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EUROPEAN GNSS (GALILEO) SERVICES

HIGH ACCURACY SERVICE (HAS)

QUARTERLY PERFORMANCE REPORT

JANUARY – MARCH 2023

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- *the Galileo High Accuracy Service, Service Definition Document available here: https://www.gsc-europa.eu/sites/default/files/sites/all/files/Galileo-HAS-SDD_v1.0.pdf*

the content of this report provides the characterisation of the Galileo Open Service and High Accuracy Service performance during the reported period using the various means and tools available at the EUSPA, and is deemed correct. Notwithstanding, the EUSPA and the European Union do not assume any responsibility or liability derived from the accuracy of the data contained therein to the extent permitted by the applicable law.

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1 INTRODUCTION

This document is the High Accuracy Service (HAS) Public Performance Report for the period of January, February and March 2023.

Starting from January 24th 2023, the EU has declared the availability of HAS Initial Service delivery, so that this document reports about its relevant performance metrics: a new edition is to be published after each quarter.

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

- ◊ Accuracy of delivered HAS Corrections, both via SIS and via IDD;
- ◊ Availability of HAS Corrections, both when disseminated via SIS and via IDD;
- ◊ Availability of HAS Coverage in the intended Service area.

In addition, information can be provided about measured values and metrics that are not subject to MPL targets, while being of interest for HAS users.

Concerning the timeliness of NAGUs [1] and metrics related Galileo Open Service, the reader is addressed to the [OS QPR], namely the Quarterly Performance Report for navigation Open Service covering the same period.

This document comprises the following sections:

Section 1: introduces this report, including the status of the Galileo constellation over the quarterly reporting period.

Section 2: provides an executive summary describing main statistics about the achieved HAS performance. Details are reported in the following chapters.

Section 3: the “Galileo High Accuracy service” is reported in terms of “Accuracy of the HAS Corrections”, “Availability of the HAS Corrections”, “Coverage of the HAS Service”.

Section 4: all the cited reference documents are listed.

Section 5: terms, acronyms and abbreviations used in the document are defined.

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

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

Table 1: Galileo reported constellation information

Satellite		CCSDS ID [hex]	orbital slot	status
ID	**PRN**			
GSAT0101	E11	3A5	B05	usable
GSAT0102	E12	3A6	B06	usable
GSAT0103	E19	3A7	C04	usable
GSAT0201 *	E18	261	non-nominal	*not usable*
GSAT0202 *	E14	262	non-nominal	*not usable*
GSAT0203	E26	263	B08	usable
GSAT0205	E24	265	A08	usable
GSAT0206	E30	266	A05	usable
GSAT0207	E07	267	C06	usable
GSAT0208	E08	268	C07	usable
GSAT0209	E09	269	C02	usable
GSAT0210	E01	26A	A02	usable
GSAT0211	E02	26B	A06	usable
GSAT0212	E03	26C	C08	usable
GSAT0213	E04	26D	C03	usable
GSAT0214	E05	26E	C01	usable
GSAT0215	E21	2C5	A03	usable
GSAT0216	E25	2C6	A07	usable
GSAT0217	E27	2C7	A04	usable
GSAT0218	E31	2C8	A01	usable
GSAT0219	E36	2C9	B04	usable
GSAT0220	E13	2C0	B01	usable
GSAT0221	E15	2C1	B02	usable
GSAT0222	E33	2C2	B07	usable
GSAT0223 †	E34	109	B03	usable
GSAT0224 ‡	E10	10B	B15	usable §

* The two Galileo Space Vehicles GSAT0201 (E18) and GSAT0202 (E14) have been temporarily removed from the provision of active service since February 18th, 2021. This was notified with NAGU 2021008, and the reason is clarified by Galileo Service Notice #05 (SNGU 2021001, [SvNOTE #5]).

† NAGU 2022016

‡ NAGU 2022034

§ auxiliary space vehicle

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:

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Table 2: Galileo Service Centre main information web pages for Galileo status

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"

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.

Regarding **GSAT0224** (**E10**), it should be noted that this space vehicle is considered as an "auxiliary" satellite and it is not located in a nominal orbit slot. It is a requirement that it shall not degrade the overall system performance, therefore, the accuracy of HAS corrections is also evaluated for this satellite.

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2 EXECUTIVE SUMMARY

During the quarterly reporting period under consideration, the measured HAS performance figures were in line with the Minimum Performance Level (MPL) targets specified in the [HAS-SDD]. Table 3 summarises the compliance with MPLs as dashboards, using the colour coding defined in Table 4.

Table 3: HAS MPL fulfilment status dashboard

HAS MPLs	target	2023 January	2023 February	2023 March
accuracy of HAS corrections, in m				
orbit				
Galileo	≤ 0.20		■■	■■
GPS	≤ 0.33		■■	■■
clock				
Galileo	≤ 0.12		■■	■■
GPS	≤ 0.15		■■	■■
code bias				
Galileo	≤ 0.50			
E1-C			■■	■■
E5-Q			■■	■■
E7-Q			■■	■■
E6-C			■■	■■
GPS	≤ 0.50			
L1 C/A			■■	■■
L2 CL			■■	■■
availability of HAS Corrections, in %				
all corrections				
Galileo only	≥ 87		■■	■■
Galileo and GPS	≥ 95		■■	■■
service coverage, in %				
all corrections	100		■■	■■

■■ SiS Dissemination | Terrestrial Dissemination

Table 4: legend of HAS MPLs verification dashboard

legend colour	interpretation
none	MPL measurement is 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)

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2.1 SUMMARY NOTES ABOUT HIGH ACCURACY SERVICE

Any MPLs and supplementary metrics provided in this report for the High Accuracy Service (HAS) are to be computed over an entire month of collected data, starting from the official introduction of the Service, as per [HAS-SDD] in force.

The declaration of HAS Initial Service provision took place on January 24th, 2023; thus, the performance parameters for Galileo HAS are included for the first time in this Quarterly Performance Report, and starting from the month of February 2023.

During both February and March, HAS satisfied all the assigned MPL targets.

Concerning the **Accuracy** of HAS Corrections:

- in February, both in the case of dissemination via SIS or terrestrial link:
  - **orbit corrections** accuracy for Galileo was **0.20** m, **0.16** m for GPS, against respective targets of **0.20** m and **0.33** m;
  - **clock corrections** accuracy (converted to units of length) for Galileo was **0.08** m, and **0.10** m for GPS, comparing to target values of 0.12 m and 0.15 m correspondingly;
  - **code bias** corrections accuracy was better than **0.24** [m] for Galileo and **0.34** [m] for GPS, comparing with (same) target of 0.50 m.
- In March, both in the case of dissemination via SIS or terrestrial link:
  - **orbit corrections** accuracy for Galileo was **0.16** m, **0.23** m for GPS;
  - **clock corrections** accuracy (converted to units of length) for Galileo was **0.07** m, and **0.11** m for GPS;
  - **code bias** corrections accuracy was not worse than **0.28** [m] for Galileo and **0.30** [m] for GPS.

The Availability of HAS Corrections has been evaluated both considering data collected at real receiver sites and by volume simulation, the latter extended to cover the whole Service area. Results are as follows, considering that target values are 87% in the case of "Galileo only", and 95% for Galileo + GPS.

- For data collected at worst (real) measurement site:
  - in February, both in the case of dissemination via SIS or terrestrial link, figures are not lower than **97.86**% for "Galileo only", and **99.96**% for Galileo + GPS;
  - in March, again both in the case of dissemination via SIS or terrestrial link, values are not lower than **93.26**% for Galileo only and **98.05**% for Galileo + GPS.
- Considering data available at the virtual nodes of a dense grid, covering all the Service area, availability at the Worst User Location (WUL) is such that:
  - in February, both in the case of dissemination via SIS or terrestrial link, figures are not lower than **96.06**% for "Galileo only", and **99.44**% for Galileo + GPS;
  - in March, both in the case of dissemination via SIS or terrestrial link, values are not lower than **91.44**% for "Galileo only" and **98.13**% for Galileo + GPS.

Service coverage was always **100**%, in all the declared Service provision area.

Regarding **publication of NAGUs**, **23 NAGUs** have been issued in the reporting period, in all cases respecting the requirements for their timeliness.

According to the [OS-SDD] and [HAS-SDD], the minimum time for publishing a NAGU before the start of a scheduled event is **48 hours** (two days), and **30 hours** (1.25 days) after the occurrence of an unscheduled one. Additional details about NAGU timeliness are presented in the [OS QPR].

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3 GALILEO HIGH ACCURACY SERVICE METRICS

Galileo High Accuracy Service (HAS), Initial Service provision was launched on January 24th, 2023, as declared by Galileo [SvNOTE #13].

As per HAS roadmap, with such announcement the EU stated the official transition from previous testing stage to the Initial Service delivery, heading towards the Full Service planned to be achieved in the future.

In the current Service provision scheme, HAS delivers corrections to the broadcast orbit ephemeris, clock offset and code bias estimates. Such corrections are rendered available through Galileo E6-B SIS and via Internet, for both Galileo and GPS, allowing users of both systems to attain an accuracy never achieved before using only the information disseminated by each of the two GNSSs.

This section gives a view of the trend for HAS relevant metrics is the first two months entirely covered by service delivery (February and March 2023). The performance parameters for Galileo HAS are included for the first time in this Quarterly Performance Report.

3.1 ACCURACY OF THE HAS CORRECTIONS

A first relevant set of MPLs consists of the accuracy of corrections [2] to:

- Galileo orbit ephemeris (Figure 1), clock offset (Figure 3) and code bias (Figure 5);
- GPS orbit ephemeris (Figure 2), clock offset (Figure 4) and code bias (Figure 6).

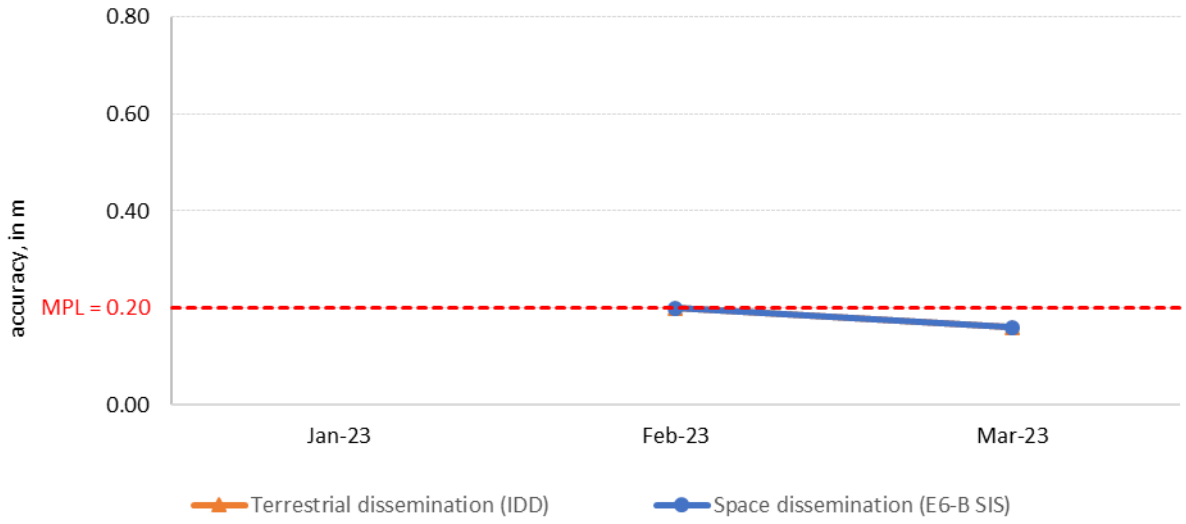

Figure 1: Galileo HAS – accuracy of the Galileo orbit corrections

[2] Ref.: [HAS-SDD], §3.2.2, Table 6; all values are expressed in engineering units of metres

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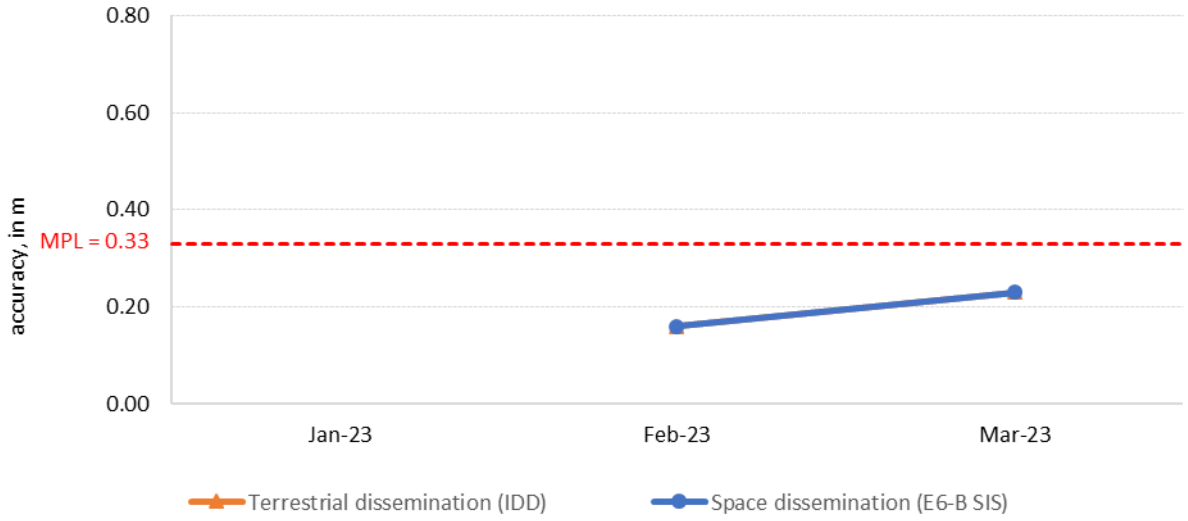

Figure 2: Galileo HAS – accuracy of the GPS orbit corrections

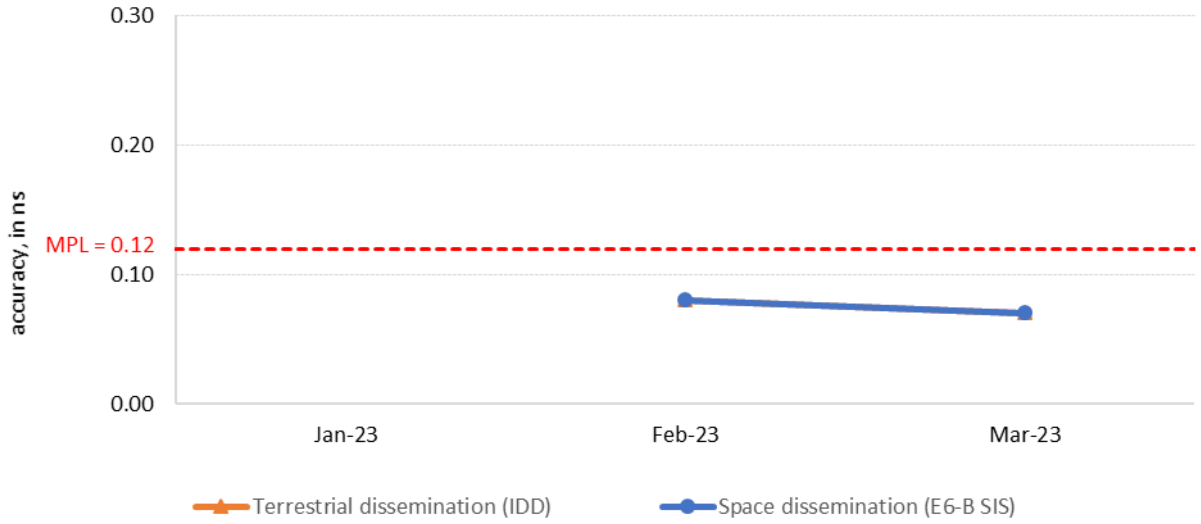

Figure 3: Galileo HAS – accuracy of the Galileo clock corrections

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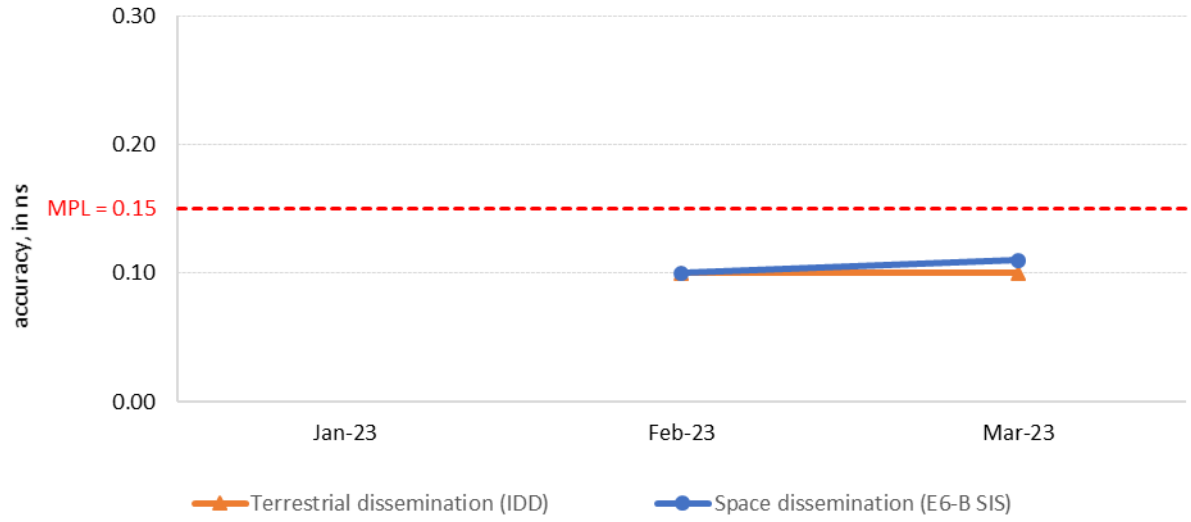

Figure 4: Galileo HAS – accuracy of the GPS clock corrections

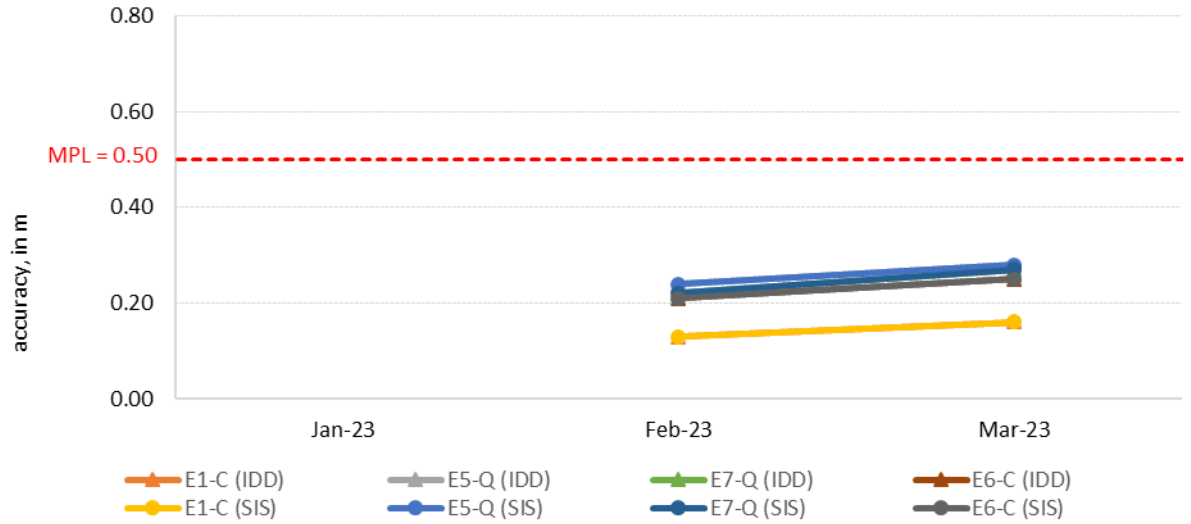

Figure 5: Galileo HAS – accuracy of the Galileo code bias corrections

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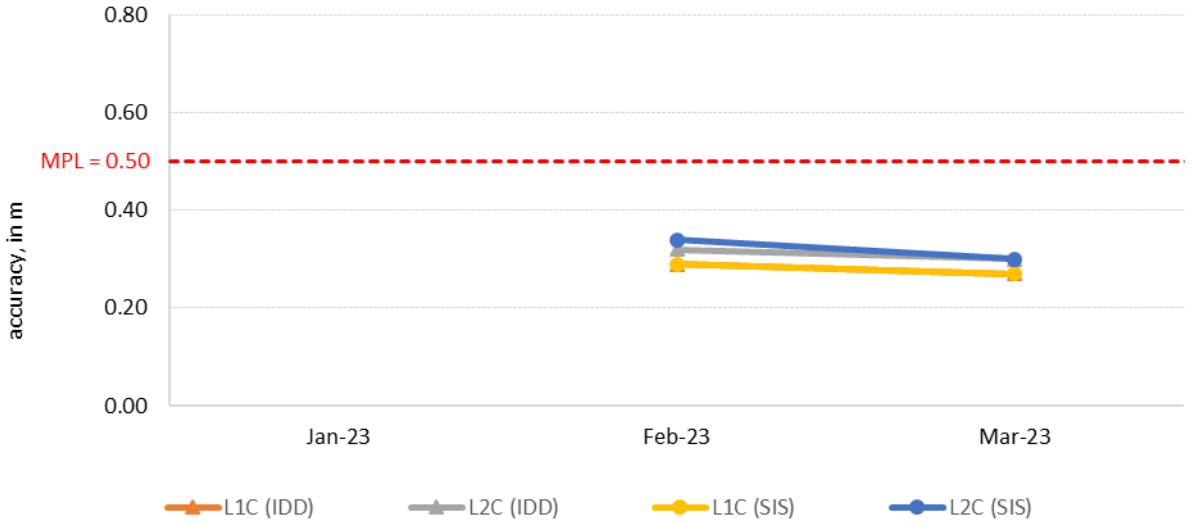

Figure 6: Galileo HAS – accuracy of the GPS code bias corrections

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3.2 AVAILABILITY OF THE HAS CORRECTIONS

The availability of HAS corrections consists of the percentage of time when they are available to the user.

The [HAS-SDD] prescribes [3] that at least 5 satellites in view need to be corrected if working in "Galileo only" positioning mode, while corrections for at least 8 space vehicles have to be available when implementing Precise Point Positioning (PPP) based on multi constellation Galileo + GPS.

Moreover, the MPL is defined for attaining value from the Worst User Location (WUL) of the Service area. As mentioned in section 2.1, due to the limited number of measurement sites w.r.t. the extension of the Service area, results are presented both based on data collected at worst (real) receiver site, as well as based on volume simulation on a dense grid of virtual nodes, accounting for the effective generation of HAS corrections and the connection plans between ground and space segment.

In particular:

- Figure 7 refers to the availability at worst (real) measurement site in the case of "Galileo only";
- Figure 8 addresses the availability at worst (real) measurement site in case of multi-constellation Galileo + GPS.

Furthermore:

- Figure 9 refers to the availability at (virtual) Worst User Location within the service area, in the case of "Galileo only";

Figure 10 addresses the availability at (virtual) Worst User Location within the service area, in case of multi-constellation Galileo + GPS.

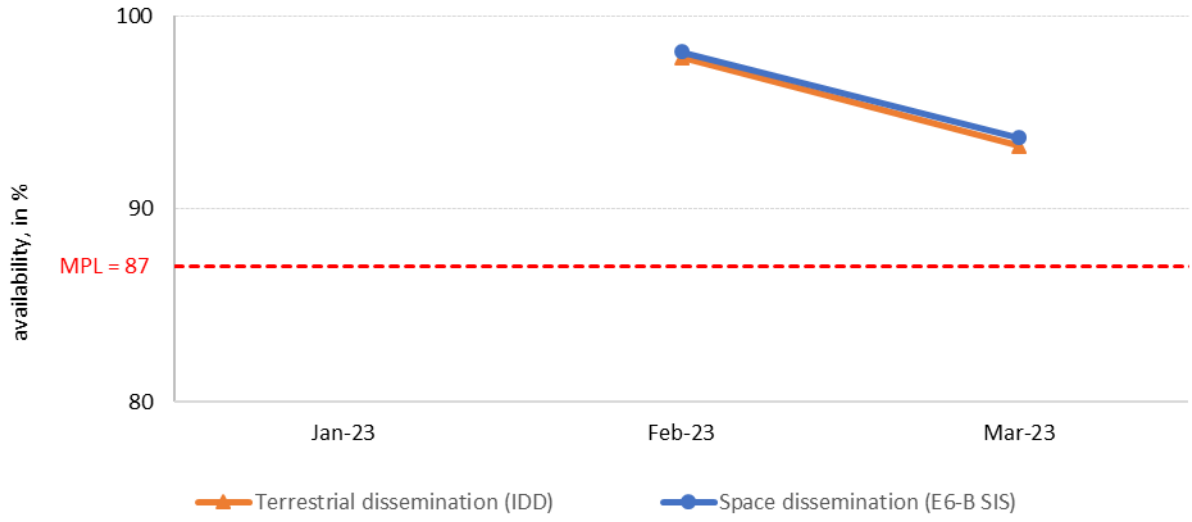

Figure 7: Galileo HAS – availability of the corrections for Galileo only modes at worst (real) measurement site

[3] Ref.: [HAS-SDD], §3.2.4, Table 7

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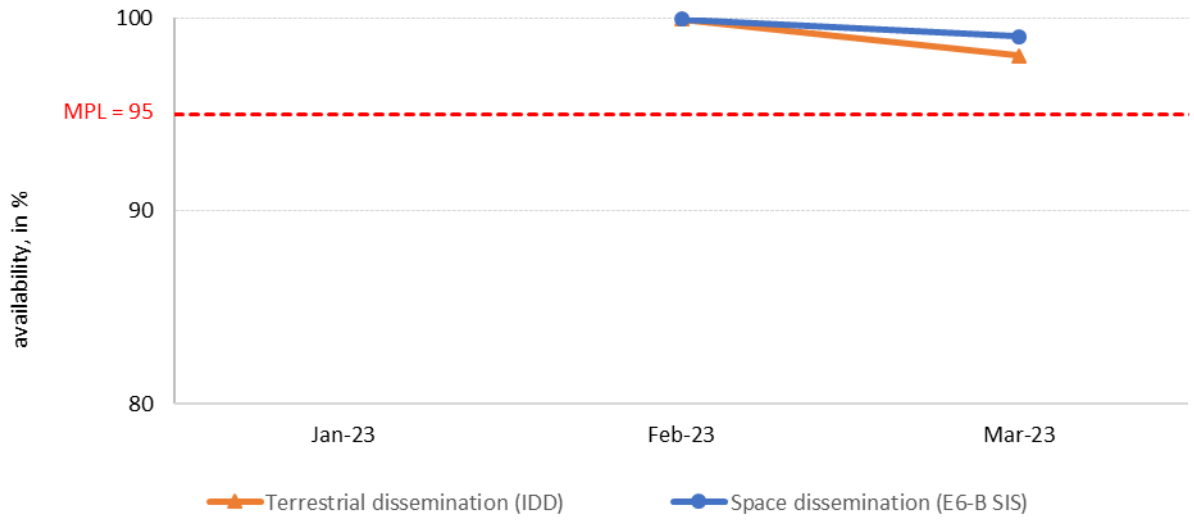

Figure 8: Galileo HAS – availability of the corrections for Galileo + GPS modes at worst (real) measurement site

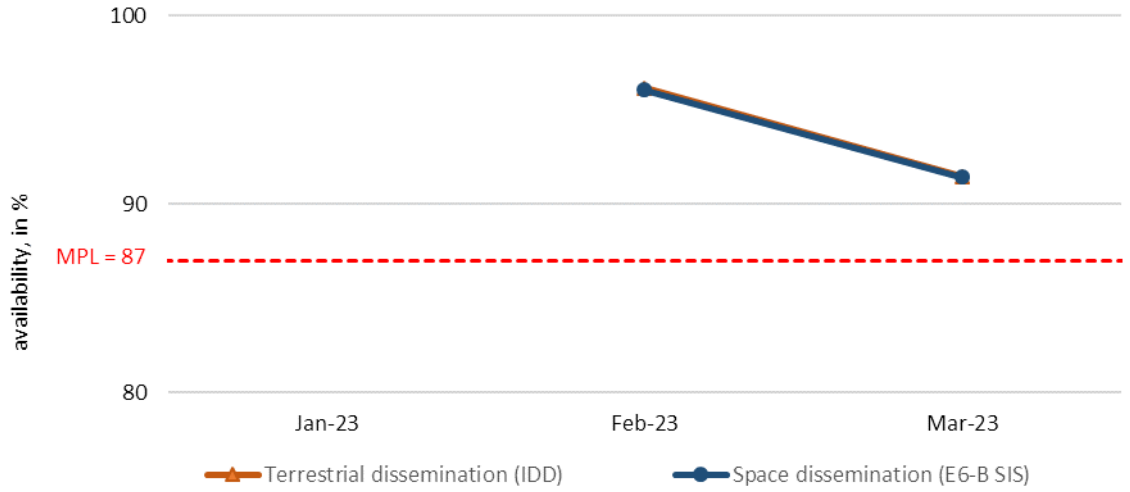

Figure 9: Galileo HAS – availability of the corrections for Galileo only modes at worst (virtual) user location in the Service area

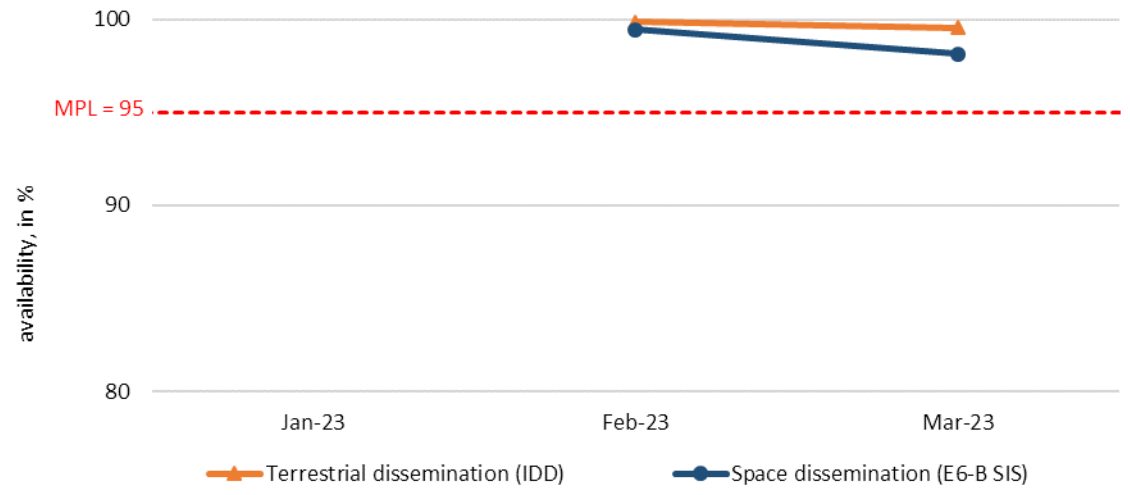

Figure 10: Galileo HAS – availability of the corrections for Galileo + GPS modes at worst (virtual) user location in the Service area

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3.3 COVERAGE OF THE HAS SERVICE

Coverage of HAS Service area was always 100% during the reporting months of February and March 2023. HAS coverage is referred to the availability of corrections via Galileo SIS and IDD, at any point inside the identified service area map.
In the current Initial Service delivery phase, the world region covered by HAS is shown in Figure 11:

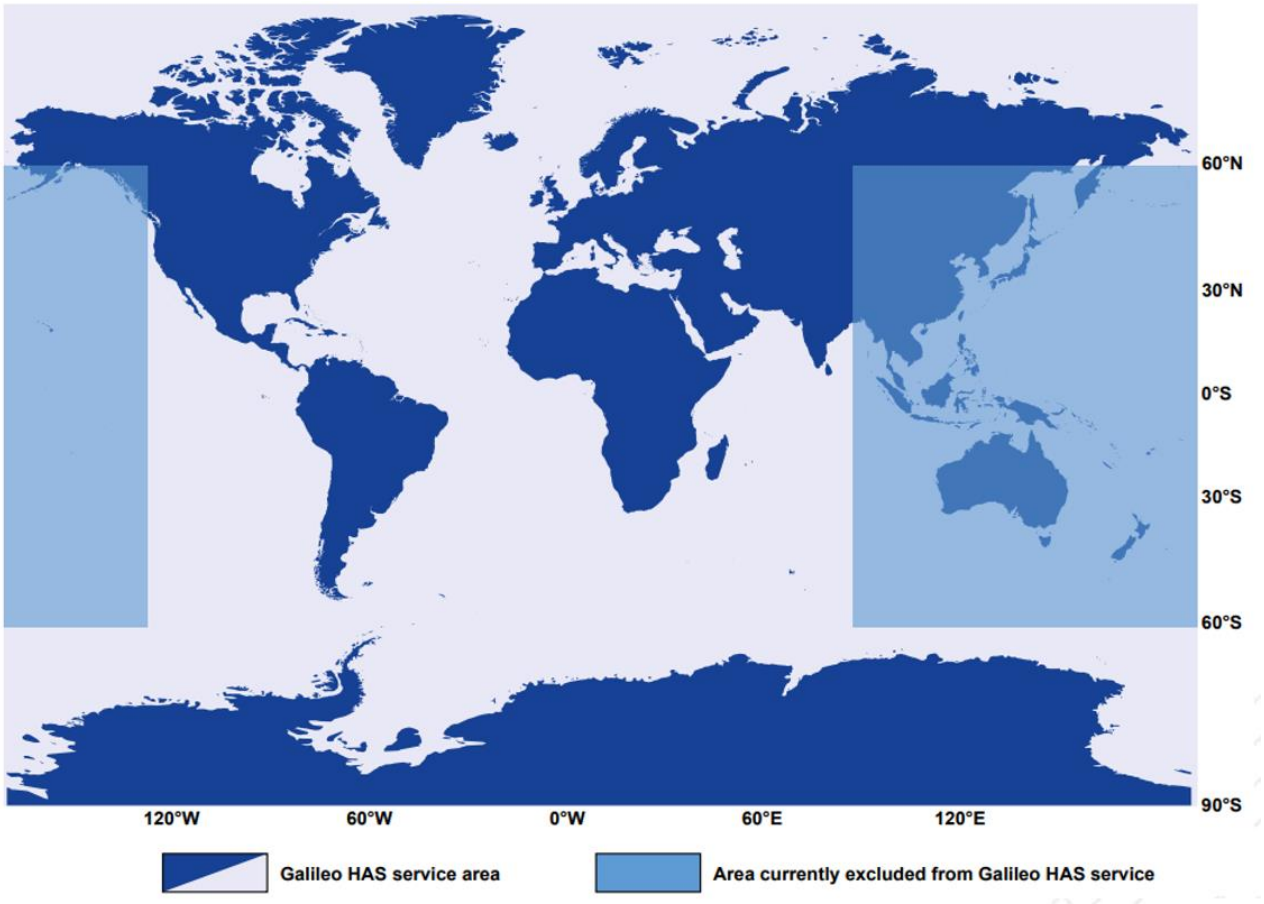

Figure 11: Galileo HAS – Service coverage area in the Initial Service delivery

Target availability is 87% in the case of “Galileo only” users, while 95% for “Galileo + GPS” ones.

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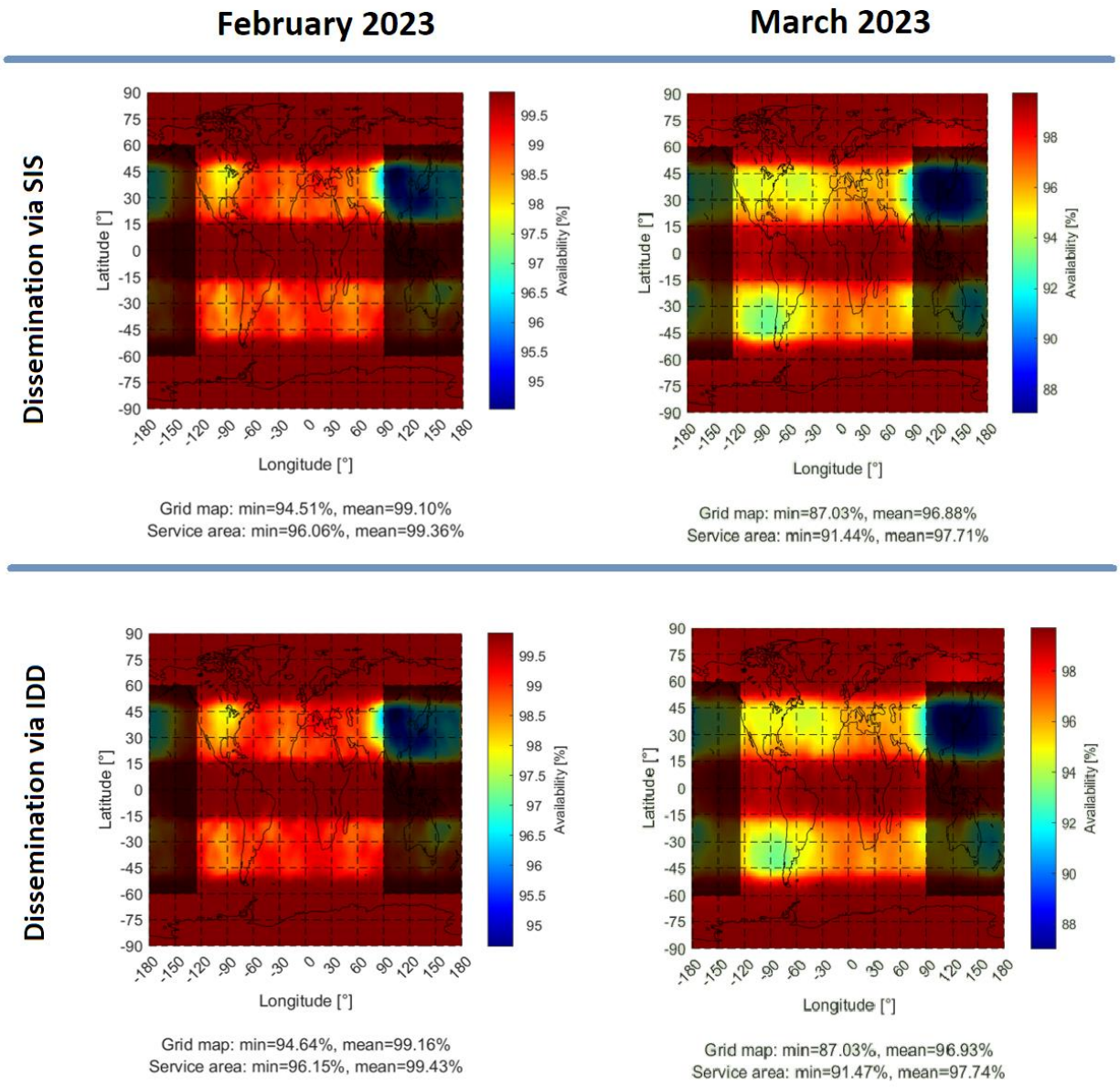

Figure 12: Galileo HAS – Availability of corrections for “Galileo only” users

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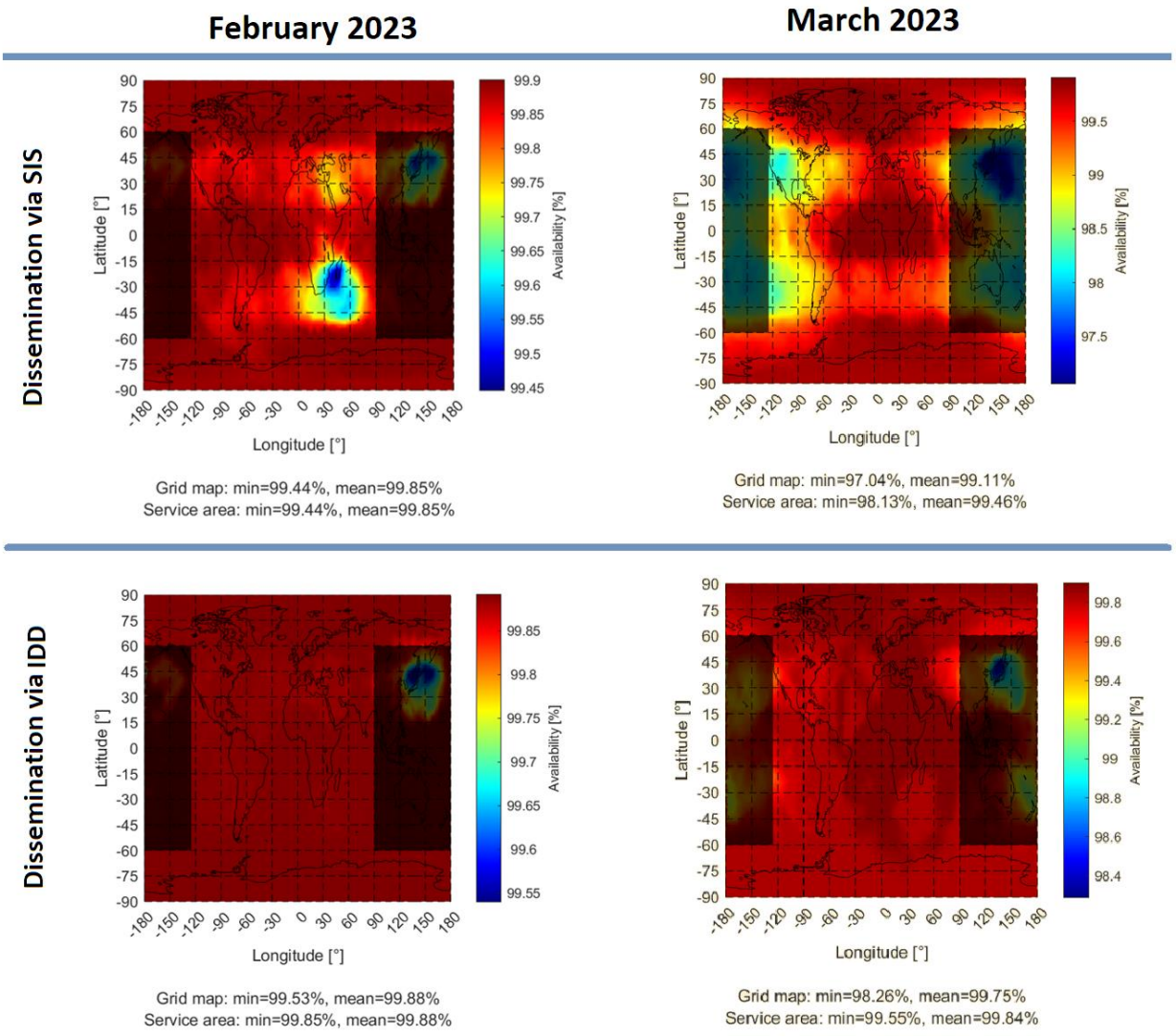

Figure 13: Galileo HAS – Availability of corrections for "Galileo + GPS" users

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4 REFERENCES

This section identifies the documents explicitly referenced in this Galileo Public Performance Report, or in any case considered of peculiar relevance for HAS users.

[SIS-ICD] European GNSS (Galileo) Open Service Signal-In-Space Interface Control Document (OS-SIS-ICD), Issue 2.0, European Union, January 2021.

[IONO] Ionospheric Correction Algorithm for Galileo Single Frequency Users, Issue 1.2, European Union, September 2016.

[OS-SDD] European GNSS (Galileo) Open Service Definition Document (OS-SDD), Issue 1.2, European Union, November 2021.

[SvNOTE #5] Galileo Service Notice #05 - Unavailability of the Galileo Auxiliary satellites GSAT0201 and GSAT0202

[SvNOTE #11] Galileo Service Note #11 - Following the successful Testing activities for the enhanced I/NAV message on GSAT0223 (E34) and GSAT0224 (E10), Galileo users are notified that, until July 2023, the on-board S/W of all FOC satellites need to be upgraded, enabling the improvement.

[SvNOTE #13] Galileo Service Notice #13 - EU announced the delivery of Galileo High Accuracy Service (HAS), open access and free of charge, based on the provision of precise corrections (for orbit, clock, code biases) transmitted by the Galileo E6-B signal in space component. HAS aims to improve the accuracy of respective engineering data transmitted with Navigation messages, allowing users to achieve a Precise Point Positioning (PPP) solution for their coordinates.

[HAS SIS-ICD] European GNSS (Galileo) HAS Signal-In-Space Interface Control Document (HAS SIS-ICD).

[HAS IDD-ICD] European GNSS (Galileo) HAS Internet Data Distribution Interface Control Document (available previa registration).

[HAS-SDD] European GNSS (Galileo) HAS Service Definition Document (HAS-SDD).

[OS QPR] Quarterly Performance Report for Open Service, covering the same period of this document. Please download it from the performance reports section of European GNSS Service Centre.

Previous documents are available to users through the web portal of the European GNSS Service Centre (http://www.gsc-europa.eu/).

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IMPORTANT NOTE

Since January 24th 2023, the new High Accuracy Service (HAS) has been declared from the EC.

HAS is accompanied by associated Interface Control Documents, necessary for the users to access and handle its data, which are both disseminated via SIS ([HAS SIS-ICD]) and via Internet ([HAS IDD-ICD]).

The commitment towards user domain about HAS performance is defined through the Minimum Performance Levels (MPLs) and associated target values reported in the HAS Service Definition Document ([HAS-SDD]).

Individual sections of the HAS Service Definition Document have been referenced throughout this report when referring to MPL target values and calculation methods.

For an exhaustive description of the Open Service and HAS Minimum Performance Levels (MPLs), the reader is referred respectively to the [OS-SDD] and [HAS-SDD] that are in force.

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5 LIST OF ACRONYMS

Acronym	Definition
AUL	Average User Location
BGD	Bias Group Delay (parameter delivered in the Navigation messages)
DF	(Galileo OS) dual-frequency combination (E1/E5a, E1/E5b)
DOP	Dilution of Precision
ECEF	Earth Centred, Earth Fixed frame coordinates
EUSPA	European Union Agency for the Space Programme
F/NAV	Navigation message provided by the E5a signal [SIS-ICD]
FOC	Full Operational Capability
GGTO	GST-GPS Time Offset
GMS	Galileo Mission Segment
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
G/S	Ground Segment
GSC	European GNSS Service Centre
GST	Galileo System Time
HAS	High Accuracy Service
HDOP	Horizontal Dilution of Precision
HPE	Horizontal Positioning Error
ICD	Interface Control Document
IDD	Internet Data Distribution (HAS)
I/NAV	Navigation message provided by the E1-B and E5b signals [SIS-ICD]
IS	(Galileo) Initial Services
MPL	Minimum Performance Level
MAC	Message Authentication Code
NAGU	Notice Advisory to Galileo Users
NAPA	No Accuracy Prediction Available
OLTN	OSNMA Live Test Notification
OS	(Galileo Navigation) Open Service
OSNMA	Galileo Open Service Navigation Message Authentication
PDOP	Position Dilution of Precision
SBDO	Stand-By Duty Officer

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Acronym	Definition
SDD	Service Definition Document
SDM	Service Delivery Manager
SF	(Galileo OS) single-frequency (E1, E5a, E5b)
SIS	Signal in Space
SISA	Signal In Space Accuracy
SISE	Signal In Space Error vector (4-dimensional)
SNGU	Service Notice to Galileo Users
toE	Time of Ephemeris
UTC	Universal Time Coordinated
VPE	Vertical Positioning Error
WUL	Worst User Location

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End of Document

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