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Determination of vertical plasma drift and meridional wind using the Sheffield University Plasmasphere Ionosphere Model and ionospheric data at equatorial and low latitudes in Brazil: Summer solar minimum and maximum conditions

J. R. Souza, M. A. Abdu, and I. S. Batista

Instituto Nacional de Pesquisas Espaciais, São José dos Campos, São Paulo, Brazil

G. J. Bailey

Department of Applied Mathematics, University of Sheffield, Sheffield, England, United Kingdom

Abstract. The *F* region critical frequency f_oF_2 and peak height h_mF_2, measured simultaneously at the equatorial location Fortaleza (4°S, 38°W, magnetic latitude = 3.5°S) and at the low-latitude location Cachoeira Paulista (22°S, 45°W, magnetic latitude = 15°S), are compared with their values calculated by the Sheffield University Plasmasphere-Ionosphere Model (SUPIM) to determine the vertical (**E**×**B**) drift velocity at the equator and the magnetic meridional wind velocity over the two locations. The calculated and observed values of f_oF_2 are then matched at both Fortaleza and Cachoeira Paulista to obtain the magnetic meridional winds over their respective conjugate locations. To account for the observed f_oF_2 diurnal variation pattern over Cachoeira Paulista, it was found necessary to include a small source of ionization, attributable to energetic particle precipitation in the South Atlantic anomaly region. The vertical drift velocity and magnetic meridional wind velocity derived for summer months during both solar minimum and solar maximum are compared with their values given by other published models. While the diurnal variation of the modeled vertical drift velocity shows general agreement with the values based on Jicamarca radar measurements (the exception being during the sunset-midnight period at solar maximum and between 2000-2300 LT at solar minimum), the magnetic meridional wind shows significant differences with respect to the Horizontal Wind Model 1990 (HWM90) [*Hedin et al.*, 1991] during both solar minimum and solar maximum at Fortaleza and at locations conjugate to Fortaleza and Cachoeira Paulista.

1. Introduction

The behavior of the equatorial and low-latitude ionosphere-thermosphere system is strongly dependent upon the **E**×**B** drift velocity and the thermospheric wind velocity. The vertical drift velocity gives rise to the equatorial ionization anomaly (also known as Appleton anomaly), which is characterized by a trough in the electron density located at the magnetic equator and two crests located symmetrically at around ±16° latitude. The vertical drift velocity has been extensively studied by means of radar data from Jicamarca, Peru [*Woodman*, 1970; *Fejer*, 1981; *Fejer et al.*, 1991]. It is known to be longitude dependent, as was shown by *Abdu et al.* [1981] for the sunset period, when it undergoes large enhancement due to the prereversal enhancement in the zonal electric field [*Woodman*, 1970; *Fejer*, 1981, *Farley et al.*, 1986; *Batista et al.*, 1986]. A longitudinal dependence of the daytime electric field has been inferred from analyses of magnetometer data by *Schieldge et al.* [1973]. Global features of the longitudinal dependence of the mean diurnal variation of the vertical drift velocity, based on analyses of AE-E satellite data, has been presented by *Fejer et al.* [1995]. Very recently, *Scherliess and Fejer* [1999] have developed an empirical model for the quiet time *F* region equatorial vertical drift velocity based on combined incoherent scatter radar observations at Jicamarca and ion drift meter observations on board the AE-E satellite.

The direct action of the thermospheric winds on the ionosphere can cause transport of plasma along the magnetic meridian. In this way, the magnetic meridional winds (MMW) contribute to the development of an asymmetric anomaly, that is, the asymmetric distribution of the electron density between the Northern and Southern Hemispheres [*Rishbeth*, 1972; *Anderson*, 1973a, b; *Bittencourt and Sahai*, 1978]. In a study by *Medeiros et al.* [1997] a method has been developed to calculate the magnetic meridional wind at the low-latitude location Cachoeira Paulista in Brazil by using the servo equations of *Rishbeth et al.* [1978] (see also *Miller et al.* [1989]), h_mF_2 data from the ionosonde at Cachoeira Paulista, and vertical plasma drifts from the Jicamarca radar that were modified in the sunset sector by vertical drift obtained from the ionosonde data over Fortaleza in Brazil. The effects of the vertical drift velocity and the magnetic meridional wind velocity on the ionosphere have been investigated through modeling studies by several authors [e.g., *Anderson*, 1973a, b; *Bailey et al.*, 1993]. In this paper, a method is presented to determine the vertical drift velocities at the equatorial locations and the magnetic meridional wind velocities at equatorial and low-latitude locations from simultaneously measured values of

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f_oF_2 and h_mF_2 over these stations and values modeled by the Sheffield University Plasmasphere-Ionosphere Model (SUPIM).

2. Experimental Data

Data sets of simultaneously measured values of f_oF_2 and h_mF_2 at the equatorial station Fortaleza (4°S, 38°W, magnetic latitude = 3.5°S) and the low-latitude station Cachoeira Paulista (22°S, 45°W; magnetic latitude = 15°S) are utilized in this study. The h_mF_2 values were calculated from ionograms using the POLAN code [*Titheridge*, 1985]. Ten magnetically quiet days of data have been selected from the solar minimum months December 1985 and January 1986. The mean 10.7-cm solar flux index ($F_{10.7}$) for these days was 72. Similarly, 10 magnetically quiet days of data have been selected from the solar maximum months November 1988 and December 1991. The mean $F_{10.7}$ value for these days was 169. Both data sets are representative of Southern Hemisphere summer conditions. Figures 1a and 1b present the 10 days of data for Fortaleza for both the solar minimum and solar maximum conditions, respectively. Similar results for the low-latitude station Cachoeira Paulista are presented in Figures 2a and 2b. The day-to-day variabilities seen in Fortaleza data are most likely produced by variabilities in the equatorial electric field and, to a lesser extent, in the meridional wind. On the other hand, the observed day-to-day variabilities in the Cachoeira Paulista data are most likely produced by variations in the magnetic meridional wind. In the bottom of Figures 1 and 2 the local time variations of the mean of the geomagnetic activity index *Kp* for the same 10-day periods are presented.

3. The SUPIM Model

The Sheffield University Plasmasphere-Ionosphere Model is a first-principles model of the Earth's ionosphere and plasmasphere [*Bailey et al.*, 1993; *Bailey and Balan*, 1996]. In the model, coupled time-dependent equations of continuity, momentum, and energy balance are solved along closed magnetic field lines to calculate values for the densities, field-aligned fluxes, and temperatures of the electrons and of the O^+, H^+, He^+, N_2^+, O_2^+, and NO^+ ions. In the present study the geomagnetic field is represented by a tilted centered dipole with the angle of tilt and magnetic declination angle given by International Geomagnetic Reference (IGRF) 1995 model. The neutral atmosphere densities and temperatures are obtained from Mass Spectrometer Incoherent Scatter 1986 (MSIS-86) [*Hedin*, 1987] and the solar EUV fluxes from the solar EUV flux model for aeronomic calculations (EUVAC) model of *Richards et al.* [1994]. The vertical plasma drift velocity and the magnetic meridional wind velocity are model inputs.

4. Methodology

The **E**×**B** plasma drift and the thermospheric meridional wind have a controlling influence on the dynamical processes and therefore on the spatial and temporal features of the distribution of plasma of the equatorial and low-latitude ionosphere. Since the magnetic field lines above the magnetic equator are horizontal the F_2 layer peak height h_mF_2 is controlled predominantly by the vertical (**E**×**B**) drift velocity; the meridional wind has little effect. Thus the observed values of h_mF_2 over an equatorial station can be used to determine the vertical drift velocity by adjustments (additions/subtractions) to the vertical drift model used by SUPIM as many times as necessary until the modeled values of h_mF_2 agree with the observed values. The vertical drift velocities so determined are then used by SUPIM, as a known parameter, in its application to determine the meridional wind over a low-latitude location at the same longitude and outside the equator region. Thus, since h_mF_2 over this location is controlled by both

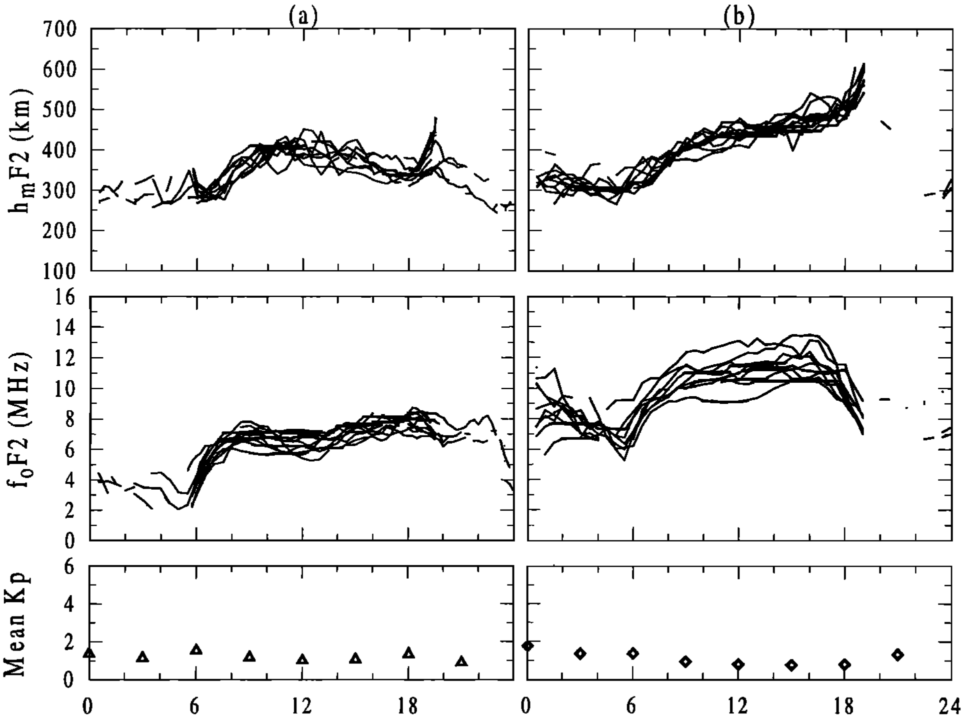

Figure 1. Observed diurnal variations of h_mF_2 and f_oF_2 for 10 magnetically quiet days over Fortaleza for (a) solar minimum conditions ($F_{10.7}$=72) and (b) solar maximum conditions ($F_{10.7}$=169). *Kp* values for the two groups are shown at the bottom.

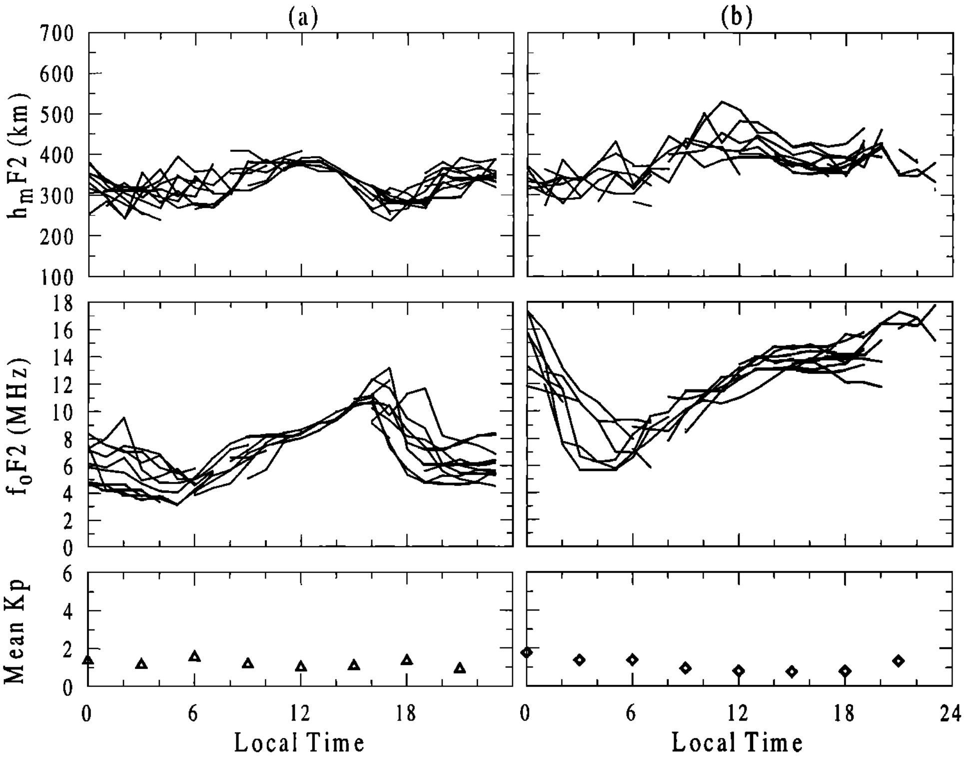

Figure 2. Same as Figure 1 except over Cachoeira Paulista.

the meridional wind and the vertical drift, and the vertical drift is known, SUPIM can be then used to determine the meridional wind that is necessary to make the modeled values of h_mF_2 agree with the observed values. In principle, it is straightforward to determine the vertical drift and magnetic meridional wind velocities by SUPIM from simultaneously observed values of h_mF_2 over a location at or very close to the magnetic equator and one at low latitude. However, the actual execution of this method involves the need to account for the simultaneously observed values of f_oF_2 at the two locations. Details of the calculation procedure are described in the following sections.

4.1. Equatorial ExB Plasma Drift Velocity

The equatorial data utilized for deriving the vertical plasma drift velocity were collected at Fortaleza. Although considered a magnetic equatorial station, being located in a region of a global maximum in the secular variation of the equatorial geomagnetic field, Fortaleza's dip angle has departed from zero over the years; during the years used for the present analysis (1985-1991) the dip angle was about −7° [*Abdu et al.*, 1996]. Calculations carried out by SUPIM have shown that at this small dip angle the electron density height profile over Fortaleza presents features of an additional layer (F_3 layer) that forms above the normal F_2 layer peak and that becomes observable in ionograms mainly during the prenoon and noon hours [*Balan et al.*, 1997]. In the work of *Jenkins et al.* [1997] it has been shown that the meridional wind contributes to the formation of this layer within a narrow region of ~1°-8° dip latitude. The relevant point to be noted for the present analysis is that the conditions that contribute, or tend to contribute, to the extra layer formation could introduce uncertainty in the determination of h_mF_2 during a few hours before and around noon.

The derivation of the equatorial vertical plasma drift is based on the following criteria: (1) its time-integrated value over a 24-hour period is zero; (2) the values of h_mF_2 during the evening-nighttime period 1700-0700 LT are exclusively controlled by vertical drift [see *Batista et al.*, 1996]; and (3) that the values of h_mF_2 during the daytime period 0700-1700 LT are affected by the meridional wind. Since the determination of the vertical drifts between 1700 and 0700 LT are based on condition (2), the value of the time-integrated vertical drift over this period is known. Thus, from conditions (1) and (2), the value of the time-integrated vertical drift for the period 0700-1700 LT is determined. The optimum values for the drift and the meridional wind during the period 0700-1700 LT are obtained by making adjustments to the drift and meridional wind until the modeled values of h_mF_2 agree with the observed values.

4.2. Magnetic Meridional Wind

All the model calculations have been carried out for a fixed magnetic meridian. For the determination of the meridional wind over Fortaleza and Cachoeira Paulista the respective latitudinal ranges 2°-9°S and 14°-24°S have been used. The model calculations showed that during a few hours on either side of noon the local meridional wind has more control on h_mF_2 over Fortaleza than it has on f_oF_2, and that the meridional winds at points conjugate to Fortaleza and Cachoeira Paulista control f_oF_2 over their respective stations. These results have been used to achieve finer adjustments to the wind using the modeled and observed values of h_mF_2 and f_oF_2. The meridional winds were obtained by making adjustments (additions/subtractions) to the meridional winds given by the Horizontal Wind Model 1990 (HWM90) [*Hedin et al.*, 1991] the standard wind model used by SUPIM. These adjustments were carried out separately for each magnetic latitude range based on the methodology described above. In this paper, all the winds are representative of 300 km altitude.

5. Derivation of the Vertical Plasma Drift and Meridional Wind

5.1. Solar Minimum

Initially, the model calculations were carried out for Fortaleza with the magnetic meridional wind given by the HWM90 model [*Hedin et al.*, 1991] and an equatorial vertical drift model based on that published by *Medeiros et al.* [1997]. The input values for the equatorial vertical drift velocity, the magnetic meridional wind velocity, and the modeled and observed values of f_oF_2 and h_mF_2 for Fortaleza are presented in Figure 3. The following points of disagreement between the model results and observations are noted: (1) there are significant departures in the modeled and observed values of f_oF_2 during the periods 1900-0545 LT and 0800-1200 LT, and (2) the calculated values of h_mF_2 are significantly less than the observed values between 0730 and 1630 LT and higher/lower than the observed values during the premidnight/postmidnight hours.

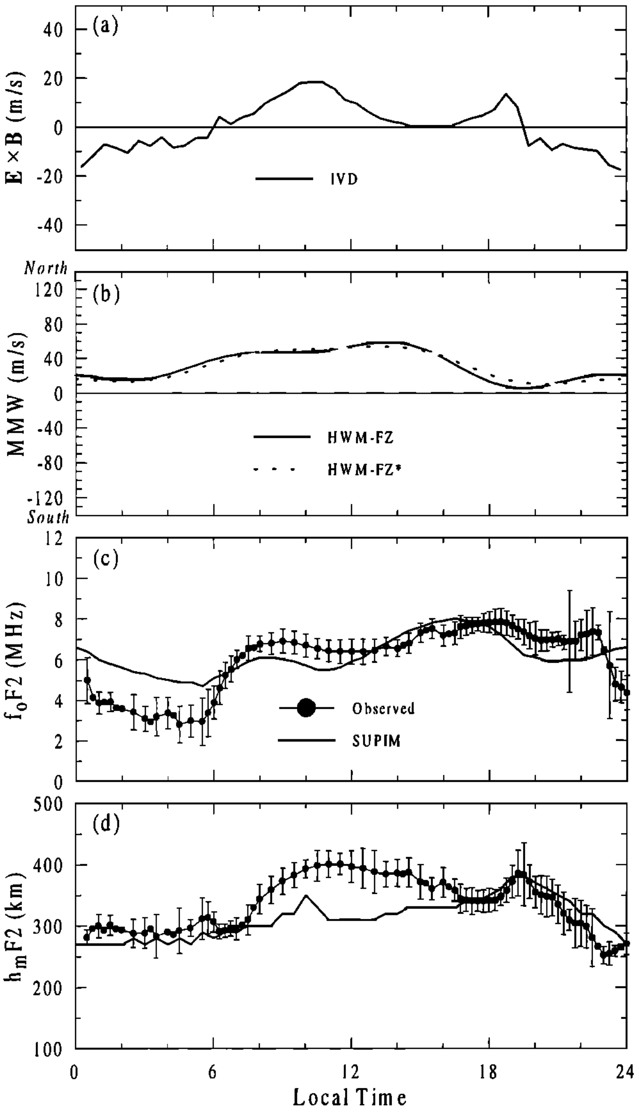

Figure 3. Diurnal variations over Fortaleza of (a) the initial vertical drift model (IVD); (b) the meridional winds at 300 km altitude according to Horizontal Wind Model 1990 (HWM90) [*Hedin et al.*, 1991], denoted by HWM-FZ for Fortaleza and HWM-FZ* for the point magnetically conjugate to Fortaleza; (c) the 10-day average values of the observed f_oF_2, with the standard deviation bars (solid dots) and the values calculated by the Sheffield University Plasmasphere-Ionosphere Model (SUPIM) (solid line) using the drift described in Figure 3a and the wind described in Figure 3b; (d) the 10-day average values of the observed h_mF_2 with the standard deviation bars (solid dots) and the values calculated by SUPIM (solid line) using drift (Figure 3a) and winds (Figure 3b). These results are for solar minimum conditions.

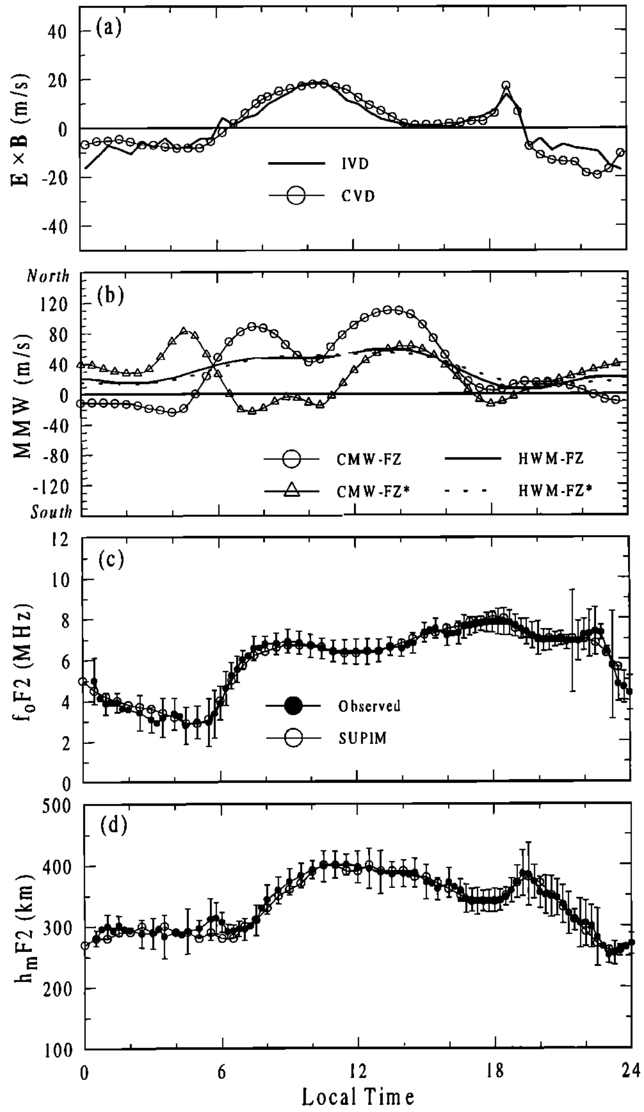

Figure 4. Diurnal variations of (a) the calculated vertical drifts (CVD) and, for comparison, the initial vertical drifts (IVD); (b) the calculated meridional winds over Fortaleza and its magnetically conjugate point, denoted as CMW-FZ and CMW-FZ*, respectively, and the winds given by HWM90 (HWM-FZ and HWM-FZ*, respectively); (c,d) the f_oF_2 and h_mF_2 calculated by SUPIM fitted with the observations that produced the new results of the Figure 4a and 4b. These results are for solar minimum conditions.

Figure 4a shows the equatorial vertical drift velocity determined from the model calculations and, for comparison purposes, the initial vertical drift. Figure 4b shows the modeled magnetic meridional winds over Fortaleza and over its magnetically conjugate point that are compared with the winds given by HWM90. The agreement between the modeled and

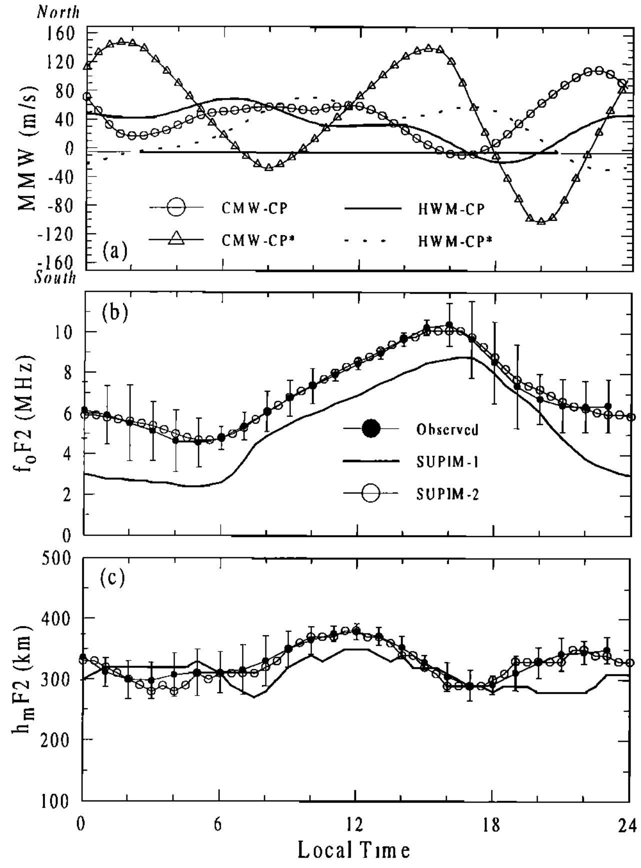

Figure 5. (a) Meridional winds over Cachoeira Paulista and its conjugate points that resulted from the calculation procedure using the SUPIM, denoted as CMW-CP and CMW-CP*, respectively, compared with the corresponding winds from HWM90; (b,c) f_oF_2 and h_mF_2 values, respectively, calculated (solid line, SUPIM-1) using the HWM90 winds of the Figure 5a and the vertical drift CVD of the Figure 4, compared with the observed values shown with dots and standard deviation) and with their final SUPIM adjusted values (represented by open circles, SUPIM-2). These results are for solar minimum conditions.

observed values of f_oF_2 and h_mF_2 that produced the vertical drift and winds calculated in this work (Figures 4a and 4b) are shown in Figures 4c and 4d. The main difference in the initial drift and that modeled occur during the period 2000-2300 LT. In this case, the modeled drift is greater in magnitude than the initial drift.

The magnetic meridional winds over Fortaleza and over its magnetically conjugate point show significant differences (Figure 4b) both in magnitude and diurnal variation when compared with the winds given by HWM90. The magnetic meridional winds given by HWM90 show very little latitudinal variation near the magnetic equator. In contrast, the winds calculated in this work over Fortaleza and its conjugate point show significant differences, and there are times when there are differences in direction.

Figure 5a presents the meridional winds obtained for Cachoeira Paulista and over its conjugate point. Figures 5b and 5c present the diurnal variations of the observed mean values of f_oF_2 and h_mF_2 together with their standard deviations. The diurnal variations denoted by SUPIM-1 and SUPIM-2 have been obtained from SUPIM using a magnetic meridional wind given by HWM90 and by the wind calculated in this work, respectively.

In both sets of calculations the calculated vertical drift pattern, see Figure 4a, was used. As Figure 5 shows, there are significant differences in the diurnal variation of f_oF_2 modeled using HWM90 and that observed at Cachoeira Paulista except around 1900 LT. The modeled values of h_mF_2 are, in general, in good agreement with the observed values with the exception of a minor difference between 0700-1300 LT and a more notable difference during the premidnight hours. The matching procedure resulted in the f_oF_2 and h_mF_2 curves identified by SUPIM-2 and the magnetic meridional winds that are required to achieve this degree of matching are plotted in Figure 5a. It may be noted that the matching of the f_oF_2 values over Cachoeira Paulista (mainly at night) required a small source of ionization. This is attributed to energetic particle precipitation in the South Atlantic magnetic anomaly (SAMA) region [*Abdu and Batista*, 1977; *Abdu et al.*, 1979]. A detailed discussion of this aspect and the results on the additional ionization source will be presented in a future publication.

A comparison of the calculated meridional winds and those predicted by HWM90 shows general agreement over Cachoeira Paulista between 0000 LT and ~1800 LT, as expected from the reasonably good agreement in the observed and calculated values (SUPIM-1 values) of h_mF_2 during these hours. There are significant differences, however, during the premidnight hours. The differences in the HWM90 meridional wind and the meridional wind calculated in this work for the point conjugate to Cachoeira Paulista is particularly noticeable. An interesting point to note is the antiphase relationship that exists in the winds given by HWM90 for Cachoeira Paulista (HWM-CP) and its conjugate point (HWM-CP*). Such a relationship is also evident, and more markedly, in the results obtained from our calculations that are denoted by CMW-CP and CMW-CP* (Figure 5a).

5.2. Solar Maximum

Calculations similar to those carried out for solar minimum conditions have been carried out for solar maximum conditions. As Figure 6 shows, the values of f_oF_2 that result from SUPIM tend to be less than the mean observed values during 0930-1230 LT, and they are significantly greater than mean observed values during 1600-0400 LT. There are significant disagreements between the values of h_mF_2 calculated by SUPIM and those observed, the calculated values being less than the observed values between 1030 and 1900 LT. After 1900 LT, the observed values of f_oF_2 and h_mF_2 are sparse owing to the occurrence of spread *F* events in the ionograms that become intense during the summer months of solar maximum. This is in contrast to the more continuous data points at these same hours during solar minimum (Figure 3) when spread *F* events are weaker and less frequent.

The vertical drift velocities and the meridional wind that resulted from the calculations for high solar flux conditions are presented in Figure 7. As Figure 7 shows, the diurnal variation of the vertical drift velocity obtained from the model calculations presents good agreement with the initial vertical drift velocities except during the sunset-premidnight hours. At these times the calculated prereversal enhancement and the premidnight, vertical drift velocities are higher than those given by the initial vertical drift model.

The meridional winds over Fortaleza and over its conjugate point have similar variations for most of the day; during the night, there are large deviations. Also, at both locations the diurnal variation of the calculated wind differs significantly from

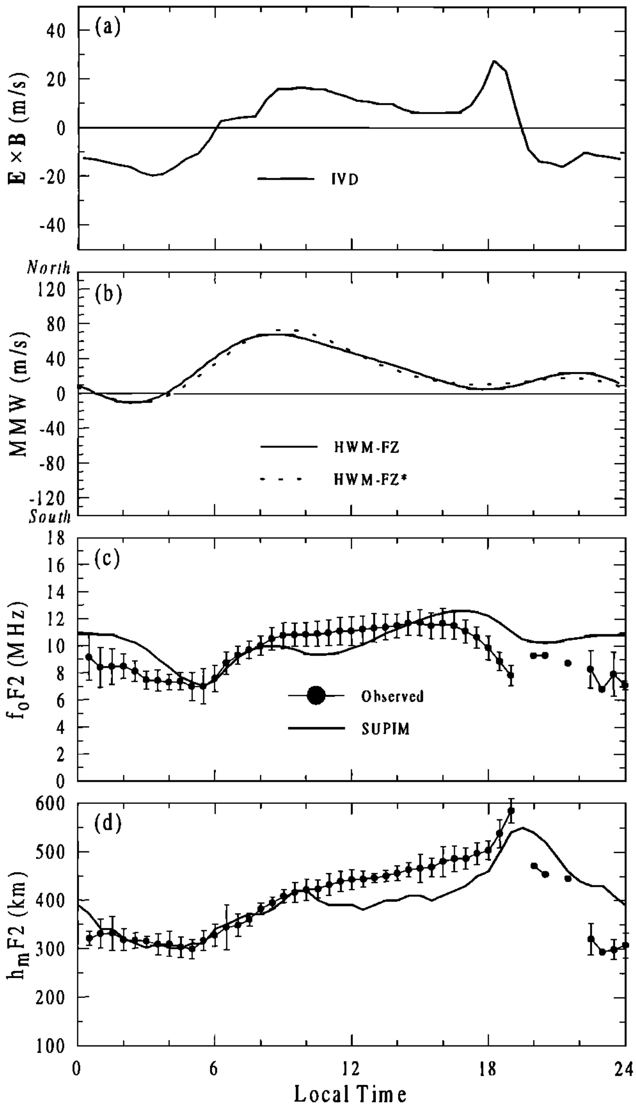

Figure 6. Same as Figure 3, but for high solar flux values.

that given by the HWM90 model. The divergence of the wind observed around midnight at solar minimum is also present here.

Figure 8a presents the meridional winds over Cachoeira Paulista and its conjugate point as given by HWM90 and from the calculation procedure described in section 4. Figure 8b shows that there are large differences during nighttime between the calculated values of f_oF_2 (denoted by SUPIM-1) and the observed values. During the daytime, such differences are small. The modeled values of h_mF_2 are in good agreement with the observed values, except at around sunrise when the calculated values are greater than observed values. Also, as in the case of solar minimum, the calculated values of h_mF_2 are less than the observed values between sunset and midnight, although to a lesser degree. A comparison of the meridional wind obtained from these calculations with those predicted by HWM90 reveals good agreement over Cachoeira Paulista throughout the day, with the exception of only a short interval around sunrise when the calculated wind is less intense in the northward direction compared to that given by HWM90. These differences are as expected from the differences in the values of h_mF_2 noted above. As was noted for solar minimum conditions, there are significant differences in the wind given by HWM90 and that resulting from SUPIM for the point conjugate to Cachoeira Paulista.

6. Discussion and Conclusions

Ionosonde data have been used in recent years to deduce, in a variety of ways, the equatorial vertical drift velocity and the low-latitude meridional wind velocity. The equatorial vertical drift velocity has been deduced during evening hours from $d(h'F)/dt$, when $h'F$ is above 300 km altitude and when the effects of recombination are negligible [*Bittencourt and Abdu,* 1981; *Abdu et al.*, 1981]. The meridional wind has been determined from F layer height information over Cachoeira Paulista by *Medeiros et al.* [1997]. This method, however, requires a realistic equatorial vertical drift model, based on independent observations, to account for its effect on h_mF_2. The resulting winds are found to be reliable during nighttime hours but seem to be less reliable during the day. The present study represents the first attempt to calculate both the equatorial vertical drift and the meridional wind on a 24-hour basis using values of f_oF_2 and h_mF_2 simultaneously recorded at an equatorial and at a low-latitude station. The method used here is based on the determination of a unique equatorial vertical drift by matching the values of h_mF_2 calculated by SUPIM with those observed over an equatorial station The conditions for arriving at a unique solution for the drift are not ideally met during a few hours of the day for our station Fortaleza (dip

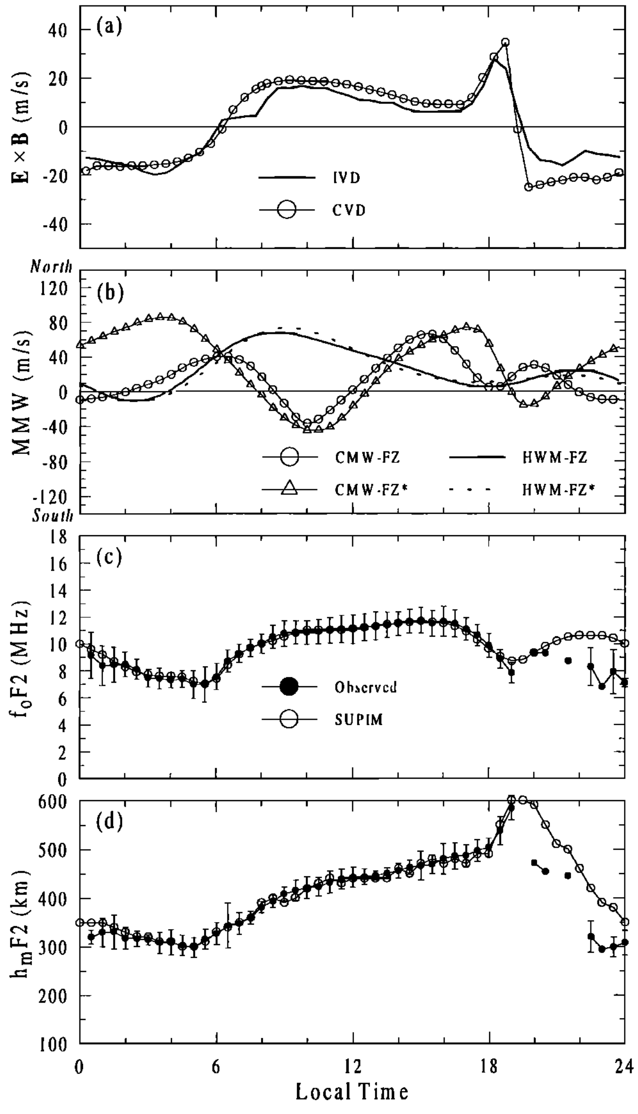

Figure 7. Same as Figure 4, but for high solar flux values.

latitude about −3.5°) because of the action of the meridional wind that results in the formation of the F_3 layer [*Balan et al.*, 1997]. This "not so ideal" situation has been overcome by using the criteria that the diurnal variation of the vertical drift, when integrated over a 24-hour period, should produce a net zero drift and that the vertical drift during nighttime hours uniquely controls the variation of h_mF_2. Thus, once the drift for the evening-morning hours is uniquely determined, the drift for the remaining hours of the day are uniquely determined apart from minor uncertainties caused by the adjustments required in the meridional wind during the few hours susceptible for F_3 layer formation. It should be noted that during these hours there is very good agreement in the calculated vertical drift and that based on the measurements made at Jicamarca radar for both solar minimum and maximum conditions (see Figures 4 and 7). This agreement may be taken as an indication that our approach is valid.

We noted that there are differences between the calculated and initial vertical drifts during sunset-premidnight hours. Since the initial drift is based on Jicamarca radar data, we may attribute such differences to the distinct geomagnetic field configurations that characterize the Peruvian and Brazilian sectors. The large longitudinal variation in the magnetic declination angle, from 4°E at Jicamarca to 21°W at Fortaleza, may produce different evening F region dynamo electric fields at the two locations which, in turn, could cause the differences in the evening-premidnight vertical drift [*Abdu et al.*, 1981; *Batista et al.*, 1986].

The meridional wind over the low-latitude location Cachoeira Paulista is calculated by using the calculated equatorial vertical drift velocity, an input parameter of SUPIM, and observations of h_mF_2. On the other hand, f_oF_2 over Cachoeira Paulista is affected by the meridional wind at the location conjugate to Cachoeira Paulista. This is due to the fact that the combined effect of the magnetic meridional wind in the northern and southern conjugate hemispheres, together with the vertical drift, determine the plasma content of the associated flux tube and hence the values of f_oF_2 in that flux tube. For a given flux tube, for example, when the winds converge/diverge (i.e., flow toward/away from the equator), the net accumulation/depletion of plasma would depend upon whether the vertical plasma drift is upward or downward. It should also be noted that a time delay (~1 to ~3 hours depending upon the length of the flux tube) is involved (as will be discussed shortly) for a change in the meridional wind to effect a corresponding change in f_oF_2 at the conjugate point. The meridional wind at the point conjugate to Cachoeira Paulista could have been checked with the help of the h_mF_2 values from that location (no data available). The f_oF_2 values over Fortaleza were used to calculate the meridional wind over its conjugate point. The data sets for both h_mF_2 and f_oF_2 values were used (depending upon the local time) in the construction of the meridional wind over Fortaleza and the local time variation of the calculated meridional wind is markedly different from that given by HWM90 (see Figures 4 and 7).

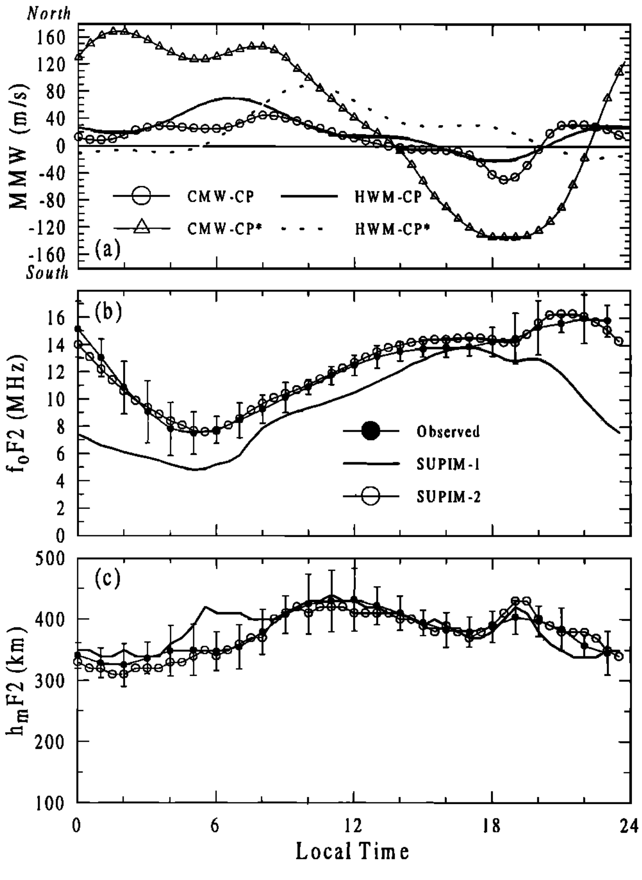

Figure 8. Same as Figure 5, but for high solar flux values.

The wind pattern that resulted from these calculations can be justified as follows:

1. The calculated values of h_mF_2 and f_oF_2 obtained using initial vertical drift and HWM90 are in agreement with the observations around 0645 LT (see Figure 3, for example). The calculated and initial vertical drifts are almost the same at around 0645 LT (Figure 4a). However, the adjusted meridional wind shows significant departure from that given by HWM90, while there is close agreement at around 0545 LT. From these observations and since the response of h_mF_2 to changes in the vertical drift does not involve any perceivable time delay, we deduce that the response time of f_oF_2 to a change in the wind is of the order of 1 hour for this case.

2. The small differences that occur during the premidnight hours between observed values of h_mF_2 and the calculated values using HWM90 and initial vertical drift (see Figure 3) are removed by using drift values given by the calculated vertical drift model at these hours (see Figure 4). However, to reduce the large differences in the corresponding values of f_oF_2, it was necessary to introduce a strong divergence in the meridional wind, i.e., a southward wind over Fortaleza and northward wind over its conjugate point. In fact, the largest differences in the calculated and observed values of f_oF_2 commences at around 2300 LT and the divergence in the wind required to reduce this difference commences at around 2130 LT, compatible with the response time mentioned above.

3. After ~0730 LT (see Figure 3) the significant differences in the values of h_mF_2 calculated using the HWM90 wind and initial drift and the observed values are reduced by increasing the northward (equatorward) wind over Fortaleza to values well above the values given by HWM90 (see Figure 4). As a result, it was found necessary to increase the southward wind over the conjugate point, i.e., to produce a maximum convergence of plasma toward equator around 0745 LT, in order to produce a delayed effect of reducing the maximum differences in the calculated and observed values of f_oF_2 around 1030 LT (see Figure 3). In this case, the response time tends to be >2 hours.

The diverging flow of the meridional wind centered at around 0000 LT (see Figure 4) appears to be associated with the phenomenon known as the equatorial midnight temperature anomaly (MTM) (see, for example, *Colerico et al.* [1996], *Sastri et al.* [1994], *Fesen et al.* [1996], and *Batista et al.* [1997]). The southward winds over Fortaleza at around 0000 LT are in accord with the winds over Cachoeira Paulista [*Medeiros et al.*, 1997] determined by the servo method [*Rishbeth et al.*, 1978] which were attributed to the MTM [*Batista et al.*, 1997]. The corresponding poleward wind over the conjugate point is stronger. Indication of the effect of a diverging flow seems to be present also at Cachoeira Paulista and at its conjugate point (see Figure 5), with the time of maximum effect displaced to postmidnight hours. In the results corresponding to high solar flux values, a similar signature is present over Fortaleza, but less evident in the results for Cachoeira Paulista (see Figures 7 and 8). In fact, the consistent behavior of our modeled winds around midnight with the winds shown by *Batista et al.* [1997] may be taken as evidence that MTM is modulating the winds over low latitudes. Also, it is important to note that the descent characteristic of h_mF_2 observed around midnight over Cachoeira Paulista, which has been attributed to the existence of the MTM [*Batista et al.*, 1997], is present in our data.

For solar maximum conditions the meridional wind over Fortaleza calculated by SUPIM is significantly different to that given by HWM90. For the case of Cachoeira Paulista, however, there is good agreement between the local wind calculated by SUPIM and that given by HWM90, there are significant differences at the conjugate points. Justifications for the reasonableness of these calculated winds can be made in the same way as for the low solar flux results.

The main conclusions from the present study are the following:

1. Ionospheric data in the form of the critical parameters, h_mF_2 and f_oF_2, simultaneously observed over an equatorial and a low-latitude location (away from the equator sector), at the same or nearby longitudes, can be used through a procedure that matches the observed values with those calculated by SUPIM to obtain unique solutions for the equatorial vertical drift and the meridional winds over the two locations with same longitude.

2. The diurnal variation of the equatorial vertical drift shows good agreement with the presently available models for low and high solar flux values based on data from Jicamarca radar. The differences observed around the sunset-premidnight hours may be attributed to the differences in configuration of the geomagnetic field, especially in the magnetic declination angle, which is ~4° at Jicamarca and -21° at Fortaleza, and possibly to the differences in the solar flux values that characterize our data sets.

3. There are significant differences in the meridional winds calculated by our procedure and those given by HWM90 over Fortaleza and over both the points conjugate to Fortaleza and Cachoeira Paulista. In contrast, the calculated winds are in good agreement with the winds given by HWM90 over Cachoeira Paulista, except few hours around the sunrise for high solar flux condition and between 2000 and 2300 LT for low solar flux condition.

4. There is a suggestion of the nighttime meridional wind being modulated as a result of the MTM, the equatorial midnight temperature maximum, over Fortaleza and Cachoeira Paulista.

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M. A. Abdu, I. S. Batista, and J. R. Souza, Instituto Nacional de Pesquisas Espaciais, C. P. 515, São José dos Campos, São Paulo, Brazil. (jonas@dae inpe br)

G. J Bailey, Department of Applied Mathematics, University of Sheffield, Sheffield, England, S3 7HR, U. K.

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