NAVIGATION
SOLUTIONS
POWERED
BY EUROPE

EUROPEAN GNSS (GALILEO) INITIAL SERVICES

OPEN SERVICE

QUARTERLY PERFORMANCE REPORT

APRIL - JUNE 2019

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

This document is the *Galileo Initial Open Service (IS OS) Public Performance Report* for the period of April, May and June 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 new edition of the Open Service – Service Definition Document [OS-SDD], v1.1, published on the GSC web portal in 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 three subsections: "Availability of the Galileo SF/DF Ranging Service", "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.

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

Section 7: The cited reference documents are listed.

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"

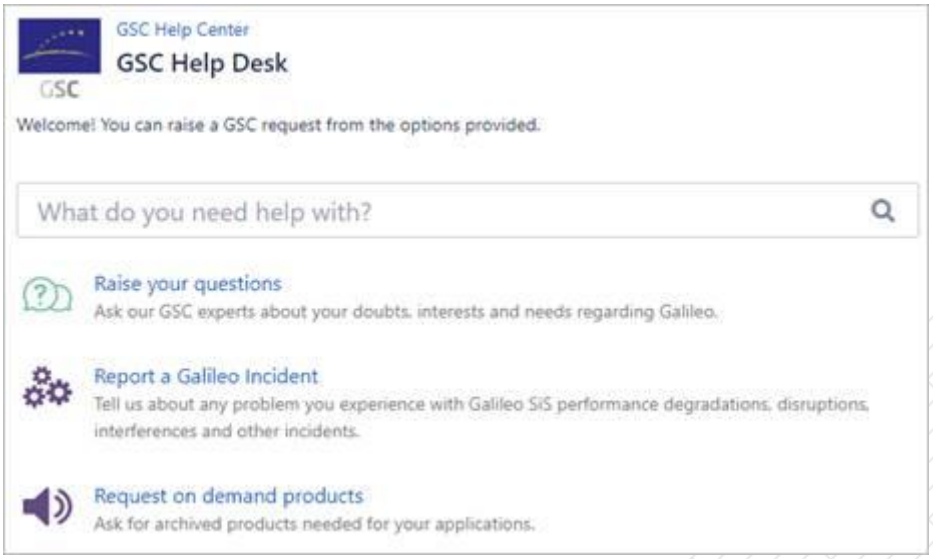


Table 2: GSC main information web pages for Galileo status

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 timely 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], generally with significant margins. The following dashboards summarise the compliance with MPLs, using the colour coding defined in the legend below:

OS MPLs	Target Value	Space Vehicle		Apr-19					May-19					Jun-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	Apr-19	May-19	Jun-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				
		Ranging Service	SF / DF Worst Case @ WUL	≥ 87%			
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)

Availability of the Galileo Ranging Service at the Worst User Location (WUL) was **100**% during April, against the MPL target of **87%**. This metric was superseded by new ones related to positioning since May 2019, and therefore its status is no longer reported in the dashboard after April.

The "per-slot" **Availability of a Healthy Signal**, with average monthly values greater than **98.7**% for every Single-Frequency (E1-B, E5a, E5b) and Dual-Frequency combination (E1/E5a, E1/E5b), is also 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 **0.20** [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 **0.15** [m] to **0.59** [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 **0.38** [m] for Single Frequency signals and **0.31** [m] for Dual Frequency signal combinations. The specified MPL threshold of **2** [m] is therefore achieved. Note that the computation method has been slightly modified according to the [OS-SDD] published in May 2019, from an arithmetic average of the per-satellite individual ranging accuracy monthly statistics to a computation in which ranging accuracy samples of all satellites are averaged over each calculation epoch before obtaining monthly statistics, providing a better characterisation of the constellation average performance.

Concerning the **UTC Time related Service**, we now distinguish between **Availability of the Dissemination** and **Availability of Determination with a given Accuracy** (i.e.: better than 31 [ns]). In both cases, metrics had a monthly value of **100**% during the entire quarterly reporting period**,** greatly exceeding the [OS-SDD] MPL targets of **87%**.

The **Availability of GGTO Determination** was **96.91**% in April, **96.65**% in May and **97.48**% May. 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** (≤ **9 [ns]**), the **UTC Frequency Dissemination Service Accuracy** (normalised offset ≤ $\mathbf{3.2\times10^{-14}}$) and the **GGTO Determination Accuracy** (≤ **10.4** [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.

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

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

With the publication of the new [OS-SDD], for the first time, the monthly metrics related to 2D Positioning (i.e.: the **Availability of HDOP ≤ 5** and the **Availability of Galileo Horizontal Positioning better than 10 [m]**) have been replaced by the new [OS-SDD] commitments related to a full **3D Positioning Service**. These are provided hereafter.

Availability of Global PDOP ≤ 6 was at least **99.6**% in April, **99.58**% in May and **99.77**% in June, 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 April, at least **99.22**% at Worst User Location (WUL) and **99.85**% at Average User Location (AUL);
- in May, at least **99.42**% at WUL and **99.90**% at AUL;
- in June, at least **99.44**% at WUL and **99.94**% at AUL.

The target MPL values are **70**% at WUL and **77%** at AUL. The new commitments are consistent with the deployment status of the Galileo constellation during the reporting period, which currently includes 22 space vehicles (since February 11th, 2019).

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 **1.89** [m] and **3.46** [m] respectively during the reporting period, as measured by the GSA network of reference receivers. The corresponding RMS values are **1.42** [m] and **2.60** [m].

In line with the [OS-SDD], no MPL is directly applicable to HPE and VPE in-field measured values.

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:

- ◊ Availability of the Galileo SF/DF Ranging Service;
- ◊ Per-slot Availability of HEALTHY Signal in Space;
- ◊ Galileo Signal in Space Ranging Accuracy.

3.1 AVAILABILITY OF THE GALILEO SF/DF RANGING SERVICE

The Availability of the Galileo SF/DF Ranging Service is computed at any user location as the percentage of time that the user is provided with at least one HEALTHY[4] Galileo Open Service (OS) Signal in Space (SiS). This information is released for the last time in this quarterly report, as the metric is made obsolete by the current [OS-SDD] in favour of new performance parameters addressing the 3D Positioning Service. The following figure shows the monthly availabilities of the Galileo Single Frequency (SF) and Dual Frequency (DF) Ranging Services at the Worst User Location (WUL) within the Navigation Service coverage area:

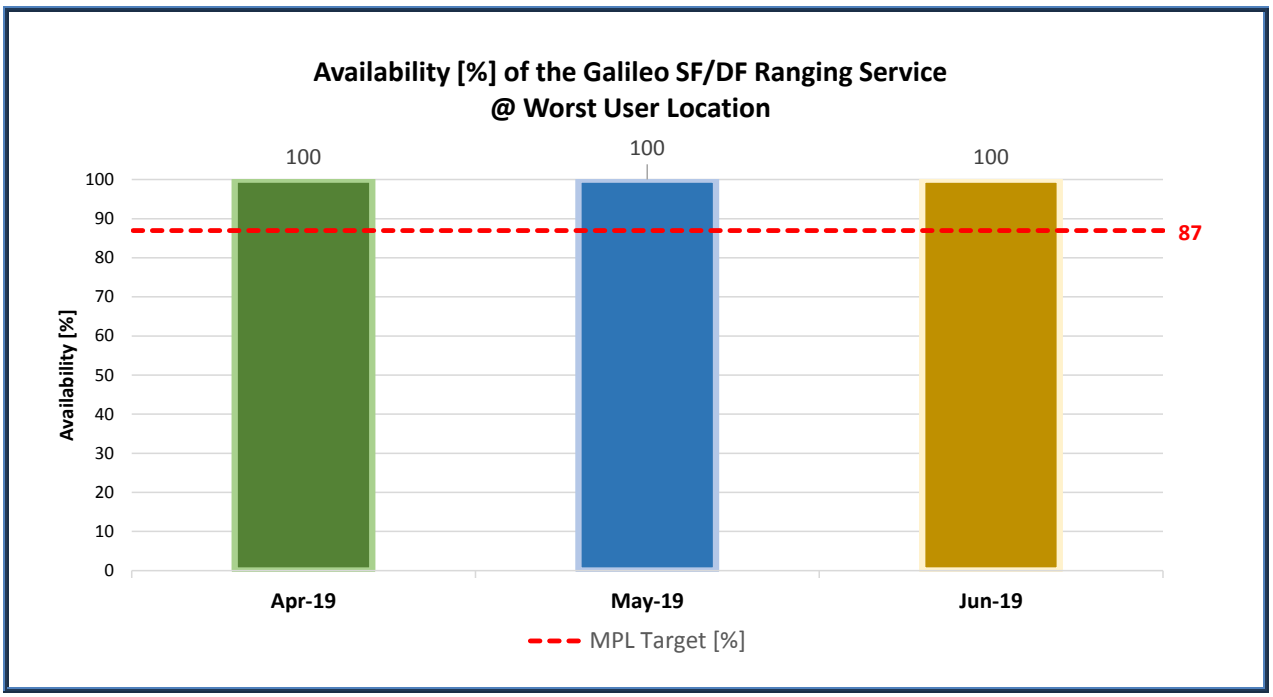


Figure 1: Monthly Availability of the Galileo SF/DF Ranging Service

4 HEALTHY Galileo Open Signal in Space is defined in [OS-SDD] .

The availability of the Galileo Single Frequency and Dual Frequency Ranging Service is **100**% during all three months, exceeding the Minimum Performance Level prescribed by the old [OS-SDD], which was specified as **87**% [5] .

3.2 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 HEALTHY [4] Galileo Open Service Signals in Space.

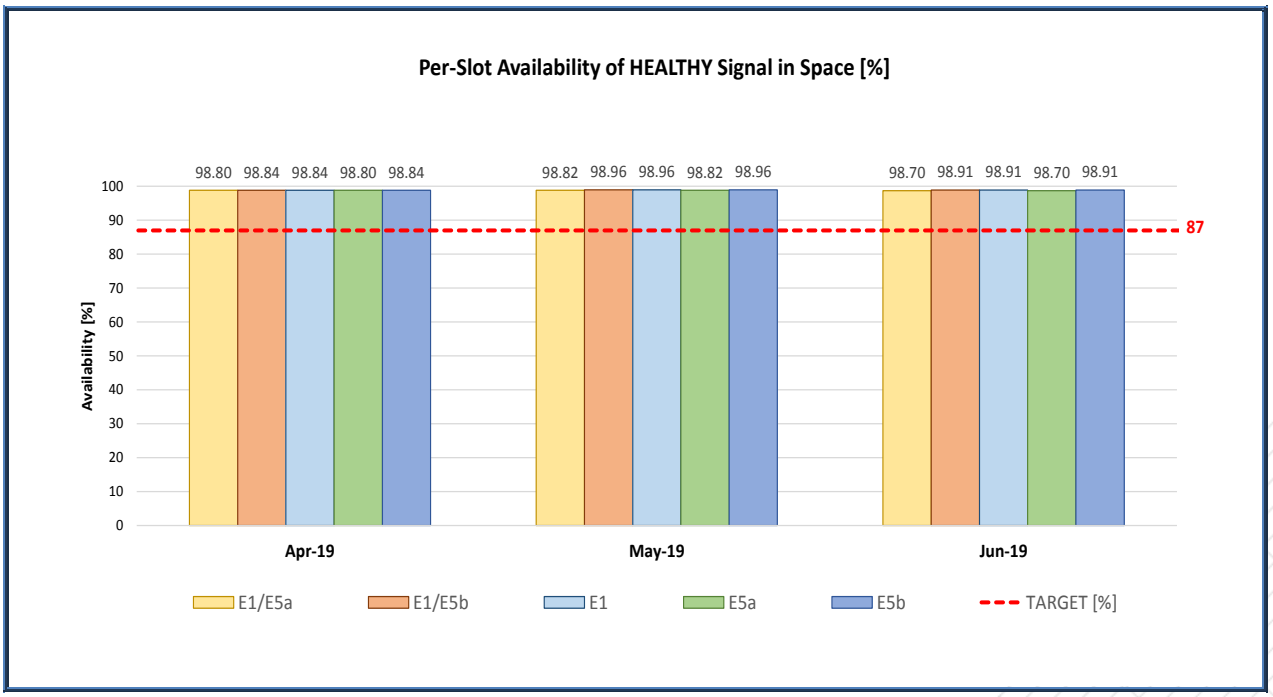


Figure 2: "Per-Slot" availability of HEALTHY Signal in Space for the reporting period

Figure 2 provides the Signal in Space "per slot" availability of Galileo HEALTHY Signals in Space, averaged over the entire constellation during 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.

---

5 Ref.: [OS-SDD] issue 1.0, §3.5.2 (Table 15) and §3.5.3 (Table 16)

6 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.

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

The achieved performance is between **98.70**% (F/NAV, June) and **98.96**% (I/NAV, May).

The availability of Galileo HEALTHY SIS, evaluated individually per frequency combination, satellite and month (without annual normalisation), was between **71.41**% and **100**%, where the lower value was due to a planned maintenance affecting GSAT-0218 (E31) in April.

3.3 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 3 and Figure 4, the 95% metric applied to the Galileo Signal in Space Ranging Accuracy "for any space vehicle", over all satellites[8] and frequency combinations, is:

- for individual space vehicles in **April**, between **0.19 [m]** and **0.59** [m] for Dual Frequency, and between **0.24** [m] and **0.56** [m] for Single Frequency;
- for individual space vehicles in **May**, between **0.19** [m] and **0.57** [m] for Dual Frequency, and between **0.25** [m] and **0.59** [m] for Single Frequency;
- for individual space vehicles in **June**, between **0.15** [m] and **0.32** [m] for Dual Frequency, and between **0.20** [m] and **0.57** [m] for Single Frequency.

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

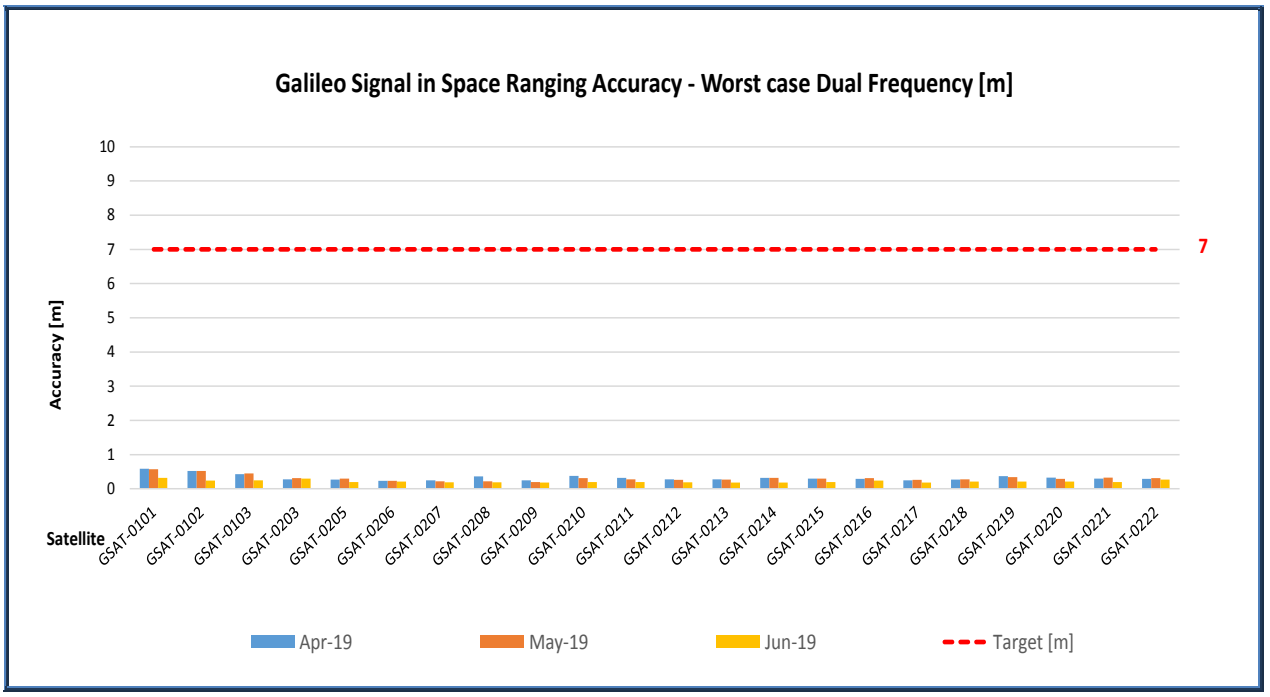


Figure 3: Monthly Galileo SIS Ranging Accuracy (95th percentile) "for any satellite", measured during reporting period for worst-case, Dual-Frequency (DF)

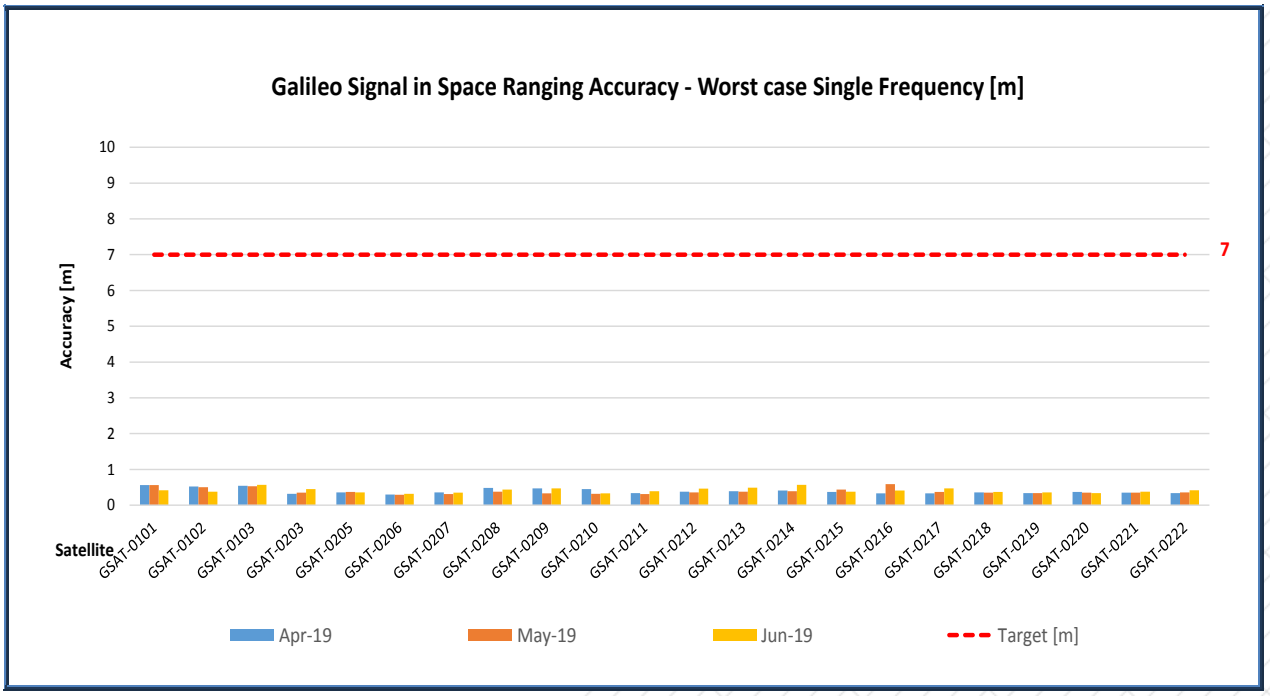


Figure 4: Monthly Galileo SIS Ranging Accuracy (95th percentile) "for any satellite", measured during the reporting period for worst-case, Single-Frequency (SF)

Compliance with the MPL in [OS-SDD] is always achieved, with a specified maximum threshold of **7** [m] [9] for the monthly performance of each individual satellite.

Figure 5 depicts the average "over all satellites" (constellation mean). Again, the [OS-SDD] MPL target of **2** [m] [10] is met by the Constellation average value.

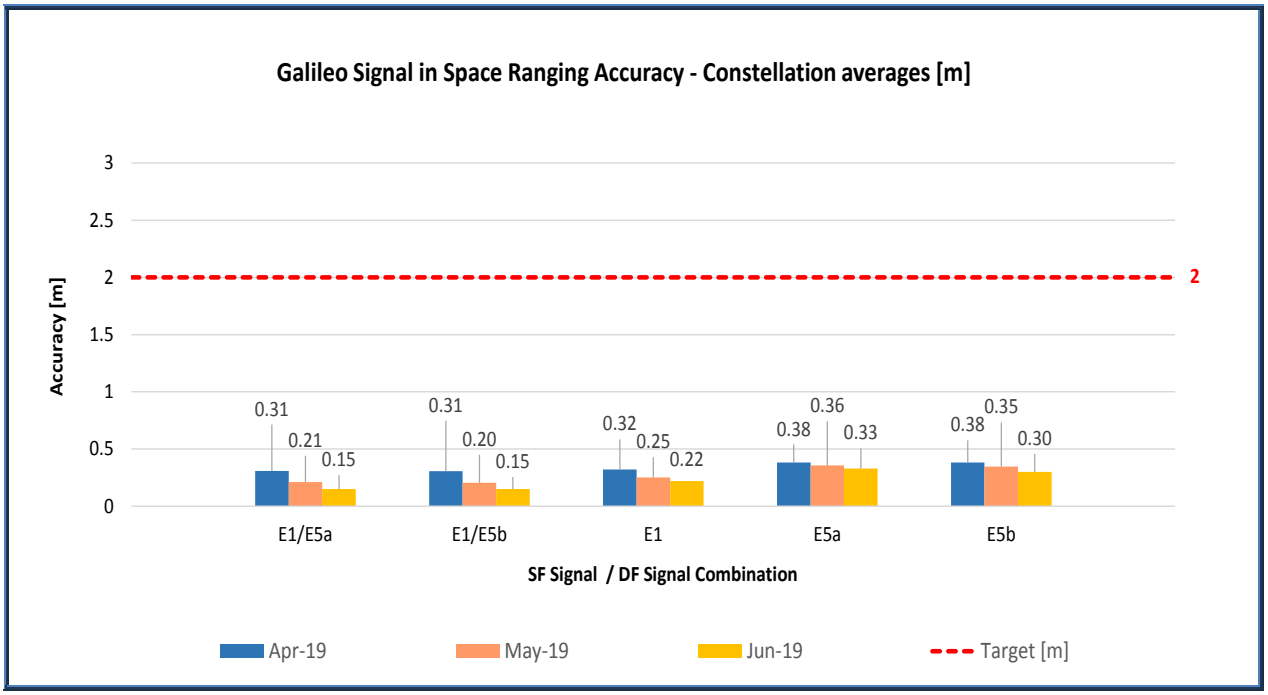


Figure 5: Monthly Galileo SIS Ranging Accuracy (95th percentile) "over all satellites" (constellation average), measured during the reporting period

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

10 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**) **Dissemination Service** is defined as the percentage of time that the system provides at least one HEALTHY [4] ranging/timing Signal in Space above a minimum elevation angle of 5 degrees. Figure 6 provides the Worst User Location (WUL) Availability of such service, computed for a virtual grid of user positions over the service coverage area.

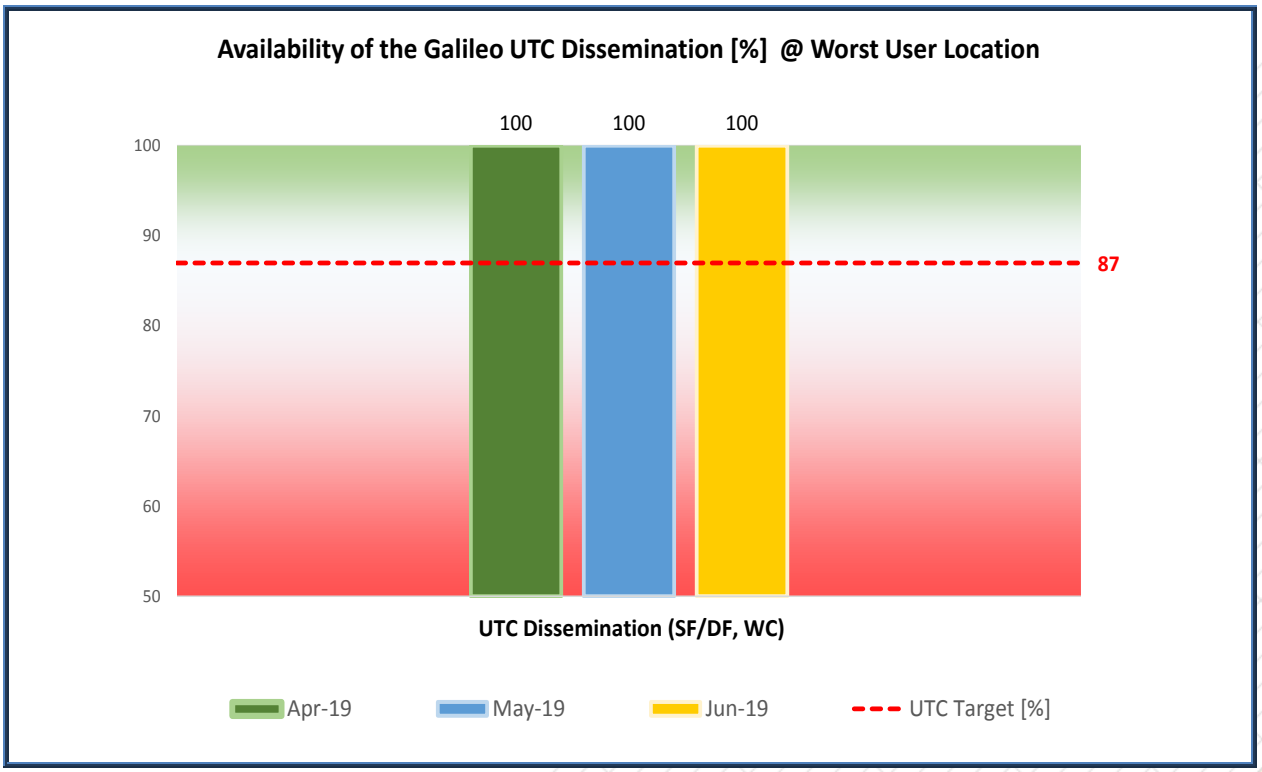


Figure 6: Monthly availability of the UTC Dissemination Service during the reporting period

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

The MPL of **87%** [11] specified by [OS-SDD] for the long term is therefore fully achieved.

As already mentioned, a new metric and commitment concerns the **Availability of UTC Determination** with the assigned accuracy threshold of 31 [ns]. Results for the observation period are given in Figure 7, with a required percentage of success of at least **87**%:

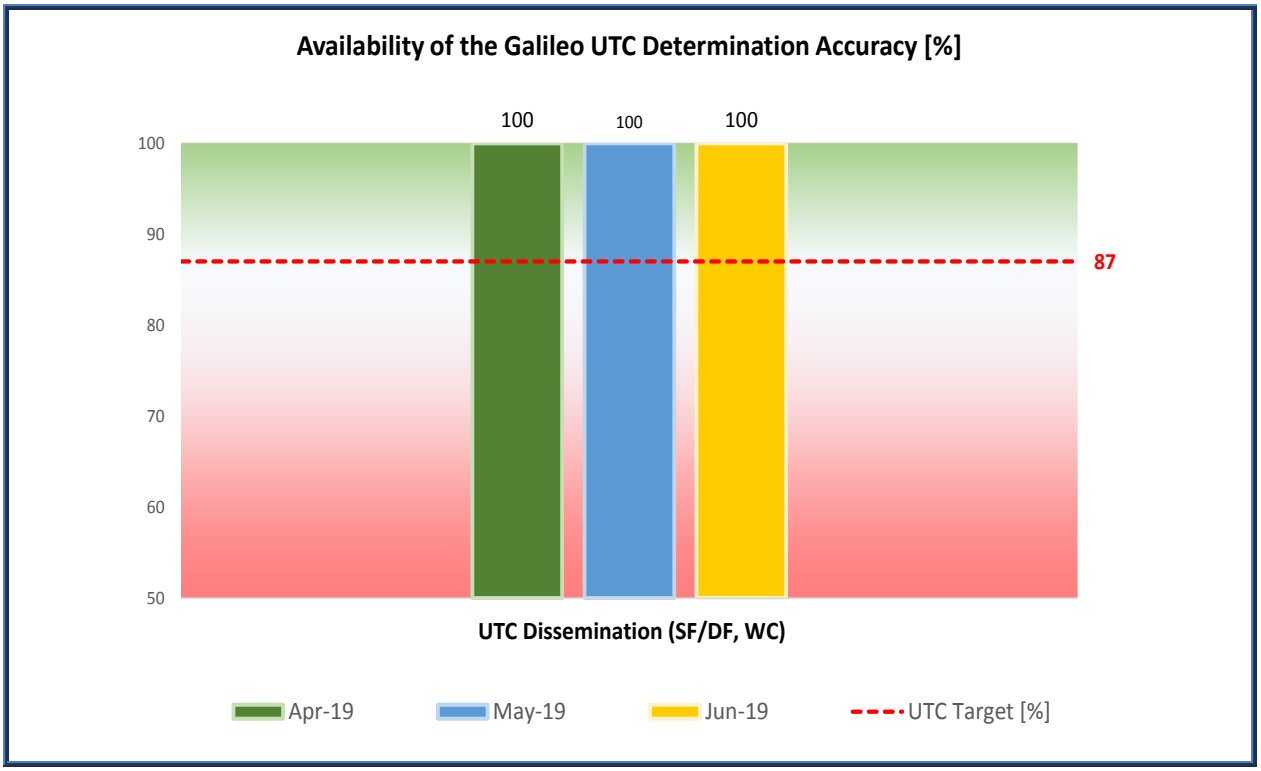


Figure 7: Monthly availability of the UTC Determination with assigned Accuracy target during the reporting period

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[12] set of coefficients within the Navigation message, acquiring SiS from a space vehicle seen above a minimum elevation angle of 5 degrees. Figure 8 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.

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

12 "Dummy" GGTO is defined in [OS-SDD] and in Galileo SiS ICD in terms of "all 1's" appearing in the GGTO parameters binary slot(s) carried by the Navigation message.

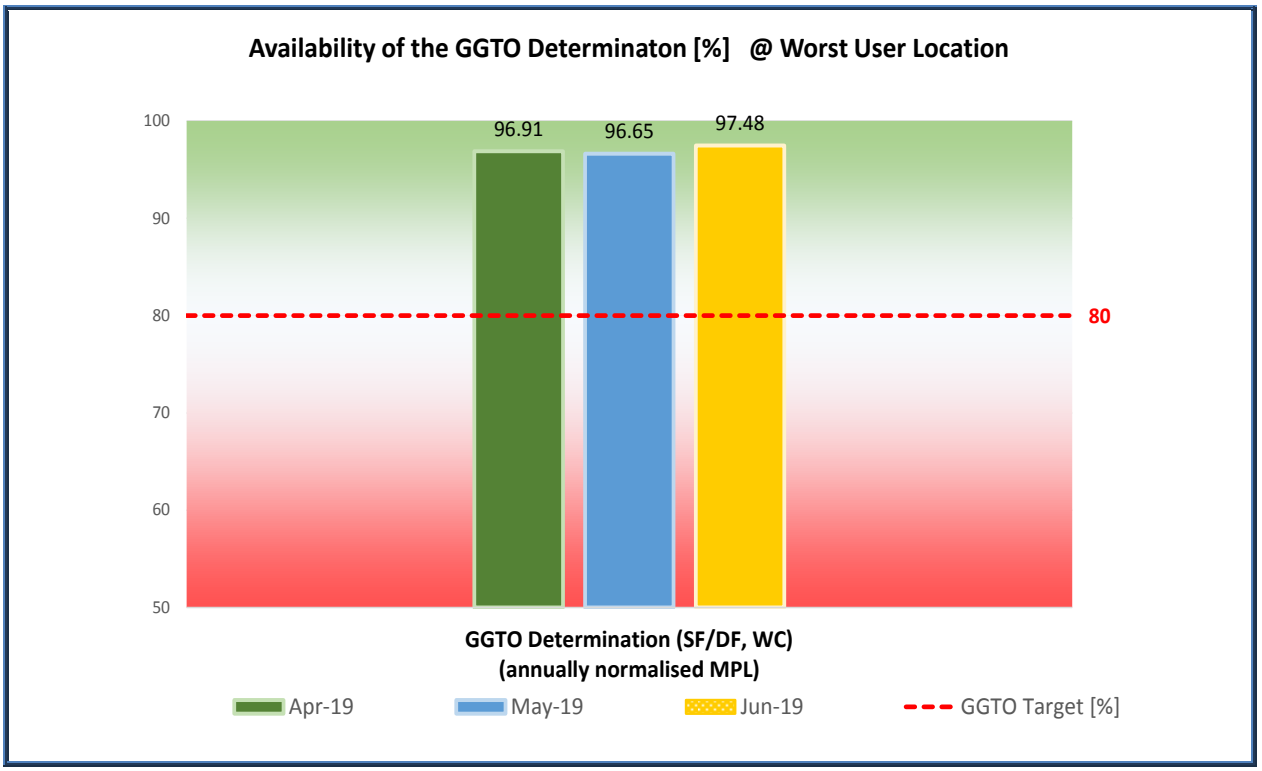


Figure 8: Annually normalised availability of the GGTO Determination, during the reporting period

The MPL of **80%** [13] 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 **94.93**% in April (ref.: NAGUs 2019011, 2019012), **96.90**% in May (ref.: NAGU 2019022, 2019023), and **100**% in June.

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 [14].

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.

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

[14] Note that the final UTC Determination Accuracy experienced by the user will also be affected by ranging errors, on top of the committed UTC Dissemination Accuracy

Figure 9 shows the 95th percentile of the daily average of the UTC Dissemination Accuracy, observed and normalised over a period of 12 months.

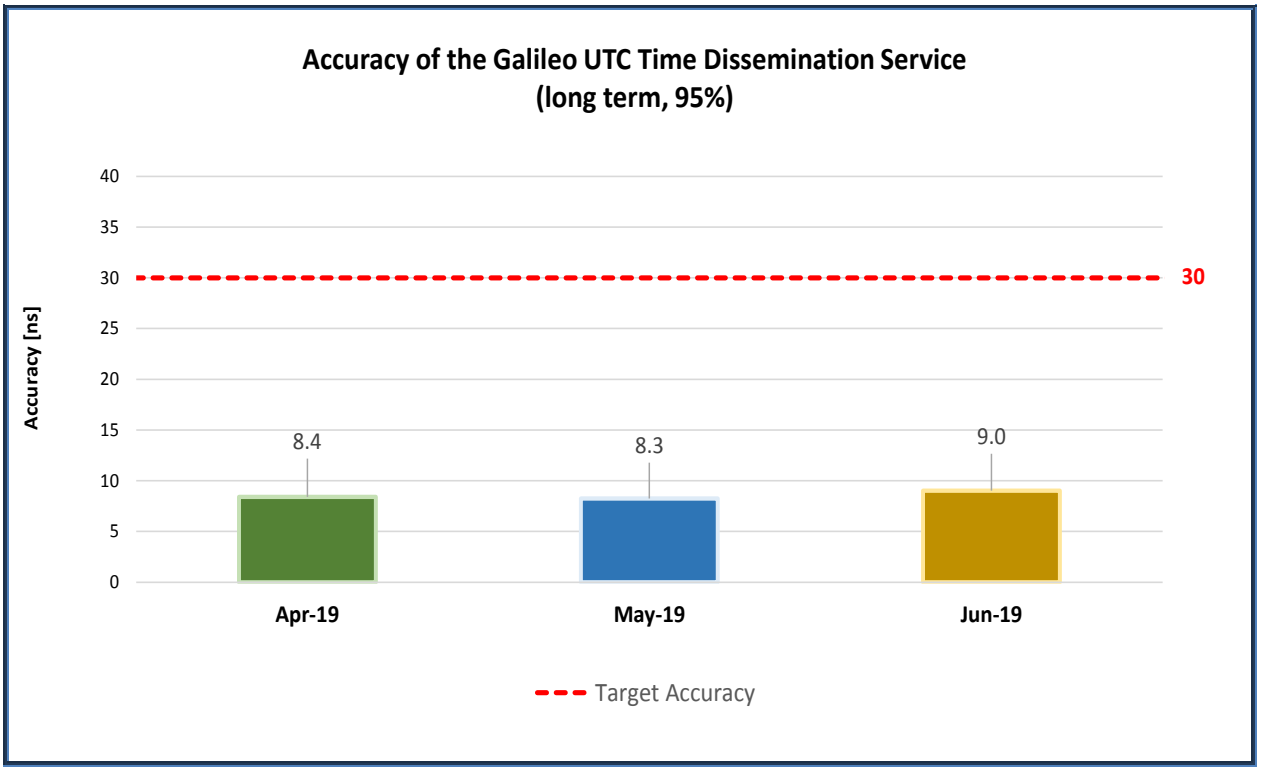


Figure 9: Long-term 95th percentile of UTC Time Dissemination Accuracy

Figure 10 shows the 95th percentile of the UTC Frequency Dissemination Accuracy, computed accumulating measurement data over the past 12 months [15].

Figure 11 shows the 95th percentile of the daily average of the GGTO Determination Accuracy, also normalised annually.

As seen in Figure 9, the long term 95th percentile of UTC (Time) Dissemination Accuracy is better than **9** [ns], well below the [OS-SDD] Minimum Performance Level specification of **30** [ns] [16]. Regarding UTC Frequency Dissemination accuracy, Figure 10 shows that the measured 95th percentile value is at most around **3E–14**, which is an order of magnitude better than the [OS-SDD] MPL normalised annual ceiling of **3.0E–13** [17].

About the GGTO Determination Accuracy, shown in Figure 11, values are consistently equal to **6.4** [ns] in April and May, but drifted to **10.4** [ns] in June, due to unplanned events taking place during

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

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

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

a system upgrade. These figures are significantly better than the [OS-SDD] MPL threshold of **20** [ns] [18].

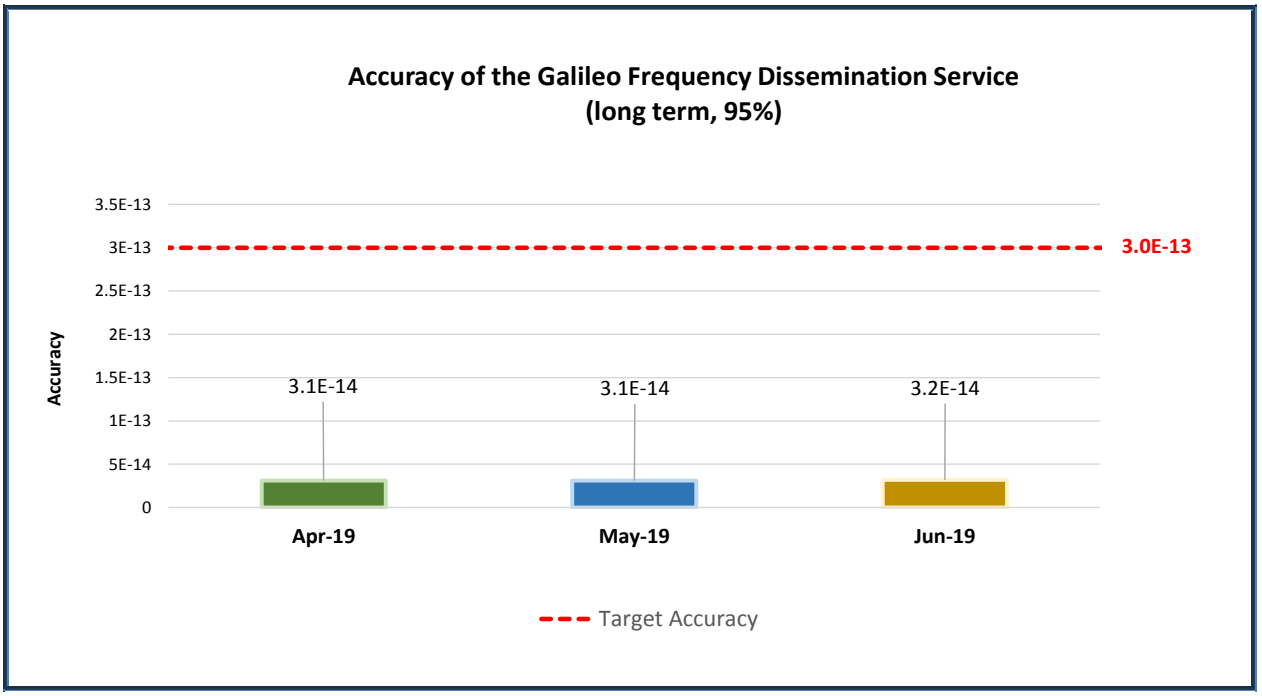


Figure 10: Long-term 95th percentile of UTC Frequency Dissemination Accuracy

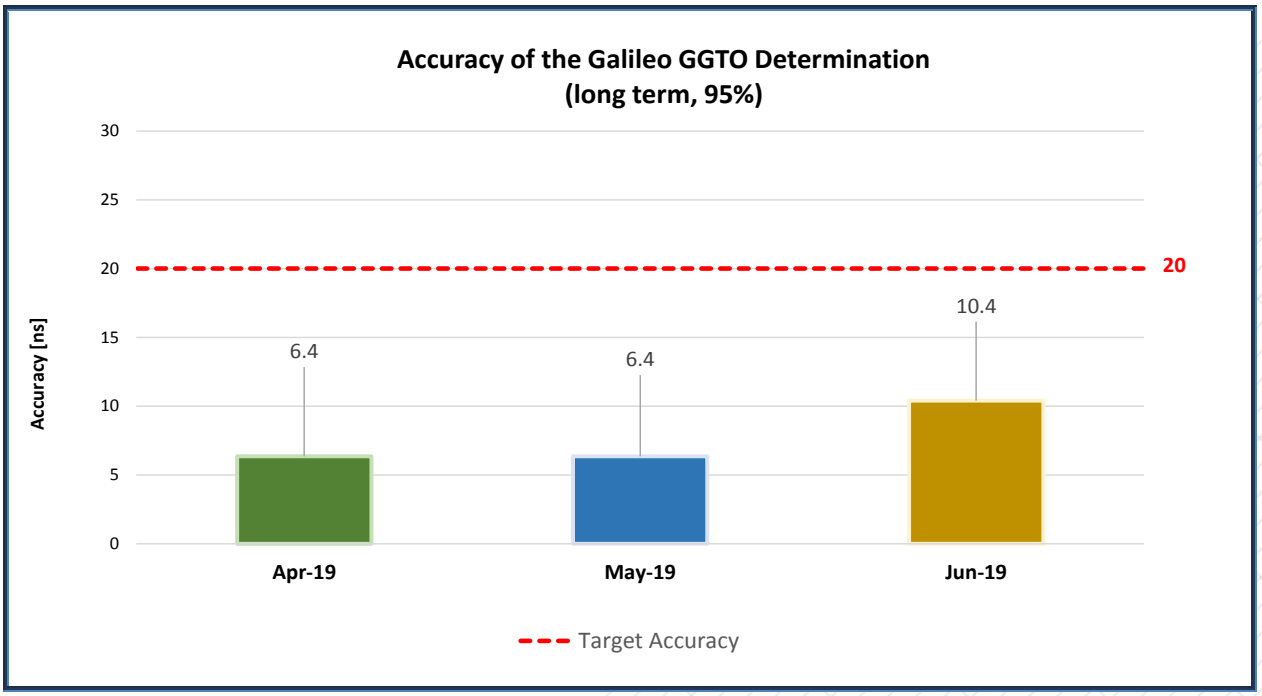


Figure 11: Long-term 95th percentile of GGTO Determination Accuracy

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

5 GALILEO POSITIONING PERFORMANCE

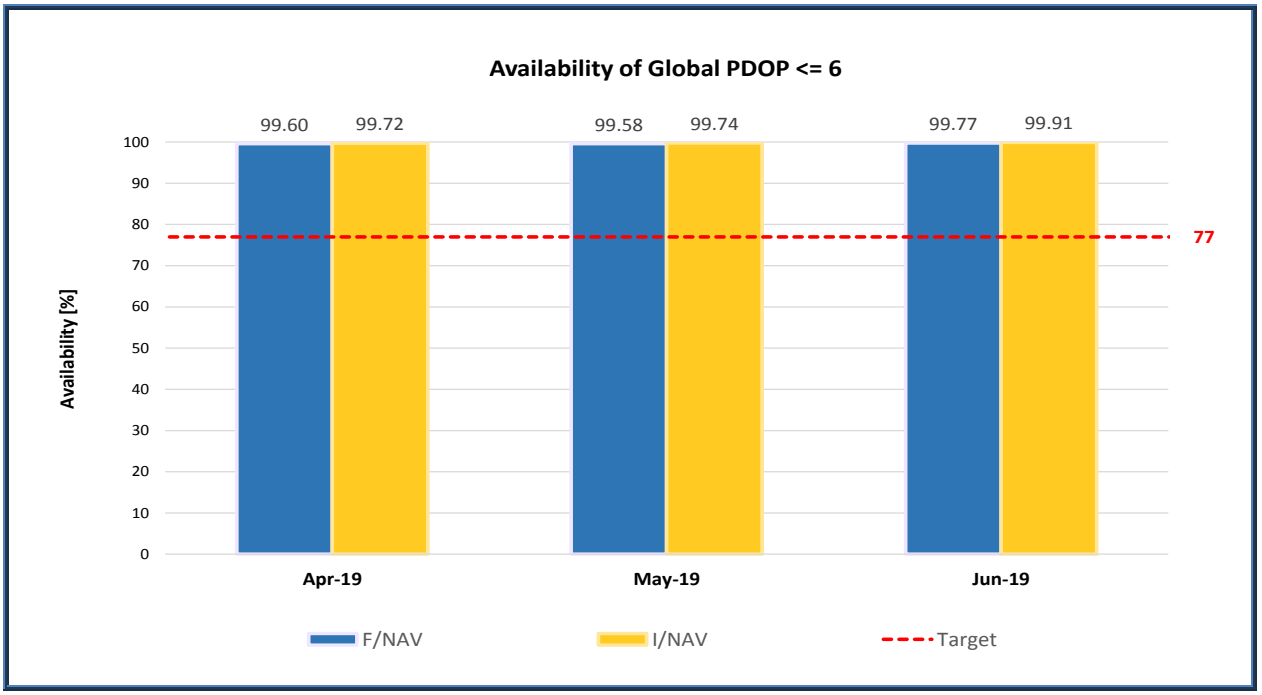
In this section of the report the following performance figures are provided for information:

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

Note that the current version of the [OS-SDD] no longer defines MPL targets for the 2D (horizontal) positioning, as the Constellation Status is sufficiently mature to provide a full 3D user localisation capability. The new 3D positioning metrics are now reported, with MPL targets assigned since May 2019.

5.1 AVAILABILITY OF THE GALILEO POSITION DILUTION OF PRECISION

The first new item introduced by the current [OS-SDD] is the global **Availability of a (3D) PDOP** (Position Dilution of Precision) less than or equal to 6, with a target MPL of **77**% [19]. Results are presented in Figure 12, which distinguishes between the cases of SIS carrying I/NAV or F/NAV messages.



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

Figure 12: Monthly Global Average Availability of PDOP ≤ 6

5.2 AVAILABILITY OF THE GALILEO POSITIONING SERVICE

The second new item introduced by the current [OS-SDD] is 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**% [20] at Worst User Location (WUL), and **77**% [21] 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 13 and Figure 14. Values are obtained by a Volume Analysis fed by measured input values concerning Ranging Accuracy, Orbit path and Healthy SIS Availability.

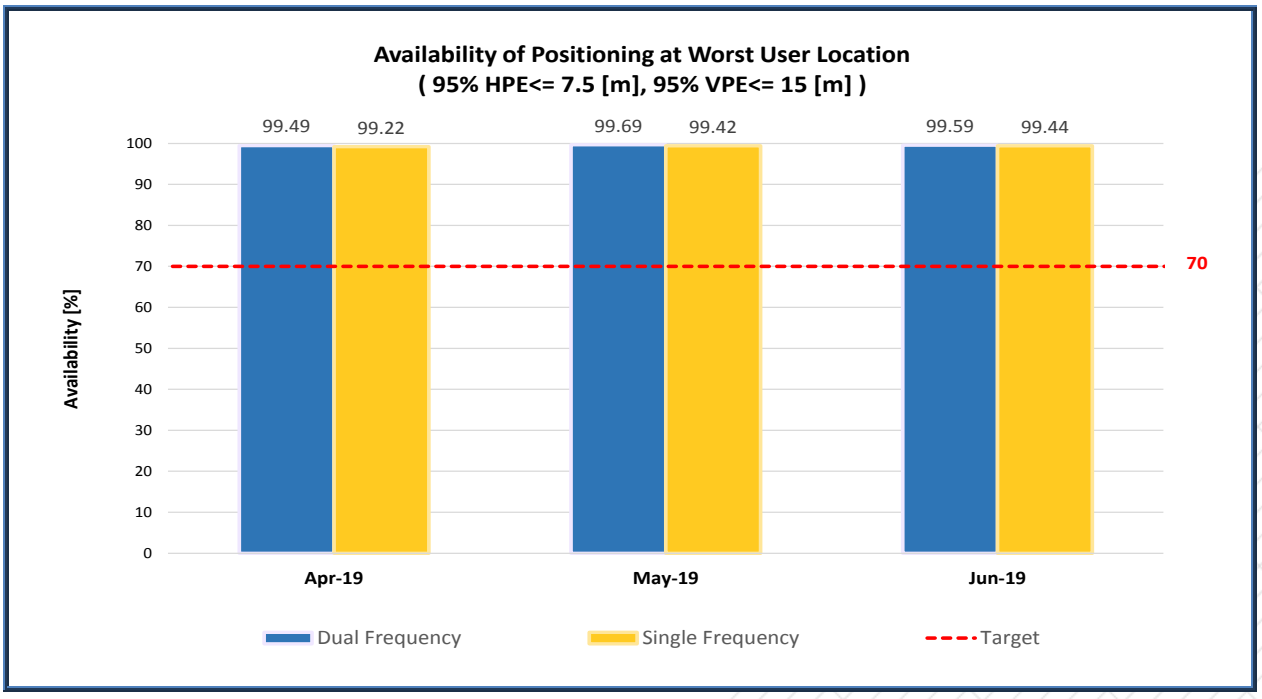


Figure 13: Availability of Positioning at Worst User Location (WUL)

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

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

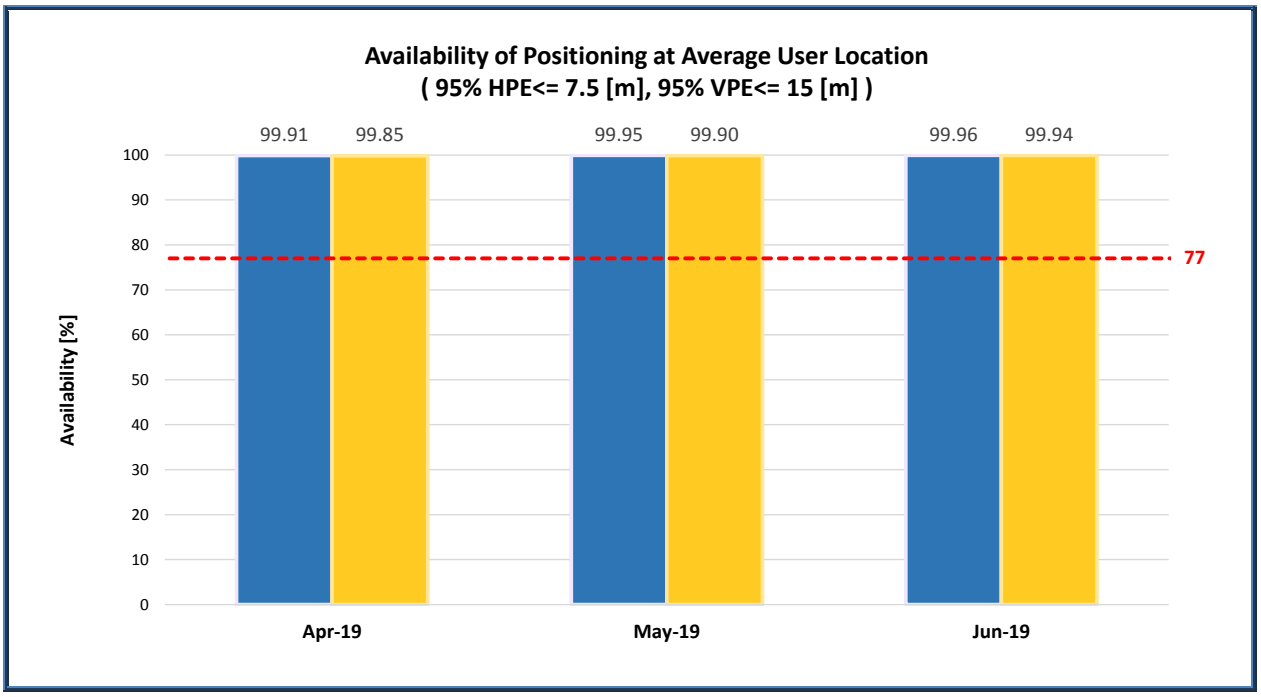


Figure 14: Availability of Positioning at Average User Location (AUL)

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 Accuracy Availability (%) commitment 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" [22].

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].

[22] The Time of Ephemeris (toE in the [OS-SDD]), also called Ephemeris Reference Time (t0E in the [SIS-ICD], section 5.1.1.), is disseminated in the Navigation message, as part of the Precision Ephemeris Set. The terms "Age of Ephemeris" mentioned by the [OS-SDD] and "Time from ephemeris reference epoch" appearing in the [SIS-ICD] are equivalent.

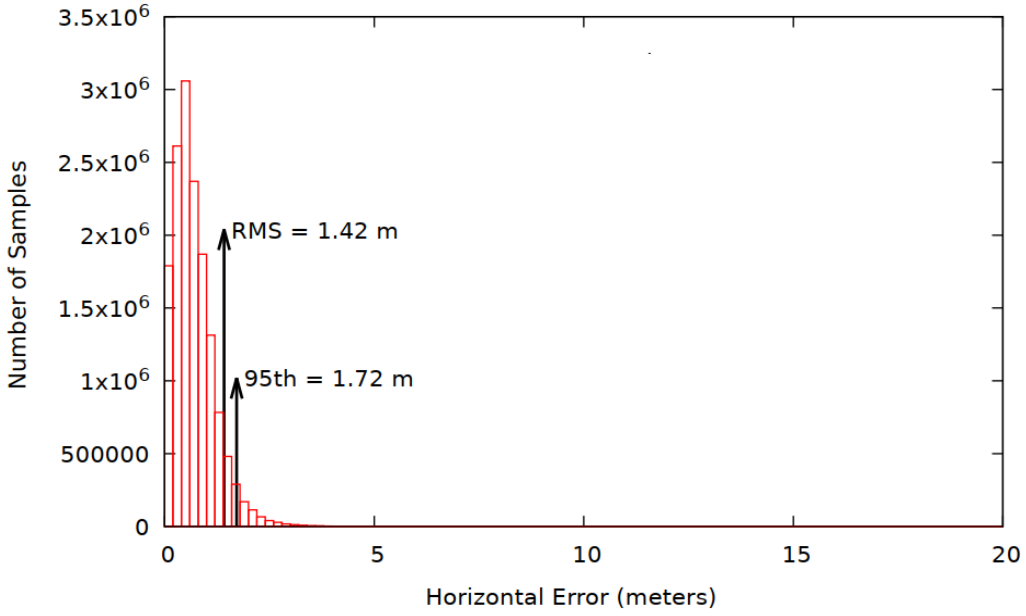
April 2019

HPE

3D Positioning

E1-E5a (DF)

F/NAV



Note: 8549 samples > 20 [m], about 0.06%

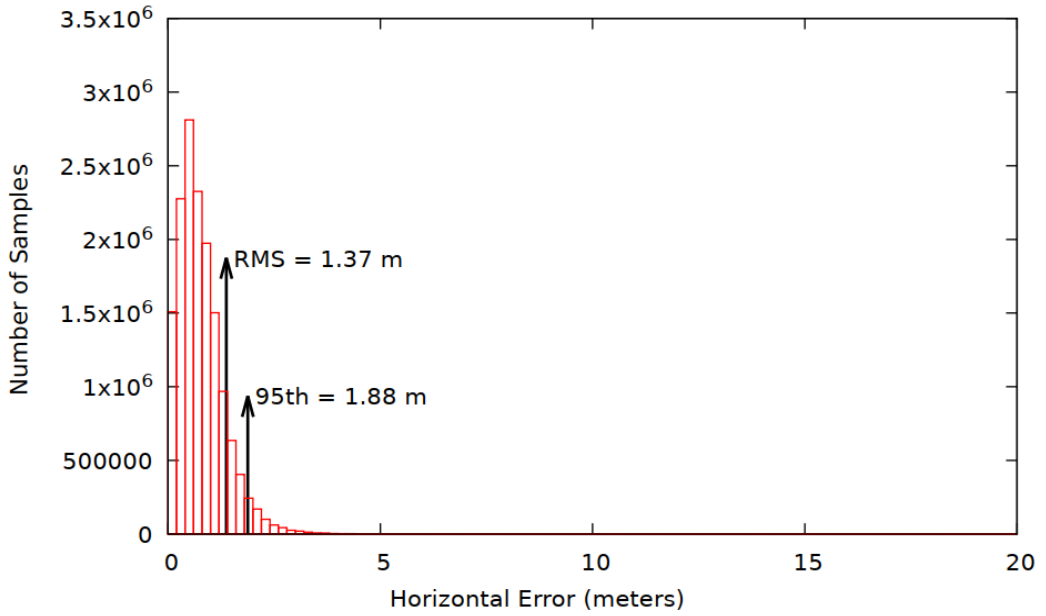
April 2019

HPE

3D Positioning

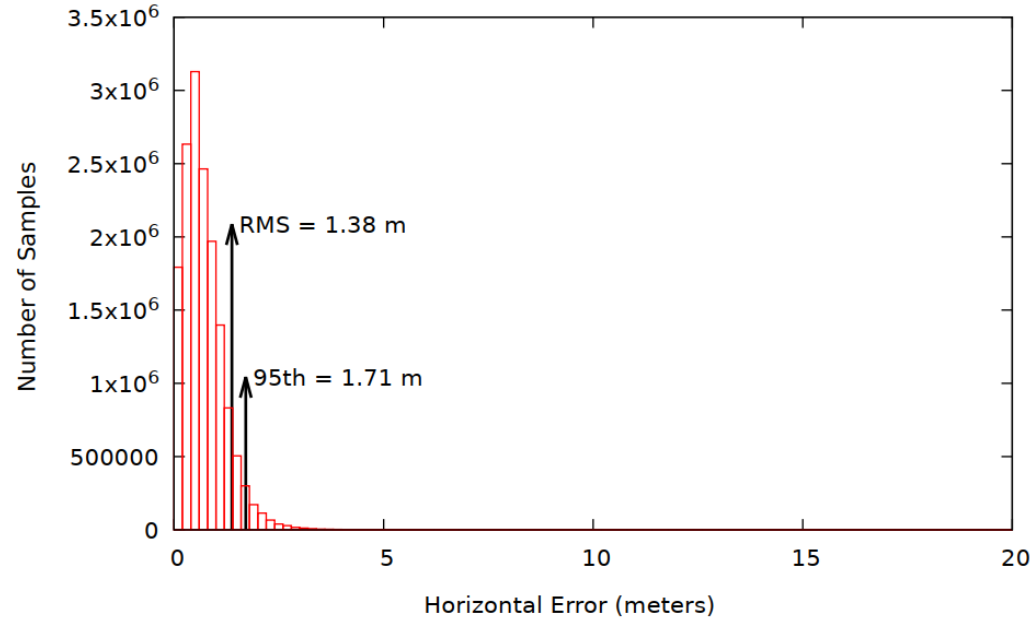
E1-E5b (DF)

I/NAV



Note: 6750 samples > 20 [m], about 0.04%

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

May 2019	
HPE 3D Positioning E1-E5a (DF) F/NAV	
Note: 7822 samples > 20 [m], about 0.05%	

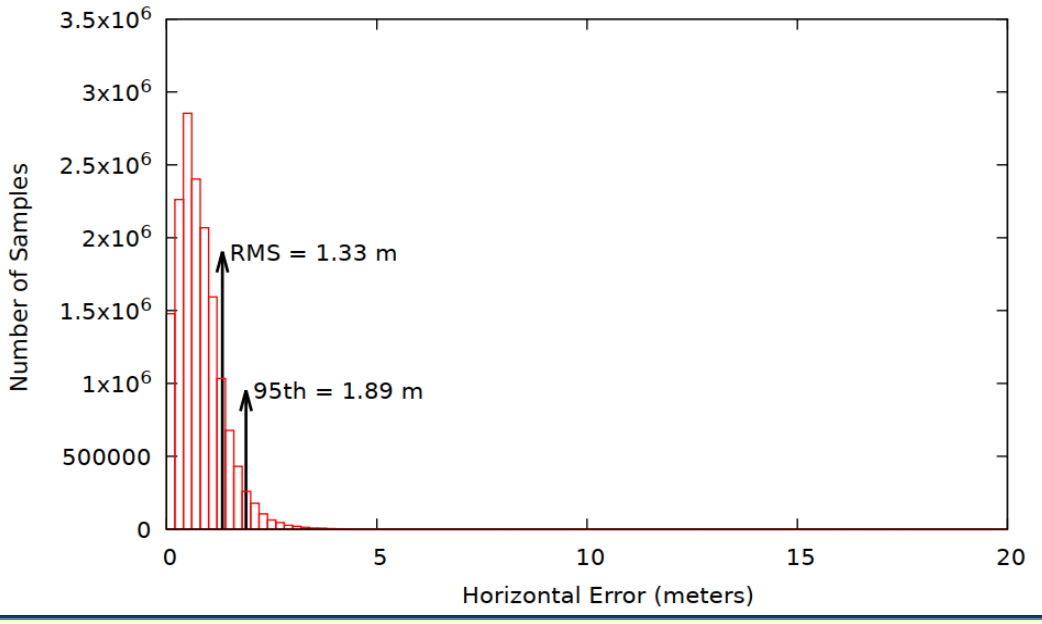
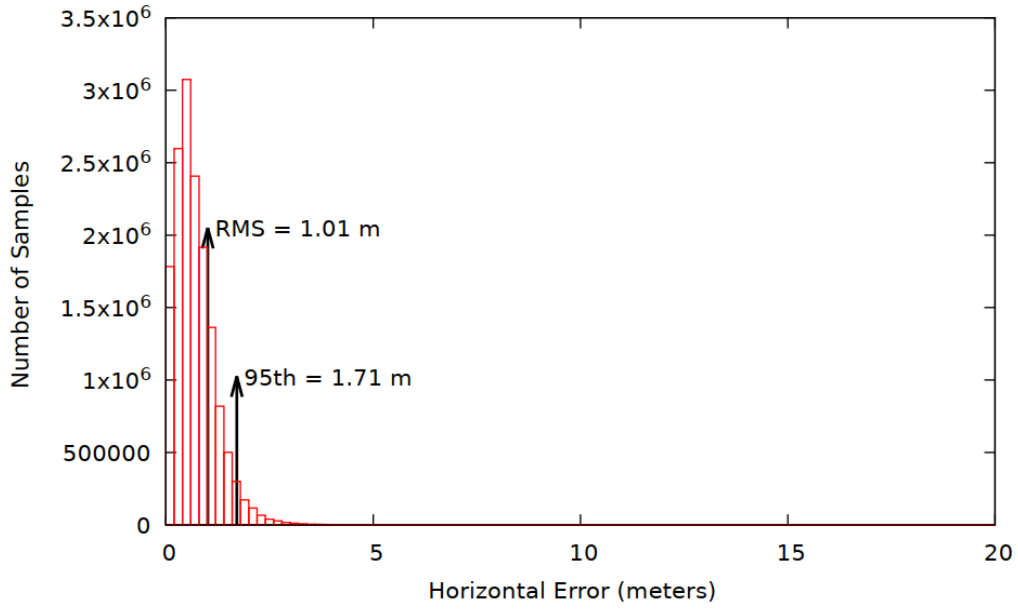
May 2019	
HPE 3D Positioning E1-E5b (DF) I/NAV	
Note: 5454 samples > 20 [m], about 0.03%	

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

June 2019	
HPE 3D Positioning E1-E5a (DF) F/NAV	
Note: 1063 samples > 20 [m], ≅ 0.01%	

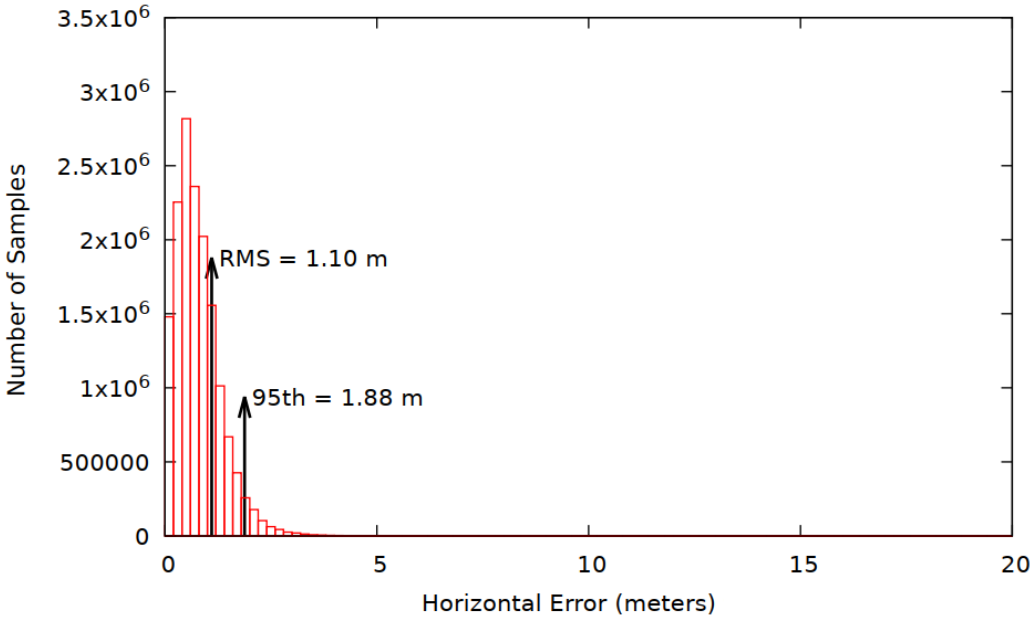
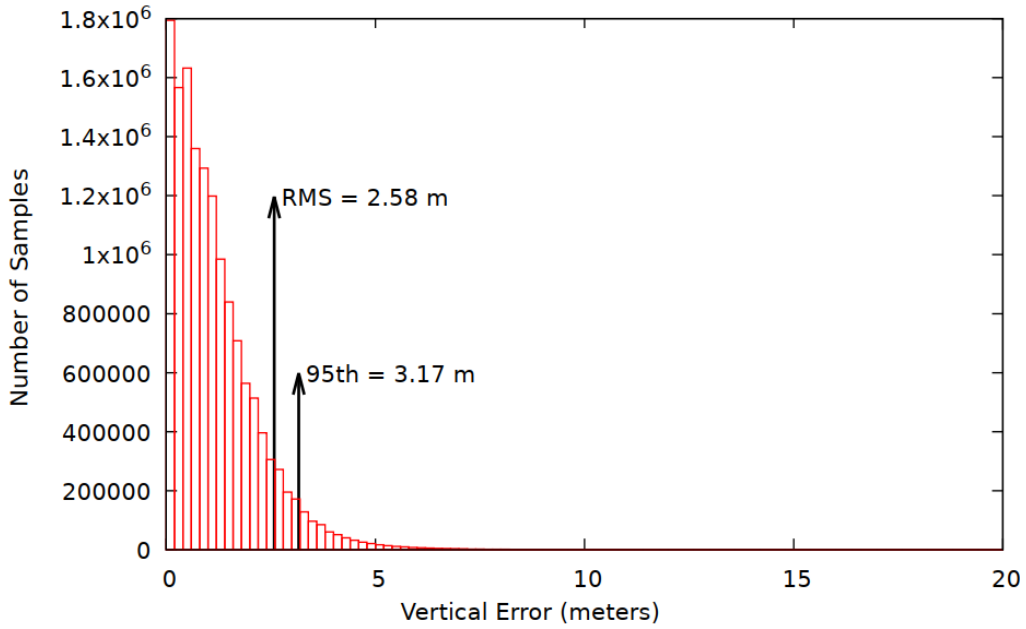
June 2019	
HPE 3D Positioning E1-E5b (DF) I/NAV	
Note: 1018 samples > 20 [m], ≅ 0.01%	

Figure 17: Horizontal Positioning Error (HPE) for "Galileo-only" users in June 2019

April 2019	
VPE 3D Positioning E1-E5a (DF) F/NAV	
Note: 11873 samples > 20 [m], about 0.08%	

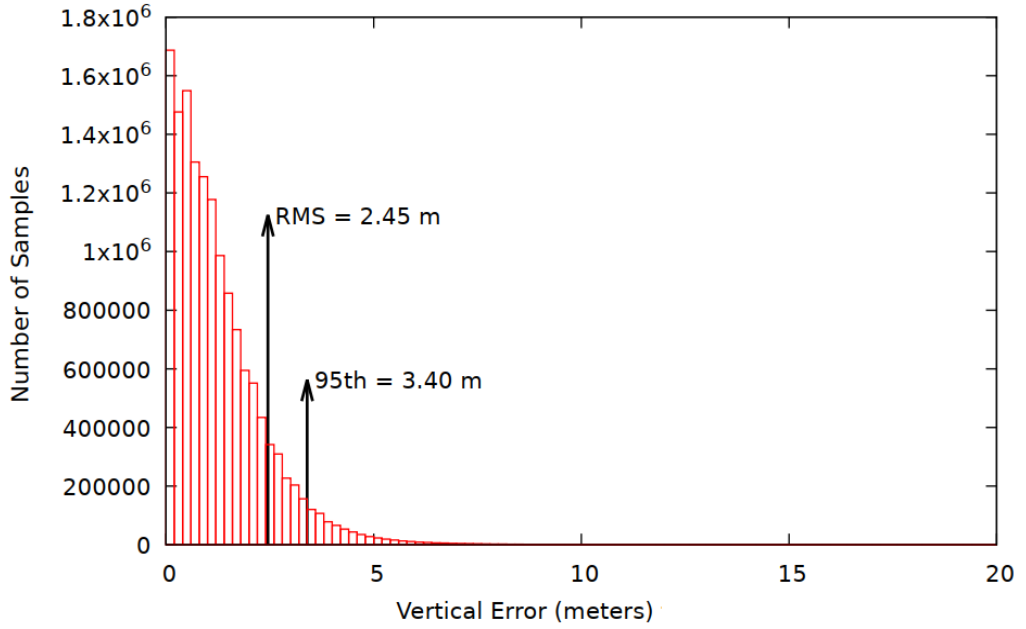
April 2019	
VPE 3D Positioning E1-E5b (DF) I/NAV	
Note: 91140 samples > 20 [m], about 0.06%	

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

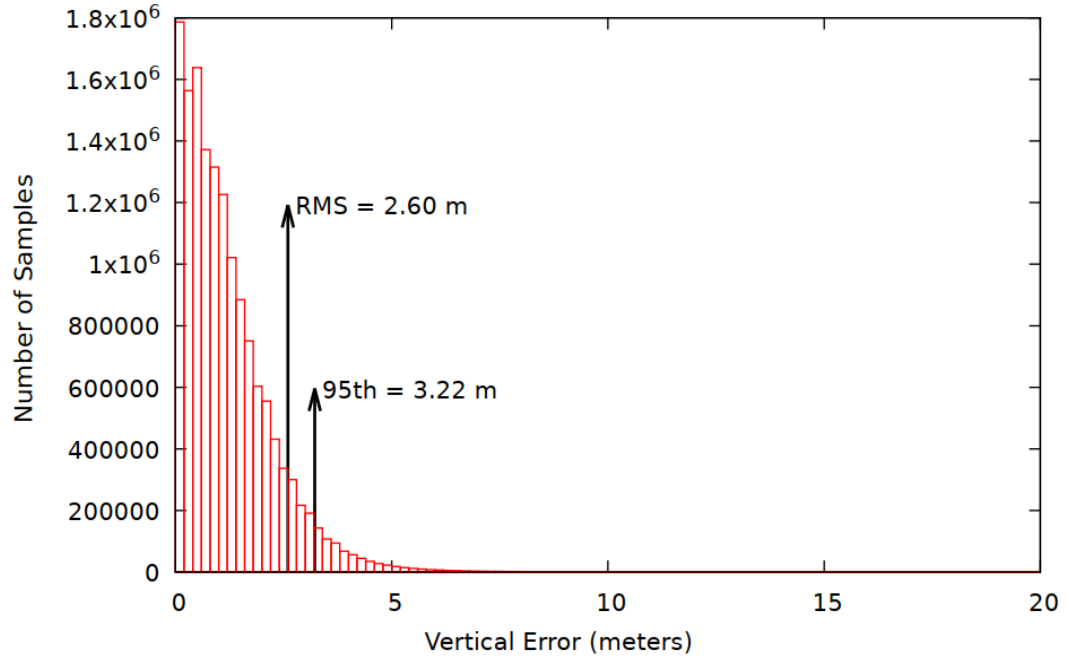
May 2019

VPE

3D Positioning

E1-E5a (DF)

F/NAV



Note: 11024 samples > 20 [m], about 0.07%

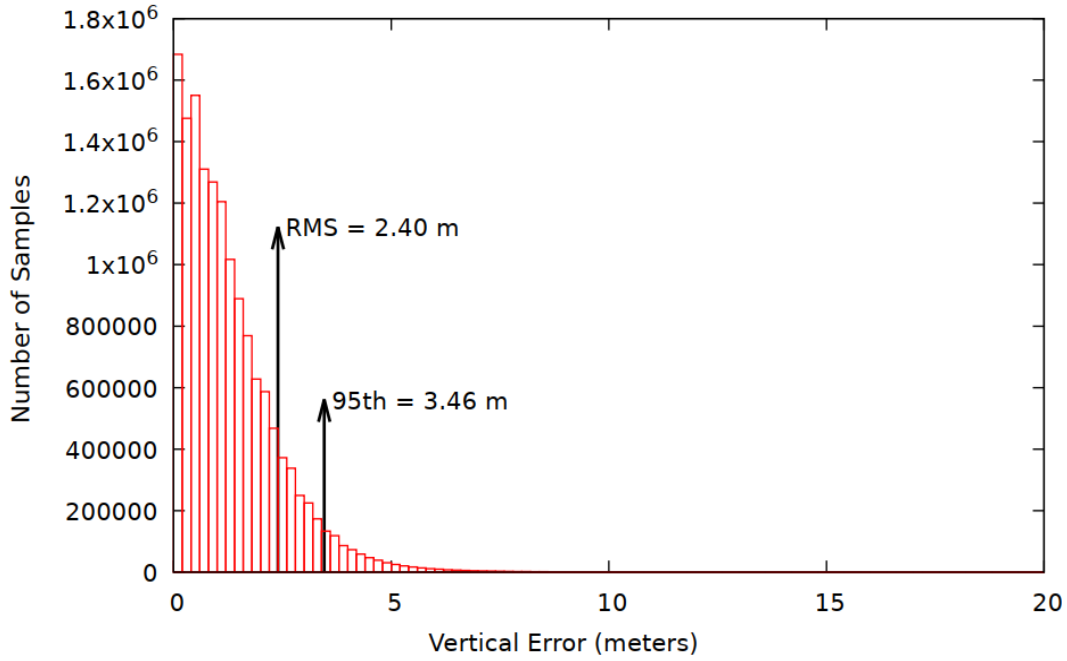
May 2019

VPE

3D Positioning

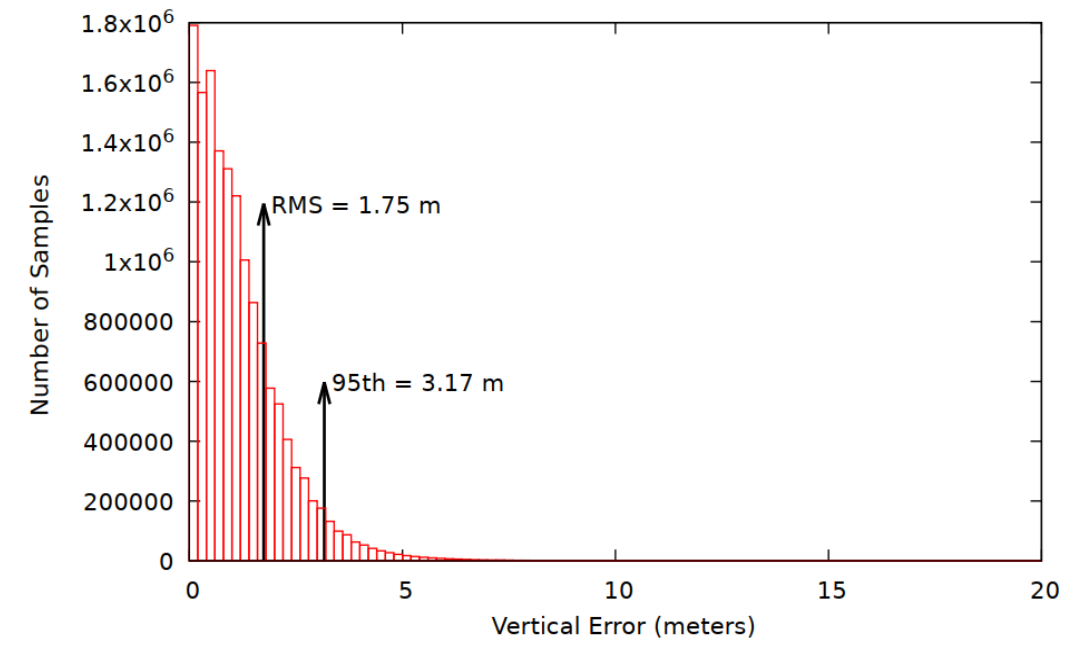
E1-E5b (DF)

I/NAV



Note: 8376 samples > 20 [m], less than 0.05%

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

June 2019	
VPE 3D Positioning E1-E5a (DF) F/NAV	
Note: 2322 samples > 20 [m], ≅ 0.02%	

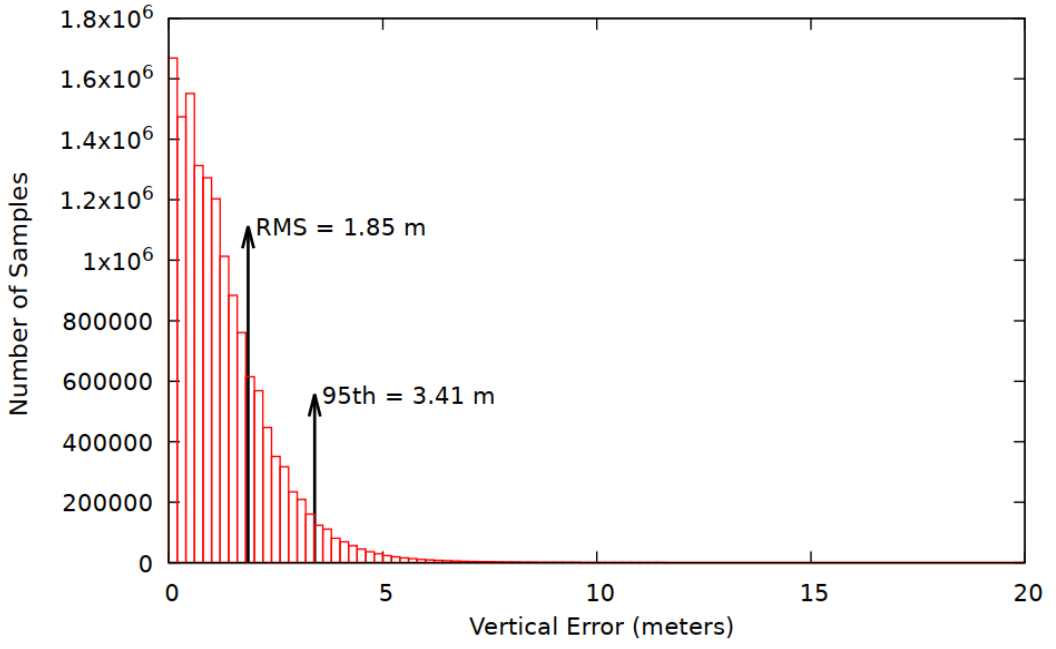
June 2019	
VPE 3D Positioning E1-E5b (DF) I/NAV	
Note: 2293 samples > 20 [m], ≅ 0.01%	

Figure 20: Vertical Positioning Error (VPE) for "Galileo-only" users in June 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)

During the reporting period, the **target MPLs for publishing NAGUs have been met in all cases.**

According to MPLs in the [OS-SDD], NAGUs related to Planned events need to be published at least **24** hours [23] before the event starts. For Unplanned events, the [OS-SDD] specifies a delay of up to **72** hours [23] from the detection of the unplanned event until a corresponding NAGU is issued.

No NAGUs issued in the period refer to unplanned events affecting the Space Segment.

During the quarter, planned NAGUs were published between **129.7** hours (best case) and **78.6** hours (worst case) in advance of the potential occurrence of an impact on service delivery. Unplanned NAGUs were published between **2.6** hours (best case) and **22.2** hours (worst case) after the related event.

Therefore the NAGU publication timeliness requirements are met with large margins.

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

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

Month	NAGU Type	Reason for publishing	Notice Advisory ID	Categorisation
April	GENERAL (TIMING AVAILABLE)	Announcing restart of nominal GGTO coefficients dissemination, from 02/04/2019 @ 13:40 UTC	2019012	U
	USABLE	Announcing restart of nominal operation of space vehicle GSAT-0222 (E33) since 09/04/2019 @ 14:50 UTC	2019013	U
	PLN_OUTAGE	Announcing maintenance on-board of GSAT-0218 (E31), starting 16/04/2019 @ 01:30 UTC	2019014	P
	USABLE	Announcing restart of nominal operation of space vehicle GSAT-0218 (E31), starting 24/04/2019 @ 15:51 UTC	2019015	U
	PLN_OUTAGE	Announcing maintenance on-board of GSAT-0208 (E08), starting 02/05/2019 @ 05:30 UTC	2019016	P
May	USABLE	Announcing restart of nominal operation of space vehicle GSAT-0208 (E08) from 02/05/2019 @ 20:13 UTC	2019017	U
	PLN_OUTAGE	Announcing maintenance on-board of GSAT-0214 (E05), starting 06/05/2019 @ 13:11 UTC	2019018	P
	USABLE	Announcing restart of nominal operation of space vehicle GSAT-0214 (E05) from 14/05/2019 @ 20:13 UTC	2019019	U
	GENERAL NOTICE	Announcing availability of SIS broadcast from space vehicle GSAT-0201 (E18), applicable only for test purpose by neglecting the setting of SHS flags. Timeliness for NAGU publication is not applicable as event does not affect services.	2019020	N/A
	GENERAL NOTICE	Announcing availability of SIS broadcast from space vehicle GSAT-0202 (E14), applicable only for test purpose by neglecting the setting of SHS flags. Timeliness for NAGU publication is not applicable as event does not affect services.	2019021	N/A
	GENERAL UNP_UNUFN	Warning on unavailability of valid GGTO broadcast coefficients starting 27/05/2019 @ 12:51 UTC	2019022	U

Month	NAGU Type	Reason for publishing	Notice Advisory ID	Categorisation
	GENERAL (TIMING AVAILABLE)	Announcing restart of nominal GGTO coefficients dissemination, from 28/05/2019 @ 13:27 UTC	2019023	U
June	UNP_SHTRCVR	Announcing recovery from maintenance activity on GSAT-0221 (E15). Due to its short duration, occurring on 04/06/2019 from 13:44 UTC to 16:38 UTC, This outage was communicated "a posteriori" by a single NAGU, as per applicable definition criteria (SIS was marginal over less than 6 hours)	2019024	U
NAGU Categorisation for timeliness evaluation: "P" = Planned, "U" = Unplanned				

Table 6: NAGUs published during 2nd 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
A new version of the OS-SDD (Issue 1.1) has been published and is in force since May 2019. This new version is now accessible for download from the European GNSS Service Centre (GSC) website.
OS-SDD Issue 1.0 can be obtained from the GSC upon 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

End of Document

European GNSS Service Centre:

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