Simulation study of the longitudinal variation of evening vertical ionospheric drifts at the magnetic equator during equinox

Geeta Vichare[1,2] and A. D. Richmond

High Altitude Observatory, National Center for Atmospheric Research, Boulder, Colorado, USA

Received 4 August 2004; revised 28 January 2005; accepted 15 February 2005; published 14 May 2005.

[1] Quiet-time low-latitude ionospheric electric fields and vertical drifts in the evening sector at equinox are examined as a function of longitude and solar activity, using simulations from the Magnetosphere-Thermosphere-Ionosphere-Electrodynamics General Circulation Model (MTIEGCM). The model inputs are held fixed with respect to universal time, in order to evaluate the contributions to longitudinal variations of the equatorial electric fields and drifts associated with zonal variations in the geomagnetic field. The simulated upward evening drift is somewhat larger than observations. It increases with solar activity at a similar rate in all longitude sectors. This rate, about 0.32–0.37 m/s per unit of 10.7 cm solar flux, is quantitatively consistent with observations in the Peruvian sector but is considerably greater than observations in the Indian sector. The simulations agree with observations in finding larger vertical drifts in the American-Atlantic sector than in the East Asian-Pacific sector, generally associated with longitudinal variations in the strength of the geomagnetic field. Relations among the longitude variations of the vertical drift, the conductivity, the eastward wind velocity, the geomagnetic declination, and gradients of the wind and declination are examined, revealing few clear correlations. However, extrema of many of these quantities are noted in the American-Atlantic sector.

Citation: Vichare, G., and A. D. Richmond (2005), Simulation study of the longitudinal variation of evening vertical ionospheric drifts at the magnetic equator during equinox, *J. Geophys. Res.*, *110*, A05304, doi:10.1029/2004JA010720.

1. Introduction

[2] The postsunset equatorial *F* region often shows large upward drifts, driven by eastward electric fields [e.g., *Fejer et al.*, 1991]. These enhanced vertical drifts, often called the prereversal enhancement or PRE, have a strong influence on the morphology of the low-latitude ionosphere and on the likelihood that scintillation-producing irregularities will develop [e.g., *Sastri*, 1982; *Anderson and Klobuchar*, 1983; *Fejer et al.*, 1999; *Abdu*, 2001; *Dabas et al.*, 2003].

[3] The equatorial electric field, plasma drift, and associated phenomena vary with longitude at a given local time [e.g., *Walker*, 1981; *Deminov et al.*, 1988; *Sastri*, 1996; *Su et al.*, 1996; *Jadhav et al.*, 2002; *Doumouya et al.*, 2003]. The vector electric field and ion drift measurements from the Dynamics Explorer-2 [*Coley and Heelis*, 1989] and low-inclination AE-E [*Fejer et al.*, 1995] satellites are in good to fair agreement with the ground-based observations at Jicamarca [*Coley and Heelis*, 1989; *Coley et al.*, 1990], India [*Sastri*, 1996], and Brazil [*Batista et al.*, 1996]. Ground-based studies have reported higher vertical drifts in the Brazilian sector [*Abdu et al.*, 1981; *Batista et al.*, 1996]. *Walker* [1981] provided evidence that the enhancement in the equatorial anomaly after sunset is more pronounced and prolonged at American than at East Asian longitudes. Similarly, *Ramesh and Sastri* [1995] found the vertical drifts in the Indian zone to be always less than that at Jicamarca. Further, *Sastri* [1996] pointed out that on an average, the vertical drifts at Jicamarca are about 82% higher than those in India. Thus experimental evidence has established the fact that the equatorial ionosphere behaves differently in various longitude sectors.

[4] The physics of the PRE and its zonal variation are still not completely understood. Feedback processes occurring among various parameters make the physical interpretation complex. According to the theory of the *F* region dynamo proposed by *Rishbeth* [1971], which seems to be the fundamental mechanism for the PRE [*Eccles*, 1998a, 1998b], neutral winds blowing across the magnetic field cause a slow transverse drift of the positive ions, perpendicular to both the winds and the magnetic field. This leads to the collection of positive charges at the top of the *F* region, which sets the vertical polarization electric field in the *F* region. This polarization field can only be neutralized by currents flowing along magnetic field lines and through the *E* layer. However, the *E* layer conductivity after sunset may be too small to close this circuit so that polarization fields build up in the *F* layer, causing the plasma to drift with the wind. The relatively steep eastward gradient of the vertical polarization field in the early evening must be

[1]Formerly Geeta Jadhav.
[2]Also at Indian Institute of Geomagnetism, Navi Mumbai, India.

0148-0227/05/2004JA010720

accompanied by a vertical gradient of the eastward field (due to the curl-free nature of the electric field), which potentially leads to a strong eastward field and upward drift in the early evening, the PRE. A number of models of the PRE have been proposed [*Heelis et al.*, 1974; *Farley et al.*, 1986; *Haerendel et al.*, 1992; *Crain et al.*, 1993; *Eccles*, 1998a]. *Eccles* [1998b] has shown, using a flux-tube-integrated model of ionospheric electrodynamics, that the *F* region zonal wind is the primary driver of the prereversal enhancement, but the relationship between the zonal neutral wind and the resulting enhanced vertical drifts is not well understood.

[5] Numerical simulations may be used to study the dependence of the equatorial electric fields on different physical parameters. *Fesen et al.* [2000] used the NCAR Thermosphere-Ionosphere-Electrodynamics General Circulation Model (TIEGCM) to show the seasonal and solar cycle variation of the low-latitude plasma drifts. *Millward et al.* [2001] examined the influence of tidal forcing on the generation of equatorial vertical drifts. To the extent that such models are successful in reproducing observed features of the drifts and their seasonal and solar cycle variations, the models may also be found to give useful information about the sources of longitudinal variations of the drifts.

[6] Many factors can contribute to the longitudinal variations of the electric fields and vertical drifts. Longitudinal variations of the geomagnetic field strength and declination, as well as of the geographic latitude of the magnetic equator, can be expected to have an influence. In a collisionless plasma, the ions and electrons move together at the velocity $\boldsymbol{V_i} = \boldsymbol{E} \times \boldsymbol{B}/\boldsymbol{B}^2$ perpendicular to the ambient magnetic field $\boldsymbol{B}$ in response to an applied electric field $\boldsymbol{E}$. This implies that the plasma drifts are inversely proportional to **B** when **E** is same for all longitudes or that **E** is proportional to **B** if the ion drifts are same for all longitudes. However, in practice, both **E** and $\boldsymbol{V_i}$ vary with longitude, and numerical simulations provide an opportunity to examine their variations. Large longitudinal variations in the geomagnetic declination angle in the American-Atlantic sector, which vary from $-5°$ to $-20°$ between the longitudes of 300° and 360°E, were invoked by *Batista et al.* [1996] to explain the high longitudinal variability of drifts in this sector. Since the geomagnetic field is accurately known, the effects of its longitudinal variations on the electric field and vertical drift can readily be investigated with a model like the TIEGCM. Other possible sources of longitudinal variations of the electric field are more difficult to evaluate. The thermospheric winds that drive the ionospheric dynamo can have longitudinal variations due to atmospheric solar tides that are not Sun-synchronous [e.g., *Hagan and Forbes*, 2002, 2003]. Magnetospheric electric fields that penetrate from high latitudes to the equator even during magnetically quiet times may also vary with universal time, and therefore with longitude, as the Earth rotates, due to the tilt of the geomagnetic dipole and other factors. *Luehr et al.* [2004] suggested that longitudinal variations of the distance of the magnetic equator from the northern and southern magnetic poles may help explain longitudinal variations in the strength of the equatorial electrojet.

[7] The main focus of the present study is to understand better the factors that affect the longitudinal pattern of the prereversal enhancement in equatorial vertical plasma drift velocities. We extend the PRE study of *Fesen et al.* [2000] using a version of the TIEGCM coupled with a model of the inner magnetospheric plasma, the Magnetosphere-Thermosphere-Ionosphere-Electrodynamics General Circulation Model (MTIEGCM) [*Peymirat et al.*, 1998], described in the next section. We concentrate on the influence of longitudinal variations in the geomagnetic field on the PRE by holding all model input parameters fixed with respect to universal time. In section 3, we examine the local time variation of different parameters such as zonal wind, eastward electric fields, and vertical plasma drifts obtained from MTIEGCM simulations for the Indian, Peruvian, and Brazilian sectors. The succeeding section presents the longitudinal pattern of peak PRE vertical drifts and discusses the model predictions in light of the observations obtained from ionosonde, radar, and satellite measurements. Sections 5 and 6 contain a discussion and conclusions, respectively.

2. Model Simulations

[8] NCAR's MTIEGCM [*Peymirat et al.*, 1998] is an extension of the TIEGCM [*Richmond et al.*, 1992], which includes the coupling between the inner magnetosphere and the ionosphere. The main difference in equatorial electrodynamics between the TIEGCM and the MTIEGCM concerns the penetration of electric fields from auroral regions to low latitudes. Because these penetration fields are relatively minor at the equator during quiet periods [e.g., *Richmond et al.*, 2003], the difference between the models is relatively unimportant for the present study. However, the baseline results we obtain can be useful for future studies of disturbed electric fields using the MTIEGCM. The MTIEGCM solves the full three-dimensional dynamical equations of the thermosphere and ionosphere self-consistently with realistic forcing. The calculation of the electric fields and plasma drifts employs a realistic (IGRF) geomagnetic field. It includes the effects of winds driven by solar heating and by vertically upward propagating diurnal and semidiurnal tides, taken from *Forbes and Vial* [1989], except for the (2,2) mode. In order to improve agreement between observed and simulated global ionospheric electric fields and Sq currents, the amplitude of the (2,2) mode was increased from 150 to 437 m and the phase was shifted about 2 hours later, from 10.3 to 0.4 (i.e., 12.4) hours local time (LT), as suggested by *Fesen et al.* [2000]. The diurnal (1,1) amplitude and phase were adjusted to agree generally with the observations of *McLandress et al.* [1996]. The model grid is 5° latitude by 5° longitude geographic, except that the electric potential is solved on a 1.86° latitude by 4.5° longitude geomagnetic grid. The model is tuned through the vertical O^+ flux at the upper boundary in order to simulate realistic background *F* region ionospheric densities.

[9] We confine our study to quiet time equinox periods. The cross-polar-cap potential is fixed to a low value, 20 kV, which indicates a low level of magnetospheric convection and hence quiet conditions [*Hairston et al.*, 1999]. This low value of the polar cap potential drop ensures very little contribution to the equatorial electric fields from magnetic activity. A magnetospheric plasma source is located at 10.44 R_E, which is the equatorial conjugate of the position of the polar cap boundary at an invariant latitude of 71.97°.

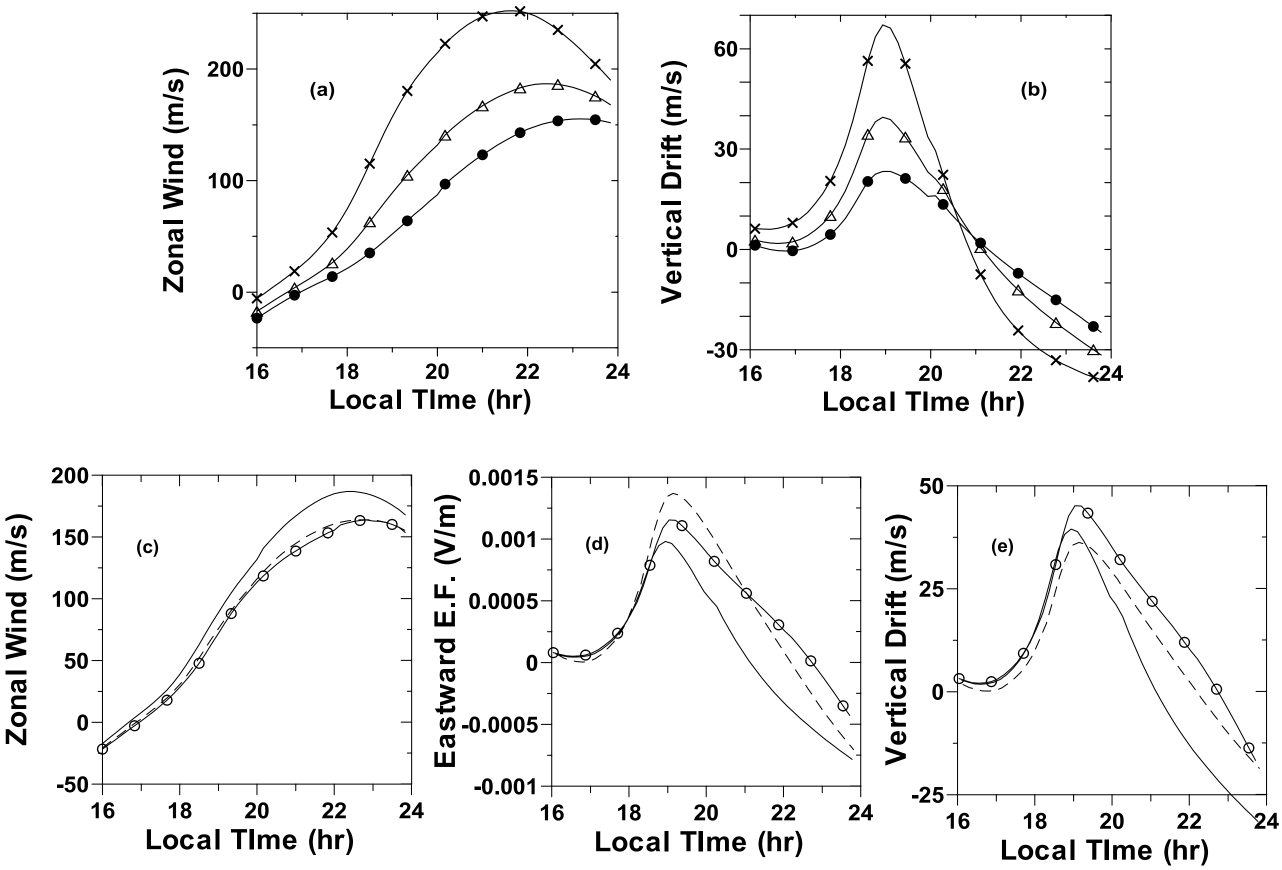

Figure 1. (a and b) Local time variation of zonal wind velocity and vertical plasma drifts for different levels of solar activity in the Peruvian sector (285°E). Line with filled circles, triangles, and crosses indicate solar flux of level 85, 120, and 200, respectively. (c, d, and e) Local time variation of zonal wind velocity, eastward electric field, and vertical plasma drifts at various longitudinal sectors for solar activity of 120. Line with open circles indicates Brazilian (320°E), solid line indicates Peruvian (285°E), and dashed line indicates Indian (80°E) longitudinal sectors.

The electron and ion temperatures of the magnetospheric source are 1 keV and 5 keV, respectively, while the plasma density is assumed to be 0.4 cm^{-3}. The nighttime electron densities between 100 km and 200 km are assumed to vary from 1500 to 3000 cm^{-3}, generally consistent with values recently summarized by *Titheridge* [2003]. All model inputs are assumed to be independent of universal time. In reality, universal time variations might be expected, such as non-Sun-synchronous tides and variations of upper boundary O^+ fluxes, but such variations have not yet been well quantified. Therefore the present study should be seen as an attempt to quantify the influences of longitudinal variations in the geomagnetic field alone on longitudinal variations in the PRE.

[10] All results will be shown at the magnetic equator and at a pressure level of $\sim 0.7 \times 10^{-5}$ Pa, corresponding to the F region at an altitude of roughly 300 km; the precise altitude of this pressure level rises and falls with solar activity.

3. Local Time Variation of Different Parameters Obtained From MTIEGCM Simulations

[11] Simulation results obtained for different levels of solar activity and in various longitudinal zones are summarized in Figure 1. Figures 1a and 1b show the eastward zonal wind and vertical plasma drift variations for the Peruvian sector. Different levels of solar activity are indicated by different symbols (see the figure caption). The figure clearly depicts the solar activity dependence of the parameters. The zonal wind velocities peak around 2200 LT, whereas vertical drifts peak around 1900 LT. The amplitudes and the hour of peak for the vertical velocities are consistent with observations [*Fejer*, 1991].

[12] Figures 1c, 1d, and 1e show the local time variation of the zonal wind, eastward electric field, and vertical plasma drift, respectively, at various longitudinal sectors for a solar activity of 120 units. Note that the zonal wind is in the geographical eastward direction, whereas the electric field points toward magnetic east. The zonal winds in the Peruvian sector are stronger compared with the Indian and Brazilian sectors. One can see from Figure 1d that the Indian sector shows the maximum electric field, while the Peruvian sector shows a weaker eastward electric field, thus indicating the dependence of the zonal electric field on the ambient magnetic field strength, which is ~33,400 nT in the Indian sector and ~22,300 nT in the Peruvian zone.

[13] The local times of peak vertical drifts for the Brazilian and Indian sectors are slightly (15 min) after

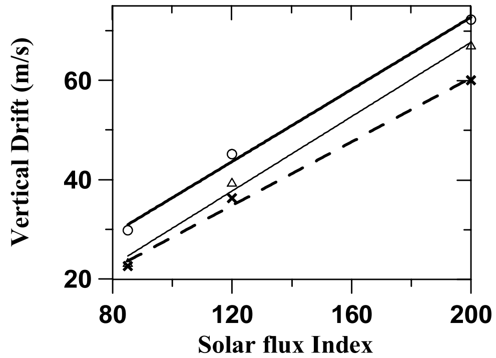

Figure 2. Variation of peak vertical velocity with solar flux index over different longitudinal sectors. Crosses, triangles, and open circles indicate Indian, Peruvian, and Brazilian sectors, respectively, whereas the lines are the best fits to the values.

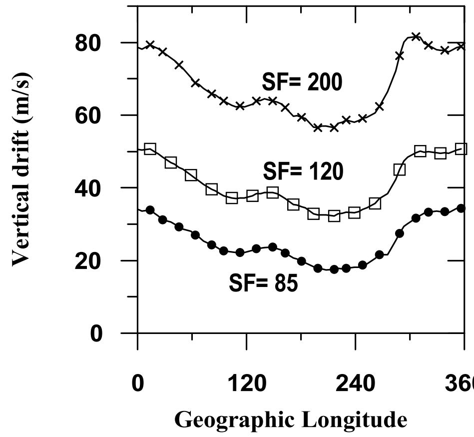

Figure 3. Zonal pattern of equatorial evening peak vertical plasma drifts at various levels of solar activity.

1900 LT, whereas that for the Peruvian sector is at 1900 LT (Figure 1e). The modeled vertical drifts have a sharp decrease after 19 hours in the Peruvian sector and hence the Indian sector appears stronger than the Peruvian zone after the occurrence of the peak. Therefore in order to highlight the longitudinal differences, we compare the peak prereversal drifts at these three longitudes. Figure 2 shows the variation of peak vertical plasma drifts with 10.7 cm solar radio flux index; various sectors are denoted by different symbols. The Brazilian zone has the highest vertical drift velocities, while the Indian sector has the lowest values at all solar activity levels. The dotted, solid, and thick solid lines indicate the best fits for the Indian, Peruvian, and Brazilian longitude zones, respectively. All zones have approximately equal slopes (Brazil = 0.36, Peru = 0.37, India = 0.32). The positive values of the slopes indicate that the modeled peak equatorial ionospheric plasma drifts increase with the solar activity level. Consequently, one can say that the dynamo responsible for the plasma drifts in the model enhances at higher solar fluxes.

[14] We should note that the solar activity variations of the PRE predicted by our MTIEGCM simulations are only partly supported by observations. Earlier work of *Ramesh and Sastri* [1995] noted very little dependence of the postsunset peak vertical drift velocities on solar activity in the Indian sector using HF phase path observations, with relatively stronger dependence in the American sectors. *Sastri* [1996] reported that the slope of the regression line between peak drift velocity and solar $F_{10.7}$ flux for Jicamarca incoherent scatter radar data, 0.29, is more than that for Kodaikanal (India), 0.11, by a factor of 2.6 in the equinox months. While the slope for Jicamarca data is not too different from the MTIEGCM value, the observed Kodaikanal slope is much smaller. However, these observational results need to be treated with caution. *Fejer et al.* [1996] noted the dependence of the plasma drift estimates on the experimental techniques used; they found that the incoherent scatter radar estimates are higher than those obtained from ionosonde measurements for the same longitudinal sector. Hence one cannot rule out the possibility of an underestimation of vertical velocities in the Indian sector due to HF phase path instrument. Nevertheless, both the present study and that of *Sastri* [1996] reveal less longitudinal difference of the peak velocity for lower solar activity than for higher activity, comparing the Indian and American sectors.

4. Zonal Variation of Vertical Plasma Drifts

[15] The longitudinal variation of peak PRE vertical drift velocities for various solar activity levels derived from MTIEGCM simulations is shown in Figure 3. The broad features we note include the larger values of drift motions in the region between 290°E and 30°E through the Greenwich meridian. This is consistent with earlier ground-based studies, which have reported higher vertical drifts in the Brazilian sector [*Abdu et al.*, 1981; *Batista et al.*, 1996]. Further, the larger zonal variability of the drifts in the American-Atlantic sector, as noted observationally by *Batista et al.* [1996], is also unambiguous in the figure.

[16] Now let us compare the simulated pattern with the observations obtained from various ground and satellite instruments. For simplicity, we have tabulated peak prereversal vertical drifts in Table 1 measured by the AE-E satellite [*Fejer et al.*, 1995, Figure 6] and ground-based instruments (*Sastri* [1996] for Kodaikanal, India, representative of 80°E; *Fejer et al.* [1996] for Jicamarca, Peru, representative of 260°E; and *Batista et al.* [1996] for Fortaleza, Brazil, representative of 320°E), and simulated by the MTIEGCM. The actual coordinates of Kodaikanal, Jicamarca, and Fortaleza are (77°28′E, dip latitude 3°N), (285°E, dip latitude 2°N), and (322°E, dip latitude 4°S), respectively.

[17] The AE measurements are for moderate to high solar activity during 1978–1979. The values for Kodaikanal and Jicamarca are taken for a solar activity level of 150.

Table 1. Vertical Drifts Obtained From Various Sources in Different Longitudinal Sectors[a]

Longitude	AE-E	Ground-Based	Present Simulation, m/s
80°E	33	24	49
180°E	28	–	44
260°E	40	30	53
320°E	50	42	61

[a]Drifts are expressed in m/s.

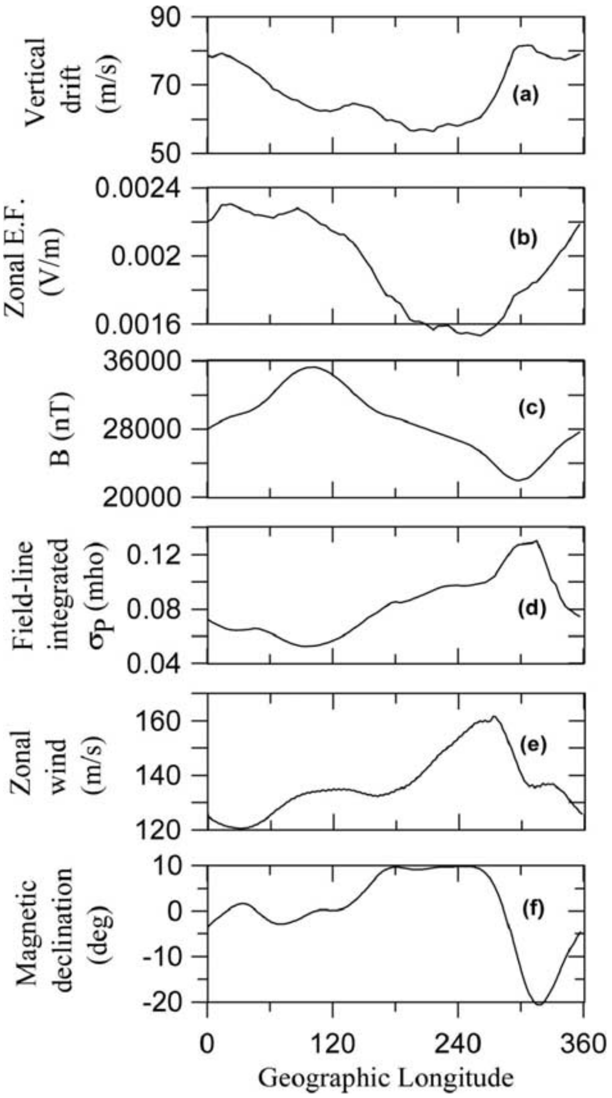

Figure 4. Longitudinal variations of various parameters at the magnetic equator at 1900 LT and about 300 km altitude: (a) vertical plasma drift velocity, (b) magnetic-eastward electric field, (c) geomagnetic field strength, (d) geomagnetic-field-line-integrated Pedersen conductivity, (e) magnetic-eastward neutral wind, and (f) geomagnetic field declination.

Fortaleza measurements are during high solar activity periods. The peak vertical drifts obtained from the present simulations are interpolated to a solar activity level of 150, using the results for moderate (120) and high (200) activity, and are at the longitudes shown in the table, except for the Peruvian sector. Since the variation with longitude is large in the American region, we have taken the ion drifts at longitude 285°E, close to Jicamarca.

[18] In regards to the AE-E measurements, it should be noted that *Fejer et al.* [1995] have provided the local time variation of the averaged values of the equatorial plasma drifts in four variable and overlapping longitude sectors and they assumed that the center of the zone was representative of the entire sector. Therefore the longitude of 180°E contains satellite measurements from 150°E to 210°E, while 260°E includes a wide longitudinal zone with most of the measurements coming from a sector more than 50° to the west of Jicamarca. It should be noted that averaging over a broad longitudinal zone could mask the true representative drift values at a specific location. The estimates quoted in Table 1 for the AE satellite are of peak prereversal drifts during equinox, which occur between 1830 and 1900 LT.

[19] Ground-based observations of vertical plasma drift velocities at various locations on the Earth show considerable day-to-day variations [*Sastri*, 1996; *Fejer et al.*, 1996; *Batista et al.*, 1996]; hence we take the average value of vertical drifts published in the literature as a representative estimate for a particular location. The local time for the peak prereversal drifts is 1900 LT at Kodaikanal, around 1848 LT at Fortaleza, and 1842 LT at Jicamarca. This is not entirely in agreement with the present modeling results, in which peak values occurred at 1900 LT in the Peruvian region and at 1915 LT in the Indian and Brazilian sectors.

[20] The model peak prereversal drifts are computed for the altitude of 300 km. The *F* region vertical plasma drifts at the time of the prereversal enhancement measured at Kodaikanal and Fortaleza correspond to an altitude close to 300 km. The Jicamarca incoherent scatter radar measures the *F* region drifts usually between 250 and 700 km, whereas *Fejer et al.* [1996] gives the average drift estimates for 300–400 km. The AE satellite measurements were made in the altitude range from 230 to 470 km. Ground-based observations of the vertical plasma drifts for the Pacific region were not available.

[21] Table 1 compares the estimates from the different methods and draws attention to the longitudinal variations. The magnitudes tend to be largest for the simulations and smallest for the ground-based observations, with the satellite observations in between. However, we cannot attribute much significance to the overall differences in magnitude because these can be influenced by somewhat different measurement altitudes and/or solar activity, as well as by measurement and model biases. The incoherent scatter radar estimates for the Peruvian sector and the HF phase path measurements at Kodaikanal are around 30 to 40% less than the satellite estimates, whereas ionosonde measurements at Fortaleza underestimate the satellite values by about 16%. *Fejer et al.* [1996] examined the relationship of incoherent scatter radar and ionosonde drift observations over the American equatorial region and found that ratios of the drift obtained from these two techniques depend on the solar activity and season. Figure 4 of their paper reveals that Jicamarca estimates are about 17% higher than the ionosonde measurements at Huancayo for a solar activity of 140 and for equinox periods. As for the simulations, we have found that the PRE drift tends to be sensitive to a number of uncertain model parameters, such as the nighttime *E* region ionization rate. Therefore we do not expect the MTIEGCM's predicted PRE magnitude necessarily to be accurate.

[22] Although interpreting differences of overall magnitudes in Table 1 among the different techniques is difficult, there may be more significance in comparing differences among the longitudinal variations of the drifts from the different techniques. The zonal pattern obtained from the present simulation study correlates well with that based on

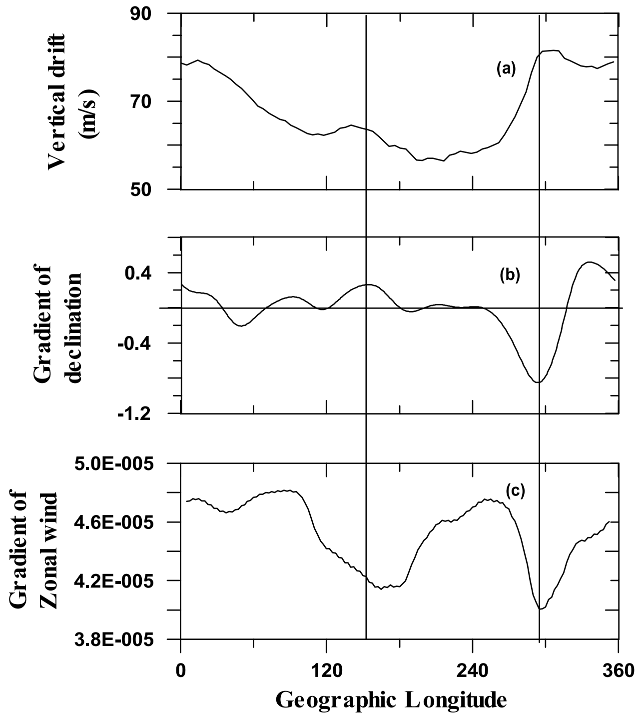

Figure 5. Zonal pattern of (a) vertical drifts, (b) gradient of declination, and (c) gradient of zonal wind.

AE satellite and ground observational estimates. Table 1 indicates that the estimates from all three sources, namely simulations, ground, and satellite observations, reveal larger values in the American sector.

[23] Our study focuses on equinox conditions. Concerning seasonal variations, Figures 5 and 6 from *Fejer et al.* [1995] indicate that in general, the daytime drifts do not change much with longitude during equinoxes or at the December solstice, whereas the average drifts show larger longitudinal variations during the June solstice. Nevertheless, the estimates taken from their plots, listed here in Table 1, do show a conspicuous zonal variation in upward drifts at dusk during equinoxes.

5. Relation of Drift to Wind and Geomagnetic Field

[24] Figure 4 shows the longitudinal variations of various quantities at 300 km above the magnetic equator at 1900 LT, for a solar activity level of 200. Note that for a given pattern of magnetic-eastward electric field and total ambient magnetic field, the longitudinal structure of vertical drifts follows through the relationship of the drift velocities with (E/B). Referring to Figures 4b and 4c, we observe that the zonal electric field pattern broadly follows the ambient magnetic field structure, but the electric field attains a minimum between 180° and 260°E instead of around 300°E (where the magnetic field strength is minimum).

[25] Field-line-integrated conductivities play an important role in the electrodynamical coupling between the *E* and *F* regions [*Farley et al.*, 1986; *Haerendel et al.*, 1992] and consequently in the mechanism of the prereversal enhancement in different longitudinal sectors. Hence we have plotted the zonal pattern of field-line-integrated conductivities in Figure 4d and found that they are strongly influenced by the ambient magnetic field strength.

[26] Referring to Figures 4a and 4e, an influence of the zonal wind on longitudinal variations of the vertical plasma drifts is not apparent. *Crain et al.* [1993] have proposed that the gradient of the eastward wind might be mainly responsible for the prereversal enhancement of the vertical drift around 1900 LT; hence it would be appropriate to examine the zonal variation of the gradient of the magnetic-eastward wind. In addition to that, careful inspection of the zonal pattern of magnetic declination angle shown in Figure 4f reveals a few interesting aspects. The declination angle is almost constant in the region between 180° and 250°E, where the vertical drifts attain the lowest magnitude, suggesting that the gradient of the declination angle may be a useful parameter in the present investigation. Therefore we examine the gradients of both quantities, namely magnetic declination and zonal wind, which are shown in Figure 5 along with the vertical drifts. (To be precise, the gradients shown in Figure 5 are computed in the horizontal direction perpendicular to the magnetic field at the magnetic equator.)

[27] In the longitude zone between 180° and 250°E, the gradient of declination is almost null and the vertical plasma drifts indicate minimum values. The gradient of declination is largest at 295°E (right vertical line in Figure 5), where the vertical drift correspondingly reaches its maximum value. A small peak in the gradient of declination at 150°E (left vertical line) coincides with an increase in the drift velocity. However, the other secondary peaks seen in the gradient of declination in the Asian sector have no counterparts in the drift velocity. Higher values of the vertical drifts in the longitude range between 290°E and 20°E through the Greenwich meridian could be associated with the large gradient of declination in that zone.

[28] The magnetic-eastward gradient of the magnetic-eastward wind at the magnetic equator shown in Figure 5c varies in a complicated manner with longitude. Its variations have no simple relation to the variations of the vertical plasma drift, in contrast to what one might expect based on a simplistic application of the theory of *Crain et al.* [1993]. In fact, the minimum neutral wind gradient occurs near the longitude of the maximum vertical drift, opposite to what the theory would seem to predict. However, because numerous other parameters vary with longitude in addition to the wind gradient, we cannot conclude that the theory of *Crain et al.* [1993] is invalid but only that this theory with its emphasis on the wind gradient does not provide a simple explanation for the longitudinal variations of the early evening vertical drift.

6. Conclusions

[29] In the present study we examine the longitudinal pattern of the prereversal enhancement in equatorial vertical plasma drift velocities at equinox, obtained by using MTIEGCM simulations and observations from various sources. Although the simulated PRE drifts are somewhat larger than the observations, there is general qualitative agreement between the simulations and the observations regarding longitudinal variations of the drift, especially concerning the tendency to maximize in the American

sector. Our simulation results show stronger vertical drift values in the region from 290°E to 20°E through the Greenwich meridian than between 150°E and 270°E. This is consistent with observations showing that the enhancement in the equatorial anomaly after sunset is more pronounced and prolonged at American longitudes than at East Asian longitudes [*Walker*, 1981]. The simulated PRE amplitude increases monotonically with the solar *F*10.7 index, consistent with the studies of *Fesen et al.* [2000] and *Millward et al.* [2001]. The solar activity dependence is similar at all longitudes in the simulations and is similar to the observed dependence in Peru but is considerably stronger than the observed dependence in India.

[30] Our examination of the longitudinal variations of various parameters thought to affect the PRE, including the conductivity, the magnetic-eastward wind velocity, the geomagnetic declination, and gradients of the wind and declination, reveals few clear correlations with the vertical drift, although extrema of many of these quantities are seen in the American-Atlantic sector, which could be associated with the large variations of the magnetic declination in that region (see Figure 4). We found no clear relation between the longitudinal variations of the PRE and those of the eastward gradient of the eastward wind as might be anticipated by simple application of the model of *Crain et al.* [1993], although this result does not disprove the model of *Crain et al.* [1993], as other factors may mask the influence of the wind gradient effects.

[31] For a more complete understanding of the zonal variations of equatorial plasma drifts, there is a need to improve the database of satellite measurements of ion drifts, electric fields, and zonal winds. Simulations using a global model like the MTIEGCM that is capable of self-consistently generating electric fields and plasma distributions under a wide range of conditions likely to occur in the ionosphere, would help to learn more about how the drifts vary with longitude. One future modeling enhancement that is needed will be the addition of tidal components that vary with longitude [e.g., *Hagan and Forbes*, 2002, 2003]. Possible influences due to longitudinal variations of other geophysical parameters (e.g., O^+ fluxes in the topside ionosphere, polar cap potential, nighttime ionospheric densities below 200 km) also need to be considered. It would also be interesting to analyze the evening time peak vertical drifts during solstices. The modeling efforts can also be extended further to study the vertical drifts around dawn. Nevertheless, considering the known limitations of the MTIEGCM, we find that the agreement of the simulation results with the experimental observations is encouraging, suggesting that the present investigation achieves reasonable success in providing a global scenario of the vertical drift velocity in the evening sector at low latitudes, and it encourages us to conduct further studies to examine the dependence of the phenomenon on magnetic activity level using numerical simulations.

[32] **Acknowledgments.** This study was supported by the National Space Weather Research Program and the NASA Sun-Earth Connection Theory Program. The authors would like to thank Ray Roble and Christophe Peymirat for useful discussions in the development and utilization of the MTIEGCM and also Astrid Maute for her assistance in running MTIEGCM. The authors are grateful to Cassandra Fesen, Maura Hagan, and two reviewers for their valuable suggestions. The National Center for Atmospheric Research is sponsored by the National Science Foundation.

[33] Shadia Rifai Habbal thanks J. Vincent Eccles and J. Hanumath Sastri for their assistance in evaluating this paper.

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A. D. Richmond, High Altitude Observatory, National Center for Atmospheric Research, 3450 Mitchell Lane, Boulder, CO 80301, USA.

G. Vichare, Indian Institute of Geomagnetism, Plot 5, Sector 18, New Panvel, Navi Mumbai, 410 206, India. (geeta@iigs.iigm.res.in)