Algorithms for the mitigation of space weather threats at low latitudes, contributing to the extension of EGNOS over Africa

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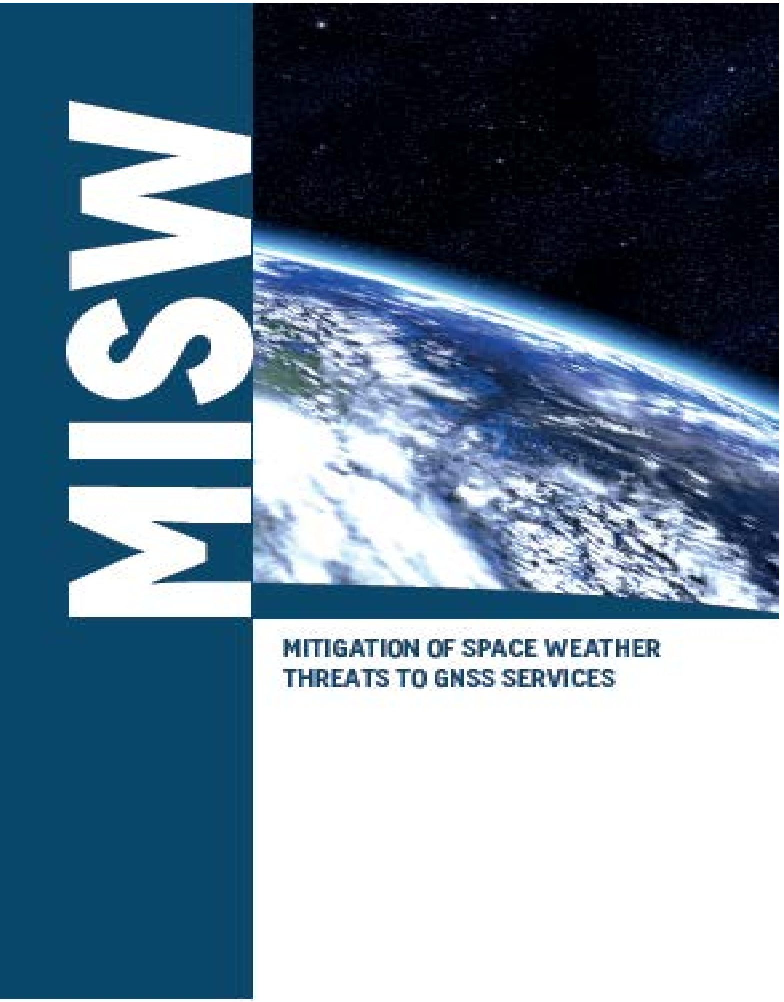
http://misw.info/

SEVENTH FRAMEWORK PROGRAMME

The challenge



WHY MISW?

- Space Weather affects many modern technologies that we take for granted
- MISW tackles research challenges associated with GNSS and Space Weather
- Bring practical solutions to European Industry

USERS

- GNSS Users rely on positioning accuracy but this may not be adequate for all applications
- Safety critical applications also need integrity of the GNSS positioning

SBAS

- SBAS systems (EGNOS in Europe) gather information that allows some mitigation of Space Weather events
- However, SBAS systems are not yet able to work in the most challenging regions and as consequence Space Weather disturbances to the ionized upper atmosphere cause navigation errors that remain uncompensated

Ionospheric Threats

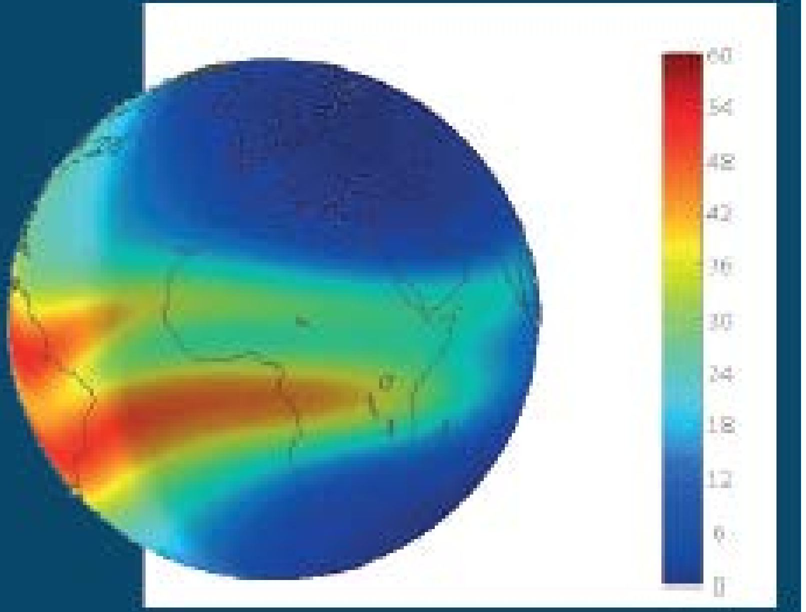


Illustration of global ionosphere at solar max. Colour contours show vertical TEC where 60 TECU are equivalent to delays on the GPS L1 signal of about 10 m vertical.

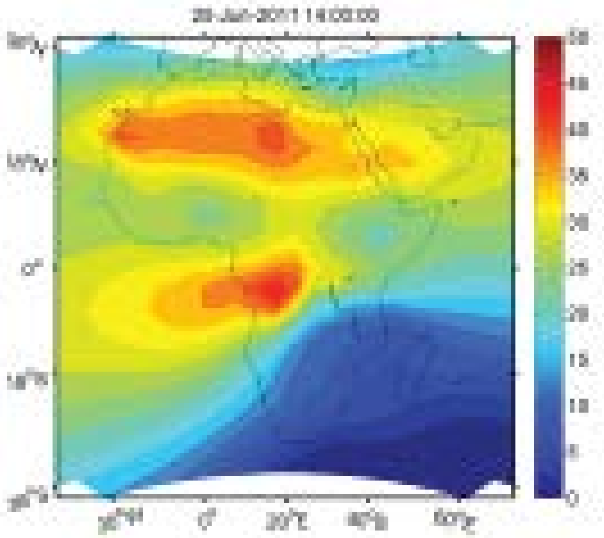
IONIZATION GRADIENTS

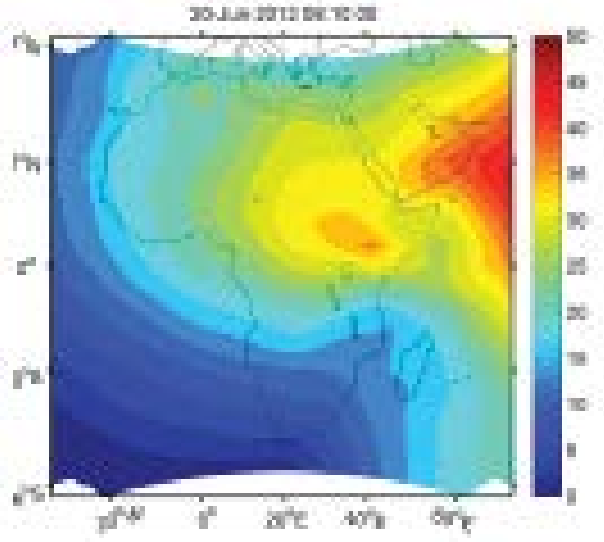
- Ionization gradients (in particular over low latitude regions) are much more structured than over Europe with high TEC gradients

SCINTILLATION

- Propagation of radio signals through ionization gradients lead to scintillation (Fluctuation of signal phase and amplitude)
- Scintillation is a serious threat to GNSS as it can disrupt receivers operation and service entirely by means of C/No fading and loss of lock

MISW Solutions





EGNOS EXTENSION

- EGNOS extends from Scandinavia in the North to Africa to the South
- These regions experience strong gradients in delay and break up of signals from scintillation
- These issues represent a technology barrier to the expansion of EGNOS geographically

MISW OBJECTIVES

- Monitor and characterize iono effects at low, mid, high latitudes
- Develop algorithms against Space Weather vulnerabilities at Receiver level and at System level
- Enable extension of EGNOS to Africa
- Devise recommendations on best practices for GNSS services with reference to Space Weather

MISW Partners

University of Bath, UK	
Thales Alenia Space ITALY, FRANCE	
University of Nottingham, UK	
Polytechnic of Torino, ITALY	
National Institute of Geophysics and Vulcanology, ITALY (INGV)	
EISCAT Scientific Assocation, SWEDEN	
European Joint Research Centre Institute for Security and Protection of Citizens - BELGIUM	
Danish Technological University - Space	
Space Research Centre - POLAND	
University of Zagreb - CROATIA	
MET Office, UK	

PARTNERS

- Under the lead of University of Bath the MISW partners include major european institutions and industry involved in GNSS and Space Weather study

STAKEHOLDERS

- Relevant entities regulating SBAS services
- Experts in Ionospheric studies
- GNSS User Communities
- GNSS Industry
- GNSS Service Providers

SUPPORTING PARTNERS

- ASECNA, SANSA, CIVIL AVIATION UNIVERSITY OF CHINA, NOAA, ESA, FAA

The concept of grid point corrections

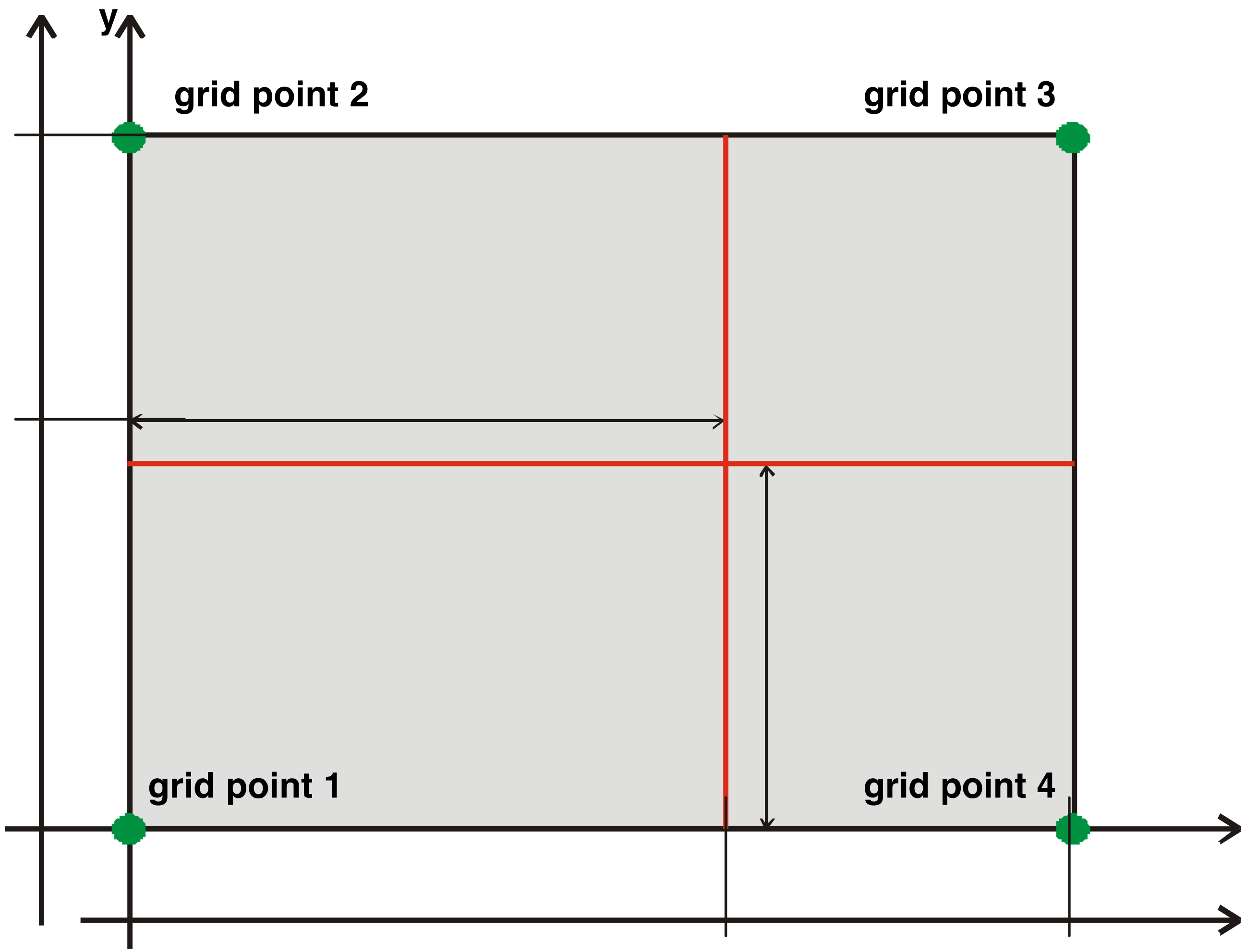
How to calculate corrections to ionopheric delays

$$\tau_{vpp}(\Phi_{pp}, \lambda_{pp}) = \sum_{i=1}^{4} W_i(x_{pp}, y_{pp})\,\tau_{vi}$$

Credit: RTCA

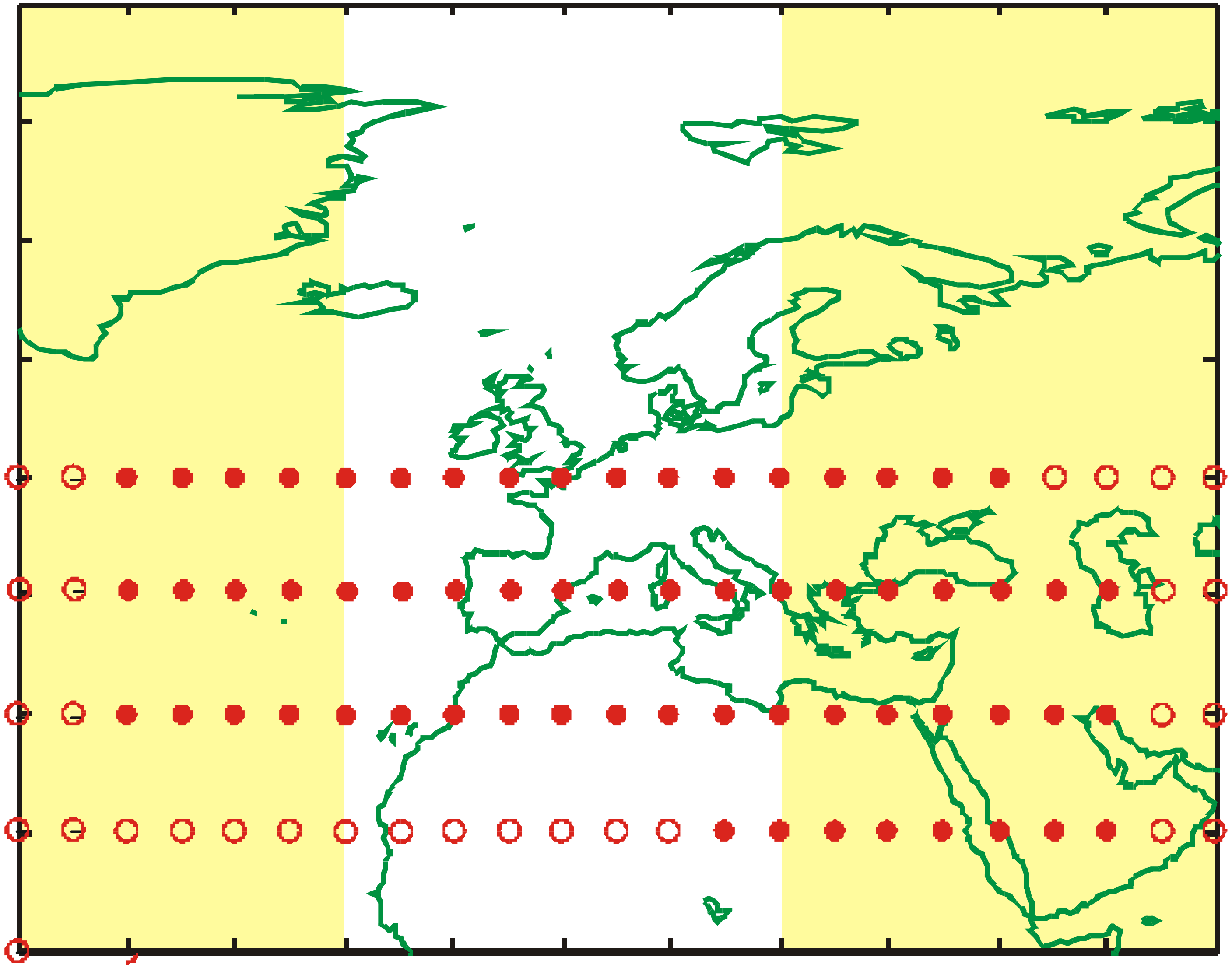
with

τ_{vpp}	vertical ionospheric delay at pierce point
τ_{vi}	vertical ionospheric delay at grid points
W_i	weighting function

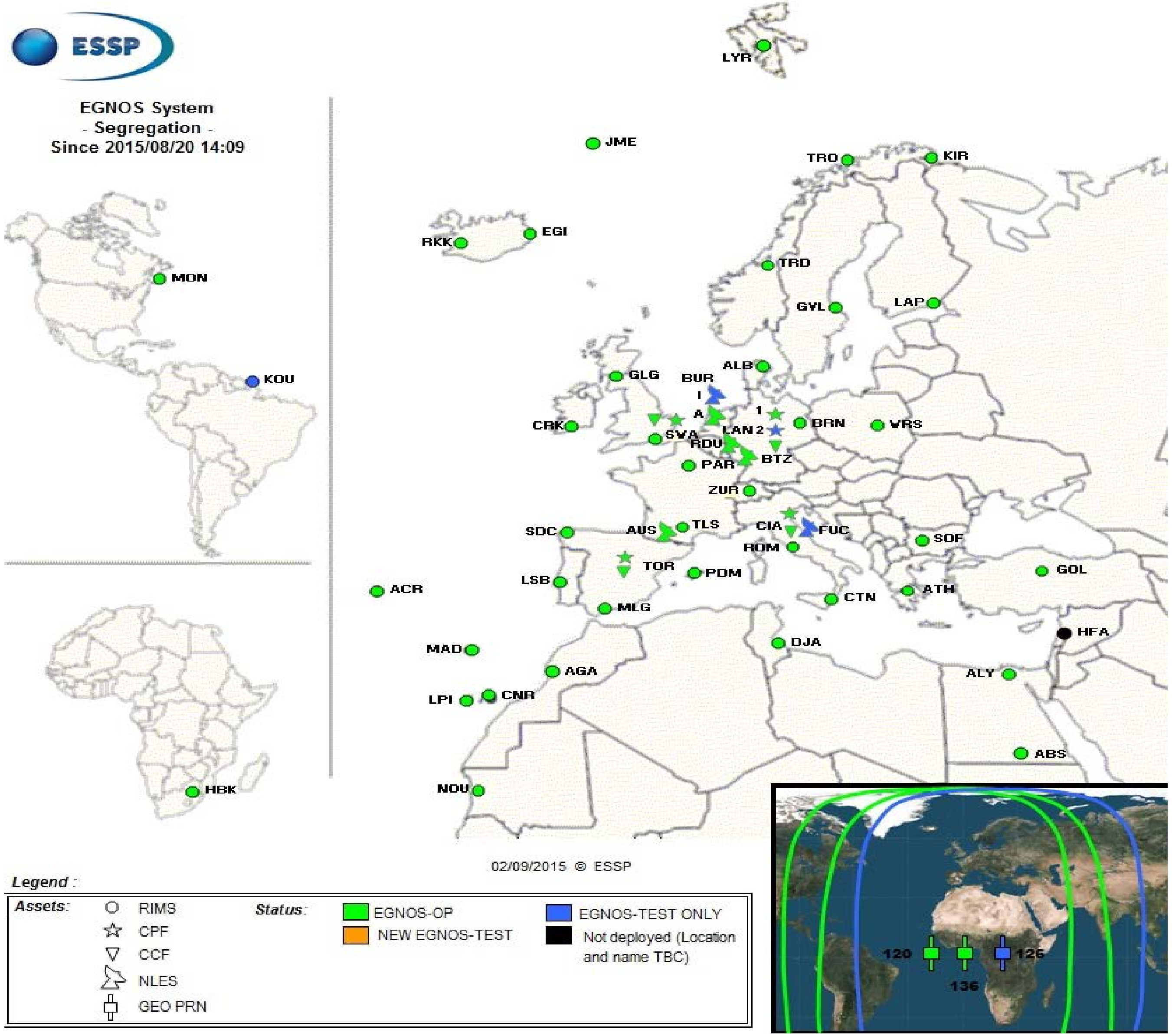


Example of ionispheric grid points

Credit: RTCA



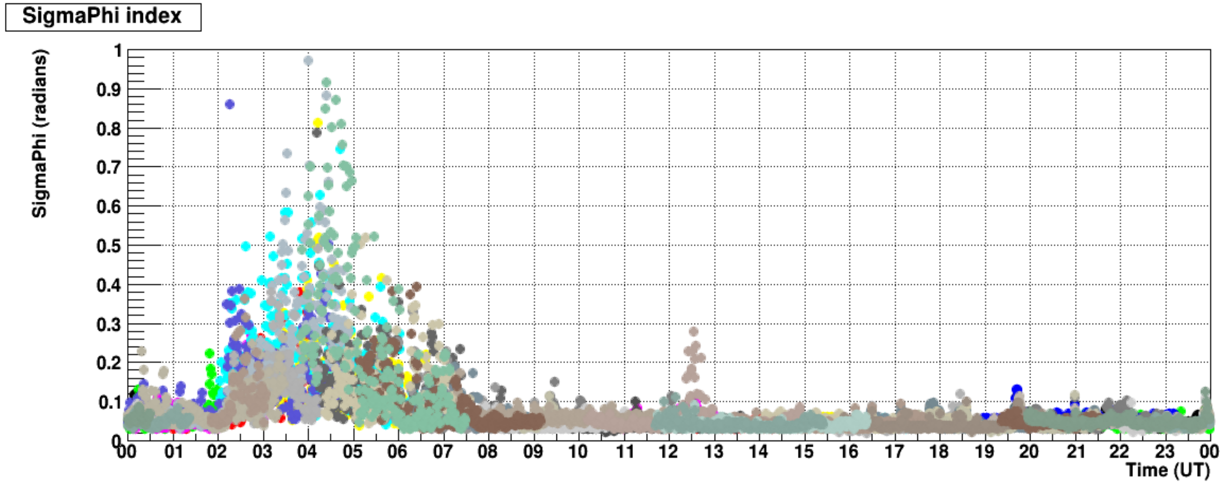
EGNOS monitoring stations – courtesy ESSP

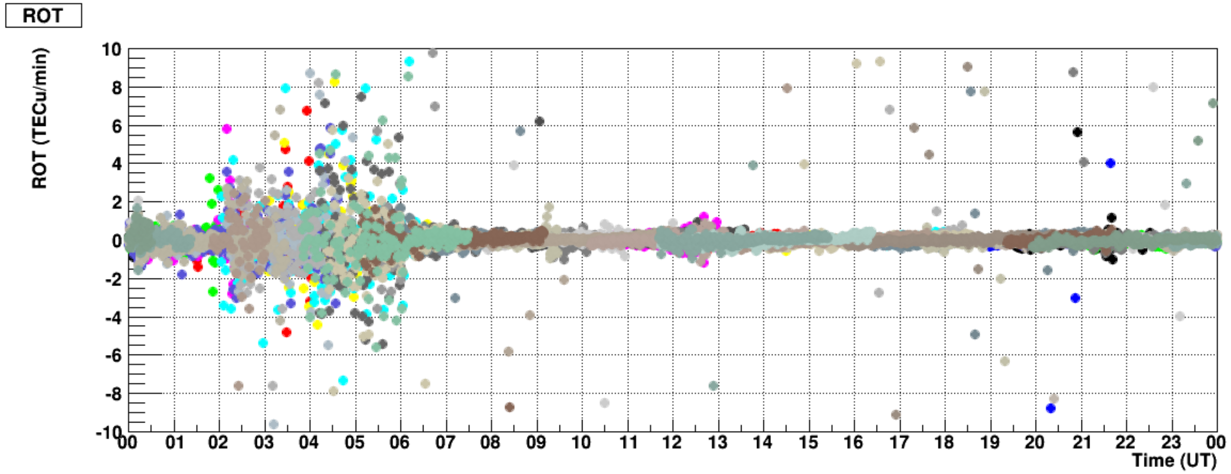


Credit: ESSP

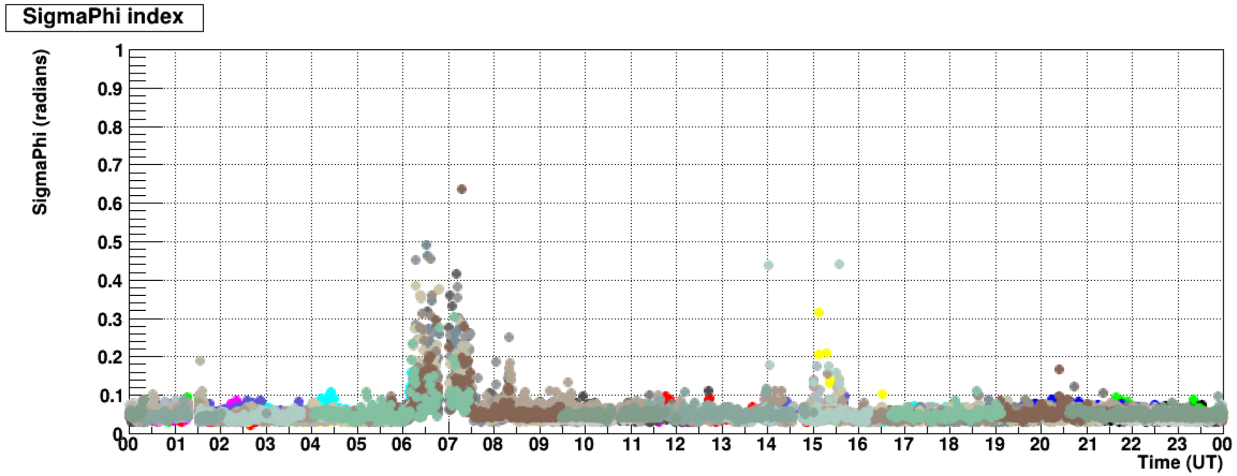
MISW Solutions: Ionospheric Scenarios

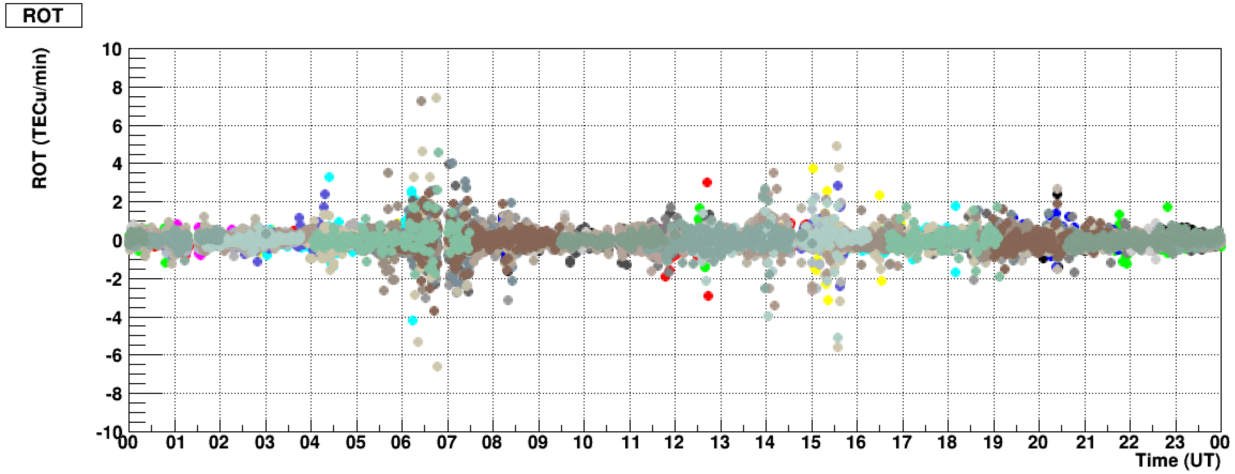
Rate of Change of TEC and Scintillation



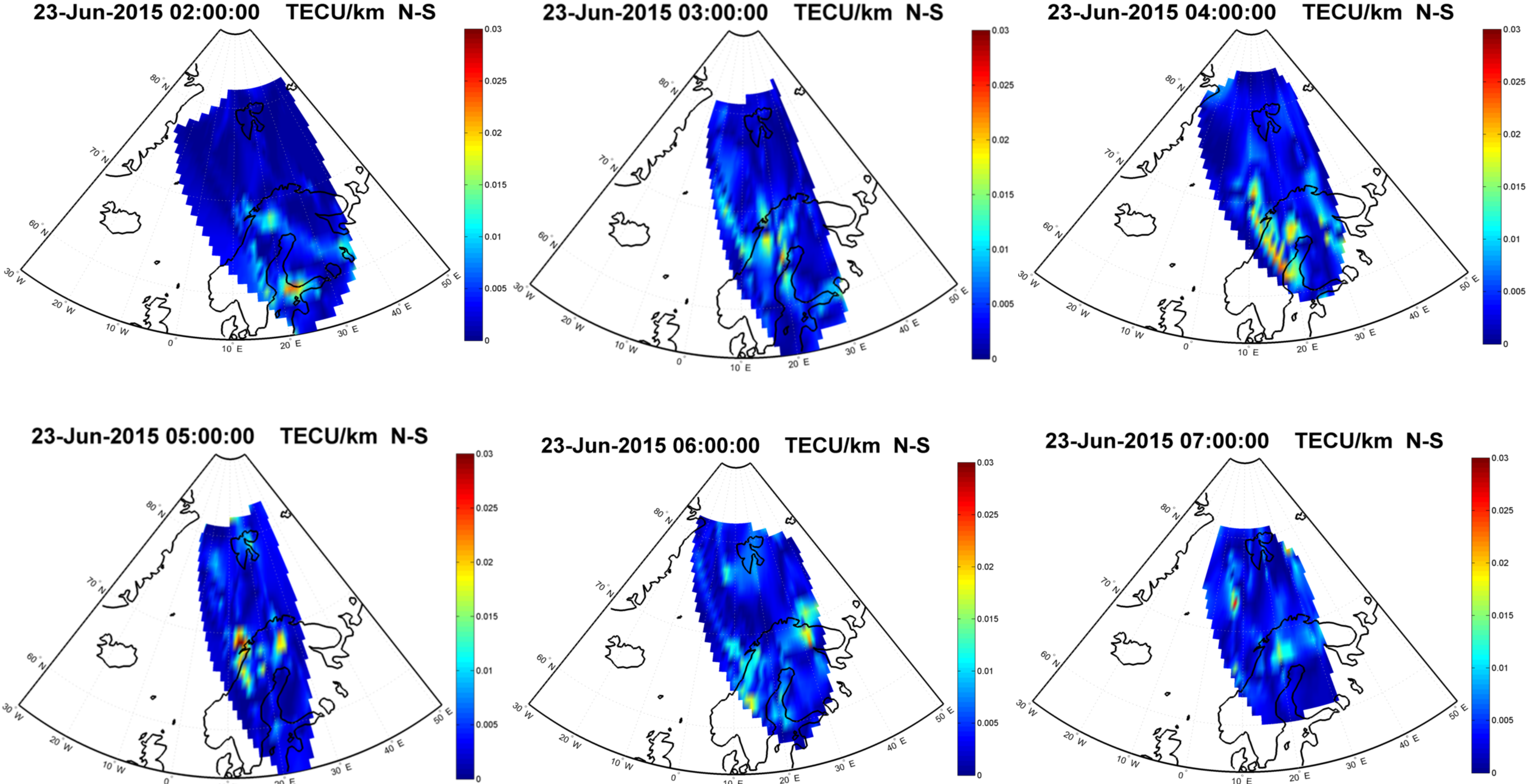


23 June 2015
Trondheim (63.42 N, 10.41 E)





23 June 2015
Ny Alesund (78.93 N, 11.06 E)



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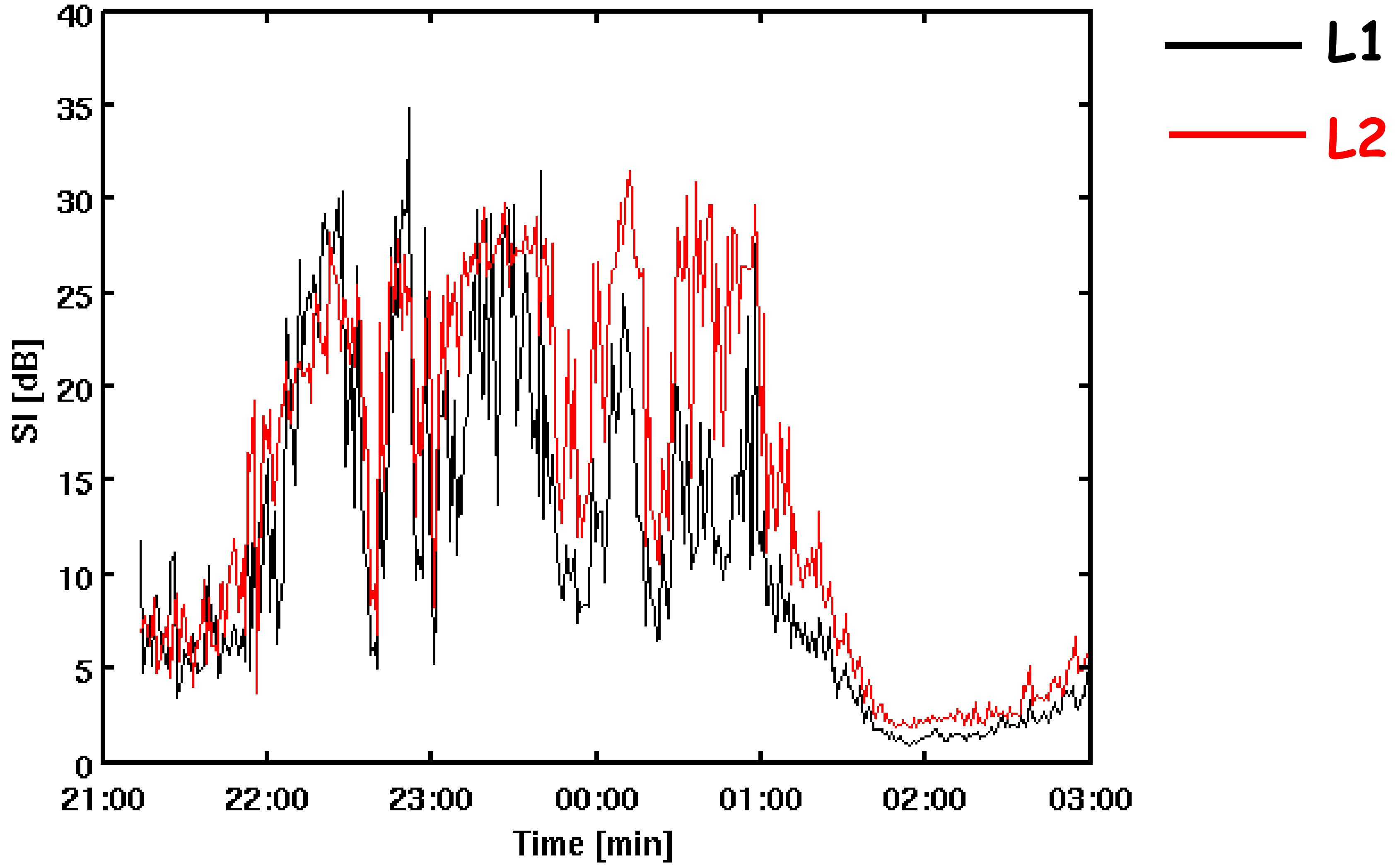
An additional problem at low latitudes: scintillation

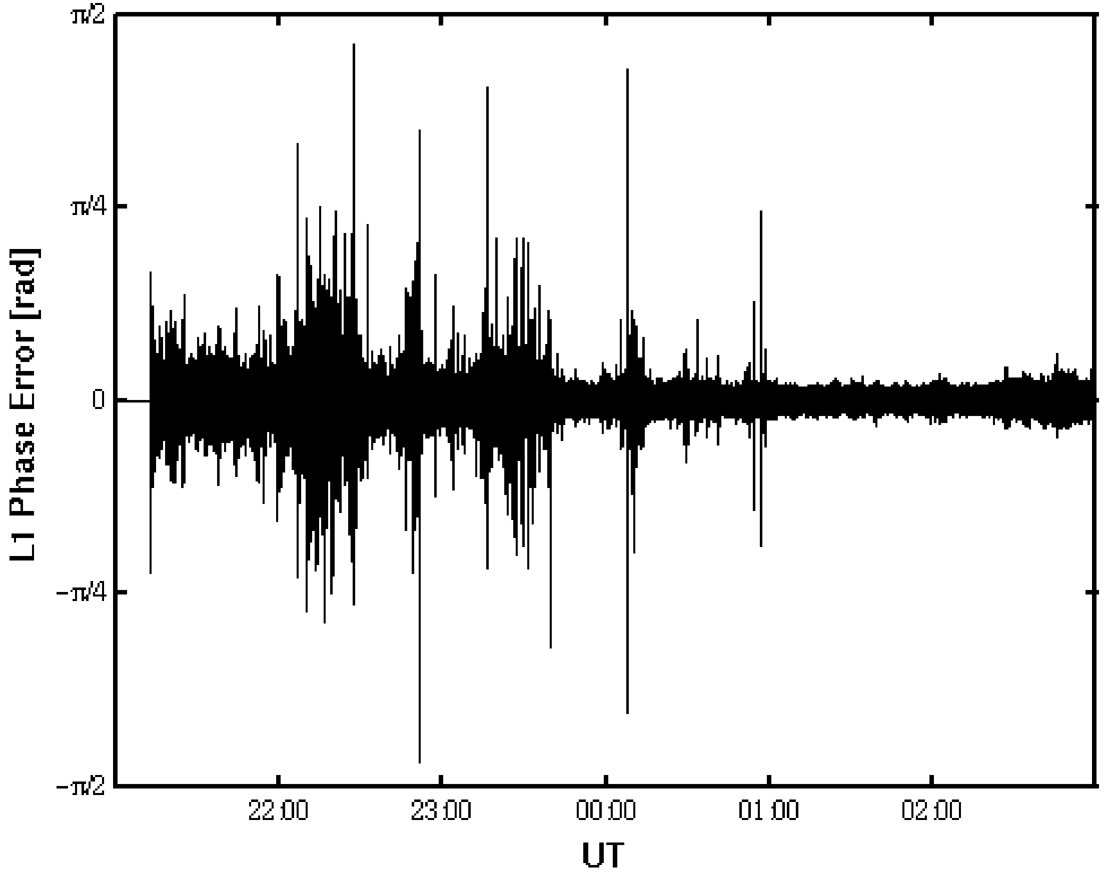
An additional problem: scintillation

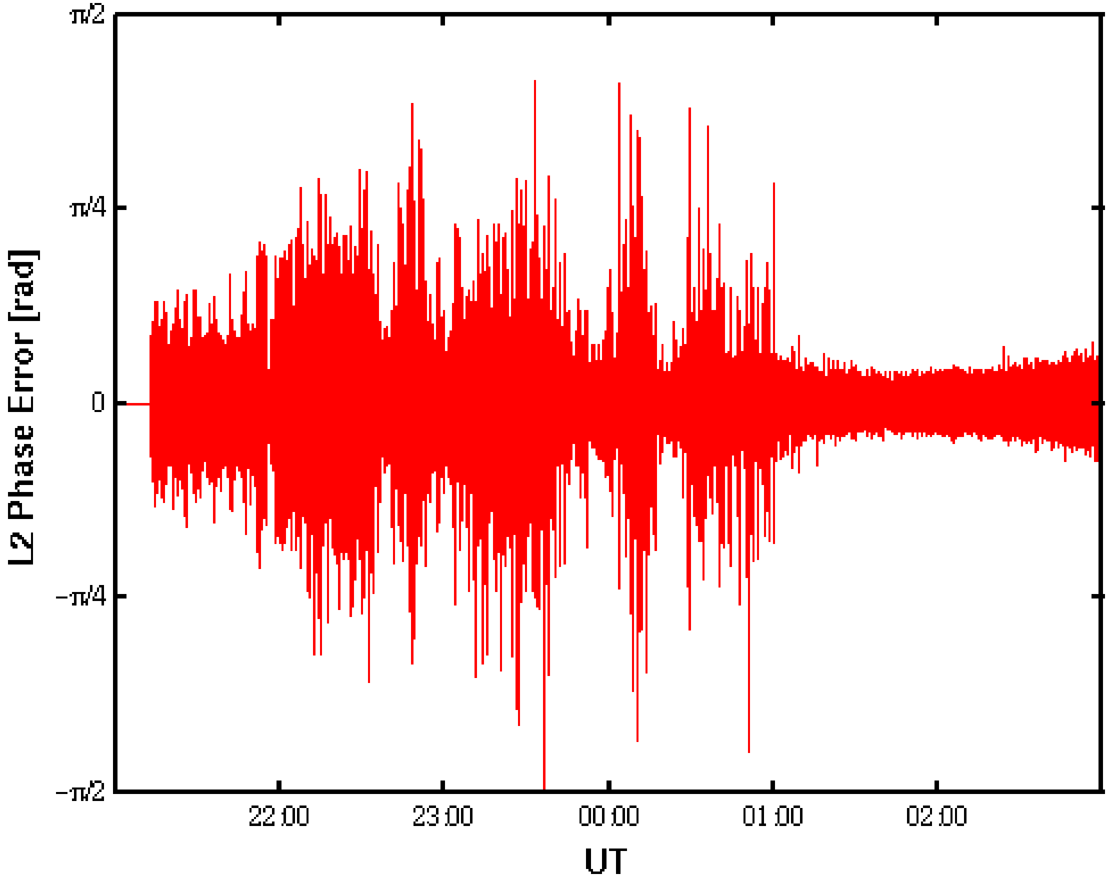


10 March 2012
PRN31

Forte et al, in preparation

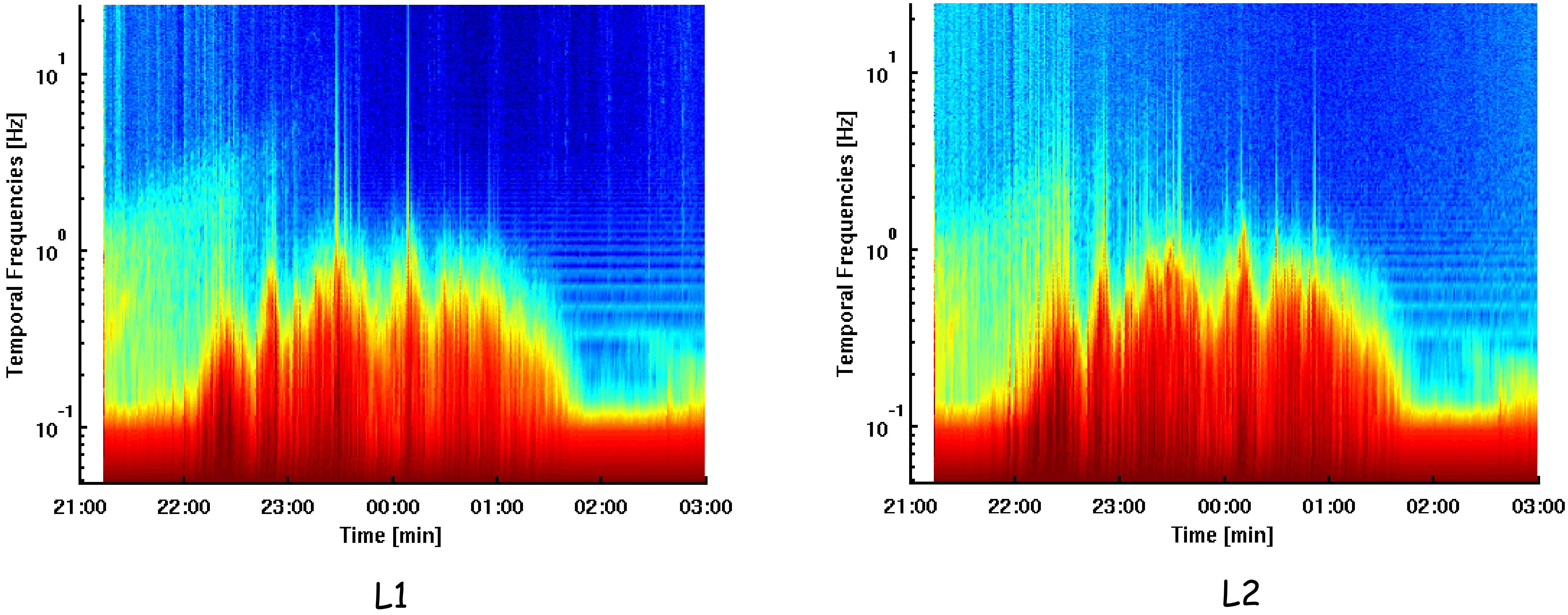
An additional problem: scintillation





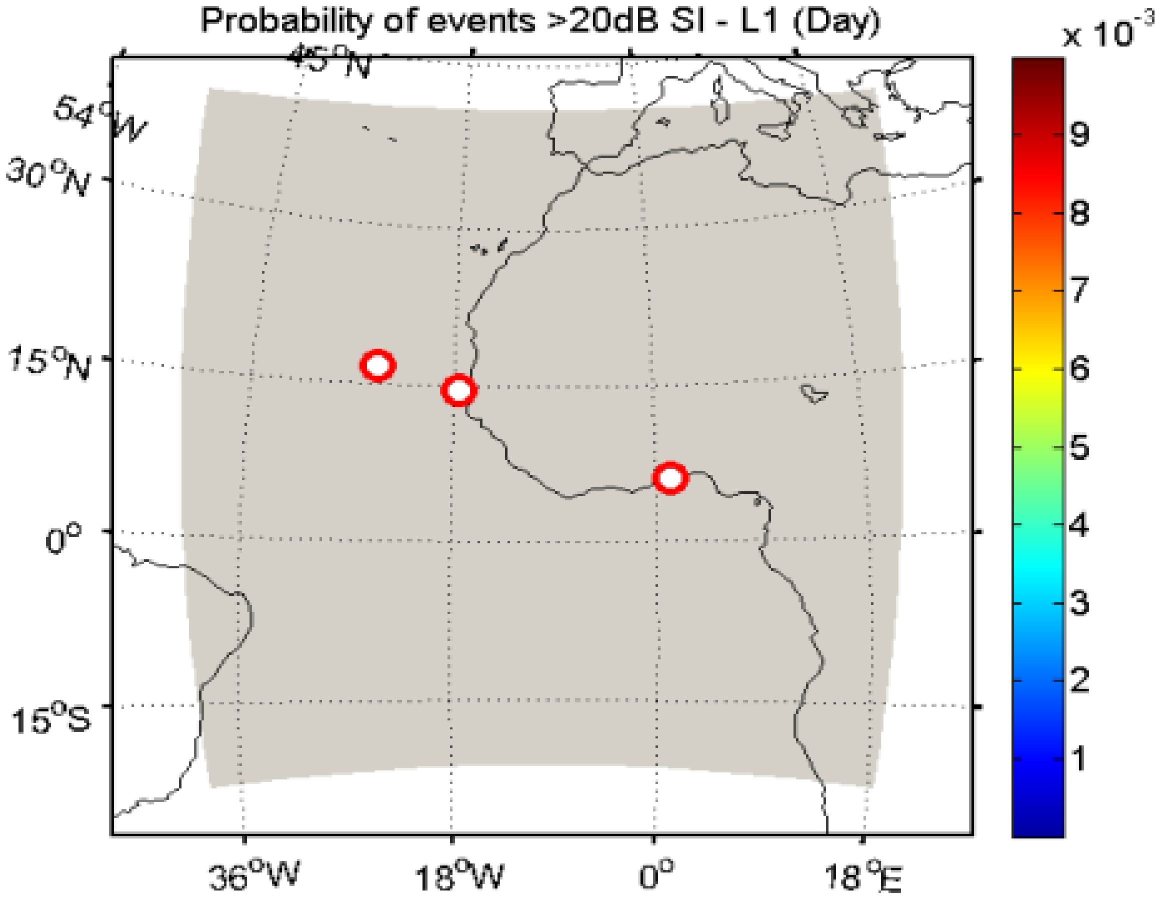
Forte et al, in preparation

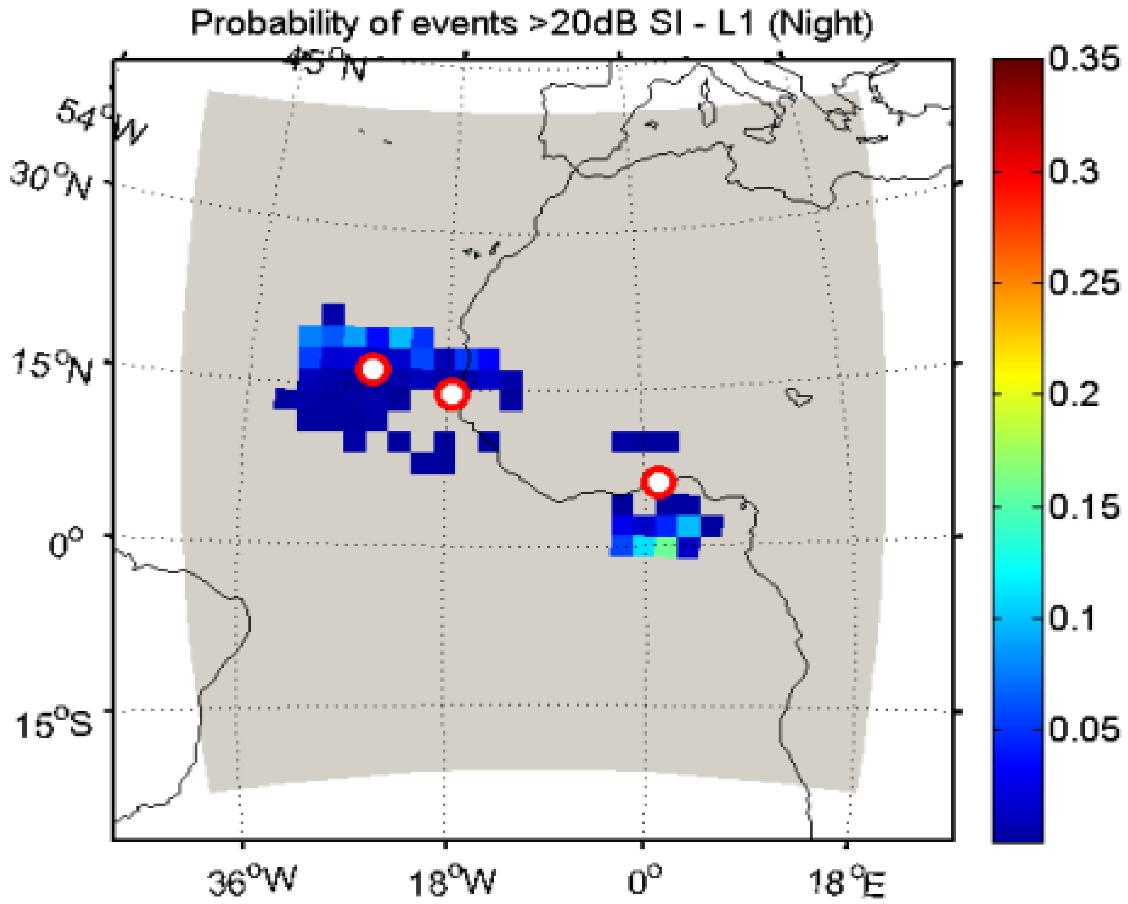
An additional problem: scintillation



Forte et al, in preparation

Scintillation: a night-time phenomenon





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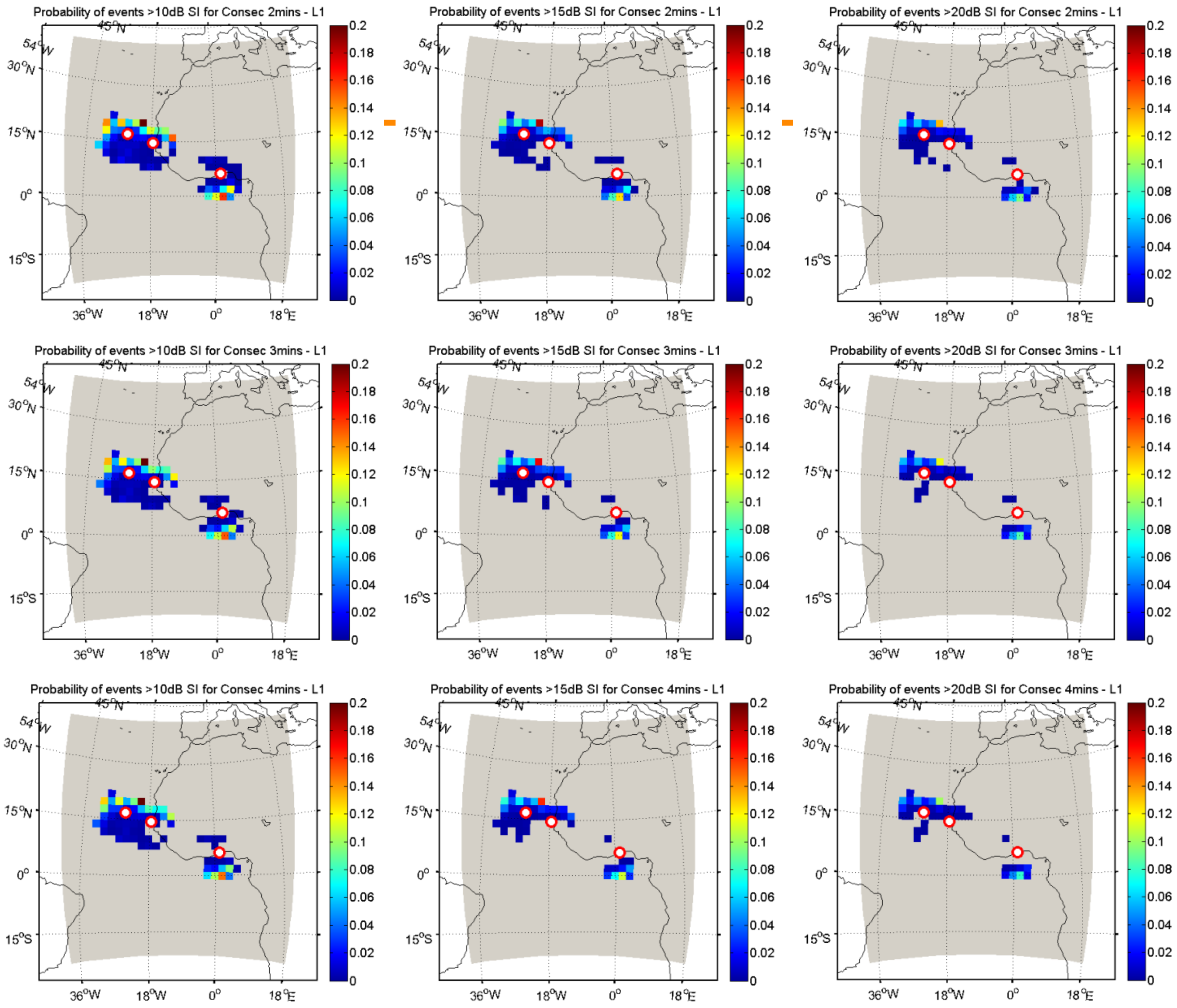


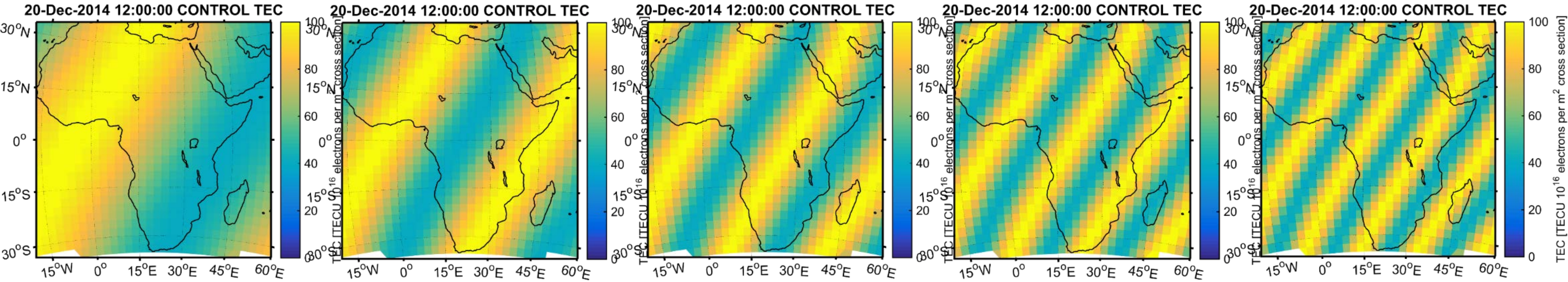
Up to 4 consecutive minutes

Forte et al, in preparation

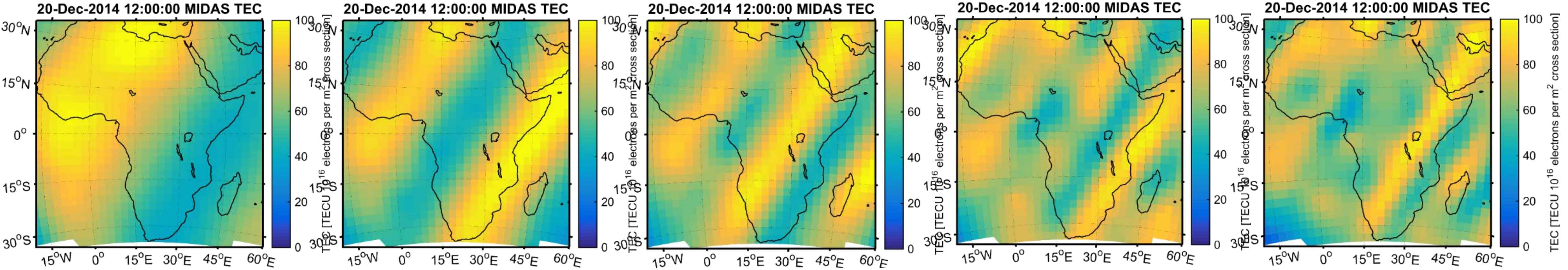
MISW Solutions: Understanding complexity and data requirement

1. Complexity

Simulated



Reconstructed



Da Dalt et al, in preparation

2. Data coverage

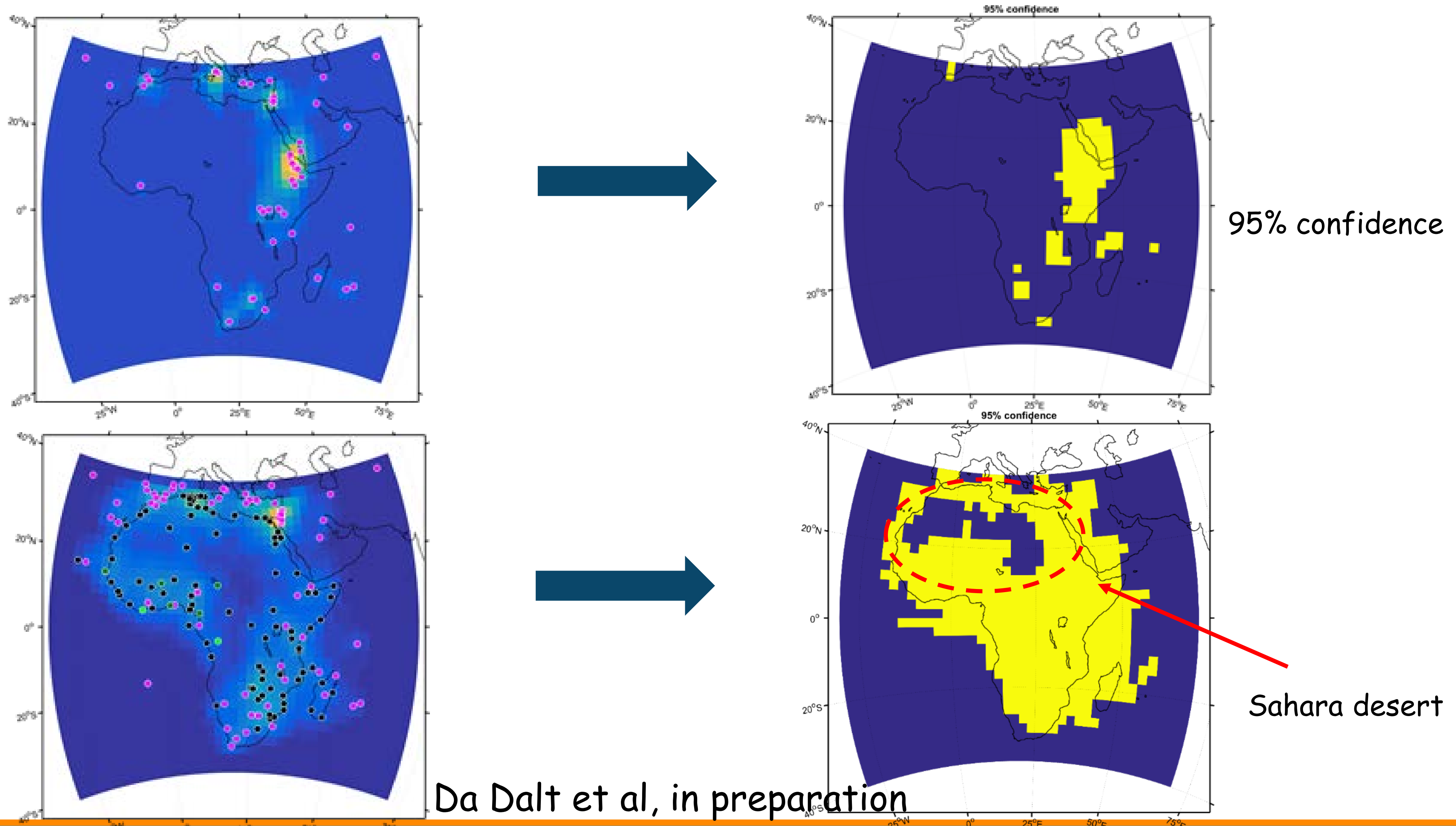
2009

Low data coverage

2015 +

simulated receivers

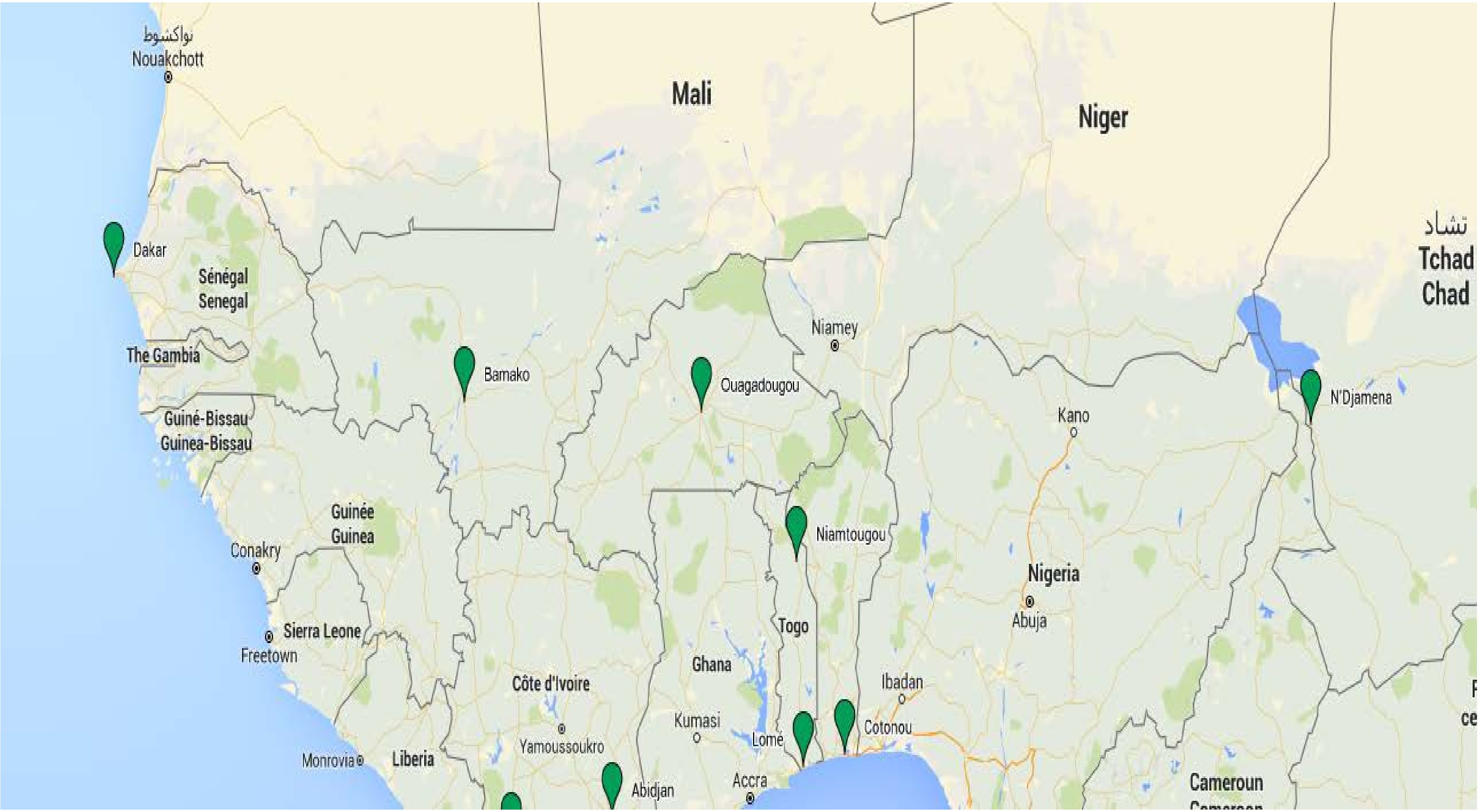
High data coverage



Da Dalt et al, in preparation

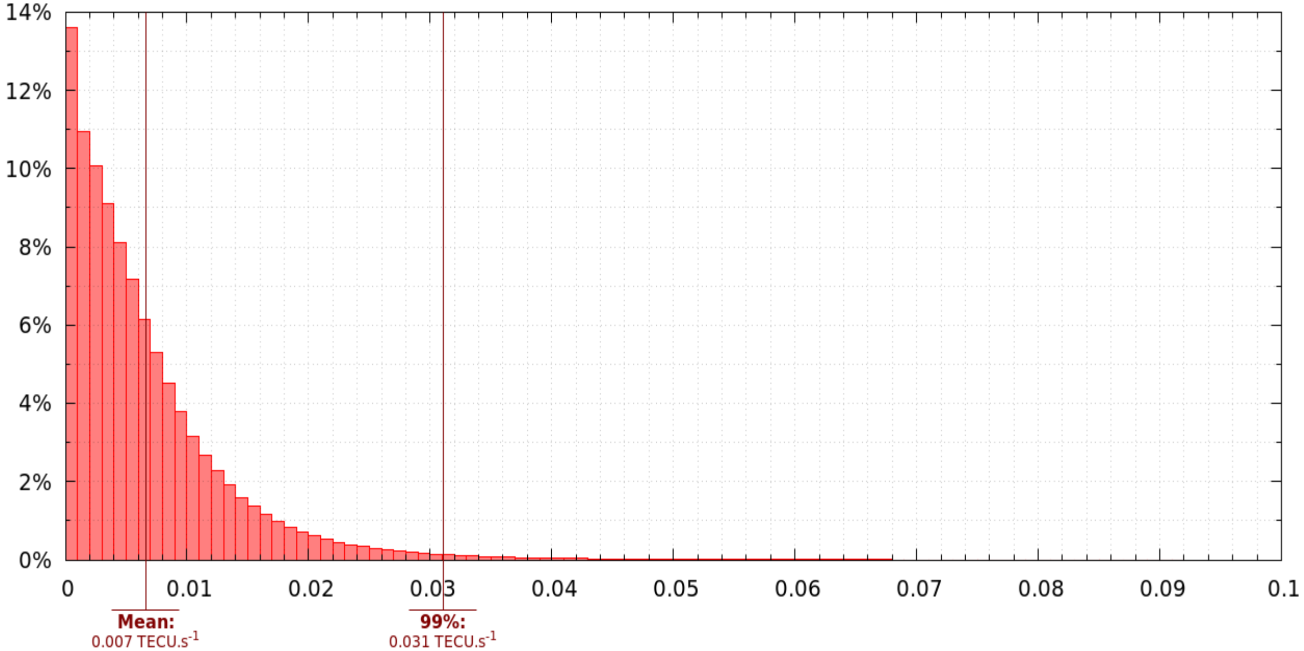
MISW Solutions: Modelling EGNOS performance over Africa under given scenarios

Data from SAGAIE network – courtesy of French CNES



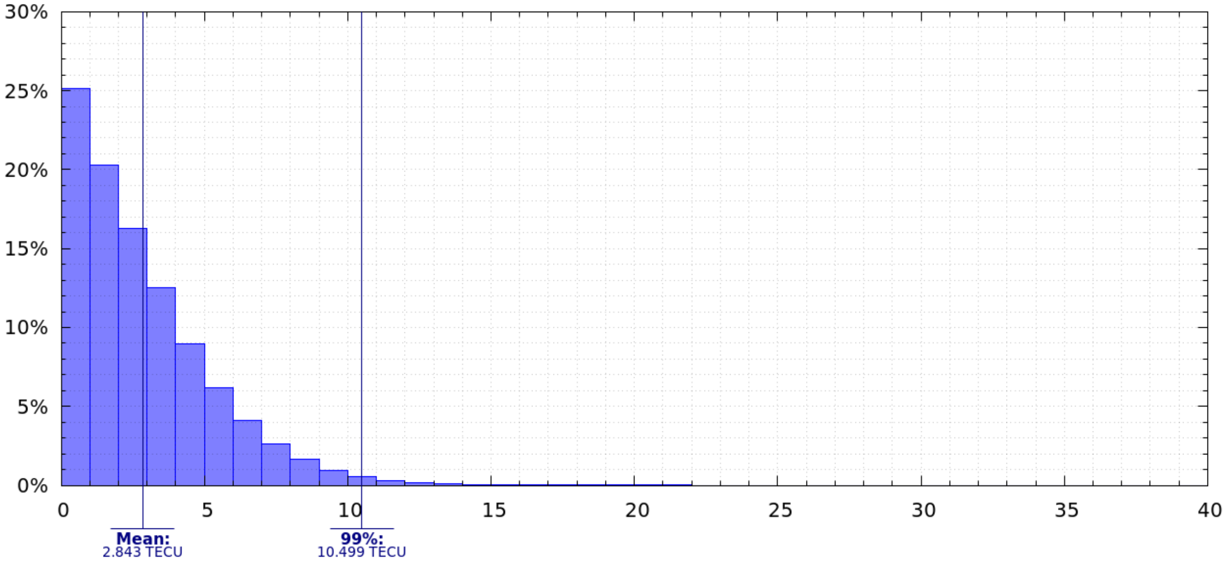
Ionisation gradients – July 2015

Temporal TEC gradient from all the stations in the chosen area



TECU/sec

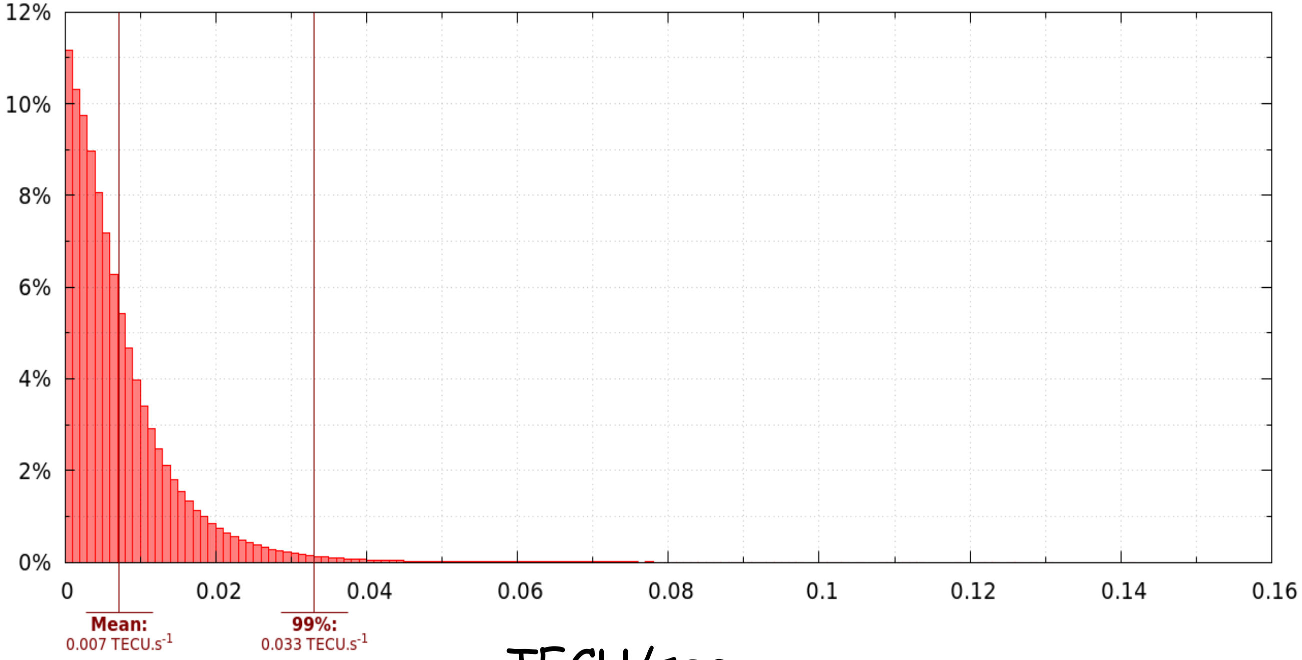
Spatial TEC gradient between two close IPPs



TECU

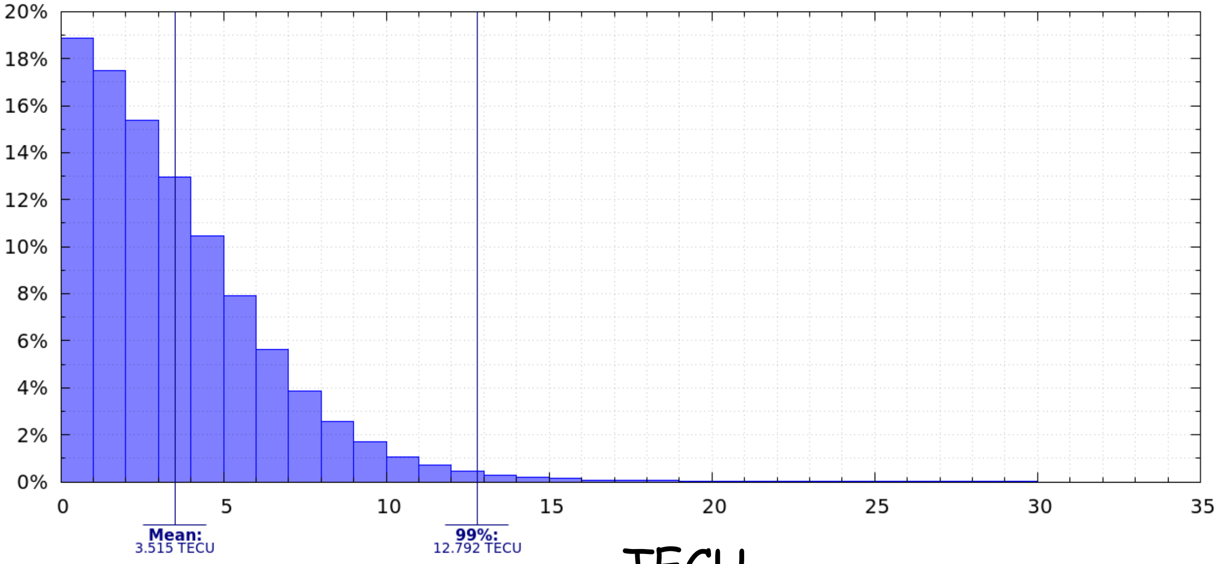
Ionisation gradients – October 2015

Temporal TEC gradient from all the stations in the chosen area



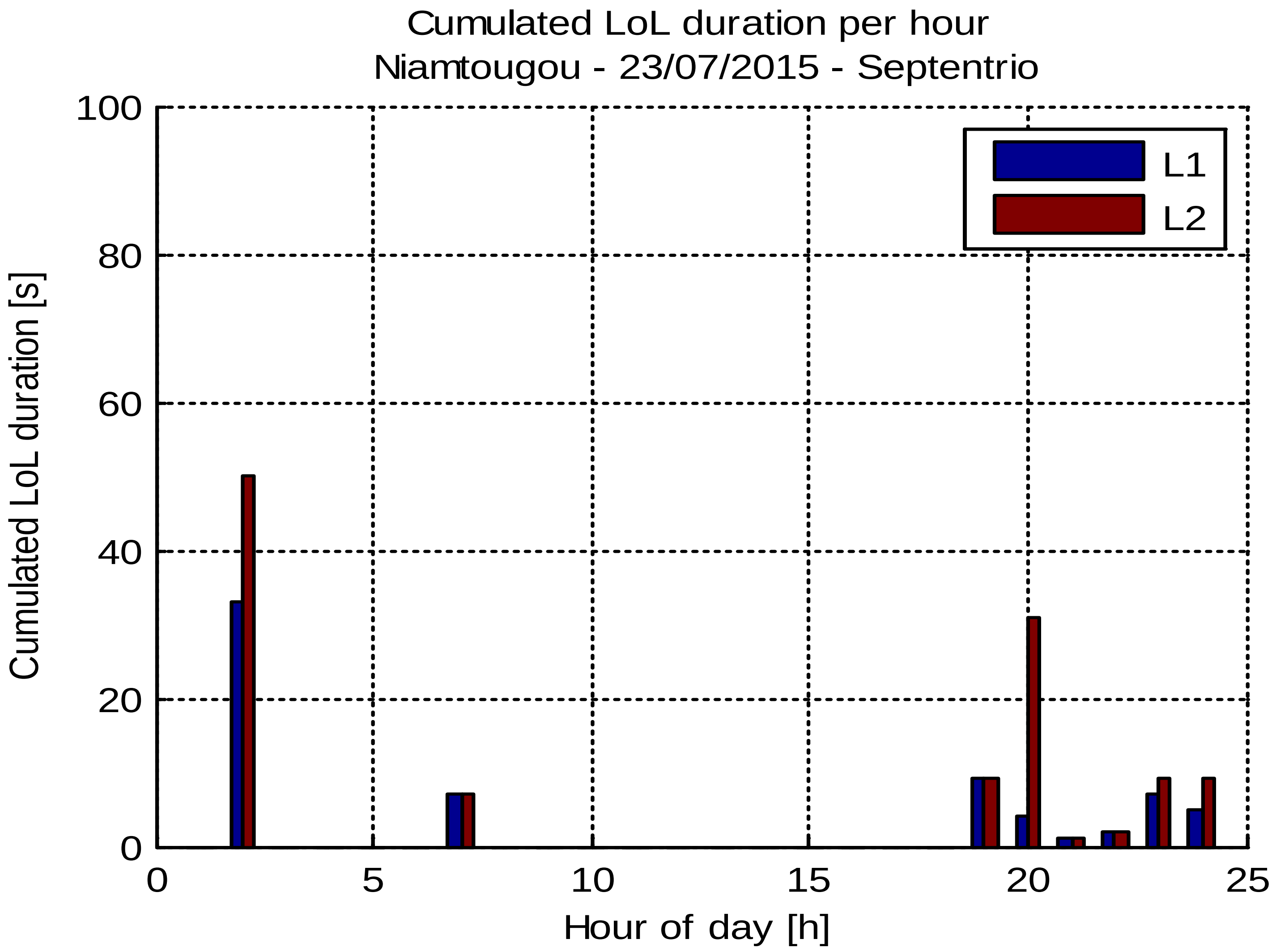
TECU/sec

Spatial TEC gradient between two close IPPs

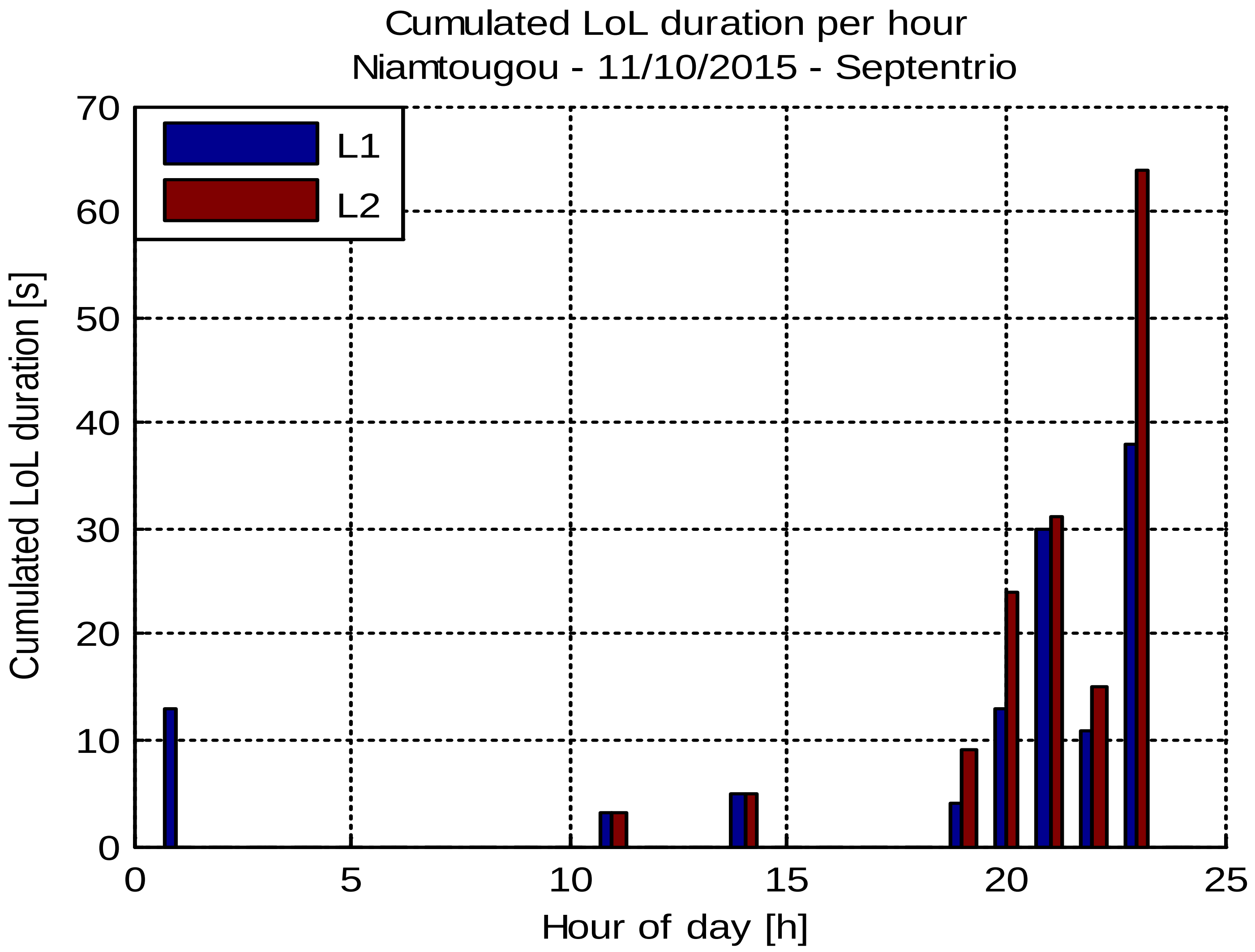


TECU

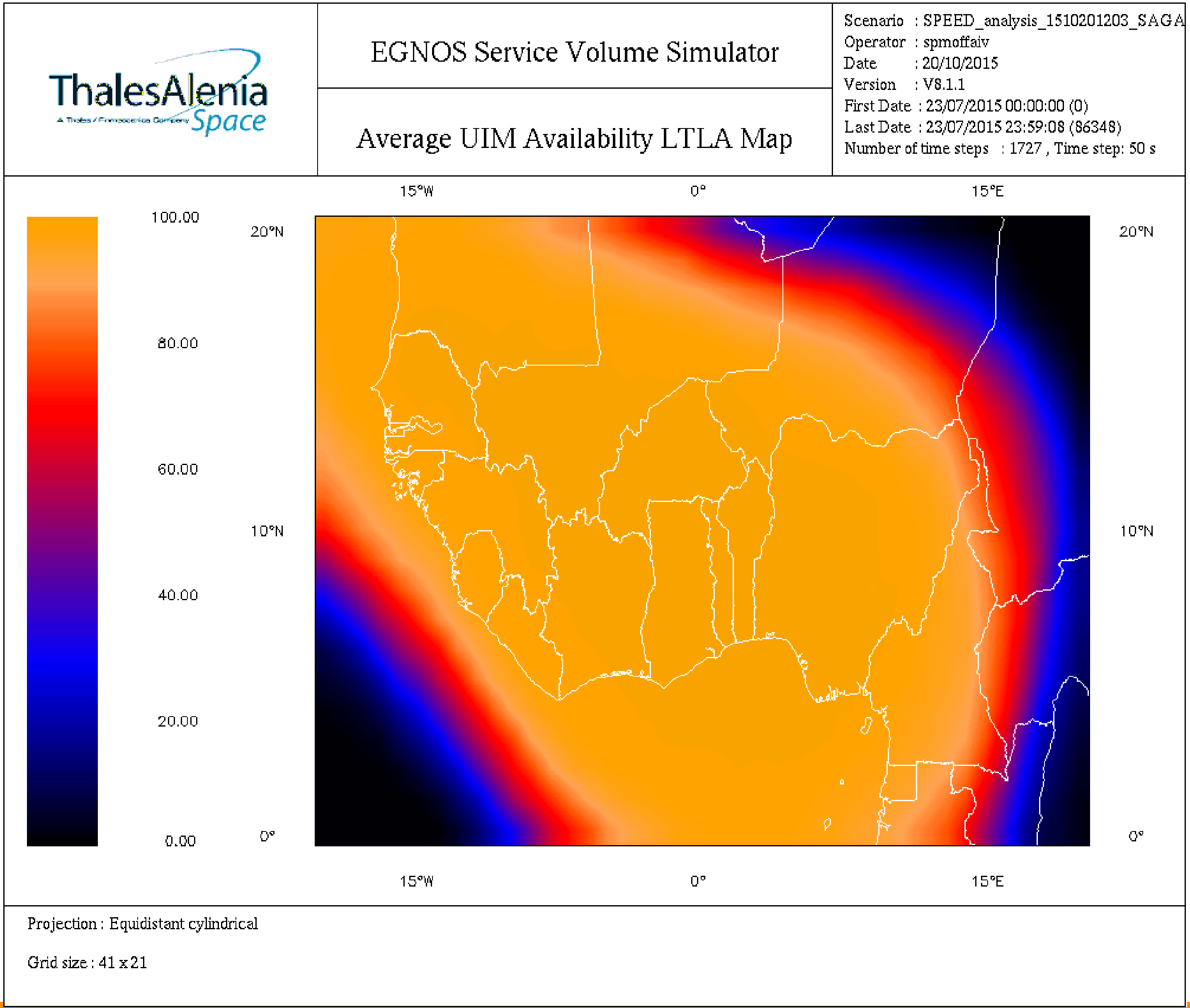
Data gaps introduced by ionospheric scintillation – July 2015



Data gaps introduced by ionospheric scintillation – October 2015

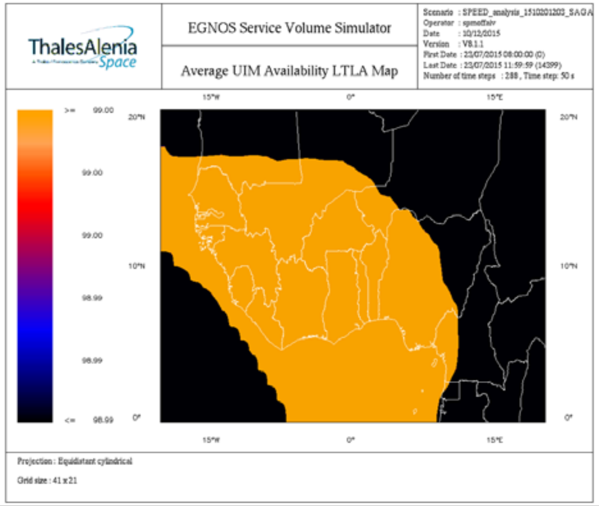


EGNOS availability – July 2015

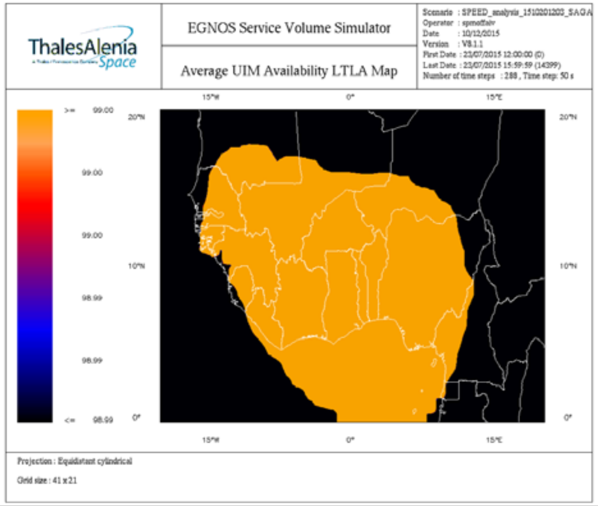


EGNOS availability – July 2015

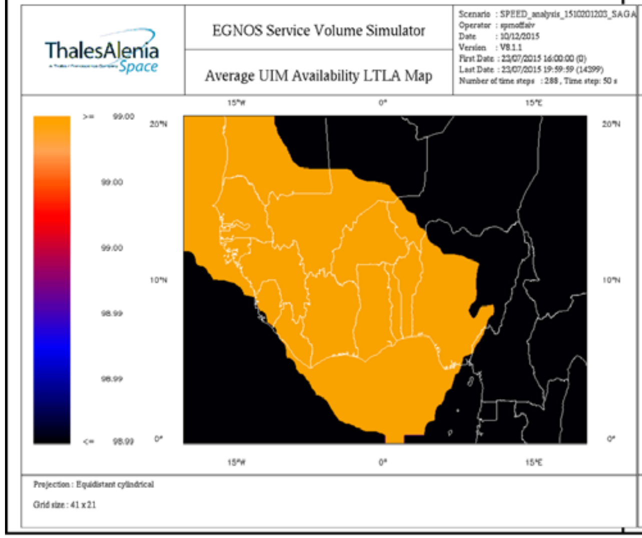
8h-12h



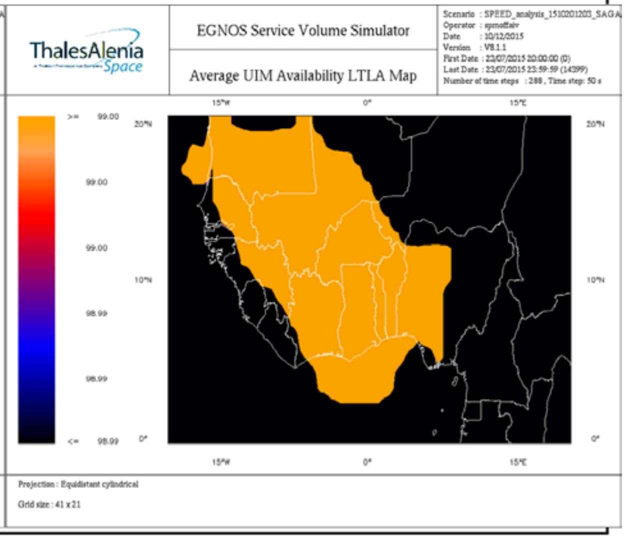
12h – 16h



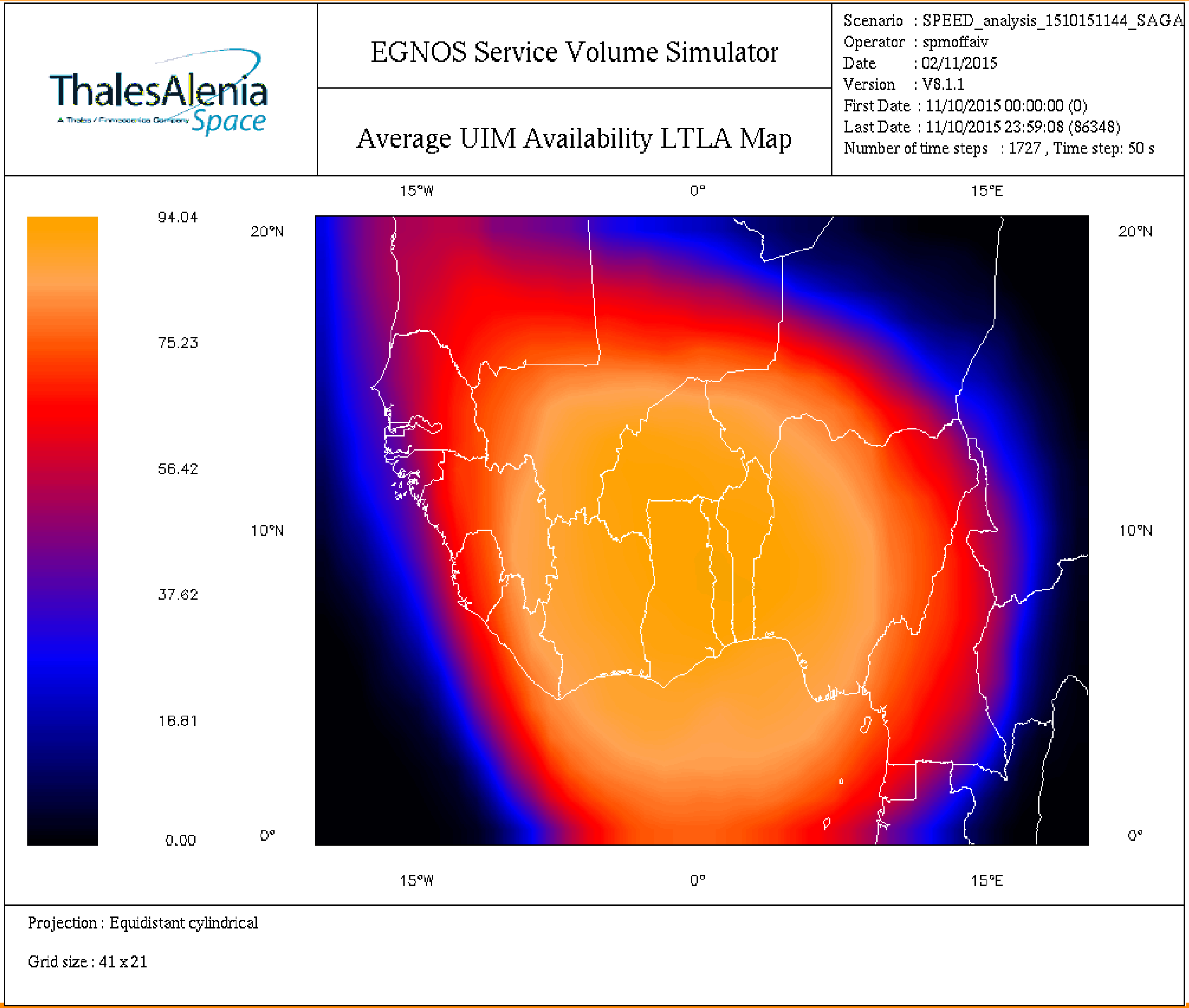
16h-20h



20h – 24h

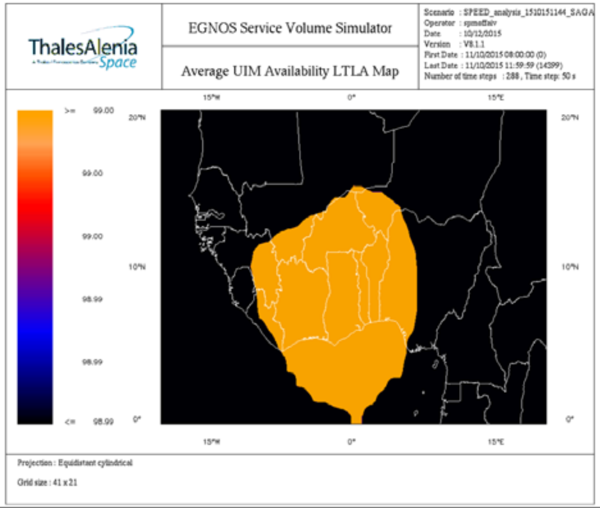


EGNOS availability – October 2015

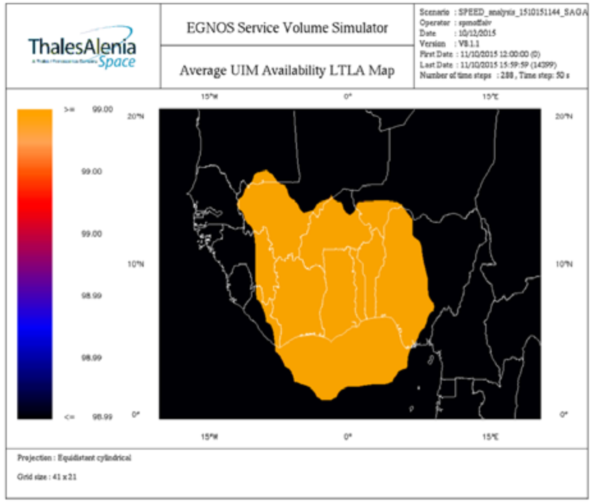


EGNOS availability – October 2015

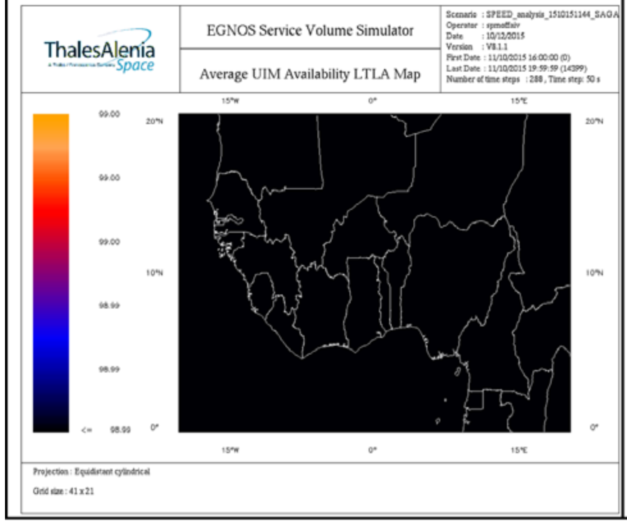
8h-12h



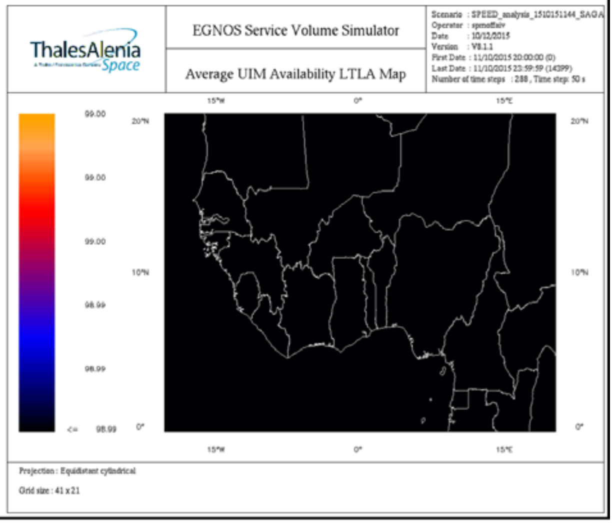
12h – 16h



16h-20h

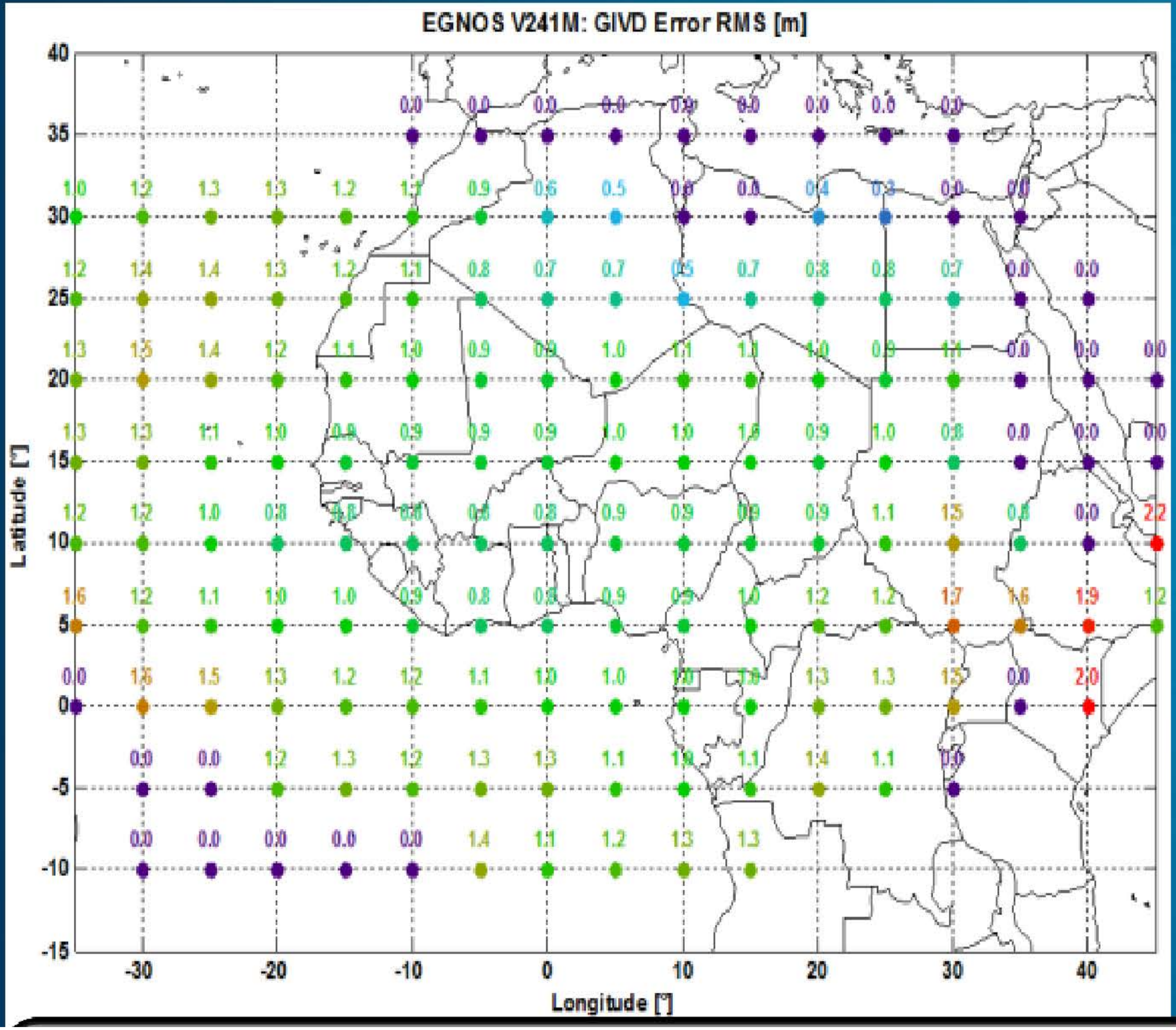


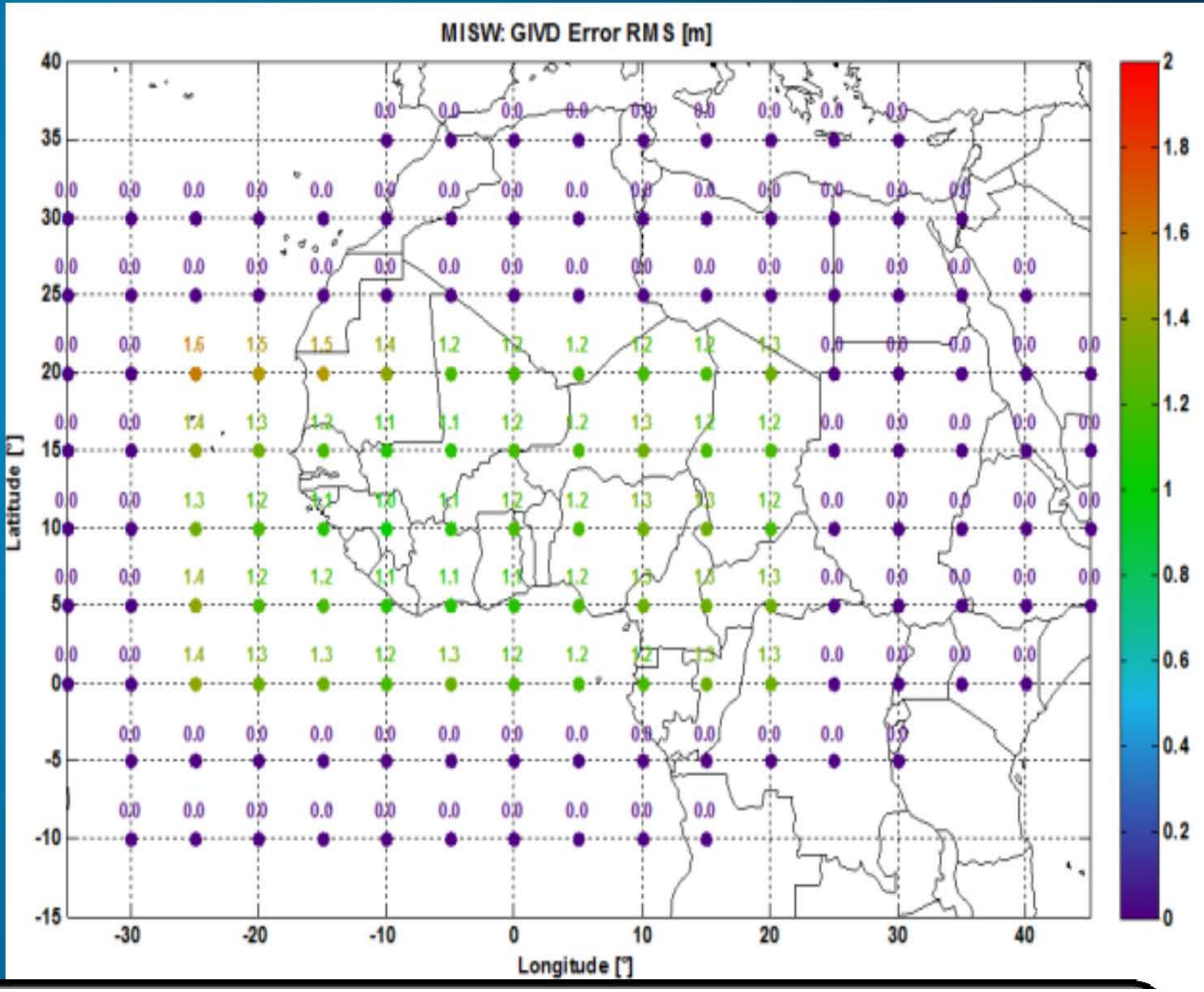
20h – 24h



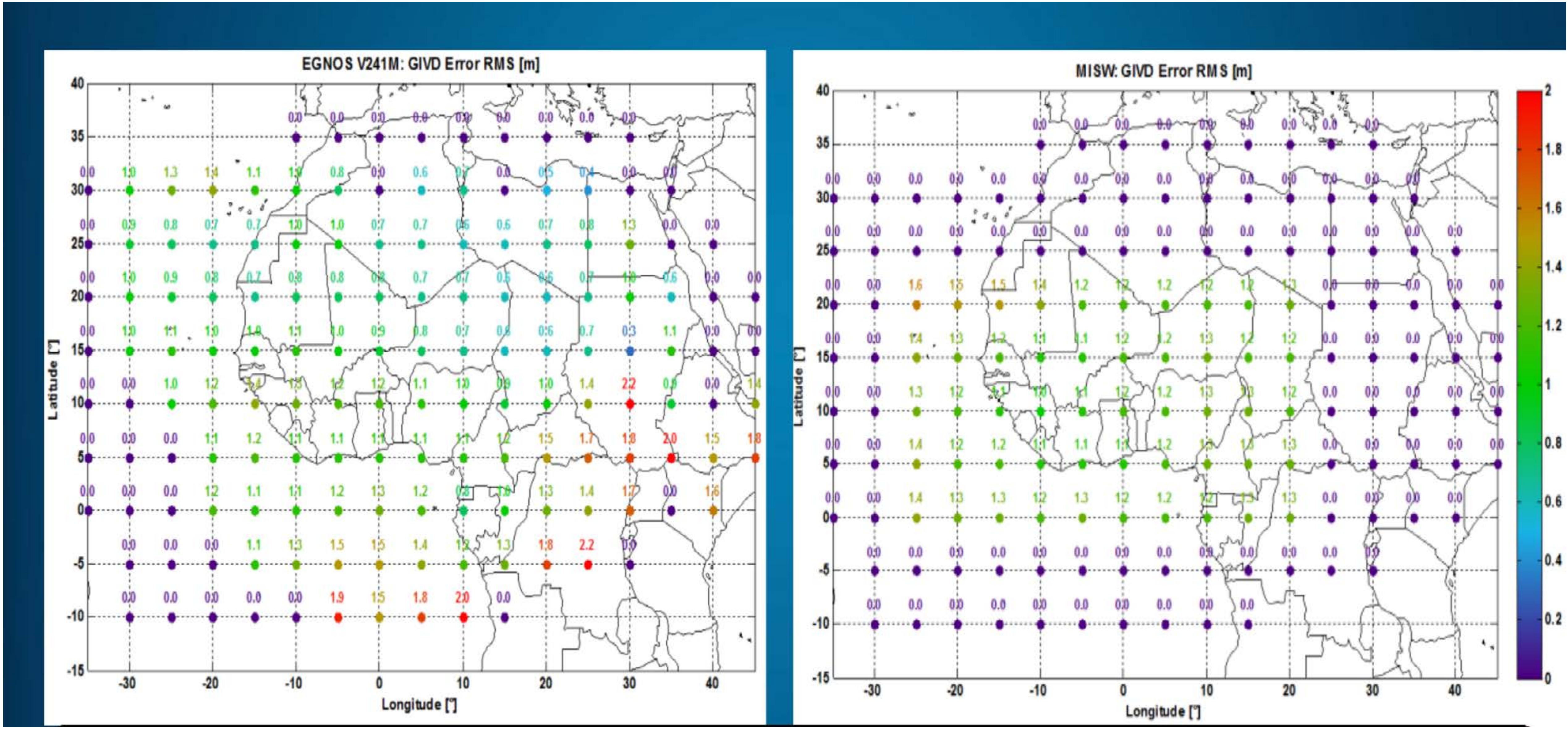
Comparison of different approaches for the grid point correction

Comparison of approaches: 23 July 2015





Comparison of approaches: 11 October 2015



MISW Solutions: Next-generation data-gap-free monitoring station

GISMO Prototype

Robust Carrier Tracking – Simulation Results

Semi-analytic simulator (Matlab)

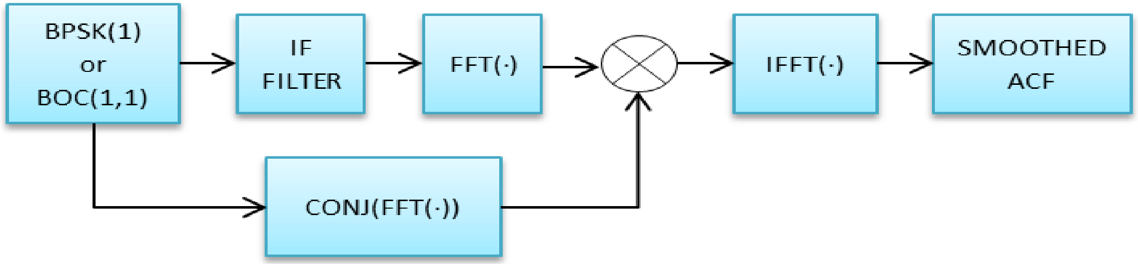
GISM Time series

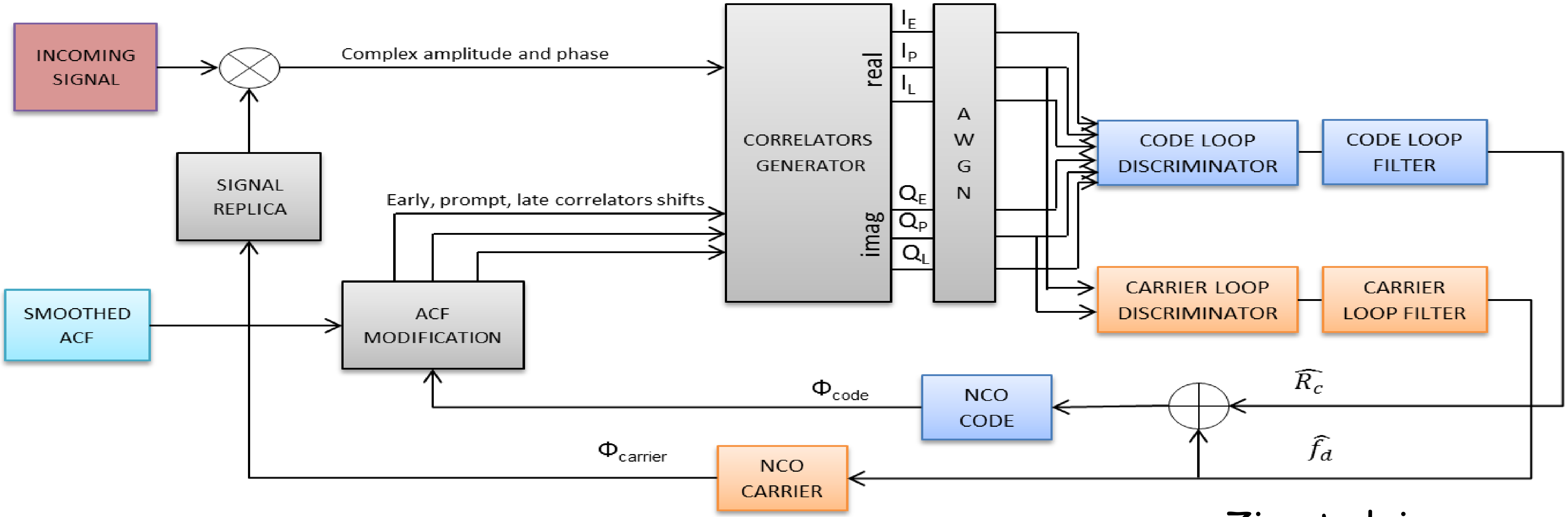
Tecniques comparisons

Semi-analytic Simulator – TASI Receiver Loops Tracking Model

Semi-analytic PLL and DLL combined model

- Simulations at different S4 conditions
  → assess phase and frequency accuracies, robustness vs CS
- Simulation at extreme S4 condition
  → assess robustness vs LoL

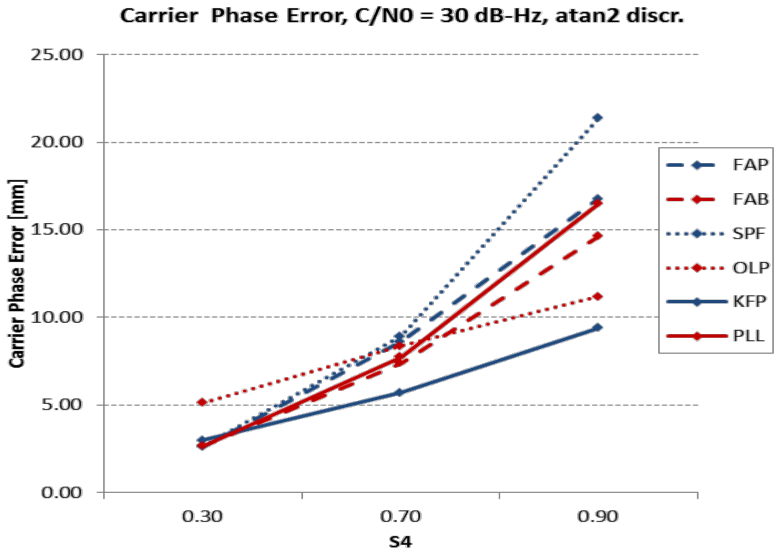


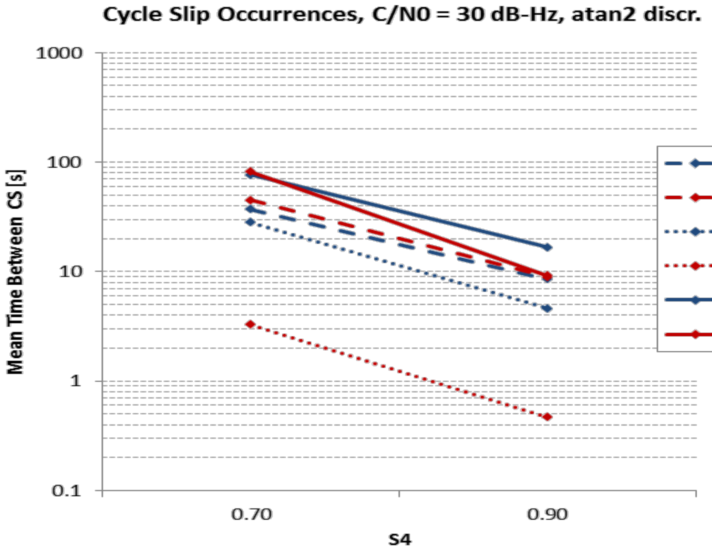


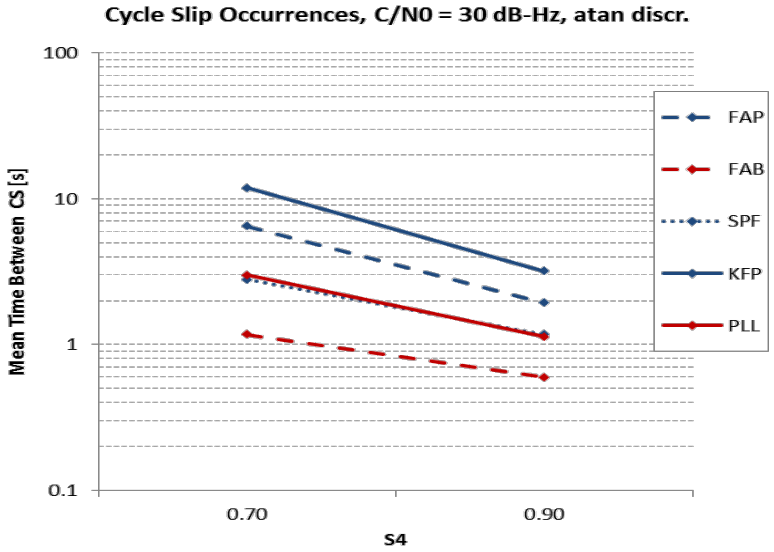
Zin et al, in preparation

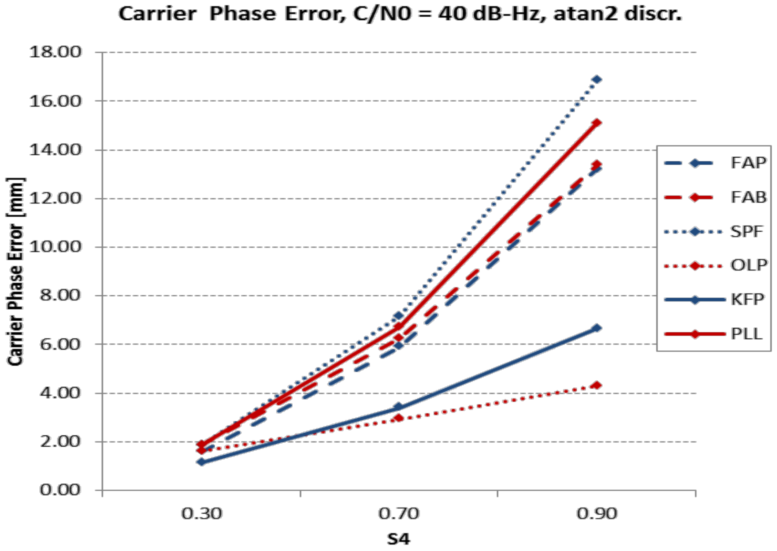
Simulation Results

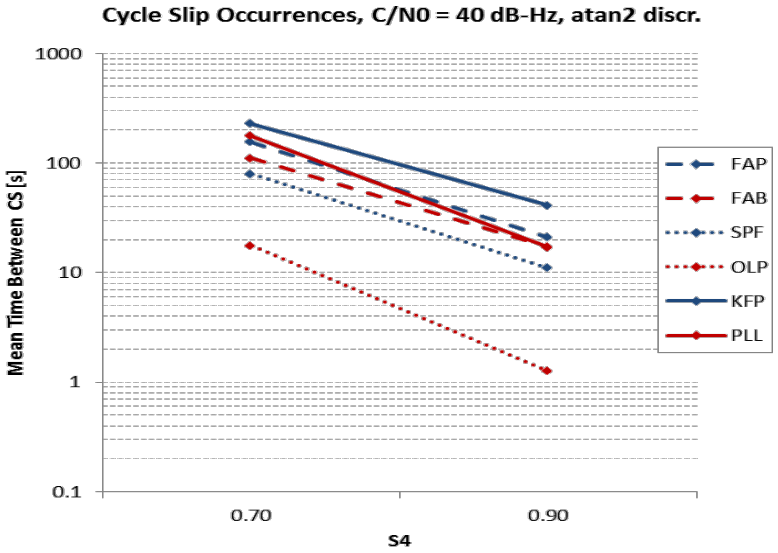
Zin et al, in preparation

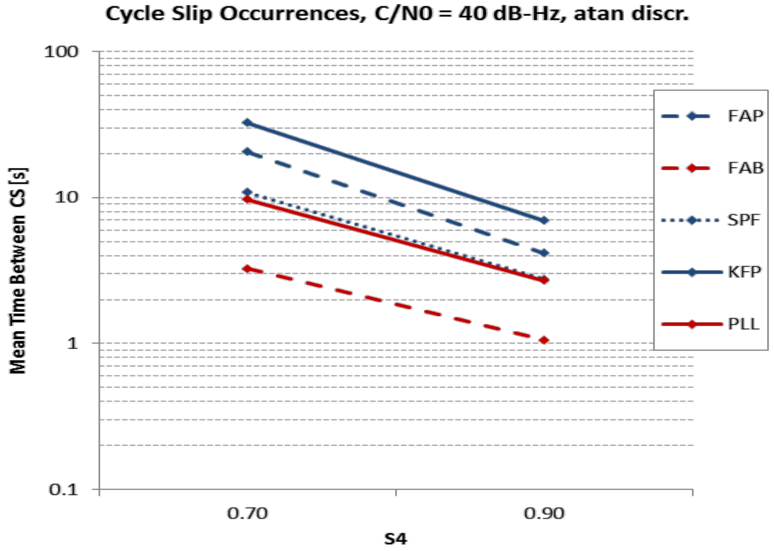




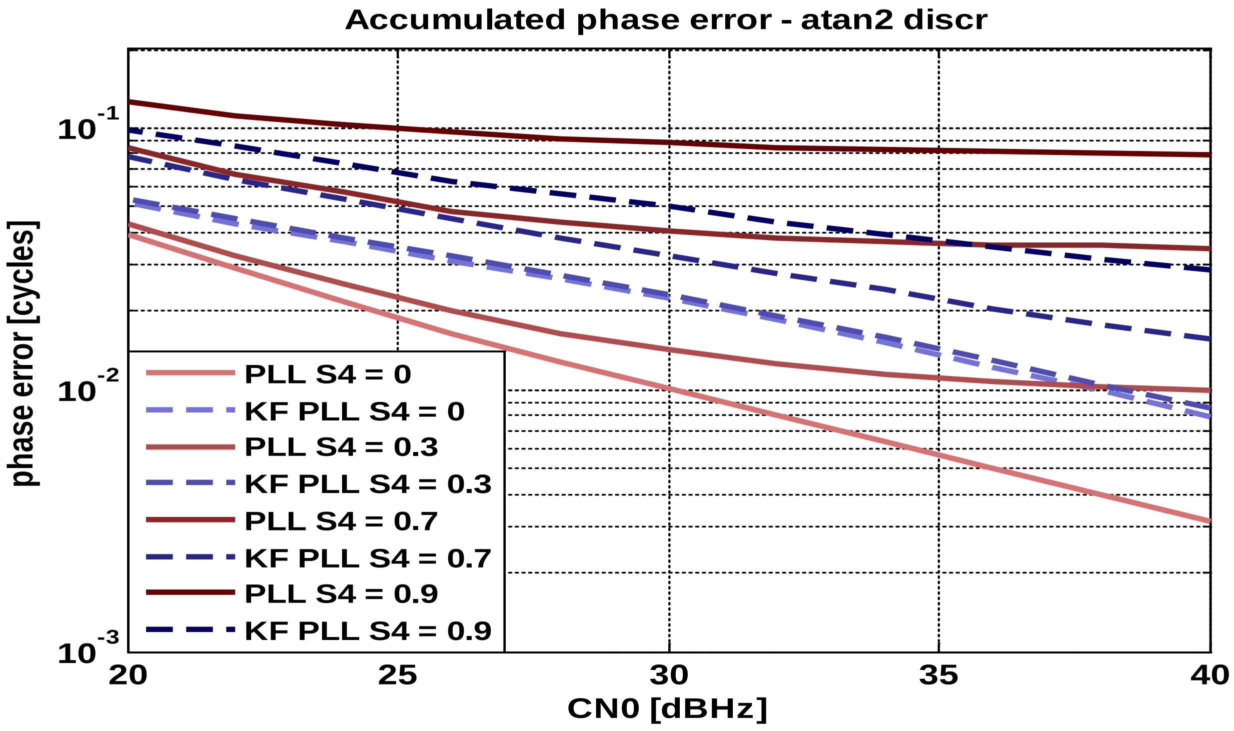


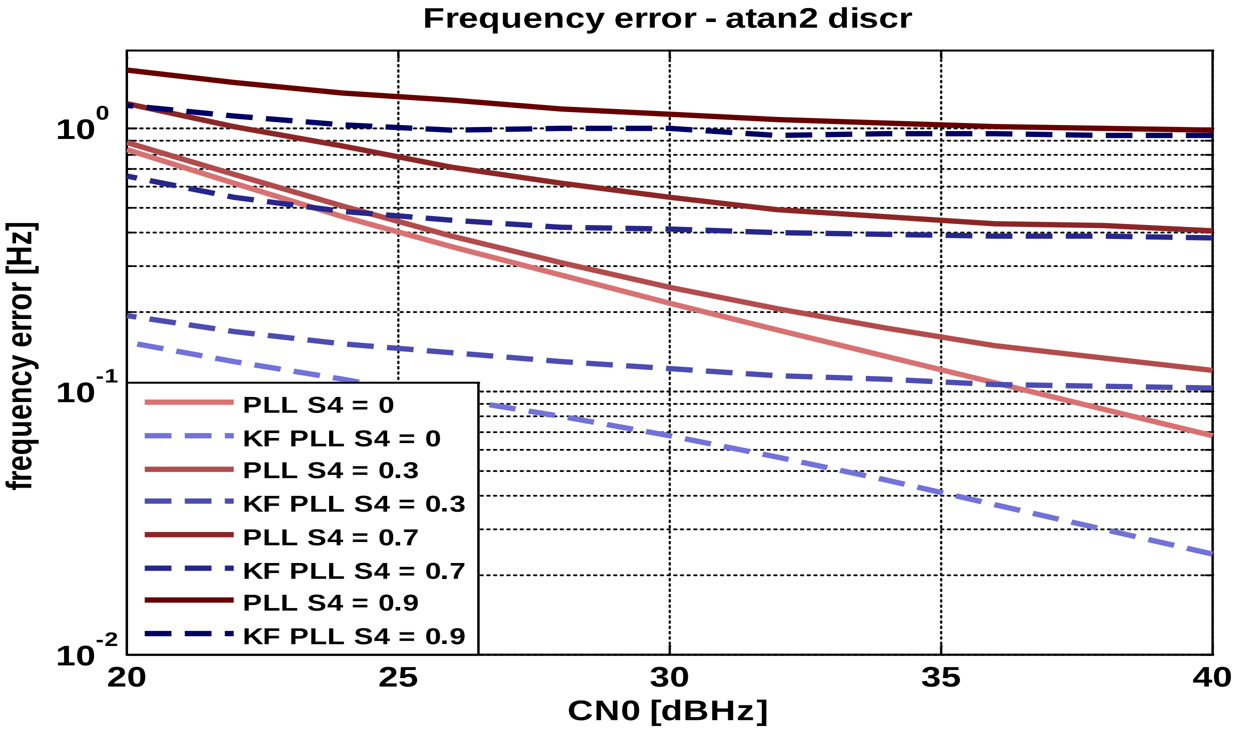






Simultator Results - Phase and Carrier Accuracy

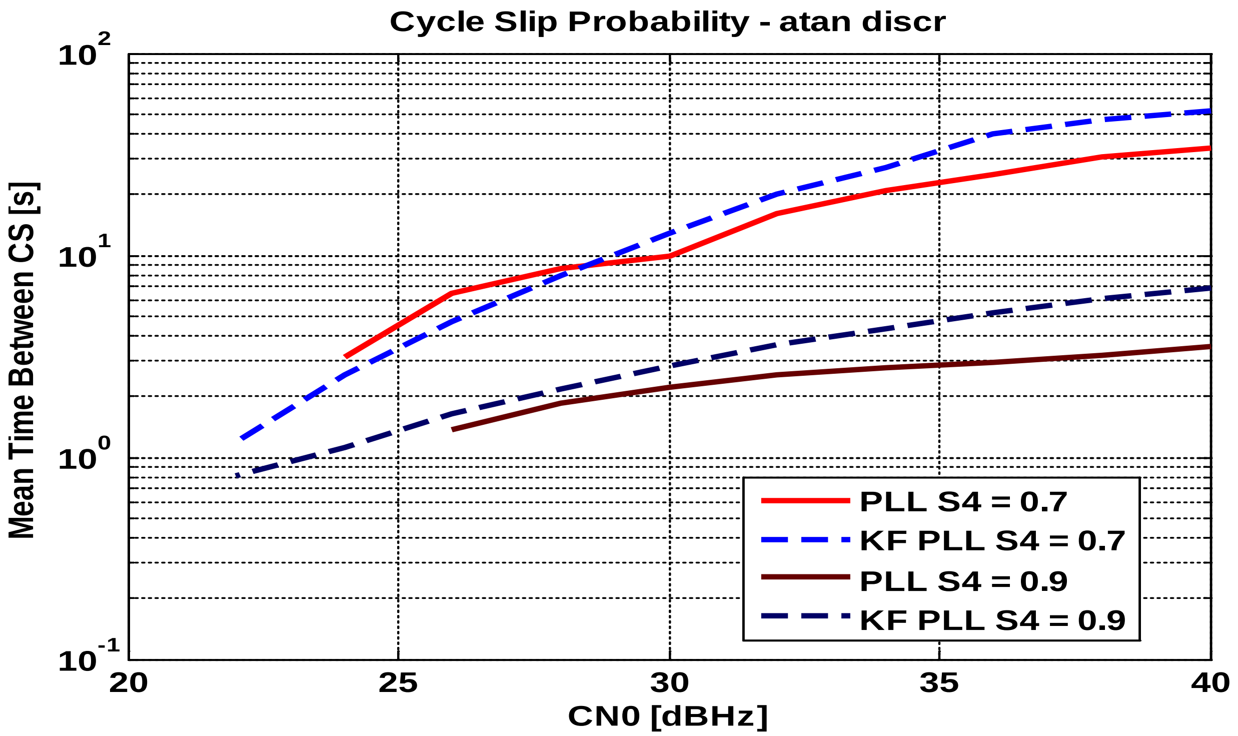


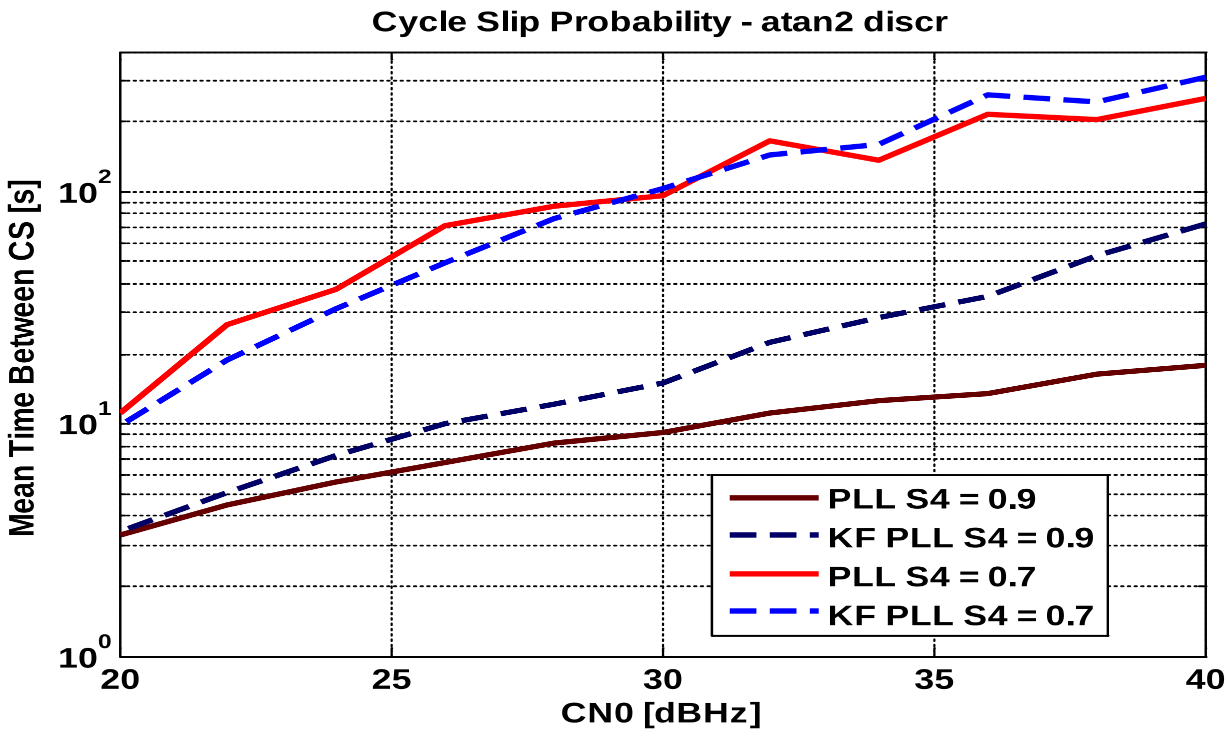


- Kalman filter results to have higher phase errors at lower scintillation, while in presence of strong scintillation it shows a great error reduction, in particular at high C/N_0 values
- The most evident advantage in the Kalman filter reduced frequency error, w.r.t. reference PLL → increasing LoL and frequency False Lock rejection

Zin et al, in preparation

Simultator Results - Robustness vs Cycle Slips





- The figures highlight that for both atan and atan2:
  - PLL performs slightly better in case of moderate scintillation,
  - a great improvement of KF has been obtained in case of extreme scintillation.

Zin et al, in preparation

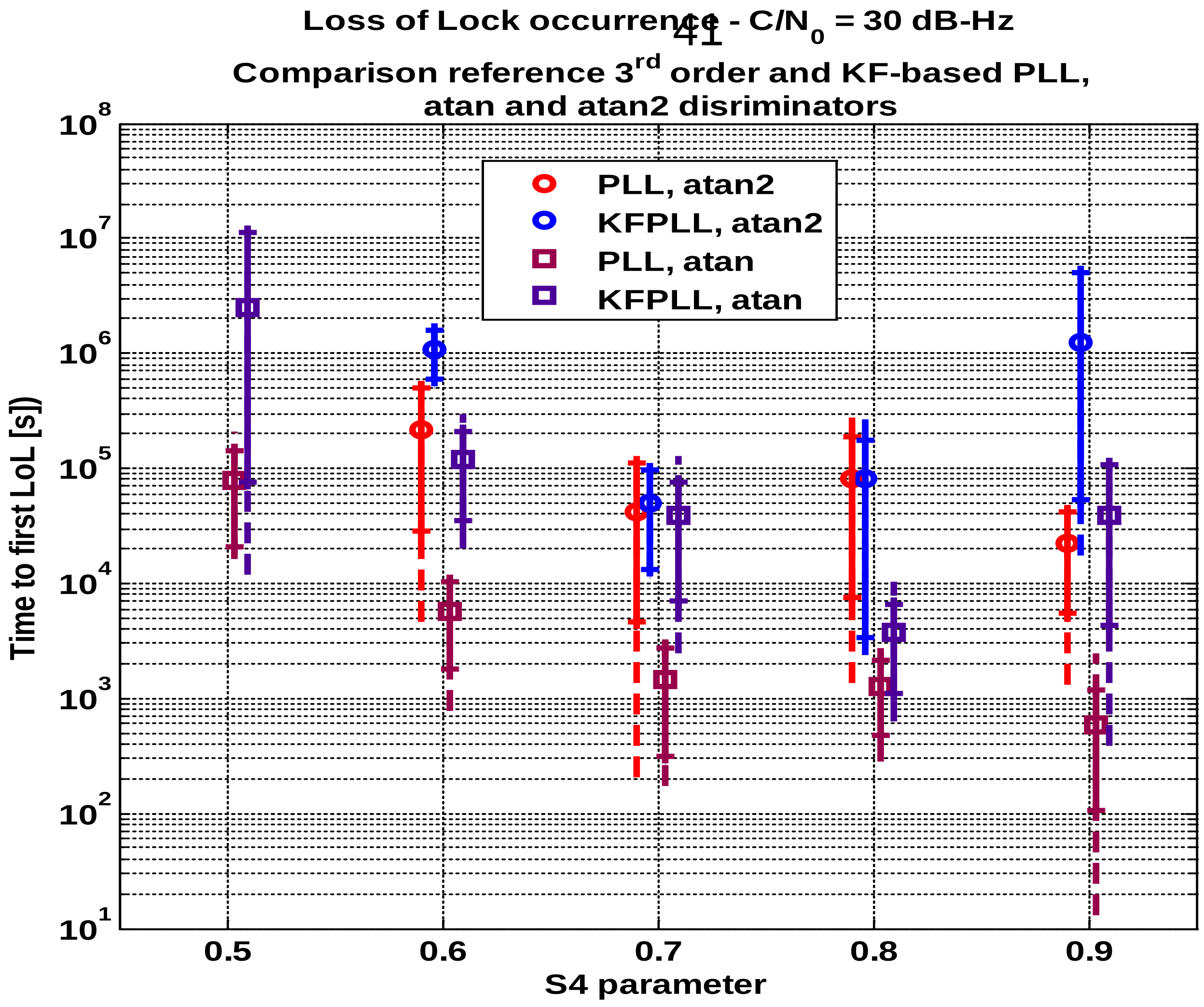
Simultator Results – Robustness vs Loss of Locks

Representation

- Mean: circled points represent average of the collected Times-to-First-LoL.
- Min-Max: vertical lines extend from minimum to maximum Time-to-First-LoL observed.
- The horizontal ticks give representation of the confidence interval

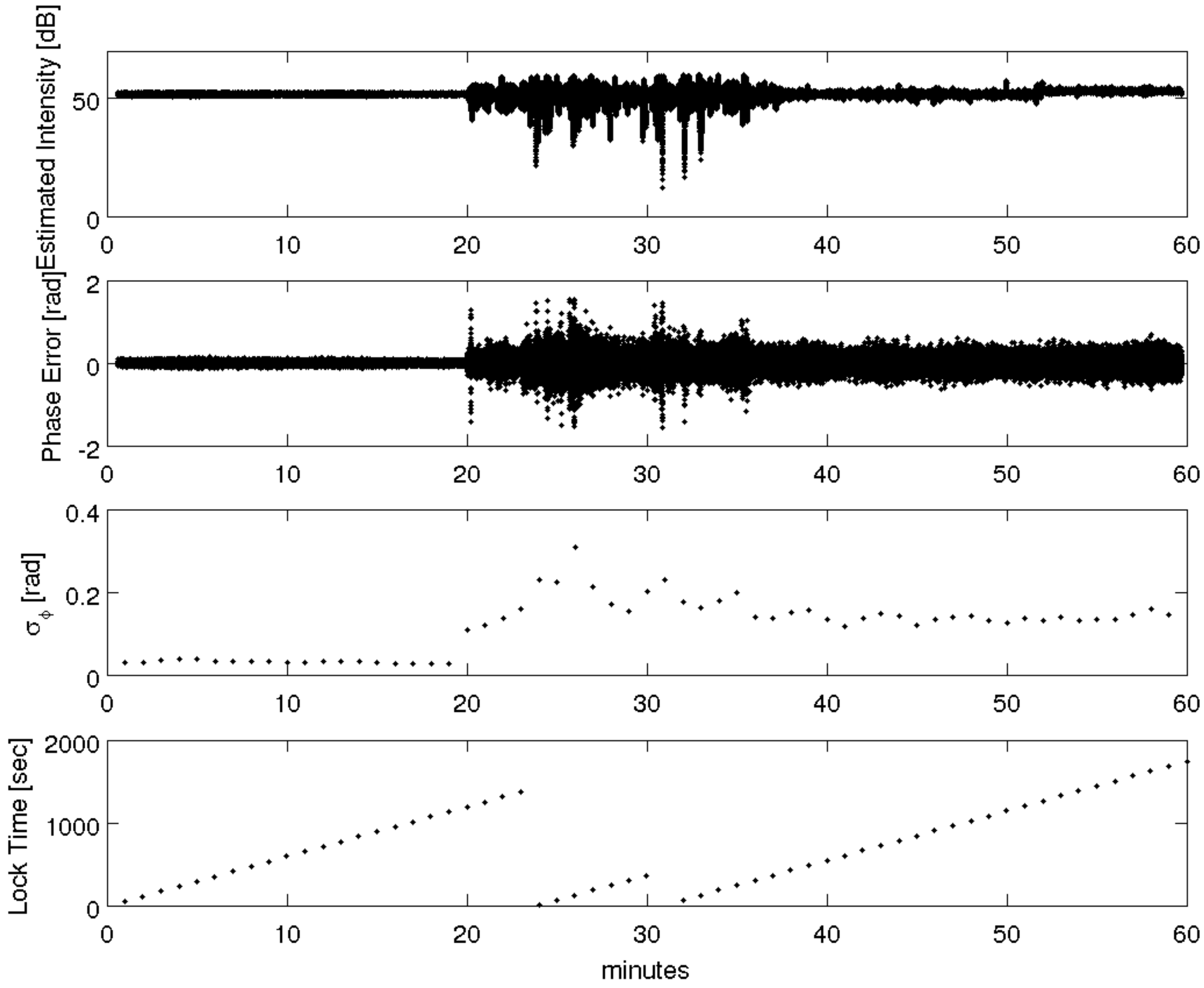
Results

- Benefits brought by KF more evident in atan case
- KF shows increasing robustness in extreme scintillation condition
- atan2 discriminator more robust than atan (no LoL at $S_4 = 0.5$)



Zin et al, in preparation

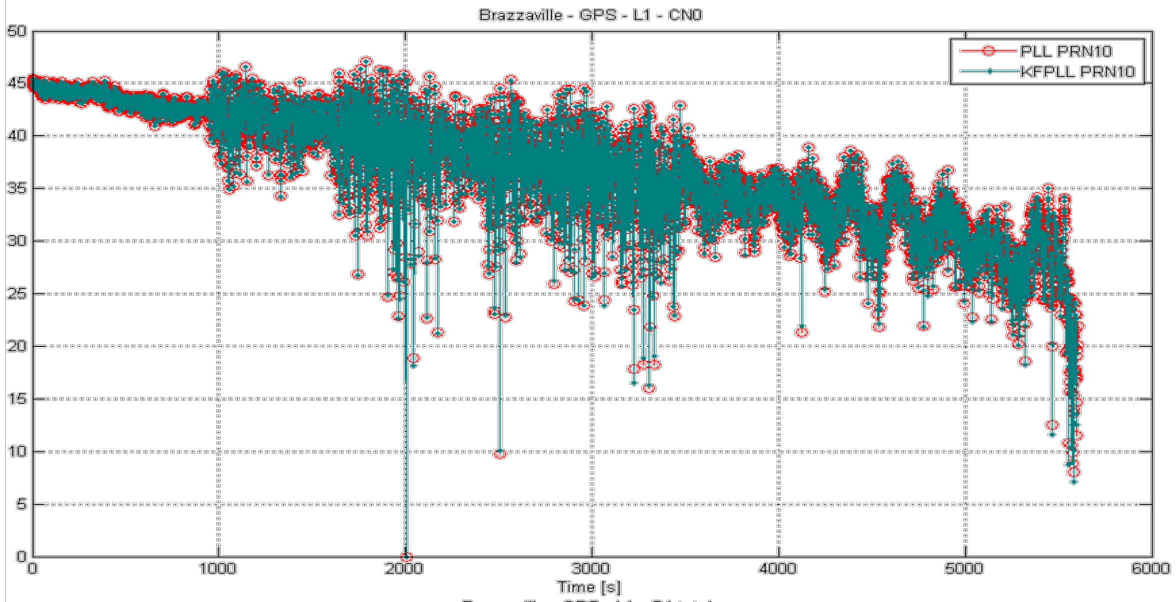
Additional tests (on-going): perturbations from real data



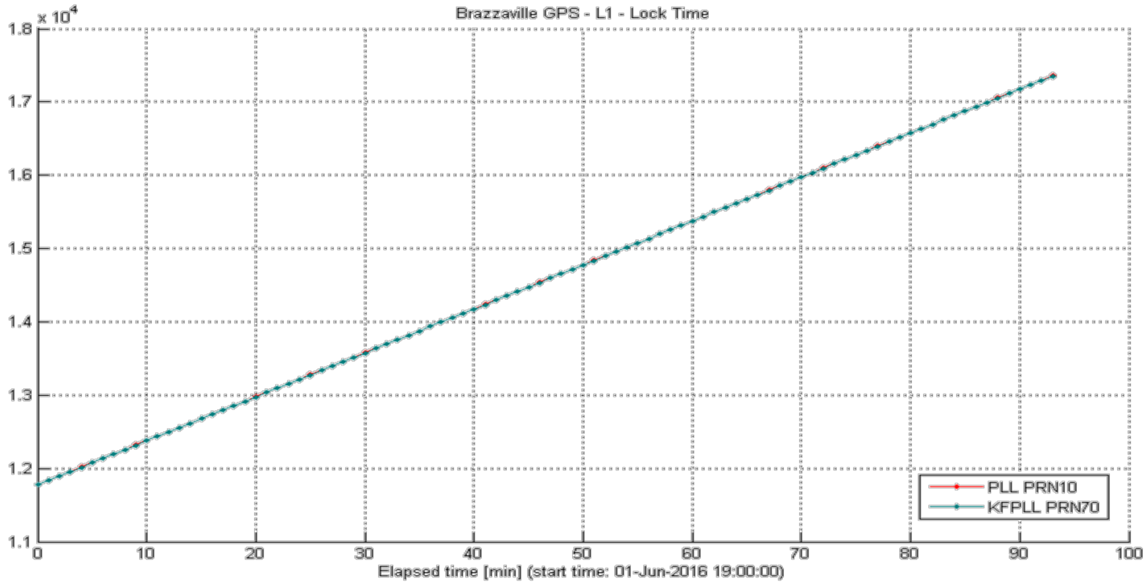
(Forte, 2012)

Updated GISMO Receiver Live Campaign

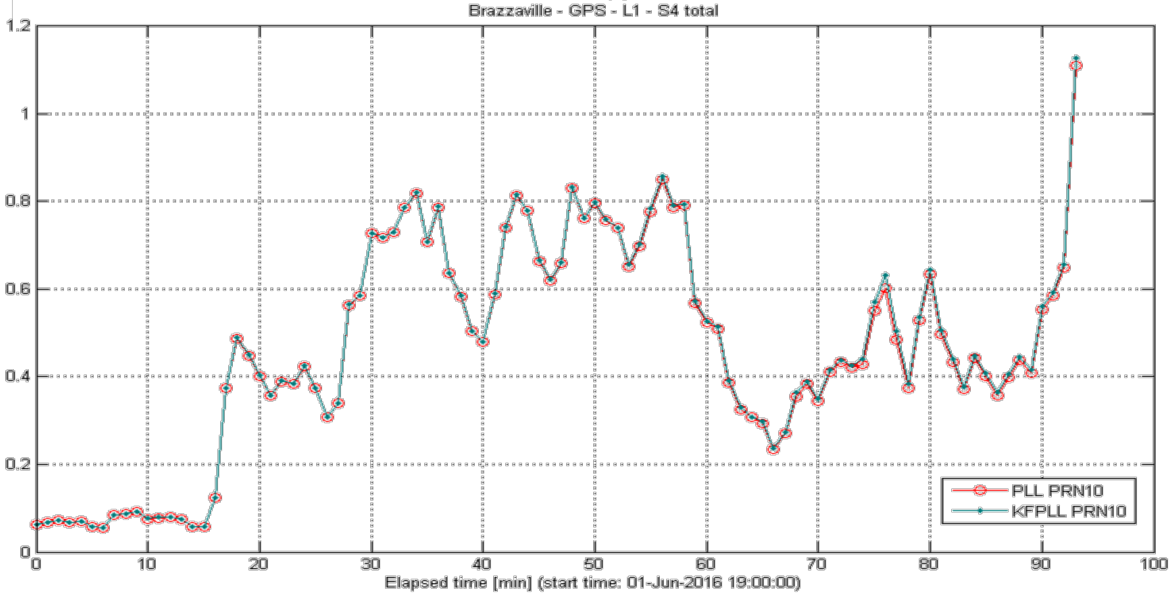
C/N0



Lock Time



S4



- Data recorded in May/June 2016 by updated GISMO RX show ionospheric scintillation activities
- Same scintillation level recorded in September/October 2015 which led to LoL
- No LoL observed for both carrier tracking strategies with new SW version

Conclusions

- Multi-constellation multi-frequency monitoring station
- All Kalman filter based PLL channels
- Intelligent Loss of Lock indicator
- Improved L2C tracking through L1CA-frequency aiding
- Improved acquisition time on GPS L5, Galileo E1BC and E5a
- Robustness in the presence of both low and high latitudes conditions
- On-going development of system algorithms

Thank you for the attention

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http://misw.info/

SEVENTH FRAMEWORK PROGRAMME