A Simple Data Assimilation Criterion to be Used by a Physical Model

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Abstract

In this work, we use the vertical total electron content (TEC) obtained from Boston College South American data chain. The data are only for the day March 24, 2015. Three latitudinal ranges covering -30º to 30º degrees, which are distributed along the magnetic meridian crossing Jicamarca (Geog. Longitude: -77º), Boa Vista-Campo Grande (Geog. Longitude: -57º) and São Luís (Geog. Longitude: -44º), respectively. Our assimilation data criterion consist of a latitudinal adjustment of the electron density calculated by the Sheffield University Plasmasphere Ionosphere Model at INPE (SUPIM-INPE) applying the same proportion as obtained from the ratio between the observed TEC and calculated by SUPIM-INPE. F-region critical frequency (foF2) and TEC registered by Digisondes operating at Boa Vista, São Luís and Campo Grande were also used in the result validations. In general, Boston College TECs show good agreement with those obtained from Digisondes for all locations, except over São Luís near 00 and 12 UT and over Campo Grande after 14 UT. The direct results from SUPIM-INPE for both foF2 and TEC have not shown good agreement with the observational data. On the other hand, it was found excellent results, mainly for TEC, after applying the data assimilation. The proportion criterion is underestimating the values of foF2 between evening and sunrise. SUPIM-INPE model seems to be overestimating the electron density decay for altitude above F-region peak, causing low ratio in observed/calculated TEC values and, consequently, low foF2.

Introduction

It is well known how much is important to have the accurate ionospheric electron content (TEC) values to obtain positioning using GNSS single-frequency. The physical models have been an essential tool for the ionospheric climatological understanding, but they are not accurate source of TEC yet.

SUPIM-INPE is a physical model of the Earth's Ionosphere and Plasmasphere. It is an enhanced version of SUPIM (Bailey and Balan, 1996) that includes the ionospheric E region in its calculation system (Souza et al. 2010, 2013). In the model, coupled time-dependent equations of continuity, momentum, and energy balance are solved along closed magnetic field lines to calculate the concentrations, field-aligned fluxes, and temperatures of the electrons and of the ionic species O^+, H^+, He^+, N^+, N_2^+, O_2^+ and NO^+.

In this study, we use TEC data to correct the electron density distribution, both spatial and temporal, calculated by SUPIM-INPE model for the South American sector. The main aim is to obtain accurate electron density and TEC to be utilized by empirical/parameterization or assimilation techniques or as inputs in a physical model.

Experimental Data

Our study was done using a data base record at the day March 24, 2015. This is a geomagnetically quiet day and representative of a moderate solar condition (F10.7 = 133). Two TEC data sets were used, one from Low-latitude Ionosphere Sensor Network (LISN)/Boston College, which cover all Latin America and another one from a Digisonde data base collected simultaneously at Boa Vista (Geog. Lat.: 2.82º N; Geog. Lon.: 60.66º W; Mag. Lat.: 9.6º N), São Luís (Geog. Lat.: 2.30º S; Geog. Lon.: 44º W; Mag. Lat.: 3.47º S) and Campo Grande (Geog. Lat.: 9.57º S; Geog. Lon.: 54.83º W; Mag. Lat.: 13.50º S). Figure 1 shows an example of TEC data map, in geographic coordinate, from LISN network for 00 UT (left hand side panel) and after its conversion to geomagnetic coordinate (right panel). A linear interpolation was applied to fill small data gaps. It is noted a well developed south crest of the equatorial ionization anomaly. The black stars on the right panel show the locations of Jicamarca (JI), Boa Vista (BV), Campo Grande (CG) and São Luís (SL) and the white vertical bar are the three selected magnetic meridians where the data assimilations are applied. The magenta line shows the magnetic equator position.

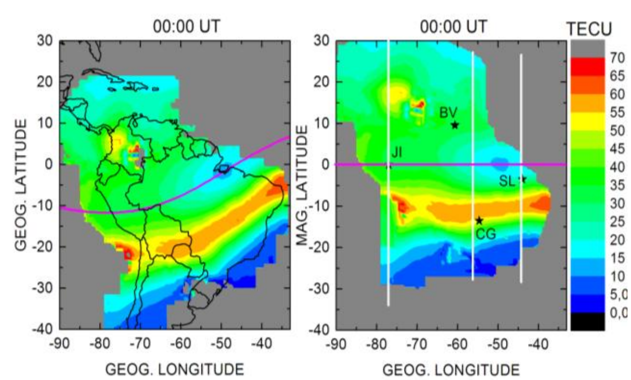

Figure 1. TEC maps in geographic coordinate over the Latin America obtained from LISN network (left panel) and its conversion for magnetic coordinate (right panel).

Data Assimilation Criterion

A simple criterion to correct the electron densities calculated by SUPIM-INPE model has been developed. It is selected a latitudinal distribution of observed TEC obtained from LISN network/Boston College and a ratio of such TEC with that from SUPIM-INPE is calculated. Considering that the shape of the altitudinal electron density from the model is coherent, it is adjusted using the same ratio as mentioned above. In other words, knowing the proportional difference between observed and calculated TEC, we correct the electron densities given by SUPIM-INPE. Since SUPIM-INPE has produced excellent results for E region (Souza et al., 2013), the adjustments were applied to altitudes above 140 km.

Results and Discussion

Figure 2 shows, for comparison purposes, two observed TEC sets: one obtained from LISN network (green dots and denoted as TEC_B.College) and another from Digisonde (black dots, named as TEC_dig). It is also presented TEC calculated by SUPIM-INPE (blue dots, named as TEC_supim-inpe) and the TEC results from the data assimilation (red dots, denoted as TEC_supim-inpe*). From the top to the bottom panels are presented the TEC comparisons for BV, SL and CG, respectively.

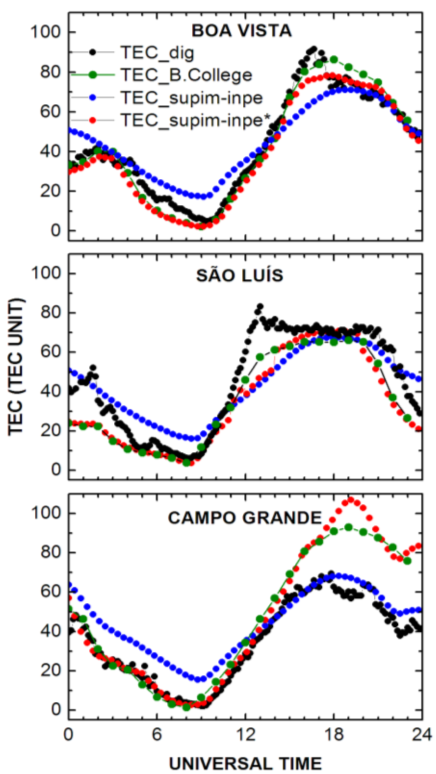

Figure 2. Diurnal TEC variation obtained from LISN network (green dots), from Digisondes (black dots), calculated by SUPIM-INPE (blue dots) and from the data assimilation (red dots). From the top to bottom are presented the comparisons for BV, SL and CG, respectively.

The TEC_B.College shows good agreement with TEC from Digisondes, except near 00 and 12 UT over SL and after 14 UT over CG. This may be an indicative that Boston College procedure (no published) to calibrate TEC, i.e., to remove bias is fine.

The discrepancy between the TEC_B.College and TEC_dig for CG after 14 UT can be explained by no clear ionograms for this period when no well defined F-region signatures were identified, consequently, contributing to an underestimated TEC (such ionograms were not shown here). SUPIM-INPE results have not presented good agreement with the observations. On the other hand, its result including data assimilation shows excellent agreement.

SUPIM-INPE results of foF2 are also evaluated. Figure 3 presents the calculated and observed values of foF2 registered simultaneously at BV, SL and CG. Similar to the TEC results, foF2 calculated by SUPIM-INPE have not presented good agreement with Digisonde observations. In general, the foF2 results improve after the data assimilation, but they are underestimated between evening and sunrise for all locations (BV, SL and CG). In order to explain such differences, it was also analyzed the vertical electron density profile as shown in Figure 4. It was selected two separate times: 09 UT (left panels) when was not found good agreement between calculated foF2 and the data and for 15 UT (right panels). For this last time, there is better agreement between them, except for CG where was found large difference. During 09 UT was noted that SUPIM-INPE shows slow decay in the electron density for altitude above F-region peak. This produces high TEC, consequently, low ratio

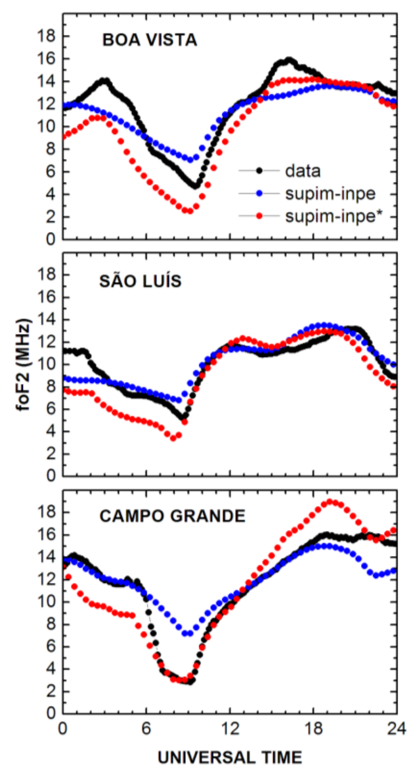

Figure 3. Same as Figure, but it shows foF2 values.

from observed divided by calculated TEC and, obviously, decrease all adjusted electron densities including foF2. We have also noted good agreement when the shape of the calculated altitudinal electron density distribution is coherent, i.e., it has the F-region peak height aligned with observed one.

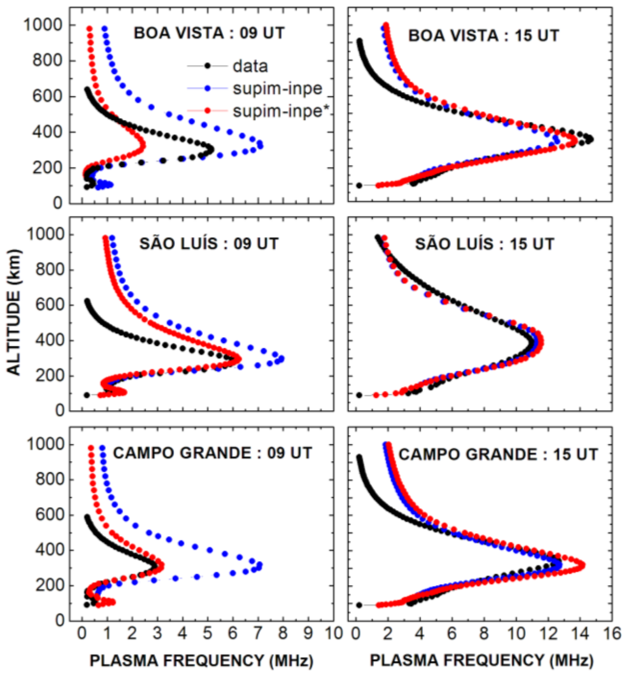

Figure 4. Vertical electron density profiles in plasma frequency unit at 09 UT (left panels) and 15 UT (right panels) for BV, SL and CG.

Figure 5 shows the modeled results for Jicamarca. Both top and bottom panels present results with and without data assimilation. TEC values obtained with the data assimilation match with the TEC from the Boston College data base, as we can see in the bottom panel. Unfortunately, it was not possible to compare the calculated values of foF2 with Digisonde data due to no edited data availability.

Remarkable Conclusions

- A simple criterion using data assimilation to improve SUPIM-INPE results has been developed. The same proportion as calculated from TEC_B.College divided by TEC_supim-inpe is applied to correct electron densities given by SUPIM-INPE model.
- TEC obtained from LISN network/Boston College shows good agreement with Digisonde TEC.
- F-region topside electron density decay calculated by SUPIM-INPE is not consistent with Digisonde one causing high TEC values, low ratio TEC_B.College/TEC_supim-inpe, consequently, low foF2 values from our data assimilation technique.

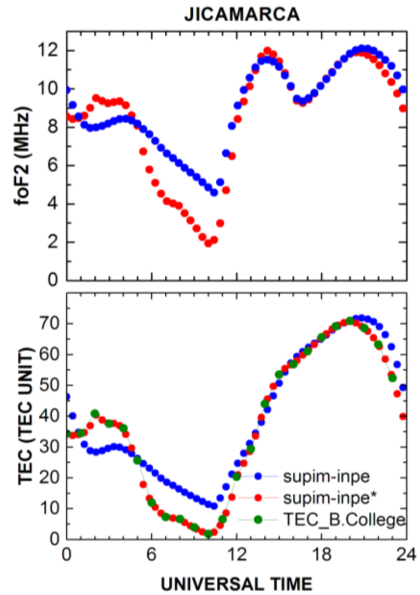

Figure 5. Diurnal variation of foF2 (top panel) and TEC (bottom panel) calculated by SUPIM-INPE (blue dots) and from the data assimilation (red dots). It is also presented observed TEC (green dots).

Acknowledgments

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References

Bailey, G.J., and N. Balan, A low-latitude ionosphere-plasmasphere model, STEP Handbook on Ionospheric Models, ed.R.W. Schunk, Utah State University, 173-206, 1996.

Souza, J., Asevedo Jr, W. dos Santos, P. Petry, A., Bailey, G.; Batista, I.; Abdu, M. Longitudinal variation of the equatorial ionosphere: Modeling and experimental results. Advances in Space Research, v. 51, n. 4, p. 654–660, 2013.

Souza, J.; Brum, C.; Abdu, M.; Batista, I.; Asevedo, W.; Bailey, G.; Bittencourt, J. Parameterized Regional Ionospheric Model and a comparison of its results with experimental data and IRI representations. Advances in Space Research, v. 46, n. 8, p. 1032–1038, 2010.