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Equatorial ionospheric vertical plasma drift model over the Brazilian region

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Abstract. Comparison between equatorial inospheric *F* region vertical plasma drift from satellite measurements [*Fejer et al.*, 1995], for the Brazilian longitude sector, and the drifts derived from ionosonde measurements around sunset shows significant differences on the prereversal peak behavior during solstices of high solar activity periods. Using ionosonde measurements around sunset and satellite measurements at other local times, we constructed an ionospheric vertical plasma drift model that is representative of the equatorial region over the Brazilian longitudes, where the magnetic declination is around -20°. The so derived drift model, here called IDM (ionosonde drift model), is used as an input to the Sheffield University plasmasphere-ionosphere model (SUPIM). It is shown that the *F* layer heights given by SUPIM with IDM are in good agreement with ionosonde measurements over the Brazilian longitudes and that IDM better simulates the *F* layer heights than the averaged drifts given by the satellite drift model [*Fejer et al.*, 1995].

1. Introduction

Since the publication of the first measurements of the *F* region vertical plasma drifts over the magnetic equator, based on the Jicamarca incoherent scatter radar data [*Woodman*, 1970; *Farley et al.*, 1970] the prereversal enhancement of the zonal electric field (vertical drift) and the role of the *F* region dynamo on its generation has been extensively investigated by both experimental and theoretical researchers [*Rishbeth*, 1971a, b; *Schieldge et al.*, 1973; *Heelis et al.*, 1974; *Fejer*, 1981; *Abdu et al.*, 1981a; *Batista et al.*, 1986; *Farley et al.*, 1986]. Ground-based measurements were used to infer the vertical plasma drifts during some specific local times, more precisely, during the prereversal enhancement that occurs around sunset [*Abdu et al.*, 1981a; *Batista et al.*, 1986]. These studies suggested large longitudinal variation of the vertical plasma drift prereversal enhancement over the South American region.

The use of satellite measurements to study equatorial *F* region electric fields and plasma drifts [*Maynard et al.*, 1988; *Coley and Heelis*, 1989; *Coley et al.*, 1990; *Heelis and Coley*, 1992] and the solar cycle, seasonal, and longitudinal effects in them [*Fejer et al.*, 1995] has contributed to a global view of the longitudinal behavior of these drifts and associated electric fields. Although the satellite data are, in principle, the most appropriate to give the broadest longitudinal coverage, the averaging procedure used to group the drifts in sectors can sometimes mask important features that occur in some specific regions. In this work we propose a model for the equatorial *F* region vertical plasma drift over the Brazilian region that should serve as input parameter to the general or local ionospheric model, whenever the results over the Brazilian region are of interest.

2. The Vertical Drift Model

Ionosonde data from Fortaleza, Brazil (4°S, 38°W, -20° magnetic declination), were used to derive the ionospheric virtual height, h'F, between 1600 and 2400 LT. Fifteen-minute data during magnetically quiet days for equinox and December and June solstices, from high and low solar activity periods, were used to construct six plots of the local time h'F average variation. The average h'F was used to obtain its time derivative $\Delta h'F / \Delta t$ that was used to derive the *F* region vertical plasma drift around sunset times, taking in account the loss term βH (where β is the loss coefficient and H is the plasma scale height), in a way similar to that described by *Krishna Murthy et al.* [1990]. *Bittencourt and Abdu* [1981] showed that, generally, during sunset and evening hours, when the *F* layer height is above 300 km, the apparent *F* layer vertical displacement velocity (dh'F/dt), inferred from ionosonde measurements, represents the true vertical drift. Below 300 km the apparent vertical velocity starts to depart significantly from the true vertical drift, owing to the increasing dominance of the recombination process at these lower heights. Those results were confirmed by *Krishna Murthy et al.* [1990]. The βH term was introduced in order to

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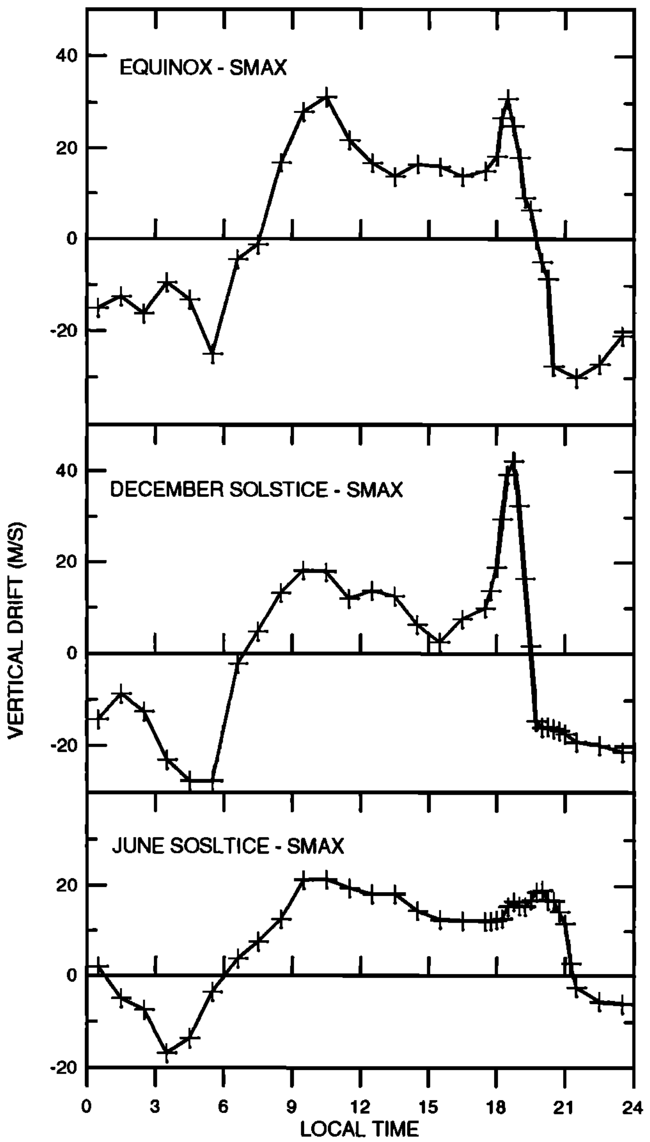

Figure 1. *F* region vertical plasma drift model for the Brazilian equatorial region during high solar activity periods.

take into account the important loss processes that occur below 300 km. They estimated the error in dN/dt obtained by using h'F (the virtual height) instead of the true height to be less than 5%. The difference between true and virtual heights is very small at the low-frequency range of the ionogram during evening and night hours because of the low underlying ionization.

On the basis of satellite results of *Fejer et al.* [1995] that (1) the *F* region vertical plasma drifts are almost independent of solar activity except around the prereversal maxima and nighttime and (2) for the Brazilian longitude sector the highest variability on the measurements was observed around sunset, we constructed the vertical *F* region plasma drift model shown in Figure 1, for the Brazilian longitude sector, based on ionosonde data around sunset and on the satellite results of *Fejer et al.* [1995] at other local times. The transition time from the satellite data to the ionosonde data used to construct the vertical *F* region plasma drift curves shown in Figure 1 varies from season to season, owing to the well-known seasonal variation of the prereversal enhancement on the *F* region vertical drift [*Fejer et al.*, 1979; *Abdu et al.*, 1981a; *Batista et al.*, 1986]. The ionosonde-derived drifts were used between 1800 and 2015 LT during equinox, between 1745 and 2130 LT during December solstice, and between 1815 and 2200 LT during June solstice. In order to make a smooth transition from the satellite to the ionosonde drifts, the values from both techniques were averaged between 1430 and 1745 LT during the June solstice. No averaging was necessary during the equinox and December solstice once the transition was already smooth. The average solar flux for the ionosonde measurements are 195, 196, and 185 for equinox and December and June solstices, respectively. The satellite data are the average from the 300°-360°E longitude sector (average longitude = 320°E), dip latitude ≤ |7.5°|, and magnetic declination ranging from -10° to -20°. The ionosonde data are from one single station, Fortaleza (dip latitude = 4°S, geographic longitude = 322°E, and magnetic declination = -20°). The vertical drifts using ionosonde data are in agreement with previous results from the same location and similar solar activity [*Abdu et al.*, 1981a; *Batista et al.*, 1986; *Batista et al.*, 1990].

Figure 2 shows *F* region vertical plasma drift in the afternoon-evening sector, inferred from ionosonde results from Fortaleza, as compared with the AE-E empirical model of *Fejer et al.* [1995]. The error bars in the ionosonde drift model (IDM) represent the standard deviation relative to the mean drift. During the equinox, high solar activity, the prereversal enhancements show somewhat different values prior to their peak amplitudes, but the phases are in reasonably good agreement. However, during the solstices, significant discrepancies are observed in the amplitude and in the phase as well. For the December solstice our results show a higher prereversal enhancement and an earlier inversion time than the satellite empirical model, and for the June solstice the prereversal enhancement and the inversion time occur later than the satellite model. Figure 5d of *Fejer et al.* [1995] for the December solstice shows fluctuations of the *F* region vertical plasma drift between 2000 and 2200 LT in the Brazilian longitude sector, larger than at any other sector. These fluctuations seem to contribute to the lowering of the prereversal enhancement of the vertical plasma drifts given by the empirical model based on satellite results, as compared with the prereversal enhancement derived from Fortaleza ionosonde results (Figure 2, December solstice). *Fejer et al.* [1995] report a correction made on the southern hemisphere daytime (0800-1700 LT) drift for the December solstice in the Brazilian and east American sector, but it seems that this correction does not apply to other local times [B. G. Fejer, private communication, 1995).

During the June solstice the vertical plasma drift derived from ionosonde shows a clear prereversal enhancement (Figure 1 and Figure 3) that is not seen in Figure 6 of *Fejer et al.* [1995] for the Brazilian longitude sector. The reversal time obtained by the two techniques also differs by almost 1 hour, and it occurs later in the ionosonde-derived drift. The ionosonde drift derived from Δh'F/Δt reflects the vertical movement of the base of the layer, while the satellite measurements were made in the altitude range from 230 to 470 km. In an earlier study comparing coincident incoherent scatter and ionosonde *F* region vertical plasma drifts, *Batista et al.* [1986] showed that the reversal times after sunset derived by the two techniques are in good agreement, although the ionosonde generally underestimates the prereversal peak amplitude. So we suppose that the observed differences are not due to the height at which each technique is measuring. Instead, the differences must be due to the great variability of the drifts in this longitude sector, owing to the high declination angles. For the Brazilian equatorial region the angle between the terminator and the magnetic meridian is the highest during the June solstice. The magnetic declination angle varies from -10° to -20° in the longitude sector between 300° and 360°E. Probably, the great discrepancies between the Fortaleza ionosonde and the satellite model results (Figure 2) for the June solstice are mainly due to the AE-E data average that is done over a wide range of longitudes. This is in close agreement with the results of *Fejer et al.* [1995], who observed significant differences in the afternoon-evening vertical plasma drifts and in their reversion times for the American-Brazilian longitude sectors, during the June solstice (see Figure 7 of *Fejer et al.* [1995]). Figure 2 also gives the ionosonde-derived vertical drifts around sunset during low solar activity conditions ($F_{10.7} < 100$). The solar cycle variation is consistent with incoherent scatter and satellite data in showing a strong dependence of the *F* region vertical drift prereversal peak on solar activity

3. The Influence of Vertical Drifts on Ionospheric Model Results

At low latitudes the eastward electric fields, responsible for the vertical drifts, are of fundamental importance for the generation of the Appleton anomaly. Many models use the *F* region vertical plasma drifts as input to calculate global electron density distribution and profiles [*Anderson,* 1973; *Anderson et al.,* 1987; *Bailey et al.,* 1993]. The Jicamarca drifts have been largely used in the models, owing to the fact that these have been the only data available until recently and that their reliability has allowed the study of the seasonal and solar cycle variation of the drifts, as well as the identification of some peculiarities that occur during magnetically disturbed periods [*Fejer,* 1981]. There is no doubt that the Jicamarca drifts are very useful in reproducing the general features of a low-latitude ionosphere, such as the Appleton anomaly, in the models. However, when the results of some models are compared with observations from the Brazilian region, the existing discrepancies are generally attributed to a longitudinal dependence of the **E**×**B** vertical plasma drift and to the magnetic declination dependent thermospheric meridional wind effects on the *F* region [*Sahai et al.,* 1990; *Bittencourt et al.,* 1992].

The large difference in magnetic declination between Jicamarca (2°E) and the Brazilian equatorial locations (magnetic declination as high as -20°) produces different seasonal dependence of the angle between the geomagnetic meridian and the terminator, and correspondingly different *E* region integrated Pederson conductivity longitudinal gradients near sunset at these stations that in turn affect the vertical *F* region plasma drift prereversal enhancements [*Batista et al.,* 1986]. This effect should certainly be taken into account in order to better simulate the ionosphere over the Brazilian region.

3.1. Model Calculations

We have used the Sheffield University plasmasphere-ionosphere model (SUPIM) [*Bailey et al.,* 1993] in order to evaluate quantitatively the influence of the different vertical drifts on the ionospheric model results. SUPIM solves the coupled time-dependent equations of continuity, momentum, and energy balance along closed field lines between base altitudes of about 130 km in conjugate hemispheres to give values for the concentrations, plasma fluxes, and temperatures of the O^+, H^+, He^+, N_2^+, O_2^+, and NO^+ ions and electrons at a discrete set of points along field lines. The input parameters to the model are for magnetically quiet ($Ap = 3$) June solstice conditions (day 172) at high solar activity ($F_{10.7} = 180$).

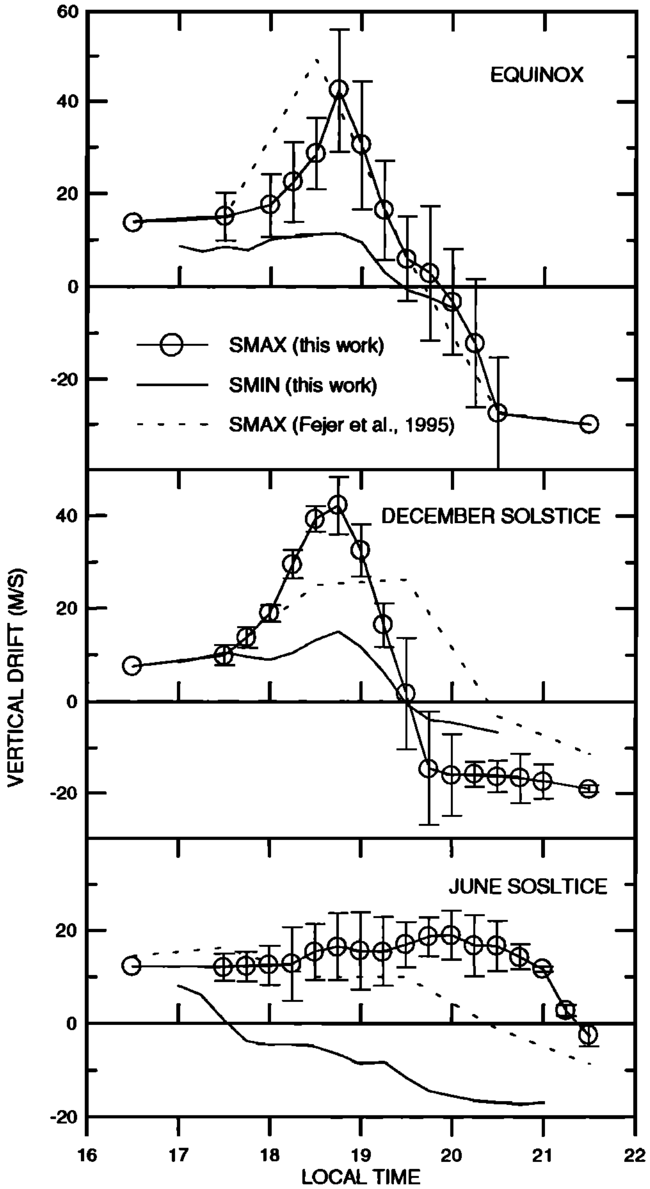

Figure 2. *F* region vertical plasma drift model around sunset for the Brazilian equatorial region during high and low solar activity periods, as compared with satellite measurements.

The neutral wind is taken from HWM90 [*Hedin et al.,* 1991], and the concentrations and temperatures of the neutral gases are obtained from MSIS86 [*Hedin,* 1987]. The solar EUV fluxes are from the EUV94 solar EUV flux model [*Tobiska,* 1991]. We use the two different models shown in Figure 3 for the vertical **E**×**B** drift velocity at the magnetic equator. In that figure the curve identified as satellite drift model (SDM) is reproduced from Figure 6 of *Fejer et al.*

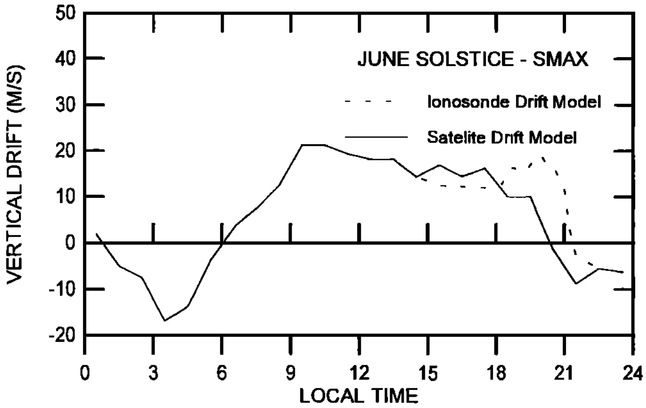

Figure 3. Ionosonde drift model and satellite drift model of the *F* region vertical plasma drift for the Brazilian equatorial region (June solstice, high solar activity periods).

[1995], for the June solstice conditions at the Brazilian longitude sector ($\bar{\phi} = 320°E$), and the curve identified as ionosonde drift model (IDM) is the vertical drift model proposed in this work for the Brazilian region (Figure 1, June solstice). The two drift models are identical except around sunset, where the IDM shows a much more pronounced prereversal enhancement than the SDM.

The purpose of the modeling is to evaluate quantitatively how the postsunset low-latitude *F* layer responds to the IDM and SDM drifts, both representative of the Brazilian low latitude but deduced using different techniques. The modeling results will be compared with ionospheric measurements over the Brazilian region. During high solar activity periods the occurrence of spread *F* on Fortaleza ionograms is very high [*Abdu et al.*, 1981b]. For this reason the only continuous available information from the ionograms are the minimum virtual height, h'F, and the virtual height at some fixed frequencies. They are representative of the real *F* layer base height, as mentioned earlier, and so can be compared with the SUPIM results.

3.2. Model Results and Discussion

Figure 4 shows the local time variation of the *F* region peak height (hmF) and the height at the fixed frequency of 4.4 MHz (hF4) given by the SUPIM model, derived using IDM and SDM, respectively. Here hF4 represents the *F* layer base height given by the SUPIM model. As we can see from the figure, the *F* region peak heights obtained using IDM and SDM are very similar until around 2030 LT, when hmF from SUPIM with SDM has already reached its maximum. On the other hand, hmF from SUPIM with IDM continues increasing, reaching its maximum 1 hour later (around 2130 LT). The difference between the two maxima is approximately 80 km, increasing to around 150 km at local midnight. Comparing the results for hF4 derived using IDM and SDM leads to conclusions similar to the ones obtained for hmF; that is, the maximum in hF4 from IDM occurs 1 hour later than the maximum in hF4 from SDM and is higher by about 100 km. The discrepancies between the heights derived from SUPIM with the two different drift models start between 2000 and 2100 LT and last until around 0300 LT (not shown here).

Also shown in Figure 4 is hmF (the *F* layer peak height) and h'F (the minimum *F* region virtual height) derived from ionosonde measurements at Fortaleza, representative of June solstice, high solar activity. The *F* layer peak height, hmF, is plotted only until 2000 LT. After this local time it is almost impossible to make ionogram real height analysis because the spread *F* occurrence over Fortaleza is very high [*Abdu et al.*, 1981b]. So only the SUPIM results between 1600 and 2000 can be compared with the measurements. We can see that the strong gradient that is observed in hmF between 1800 and 2000 LT is better simulated by SUPIM with IDM than by SUPIM with SDM. We use the observed h'F to compare with the modeled hF4 because both are representative of the *F* layer base height. As we can see from Figure 4, there is excellent agreement between the measured h'F and hF4 derived from SUPIM with IDM. The two curves reach the maximum at around the same local time, and around midnight the *F* layer base height is above 350 km. The hF4 derived from SUPIM with SDM does not reproduce the observed h'F behavior. Its maximum occurs about 1 hour earlier than the observed results, and the difference in height is around 100 km. It is clear from the above results that the use of IDM as an input of an ionospheric model gives a much better agreement with Fortaleza measurements than the SDM. The differences between the SUPIM results are due to the different **E**×**B** drifts used as input to the simulation. IDM shows a clear prereversal enhancement that is not seen in SDM (Figure 3), and its inversion time is later than on the SDM. As a consequence of this difference the layer height derived from SUPIM is much higher when IDM is used as input than when SDM is taken. All the low-latitude electrodynamics will be affected as well.

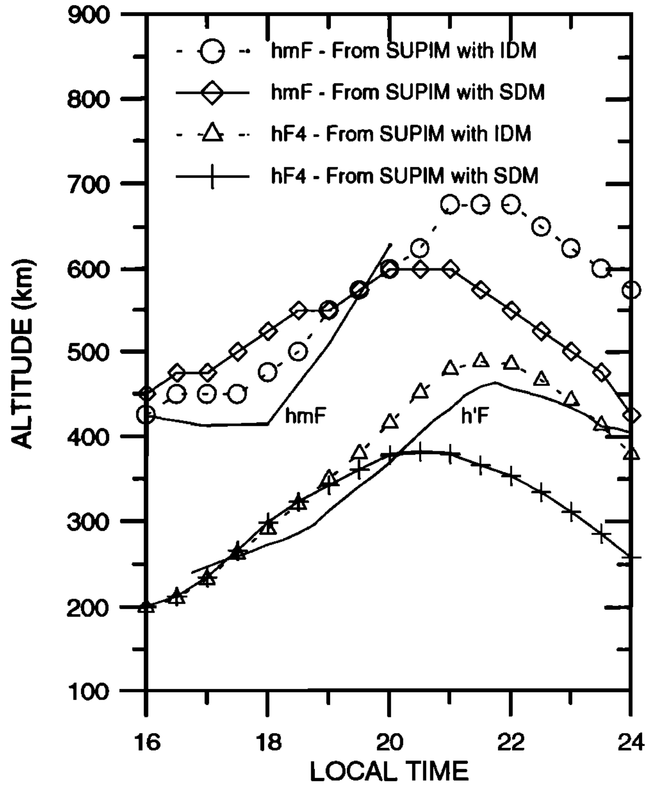

Figure 4. Equatorial *F* layer heights derived from SUPIM with IDM and SDM, as compared with ionosonde measurements.

3.3. Thermospheric Neutral Wind Effect on *F* Region Heights

Since Fortaleza is not located exactly at the magnetic equator (dip latitude = 4°S), it is useful to investigate the influence of the thermospheric wind on the *F* region heights and, consequently, on the ionosonde-derived drifts. The neutral wind component along the magnetic meridian can be calculated as $U_M = U \cos D + V \sin D$, where U and V are the meridional and zonal components of the thermospheric neutral wind, respectively, and D is the magnetic declination angle (-20° for Fortaleza). The *F* region vertical movement due to the thermospheric wind is given by $U_z = U_M \sin I \cos I$, where I is the dip angle (-7° for Fortaleza). In the absence of wind measurements over Fortaleza we used the HWM87 and HWM90 models [*Hedin et al.*, 1988, 1991] to calculate U_z. During the equinox and December solstice the contribution of U_z to the vertical ionization movement around sunset is almost negligible when compared with $\Delta h'F/\Delta t$ deduced from ionograms. During the June solstice, U_z is of the order of -12 m s^{-1} between 2100 and 2200 LT, becoming comparable to the $\Delta h'F/\Delta t$. In this case the *F* region vertical plasma drift due to the electric field alone should be calculated as $V_z = \Delta h'F/\Delta t - U_z$. This would yield ionosonde-based V_z values for the June solstice higher than the ones represented in Figures 1, 2, and 3 around the prereversal enhancement. We used this new drift model as an input for the SUPIM code and observed that the effect of introducing a correction due to the Hedin wind in the ionosonde-derived drift increased the heights for more than 120 km when compared with the results using the IDM model without the wind effect. These results are not supported by the ionosonde *F* layer heights observed over Fortaleza. If we hypothesize that the difference between IDM and SDM is just due to neutral winds, this should imply a large equatorial wind at local times around and after sunset, over Fortaleza. However, this hypothesis is not supported by thermospheric neutral wind velocities deduced from Fabry-Perot interferometer measurements of Doppler shift of the OI 630.0 nm airglow emission line carried out over low and equatorial latitudes in Brazil [*Sahai et al.*, 1992] and in Peru [*Biondi et al.*, 1990, 1991] that show southward meridional winds between 1800 and 2200 LT (or even 2400 LT). *Bailey et al.* [1993] observed a much better agreement between nighttime Jicamarca observations and model calculations when the wind was "turned off" in the model. In our study it seems that the IDM is the most appropriate drift model to explain the observed *F* region heights.

4. Summary and Conclusions

We have proposed an ionospheric *F* region vertical plasma drift model for the equatorial region over the Brazilian longitudes, where the magnetic declination attains a global maximum of around -20°. The model is based on ionosonde measurements around sunset and on satellite results elsewhere. The comparison of this ionosonde drift model with the satellite drift model from *Fejer et al.* [1995] shows that the prereversal peak phases are in very good agreement during the equinox, but the discrepancies in amplitude and phase are significant during the solstices. We have used the Sheffield University plasmasphere-ionosphere model (SUPIM) in order to investigate the influence of the IDM and the SDM on the ionospheric model results. Our results showed that IDM is much better than the SDM in simulating the ionospheric height measurements over Fortaleza, Brazil. Although the satellite data give a global coverage of the drift measurements, it seems that the averaging procedure is filtering out some important features of the prereversal enhancement, at least in the Brazilian longitude sector where the magnetic declination is very high. It would be useful to use narrower longitude bins, at least in the longitude sector between 300° and 360°E. While this is not available, the IDM should be used whenever results over the Brazilian low-latitude region are concerned.

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