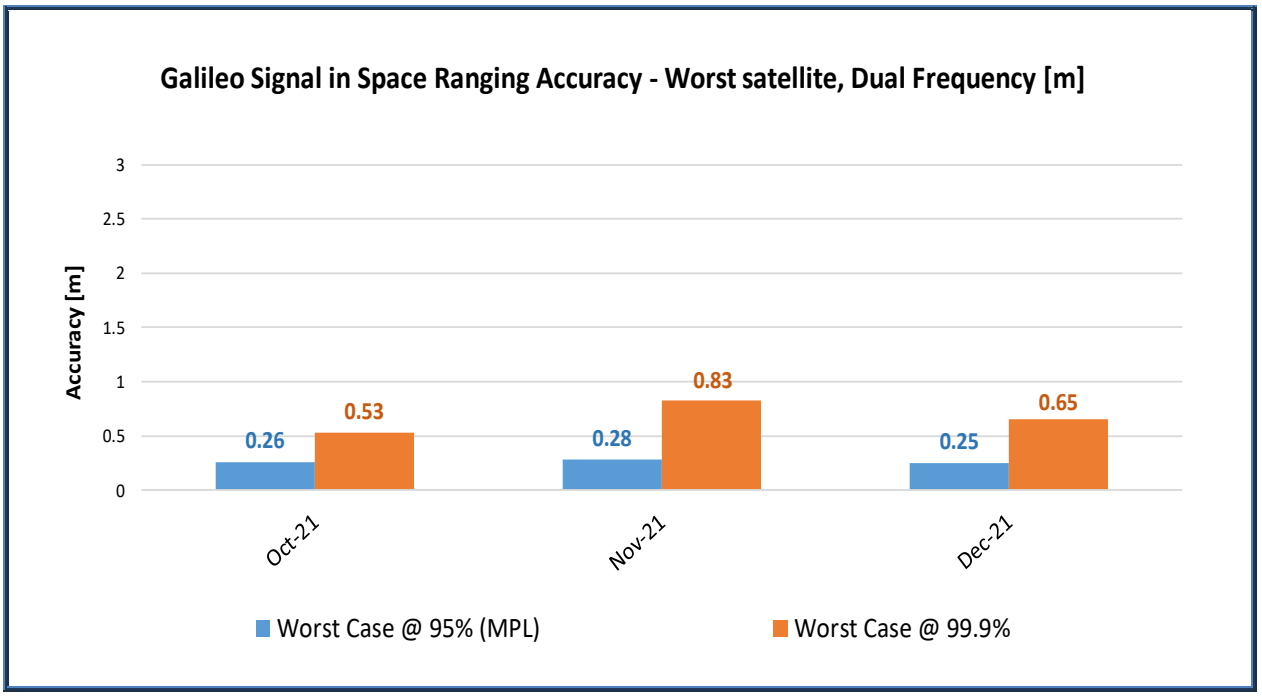
Figure 6 and Figure 7 show the monthly 95% confidence level metric for Galileo Signal in Space Ranging Accuracy, to be compared against the MPL target levels. Computation is applied "for any space vehicle", over all satellites [8] and frequency combinations [9], achieving the following results:

- for individual space vehicles in **October**, worst case values of **0.26** [m] for Dual Frequency and **0.71** [m] for Single Frequency. The best-case values over the month are **0.16** [m] and **0.20** [m], respectively.
- for individual space vehicles in **November**, worst case values of **0.28** [m] for Dual Frequency and **0.62** [m] for Single Frequency. The best-case values over the month are **0.15** [m] and **0.20** [m], respectively.
- for individual space vehicles in **December**, worst case values of **0.25** [m] for Dual Frequency and **0.62** [m] for Single Frequency. The best-case values over the month are **0.16** [m] and **0.20** [m], respectively.

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

[8] Satellites in nominal slots plus Auxiliary Satellites.

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



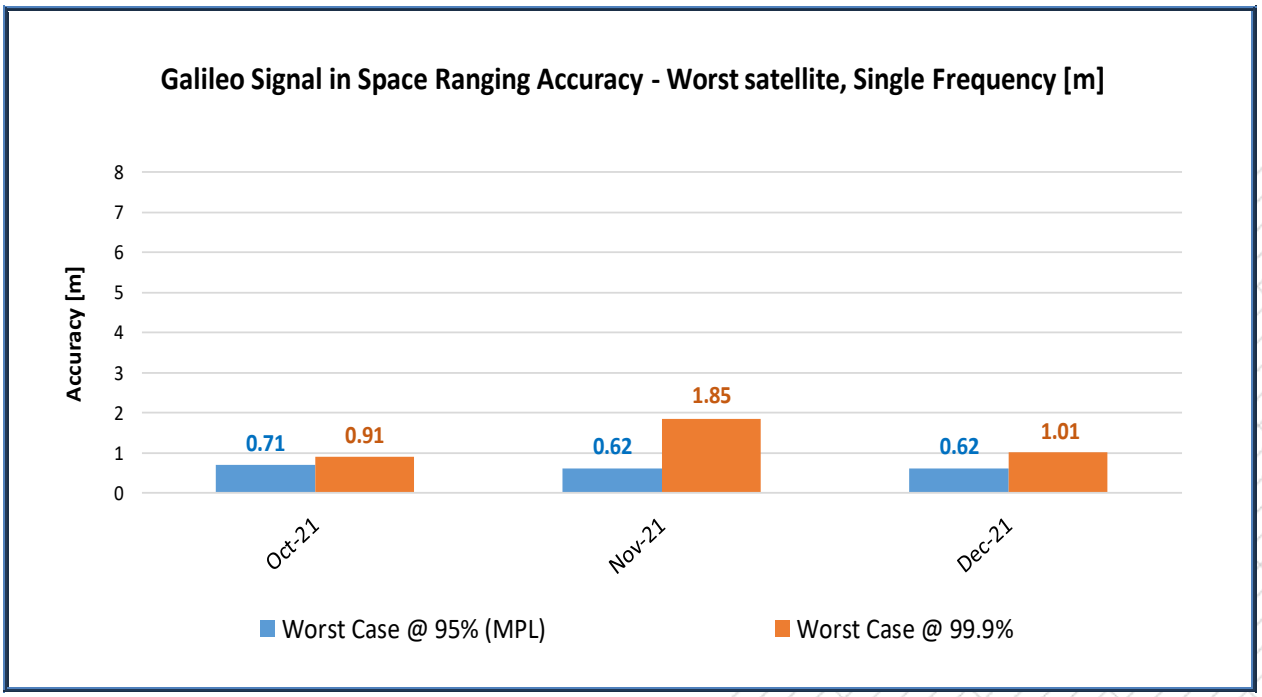
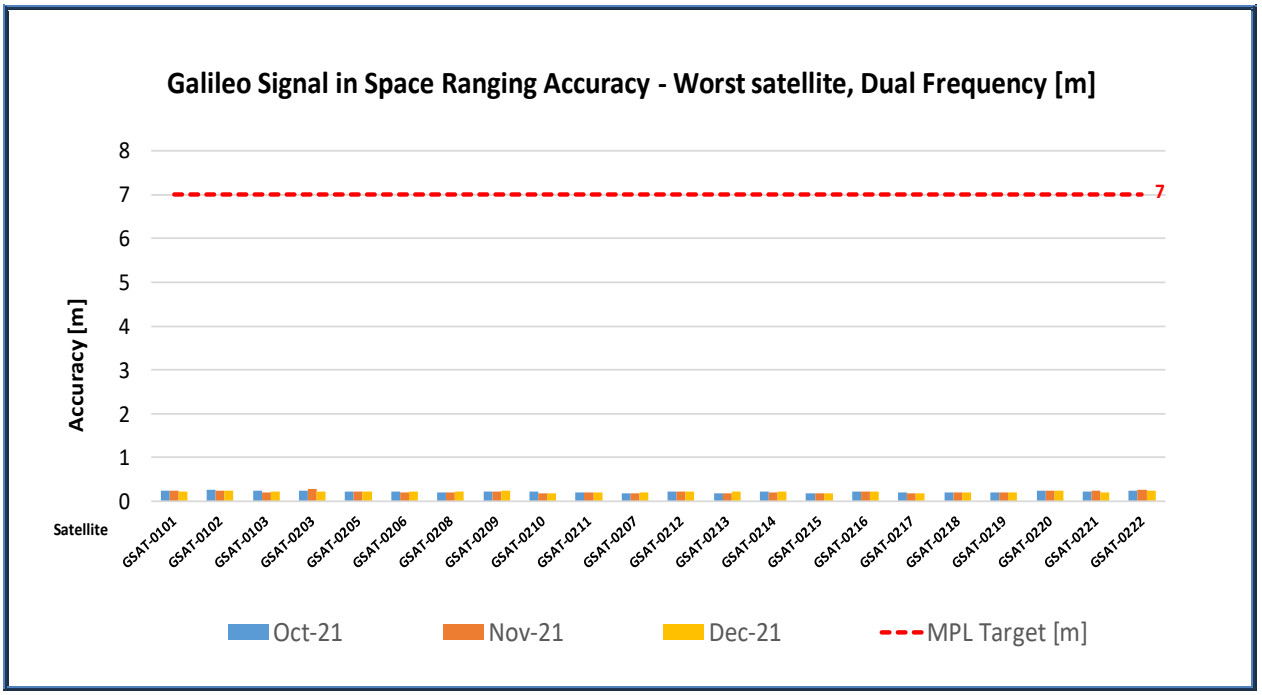


Figure 5 : Worst-case, monthly Galileo SIS Ranging Accuracy (at 95th and 99.9th confidence level percentiles) "for any satellite", any SIS (SF and DF combinations)



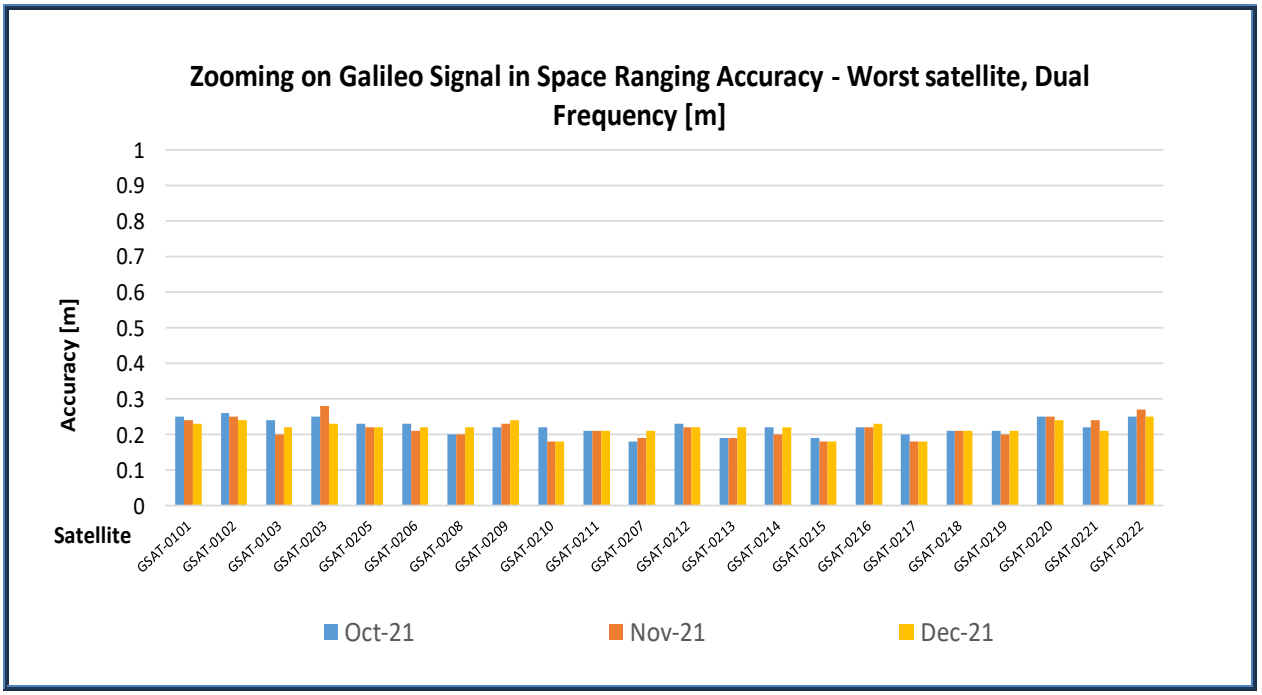
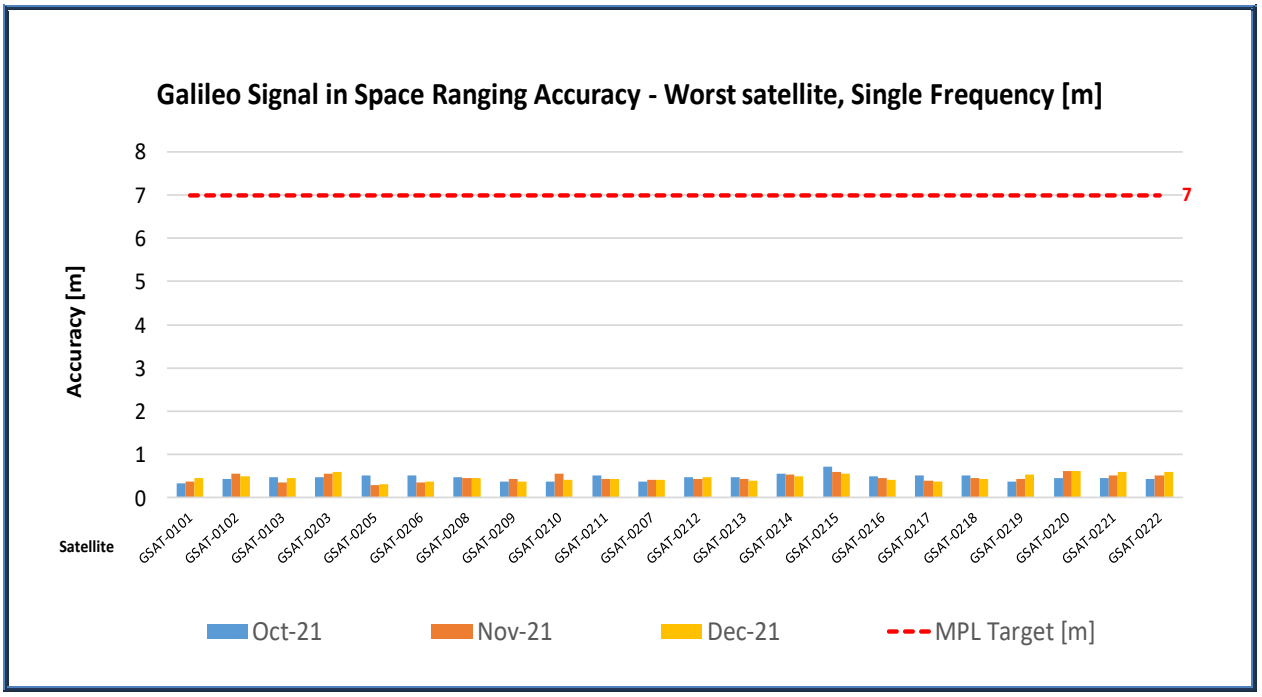


Figure 6 : Monthly Galileo SIS Ranging Accuracy (95th percentile) "for any satellite", measured during reporting period for worst-case, Dual-Frequency (DF)



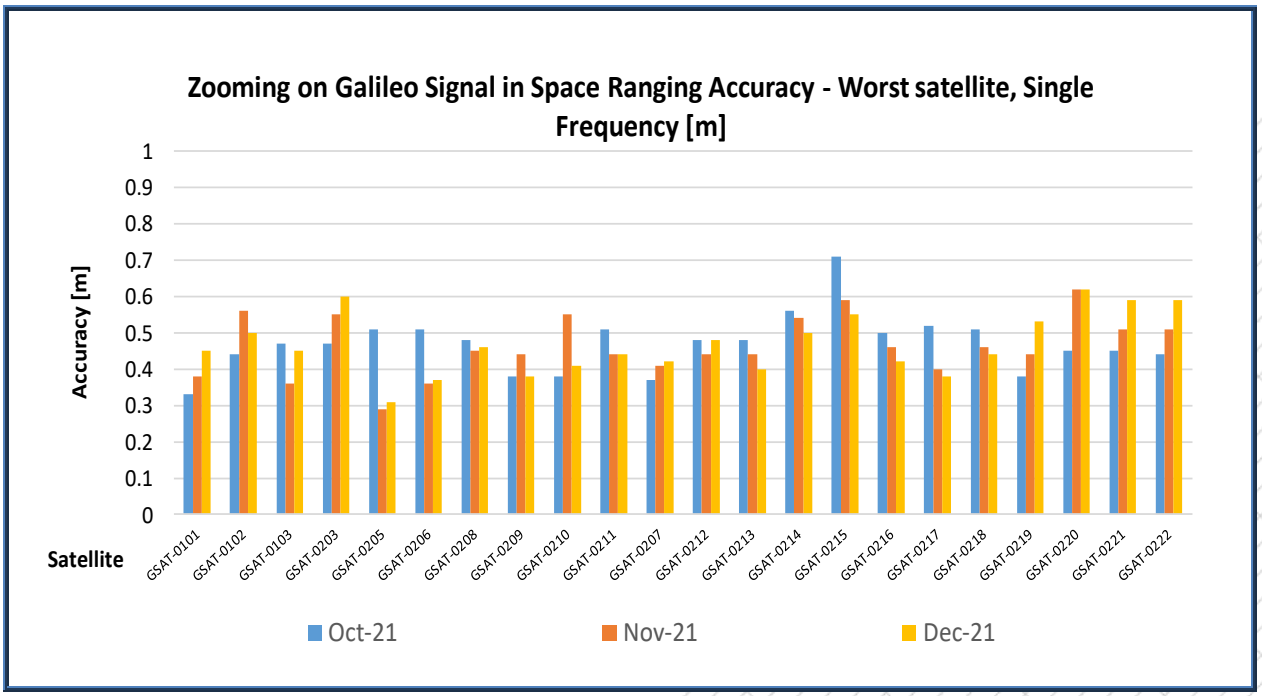


Figure 7 : Monthly Galileo SIS Ranging Accuracy (95th percentile) "for any satellite", measured during the reporting period for worst-case, Single-Frequency (SF)

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] [10] 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] [11] is met by the Constellation average value.

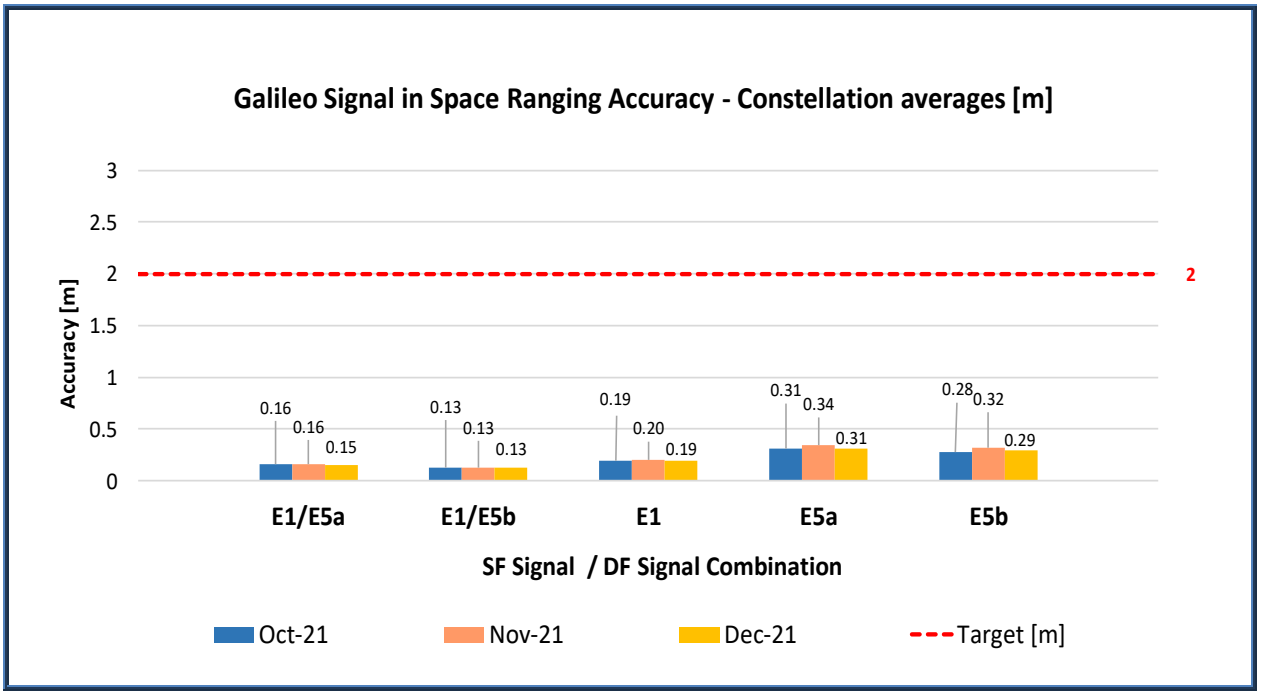


Figure 8 : Monthly Galileo SIS Ranging Accuracy (95th percentile) "over all satellites" (constellation average), measured during the reporting period

10 Ref.: [OS-SDD] issue 1.1, §3.3.1 (Table 9)

11 Ref.: [OS-SDD] issue 1.1, §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 9 provides the Worst User Location (WUL) Availability of such service, computed for a virtual grid of user positions over the service coverage area.

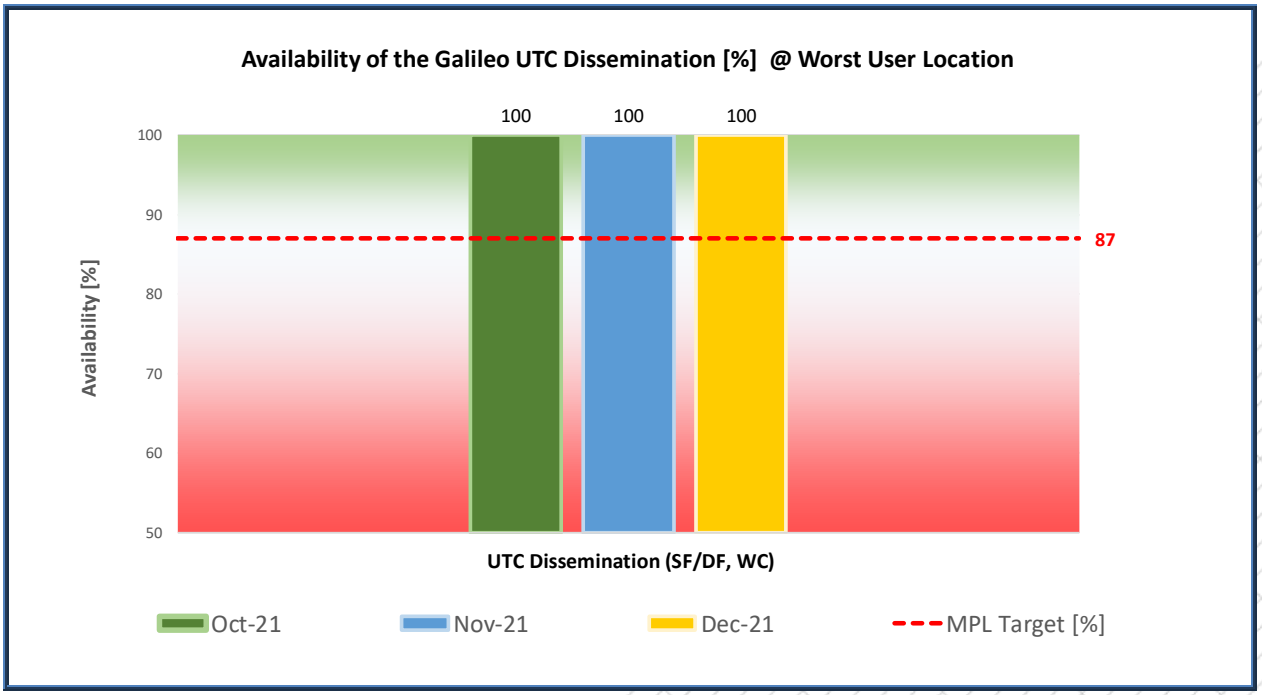


Figure 9 : Monthly availability of the UTC Dissemination Service during the reporting period

As shown in Fig. 6, the monthly (short-term) availability of the Galileo UTC Dissemination Service

achieved 100% during all three months of the reporting period. The MPL of 87% [12] specified by [OS-SDD] for the long term 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 of at least 87%.

Similarly to the case of UTC Dissemination, targets for Availability are met with an availability of 100% during the entire quarter:

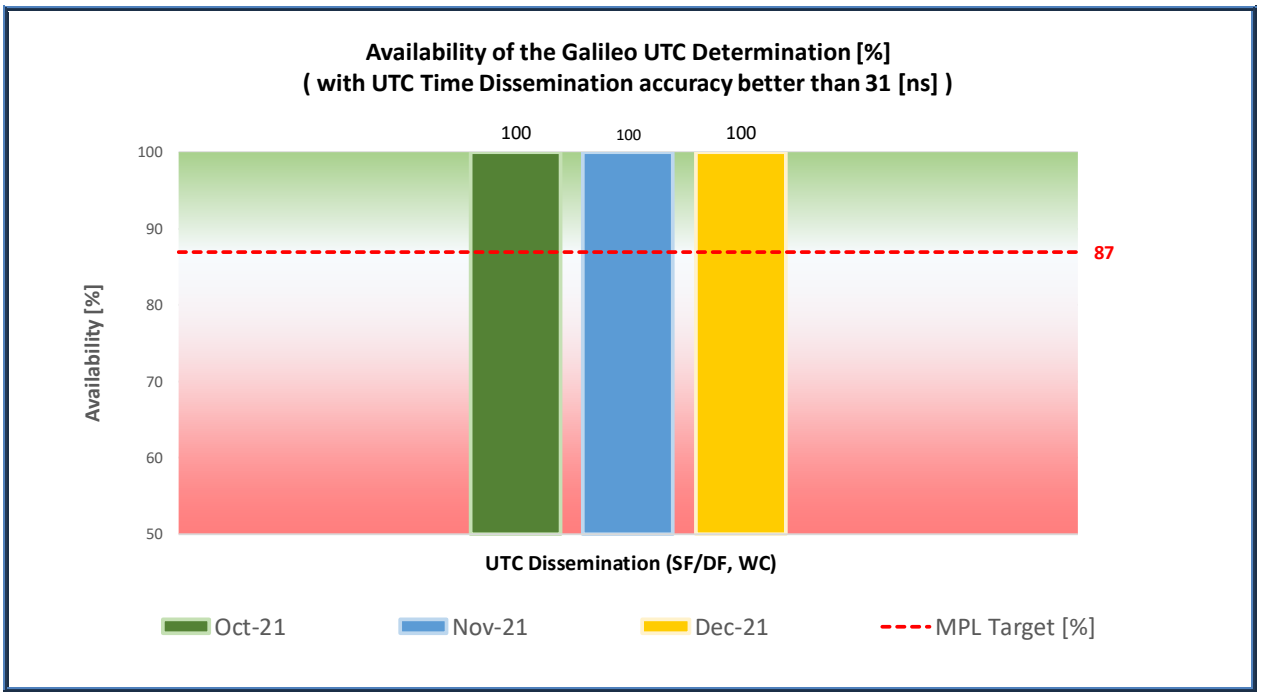


Figure 10 : Monthly availability of the UTC Determination with assigned Accuracy target during the reporting period

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[13] 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 normalised annually by accumulating data over the previous 12 months, as per [OS-SDD] MPL definition.

12 Ref.: [OS-SDD] issue 1.1, §3.4.2 (Table 14)

13 "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.

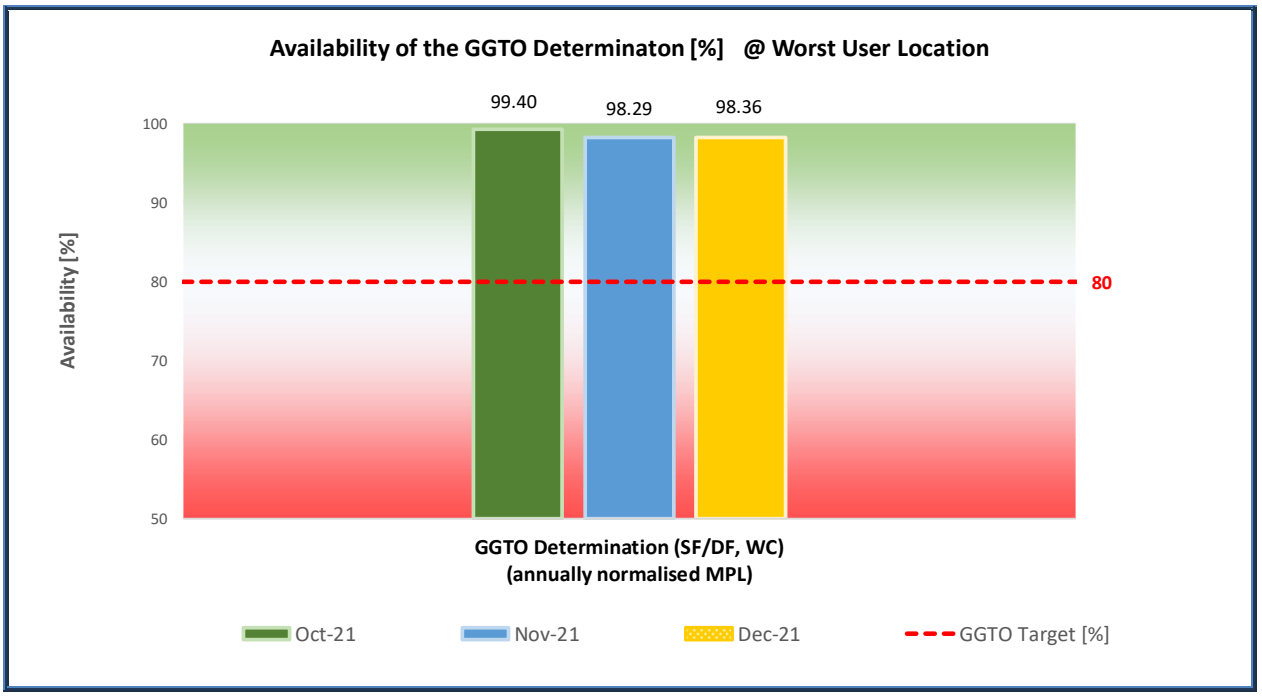


Figure 11 : Annually normalised availability of the GGTO Determination, during the reporting period

The MPL of 80% [14] specified by [OS-SDD] for the long term is fully achieved. The monthly (short-term) Galileo user GGTO Determination capability, which is not shown in the figures and not subject to an MPL target, was 100% in October and December, while 86.64% in November, due to the dissemination of "dummy" GGTO coefficients.

4.2 ACCURACY OF GALILEO TIME CORRELATION PARAMETERS

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 [15].

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.

Figure 12 shows the 95th percentile of the daily average of the UTC Dissemination Accuracy, observed and normalised over a period of 12 months.

[14] Ref.: [OS-SDD] issue 1.1, §3.5.1.2 (Table 20)

[15] 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

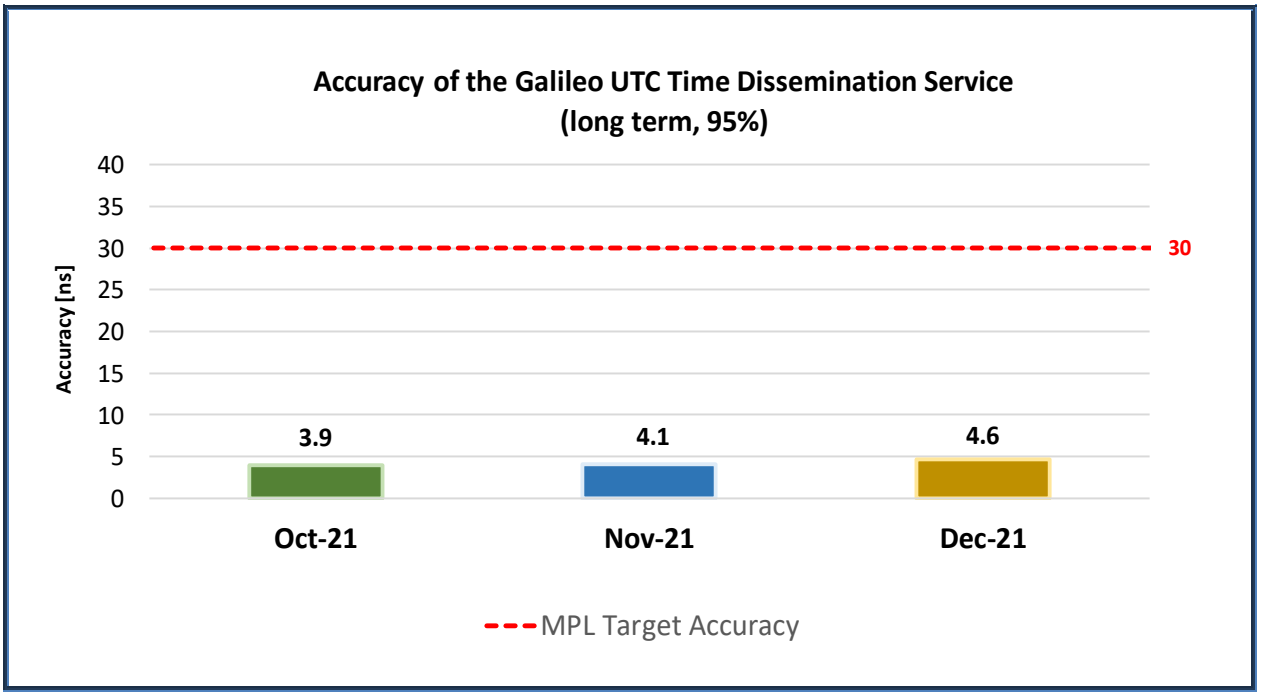


Figure 12 : Long-term 95th percentile of UTC Time Dissemination Accuracy

Figure 13 shows the 95th percentile of the UTC Frequency Dissemination Accuracy, computed accumulating measurement data over the past 12 months [16]. Figure 14 shows the 95th percentile of the daily average of the GGTO Determination Accuracy, also normalised annually.

As seen in Figure 12, the long term 95th percentile of 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] [17]. Regarding UTC Frequency Dissemination accuracy, Figure 13 shows that the measured 95th percentile value is less than or equal to 1.5E–14, which is an order of magnitude better than the [OS-SDD] MPL normalised annual ceiling of 3.0E–13 [18].

About the GGTO Determination Accuracy, shown in Figure 14, the measured values are constantly equal to 3.2 [ns] in the quarterly reporting period. These figures are within the [OS-SDD] MPL threshold of 20 [ns] [19], computed with a confidence level of 95% by accumulating daily samples over a sliding time window of 12 months.

16 Long-term figures result from processing measurements accumulated since last 12 months

17 Ref.: [OS-SDD] issue 1.1, §3.3.3 (Table 11)

18 Ref.: [OS-SDD] issue 1.1, §3.4.4 (Table 12)

19 Ref.: [OS-SDD] issue 1.1, §3.5.1.2 (Table 19)

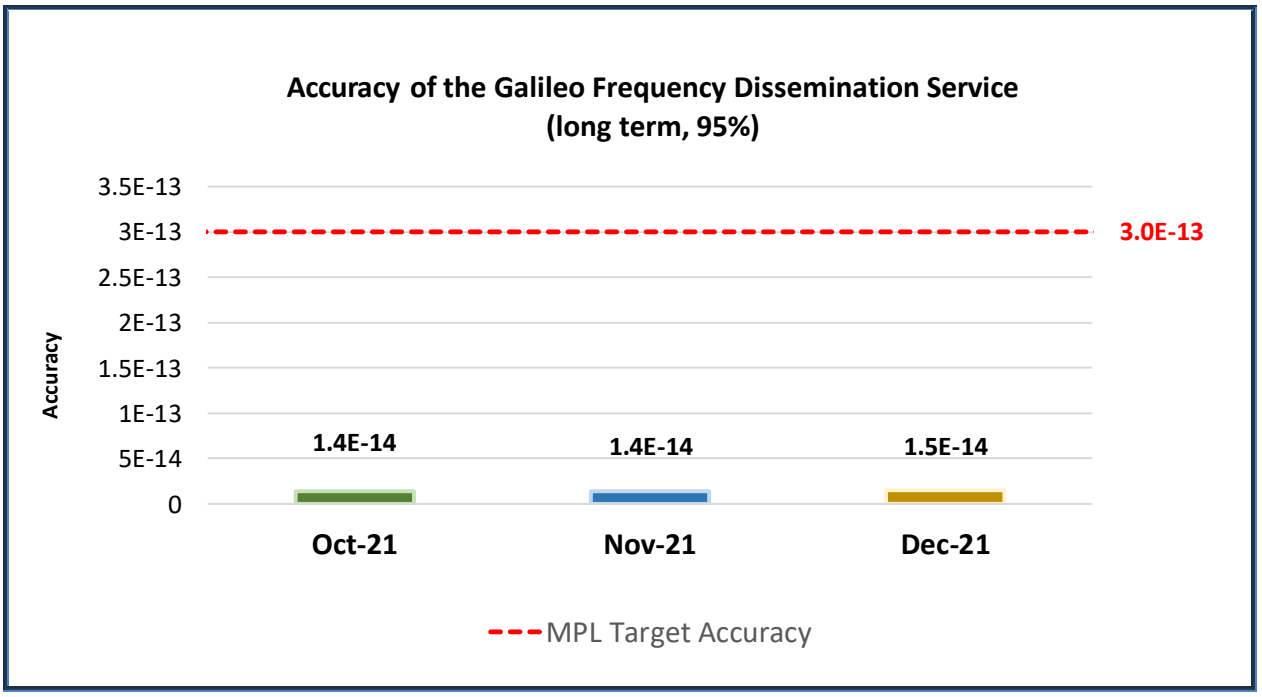


Figure 13 : Long-term 95th percentile of UTC Frequency Dissemination Accuracy

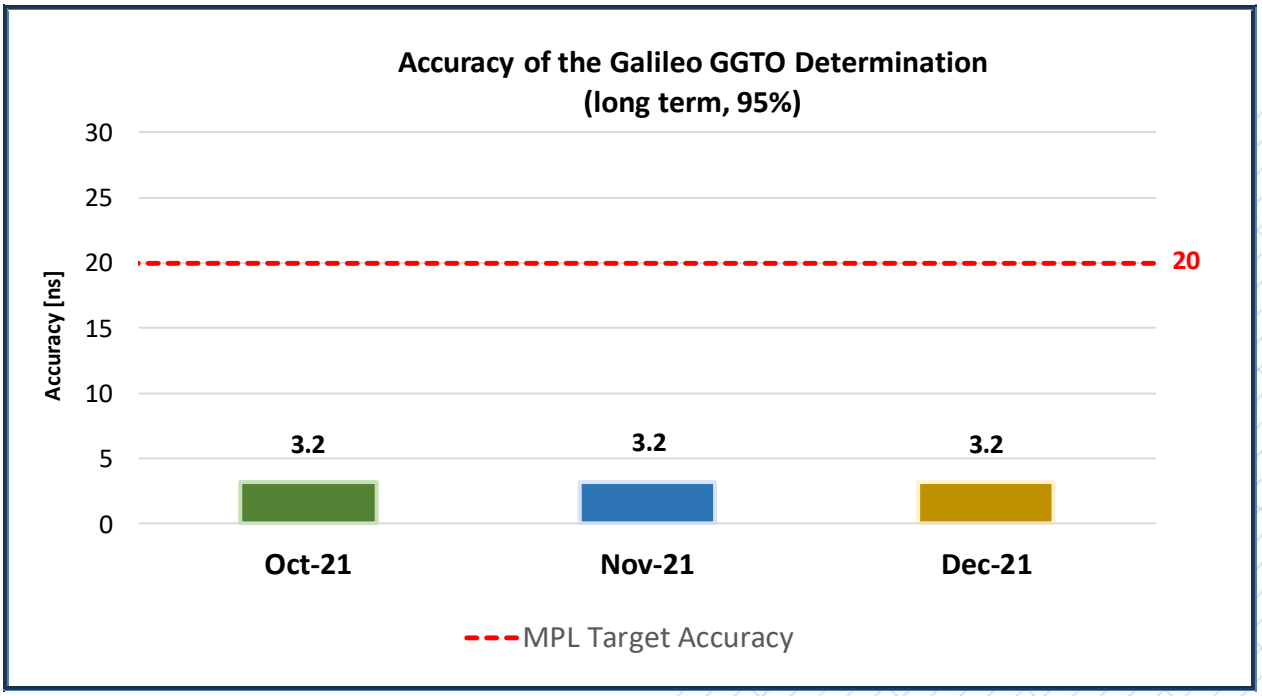


Figure 14 : Long-term 95th percentile of GGTO Determination Accuracy

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

Applicable [OS-SDD] defines an MPL on the global **Availability of a (3D) PDOP** (Position Dilution of Precision) less than or equal to 6, with a target of **77%** [20]. Results are presented in Figure 15, which distinguishes between the cases of SIS carrying I/NAV or F/NAV messages. With figures greater than **99.52**%, the target value is exceeded with significant margin.

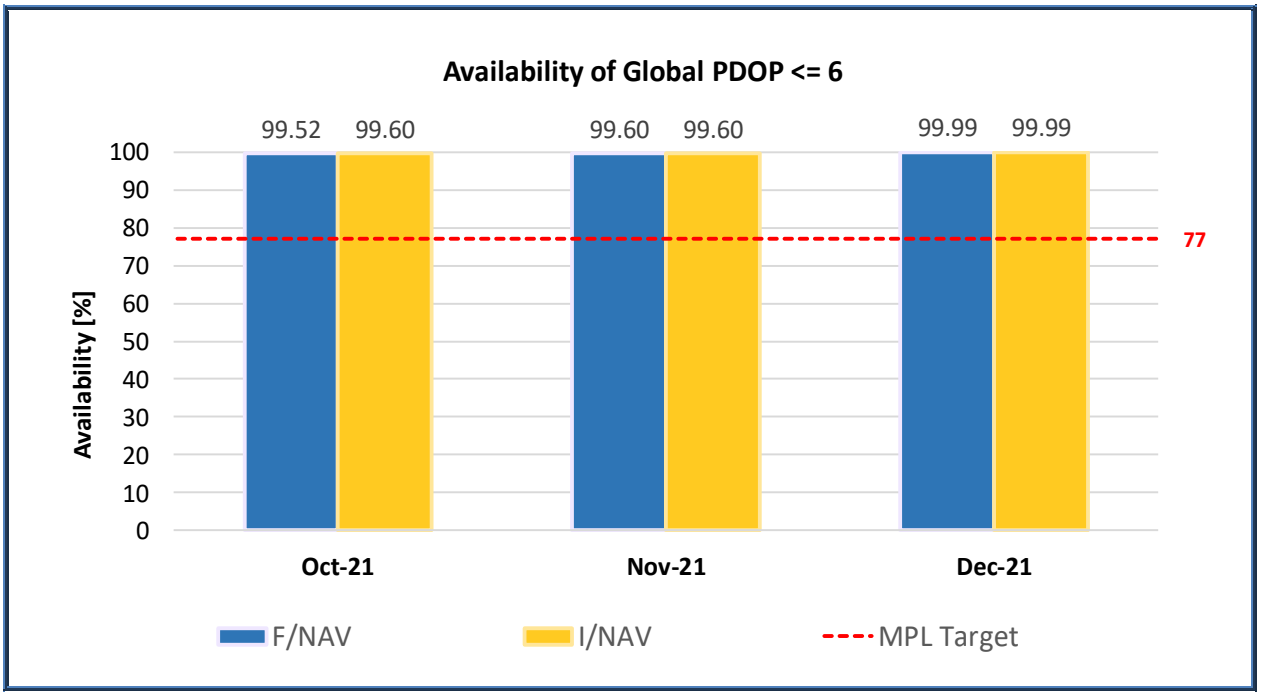


Figure 15 : Monthly Global Average Availability of PDOP ≤ 6

[20] Ref.: [OS-SDD] issue 1.1, §3.4.3 (Table 15)

For the sake of completeness, Figure 16 shows the Availability of a (3D) PDOP ≤6 at Worst User Location, which is not currently subject to an MPL target:

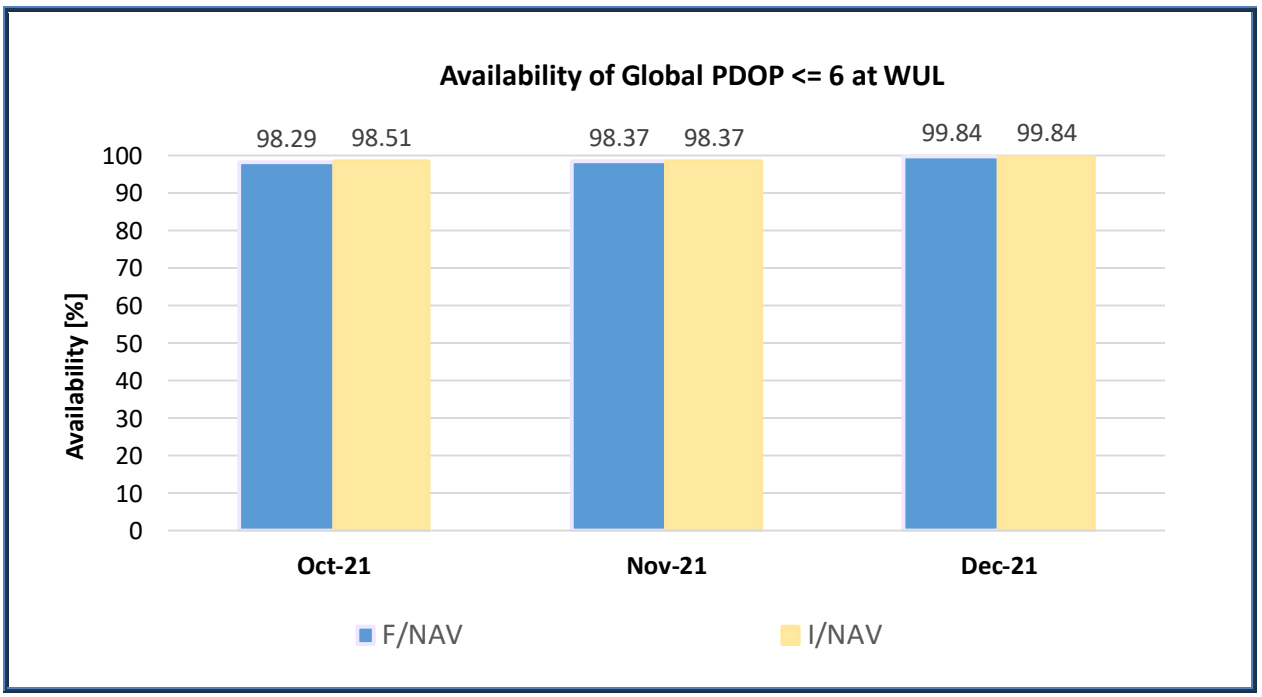


Figure 16 : Monthly Global Availability of PDOP ≤ 6 at Worst User Location

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

Different targets are assigned: **70%** [21] at Worst User Location (WUL), and **77%** [22] 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.

[21] Ref.: [OS-SDD] issue 1.1, §3.4.4 (Table 17)

[22] Ref.: [OS-SDD] issue 1.1, §3.4.4 (Table 16)

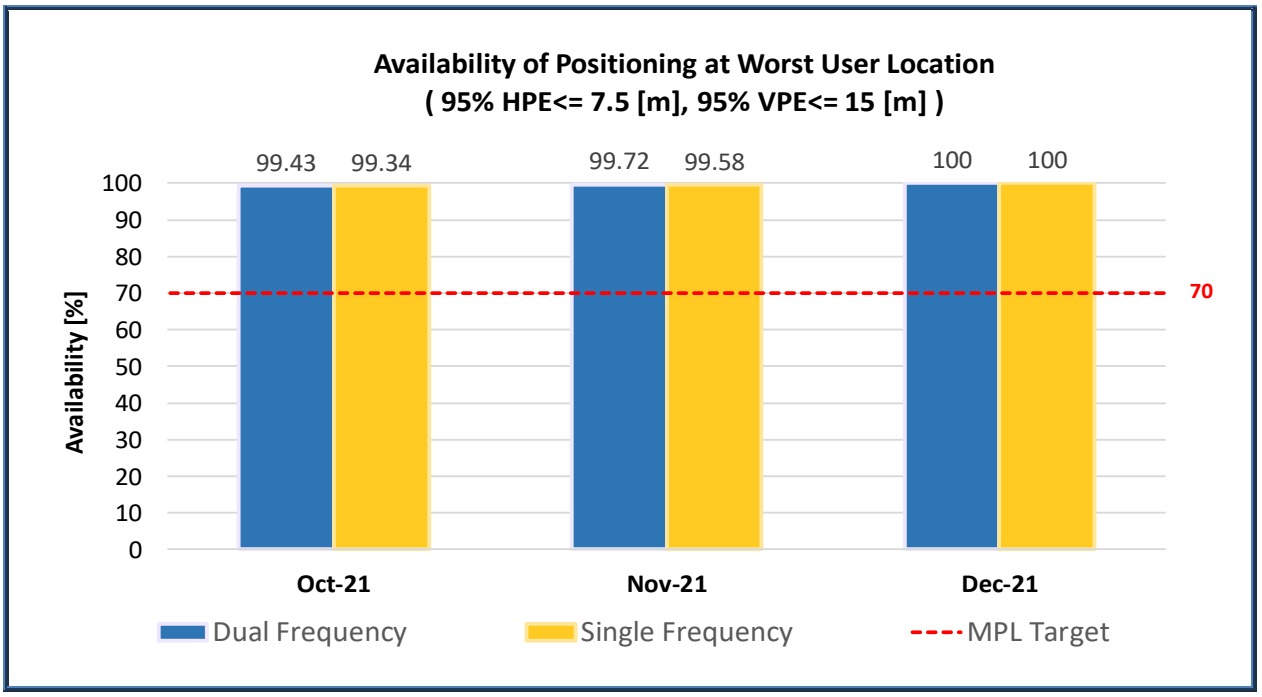


Figure 17 : Availability of Positioning at Worst User Location (WUL)

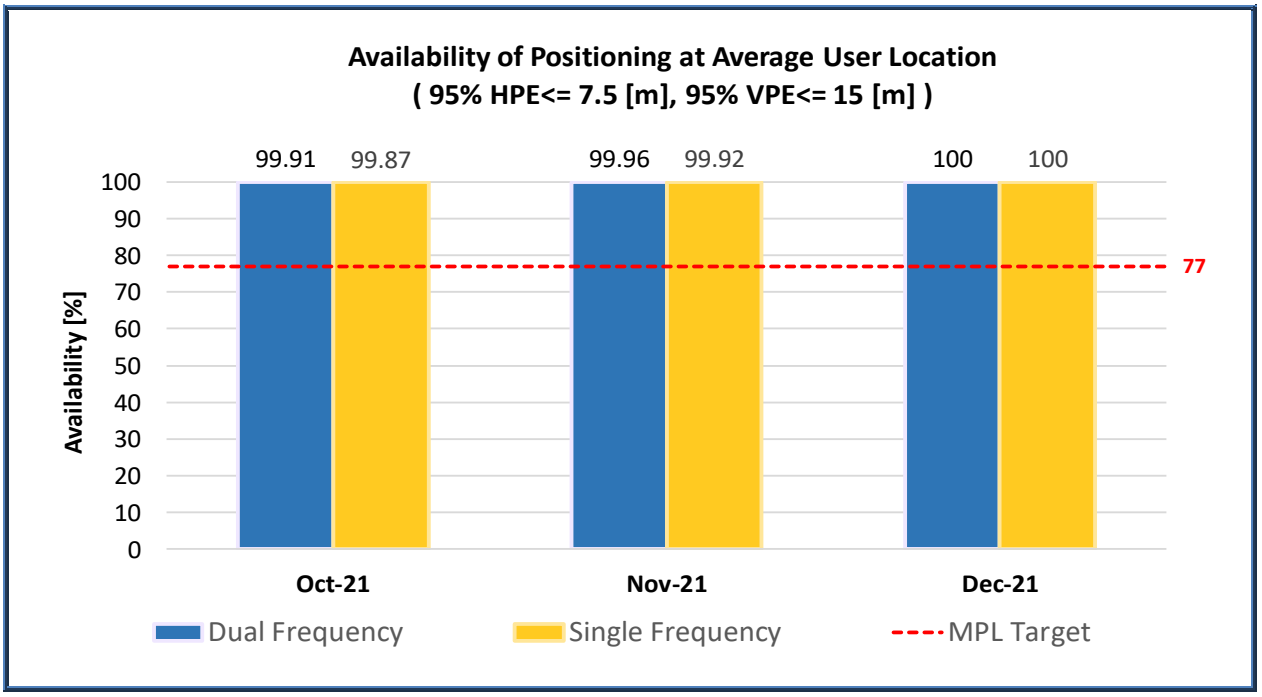


Figure 18 : Availability of Positioning at Average User Location (AUL)

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" [23].

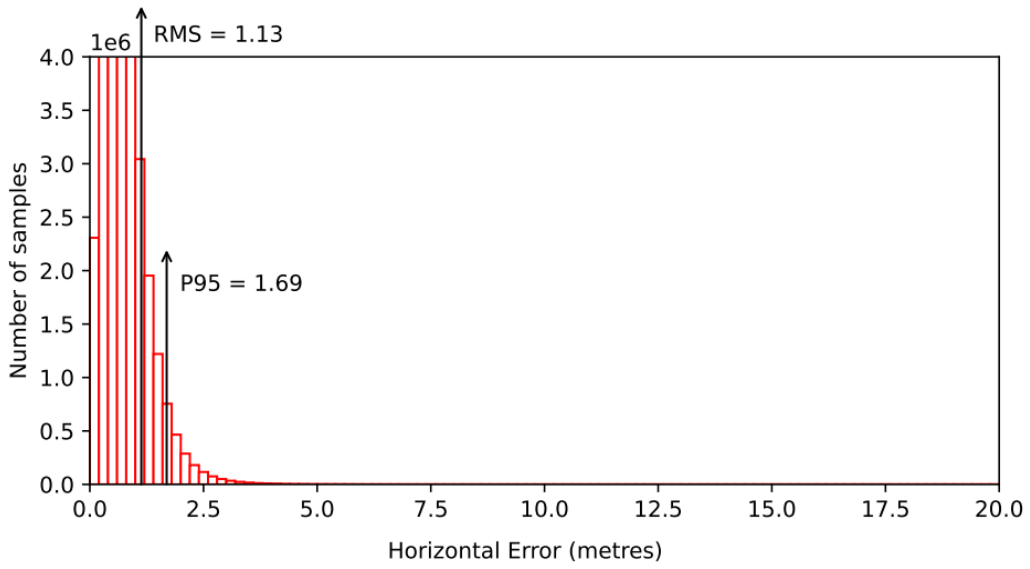
As specified in the [OS-SDD], Navigation message coefficients with an "Age of Ephemeris" beyond 4 hours are no longer considered valid, so that ranging observables from the corresponding satellite and signal should not be used for positioning and/or time measurement purposes.

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 January 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.

[23] 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.

October 2021	
HPE 3D Positioning E1-E5a (DF) F/NAV	
Note: 16410 samples > 20 [m], about 0.049% of total	

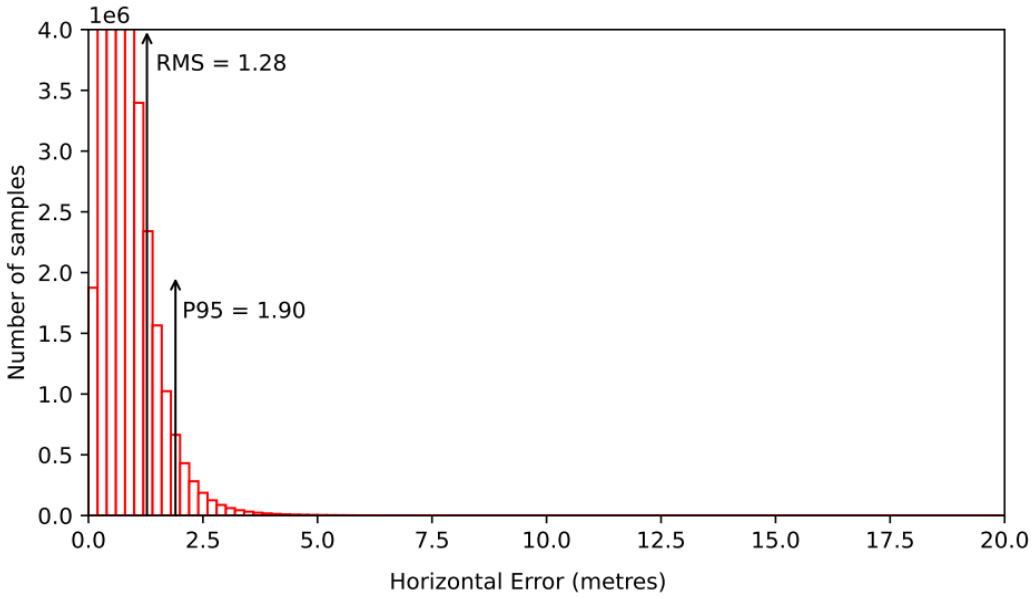
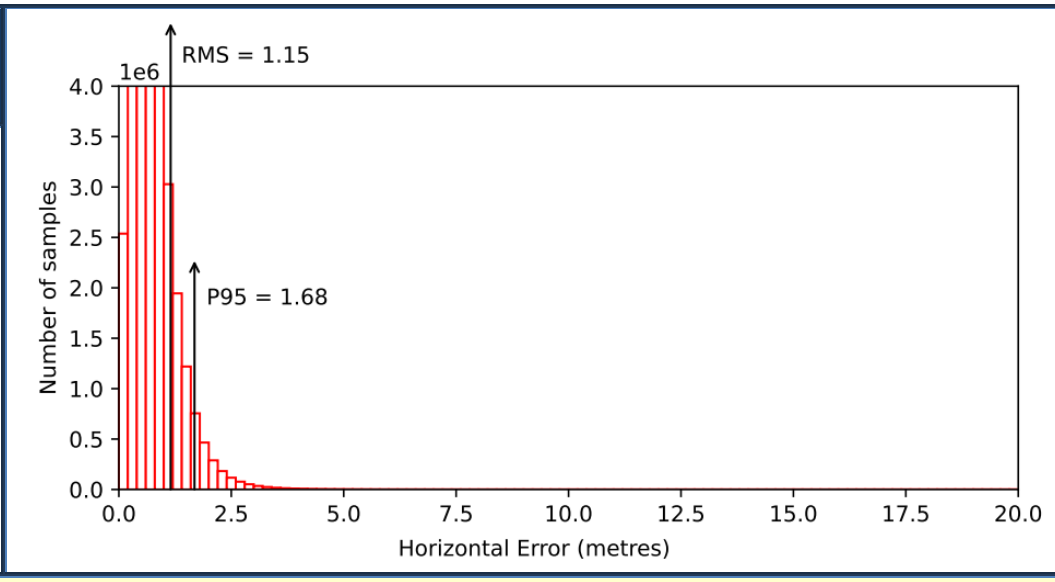
October 2021	
HPE 3D Positioning E1-E5b (DF) I/NAV	
Note: 20174 samples > 20 [m] , about 0.060% of total	

Figure 19 : Horizontal Positioning Error (HPE) for "Galileo-only" users in October 2021

November 2021	
HPE 3D Positioning E1-E5a (DF) F/NAV	
Note: 18565 samples > 20 [m] , about 0.053% of total	

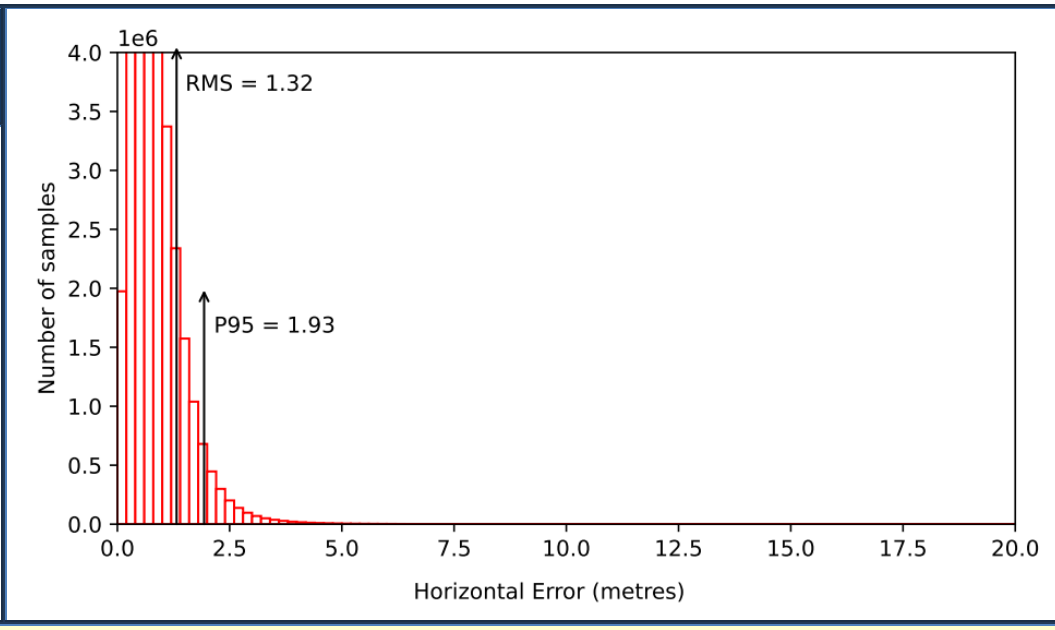
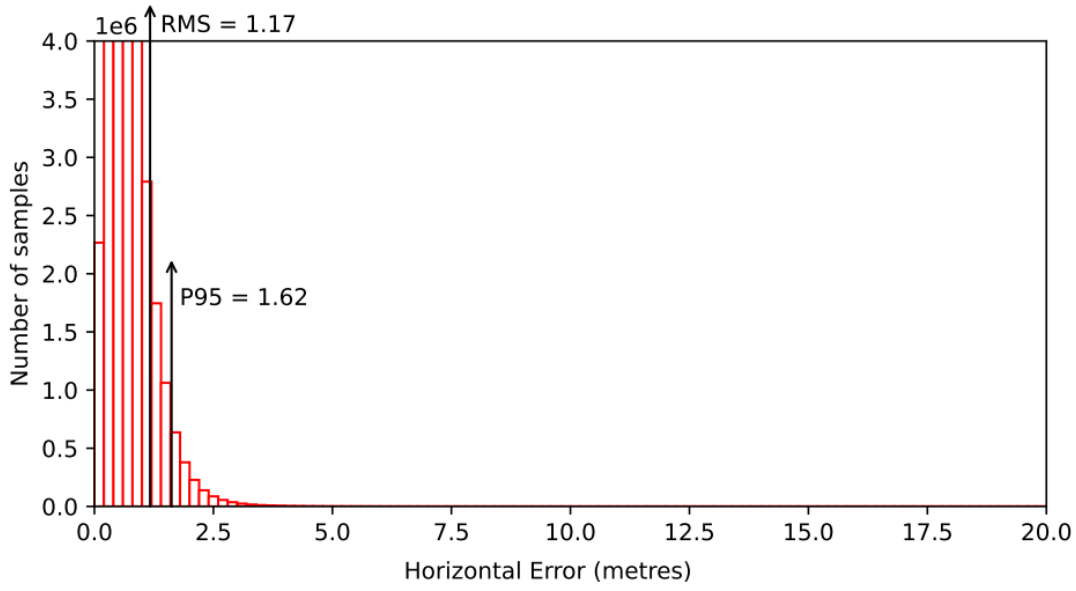
November 2021	
HPE 3D Positioning E1-E5b (DF) I/NAV	
Note: 22749 samples > 20 [m] , about 0.066% of total	

Figure 20 : Horizontal Positioning Error (HPE) for "Galileo-only" users in November 2021

December 2021	
HPE 3D Positioning E1-E5a (DF) F/NAV	
Note: 18758 samples > 20 [m] , about 0.059% of total	

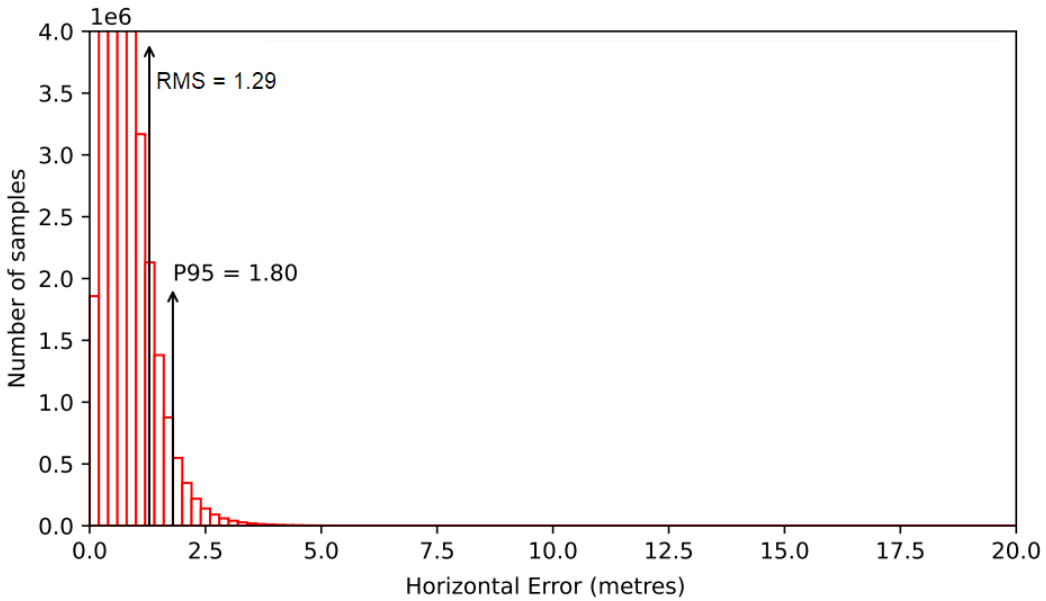
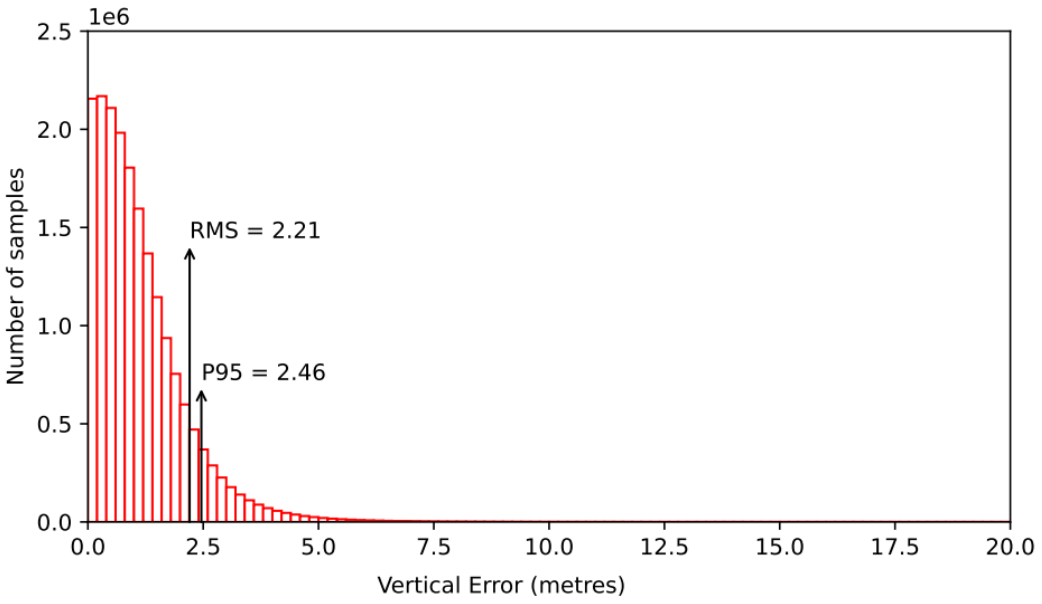
December 2021	
HPE 3D Positioning E1-E5b (DF) I/NAV	
Note: 21260 samples > 20 [m] , about 0.067% of total	

Figure 21 : Horizontal Positioning Error (HPE) for "Galileo-only" users in December 2021

October 2021	
VPE **3D Positioning** **E1-E5a (DF)** **F/NAV**	
Note: 21653 samples > 20 [m] , about 0.064% of total	

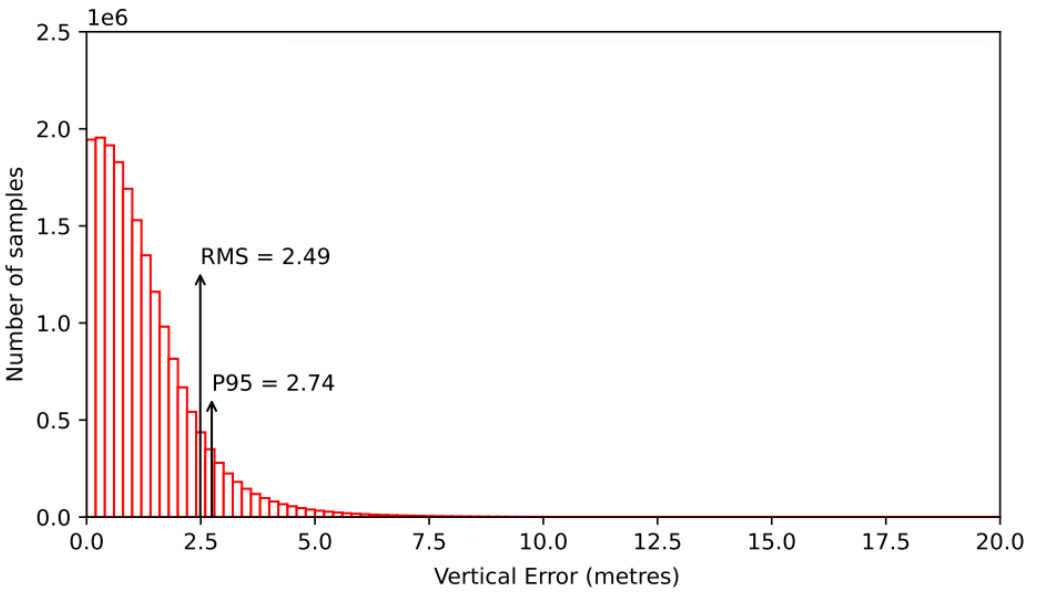
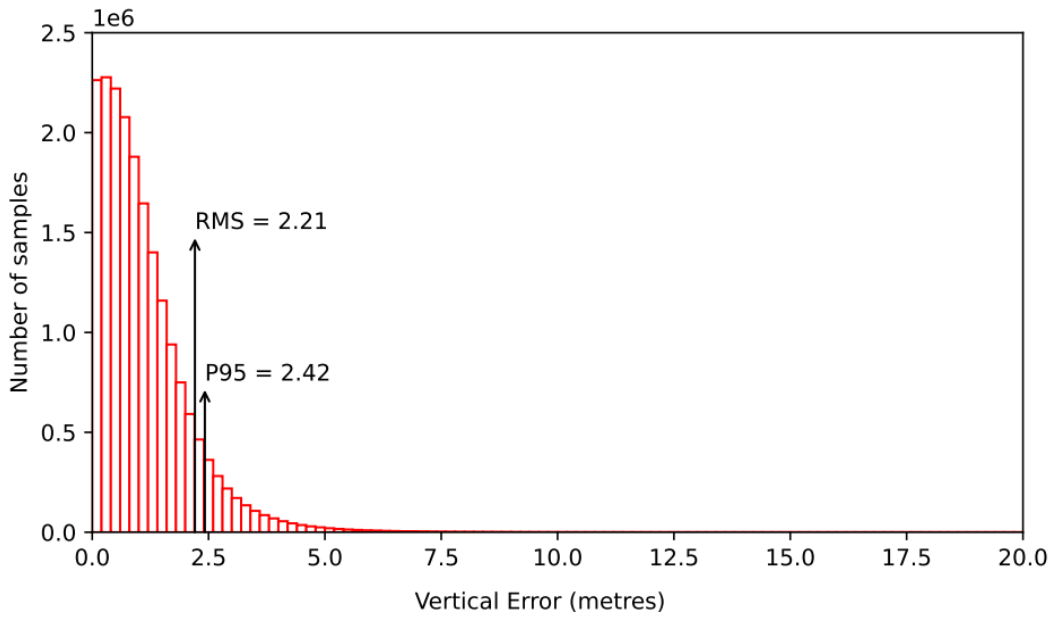
October 2021	
VPE **3D Positioning** **E1-E5b (DF)** **I/NAV**	
Note: 22852 samples > 20 [m] , about 0.068% of total	

Figure 22 : Vertical Positioning Error (VPE) for "Galileo-only" users in October 2021

November 2021	
VPE 3D Positioning E1-E5a (DF) F/NAV	
Note: 24047 samples > 20 [m] , about 0.069% of total	

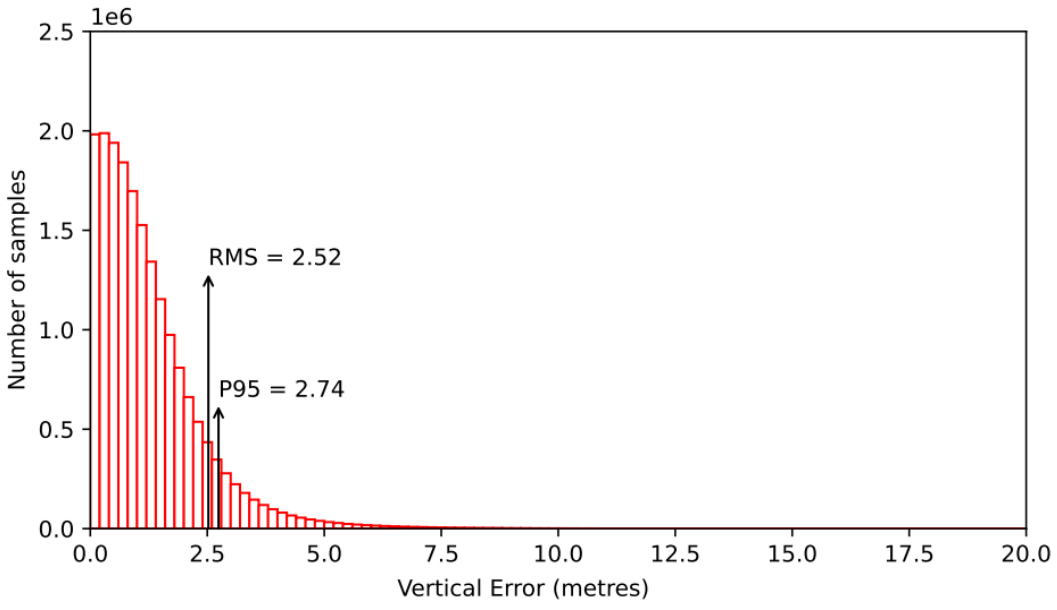
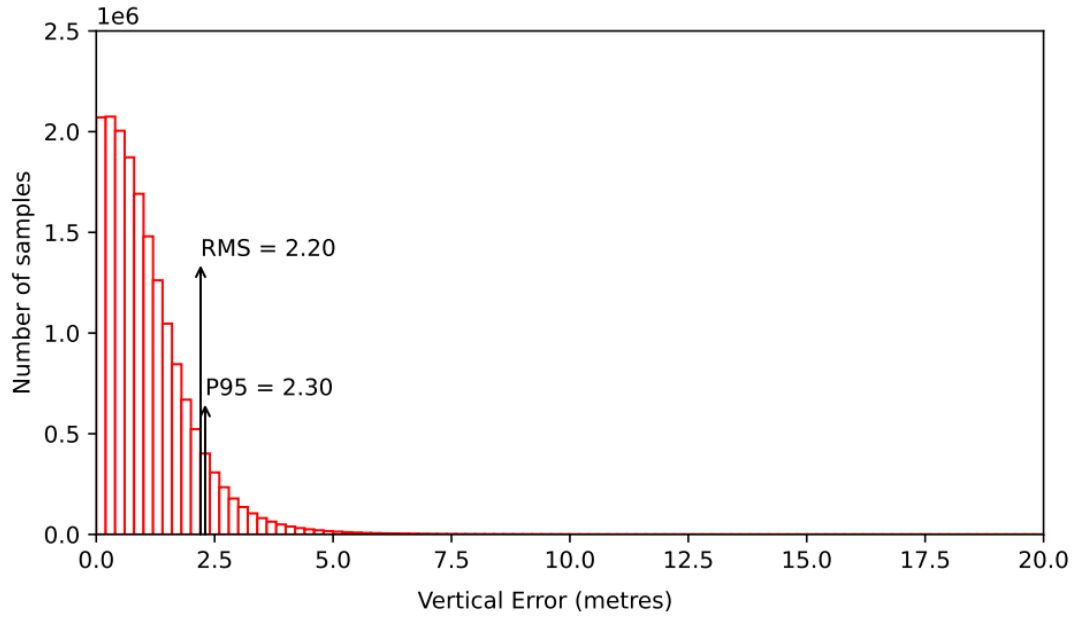
November 2021	
VPE 3D Positioning E1-E5b (DF) I/NAV	
Note: 25080 samples > 20 [m] , about 0.073% of total	

Figure 23 : Vertical Positioning Error (VPE) for "Galileo-only" users in November 2021

December 2021	
VPE 3D Positioning E1-E5a (DF) F/NAV	
Note: 23437 samples > 20 [m] , about 0.074% of total	

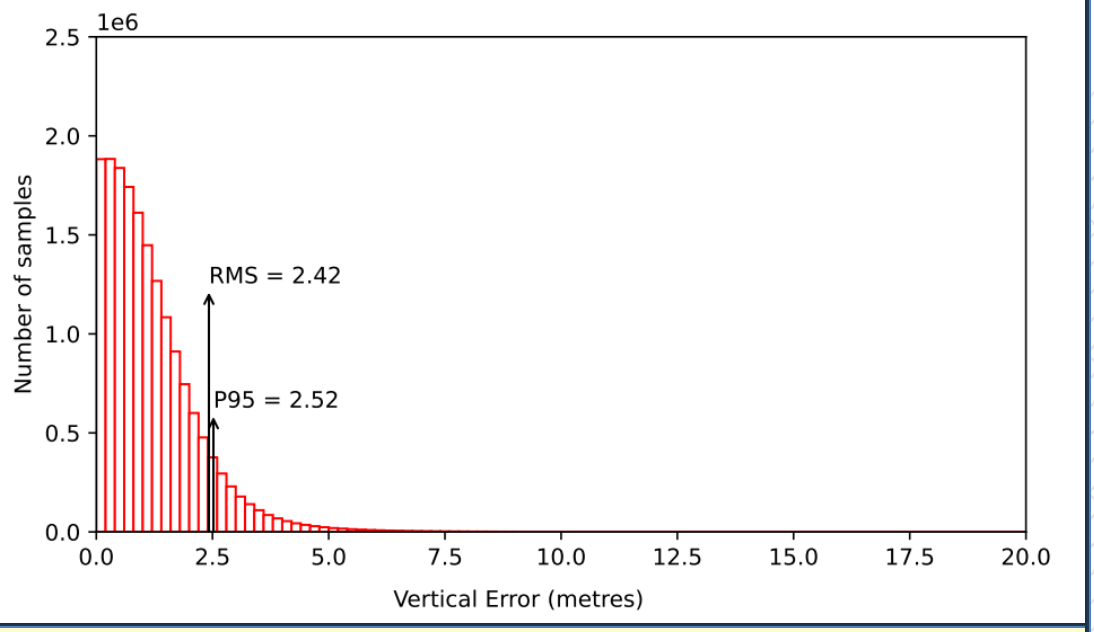
December 2021	
VPE 3D Positioning E1-E5b (DF) I/NAV	
Note: 24176 samples > 20 [m] , about 0.076% of total	

Figure 24 : Vertical Positioning Error (VPE) for "Galileo-only" users in December 2021

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-archive (Archived user Notifications)

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

According to MPLs in the [OS-SDD], NAGUs related to Planned events need to be published at least 24 hours [24] before the event starts. For Unplanned events, the [OS-SDD] specifies a delay of up to 72 hours [24] 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, 9 NAGUs have been published, belonging to the "Unplanned" category. In particular:

- in October, 1 NAGU was issued, category "planned";
- in November, 7 NAGUs were issued; only one of them treated as "planned", even if a second one corresponds to a short-term outage corresponding to a planned on-board maintenance, whilst communicated after its execution;
- in December, 1 NAGU has been published, related to the successful launch L11 which has put two new space vehicles into orbit: GSAT-0223 (E34) and GSAT-0224 (E10).

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

[24] Ref.: [OS-SDD] issue 1.1, §3.6.1 (Table 21)

Month	NAGU Type	Reason for publishing	Notice Advisory ID	NAGU Categ.	Timeliness
October	PLN_MANV	Warning about the unavailability of GSAT-0206 (E30), all Navigation signals, since 25/10/2021 @ 11:45 UTC, with service recovery estimated on 05/11/2021	2021016	P	Timely published **3.84** days before the planned event
November	USABLE	Announcing the recovered availability of GSAT-0206 (E30), all Navigation signals, since 04/11/2021 @ 23:51 UTC	2021017	U	Timely published **0.631** days after the event
	PLN_MANV	Warning about the unavailability of GSAT-0203 (E26), all Navigation signals, since 15/11/2021 @ 05:00 UTC	2021018	P	Timely published **3.65** days before the planned event
	EXTNS	Extending outage duration envisaged for satellite GSAT-0203 (E26).	2021019	U	Timely published **0.166** days after the corresponding decision undertaken by the Galileo Mission Manager
	UNP_SHTRCVR	Announcing recovery after short term unavailability of GSAT-0222 (E33), all Navigation signals, occurred on 24/11/2021 from 14:03 until 16:30 UTC	2021020	U	Timely published **0.908** days after the event. This NAGU corresponds to a planned operation, but is treated as an unplanned one, being communicated "a posteriori"
	GENERAL (TIMING UNP_UNUFN)	Advising users about lack of transmission of valid GGTO coefficients, since 25/11/2021 @ 12:15 UTC (until further notice).	2021021	U	Timely published **0.184** days after the event.

Month	NAGU Type	Reason for publishing	Notice Advisory ID	NAGU Categ.	Timeliness
	USABLE	Announcing the recovered availability of GSAT-0203 (E26), all Navigation signals, since 26/11/2021 @ 10:40 UTC	2021022	U	Timely published **0.257** days after the event.
	GENERAL (TIMING USABLE)	Announcing the recovered broadcast of valid GGTO parameters, since 29/11/2021 @ 13:00 UTC	2021023	U	Timely published **0.181** days after the event.
December	GENERAL (LAUNCH)	Announcing the occurred launch of Galileo satellites GSAT-0223 (E34) and GSAT-0224 (E10) on 05/12/2021 @ 00:19 UTC. Space vehicles are planned to be positioned respectively in slots B03 and B15 of the constellation	2021024	U	Timely published **0.612** days after the event.
NAGU Categorisation for timeliness evaluation: "P" = Planned, "U" = Unplanned					

Table 6 : NAGUs published during 4th Quarter of 2021

7 GALILEO OSNMA PERFORMANCE

In November 2021, as per [SvNOTE #09], EUSPA officially initiated the OSNMA "Public Observation Test Phase", which implies 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 magnitudes characterising the quality of delivered OSNMA Service are not currently subject to any MPL target, they are of interest and starting with this Quarterly Report we will inform about them.

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 characterization 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].

- 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:

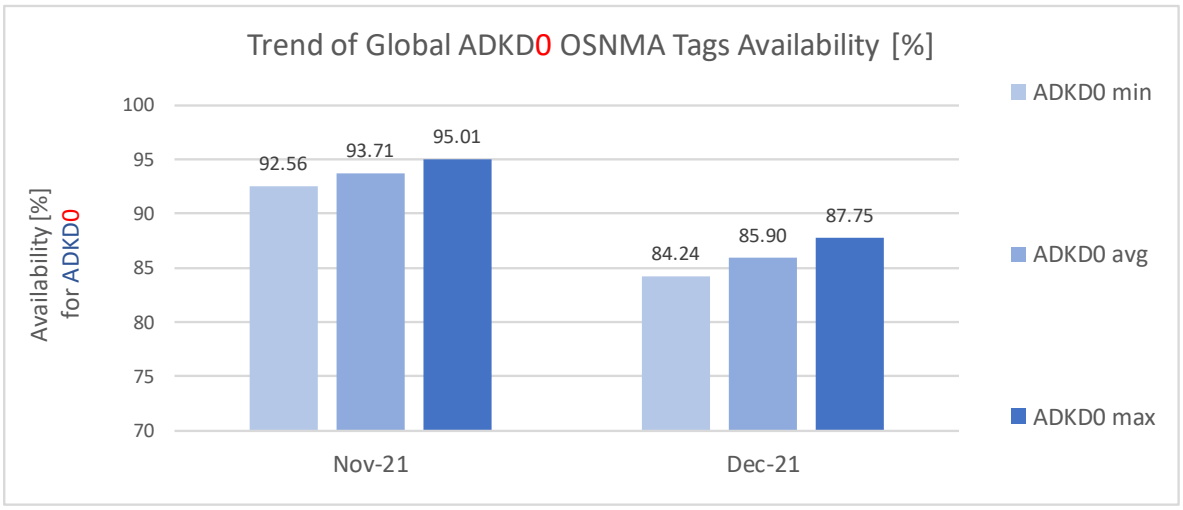


Figure 25 : Availability of Tags for Galileo I/NAV orbit & clock data (ADKD0)

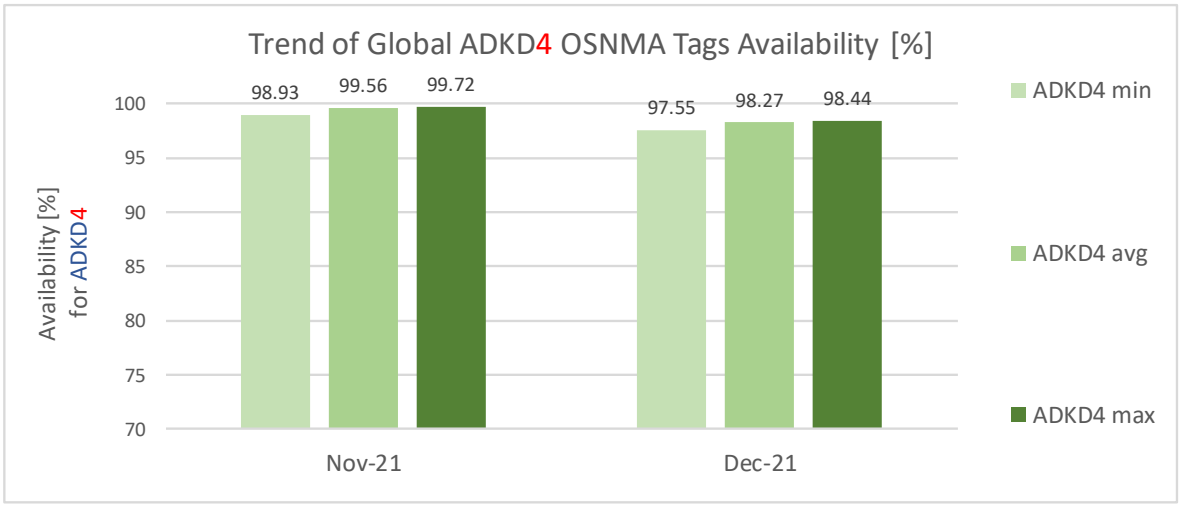


Figure 26 : Availability of Tags for the GST-UTC and GGTO Parameters (ADKD4)

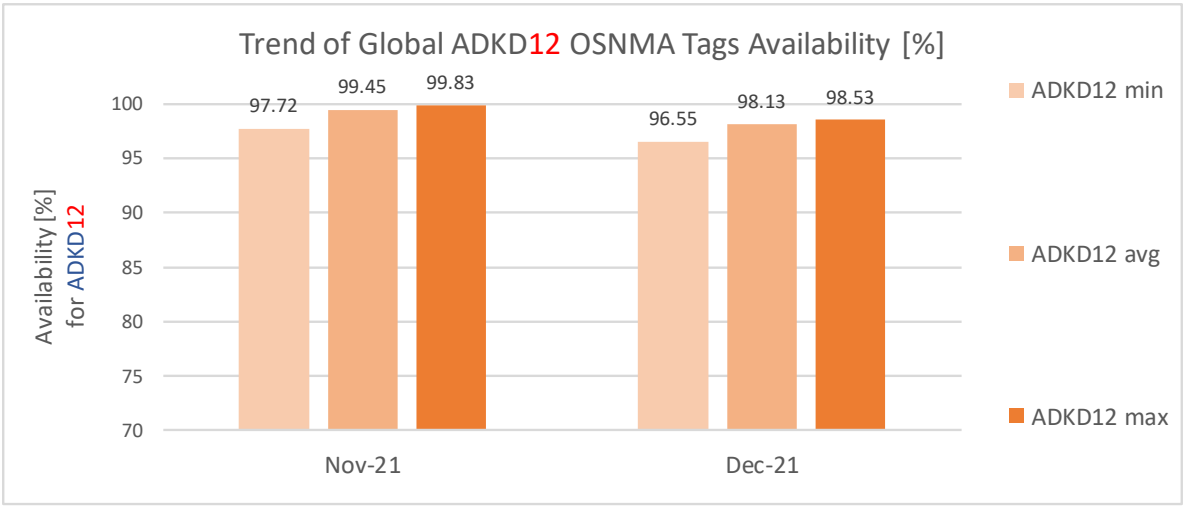


Figure 27 : Availability of Tags for Galileo I/NAV orbit & clock data (ADKD12)

In November, two planned events impacted the availability of OSNMA Tags: operations on GSAT-0203 (E26) and GSAT-0206 (E30), the former (ref. NAGUs: 2021018 , 2021019 2021022) lasting approximately 11 days and 6 hours of the month (from 15/11 to 26/11/2021), the second around 4 days in November (ref. NAGU 2021017). In December, availability figures appear slightly reduced with respect to the previous month, especially in the case of ADKD0. This was due to a temporarily reduced OSNMA data broadcasting capability.

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):

			Nov-21	Dec-21
Successful OSNMA Tags [%]	Single Frequency	ADKD0	99.89	99.97
		ADKD4	99.97	99.98
		ADKD12	99.94	99.98
	Dual Frequency	ADKD0	99.89	99.97
		ADKD4	99.97	99.98
		ADKD12	99.94	99.98

Figure 28: Statistics for Dual Frequency – Succesful OSNMA Tags

During the reporting quarter, no verification failures took place for the DSM, TESLA keys and MACSEQ elements.

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 1.1, European Union, May 2019.

[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, a new OS-SDD version (Issue 1.2) is in force, and is the version that is immediately accessible for download from the European GNSS Service Centre (GSC) website.

However, this report still refers to Issue 1.1 of the [OS-SDD], which has been in force since May 2019 and remained applicable until Q4/2021. This issue can still be obtained from the GSC, upon user request.

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 the [OS-SDD] have been referenced throughout this report when referring to MPL target values.

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
OS	(Galileo Navigation) Open Service
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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