NeQuick G performance: 2 year global results

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UNOOSA ICG 10 – Working Group B

Boulder, CO, U.S., 04 November 2015

esa

European Space Agency

GALILEO

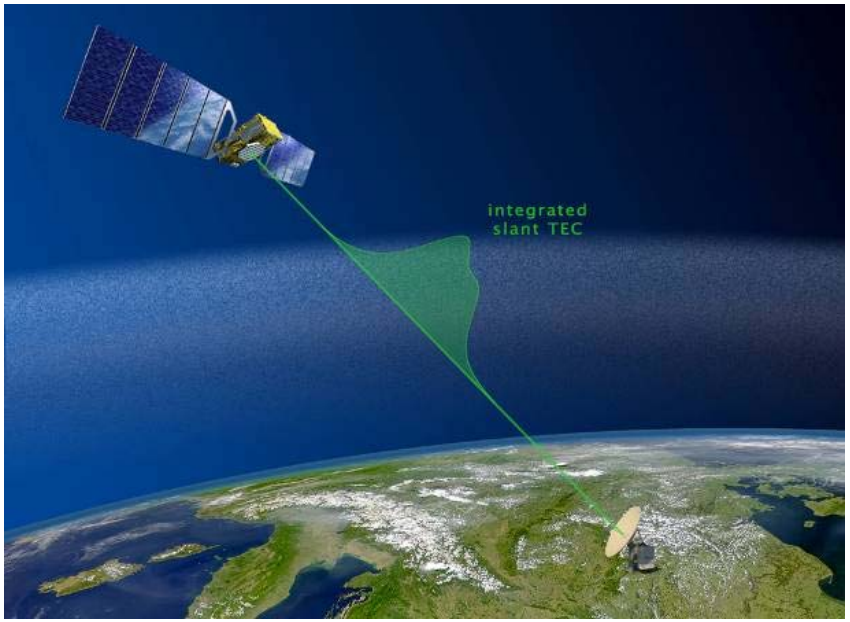
EGNOS

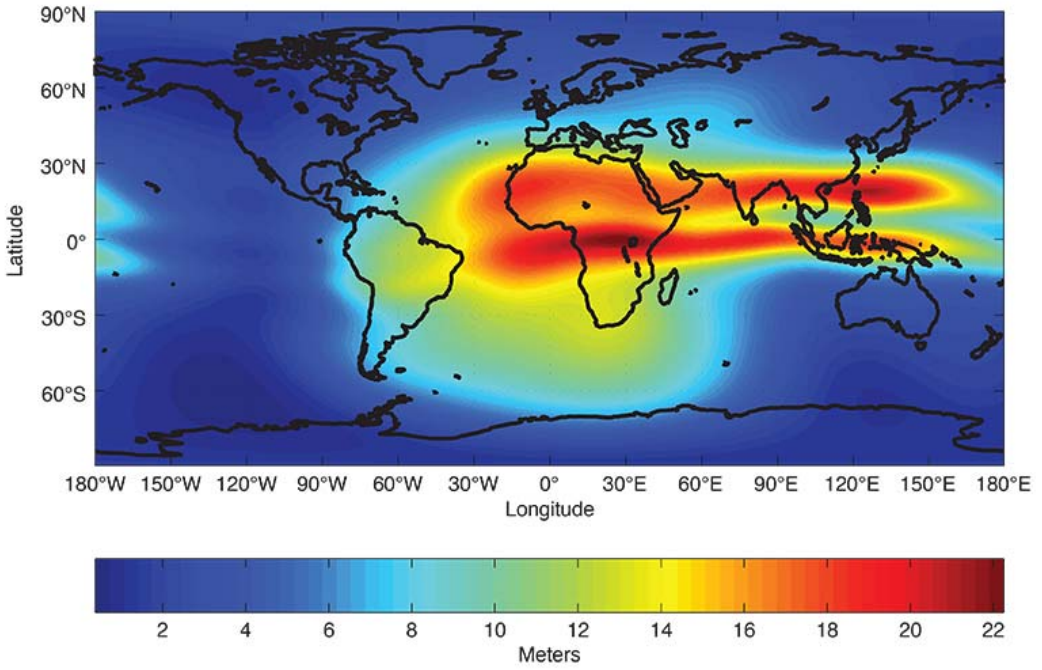
Navigation solutions powered by Europe

Overview

- Background
  - NeQuick model
  - Galileo ionospheric correction algorithm
- Performance results
  - IOV Results
  - *FOC* Results
- Specification Document for users
- Summary

NeQuick Model





- Climatological (monthly mean) model of electron density
  - 3D (as opposed to single-layer ionospheric models SBAS, Klobuchar)
  - Driven by monthly-mean Solar Flux F10.7
- Recommended by ITU-R for propagation prediction
- Based on profiles of ionospheric layers
- Adapted in Galileo for nowcasting based on recent observations

Hochegger, G., B. Nava, S.M. Radicella and R. Leitinger (2000): A family of ionospheric models for different uses,Phys. Chem. Earth, 25 (4), 307-310.
Radicella, S.M. and R. Leitinger, “The evolution of the DGR approach to model electron density profiles”, Adv. *Space Res*., Vol. 27, Issue 1, pp. 35-40, 2001.

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Galileo Ionospheric Algorithm for Single-Frequency Users

- Navigation message broadcast:
  - 3 Az (Effective ionisation level) coefficients.
- Based on an adaptation of the 3D empirical climatological electron density model NeQuick → ***NeQuick G***
  - From monthly-mean climatological modelling to real-time corrections.
  - Including a number of evolutions from NeQuick 1.
  - Galileo specific version of geomagnetic field model (modip file)
  - Adaptations due to software engineering process.

Parameter	Definition	Bits	Scale factor	Unit
a_{i0}	Effective Ionisation Level 1st order parameter	11	2^{-2}	sfu**
a_{i1}	Effective Ionisation Level 2nd order parameter	11*	2^{-8}	sfu**/degree
a_{i2}	Effective Ionisation Level 3rd order parameter	14*	2^{-15}	sfu**/degree^2
SF_1	Ionospheric Disturbance Flag for region 1	1	N/A	dimensionless
SF_2	Ionospheric Disturbance Flag for region 2	1	N/A	dimensionless
SF_3	Ionospheric Disturbance Flag for region 3	1	N/A	dimensionless
SF_4	Ionospheric Disturbance Flag for region 4	1	N/A	dimensionless
SF_5	Ionospheric Disturbance Flag for region 5	1	N/A	dimensionless
Total Ionospheric Correction Size		**41**		

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Correction Algorithm: End-to-End Overview

SENSOR STATION

Observe slant TEC in Sensor Stations for 24 hours

↓

Optimise effective ionisation parameter for NeQuick to match observations

↓

SATELLITE

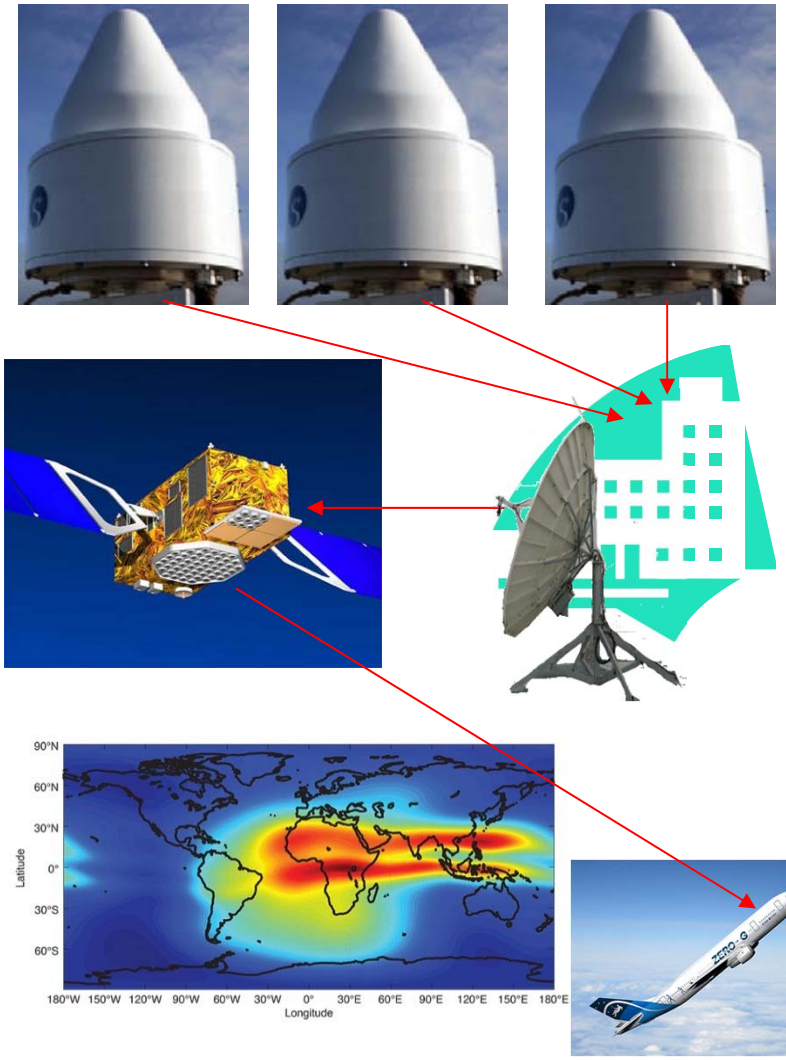
Broadcast effective ionisation parameter in Navigation message

$$Az = a_0 + a_1 \cdot \mu + a_2 \cdot \mu^2$$

↓

USER RECEIVER

Calculate slant TEC using NeQuick G with broadcast parameter. Correct for Ionospheric delay at frequency in question.



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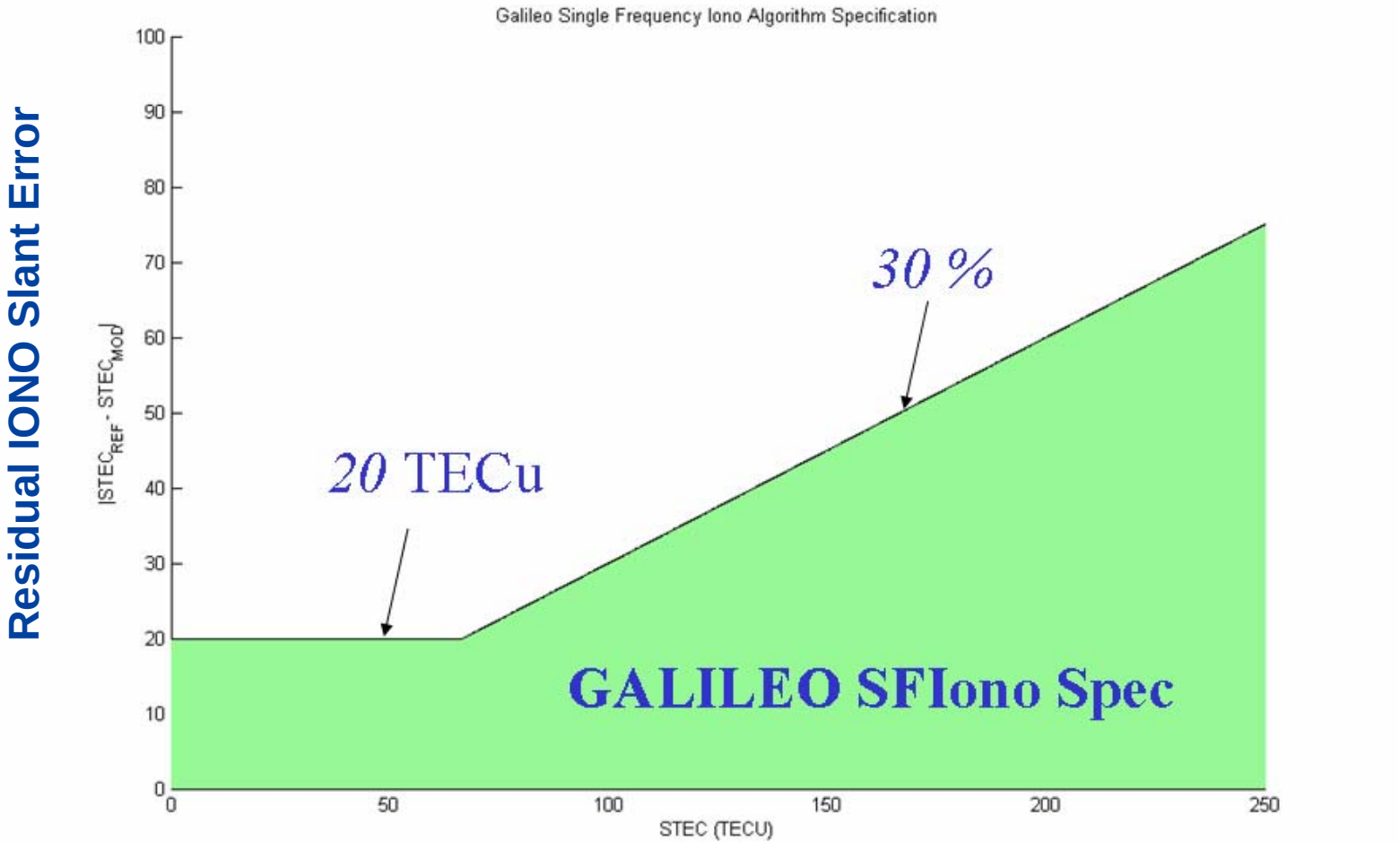
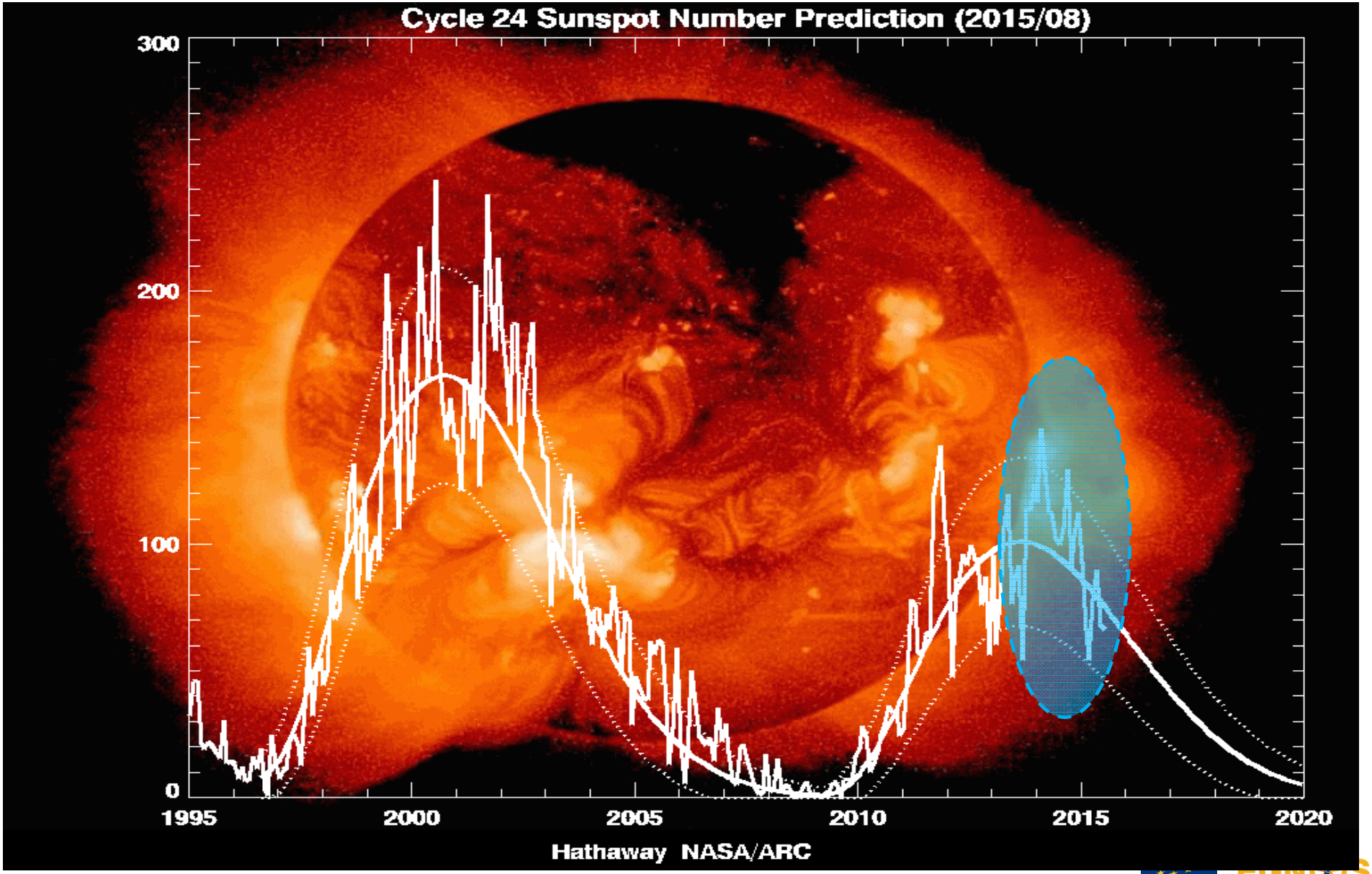
Performance Objectives



Actual IONO Slant delay

During solar maximum – but a mild one!



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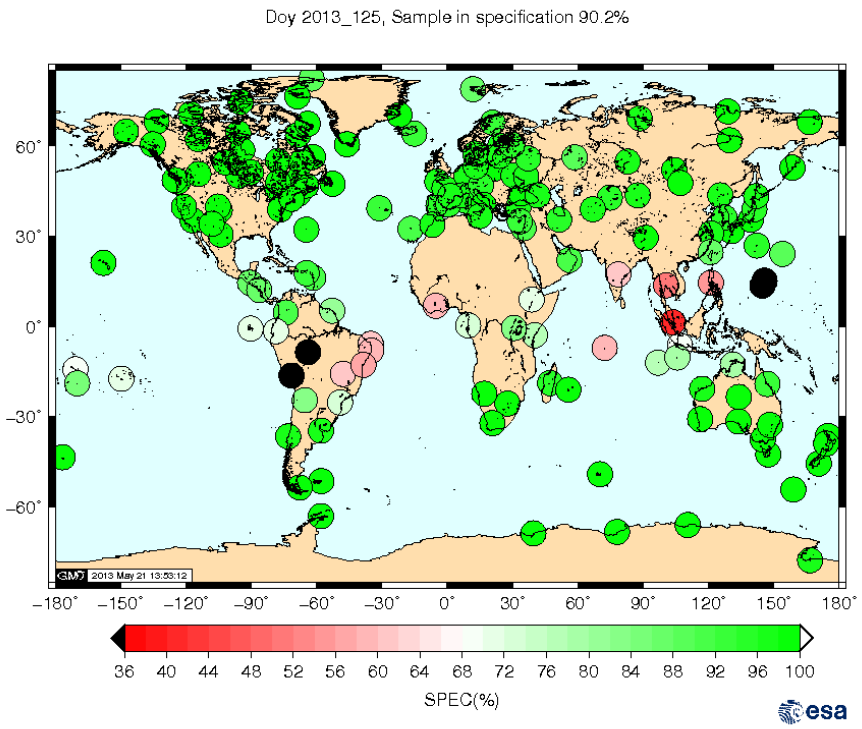
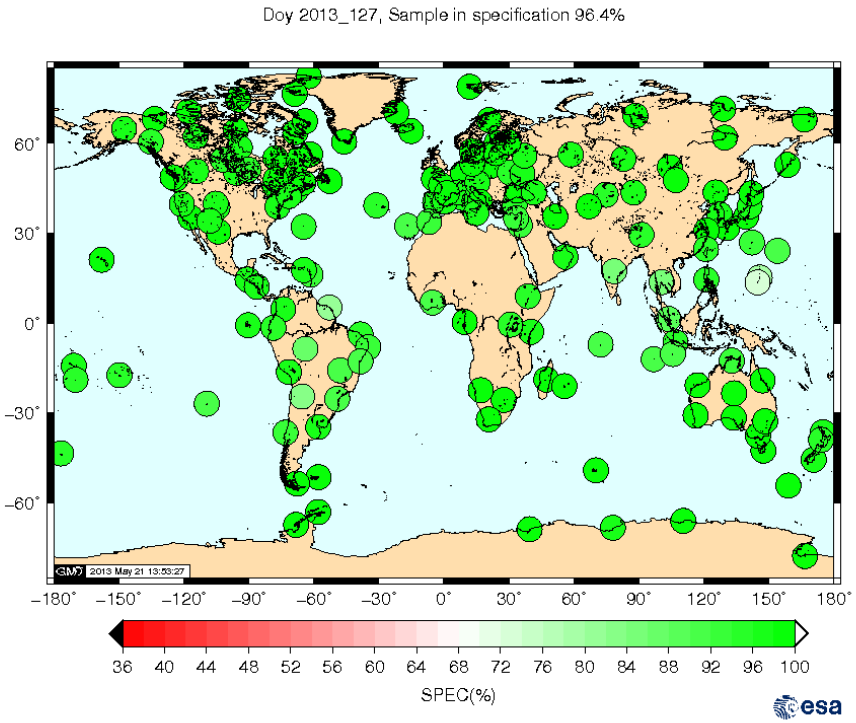
IOV Results

Galileo broadcast

>100 stations, reference ionosphere based on dual-freq IONEX-levelled



doy 125/2013
“bad” day
overall 90.2% inside spec



doy 127/2013
“good” day
overall 96.4% inside spec

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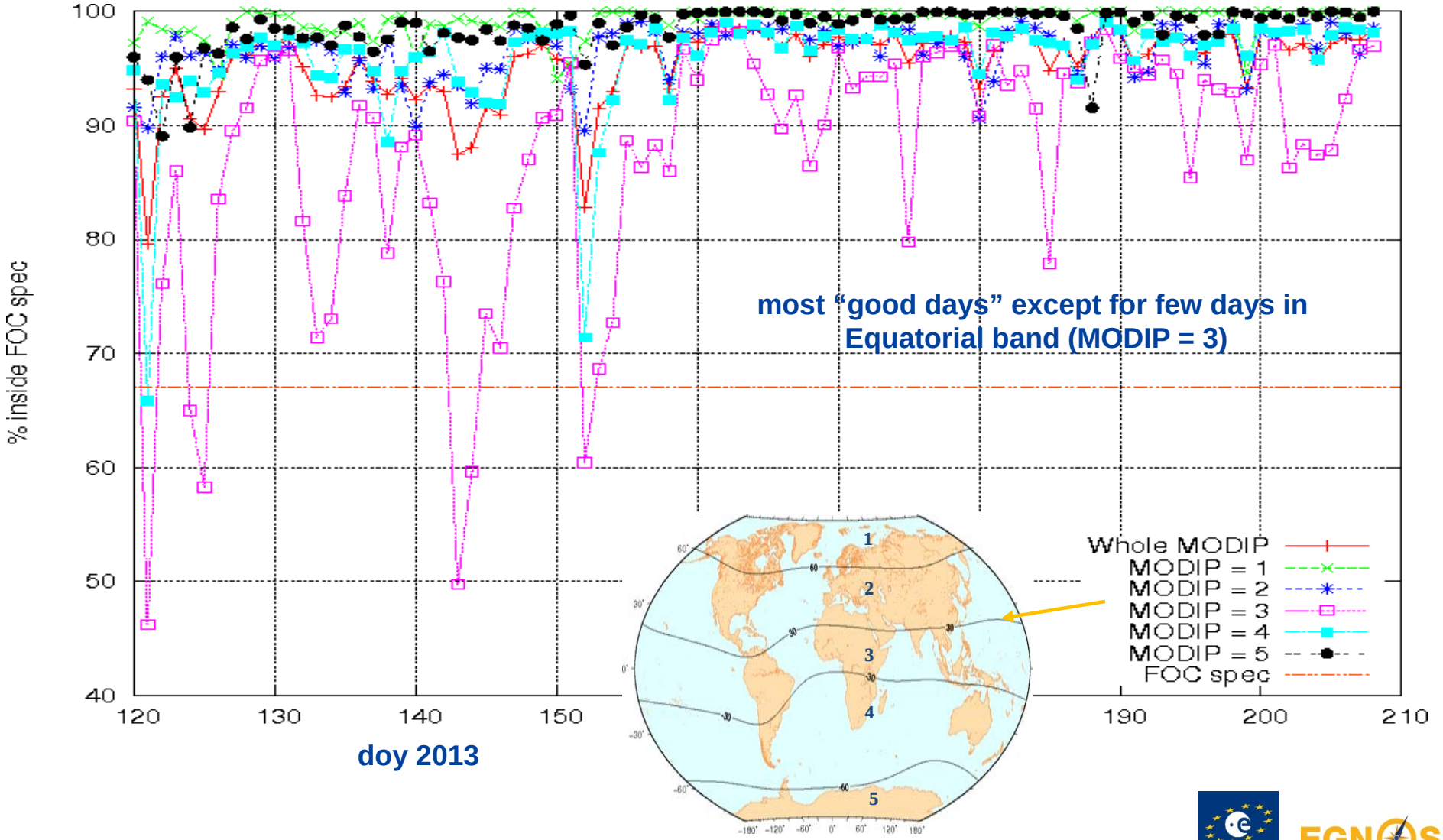
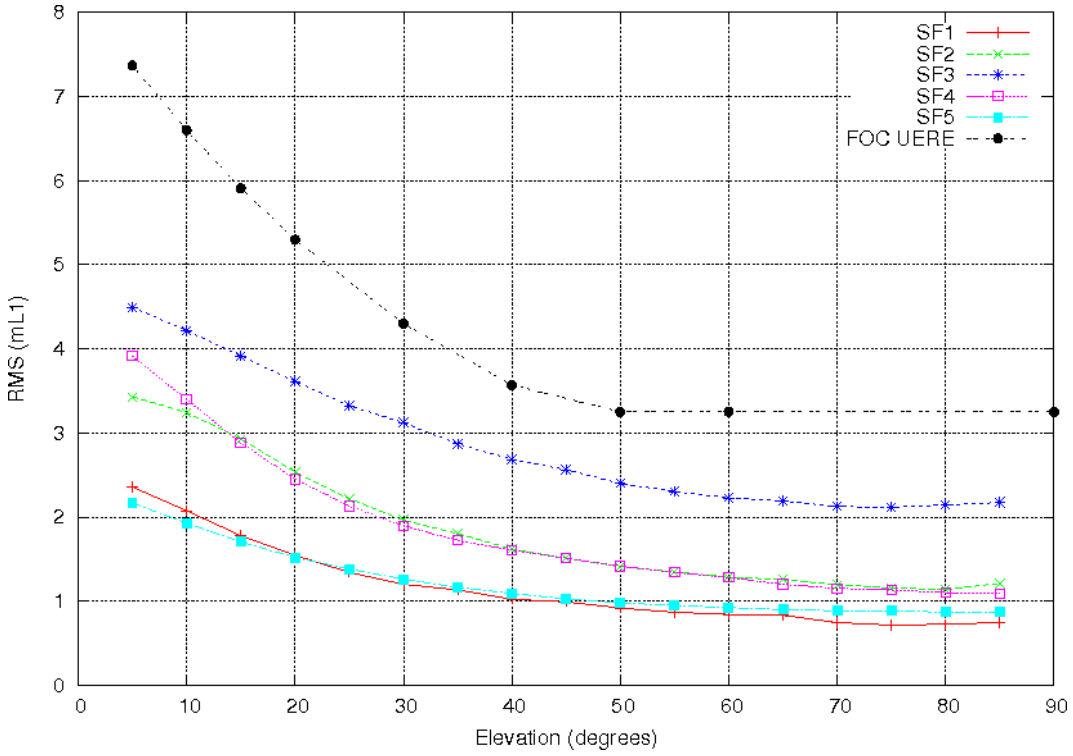
IOV Results: % inside spec.



MODIP = Modified DIP. MODIP is related with geomagnetic field

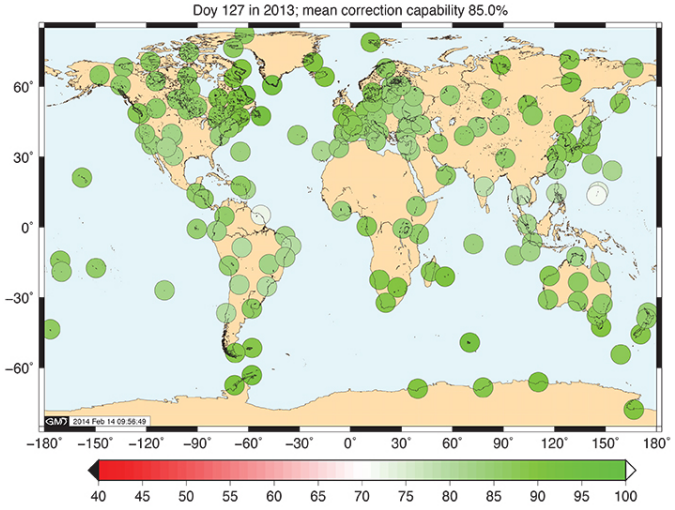
IOV Results: Iono. Contribution to UERE

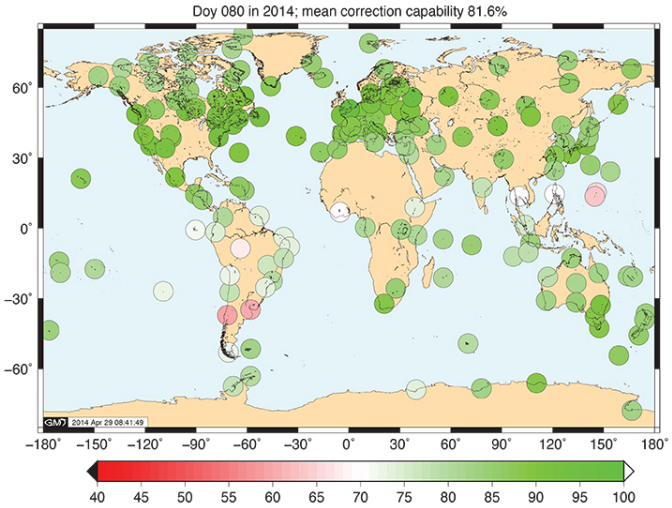
	Elevation angle (degrees)								
	5	10	15	20	30	40	50	60	90/85
Spec	*737.0*	*660.0*	*591.0*	*530.0*	*430.0*	*357.0*	*325.0*	*325.0*	*325.0*
SF1	235.8	207.5	178.0	154.6	120.1	102.2	91.7	84.4	74.5
SF2	343.0	324.5	293.1	253.7	196.4	161.9	141.0	128.7	121.3
SF3	449.5	421.8	391.6	361.5	312.2	268.5	240.1	222.9	217.4
SF4	391.6	339.9	288.2	245.1	189.7	160.7	141.6	128.1	109.0
SF5	216.7	192.7	170.6	152.1	126.2	109.0l	97.9	92.4	86.8



IOV Results: Iono. Corr. Capability (%)

Galileo broadcast

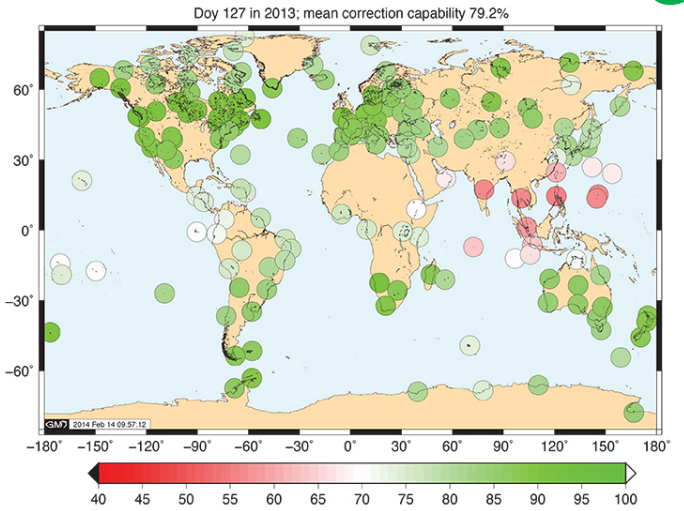


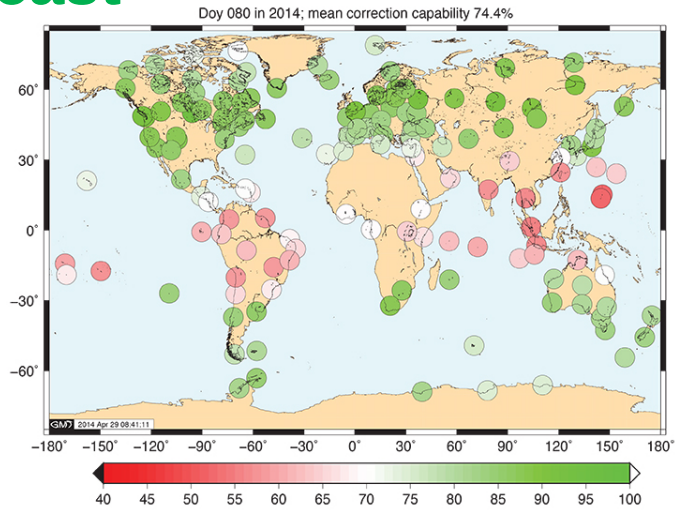


Doy 127/2013

Doy 080/2014

GPS broadcast





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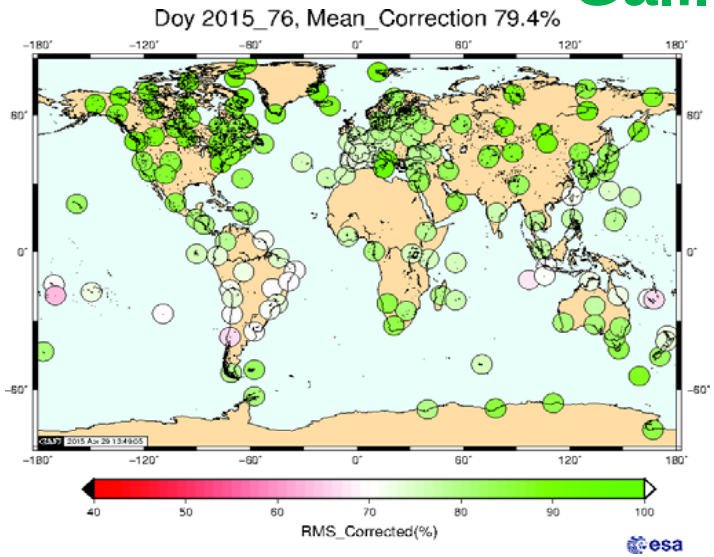
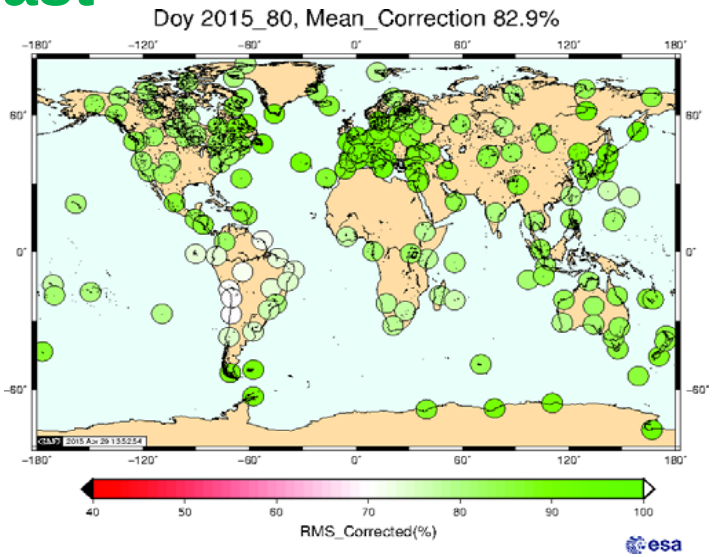
FOC Results: Iono. Corr. Capability (%)

Galileo broadcast

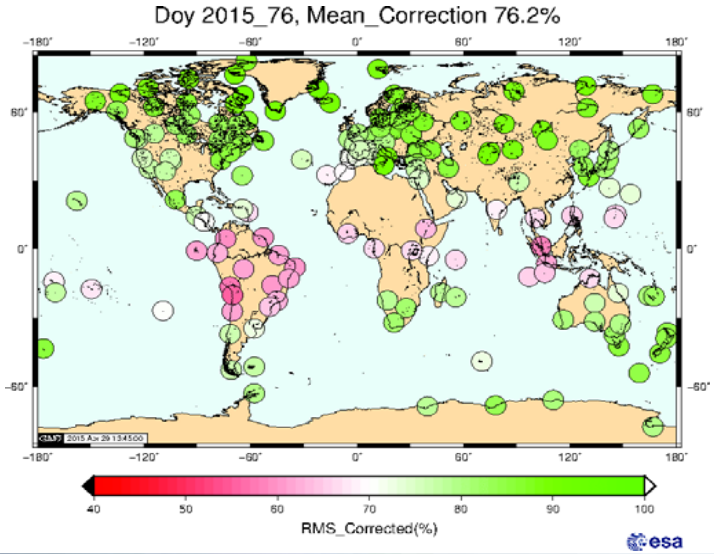


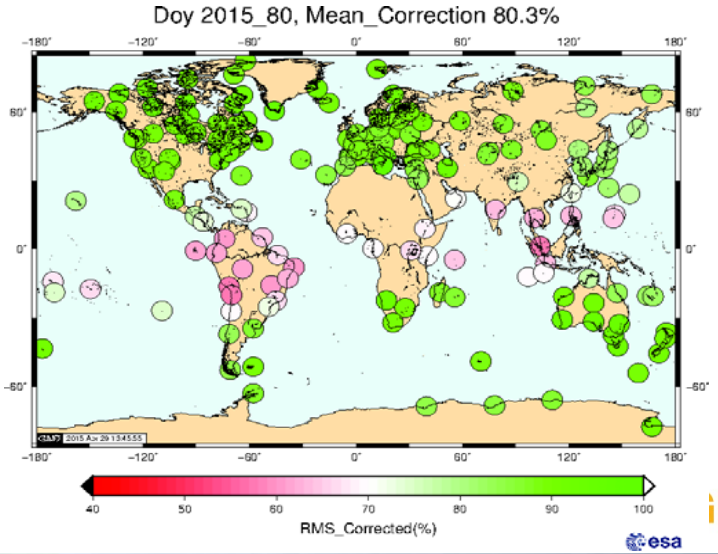


Doy 76/2015 (St. Patrick's storm)

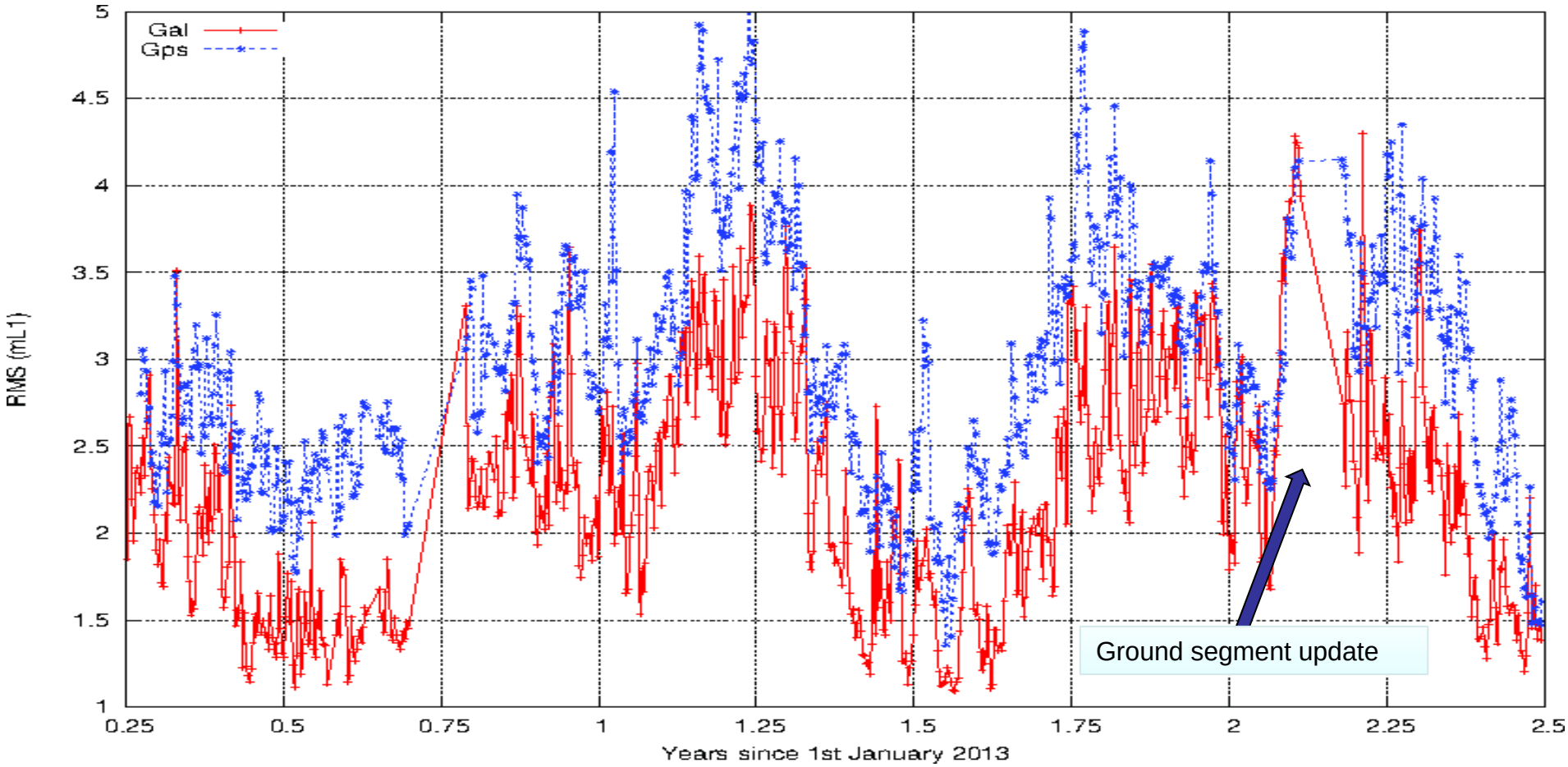
Doy 080/2015

GPS broadcast





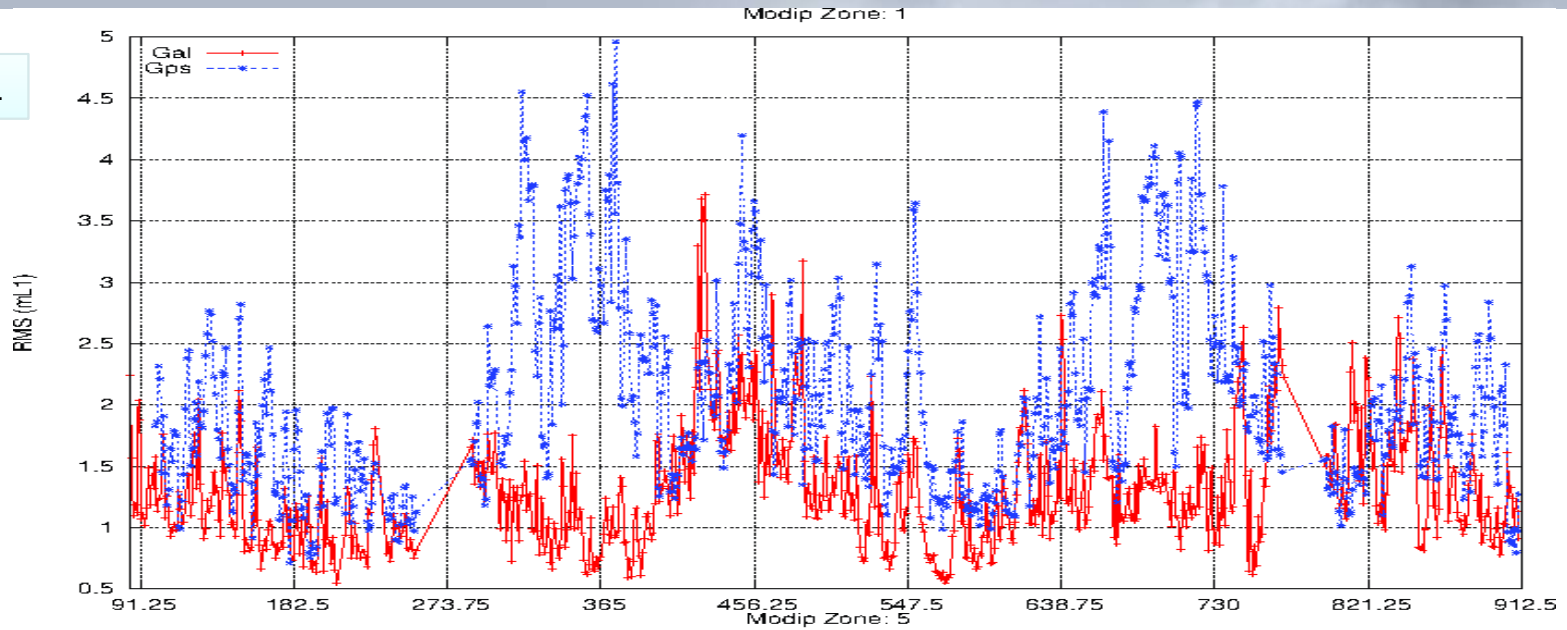
IOV+FOC: Residual RMS error (m_{L1}) – daily 2013-2015



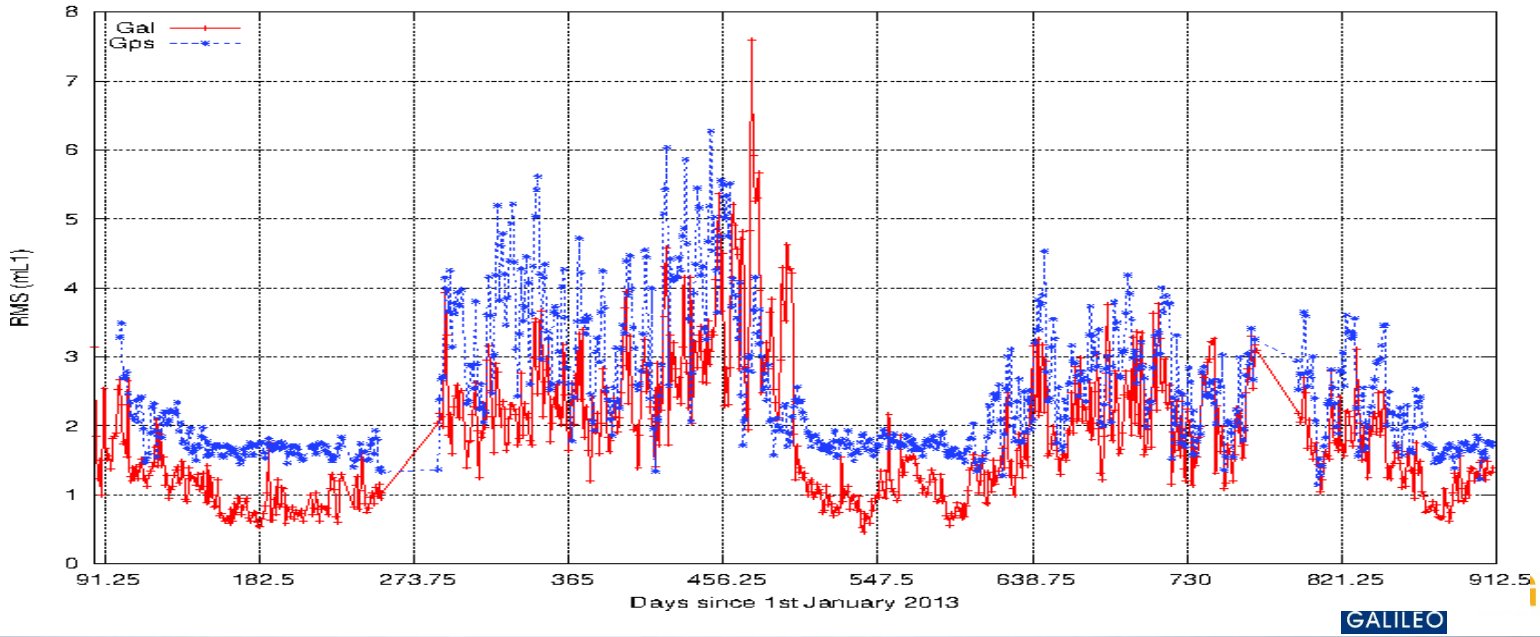
- Broadcast NeQuick G performance very good despite the low number of satellites used to drive the model
- RMS for all stations

IOV+FOC: Residual RMS error (m_{L1}) – daily 2013-2015

MODIP 1



MODIP 5



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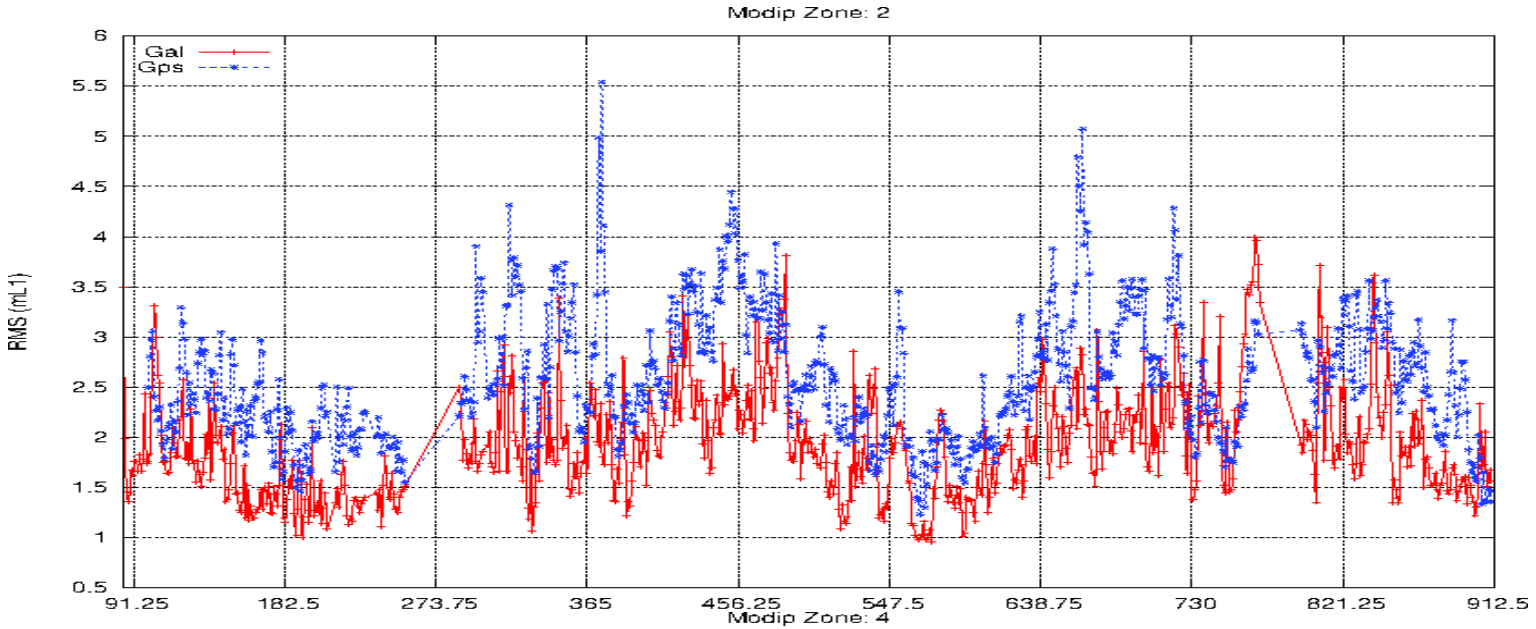
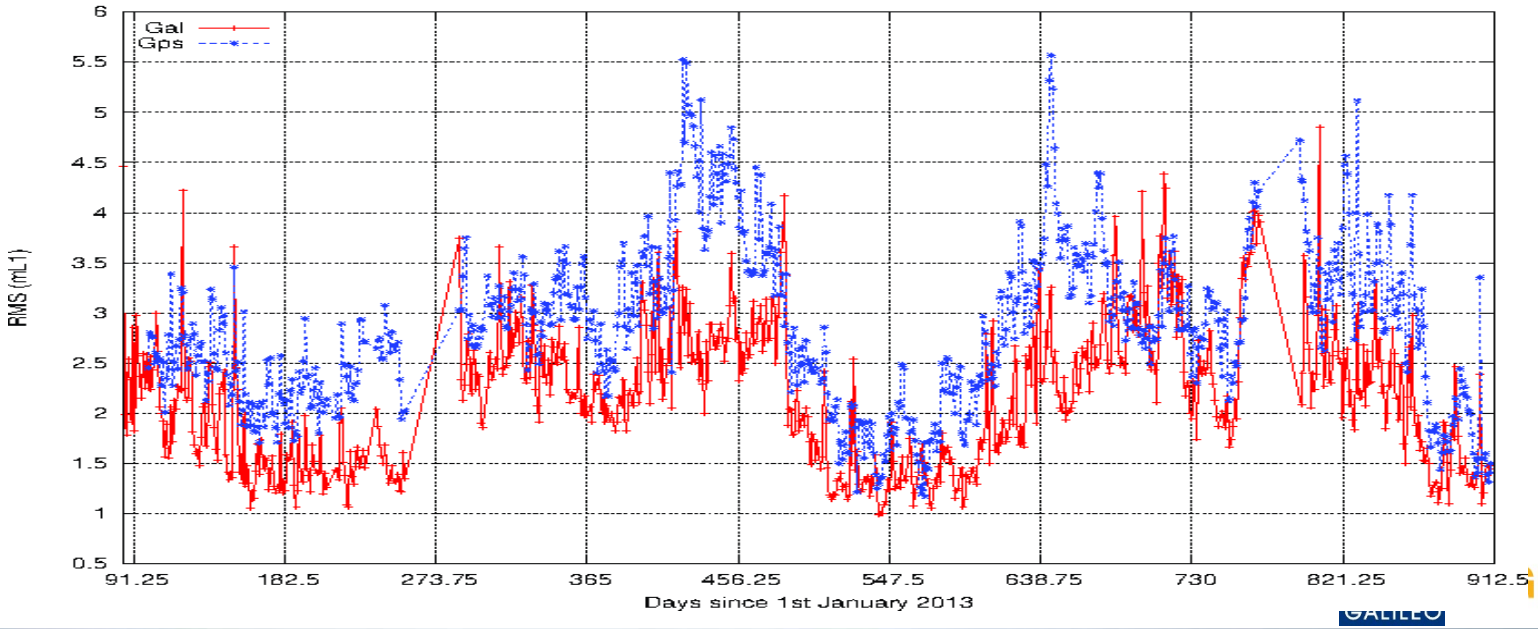
IOV+FOC: Residual RMS error (m_{L1}) – daily 2013-2015

MODIP 2

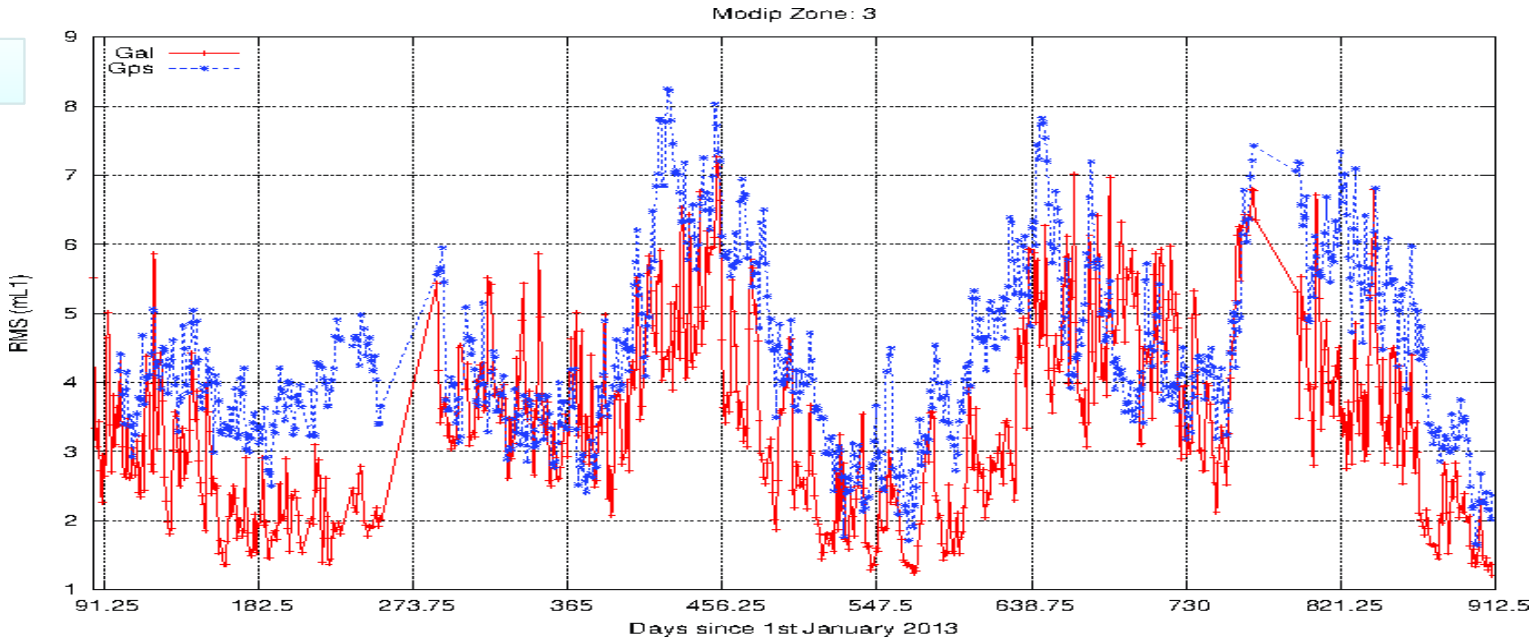


MODIP 4



IOV+FOC: Residual RMS error (m_{L1}) – daily 2013-2015

MODIP 3

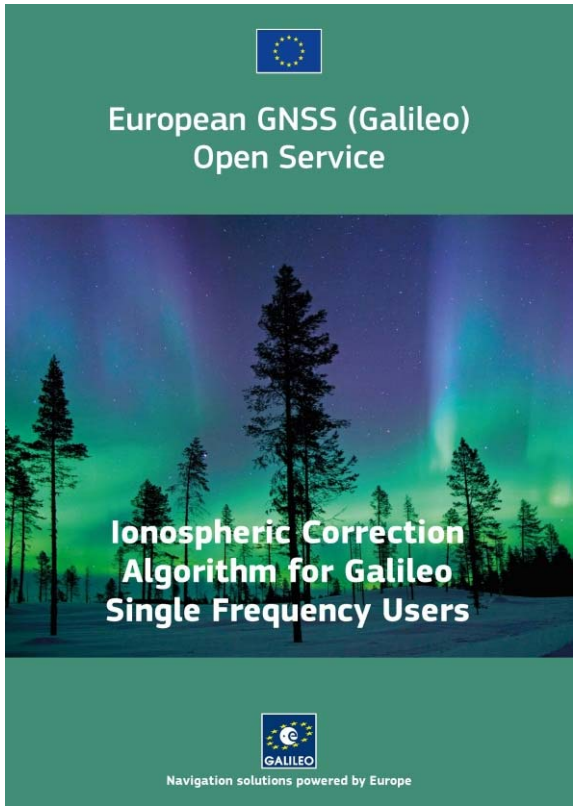


- Broadcast NeQuick G performance very good despite the low number of satellites used to drive the model

Specification document for users

- ★ Full step-by-step methodology and description
- ★ Complementary files
- ★ Input / Output validation files
- ★ Appendix with pseudo-code implementation
- ★ Related action of ICG9 completed with the publication of the document

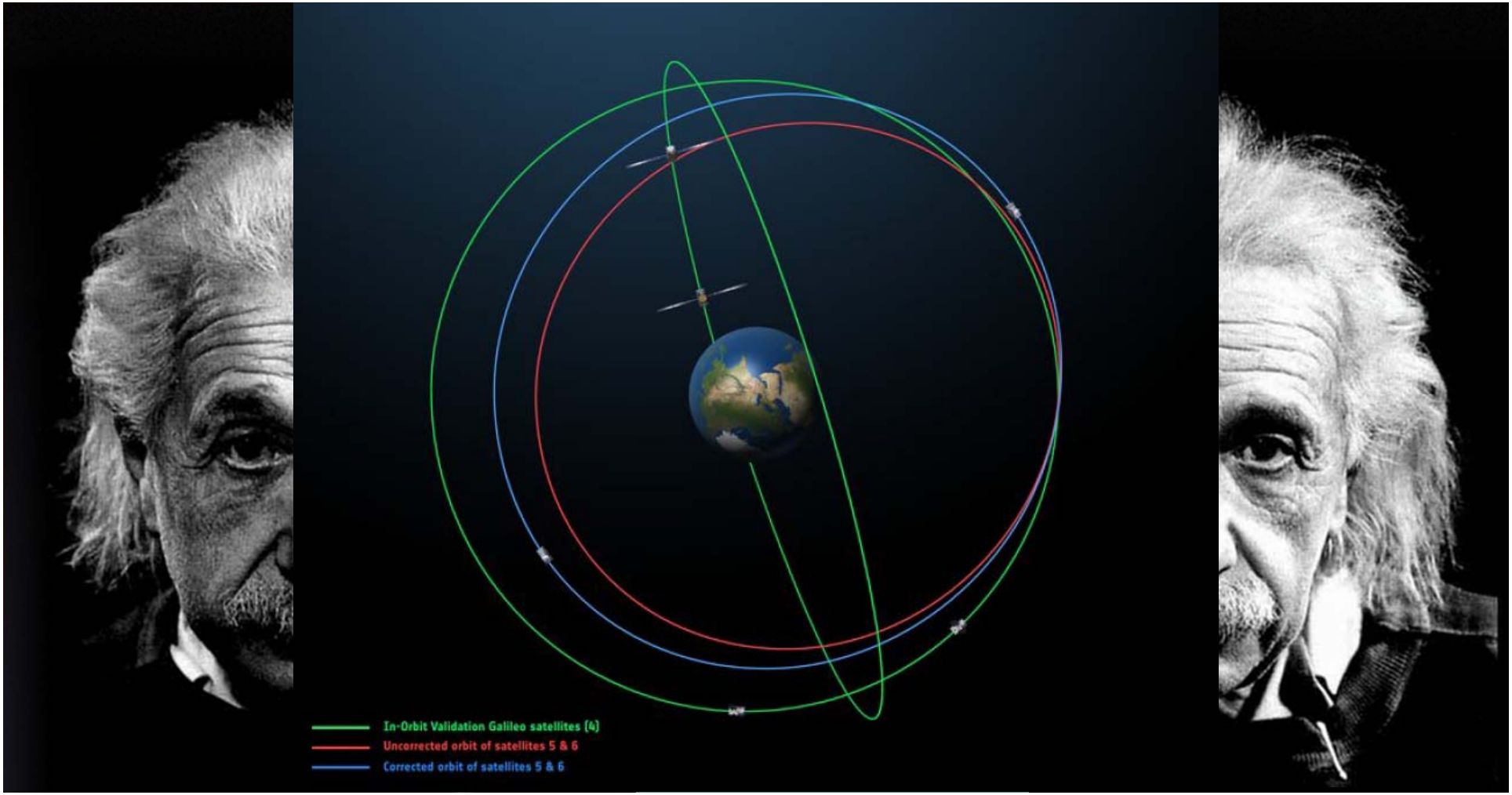
http://www.gsc-europa.eu/education-communication/communication/programme-reference-documents



Summary

- The Galileo ionospheric single frequency correction algorithm with the current reduced Galileo infrastructure shows great performance for all stations around the globe.
- It shows a correction capability over 70% rms (with a lower bound of 20 TECU).
- The Galileo Single Frequency Correction Algorithm together with the Nequick G model are available since April 2015.

Feedback/validation by the user community important !!



Relativity Test with Galileo Satellites in Non-Nominal Orbits

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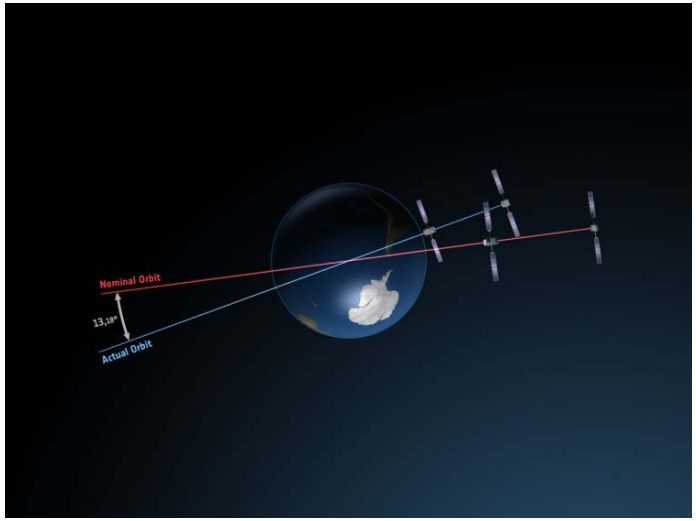
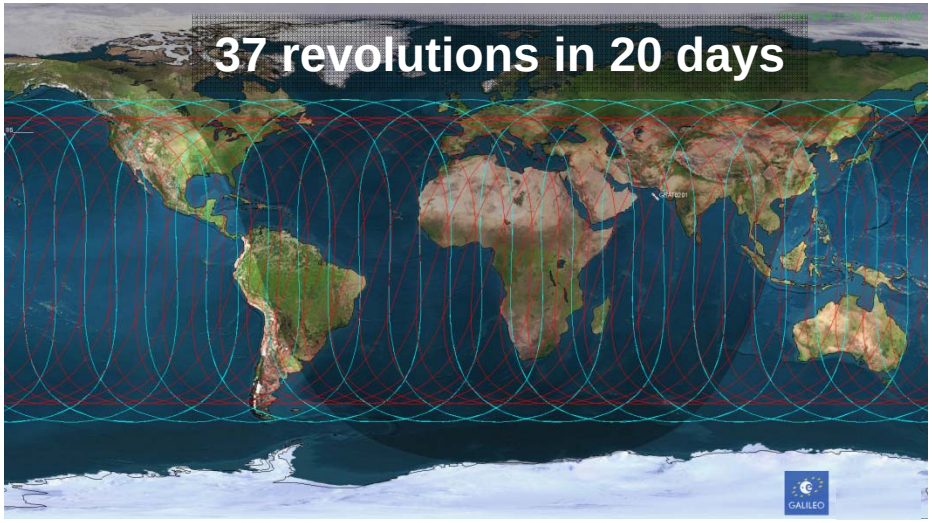
GSAT0201/0202 Orbit Recovery

★ VS09 Orbit injection anomaly left GSAT0201/0202 in eccentric orbits

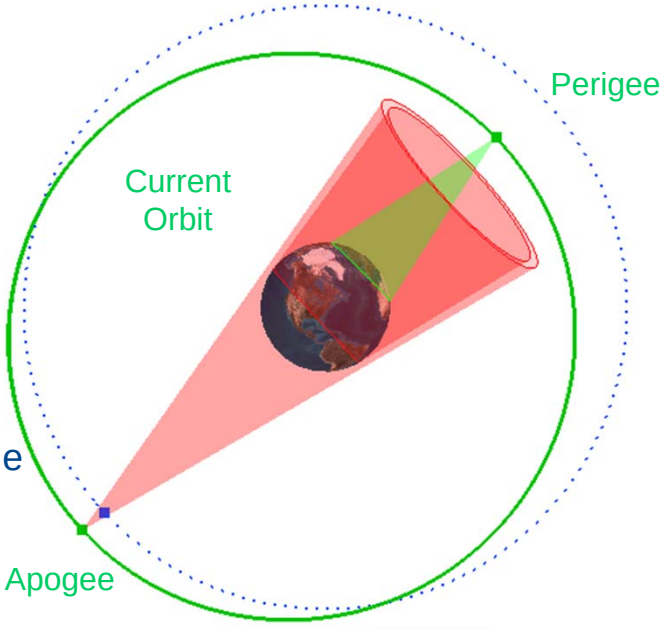




★ Both spacecraft safely raised to higher orbit

★ Satellites currently transmitting Dummy Navigation Message

- ✓ Perigee raised from **13700** to **17200** km
- ✓ Eccentricity reduced from **0.23** to **0.15**
- ✓ Above Van Allen belts & Earth Sensors in operational range



GSAT0201/0202: General relativity tests

- GSAT0201/0202 are perfect candidates to test Gravitational Redshift:

  1. The elliptic orbits produce a regular modulation of the gravitational redshift.
  2. On-board PHM clocks offer unique clock stability
  3. Long satellite life-time with possibility to integrate measurements during a long time
  4. Satellites are permanently monitored and include Laser tracking (SLR) possibilities
  5. No interference on potential nominal use of Satellites 5 and 6 for Navigation
  6. Potentially, the achievable accuracy of the gravitational redshift measurements could become “state of the art” (today best measurements are still based on GP-A experiment performed in 1976)

- Two parallel ESA studies on-going with SYRTE/Observatoire de Paris and ZARM/University of Bremen to perform these tests in detail.

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