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Ionospheric model adaptation to experimental data.

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Ionospheric model adaptation to experimental data

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Outline

- The NeQuick model
  - Brief description
- Review of:
  - Adaptation methods developed to update NeQuick with experimental data
    - Description
    - Examples
  - Adaptation methods applied to IRI
    - Description
    - Examples
- Remarks

Introduction

- Empirical models like IRI and NeQuick have been developed as climatological models, able to reproduce the typical median condition of the ionosphere.

- For practical applications (GNSS) there is a need to have models able to reproduce the current conditions of the ionosphere.

- Considering that there is an increasing availability of experimental data even in real time (GPS, ionosondes). Schemes to adapt models to ionospheric data have been developed.

- It must be noted that several electron density reconstruction techniques have been developed. They are of different complexity and rely on different kinds of data.

Introduction

- The Global Assimilative Ionospheric Model (GAIM) [Wang et al., 2004], for example, is based on assimilation of data originating from different sources and implies the use of first principle models.

- The Electron Density Assimilative Model (EDAM) [Angling and Khattatov, 2006] provides a means to assimilate ionospheric measurements into a background ionospheric model (that can be the IRI).

Introduction

- The retrieval methods that will be proposed in this presentation aim to be simpler, being based on empirical electron density model adaptation to GPS (or GPS and Ionosonde)-derived data only.

- In particular the technique used to adapt the model to the ionospheric data relies on the use of "effective" indices, that are defined on the bases of models and experimental (ionospheric) data.

- For example one of the first effective parameter that has been proposed is the "effective sunspot number" (SSNe). This parameter valid for a set of foF2 observations has been defined as the SSN value that, when used as input to the URSI foF2 model, gives a weighted zero-mean difference between the observed and the modeled foF2 values.

The NeQuick model

The NeQuick model (V.2)

- NeQuick is a three dimensional and time dependent ionospheric electron density model particularly designed for trans-ionospheric propagation applications.

- The model has been developed at the Aeronomy and Radiopropagation Laboratory of The Abdus Salam International Centre for Theoretical Physics (ICTP), Trieste, Italy, and at the Institute for Geophysics, Astrophysics and Meteorology (IGAM) of the University of Graz, Austria.

- It is based on the DGR "profiler" proposed by Di Giovanni and Radicella [1990] and subsequently modified by Radicella and Zhang [1995].

The NeQuick model (V.2)

- The NeQuick formulation is continuously updated in order to improve its capabilities in providing representations of the ionosphere at global and regional scales.

- At present, the version 2 of the model has been finalized.

- Reference: B. Nava, P. Coïsson, S. M. Radicella, A new version of the NeQuick ionosphere electron density model, Journal of Atmospheric and Solar-Terrestrial Physics, doi:10.1016/j.jastp.2008.01.015, 2008.

The NeQuick model formulation

- The model formulation includes 6 semi-Epstein layers with modeled thickness parameters and is based on anchor points defined by foE, foF1, foF2 and M3000 values.
- These values can be modeled (e.g. ITU-R coefficients for foF2, M3000) or experimentally derived.
- The NeQuick topside formulation is based on an empirical k parameter that controls the topside profile shape.
- NeQuick inputs are: position, time and solar flux; the output is the electron density at the given location and time.
- NeQuick package includes routines to evaluate the electron density along any ray-path and the corresponding Total Electron Content (TEC) by numerical integration.

Profile formulation

The profile formulation is a sum of Epstein-layers for the E, F1 and F2 ionospheric layers:

$$N_{DGR}(h) = NE(h) + NF1(h) + NF2(h)$$

$$\begin{aligned}
NE(h) &= \frac{4Nm*E}{\left(1+\exp\left(\frac{h-hmE}{BE}\right)\right)^2}\exp\left(\frac{h-hmE}{BE}\right) \\
NF1(h) &= \frac{4Nm*F1}{\left(1+\exp\left(\frac{h-hmF1}{B1}\right)\right)^2}\exp\left(\frac{h-hmF1}{B1}\right) \\
NF2(h) &= \frac{4Nm*F2}{\left(1+\exp\left(\frac{h-hmF2}{B2}\right)\right)^2}\exp\left(\frac{h-hmF2}{B2}\right)
\end{aligned}$$

$$\begin{aligned}
Nm*E &= NmE - NF1(hmE) - NF2(hmE) \\
Nm*F1 &= NmF1 - NF2(hmF1) \\
Nm*F2 &= NmF2 - 0.1NmF1
\end{aligned}$$

Height of layer maxima

The height of each layer is modeled by an empirical relation:

$$hmE = 120,$$

$$hmF1 = \frac{hmE + hmF2}{2},$$

$$hmF2 = \frac{1490MF}{M + \Delta M} - 176,$$

where

$$\Delta M = \begin{cases} 0.253/(foF2/foE \\ \quad -1.215) - 0.012, \\ -0.012 & \text{if } foE = 0, \end{cases}$$

$$MF = M\sqrt{\frac{0.0196M^2 + 1}{1.2967M^2 - 1}}$$

and

$$M = M(3000)F2.$$

Thickness parameters

The (bottomside) layer thickness parameters are given by:

$$BE_{bot} = 5,$$

$$BE_{top} = \max(0.5(hmF1 - hmE), 7),$$

$$B1_{bot} = 0.5(hmF1 - hmE),$$

$$B1_{top} = 0.3(hmF2 - hmF1),$$

$$B2_{bot} = \frac{0.385NmF2}{(dN/dh)_{max}},$$

Layer electron density maxima

Thitheridge model for foE:

$$(foE)^2 = a_e^2 \sqrt{F10.7} \, (\cos \chi_{eff})^{0.6} + 0.49$$

Model for foF1:

$$foF1 = \begin{cases} 1.4 foE & \text{if } foE \geqslant 2, \\ 0 & \text{if } foE < 2, \\ 0.85 * 1.4 foE & \text{if } 1.4 foE > 0.85 foF2 \end{cases}$$

Numerical maps for foF2 and M3000, the basic use is with ITU-R coefficients.

NeQuick topside

The NeQuick topside is based on a semi-Epstein layer formulation with a height-dependent thickness parameter H:

$$N(h) = \frac{4NmF2}{(1+\exp(z))^2}\exp(z)$$

$$z = \frac{h - hmF2}{\underbrace{H_0\left[1 + \frac{rg(h-hmF2)}{rH_0 + g(h-hmF2)}\right]}_{H}}$$

$r = 100 \qquad g = 0.25$

NeQuick topside

With

$$H_0 = k\,B2_{bot}$$

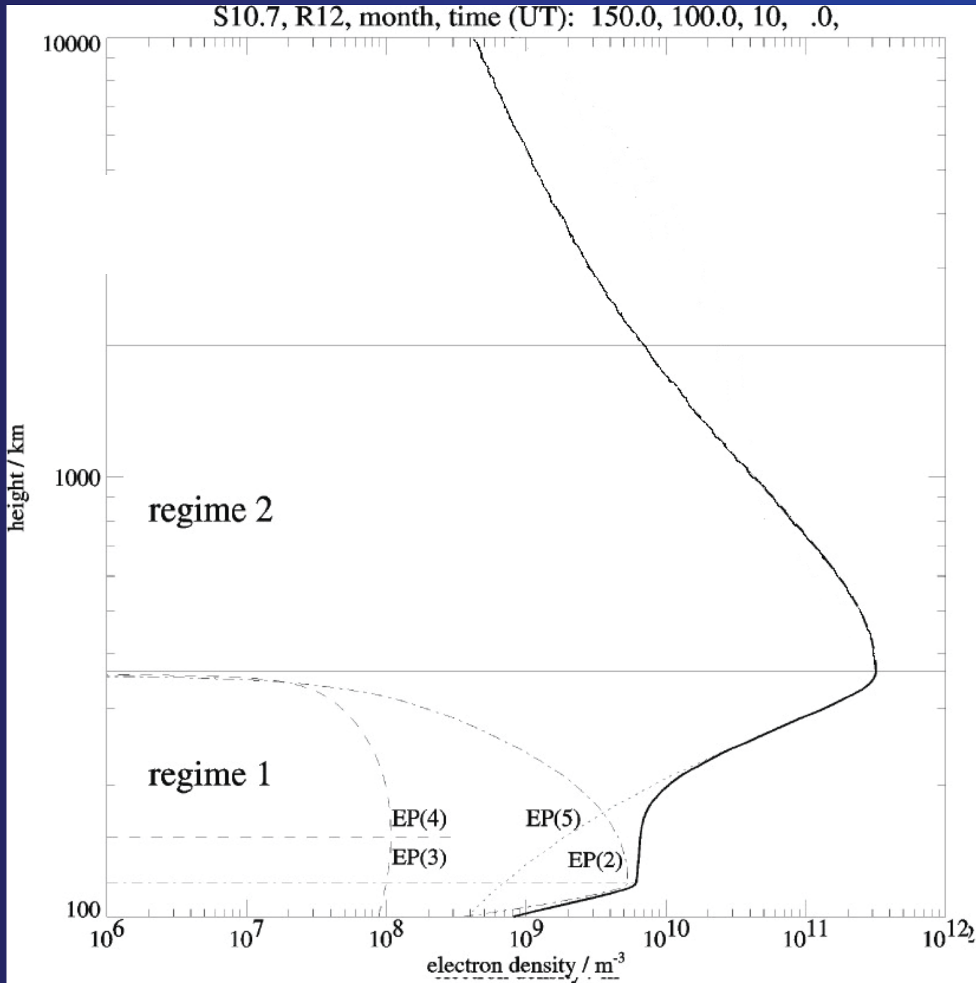
The k parameter formulation is based on ISIS2 topside profiles: experimental k values have been derived from selected profiles.

$$k = 3.22 - 0.0538 foF2 - 0.00664 hmF2 + 0.113 \frac{hmF2}{B2_{bot}} + 0.00257 R12$$

$k \geq 1$

NeQuick profile

NeQuick electron density profile



Model adaptation

Model(s) features relevant to implement adaptation techniques.

- The model can be considered as profiler.
  - The profile formulation is based on anchor points modeled in terms of ionosonde parameters (e.g. foE, foF1, foF2 and M(3000)F2).
- For a given epoch & ray-path the model TEC is a monotonic function of the solar activity index, that can be regarded as an "effective ionization level" parameter.

Adapting NeQuick model to vertical TEC maps

vTEC map data ingestion

At a given epoch

One vTEC map

↓

Minimize the mismodelings

$|vTECexp_i - vTECmod(az)_i|$

↓

Az (effective F10.7) grid

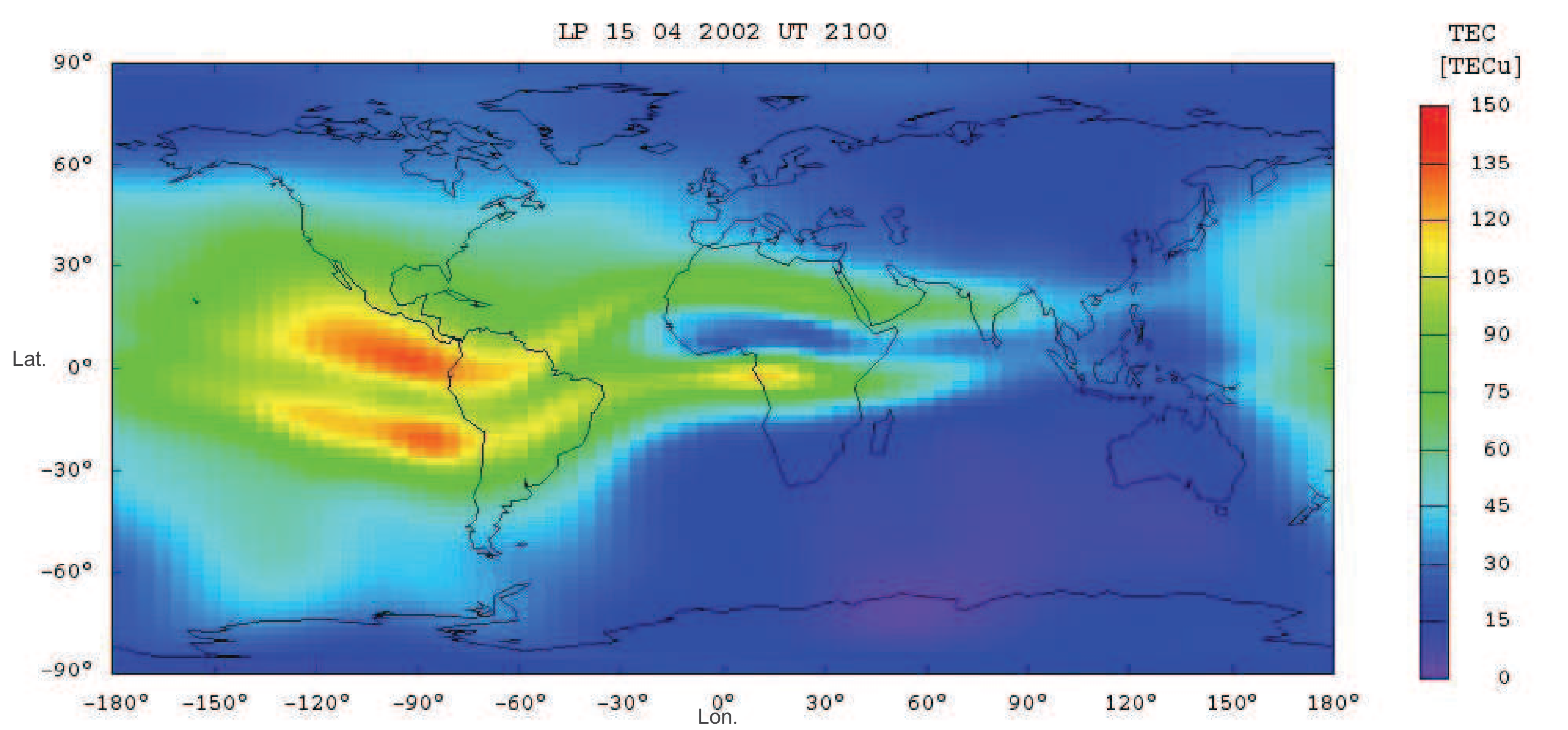
↓

Use NeQuick to reconstruct the 3D electron density of the ionosphere that reproduces the starting vTEC map

↓ Reconstruct sTEC along any ray-path

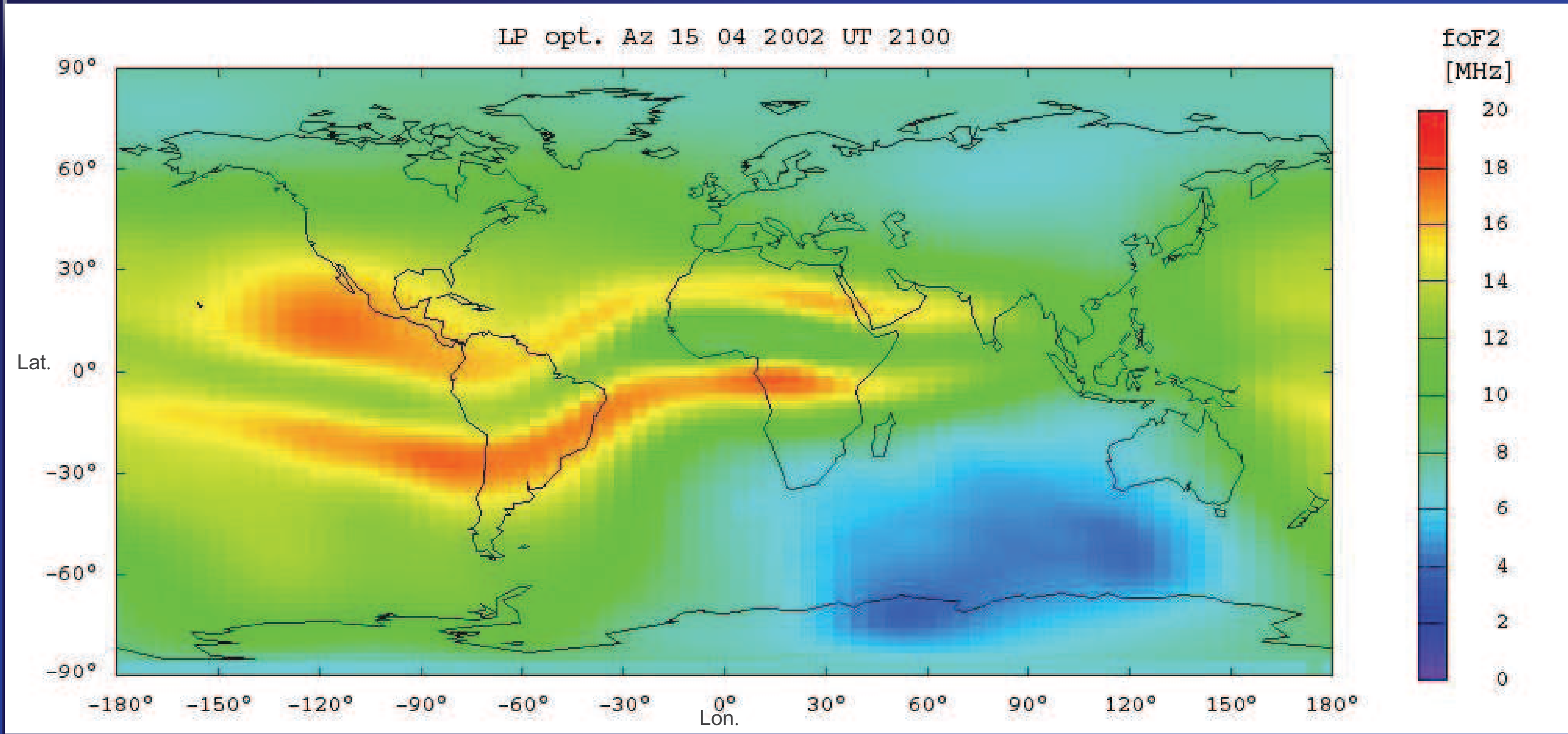
↓ Reconstruct foF2 maps

vTEC map La Plata



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°

Adapting NeQuick model to experimental slant TEC data at a given location

(For possible near real time applications)

sTEC data ingestion, single stat.

At a given epoch

One station, n experimental sTEC (n satellites)

↓

Minimize RMS of the TEC mismodelings
as a function of (formally) F10.7

↓

Az (effective F10.7) at the station, for the given epoch

↓

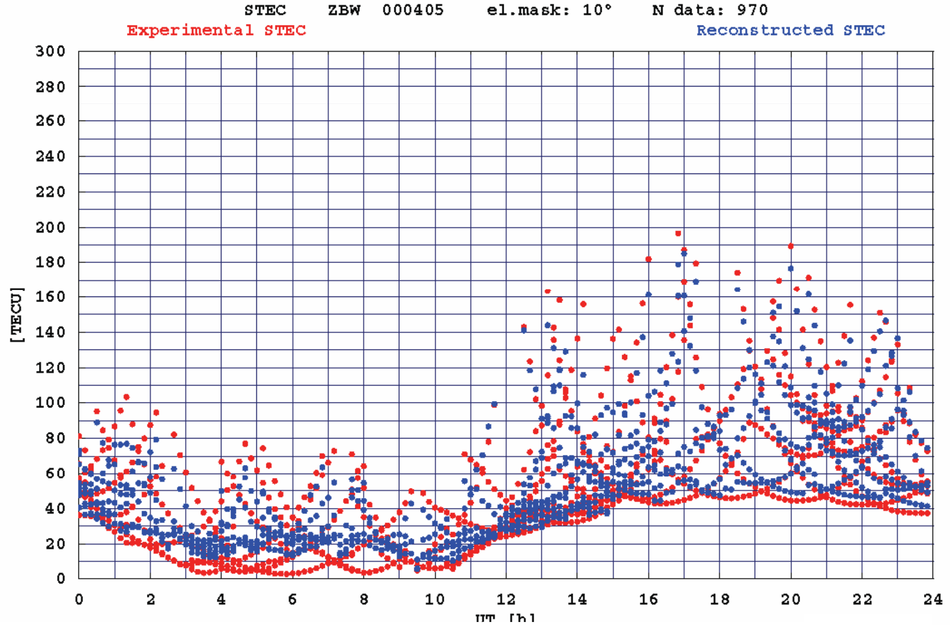
Use NeQuick to retrieve (locally) the 3D
electron density of the ionosphere

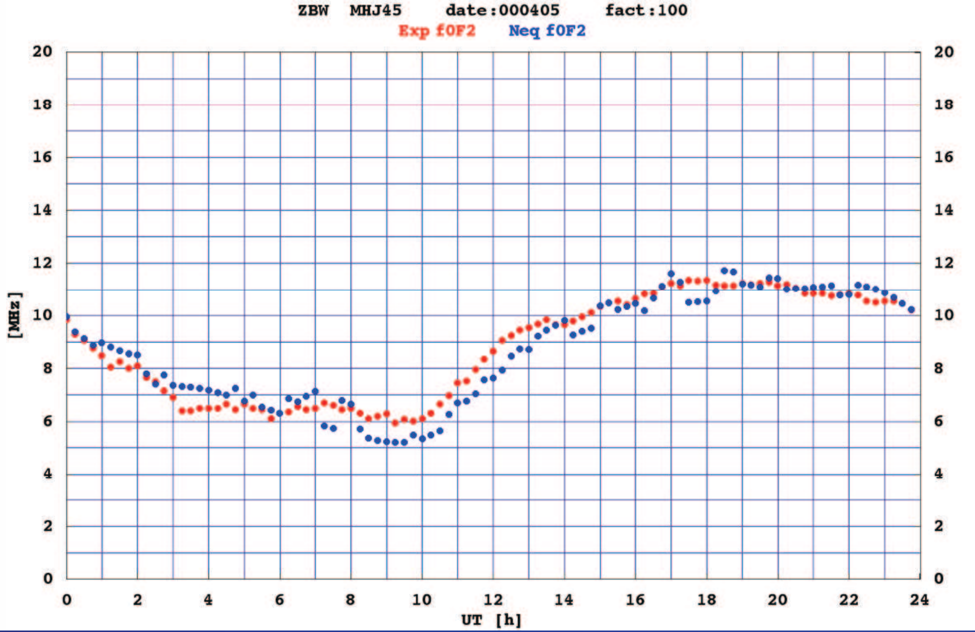
↓ ↓

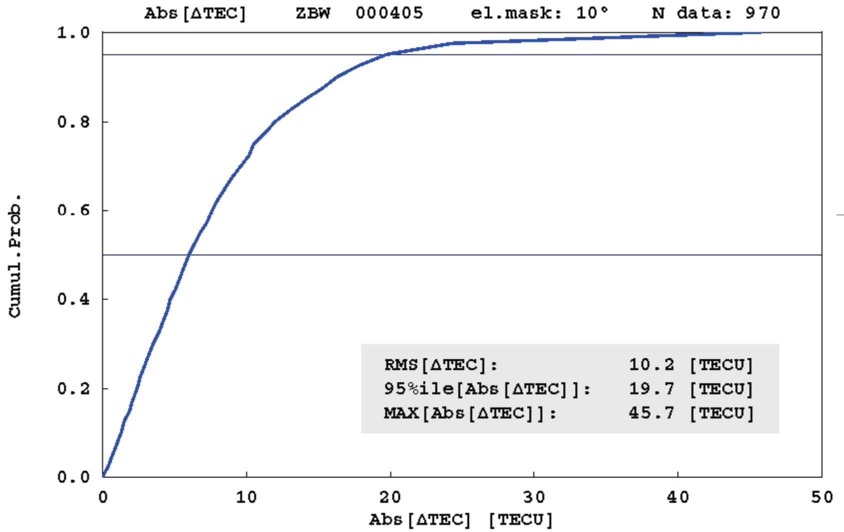
Reconstruct TEC along any
Station-to-satellite ray-path

Retrieve the foF2 values at
the Station

sTEC data ingestion, single stat.







Experimental and reconstructed sTEC

Experimental and retrieved foF2

Cumulative distribution of Abs[mismodeling]

Adapting NeQuick model to experimental slant TEC data at several locations

sTEC data ingestion, multi stat.

At a given epoch

m sTECexp (several stations & satellites)

↓

Minimize each mismodeling

$|sTECexp_i - sTECmod(az)_i|$

↓

Scattered Az_i → Interpolate to get regularly spaced grid

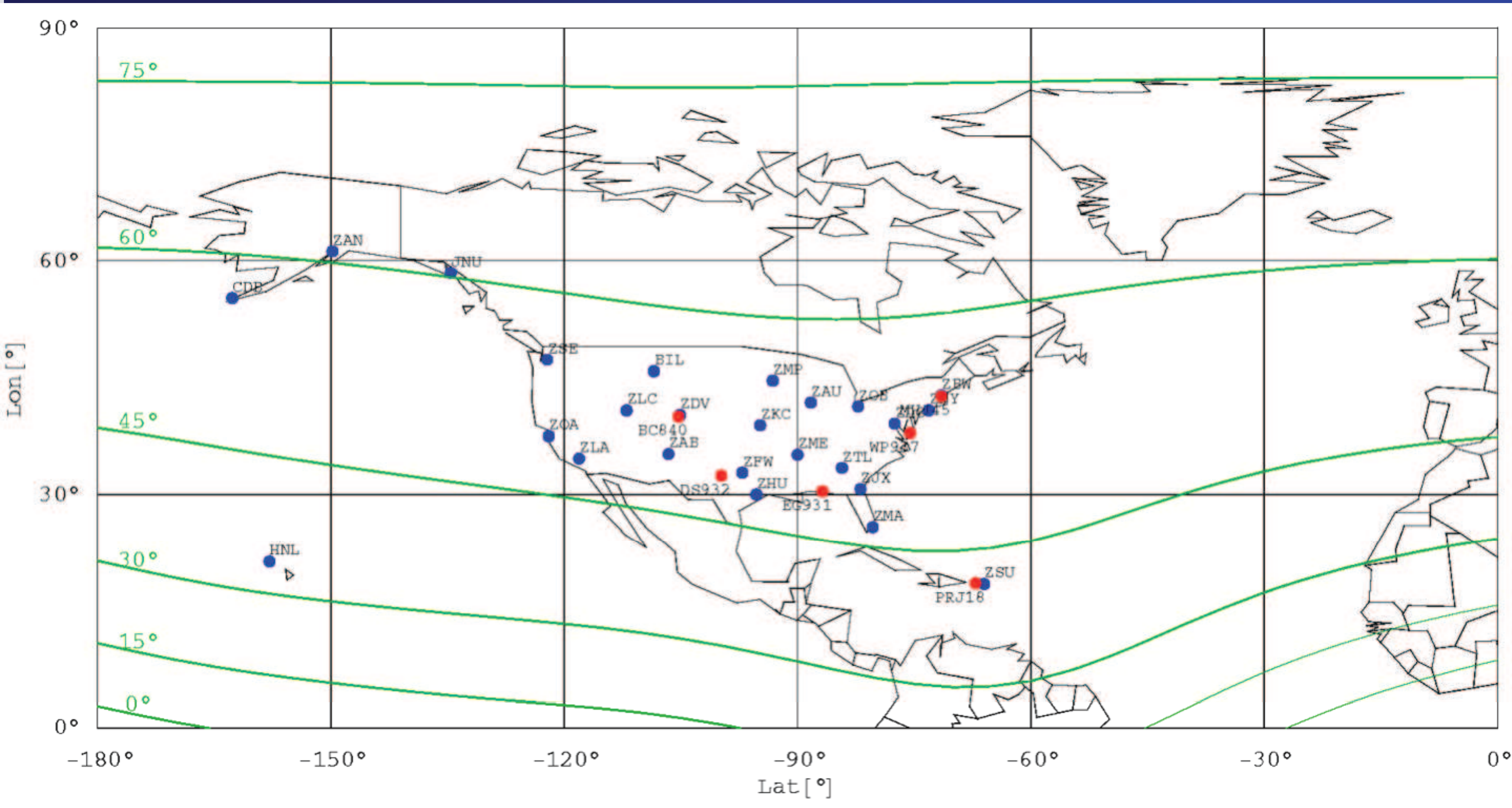
↓

Use NeQuick to reconstruct the 3D electron density of the ionosphere

↓ Reconstruct TEC along any given ray-path

↓ Reconstruct any foF2 value (foF2 map)

Stations & ionosondes locations

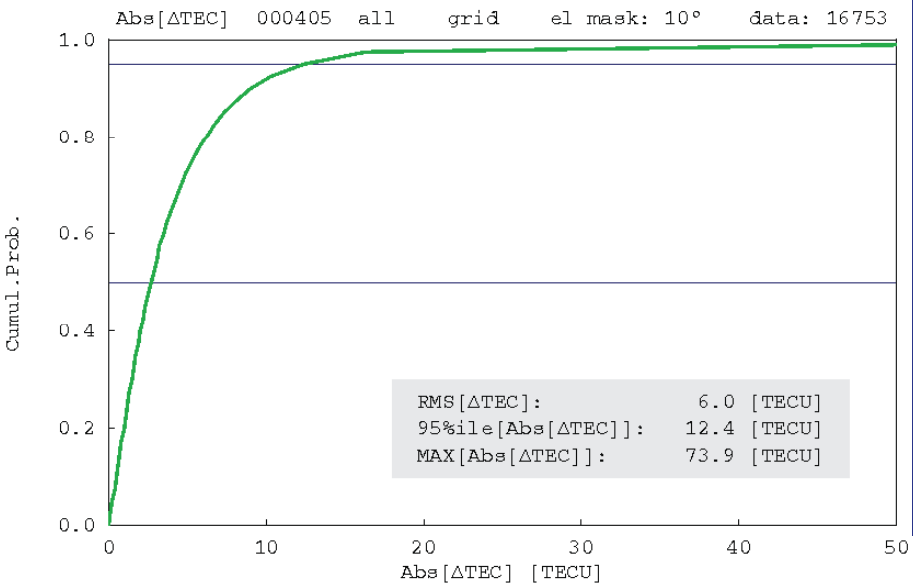


GPS receivers

Ionosondes

Modip isolines

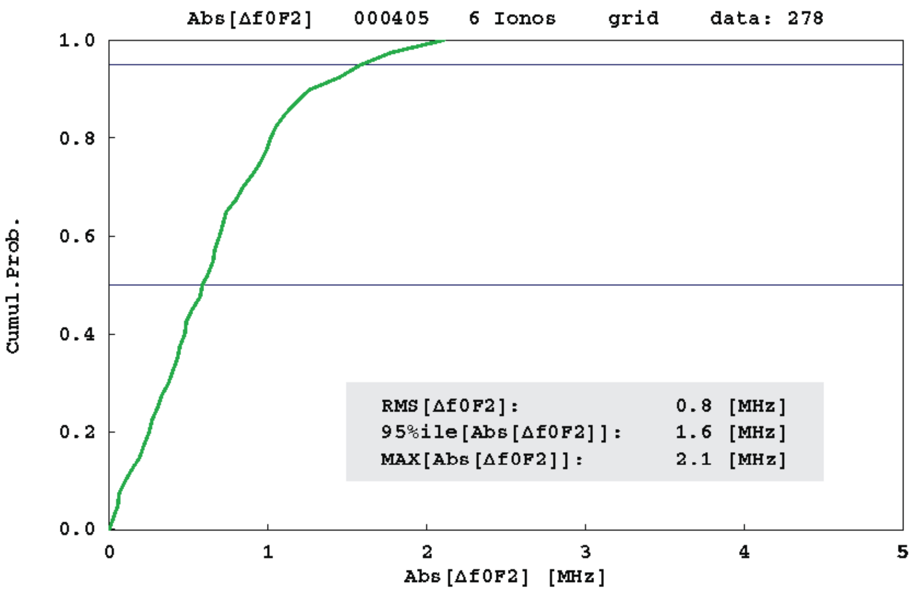
sTEC data ingestion, multi stat.

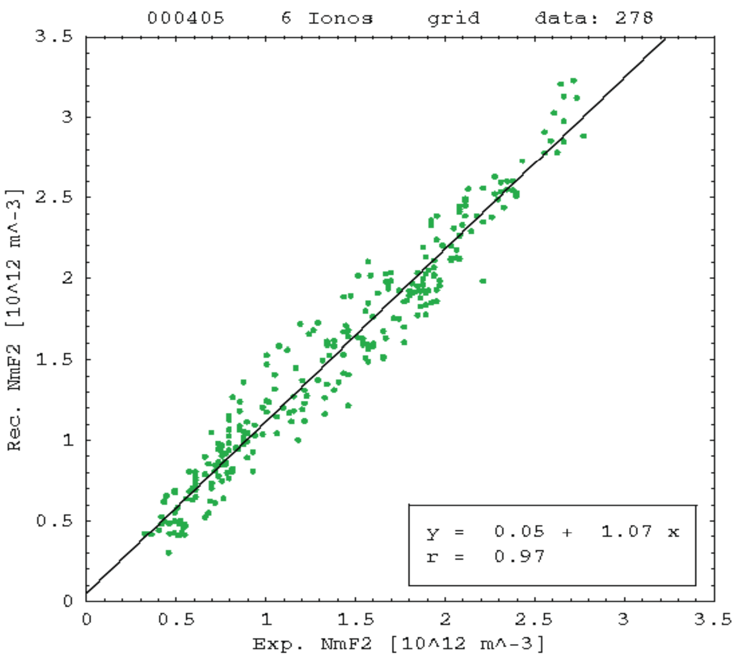


sTEC error

foF2 error

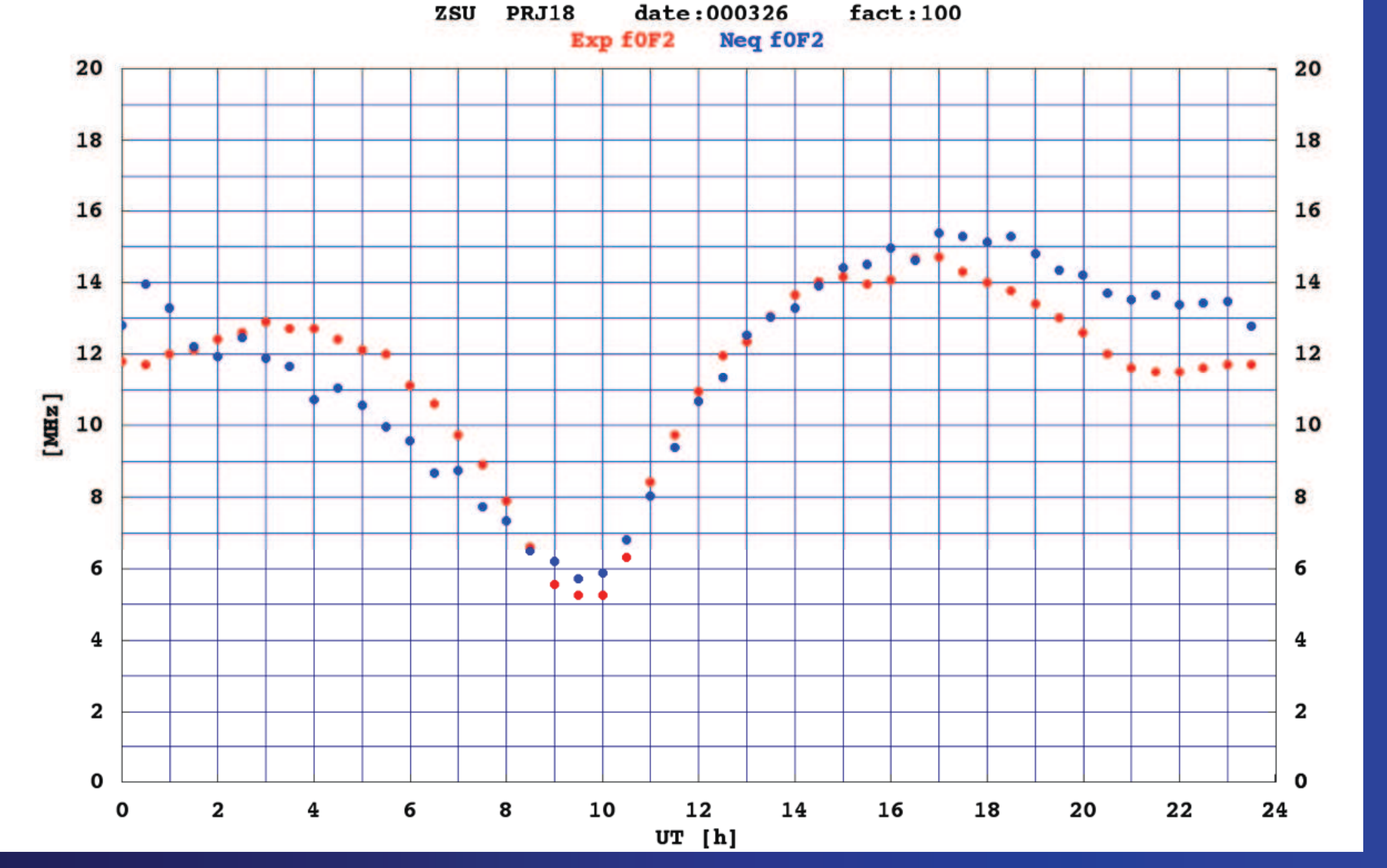
NmF2 exp.& rec.





Remark

Model is adapted to TEC but foF2 is not always adequately retrieved.

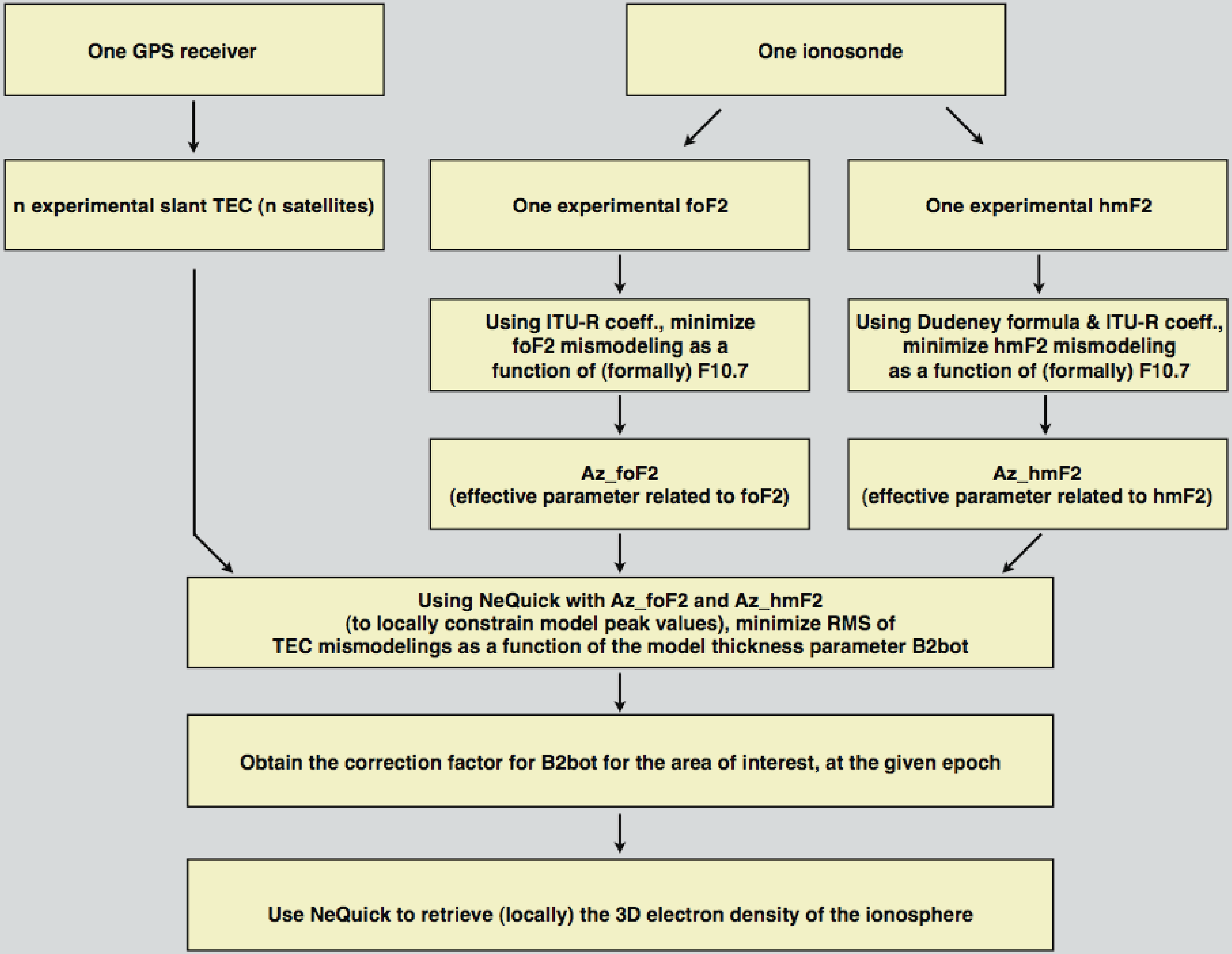


The results of these studies have indicated that there is the need to further improve the model formulation in terms of slab thickness.

Adapting NeQuick model to experimental slant TEC and foF2 data at a given location

(Use of slab thickness to constrain the NeQuick profile shape parameter)

At a given epoch:

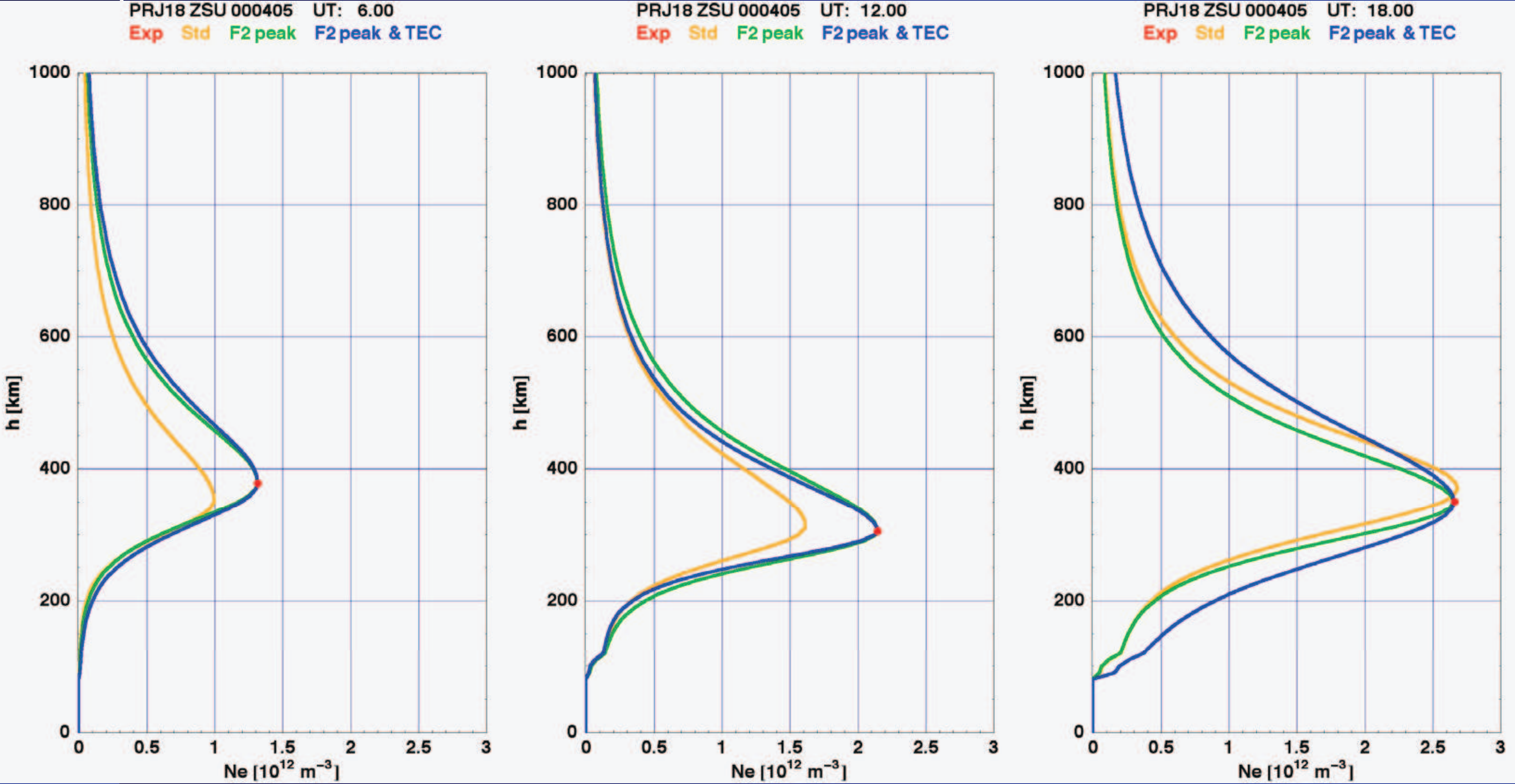


Remarks

- The use of two effective parameters has been considered in order to use the ITUR coefficients to estimate foF2 and hmF2 in a region surrounding the ground station.

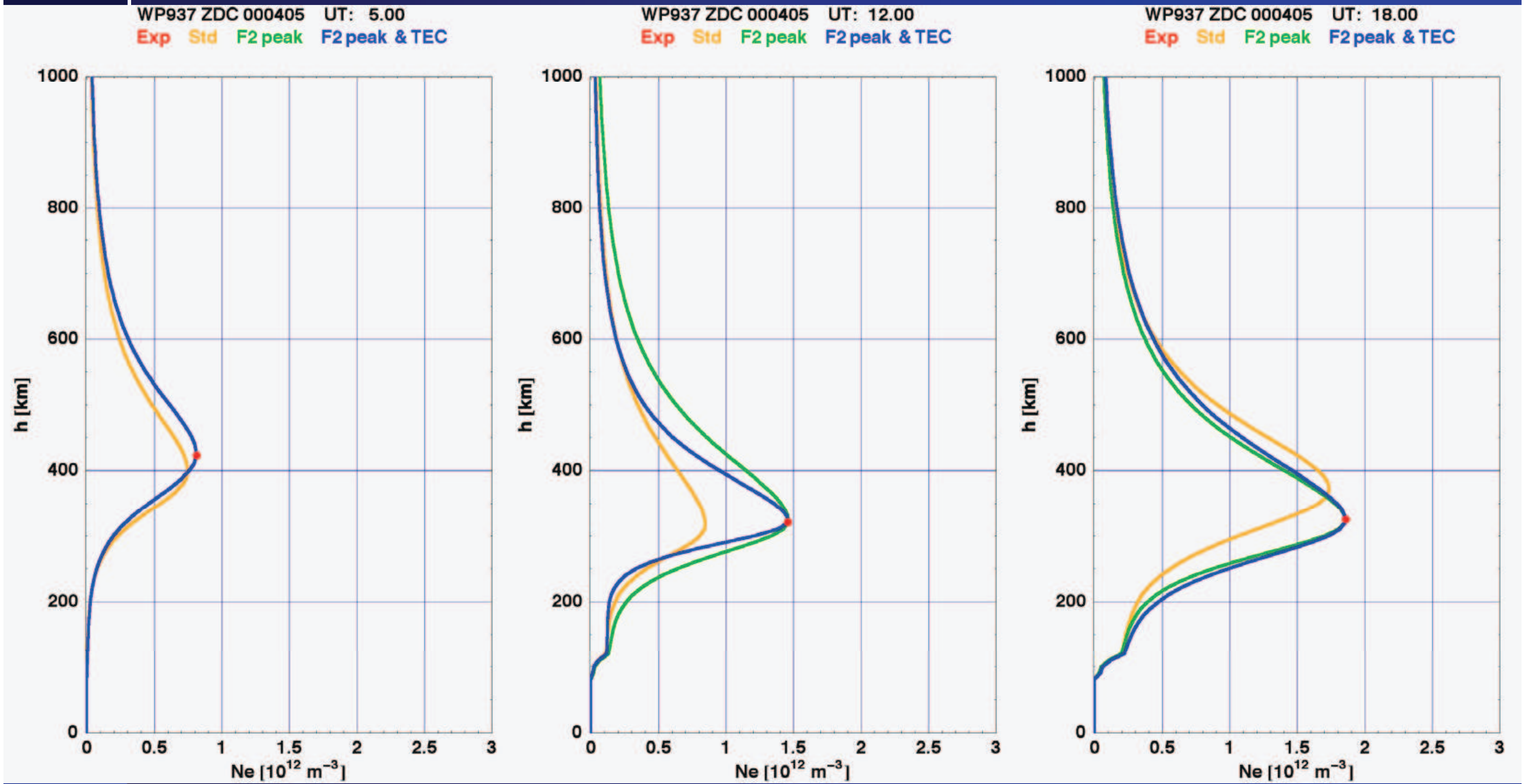
- In this way the peak parameter values can be estimated for a slant TEC computation.

Adaptation to GPS and Ionosonde data



Retrieved electron density profiles at Puerto Rico for the day 5 Apr 2000.

Adaptation to GPS and Ionosonde data



Retrieved electron density profiles at Wallops Islands for the day 5 Apr 2000.

Adaptation method validation

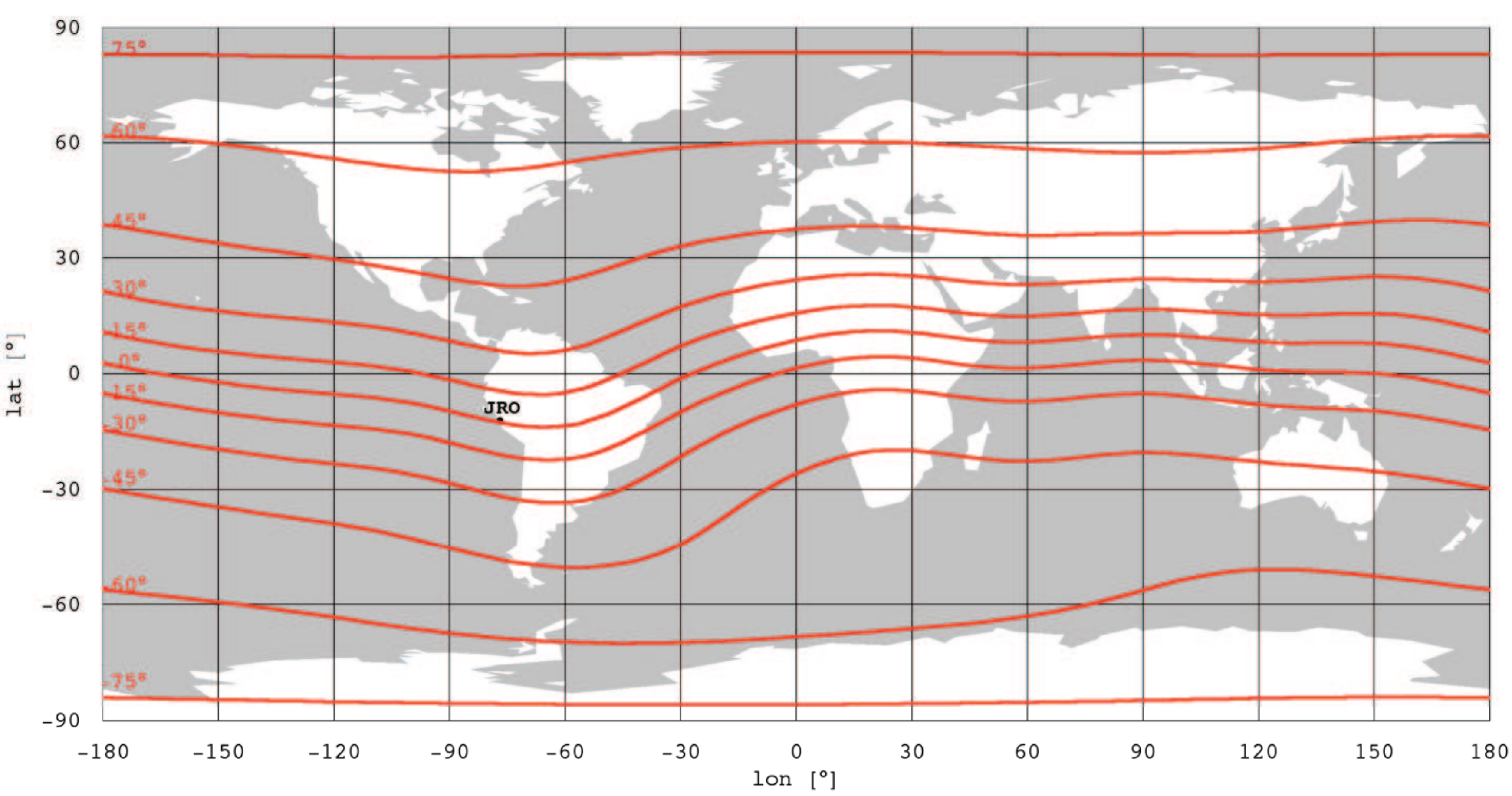
Use JRO profiles to simulate the process of adapting NeQuick to GPS derived TEC and ionosonde peak parameters data.

TEC and peak parameters are known from the profile.

↓

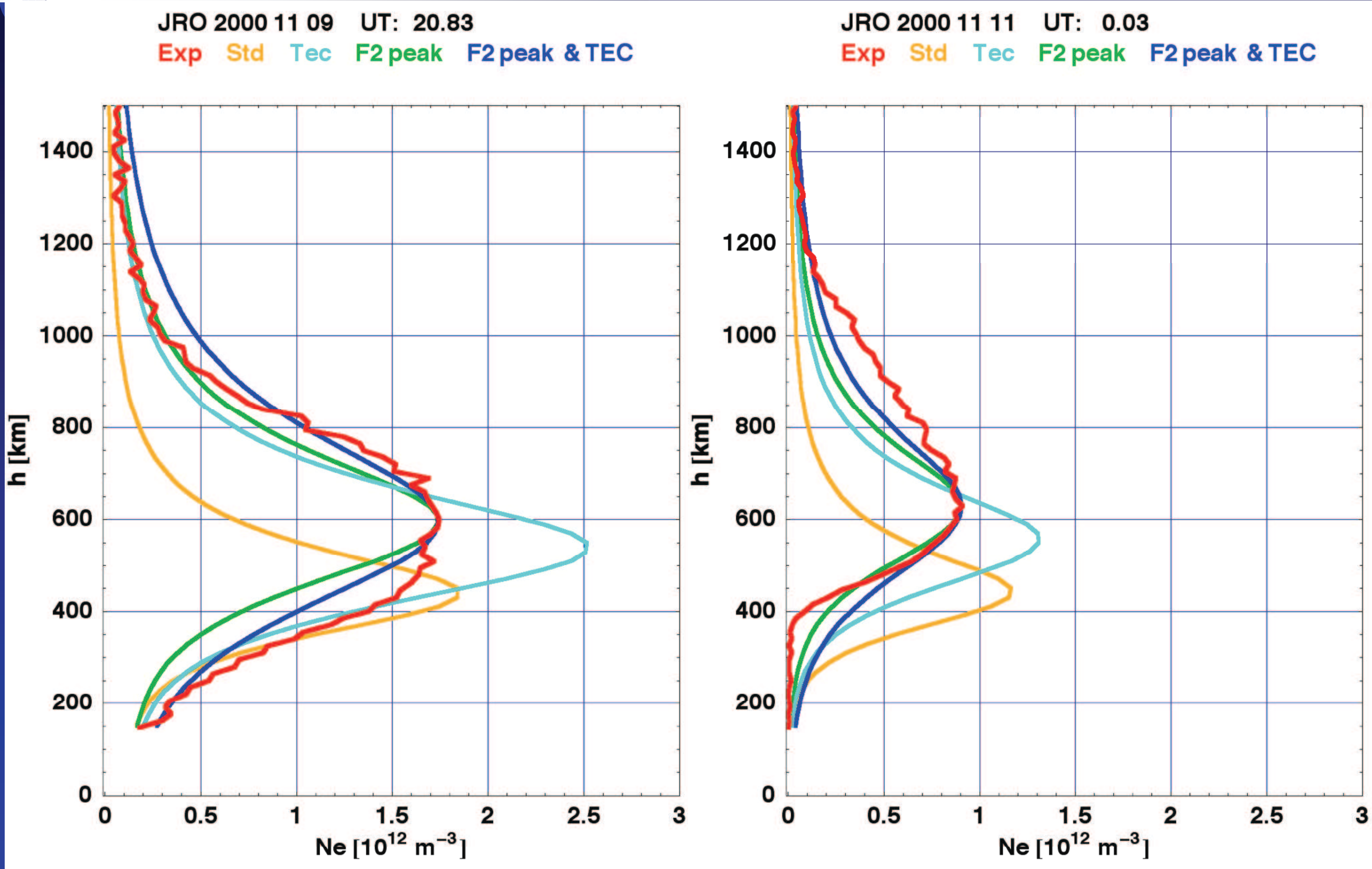
After model adaptation it is possible to compare profiles in order to evaluate the adaptation technique effectiveness.

Adaptation method validation



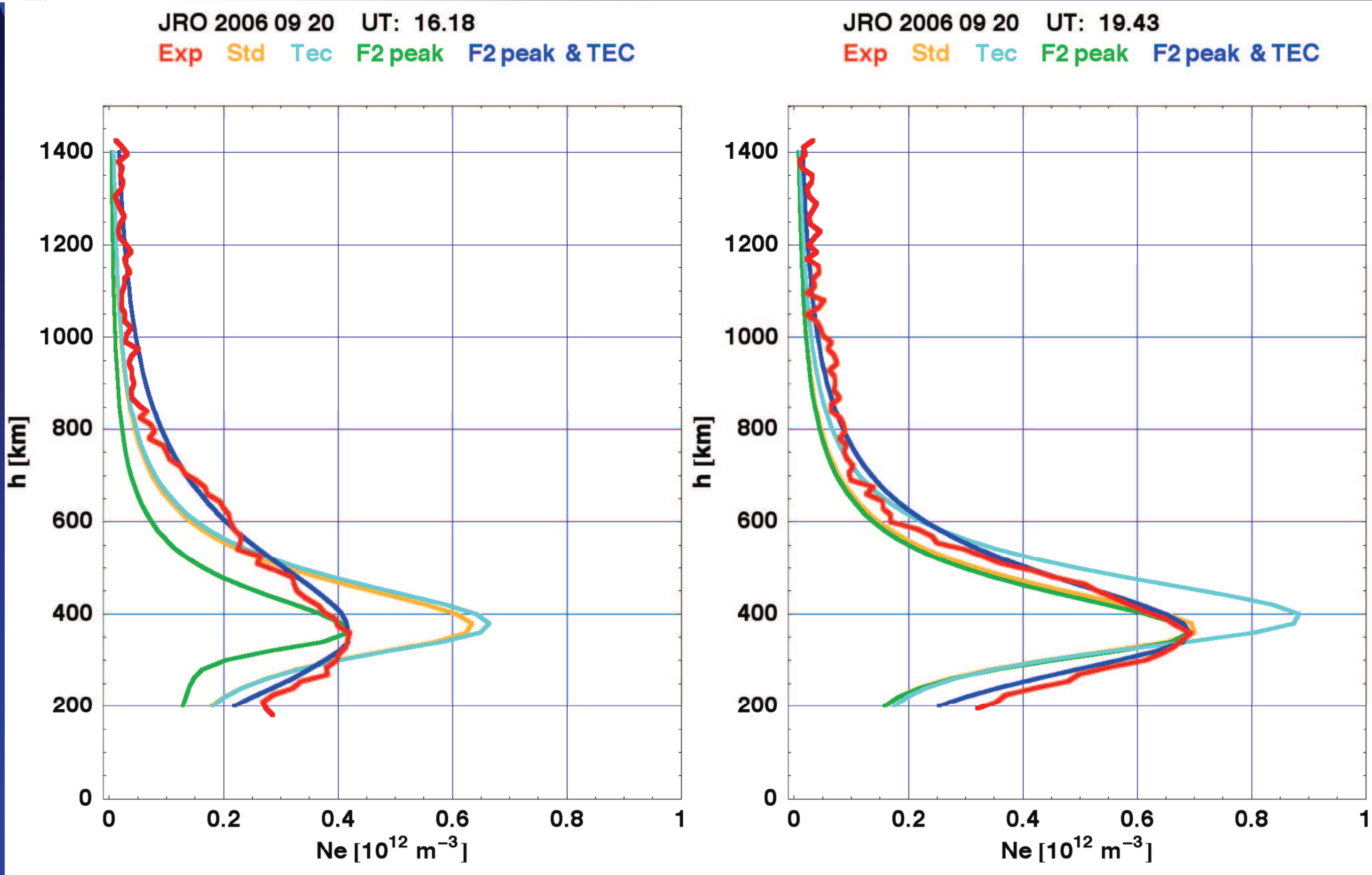
Jicamarca Radio Observatory (JRO) location

Adaptation method validation



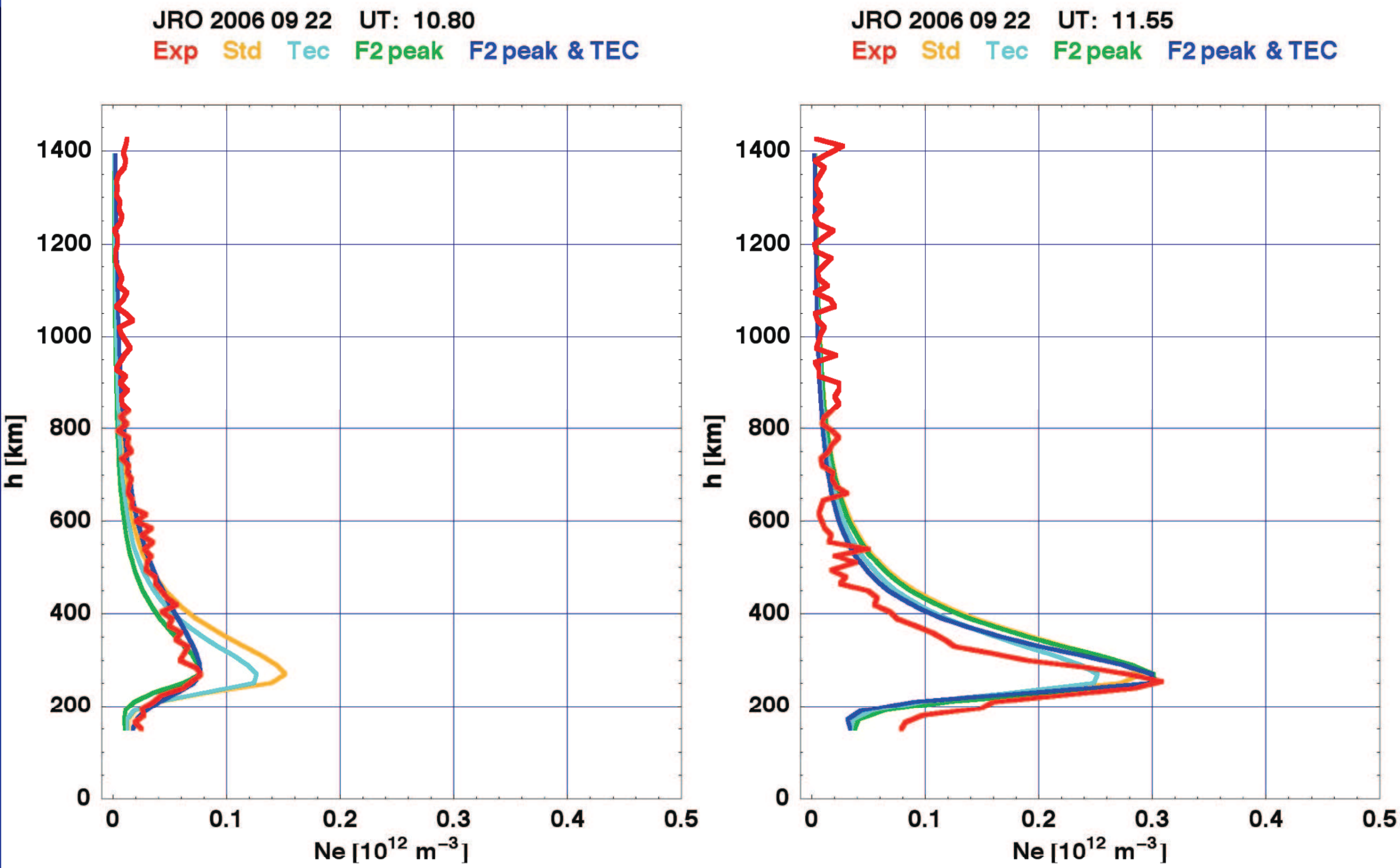
Model: NeQuick

Adaptation method validation



Model: NeQuick

Adaptation method validation



Model: NeQuick

Adapting IRI model to experimental slant TEC data at a given location

(For possible near real time applications)

The Model

- D. Bilitza, International reference Ionosphere 2000, Radio Sci., 36(2), 261 – 275, 2001.

- D. Bilitza and Reinisch, B., International Reference Ionosphere 2007: Improvements and new parameters, J. Adv. Space Res., doi:10.1016/j.asr.2007.07.048, 2008.

Remarks

Difficulties to implement NeQuick integration routine into IRI

Long integration time needed to obtain a slant TEC value with IRI

↓

Use equivalent vTEC instead of sTEC

↓

Mapping function errors (elevation, azimuth, station latitude, ...)

Small impact: elevation mask > 10° and usually 6 satellites used to compute IG12

IRI height integration limit of 2000 km

↓

Bias in comparison with “experimental” TEC up to 20000 km

Small impact: small TEC percentage is expected from 2000 to 20000 km

sTEC data ingestion, single stat.

At a given epoch

One station, n experimental sTEC (n satellites)

Minimize RMS of the equivalent vTEC mismodelings as a function of IG12

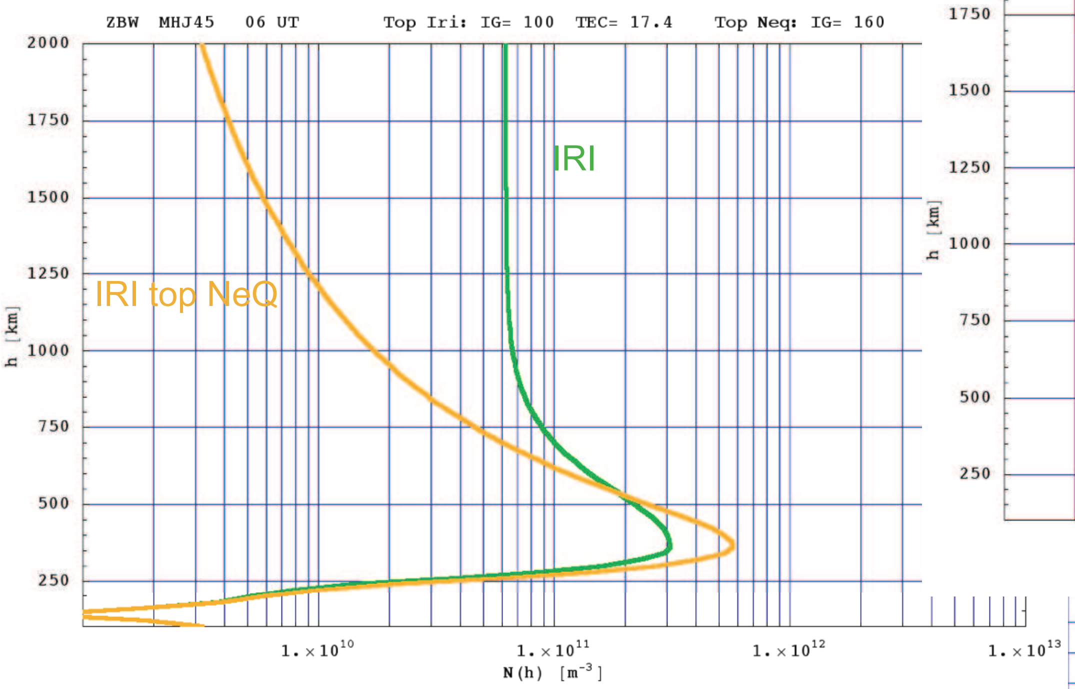
IG12 at the station, for the given epoch

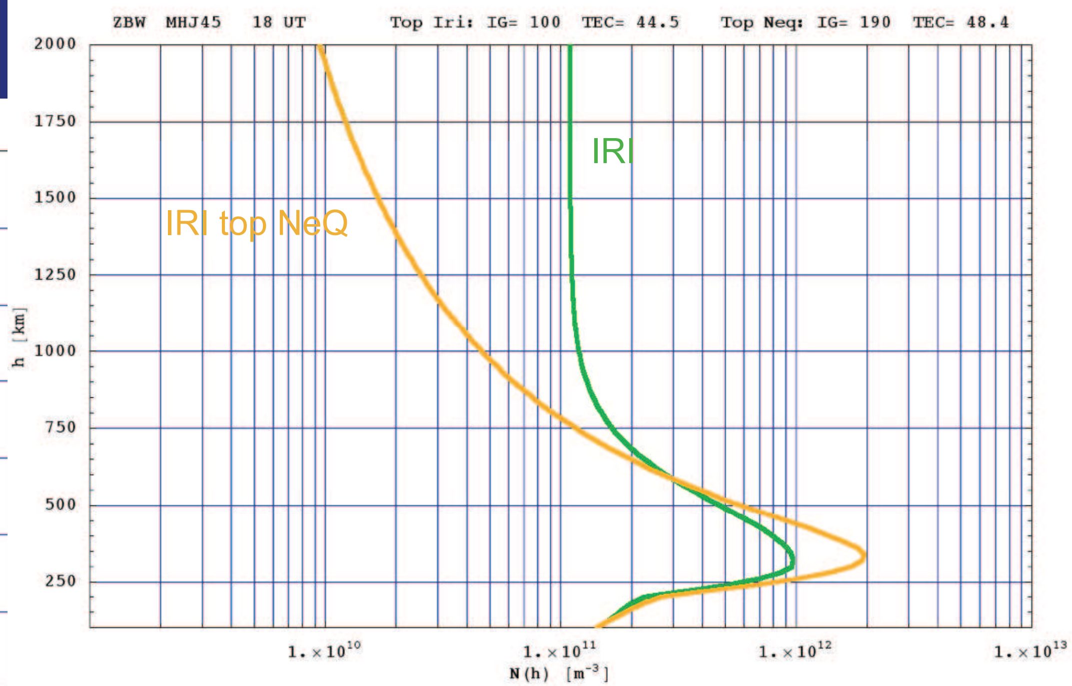
Use IRI to retrieve (locally) the 3D electron density of the ionosphere

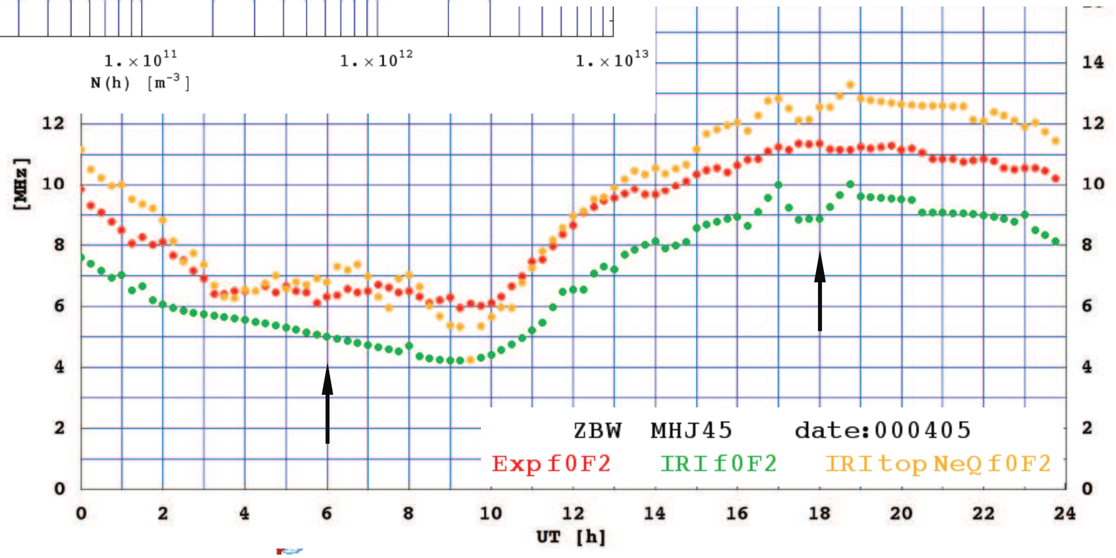
Reconstruct TEC along any Station-to-satellite ray-path

Retrieve the foF2 values at the Station

Results: fof2 comparisons







Millstone Hill

Adapting IRI model to experimental vertical TEC and foF2 data at a given location

(Use of slab thickness to constrain the IRI profile shape parameters)

Remarks

- In the case of IRI, the experimental values of foF2 and hmF2 have been directly used as input and the concept of effective ionization level has not been used to reproduce the experimental values of foF2 and hmF2.

- The same modulating coefficient has been applied to B0 and B2bot in order to modify the profile thickness.

Adaptation method validation

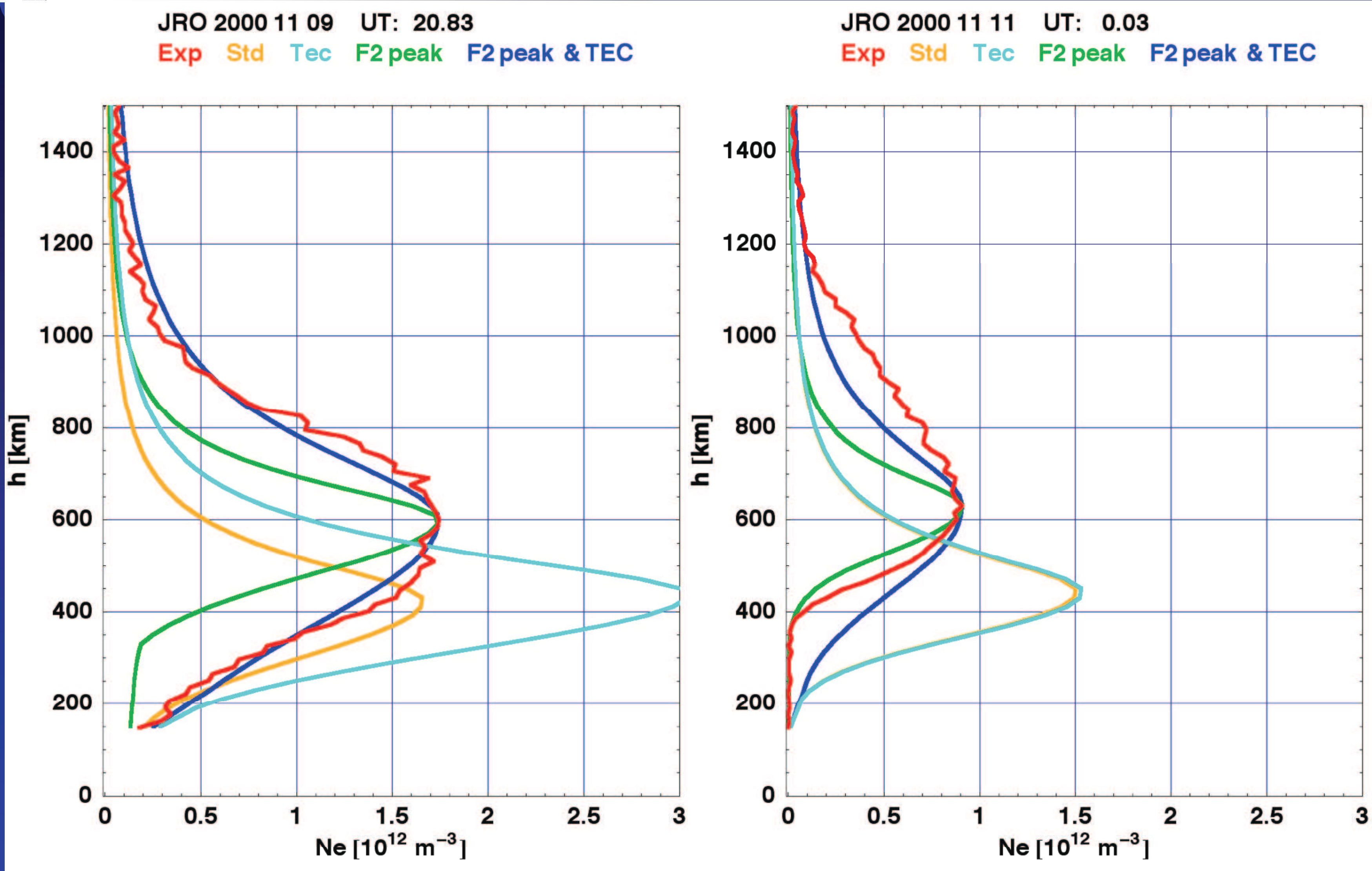
Use JRO profiles to simulate the process of adapting NeQuick to GPS derived TEC and ionosonde peak parameters data.

TEC and peak parameters are known from the profile.

↓

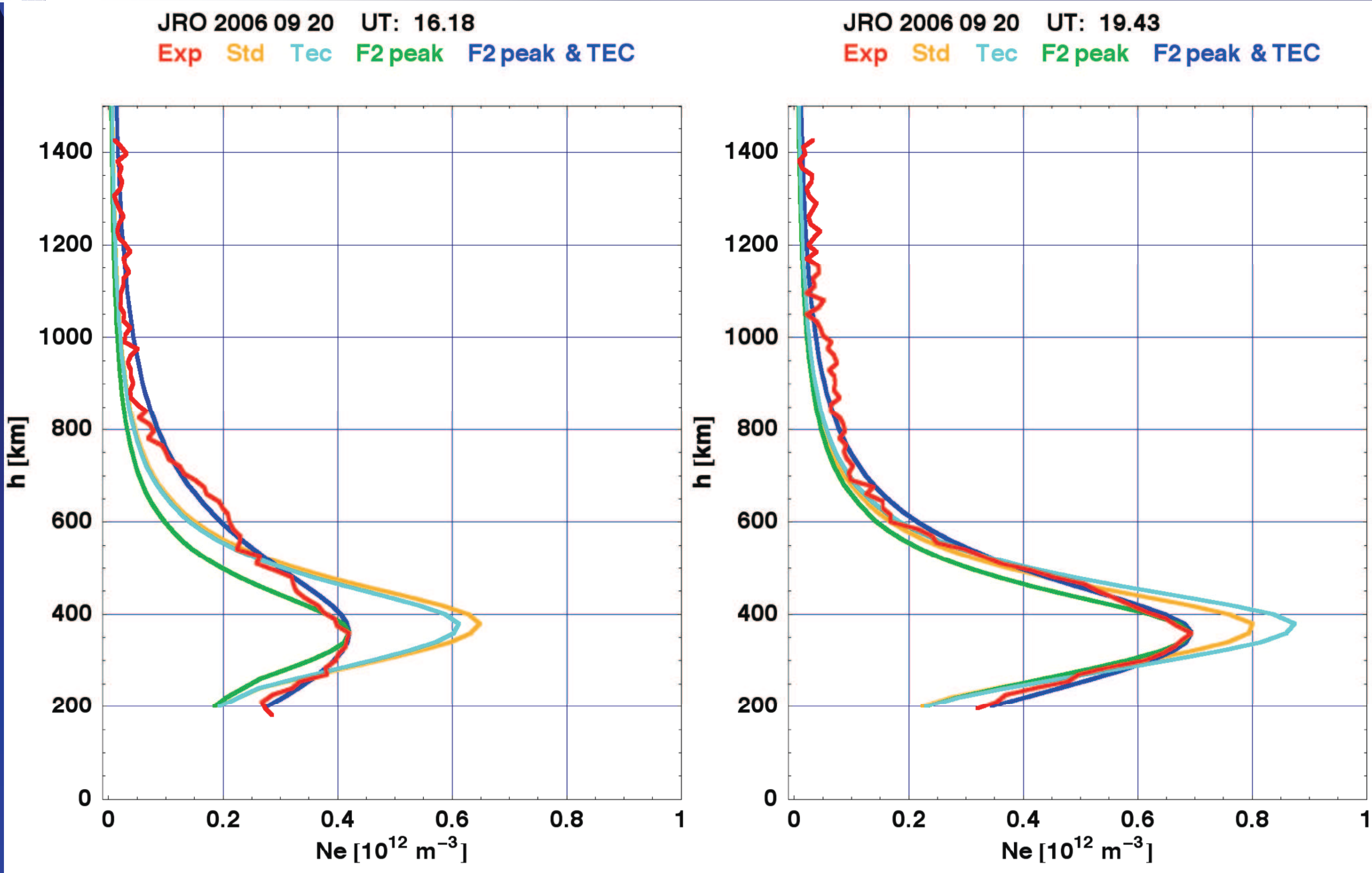
After model adaptation it is possible to compare profiles in order to evaluate the adaptation technique effectiveness.

Adaptation method validation



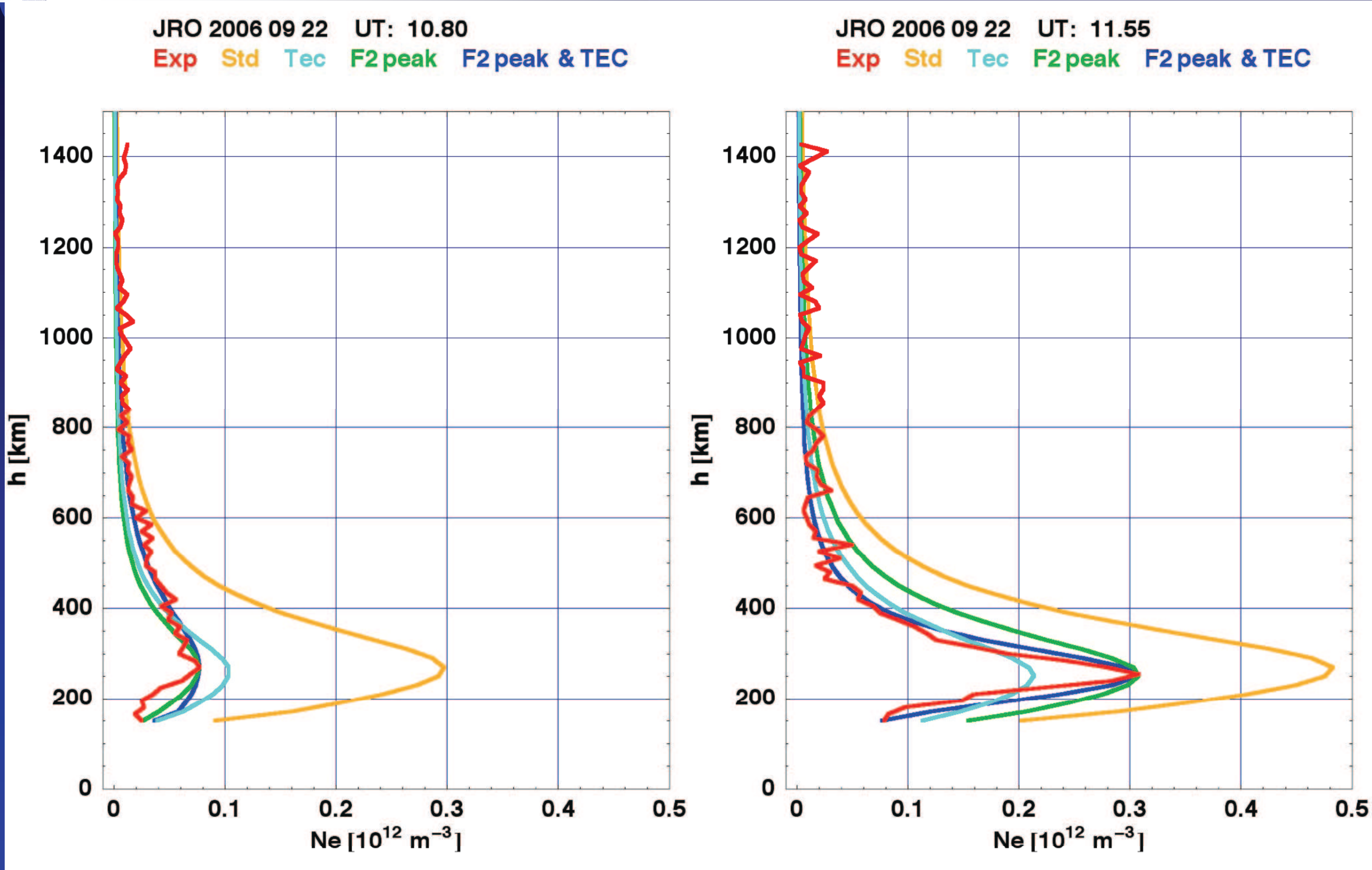
Model: IRI

Adaptation method validation



Model: IRI

Adaptation method validation



Model: IRI

Remarks

- The studies carried out with JRO profiles have indicated that the contemporary availability of TEC and foF2 (plus hmF2) data can be considered as a "minimum requirement" for the implementation of an effective electron density retrieval technique based on model adaptation to experimental data.
- Nevertheless, the proposed adaptation scheme also indicated a possible strategy to improve the analytical formulation of the model.
- For example it is possible to separate the contribution of the bottomside and the topside in order to have a modulating coefficient for each part of the profile.

Next step

- Ingest Radio Occultation measurements into NeQuick model.

Acknowledgments

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Thank you for your attention

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- Di Giovanni, G., Radicella, S.M., 1990. An analytical model of the electron density profile in the ionosphere. Advances in Space Research 10 (11), 27–30.
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