The NeQuick Ionospheric Electron Density Model and Space Weather

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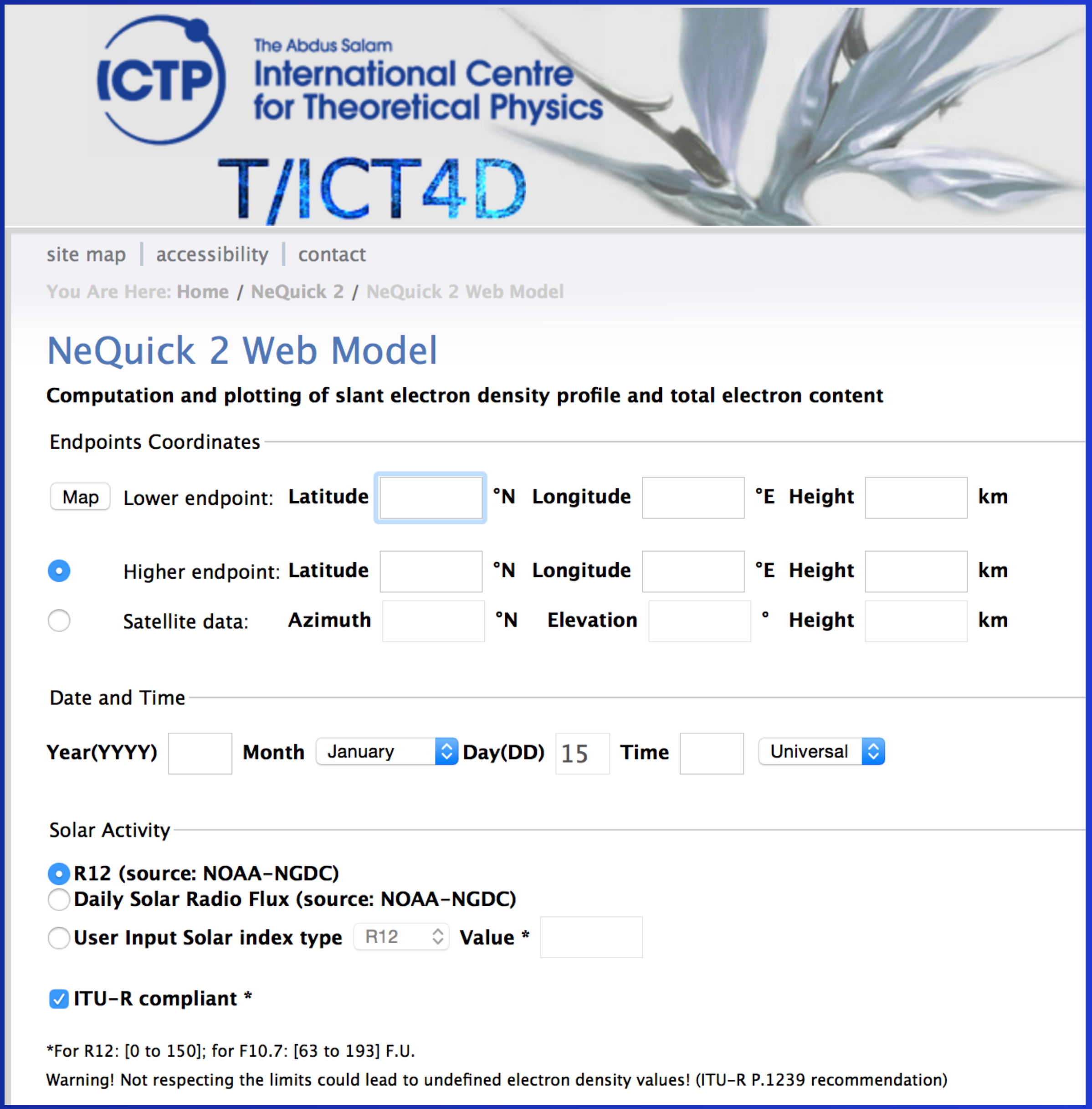
NeQuick

- The NeQuick 2 (Nava et al., 2008) is an ionospheric electron density model developed at the T/ICT4D Laboratory of The Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, Italy, in collaboration with the Institute for Geophysics, Astrophysics and Meteorology (IGAM) of the University of Graz, Austria.



- It is a quick-run empirical model particularly designed for trans-ionospheric propagation applications, conceived to reproduce the median behavior of the ionosphere.

- http://t-ict4d.ictp.it/nequick2

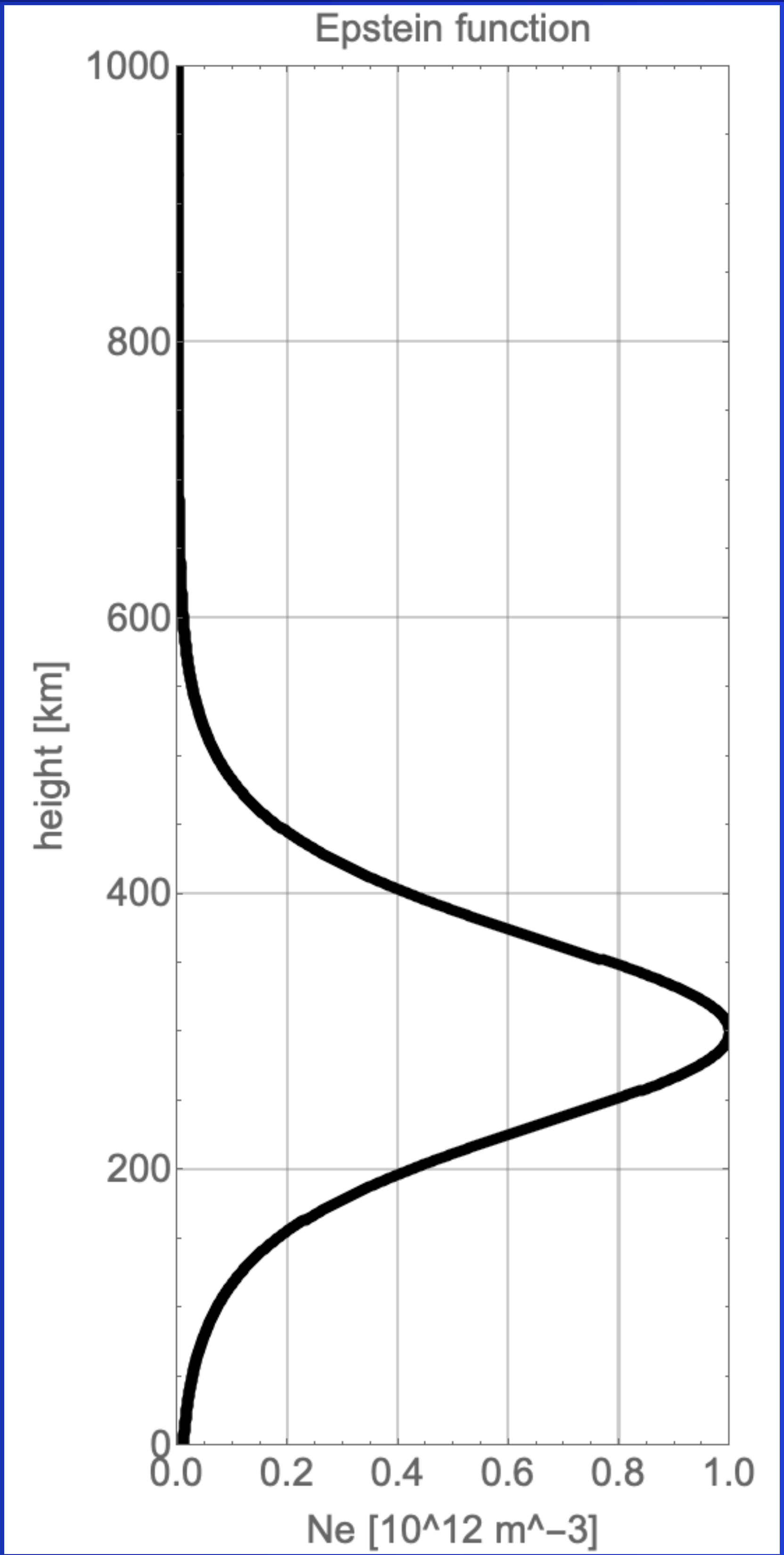
NeQuick

- The model profile formulation includes 6 semi-Epstein layers with modeled thickness parameters and is based on anchor points defined by foE, foF1, foF2 and M(3000)F2 values.

- These values can be modeled (e.g. ITU-R coefficients for foF2, M(3000)F2) or experimentally derived.

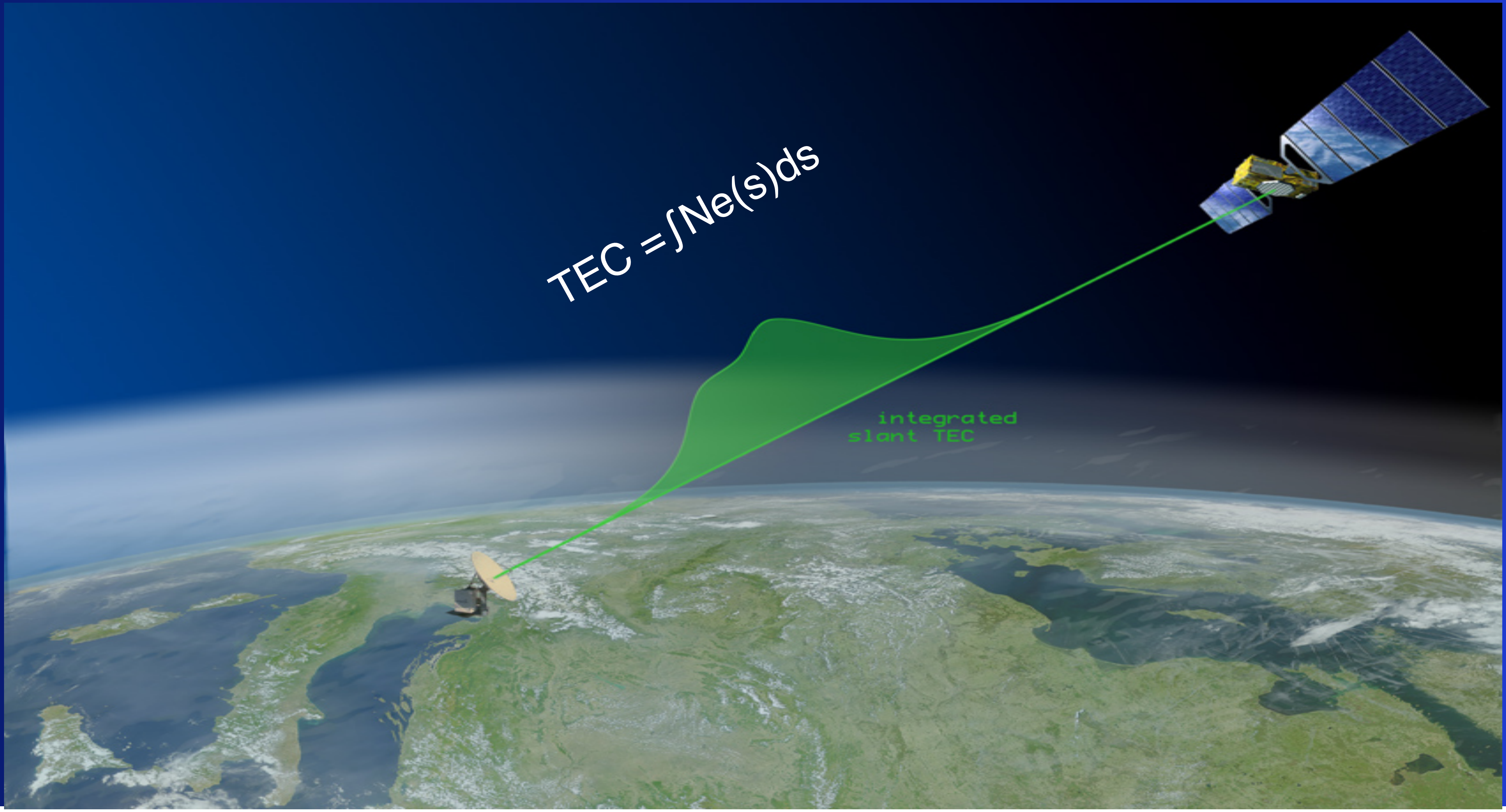
- NeQuick inputs are: position, time and solar flux; the output is the electron concentration at the given location and time.

$$N(h; hmax, Nmax, B) = \frac{4Nmax}{(1 + \exp(\frac{h-hmax}{B}))^2} \exp(\frac{h - hmax}{B})$$



NeQuick

- NeQuick package includes routines to evaluate the electron density along any “ground-to-satellite” ray-path and the corresponding Total Electron Content (TEC) by numerical integration.



Data ingestion into NeQuick

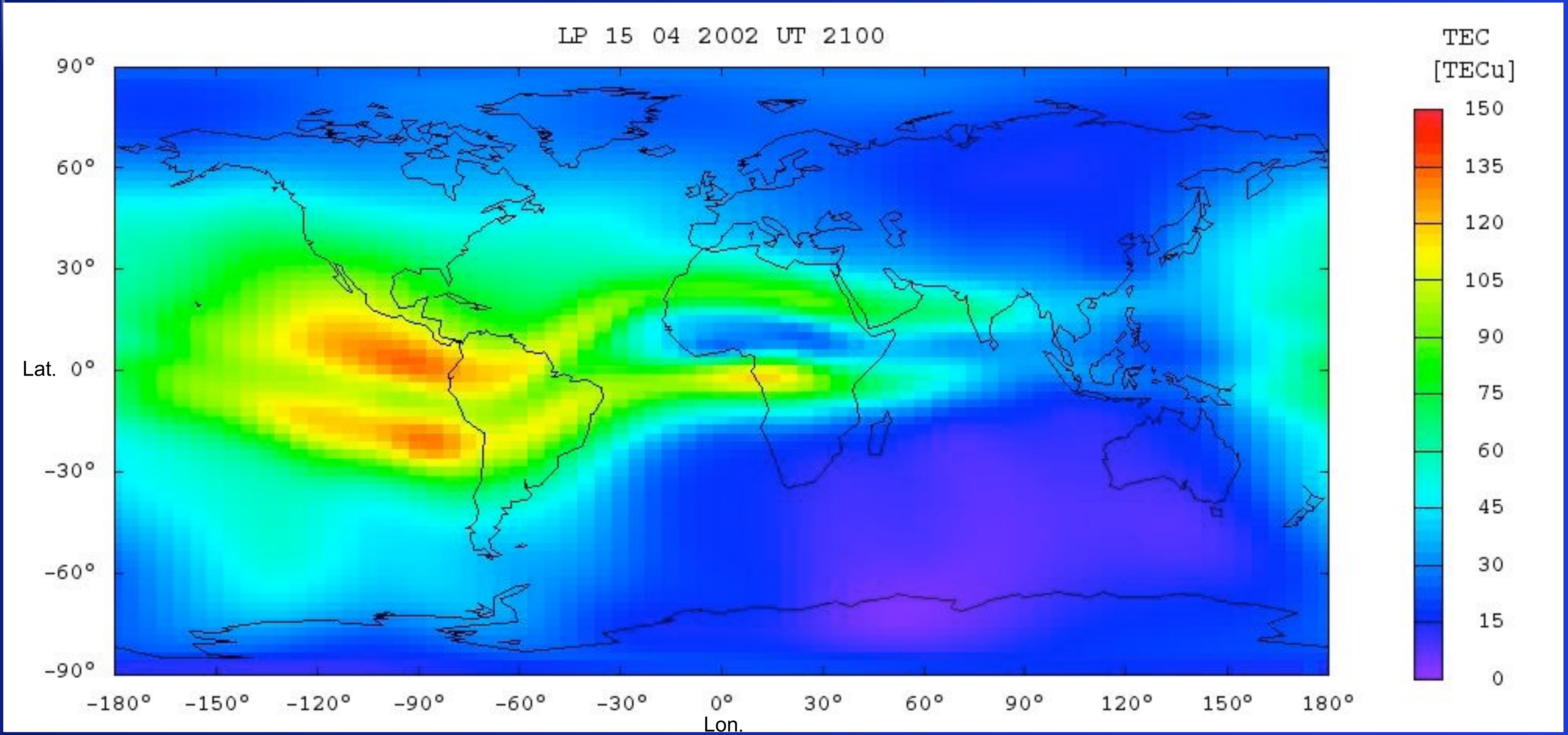
- Empirical models like NeQuick have been conceived to reproduce the median behavior (“climate”) of the ionosphere.

- For research purposes and practical applications, it is necessary to estimate the 3-D electron density of the ionosphere for current conditions ("weather").

- Considering the increasing availability of experimental data even in real time, several assimilation schemes have been developed. They are of different complexity and rely on different kinds of data.

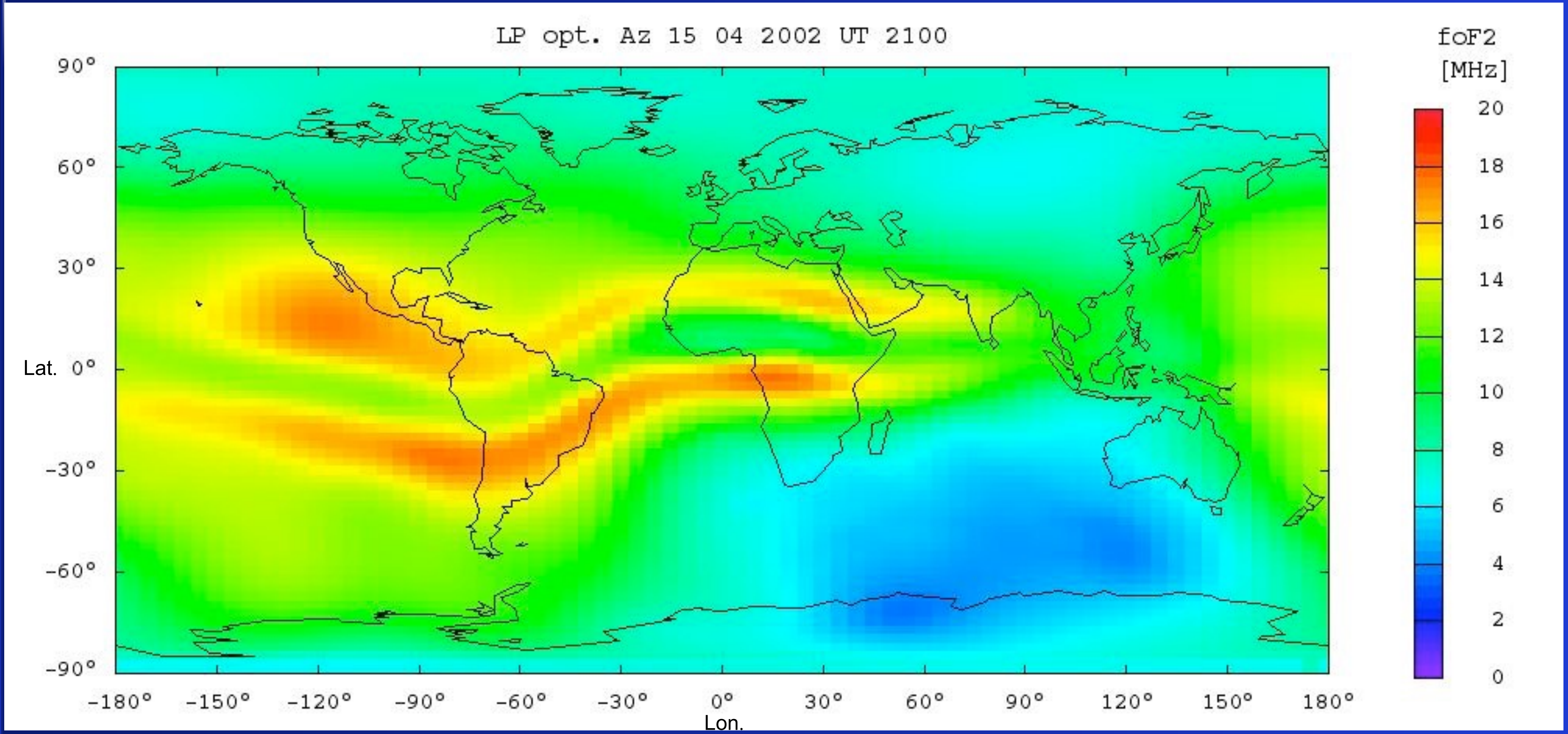
- In the case of NeQuick, (multiple) effective parameters have been utilised to adapt the model to GNSS-derived TEC data (and ionosonde measured peak parameters values). In the following, specific examples will be outlined.

vTEC data ingestion



grid points:
lat.=-90°, 90° step 2.5°
lon.=-180°, 180° step 5°

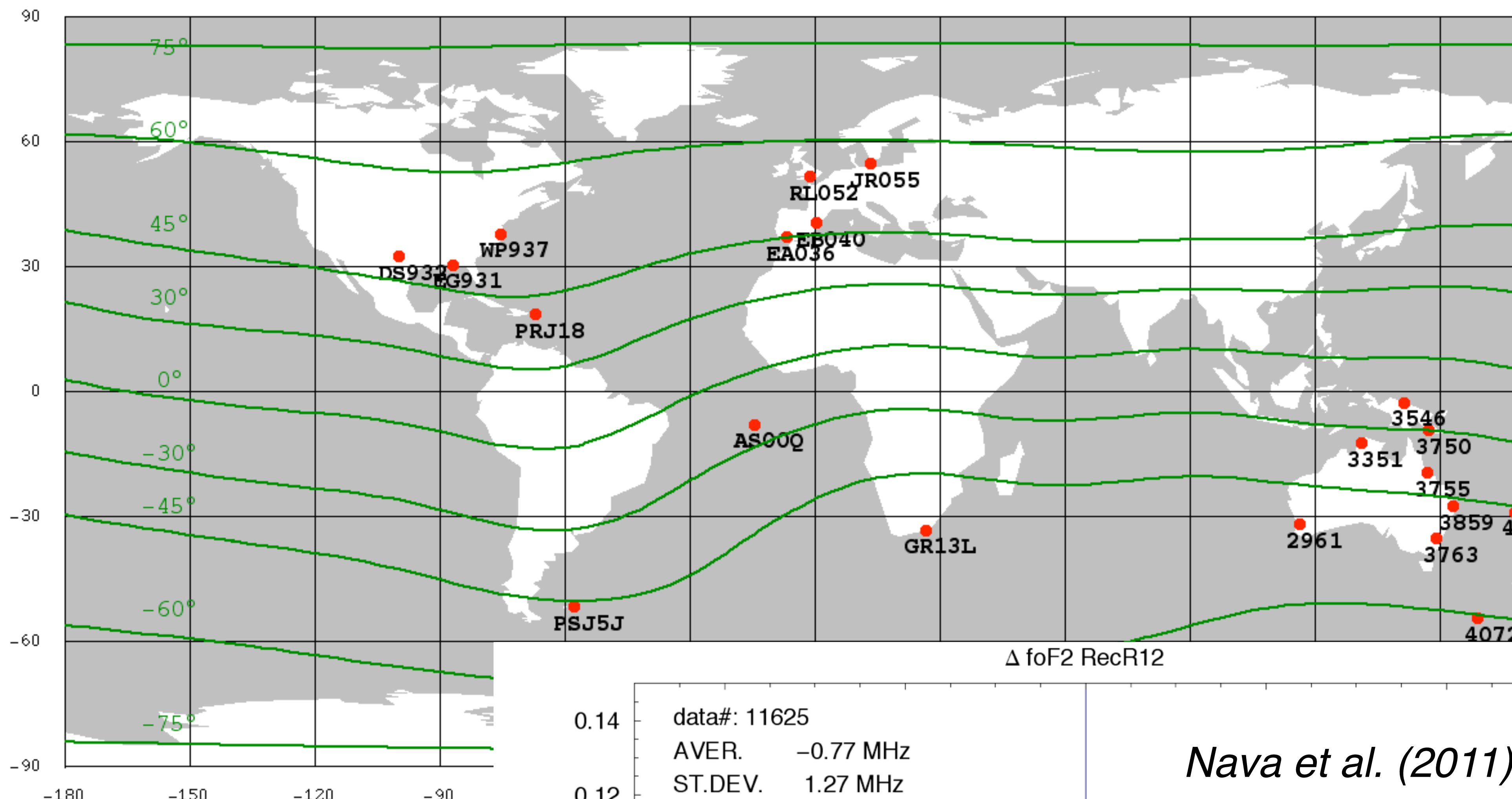
Reconstructed foF2 map

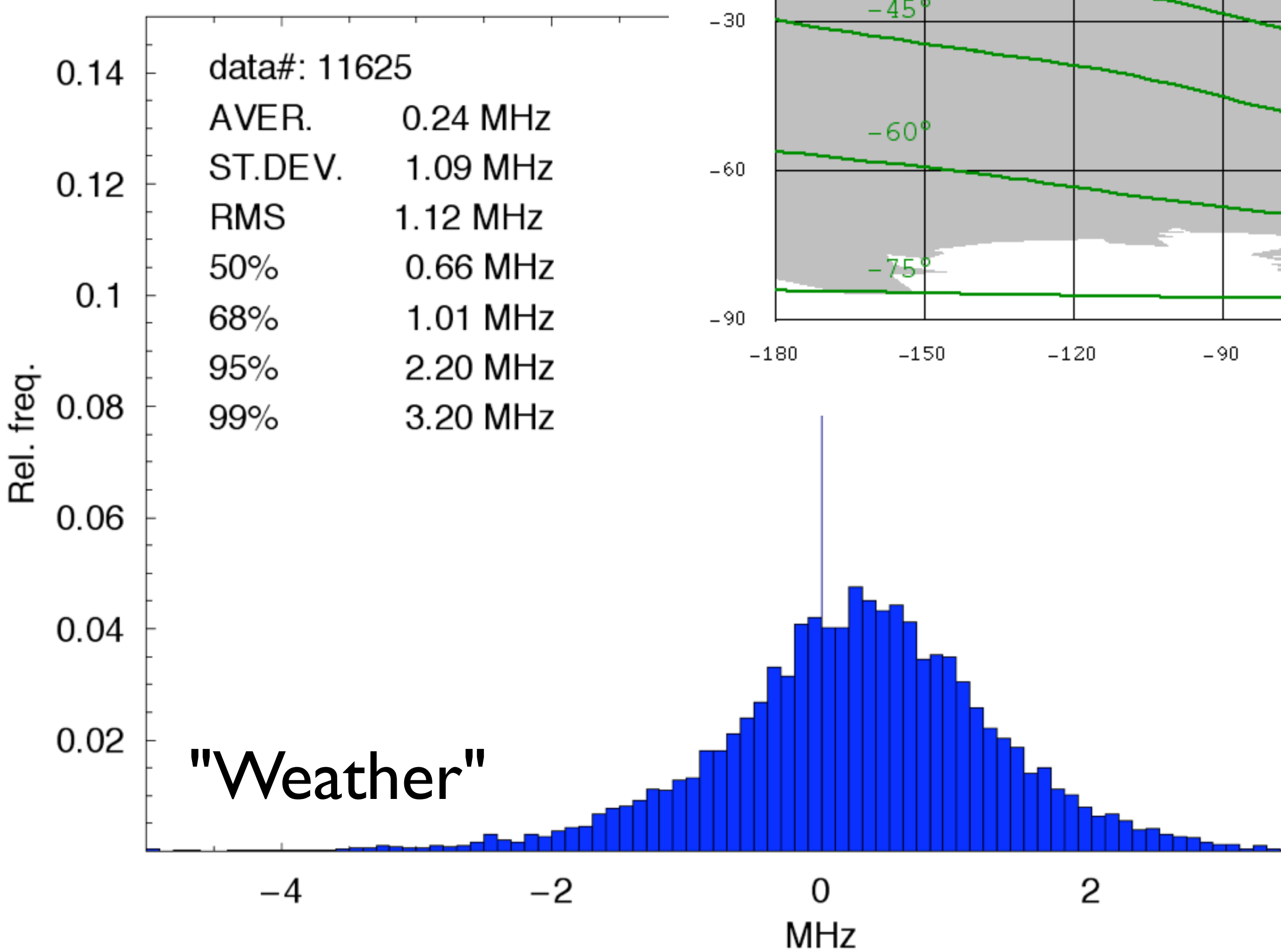


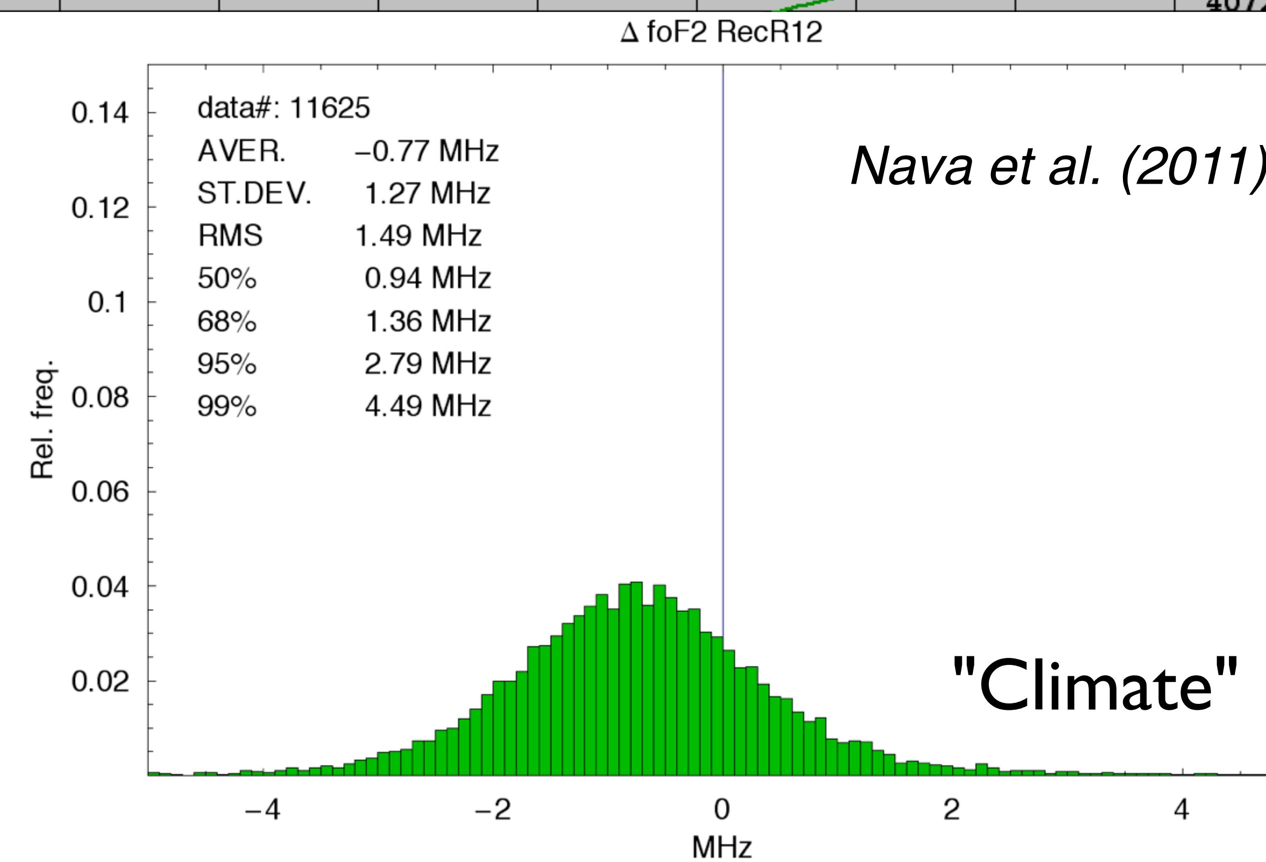
grid points:
lat.=-90°, 90° step 2.5°
lon.=-180°, 180° step 5°

NeQuick2: validation results (example: HSA)

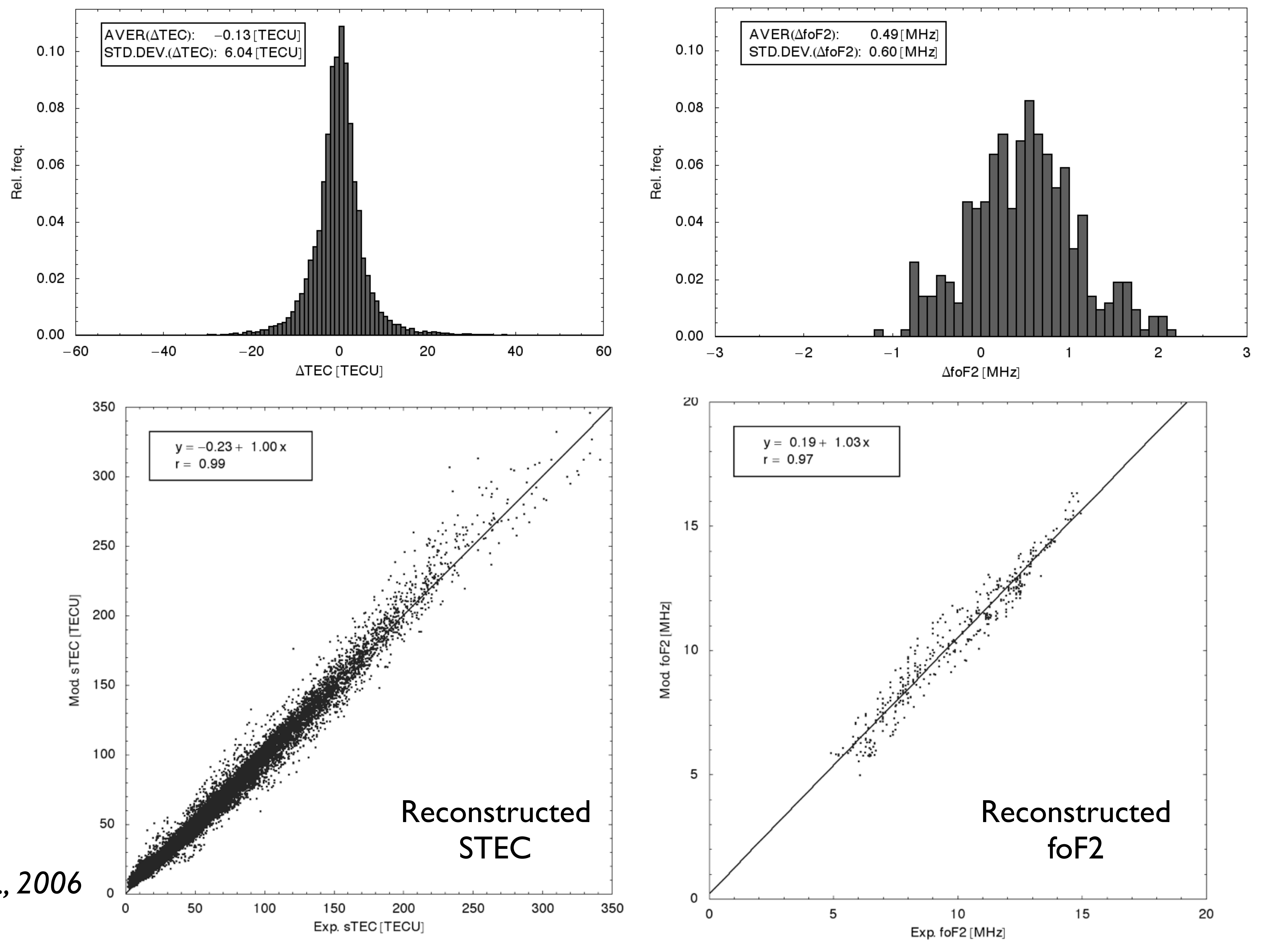
foF2 error statistics (Apr 2000)





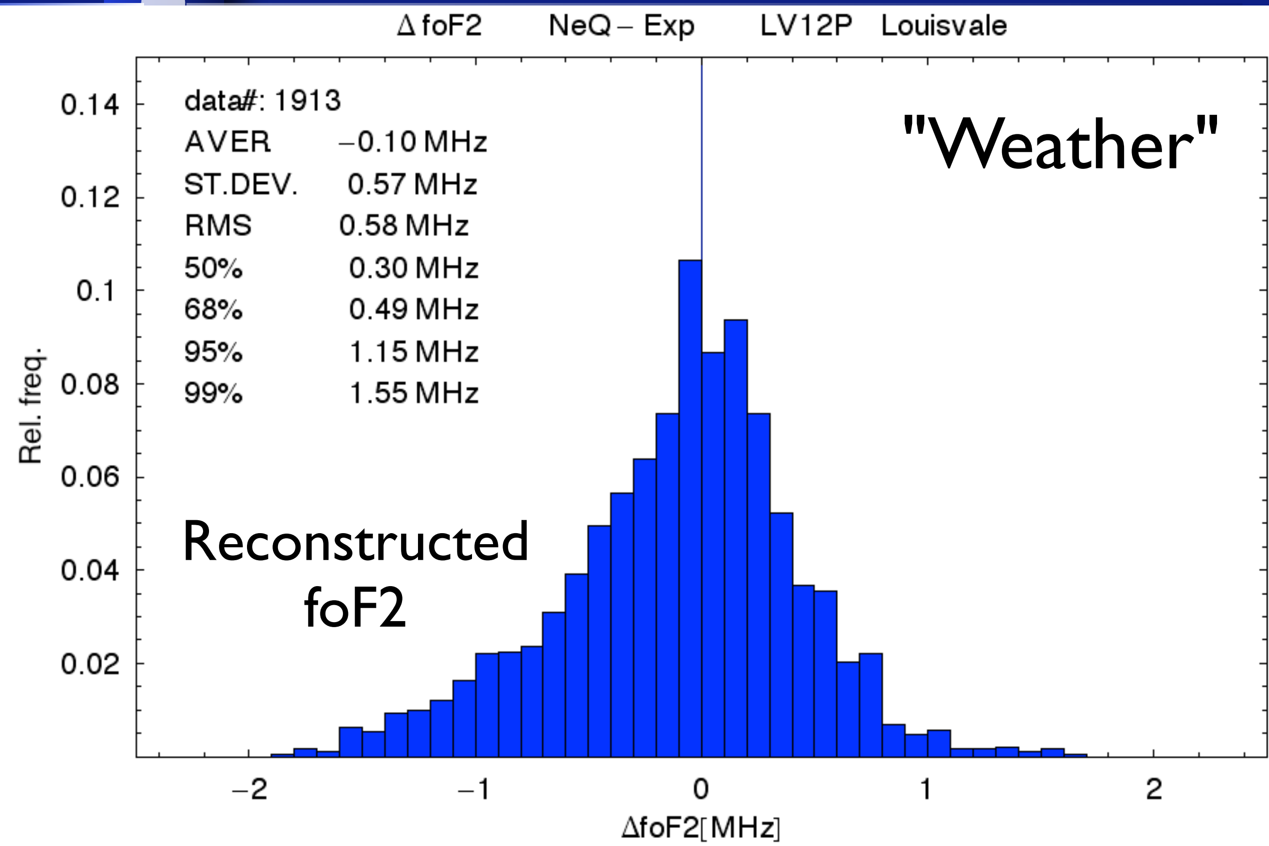


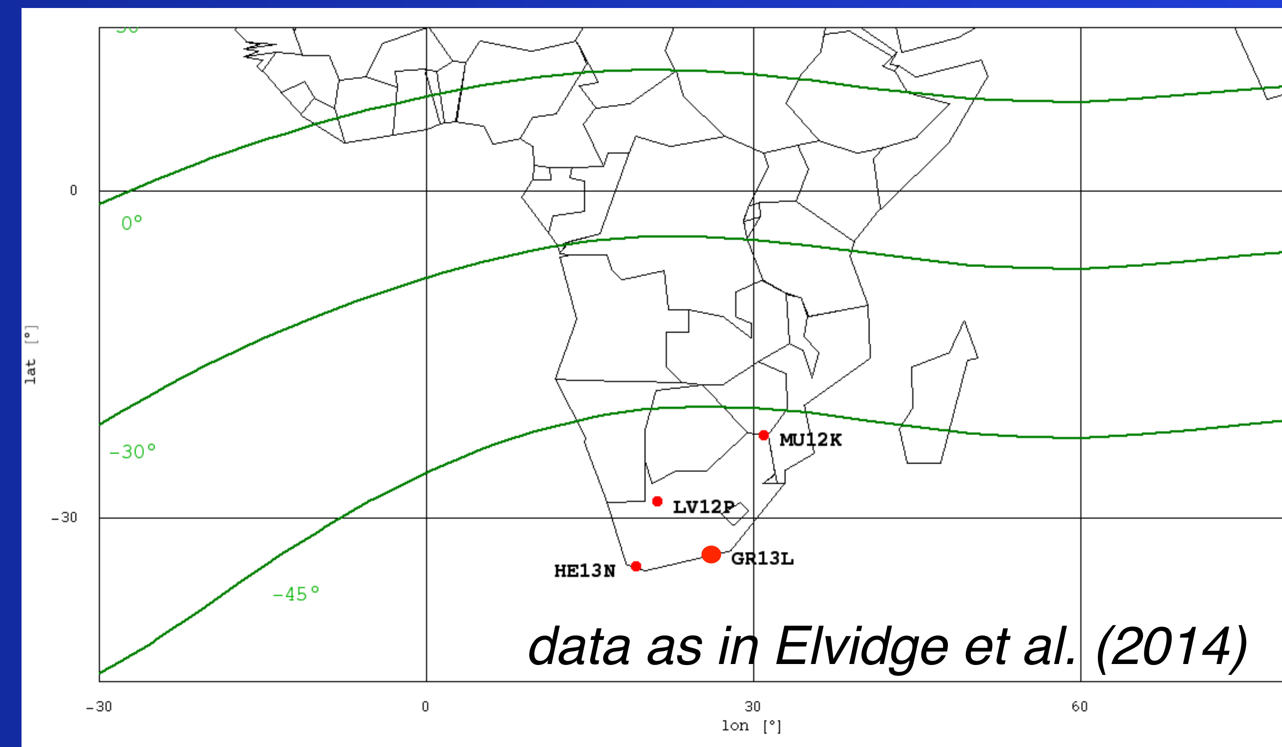
sTEC data ingestion; error statistics (000405)

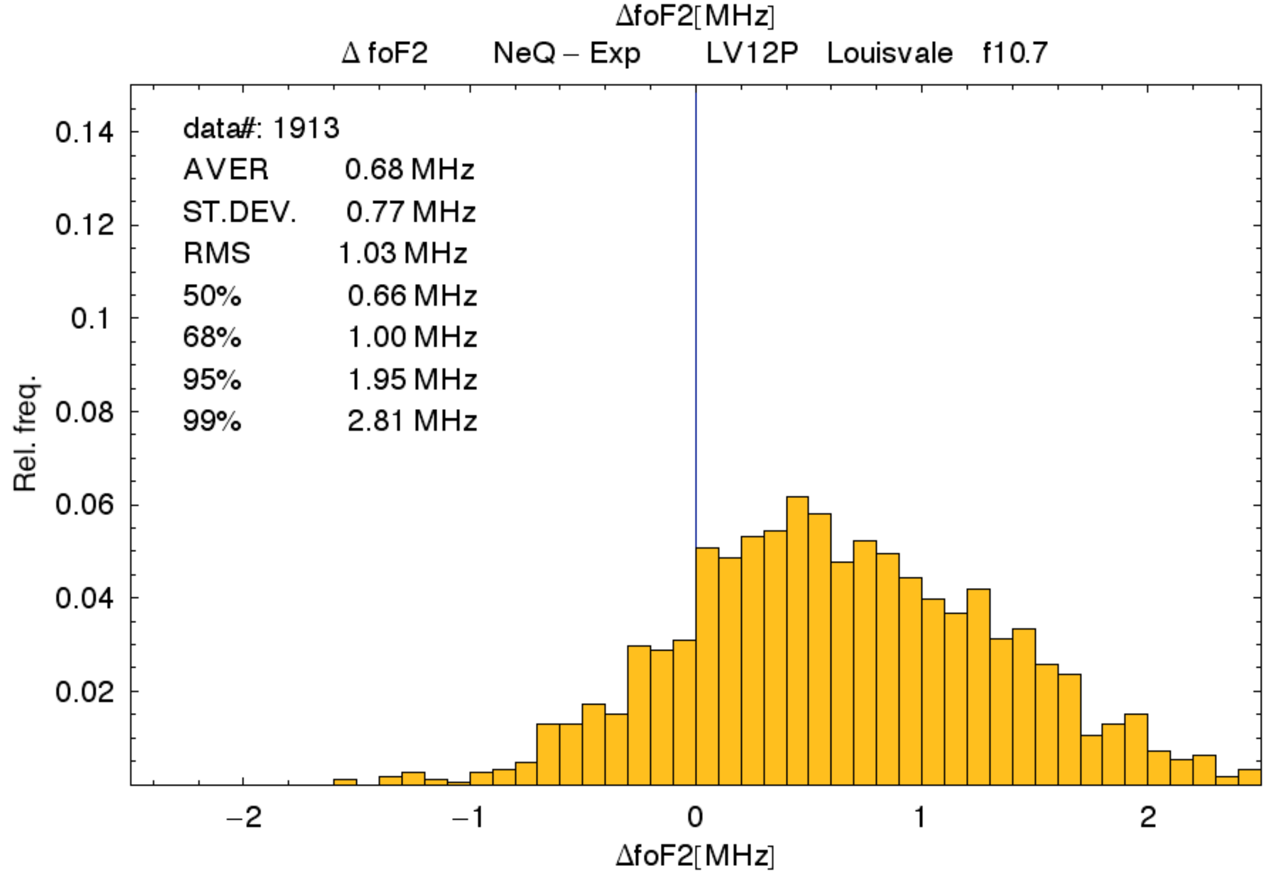


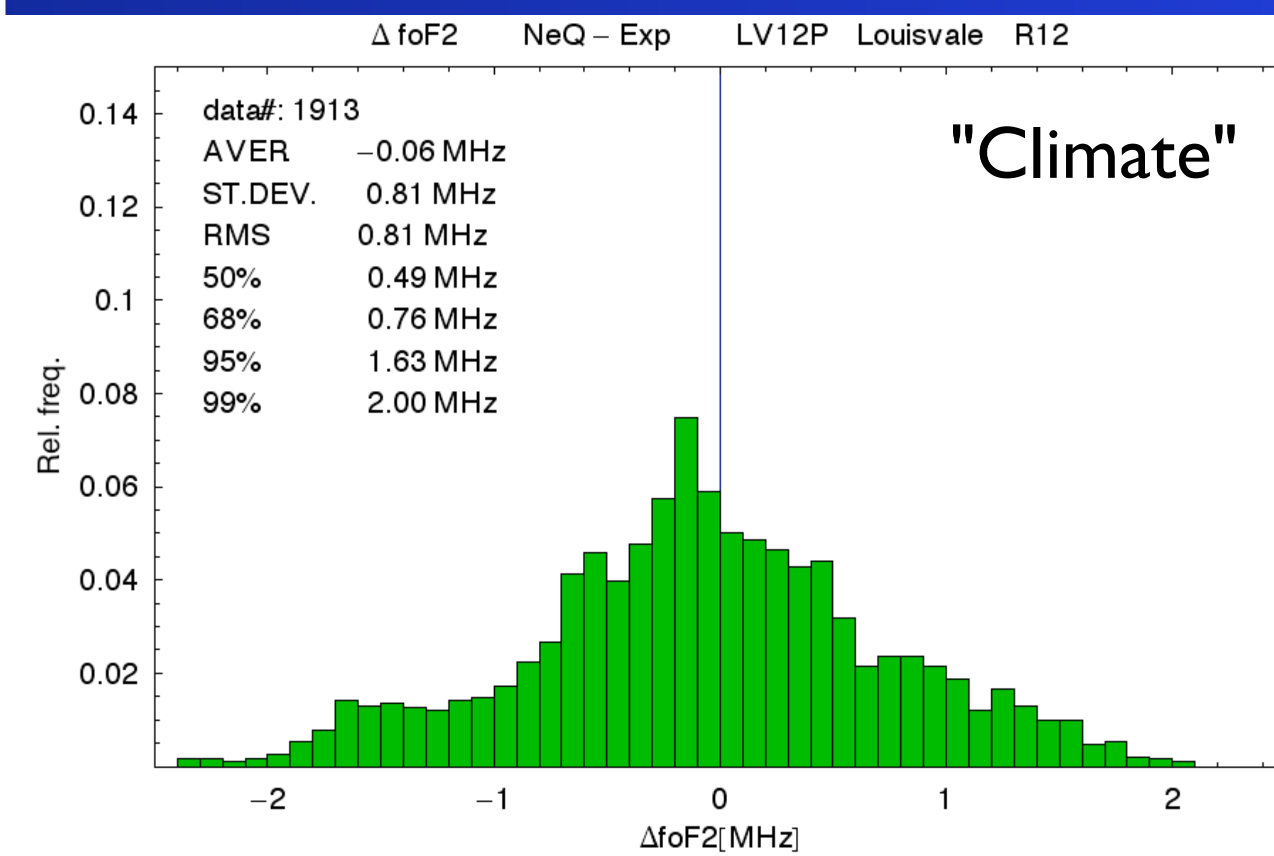
Nava et al., 2006

foF2 data ingestion; error statistics, Sep 2011

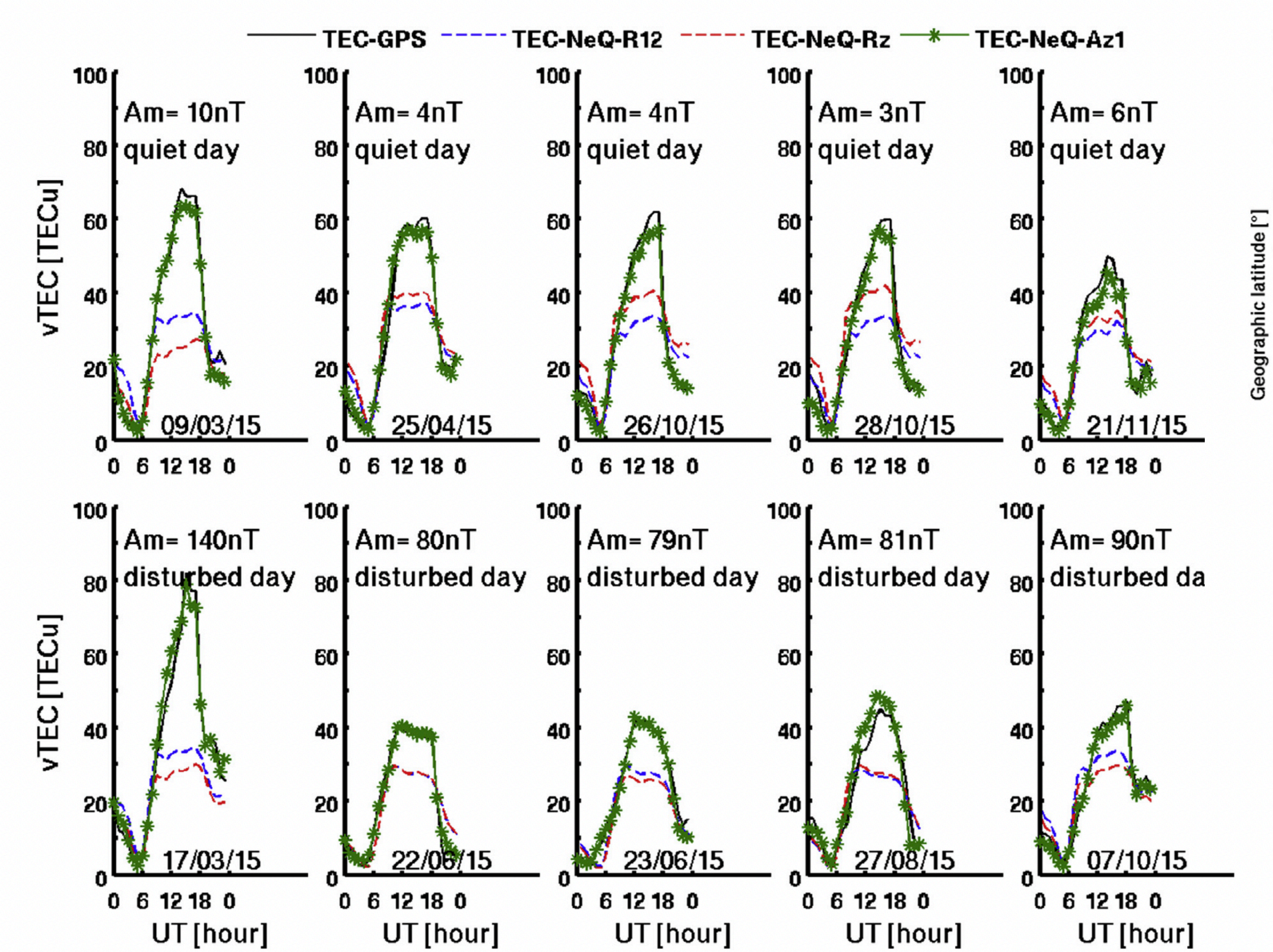


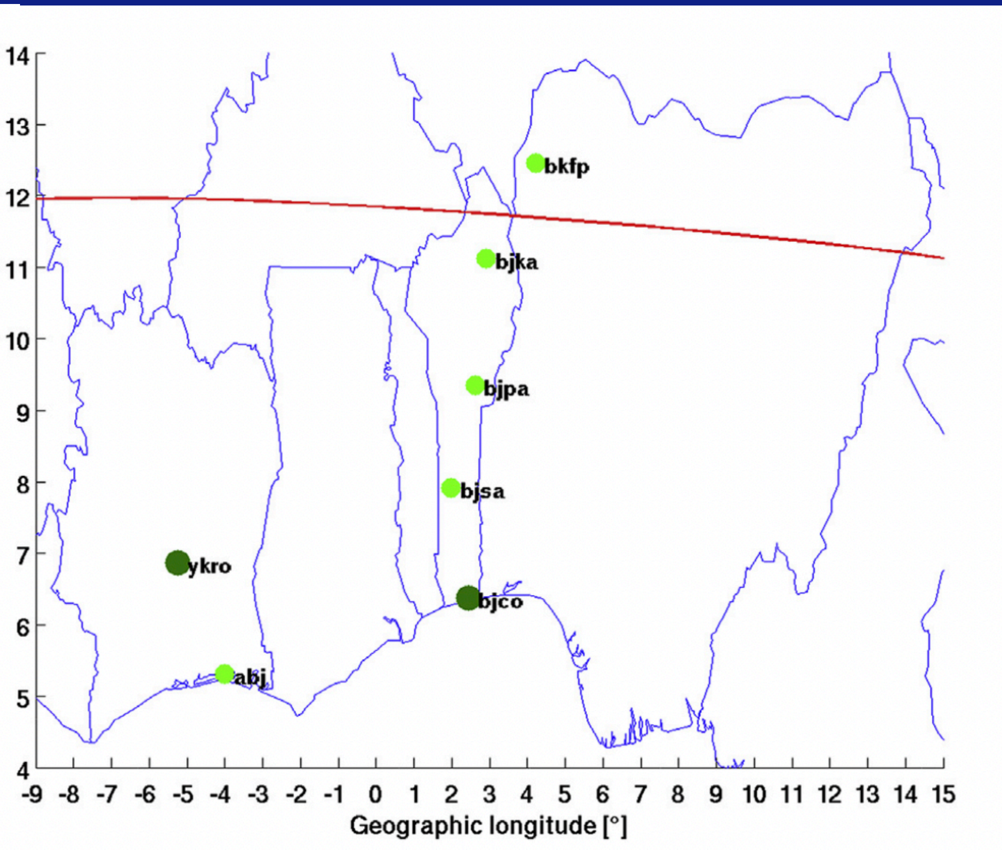






vTEC ingestion; geomagnetically disturbed period

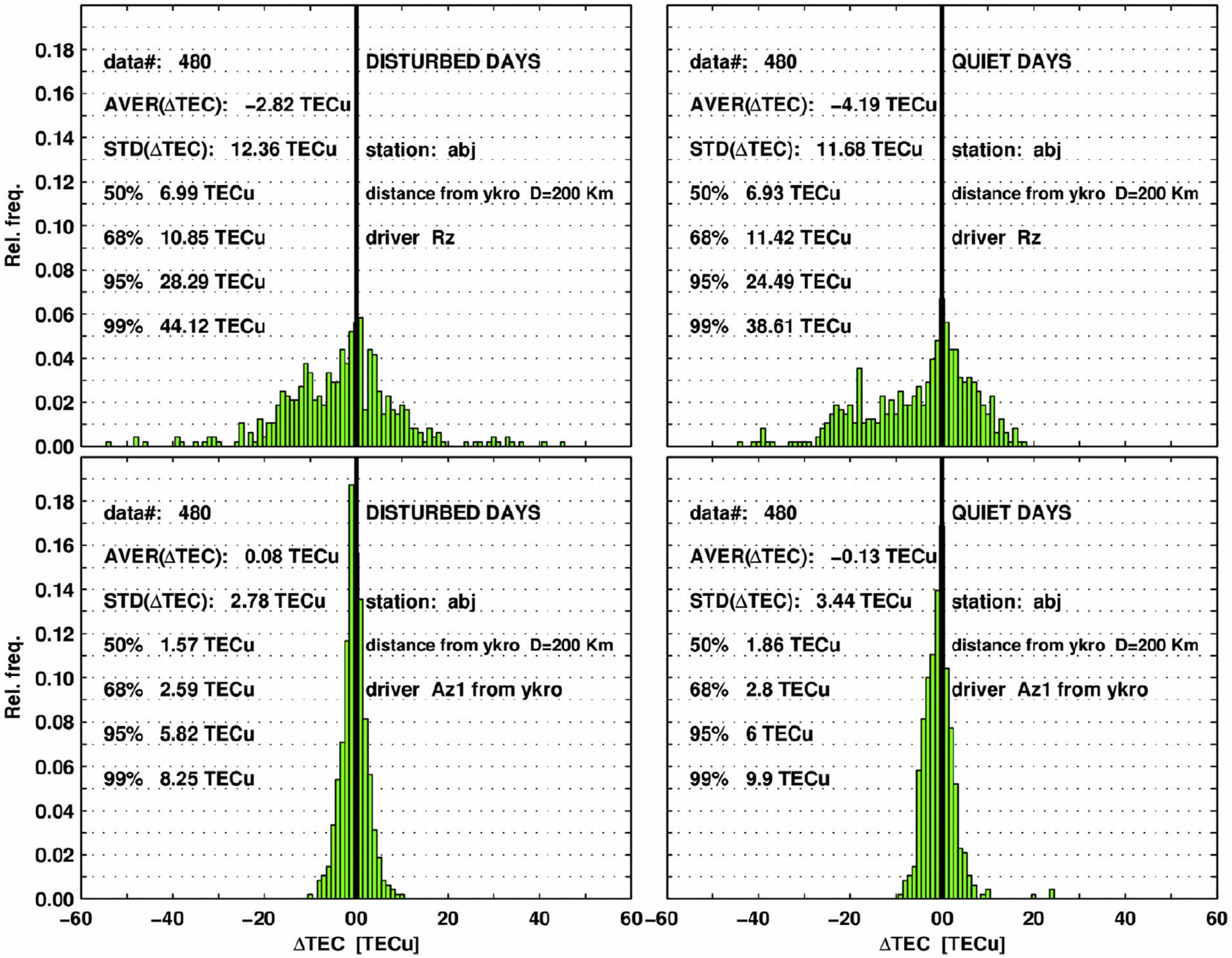


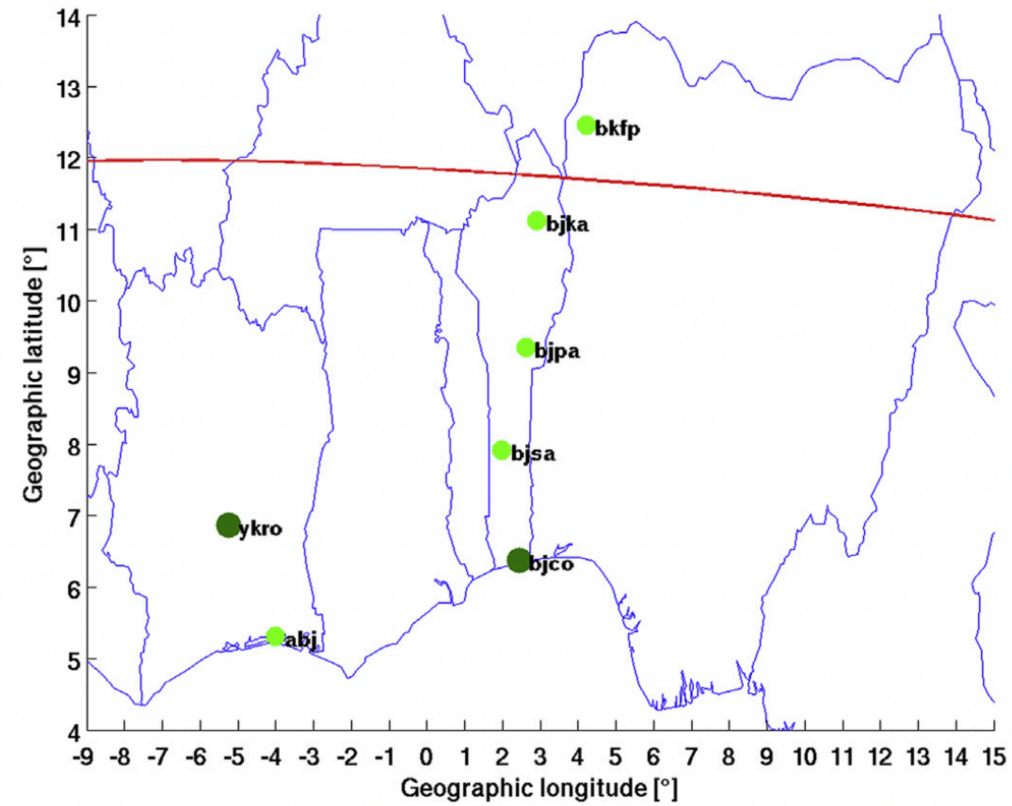


Yao et al., 2018

vTEC at abj station during 5 quietest days (top) and 5 disturbed days (bottom) in 2015. TEC-GPS: black line; TEC-NeQuick 2 driven by R12: dashed blue line; TEC-NeQuick 2 driven by Rz: dashed red line; TEC-NeQuick 2 driven by the effective f10.7 as inferred from ykro data: green line with star symbol.

vTEC ingestion; geomagnetically disturbed period



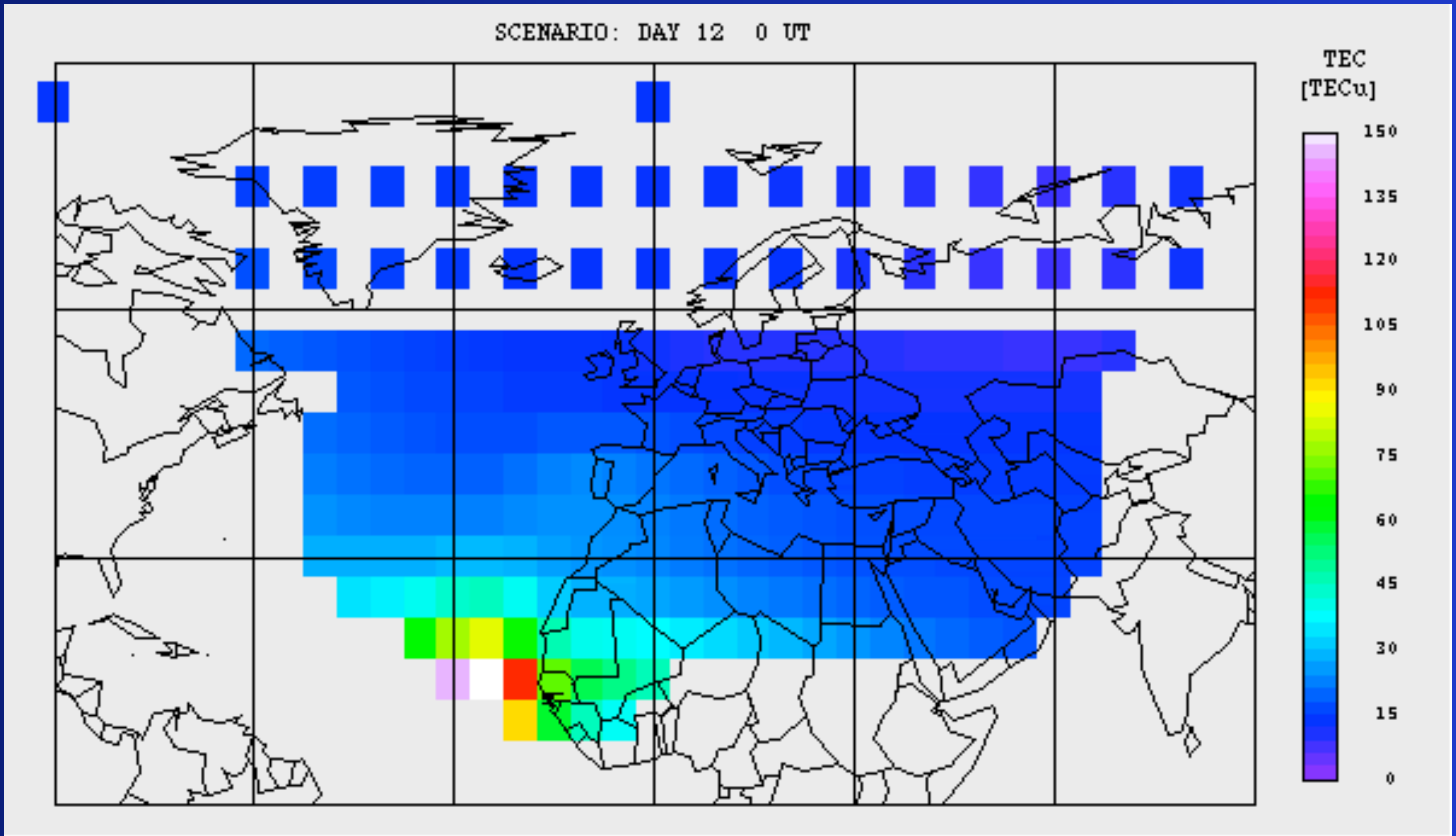


Yao et al., 2018

Distribution of the differences between modeled and experimental vertical TEC during geomagnetically disturbed days (left) and quiet days (right) in 2015 at abj station. NeQuick 2 is driven by the daily sunspot number Rz (top) and the effective solar flux Az1 as inferred from ykro data (bottom).

NeQuick for assessment studies

- Nevertheless, the first attempt to describe the ionospheric weather has been performed by merging monthly average foF2 (M(3000) F2) global maps with single epoch foF2 (M(3000)F2) grid-point measurements (Leitinger et al., 2001). This allowed generating “worst case” ionospheric scenarios (including geomagnetically disturbed conditions) for assessment of the operational ionospheric algorithms of EGNOS.



The BLUE algorithm

To further improve the NeQuick performance in retrieving the 3D electron density of the Ionosphere, a minimum variance least-squares estimation has also been utilised to assimilate ground and space-based TEC data into the model, considered as a background.

Best Linear Unbiased Estimator (BLUE)*

$\mathbf{y}$ vector of observations

$\mathbf{x}_b$ background model state

$\mathbf{x}_a$ analysis model state

$\mathbf{H}$ observation operator

$\mathbf{R}$ covariance matrix of observation errors

$\mathbf{B}$ covariance matrix of background errors

$\mathbf{A}$ covariance matrix of analysis errors

*http://www.ecmwf.int/newsevents/training/rcourse_notes/DATA_ASSIMILATION/ASSIM_CONCEPTS/Assim_concepts2.html#962570

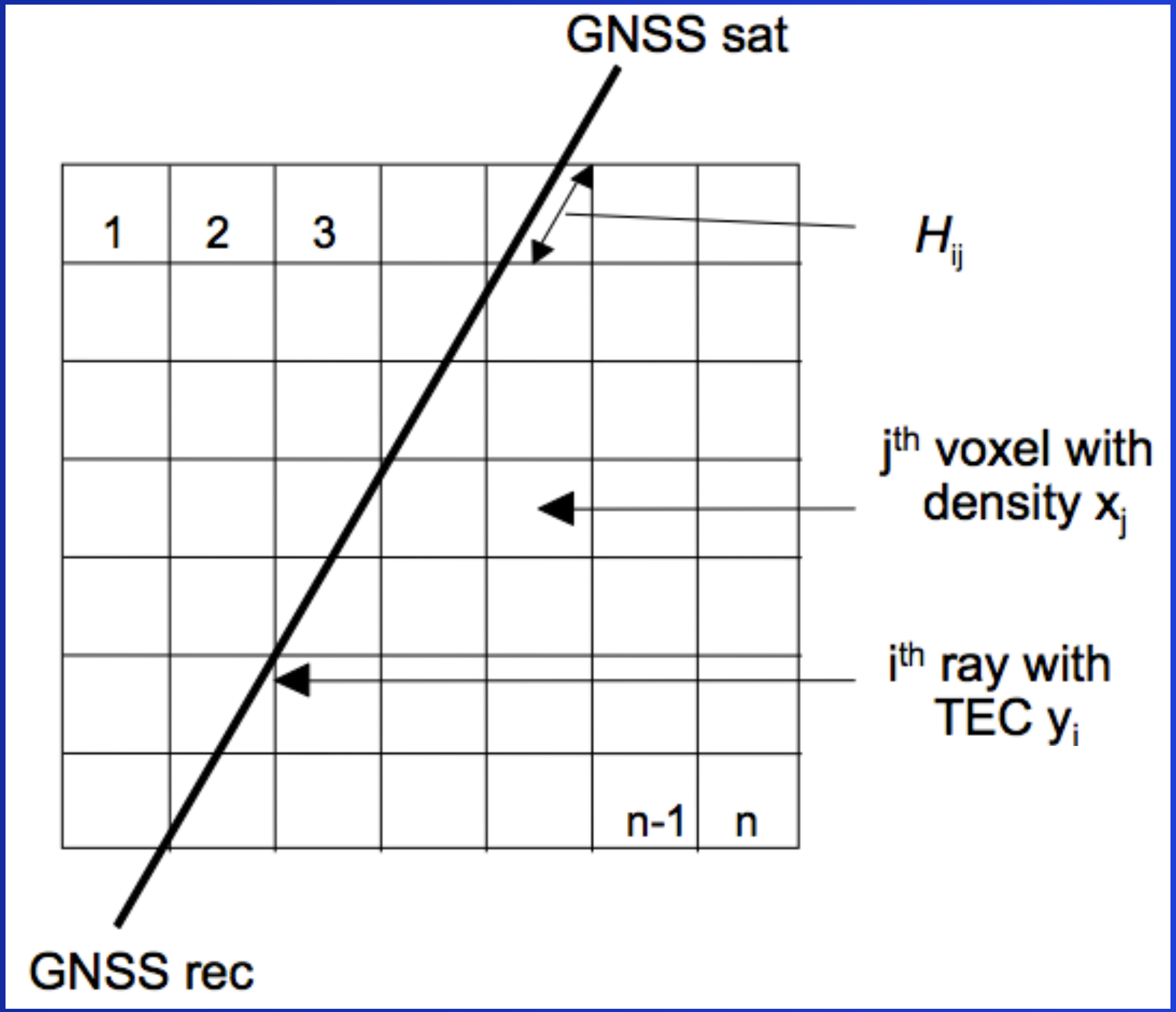
The BLUE algorithm

The optimal least-square estimator (BLUE analysis) is defined by

$$\mathbf{x_a} = \mathbf{x_b} + \mathbf{K}\,(\mathbf{y} - \mathbf{H}\mathbf{x_b})$$

$$\mathbf{K} = \mathbf{B}\mathbf{H}^T(\mathbf{H}\mathbf{B}\mathbf{H}^T + \mathbf{R})^{-1}$$

$$\mathbf{A} = (\mathbf{I}-\mathbf{K}\mathbf{H})\mathbf{B}$$



In our case:

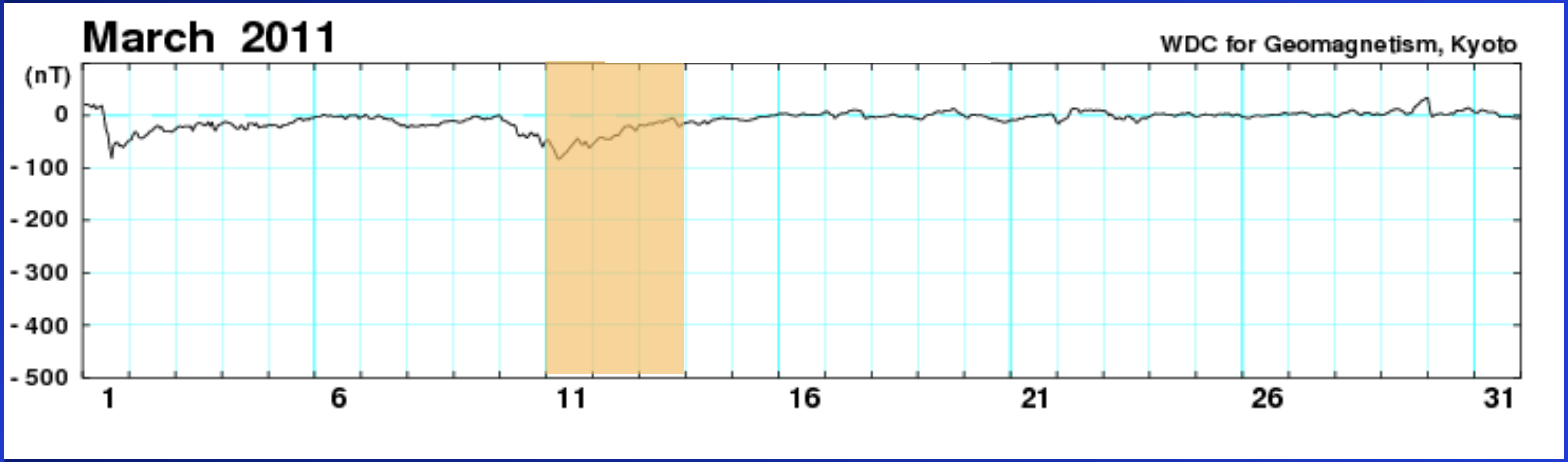
y = GNSS sTEC
$\mathbf{x_b}$ = NeQuick electron density
$\mathbf{x_a}$ = retrieved electron density
H -> “crossing lengths” in “voxels”

Simple formulation for **B** has been adopted (**R** is diagonal)

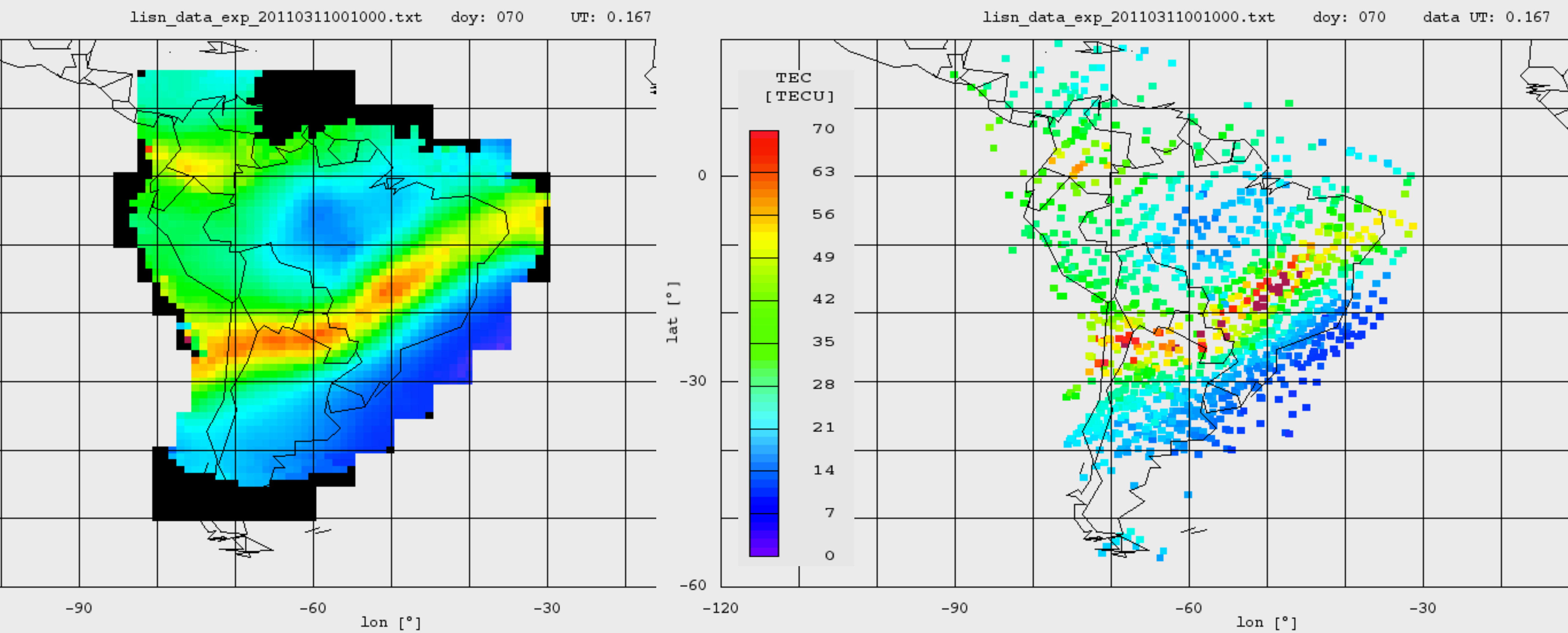
GNSS TEC DA - Example 1

- For the assimilation
  - Calibrated ground-based GNSS-derived slant TEC data from about 150 receivers of the LISN network (C. Valladares), located in the South American region.

- The data correspond the period 11-13 March 2011



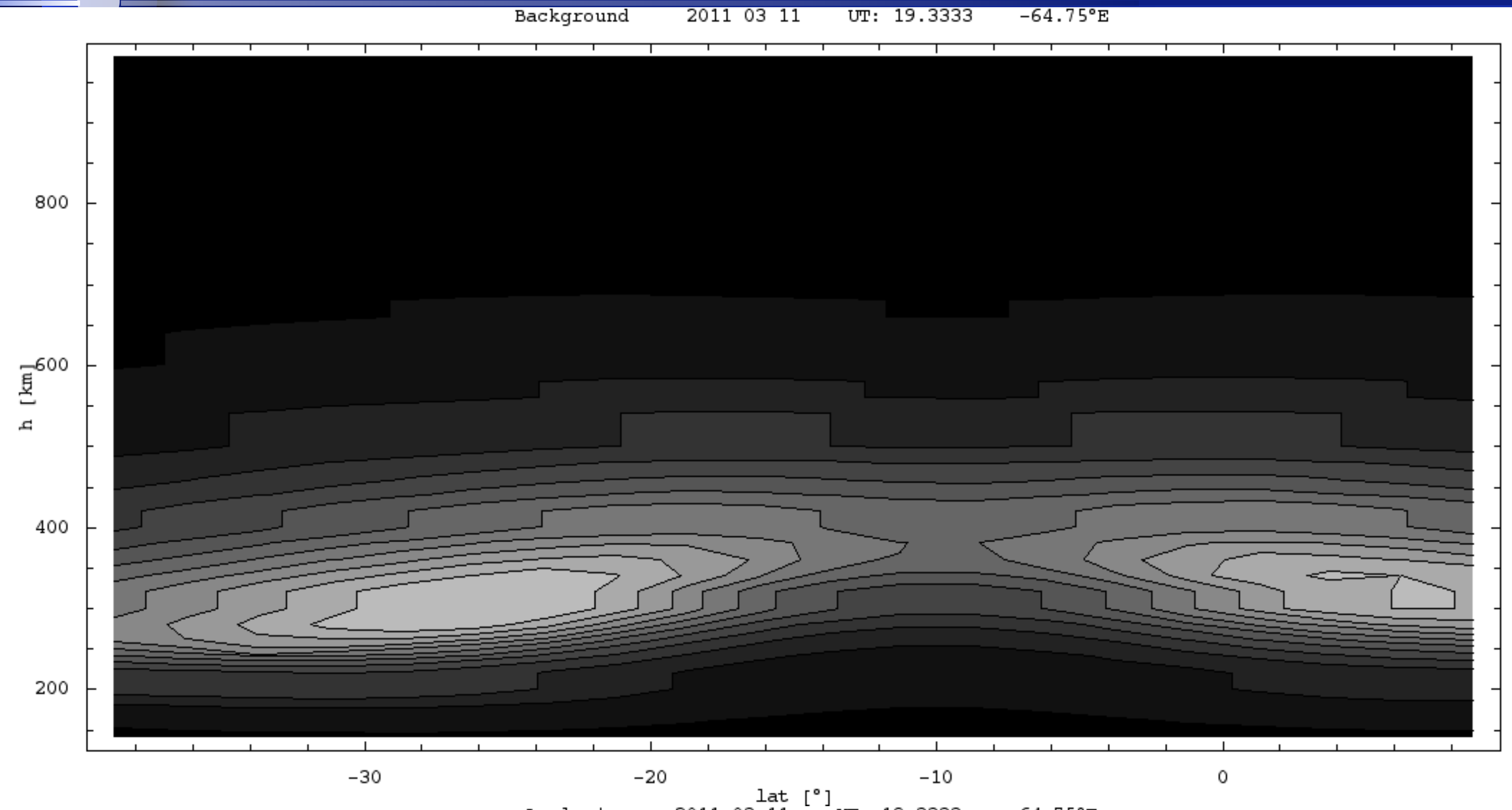
LISN: 3 days data (2011/03/11-12-13)

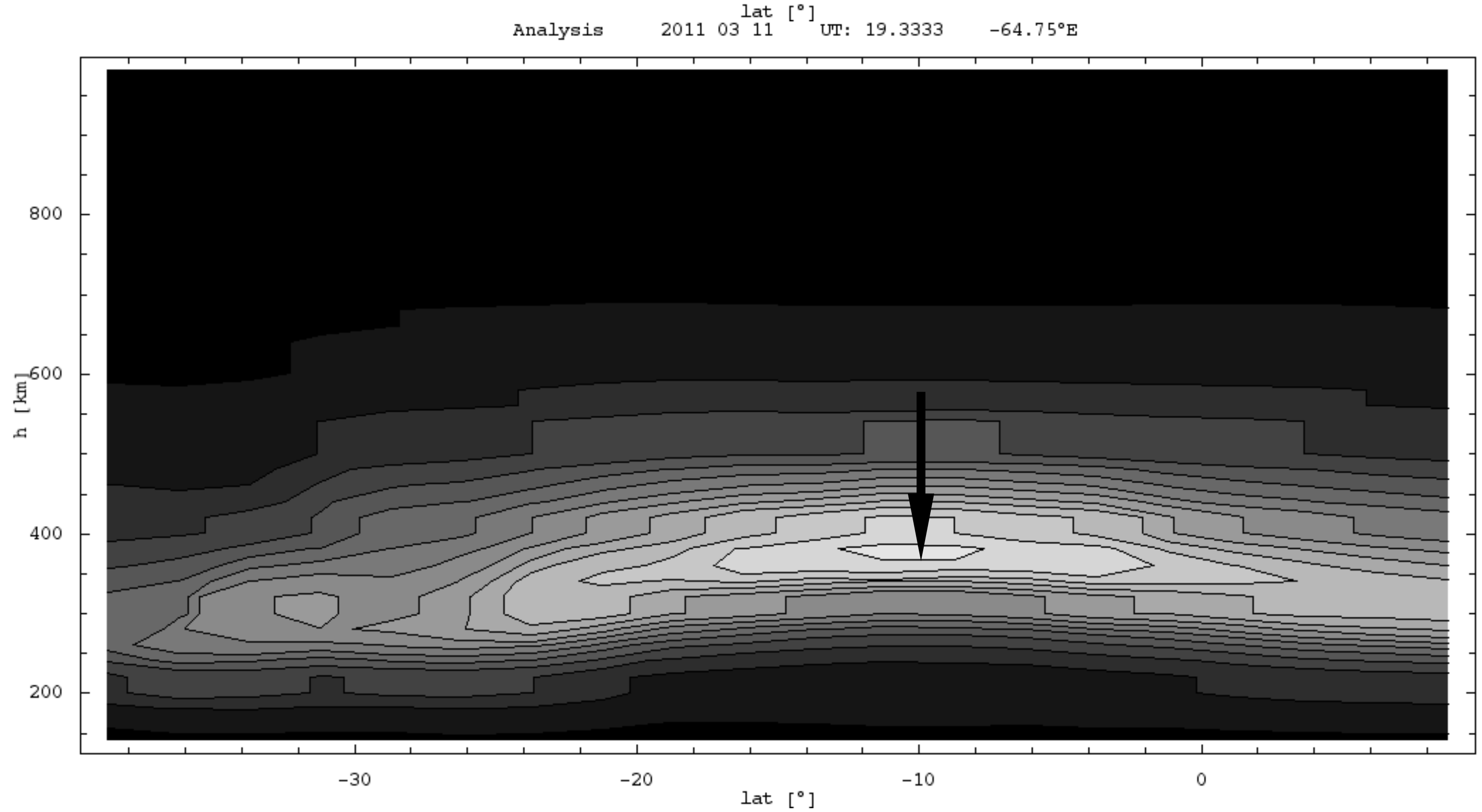


Equivalent vertical TEC
(LS adjustment)

Equivalent vertical TEC
at the pierce points

Assimilation effect

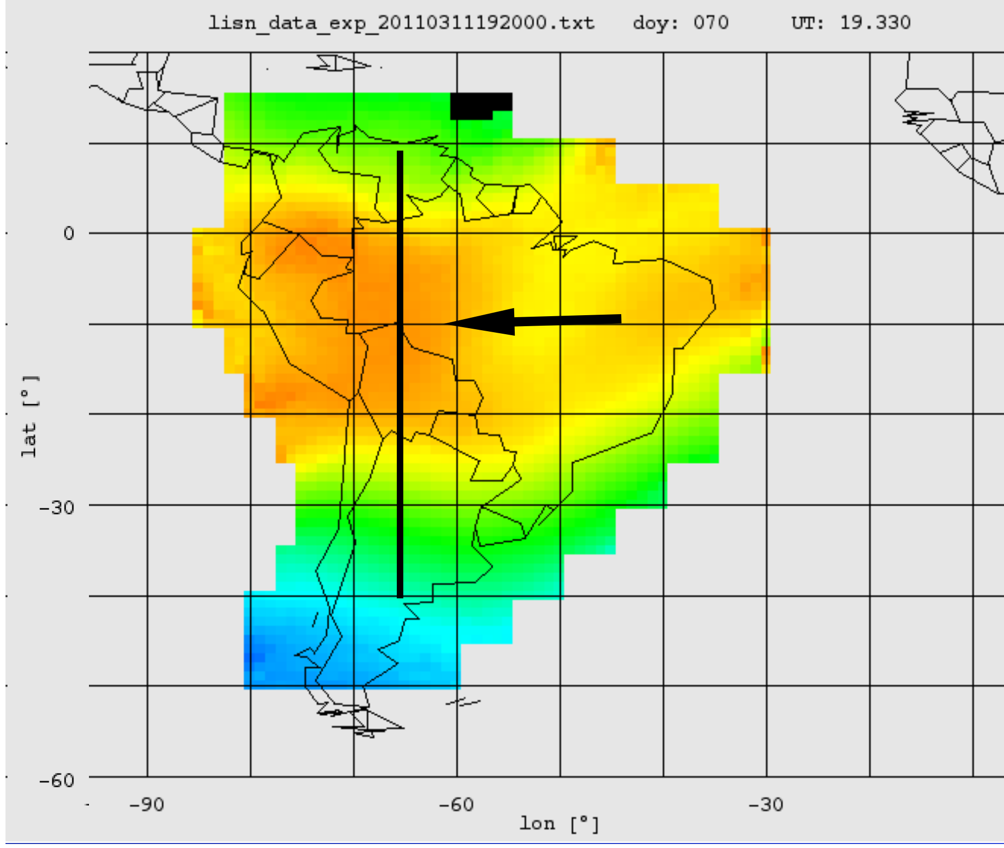




Background model

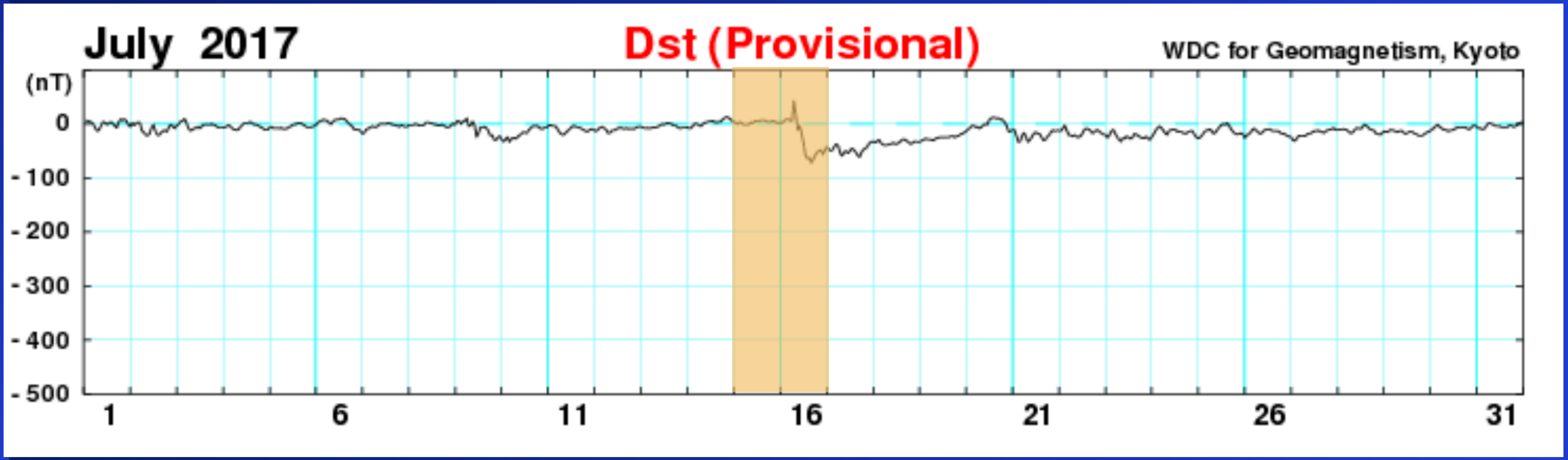
Cross section
19:33UT; -64.75°E
from -40°N to 10°N

Analysis

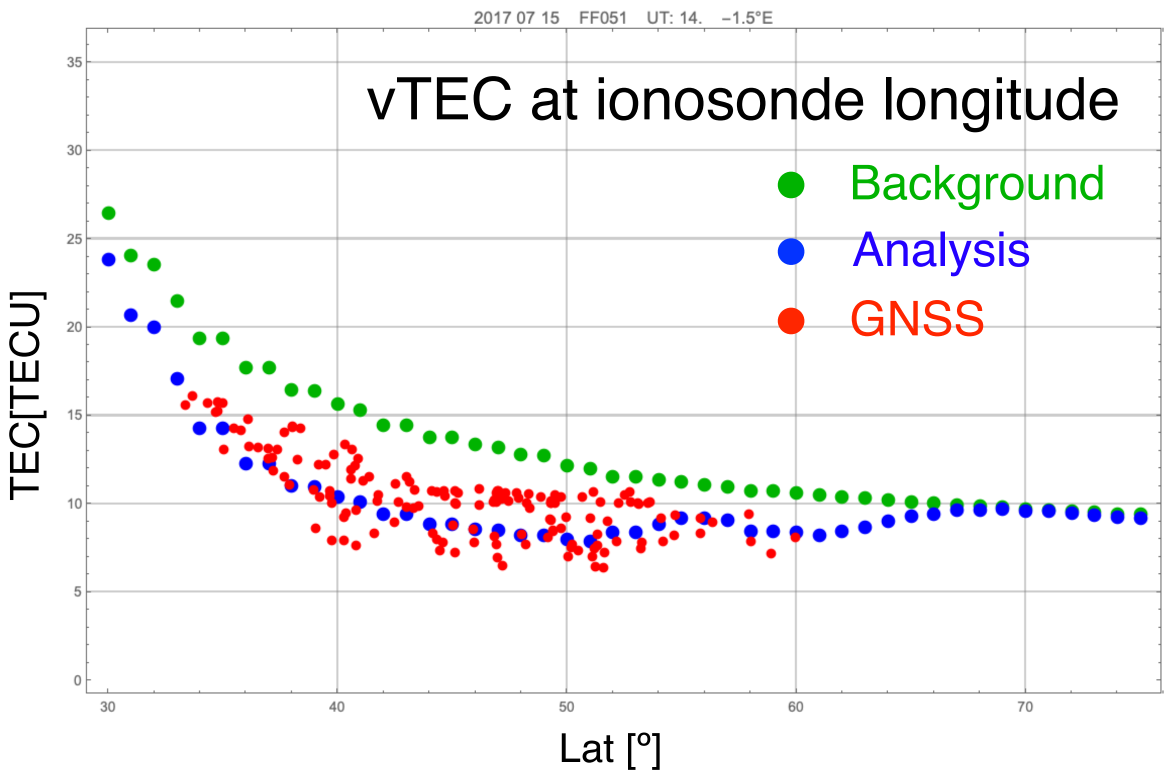


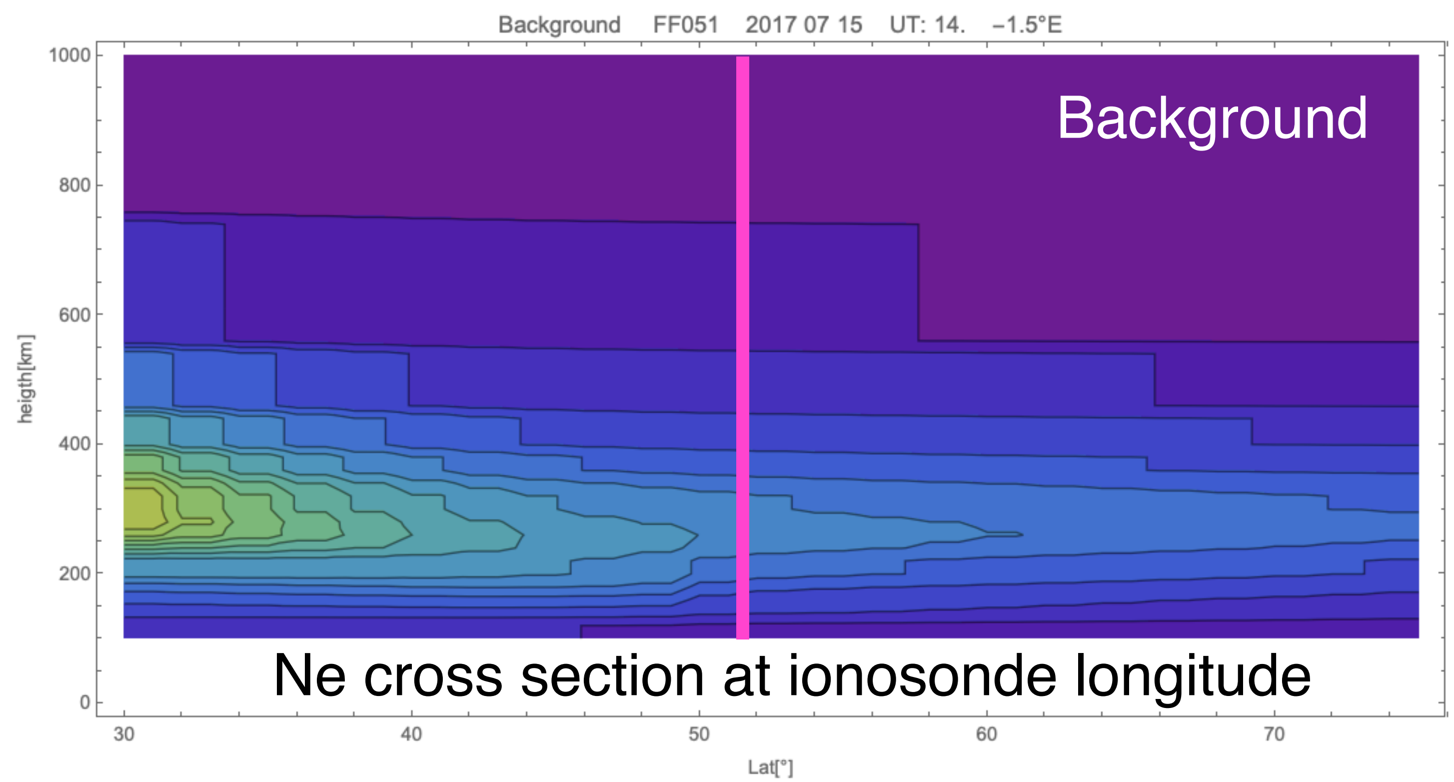
GNSS TEC DA - Example 2

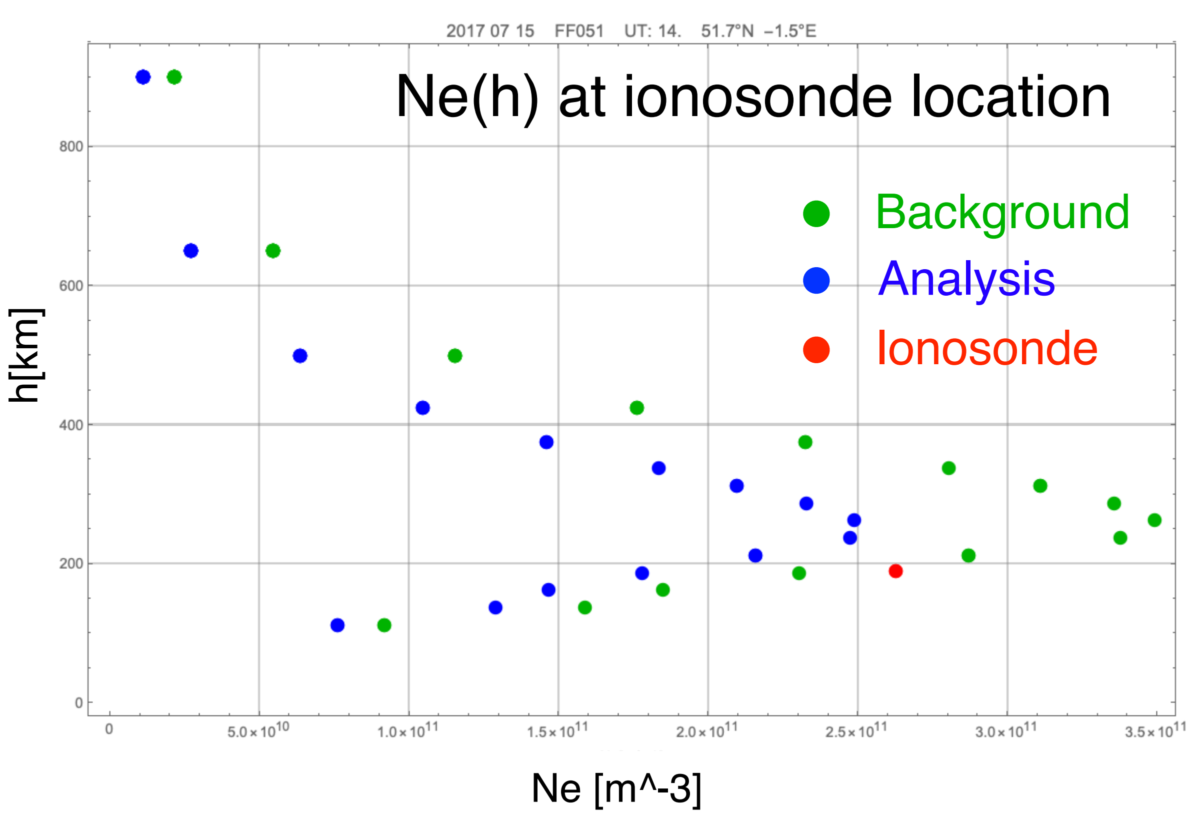
- For the assimilation
  - Calibrated (as in Themens et al. 2015) ground-based GNSS-derived slant TEC data from about 300 receivers located in the European region.
- For the validation
  - Manually scaled foF2 data obtained from Tromso (69.7ºN, 9.0ºE), Fairford (51.7ºN, 1.5ºW) and Juliusruh (54.6ºN, 13.4ºE) ionosondes at 1 hour time interval (only the result corresponding to Fairford will be illustrated).
- The data correspond the period 15-16 July 2017

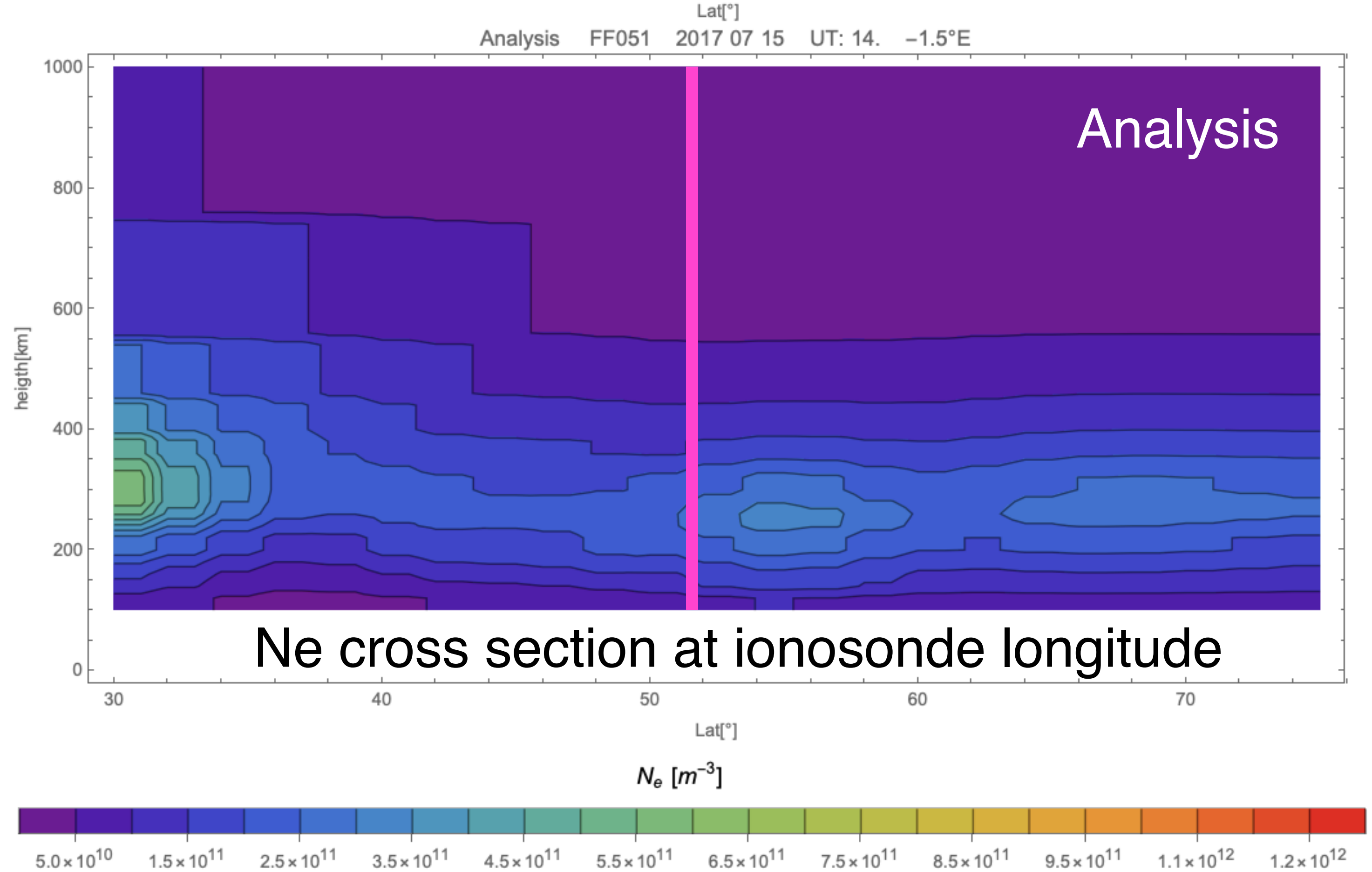


Results: 15 July 2017; 14:00UT; FF051

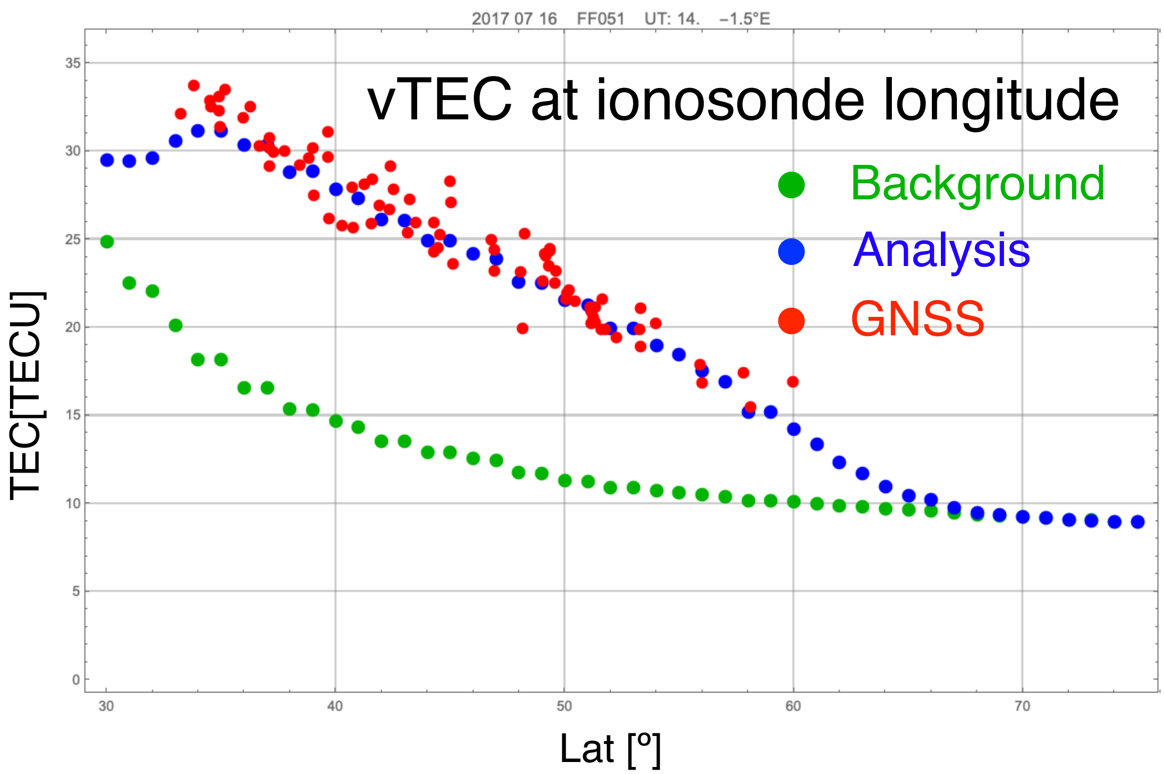


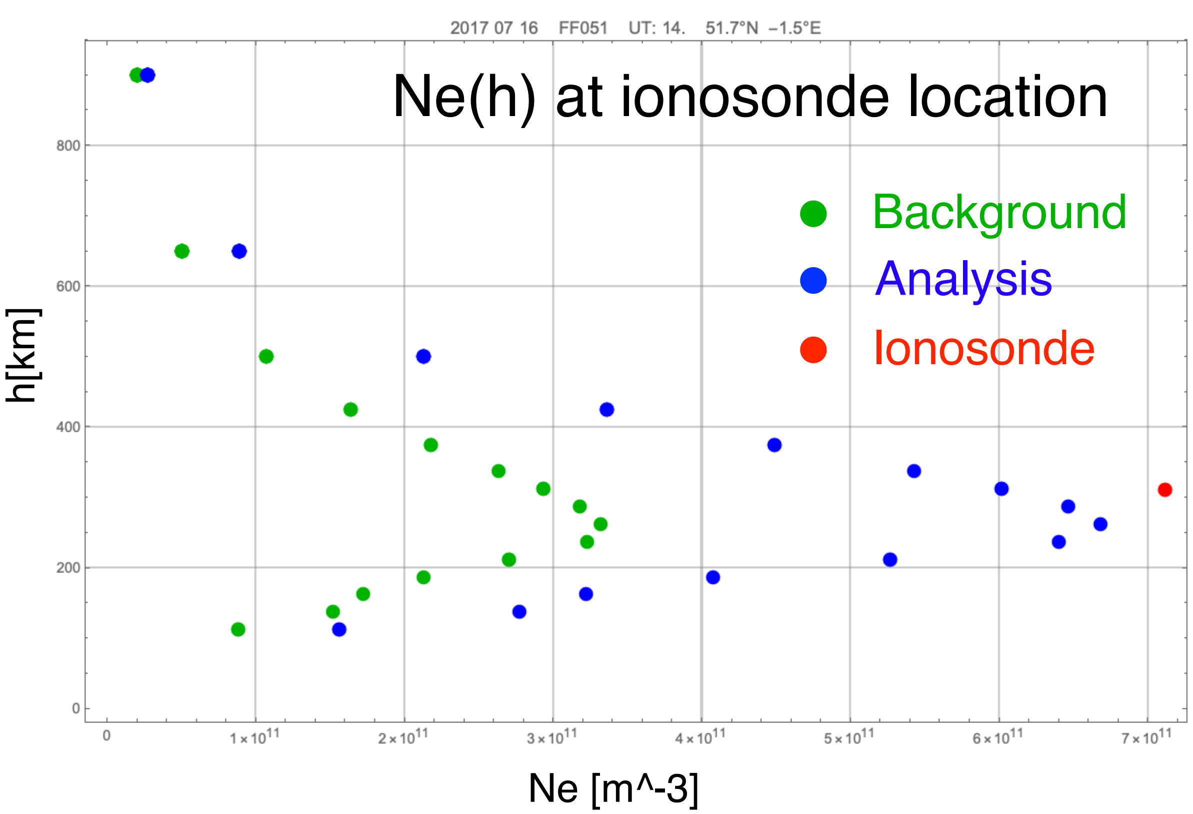


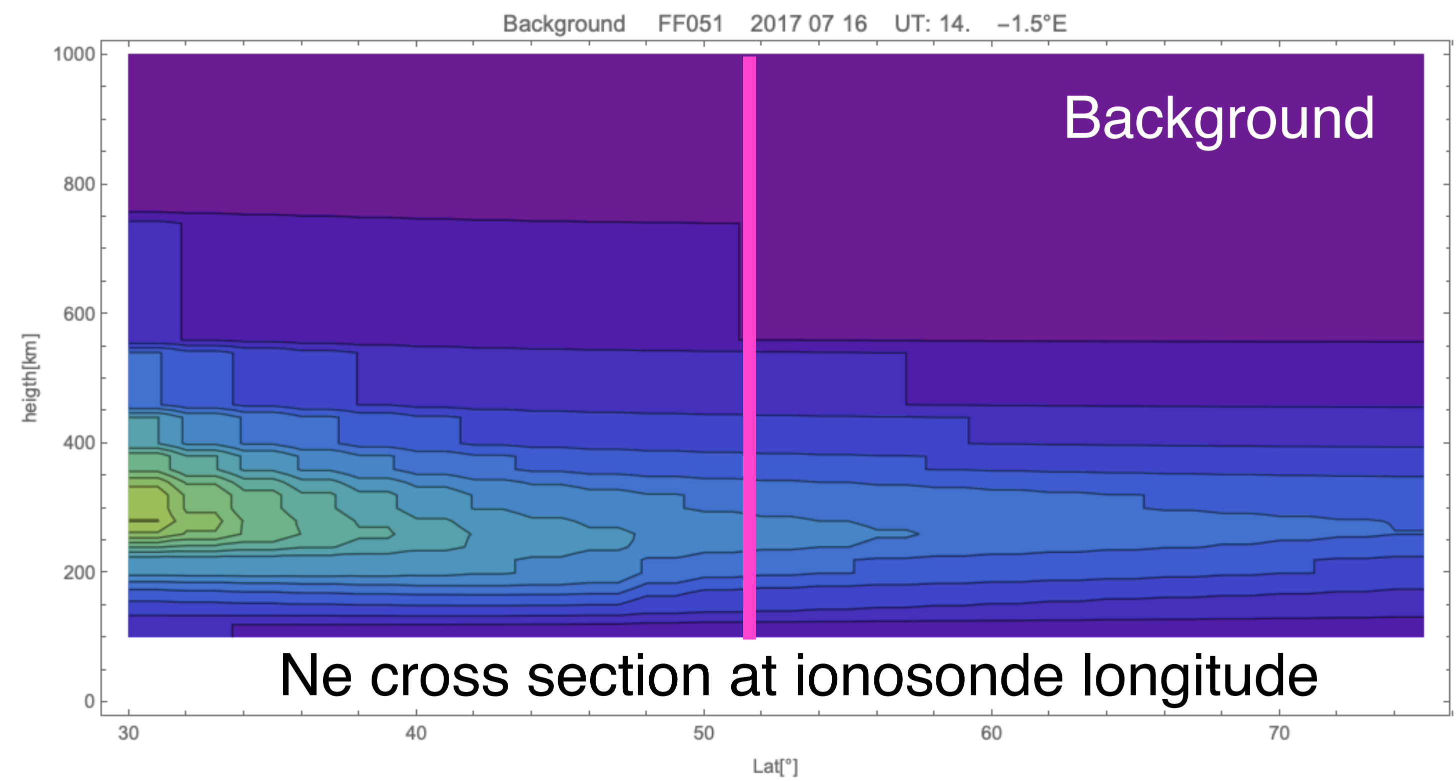


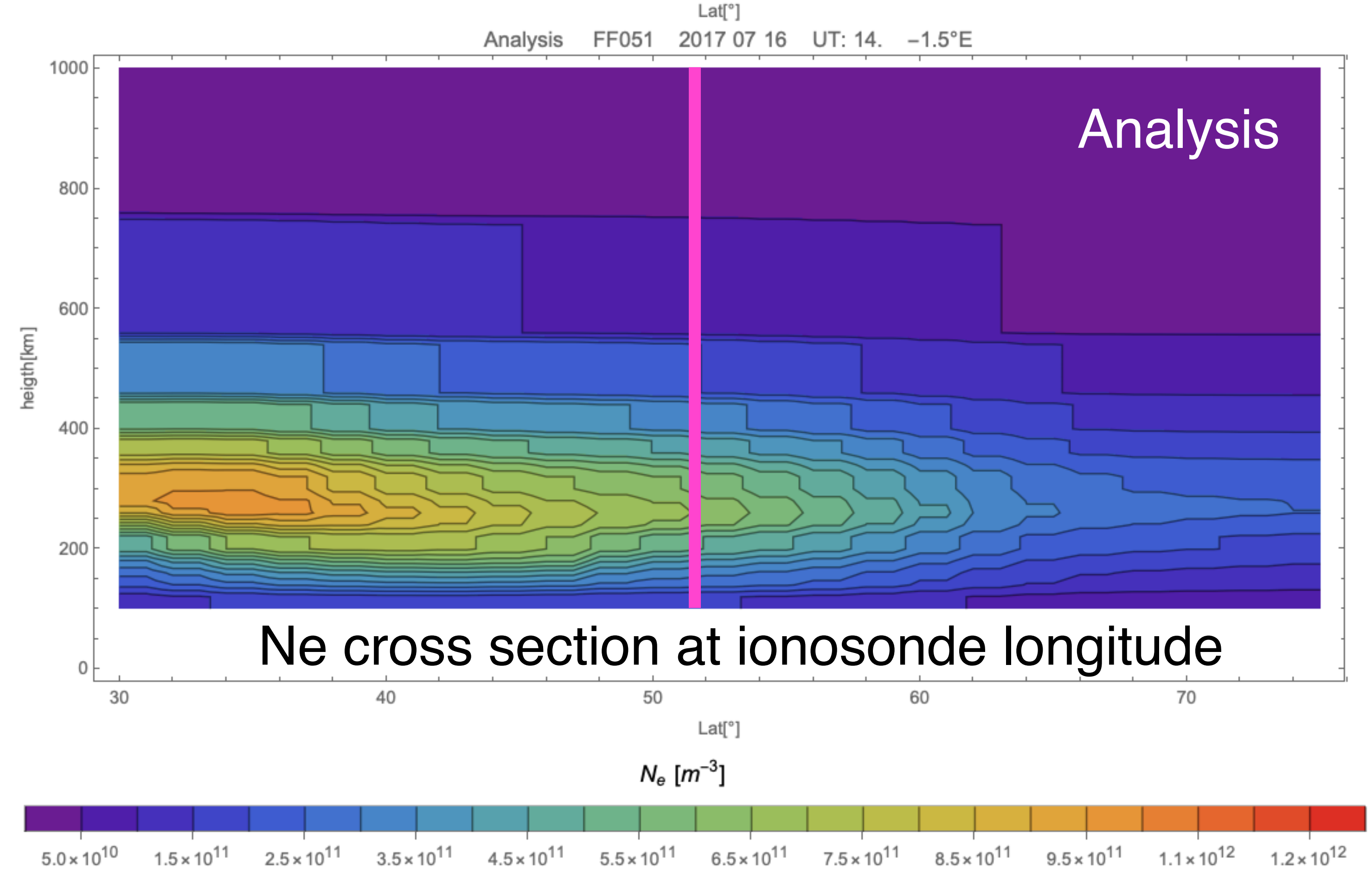


Results: 16 July 2017; 14:00UT; FF051

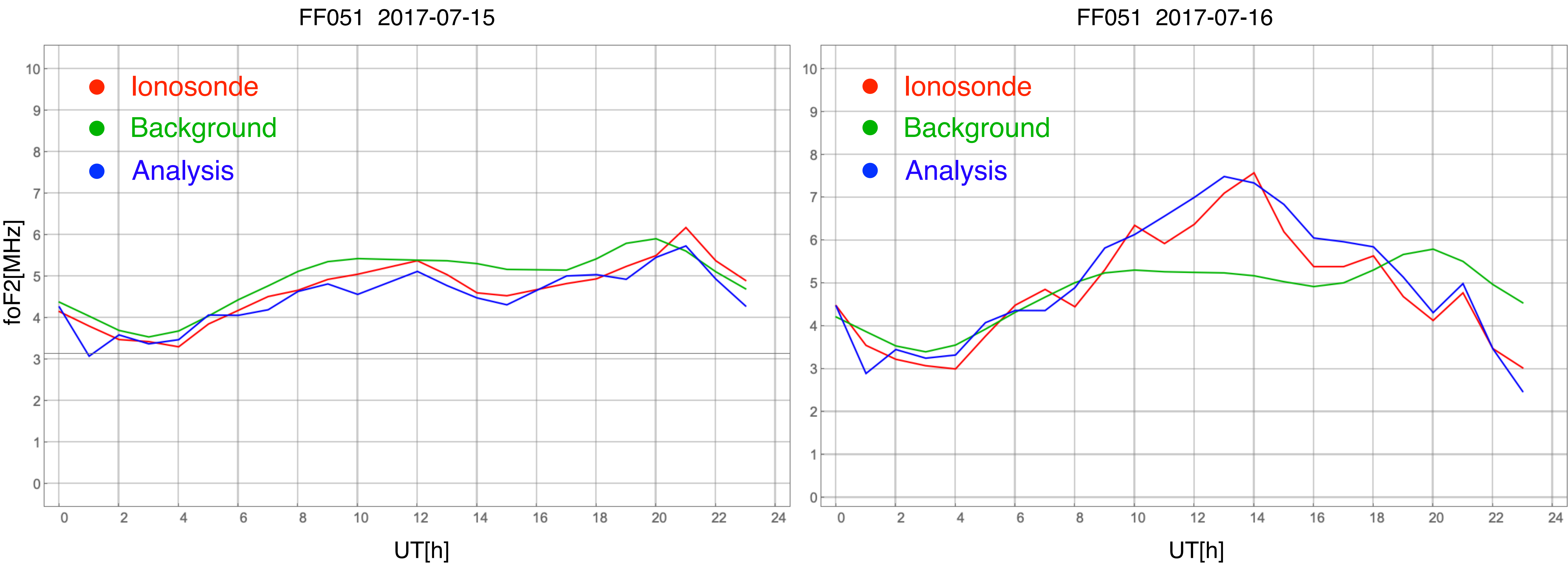








Results: 15-16 July 2017 (sTEC DA)



foF2 time evolution at ionosonde location

Conclusions

- Specific examples have been presented to indicate that the NeQuick model can provide realistic “weather-like” descriptions of the 3-D electron density of the ionosphere, if suitable data ingestion and assimilation techniques are used.
- The ingestion techniques relying on the use of effective parameters allow NeQuick model to describe the storm-time space weather effects in terms of TEC.
- The analysis results have confirmed the effectiveness of the assimilation method based on the BLUE algorithm in reconstructing foF2, especially during geomagnetically disturbed conditions.

References

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Thank you for your attention