Thermospheric Neutral Wind Role on the Equatorial and Low-latitude Ionosphere During Conjugate Point Experiment Campaign

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Abstract

The thermospheric neutral wind plays important control in the temporal and spatial ionospheric plasma distribution at equatorial and low latitude sectors. For example, it is responsible for the F3 layer formation and for the asymmetry in the equatorial ionization anomaly crests. In this work, we have investigated the effects of the neutral winds on both E and F region over the Brazilian sector during one day, October 10, 2002, of Conjugate Point Experimental (COPEX) campaign. To calculate the ionospheric response to wind change the Sheffield University Plasmasphere Ionosphere Model at INPE (SUPIM-INPE) was used, in which the winds from two different versions of the Horizontal Wind Models (HWM93 and HWM07) were analyzed. As expected, the model results have not shown wind effects in the control of the plasma distribution near E region peak for equatorial and low latitude sectors. On the other hand, the F region variations due to the winds are complex and involve non-linear processes. Some changes in foF2 in response to wind are seen after ~3 hours. There is evidence that, for the day October 10, 2002, the lifetime of the equatorial ionization anomaly crests after midnight was significantly increased due to convergent winds near the conjugates points. The origin of such winds may be from the equatorial midnight temperature maximum (MTM) phenomenon. Equatorward wind contributes to increase the poleward expansion of equatorial ionization crests.

Introduction

The dynamics of the equatorial and low latitude ionosphere is greatly dominated by vertical E×B drift, diffusion and effective neutral wind, i.e., wind component along the geomagnetic field (B). In fact, the ionospheric motion occurs basically in two dimensions, parallel and perpendicular to the magnetic field, of course, only in the magnetic meridian plane (Anderson 1973, Balan and Bailey, 1996, Shunck et al. 1996, Huba et al. 2000 and Bittencourt et al. 2007). The movement due to diffusion and wind are mostly efficient along B. Obviously, resulting of these forces with E×B action modifies the perpendicular plasma distribution, as for example, during F3 layer formation (Balan and Bailey, 1999, Batista et al., 2000). In this work, we use SUPIM-INPE model (htpp://www2.inpe.br/climaespacial/portal/tec-supim-previsao) plus E and F region peak parameters from COPEX campaign (Reinisch et al., 2004, Abdu et al., 2004, 2009, Sobral et al., 2009) to investigate the equatorial and low-latitude ionosphere responses to thermospheric neutral wind variations. In the modeling analysis the winds from the Horizontal Wind Model, versions of 1993 (HWM93, Hedin et al., 1995) and 2007 (HWM07, Drob et al., 2008) were considered.

SUPIM is a first-principles model of the Earth's Ionosphere and Plasmasphere that has been developed over the last three decades by Professor Graham John Bailey from University of Sheffield. 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_2^+, O_2^+ and NO^+. SUPIM-INPE is an enhanced version of SUPIM that includes the low latitude ionospheric E region in its calculation scheme. It has been developed at the Aeronomy Division of the Center for Atmospheric and Space Science at INPE. This new version has extended the calculations along the magnetic field lines from its original lower limit of 120 km down to 80 km in both hemispheres. Other new feature of this enhanced version is the calculation for the seventh ion N^+. The main input parameters of the model are: ionizing solar flux, neutral atmosphere densities and temperatures, vertical plasma drift velocities and neutral wind velocities.

Experimental data from COPEX and the vertical E×B drift velocities

The COPEX campaign was held in Brazil between Oct-Dec 2002, in which simultaneous data were collected at Boa Vista (BV, northern conjugate point, mag. lat. = 11°), Cachimbo (CH, near mag. equator, mag. lat. = -1.75°) and Campo Grande (CG, southern conjugate point, mag. lat.=-11°). The critical frequencies and their corresponding heights of both E (foE, hmE) and F (foF2, hmF2) regions registered at COPEX sites were analyzed. We select only the day October 10, 2002. It is a geomagnetically quiet day and also a representative day of solar maximum condition (F10.7=171). The idea is: understanding what happens in an isolated day it is possible to understand the day-to-day variabilities opening opportunity for an improved ionospheric predictions. The E×B drift velocity used by SUPIM-INPE as input parameter is shown in Figure 1. It was calculated using the model by Scherliess and Fejer (1999), except during evening time when the approximation V_z=dh'F/dt was used, where h'F is the minimum virtual height of the F-layer obtained from digisonde data collected at CH. For comparison proposes, Figure 1 also presents the drift registered at Jicamarca, as it will be discussed in the next section.

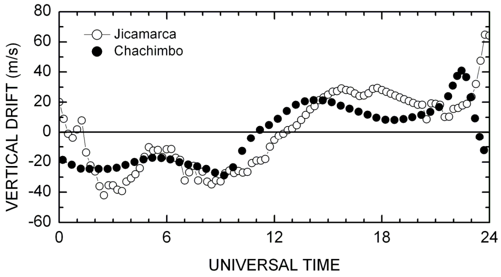

Figure 1. Diurnal variations of the vertical E×B drift velocities.

Results and Discussions

We show here a comparison between the main ionospheric peak parameters (foE, hmE, foF2 and hmF2) calculated by SUPIM-INPE model and experimental data from three different locations strategically aligned in the magnetic meridian, as defined in the COPEX campaign. Figure 2 presents the observed and calculated values of the E region peak parameters, foE (1st column) and hmE (2nd column) for BV (1st line), CH (2nd line) and CG (3rd line). The modeled results were obtained considering the winds given by HWM93 (blue dots) and HMW07 (red open dots).

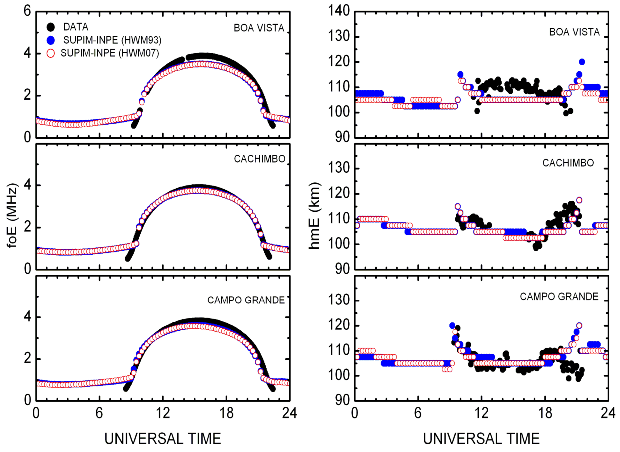

Figure 2. Observed and calculated values of the E region critical parameters, foE (1st column) and hmE (2nd column) for BV (1st line), CH (2nd line) and CG (3rd line).

Even though using so different wind intensities, as shown in Figure 3, SUPIM-INPE produces equal results for the E region. It is well known that the winds do not affect the low altitude ionosphere, therefore, these results were already expected. On the other hand, since the calculated values of both foE and hmE show good agreement with data we may consider this analysis as a complete SUPIM-INPE validation for the E region. The effective winds presented in Figure 3, as mentioned above, were obtained by HWM93 and HMW07 models for a fixed altitude of 105 km. The three panels (from above to below) show the winds over BV, CH and CG, respectively.

F region shows a more complex response to the wind involving non-linear dependencies. Batista et al. (2011), explained that the ionization distribution changes in the equatorial and low latitude F region, in response to winds, may occur after 2-3 hours and a better understanding of such changes, mainly in the equatorial ionization anomaly crests, must consider the integrated wind effects along the magnetic meridian. Figure 4 shows the effective wind calculated by HWM93 (in blue color) and HWM07 (in red) models for 300 km and over each COPEX sites. Note that the winds calculated by HWM07 are basically northward. In contrast, the winds obtained by HWM93 show lower intensities and are oscillating sometimes northward-sometimes southward in almost equal time interval. For this last case, the ionosphere response is represented by the foF2 variations (curve SUPIM-INPE(HWM93) in Figure 5) and shows a symmetric ionization in relation to the magnetic equator, except few hours after sunrise.

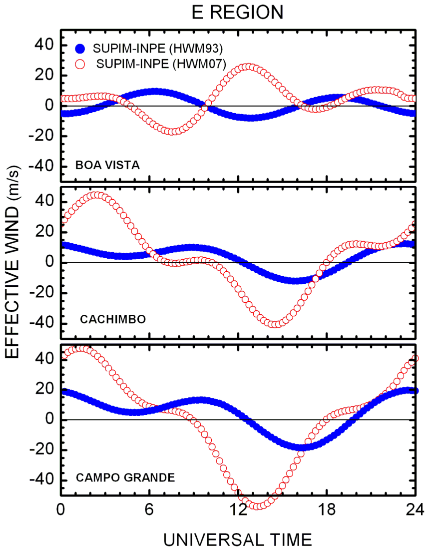

Figure 3. Effective winds calculated by HWM93 (in blue color) and HWM07 (in red) models for 105 km over each COPEX sites (BV, CH and CG).

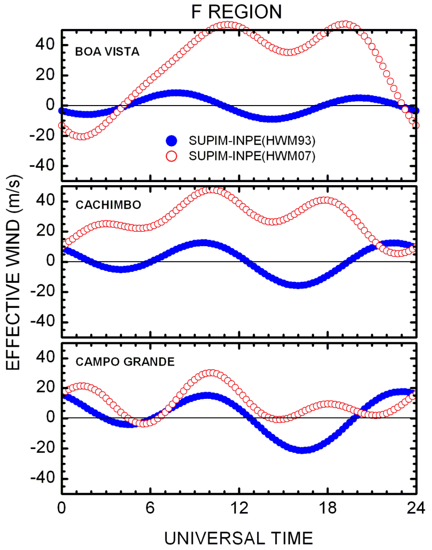

Figure 4. Same as Figure 3, but the winds are for 300 km.

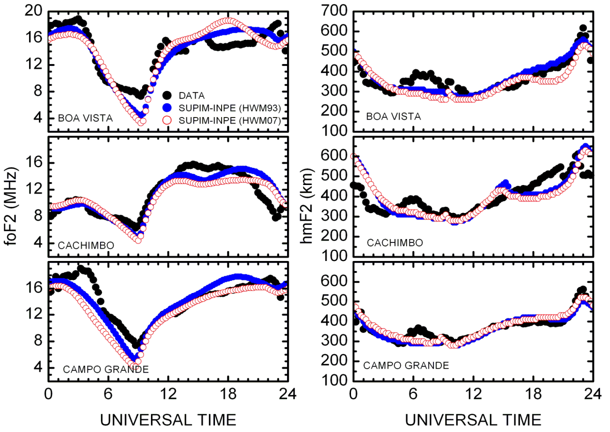

Figure 5. Same as Figure 2, but for the F region parameters.

The ionospheric variations due to the winds from HWM07 (denoted as SUPIM-INPE(HWM07) in Figure 5), as expected, present a strong asymmetry in the equatorial ionization anomaly (EIA). The maximum crest is in northern hemisphere most of the times, obviously, due to the northward wind. The SUPIM-INPE results using HWM07 seem to be more coherent than that one using HWM93, mainly for CG where an excellent agreement with both foF2 and hmF2 data is observed during a long time period (10-24UT). For this reason, we focus the discussion on the results calculated with HWM07 from here on. SUPIM-INPE(HWM07) has underestimated both foF2 and hmF2 over all COPEX sites near 07UT. Since during this time hmF2 data increase simultaneously at BV, CH and CG and such tendency is not presented in the results, it means a clearly vertical E×B drift effects that were not properly considered in the modeling. The uplift of the F layer due to an upward E×B drift before sunrise can decrease recombination, consequently, more ionization remains during such time. Evidence that vertical E×B drift increased in the morning of October 10 can be seen in the incoherent scatter radar measurements at Jicamarca, shown in Figure 1. We believe that the vertical E×B drift may have presented higher values for the COPEX sector than for Jicamarca due to the significant F layer elevation observed in hmF2 data (see Figure 5).

Wrong wind actions have caused large discrepancies between SUPIM-INPE(HWM07) results for foF2 near 18UT, between 13-19UT and also near 03UT over BV, CH and CG, respectively. A wind divergence was responsible for the southern crest dissipation over CG (mag. lat. = -11^o). Figure 6 shows a magnetic meridional cross section of the effective wind calculated by HWM07 model in which we can see such divergence in the F region near CG and a convergence at its conjugate point BV (mag. lat. = 11^o). The wind convergence over BV explains the better level of agreement between the calculated value of foF2 and data. We believe that, due to the absence of ionization source during nighttime, the convergent wind over CG near 03UT is the unique way to have a foF2 enhancement, as presented in the data. To have convergent wind at both sites BV and CG, as we are suggesting, in somewhere between them must exist a divergent point. The physical reason for its existence may be associated with the equatorial midnight temperature anomaly (see, for example, Colerico et al., 1996, Sastri et al.,1994, Batista, et al.,1997 and Souza et al., 2000).

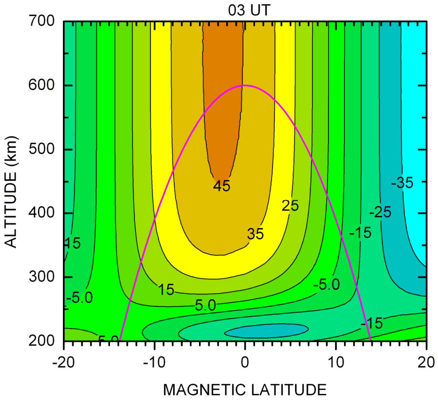

Figure 6. Magnetic meridional cross section of the effective wind calculated by HWM07 model. The magenta curve shows a dipolar field line with apex of 600 km.

Correct wind action can be seen over the area near CG. The equatorward winds contributed to keep the southern anomaly crest centre a little bit away from CG in poleward direction for a long time (10-24UT). This crest expansion was responsible for the good match between calculated and observed values of both foF2 and hmF2.

Over BV, it is interesting to note that while the calculated values of foF2 (hmF2) start to have an anomalous increase (decrease) at 1530UT, the data show an inverse way, i.e, observed foF2 decreases and hmF2 increases. The modeled results of foF2 presented a maximum at 18UT. The role of the wind for this case can be understood as follow: the northward wind, as presented in Figure 4, dragged the ionization decelerating and accelerating before and after 15UT, respectively. The inertial effects of such dynamics compress and push down F layer producing a maximum foF2 after 3 hours. In contrast, the experimental data show a minimum. This suggests that a resulting effect due to an equatorward wind, vertical drift and diffusion moves the anomaly crest poleward producing a minimum in foF2. The low calculated values of foF2 over CH between 13-19UT justify the need of an equatorward wind coming from BV to converge near the magnetic equator that will increase foF2 and hmF2 also near the equator area and improve the results over CH.

Main Conclusions

- The analysis of SUPIM-INPE results have confirmed that there is no wind effects on the control of the plasma distribution near E region peak for equatorial and low latitude sectors.
- F region variations due to the winds are complex and involve non-linear processes. Some foF2 changes in response to winds are seen after ~3 hours.

- There is evidence that, for the day October 10, 2002, the lifetime of the equatorial ionization anomaly crests after midnight can be significantly controlled by convergent winds near the COPEX conjugate points, BV and CG. The origin of such winds may be from the equatorial midnight temperature maximum (MTM) phenomenon.
- Equatorward wind contributes to increase the poleward expansion of equatorial ionization crests during upward E×B drift times.

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