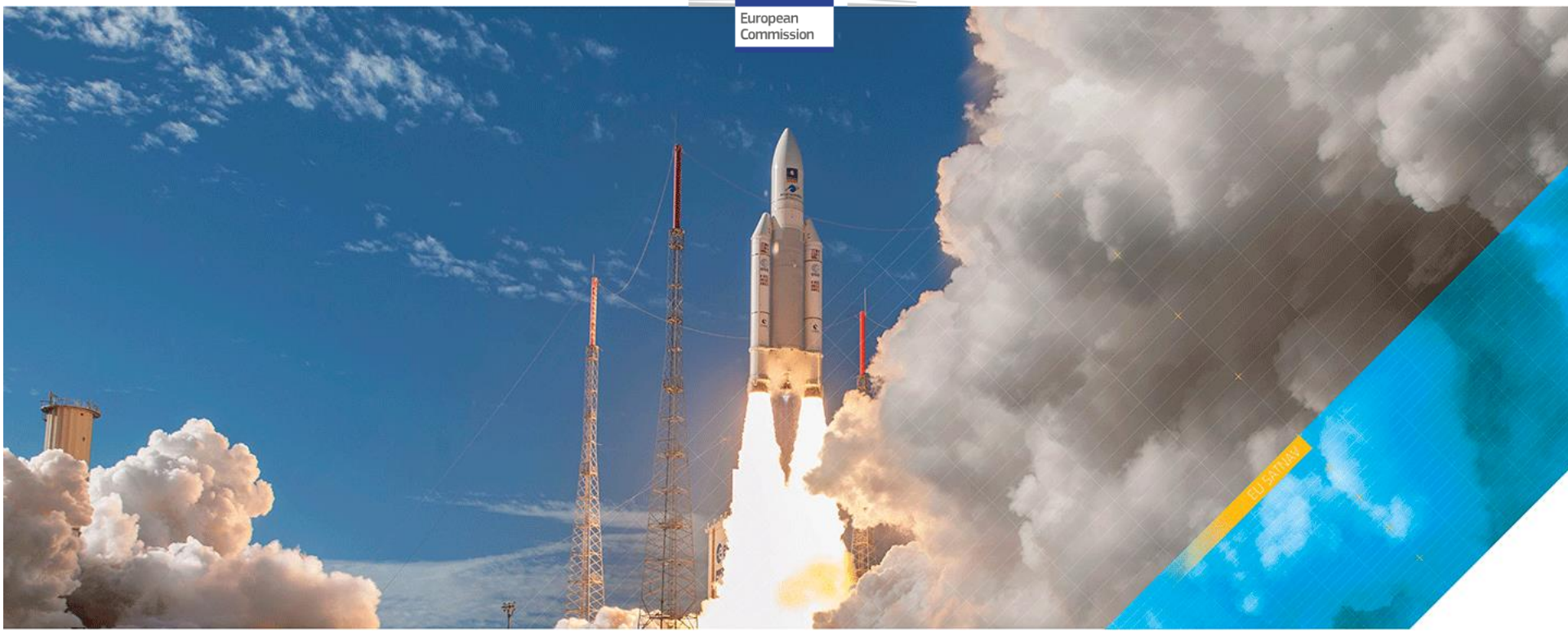

Briefing on Galileo HAS status, and possible cooperation with GPS

Dec 9 2021 U.S. PNT Advisory Board

Ignacio Fernandez-Hernandez

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- What is Galileo High Accuracy Service (HAS)
- Test results
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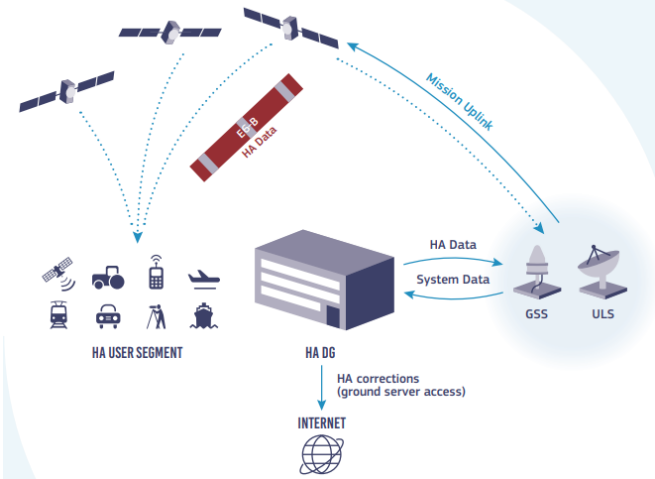
What is Galileo High Accuracy Service (HAS)

- Galileo HAS is the PPP correction service of Galileo
- It provides orbit, clock and bias corrections (code and soon phase) for Galileo and GPS
- It uses the Galileo E6-B signal (1278.75 MHz), at 448 bps, as a transmission channel
- It also uses a real-time ground channel with RTCM-like corrections
- It will transmit iono corrections (at least in Europe) to speed up convergence time



What is Galileo High Accuracy Service (HAS)

	Phase 0 SIS Testing	Phase 1 Initial Service	Phase 2 Full Service
Coverage	EU+	EU+	Global
Orbit corrections	Y	Y	Y
Clock corrections	Y	Y	Y
Code biases	Y	Y	Y
Phase biases	N	Y	Y
Galileo corrected signals	E1, E5a, E5b, E6	E1, E5a, E5b, E5, E6	E1, E5a, E5b, E5, E6
GPS corrected signals	L1, L2P	L1, L2C	L1, L2C, L5
Horizontal accuracy requirement 95%	N/A	<20 cm	<20 cm
Vertical accuracy requirement 95%	N/A	<40 cm	<40 cm
Availability	N/A	99%	99%
Convergence time requirement Global, no ionosphere (Service Level 1)	N/A	<300 s	<300 s
EU, ionosphere corrections (Service Level 2)	N/A	N/A	<100 s
Ground channel	N	Y	Y
Ground reference stations	14 (GSS)	14 (GSS)	To be defined
Max. sat. downlinks (448 bps)	20 (ULS Ant.)	20 (ULS Ant.)	To be defined
Authentication	N	N	Y
Start	**2020**	**2022**	**2024+**

Test results: corrections accuracy

- Results from Sept 2020, but representative of current performance
- Aggregate (all satellites, all epochs) RMS error *after* HAS corrections:

Constellation	Radial (N), RMS [cm]	Along (T), RMS [cm]	Across (W), RMS [cm]	1D RMS [cm]	Clock-StdDev (1-Sigma)[ns]
Galileo	3.2	6.9	5.1	5.3	0.15 (4.5 cm)
GPS	3.2	9.9	4.9	6.6	0.26 (8 cm)

$$RMS_{1D} = \sqrt{\frac{RMS_N^2 + RMS_T^2 + RMS_W^2}{3}}$$

- Per-satellite SISE, Average and 95%, Galileo E1-E5a (as per Gal SDD, global avg.):

Sat	E12	E24	E09	E04	E08	E30	E13	E07	E15	E11	E26	E33	E03	E31	E02	E36	E27	E25	E21	E05	E19	Gal all-sat avg.
Avg [m]	0.057	0.045	0.067	0.059	0.047	0.039	0.032	0.029	0.029	0.083	0.042	0.05	0.047	0.028	0.037	0.047	0.038	0.038	0.035	0.064	0.056	**0.046**
P95 [m]	0.118	0.076	0.167	0.114	0.079	0.069	0.061	0.055	0.055	0.186	0.071	0.1	0.111	0.075	0.06	0.108	0.082	0.088	0.073	0.149	0.103	**0.095**

$$SISE_{GlobalAverage}(t) = \sqrt{0.96910 \cdot R(t)^2 + CLK(t)^2 + 0.01545 \cdot (A(t)^2 + C(t)^2) + 1.96881 \cdot CLK(t) \cdot R(t)}$$

- Per-satellite SISE, Average and 95%, GPS L1C/A-L2P (as per Gal SDD, global avg.):

Sat	G15	G11	G09	G03	G22	G17	G18	G13	G12	G20	G21	G27	G19	G24	G05	G28	G31	G07	G10	G30	G16	G32	G06	G25	G01	G26	G08	GPS all-sat avg.
Avg[m]	0.055	0.097	0.056	0.069	0.051	0.066	0.101	0.069	0.056	0.052	0.057	0.095	0.124	0.066	0.042	0.06	0.072	0.043	0.093	0.15	0.066	0.05	0.116	0.058	0.093	0.089	0.081	**0.075**
P95[m]	0.11	0.426	0.107	0.148	0.1	0.229	0.239	0.155	0.102	0.113	0.107	0.19	0.193	0.137	0.078	0.102	0.117	0.08	0.285	0.224	0.129	0.096	0.2	0.153	0.169	0.196	0.15	**0.16**

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$SISE_{GlobalAver}$

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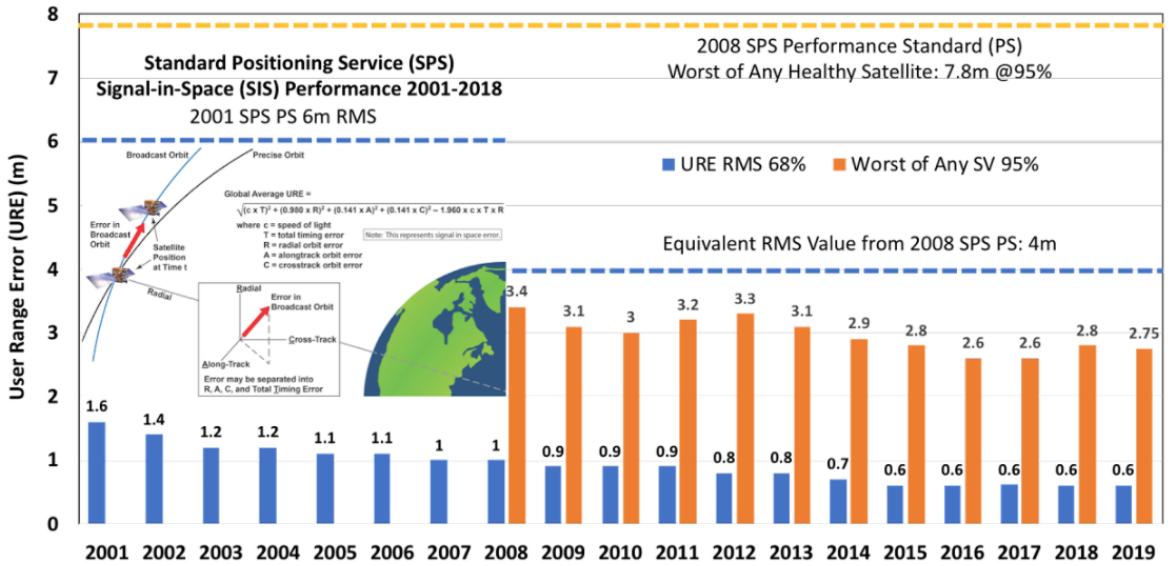

Figure 1.19: Standard Positioning Service (SPS) Signal-In-Space (SIS) ranging errors (SISRE) performance from 2001 to 2019. The steady decreasing error indicates improving accuracy over the time period.

Source: Chapter 1 "Introduction, Early History, and Assuring PNT (PTA)" Bradford Parkinson, Y. Jade Morton, Frank van Diggelen, James Spiler Jr., From: "Position, Navigation, and Timing Technologies in the 21st Century", Morton, van Diggelen, Spilker, and Parkinson. IEEE-Wiley 2020.

Test results: corrections accuracy

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Sat	E12	E24	E09	E04	E08	E30	E13	E07	E15	E11	E26	E33	E03	E31	E02	E36	E27	E25	E21	E05	E19	Gal all-sat avg.
Avg [m]	0.057	0.045	0.067	0.059	0.047	0.039	0.032	0.029	0.029	0.083	0.042	0.05	0.047	0.028	0.037	0.047	0.038	0.038	0.035	0.064	0.056	**0.046**
P95 [m]	0.118	0.076	0.167	0.114	0.079	0.069	0.061														0.103	**0.095**

$$SISE_{GlobalAverage}(t) = \sqrt{0.96910 \cdot R(t)^2 + CLK}$$

- Per-satellite SISE, Average and 9

Sat	G15	G11	G09	G03	G22	G17	G18	G13	G12	G08	GPS all-sat avg.
Avg[m]	0.055	0.097	0.056	0.069	0.051	0.066	0.101	0.069	0.056	0.081	**0.075**
P95[m]	0.11	0.426	0.107	0.148	0.1	0.229	0.239	0.155	0.102	0.15	**0.16**

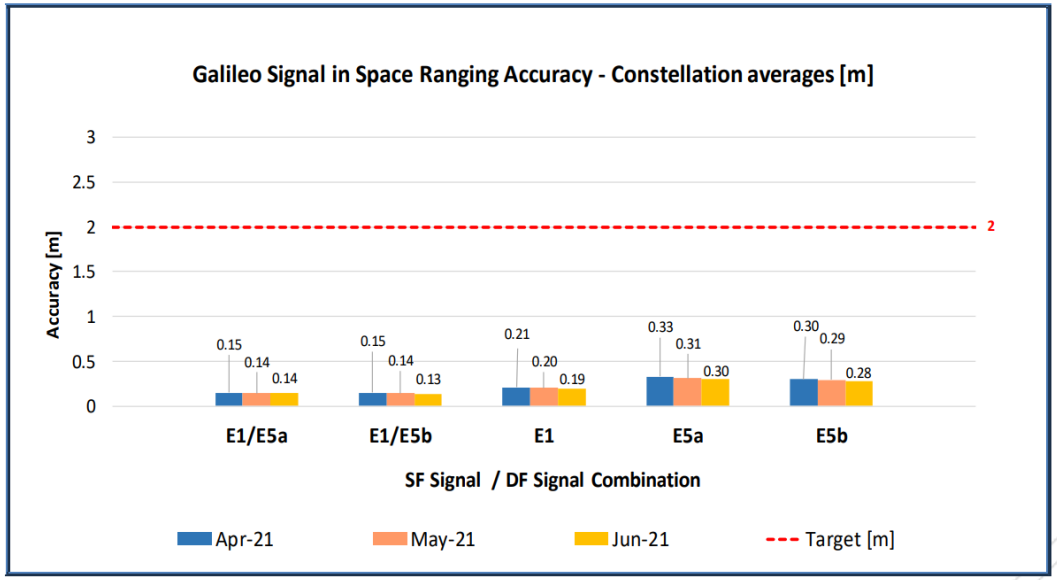
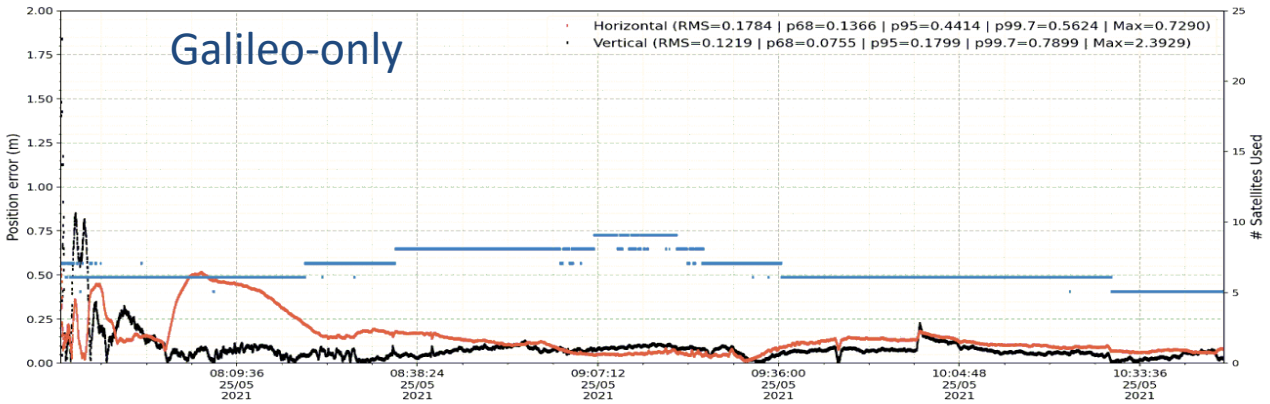
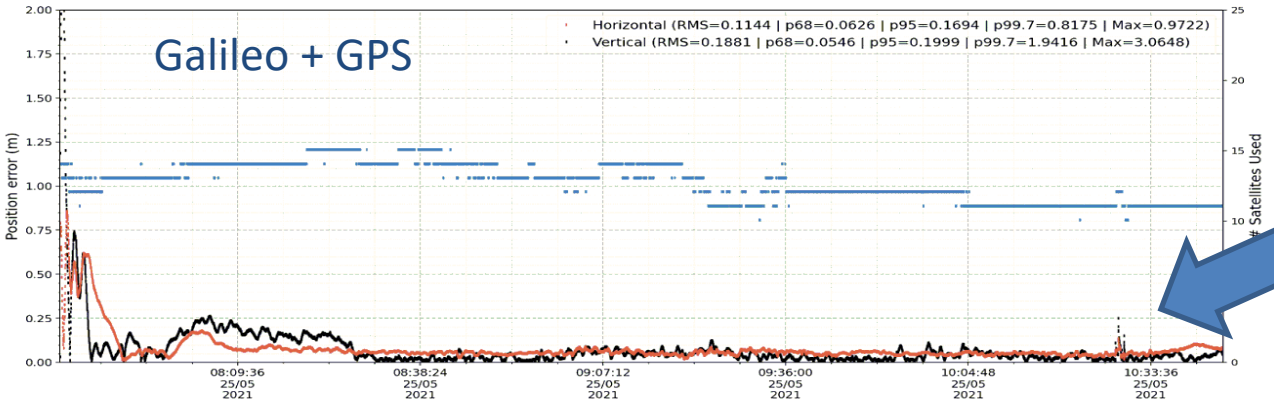


Figure 8 : Monthly Galileo SIS Ranging Accuracy (95th percentile) "over all satellites" (constellation average), measured during the reporting period

Test results: position accuracy

- HAS (demo) PPP results **with real signal-in-space**, 25th May 2021:
  - Clock update rate: 10 seconds
  - Orbit update rate: 50 seconds
  - Corrections for Gal I/NAV (E1/E5b iono free) and GPS LNAV (L1C/A-L2P iono free). Orbit correction to be improved by some cm but small impact in user
  - No code or phase biases
- Location: GMV, Tres Cantos, Spain
- Topcon CR-G5 Antenna, Septentrio AsteRx4, GMV Magic PPP
- Iono-free, floating ambiguity solution





Results after convergence

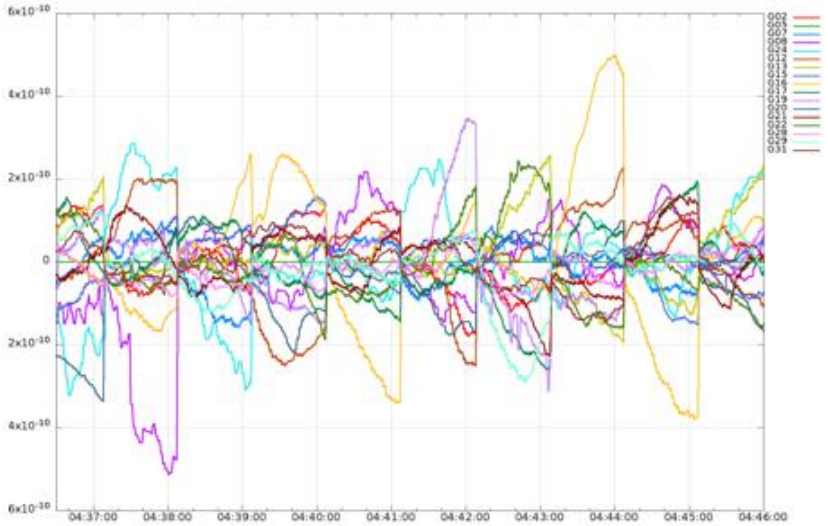
GNSS used	HPE (95%) [m]	VPE (95%) [m]
Galileo	0.162	0.182
Galileo + GPS	0.089	0.078

Ripple seems due to GPS IIR,IIR-M clocks

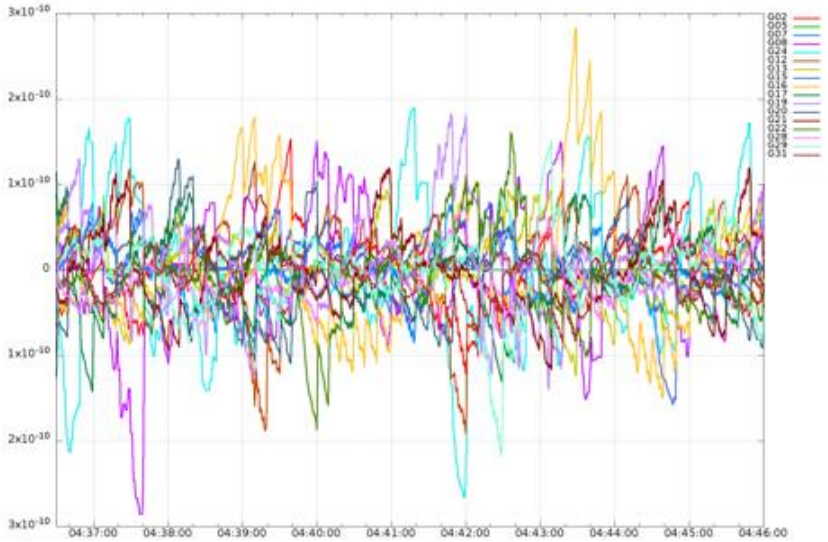
GPS IIR, IIR-M

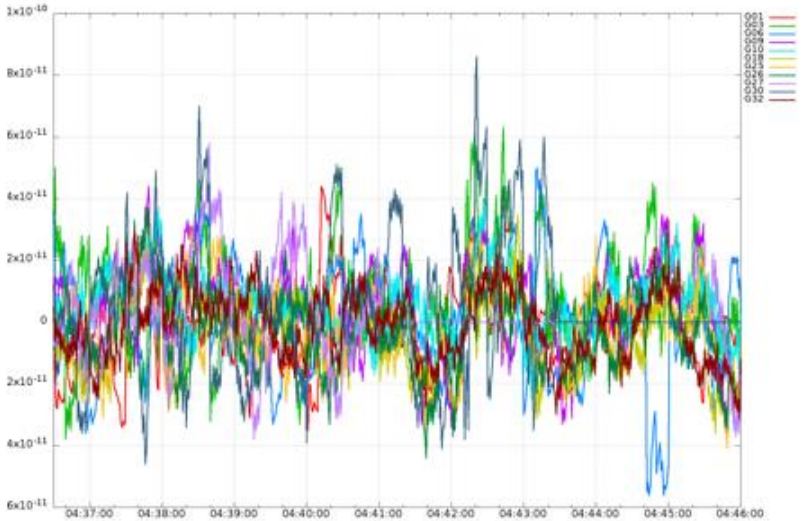
GPS IIF, III

60s



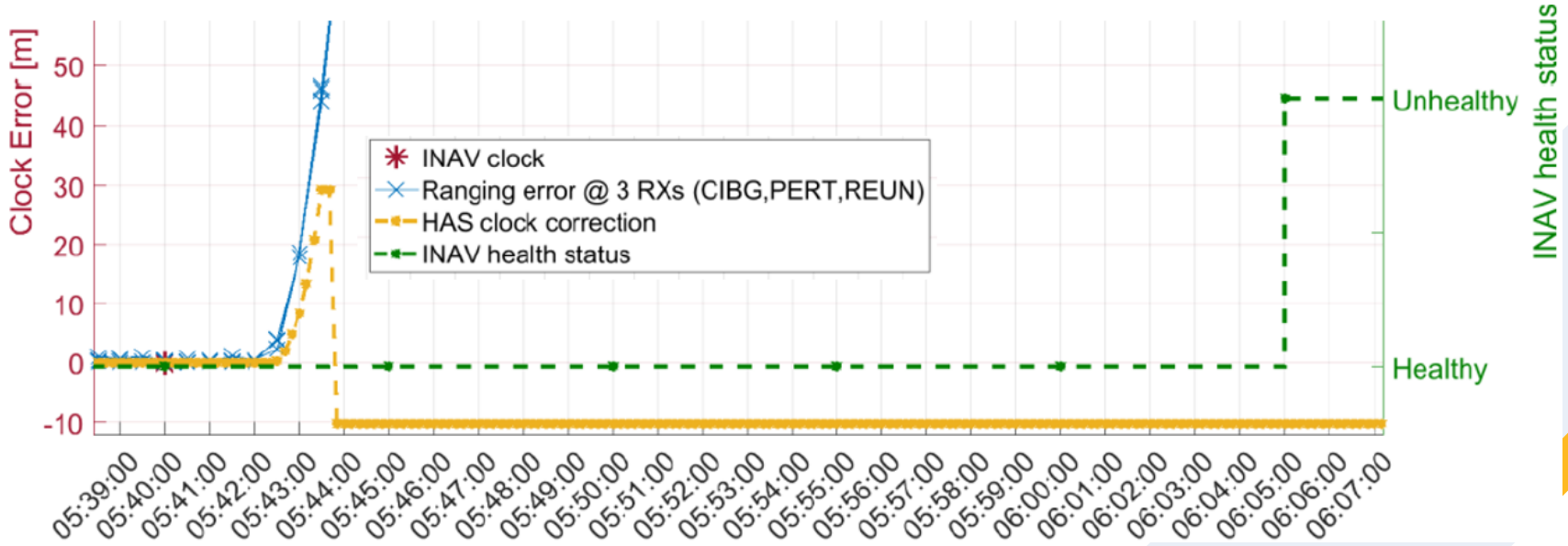
10s





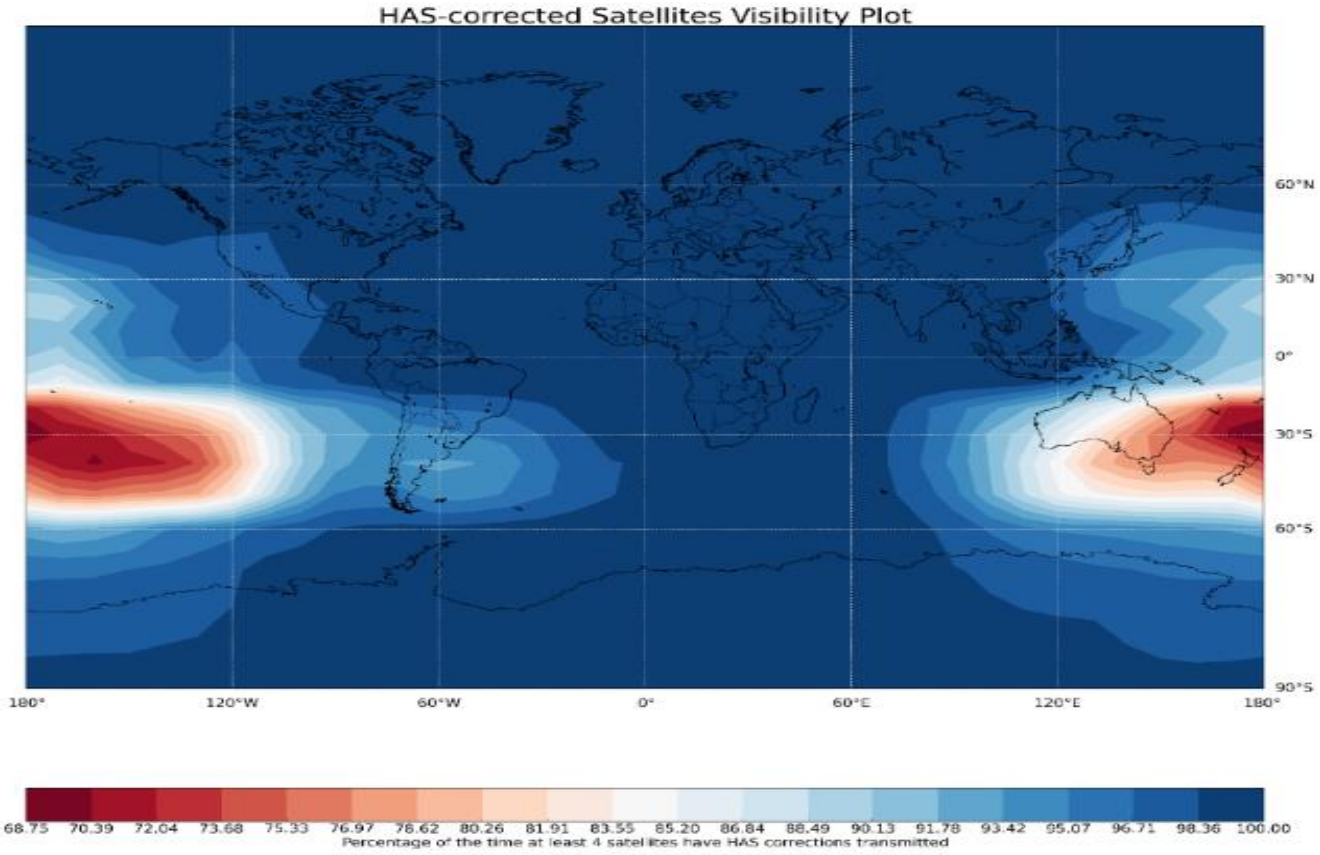
GPS reconstructed clock errors for blocks IIR, IIR-M, IIF and III, with a 60-second and 10-second update rate

HAS clock corrections E01-GSAT0210, 5/9/21 (E1E5b)



Source: I. Martini et al. “Satellite Anomaly Detection with PPP Corrections: A Case Study with Galileo’s High Accuracy Service”, ITM 2022

Test results: coverage



- N_u = 4, N_{DoC} = 2: 4 satellites visible by the user, with each satellite visible by at least 2 stations
- To be improved soon with more stations
- Galileo-only. Does not include GPS

Next steps

- **Dec-Jan 2021**: Internal testing of some recent upgrades
- **Q1 2022**: Publish HAS Phase 1 ICD
- **Q1-Q4 2022**: SIS in «test mode», including service validation tests (non-continuous broadcast)
- **Q3 2022**: Ground correction service available
- **Q4 2022**: Phase 1 service declaration (EU+ coverage, Galileo & GPS L1/L2, ground message, no iono message yet), SIS «operational»
- **2024 (TBC)**: Phase 2 declaration, including GPS L1/L5, HA iono message in Europe. Global coverage. Data authentication
- **2030+**: G2G HAS with improved performance

More information:
https://www.gsc-europa.eu/sites/default/files/sites/all/files/Galileo_HAS_Info_Note.pdf

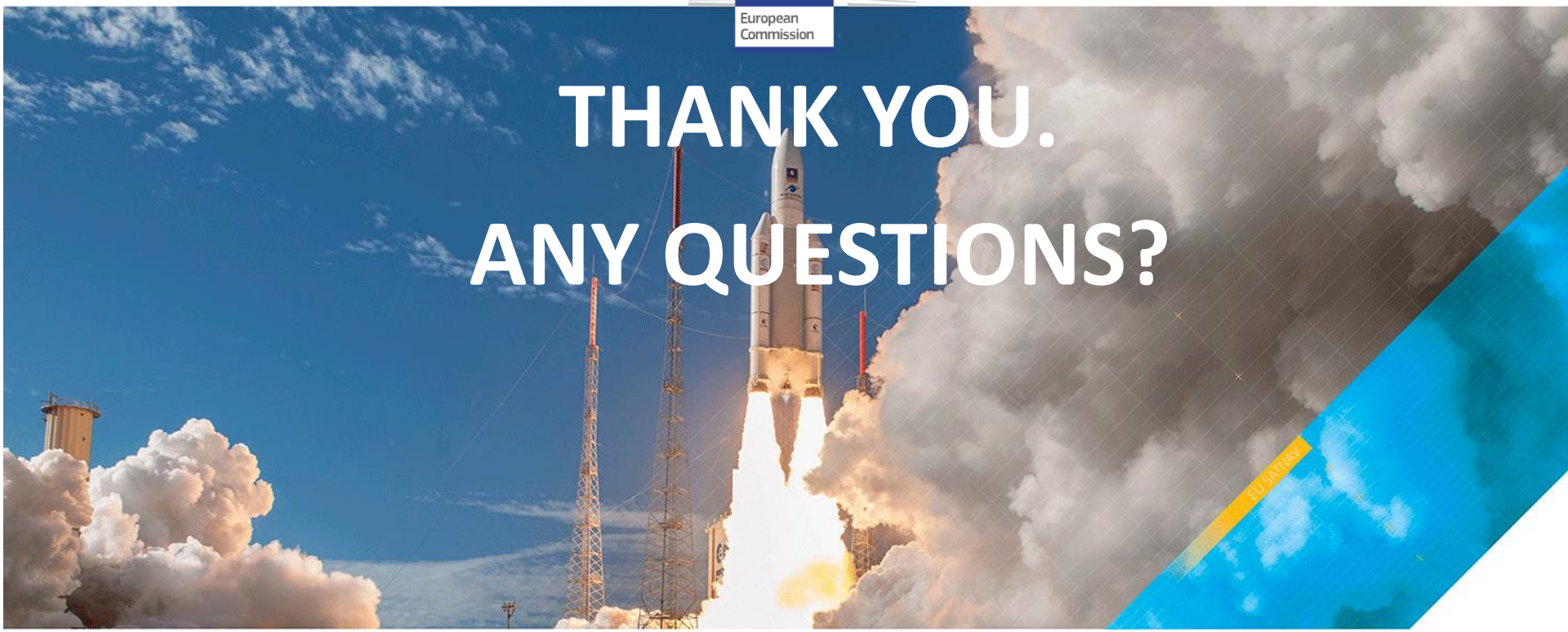
I. Fernandez-Hernandez, A. Chamorro-Moreno, S. Cancela-Diaz, J. D. Calle-Calle, P. Zoccarato, D. Blonski, T. Senni, J. d. Blas, C. Hernández, J. Simón and A. Mozo, "Galileo High Accuracy Service: Initial Definition and Performance," GPS Solutions, TBD.
I. Martini, M. Susi, M. Paonni, M. Sgammini, I. Fernandez-Hernandez, "Satellite Anomaly Detection with PPP Corrections: A Case Study with Galileo's High Accuracy Service", ITM 2022

Acknowledgements: S. Cancela, A. Chamorro

Possible US-EU cooperation?

- ***Cooperation topics must be discussed in the context of the EU-US Cooperation Agreement, currently under review between EC DEFIS (B3) and US State Dept.***

- HAS topic can be added to the work programme (currently not covered)
- Topics to address could be similar to those in other areas (e.g. ARAIM): i.e. examine possible synergies, ease interoperability, improve performance for the end users…
- Discussion of other topics?



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