Intercomparison of LIEDR and NeQuick ionospheric modeling using radio occultation and ionosonde measurements

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Outline

- Motivation
- LIEDR
- NeQuick
- Intercomparison methodology
- Results
- Summary

Local Ionospheric Electron Density profile Reconstruction (LIEDR)

An automatic system for real-time specification of the local ionosphere was developed and installed at the RMI Geophysical Centre in Dourbes (50.1°N, 4.6°E). The system, dubbed LIEDR (Local Ionospheric Electron Density profile Reconstruction), acquires measurements from a digital ionosonde and a collocated GNSS receiver, processes the incoming measurements, computes the full-height ionospheric electron density profile, and displays the resulting profilograms.

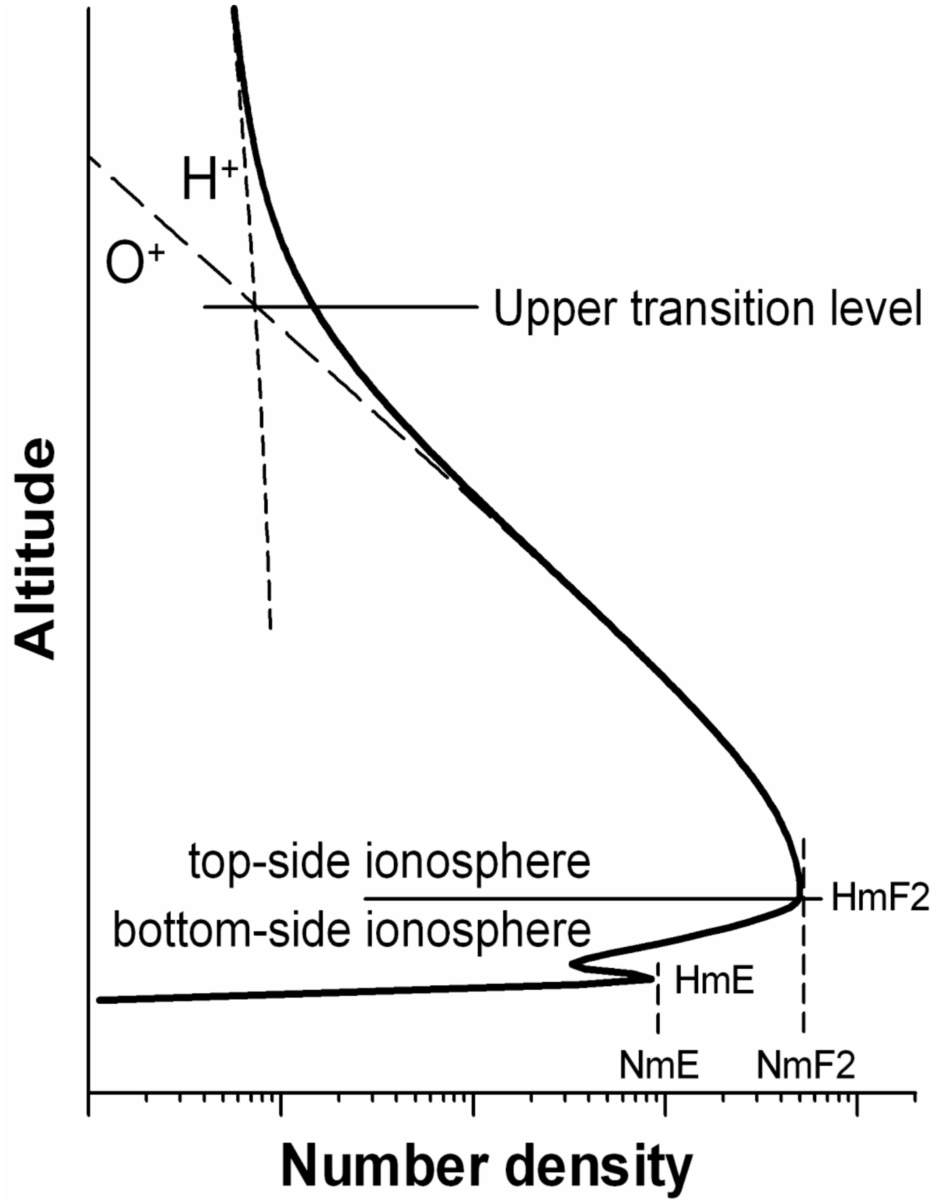
NeQuick

NeQuick is a quick-run model developed at the ICTP with collaboration of the University of Graz. It reproduces the median ionosphere behavior and is particularly designed for trans-ionospheric propagation applications. To provide the 3D ionospheric electron density distribution for current conditions, various ionospheric electron density reconstruction techniques, based on the NeQuick adaptation to GNSS TEC data and ionosonde measured peak parameters, have been developed.

Motivation

To compare the modeling capabilities of LIEDR and NeQuick by using ionospheric radio occultation (IRO) and vertical incidence sounding (VIS) measurements.

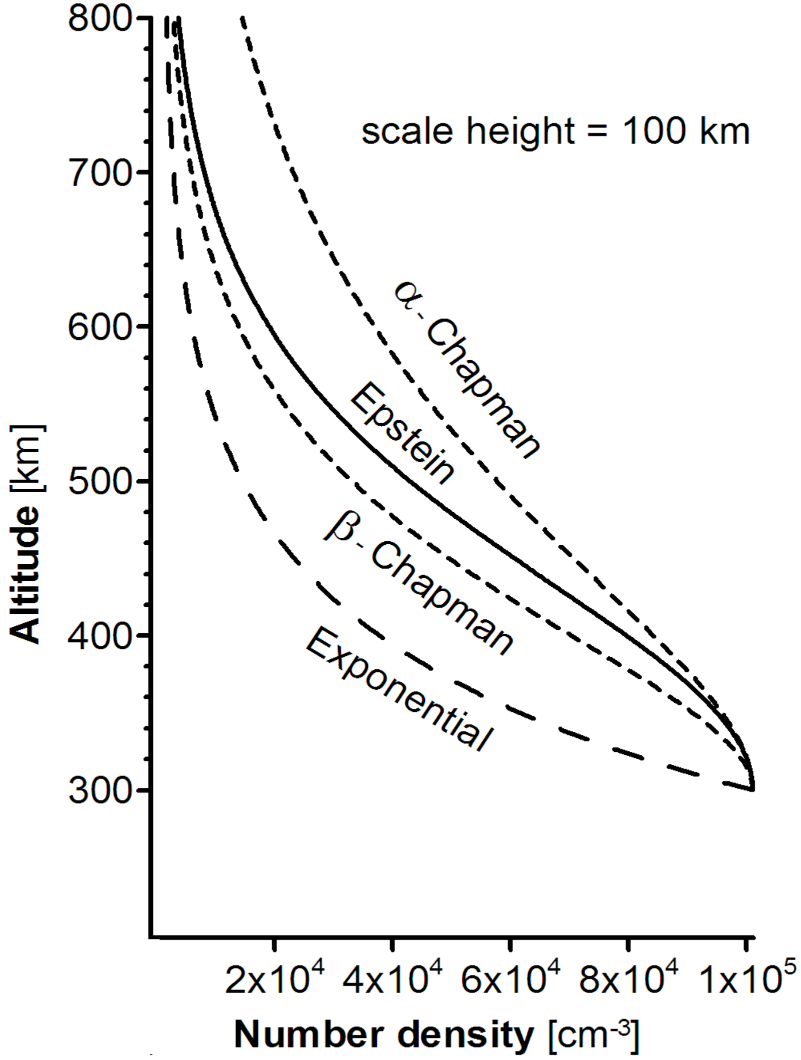
LIEDR - Method



- Key parameters (profile):
  - peak densities and heights
  - ionospheric scale height
  - ion transition height (level)
- Principal difficulties (reconstruction):
  - topside electron profile
  - concurrent and collocated data
- Possible approaches:
  - directly model the electron profile
  - model the ion profiles first

Stankov et al. (2003): A new method for reconstruction of the vertical electron density distribution in the upper ionosphere and plasmasphere. Journal of Geophysical Research, 108(A5), 1164, doi:10.1029/2002JA009570.

LIEDR - Method



Functions used for the topside electron density profile, scale height fixed at 100 km.

- **Epstein (secant hyperbolic) profiler**

$$N_i(h) = N_i(h_m)\, sech^2\left(\frac{h-h_m}{2\,H_i}\right)$$

$$sech(h) = 1/\cosh(h) \quad \cosh(x) = 0.5\,(\exp(h)+\exp(-h))$$

- **Chapman profilers**

$$N(h) = N(h_m)\exp\left\{c\left[1-\frac{h-h_m}{H}-\exp\left(-\frac{h-h_m}{H}\right)\right]\right\}$$

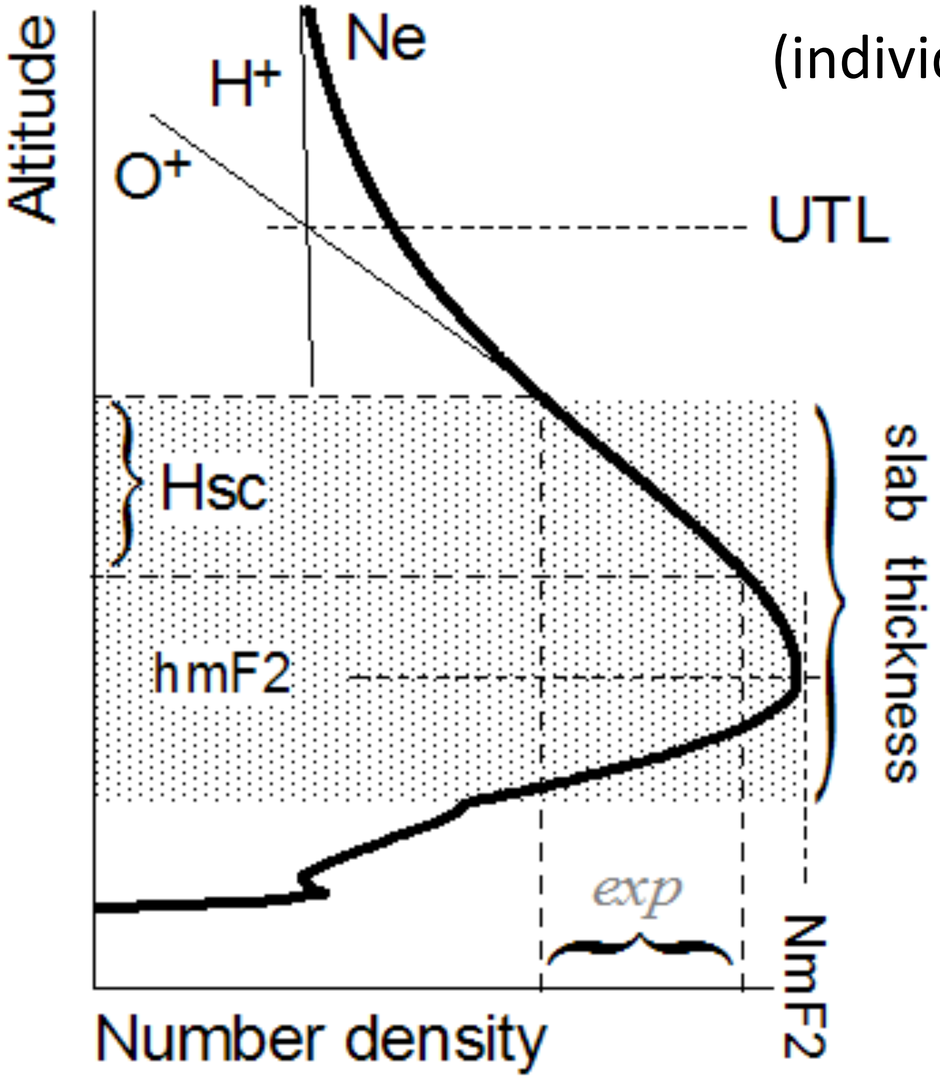
α - Chapman ($c = 0.5$), β - Chapman ($c = 1$)

- **Exponential profiler**

$$N_i(h) = N_i(h_m)\, exp\left(-\frac{h-h_m}{H_i}\right)$$

Stankov et al. (2003): A new method for reconstruction of the vertical electron density distribution in the upper ionosphere and plasmasphere. Journal of Geophysical Research, 108(A5), 1164, doi:10.1029/2002JA009570.

LIEDR - Method



Unknown parameters
(individual ion profiles reconstruction approach)

- H_{O+} , O^+ topside scale height
- N_{mO+} , O^+ density at peak height
- H_{H+} , H^+ topside scale height
- N_{mH+}, H^+ density at peak height

Stankov et al. (2003): A new method for reconstruction of the vertical electron density distribution in the upper ionosphere and plasmasphere. Journal of Geophysical Research, 108(A5), 1164, doi:10.1029/2002JA009570.

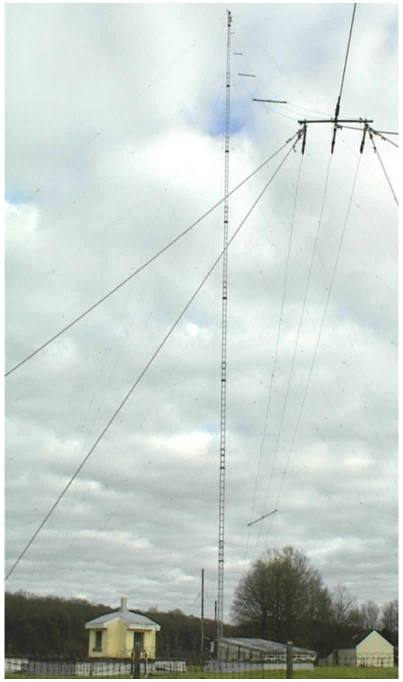
LIEDR - Input

GNSS measurements

NovAtel GPStation-6 (TM)
Sampling rate: (max) 50 Hz
Tracking: 120 channels

Vertical Incidence Sounding

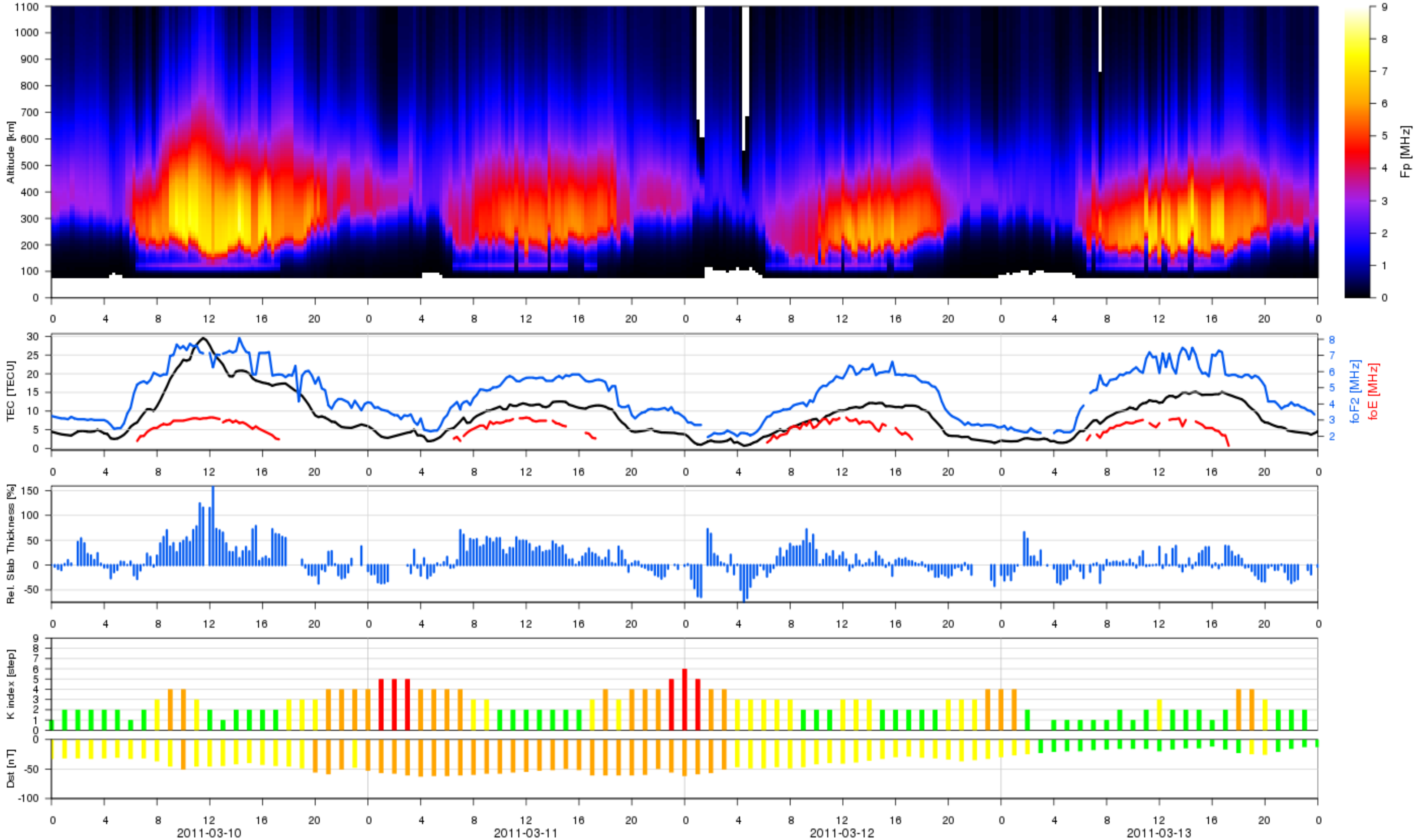
Sounder: Lowell Digisonde 4D
Location: Dourbes (50.1ºN, 4.6ºE)
URSI code: DB049
Cadence (nominal): 5 min



LIEDR - Output

http://ionosphere.meteo.be/ionosphere/liedr

$$f_p[MHz] \approx c_p\, N_e^{0.5}[el/m^3]$$
$$c_p = 0.898 \times 10^{-5}$$



Stankov et al. (2011): Local ionospheric electron density profile reconstruction in real time. Adv. Space Res. 47(7), 1172-1180.

The NeQuick 2 model

- To describe the electron density of the ionosphere above 100 km and up to the peak of the F2 layer, NeQuick uses a profile formulation that includes five semi-Epstein layers with modeled thickness parameters.

$$N_{bot}(h) = N_E(h) + N_{F1}(h) + N_{F2}(h)$$

$$N_E(h) = \frac{4Nm^*E}{\left(1+\exp\left(\frac{h-hmE}{BE}\xi(h)\right)\right)^2}\exp\left(\frac{h-hmE}{BE}\xi(h)\right)$$

$$N_{F1}(h) = \frac{4Nm^*F1}{\left(1+\exp\left(\frac{h-hmF1}{B1}\xi(h)\right)\right)^2}\exp\left(\frac{h-hmF1}{B1}\xi(h)\right)$$

$$N_{F2}(h) = \frac{4NmF2}{\left(1+\exp\left(\frac{h-hmF2}{B2}\right)\right)^2}\exp\left(\frac{h-hmF2}{B2}\right)$$

The NeQuick 2 model

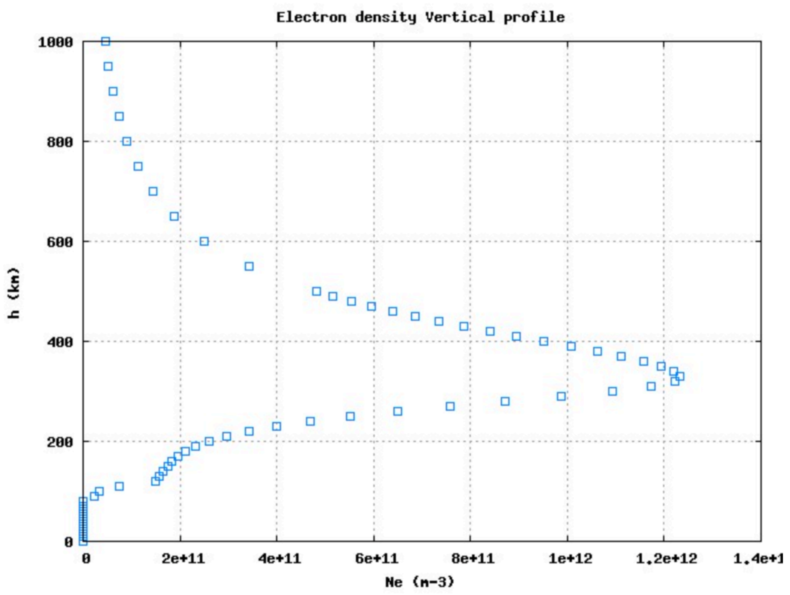
- Three profile anchor points are used: the E layer peak, the F1 peak and the F2 peak, that are modelled in terms of the ionosonde parameters foE, foF1, foF2 and M(3000)F2. These values can be modelled or experimentally derived (=> data ingestion).

- The model topside is represented by a semi-Epstein layer with a height-dependent thickness parameter empirically determined.

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

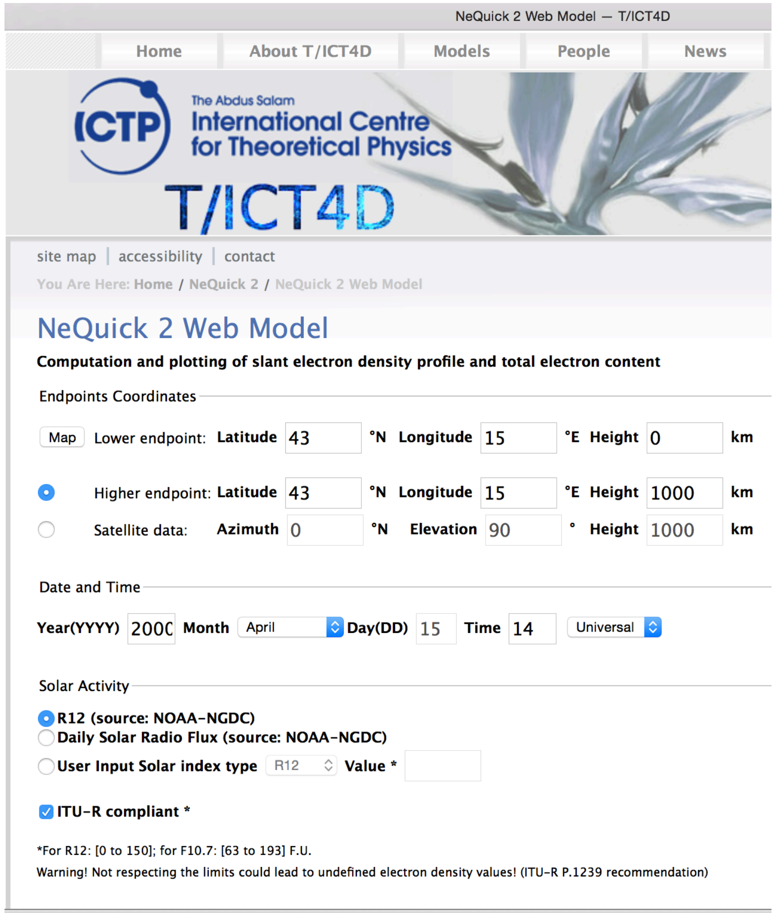
$$z = \frac{h - hmF2}{H}$$

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



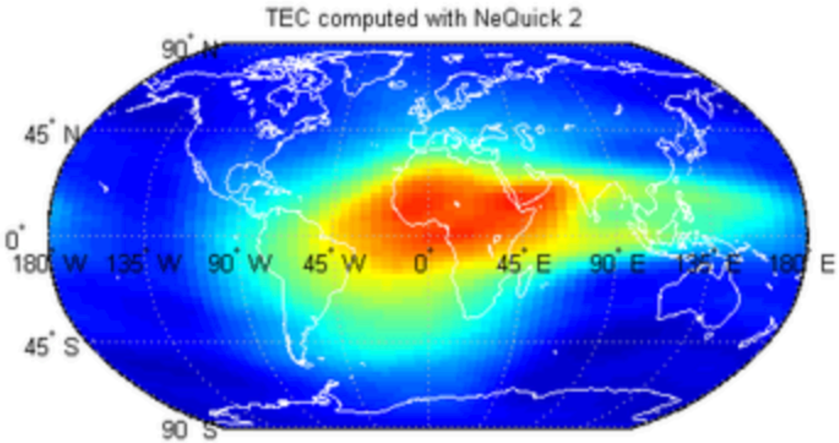
The NeQuick 2 model

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



- NeQuick 2 online:

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



- In the present study a modified NeQuick has been used to allow for data ingestion.

Intercomparison - Methodology

- Ionosonde-derived values of the ionosphere key parameters, such as the F2-layer critical frequency, f_oF_2, and peak height, h_mF_2, can be utilized in validating IRO-derived peak densities and heights.

- Both sets of (IRO and VIS) data can be employed in evaluating the performance of the LIEDR and NeQuick reconstruction of the ionospheric electron density profiles.

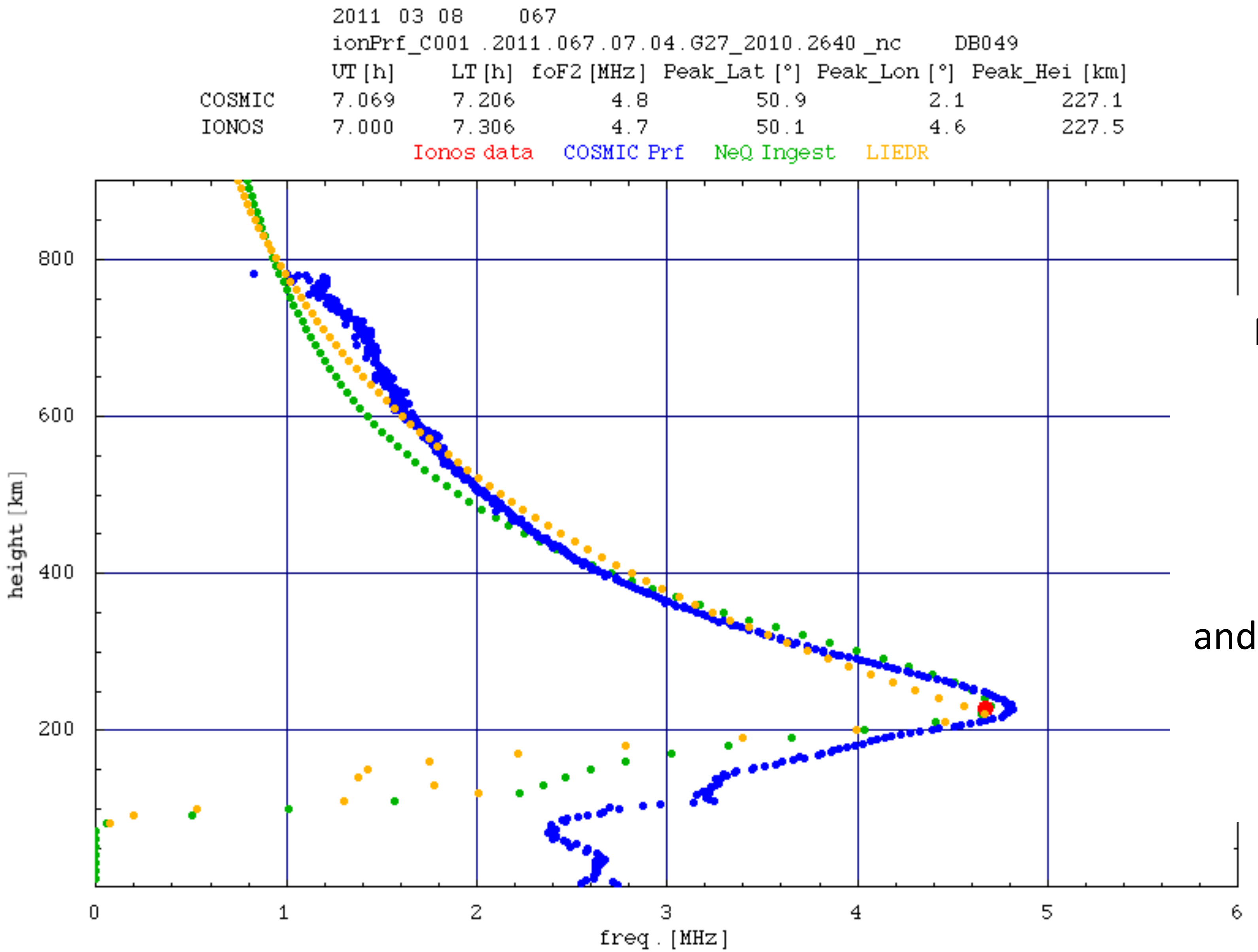
Data selection:

IRO: All cases of COSMIC IRO measurements that produced vertical electron density profiles within 2.5° in latitude and 5° in longitude from the Dourbes ionosonde station in the course of a month (March 2011)

VIS: Digisonde-4D, sounding rate – once every 15 minutes, selected only IRO events within 5 minutes from each sounding (about 2-3 cases per day were identified and used in the analysis)

Evaluation of LIEDR and NeQuick based on ionosonde and IRO data

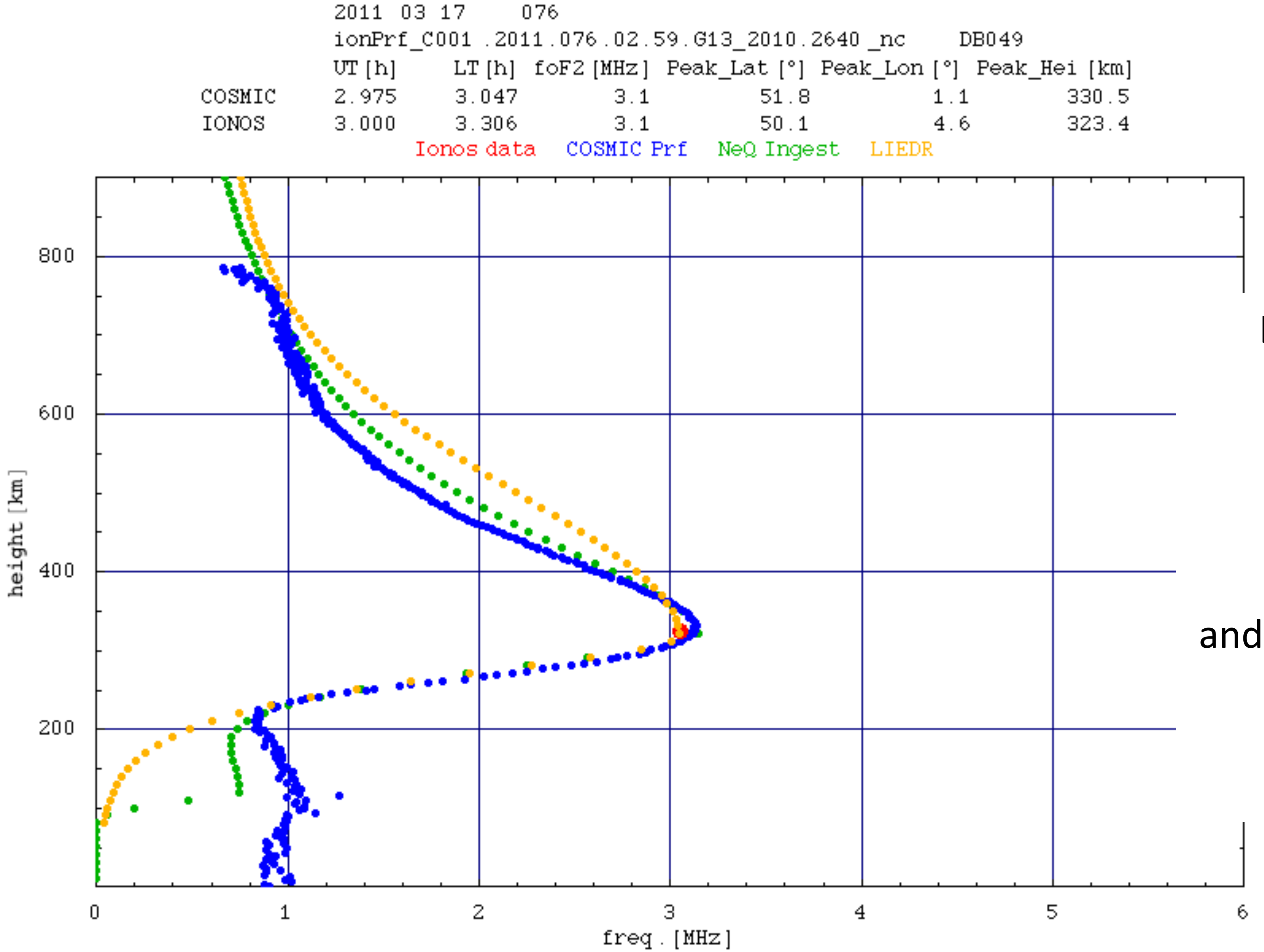
Day-time



Ionospheric plasma frequency profiles above Dourbes as reconstructed with LIEDR (yellow), NeQuick (green), and COSMIC IRO (blue) for March 08, 2011 at 07:00 UT (day-time)

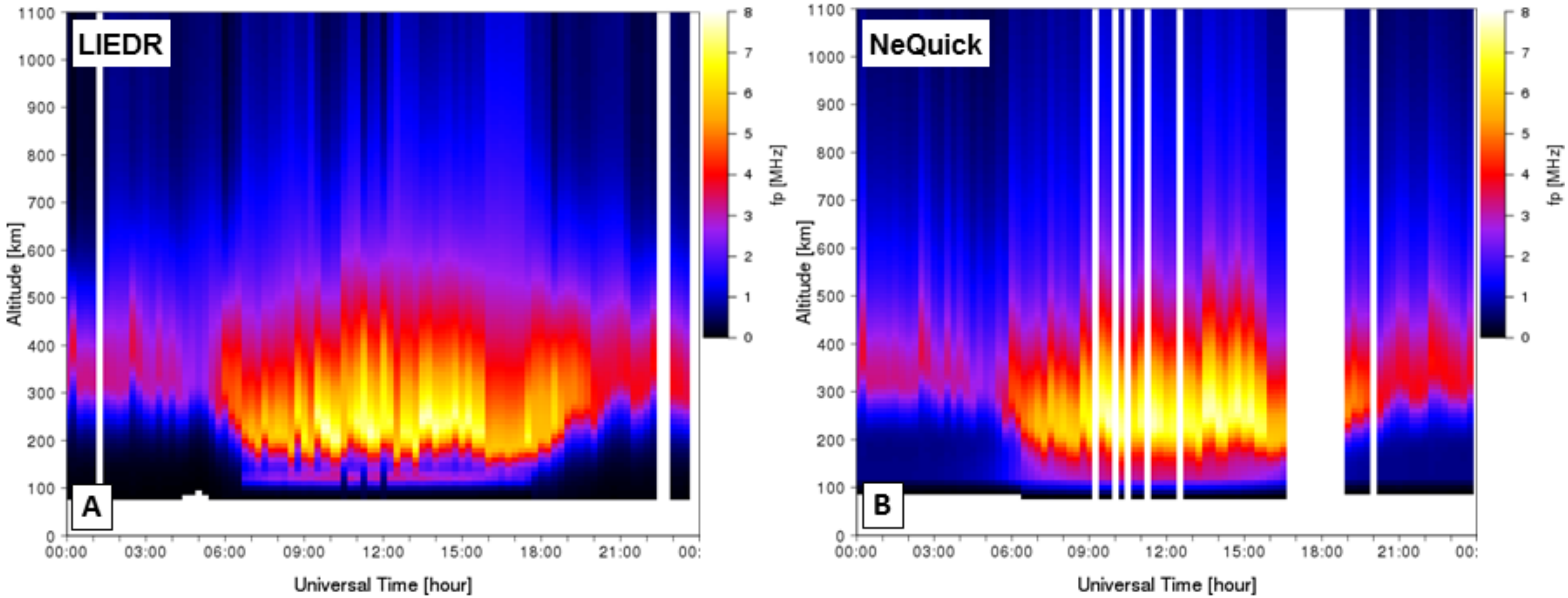
Evaluation of LIEDR and NeQuick based on ionosonde and IRO data

Night-time



Ionospheric plasma frequency profiles above Dourbes as reconstructed with LIEDR (yellow), NeQuick (green), and COSMIC IRO (blue) for March 17, 2011 at 03:00 UT (night-time)

Comparison between LIEDR and NeQuick based on ionosonde data



Vertical profiles of the ionospheric plasma frequency above Dourbes as reconstructed via LIEDR (panel A) and NeQuick (panel B) for March 17, 2011

Summary

- The preliminary results show that the concept of using IRO and VIS measurements for evaluating the LIEDR and NeQuick performance is feasible and worthwhile. It is reasonable to assume that the IRO-derived topside electron density profile is realistic, taking into account the fact that in the IRO procedure the errors accumulate from higher to lower altitudes.

- Validation of the modeled topside electron density profiles with the help of topside sounder data and, at the same time, verifying the suitability of the Chapman curve as a topside profiler.

- Additional efforts will be spent also on evaluating the possibilities of using these particular IRO events as “ground truth” data for the overall improvement of both models.

References

[1] Stankov, S.M., Jakowski, N., Heise, S., Muhtarov, P., Kutiev, I., Warnant, R. (2003). A new method for reconstruction of the vertical electron density distribution in the upper ionosphere and plasmasphere. Journal of Geophysical Research, 108(A5), 1164, doi:10.1029/2002JA009570.

[2] Stankov, S.M., Jakowski, N., Heise, S. (2005). Reconstruction of ion and electron density profiles from space-based measurements of the upper electron content. Planetary and Space Science, 53(9), 945-957, doi:10.1016/j.pss.2005.04.008.

[3] Stankov, S.M., Stegen, K., Muhtarov, P., Warnant, R. (2011). Local ionospheric electron density profile reconstruction in real time from simultaneous ground-based GNSS and ionosonde measurements. Advances in Space Research, 47(7), 1172-1180, doi:10.1016/j.asr.2010.11.039.

[4] Nava, B., Radicella, S.M., Leitinger, R., Coïsson, P. (2006). A near-real-time model-assisted ionosphere electron density retrieval method. Radio Science, 41(6), RS6S16, doi: 10.1029/2005RS003386.

[5] Nava, B., Coisson, P., Radicella, S.M. (2008). A new version of the NeQuick ionosphere electron density model. Journal of Atmospheric and Solar-Terrestrial Physics, 70(15), 1856–1862, doi:10.1016/ j.jastp.2008.01.015.

[6] Nava, B., Radicella, S.M., Azpilicueta, F. (2011). Data ingestion into NeQuick 2. Radio Science, 46(6), RS0D17, doi:10.1029/2010RS004635.

[7] Haralambous, H., Oikonomou, C. (2013). Study of topside electron density profiles obtained by COSMIC satellites and an ionosonde over Cyprus during a four year period, IEEE Geoscience and Remote Sensing Symposium (IGARSS), 21-26 July 2013, Melbourne, Australia.

[8] Verhulst, T., Stankov, S.M. (2015). Ionospheric specification with analytical profilers: Evidences of non-Chapman electron density distribution in the upper ionosphere. Advances in Space Research, 55(8), 2058–2069, doi:10.1016/j.asr.2014.10.017.

Acknowledgements

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Thank you for your attention