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EUROPEAN GNSS (GALILEO) INITIAL SERVICES

OPEN SERVICE

QUARTERLY PERFORMANCE REPORT

JULY - SEPTEMBER 2019

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1 INTRODUCTION

This document is the *Galileo Initial Open Service (IS OS) Public Performance Report* for the period of July, August and September 2019. Following the declaration of Initial Services 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.

Note that this document evaluates Galileo actual performance with respect to the evolved commitments as per the latest edition of the Open Service – Service Definition Document [OS-SDD], v1.1, published on the GSC web portal since May 2019.

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

- ◊ Galileo Initial 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 Initial 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.

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

Section 8: 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	Available
GSAT-0102	12	3A6	B06	Available
GSAT-0103	19	3A7	C04	Available
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

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"

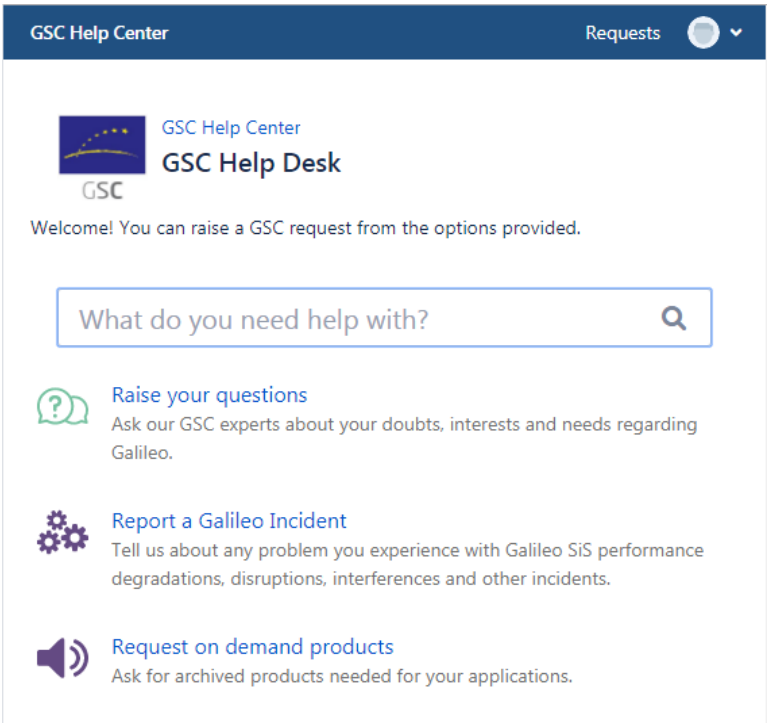


Table 2: GSC main information web pages for Galileo status

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 this quarterly reporting period, the measured Galileo Initial Open Service performance figures exceed the Minimum Performance Level (MPL) targets specified in the [OS-SDD], with the exception of the UTC availability MPLs in July. The following dashboards summarise the compliance with MPLs, using the colour coding defined in the legend below:

OS MPLs	Target Value	Space Vehicle	July-19					August-19					September-19				
			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	Jul-19	Aug-19	Sep-19
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%			
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 **96.87**% for every Single-Frequency (E1-B, E5a, E5b) and Dual-Frequency combination (E1/E5a, E1/E5b), is significantly above the MPL threshold of **87%**. The figures are normalised annually, according to the MPL definition, by a moving average applied over the last 12 months.

The **Signal in Space Ranging Accuracy** shows a 95th percentile monthly accuracy between **0.22** [m] and **0.57** [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 **0.16** [m] to **0.34** [m]. Compliance with the [OS-SDD] MPL, where the threshold is specified as **7** [m], is achieved with large margins.

The average **Ranging Accuracy at constellation level** (over "All Satellites") provides figures "per signal" that are better than **0.31** [m] for Single Frequency signals and **0.21** [m] for Dual Frequency signal combinations. The specified MPL threshold of **2** [m] is therefore achieved.

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 characterized. In both cases, metrics had a monthly value of **81.7** % in July and **100** % during the rest of quarterly reporting period**,** thus not achieving the committed target in July, while exceeding the [OS-SDD] MPL targets of **87%** in August and September.

The performance degradation in July was due to a technical incident related to the Galileo ground infrastructure. The incident led to a temporary interruption of the Galileo initial navigation and timing services, and was fully recovered on July 22nd, as announced through NAGU 2019028. The incident was communicated to the Galileo users through NAGUs 2019025, 2019026, 2019027 and 2019028 and related news published on the GSC web portal. More details are provided in Annex A.

The **Availability of GGTO Determination** metric was **95.68**% over the whole quarter. Annually normalised figures provided in §4.1 are obtained with an average applied over the last 12 months. The measured values are comfortably above the [OS-SDD] MPL target of **80%.**

Good values are achieved for the **UTC Time Dissemination Service Accuracy** (≤ **14.4 [ns]**), the **UTC Frequency Dissemination Service Accuracy** (normalised offset ≤ $\mathbf{4.5\times10^{-14}}$) and the **GGTO Determination Accuracy** (≤ **13.7** [ns]), all computed by accumulating samples over the previous 12 months. The [OS-SDD] MPL targets, which are respectively **30** [ns], $\mathbf{3\times10^{-13}}$ and **20** [ns], are all met.

The [OS-SDD] includes commitments related to a full **3D Positioning Service** that are consistent with the achieved deployment status of the Galileo constellation, which currently includes 22 space

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

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

vehicles actively contributing to the provision of navigation services. Associated metrics are as follows.

Availability of Global PDOP ≤ 6 was at least **81.27** % in July, **99.71** % in August and **99.36** % in September, 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 July, at least **80.69** % at Worst User Location (WUL) and **81.51** % at Average User Location (AUL);
- in August, at least **99.59** % at WUL and **99.94** % at AUL;
- in September, at least **98.83** % at WUL and **99.75** % at AUL.

The target MPL values are **70**% at WUL and **77%** at AUL. It is noted that, even if the MPLs are met, the availability figures are significantly degraded in July compared to the nominal monthly situation. These degraded values are the result of the service incident that occurred in July (ref.: Annex A).

The availability figures are complemented with measured "Galileo-only" 3D positioning performance, attainable when PDOP ≤ 6. 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 **2.02** [m] and **3.65** [m] respectively during the reporting period, as measured by the GSA network of reference receivers. The corresponding RMS values are **1.47** [m] and **2.65** [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.

3 INITIAL OPEN SERVICE RANGING PERFORMANCE

In this section of the report the following performance figures for the Galileo Initial 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, as the percentage of time that the specific satellite broadcasts Galileo Open Service Signals in Space which are considered "HEALTHY" according to [OS-SDD] rules, concerned with the configuration of specific L-band SIS status flags and the validity period of Navigation messages.

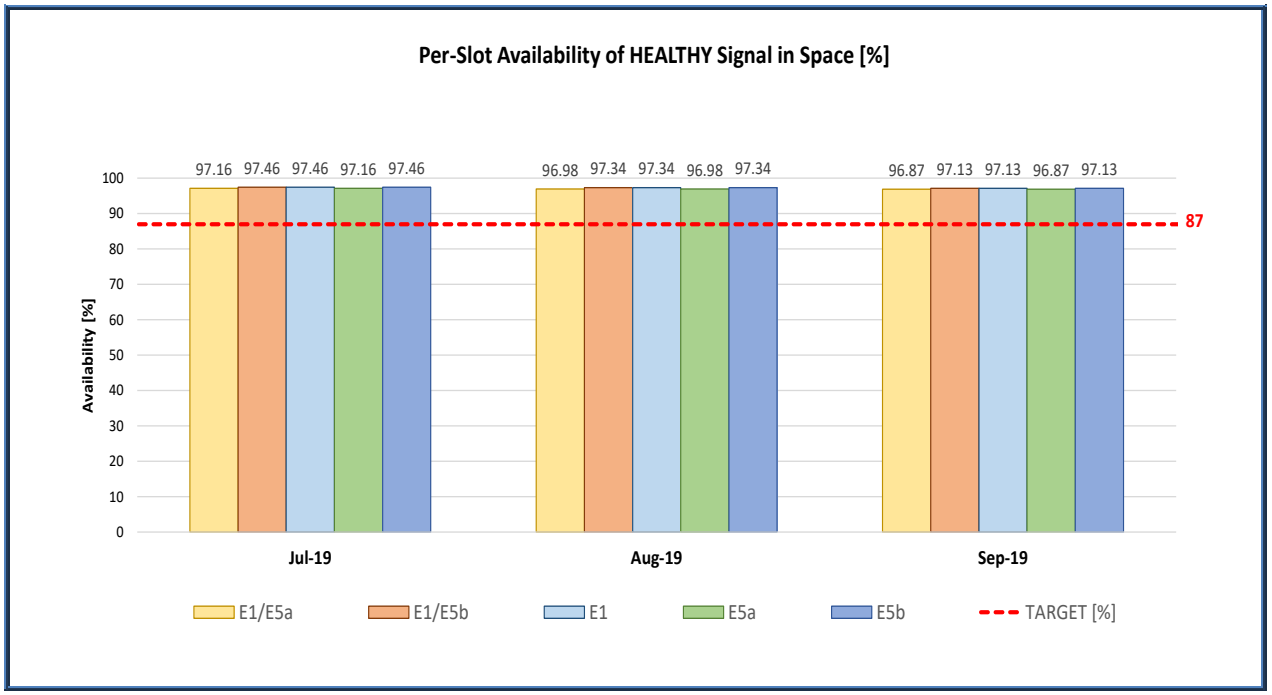


Figure 1: "Per-Slot" availability of HEALTHY Signal in Space for the reporting period

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

The [OS-SDD] Minimum Performance Level (MPL) specifies **87%** [5] as the target value for this constellation metric.

The achieved performance is between **96.87**% (F/NAV, September) and **97.46**% (I/NAV, July).

The availability of Galileo HEALTHY SIS, evaluated individually per frequency combination, satellite and month (without annual normalisation), was between **75.31**% and **100**%, where the lower value was due to the service incident that occurred in July 2019 (ref.: Annex A).

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 **July**, between **0.17 [m]** and **0.34** [m] for Dual Frequency, and between **0.24** [m] and **0.57** [m] for Single Frequency;
- for individual space vehicles in **August**, between **0.16** [m] and **0.27** [m] for Dual Frequency, and between **0.22** [m] and **0.50** [m] for Single Frequency;
- for individual space vehicles in **September**, between **0.16** [m] and **0.32** [m] for Dual Frequency, and between **0.25** [m] and **0.55** [m] for Single Frequency.

account only those space vehicles that are declared active members of the constellation during the whole month.

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

[6] Data for each month takes into account only those space vehicles that are declared active members of the constellation during the whole month.

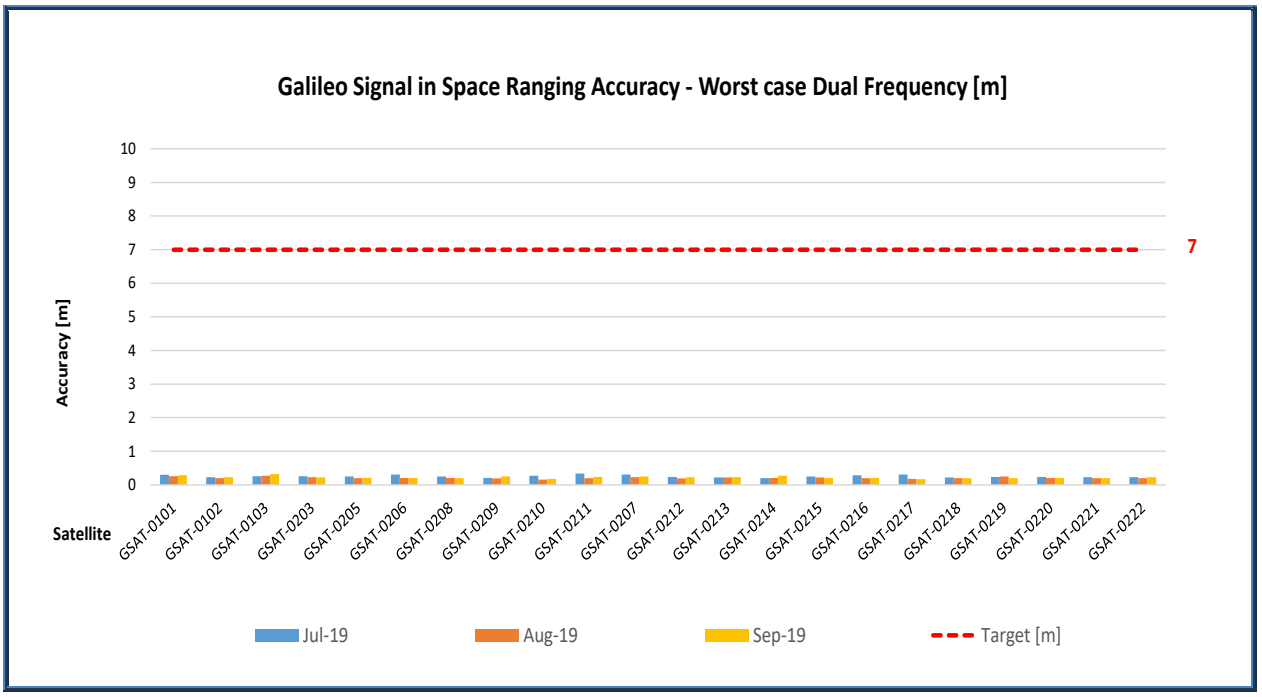


Figure 2: Monthly Galileo SIS Ranging Accuracy (95th percentile) "for any satellite", measured during reporting period for worst-case, Dual-Frequency (DF)

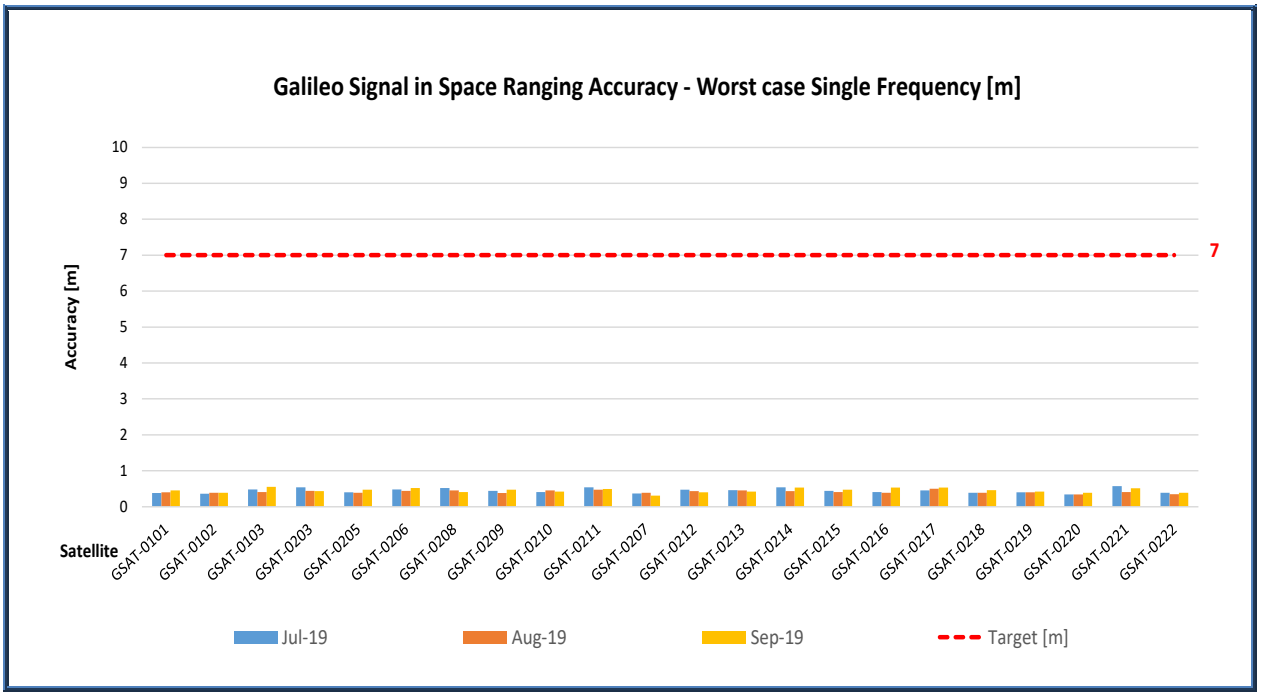


Figure 3: Monthly Galileo SIS Ranging Accuracy (95th percentile) "for any satellite", measured during the reporting period for worst-case, Single-Frequency (SF)

Compliance with the MPL in [OS-SDD] is always achieved, 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.

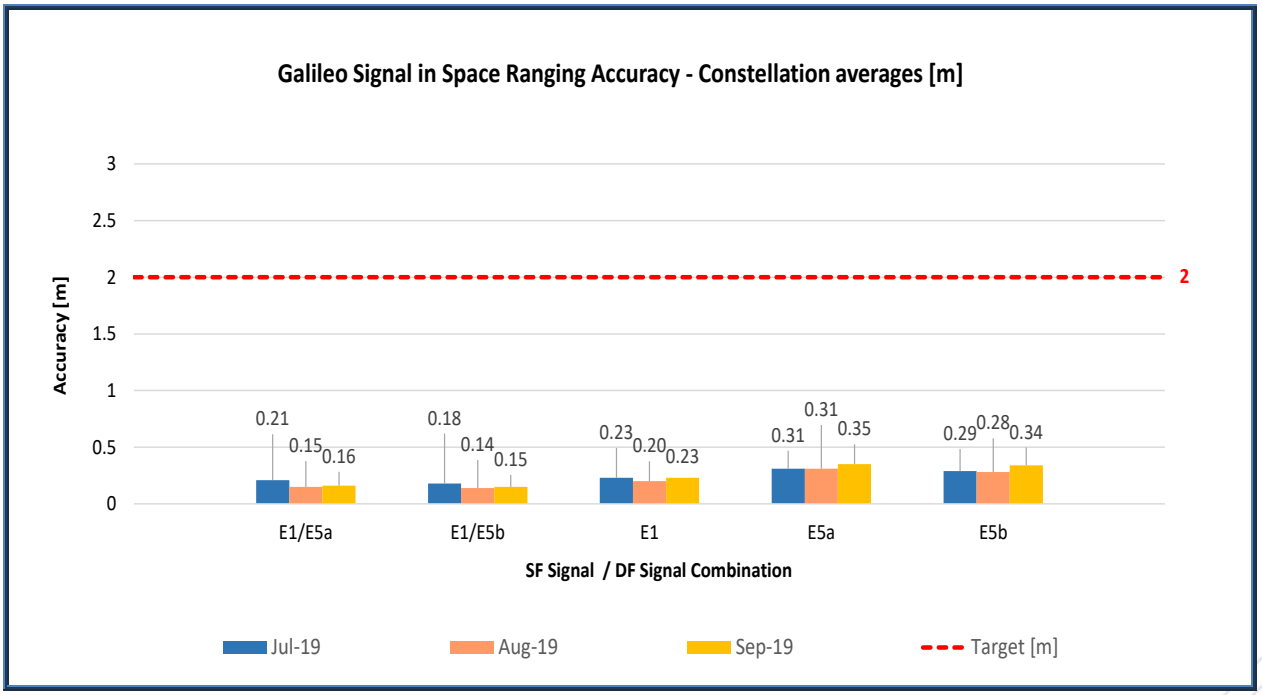


Figure 4: Monthly Galileo SIS Ranging Accuracy (95th percentile) "over all satellites" (constellation average), measured during the reporting period

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.

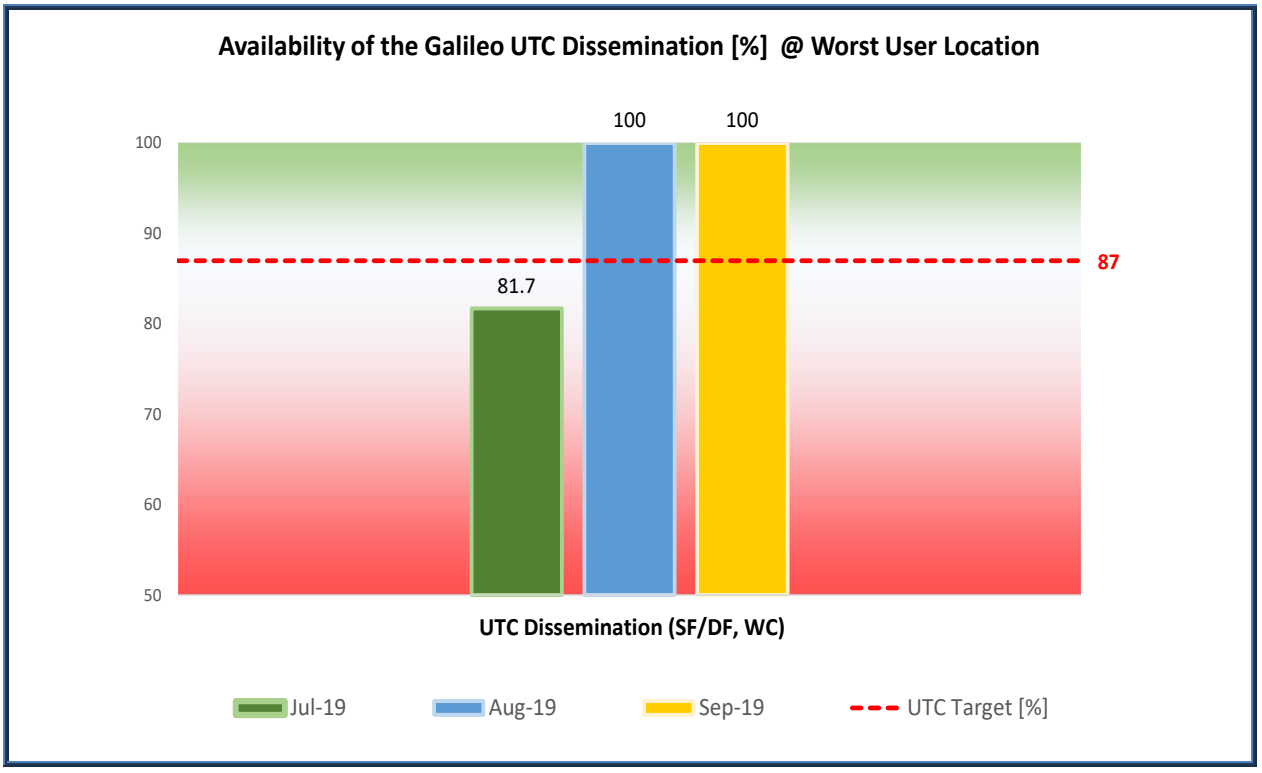


Figure 5: Monthly availability of the UTC Dissemination Service during the reporting period

As shown in Fig. 6, the monthly (short-term) availability of the Galileo UTC Dissemination Service achieved **81.7** % in July, and **100** % during the rest of quarterly reporting period.

The MPL of **87%** [9] specified by [OS-SDD] for the long term is therefore not achieved in July, while it is in August and September. This is again a side effect of the occurred incident (ref.: Annex A).

About 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, and for the same reason, targets for Availability are met in August and September, whilst they are not in July:

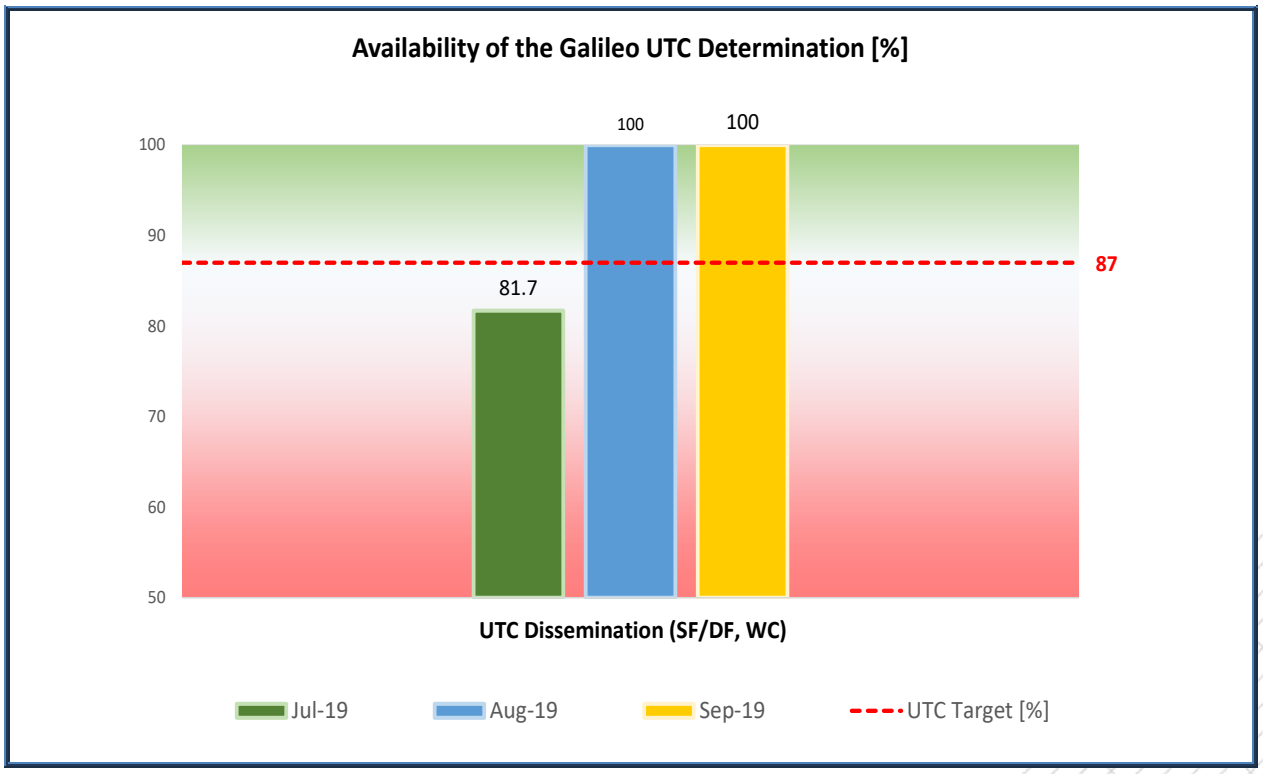


Figure 6: Monthly availability of the UTC Determination with assigned Accuracy target during the reporting period

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.

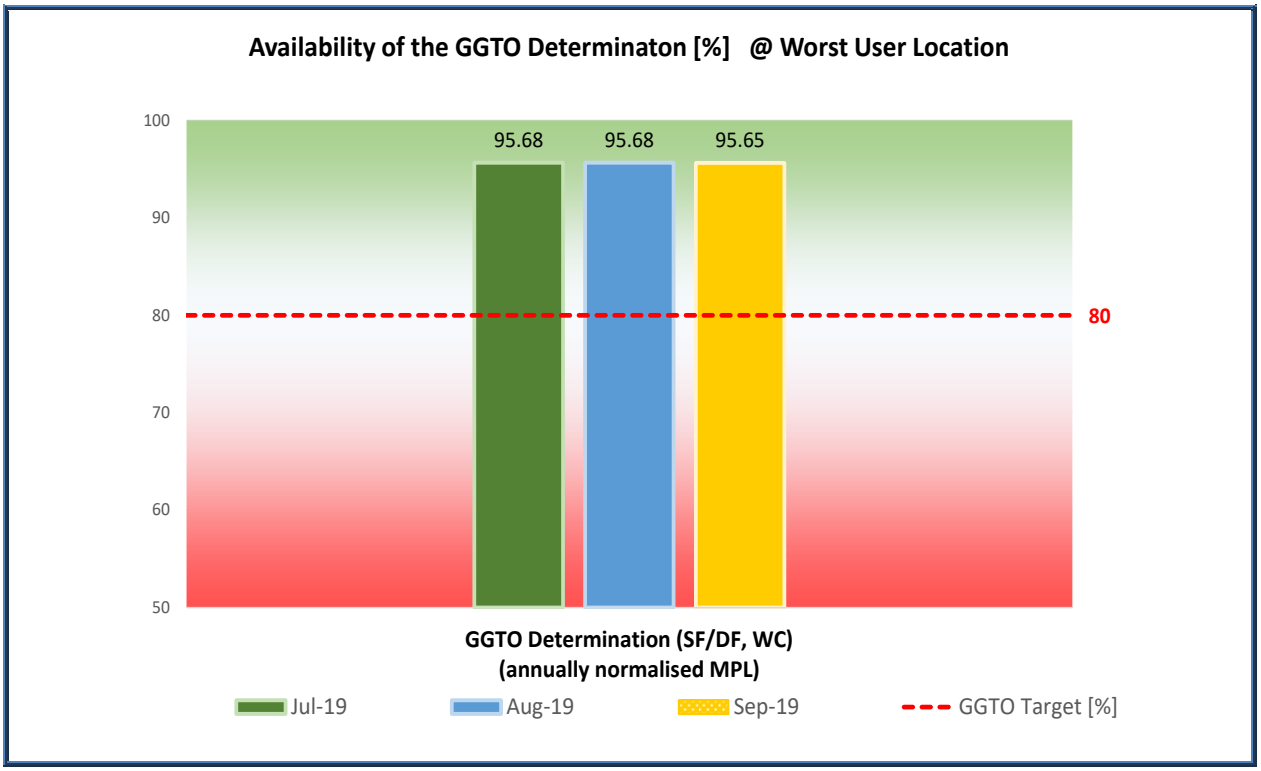


Figure 7: Annually normalised availability of the GGTO Determination, during the reporting period

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, was **78.47** % in July, (ref.: NAGUs 2019029 , 2019030 and service Incident description in Annex A), **100** % in August, and **100** % in September.

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

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.

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

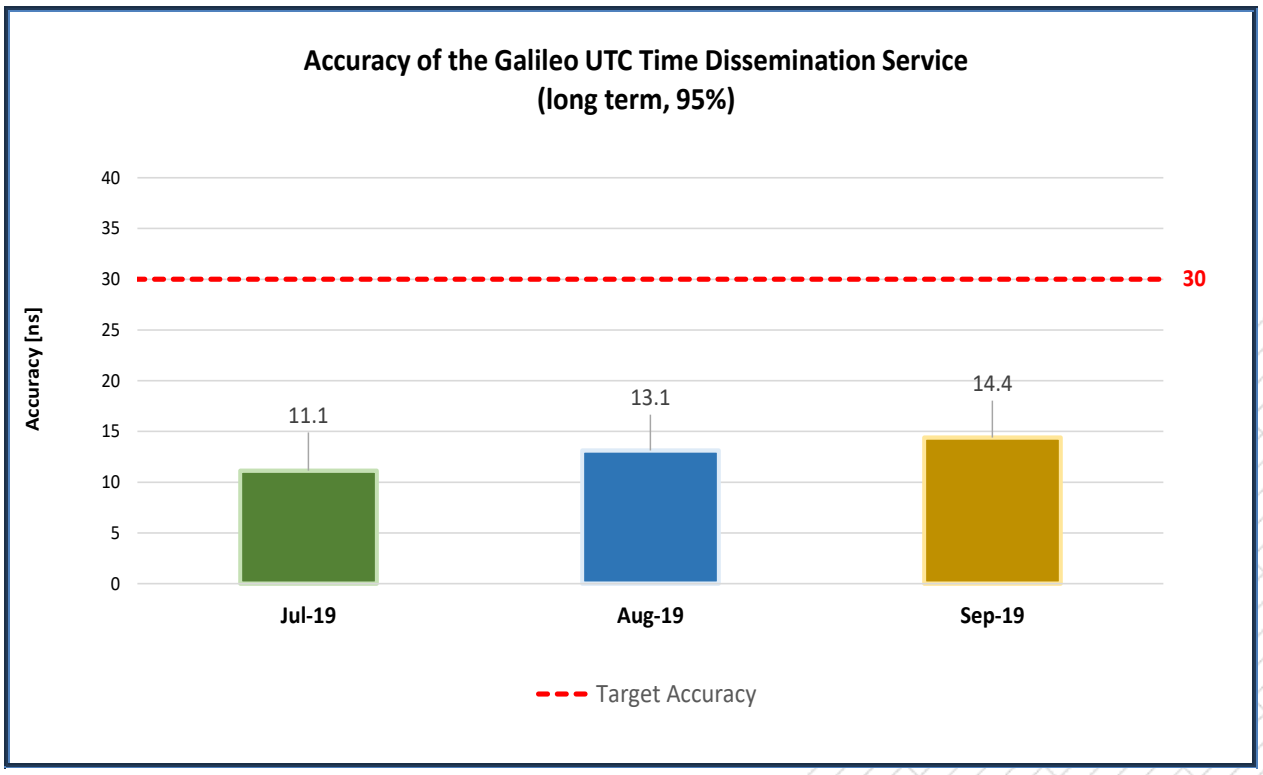


Figure 8: Long-term 95th percentile of UTC Time Dissemination Accuracy

Figure 9 shows the 95th percentile of the UTC Frequency Dissemination Accuracy, computed accumulating measurement data over the past 12 months [13].

[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

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

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 better than **14.4** [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 at most around **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, values are consistently equal to **12.9** [ns] in July, **13.5** in August and **13.7** [ns] in September; These figures are better than the [OS-SDD] MPL threshold of **20** [ns] [16].

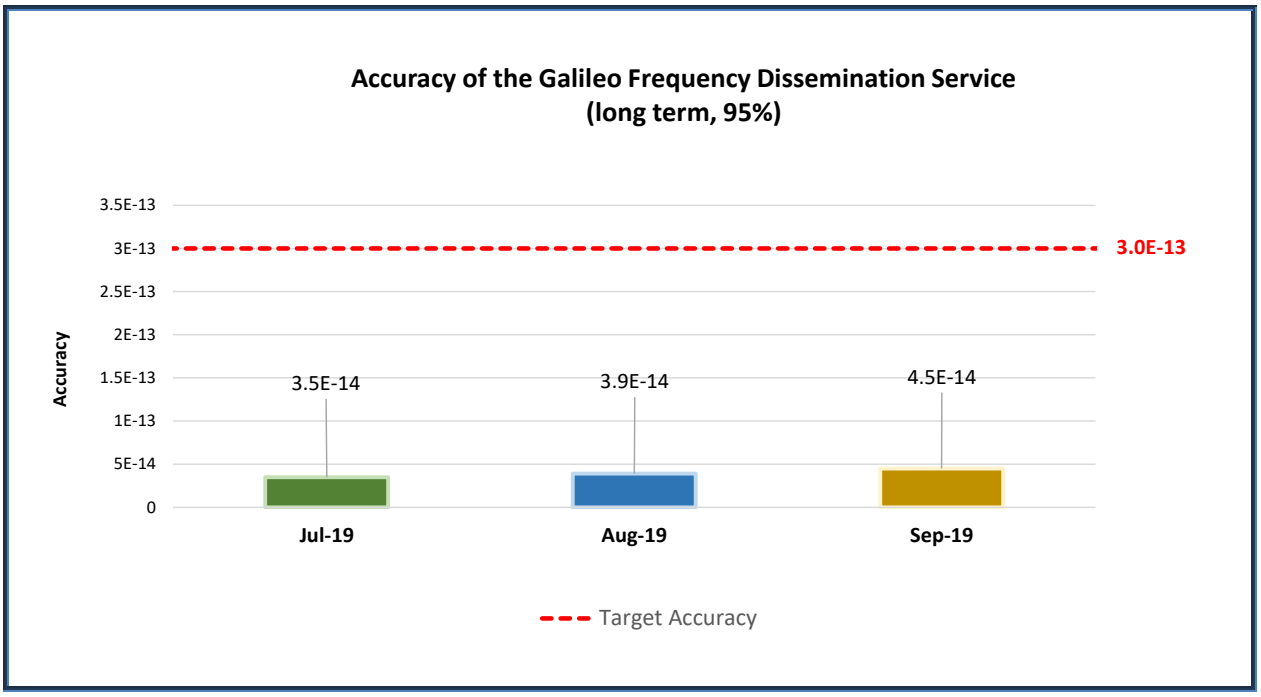


Figure 9: Long-term 95th percentile of UTC Frequency Dissemination Accuracy

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)

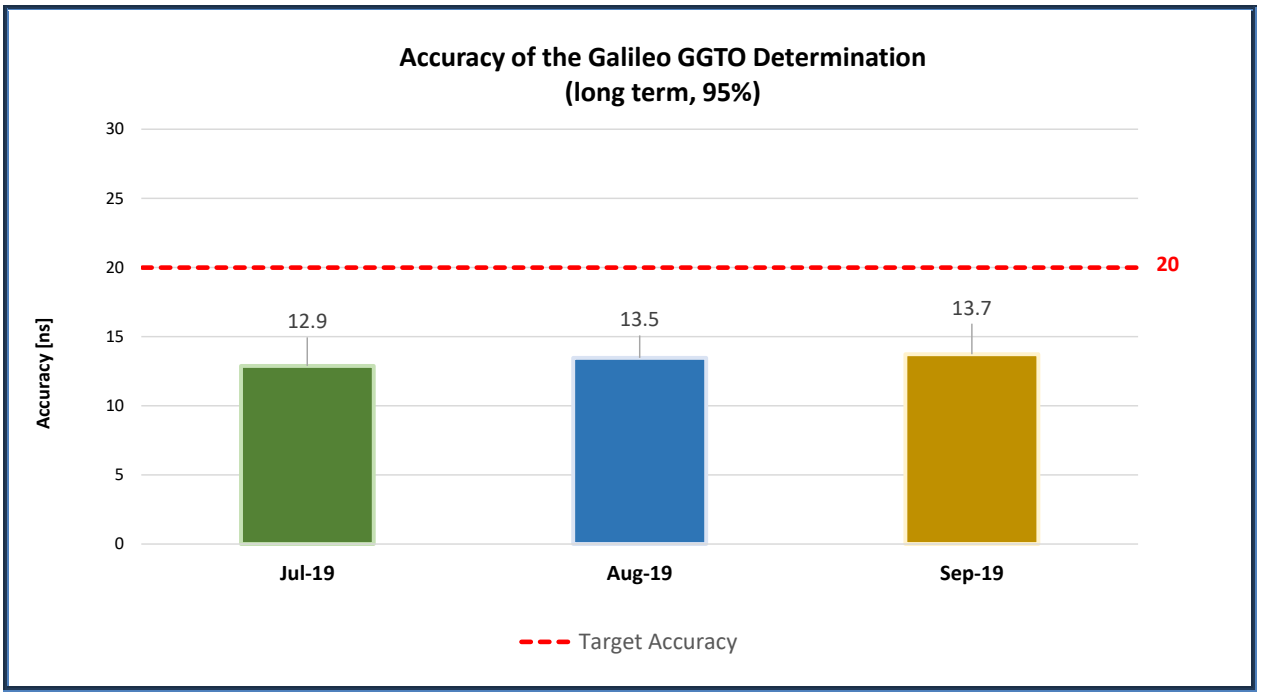


Figure 10: Long-term 95th percentile of GGTO Determination Accuracy

The slight degradation trend of timing related metrics versus previous quarter is an effect of infrastructure upgrade activities taking place during the quarter. It will be corrected by calibration in order to bring performance back to the nominal values already experienced in the past.

5 GALILEO POSITIONING PERFORMANCE

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

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

5.1 AVAILABILITY OF THE GALILEO POSITION DILUTION OF PRECISION

Applicable [OS-SDD] defines MPLs 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.

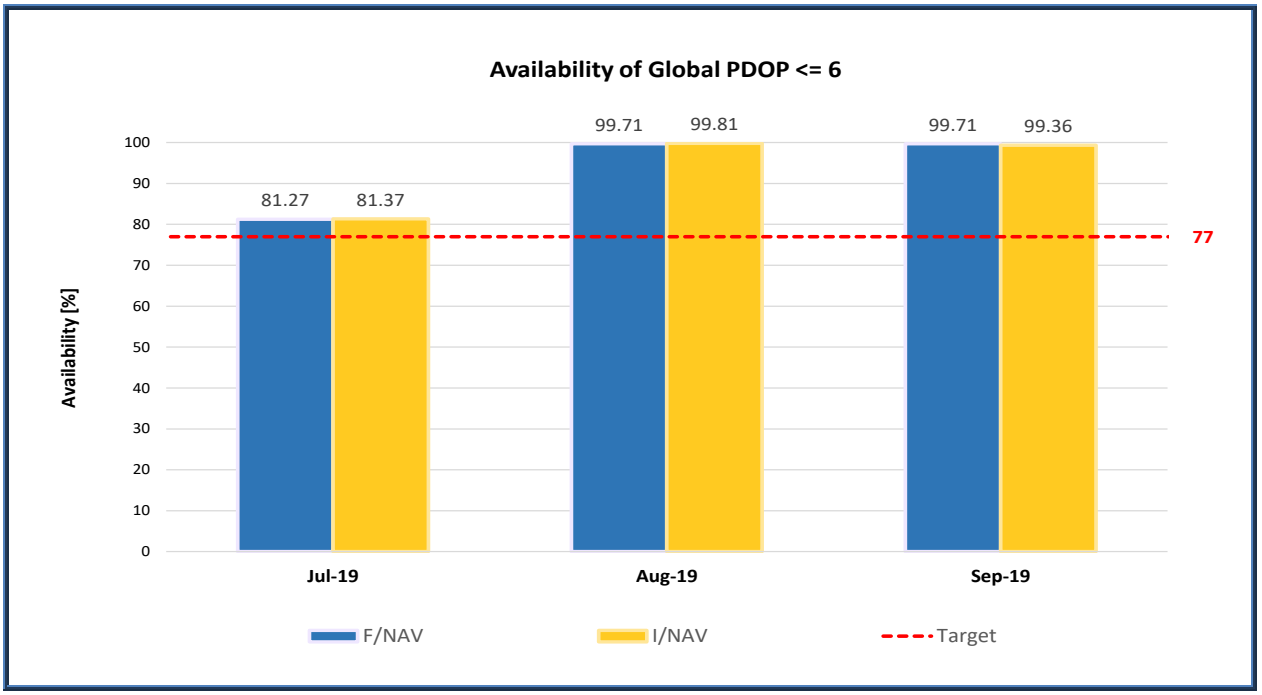


Figure 11: Monthly Global Average Availability of PDOP ≤ 6

Low availability in July is determined by the occurred Service Incident (ref.: Annex A).

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

5.2 AVAILABILITY OF THE GALILEO POSITIONING SERVICE

Applicable [OS-SDD] defines that the **Availability of Positioning**, given that location error due to system contribution, evaluated at 95%, 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). 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. Values are obtained by a Volume Analysis fed by measured input values concerning Ranging Accuracy, Orbit path and Healthy SIS Availability.

Again, low availability in July is determined by the occurred Service Incident (ref.: Annex A).

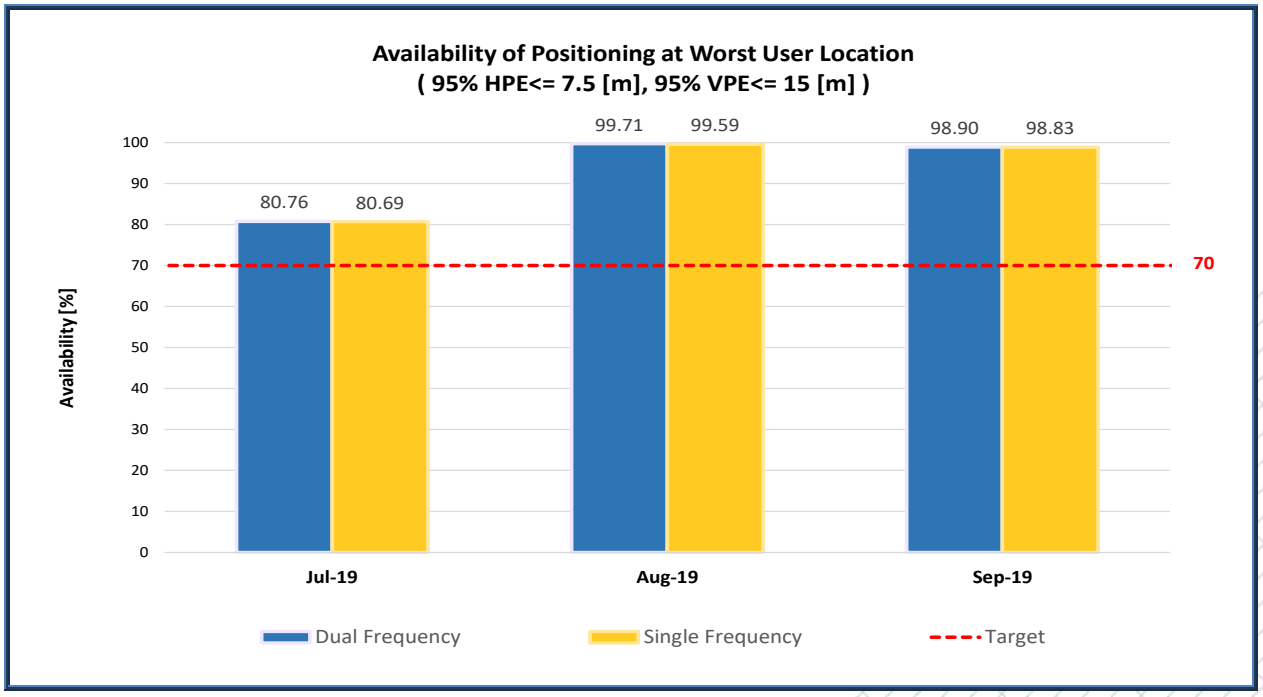


Figure 12: Availability of Positioning at Worst User Location (WUL)

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

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

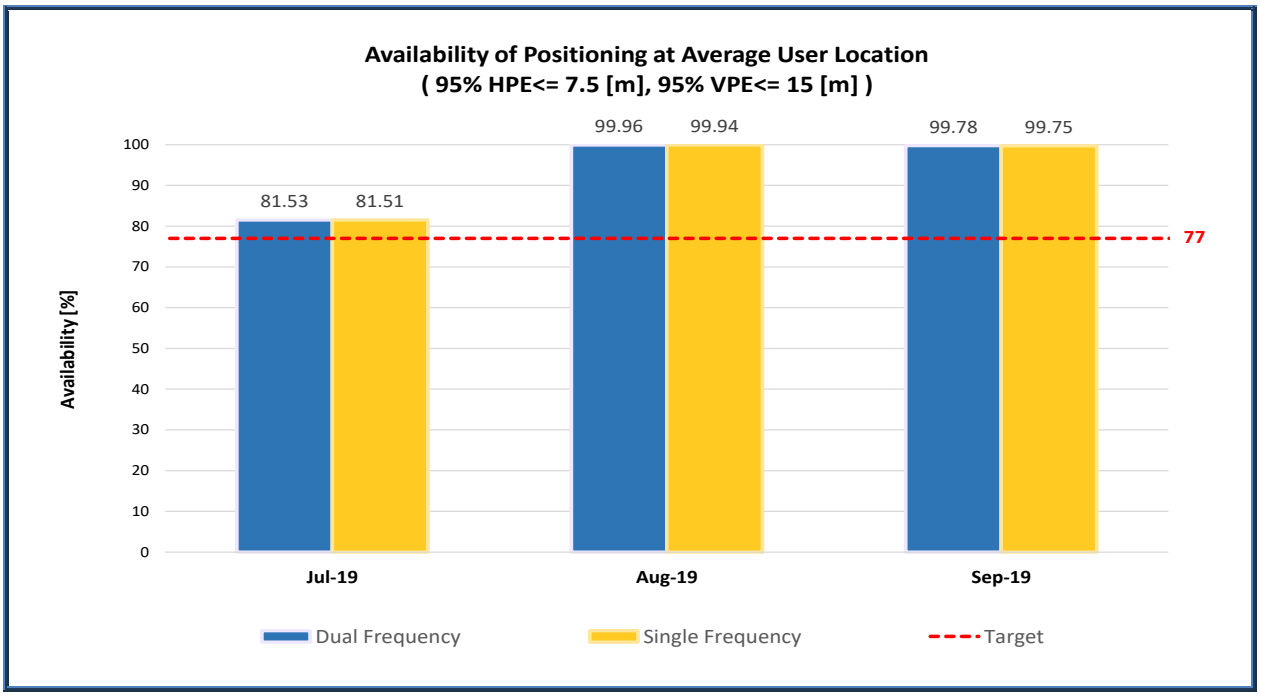


Figure 13: Availability of Positioning at Average User Location (AUL)

5.3 GALILEO MEASURED POSITIONING PERFORMANCE

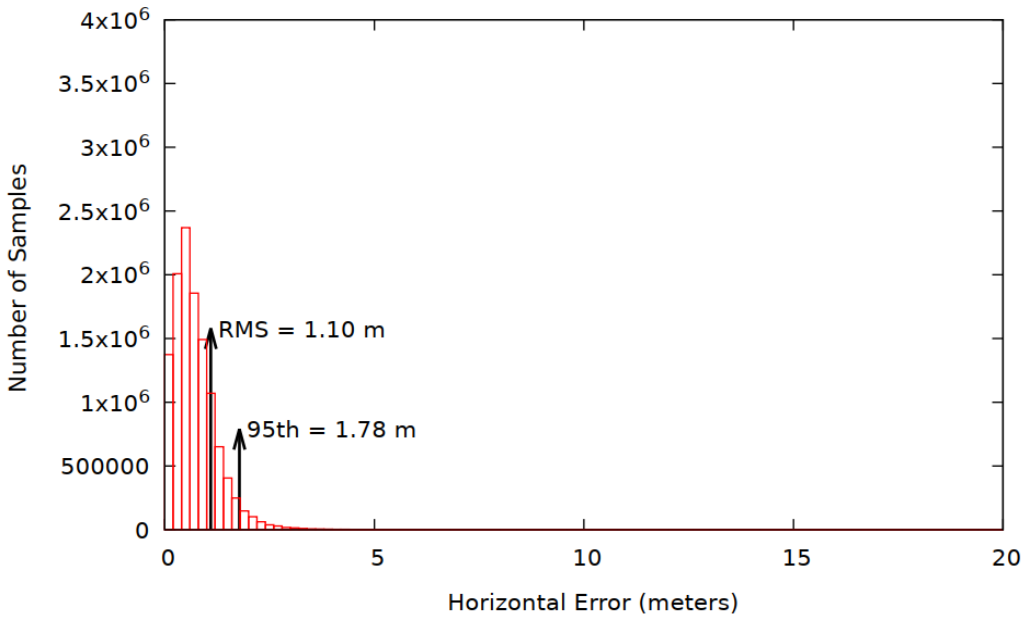
Although the Galileo FOC constellation is not yet complete, since May 2019 the 3D Positioning Service achievable with the Galileo system is subject to (%) commitment regarding the attainable Availability for given Positioning Accuracy targets, demonstrated by Volume Analyses and reported in the previous 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 about SIS health status and "Age of Ephemeris" [20]. The results include samples affected by local issues, not due to Galileo SIS, which are not actually filtered by using any automatic outliers detection.

To this aim 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.

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].

[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.

July 2019	
HPE 3D Positioning E1-E5a (DF) F/NAV	
Note: 1162 samples > 20 [m], about 0.01 %	

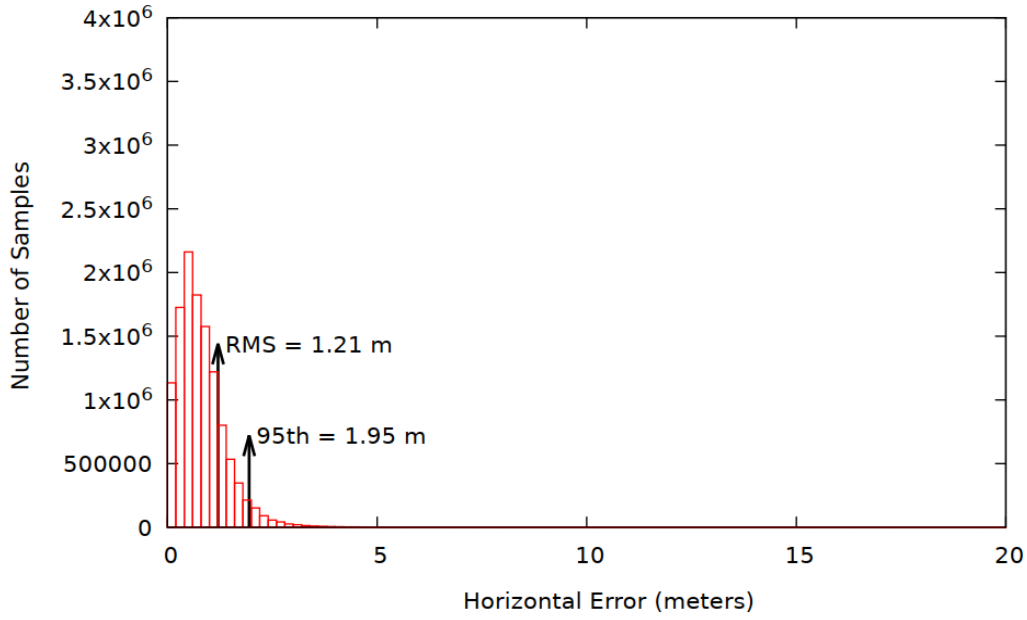
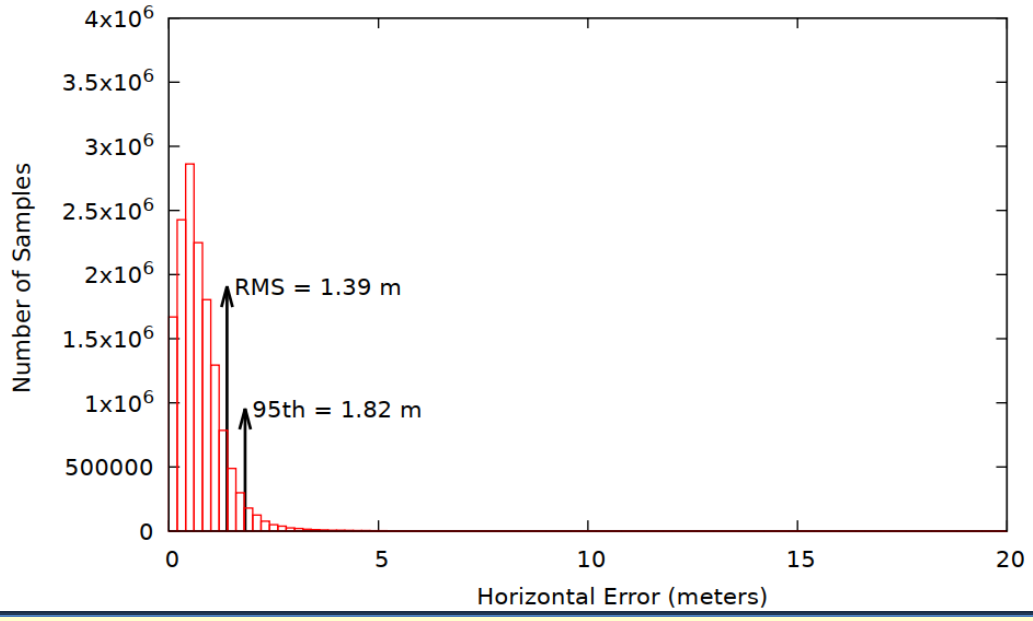
July 2019	
HPE 3D Positioning E1-E5b (DF) I/NAV	
Note: 1323 samples > 20 [m], about 0.01 %	

Figure 14: Horizontal Positioning Error (HPE) for "Galileo-only" users in July 2019

August 2019	
HPE **3D Positioning** **E1-E5a (DF)** **F/NAV**	
Note: 9019 samples > 20 [m], about 0.06 %	

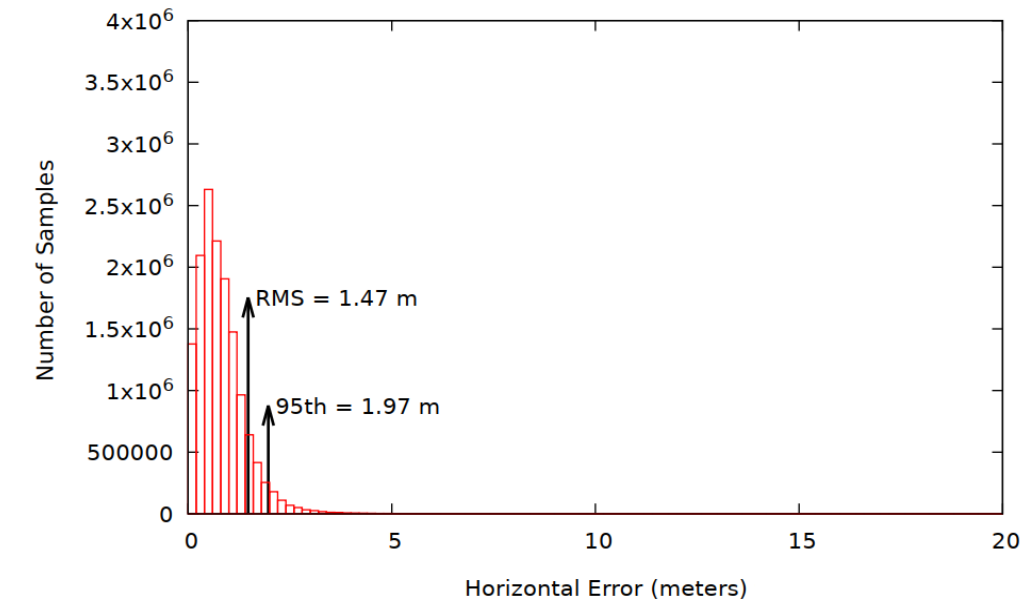
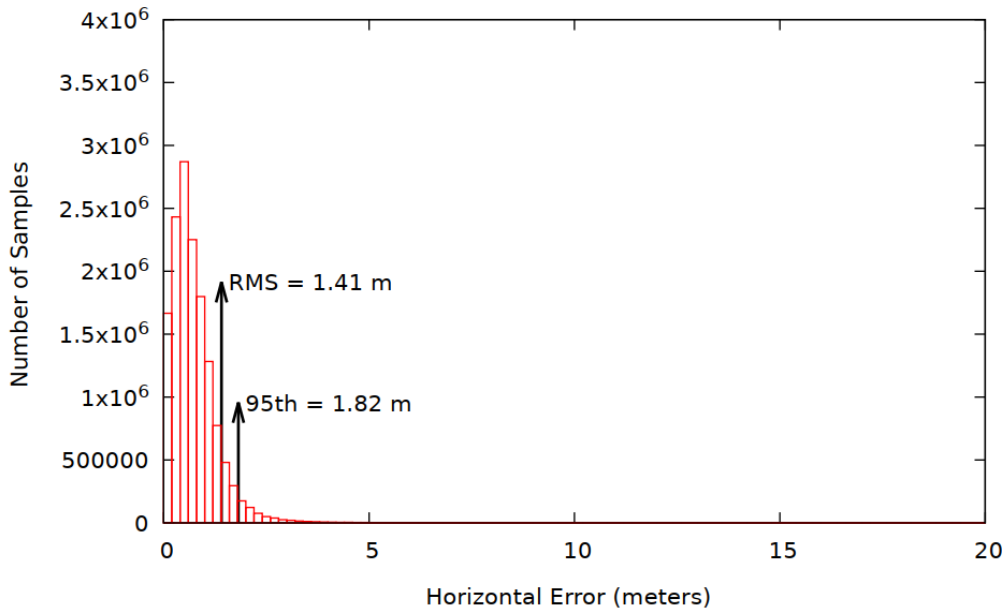
August 2019	
HPE **3D Positioning** **E1-E5b (DF)** **I/NAV**	
Note: 9365 samples > 20 [m], about 0.06 %	

Figure 15: Horizontal Positioning Error (HPE) for "Galileo-only" users in August 2019

September 2019	
HPE 3D Positioning E1-E5a (DF) F/NAV	
Note: 8807 samples > 20 [m], about 0.06 %	

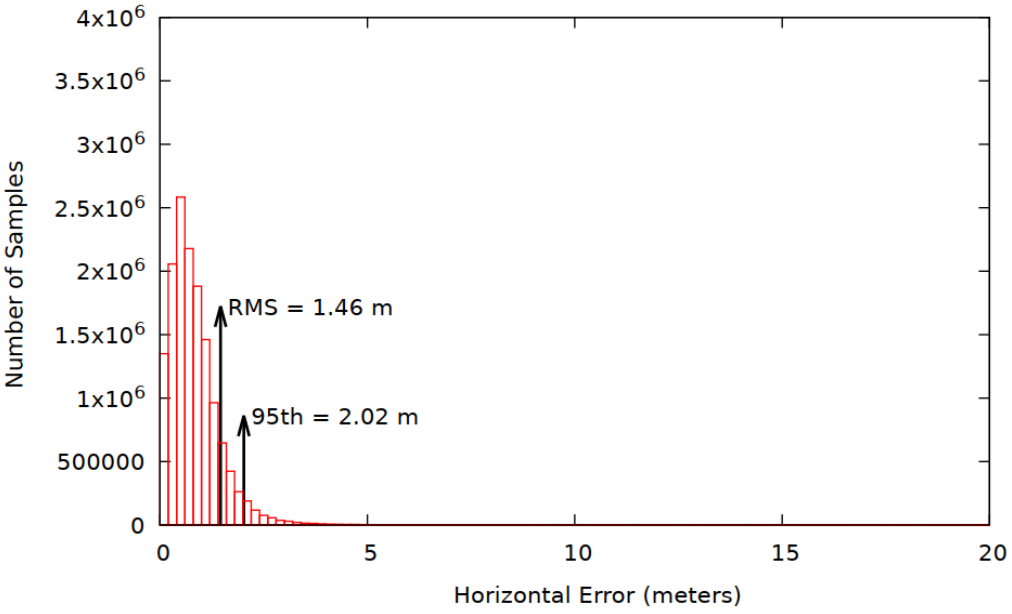
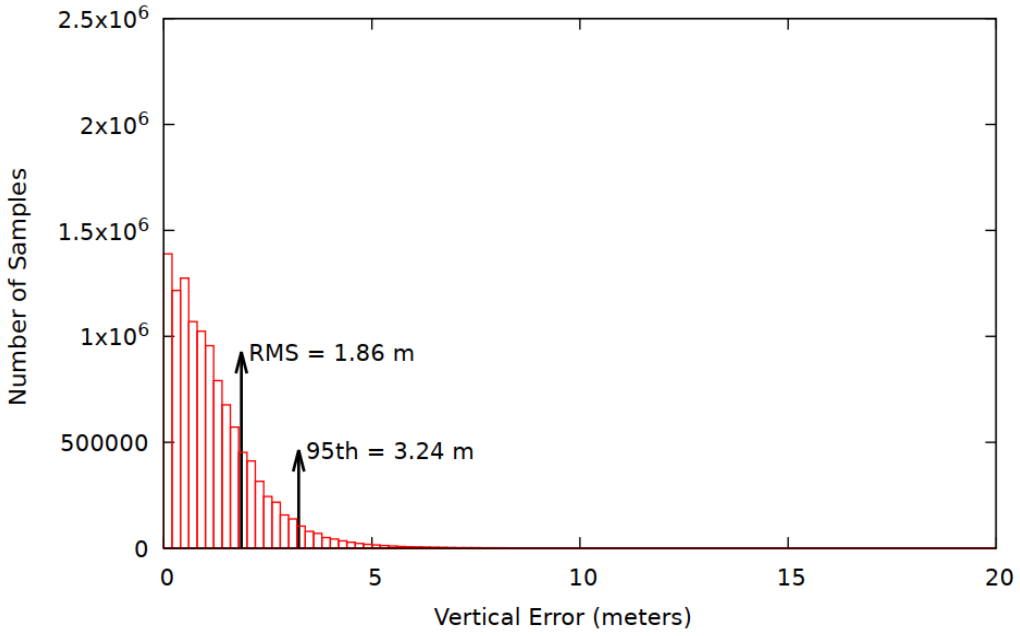
September 2019	
HPE 3D Positioning E1-E5b (DF) I/NAV	
Note: 8217 samples > 20 [m], about 0.06 %	

Figure 16: Horizontal Positioning Error (HPE) for "Galileo-only" users in September 2019

July 2019	
VPE 3D Positioning E1-E5a (DF) F/NAV	
Note: 1997 samples > 20 [m], about 0.02 %	

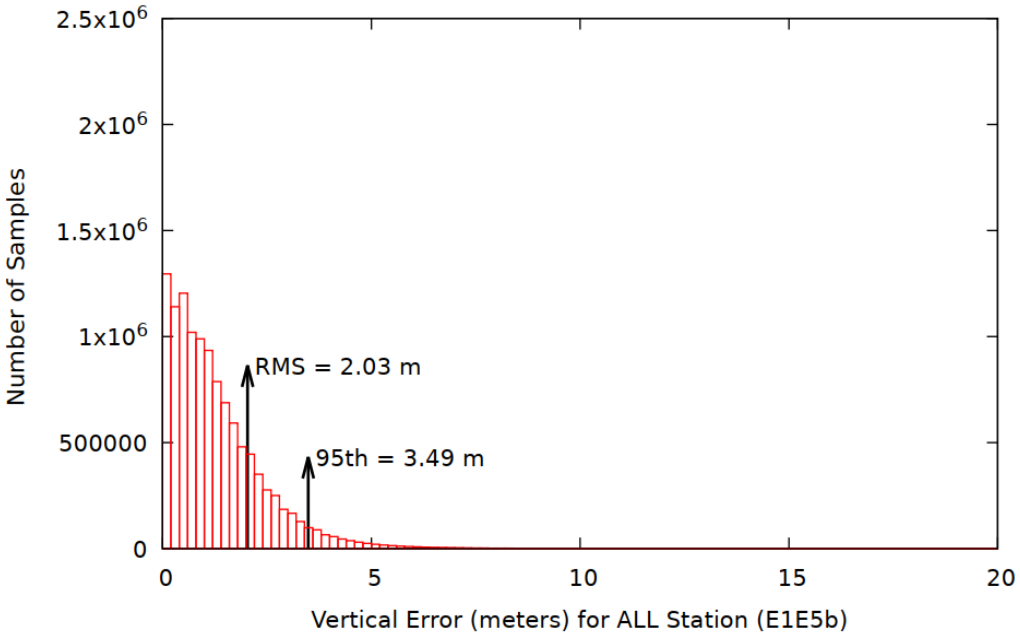
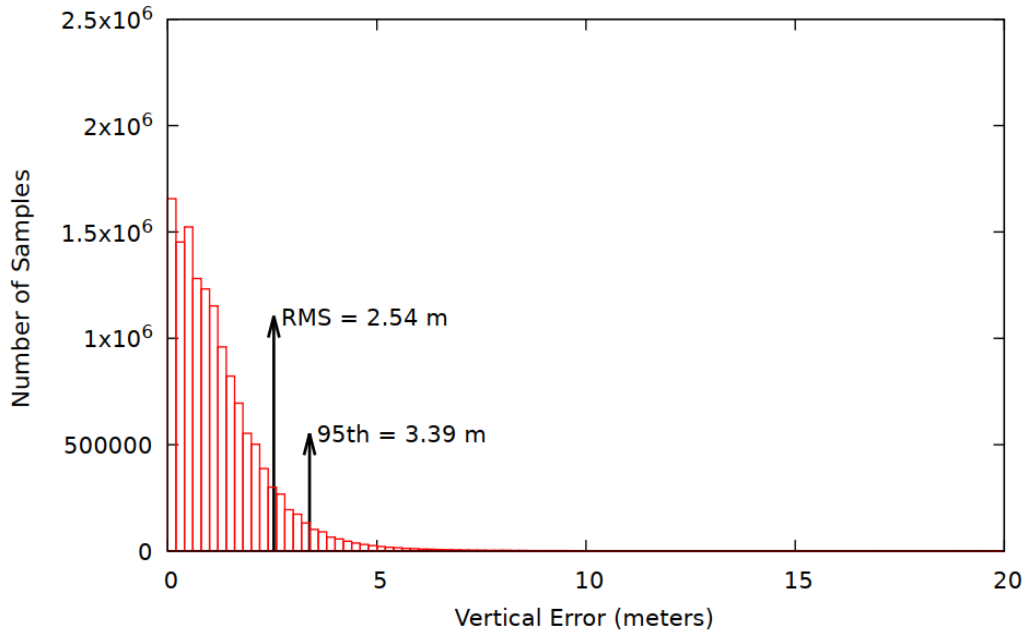
July 2019	
VPE 3D Positioning E1-E5b (DF) I/NAV	
Note: 2240 samples > 20 [m], about 0.02 %	

Figure 17: Vertical Positioning Error (VPE) for "Galileo-only" users in July 2019

August 2019	
VPE 3D Positioning E1-E5a (DF) F/NAV	
Note: 20136 samples > 20 [m], about 0.14 %	

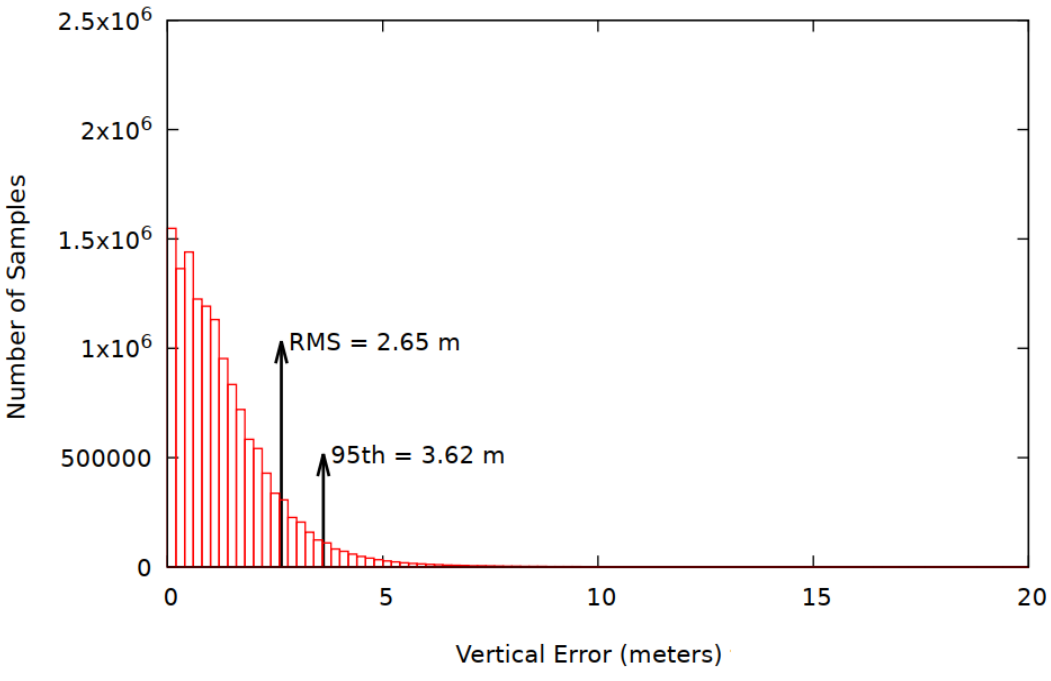
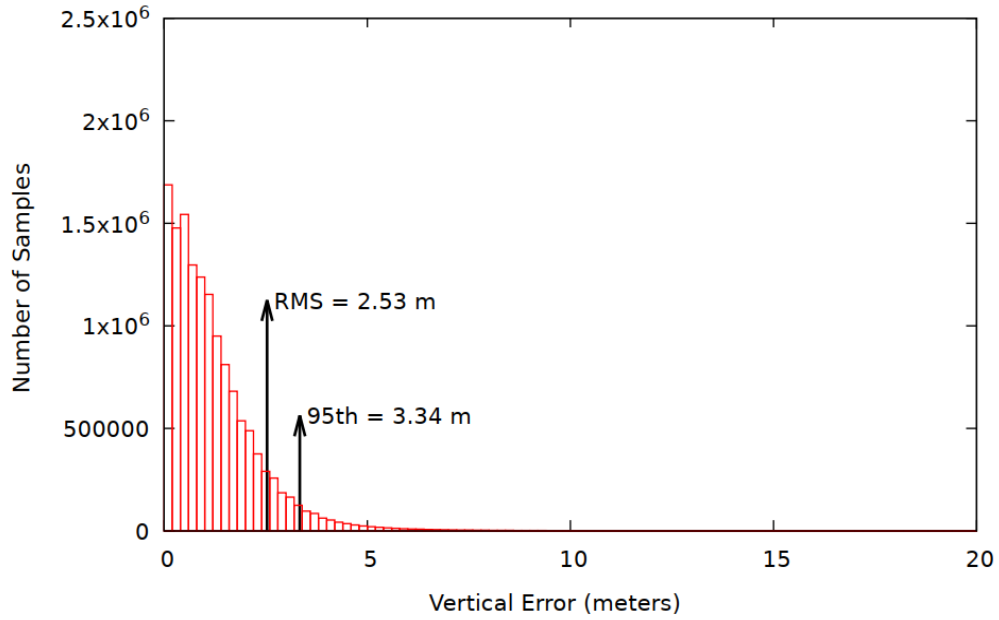
August 2019	
VPE 3D Positioning E1-E5b (DF) I/NAV	
Note: 19121 samples > 20 [m], about 0.13 %	

Figure 18: Vertical Positioning Error (VPE) for "Galileo-only" users in August 2019

September 2019	
VPE 3D Positioning E1-E5a (DF) F/NAV	
Note: 21478 samples > 20 [m], about 0.15 %	

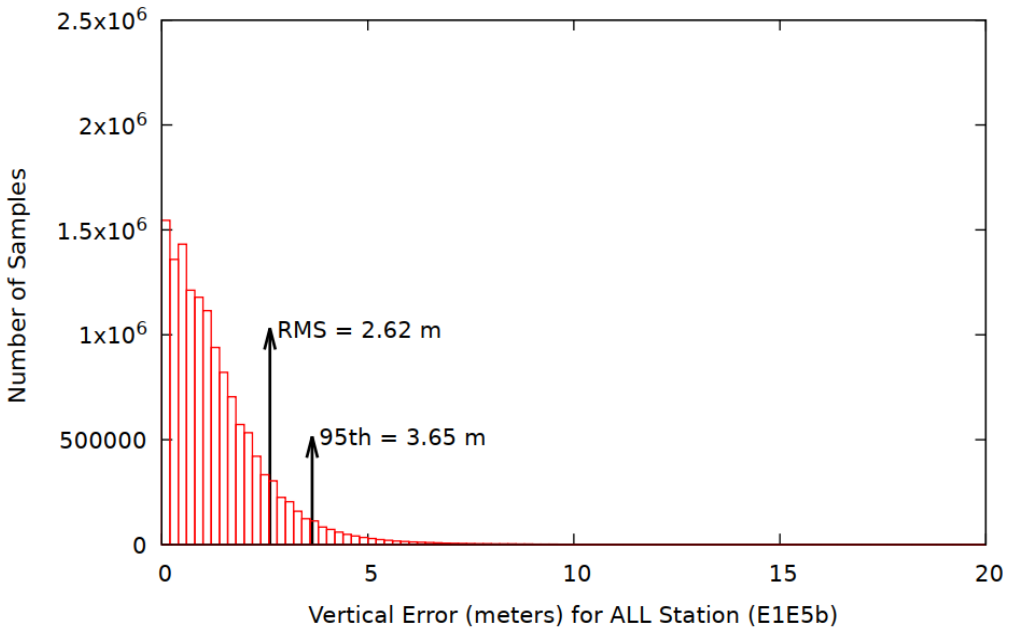
September 2019	
VPE 3D Positioning E1-E5b (DF) I/NAV	
Note: 19649 samples > 20 [m], about 0.13 %	

Figure 19: Vertical Positioning Error (VPE) for "Galileo-only" users in September 2019

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.

During the quarter, no planned NAGUs were issued. Unplanned NAGUs were published between **0.83** hours (best case) and **42.42** hours (worst case) after the related event. NAGU publication timeliness requirements were met with large margins.

The summary of NAGUs that have been published during the reporting period is as follows:

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

Month	NAGU Type	Reason for publishing	Notice Advisory ID	Categorisation
July	GENERAL	Announcing Galileo Navigation Service degradation until further notice, involving all Galileo satellites, starting from 11/07/2019 @ 01:00 UTC	2019025	U
	GENERAL	Declaring Galileo service outage and indicating "don't use" for (all) constellation signals from 12/07/2019 @ 01:50 UTC.	2019026	U
	GENERAL	Announcing Galileo service restoring, with potential instabilities, starting from 17/07/2019 @ 20:52 UTC.	2019027	U
	GENERAL	Announcing Galileo service finally re-established starting from 22/07/2019 @ 17:00 UTC	2019028	U
	GENERAL	Warning about unavailability of GGTO, with dissemination of "dummy" parameters starting from 27/07/2019 @ 12:51 UTC	2019029	U
	GENERAL	Announcing valid GGTO dissemination parameters available again starting from 28/07/2019 @ 13:17 UTC	2019030	U
August	UNP_SHTRCVR	Reporting about a short term outage on Galileo satellite GSAT-0218 (E31), starting 14/08/2019 @ 06:39 UTC, recovered in a few hours. This event was operationally planned but –according to the rules–, as far as healthy SIS unavailability occurred over a short time, service outage was communicated "a posteriori" and NAGU is to be considered "Unplanned	2019031	U
September	No NAGU was published in September 2019			
NAGU Categorisation for timeliness evaluation: "P" = Planned, "U" = Unplanned				

Table 6: NAGUs published during 3rd Quarter 2019

7 REFERENCES

This section identifies the documents explicitly referenced in this Galileo Initial 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.

Previous documents are made available to users through the web portal of the European GNSS Service Centre (http://www.gsc-europa.eu/), exception made for the Issue 1.0 of 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.
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
SDD	Service Definition Document
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

Annex A July Service Incident

On July 10th 2019, Galileo was affected by a technical incident related to its ground infrastructure, which resulted in an interruption of the Galileo initial navigation and timing services.

The technical issue was solely related to the ground infrastructure in the Galileo control centres, not to the Galileo satellites. The incident impacted the time and orbit determination function. It was caused by a series of unrelated events that impacted the synchronisation of elements of the Galileo ground system. It prevented the correct generation of navigation messages and as a result there was no uplink to the entire Galileo constellation. Consequently, the services were declared unusable.

The incident occurred while the system was undergoing a major upgrade aimed at increasing robustness and resilience of the system, including security aspects, before reaching Full Operational Capability. During this upgrade, the nominal redundancy between the Control Centres was not available.

The incident was caused by a combination of events that occurred quasi-simultaneously and independently, in a context of temporary limitation of redundancy due to the upgrade of the Galileo Control Centres, and that occurred in a short time sequence, leading to a complex failure propagation mechanism.

The recovery of Galileo initial services took six days due to a combination of factors:

- A comprehensive analysis of system data logs was necessary in order to understand the complex sequence of events.
- Analysis of the data logs allowed understanding the cause of the incident but the system convergence capacity had already elapsed.
- The temporary limitation of system redundancy due to the ongoing major upgrade, which limited the convergence capacity of the system.

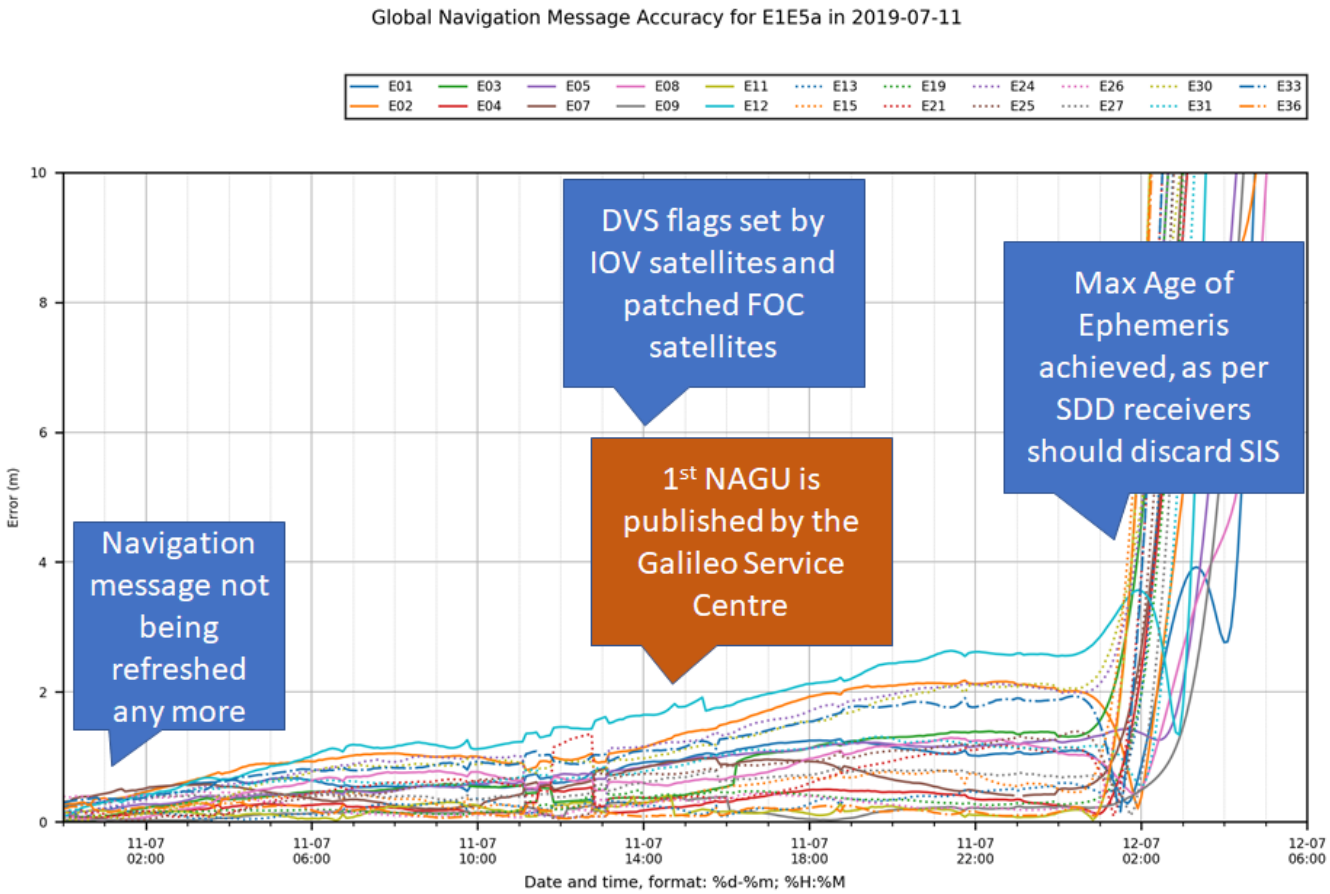


Figure 20: Evolution of Ranging Accuracy and main SIS health status related events

The European Commission set up an independent Inquiry Board in September 2019 to analyse the root causes of the incident and provide recommendations. The Board was composed of high-level members and experts with proven track records in complex operational projects, in the transport and defence sectors.

The Board delivered its final recommendations to the European Commission at the beginning of November, to be put into operation at programme and service provision management level.

At the time of publication of this report, the Galileo programme has developed an initial action plan for the implementation of the Board's recommendations, with several of them being already accomplished.

End of Document

European GNSS Service Centre:

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