The Abdus Salam International Centre for Theoretical Physics

Data Assimilation & Ingestion into NeQuick and IRI models using ground and space based ionospheric data

Yenca Migoya-Orué (ICTP)

Eastern Africa GNSS and Space Weather Capacity Building Workshop - 21-25 Jun 2021

01

INTRODUCTION

To DA/DI

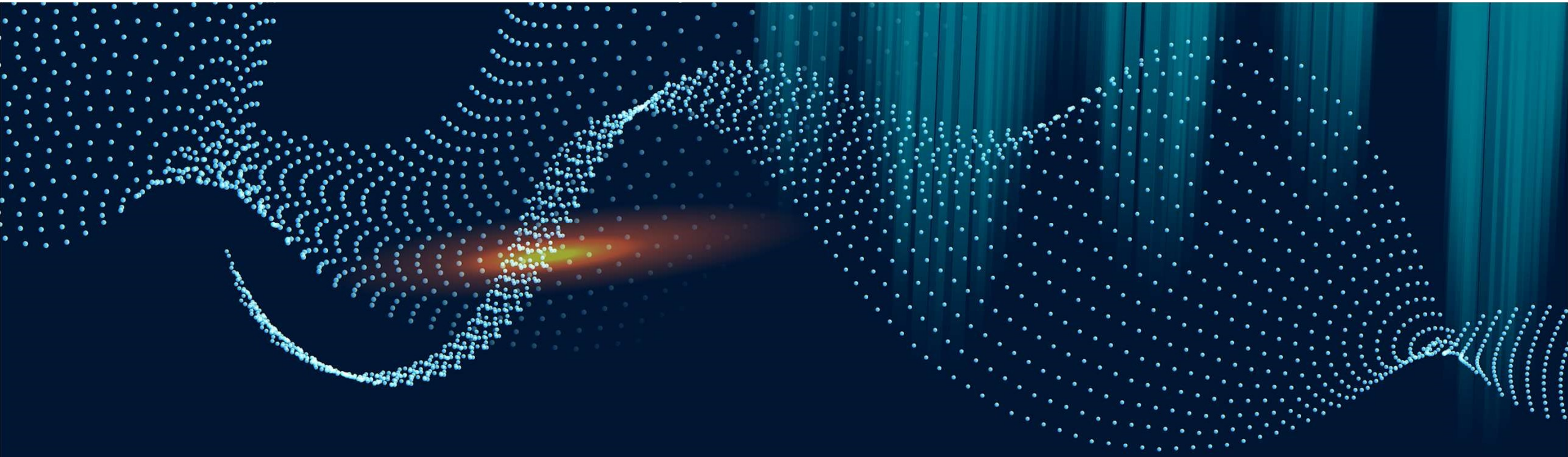
02

SHOWCASE

Examples of DA/DI Application to Empirical Models

03

SUMMARY



01 INTRODUCTION

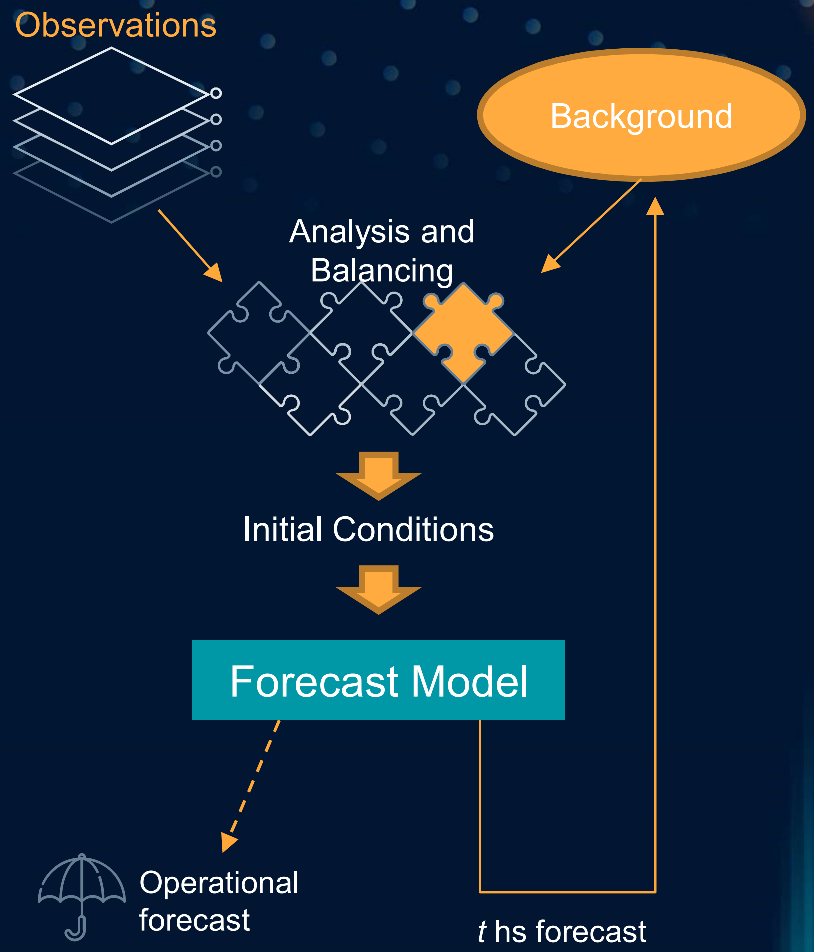
Data Assimilation/ Data Ingestion

No model is able to reproduce by itself in a satisfactory way both the “climate” and the “weather” of the Earth ionosphere.

Data Assimilation

- NWP-> initial-value problem: “*given an estimate of the present state of the atmosphere, the model simulates (forecasts) its evolution.*”

- **Data Assimilation:**
  “using all the available information, to determine as accurately as possible the state of the atmospheric (or oceanic) flow.”
  Talagrand, 1997

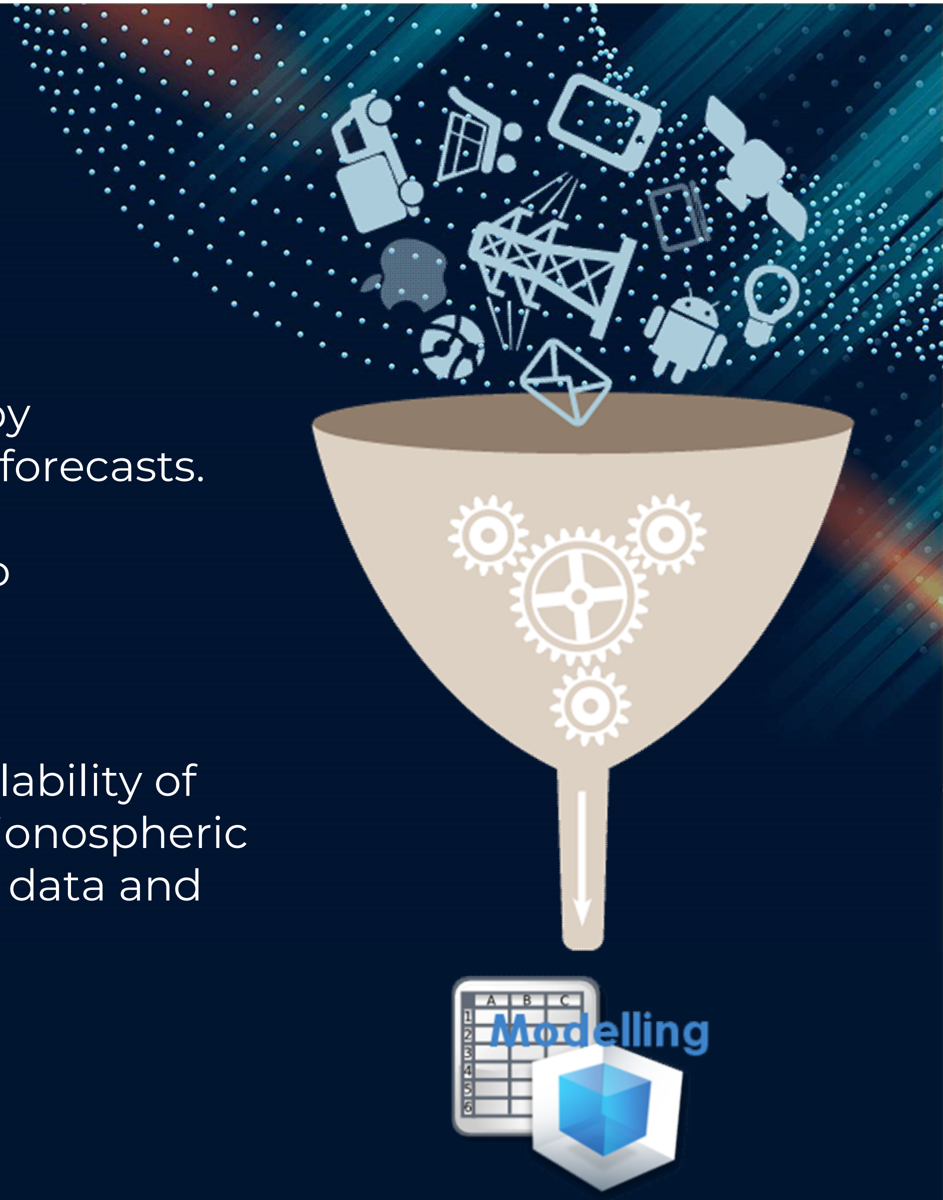


Data Assimilation

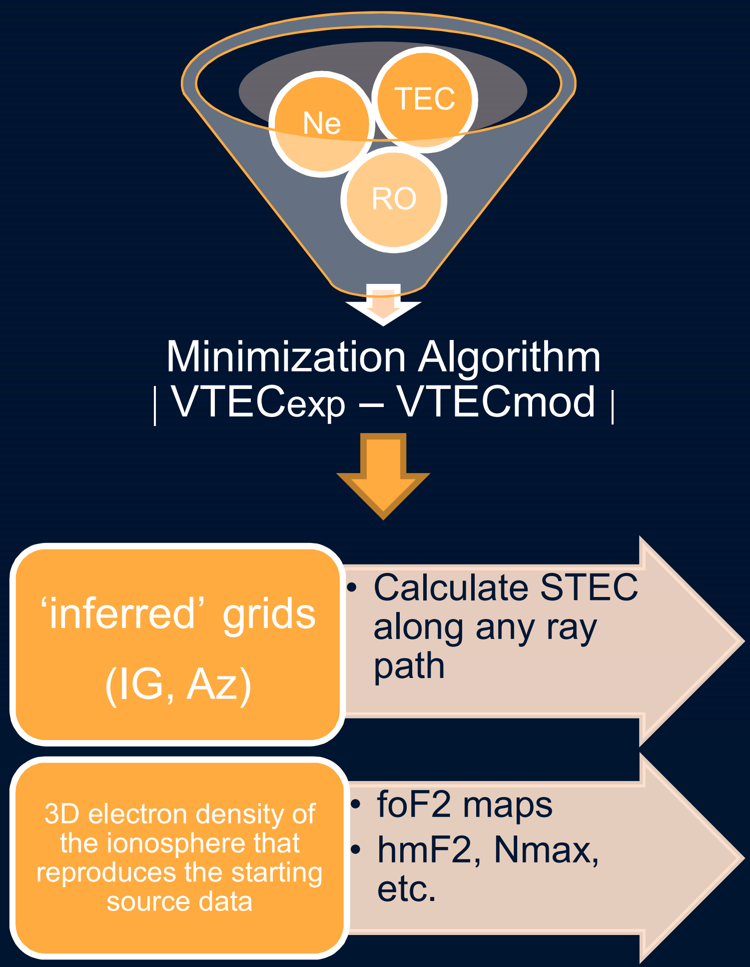
DA techniques have successfully been applied by meteorologists to improve operational weather forecasts.

Such techniques have also been introduced into ionospheric research and application.

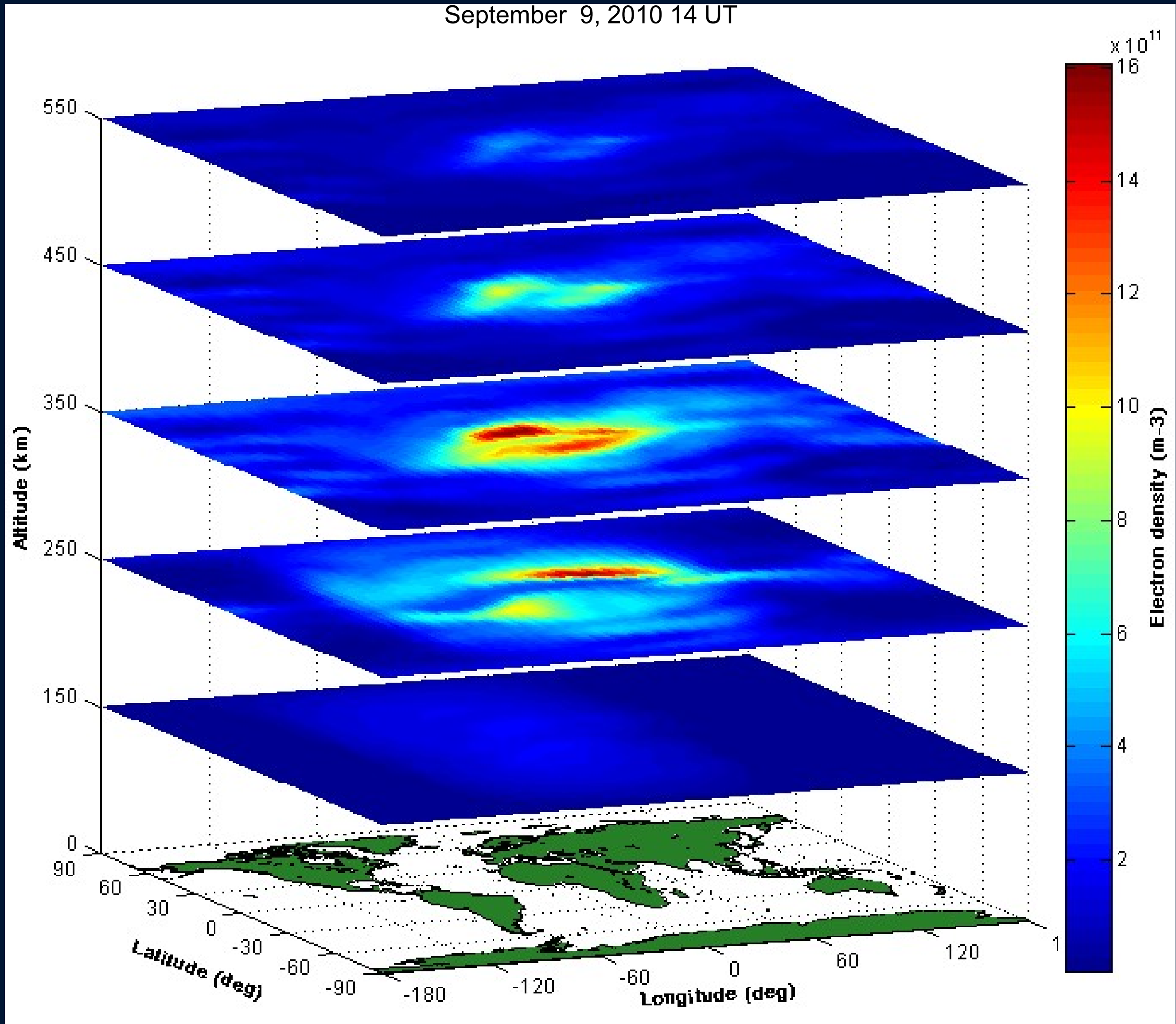
This was possible because of the increasing availability of experimental data even in real time (solar data, ionospheric ground and space-based GNSS data, ionosonde data and radar data).



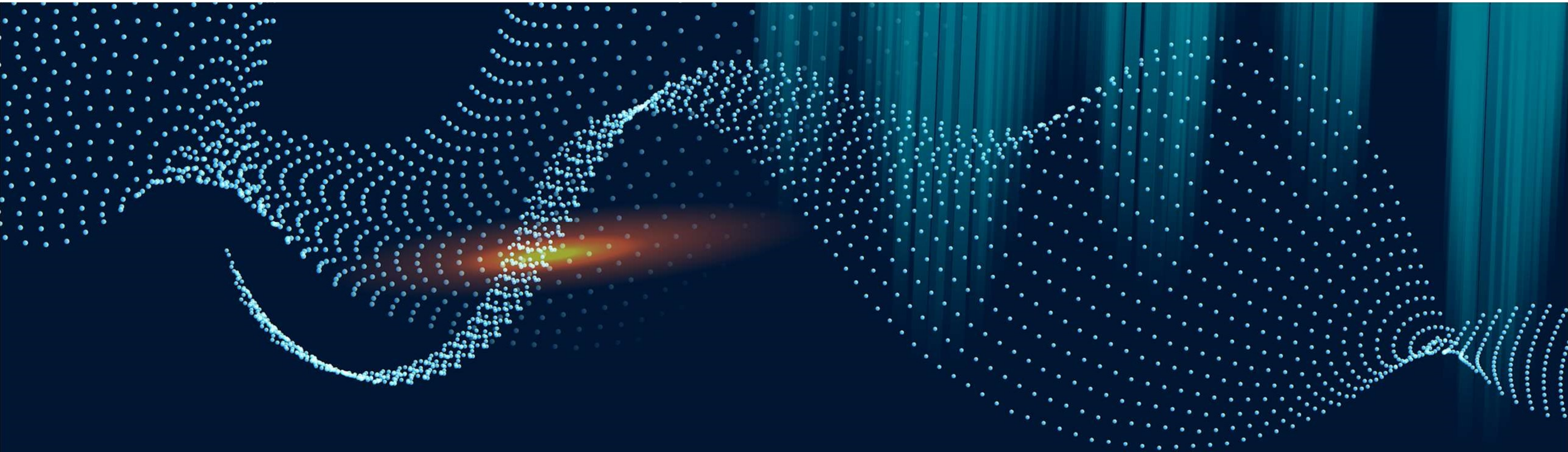
Data Ingestion



- Is one of the earliest and most simplistic approaches to data assimilation.
- The model states are directly replaced with the observations.



Example of horizontal sliced maps of global Ne at different heights (150 to 550 km) after GIM DI



02 SHOWCASE

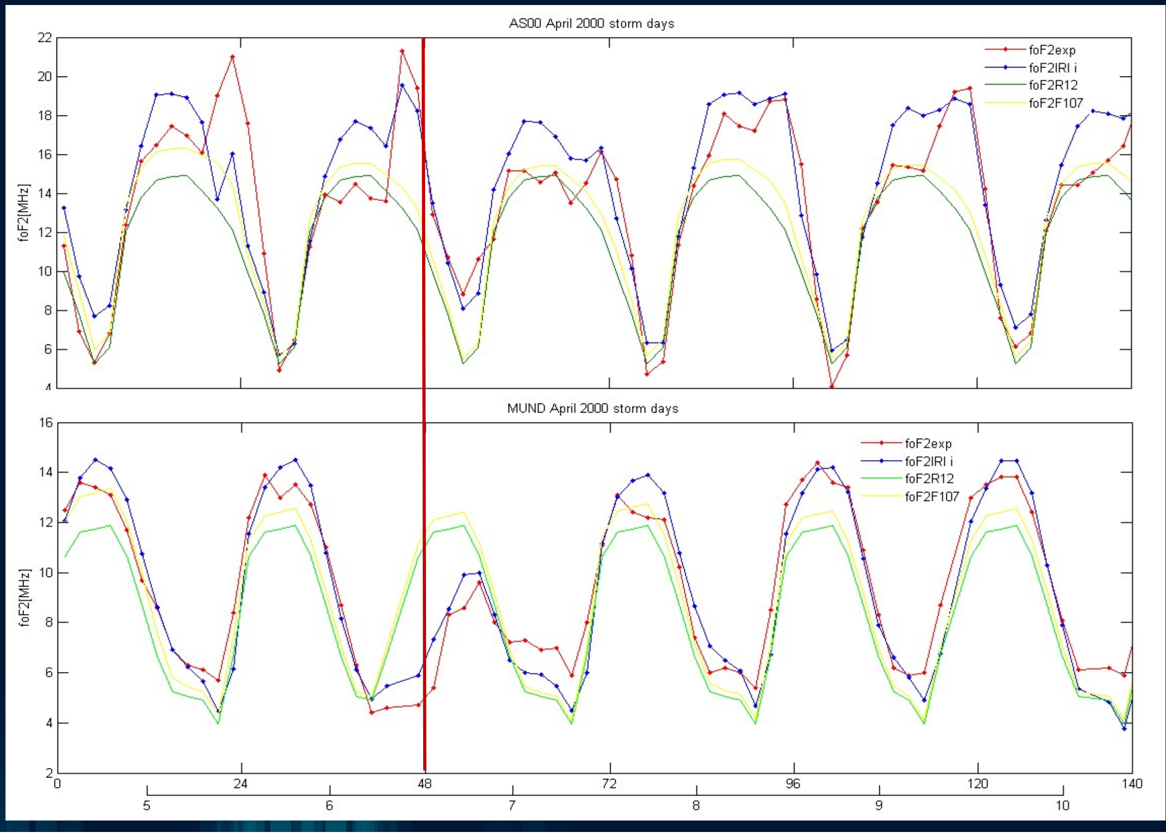
DA/DI Application Examples

GNSS derived TEC ingestion into IRI 2012

CODE VTEC maps have been ingested into IRI2012 aiming to provide a global ‘weather’ 3D specification of the electron density of the ionosphere, as in Nava et al., 2011.

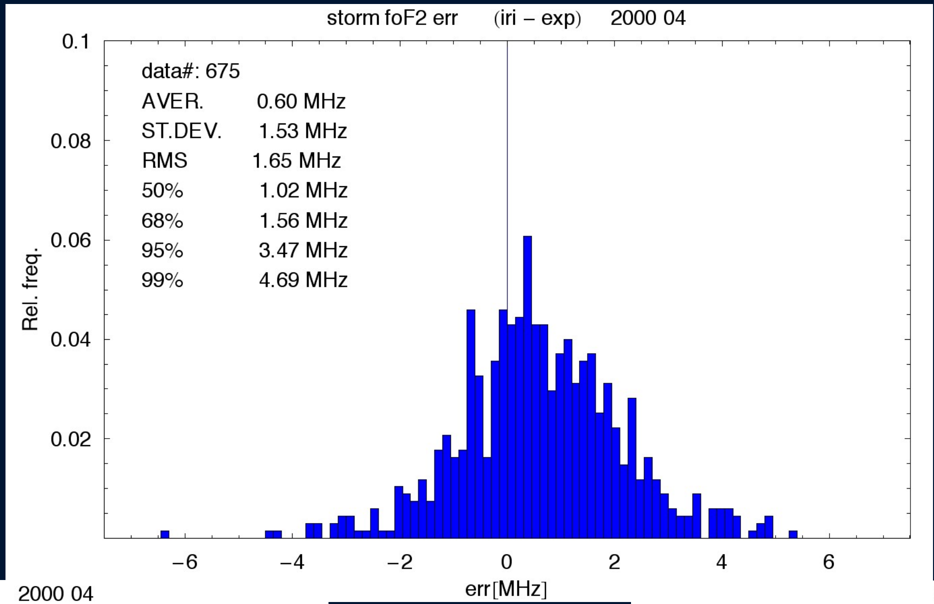
Migoya-Orue et al., 2015 showed the reconstruction of foF2 with IRI2012 when it is driven by ‘inferred’ IG12 after the ingestion and its comparison with experimental (ionosonde) foF2 values.

foF2 comparison during storm days April 2000

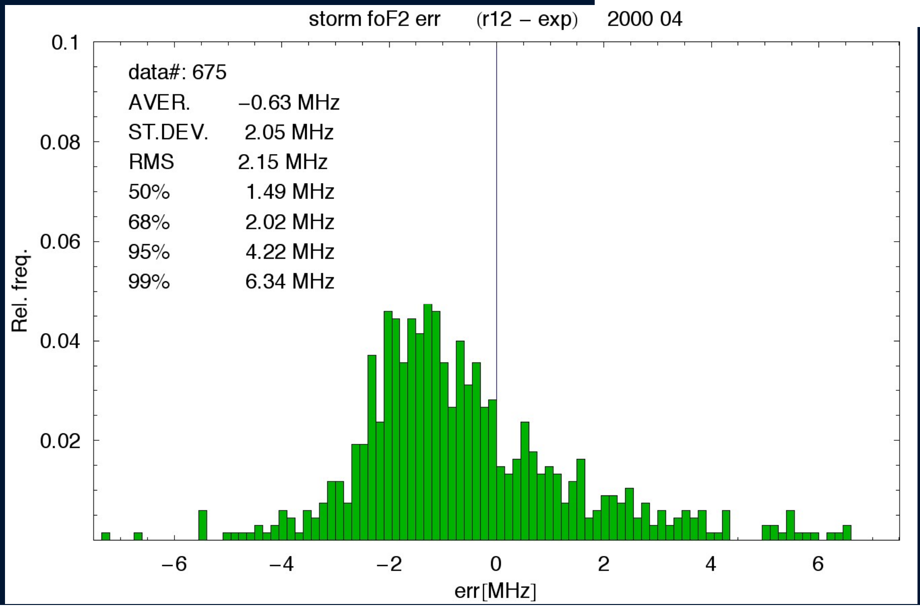


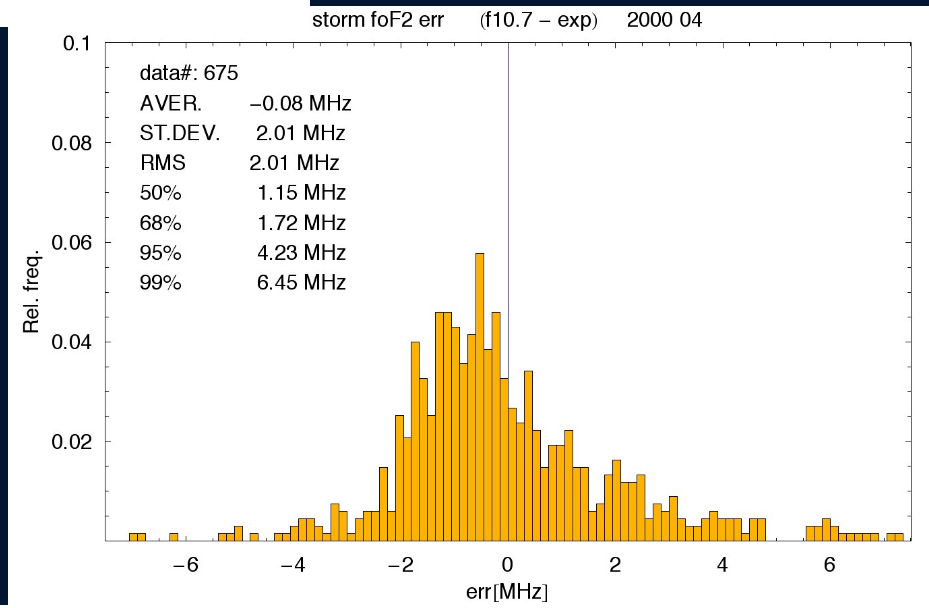
GNSS derived TEC ingestion into IRI 2012

foF2 differences during storm days April 2000



Migoya-Orué et al., 2015, Adv.in Space Research.



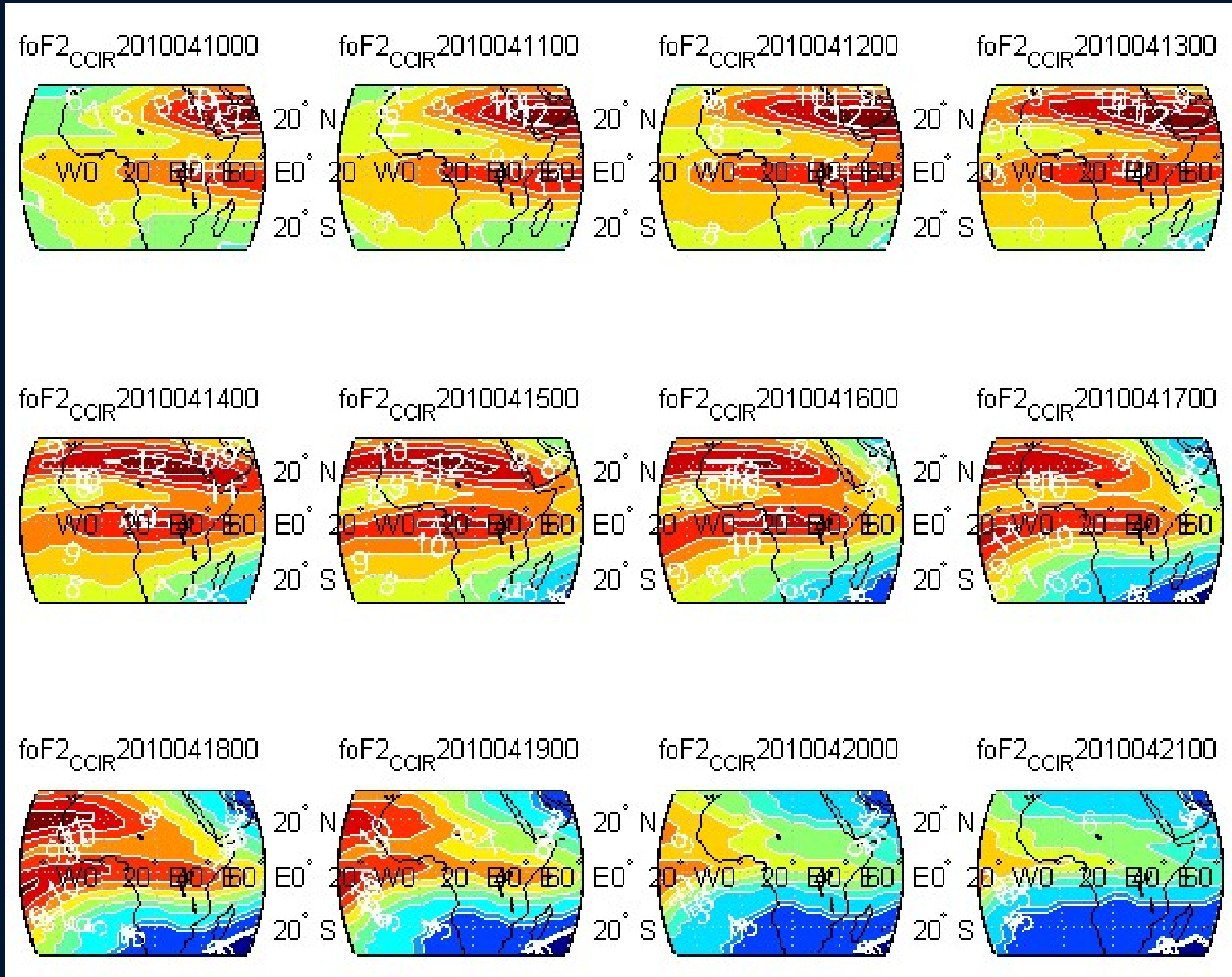


Reconstruction of the African EIA using NeQuick and GIM VTEC ingestion

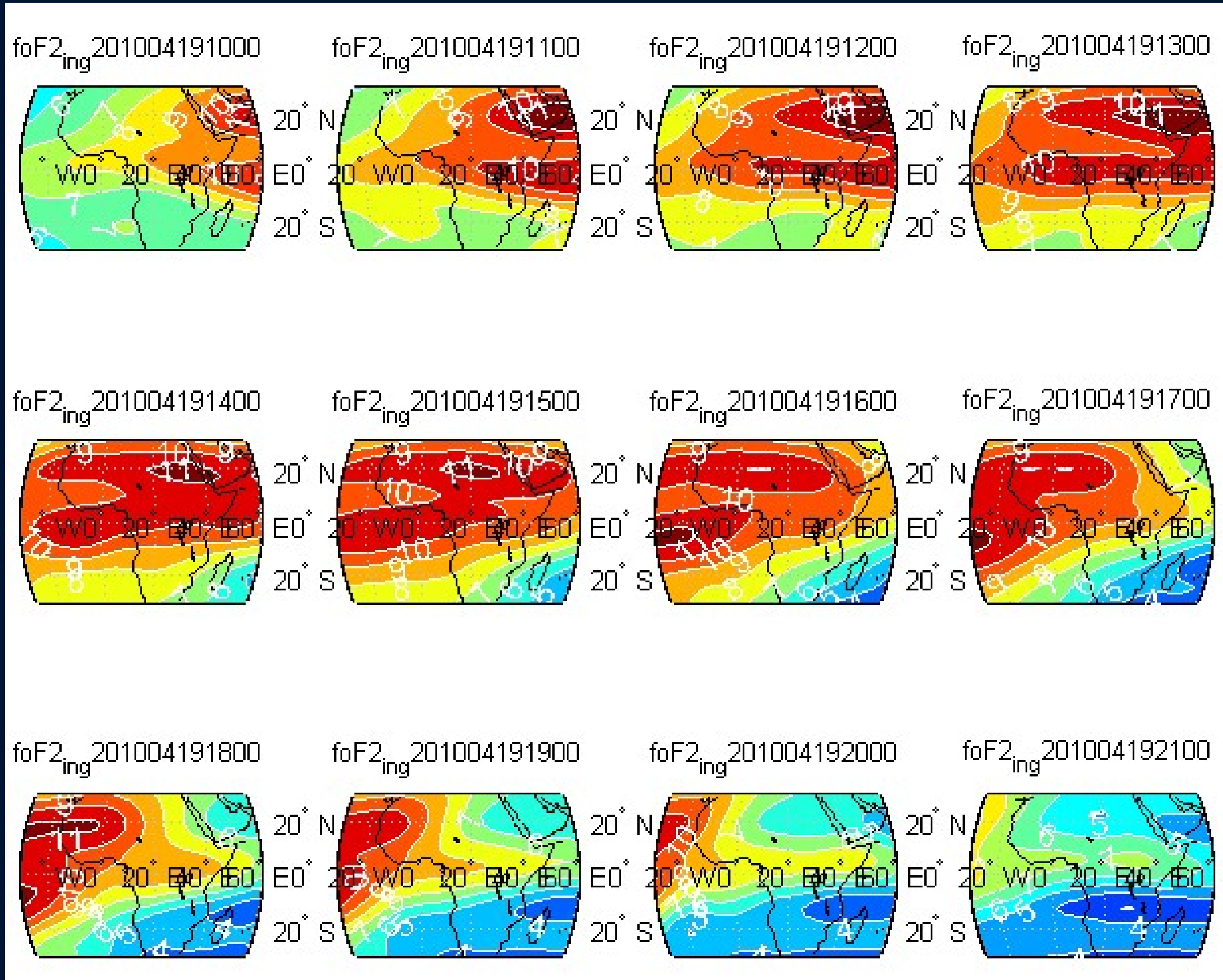
- The NeQuick 2 has been used as a reference model for the 3D representation of the ionosphere over Africa.

- Through the application of a DI technique it was possible to adapt the model to a specific dataset (GIM) in order to generate **‘effective’ parameters**, *Az* to be used in place of the standard solar activity drivers (R12, F10.7).

- The *Az* grids obtained were used in a reconstruction process to obtain a 3D representation of the ionosphere.



Contour maps of retrieved foF2 for one day of Apr 2010 at different hours. The RIMs correspond to modeled foF2 with ITU-R (CCIR) driven by daily F10.7.



Contour maps of retrieved foF2 for one day of Apr 2010 at diff hours. The RIMs correspond to estimated foF2 by NeQuick after CODE TEC maps ingestion.

Migoya-Orué, et al, 2017, Adv. Space Res.

Ionospheric parameters DI

Base Point (BP)

Inflection point of Ne below the F2 peak.
Where the height gradient is maximum.

NeQuick model Thickness Parameter

Uses this BP as an anchor point to define a thickness parameter of the F2 bottomside of the EDP, which is named **B2bot.**

$$B2 = 0.385\ NmF2 / dN/dh_{max}$$

(Mosert de Gonzalez and Radicella., 1990)

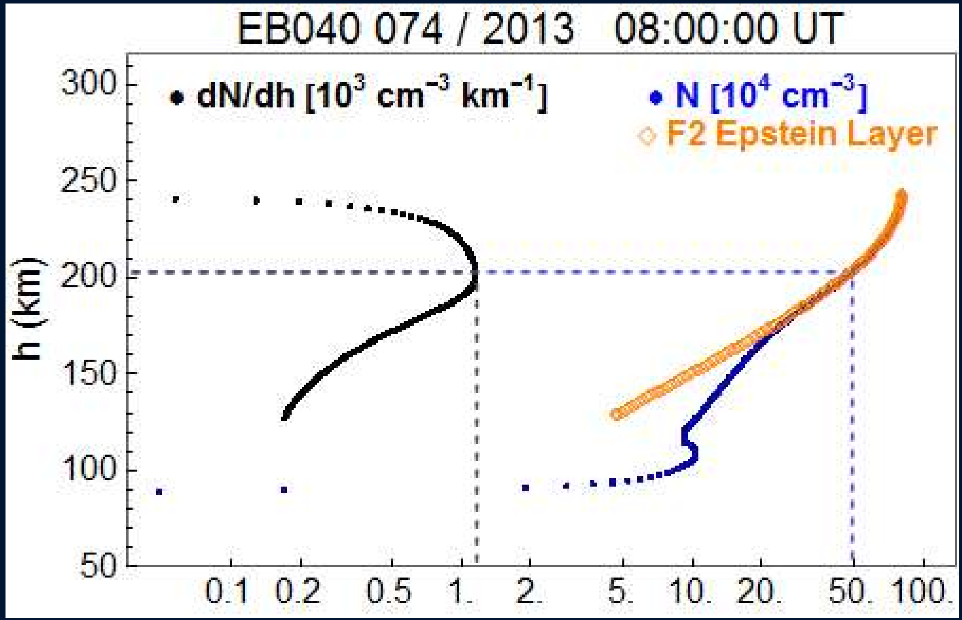
(Alazo-Cuartas and Radicella., 2017)

IRI model Thickness Parameters

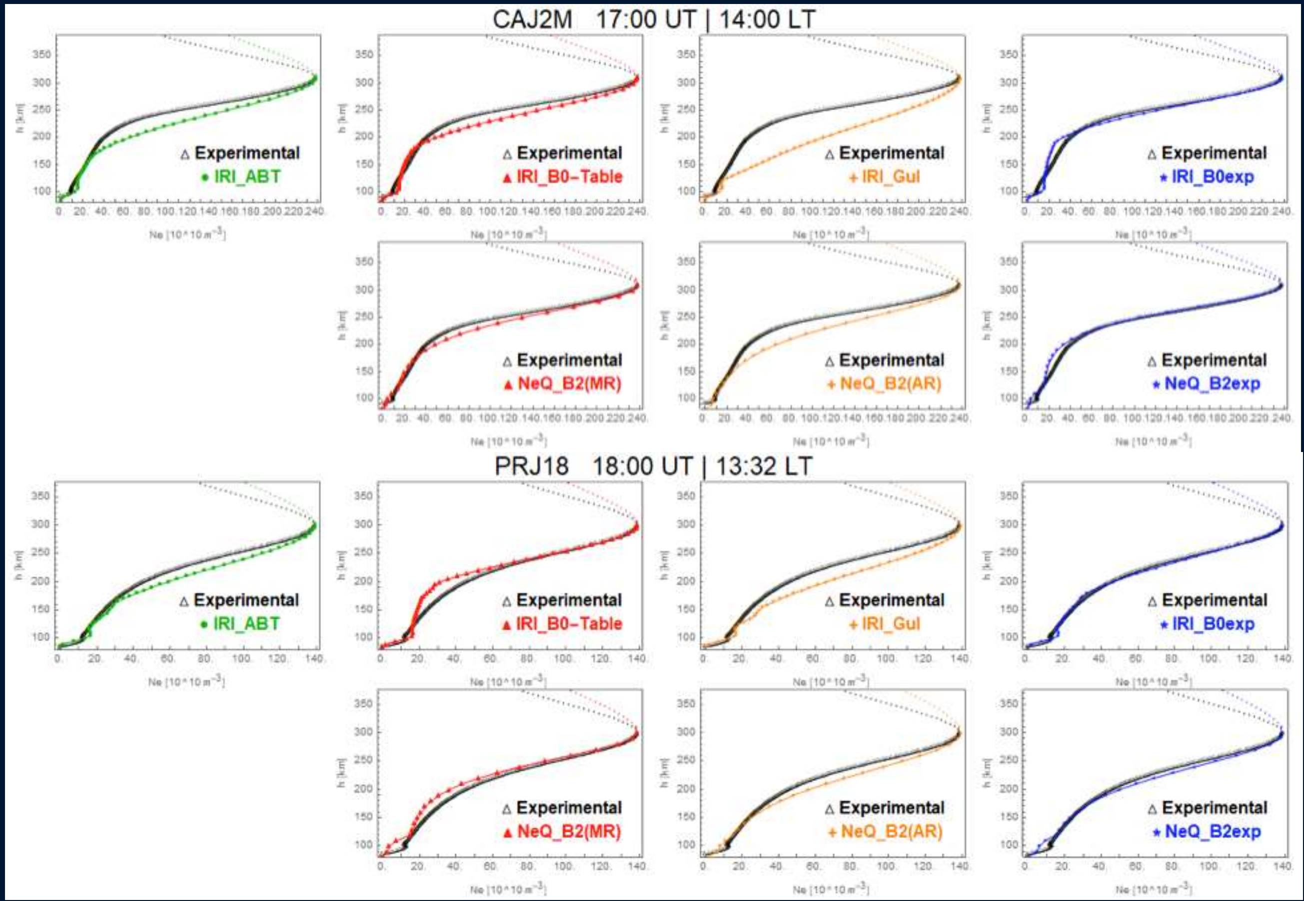
B0 = hmF2 – *hx*

with *hx* being the height where NIRIx= 0.24*NmF2

- GUL-1987 *(Gulyaeva, 1987)*
- BIL-2000 (B0-table) *(Bilitza et al., 2000)*
- ABT 2009 *(Altadill et al., 2009)*



Thickness parameters DI

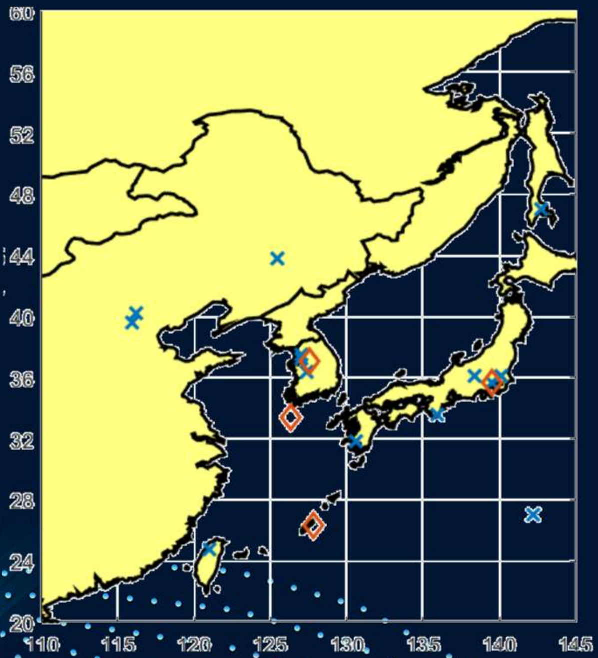


Experimental and modeled EDP with different options of B0 (IRI) and B2(NeQuick) and corresponding "experimental" B0 (B0exp) and B2(B2exp) for Cachoeira Paulista and Ramey. Day 16 March 2015.

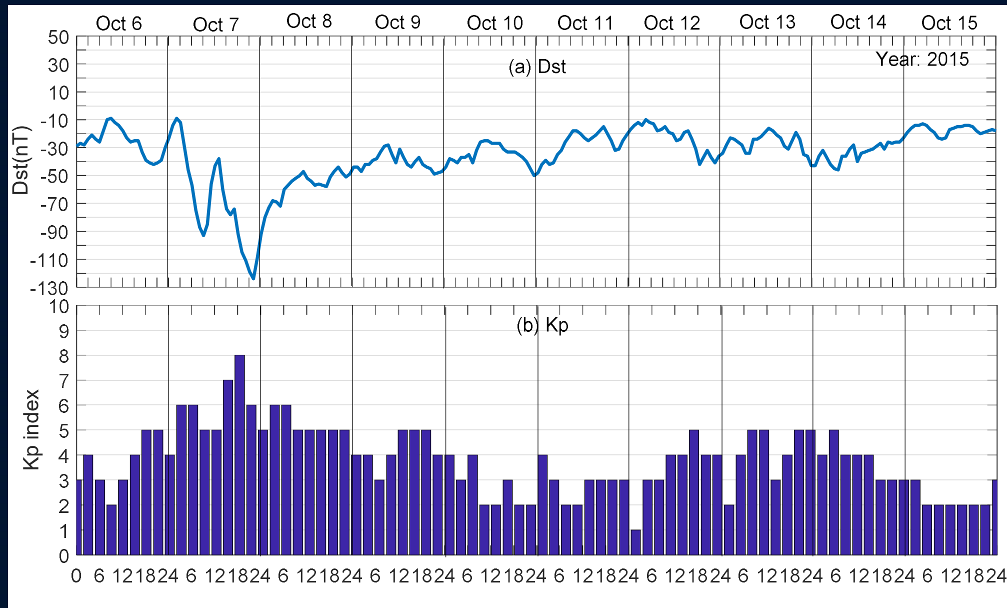
- Comparison of experimental and modeled Ne profiles with different thickness parameters options.
- The Ne profiles closest to the experimentally derived ones are those obtained by ingesting NmF2, hmF2 with the addition of B0 or B2 when IRI or NeQuick are used.

Radicella et al., 2021, Adv.in Space Research.

Data Assimilation into NeQuick through Kalman filtering technique



GPS and ionosonde stations used in the study



$$y = Hx_b + w$$

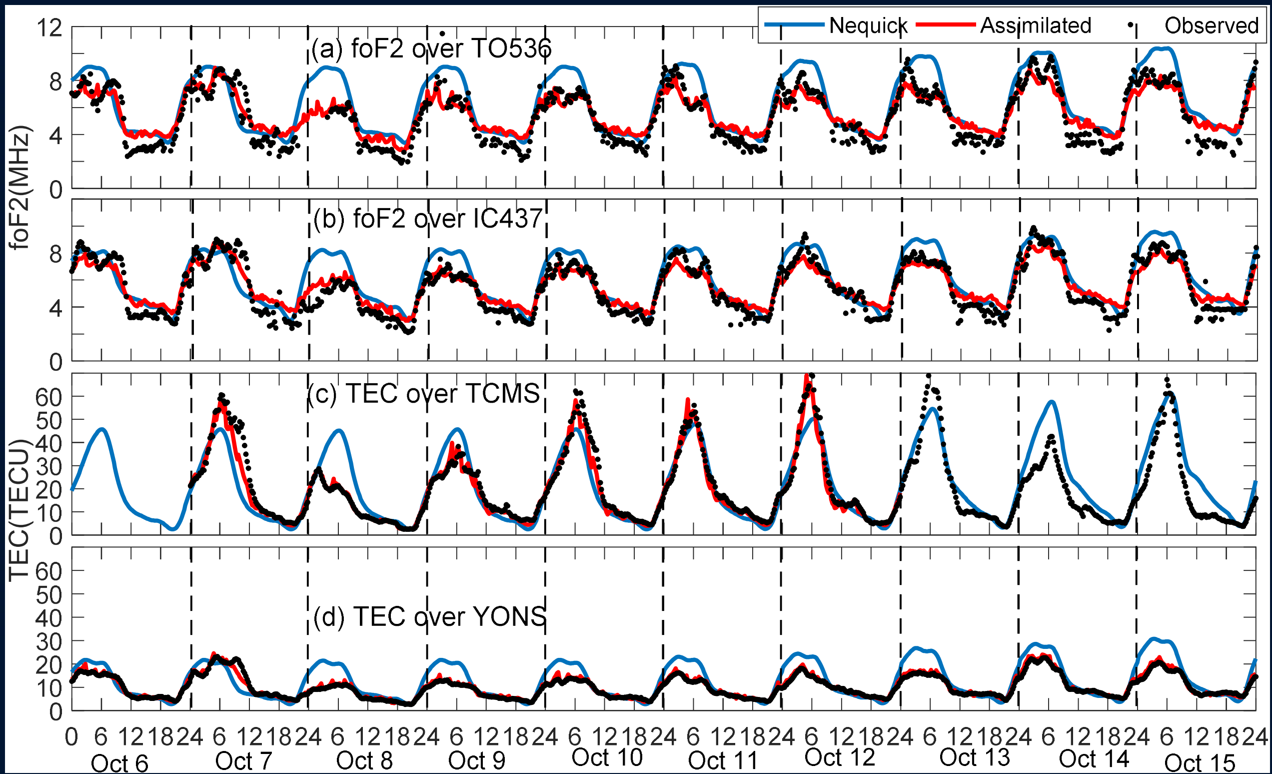
$$x_a = x_b + K(y - Hx_b)$$

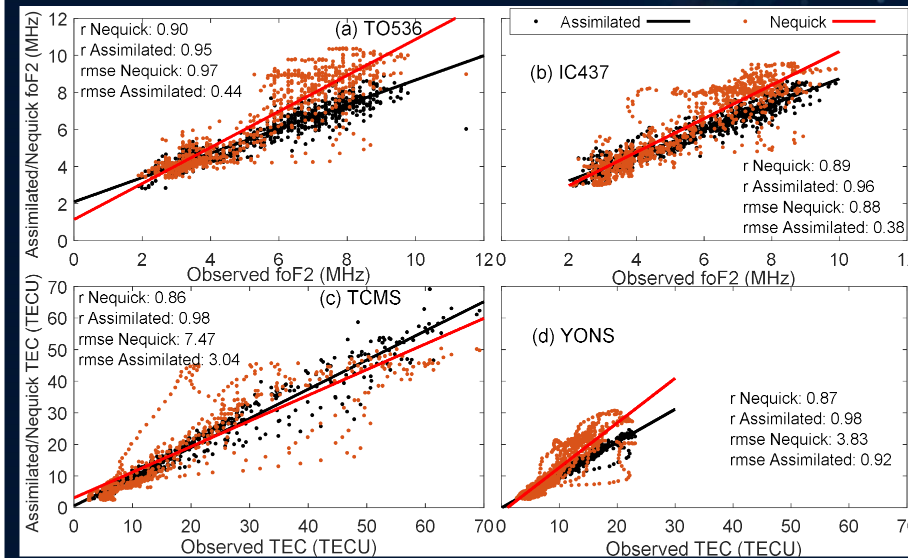
$$K = BH^T(HBH^T + R)^{-1}$$

$$\begin{pmatrix} x_a^1 \\ x_a^2 \\ \cdot \\ \cdot \\ \cdot \\ x_a^n \end{pmatrix} = \begin{pmatrix} x_b^1 \\ x_b^2 \\ \cdot \\ \cdot \\ \cdot \\ x_b^n \end{pmatrix} + K\left(\begin{pmatrix} y_1 \\ y_2 \\ \cdot \\ \cdot \\ \cdot \\ y_n \end{pmatrix} - H\begin{pmatrix} x_b^1 \\ x_b^2 \\ \cdot \\ \cdot \\ \cdot \\ x_b^n \end{pmatrix}\right)$$

Mungufeni et al. 2021, to be submitted

TEC Assimilation into NeQuick through Kalman filtering technique





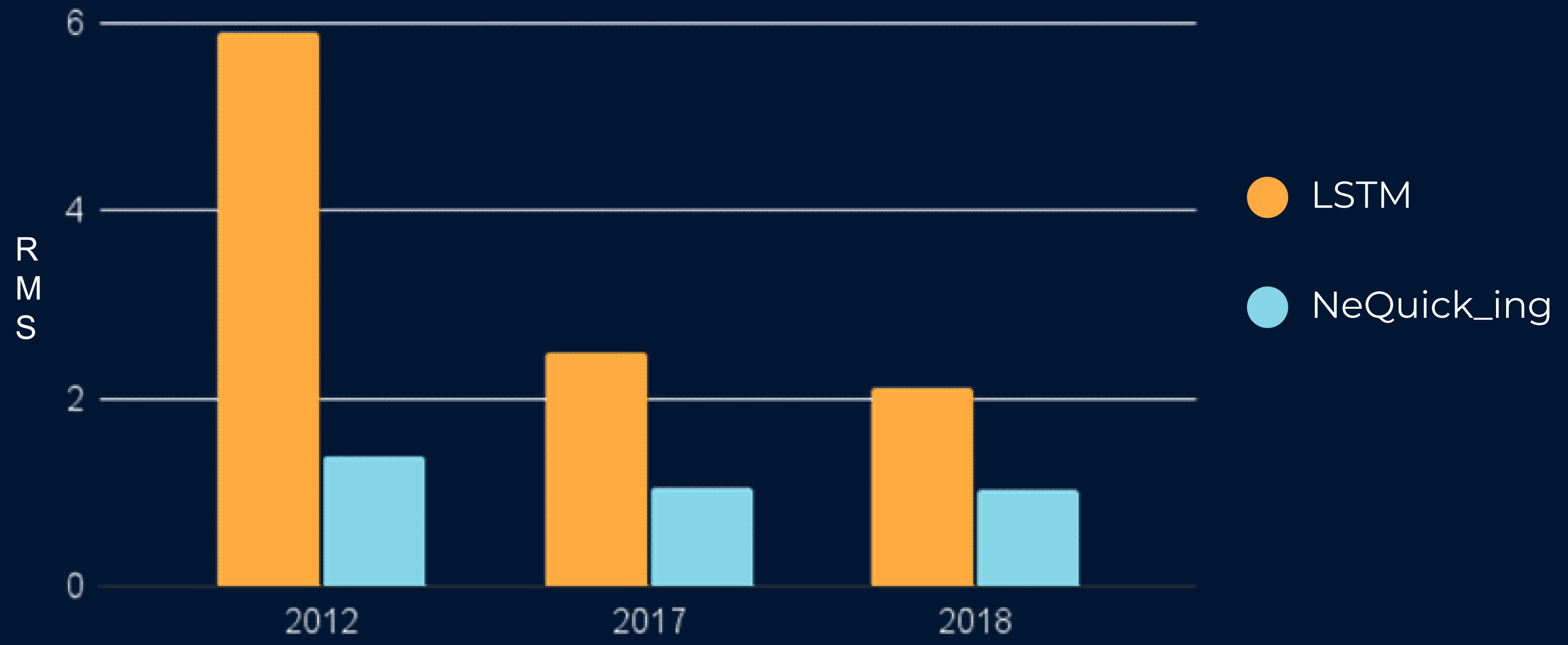
foF2 variation over (a)TO536 and (b)IC437 and TEC variations over (c)TCMS and (d)YONS

Mungufeni et al. 2021, to be submitted

LSTM vs NeQuick ingested model

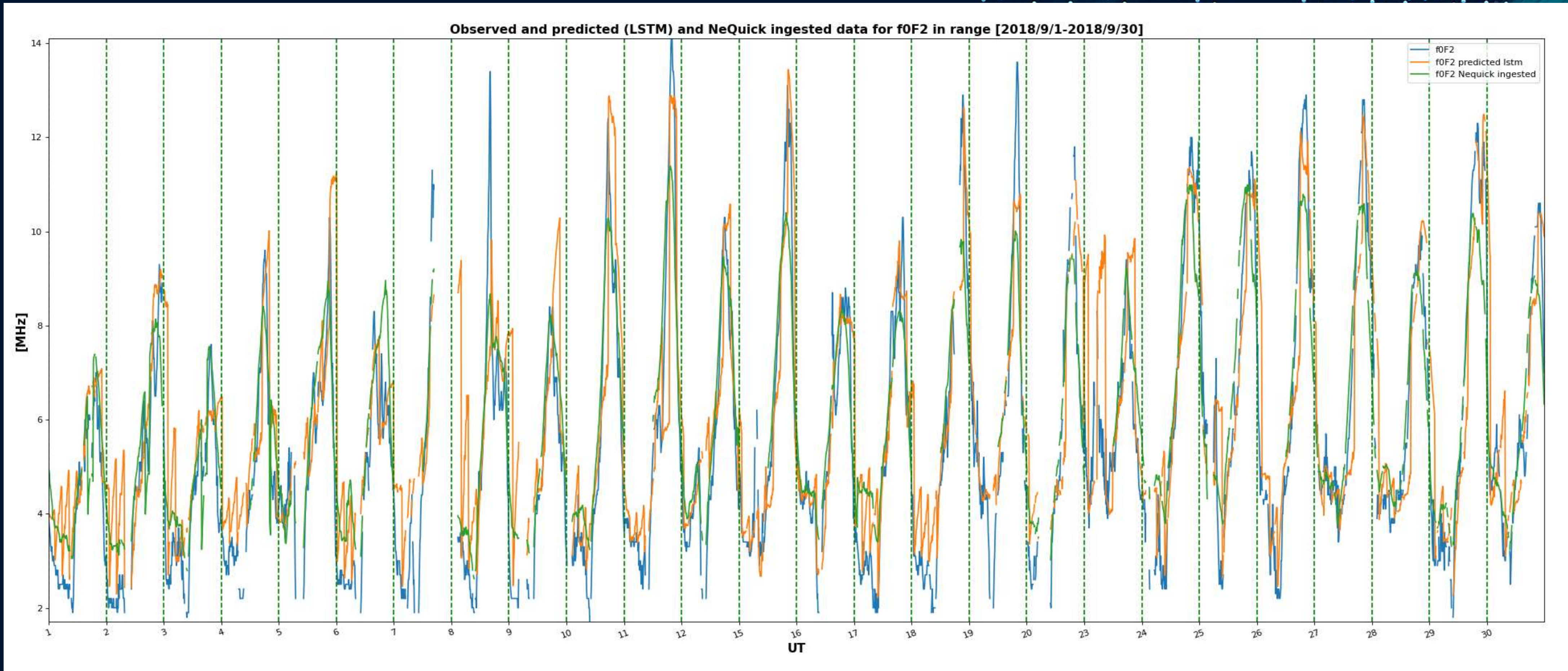
LSTM are a special kind of RNN, capable of learning long-term dependencies.

- 1 hidden layer, 5 neurons
- Training Data range: 01/01/2017 to 30/08/2017
- Missing data: % 16.1
- Data Split: %70 training (%20 validation), %30 test



Molina et al., in preparation

LSTM vs NeQuick ingested



Observed vs LSTM – NeQuick ingested models (Tucumán, September 2018)

Molina et al., in preparation

SUMMARY

- The assimilation/ingestion of ionospheric data into empirical models like NeQuick and IRI allows to provide a global 3D specification of the electron density of the ionosphere.

- It has been showed examples of the prediction of TEC, Ne and foF2 with NeQuick and IRI by assimilating/ingesting different ionospheric data series and some comparisons with experimental values and other models.

CONCLUSIONS

- An approach of DA/DI to represent ionospheric global and regional variations overcomes problems of lacking weather features in climatological ITU-R coefficients based models.

- We showed that the ingestion of experimental parameters (ionosonde derived) like peak and thickness parameters improves the performance of IRI and NeQuick models.

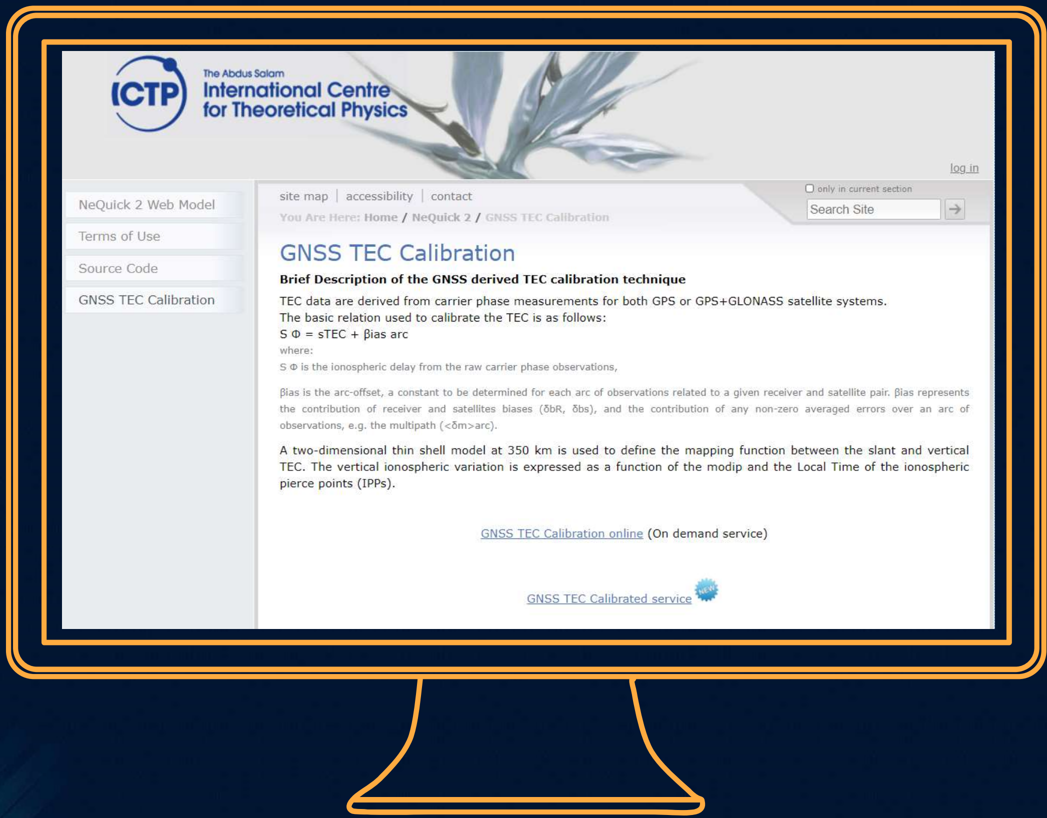
- Results show that the DA/DI approach is able to improve the reproduction of the 'weather' variability of the F2 peak frequency and VTEC.

REFERENCES

- Nava, B., Coisson, P., Amarante, G.M., Azpilicueta, F., Radicella, S.M., 2005. A model assisted ionospheric electron density reconstruction method based on vertical TEC data ingestion. Ann. Geophys. 48 (2),313–320.
- Migoya-Orue´, Y.,Nava,B.,Radicella,S.,Alazo-Cuartas, K.,2015.GNSS derived TEC data ingestion into IRI 2012. Adv. Space Res. 55 (8, 15), 1994–2002.
- Migoya-Orué Y., O. Folarin-Olufunmilayo, S. Radicella, K. Alazo-Cuartas and A.B. Rabiu (2017), Evaluation of NeQuick as a model to characterize Equatorial Ionization Anomaly over Africa using data ingestion, *Adv. Space Res.*, 2017.
- Mosert de González, M., and S. M. Radicella, On a characteristic point at the base of the F2 layer, Adv. Space Res. Vol. 10. No. 11. pp. 11-17, 1990.
- Nava, B., Coïsson, P., Radicella, S.M., A new version of the NeQuick ionosphere electron density model. J. Atmos. Sol.-Terr. Phys.. http://dx.doi.org/10.1016/j.jastp.2008.01.015. 2008.
- S. M. Radicella, K. Alazo-Cuartas, Y. O. Migoya-Orué and A. Kashcheyev,"Thickness parameters in the empirical modeling of bottomside electron density profiles", artículo publicado en enero del corriente año en Advances in Space Research, 2021, ISSN 0273-1177, https://doi.org/10.1016/j.asr.2020.12.037.

GNSS TEC DATA

https://t-ict4d.ictp.it/nequick2/gnss-tec-calibration



THANKS!

yenca@ictp.it