RÉPUBLIQUE FRANÇAISE
Liberté Égalité Fraternité

CNES CENTRE NATIONAL D'ÉTUDES SPATIALES

GALILEO

ORGANISATION, PERFORMANCES, SERVICES DE HAUTE PERFORMANCE/SÉCURISATION

UNIVERSITÉ GRENOBLE ALPES

CYBERSKILLS WORKSHOP
DISTRIBUTION SÉCURISÉE DU TEMPS ET SYSTÈMES SPATIAUX

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14/11/2024

SOMMAIRE

01
ORGANISATION

CHRONOLOGIE PASSÉE

26 mai 2003
Début du projet

Décembre 2005
Premiers satellites de tests

23 novembre 2007
Réorganisation du programme

août 2014
Premiers satellites opérationnels

15 décembre 2016
Premiers services opérationnels

aujourd'hui
25 satellites utilisables
2 en cours de mise en service

Objectif
27 opérationnels
+3 de réserve

CHRONOLOGIE FUTURE

G2G
Approvisionnement
par lots

Segment sol
Evolution

Nouveaux services
Nouveaux concepts

Introduction progressive
Nouveaux services
Meilleurs performances

G2G
Initial Operational Capability
IOC ~2030
Full Operational Capability
FOC ~ 2035

UNE GOUVERNANCE EUROPÉENNE, SOUVERAINE ET CIVILE

Programmes EGNSS

Système de positionnement par satellites européen

European Geostationary Navigation Overlay Service
Système d'augmentation par satellite européen

Vision politique

European Parliament

European Council

Règlement ESPACE
Galileo & EGNOS

Gestion du programme

European Commission
- Program security
- Funding

Implémentation

European Space Agency
- Design système
- Maintenance & Améliorations
- R&D pour l'évolution

European Union Agency for the Space Program (ex GSA)
- Fournisseur de service

Industriels
- support et ingénierie système
- segment spatial
- mission
- contrôle
- lancements
- opérations de la constellation

Opérateurs
- Services Galileo (space opal)
- SAR Galileo
- EGNOS (ESSP)

LE RÔLE DU CNES

Programmes EGNSS

Vision politique

Règlement ESPACE
Galileo & EGNOS

Gestion du programme

Participation aux Groupes de Travail
évolution des systèmes et services futurs

Implémentation

Support indépendant à la surveillance
des performance des systemes EGNSS

Industriels

Support aux industriels

MINISTÈRE
DES ARMÉES
ET DES ANCIENS
COMBATTANTS
Liberté
Égalité
Fraternité

CDE
SGDSN
DGA

SEGMENTS ET LOTS

85 M€

- Support et ingénierie système, architecture et conception
  - Thales Alenia Space (TAS)
  - Services de soutien du système pour l'intégration et la validation du système Galileo

1000 M€

- Segment spatial
  - OHB-System AG, filiale d'OHB Technology AG (OHB.XE) (1er lot)
  - Construction de 14 satellites opérationnels (1er lot)

250 M€

- Segment sol de mission
  - Thales Alenia Space (TAS)

40 M€

- Segment sol de contrôle
  - Airbus Defence and Space (ADS)

397 M€

- Lancements
  - Arianespace
  - Soyouz, Ariane 5, Falcon 9, Ariane 6

194 M€

- Opérations de la constellation de 30 satellites
  - Spaceopal

02
PERFORMANCES

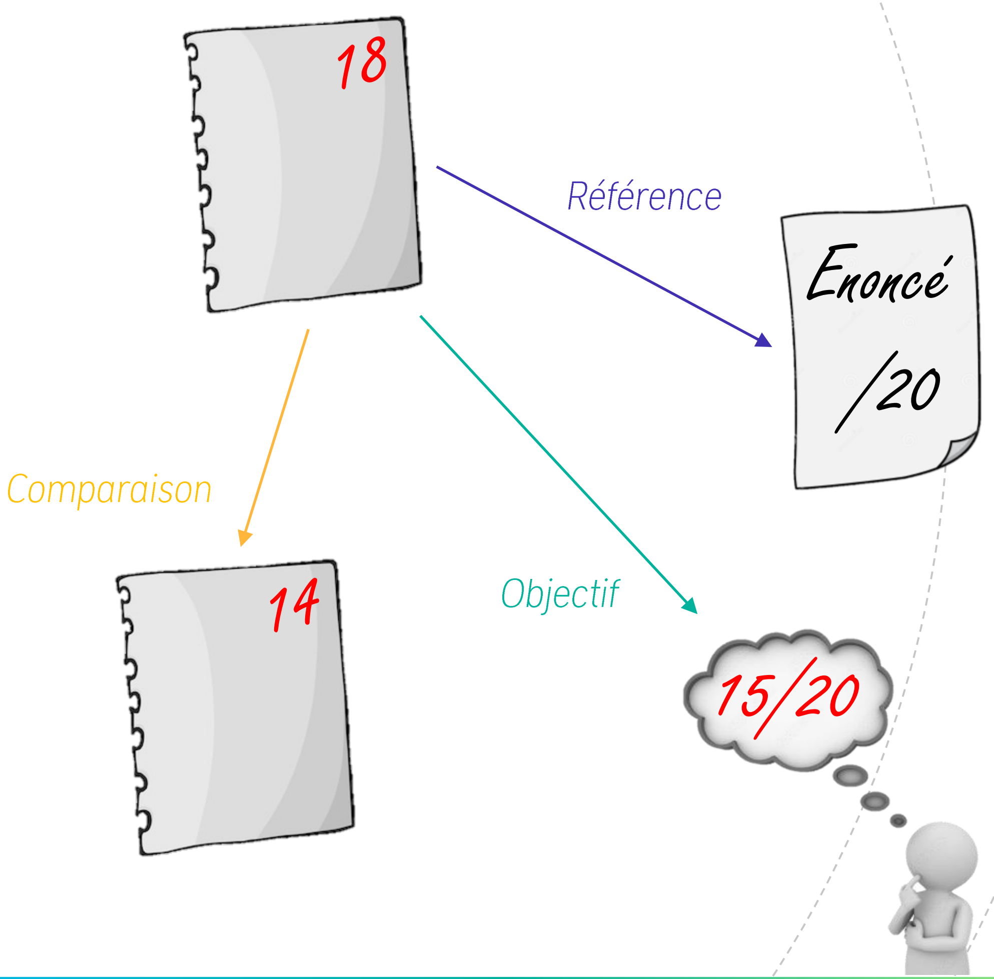
NOTION DE PERFORMANCE GÉNÉRALE

1. **Notion de résultats → quantification ou qualification de quelque chose**
   - Donner une valeur ou un adjectif qualificatif (bon, moyen, mauvais)
   - Par exemple, un élève a eu 18 à un contrôle sur table

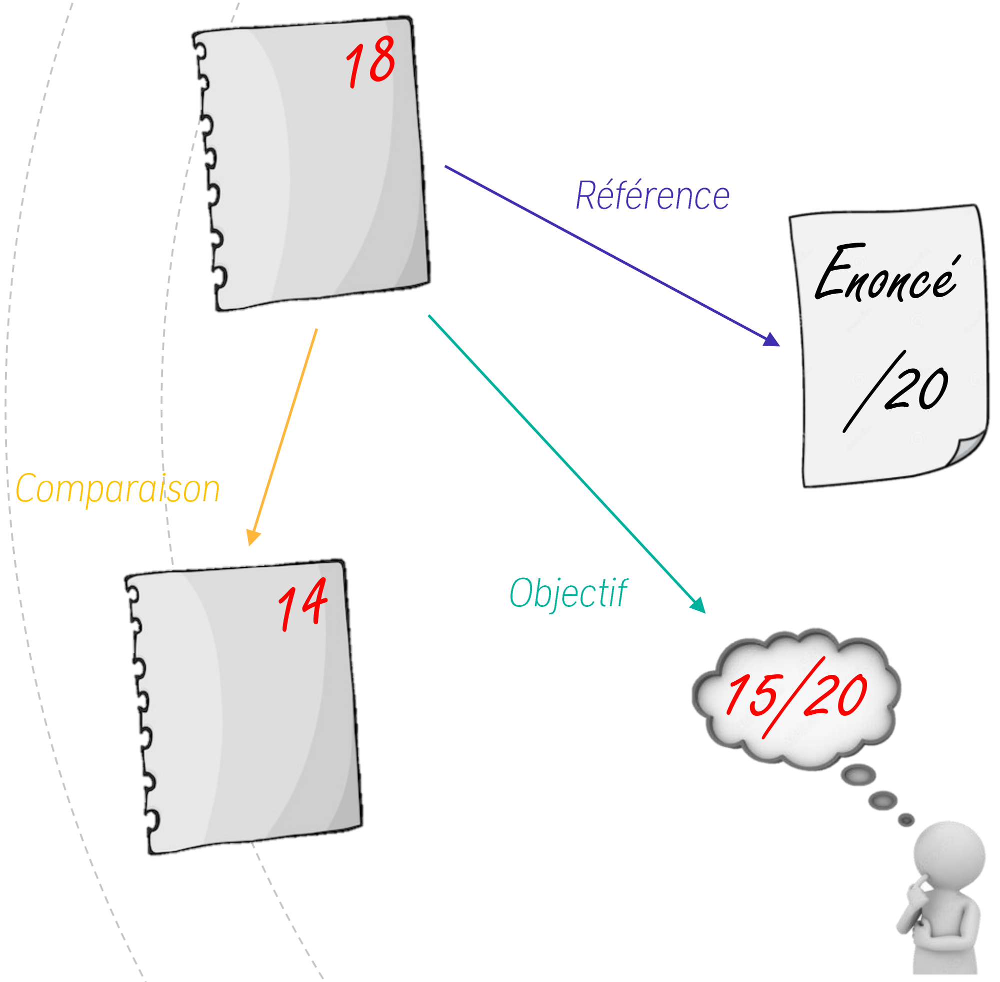
2. **Notion de référence → ce à quoi on compare le résultat**
   - « Bon » mais par rapport à quoi ? → A une référence
   - 18/20 → résultat obtenu : 18, la référence étant 20/20 (le maximum ou l'attendu)

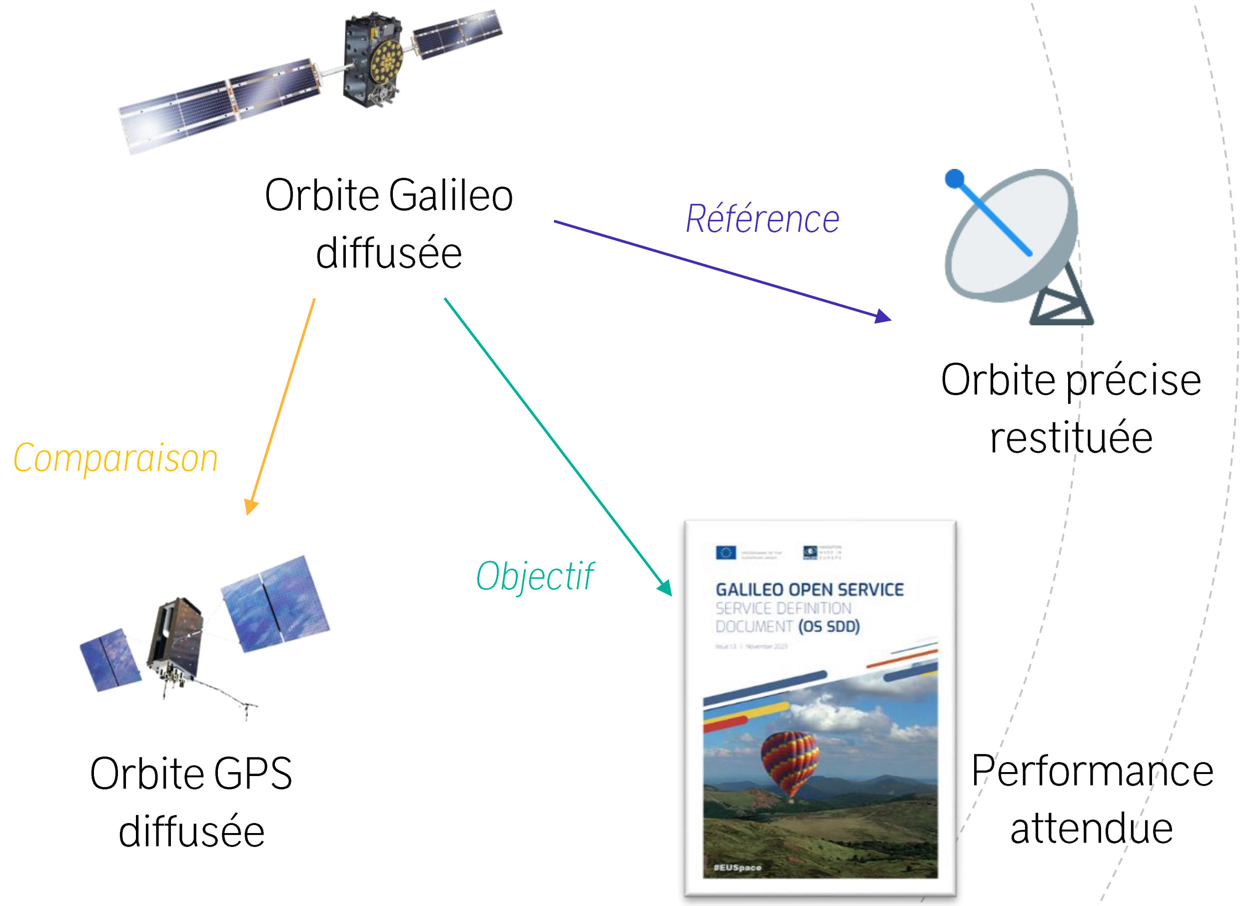
3. **Notion de comparaison → où se situe le résultat obtenu**
   - Nous avons eu 18/20, et quelqu'un d'autre à eu 14/20
   - 18/20 est donc mieux classé (notion de classement)

4. **Notion d'objectif → le résultat obtenu est-il suffisant par rapport à l'objectif fixé ?**
   - Objectif : 15/20, résultat obtenu : 18/20 → objectif validé
   - Notion de progression → amélioration du résultat par rapport à l'objectif visé



PERFORMANCE APPLIQUÉE AU GNSS





PERFORMANCES OS

>99%

Disponibilité de service partout dans le monde

<20cm

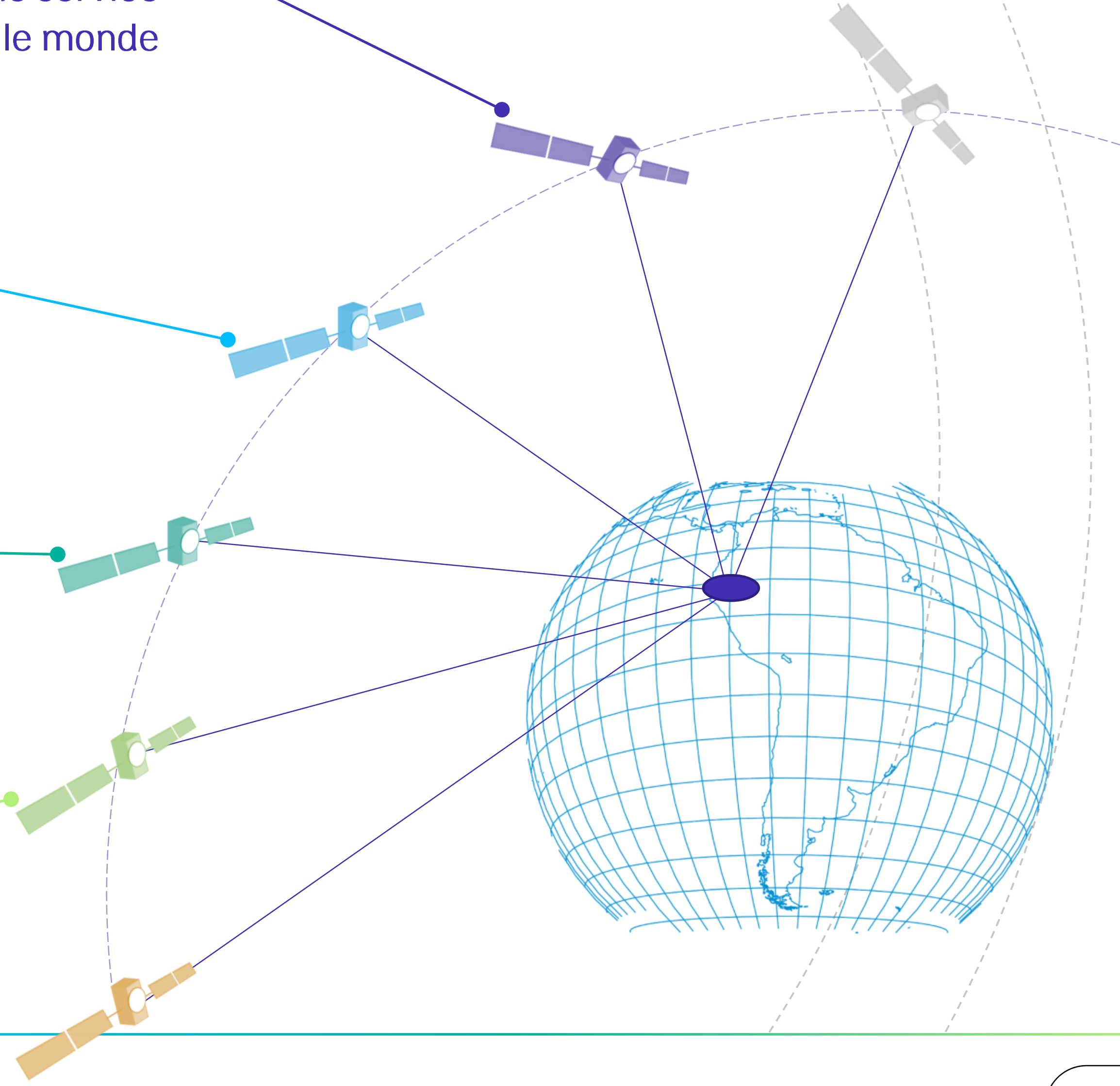
Précision des données de navigation diffusées

1m

Précision de position statique en 2D

5-10cm/s

Précision de vitesse statique en 3D



MINIMUM PERFORMANCE LEVEL
OS – SDD – 1.3
GALILEO OS ACCURACY

- For ranging services:
  - Galileo SIS Ranging Accuracy for any satellite;
  - Galileo SIS Ranging Accuracy over all satellites;
  - Galileo SIS Ranging Accuracy at higher percentiles;
  - Galileo SIS Range Rate Accuracy for any satellite.
- For timing services:
  - Galileo SIS UTC Time Dissemination Accuracy;
  - Galileo SIS UTC Frequency Dissemination Accuracy;
  - Galileo OS UTC Time Determination Accuracy.
- For positioning Service:
  - Galileo OS Positioning Accuracy

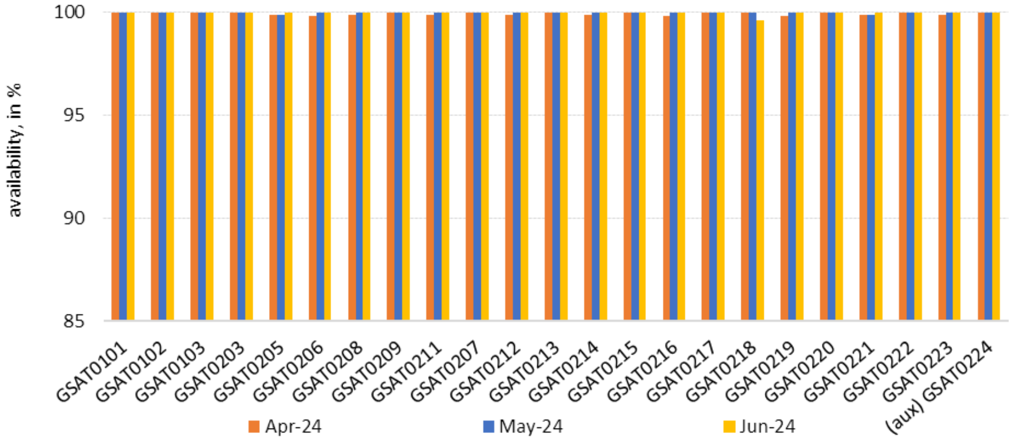
GALILEO SIS RANGING ACCURACY MPL FOR ANY SATELLITE	CONDITIONS AND CONSTRAINTS
For each DF combination: ≤ 7m (95%) Global average, Over all AODs	• Calculated over a period of 30 days • For any healthy OS SIS above a minimum elevation angle of 5 degrees • Propagation and user contributions excluded

Galileo SIS Ranging Accuracy MPL for any Satellite (DF only)

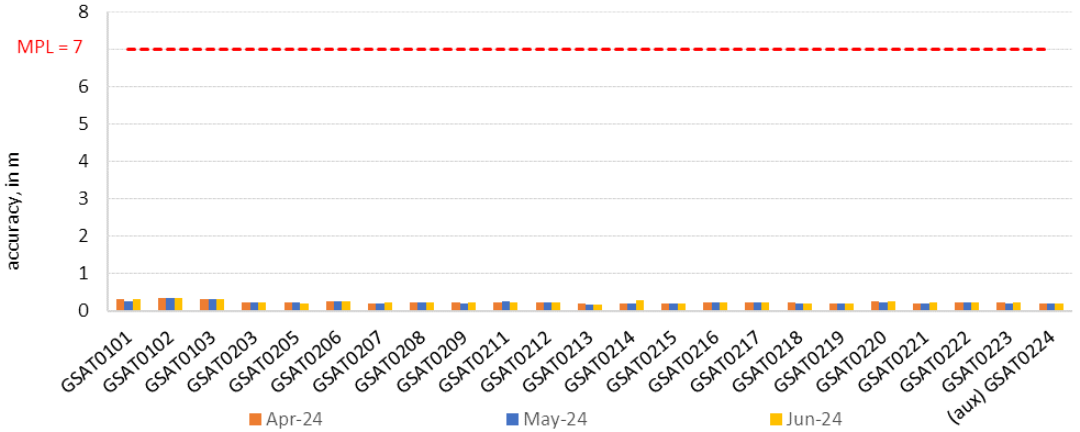
MINIMUM PERFORMANCE LEVEL
OS – SDD – 1.3
GALILEO OS AVAILABILITY

- OS availability performance
  - Per-Slot Availability.
  - Availability of the Galileo OS UTC Time Dissemination Service.
  - Availability of the Galileo OS position dilution of precision (PDOP).
  - Availability of the Galileo OS Positioning Service
  - Availability of the Galileo OS UTC Time Determination Service.

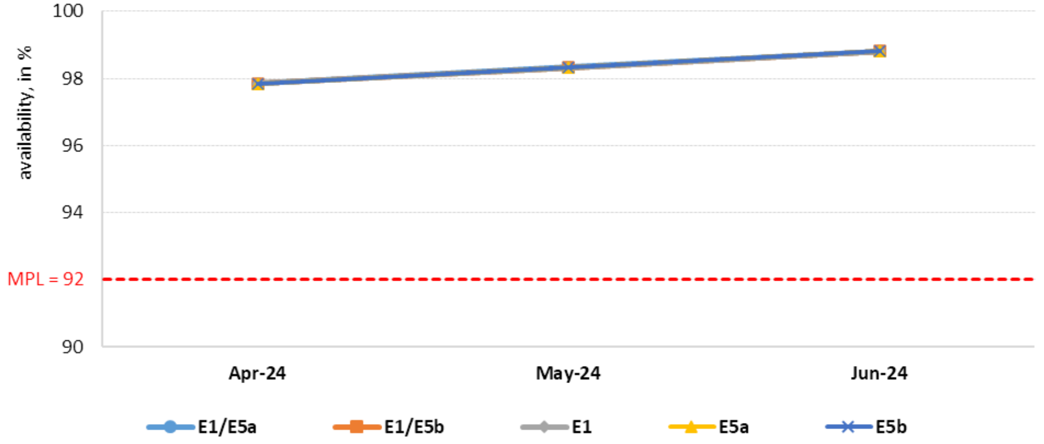
MINIMUM PERFORMANCE LEVEL
OS – SDD – 1.3



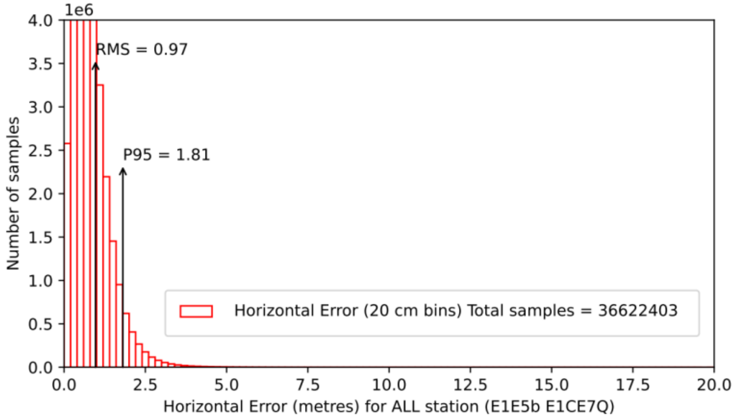
"per satellite" worst-case signal in space availability of healthy signal in space for the reporting period



monthly Galileo signal in space ranging accuracy (95th percentile) for any satellite,



"per slot" availability of healthy signal in space for the reporting period



Horizontal Positioning Error (m) for E1-E5b (DF) I/NAV

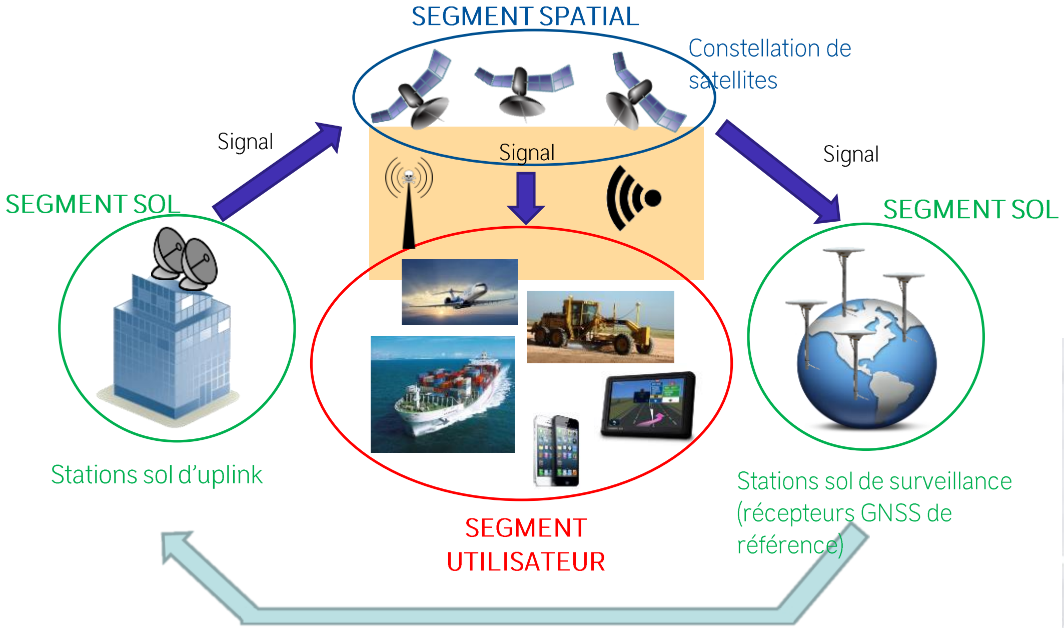
03

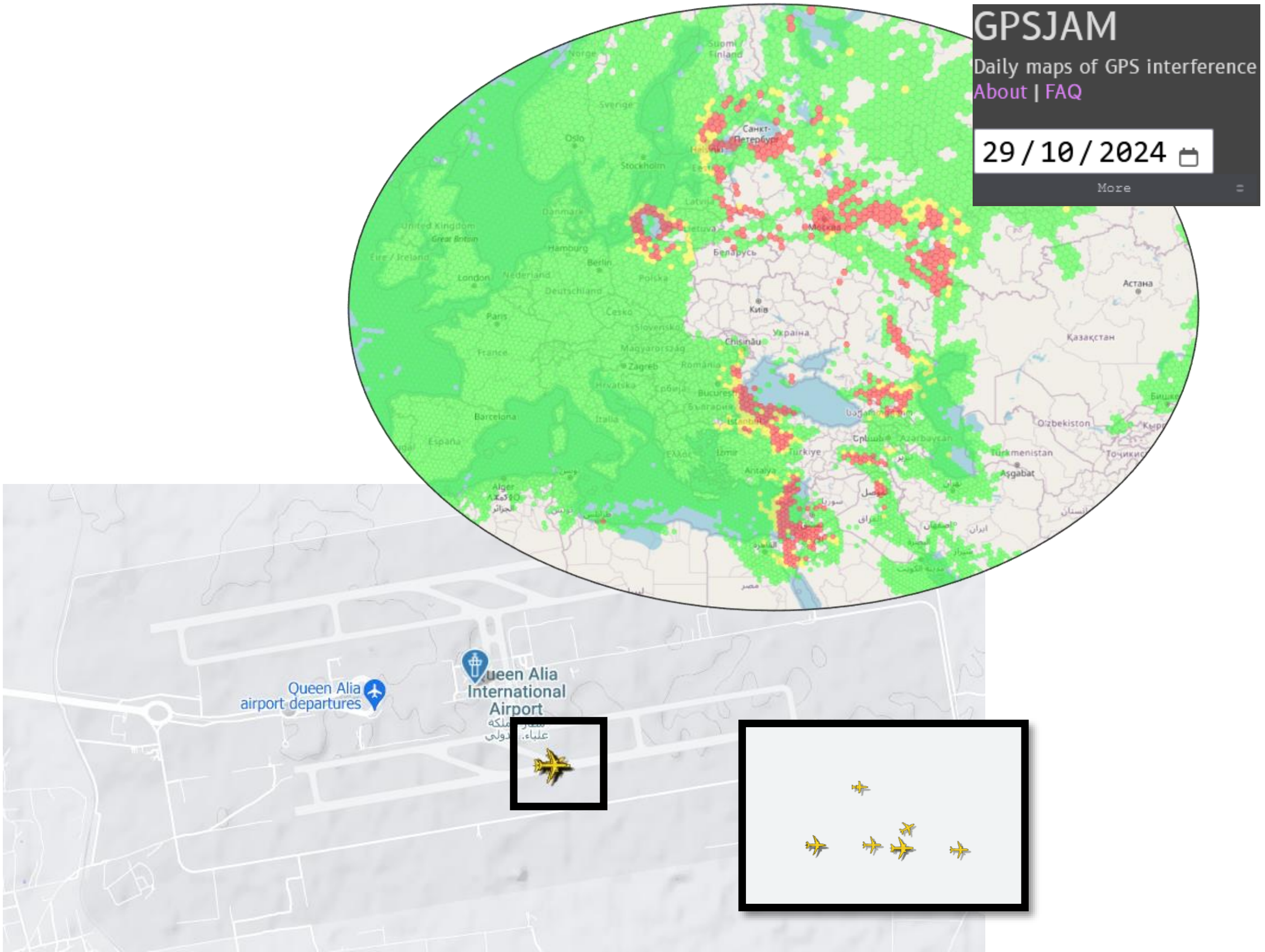
SERVICES DE HAUTE PERFORMANCE & SÉCURISATION

SERVICES DE HAUTES PERFORMANCES

OS	PRS	OSNMA	CAS SAS	HAS	TS	SAR	EWSS
2016: Initial Service; 2025: FOC	2025: FOC	2024: End testing activities	G2G	2023: Initial Service; 2026: FOC	G2G: Timing Service Level Monitoring	2016: Initial Service; 2020: Return Link Service	2025: Service Declaration
Open Service	Public Regulated Service	Open Service Navigation Message Authentication	Commercial Authentication Service Signal Authentication Service	High Accuracy Service	Timing Service	Search & Rescue	Emergency Warning Satellite Service
Free-of-charge PNT services to users around the world	Encrypted navigation service for governmental authorized users that require high continuity	Navigation Message Authentication	Authenticated positioning service by complementing the OSNMA with E6 based ranging authentication capabilities	Free-of-charge high-accuracy positioning service for higher performance than OS	Provides timing and synchronisation information Monitoring of GST and UTC products	Contributes to lifesaving missions by swiftly relaying radio beacon distress signals to relevant SAR crews	Broadcasts alerts globally to Galileo-enabled devices for enhanced emergency response and resilient risk management

BROUILLAGE / LEURAGE



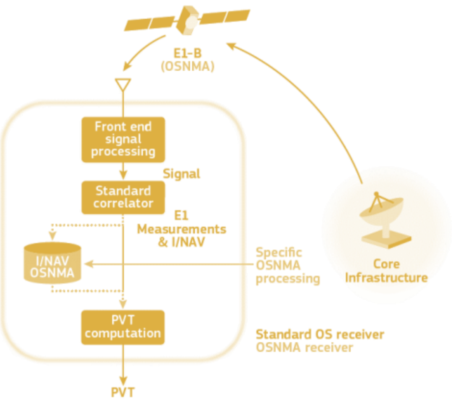


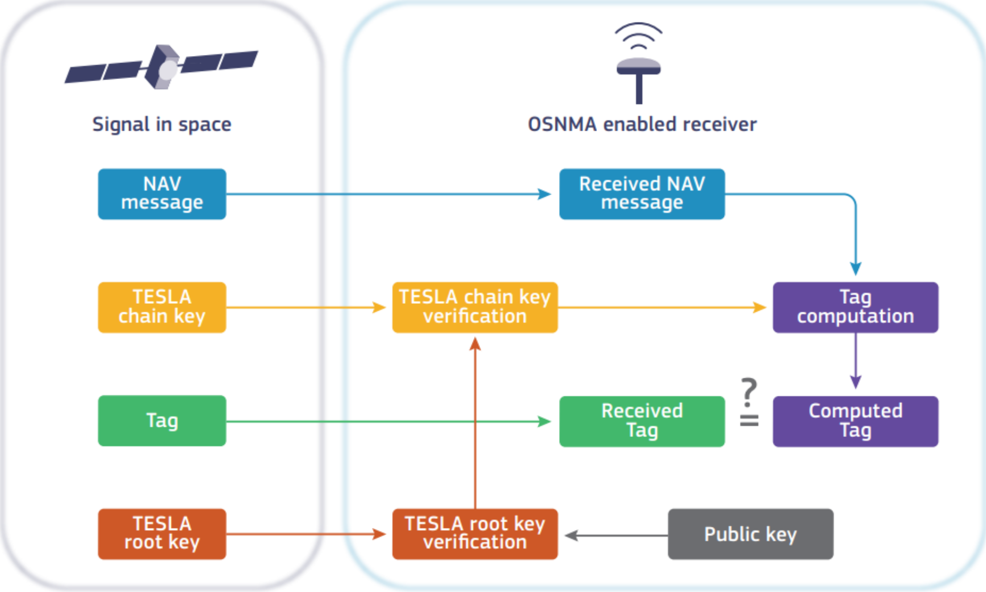
https://gpsjam.org/
https://www.flightradar24.com
http://spoofing.skai-data-services.com/

OSNMA

OPEN SERVICE NAVIGATION MESSAGE AUTHENTICATION

- Signal
  - Galileo E1B data message (I/NAV)
  - OSNMA field (40 bits)
    - HKROOT (8 bits): Global headers + Digital Signature Message (DSM)
    - MACK (32 bits): MAC + key
- TESLA protocol
  - Timed Efficient Stream Loss-Tolerant Authentication
  - Low bandwidth to transmit the authentication information
  - Tolerance to data loss (in case a message is lost)
  - Asymmetric cryptography (public-key cryptographic)
- In brief, the receiver
  - Demodulates the navigation data and a Message Authentication Code (MAC)
  - Demodulates the key required to authenticate the MAC.
    This key is broadcast by the system with some delay.
  - Authenticates the key with a previous key or from the root key
  - Re-generates the MAC key with the data, which should match the previously received MAC.

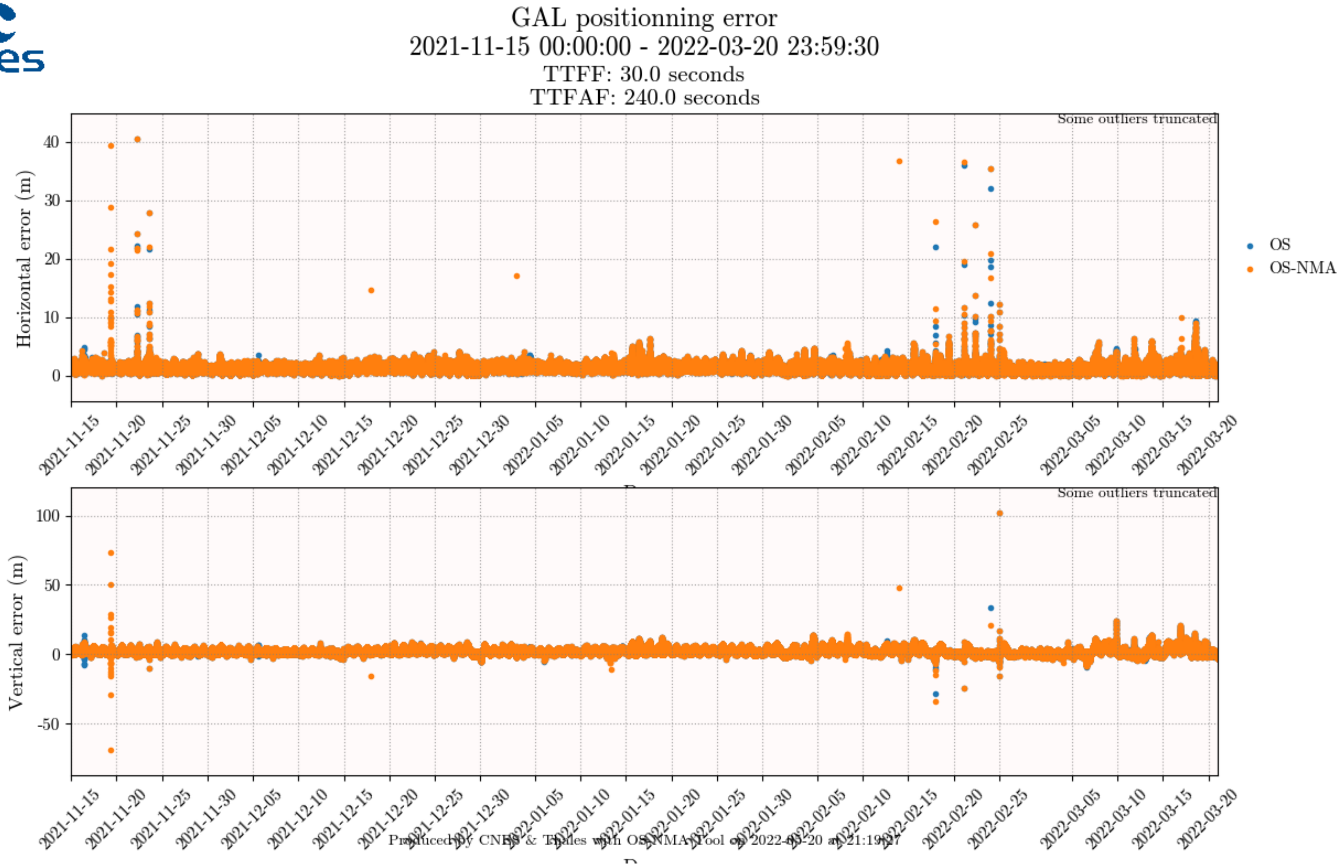


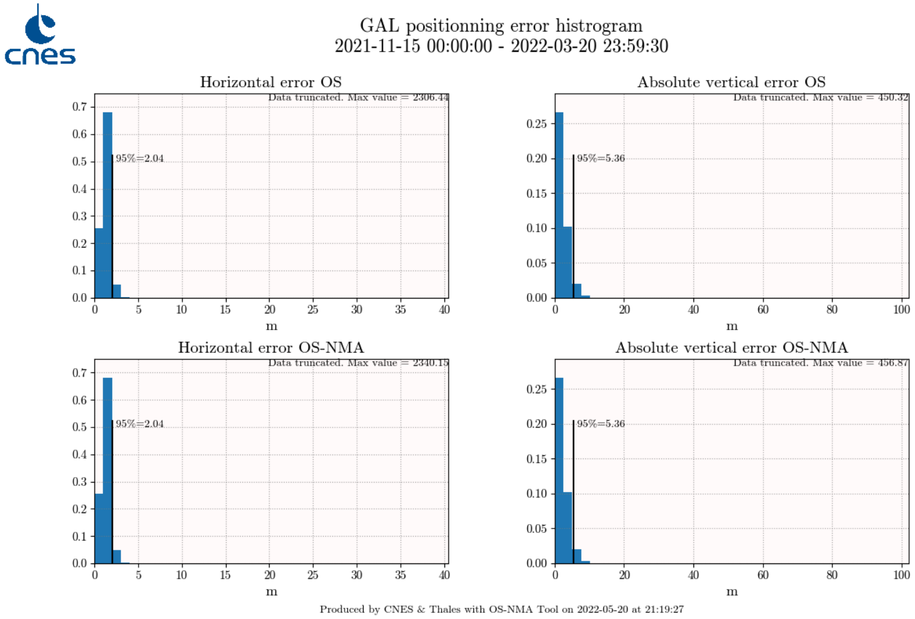


OSNMA

OPEN SERVICE NAVIGATION MESSAGE AUTHENTICATION

TEST RESULTS



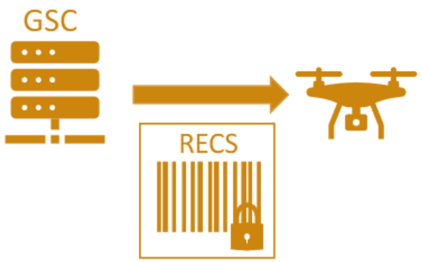


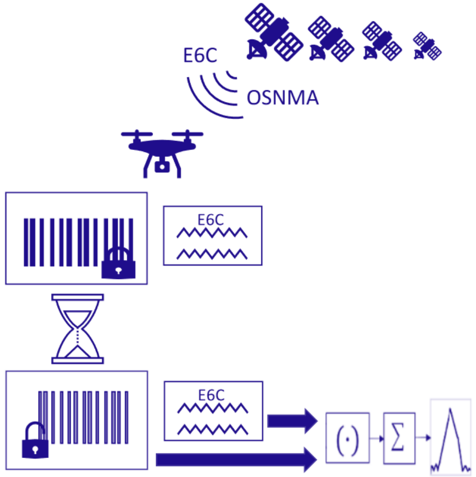
CAS
COMMERCIAL AUTHENTICATION SERVICE

- History
  - Originally « Commercial Service”, as CS Authentication
    then renamed as “Commercial Authentication Service” (CAS)
  - “Semi-assisted” concept “Assisted Commercial Authentication Service” (ACAS)
  - EU decision to provide signal authentication for free
    “Signal Authentication Service” (SAS)
- Signal
  - Galileo E6 signal consists of two components (E6B data signal & E6C pilot signal)
  - E6C pilot signal: currently unencrypted → capability is there to encrypt E6C

CAS
COMMERCIAL AUTHENTICATION SERVICE

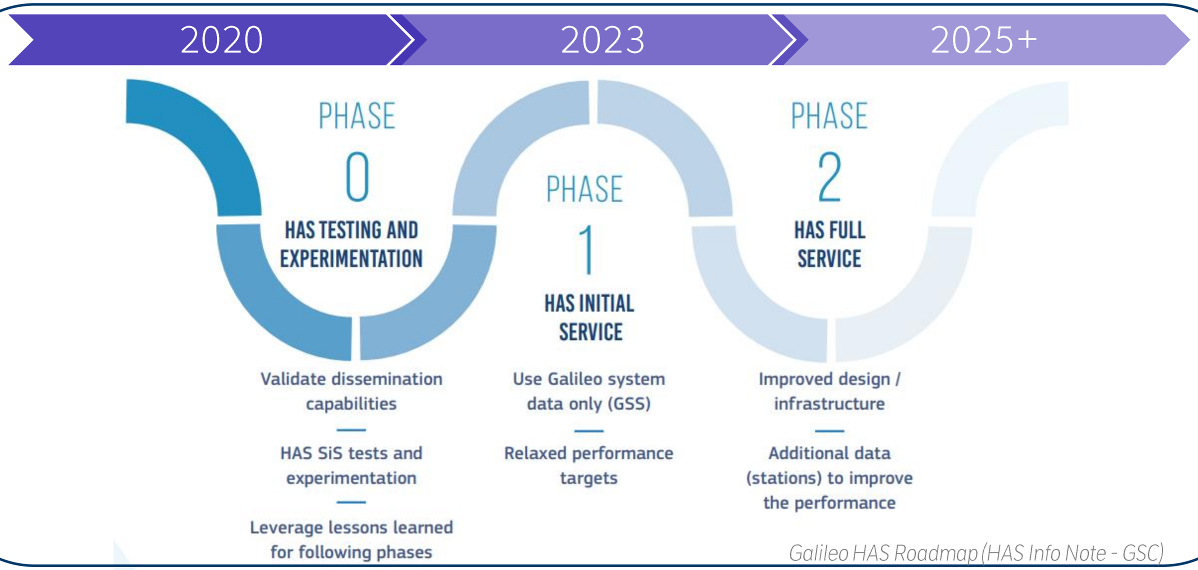
- Semi-assisted concept
  - encrypted E6C signal
  - internet service providing future fragments (snippets) of the encrypted code sequences
- Principle
  - Download some Re-Encrypted Code Sequences (RECS) from SAS server
  - Store E6C signal
  - Wait for OSNMA key and decrypt RECS with OSNMA(-based) key
    -> get the Encrypted Code Sequence (ECS)
  - Correlate ECS with snapshot
  - If OK: E6C pseudorange measurement is considered authentic





HAS
HIGH ACCURACY SERVICE

Currently
Only orbit, clock, code biases



Galileo HAS Roadmap (HAS Info Note - GSC)

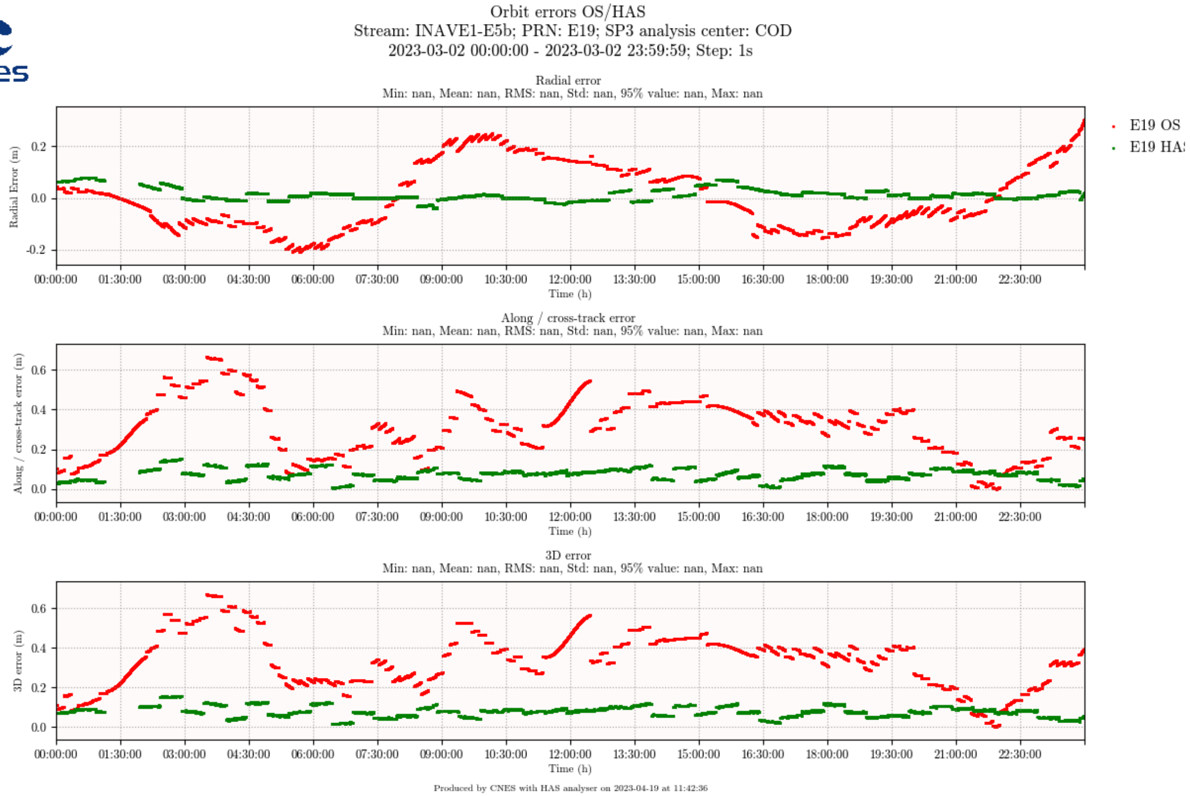
Signal
Galileo E6-B

GAL: I/NAV
GPS: LNAV

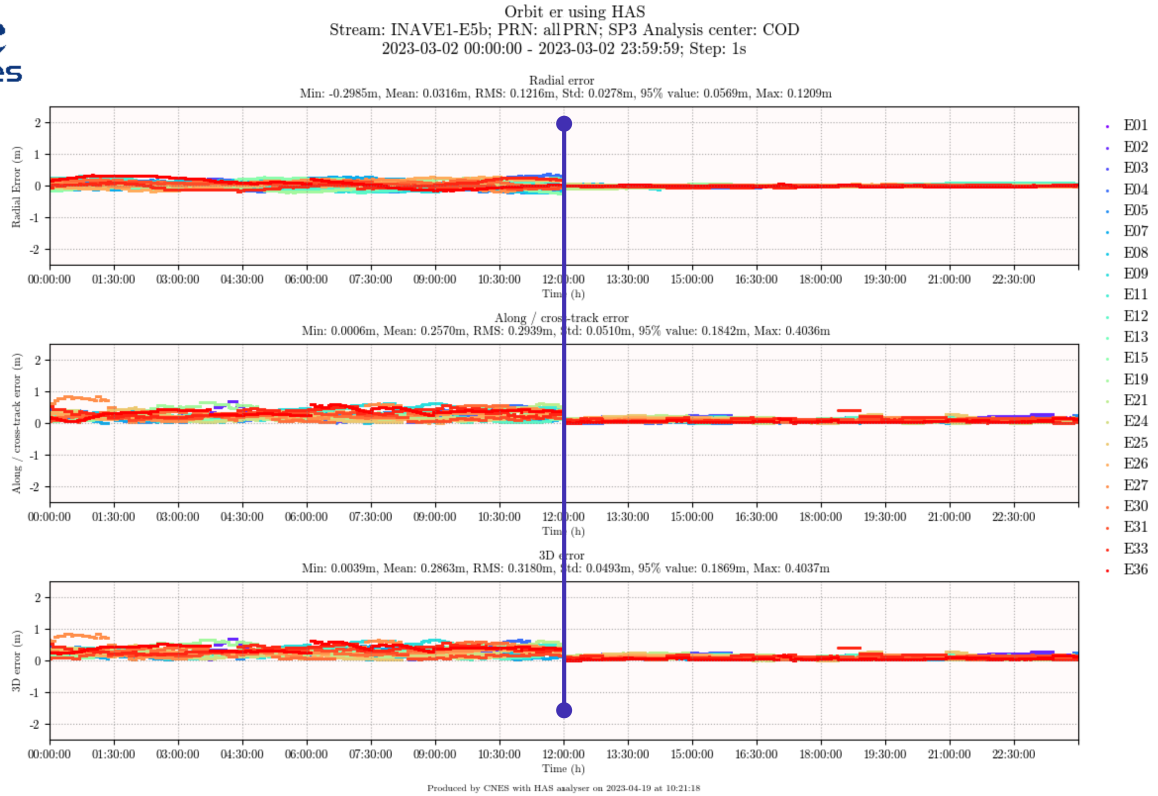
	Service Level 1 (SL1)	Service Level 2 (SL2)
Coverage	Global	European Coverage Area (ECA)
Corrections	Orbit, clock, biases (code and phase)	Orbit, clock, biases (code and phase) + atmospheric corrections
Format	Open format similar to Compact- CSSR	
Dissemination	Galileo E6B using 448 bits per satellite per second / terrestrial (internet)	
Constellations	Galileo and GPS	
Corrected Frequencies	Galileo E1/E5a/E5b/E6/E5 AltBOC GPS L1/L5/L2C	
Horizontal Accuracy (95%)	<20cm	<20cm
Vertical Accuracy (95%)	<40cm	<40cm
Convergence Time	<300s	<100s
Availability	99%	99%
User HelpDesk	24/7	24/7

HAS

HIGH ACCURACY SERVICE INITIAL SERVICE



Evolution of OS vs HAS orbit error for PRN E19



Evolution of OS vs HAS orbit error for all Galileo PRN

Performances of Galileo HAS satellite orbit corrections – 1st to 14th March 2023

3D orbit	OS	HAS	MPL HAS
Galileo	0,39	0,13	≤ 20cm

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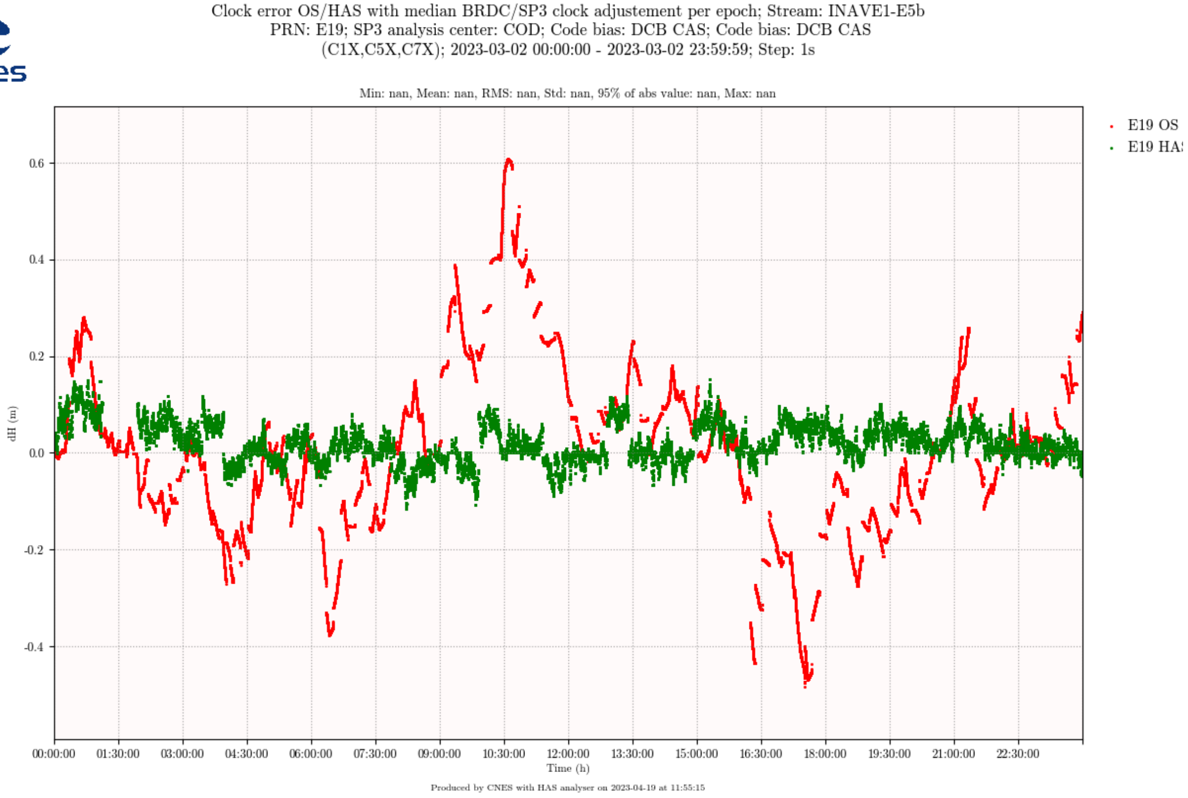
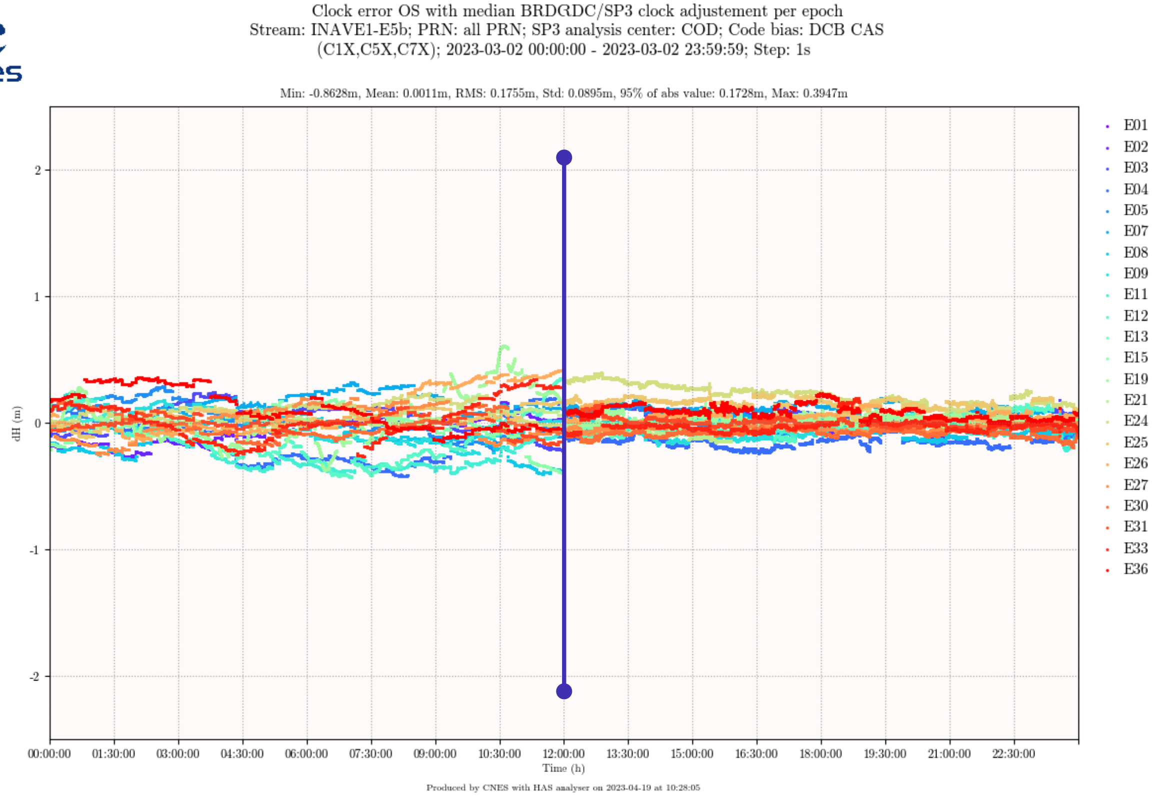
HAS
HIGH ACCURACY SERVICE
INITIAL SERVICE



Evolution of OS vs HAS clock error for PRN E19



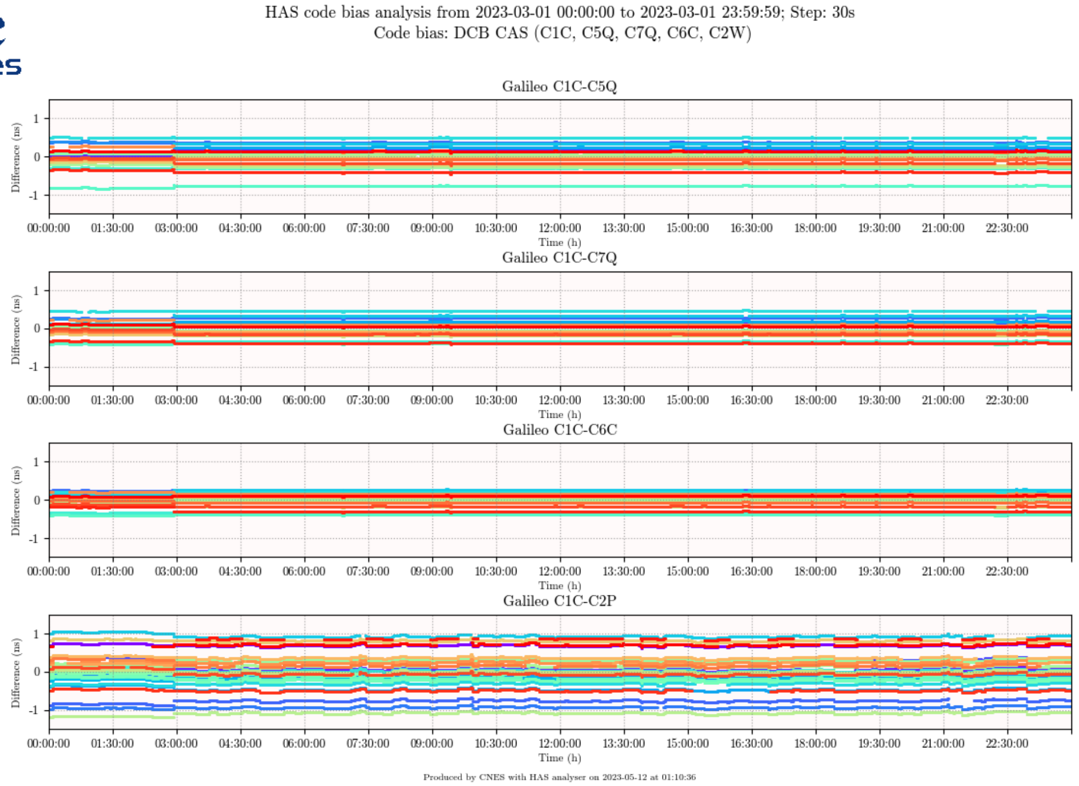
Evolution of OS vs HAS clock error for all Galileo PRN

Performances of Galileo HAS clock corrections – 1st to 14th March 2023

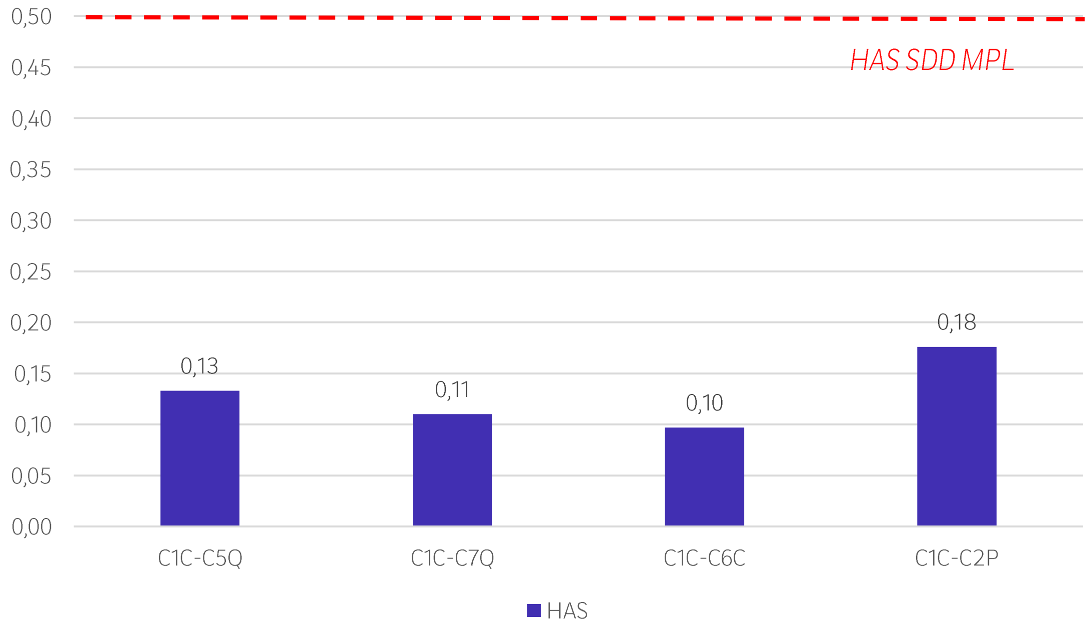
Clock	OS	HAS	MPL HAS
Galileo	0,22	0,11	≤ 12cm

HAS

HIGH ACCURACY SERVICE INITIAL SERVICE



Evolution of HAS code bias error for all Galileo PRN



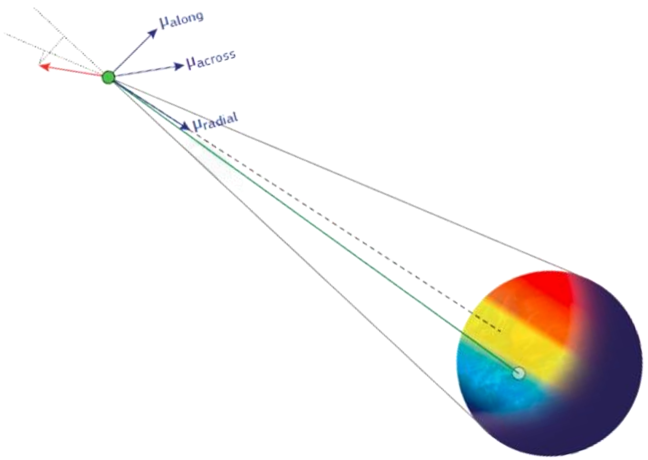
HAS Code bias vs CAS DCB (m) – 95% of RMS values

Performances of Galileo HAS code bias – 1st to 14th March 2023

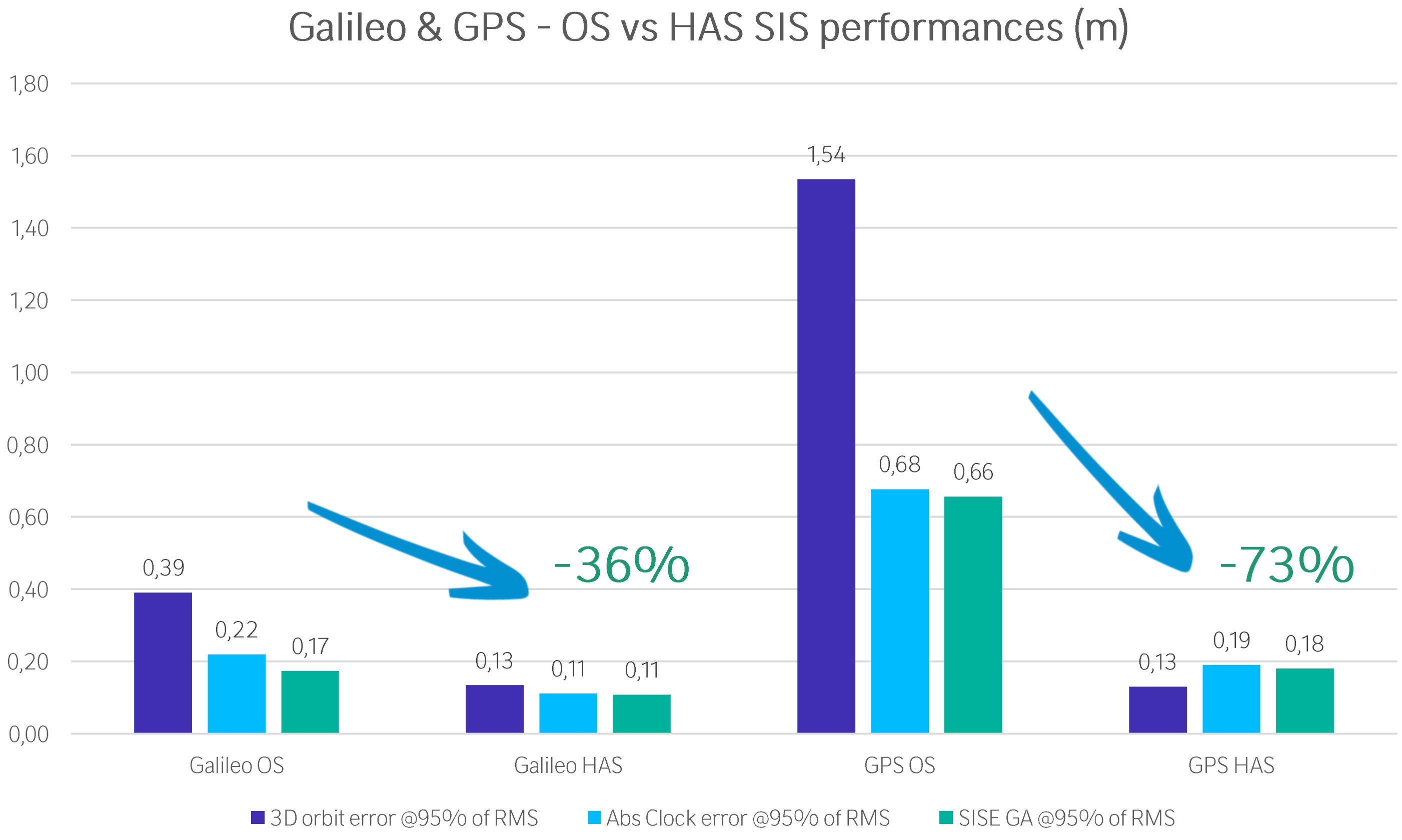
Code bias	C1C-C5Q	C1C-C7Q	C1C-C6C	MPL HAS
Galileo	0,13	0,11	0,10	≤ 50cm

HAS
HIGH ACCURACY SERVICE

INITIAL SERVICE



Galileo OS SDD v1.2



MERCI DE VOTRE ATTENTION

DES QUESTIONS ?