The NeQuick G model

R.Orus, R. Prieto-Cerdeira

Workshop on the Use of Global Navigation Satellite Systems for Scientific Applications

Trieste, 02 / 12 / 2014

European Space Agency

Navigation solutions powered by Europe

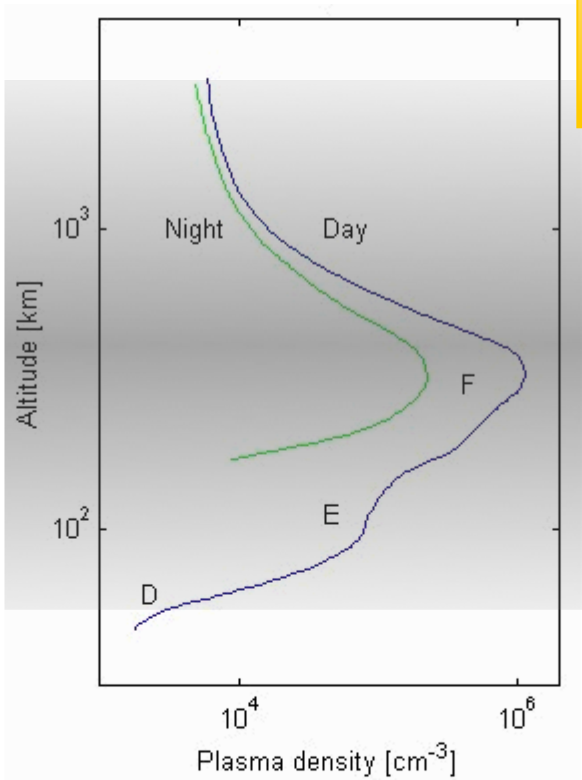
Overview

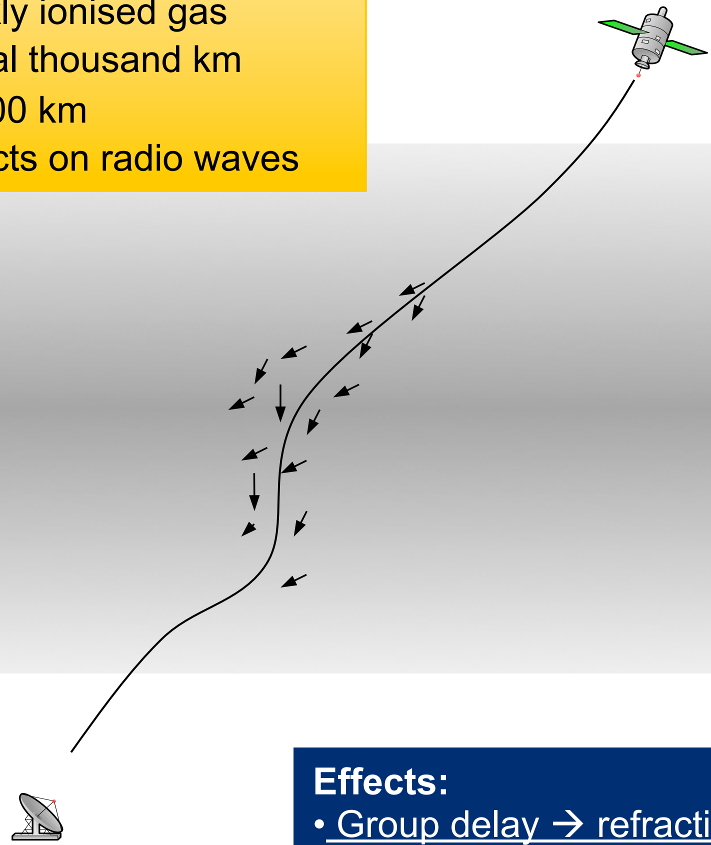
- Background
  - NeQuick model
  - Galileo ionospheric correction algorithm
- Performance results
- Specification Document
- Summary

Ionospheric Effects on GNSS

Ionosphere:

Region of weakly ionised gas
50 km to several thousand km
Peak ~350 – 400 km
Dispersive effects on radio waves





Effects:

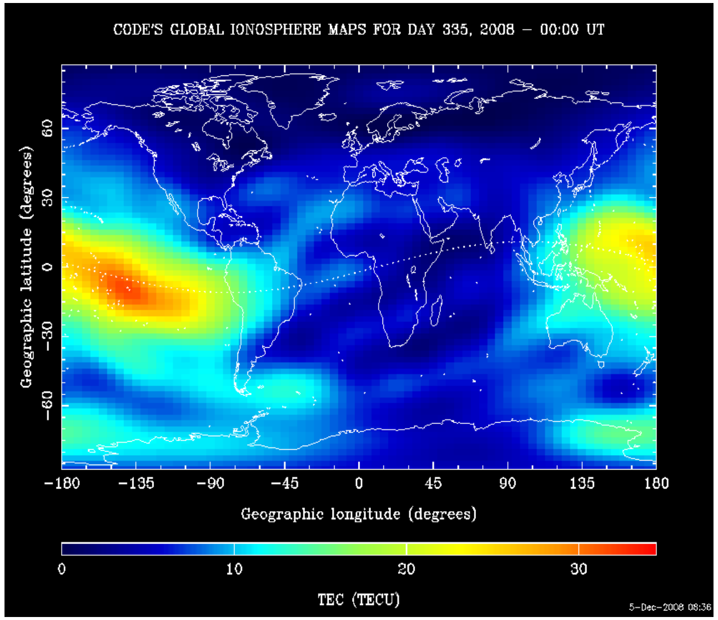
- Group delay → refractive index
- Amplitude/phase rapid variations→ scintillations
- Faraday rotation
- Ray bending

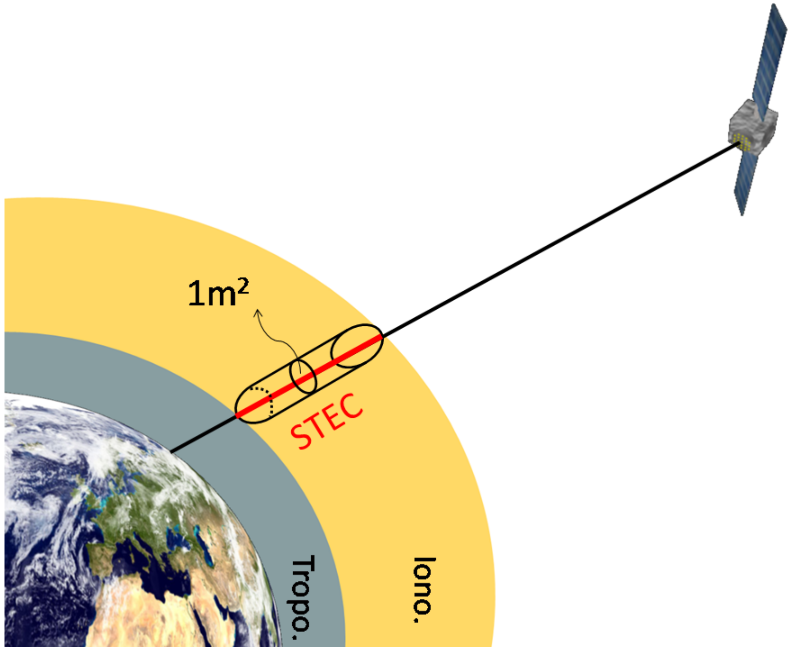
GALILEO EGNOS

Trans-ionospheric group delay (and phase advance)

Pseudorange error [meters] due to ionospheric delay (1st order):

$$\sigma_{iono} \approx \frac{40.3}{f^2} \cdot TEC \,[\text{meters}]$$





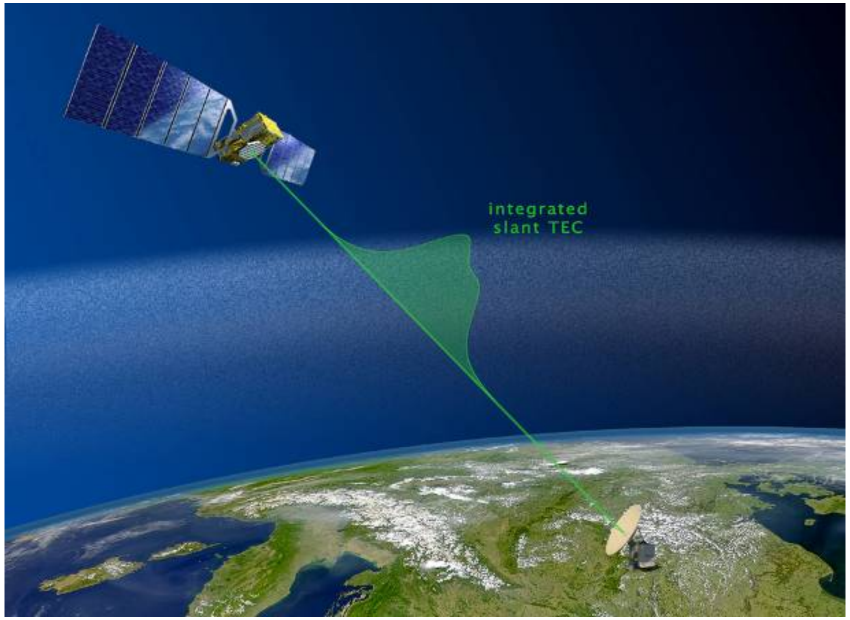
Credits: C. Carrano (Boston College)

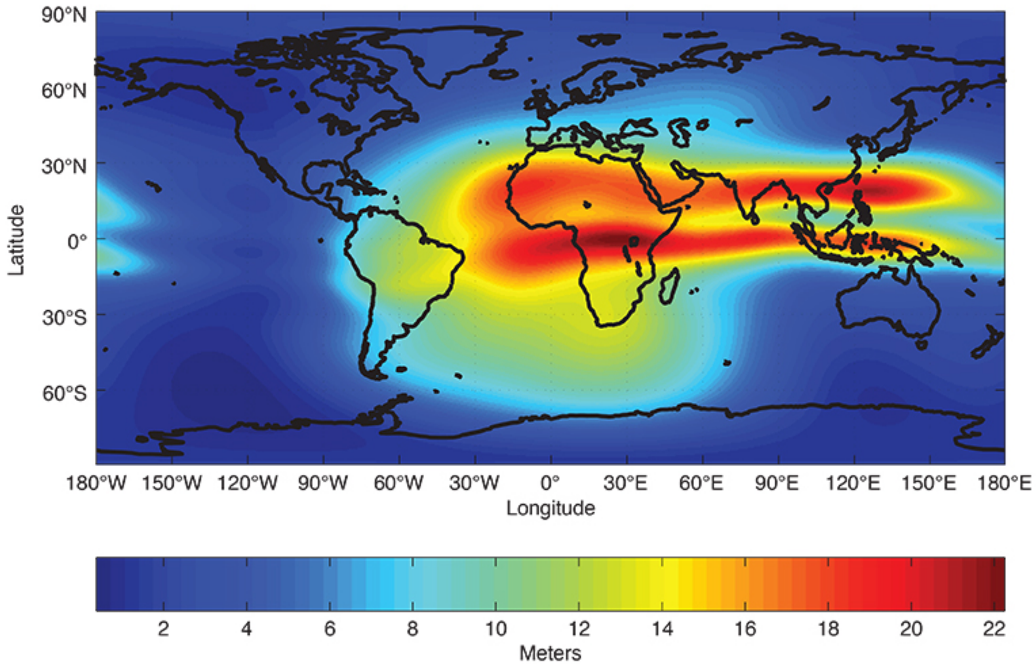
TEC = Total Electron Content

Integrated electron density through a given path

1 TECU = 10^{16} el/m^2 ≈ 16 cm in L1

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.

GALILEO EGNOS

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**		

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

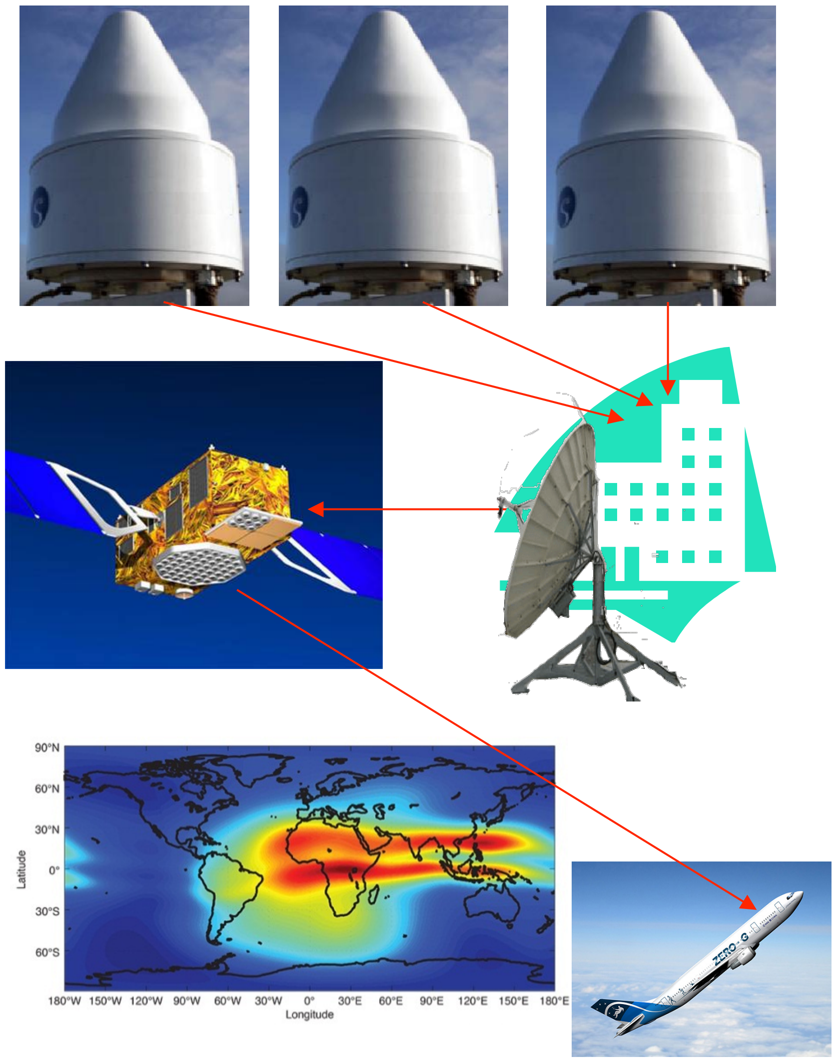
Broadcast effective ionisation parameter in Navigation message

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

↓

USER RECEIVER

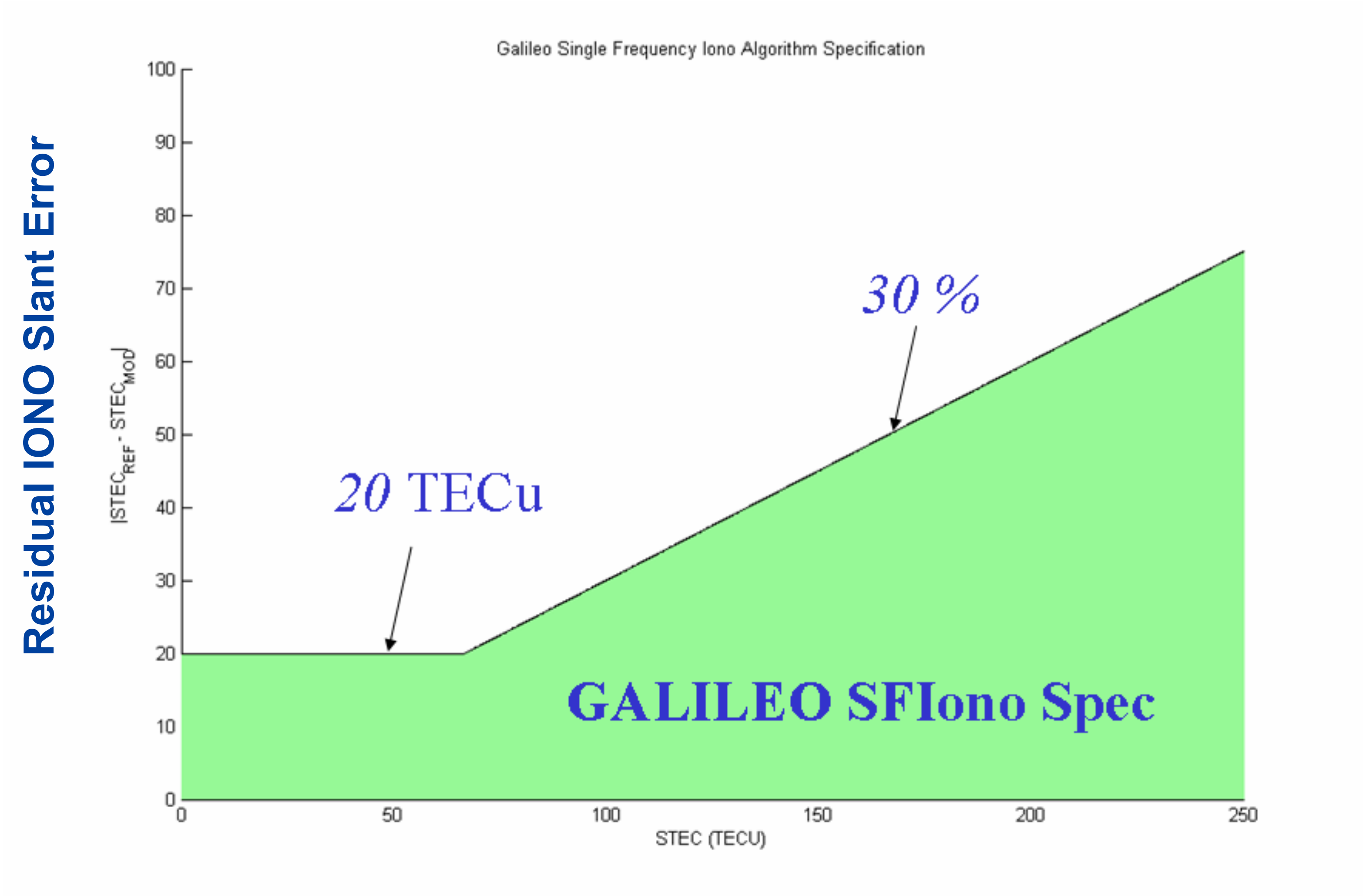
Calculate slant TEC using NeQuick G with broadcast parameter. Correct for Ionospheric delay at frequency in question.



GALILEO EGNOS

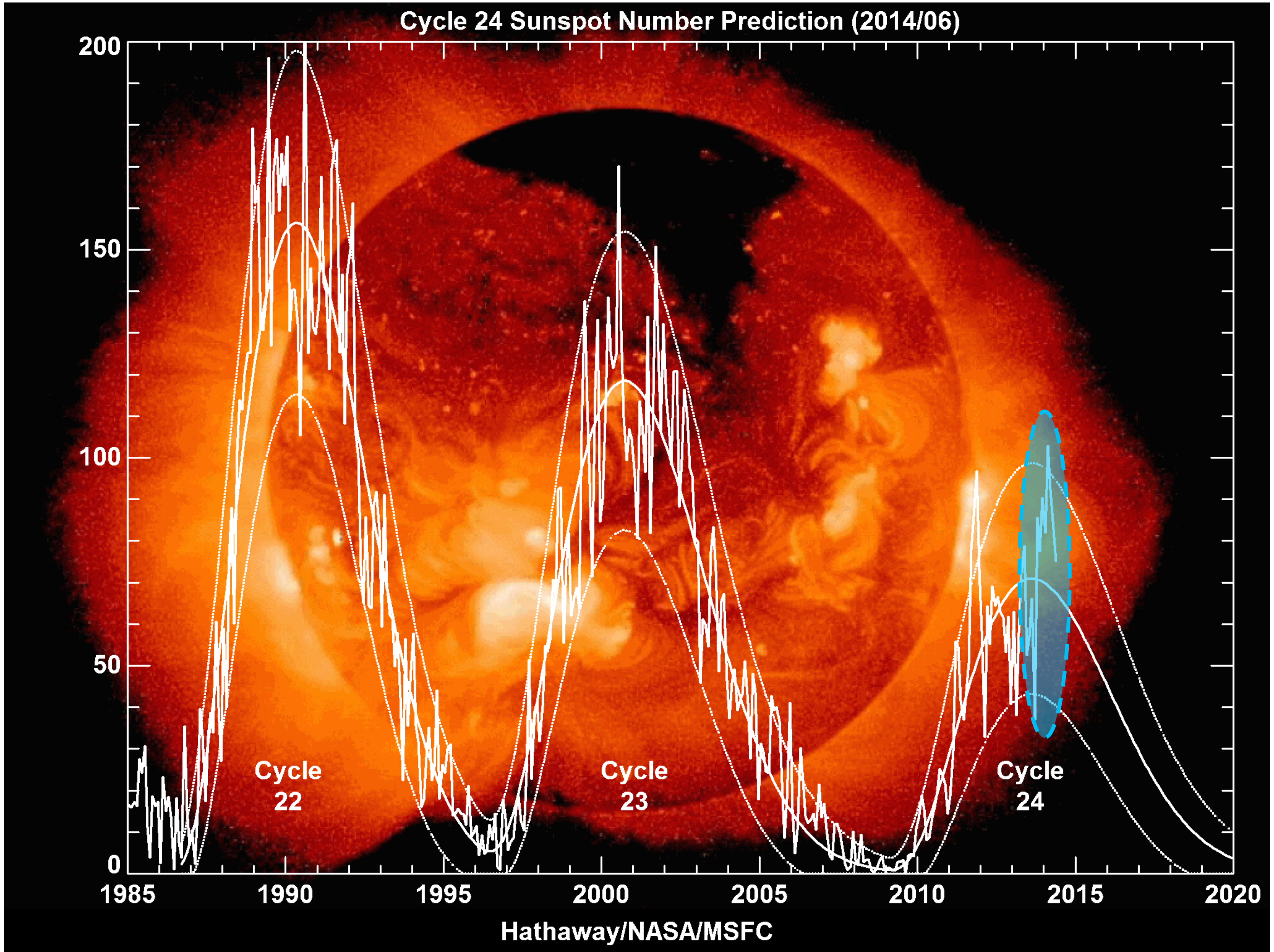
Performance Objectives

Residual IONO Slant Error



Actual IONO Slant delay

During solar maximum – but a mild one!

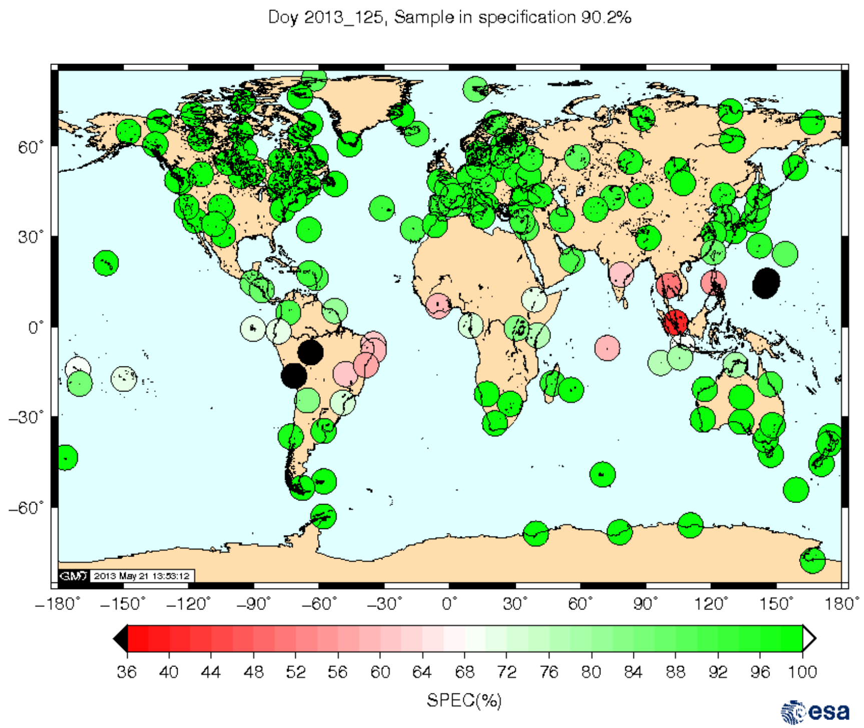


GALILEO EGNOS

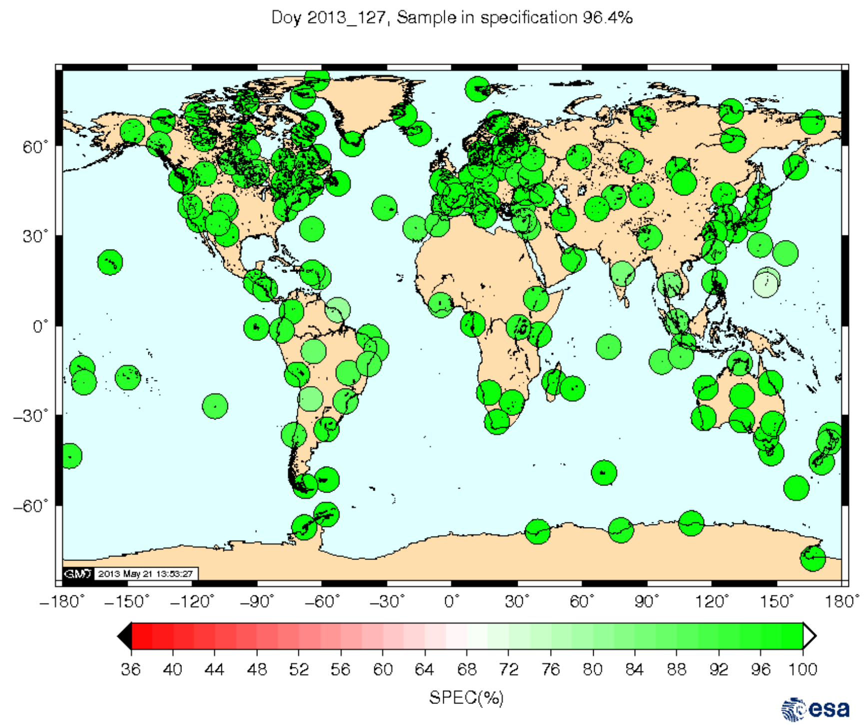
Compliance to Target Performance

Galileo broadcast

White to green >= 70% correction level
>100 stations, reference ionosphere based on dual-freq IONEX-levelled



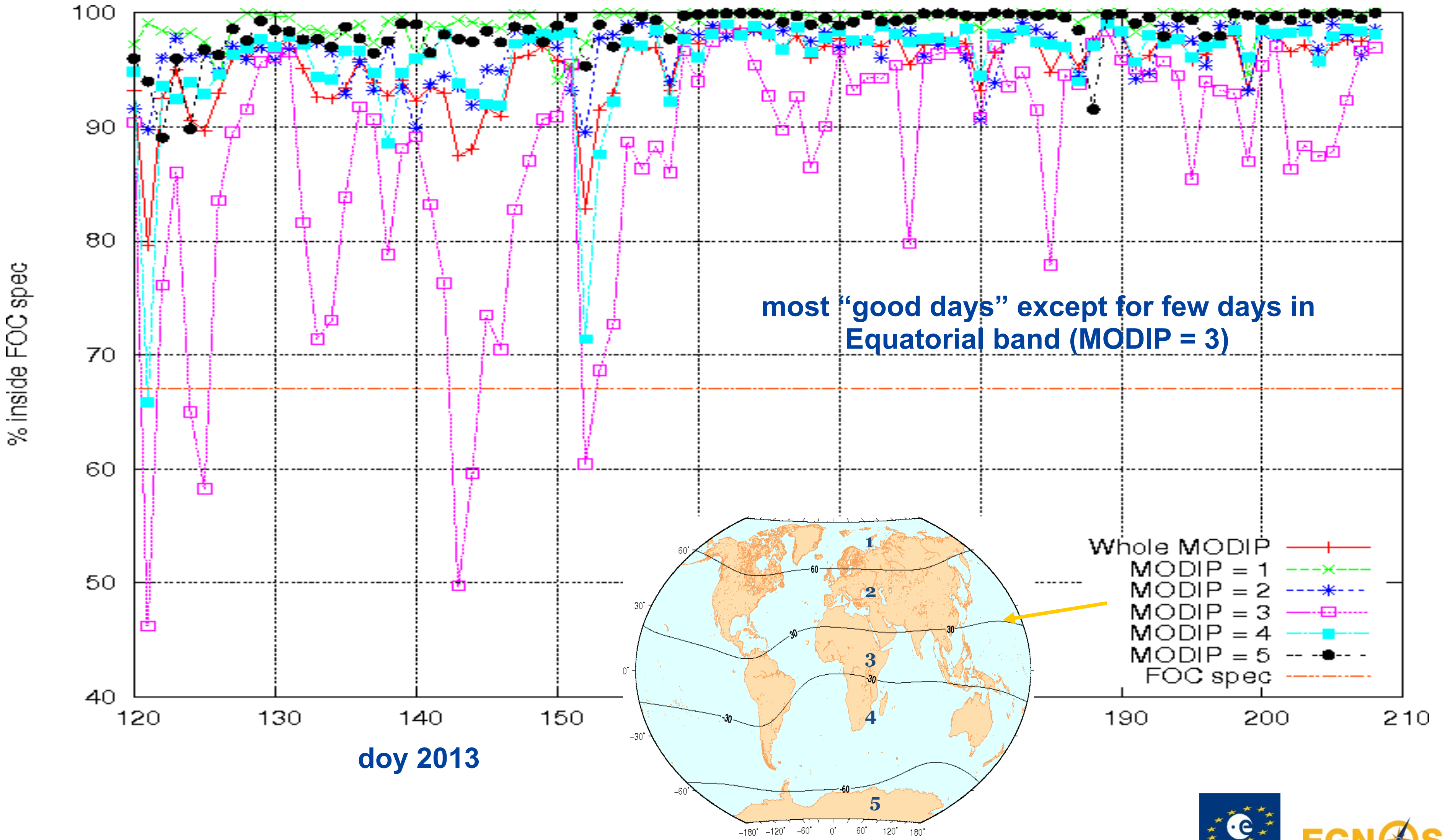
doy 125/2013
"bad" day
overall 90.2% inside spec



doy 127/2013
"good" day
overall 96.4% inside spec

GALILEO EGNOS

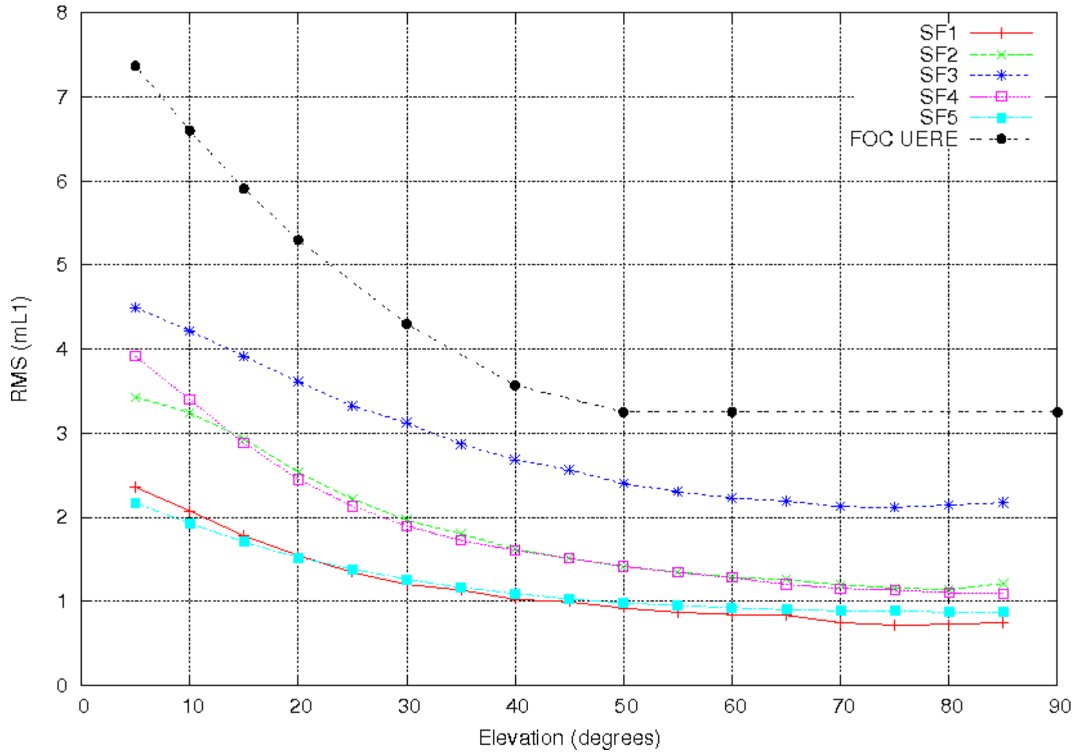
Compliance to Target Performance



MODIP = Modified DIP. MODIP is related with geomagnetic field

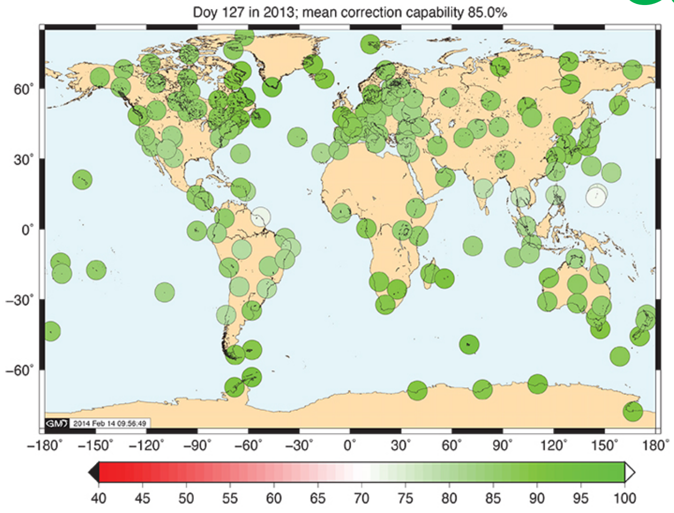
Actual Iono UERE residual Contribution for Single Frequency Users per Region (SFi)

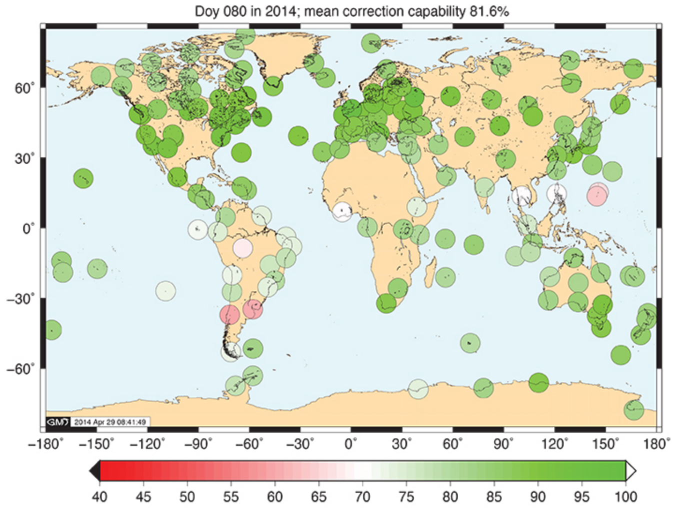
	Elevation angle (degrees)								
	5	10	15	20	30	40	50	60	90/85
Spec	*737.0*	*660.0*	*591.0*	*530.0*	*430.0*	*357.0*	*325.0*	*325.0*	*325.0*
SF1	235.8	207.5	178.0	154.6	120.1	102.2	91.7	84.4	74.5
SF2	343.0	324.5	293.1	253.7	196.4	161.9	141.0	128.7	121.3
SF3	449.5	421.8	391.6	361.5	312.2	268.5	240.1	222.9	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



Ionospheric Correction Capability (%)

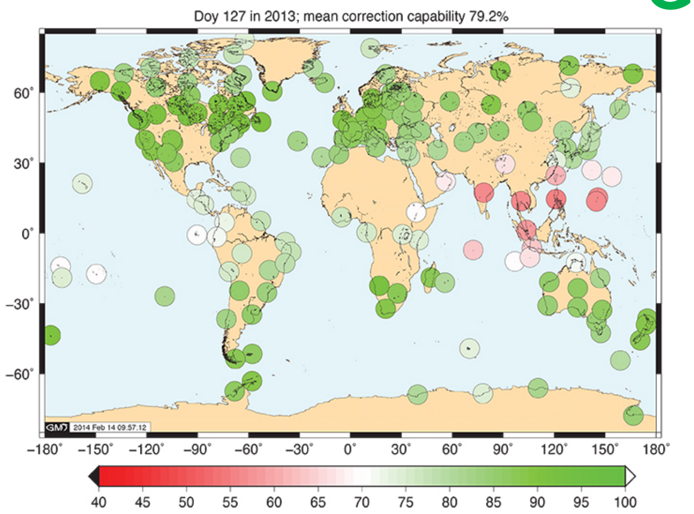
Galileo broadcast

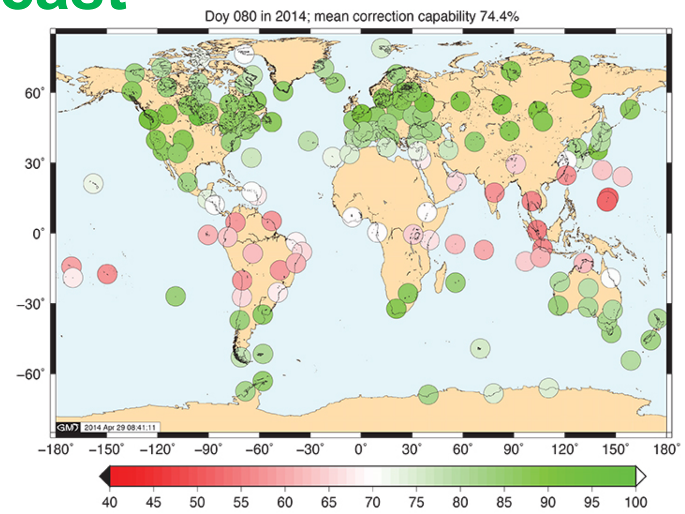




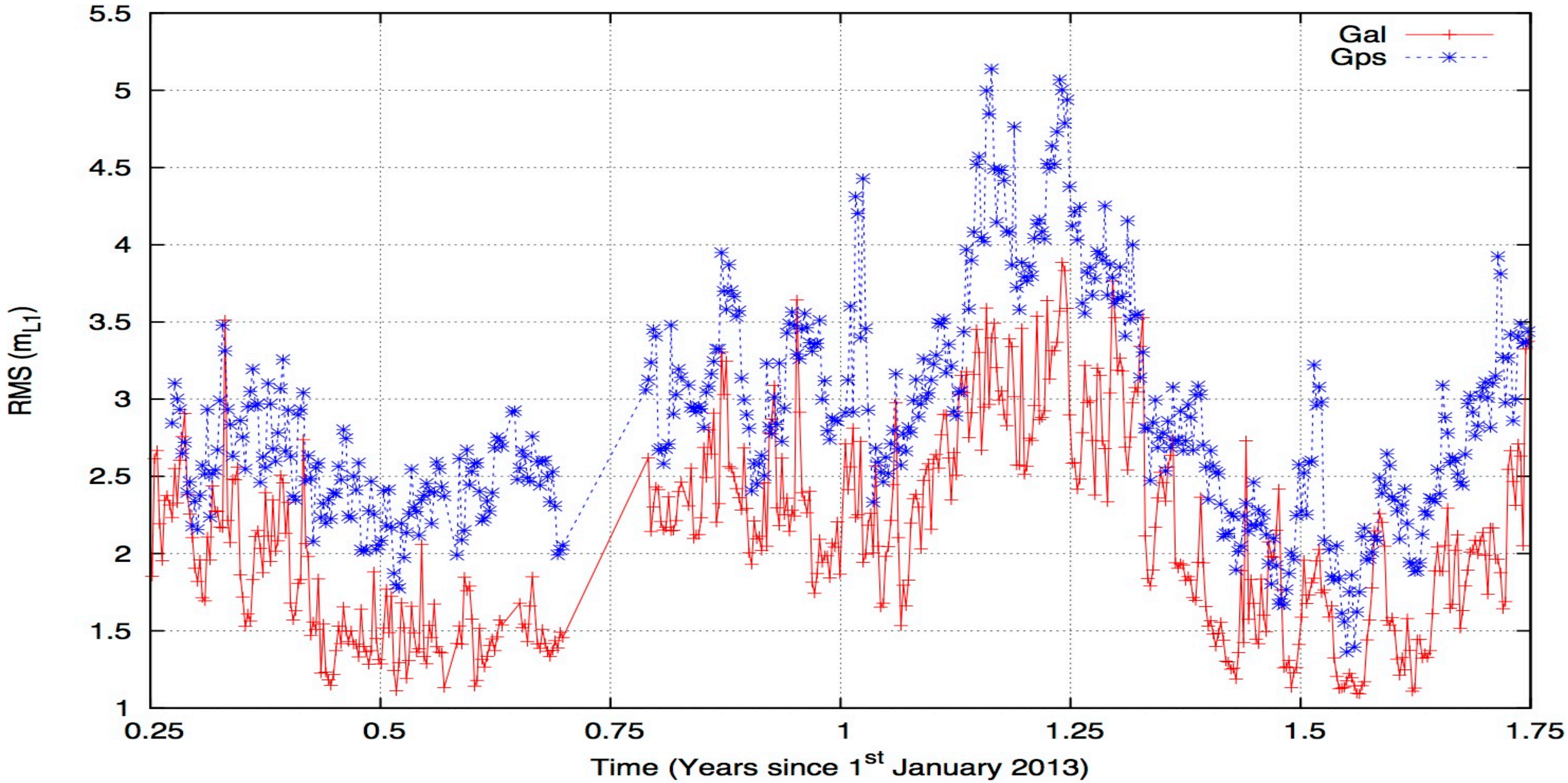
doy 127/2013 **doy 080/2014**

GPS broadcast



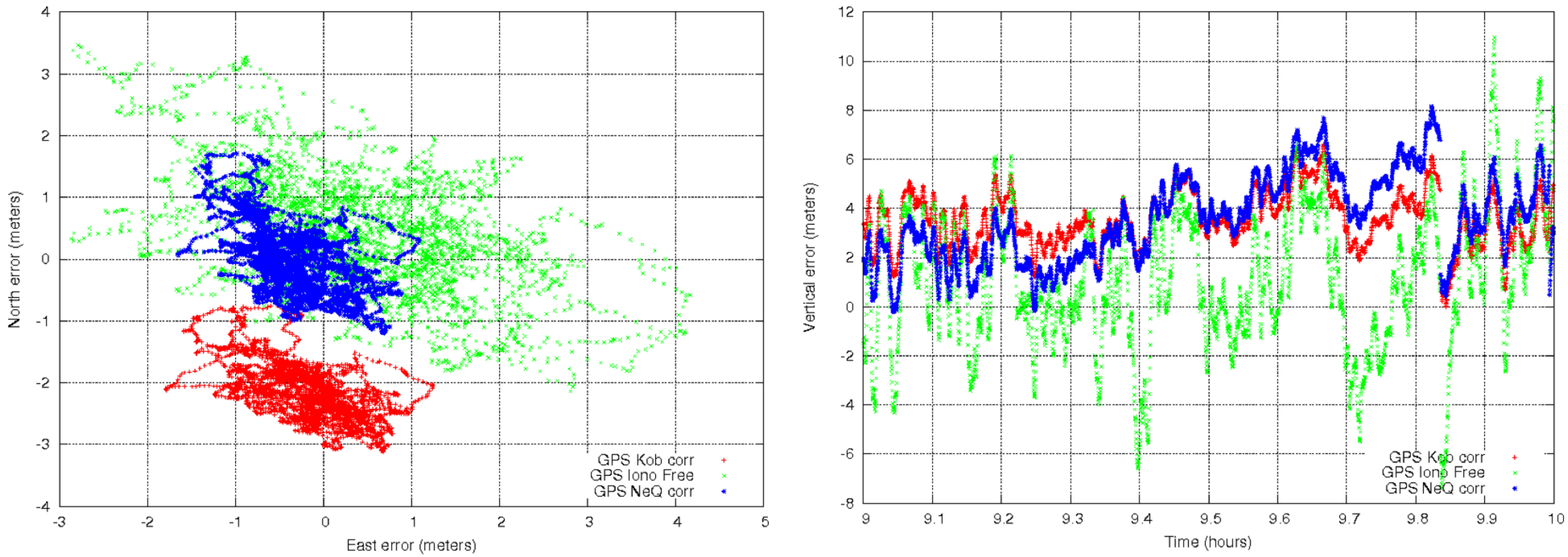


Residual RMS error (meters$_{L1}$) - daily evolution 2013-2014



- Broadcast NeQuick G performance very good despite the low (3-4) number of satellites used to drive the model

Positioning Error (GPS – low-latitude)



Horiz. (left) and Vert. (right) GPS positioning error on L1 and single-frequency NeQuick G correction (blue), L1 and GPS ICA (red) and dual-frequency ionospheric-free (green) for low-latitude station Malindi (doy 172, 2013)

International Activities

- ★ Nequick-G performance results presented at the UN ICG-9, Prague, 10-14 Nov 2014.
- ★ Benefits of Nequick-G well recognized.
- ★ Adopted Recommendation:

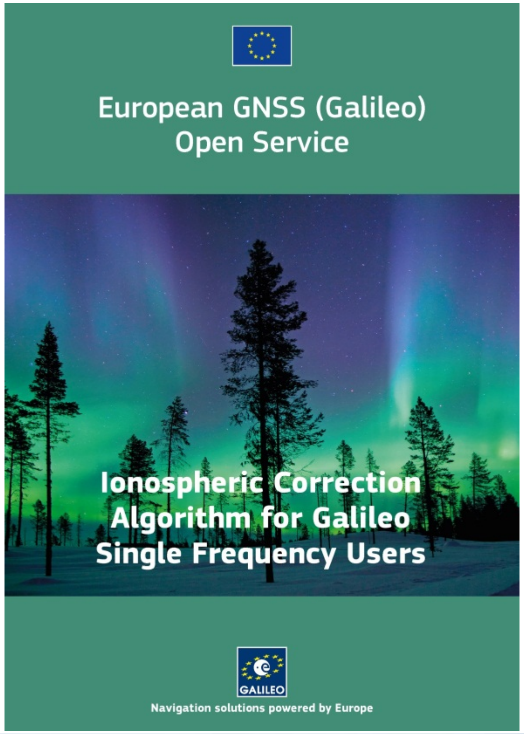
For the Service Providers and interested users participating in the ICG, to assess the performance and usability of a Nequick ionospheric correction algorithm for the single frequency users similar to the one adopted by Galileo in view of its expected good performance compared with other models, i.e. at low latitudes

ICG International Committee on Global Navigation Satellite Systems

GALILEO EGNOS

Specification document - Contents

- ★ Full step-by-step methodology and description
- ★ Complementary files
- ★ Input / Output validation files
- ★ Appendix with pseudo-code implementation



Summary

- The Galileo ionospheric single frequency correction algorithm with the current reduced Galileo infrastructure shows great performance for all stations around the globe.
    - Globally, above 85% within specification (FOC requirement is >68% inside specification).
- It shows a correction capability over 70% rms (with a lower bound of 20 TECU).
- Benefits recognized at international level (UN ICG)
- The Galileo Single Frequency Correction Algorithm together with the Nequick G model are ready to be published.
    - Feedback/validation by the user community important

Thank you

European Space Agency

GALILEO EGNOS

Navigation solutions powered by Europe