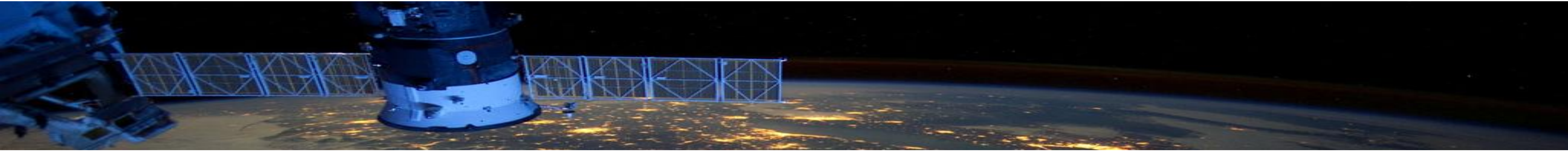

Optimizing GNSS Positioning by Integrating Regional Ionospheric Variability into Correction Algorithms

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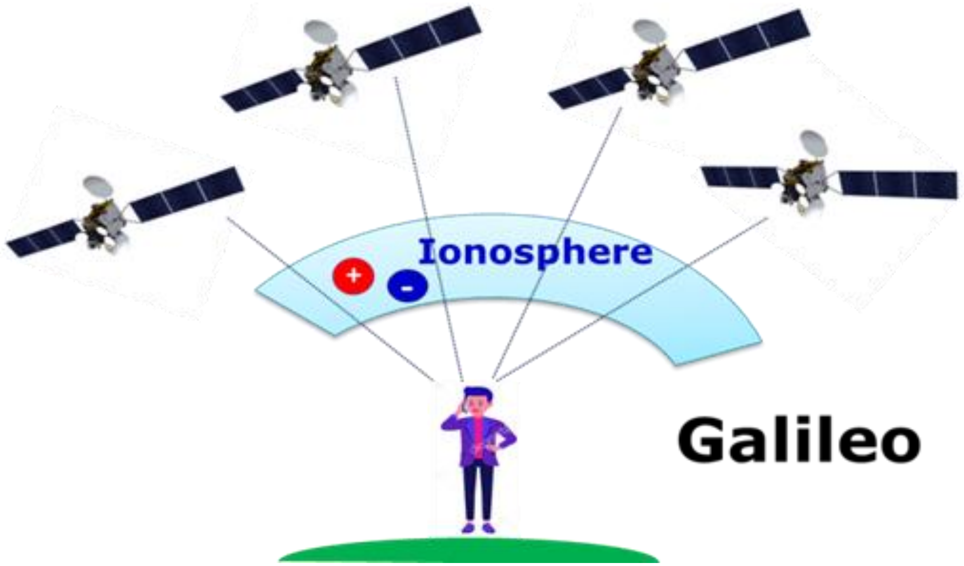
The International Reference Ionosphere and NeQuick – Improving the Representation of the Real-Time Ionosphere; 29 Sept-10 Oct, 2025 – ICTP, Trieste, Italy

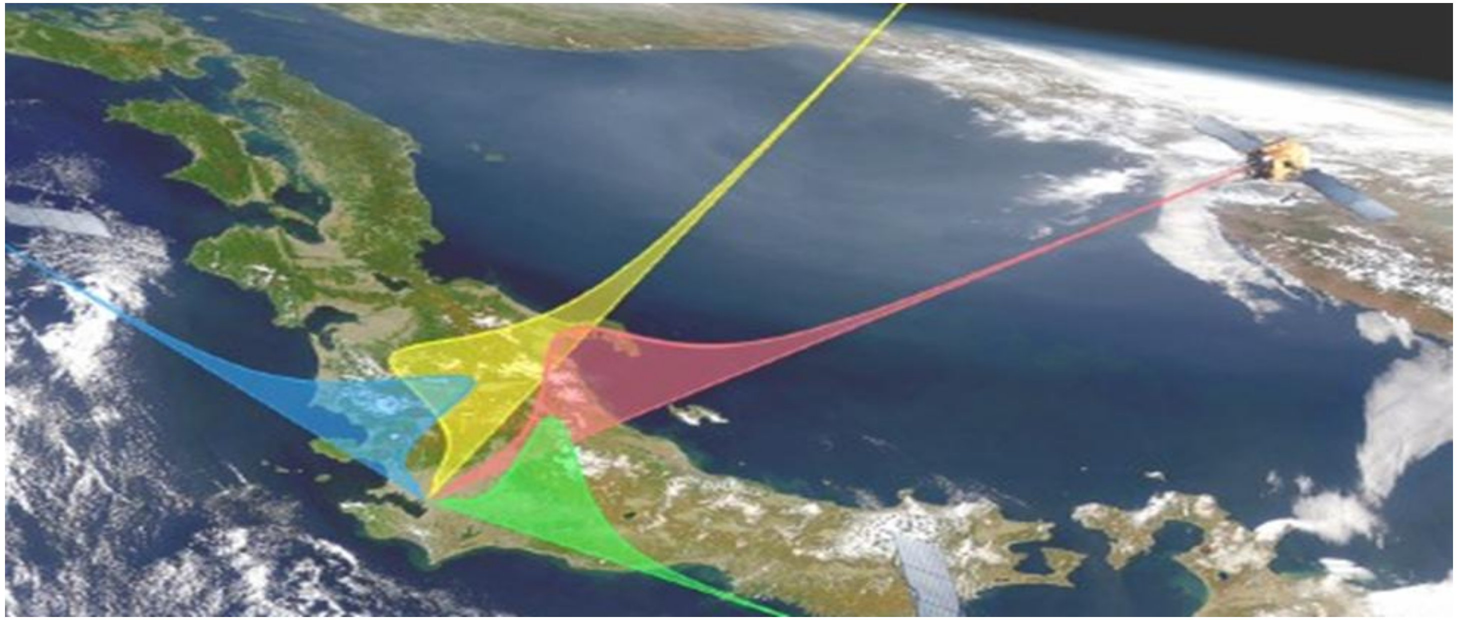
NeQuick

- Semi-empirical climatological model that describes spatial and temporal variations of the ionospheric electron density at a given time and location.

- NeQuick provides global or regional electron density maps as well, to represent ionospheric conditions.

- NeQuick model was adopted as the basis of the real-time ionospheric correction algorithm (NeQuick–G) used for Galileo single-frequency positioning ionospheric correction.



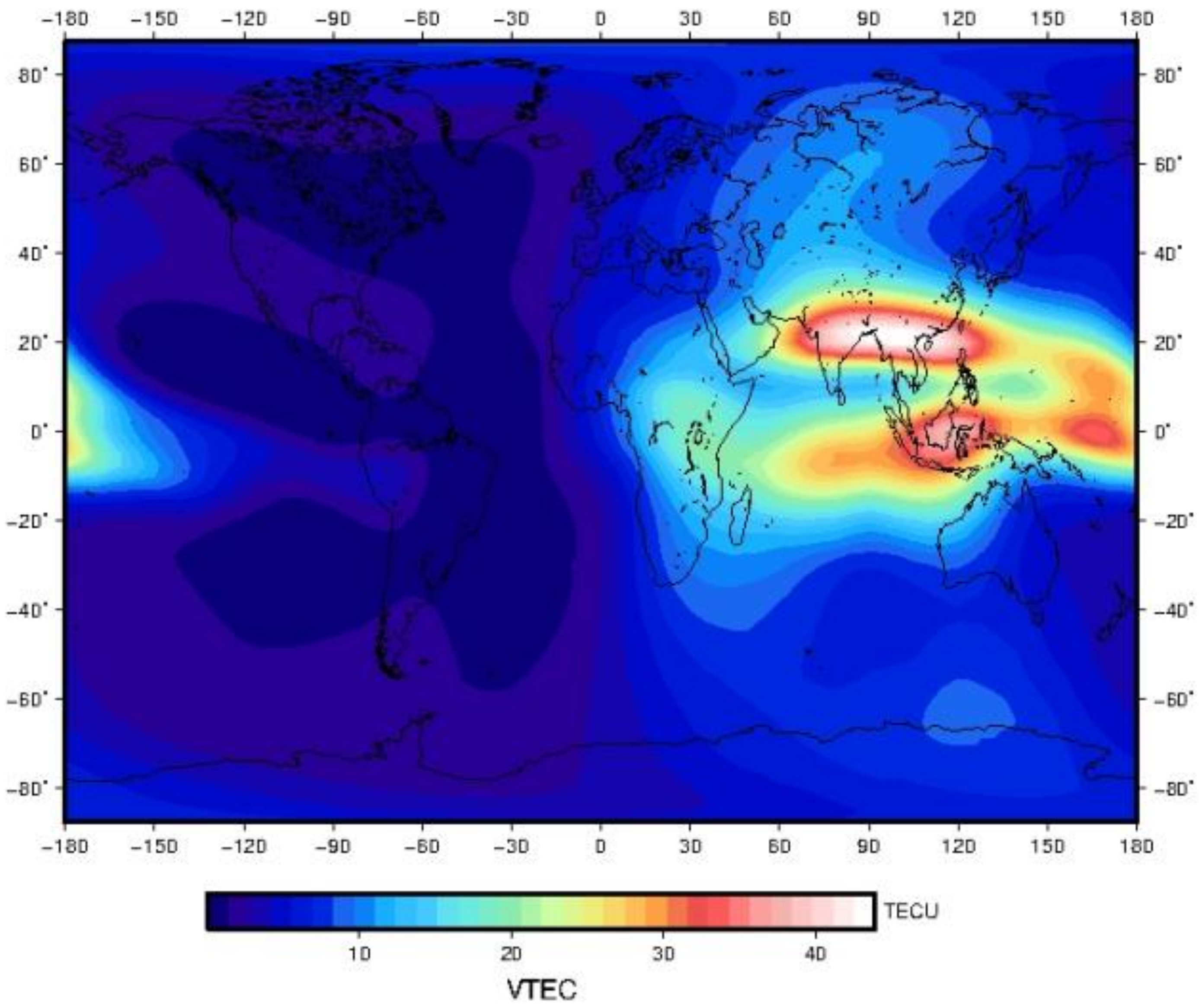


NeQuick-G

- NeQuick-G is now available to download on the GSC website as a result of recoding by engineers at the EU's Joint Research Centre.

- Software was released as a free and open-source software under the terms of the European Union Public Licence (EUPL).

- The open-source code is now ready to be implemented on single-frequency platforms and can be used without limitation.



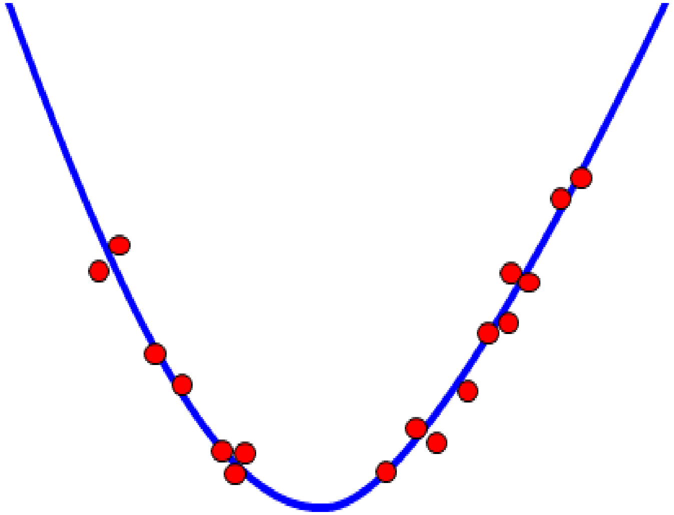
Az in NeQuick-G

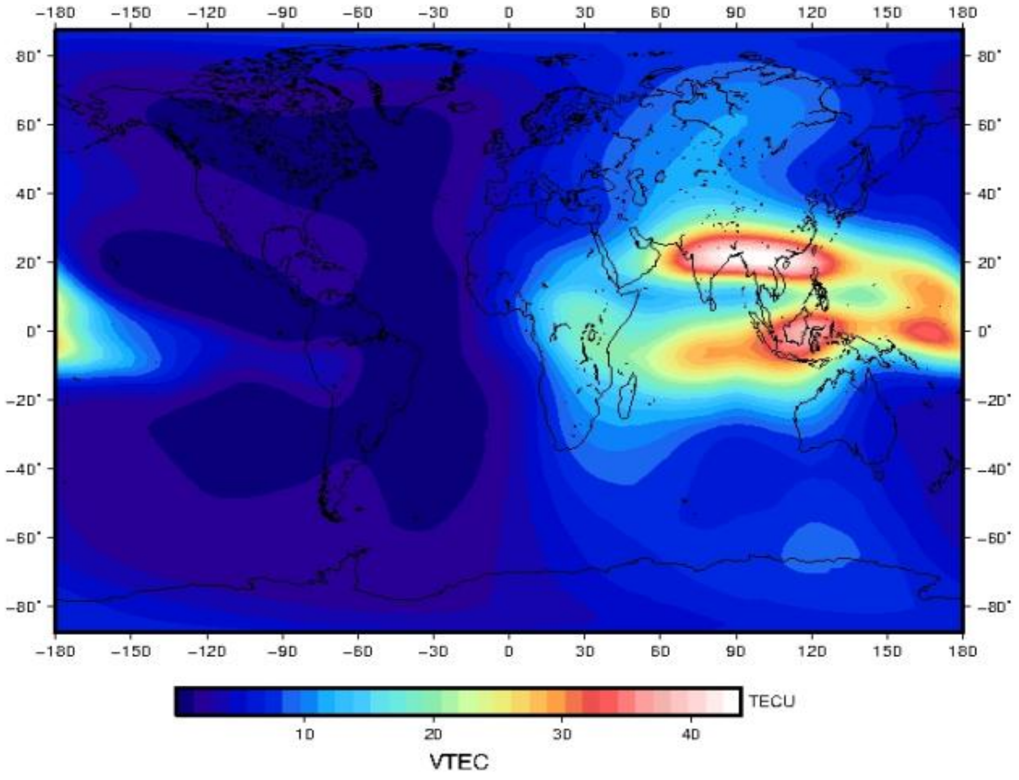
- A key input parameter for NeQuick–G is the effective ionization parameter (Az)

- Represents the solar activity information ingested into the model and is provided as a second order polynomial in the Galileo broadcast message to single-frequency users

- This is the main underlying extension over the original NeQuick specification which was formulated on the basis of R12, or the 10.7 cm solar radio flux, (F10.7)

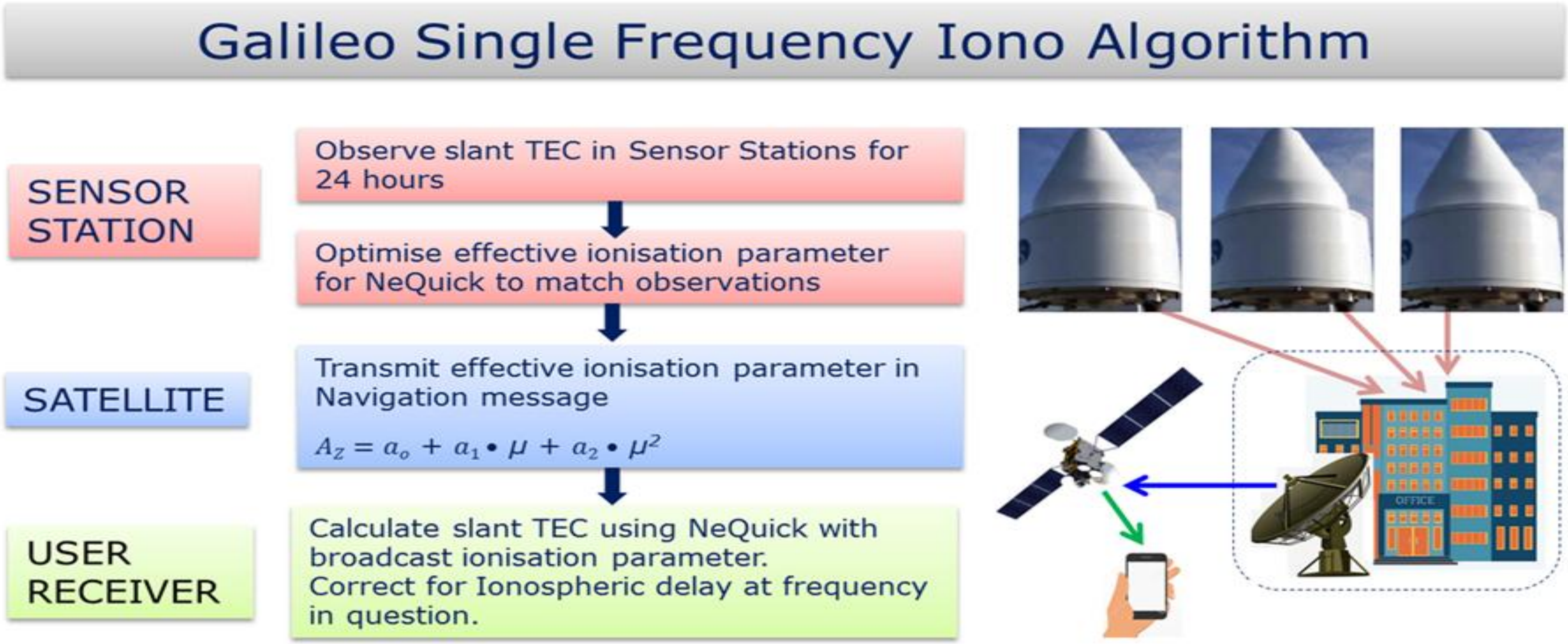
Optimise Az(μ)





NeQuick-G operation

The coefficients of the polynomial are estimated daily from a number of permanent Galileo monitoring stations during the previous 24 hours as a function of modified dip latitude (**modip**) to take the daily variation of the solar activity and the user's local geomagnetic conditions into account at the receivers' location.



SERVice for ImproviNg Galileo operation over Cyprus (SERVING)

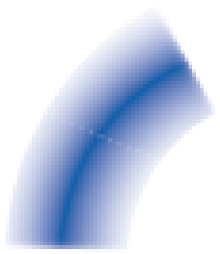
Specific Scientific and Technological Objectives:

Explore techniques to improve and optimize the Galileo single frequency users' positioning algorithm in a context of assisted GNSS driven by a regional and therefore more accurate ionospheric representation

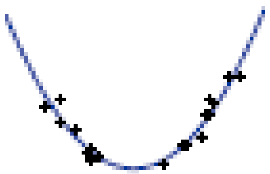
Basic idea

On a long-term scale this improvement is achieved through updating of the long-term median ionospheric characteristics (in the form of 12 files).

On a short-term scale this improvement is enhanced by driving the NeQuick-G algorithm with a more accurate estimation of the ionisation level obtained with a GNSS receiver in Cyprus on a local scale as opposed to a less accurate global scale estimation which is applied in the context of Galileo.



Measure
sTEC



Optimise
$Az(\mu)$

Run
NeQuick

CCIR in NeQuick-G

- The most significant contribution to TEC comes from the F layer.

- The key parameters to describe the electron density profile specification of NeQuick–G are foF2 and M(3000)F2, the critical frequency at the F2 layer and the propagation factor, respectively.

- These are calculated from **International Radio Consultative Committee** (**CCIR**) maps that are based on the monthly median values of foF2 and M(3000)F_2 from all available ionosondes (about 150 stations) during the years 1954 to 1958, corresponding to an approximate 10,000 station-months of data.

Representation of Diurnal and Geographic Variations of Ionospheric Data by Numerical Methods*

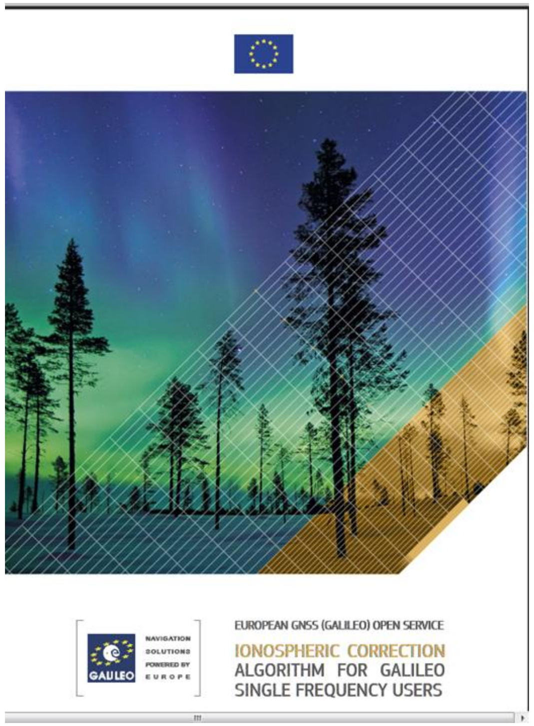
William B. Jones and Roger M. Gallet

For i=1,..,76 calculate the Fourier time series for *foF2*:

$$cf2_i = af2_{i,1} + \sum_{k=1}^{6} \left[af2_{i,2k} \sin(kT) + af2_{i,2k+1} \cos(kT) \right]$$

For i=1,..,49 calculate the Fourier time series for *M*(3000)F2:

$$cm3_i = am3_{i,1} + \sum_{k=1}^{4} \left[am3_{i,2k} \sin(kT) + am3_{i,2k+1} \cos(kT) \right]$$



CCIR adjusted over Cyprus

Based on the simple approach that is under investigation here we attempted to modify the coefficients and not the structure of the CCIR files that was fully preserved.

This approach was necessary as we aimed towards a regional improvement (over the area of Cyprus) without affecting the model formulation. In attempting to achieve this task most of the coefficients of the CCIR files were set to zero apart from those limited ones that were manipulated to produce the median values estimated with the (high quality manually scaled) extended Cyprus digisonde dataset.

Compute the array of interpolated coefficients for *foF2*

AF2: $af2_{j,k}$ $j=1,\ldots,76;$ $k=1,\ldots,13$

AF2 elements are calculated by linear combination of the elements of *F2*:

$$af2_{j,k} = f2_{1,j,k}\left(1 - \frac{Az_R}{100}\right) + f2_{2,j,k}\frac{Az_R}{100} \qquad j=1,\ldots,76; \quad k=1,\ldots,13$$

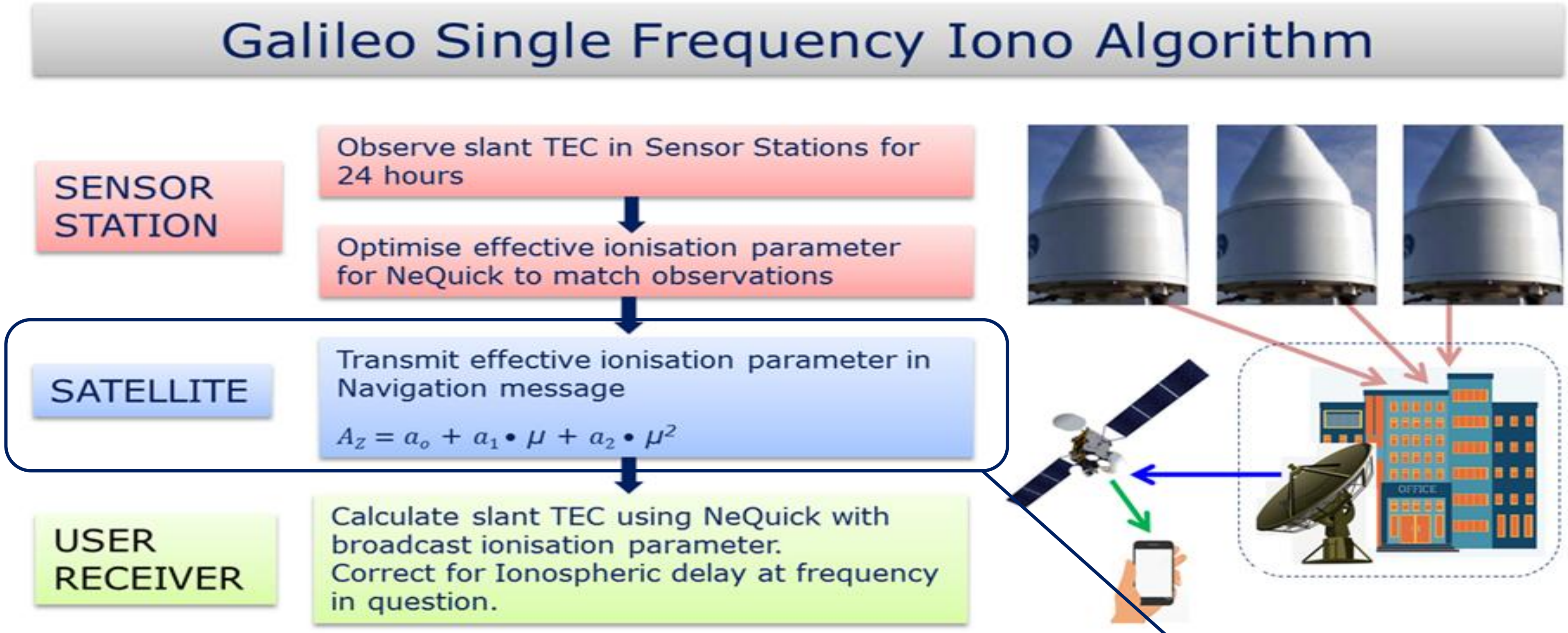
Compute the array of interpolated coefficients for *M(3000)F2*:

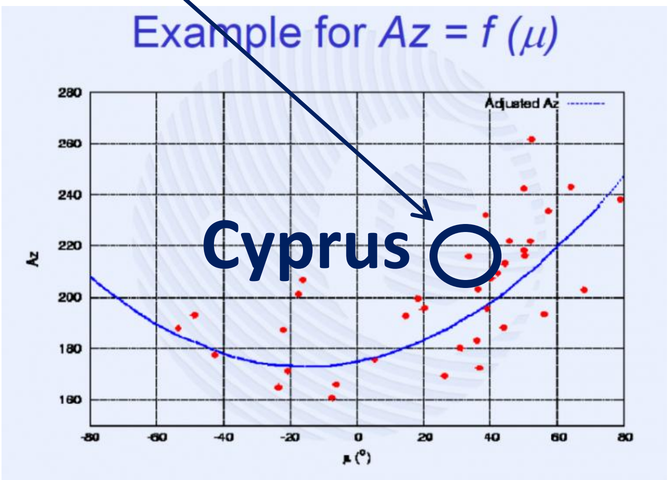
Am3: $am3_{j,k}$ $j=1,\ldots,49;$ $k=1,\ldots,9$

Am3 elements are calculated by linear combination of the elements of *Fm3*:

$$am3_{j,k} = fm3_{1,j,k}\left(1 - \frac{Az_R}{100}\right) + fm3_{2,j,k}\frac{Az_R}{100} \qquad j=1,\ldots,49; \quad k=1,\ldots,9$$

NeQuick-G



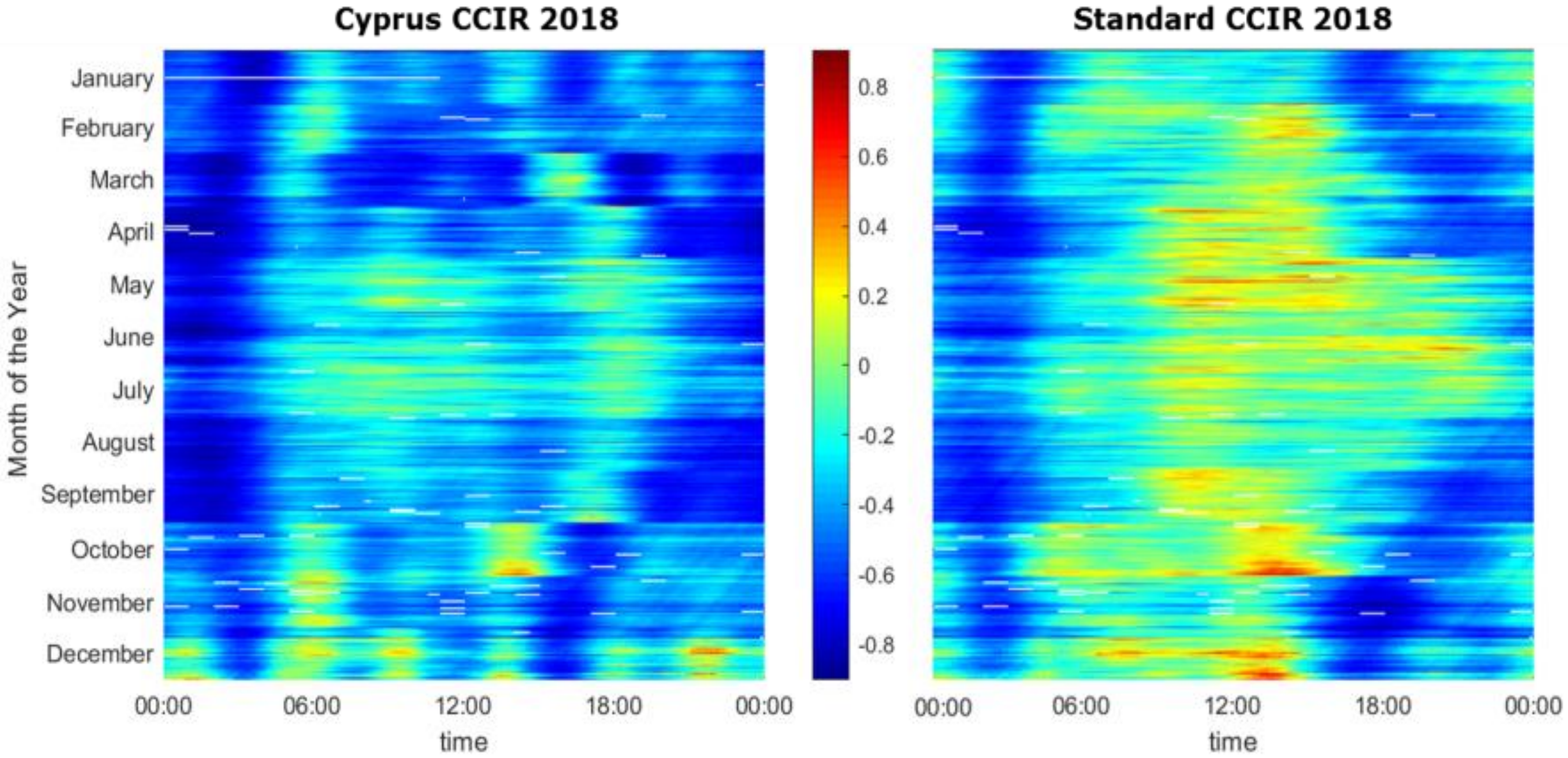


Calculate Az for next day based on STEC values from Cyprus to provide a local value of Az (by optimising Az to account for the minimum discrepancy between model and regional STEC values) to produce a representative Az value over Cyprus.

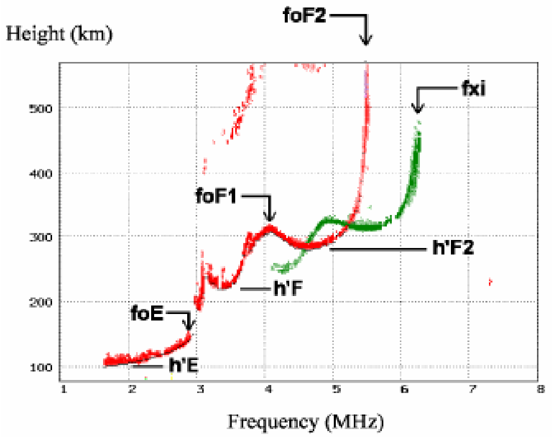
NeQuick-G with true Az parameters

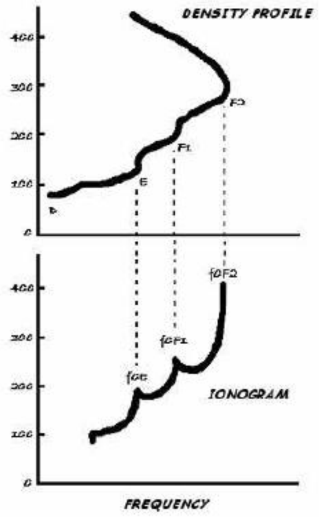
- ✓ We have tested NeQuick-G with existing standard (Global) and Cyprus based CCIR files
- ✓ We have used actual Az parameters broadcasted in GALILEO satellites in 2018
- ✓ Clear benefit of local CCIR on NeQuick-G performance over Cyprus was demonstrated

Percentage: (NeQuick G VTEC – Observed VTEC)/ Observed



SERVING short-term operation mode





Get all ionograms from previous day

Autoscale ionograms

Extract foF2 and M(3000)F2 values

Determine **Short CCIR files** using χ2 minimisation

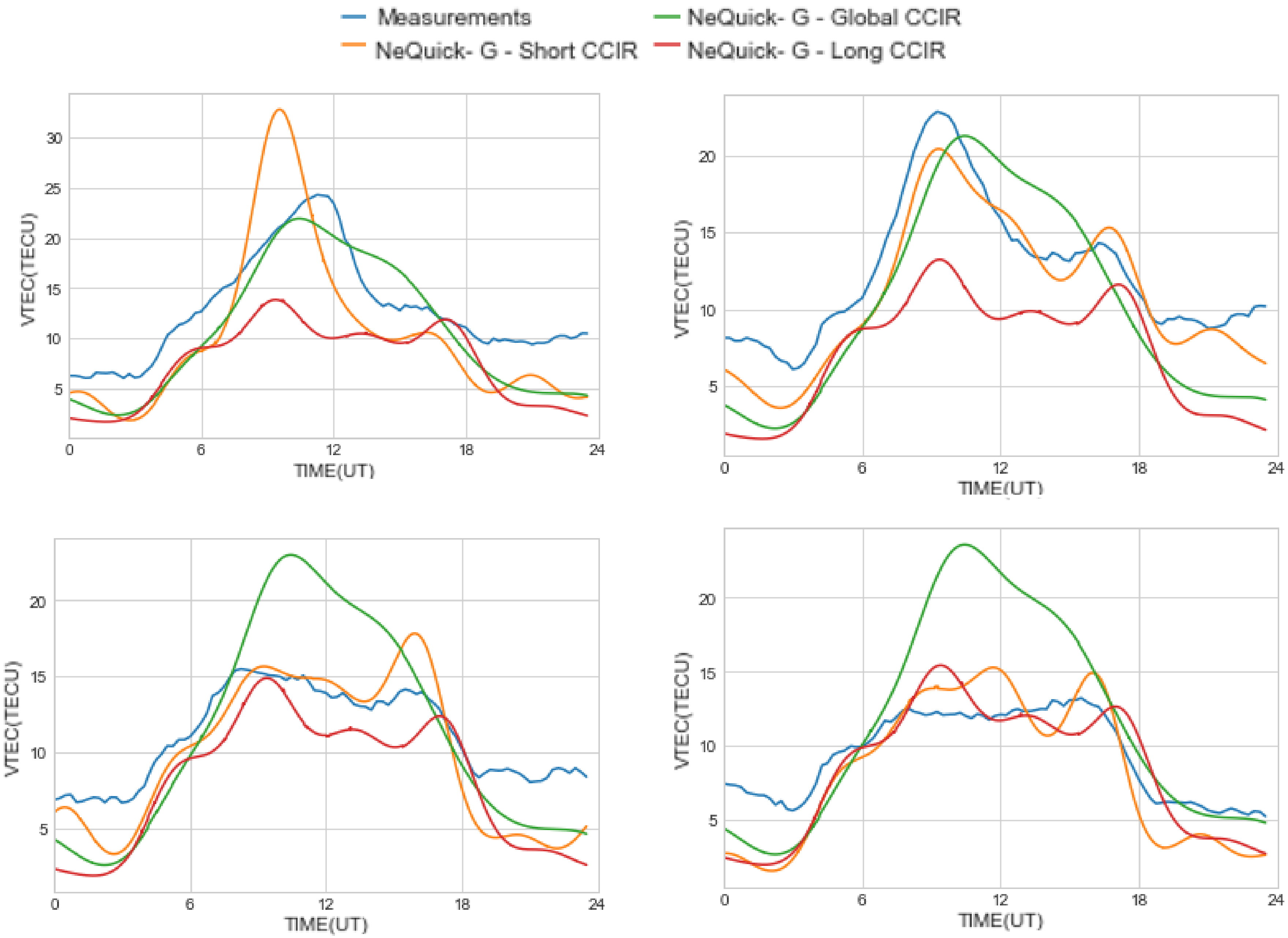
Run NeQuick-G to determine optimum ionization level **Az**

Estimate calibrated VTEC from local GNSS receiver from previous day RINEX file

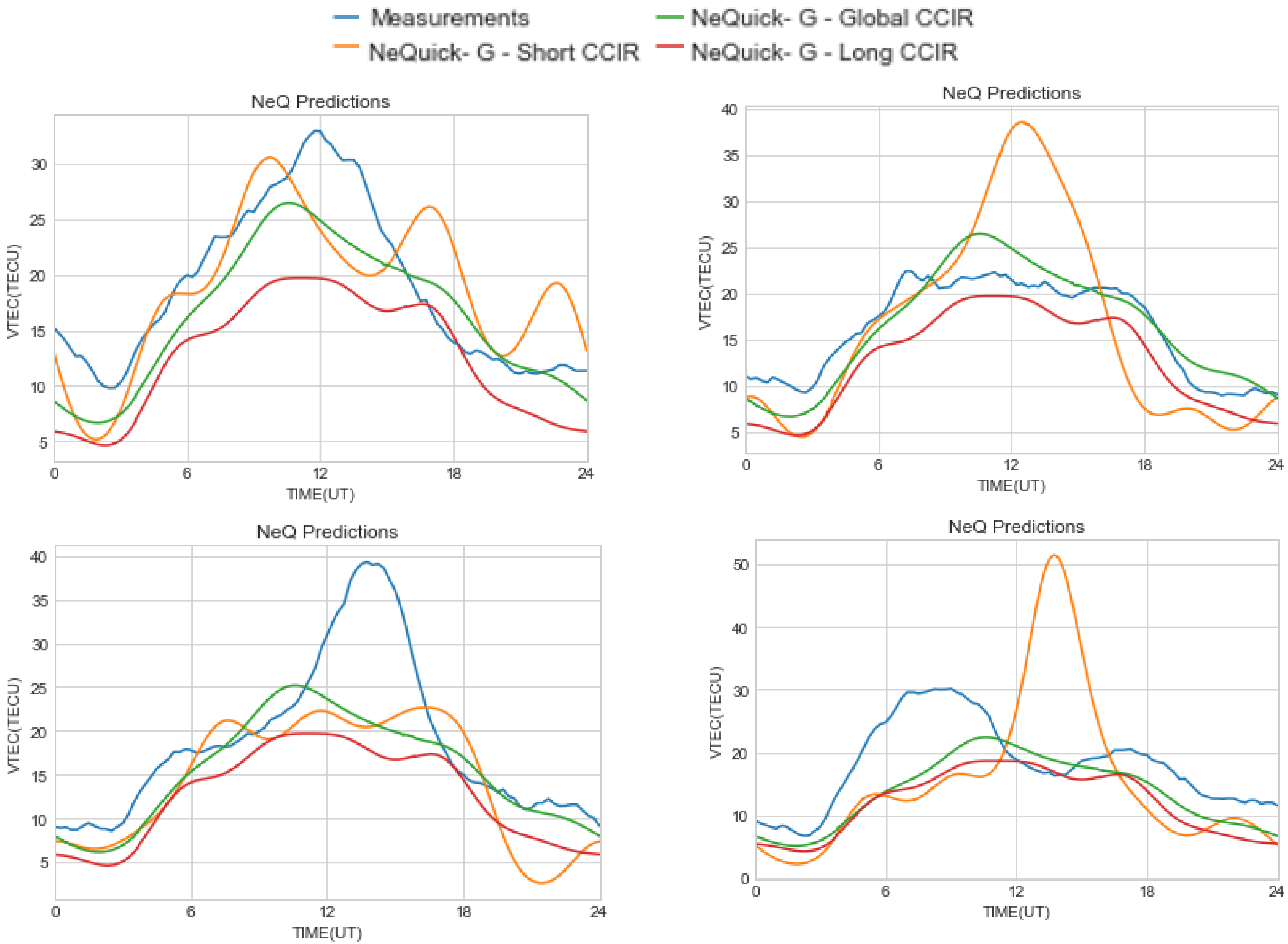
Use optimized **Az** and **CCIR** to run NeQuick-G next day

Ionospheric station exploitation for short-term improvement

SERVING short-term example



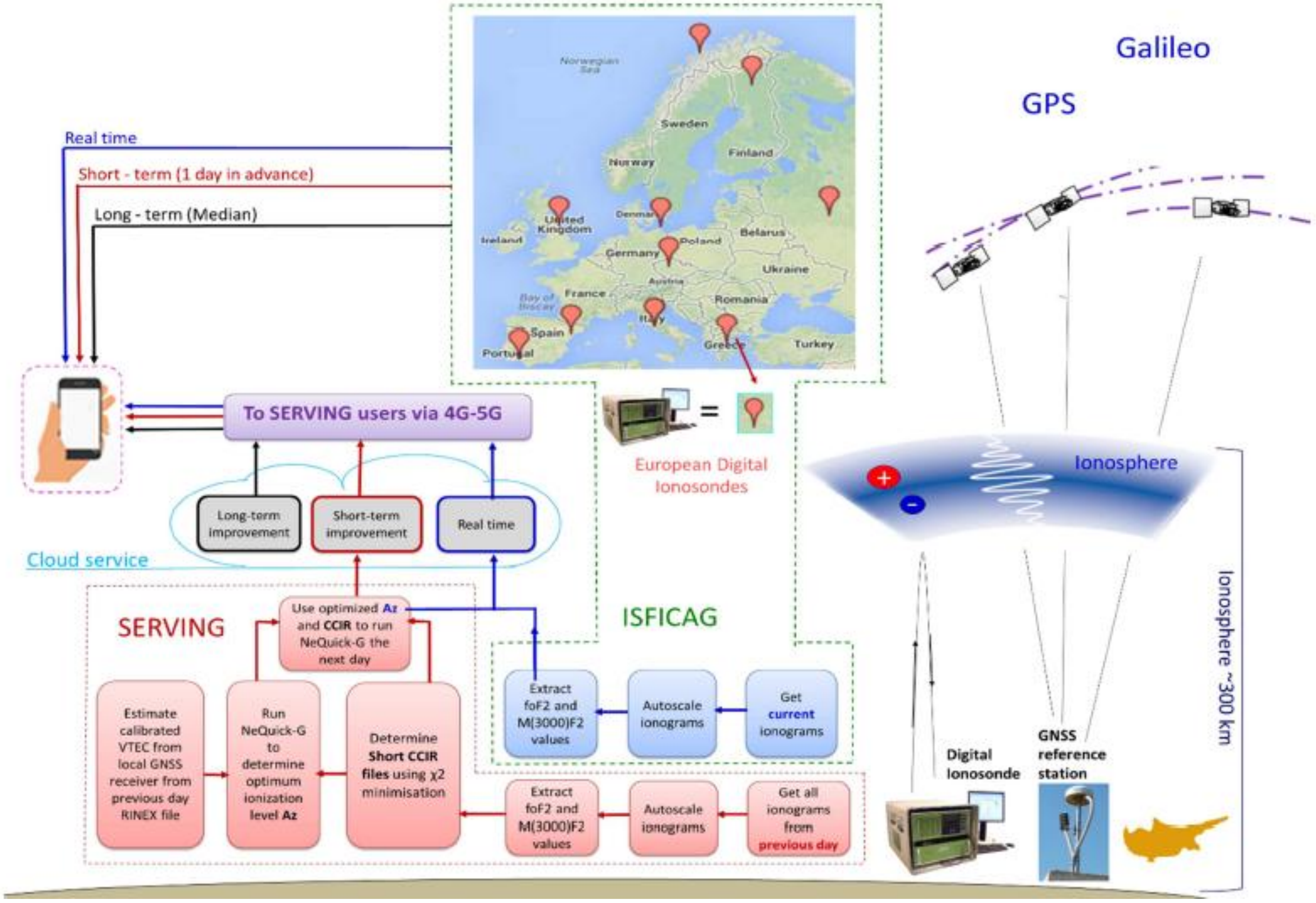
SERVING challenges (day-to-day variability)



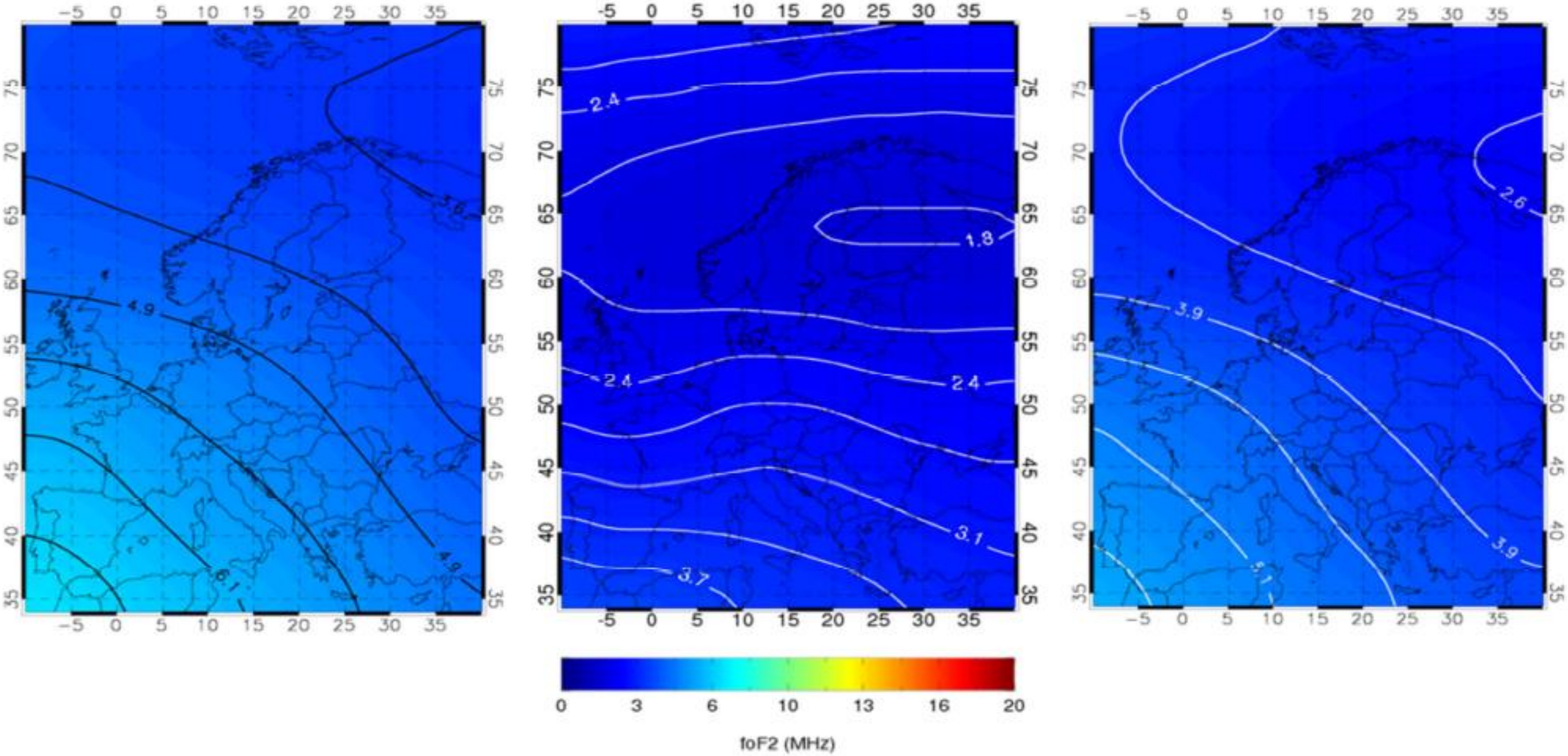
SERVING prospects over Europe

We can apply the SERVING concept over Europe with good ionosonde coverage

Improving Single Frequency Ionospheric Correction Algorithm for Galileo (ISFICAG)



Real-time improvement of SERVING all over Europe : Locations in between European Ionosonde stations

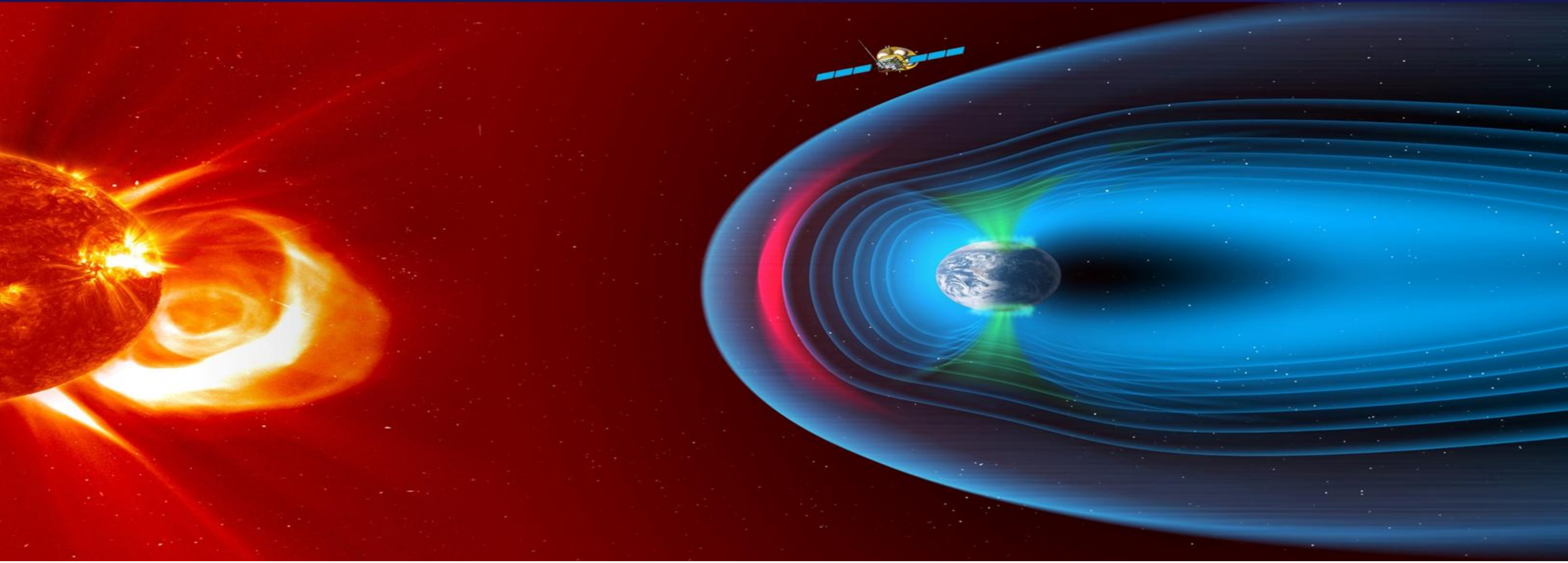


For locations in Europe, in between ionosondes, foF2 will be obtained from the foF2 maps provided by European Ionosonde Service (EIS), in the frames of ESA Space Situational Awareness (SSA).

SERVING prospects on a global scale

We can apply the SERVING concept in any part of the world that operates an ionospheric sounder (within a radius of 1000 km).

THANK YOU!



Acknowledgements

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ΘΑΛΕΙΑ 2021-2027

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