Preliminary analysis of a method to improve the initial conditions of the ionosphere for ionospheric tomography

Fabricio S. Prol (1,2), Manuel Hernández-Pajares (1), Paulo O. Camargo (2), Marcio T. A. H. Muella (3)

(1) UPC-IonSAT res. Group, Barcelona, Spain, (2) UNESP, Presidente Prudente – SP, Brazil

(3) UNIVAP, São José dos Campos – SP, Brazil

[fabriciosprol@gmail.com, manuel@ma4.upc.edu, paulo@fct.unesp.br, mmuella@univap.br]

IGS Workshop 2017, 3-7 July 2017, Paris, France

Abstract: Experimental analysis are under investigation to improve the initial conditions of the ionosphere for ionospheric tomography over the Brazilian region. We present an overview of the mostly promising approaches found by the authors to estimate initial conditions for regional tomography using data from GNSS, Radio Occultation and Ionosondes obtained by global networks.

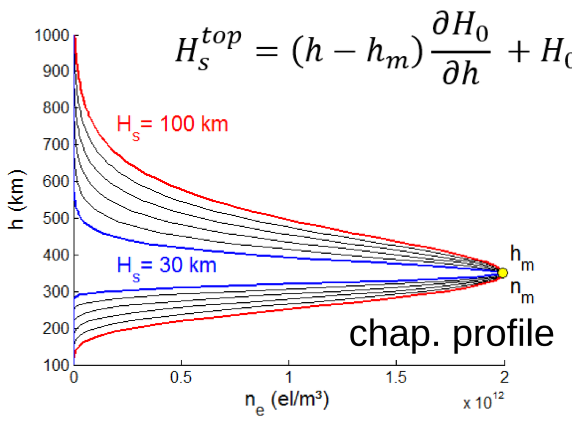
1. Vary Chapman

- Electron density retrieved from NeQuick profile is fitted to VTEC from GIMs separately for each profile.

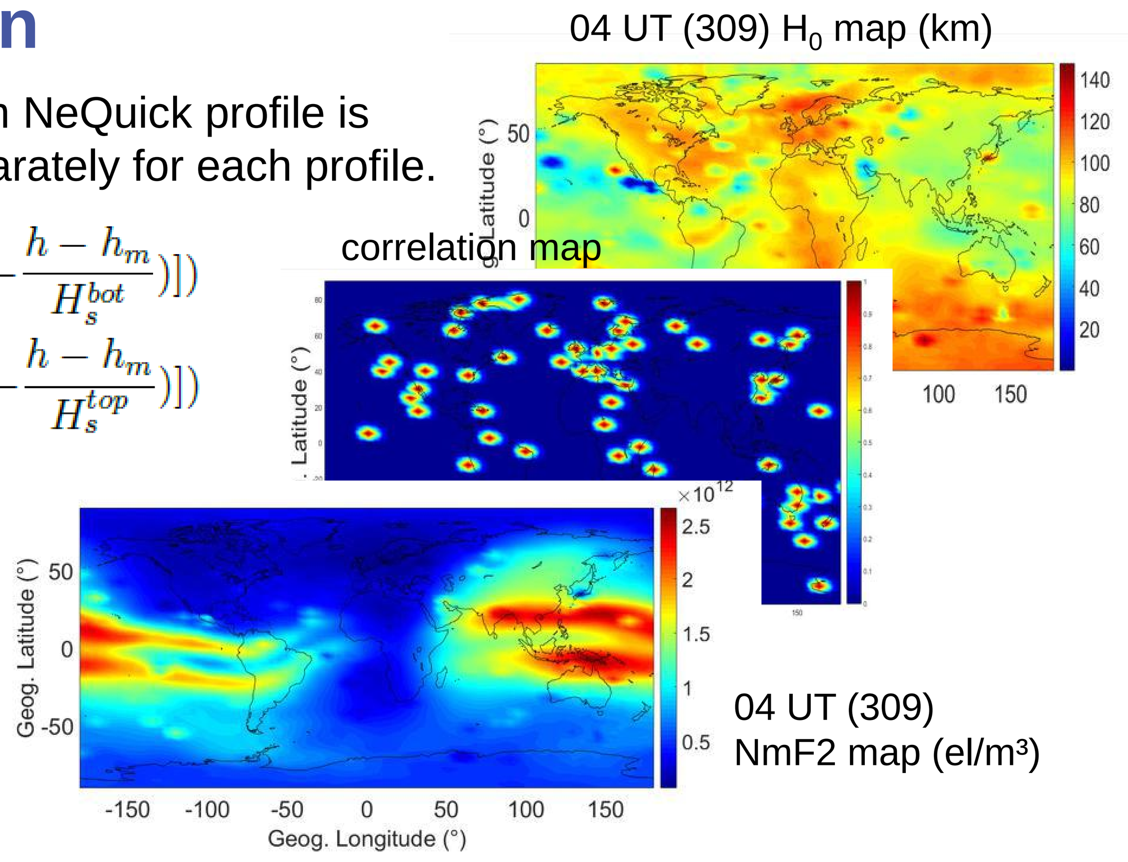
$$n_e^{bot} = n_m exp([1 - \frac{h-h_m}{H_s^{bot}} - exp(-\frac{h-h_m}{H_s^{bot}})])$$

$$n_e^{top} = n_m exp([1 - \frac{h-h_m}{H_s^{top}} - exp(-\frac{h-h_m}{H_s^{top}})])$$

$$H_s^{top} = (h-h_m)\frac{\partial H_0}{\partial h} + H_0$$



chap. profile



04 UT (309) H_0 map (km); correlation map; 04 UT (309) NmF2 map (el/m³)

- needs a spatial-correlation map of HmF2 and NmF2
- needs a-priori specification of the layers

2. Shape Function (SF)

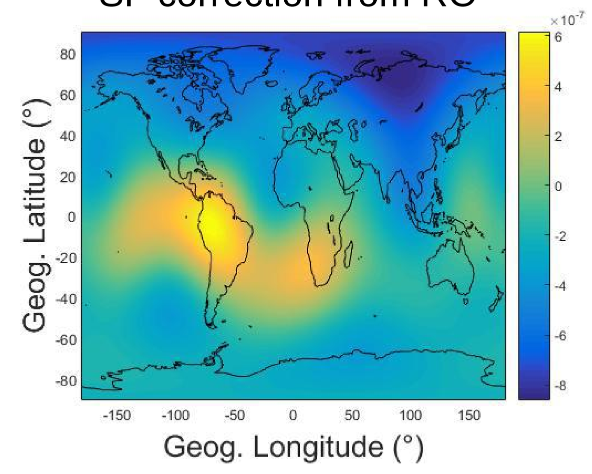
- SF are calculated with NeQuick and then multiplied by VTEC from GIMs, plus a correction from RO.
- Difficult to incorporate Slant TEC or ionosonde data.

$$n_e = SF \cdot vT^g$$

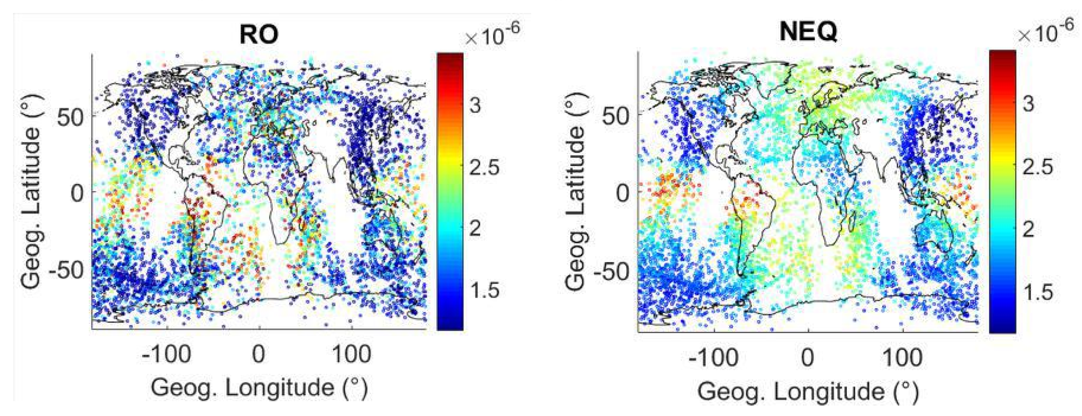
$$SF = \frac{n_e^n}{vT^n} + \left(\frac{n_e^{ro}}{vT^{ro}} - \frac{n_e^n}{vT^n}\right)$$

Spherical Harmonic with 5 degrees

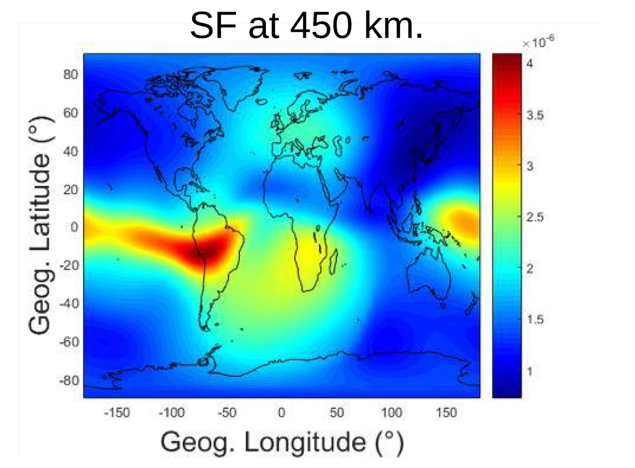
SF correction from RO



SF of six days in Local Time using RO and NeQuick at 450 km.



SF at 450 km.

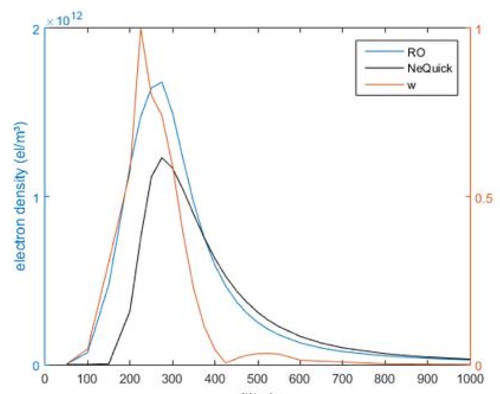


3. Reconstruction Technique

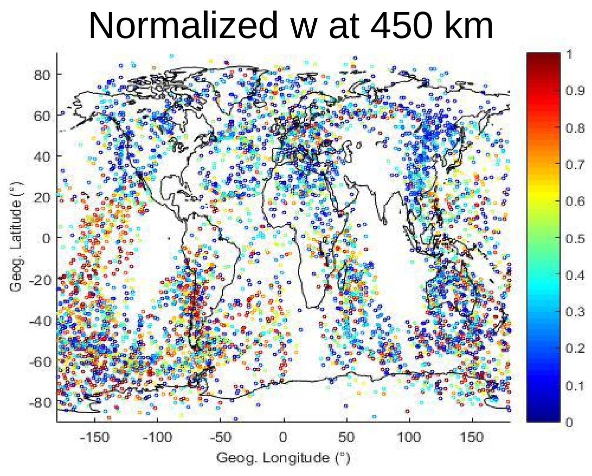
- The electron density is updated iterativiely to fit NeQuick into TEC of GIMs.
- there is no clear way for the definition of the weighting parameter w.
- does not include the covariance matrix, such as in least square estimations.

ART $$n_{ej}^{k+1} = n_{ej}^k + w\frac{(T_{obs} - \sum n_{ej}^k d_{ij})}{\sum d_{ij}^2} d_{ij}$$

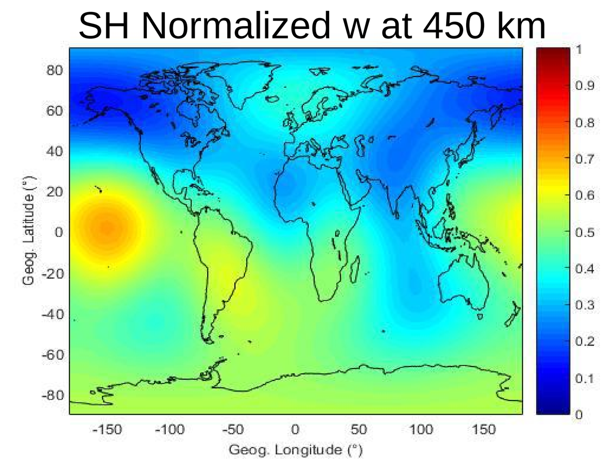
MART $$n_{ej}^{k+1} = n_{ej}^k \left(\frac{T_{obs}}{\sum n_{ej}^k d_{ij}}\right)^{w\frac{d_{ij}}{d_m}}$$

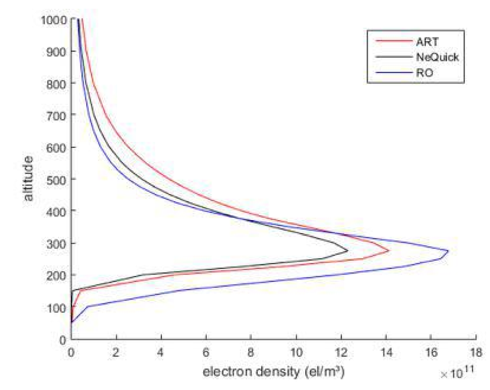


Normalized w at 450 km



SH Normalized w at 450 km





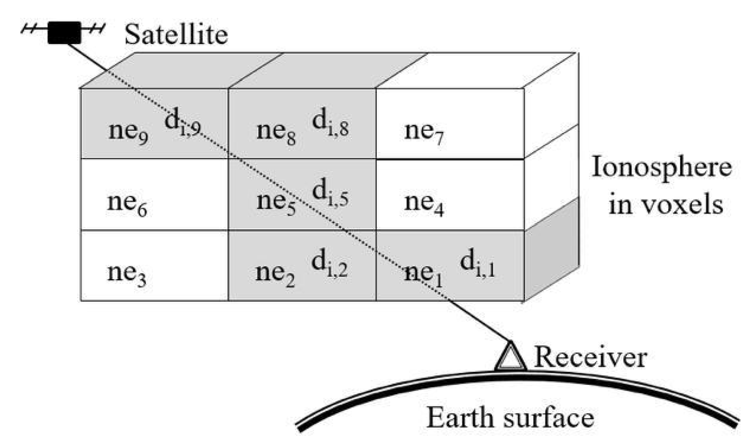
4. Kalman Filter

- Simplifications were made by disconsidering the covariances and the dynamics.
- TEC observations were derived from GIM files
- Resolution was set to 4° x 8° in lat/lon.

$$\begin{bmatrix} T_1 \\ \vdots \\ T_i \end{bmatrix} = \begin{bmatrix} d_{11} & \dots & d_{1j} \\ \vdots & \ddots & \vdots \\ d_{i1} & \dots & d_{ij} \end{bmatrix} \begin{bmatrix} n_{e1} \\ \vdots \\ n_{ej} \end{bmatrix}$$

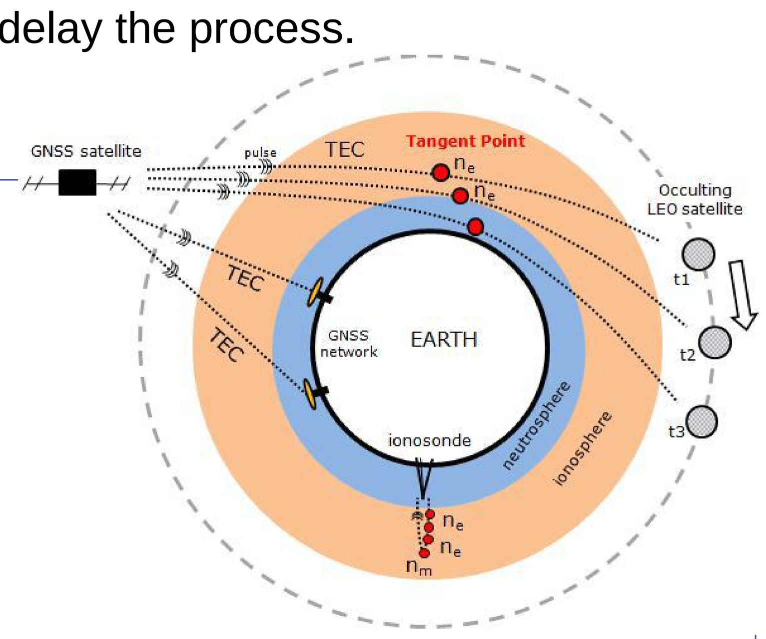
$$\mathbf{x_t} = \mathbf{x_{t-1}} + \mathbf{TK}(\mathbf{l_b} - \mathbf{A}\,\mathbf{x_{t-1}})$$

$$\mathbf{T} = exp[-(\mathbf{r_i} - \mathbf{r_j} - v_i\Delta t)^2/\tau^2]$$



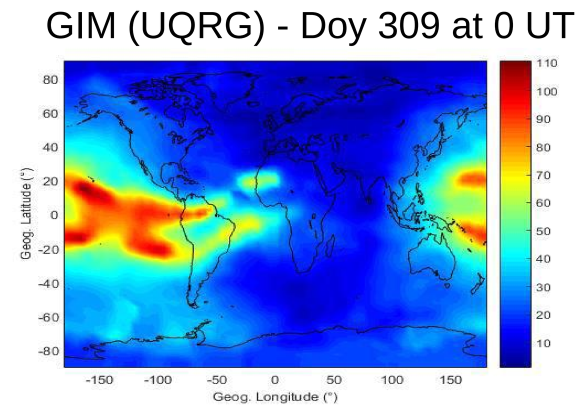
- needs powerful computers.
- simplifications or regional solutions may be required.
- forward estimations using physical models may delay the process.

5. Data and Analysis

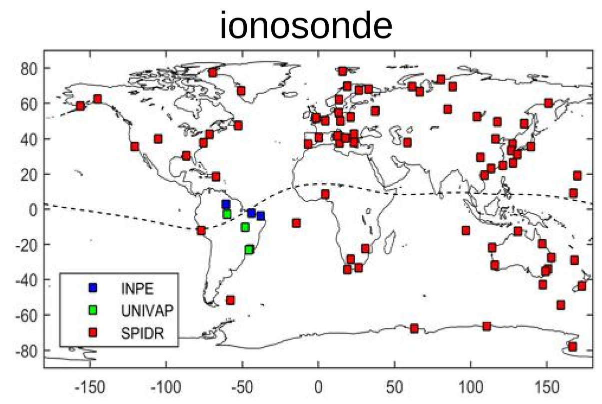


INPUT Data

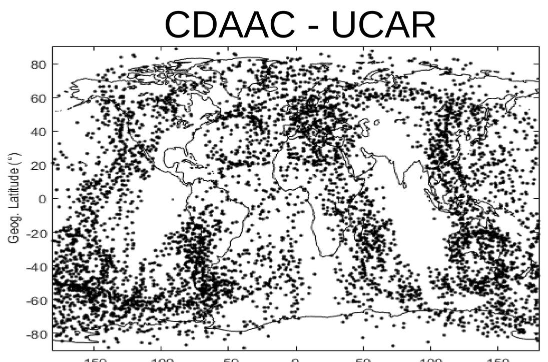
GIM (UQRG) - Doy 309 at 0 UT



ionosonde



CDAAC - UCAR



- VTEC from GIMs
- Ionospheric profiles from RO
- Bottomside from Ionosonde
- Ionospheric profiles from NeQuick

Preliminary Validation based on the RMSE

- RO data was used in the modeling process.
- Ionosonde data was manually scaled.
- Only ionosonde over Brazil was used.

RMSE of NmF2 using RO and independent ionosonde data

Method	RO (MHz)	Ionosonde (MHz)
Vary Chap	1.2	2.8
Shape Function	1.3	2.3
ART	1.1	2.3
Kalman Filter	2.1	3.3
a priori	1.5	3.1

RMSE were obtained using reference data from doys 309 to 314 of 2013

- RMSE of NmF2 was more promising for Shape Function and ART;
- RMSE of HmF2 was quite similar in comparison to the NeQuick result.

Conclusions and Future Work

- First analysis of four methods to improve the initial conditions of ionospheric tomography have been presented.
- Three dimensional (3D) global maps were obtained and incorporated to RO data, were the global modeling gave us the opportunity to use a plenty number of RO data that would be discarded if we were using a regional approach. The 3D global maps were validated against independent data over Brazil and RMSE results showed that most of the approaches gave us a more reliable information for regional applications.
- Such results shows that Shape Functions (SF) and ART (both corrected by RO) are emerging potential to be used as initial condition for the ionospheric tomography.
- In future works, the validation of SF and ART will be done systematically, considering a set of distinct conditions of the ionosphere.

References and Acknowledgements

- *Hernández-Pajares, M, Juan JM, Sanz J (2000) Improving the Abel inversion by adding ground GPS data to LEO radio occultations in ionospheric sounding. Geophysical research letters 27(16):2473-2476.*
- *Olivares-Pulido G, Hernández-Pajares M, Aragón-Angel A, Garcia-Rigo A. (2016) A linear scale height Chapman model supported by GNSS occultation measurements. J. Geophys. Res. Space Physics 121:7932–7940*
- *Prol FS, Camargo PO (2016) Ionospheric tomography using GNSS: multiplicative algebraic reconstruction technique applied to the area of Brazil. GPS Solutions 20(4):807-814.*

Acknowledgements: The first author is grateful to UPC-IonSAT for the financial support. Also, this work was jointly funded by Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP) under grants 2015/15027-7 and 2016/22011-2, Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), under grant 479965/2013-7. The authors are grateful to IGS for providing GIM (Global Ionospheric Maps), to CDAAC (Cosmic Data Analysis and Archive Center) for providing Radio-Occultation data and to SPIDR (Space Physics Interactive Data Resource) and INPE (Instituto Nacional de Pesquisas Espaciais) for providing ionosonde data. The authors also acknowledge NASA (National Aeronautics and Space Administration) and ICTP (International Centre for Theoretical Physics) for the use of IRI (International Reference Ionosphere) and NeQuick models.