Measurements of the plasma vertical and zonal drift velocities: comparison of the results from Digisondes and Incoherent Scatter Radar during the COPEX campaign

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Abstract

Simultaneous measurements taken by instruments located at the Brazilian and Peruvian longitudinal sectors are presented in this work. These studies show the vertical and zonal drift velocity time series obtained in two periods of observation in October and November, 2002, during the COPEX campaign. Three instruments provided the data: two Digisondes (DPS-4 type), one located at Cachimbo (9.5°S, 54.8°W, dip -4.25°), Brazil, and another one located at the Jicamarca Radio Observatory (11.95°S, 76.87°W, dip ~ 1°), and the Incoherent Scatter Radar also operates at Jicamarca. Earlier work has shown a comparative study of the vertical drift velocity obtained from these instruments (Bertoni et al., 2006). The values of the vertical velocity measurements at the two longitude sectors, Jicamarca (JIC) and Cachimbo (CAC), presented very reasonable correlation, around sunset/evening hours, during moderate magnetic activity. In this paper, we have processed the zonal component of the ionospheric plasma drift velocity. Our results show that the Digisonde drift velocity local time variation, for both the vertical and zonal components, follow the same behavioral trends as that of the velocities from the ISR, during most of the nighttime hours, including the afternoon and sunrise hours. It motivates us to use the zonal velocity of the ionospheric plasma (vertical dynamo electric fields) obtained by Digisondes, in order to further discuss the behavior of zonal and vertical plasma drift for periods conditioned by quiescent and disturbed magnetic and solar activity around the time ranges with good correlation.

Introduction

Comparative studies of two techniques for ionospheric sounding are presented in this work, that allow us to better understand the coupling processes involved in the Magnetosphere-Ionosphere-Thermosphere system, during quiescent and disturbed conditions of the solar activity. It is helpful to validate these different techniques, as an attempt for contributing to further improvements of theoretical and empirical models, as well as an attempt to address the space weather issues.

In this work, we have used simultaneous measurements by digital ionosondes/Digisondes (Reinisch et al., 1996, 1998) in Brazil and Peru, and by the Incoherent Scatter Radar from the Jicamarca Radio Observatory (Woodman and Hagfors, 1969). Figure 1 shows a map with these locations along with some magnetic inclination angle isolines (based on the IGRF model, available at NGDC/NOAA website). Few magnetic field intensity contour isolines show the South Atlantic Magnetic Anomaly.

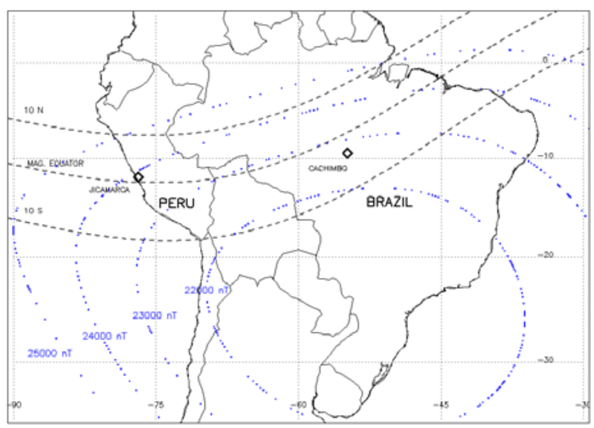

Figure 1 – Instruments locations and configuration of the geomagnetic inclination angle isolines. In addition, it is noticed that the Brazilian magnetic longitude sector presents larger magnetic declination angles as compared with the Peruvian sector, as well as some contour isolines of the South Atlantic Magnetic Anomaly.

The Digisonde measurements of the ionospheric drift velocity are based on the Doppler interferometry (for more details on these calculations, see Scali et al., 1993, 1995; Bullett, 1994). An applicative called Drift-Explorer was developed (Reinisch et al., 2005). The Incoherent Scatter Radar (ISR) from Jicamarca Radio Observatory, Peru, uses a technique that is able to sound by 15 km steps, from approximately 45 km all the way up to the ionospheric top side region. The ionosondes are able to sound up to the peak density of the F-region (~ 300 km). Automatic scaling of the ionograms is carried out with a software package called ARTIST that provides us with the true-height profiles up to the critical frequency region derived from the ionograms and a model based on the parabolic parameters provides us with the topside profile (Huang and Reinisch, 2001; Reinisch and Huang, 2001).

The vertical drift velocity measurements by Digisonde may be influenced by factors such as chemical production and loss of plasma species, transport by ambipolar diffusion of the plasma, gravitational acceleration, all adding to the electromagnetic drift of the plasma (the E x B drift) itself. Therefore, the ionosonde measurements represent a combination of these components. They are in competitive equilibrium all day long up to the nighttime hours when the photochemical production processes are absent, and the chemical losses and transport phenomena become predominant.

The measurements of the ionospheric plasma velocities, using the ISR technique with a very good signal-to-noise relation are representative of the E x B drift component, (for more details on the ISR technique, see Woodman et al.,1969, 1970).

The results obtained, in this work, are part of an important experimental campaign: The Conjugate Point Experiment campaign (COPEX). It was conducted in Brazil under an international collaboration effort for coordinated studies about the Magnetosphere-Ionosphere-Thermosphere system (see, for example, Batista et al., 2008; Sobral et al., 2009; Abdu et al., 2009).

Our results demonstrate the viability of using the ionosonde technique to further understand the relationship of the vertical and zonal components of the ionospheric plasma drift velocity in different conditions of solar and magnetic activity levels. Therefore this technique may be proven to be useful in order to evaluate solar and magnetic activities impacts on the electrical coupling within the system as a whole.

Results

The observations made during October 7-11, 2002, are displayed in Figure 2, which shows the vertical drift (left

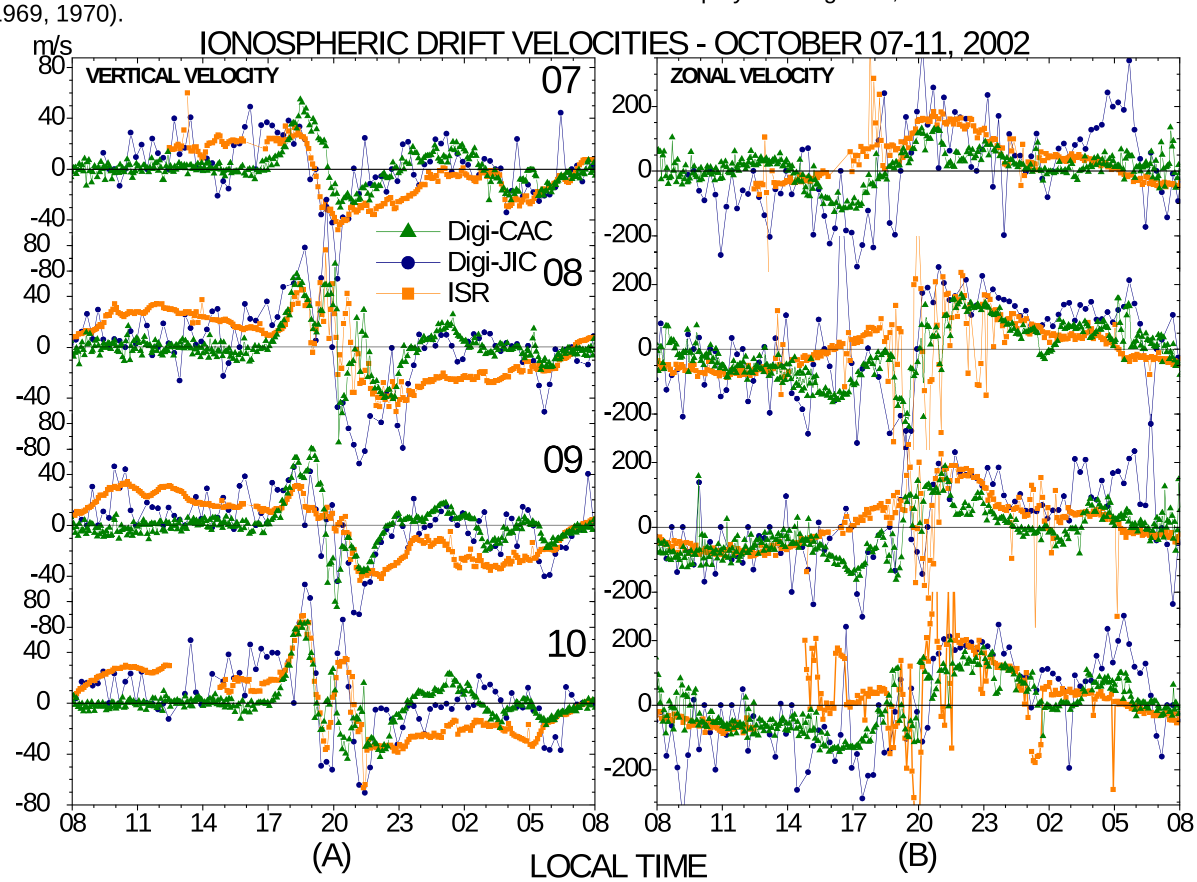

Figure 2 – Vertical (A) and zonal (B) drift velocities as measured by ISR, and both DPS4 systems, for the period P1: October 07-11, 2002.

The simultaneous measurements shown in this paper are an excellent opportunity and as well as an attempt to better understand the ionospheric velocity variability as measured by the Digisondes and the incoherent scatter radar.

panels) and zonal drift (right panels) as obtained from these instruments. According to the ISR measurements, the ionospheric vertical drift velocity is upward (positive), during the daytime and downward (negative) during the nighttime. Around the sunset and evening hours, we see the so-called pre-reversal velocity enhancement (PRE) (see, for example, Fejer, 1991, and references therein).

From a visual inspection comparing ISR and CAC vertical velocities, we may note that there is a very reasonable qualitative agreement of the trends seen in the two curves. It can be seen the PRE occurs around the same local time hours (sunset/evening). However, during the daytime hours the ionosonde measurement show consistently almost null velocity. This is due to the ionization balance by chemical and dynamical processes at radio reflection region sampled by the ionosonde measurements (see, for example, Bertoni et al., 2006). During the nighttime hours, the ionosonde velocities are slightly positive after 23:00 LT which diverges from ISR measurements that show negative values during nighttime hours. Chemical loss effects are responsible for this apparent upward motion of the ionospheric plasma as seen by ionosonde. It is necessary to apply some corrections to obtain the electromagnetic drift velocity as it is observed by the ISR. Regarding the Digisonde measurements at Jicamarca it is seen that the vertical drift present significant fluctuations as compared to the CAC drift velocity data. This is due to the different sounding cadence times: each 15 minutes at Jicamarca and 4-5 minutes at CAC.

Considering the interval from October 7-11, 2002 in Figure 2, on day 8, for CAC and JIC, the vertical velocity peaked twice in the evening hours, possibly suggesting the presence of a wave-like process of propagating penetration electric field, reaching different longitude sectors at same local time. Less apparent than on the previous day, on October 9, the PRE show some

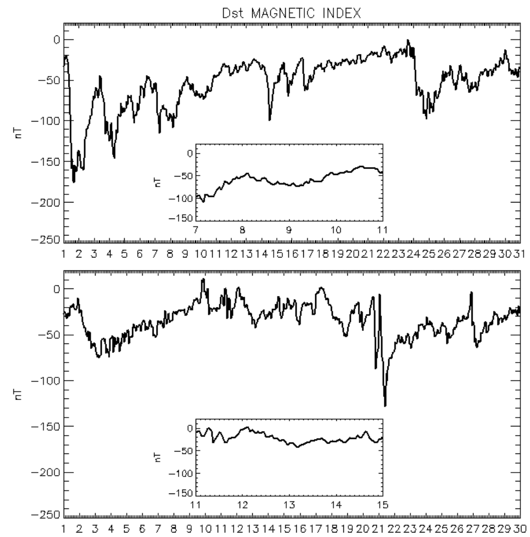

Figure 3 – Variation of Dst magnetic index measured during October 7-11, and November 11-15, 2002.

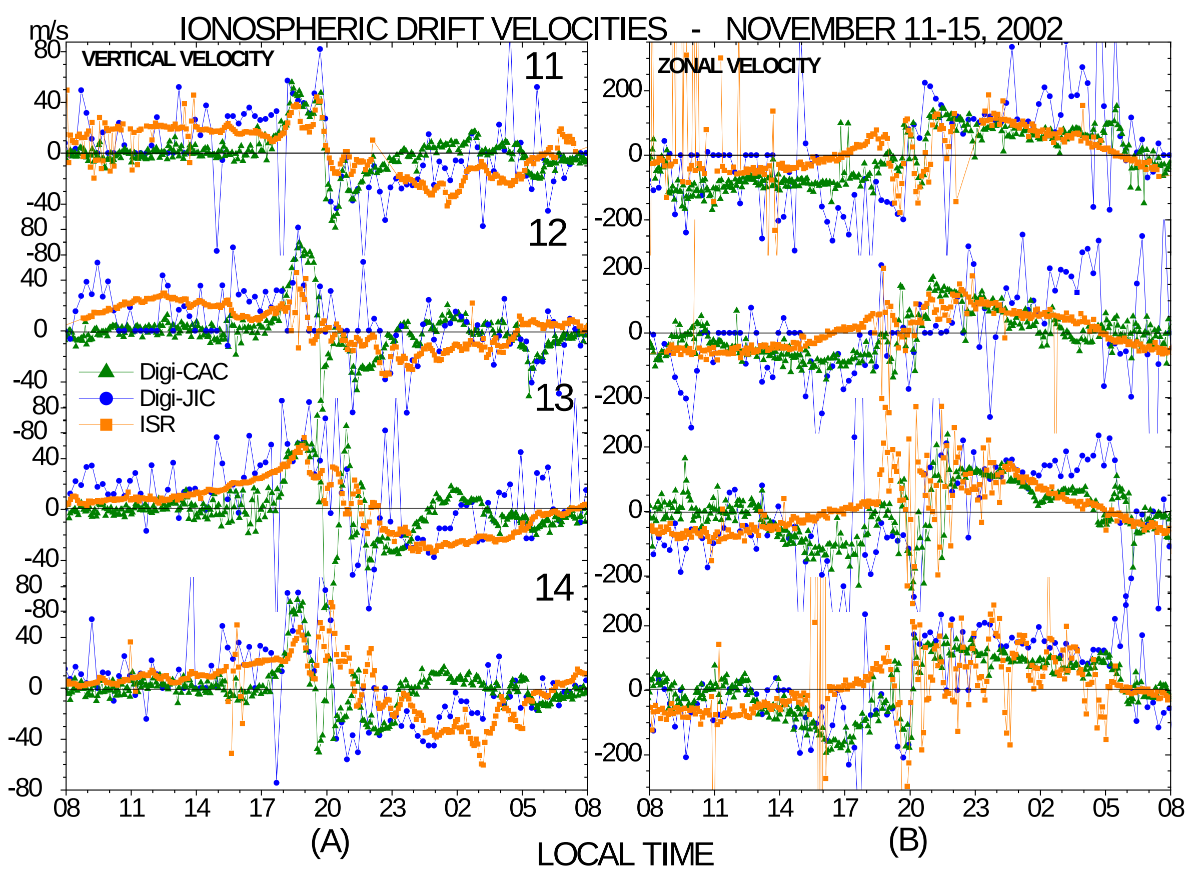

Figure 4 - Vertical (A) and zonal (B) ionospheric velocities measured by ISR and Digisonde at Jicamarca and Cachimbo for the period of 11-15 November, 2002.

tendency to have more than one peak. On day 10 there is another example of a day with two vertical velocity peaks. The second peak occurs around 20:00 local time over Jicamarca (LT ~ UT – 5h, at Jicamarca, and LT ~ UT – 4h, at Cachimbo). Some degree of disturbance dynamo activity appears to have occurred as a consequence of a weak to moderate intensity geomagnetic storms sequence, during this period of observation (October 7-11, 2002). The Dst index displayed in Figure 3, shows a minimum of -107 nT on October 7, at 08:00 UT (available at WDC-C2, Kyoto University website), and the recovery phase lasted up to October 11.

Turning attention to the zonal drift velocity plots in Figure 2, it is known from previous works that the zonal component of the drift velocity as measured by the ISR show positive (eastward) values, during the nighttime hours and negative (westward), during the daytime (see, for example, Fejer et al., 1991). Our results for CAC measurements exhibit roughly the same trends. However, between 15-19 LT, it is observed a consistent difference between the data from CAC ionosonde and ISR, just around the time when there is a reversal from westward to eastward in the ISR velocity (at 16:00 LT). There appears to be present a westward increase during the evening hours in the zonal drift as measured by the Cachimbo Digisonde. The reason for this feature needs to be investigated.

The ISR zonal drift velocity shows an eastward peak around 22:00 LT, and the Digisonde curves show some fluctuating values, but positive and, in very reasonable agreement with the ISR drift velocity during most of the nighttime hours, including the sunrise hours and afternoon local times. The rapid variations observed the post sunset hours by both the techniques are caused by the occurrence of the Equatorial Spread-F irregularities.

Regarding the second period, November 11-15, 2002, which data are displayed in Figure 4, the level of magnetic activity was lower, although the Dst exhibited a minimum of -38 nT, on October 13, at 07:00 UT, lasting up to the next day, that is, it occurred a weak disturbed geomagnetic event. We see good correlation between the vertical drift velocity measurements, suggesting that prompt penetration electric fields travels as a wave-like phenomenon, and it makes clear that disturbed dynamos are localized wave-like phenomena, whose signatures are seen at different local times (longitudinal sectors) of occurrence, but at the same universal time.

Looking at the zonal drift velocity curves, the same agreement as seen in the first period, suggests us that the zonal drift velocity may have little variation with longitude and, this way, the zonal drift velocities measured by Digisondes represent the ***E*** x ***B*** zonal velocity component, after applying some corrections for the ionization balance. However, further studies are necessary to better understand why the zonal and vertical components have so different behavior.

According to Abdu et al. (1998) a vertical electric field, E_V, in the F-region may result from 1) Hall conduction, 2) neutral wind dynamo and 3) vertical currents arising from divergence of horizontal currents. It can be expressed by the following equation (Haerendel et al., 1992):

$$E_V = \frac{\sum_H}{\sum_P} E_{EW} - BU_{EW}^{P} + \frac{J_V}{\sum_P}$$

Σ_H and Σ_P denote the field line integrated Hall and Pedersen conductivities, and it is indicative of the E and F regions electrical coupling; the second term is related to the competitive effects of the thermospheric wind and magnetic field; and eventually, the third term relates the E-region electric field. Studies of a geomagnetic storm event occurred on October 24, 2002, using measurements of the vertical and zonal drift velocities during the COPEX campaign, are in progress for discussing in further details the relations between these components of the ionospheric drift velocities and the impacts over the ionosphere over the magnetic equator and conjugate points in the Brazilian sector, which is characterized for large magnetic declination angles (within ~ 13 - 21° W).

Our results show that it is encouraging to use ionosonde drift velocity measurements for studying the electrical coupling of the Magnetosphere-Ionosphere-Thermosphere system. In addition, expanded time series should be able to study the influences of the solar and geomagnetic activity, during quiescent and transient terms, and, due to the configuration of the instrumental arrays setup locations, increasing our understanding about the characteristic aspects of the South Atlantic Magnetic Anomaly.

Conclusions

Two periods of simultaneous measurements obtained by different ionospheric radio sounding techniques, namely, ionosonde and incoherent scatter radar were studied, and the drift velocities obtained by them were compared. One of the instruments, the Digisonde, performed measurements as part of an important campaign carried out in Brazil, called COPEX (Conjugate Point Experiment), in October-December, 2002, and the other two instruments were operated at Jicamarca Radio Observatory. The main conclusions may be summarized as it follows.

The comparisons of the drift velocities show that there is reasonably good agreement in the local time variation trends between the two results with respect both the vertical and zonal drifts.

There is agreement in the precise values of the vertical drift during the evening hours of the prereversal enhancement in this drift. During night hours the digisonde drift suffers modification due to recombination process resulting larger velocity than that observed by the ISR.

There is good agreement between the zonal velocities as measured by the two techniques generally throughout the day and night hours. Only during the evening hours the digisonde drift shows systematic deviation westward with respect to the ISR drifts. This aspect needs further investigation.

Both the ISR and digisonde drifts show similar features (in terms of vertical drift variations) in response to disturbance electric fields during magnetic storms of weak intensity.

It is observed that there is a good potential for applying similar analysis to a larger data base and to study the possible impacts of the solar and geomagnetic activity, during quiescent and transient periods over the Magnetosphere-Ionosphere-Thermosphere system, and the SAMA region.

Acknowledgments

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References

Abdu, M. A., et al. (2009), Conjugate Point Equatorial Experiment (COPEX) campaign in Brazil: Electrodynamics highlights on spread *F* development conditions and day-to-day variability , *J. Geophys. Res.* , 114 , A04308, doi:10.1029/2008JA013749.

Abdu, M.A., Jayachandran, P.T., MacDougall, J., Cecile, J.F., Sobral, J.H.A., 2008. Equatorial F region zonal plasma irregularity drifts under magnetospheric disturbances. Geophysical Research Letters, 25 (22), 4137-4140.

Batista, I., Abdu, M. A., Carrasco, A.J., Reinisch, B.W., Paula, E.R. de, Schuch, N.J., Bertoni, F., 2008. Equatorial spread F and sporadic E-layer connections during the Brazilian Conjugate Point Equatorial Experiment (COPEX). Journal of Atmospheric and Solar-Terrestrial Physics, 70, 1133–1143, doi:10.1016/j.jastp.2008.01.007.

Bertoni, F. C. P., Batista, I. S., Abdu, M. A., Kherani, E. A., 2006. A comparison of ionospheric vertical drift velocities measured by Digisonde and Incoherent Scatter Radar at the magnetic equator. Journal of Atmospheric and Solar-Terrestrial Physics, 68, 669-678, doi:10.1016/j.jastp.2006.01.002.

Bullett, T. W., 1994. Mid-latitude ionospheric plasma drift: a comparison of digital ionosonde and incoherent scatter radar measurements at Millstone Hill. PhD Thesis, Center for Atmospheric Research, University of Massachusetts Lowell.

Fejer, B. G., 1991. Low latitude electrodynamic plasma drifts: a review. Journal of Atmospheric and Terrestrial Physics, 53 (8), 677-693.

Fejer, B. G.; Paula, E. R. de; Gonzalez, S. A.; Woodman, R. F., 1991. Average vertical and zonal F region plasma drifts over Jicamarca. Journal of Geophysical Research, 96 (A8), 13901-13906.

Haerendel, G., 1992. Theory for modeling the equatorial evening ionosphere and the origin of the shear in the horizontal plasma-flow. Journal of Geophysical Research, 97 (A2), 1209-1223.

Huang, X., B. W. Reinisch, and D. Bilitza, IRI in Windows environment. *Adv. Space Res., 27*, 127-131, 2001.

Reinisch, B. W., 1996. Modern Ionosondes, in *Modern Ionospheric Science*, edited by H. Kohl, R. Ruster, and K. Schlegel, European Geophysical Society, 37191 Katlenburg-Lindau, Germany, 440-458.

Reinisch, B.W., Scali, J.L., Haines, D.M., 1998. Ionospheric drift measurements with ionosondes. Annali di Geofisica, 41, 695–702.

Reinisch, B.W. and X. Huang, Deducing topside profiles and total electron content from bottomside ionograms, *Adv. Space Res*., *27*, 23-30, 2001.

Reinisch, B. W., X. Huang, I. A. Galkin, V. Paznukhov, and A. Kozlov, Recent advances in real-time analysis of ionograms and ionospheric drift measurements with digisondes, *J. Atmos. Solar-Terr. Physics, 67*, 1054-1062,.

Scali, J. L.; Reinisch, B.; Dozois, C.; Bibl, K.; Kitrosser, D.; Haines, M.; Bullett, T., 1993. Digisonde drift analysis: manual. Center for Atmospheric Research, University of Massachusetts Lowell.

Scali, J. L.; Reinisch, B. W.; Heinselman, C. J.; Bullet, T. W. , 1995. Coordinated digisonde and incoherent scatter radar F region drift measurements at Sondre Stromfjord. Radio Science, 30 (5), 1481-1498.

Sobral, J. H. A., et al., 2009. Ionospheric zonal velocities at conjugate points over Brazil during the COPEX campaign: Experimental observations and theoretical validations, J. Geophys. Res., 114, A04309, doi:10.1029/2008JA013896.

Woodman, R. F., Hagfors, T., 1969. Methods for the Measurement of Vertical Ionospheric Motions Near the Magnetic Equator by Incoherent Scattering. Journal of Geophysical Research 74 (5), 1205-1212.

Woodman, R. F., 1970. Vertical Drift Velocities and East-West Electric Fields at the Magnetic Equator. Journal of Geophysical Research , 75 (31), 6249-6259.