Status of NeQuick G after the Solar Maximum of Cycle 24

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esa

European Space Agency

GALILEO

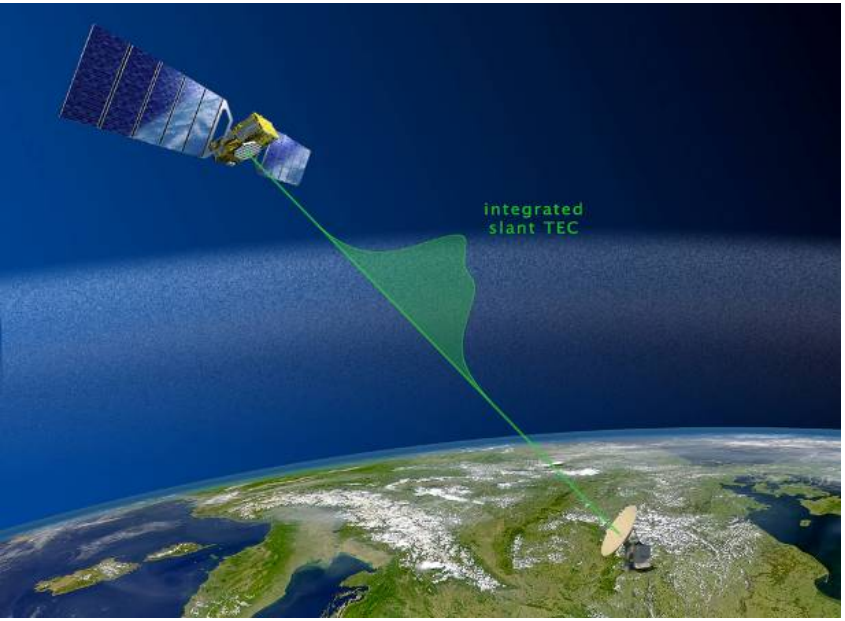
EGNOS

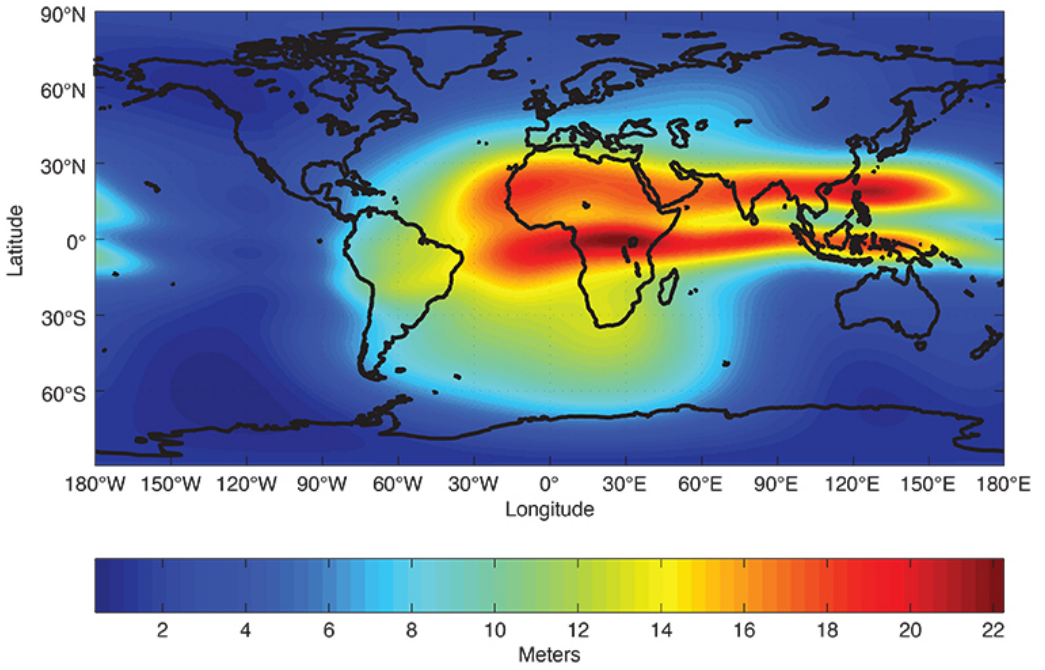
Navigation solutions powered by Europe

Overview

- Background
  - NeQuick model
  - Galileo ionospheric correction algorithm
- Performance results
  - IOV Results
  - *FOC* Results
- Position Error compared to EGNOS Iono
- Galileo Single frequency position on March 2016
- 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.

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**		

GALILEO EGNOS

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

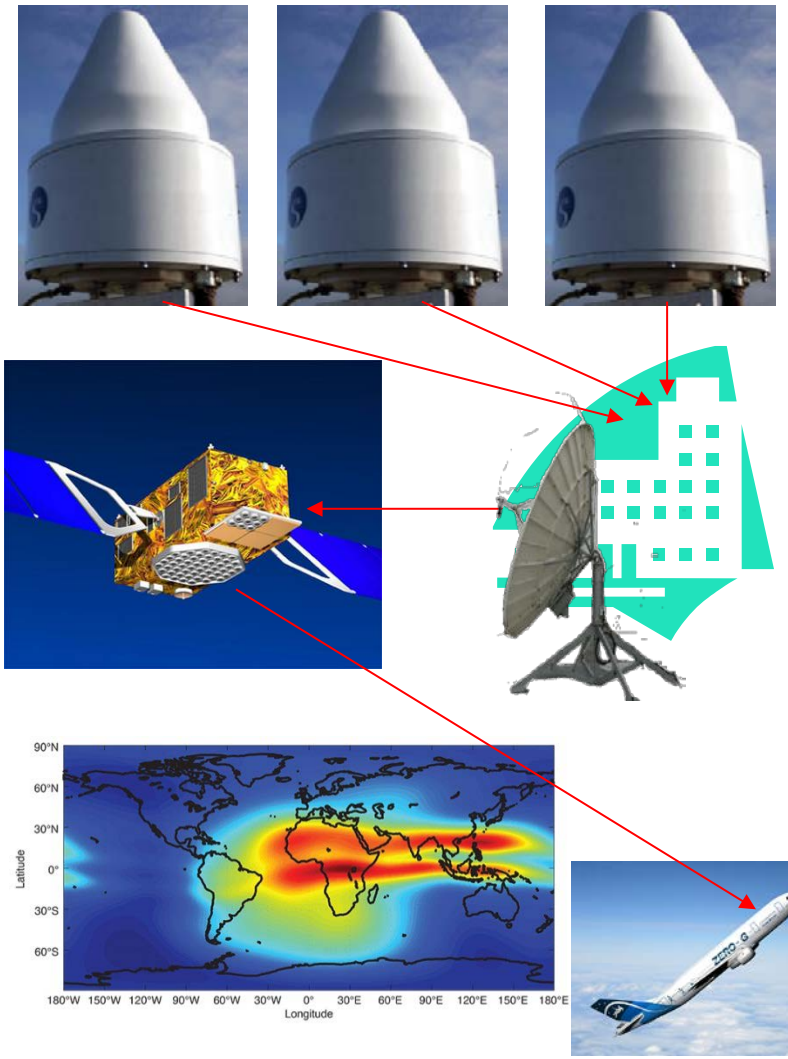
Broadcast effective ionisation parameter in Navigation message

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

↓

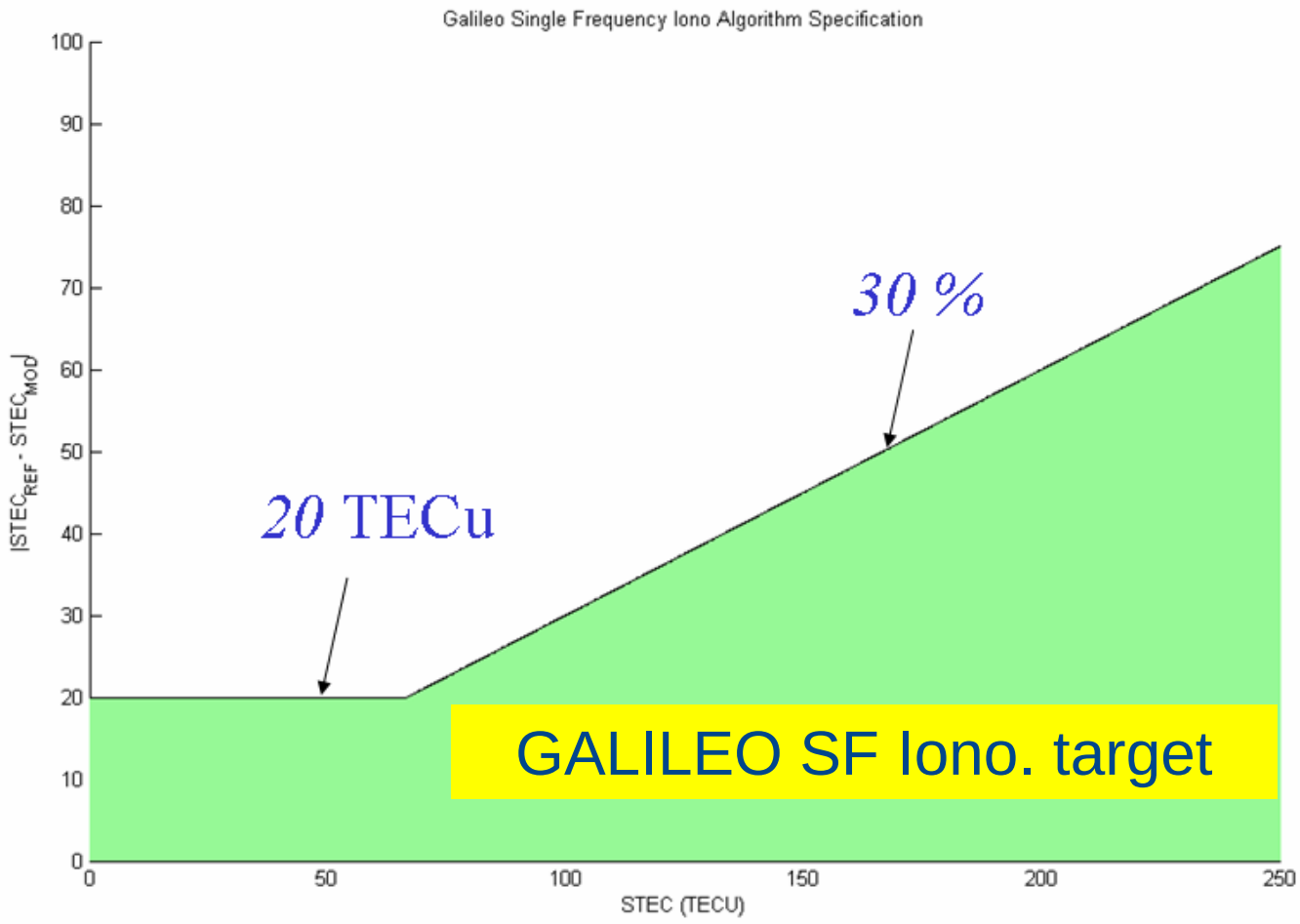
USER RECEIVER

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



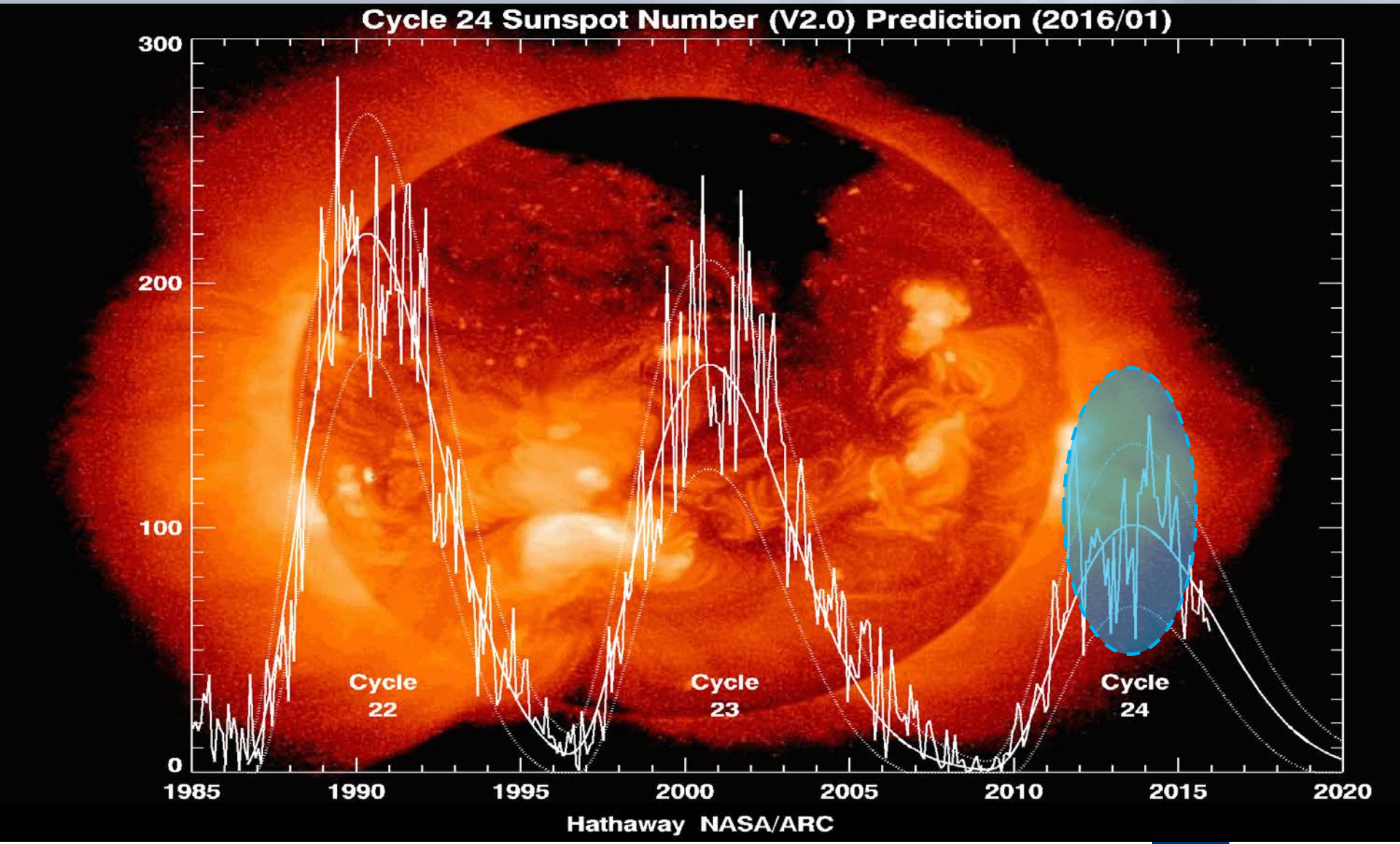
GALILEO EGNOS

Performance Objectives



Actual IONO Slant delay

During solar maximum – but a mild one!

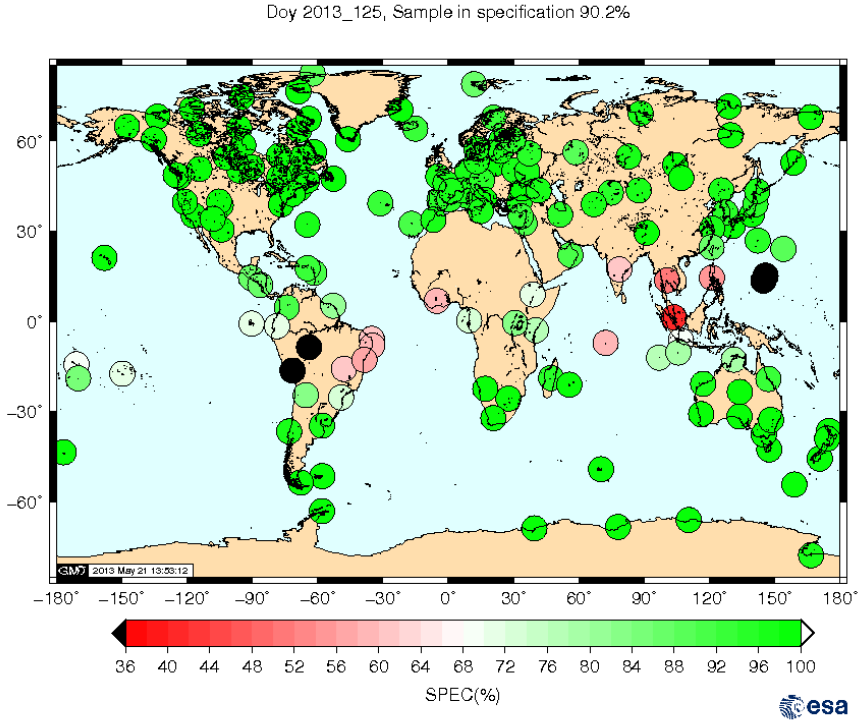


GALILEO EGNOS

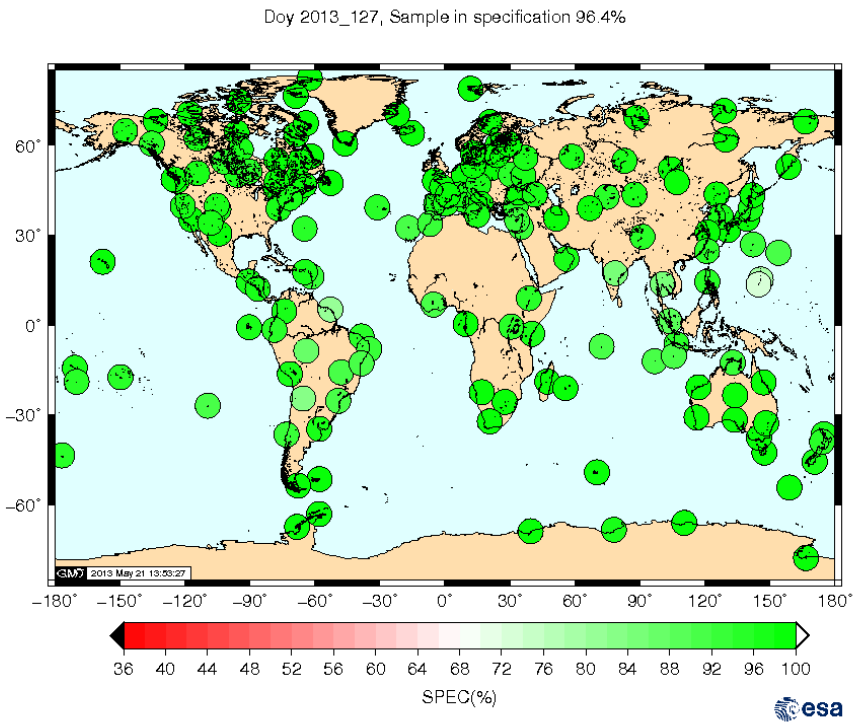
IOV Results

Galileo broadcast

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



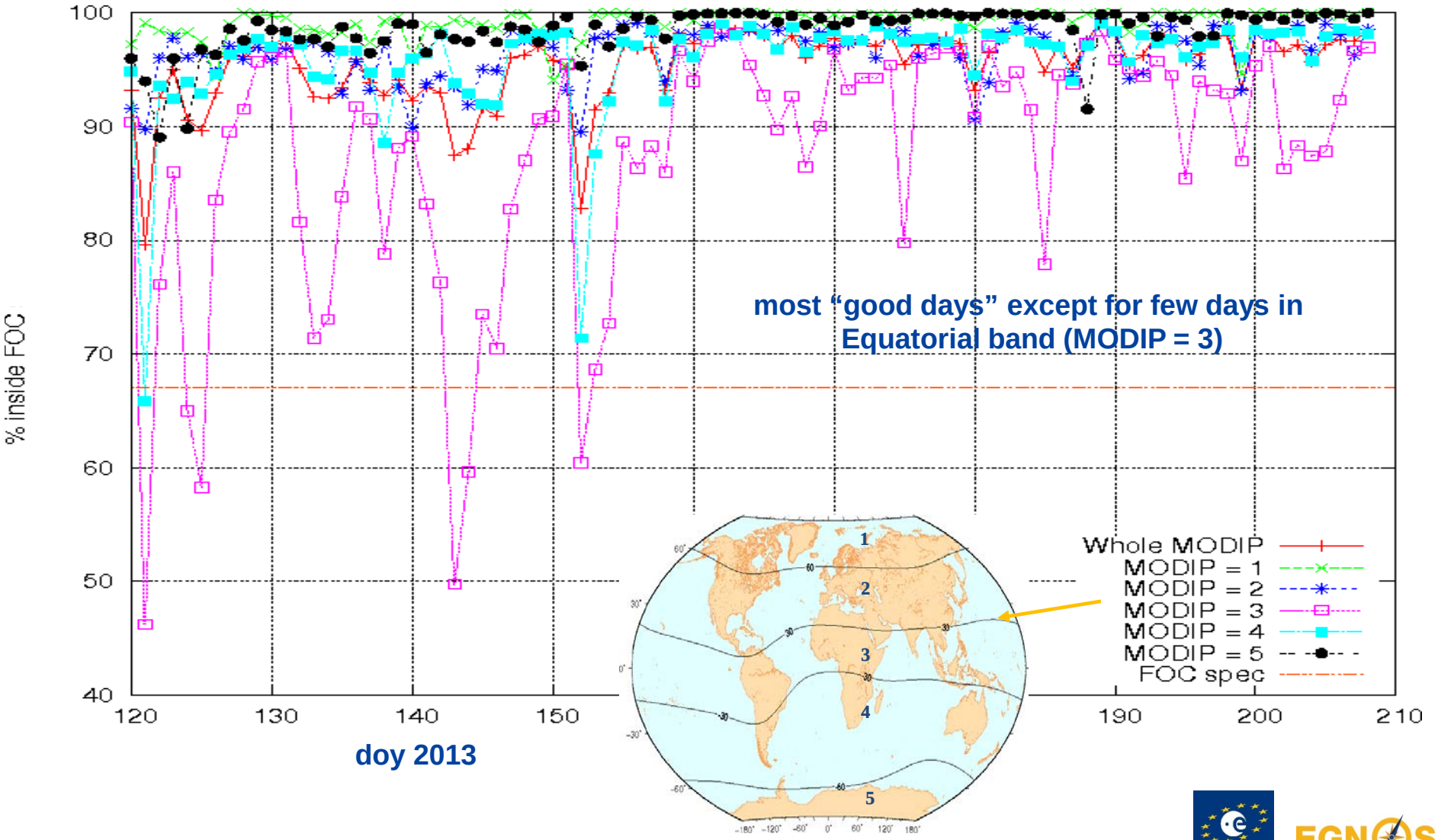
doy 125/2013
“bad” day
overall 90.2% inside spec



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

GALILEO EGNOS

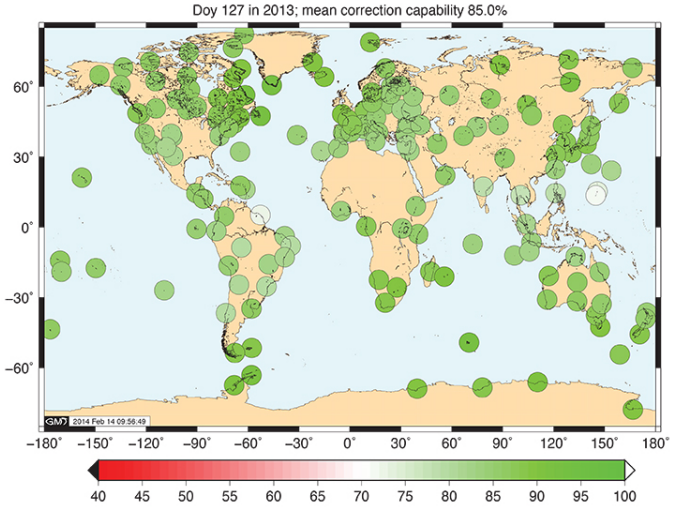
IOV Results: % inside target

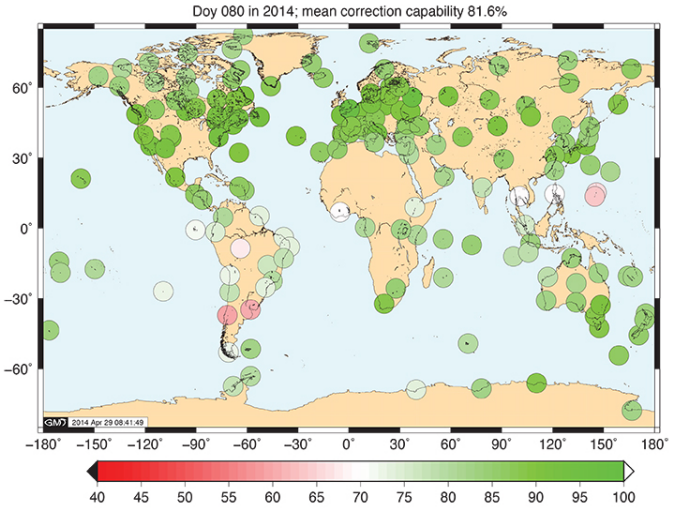


MODIP = Modified DIP. MODIP is related with geomagnetic field

IOV Results: Iono. Corr. Capability (%)

Galileo broadcast

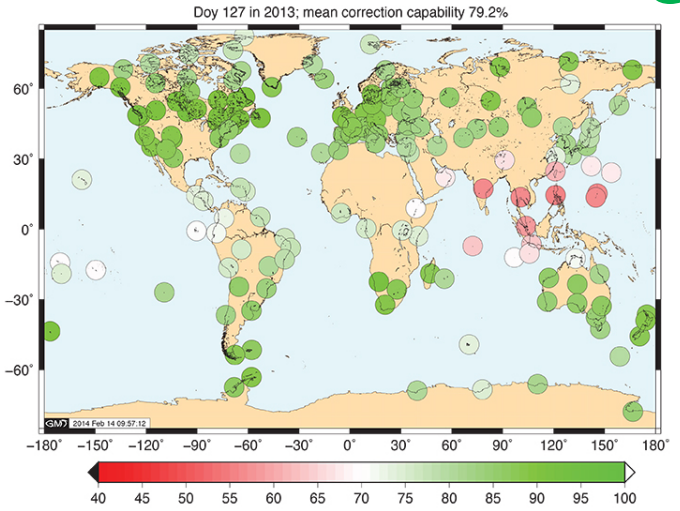


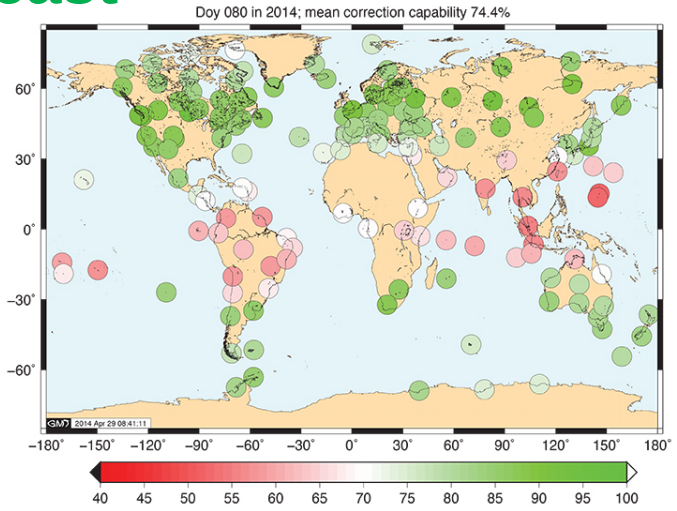


Doy 127/2013

Doy 080/2014

GPS broadcast

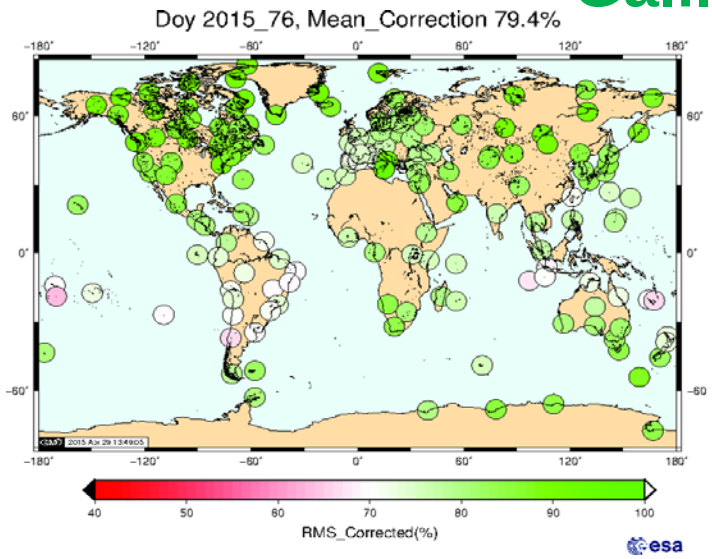


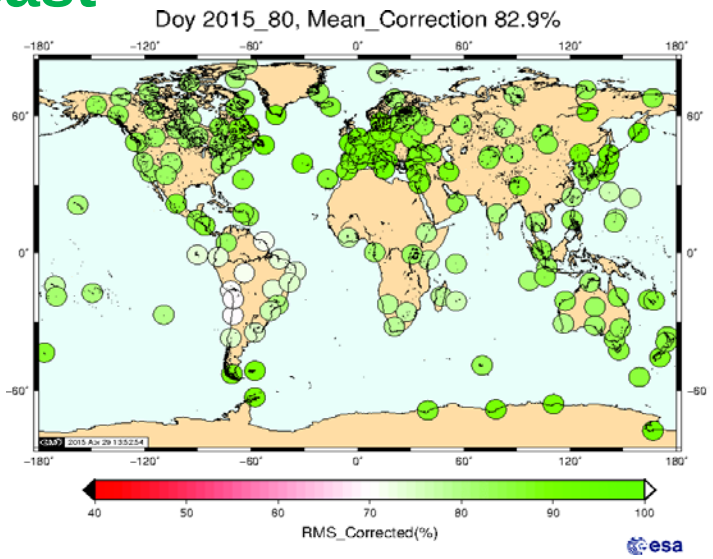


GALILEO EGNOS

FOC Results: Iono. Corr. Capability (%)

Galileo broadcast

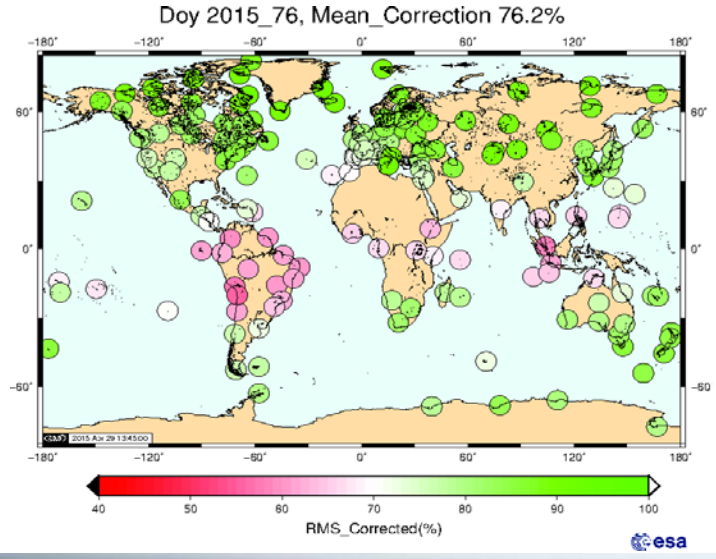


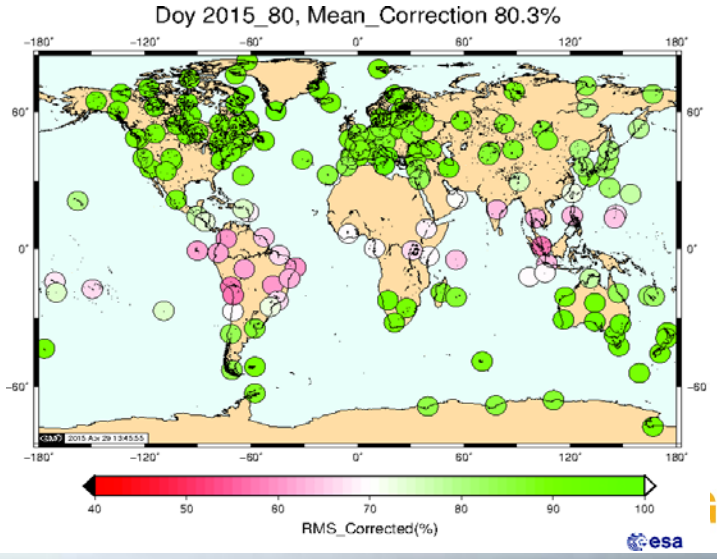


Doy 76/2015 (1st day St. Patrick's storm)

Doy 080/2015

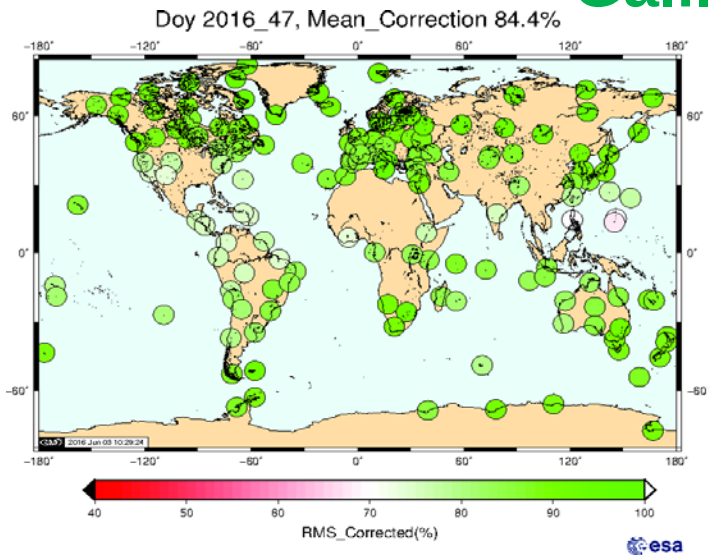
GPS broadcast



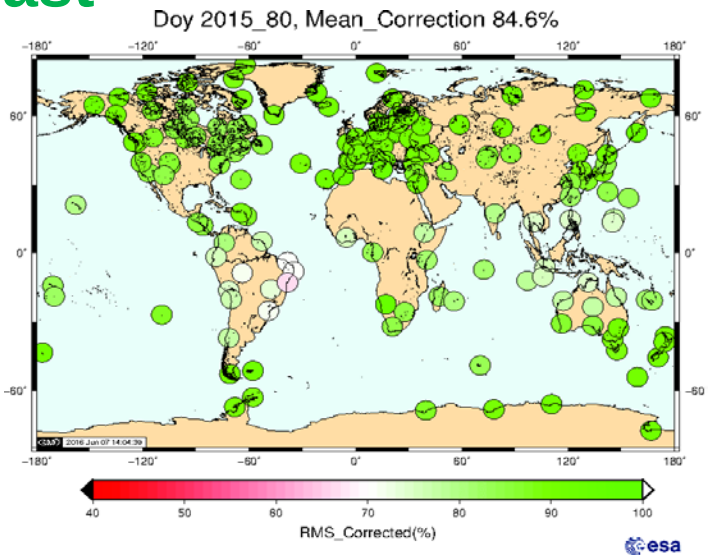


FOC Results: Iono. Corr. Capability (%)

Galileo broadcast

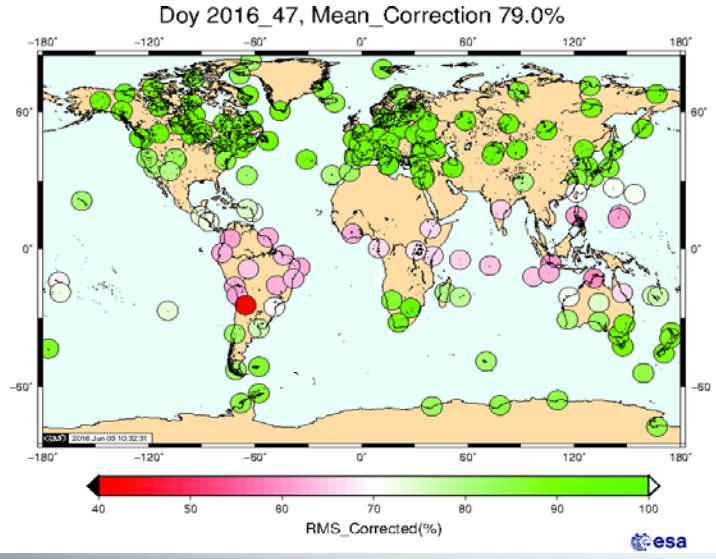


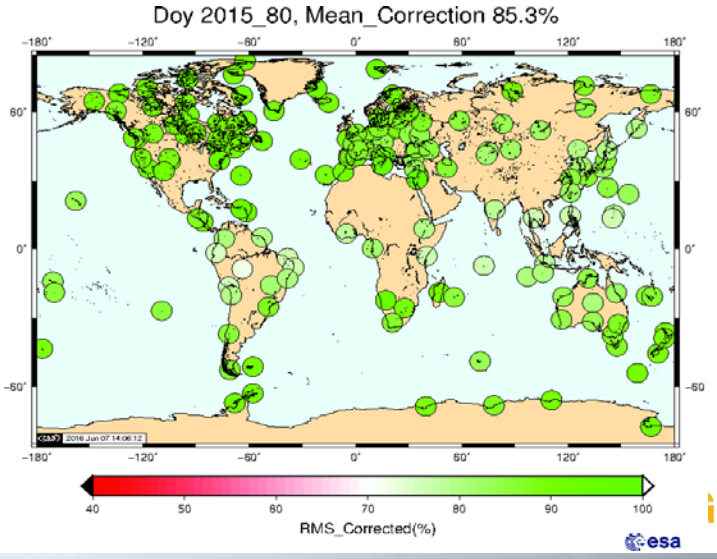
Doy 047/2016 (high kp)



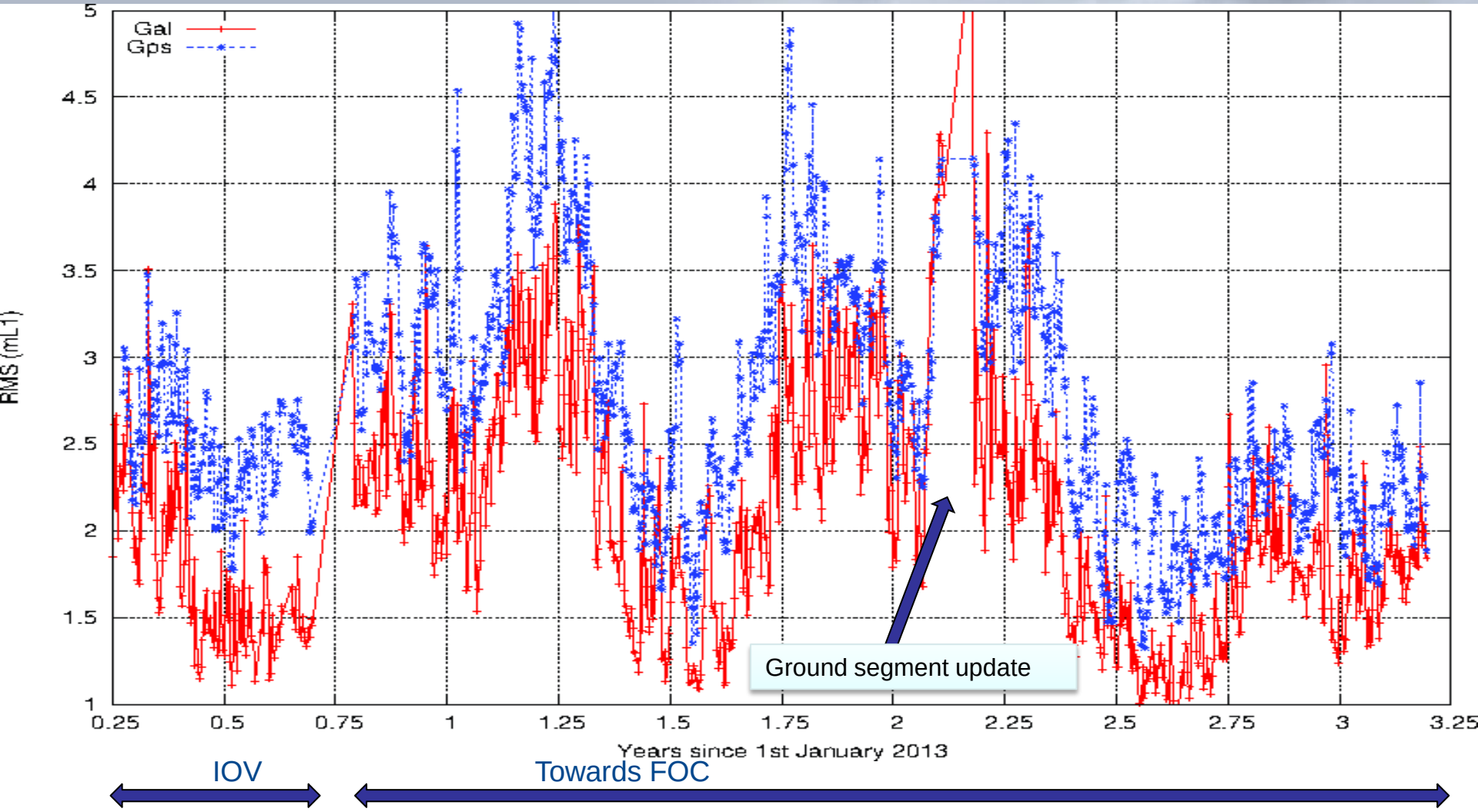
Doy 080/2016

GPS broadcast





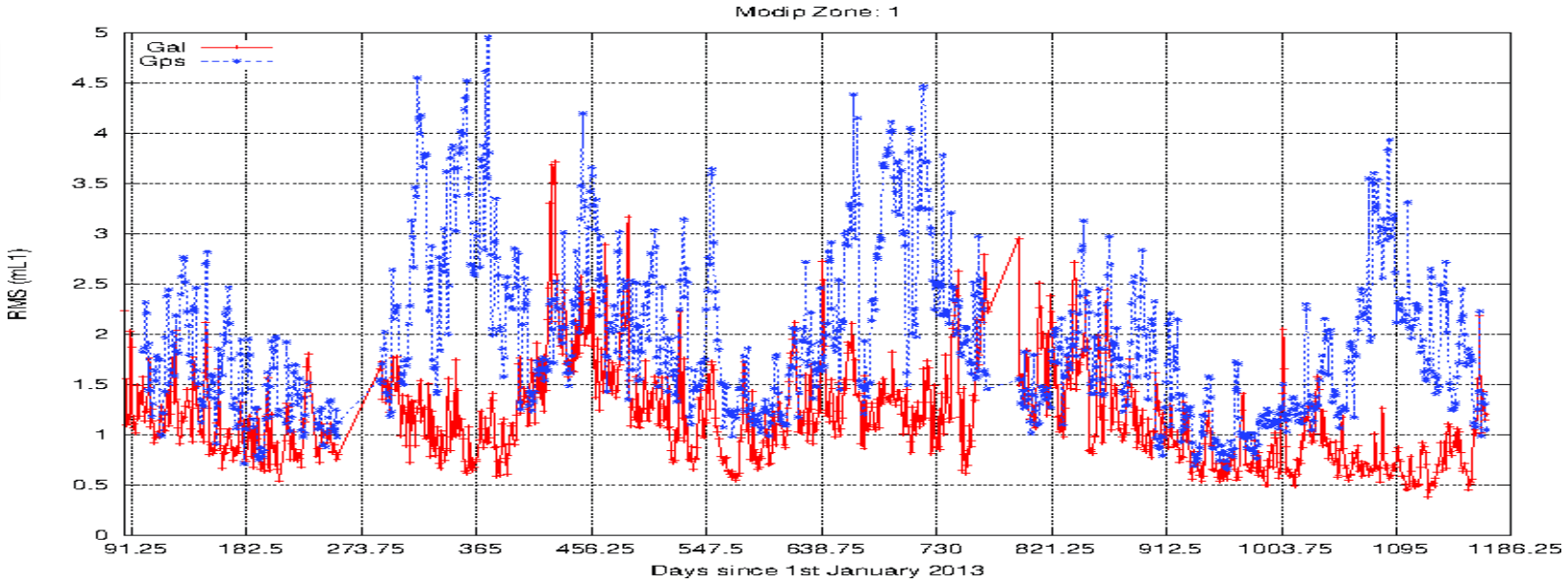
IOV+FOC: Residual RMS error (m_{L1}) – daily 2013-2016



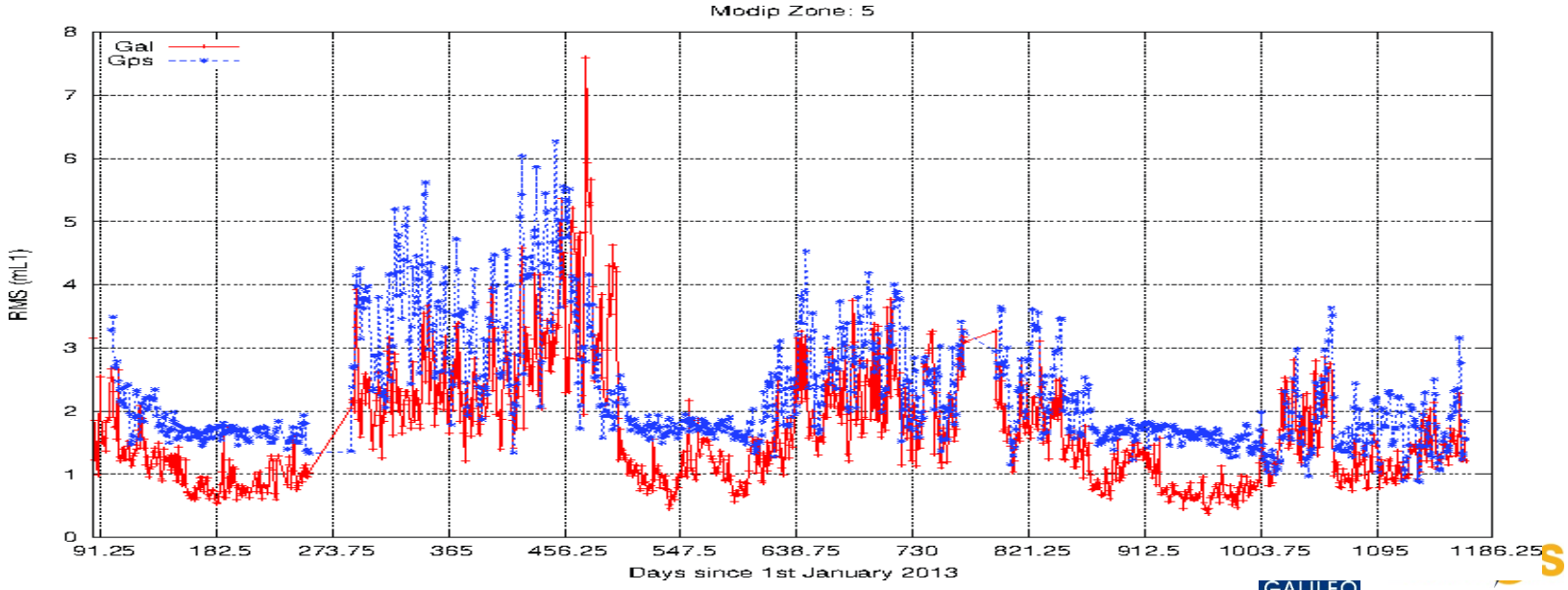
- Broadcast NeQuick G performance very good despite the low number of satellites used to drive the model

IOV+FOC: Residual RMS error (m_{L1}) – daily 2013-2016

MODIP 1

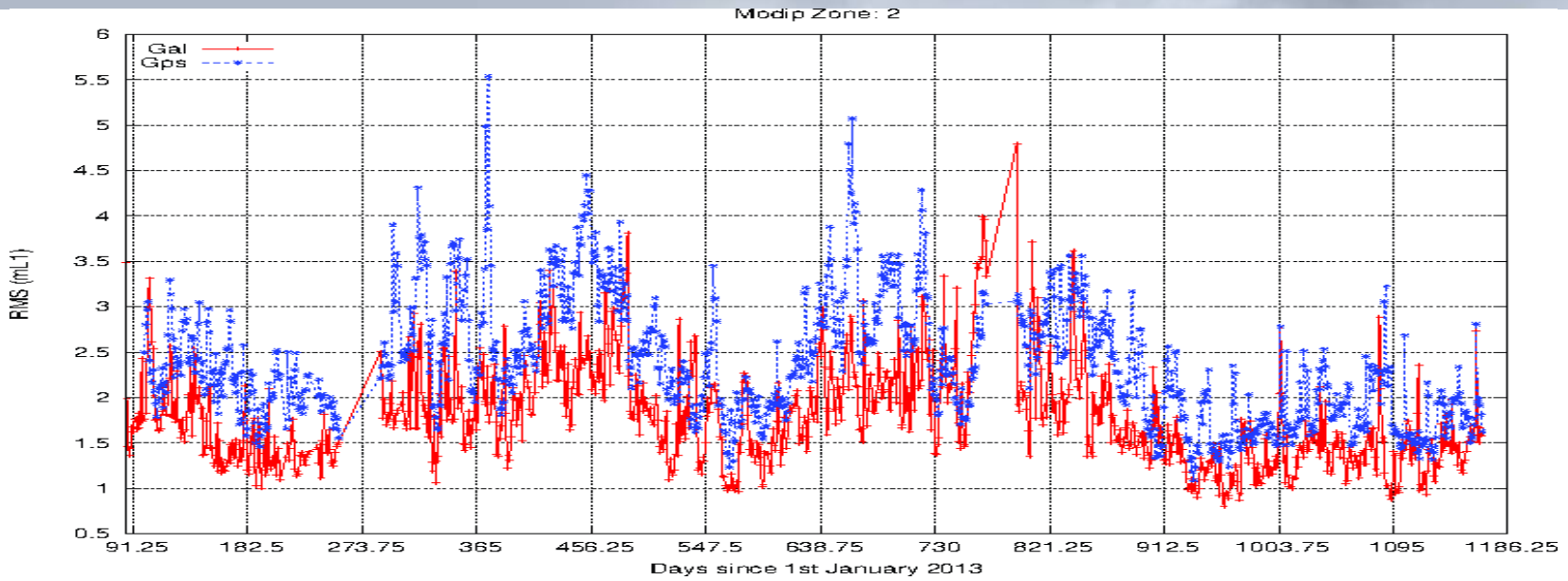


MODIP 5

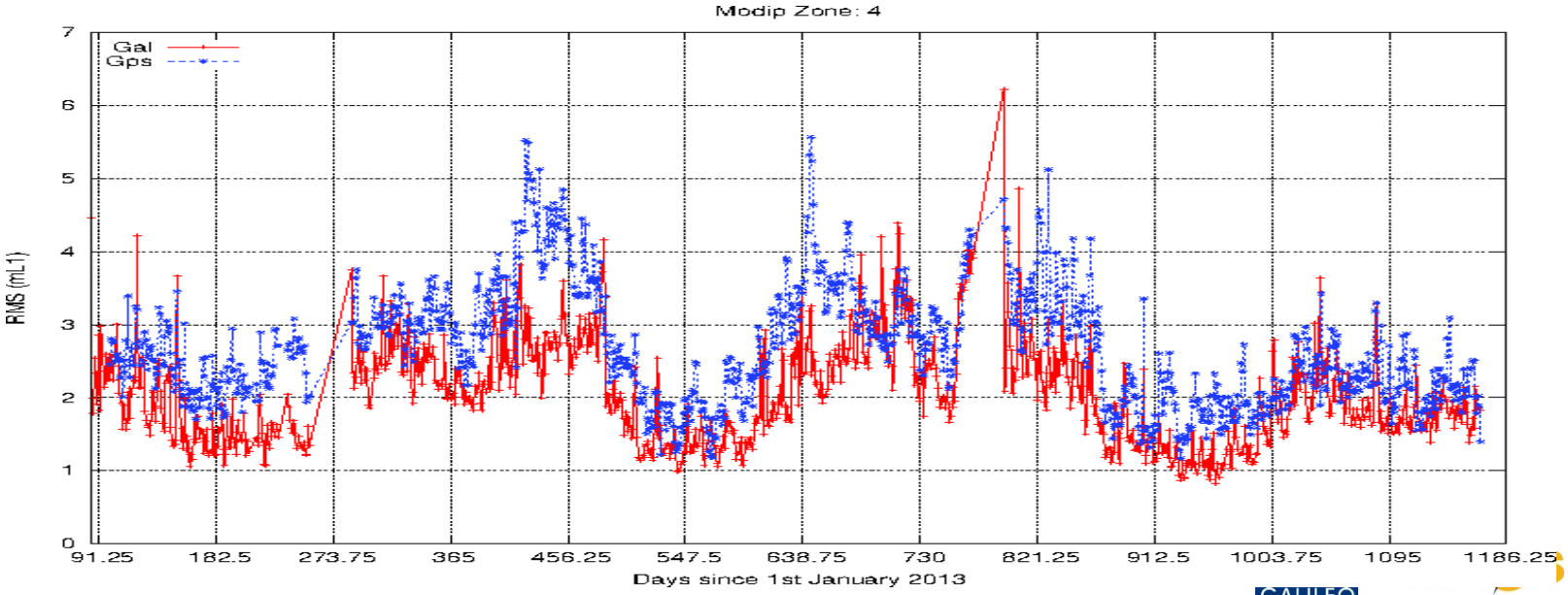


IOV+FOC: Residual RMS error (m_{L1}) – daily 2013-2016

MODIP 2

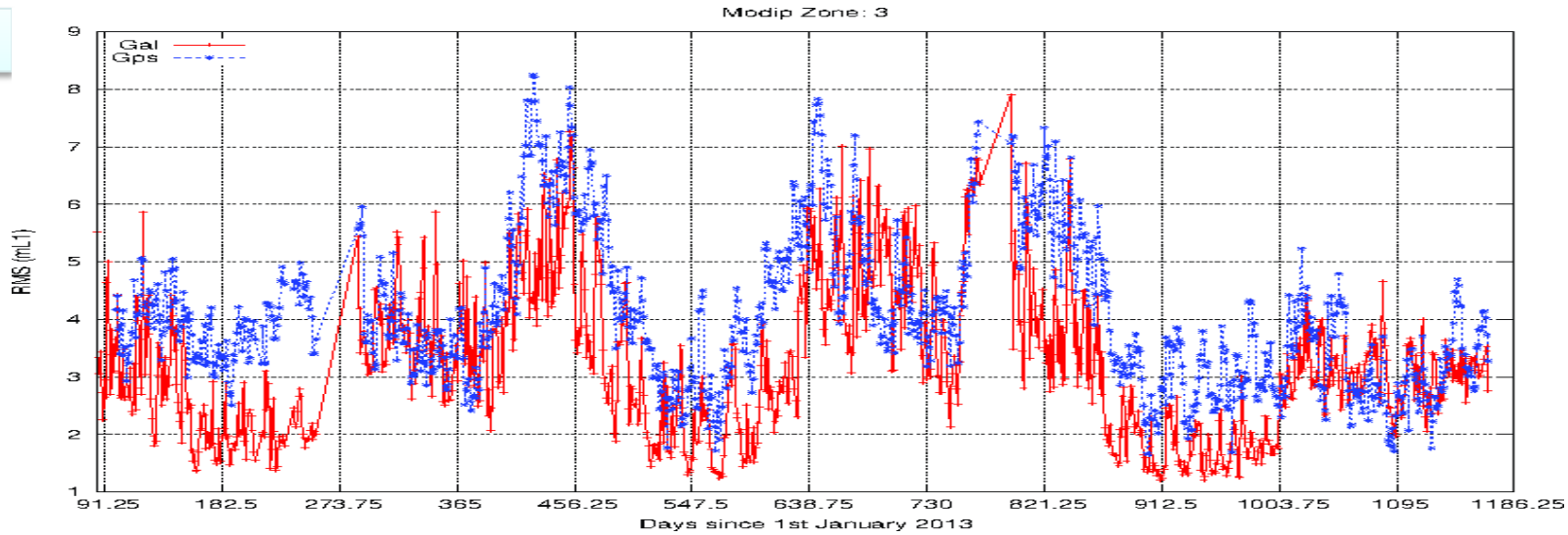


MODIP 4



IOV+FOC: Residual RMS error (m_{L1}) – daily 2013-2016

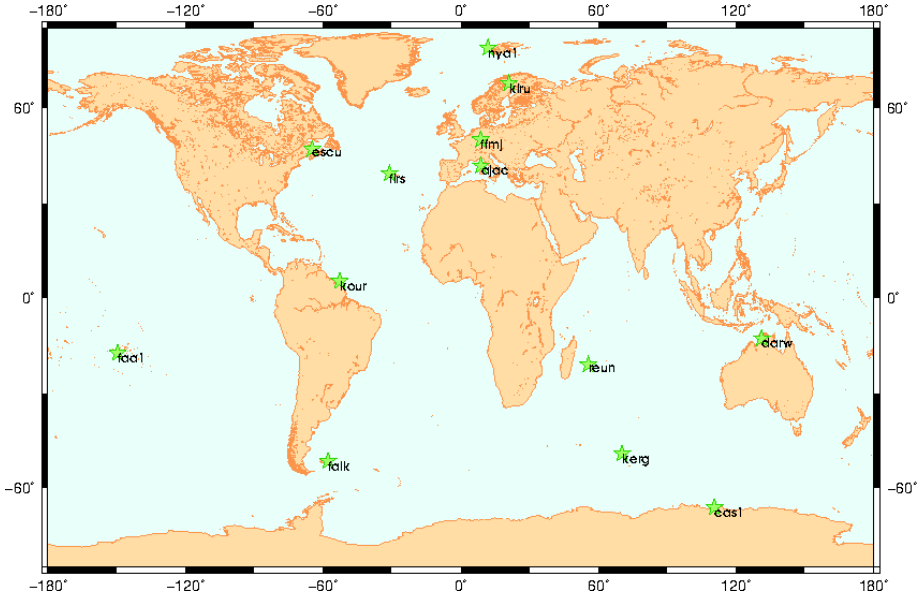
MODIP 3

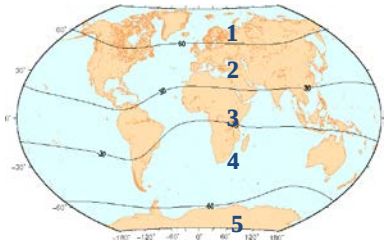


- Broadcast NeQuick G performance very good despite the low number of satellites used to drive the model

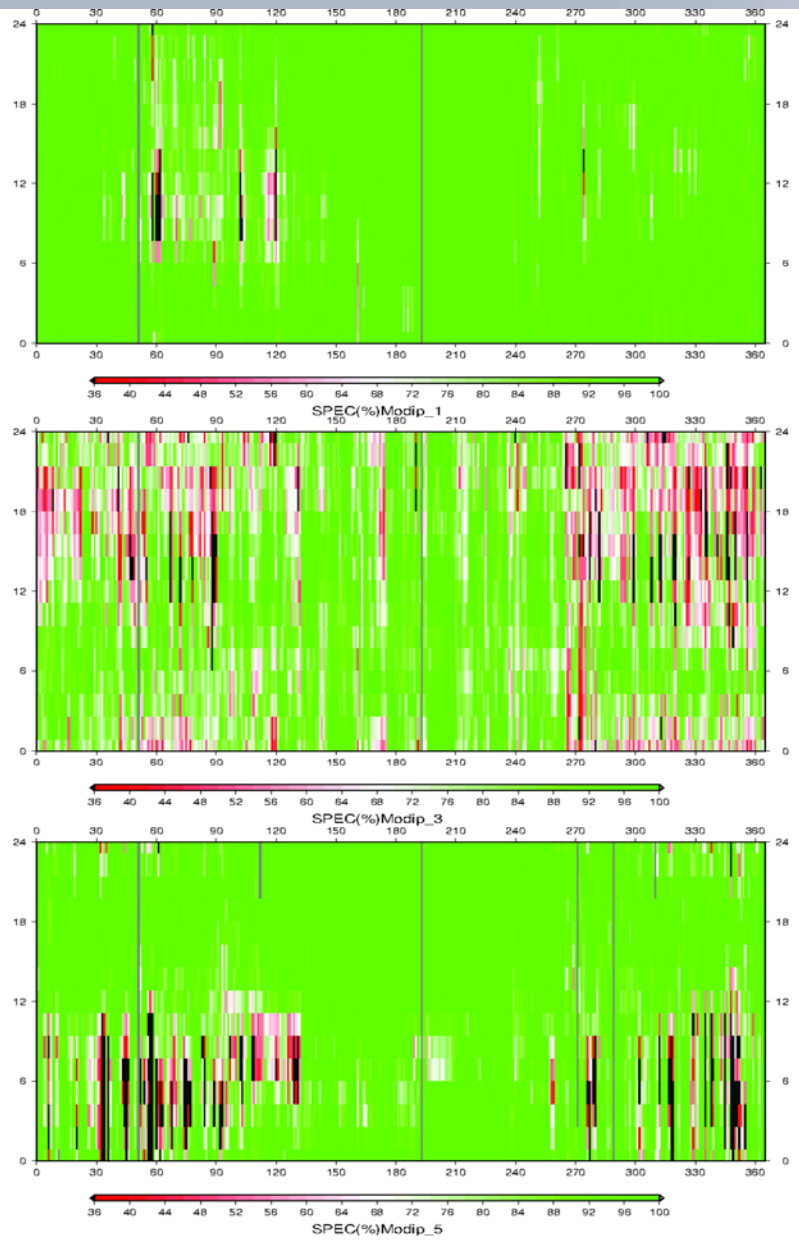
Percentage inside target performance

- Study done with MGEX receivers to simulate Ground segment of Galileo
- % inside target in bins of 100 minutes
- Showing full years in Solar Maximum 2014 – 2015 and MODIP zones



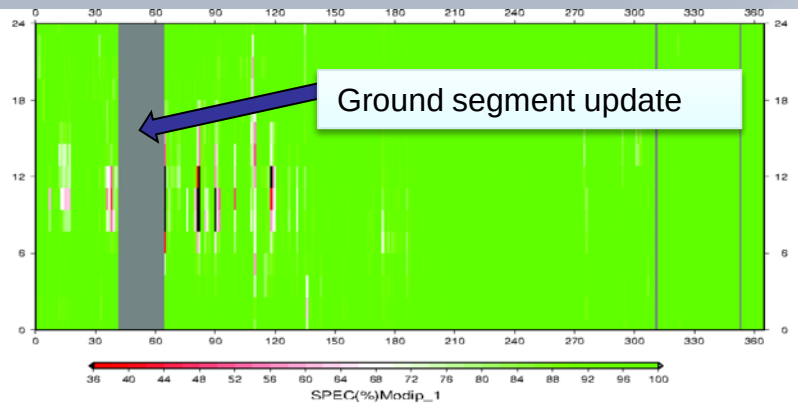


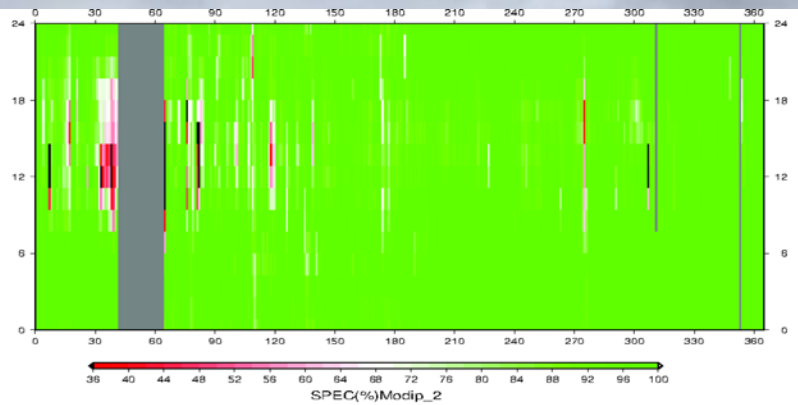
Percentage inside target for 2014

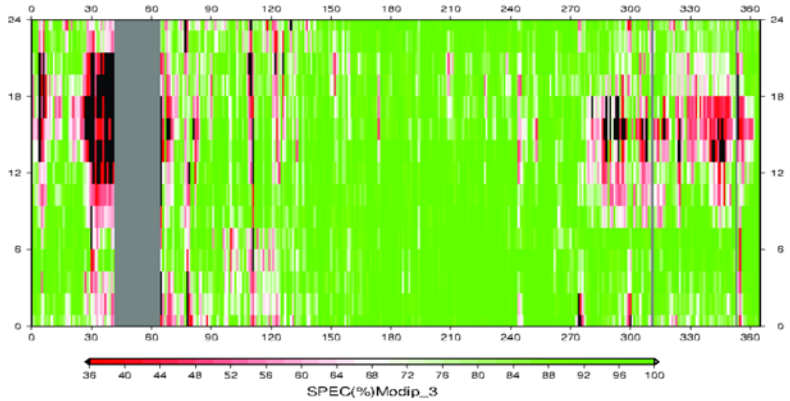


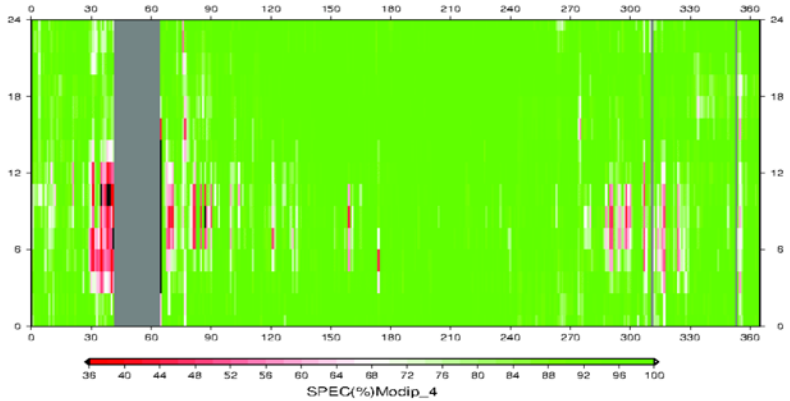
- Clear seasonal dependency of the % distribution. As expected Modip 3 is the most affected

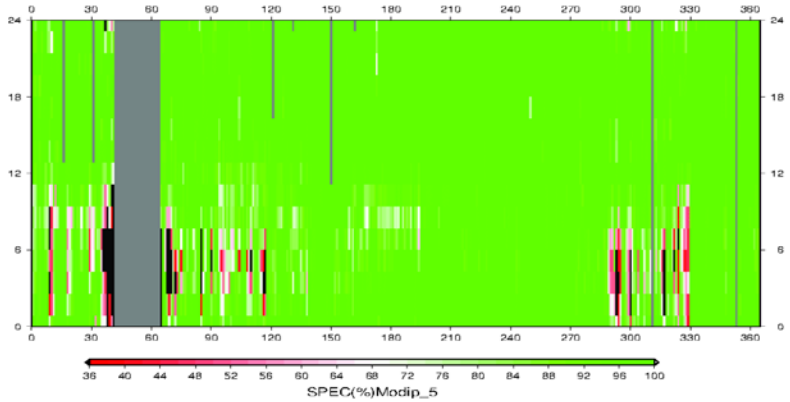
Percentage inside target for 2015









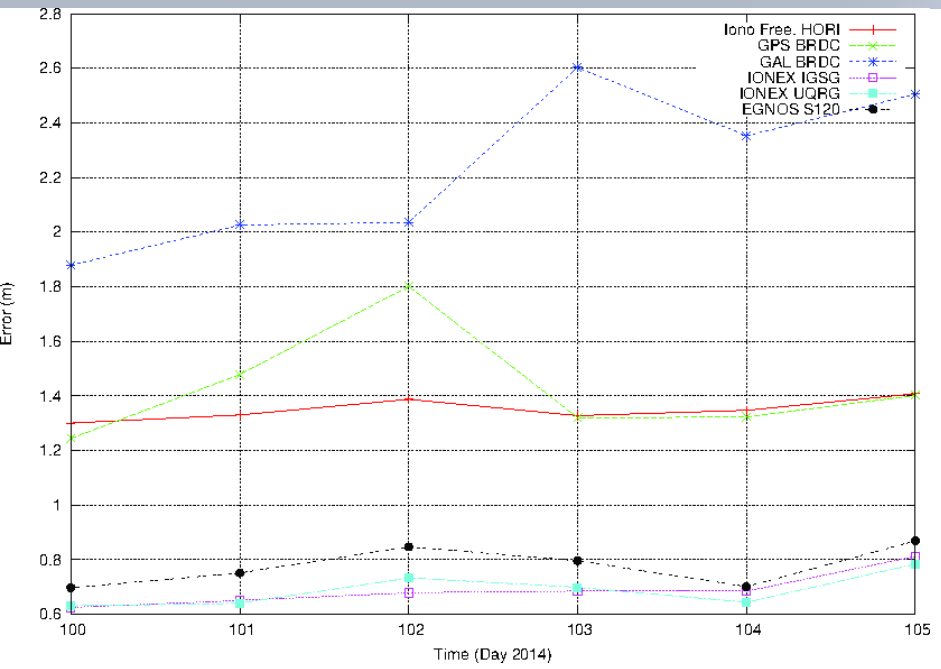


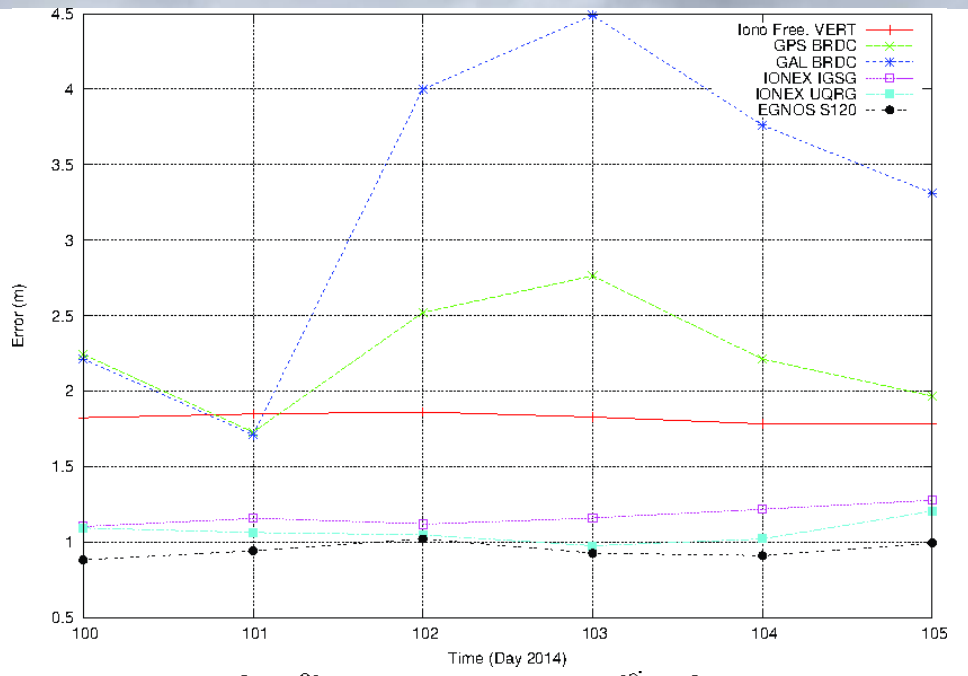
- Clear seasonal dependency of the % distribution. As expected Modip 3 is the most affected. Improvement over 2014.

Positioning error compared to EGNOS

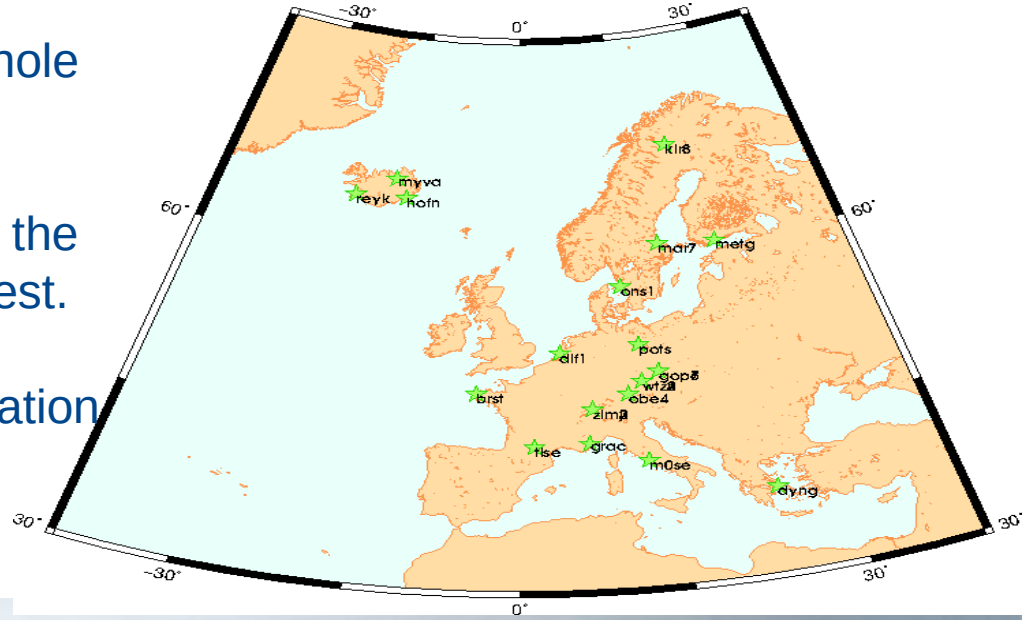
- The baseline is to use GPS satellites changing the ionospheric model and using precise orbits and clocks.
- **Examples** of *disturbed* days on 2014 and 2015, showing both *good and bad* NeQuick G performances.
- EMS data for EGNOS calculation presents problems of availability for all GEO in some storms
- The periods are:
  - 100 – 104 of 2014 (Europe)
  - 155 – 162 of 2014 (Europe)
  - 71 – 85 2015 (St. Patrick storm, Global
  - 83 – 89 2015 (post St. Patrick storm, Europe)

Positioning error compared to EGNOS Iono

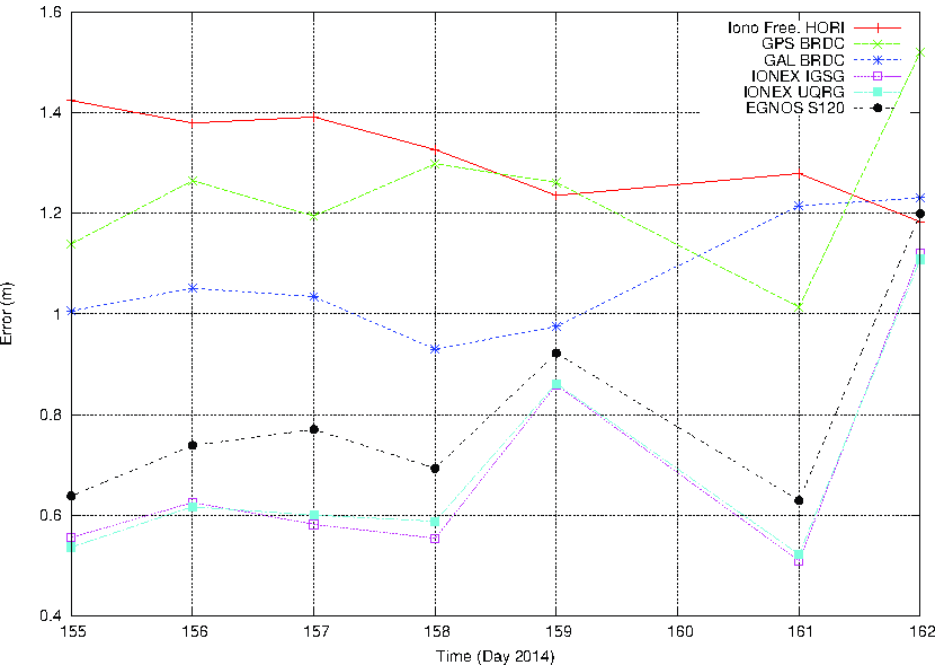


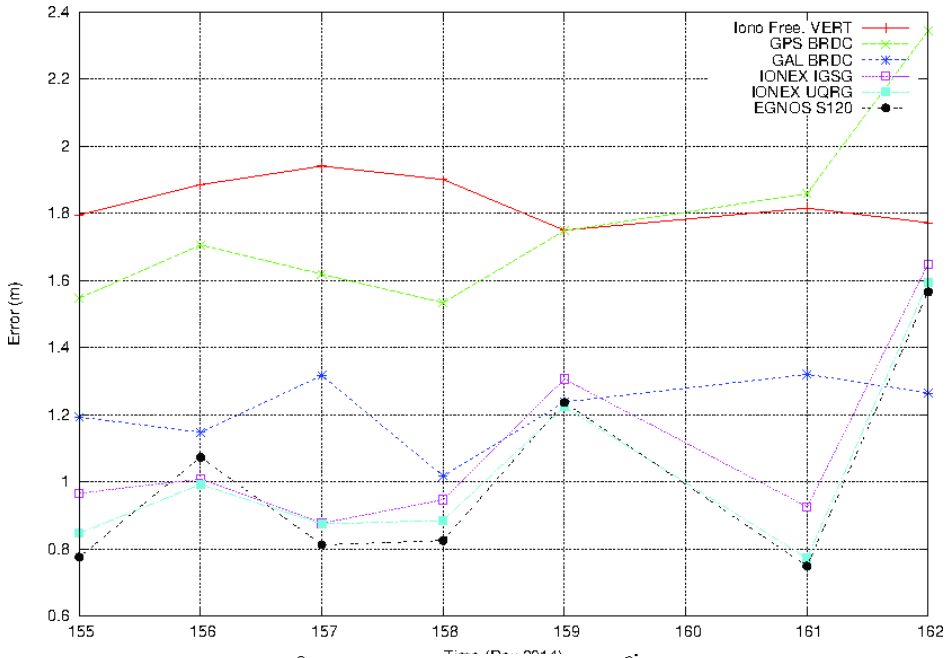


- Moderate activity kp<5 during the whole 5 days, peak on doy 102.
- NeQuick G affected on the day after the storm, but low performance on the rest.
- Coincides with low % inside specification for this period on MODIP 2.

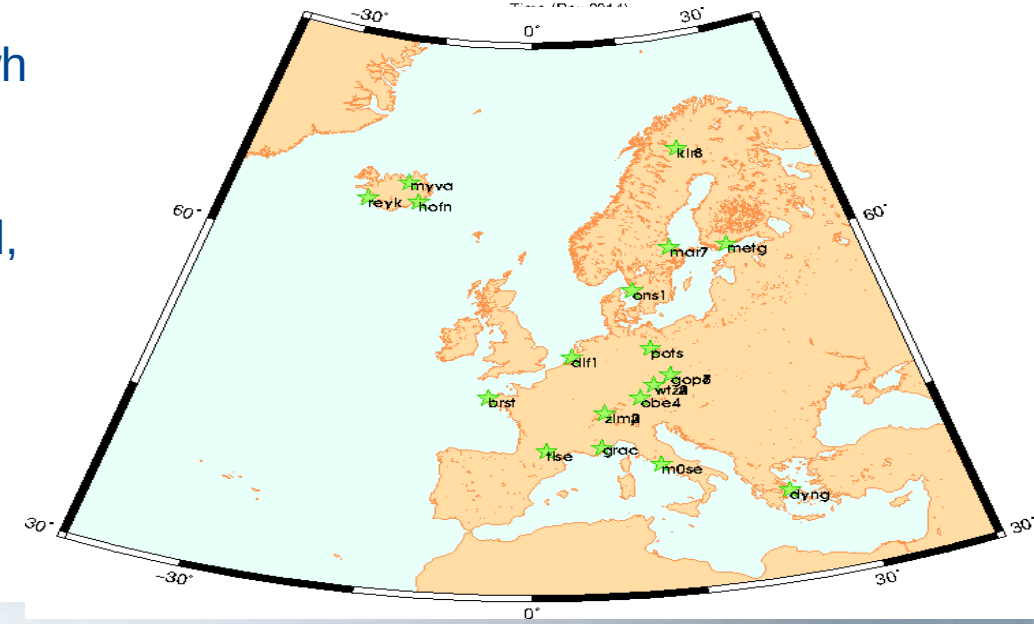


Positioning error compared to EGNOS Iono

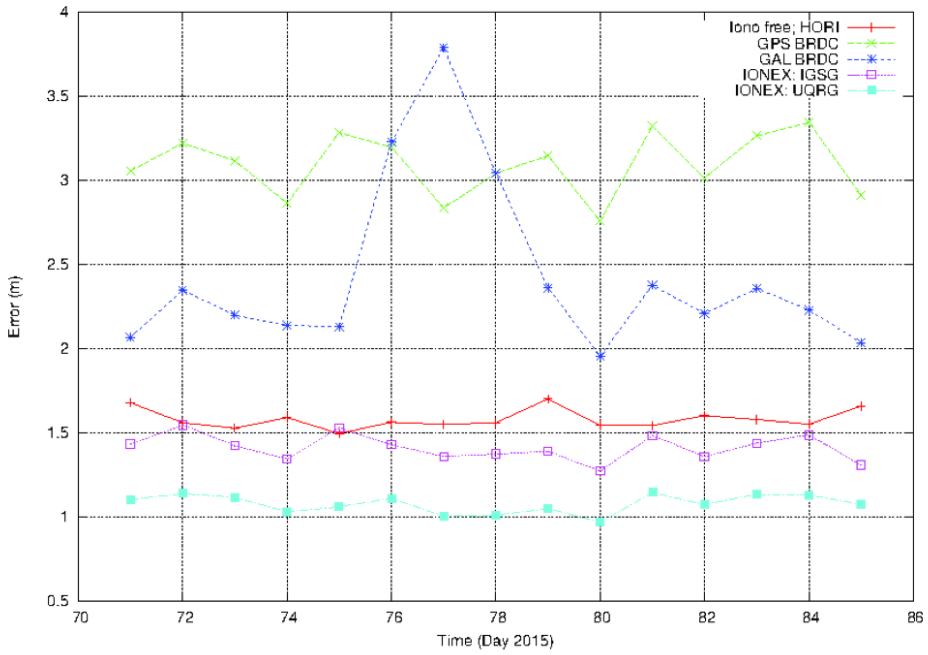


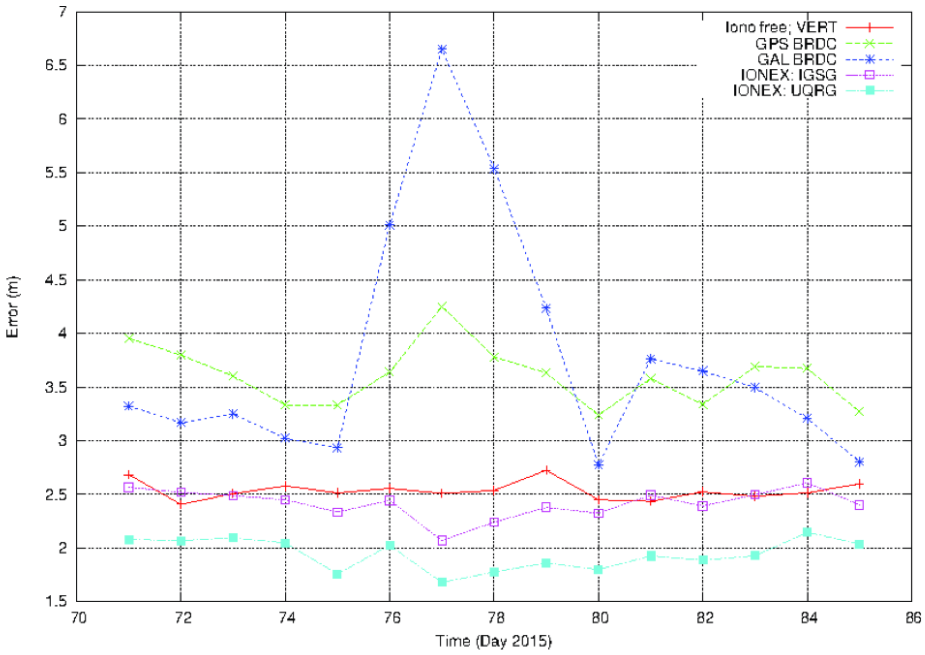


- Moderate activity kp<6 during the wh 5 days, peak on doy 159.
- NeQuick G not significantly affected, being the solution better than dual frequency.

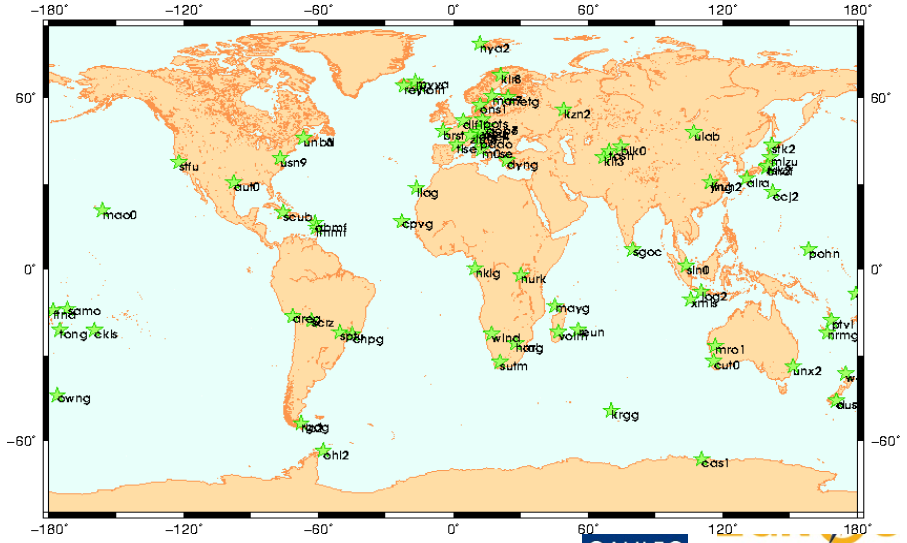


Positioning error compared to EGNOS Iono

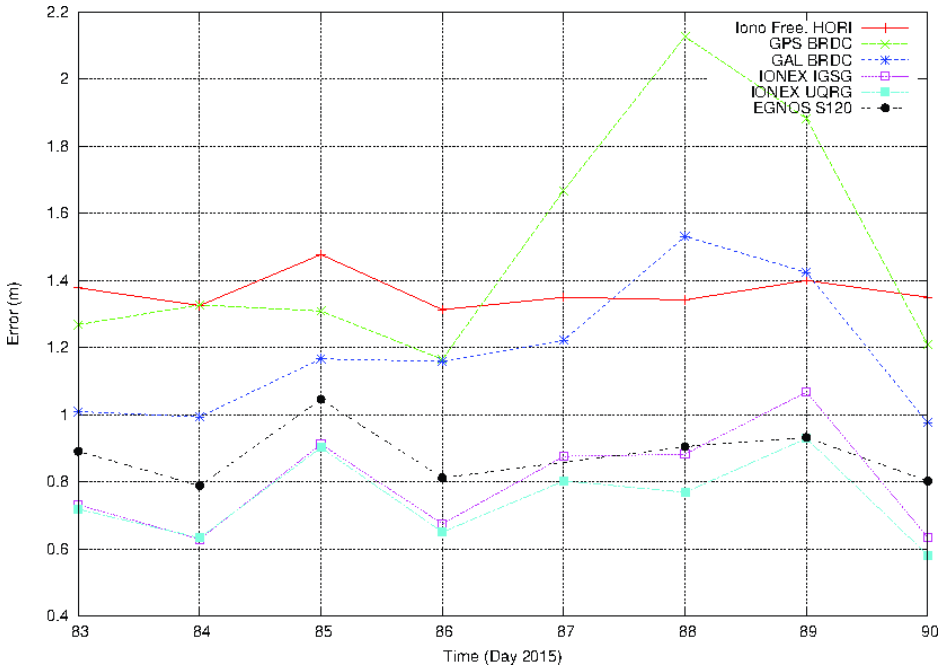


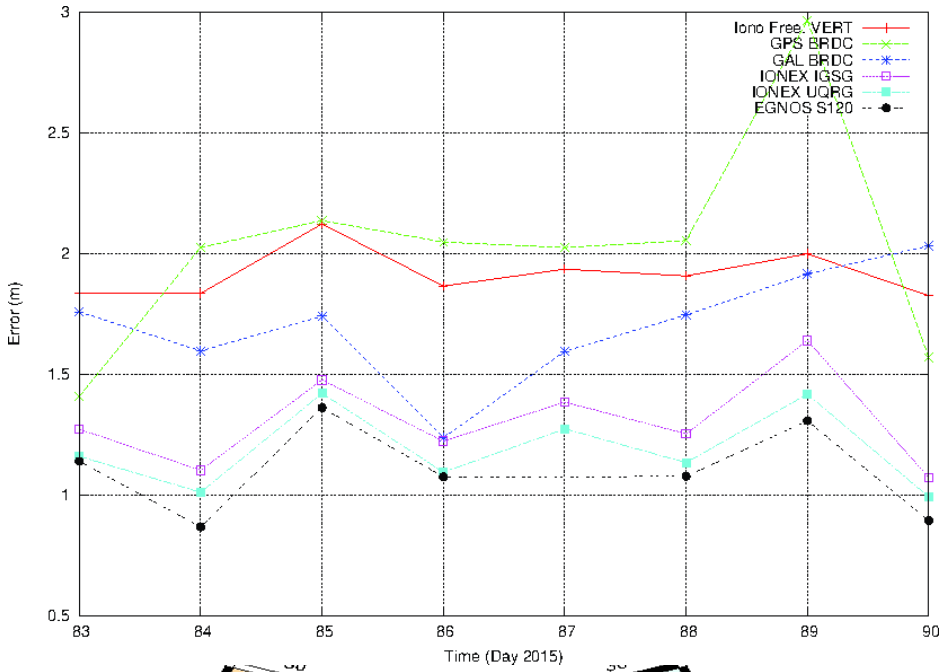


- NeQuick G is affected on the position domain during St. Patrick storm due to that the coefficients are frozen for the whole storm.
- Out of the storm the global positioning error is very good for this period.

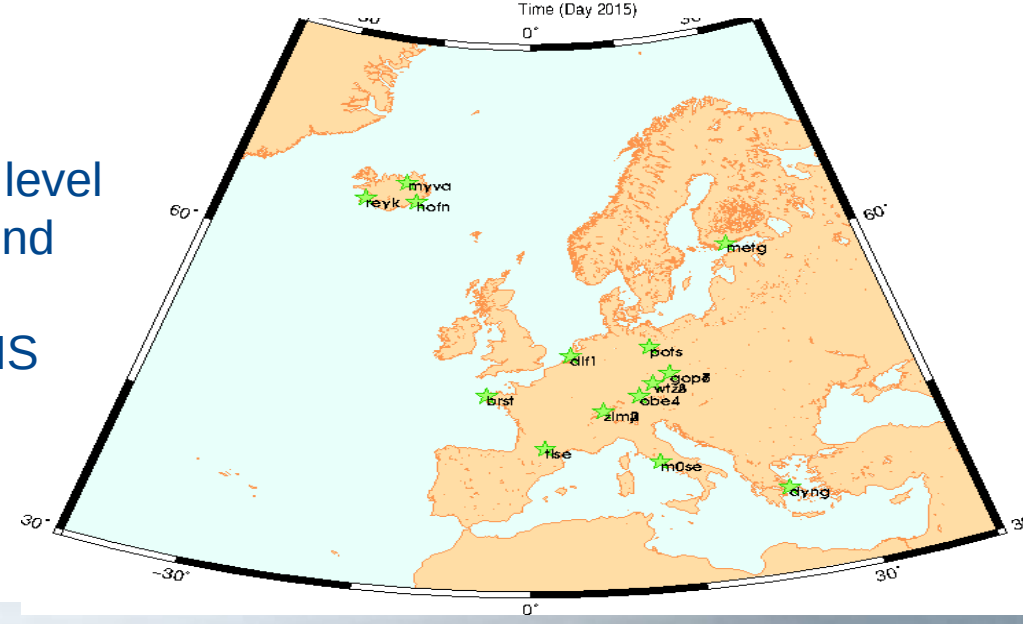


Positioning error compared to EGNOS Iono



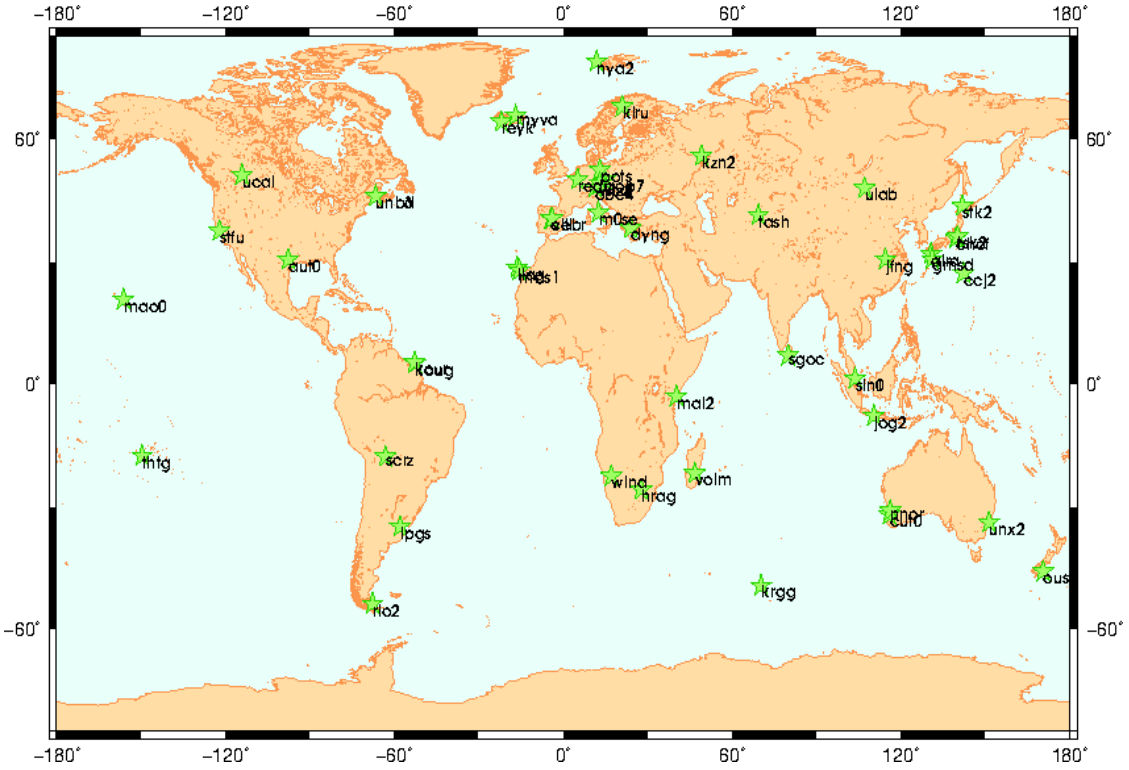


- Post St. Patrick storm period
- NeQuick G performs in a very good level for this week. Keeping the global trend
- EGNOS exhibit problems on the EMS data repository



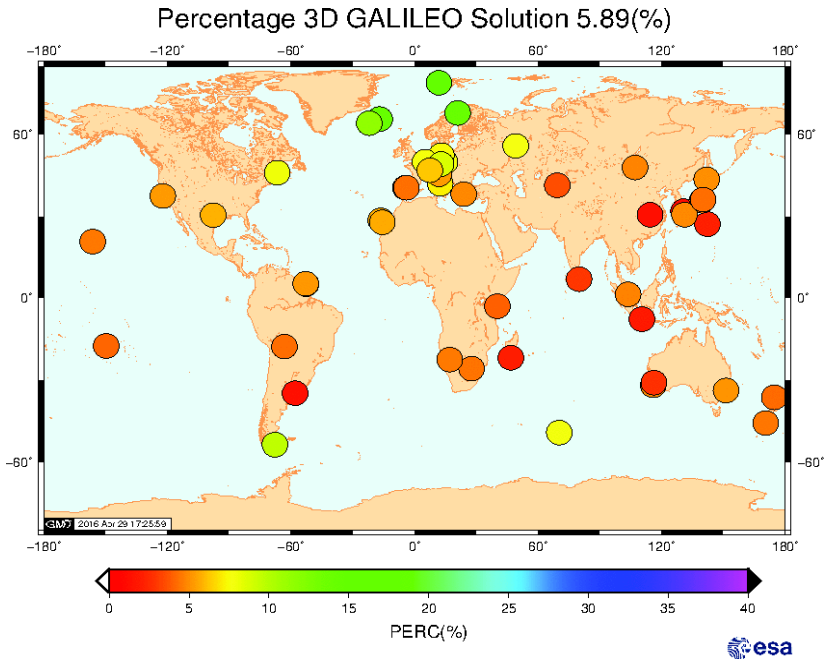
Galileo Single frequency position on March 2016

- Example of the capability with Galileo stand-alone on March 2016, single and dual frequency.
- 52 MGEX stations with Galileo and GPS broadcast messages.



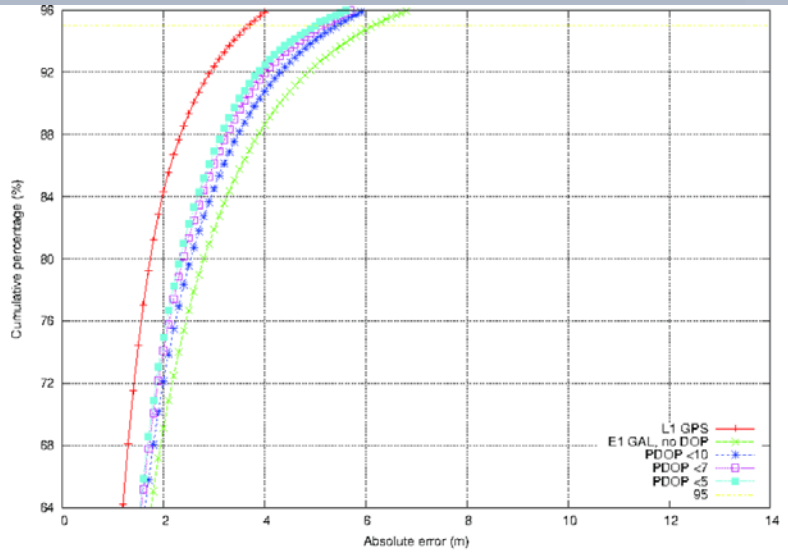
Galileo Single frequency position on March 2016

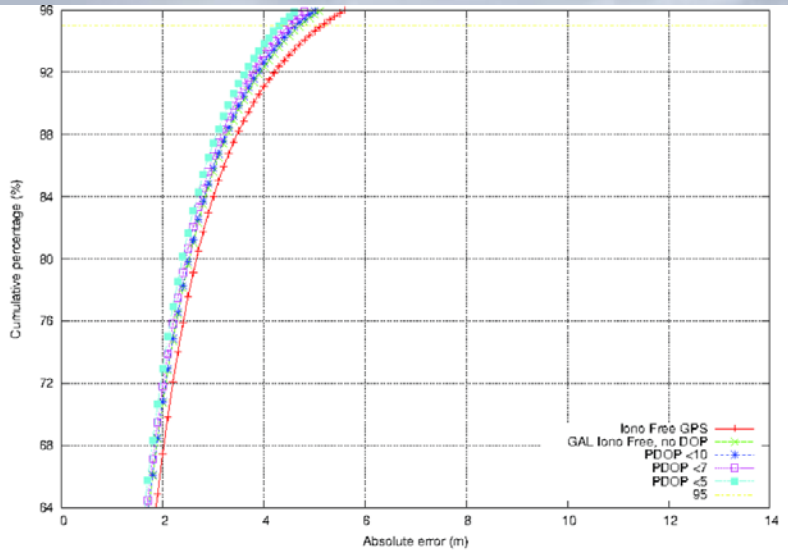
		Horizontal	Vertical	Horizontal	Vertical
		68% percentile		95% percentile	
	GPS L1	1.3	1.9	3.6	5.4
	GPS L2	1.8	2.6	5.8	7.7
	GPS Iono Free	2.4	3.9	4.9	9.3
INAV	GAL E1	1.9	2.8	6.0	10.4
INAV	*GAL E5b*	*2.9*	*3.9*	*9.6*	*15.0*
INAV	*GAL Iono Free*	*2.0*	*2.5*	*4.7*	*7.0*
FNAV	GAL E1	2.0	2.8	6.0	10.7
FNAV	GAL E5a	2.8	4.4	9.3	15.1
FNAV	GAL Iono Free	2.1	3.0	5.4	8.5



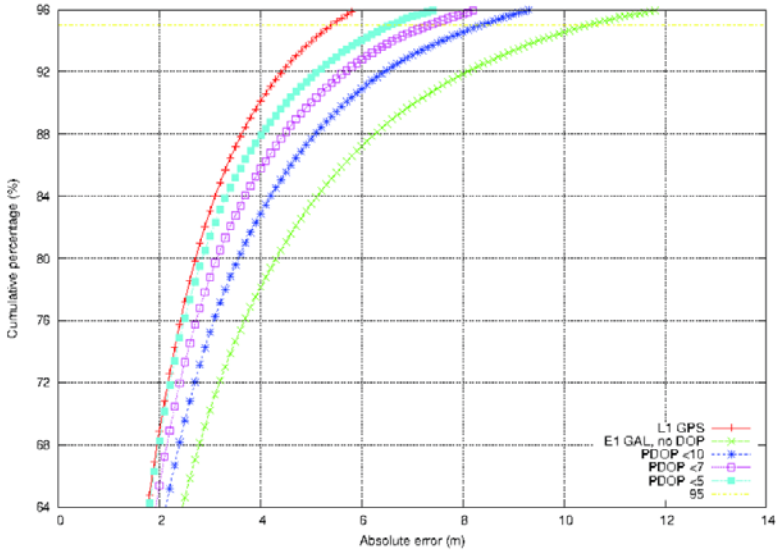
- GPS used with full constellation but with NeQuick G ionosphere.
- Galileo stand alone average 6% of FNAV solutions (with Max around 16%) with respect GPS, with very good performance despite using only 4 – 5 satellites for the solutions.
- INAV in MGEX is not so well tracked. Usually receivers are tracking E1, E5a and not E5b.

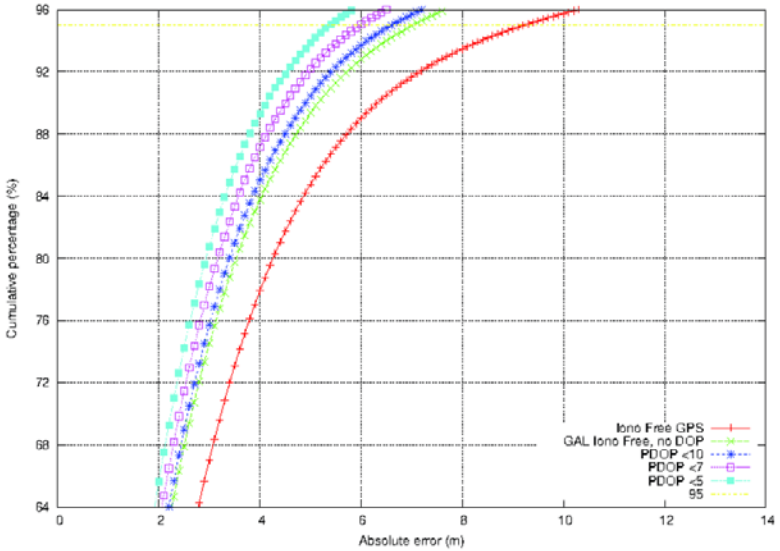
Galileo Single frequency position on March 2016





Horizontal





Vertical

Single frequency

Dual frequency (E1, E5a)

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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).
- The Galileo Single Frequency Correction Algorithm together with the Nequick G model are available since April 2015.
    - Feedback/validation by the user community important
- Performance on position domain of using NeQuick G on several active days shows a non-consistent behavior. It is expected to improve over time as the Galileo system is deployed.
- Results of Single frequency user using Galileo shows good performance despite the low number of satellites used.

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Thank you

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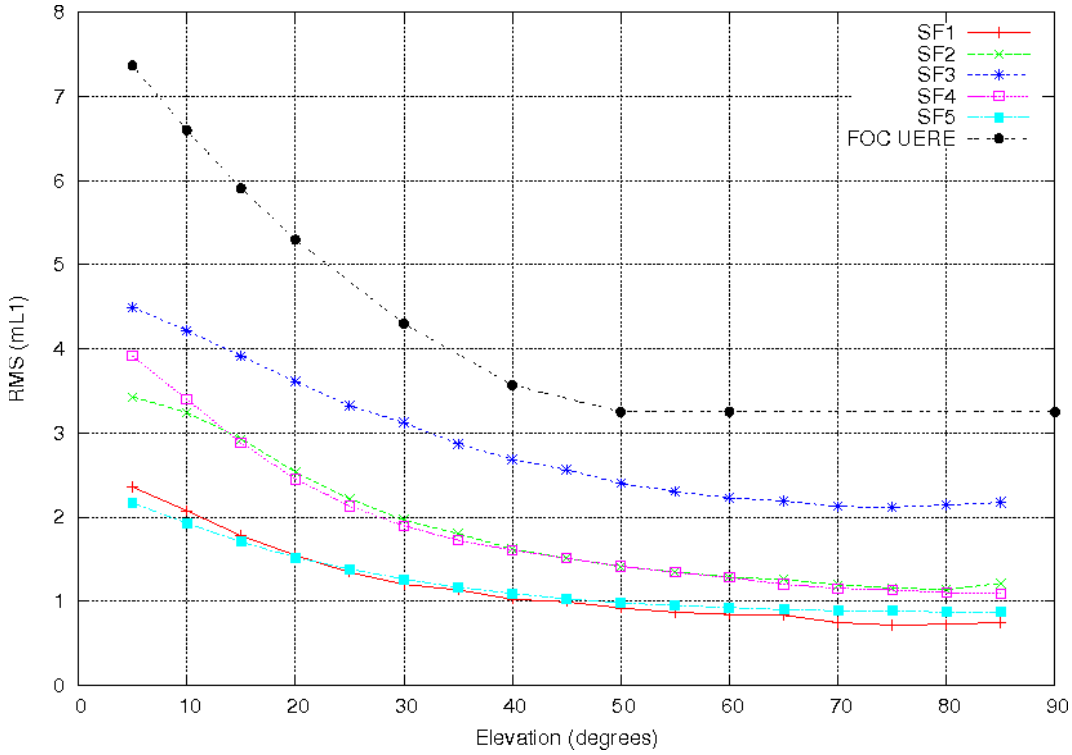
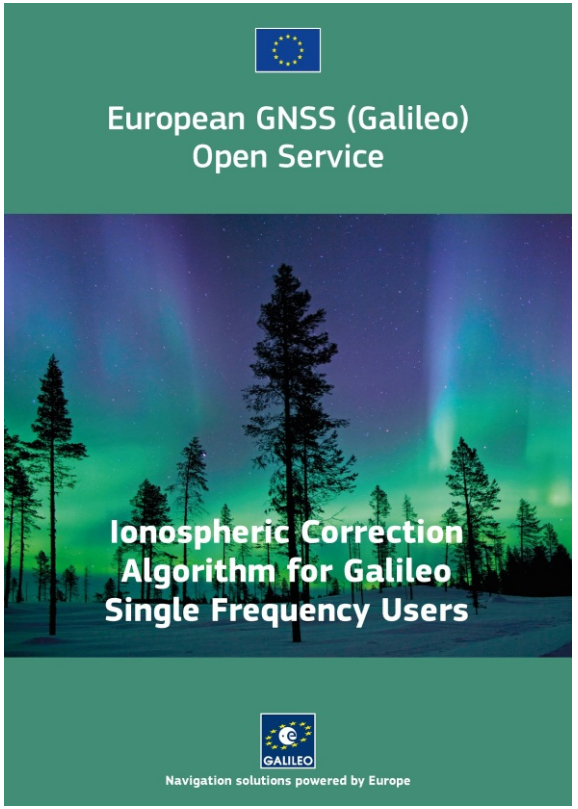
IOV Results: UERE

	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



Specification document - Contents

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



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

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