Galileo Performance Update

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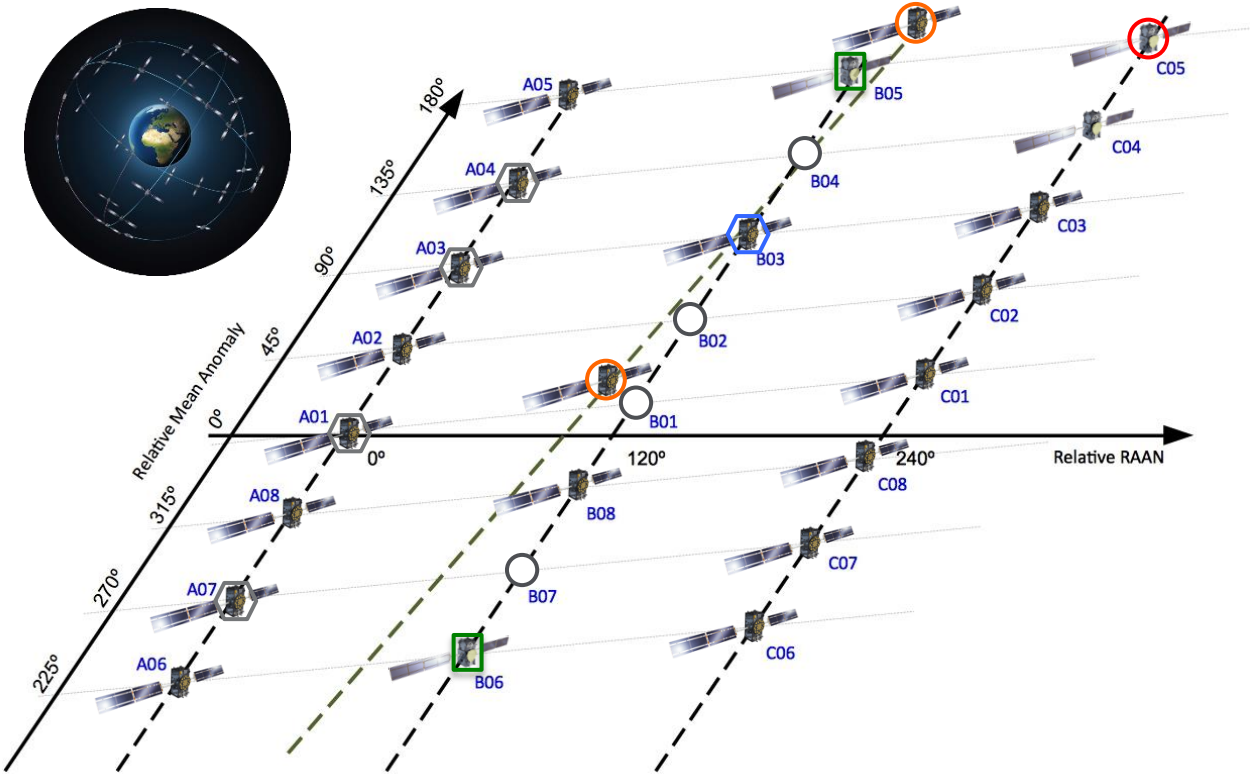
United Nations/Argentina Workshop on the Applications of GNSS
19-23 March 2018, Falda del Carmen, Argentina

Galileo Constellation Status



Navigation Payload (14 Operational)

22 satellites in orbit

4 under commissioning

2 in testing

1 spare

1 unavailable

Search and Rescue Payload (15 Operational)

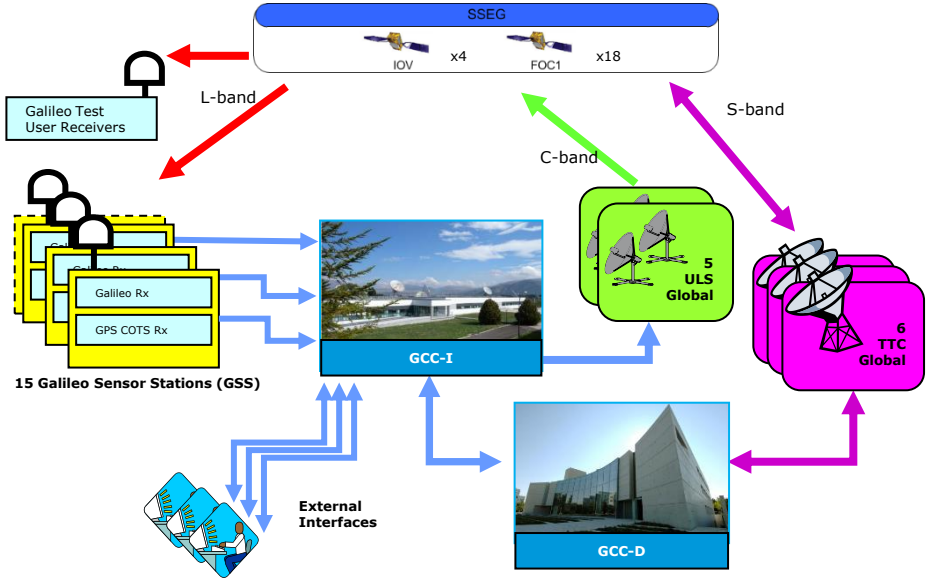
2 out of 22 satellites with no SAR Transponder (by design)

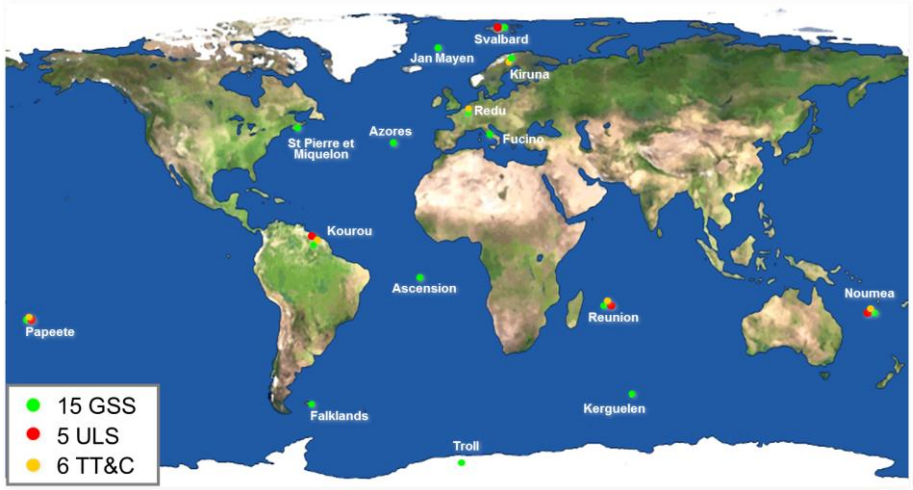
4 under commissioning

1 spare

4 unoccupied reference slots

Galileo Ground Infrastructure





Two fully operational Galileo Control Centers: GCC-I Fucino (GMS) and **GCC-D** Oberpfaffenhofen (GCS)

- 15 **Galileo Sensor Stations**, 5 **Up-Link Stations**, 6 **Telemetry Tracking & Command Stations**

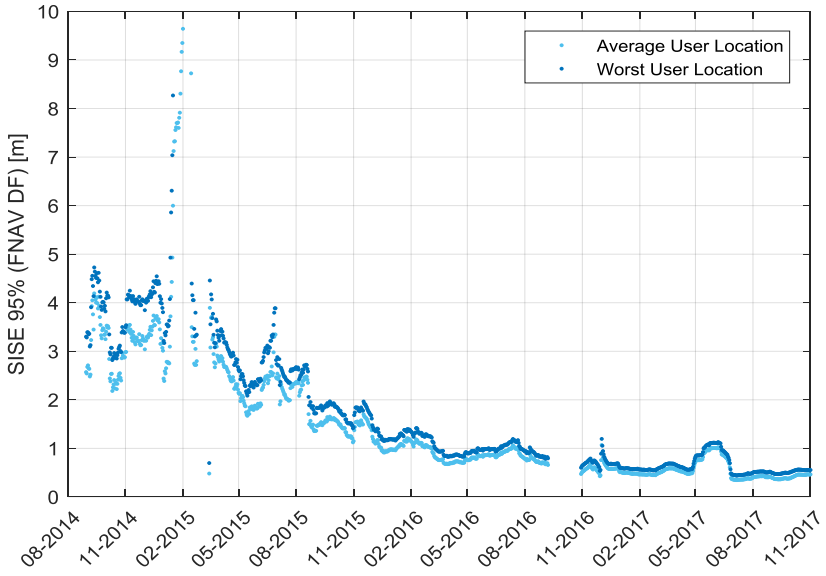
Enhanced Ground Segment capabilities are being deployed

- **Ground Control Segment (GCS)**, improved spacecraft control automation and an additional Telemetry, Tracking and Command (TTC) station in Papeete.
- **Ground Mission Segment (GMS),** improved robustness of the Galileo System Time (GST) realization by enabling seamless Precise Timing Facility (PTF) switch capability, providing additional redundancy in the Galileo Sensor Stations and Uplink stations network, and improved mission monitoring capabilities.

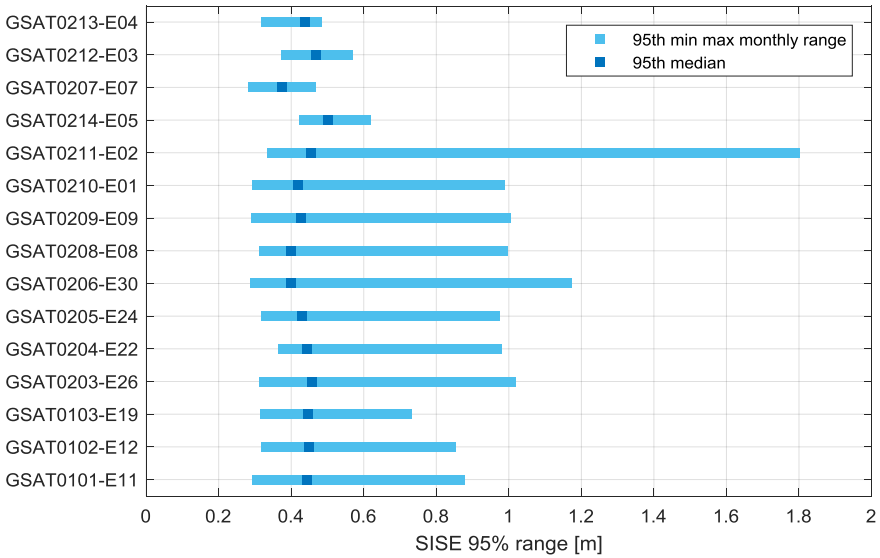
GALILEO SIS Error (CM)

	AVG SIS	BEST SIS	WORST SIS
DEC 17	26.0	18.0	37.0

Galileo SISE Service History



SISE Constellation 95% (FNAV), 30 days moving average
September 1, 2014 – December 31, 2017



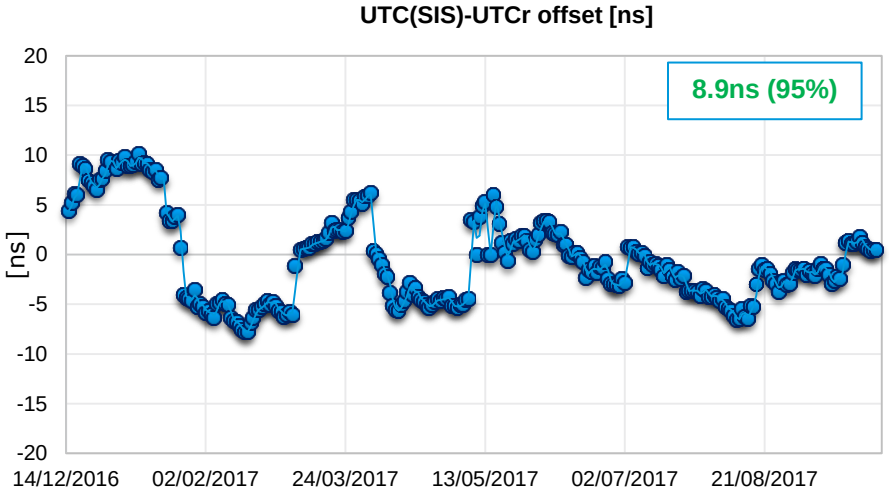
SISE 95th (FNAV) errors computed over calendar months December 1, 2016 – December 31, 2017

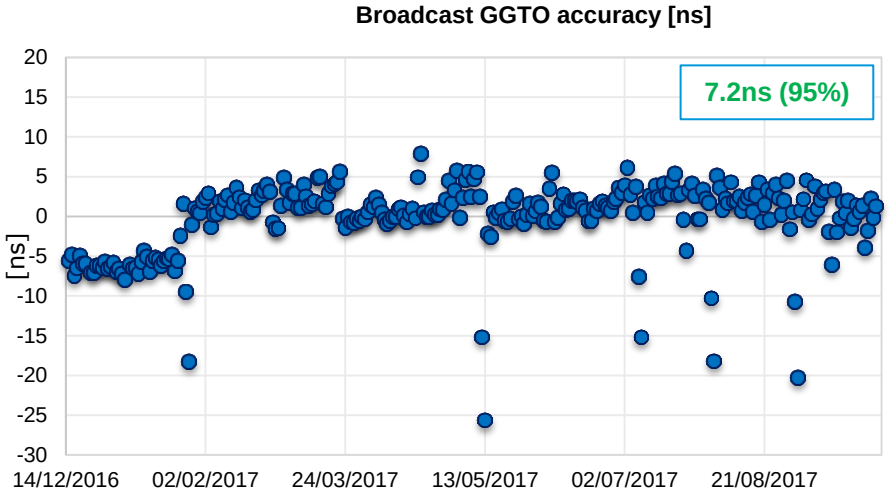
- **Decreasing Ranging Error trend mainly driven by the ground segment enhancements**

	Constellation	Worst Satellite
SISE Global Average 95% [m]	**0.44**	**0.52**
SISE Global Average RMS [m]	**0.26**	**0.37**

Results in December 2017

System Timing Performance Metrics





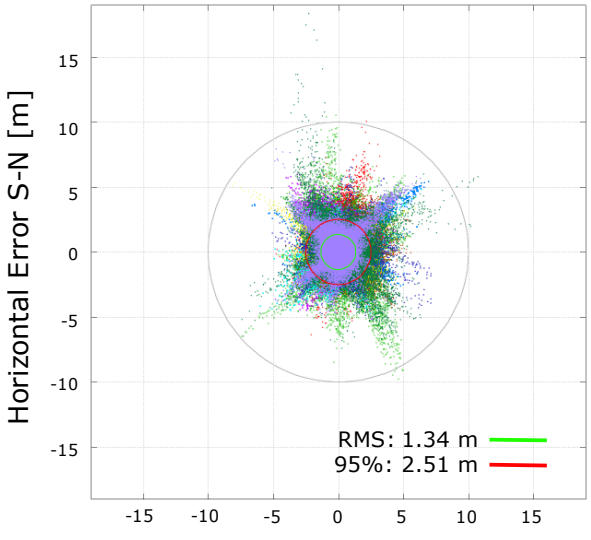
UTC(SIS) accuracy 8.9ns (95%) < 30ns IS target

GGTO accuracy 7.2ns (95%) < 20ns IS target

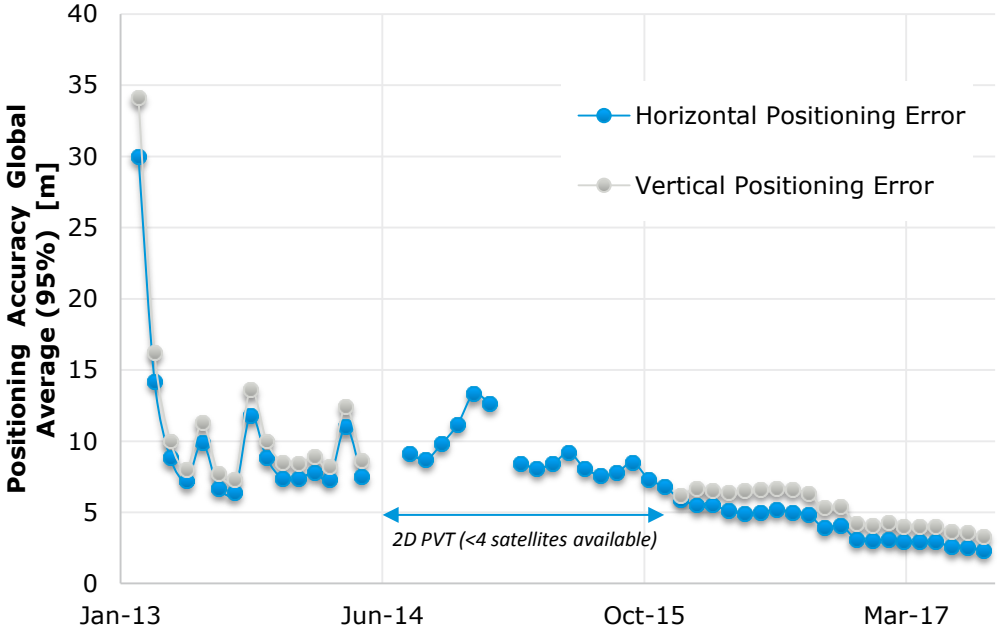
- The time dissemination accuracy is evaluated through the measurements of a **standard timing calibrated GPS/Galileo receiver** operated in a UTC(k) laboratory (PTB, INRIM).

Positioning Performance & Availability

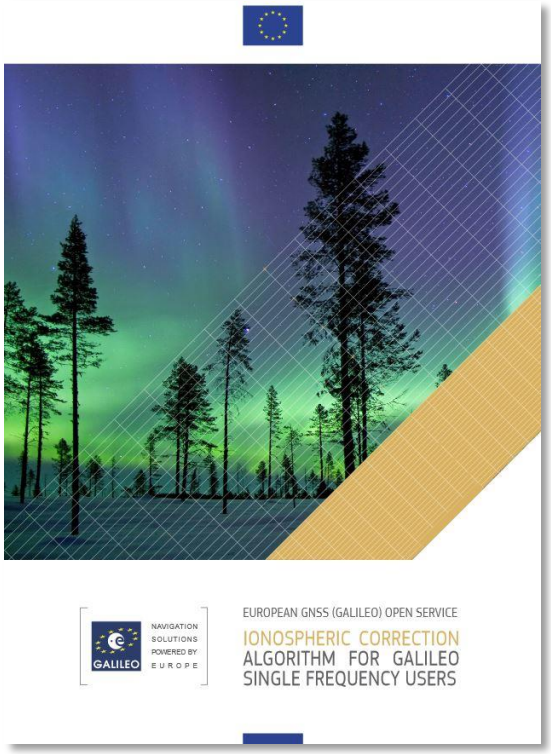
- 4 more satellites (L9) under commissioning (operational in mid-2018)
- Satellites in operational constellation: 14 → 18
- Availability of H. Accuracy <10 m 86% → 96% (Average User Location)
- Global PDOP <=6 availability 73% → 95% (Average User Location)



Dual Frequency Horizontal Accuracy measured by global Receiver Network (10 – 13 Dec. 2017)

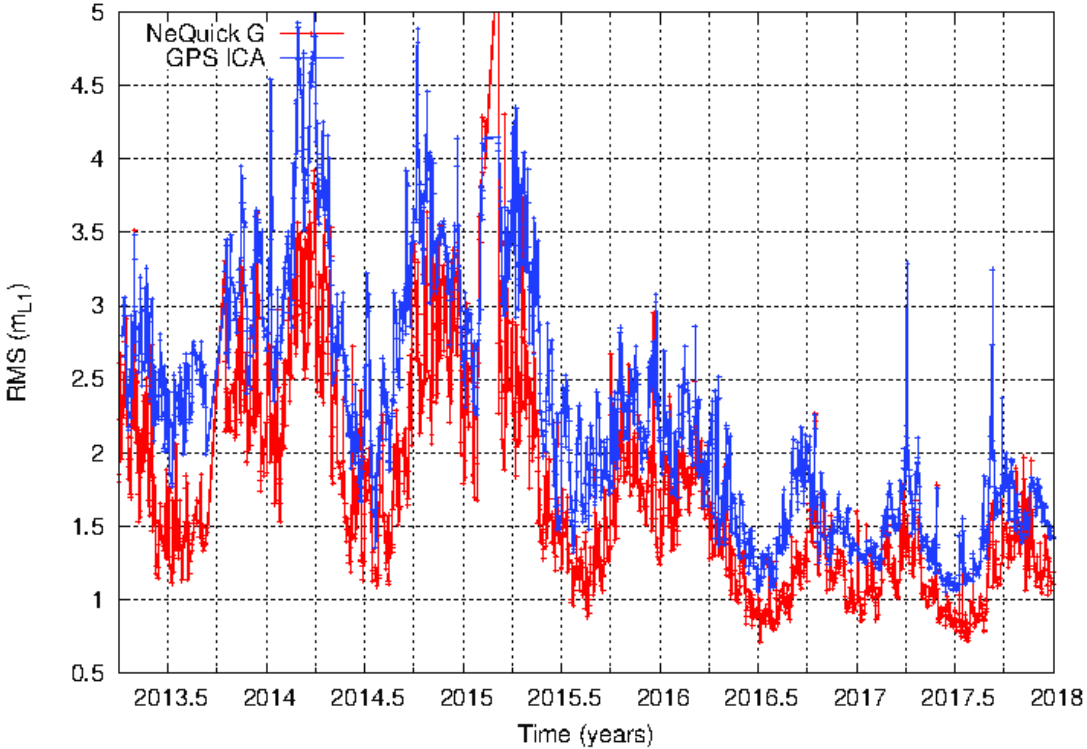


Galileo uses and advanced ionospheric model: NeQuick G



- 3D and time dependent ionospheric electron density model.
- Empirical climatological representation of the ionosphere.
- Adapted from NeQuick model developed by the Abdus Salam International Center of Theoretical Physics (ICTP).
- Based on Galileo measurements, the Galileo ground segment computes the best fit of an effective ionization level parameter to be used for correcting the ionospheric error of single-frequency users.

NeQuick G Performance



Global RMS error from March 2013 to December 2016 for NeQuick G (Galileo) and Klobuchar (GPS) models taken from global network of stations and billons of STEC measurements

The value of multi-GNSS: availability in urban canyons

5 deg mask	45 deg mask	45 deg mask and Galileo disabled
		
35 sats from 5 systems Over-dimensioned solution	6 sats. from 4 systems. 7 unknowns to solve. Possible thanks to GGTO	5 sats. from 3 systems. 6 unknowns to solve. Instantaneous Point Pos. not solvable

Instantaneous Point Positioning requires N unknowns to be solved. With M systems N is equal to:

$N = 4_{(x,y,z,t)} + (M-1)_{\text{intersystem offsets}}$

Galileo is on most smartphones

33 Galileo-enabled smartphones as of Jan. 2018 and growing…
www.usegalileo.eu

Brand	Type
Apple	iPhone 6s
Apple	iPhone 8 Plus
Apple	iPhone 7 Plus
Apple	iPhone 7
Apple	iPhone 8
Apple	iPhone 6s Plus
Apple	iPhone 10/X
Asus	Asus Zenfone 4
bq	Aquaris V Plus
bq	Aquaris V
BQ	Aquaris X Pro
BQ	Aquaris X5 Plus
BQ	Aquaris X
Google	Google Pixel 2 XL
Google	Pixel 2
Huawei	P10 plus
Huawei	P10
Huawei	Mate 9 pro
Huawei	Mate 9
LG	LG V30
LG	V30
Meizu	Meizu Pro 7 Plus
Meizu	Meizu Pro 7
Motorola	Motorola Moto X4
Motorola	Moto X4
Nokia	Nokia 8
Oneplus	Oneplus5
Samsung	Galaxy Tab S3
Samsung	S8
Samsung	S8+
Samsung	Samsung Note 8
Sony	Xperia XZ Premium
Vernee	Apollo 2

Example: Samsung S8+

Testing with chip receiver manufactures prior to commercialization was very benefitial

8 chips tested

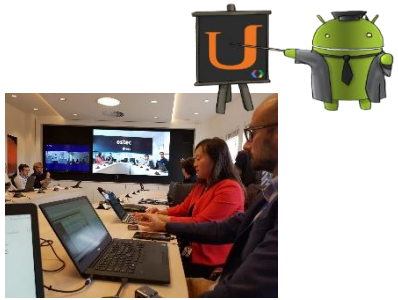
90 hours live tests per chip

300 hours lab tests per chip

Begin: Dec. 2013 End: Dec. 2016

"Galileo APP" development – ESA 2017 competition

An opportunity for educational activities

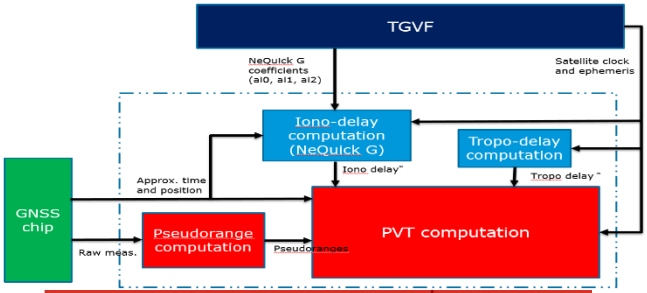


LEARN

TEST

DEVELOP

PROMOTE



http://www.esa.int/galileosmartphone
(on ESA intranet)

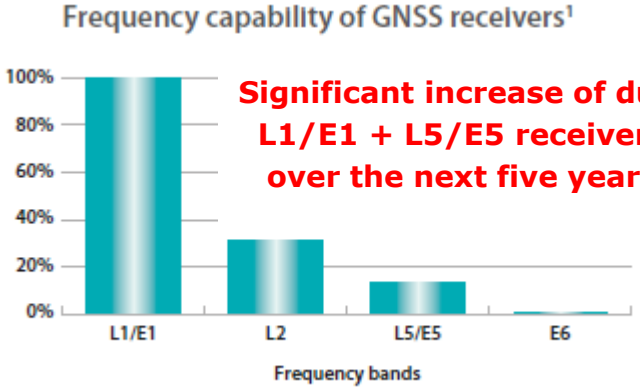
Google Play Store

Multi GNSS Dual Frequency

- Dual-frequency will be a key enabler of improved accuracy and integrity
- Dual-frequency receivers will be increasingly used for more advanced automation towards fully self-driving vehicles.

Galileo E5 is the most suitable choice for a second frequency:

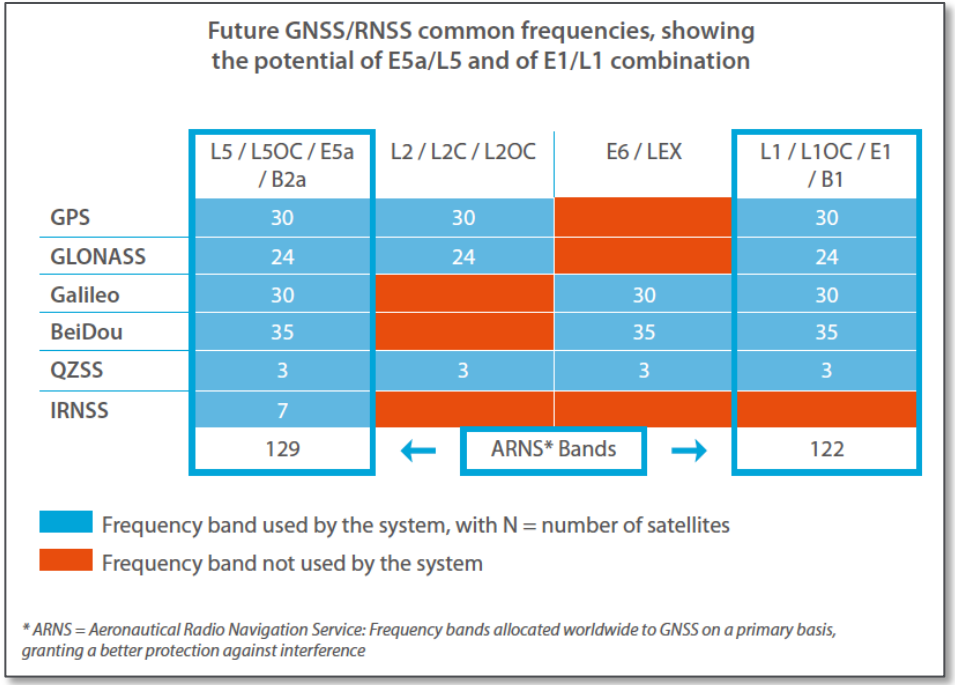
- Roughly twice as many satellites broadcasting on L5/E5 than on L2
- The L5/E5 signals offer superior multipath mitigation and better accuracy than L2 (10.23MHz vs. 1MHz)
- The received power on L5/E5 is 3dB higher than on L2C, a very significant advantage for use in constrained environments



Source: GSA GNSS User Technology report

Multiple frequencies benefits

- **Improved accuracy**: Dual-frequency capable devices can estimate and compensate for ionospheric delays
- **Access to RTK and PPP techniques** and use of triple-frequency receivers enable further improvement of the ambiguity resolution algorithms, e.g. through the TCAR technique
- **Improved robustness**: frequency diversity can be a basic but very efficient protection against jamming.



Satellite Metadata for High Accuracy Services

Requested by

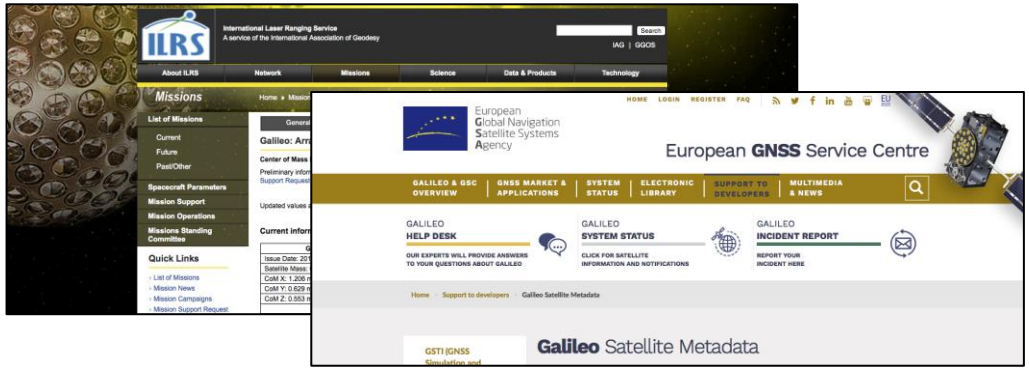
- Galileo scientific advisory committee (GSAC)
- International GNSS Service (IGS)

Status

- Galileo IOV Satellite Metadata released during Initial Service Declaration (Dec-2016)
- Galileo FOC metadata released (Oct-2017)
- Galileo FOC metadata update for L9 and 10 (planned 2018)

Content

- Attitude Law
- Mass and Centre Of Mass evolution
- Navigation Antenna Phase Centre Corrections
- Geometry and optical properties
- Laser Retro Reflector Location
- Satellite Group Delay

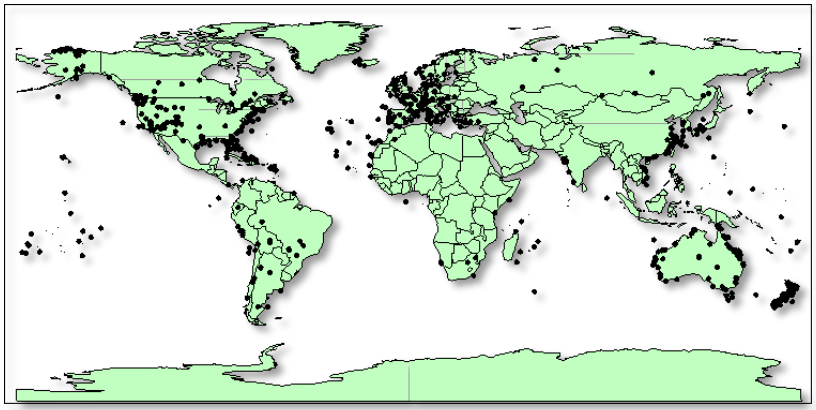


https://www.gsc-europa.eu/support-to-developers/galileo-iov-satellite-metadata#2

https://ilrs.cddis.eosdis.nasa.gov/missions/satellite_missions/current_missions/ga01_com.html

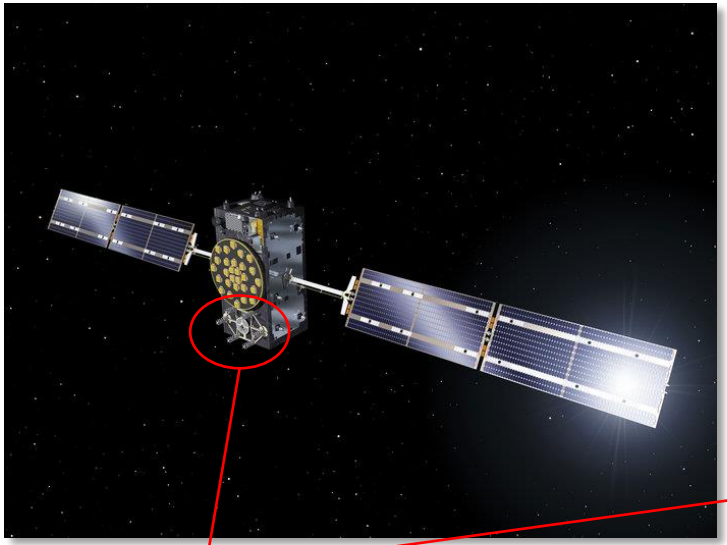
Galileo is the forerunner of MEOSAR in COSPAS/SARSAT

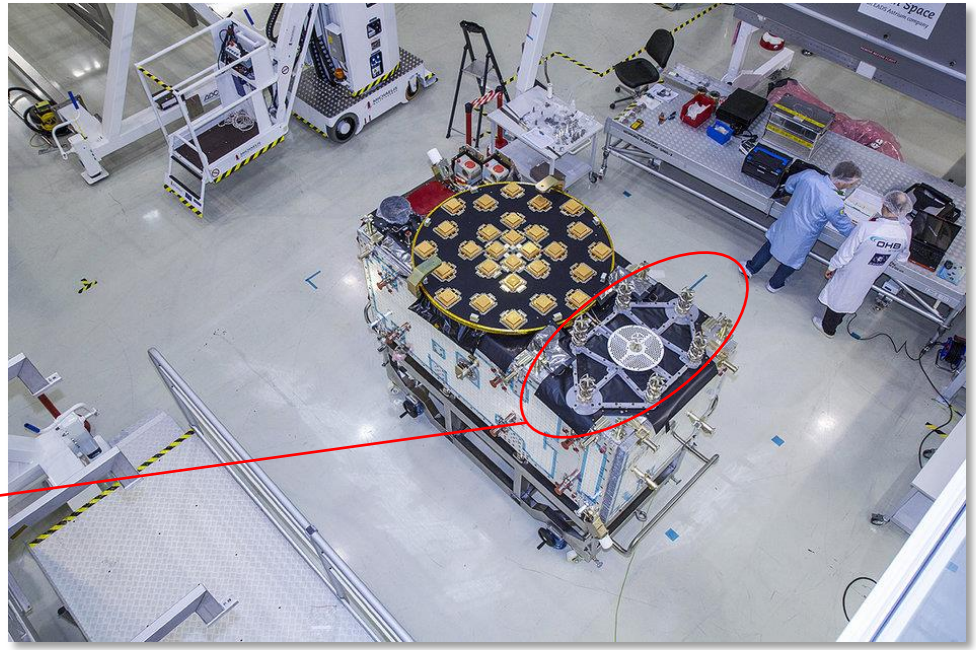
- More than 2.000.000 C/S distress beacons worldwide
- More than 2.000 persons rescued per year thanks to C/S
- Without Galileo, localization is up to 4H and 10 KM
- With Galileo, localization is down to **10 min** and **2 Km**
- **15 transponders available** and **return link planned end of 2018**



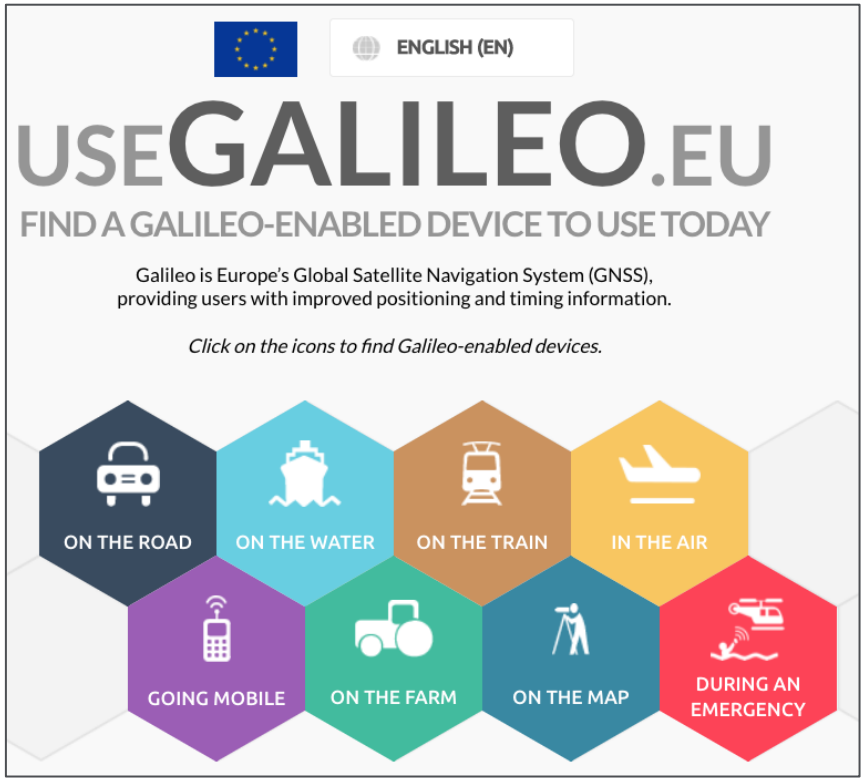
SAR events assisted by C/S during 2015

Search and Rescue is a very important mission in Galileo





SAR antenna occupies a large part of satellite antenna panel


ENGLISH (EN)
USEGALILEO.EU
FIND A GALILEO-ENABLED DEVICE TO USE TODAY
Galileo is Europe's Global Satellite Navigation System (GNSS),
providing users with improved positioning and timing information.
Click on the icons to find Galileo-enabled devices.
ON THE ROAD
ON THE WATER
ON THE TRAIN
IN THE AIR
GOING MOBILE
ON THE FARM
ON THE MAP
DURING AN EMERGENCY

Conclusions

- Galileo is in service since 15th December 2016
- Constellation deployment "boosted" by Ariane-5 launches: 22 satellites in orbit (14 operational)
- **Positive trends in all performance domains since Initial Services declaration**
- Despite the large number of satellites in orbit from multi-GNSS systems, they are all adding value to use of GNSS in narrow urban canyons.
- Galileo broadcast of GPS to Galileo time-offset adds flexibility to user solutions.
- Adoption of Galileo single frequency (L1) by the mass market is a reality.
- Galileo satellite metadata published in 2017 to support high accuracy and scientific applications.
- Galileo SAR Repeaters are the main contribution to COSPAS-SARSAT.
- **Looking forward to the introduction of Galileo dual frequency receivers in mass-market.**