POLarGIMs: Time evolution of vertical electron content distribution in polar ionosphere from UPC-GIM TOMION runs

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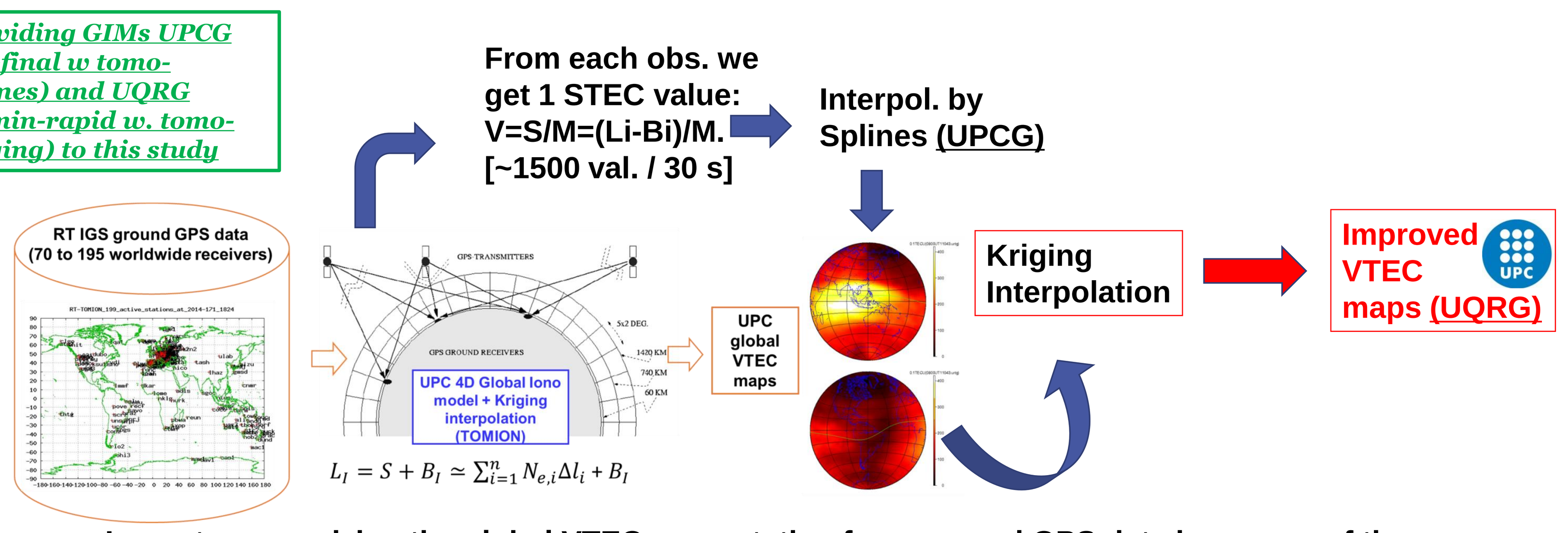
IGS Workshop 2018, 29 October - 2 November 2018, Wuhan, China

Summary: During this year we celebrate 20 years of continuous generation and improvement of global ionospheric maps (GIM) of vertical total electron content (VTEC) in the context of the International GNSS Service (IGS, see for instance Roma-Dollase et al. 2018). We present the time series of the vertical distribution of polar electron content derived from the most daily-basis tomographic runs performed by one of the IGS ionospheric analysis centers: UPC-IonSAT (Hernández-Pajares et al. 1999). We will focus in particular on two points: (1) in the comparison of the derived ionospheric effective height with other approaches, and (2), in the study of the predictability of the top side electron content fraction which might lead to the extension of the Barcelona Ionospheric Mapping Function (BIMF-nml, Lyu et al. 2018) to polar regions, with the associated potential improvement for GNSS users in such regions.

1. Baseline: Global tomographic UPC-IonSAT runs since 1998.5 with UPC-IonSAT TOMION-v1 software

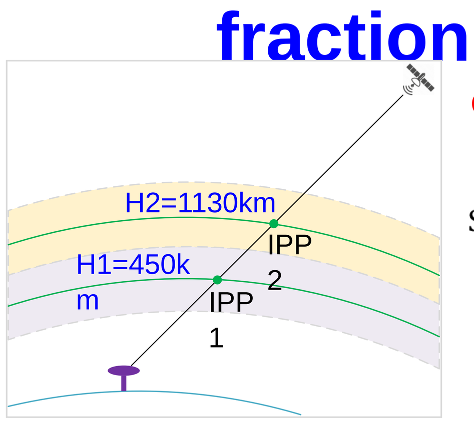


Layout summarizing the global VTEC computation from ground GPS data by means of the UPC TOMION software, including the main tomographic model equation[*]

[*](data: ionospheric combination of carrier phases LI, and length intersection within each voxel, ∆li; unknowns: its ambiguity BI, the STEC, S, which includes the mean electron density within each given voxel, Ne,i).

(see for instance Hernández-Pajares, M et al.,1999. *New approaches in global ionospheric determination using ground GPS data*. Journal of Atmospheric and Solar-Terrestrial Physics 61, pp. 1237–1247.).

2. Two ways of improving the ionospheric mapping function: Topside electron content fraction (μ_2) and the effective height (h)



Condensed two-layer Assumption

$$\mathrm{STEC} = \left(1-\mu_2^{ipp1}\right)M^{ipp1}V^{ipp1} + \mu_2^{ipp2}M^{ipp2}V^{ipp2}$$

$$\mu_2 = \frac{N_2}{N_1+N_2} = \frac{P_2}{P_1+P_2} = \frac{P_2}{V}$$

$$M = \frac{S}{V} \simeq \int_{REC}^{TRA} \frac{N}{V}\frac{1}{\cos X}\,dh \simeq \sum_i \frac{P_i}{V}\frac{r_i}{\sqrt{r_i^2-p^2}}$$

$$h = \frac{M}{\sqrt{M^2-1}}p - r_e$$

where V^{ipp1}, V^{ipp2} are VTECs at IPP1 and IPP2, respectively;
M^{ipp1}, M^{ipp2} are standard mapping functions at IPP1 and IPP2, respectively;
μ_2^{ipp1}, μ_2^{ipp2} are μ_2 ratio values at IPP1 and IPP2, respectively.

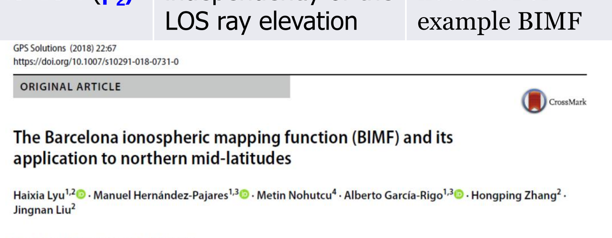
	PROS	CONS
IONOSPHERIC EFFECTIVE HEIGHT (h)	Simple interpretation and application modifying the standard mapping function.	Its definition depends on a reference elevation.
TOPSIDE ELECTRON CONTENT FRACTION (μ_2)	Ionospheric mapping function defined independently of the LOS ray elevation	A new ionospheric mapping function formulation is needed: For example BIMF

$$\mathrm{STEC} = \left(1-\mu_2^{ipp1}\right)M^{ipp1}V^{ipp1} + \mu_2^{ipp2}M^{ipp2}V^{ipp2}$$

$$\mu_2(td,lt) = a_0(td) + a_1(td)\cdot lt + a_2(td)\cdot lt^2 + a_3(td)\cdot lt^3 + a_4(td)\cdot lt^4$$

$$a_i(td) = C_i^{(0)} + \sum_{k=1}^{n\_T_{a_i}}\left(C_i^{(2k-1)}\cdot\sin\left(2\pi\cdot\frac{td}{T_i^{(k)}}\right) + C_i^{(2k)}\cdot\cos\left(2\pi\cdot\frac{td}{T_i^{(k)}}\right)\right)$$

where, td = mjd − 50965, lt is local hour of IPP


GPS Solutions (2018) 22:67
https://doi.org/10.1007/s10291-018-0731-0

ORIGINAL ARTICLE

The Barcelona ionospheric mapping function (BIMF) and its application to northern mid-latitudes

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Received: 26 May 2017 / Accepted: 17 April 2018
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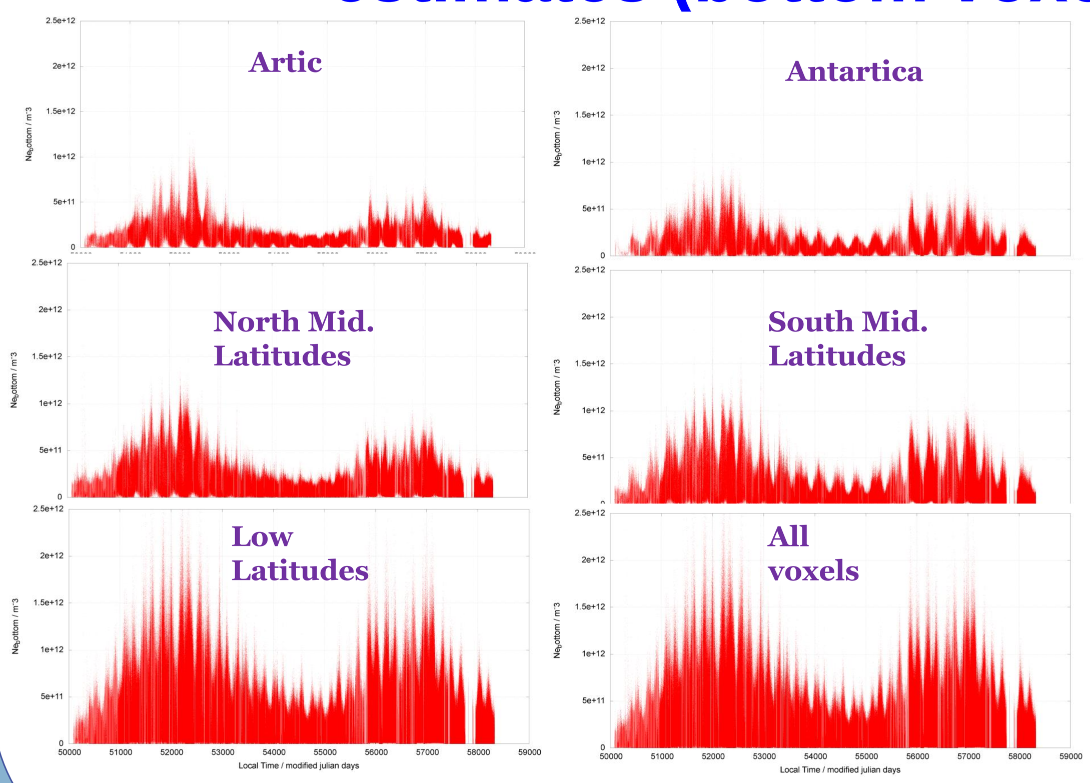
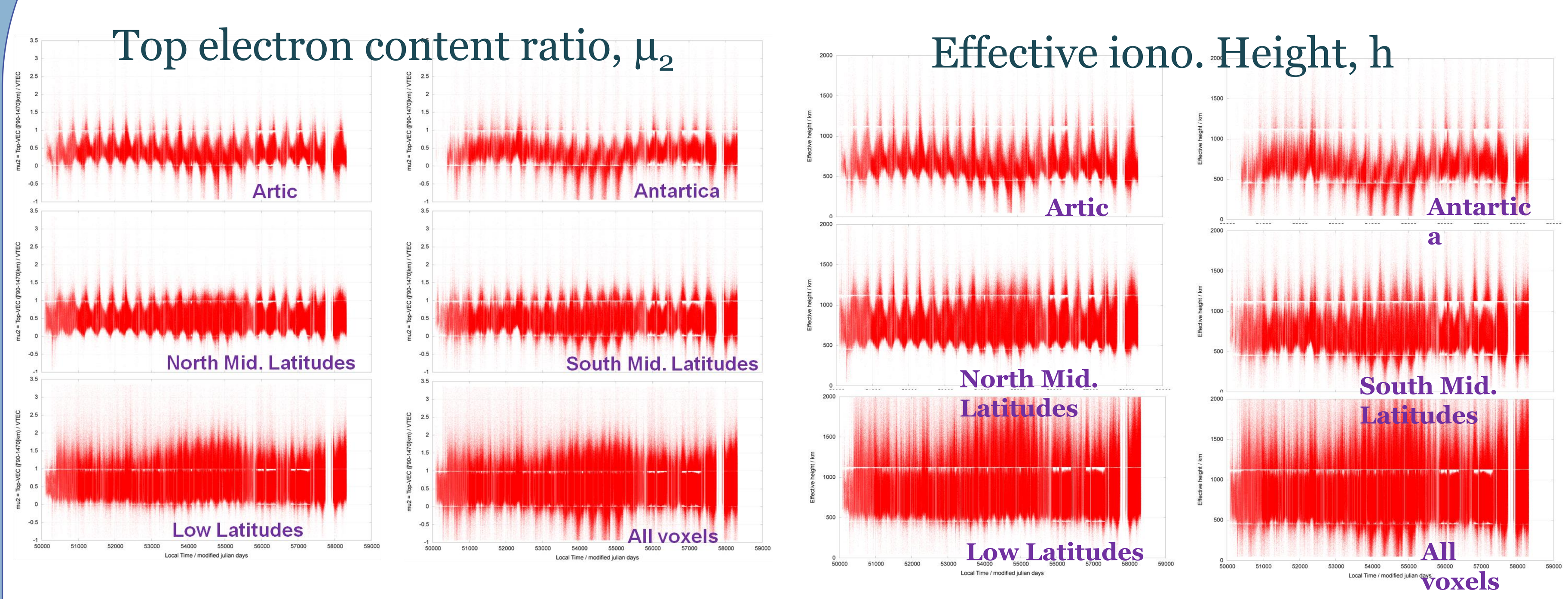
- BIMF is based on a climatic prediction of the distribution of the top-side electron content fraction, regarding to the vertical total one (depending on local-time and date; and no observations are needed).
- Compared to the standard mapping function, only one additional parameter μ2 - the shape function of the second layer (on top) - is needed, provided in terms of a low-degree polynomial function on local time with coefficients previously fitted on few significant terms of Fourier series on time (from dual-layer tomographic UPC runs since 1998.4 to 2009.4).
- In terms of its implementation, no external data are required, which is very convenient for applications, mainly because BIMF is climatic.
- The first version of BIMF (BIMF-nml, for North Mid latitudes) improves the application of ionospheric corrections from VTEC maps provided by different analysis centers, indicating the physical consistency of the BIMF climatic modelling of the topside electron content fraction.

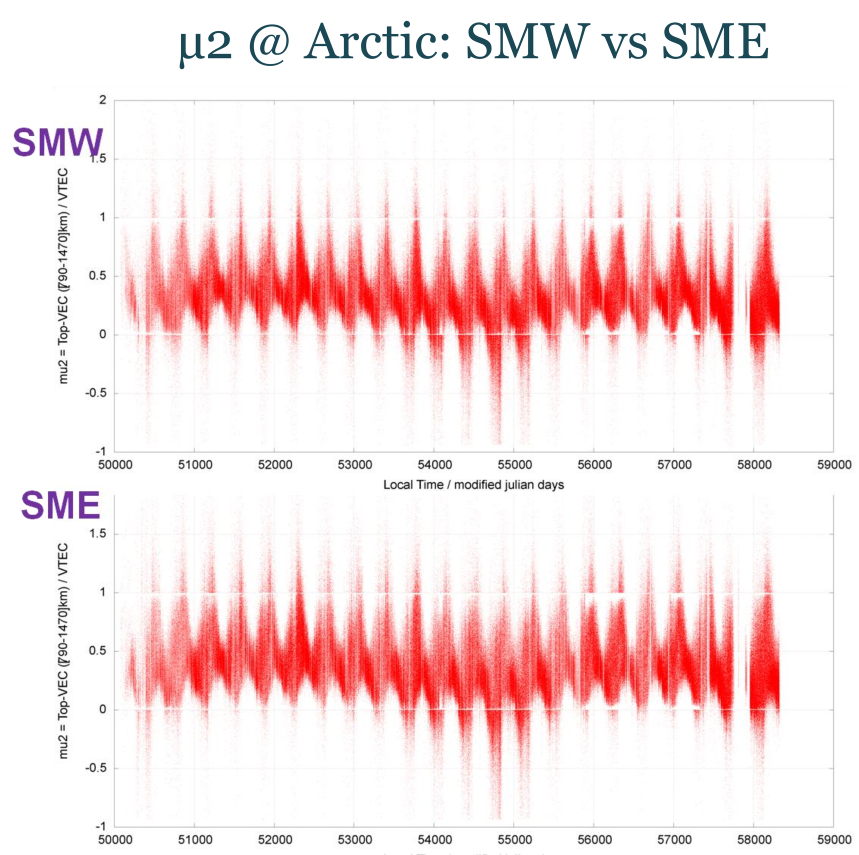
3. Extracting the electron content TOMION estimates (bottom voxels shown)

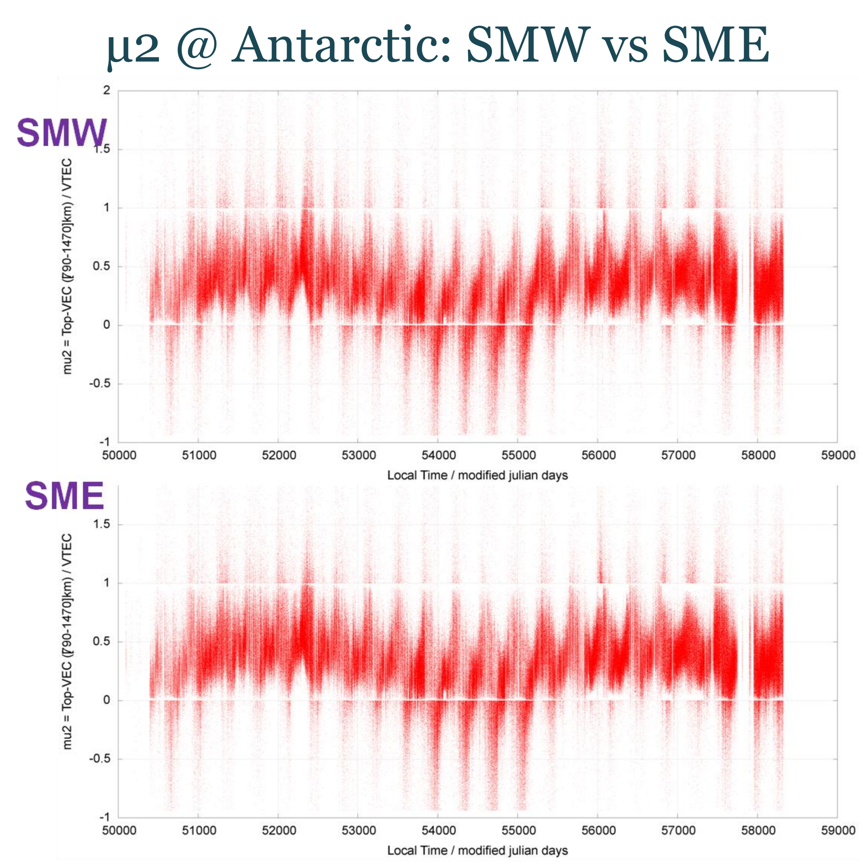


1) The mean electron densities, {Ne}, have being worldwide estimated since 1996 with an adaptative grid (Hernández-Pajares et al. 1997) each 15 min within TOMION Kalman filter, and stored each 2 hours (Hernández-Pajares et al. 1999, Roma-Dollase et al. 2018).
2) The voxels are partitioned in 5 regions by latitude, Φ: Arctic (AR, Φ ≥ 60º), Antarctica (AN, Φ ≤ -60º), North-Mid latitudes (NM, 30º≤ Φ < 60º), South-Mid latitudes (SM, -60º< Φ ≤ -30º),Low latitudes (LO, -30º< Φ < 30º).

4. Vertical distribution evolution of electron content per region since 1996 to 2018: μ_2 & h







In dipolar solar-geomagnetic coordinates both West and East time series are much similar, in particular at the minimum part of the solar cycle in Antarctica.

The clean mu2 dependence for Arctic and Antarctica strongly suggest the possibility of building an useful BIMF-polar, similarly to the above introduced BIMF-nml (Lyu et al. 2018).

Conclusions and Future Work

- The temporal evolution of the vertical distribution of electron content, determined from +20 years of continuous TOMION runs to build the IGS UPC GIMs (UPCG & UQRG) is presented.
- This information can provide new knowledge in the new future on the polar ionosphere during the most recent two solar cycles, which might be useful for different users in the future:
  - ✓Effective height assessment.
  - ✓A potentially better mapping function based on the prediction of the topside electron content fraction over Artic and Antartica.

Acknowledgements: This work has been partially supported by EC-JRC funded activity POLarGIMs, the CSC and WHU scholarships. We also acknowledge the IGS and other data provider agencies for the GNSS data and products.

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