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EUROPEAN GNSS (GALILEO) INITIAL SERVICES

OPEN SERVICE

QUARTERLY PERFORMANCE REPORT

OCTOBER - DECEMBER 2020

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1 INTRODUCTION

This document is the *Galileo Open Service (IS OS) Public Performance Report* for the period of **October, November and December 2020**. 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)[1].

The document comprises the following sections:

Section 1: Provides an introduction to 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: The cited reference documents are listed.

Section 8: The adopted terms, acronyms and abbreviations are defined.

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

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

Satellite Code	SV ID (PRN)	CCSDS ID [hex]	Orbital Slot	Status
GSAT-0101	11	3A5	B05	Available
GSAT-0102	12	3A6	B06	Available
GSAT-0103	19	3A7	C04	Available
GSAT-0201	18	261	not-nominal	Auxiliary, since November 30th, 2020
GSAT-0202	14	262	not-nominal	Auxiliary, since November 30th, 2020
GSAT-0203	26	263	B08	Available
GSAT-0205	24	265	A08	Available
GSAT-0206	30	266	A05	Available
GSAT-0207	7	267	C06	Available
GSAT-0208	8	268	C07	Available
GSAT-0209	9	269	C02	Available
GSAT-0210	1	26A	A02	Available
GSAT-0211	2	26B	A06	Available
GSAT-0212	3	26C	C08	Available
GSAT-0213	4	26D	C03	Available
GSAT-0214	5	26E	C01	Available
GSAT-0215	21	2C5	A03	Available
GSAT-0216	25	2C6	A07	Available
GSAT-0217	27	2C7	A04	Available
GSAT-0218	31	2C8	A01	Available
GSAT-0219	36	713	B04	Available
GSAT-0220	13	704	B01	Available
GSAT-0221	15	705	B02	Available
GSAT-0222	33	706	B07	Available

Table 1 : Galileo Reported Constellation Information

According to NAGUs 2020019 and 2020020, the two Galileo Space Vehicles GSAT-0201 (E18) and GSAT-0202 (E14) have been declared usable since 30/11/2020 @ 08:32.

These satellites are considered as "auxiliary" satellites [SvNOTE], therefore it is expected that they will contribute positively when their SIS is healthy, and will in any case never worsen the positioning and timing performance experienced by the users. For such satellites, there is no commitment on availability of healthy SIS.

Thus, since December 2020 their Ranging Accuracy has been monitored and is subject to the same MPL thresholds as all the other active Galileo Space Vehicles.

Nevertheless, as they occupy non-nominal orbital slots, their availability does not contribute to the Per-Slot Availability of Healthy SIS.

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.

A service outage occurred in December 2020, as per NAGU 2020021 ; more details are provided in the Executive Summary.

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 legend below:

OS MPLs	Target Value	Space Vehicle		October-20					November-20					December-20				
				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-0201	E18															
		GSAT-0202	E14															
		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-20	Nov-20	Dec-20
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-20	Nov-20	Dec-20
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**, with average monthly values greater than **98.65**% for every Single-Frequency (E1-B, E5a, E5b) and Dual-Frequency combination (E1/E5a, E1/E5b), is considerably above the MPL threshold of **87%**. The monthly figures are then normalised annually, according to the MPL definition, by a moving average applied over the most recent 12 months.

The **Signal in Space Ranging Accuracy** shows a 95th percentile monthly accuracy between **0.23** [m] and **0.59** [m] for individual space vehicles ("Any Satellite") on Single Frequency observables.[2] For Dual Frequency signal combinations[3], the figure is in the range from **0.17** [m] to **0.44** [m]. Compliance with the [OS-SDD] MPL, where the threshold is specified as **7** [m], is achieved with considerable margins by all satellites of the Galileo constellation.

The average **Ranging Accuracy at constellation level** (over "All Satellites") provides figures "per signal" that are better than or equal to **0.34** [m] for Single Frequency signals and **0.20** [m] for Dual Frequency signal combinations. Achieved results 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. In both cases, metrics had a monthly value of **100**% during the first two months of quarterly reporting period, and **99.22**% in December, while the [OS-SDD] MPL targets are **87%**.

The **Availability of GGTO Determination** metric was **99.44**% during the first two months and **99.38**% in December. Annually normalised figures provided in §4.1 are obtained with an average

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

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

applied 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** (**11.6** [ns] in October, dropping down to **9.8** [ns] in December), the **UTC Frequency Dissemination Service Accuracy** (normalised offset ≤ $\mathbf{1.4\times10^{-14}}$) and the **GGTO Determination Accuracy** (**10.3** [ns] in October, reducing to **9.6** [ns] in December). The [OS-SDD] MPL targets, which are respectively **30** [ns], $\mathbf{3\times10^{-13}}$ and **20** [ns], are all met; all figures related to time accuracy are computed by accumulating daily measurement samples over the previous 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:

Both for F/NAV and I/NAV, the **Availability of Global PDOP ≤ 6** was **99.96**% in October, **99.92**% in November and **99.18**% in December, against a target MPL of **77**%.

Availability of Positioning, given the conditions that 95% HPE ≤ 7.5 [m] and, at the same time, 95% VPE ≤ 15 [m], equals:

- in October, at least **99.93**% at WUL and **99.99**% at AUL;
- in November, at least **99.73**% at WUL and **99.97**% at AUL;
- in December, at least **99.13**% at WUL and **99.21**% at AUL.

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 real network of receivers. 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 **1.92** [m] and **3.32** [m] respectively during the reporting period, as measured by the GSA network of reference receivers. The corresponding RMS values, which are also not subject to an MPL assessment, are respectively **1.10** [m] and **1.77** [m].

Regarding **Publication of NAGUs**, [OS-SDD] MPLs are met during the whole period for both Planned and Unplanned events. The target of at least **24** hours before the start of a scheduled event, as well as not more than **72** hours after an unscheduled one, is achieved in all cases. Additional details about NAGU timeliness are presented in § 6.

On the December 2020 Galileo Service Outage

Galileo, the EU's satellite navigation system, has been providing operational services since December 2016. The Galileo signals can be used "standalone" or in combination with those of other satellite navigation systems in receivers enabled for multi-constellation reception. Galileo already today provides PNT performance that is well within the commitments reported in the Service Definition Document ([OS-SDD]).

In the early hours of Monday 14 December (UTC), Galileo experienced a technical anomaly that temporarily affected the Galileo System, causing unavailability of the satellite signals for several hours. Since the Galileo architecture is based on multiple redundancy, the faulty equipment could be isolated and nominal service was resumed a few hours after the event.

Following a detailed investigation, the exact sequence of events and the root cause that led to the service incident have been identified.

The Galileo Service was affected on 13 December at 23:55 UTC by an anomaly in the orbit & time determination function of the ground segment of the system. During the incident, the Galileo signal in space automatically and immediately notified the users that the data being transmitted was potentially unreliable. The System was reconfigured and restored to its nominal state as of 14 December at 06:12 UTC. A "Notice Advisory to Galileo Users" (NAGU) about the incident was published on 14 December at 14:00 UTC, as well as two "News Items" on 14 December at 12:00 UTC and 15 December at 21:00 UTC.

The triggering event is confirmed to be the failure of an atomic clock in the Precise Time Facility of the Galileo ground segment. The particular failure mode at stake prevented nominal reconfiguration of the system to ensure service continuity. The anomaly was however rapidly detected and the system protected users from excessive errors by automatically setting the SISA parameter to "NAPA".

All users whose equipment processes the signal status flags as defined in the [OS-SDD] were protected during the service incident. On the other hand, some user receivers may have disregarded the signal status flags and used the erroneous data, which would have resulted in significant positioning errors (up to tens of kilometers). From a performance metric point of view, this incident reduced the availability of the Galileo Open Service in December, namely the per-slot availability, the availability of positioning (and PDOP) and the availability of timing (UTC and GGTO dissemination, and UTC determination).

A new release of the Orbit Determination and Time Synchronization software was rapidly deployed to address the issue and improve the protection mechanisms in the ground segment. This will prevent re-occurrence of any such event and guarantee continuity of services under similar anomalous conditions.

Based on Galileo user feedback received at the GNSS Service Centre (GSC), and in order to improve the notification to the users in case of a service incident, several additional steps have been taken.

While the "Notice Advisory to Galileo Users" (NAGU) will remain the main communication means to notify users of specific activities/events in the Galileo System that have an impact on the service performance, the publication of "News Items" on the GSC web portal is not considered to be the appropriate way to complement this information. Instead, "Service Notices" will be systematically used to ensure that users have adequate visibility on this type of information. To this end, the following measures are being implemented:

- the "Service Notices" page is being moved to a more appropriate section of the GSC web portal (under "System and Service Status");
- all GSC registered users who subscribed to receive such notifications, will receive an automatic notification via email;
- all GSC registered users will be informed about these improvements.

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;
- ◊ Galileo Signal in Space Ranging Accuracy.

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 that are considered "HEALTHY" according to [OS-SDD] rules regarding the configuration of specific L-band SIS status flags and the validity period of Navigation messages.

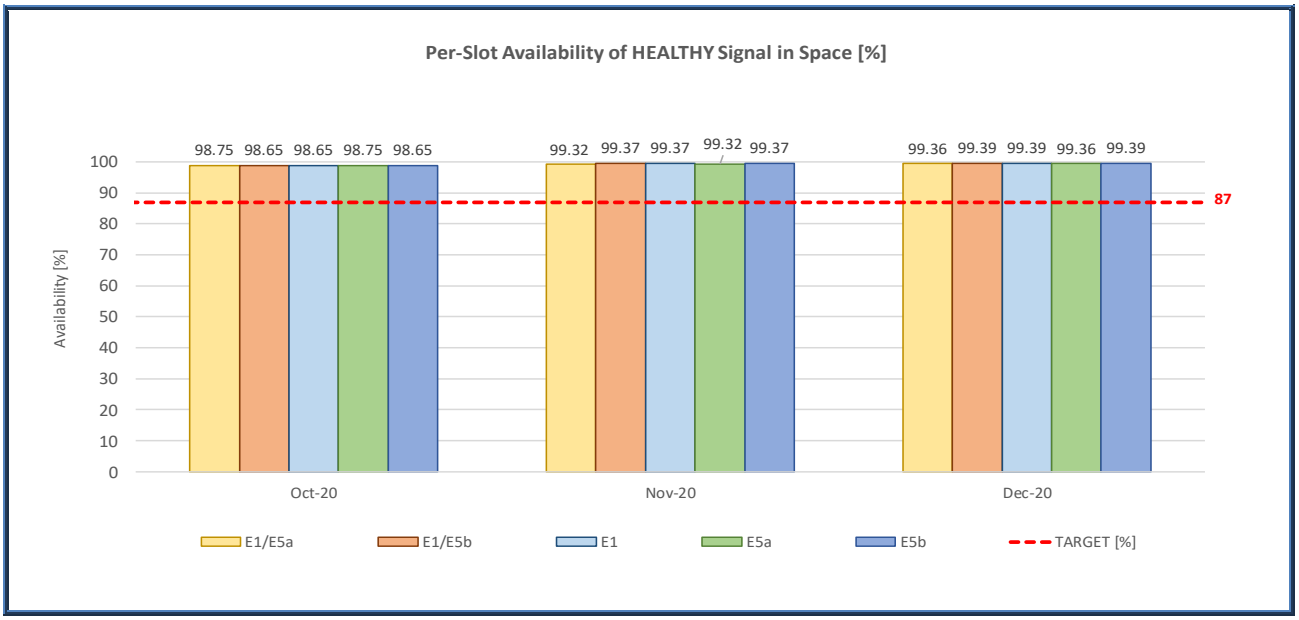


Figure 1 : "Per-Slot" availability of HEALTHY Signal in Space for the reporting period

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.[4]

[4] The [OS-SDD] foresees an "annual normalisation", which is implemented with an incremental averaging process, accumulating data over the previous 12 months. Data for each month takes into account only those space vehicles that are declared active members of the constellation during the whole month. Auxiliary Space Vehicles GSAT-0201 (E18) and GSAT-0202 (E14) are not included.

The [OS-SDD] Minimum Performance Level (MPL) specifies **87%** [5] as the target value for this constellation metric. The achieved performance is between **98.65**% (SIS E1, SIS E5b and Dual Frequency combination E1-E5b, October) and **99.39**% (SIS E1, SIS E5b and Dual Frequency combination E1-E5b, December).

The availability of Galileo HEALTHY SIS, evaluated individually per frequency combination, satellite and month (without annual normalisation), is not subject to an MPL target. During the quarter, low values were observed for the following satellites:

- In October:
  - All usable space vehicles achieved a monthly availability of healthy SIS equal to 100%, with the exception of GSAT-0211 (E02), with 93.9% for SIS E1, SIS E5b and Dual Frequency combination E1-E5b;
- In November:
  - All usable space vehicles achieved a monthly availability of healthy SIS equal to 100%, with the exception of GSAT-0101 (E11), with 92.79% for all frequencies, and GSAT-0219 (E36), with 98.95% for SIS E5a and Dual-Frequency combination E1-E5a and 99.38% for SIS E1, SIS E5b and Dual Frequency combination E1-E5b;
- In December:
  - A service outage occurred on December 14th, lowering the availability of all Space Vehicles, due to marginality of all SIS from the entire Space Segment over some hours. This means that over the same period, according to NAGU 2020021, Galileo positioning and timing were not available. Nevertheless, over the entire month, with the exception of GSAT-0210 (E01), which had 93.35% for SIS E5a and Dual-Frequency combination E1-E5a and 93.03% for SIS E1, SIS E5b and Dual Frequency combination E1-E5b, all the other satellites had at least a healthy SIS availability of 99.07%.

Notwithstanding the service outage in December, the availability values in Figure 1 are higher during December than in the previous months. This can be attributed to the lingering effects of the 12-month normalization process:

- In November 2019, GSAT-0101 had a very low healthy SIS availability: only 8.76%, all signals, and this impacted the 12-month moving averages including this period, up to October 2020;
- In December 2019, GSAT-0210 had healthy SIS availability of 87.59% for I/NAV, while GSAT-0102, GSAT-0208, GSAT-0212 and GSAT-0220 had availability around 94% for F/NAV, impacting the moving averages up to November 2020.

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

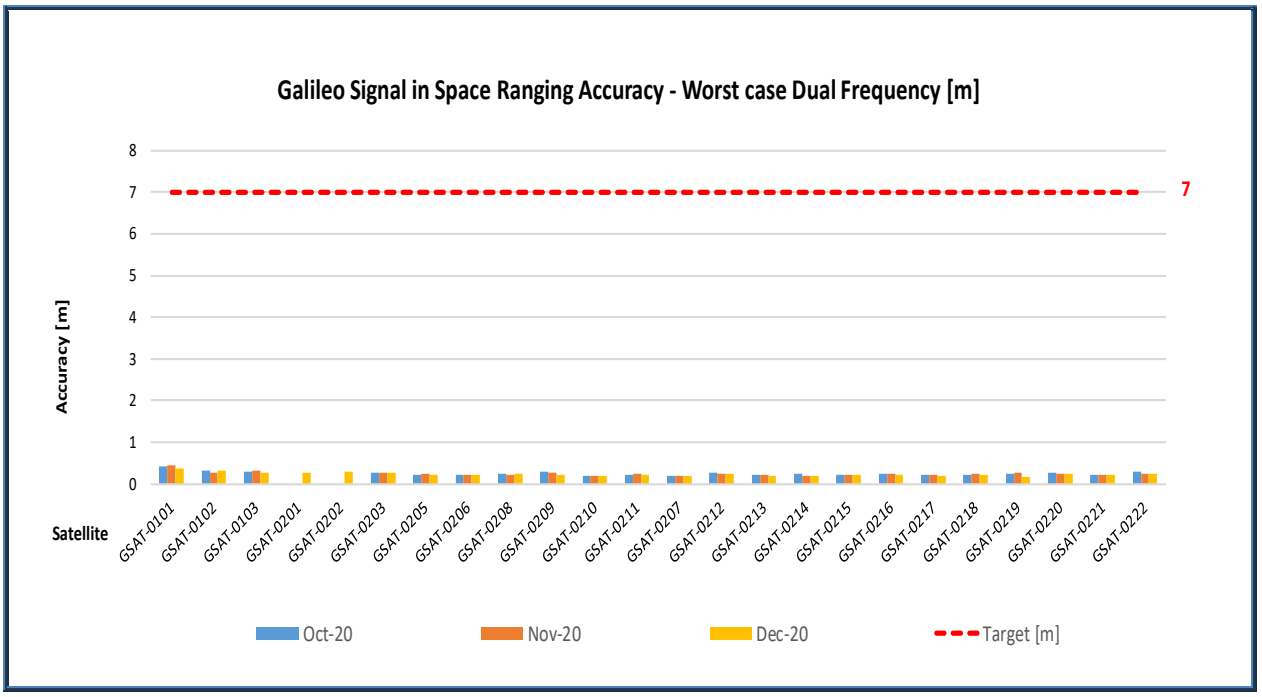
3.2 GALILEO SIGNAL IN SPACE RANGING ACCURACY

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.

As shown in the following Figure 2 and Figure 3, the 95% metric applied to the Galileo Signal in Space Ranging Accuracy "for any space vehicle", over all satellites[6] and frequency combinations, is:

- For individual space vehicles in **October**, worst case values of **0.41** [m] for Dual Frequency and **0.67** [m] for Single Frequency. The best case values over the month are **0.17** [m] and **0.23** [m], respectively.
- for individual space vehicles in **November**, worst case values of **0.44** [m] for Dual Frequency and **0.62** [m] for Single Frequency. The best case values over the month are **0.18** [m] and **0.23** [m], respectively.
- for individual space vehicles in **December**, worst case values of **0.36** [m] for Dual Frequency and **0.62** [m] for Single Frequency. The best case values over the month are **0.17** [m] and **0.23** [m], respectively.

[6] Satellites in nominal slots plus Auxiliary Satellites.



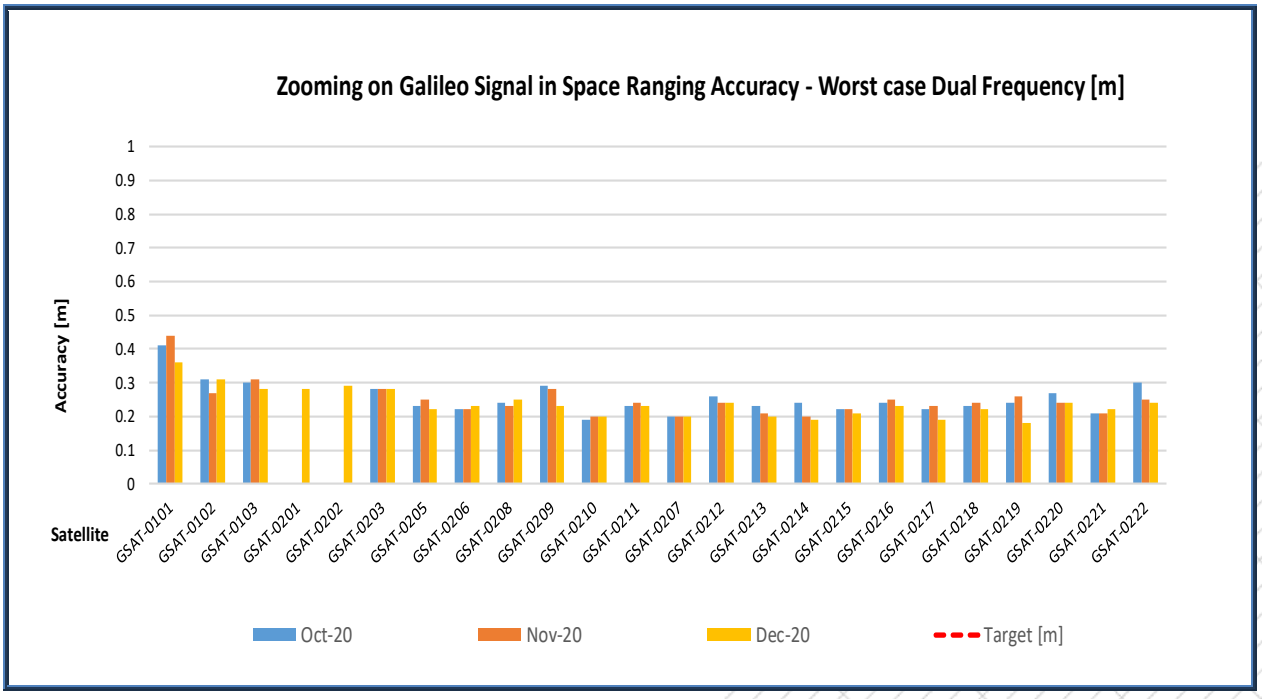
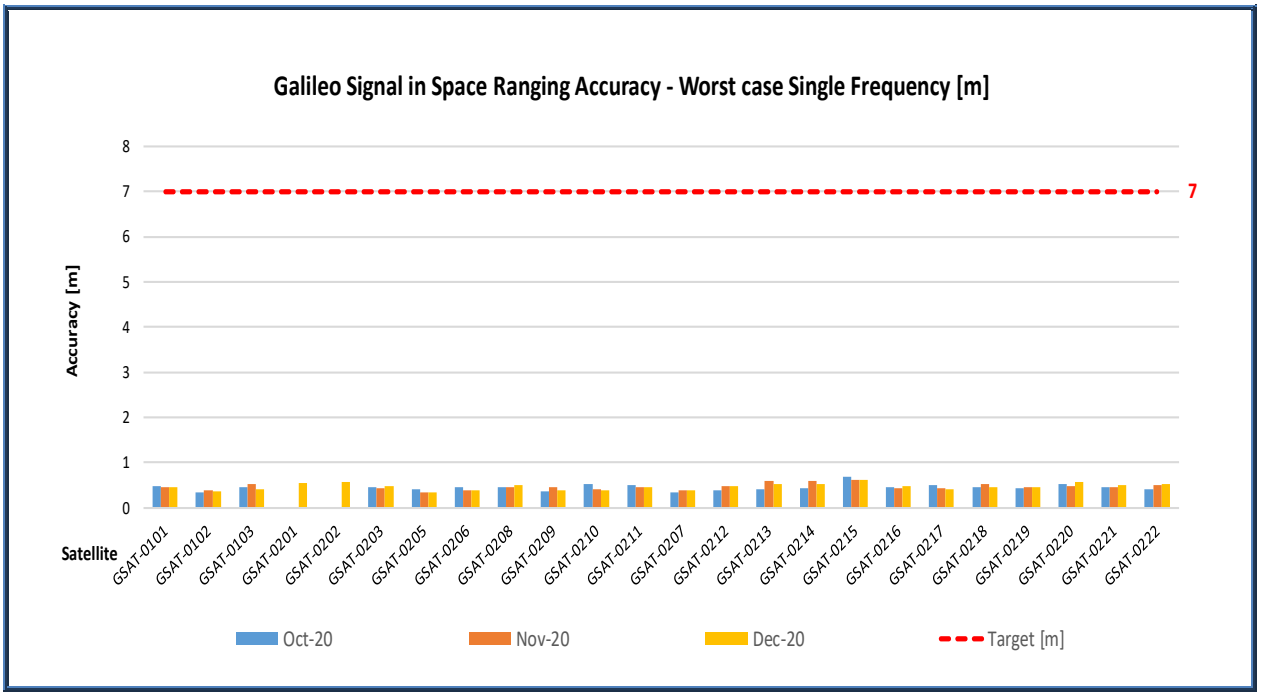


Figure 2 : Monthly Galileo SIS Ranging Accuracy (95th percentile) "for any satellite", measured during reporting period for worst-case, Dual-Frequency (DF)



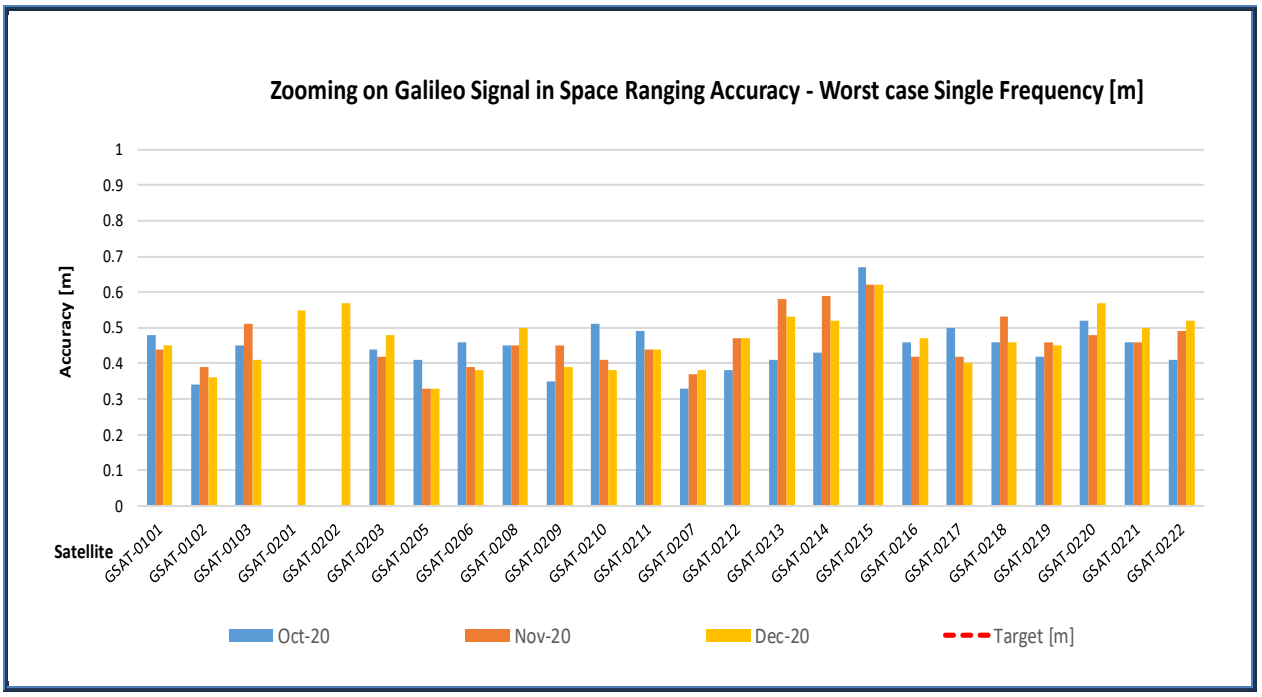


Figure 3 : Monthly Galileo SIS Ranging Accuracy (95th percentile) "for any satellite", measured during the reporting period for worst-case, Single-Frequency (SF)

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

Figure 4 depicts the average "over all satellites" (constellation mean). Again, the [OS-SDD] MPL target of **2** [m] [8] is met by the Constellation average value.

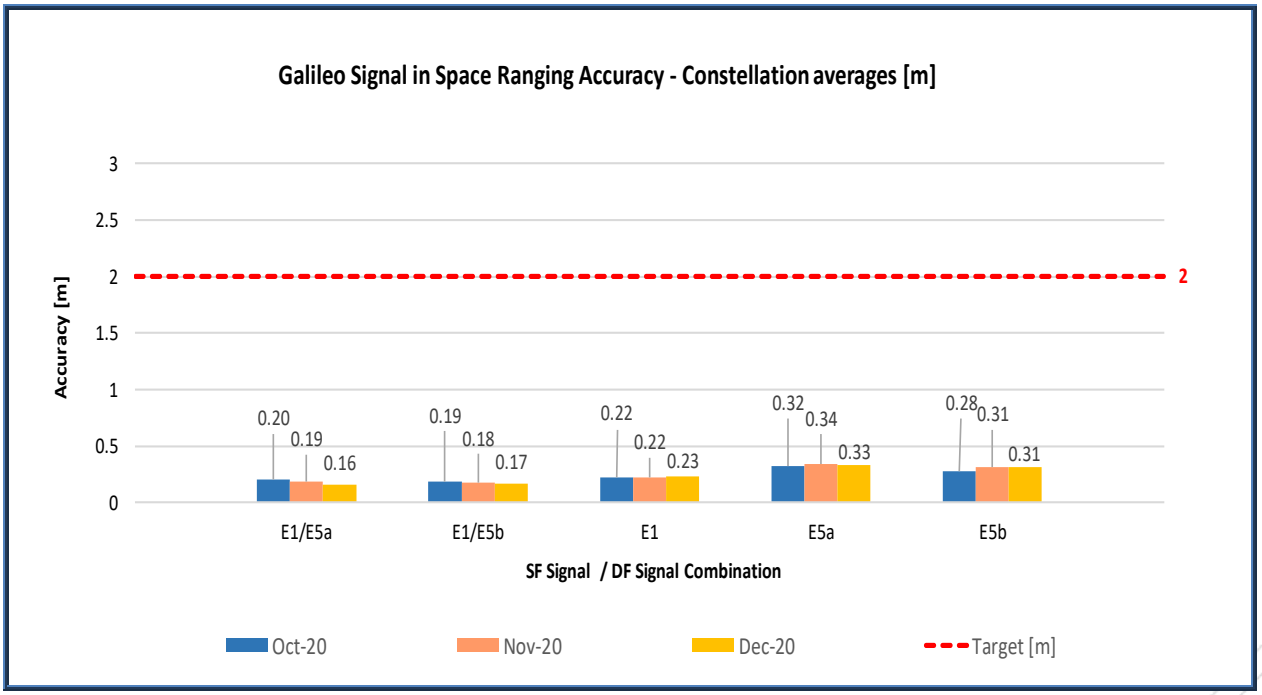


Figure 4 : Monthly Galileo SIS Ranging Accuracy (95th percentile) "over all satellites" (constellation average), measured during the reporting period

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

8 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 5 provides the Worst User Location (WUL) Availability of such service, computed for a virtual grid of user positions over the service coverage area.

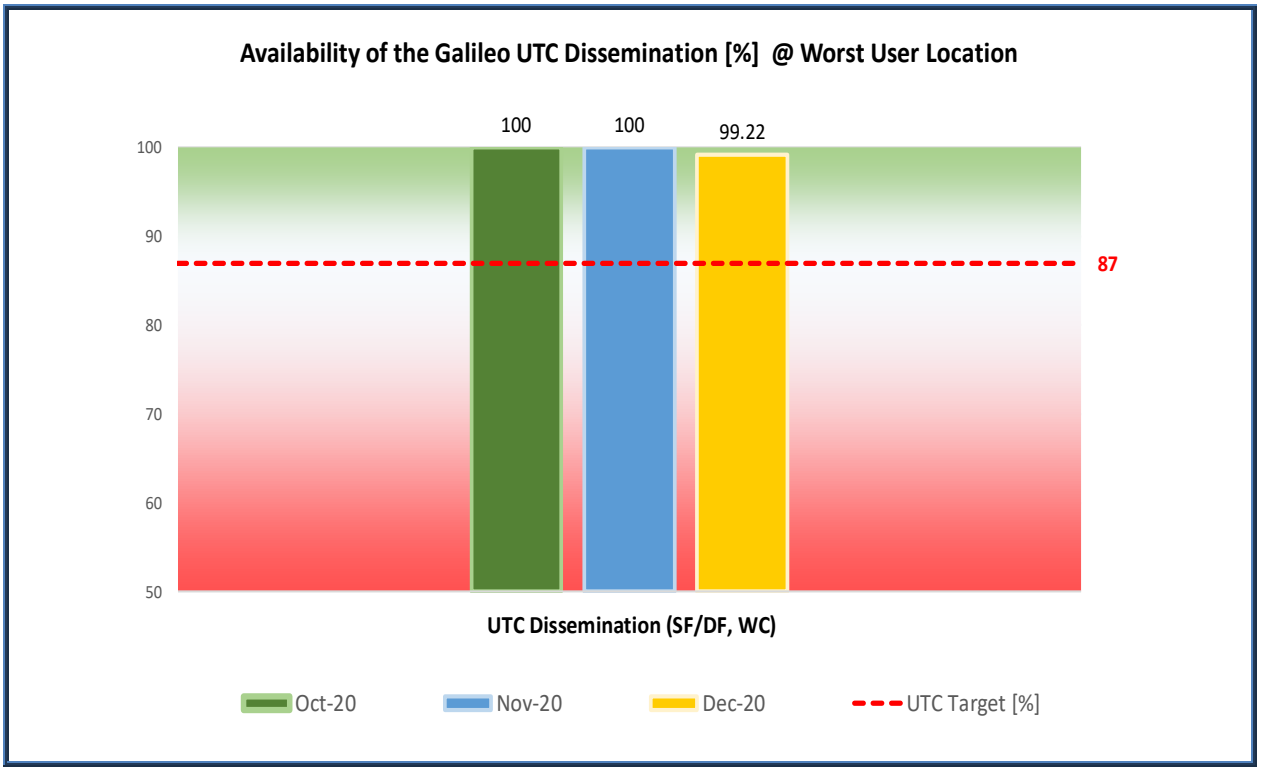


Figure 5 : Monthly availability of the UTC Dissemination Service during the reporting period

As shown in Fig. 6, the monthly (short-term) availability of the Galileo UTC Dissemination Service achieved **100**% during the first two months of the reporting period, while it was **99.22**% in

December. The MPL of **87%** [9] specified by [OS-SDD] for the long term is therefore fulfilled.

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 6, 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 October and November, while figure is **99.22**% in December:

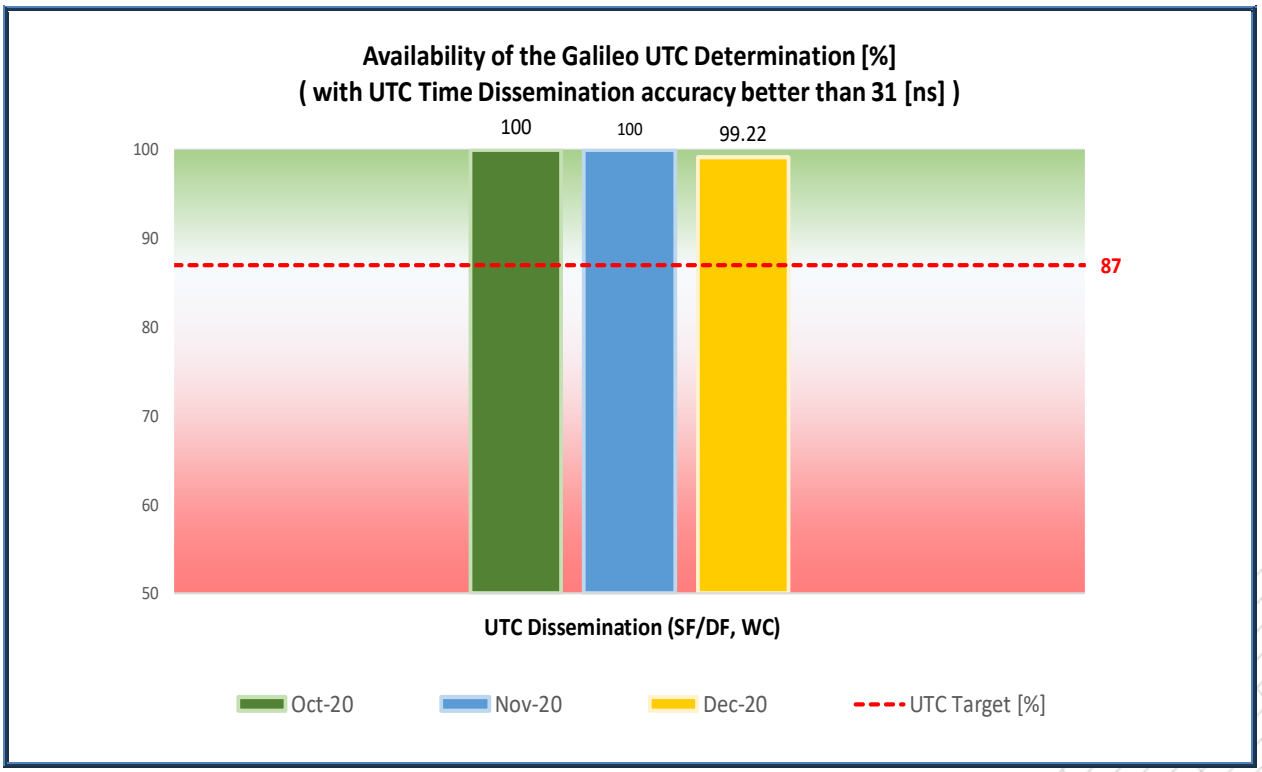


Figure 6 : Monthly availability of the UTC Determination with assigned Accuracy target during the reporting period

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[10] set of coefficients within the Navigation message, acquiring SiS from a space vehicle seen above a minimum elevation angle of 5 degrees. Figure 7 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.

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

10 "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.

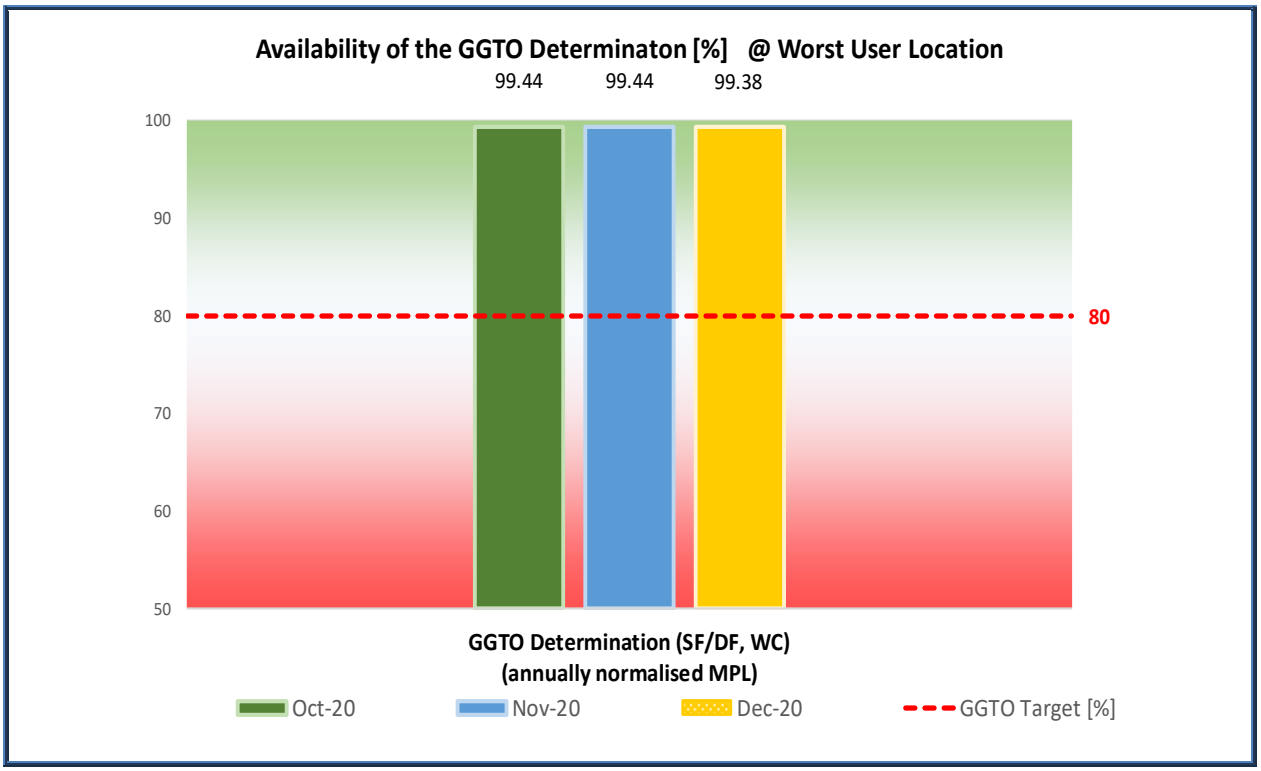


Figure 7 : Annually normalised availability of the GGTO Determination, during the reporting period

The MPL of **80%** [11] 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 always **100**% during the reporting period: no NAGUs were published announcing the dissemination of "dummy" 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 [12].

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.

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

[12] 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 8 shows the 95th percentile of the daily average of the UTC Dissemination Accuracy, observed and normalised over a period of 12 months.

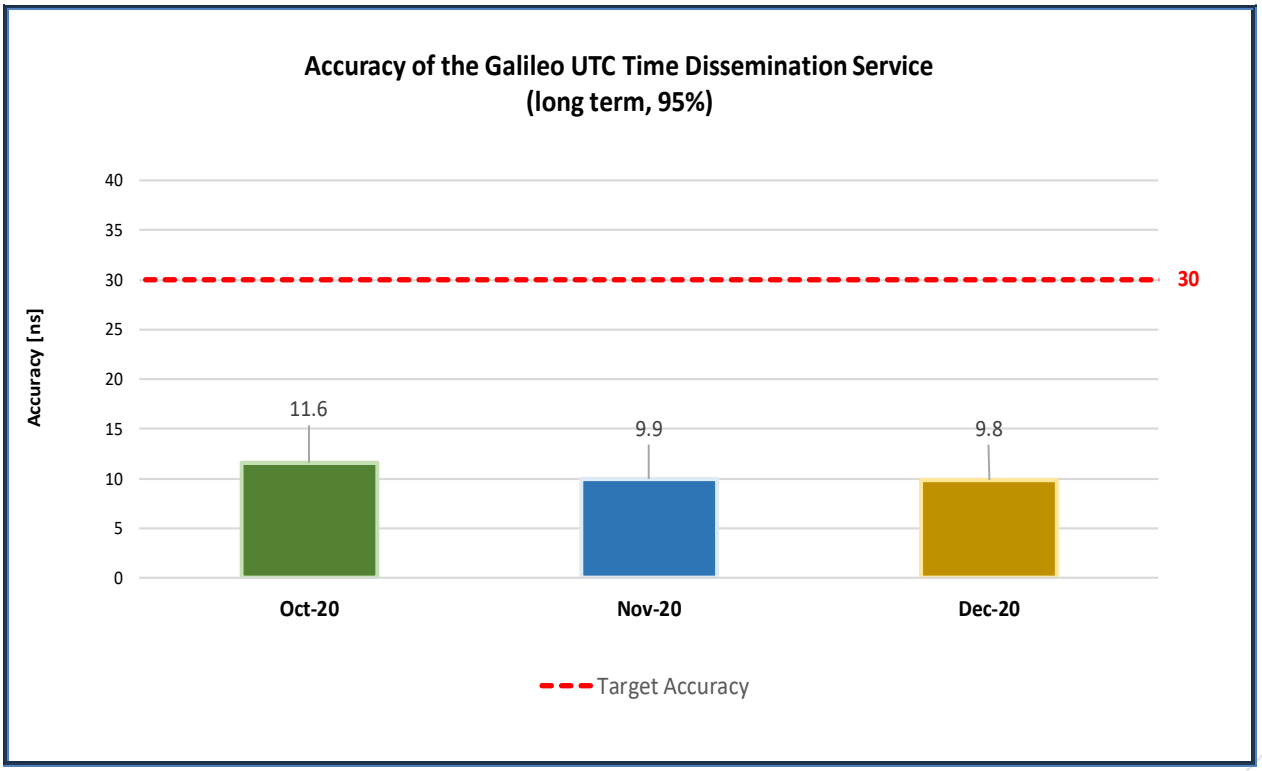


Figure 8 : Long-term 95th percentile of UTC Time Dissemination Accuracy

Figure 9 shows the 95th percentile of the UTC Frequency Dissemination Accuracy, computed accumulating measurement data over the past 12 months [13]. Figure 10 shows the 95th percentile of the daily average of the GGTO Determination Accuracy, also normalised annually.

As seen in Figure 8, the long term 95th percentile of UTC (Time) Dissemination Accuracy is slowly reducing from **11.6** [ns] to **9.8** [ns], well below the [OS-SDD] Minimum Performance Level specification of **30** [ns] [14]. Regarding UTC Frequency Dissemination accuracy, Figure 9 shows that the measured 95th percentile value is less than or equal to **1.4E–14**, which is an order of magnitude better than the [OS-SDD] MPL normalised annual ceiling of **3.0E–13** [15].

About the GGTO Determination Accuracy, shown in Figure 10, the measured values are improving from **10.3** [ns] to **9.6** [ns] in the quarterly reporting period. These figures are within the [OS-SDD] MPL threshold of **20** [ns] [16]. Since the end of January, the short term (monthly) timing accuracy related metrics (which are not subject to MPL targets) exhibit much better performance, due to a

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

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

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

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

fine calibration performed at the end of January, after the Galileo infrastructure upgrade activities that took place. However, this improvement is not visible looking at the MPLs of the quarter, due to the computation of 95% over a long term (sliding window of 12 months).

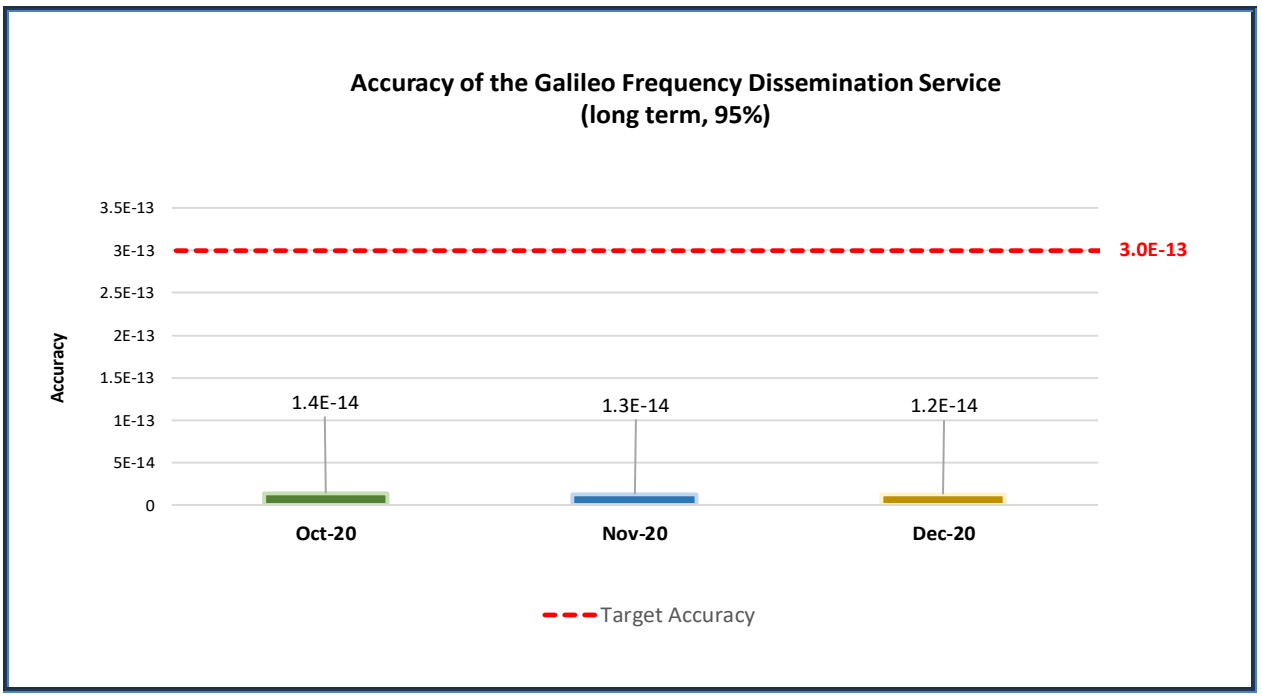


Figure 9 : Long-term 95th percentile of UTC Frequency Dissemination Accuracy

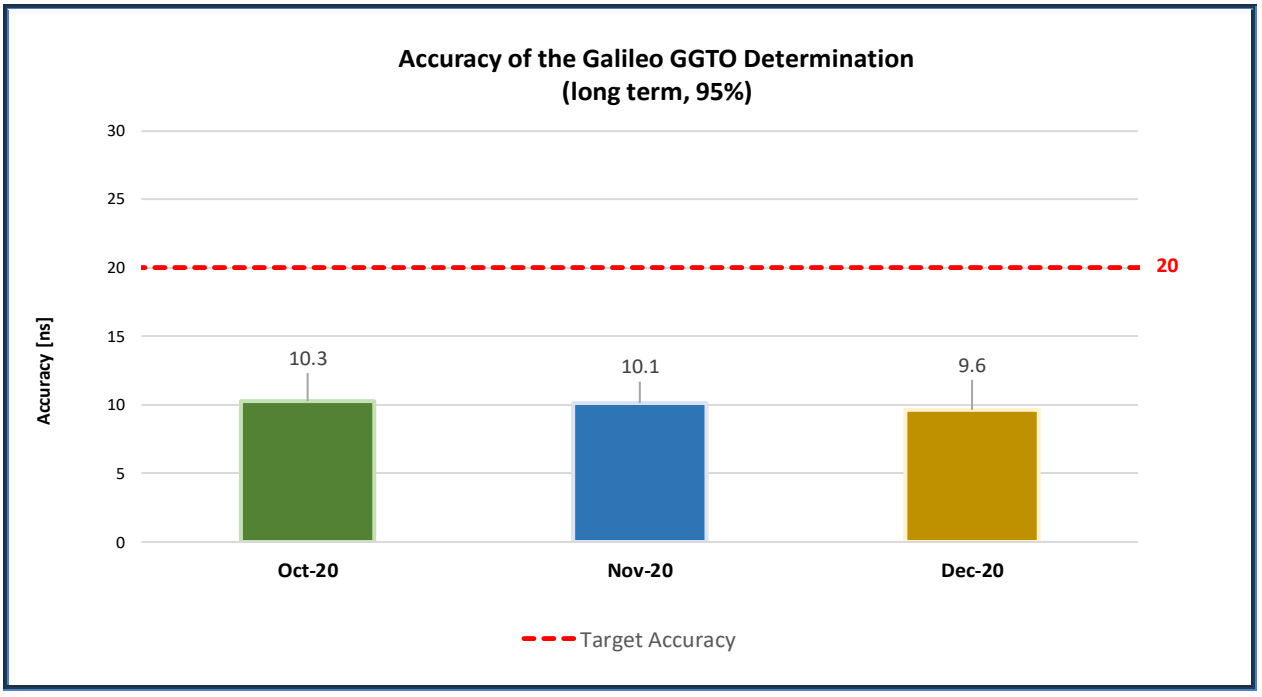


Figure 10 : Long-term 95th percentile of GGTO Determination Accuracy

5 GALILEO POSITIONING PERFORMANCE

In this section of the report the following performance figures are provided for information:These parameters are reported considering only satellites in nominal slots.

- ◊ 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**% [17]. Results are presented in Figure 11, which distinguishes between the cases of SIS carrying I/NAV or F/NAV messages. With figures of **99.18**% at least, the target value is exceeded with significant margin.

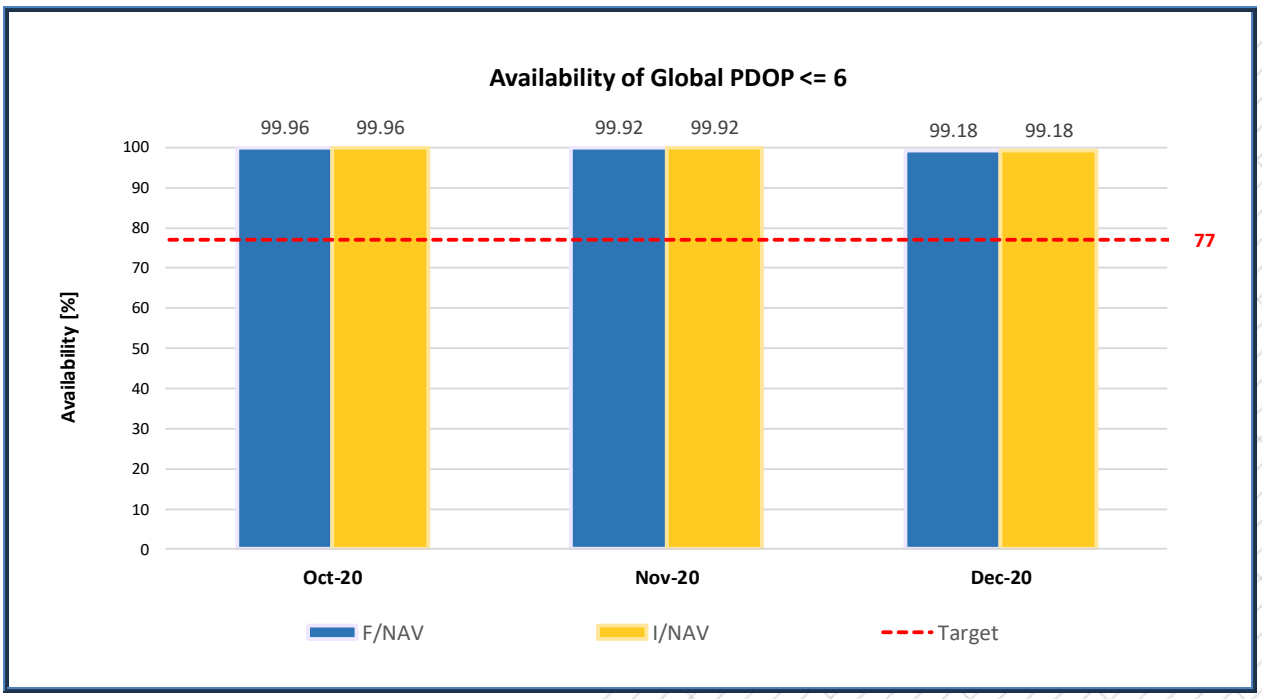


Figure 11 : Monthly Global Average Availability of PDOP ≤ 6

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

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**% [18] at Worst User Location (WUL), and **77**% [19] 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 12 and Figure 13. Target values are met with large margins.

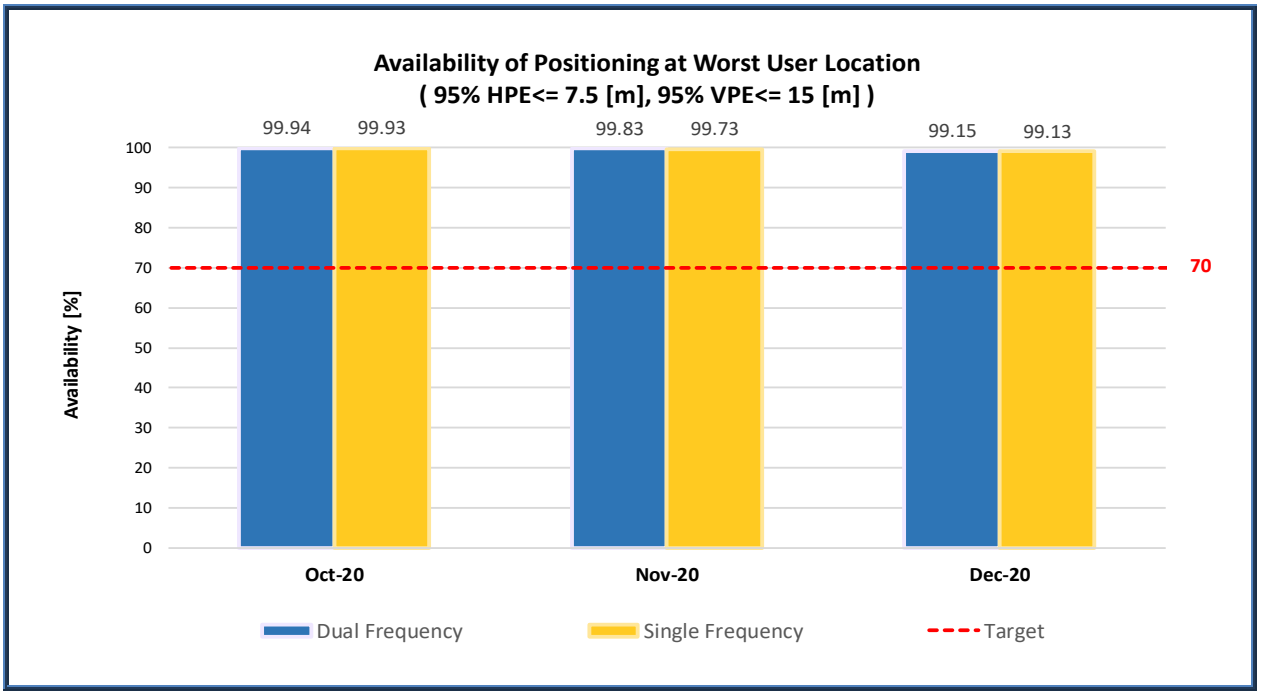


Figure 12 : Availability of Positioning at Worst User Location (WUL)

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

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

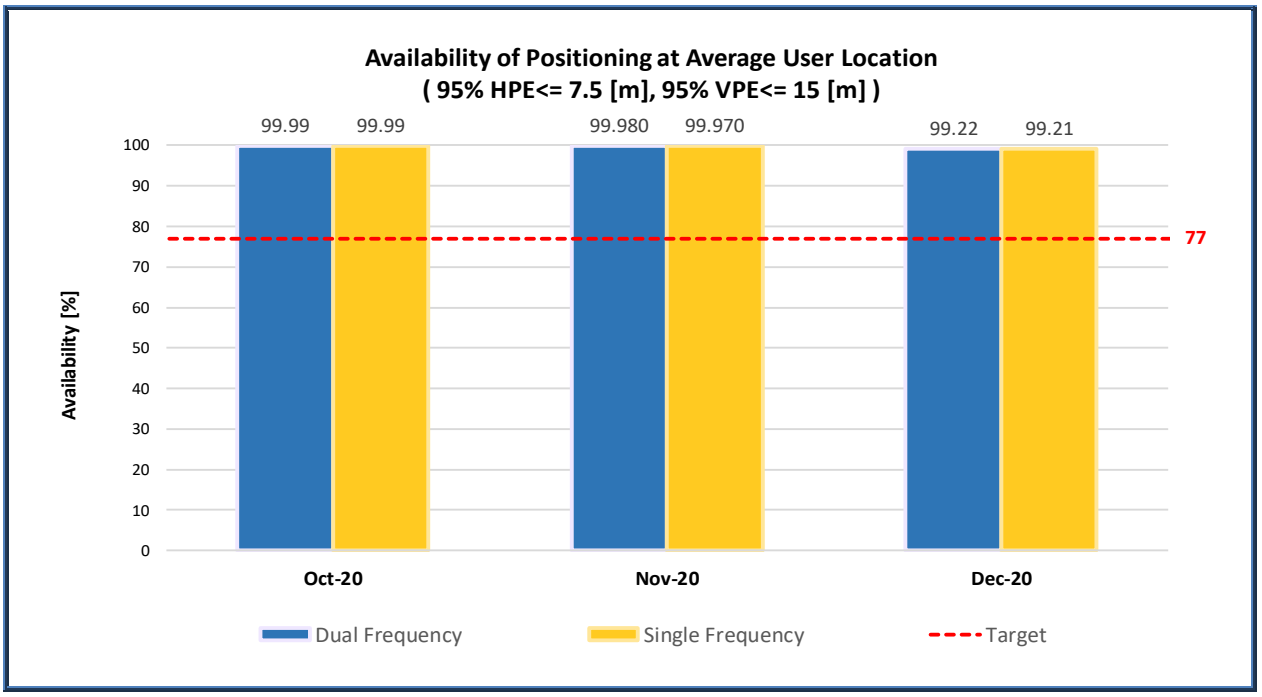


Figure 13 : Availability of Positioning at Average User Location (AUL)

5.3 GALILEO MEASURED POSITIONING PERFORMANCE

Although the Galileo FOC constellation is not yet completely deployed, since May 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" [20].

To this end it is recalled that, 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 outliers detection filtering, which was introduced since 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.

[20] 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.

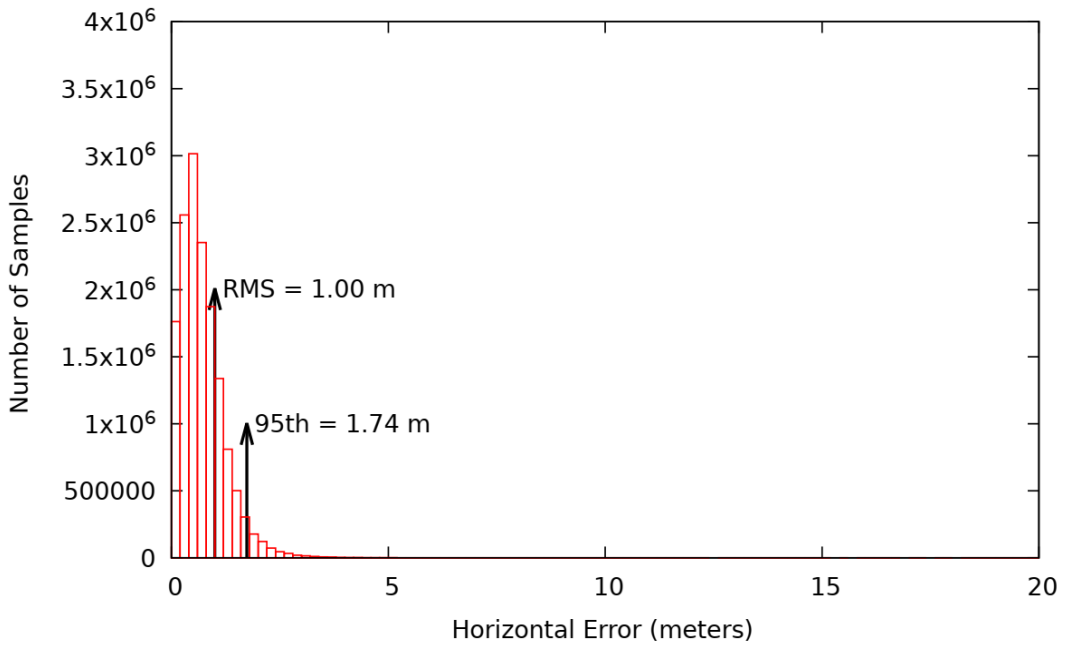
October 2020

HPE

3D Positioning

E1-E5a (DF)

F/NAV



Note: 160 samples > 20 [m], less than 0.01 %

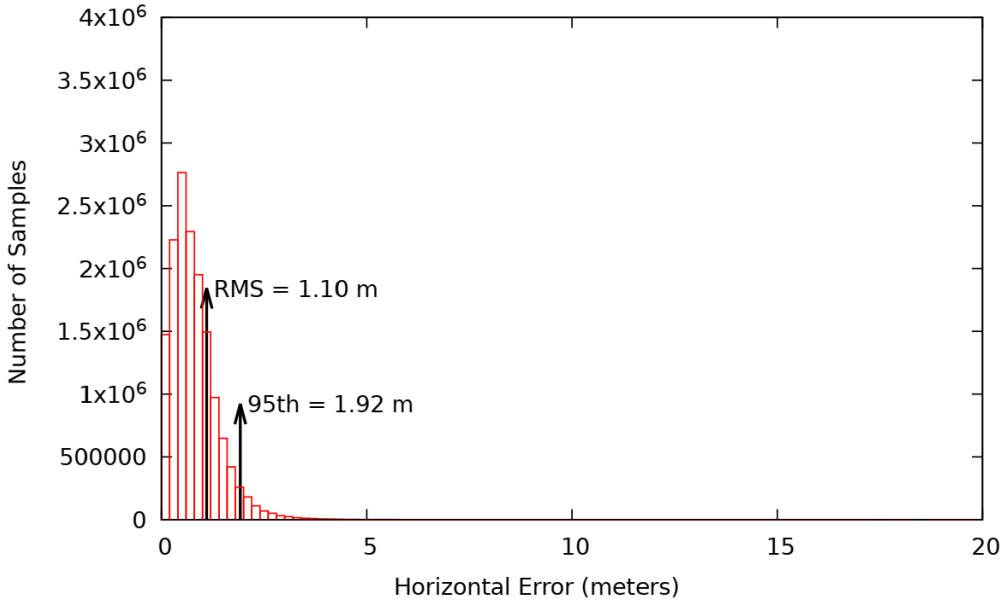
October 2020

HPE

3D Positioning

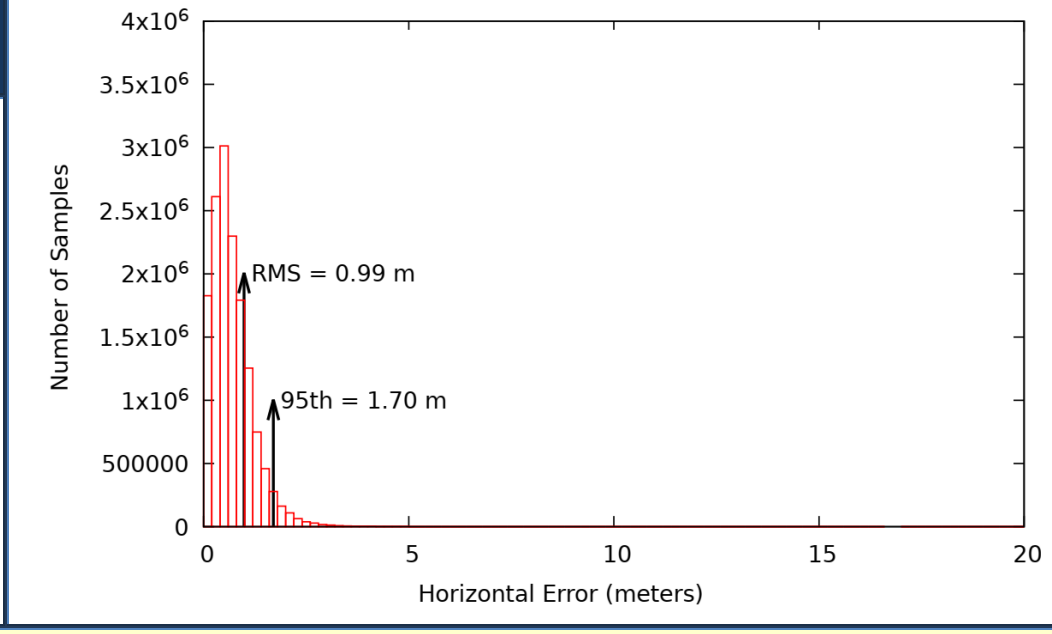
E1-E5b (DF)

I/NAV



Note: 190 samples > 20 [m], less than 0.01 %

Figure 14 : Horizontal Positioning Error (HPE) for "Galileo-only" users in October 2020

November 2020	
HPE 3D Positioning E1-E5a (DF) F/NAV	
Note: 326 samples > 20 [m], less than 0.01 %	

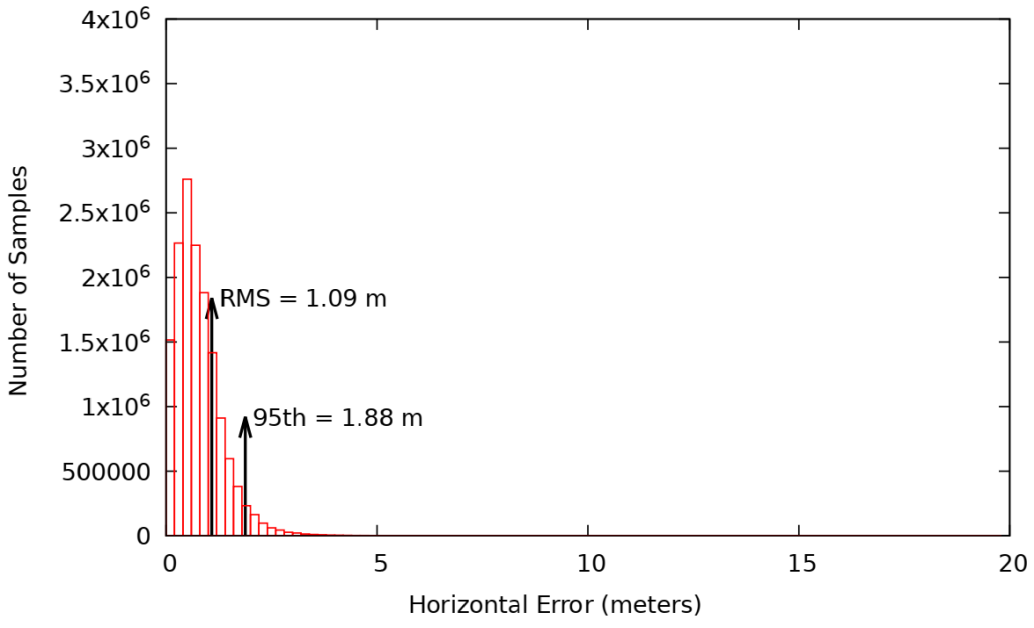
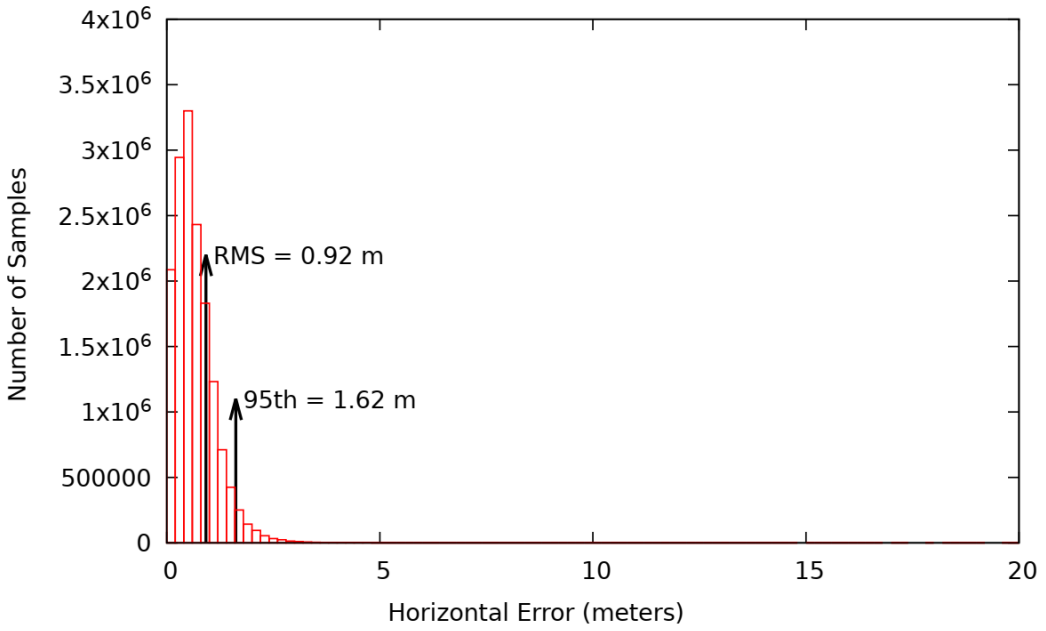
November 2020	
HPE 3D Positioning E1-E5b (DF) I/NAV	
Note: 365 samples > 20 [m], less than 0.01 %	

Figure 15 : Horizontal Positioning Error (HPE) for "Galileo-only" users in November 2020

December 2020	
HPE 3D Positioning E1-E5a (DF) F/NAV	
Note: 181 samples > 20 [m], less than 0.01 %	

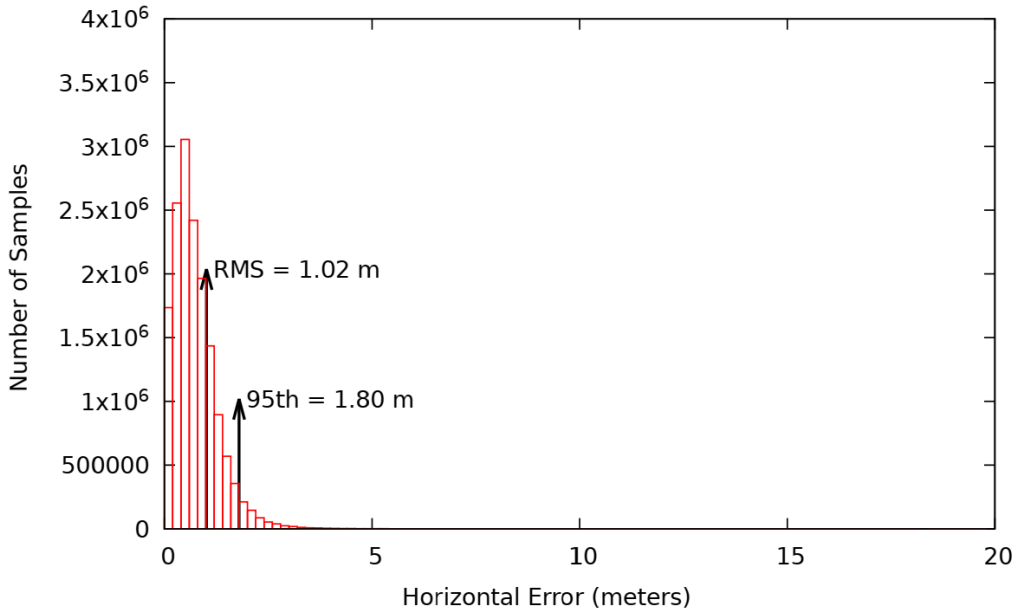
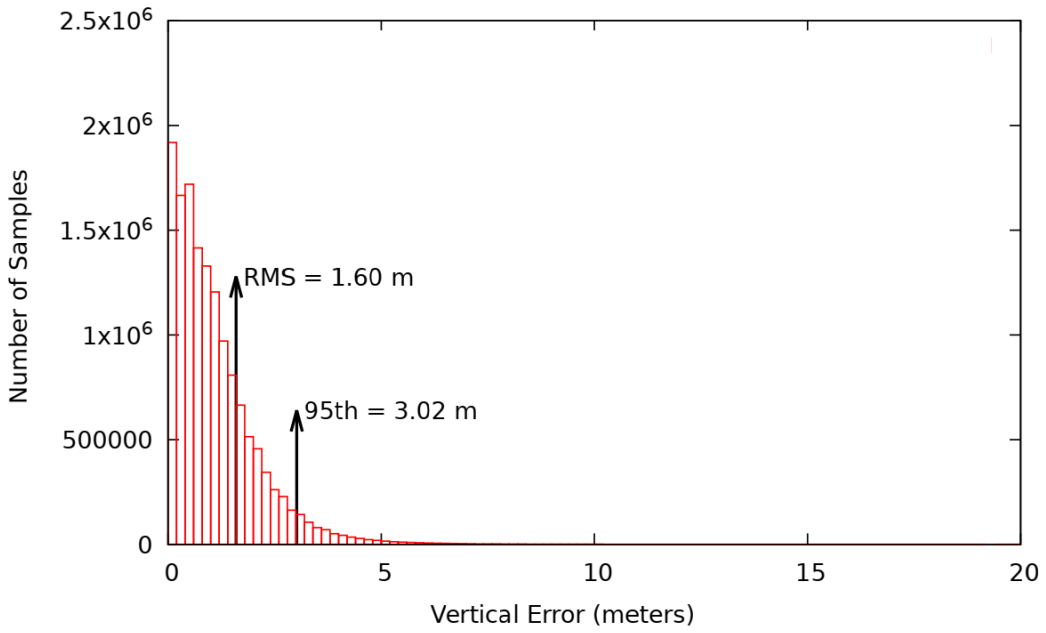
December 2020	
HPE 3D Positioning E1-E5b (DF) I/NAV	
Note: 197 samples > 20 [m], less than 0.01 %	

Figure 16 : Horizontal Positioning Error (HPE) for "Galileo-only" users in December 2020

October 2020	
VPE 3D Positioning E1-E5a (DF) F/NAV	
Note: 263 samples > 20 [m], less than 0.01 %	

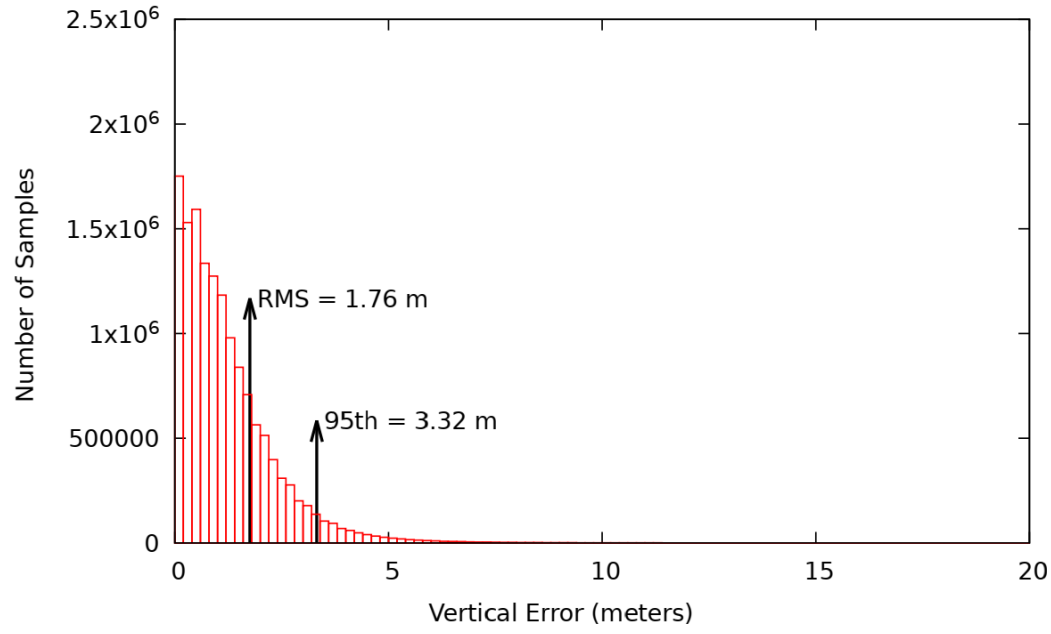
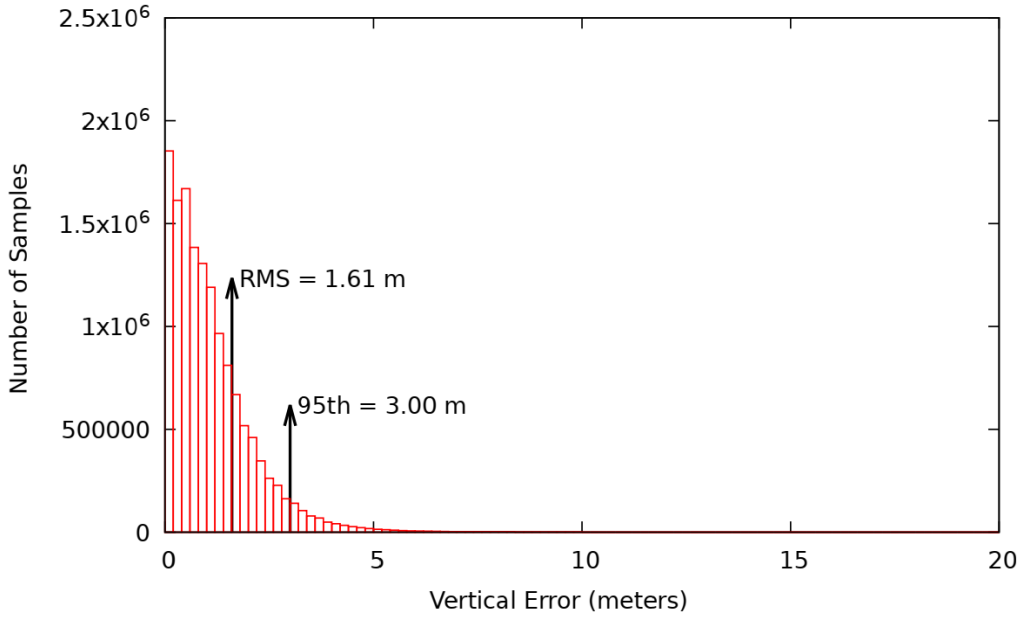
October 2020	
VPE 3D Positioning E1-E5b (DF) I/NAV	
Note: 410 samples > 20 [m], less than 0.01 %	

Figure 17 : Vertical Positioning Error (VPE) for "Galileo-only" users in October 2020

November 2020	
VPE 3D Positioning E1-E5a (DF) F/NAV	
Note: 447 samples > 20 [m], less than 0.01 %	

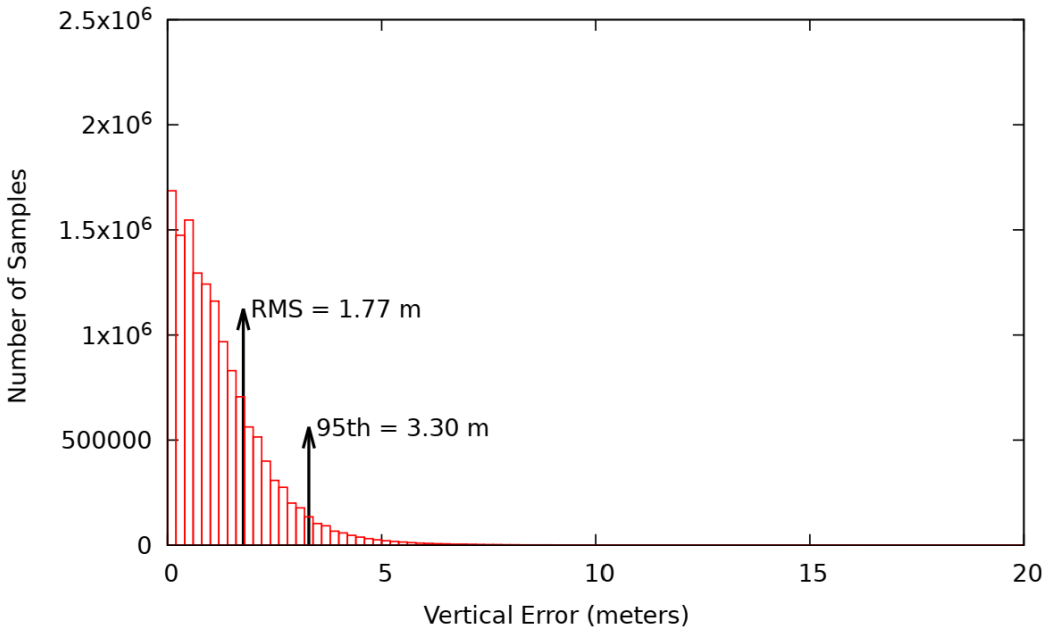
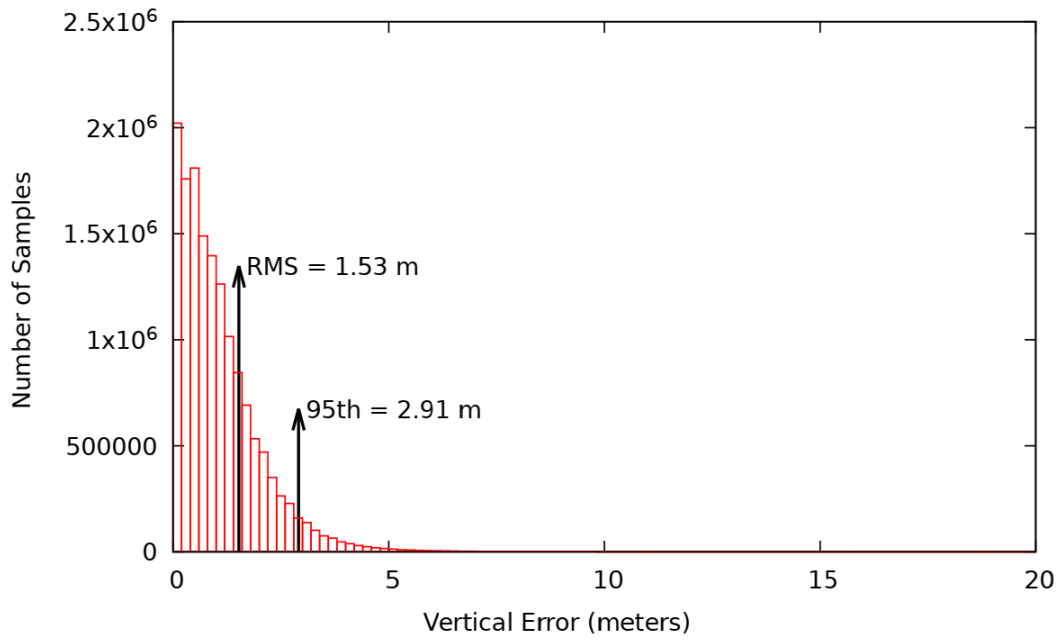
November 2020	
VPE 3D Positioning E1-E5b (DF) I/NAV	
Note: 516 samples > 20 [m], less than 0.01 %	

Figure 18 : Vertical Positioning Error (VPE) for "Galileo-only" users in November 2020

December 2020	
VPE 3D Positioning E1-E5a (DF) F/NAV	
Note: 324 samples > 20 [m], less than 0.01 %	

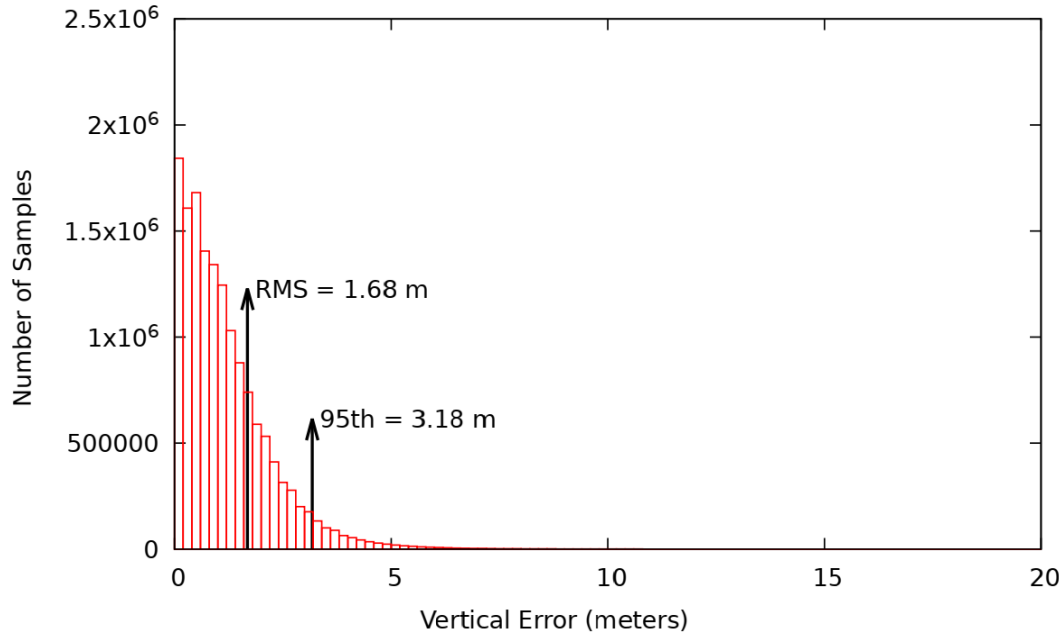
December 2020	
VPE 3D Positioning E1-E5b (DF) I/NAV	
Note: 385 samples > 20 [m], less than 0.01 %	

Figure 19 : Vertical Positioning Error (VPE) for "Galileo-only" users in December 2020

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 [21] before the event starts. For Unplanned events, the [OS-SDD] specifies a delay of up to **72** hours [21] 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 only one "Planned" NAGU was issued, and there were 5 NAGUs belonging to the category "Unplanned", of which one of them was related to the Service Incident in December. In particular:

- in October, no planned operations were scheduled; the "Unplanned" NAGU 2020016 corresponds to the recovery of GSAT-0205 (E24) nominal operational capability after on-board maintenance;
- in November, a couple of NAGUs (2020017, 2020018) correspond to a planned operation for GSAT-0101 (E11) on-board clock maintenance. Additional two NAGUs (2020019, 2020020) announce the initial usability of the auxiliary Space Vehicles GSAT-0201 (E18) and GSAT-0202 (E14) launched on anomalous orbits;
- in December, NAGU 2020021 is the only one related to an outage, which affected the entire Galileo constellation for approximately 6 hours, with corresponding unavailability of

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

positioning and timing services. This was unplanned, and published some hours after the situation was successfully resolved.

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

Month	NAGU Type	Reason for publishing	Notice Advisory ID	NAGU Categ.	Timeliness
October	USABLE	Announcing restart of GSAT-0205 (E24) nominal operational capability, starting from 30/09/2020 @ 19:04 UTC	2020016	**U**	Publication of NAGU occurred around 20 hours (**0.827** days) after the recovery
November	PLN _OUTAGE	Announcing temporary suspension of Navigation services from GSAT-0101 (E11), due to on-board clock maintenance, starting from 09/11/2020 @ 05:05	2020017	**P**	Publication of NAGU occurred around 60.2 hours (**2.51** days) after the recovery
	USABLE	Announcing restart of GSAT-0101 (E11) nominal operational capability, starting from 11/11/2020 @ 08:20	2020018	**U**	Publication of NAGU occurred around 8.5 hours (**0.351** days) after the recovery
	USABINIT	Announcing initial usability for Navigation Services of GSAT-0201 (E18), starting from 30/11/2020 @ 08:32	2020019	**U**	Publication of NAGU occurred around around 4.6 hours (**0.193** days) after the event
	USABINIT	Announcing initial usability for Navigation Services of GSAT-0201 (E18), starting from 30/11/2020 @ 08:32	2020020	**U**	Publication of NAGU occurred around around 4.6 hours (**0.193** days) after the event
December	SERVICE DEGRADATION	Warning user domain that a service degradation affected all Galileo satellites, starting 14/12/2020 @ 00:00 UTC, ending @ 06:12 UTC; all satellites providing back nominal signals as of 06:55 UTC	2020021	**U**	Publication of NAGU occurred 14 hours (**0.583** days) after the outage
NAGU Categorisation for timeliness evaluation: "P" = Planned, "U" = Unplanned					

Table 6 : NAGUs published during 4th Quarter of 2020

7 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 1.3, European Union, December 2016

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

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
Issue 1.1 of the [OS-SDD] is in force since May 2019. This version is accessible for download from the European GNSS Service Centre (GSC) website.
The previous OS-SDD version (Issue 1.0) can still be obtained from the GSC, upon user request.

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.

8 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
F/NAV	Navigation message provided by the E5a signal [SIS-ICD]
FOC	Full Operational Capability
GSA	European Global Navigation Satellite Systems Agency
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)
toE	Time of Ephemeris
UTC	Universal Time Coordinated
VPE	Vertical Positioning Error
WUL	Worst User Location

End of Document

European GNSS Service Centre:

https://www.gsc-europa.eu/