1. Publication Nº INPE-3023-PRE/461	2. Version 4th*	3. Date Feb., 1984	5. Distribution ☐ Internal ☒ External ☐ Restricted
4. Origin DGA/DIO			Program IONOSFERA
6. Key words - selected by the author(s) IONOSPHERIC PLASMA BUBBLES ZONAL VELOCITIES			
7. U.D.C.: 523.4-853			
8. Title EQUATORIAL IONOSPHERIC PLASMA BUBBLE IRREGULARITY OCCURRENCE AND ZONAL VELOCITIES UNDER QUIET AND DISTURBED CONDITIONS, FROM POLARIMETER OBSERVATIONS		10. Nº of pages: 19	
		11. Last page: 18	
9. Authorship M.A. Abdu I.S. Batista J.H.A. Sobral E.R. de Paula I.J. Kantor		12. Revised by J. A. Bittencourt	
Responsible author		13. Authorized by Marco Antonio Raupp Director General	
14. Abstract/Notes <p>Amplitude scintillation and Faraday rotation angle fluctuations of satellite VHF beacons registered by electronic polarimeters operated at two stations spaced 110 km apart in the magnetic east-west direction namely, Cachoeira Paulista, 22°41'S, 45°51'W, dip angle of -26°, in Brazil are analyzed for equinoctial and summer months of 1982-1983 to determine the irregularity patch occurrence characteristics and their zonal velocities under varying levels of magnetic disturbances. The scintillation patch occurrences and total electron content fluctuations representing plasma depletion structures decrease during premidnight hours and are enhanced in the postmidnight period. The occurrences often extend to morning hours, with increasing magnetic activity index. While the night events are associated with eastward irregularity patch motion, the morning events have westward velocities (the reversal) occurring around 0400 LT, reflecting the morning velocity reversal in the F region bulk plasma motion reported earlier from Jicamarca radar measurements. The westward plasma bubble motions reported here represent the first observation of this kind. Another important findings from the present investigation is a clear tendency for the zonal plasma motion, namely, the equatorial meridional electric field, to become enhanced mainly in the premidnight hours immediately following strong magnetic activity.</p>			
15. Remarks This work was partially supported by the FNDCT, under contract FINEP-537/CT. Submitted for presentation at International Symposium on Equatorial Aeronomy - ISEA, March 1984 and submitted for publication in the JGR. *Revised work in August, 1985.			

EQUATORIAL IONOSPHERIC PLASMA BUBBLE IRREGULARITY OCCURRENCE AND ZONAL VELOCITIES UNDER QUIET AND DISTURBED CONDITIONS, FROM POLARIMETER OBSERVATIONS

M. A. Abdu, I. S. Batista, J. H. A. Sobral, E. R. de Paula, and I. J. Kantor

Instituto de Pesquisas Espaciais, Conselho Nacional de Desenvolvimento Científico e Tecnológico
São José dos Campos, São Paulo, Brazil

Abstract. Amplitude scintillation and Faraday rotation angle fluctuations of satellite VHF beacons registered by electronic polarimeters operated at two stations spaced 110 km apart in the magnetic east-west direction namely, Cachoeira Paulista, $22^{\circ}41'S$, $45^{\circ}W$, dip angle of -26° , and São José dos Campos, $23^{\circ}12'S$, $45^{\circ}51'W$, dip angle of -26° , in Brazil are analyzed for equinoctial and summer months of 1982-1983 to determine the irregularity patch occurrence characteristics and their zonal velocities under varying levels of magnetic disturbances. The scintillation patch occurrences and total electron content fluctuations representing plasma depletion structures decrease during premidnight hours and are enhanced in the postmidnight period. The occurrences often extend to morning hours, with increasing magnetic activity index. While the night events are associated with eastward irregularity patch motion, the morning events have westward velocities (the reversal) occurring around 0400 LT, reflecting the morning velocity reversal in the F region bulk plasma motion reported earlier from Jicamarca radar measurements. The westward plasma bubble motions reported here represent the first observation of this kind. Another important finding from the present investigation is a clear tendency for the zonal plasma motion, namely, the equatorial meridional electric field, to become enhanced mainly in the premidnight hours immediately following strong magnetic activity.

1. Introduction

Equatorial ionospheric total electron content (TEC) undergoes significant fluctuations produced by the dynamics of the flux-tube-aligned plasma-depleted regions that often characterize nighttime irregularity events. Different characteristics of these depleted regions (or plasma bubbles), such as their development, structure, dynamics, and morphology, have been the subjects of extensive investigations in recent years (see, for example, McClure et al. [1977], Woodman and La Hoz [1976], Tsunoda [1981], Basu and Basu [1981], Kelley et al. [1976], Weber et al. [1978], Sobral et al. [1980], and Abdu et al. [1983],

1985]). The field-aligned depletions develop from the bottomside F layer and often rise up to over 1000 km with vertical rise velocities up to hundreds of meters per second. A mature bubble structure, having dimensions from tens to hundreds of kilometers transverse to the magnetic fieldline, thus extends several degrees to either side of the magnetic equator and drifts in zonal directions with velocities approaching the velocity of the ambient plasma. Signatures of these depletions and their associated irregularities in Faraday rotation angle (representative of the TEC of the ionosphere) and amplitude of the geostationary satellite VHF beacon have been investigated in recent years using VHF electronic polarimeters and scintillation receivers operated at equatorial and low-latitude sites [Klobuchar et al., 1978; Klobuchar and Aarons, 1980; Yeh et al., 1981; Das Gupta et al., 1983; Abdu et al., 1985]. The observations from low-latitude regions located in the equatorial anomaly region, such as Ascension Island, Calcutta, and São José dos Campos, have, in particular, revealed strong Faraday rotation fluctuations in the presence of amplitude scintillation and range spread F in ionograms. In fact, the polarimeter measurements by Abdu et al. [1985] at São José dos Campos ($23^{\circ}12'S$, $45^{\circ}51'W$, dip angle of -26°) and Cachoeira Paulista ($22^{\circ}41'S$, $45^{\circ}W$, dip angle of -26°), located near the equatorial anomaly crest region, have shown both the fast fluctuations in the Faraday rotation angle having periods of the order of seconds, characteristic of the depolarization effect discussed by Das Gupta et al. [1983] and Lee et al., [1982] as well as slower fluctuations (rather, TEC fluctuations) having periods of the order of a few minutes. The latter class of fluctuations arose from TEC modulation by plasma bubble structures having field line perpendicular dimensions of the order of a few tens of kilometers [Abdu et al., 1985]. Thus the correlation times of the TEC fluctuations between the two polarimeter sites, located exactly in the magnetic east-west direction, were used to deduce plasma bubble structure zonal velocities. The measurements by Abdu et al. [1985] made use of the VHF (~ 136 MHz) beacon from the GOES 3 satellite (having subionospheric points at 350 km of -21.4° latitude and -50.3° longitude for reception at São José dos Campos) that had a propagation path westward of the polarimeter location meridian, and the zonal velocities present by them represented the average summer 1981-1982 conditions. We have carried out similar measurements of TEC fluctuations and amplitude scintillations, during the equinoctial and summer months of 1982-1983, on a VHF beacon from the satellite SIRIO (having

subionospheric points at 350 km of -21.5° latitude and -43.5° longitude and thus representing a propagation path eastward of the polarimeters). In the present paper the results from these measurements are analyzed to determine the statistical behavior of the zonal velocities and that of the associated scintillation-producing irregularity occurrences, under different levels of magnetic disturbances. One of the important highlights of the present results is our detection and measurement of westward velocities of plasma bubbles when they occur during morning hours under enhanced magnetic disturbance conditions (see also Aarons and Das Gupta [1984]). Further, the zonal plasma bubble velocities which represent the equatorial meridional electric field are seen to undergo significant fluctuations during magnetically active periods.

2. Experimental Results

On the basis of the observed strong correlation of the nighttime TEC fluctuations (slow or fast) with amplitude scintillation and range spread F events, Abdu et al. [1985] interpreted the eastward velocities obtained from their polarimeter data as representing the velocities of plasma bubble substructures whose sizes typically range from 50 to 100 km. An example of TEC fluctuations events recorded in the postsunset hours at São José dos Campos and Cachoeira Paulista is shown in Figure 1. The features marked aa', bb', etc., represent well-defined correlation time differences (Δt) between the two stations. A careful examination will show that the correlation time increases toward later local times, suggesting a corresponding decrease in the drift velocities if we assume a "frozen in" hypothesis for the plasma bubble structures. We have analyzed a large number of such events observed on the geostationary satellite SIRIO simultaneously at the two locations, during the period from December 1982 to January 1983. The velocities were calculated using the Δt and the subionospheric separation for the two locations for a mean F layer peak height of 400 km (the variation in this distance is very small for a large range of the F_2 peak heights). The mean zonal velocities obtained from this analysis representing the summer 1982-1983 conditions are presented in Figure 2 (the curve marked by open circles). All the velocities obtained during a given 1-hour interval have been used to obtain the mean value plotted at the middle of that interval. The standard deviations in these values are also shown. For comparison we have shown in the same figure the 1981-1982 summer average velocities obtained using GOES 3.

Fig. 1

Fig. 2

Good agreement is evident between the two sets of results. The mean eastward velocities show a peak around 2000-2100 LT and a steady decrease from then on to reach zero around 0400 LT and a reversal to westward after that time. This local time variation pattern (including the velocity reversal time around 0400 LT) is in excellent agreement with that of the F region ambient plasma zonal velocities measured by the Jicamarca radar as reported by Fejer et al. [1981] (also B. G. Fejer et al., unpublished manuscript, 1985). The local time pattern in the eastward velocity region of our results is also in good agreement with that of the scintillation patch velocities obtained from closely spaced (248 m) receivers at 255 MHz by Yeh et al. [1981] over Natal in Brazil and those obtained using a similar technique by Aarons and Whitney [1980] over Ancon, Peru. The airglow depletion patch velocities reported by Mendillo and Baumgardner [1982] over Ascencion Island and by Sobral et al. [1985] over Cachoeira Paulista also showed a similar local time pattern. There are, however, important differences among the magnitudes of the velocities in these different results, whose possible implications for the F region bulk plasma velocity shears have been discussed by Abdu et al. [1985].

2.1. Magnetic Disturbance Effects on Irregularity Occurrences

Amplitude scintillation events occur simultaneously with the Faraday rotation angle fluctuation (fast or slow) registered by the polarimeters and in many cases continue well after these fluctuations subside. We have analyzed these scintillation events during the months of October, November, and December 1982 and January and February 1983 (predominantly summer months) to determine statistically possible magnetic control on their local time occurrence pattern. Occurrence percentages and mean scintillation amplitudes (in decibels) were determined by dividing the data for this period into three groups representing magnetic activity levels with the 3-hour Kp index having values of (≤ 2), ($2 < Kp \leq 4$), and (> 4). The local time variations of occurrence percentages and scintillation levels for these three groups are presented in Figure 3. In general, the amplitude of scintillations follows the percentage of their occurrence. For $Kp \leq 2$ and $2 < Kp \leq 4$ the two parameters presented almost similar trends dominated by a premidnight peak between 2100 and 0000 LT. For $Kp > 4$ the local time pattern undergoes significant alterations presenting a pronounced postmidnight enhancement primarily with reference to the premidnight inhibition of these events. Similar results have been reported for equatorial stations of Natal

F. g. 3

and Huancayo by Aarons et al. [1980] and by Rastogi et al. [1981]. A case by case study of individual event responses to magnetospheric disturbances would have been more interesting in that a detailed picture of the global coupling of the related phenomena could be explored. One important obstacle for realizing such a study is the nonavailability of an auroral activity index for the southern hemisphere. However, even a preliminary analysis using the 3-hour Kp values of some individual events presented below would show significantly different and more detailed response behavior from that represented by the statistical picture given above.

Fig. 4

Figure 4 presents two individual plasma bubble and VHF scintillation events during postmidnight-morning hours of two consecutive nights, on December 21 and 22 1982, that occurred during a magnetically disturbed epoch (from December 17 to 22 there were continuous disturbances of moderate to severe intensity). The 3-hour magnetic activity index Kp was ≥ 4 on both nights just prior to these events. Plasma bubble structures and scintillation-producing irregularities occurred from 0100 to 0310 LT on December 21. The velocities of the structures were clearly eastward as indicated by the features marked a, b, and a', b' on the TEC curves for São José dos Campos and Cachoeira Paulista, respectively. The eastward bubble velocity is 120 m s^{-1} . On December 22 the magnetic activity was significantly higher (Kp=7-) in the postmidnight period till 0300 LT than it was on the preceding night. VHF scintillation was registered from 0340 LT till 0700 LT, and significant TEC depletions were observed till about 0500 LT, after which the weaker TEC fluctuations were superimposed over the steep slope of the morning sunrise increase in TEC. The most interesting aspect of this event is that the TEC depletions have westward velocities. The velocities have been determined to be 90 m s^{-1} . It appears that these depletions and scintillation irregularities were generated in the ionosphere east of Cachoeira Paulista, where the ambient F region zonal velocity had reversed from its nighttime eastward direction to the morning westward direction. The plasma bubble irregularities, therefore, might have been carried westward by the ambient plasma. This observation shows that the presence of eastward neutral wind is not a necessary condition for plasma bubble generation, at least in the early morning hours.

Fig. 5

Another example of a morning bubble event associated with magnetic disturbance is presented in Figure 5. In this figure the eastward bubble velocity is evident only till a little after 0300 LT. At later hours the bubble structure

features become less correlated at the two locations owing to the velocity reversal in the ambient plasma occurring near 0400 LT. However, the reversal time does not seem to be clearly defined on this morning, and hence the TEC structures at these times did not have correlations clear enough to permit determination of westward velocities.

2.2. Magnetic Disturbance Effects on Plasma Bubble Zonal Velocities

Fig. 6

Magnetic storm effects on the plasma bubble zonal velocities were investigated by dividing the velocity data into three groups representing 12-hour sums of $K_p < 7$, $7 < K_p < 15$, and $K_p > 15$. Further, two criteria were used, namely, the K_p values occurring simultaneously with the events (criterion 1) and the K_p values occurring in the 12-hour interval immediately preceding the night of the events (criterion 2). The results of these analyses are presented in Figure 6. The standard deviations in the velocities for the quietest nights (12-hours K_p sum of < 7) shown in this figure are significantly less than those in Figure 2, which represented all the nights of measurement. In other words, a clear reduction of the geophysical noise in the zonal plasma velocities, namely, in the meridional electric field component, is observed under magnetically quiet conditions. From Figure 6 we could see that the plasma zonal velocities do not undergo changes (except, perhaps, near 2000-2100 LT) when changes in simultaneous K_p values (criterion 1) are considered. In the plot using criterion 2 there appears to be a clear tendency for eastward velocities to increase on the nights immediately following magnetic disturbances. This increase seems to be dominant during the premidnight hours and has a striking resemblance to the statistical results of Gonzales et al. [1983] showing a perceptible enhancement, within a similar local time interval (see their Figure 3), in the downward meridional electric field component measured by Jicamarca incoherent scatter radar during magnetically very active periods. Another important feature of Figure 6 is the extension of the bubble occurrences to morning hours, permitting determination of the plasma velocities that are westward at these hours. Such morning bubble occurrences represent, however, magnetically disturbed conditions.

3. Discussion and Conclusions

Observations on geostationary satellite VHF beacons using an east-west spaced polarimeter system over low-latitude locations in Brazil have permitted determination of the zonal velocity component of plasma-depleted regions in the equatorial ionosphere. Possible influence of bubble vertical rise velocities in the observed Δt has been discussed by Abdu et al. [1985]. As has been shown by radar measurements, the vertical velocity could be large during the growth phase of a bubble [Tsunoda, 1981]. Hanson and Bamgboye [1984] have measured, using the Atmosphere Explorer E satellite ion drift meter, large vertical as well as horizontal ions velocities in the meridional plane inside the plasma bubbles. Although a close relationship is expected between these bubble ion velocities and the plasma bubble velocities measured by radar, many details of this relationship do not seem to be clearly established. Our present measurements, however, refer more to the end of the growth phase of a bubble, when the vertically extended bubble structure is associated with relatively small rise velocities [Hanson and Bamgboye, 1984; Tsunoda, 1981], with the bubble dynamics dominated by zonal velocities approaching the velocity of the ambient plasma [Ossakow and Chaturvedi, 1978; Tsunoda et al., 1981]. The reason for this situation is that our low-latitude polarimeters detect mature flux-tube-aligned bubble structures whose vertical extension reaches up to or beyond the apex of the field line (around 700 km) that meets the low-latitude F layer peak subionospheric point. This reasoning is amply substantiated by the results in Figure 2 that show the velocities measured by GOES 3 that has a propagation path westward of the magnetic meridian of the polarimeters and those measured from SIRIO that has an eastern propagation path, and as has been explained by Abdu et al. [1985], the good agreement between the mean velocities measured on these two paths clearly rules out any significant influence of vertical bubble movements in the deduced zonal velocities. It is worth pointing out further that the velocity measured by the present technique represents the real (and not an apparent) zonal velocity of the plasma bubble structures, since we are deducing it from the observed correlation time for TEC structures (having field line perpendicular dimensions of a few tens of kilometers [Abdu et al., 1985] that have retained their integrity in the longitudinal distance of 110 km that separates the two polarimeters. It is reasonable to consider further that a bubble with a given percentage depletion will produce the

maximum effect on the TEC when that bubble occurs at the F layer peak (rather than at other heights) such that our measured velocities should represent a height averaged value near the F layer peak. According to the theoretical and experimental results on the ambient plasma and plasma bubble zonal velocity height variation (see, for example, Anderson and Mendillo [1983], Kudeki et al. [1981], and Tsunoda et al. [1981], these velocities should correspond closely to the peak value of the height distribution. The local time variation pattern of the velocities obtained by us is in excellent agreement with those obtained from other observations, from Jicamarca radar, from VHF scintillations on closely spaced receivers, and from airglow depletion patches. However, our low-latitude zonal velocities are found to be, in general, significantly higher than the equatorial values obtained by other workers, which suggests the existence of a latitudinal variation in the plasma zonal velocities. Possible implications of such a latitudinal velocity gradient for the vertical shears in plasma flow over the equator have been discussed by Abdu et al. [1985].

The VHF scintillation-producing irregularities occurring during the TEC depletion events have a peak occurrence rate from ~2100 to 0000 LT during quiet to moderate magnetic disturbance conditions. For severely disturbed conditions (defined here as being represented by $K_p > 4$) the irregularity strength and occurrence rates get inhibited during premidnight hours and get relatively enhanced during postmidnight to morning hours. Individual events, under the disturbed conditions, are seen occurring well into the morning hours, and in many cases (such as the case of December 22, 1982, shown in Figure 4) they follow closely large increases in the 3-hour magnetic activity index K_p . The velocities of these plasma bubble are eastward when they occur before around 0300 LT and westward when they occur at later hours in the morning, reflecting the bulk plasma zonal flow pattern at these times. Analysis of zonal velocities in search of their possible response to magnetic disturbances seems to suggest that there is a clear tendency toward higher eastward plasma bubble velocities on nights immediately following severe magnetic disturbances. One could speculate over the different, but interrelated, geophysical processes, such as changes in magnetospheric convection fields, auroral zone conductivity variations from substorm-induced particle precipitation events, enhancements in the disturbance dynamo action, etc., as responsible, to different degrees, for the meridional electric field enhancements observed in our low-latitude data. An intermediate (and perhaps additional) mechanism,

though it could be related to the different magnetospherically induced sources, might be the possible increases in the F layer peak heights (causing corresponding increases in the effective plasma bubble and associated irregularity heights) often observed under magnetically disturbed conditions over low latitudes. In the presence of a shear flow in the F region plasma zonal motion (see, for example, Tsunoda et al. [1981], Kudeki et al. [1981], and Abdu et al. [1985]), an increase in the mean (or effective) height of the plasma bubble irregularities considered here as tracers of the ambient plasma could result in an increase in their zonal velocities as well. Clear identification of the likely sources for the observed magnetospheric disturbance effects in the zonal plasma velocities should be sought on the basis of a case by case investigation of a large set of events, with simultaneous interplanetary, magnetospheric, and high-latitude ionospheric data. We plan to undertake such a detailed investigation in the immediate future.

Acknowledgments. The authors are thankful to our technical staff, particularly to Sinval Domingos and Francisco de Paula Vitor Mesquita, for good maintenance of our polarimeter operations at São José dos Campos and Cachoeira Paulista. The polarimeter at São José dos Campos was kindly loaned to us by Aldo Vieira da Rosa (from the University of Campinas), to whom we express our profound thanks. This work was partially supported by the Fundo Nacional de Desenvolvimento Científico e Tecnológico under contract FINEP-537/CT.

The Editor thanks J. P. McClure and Santimay Basu for their assistance in evaluating this paper.

References

- Aarons, J., and A. Das Gupta, Equatorial scintillations during the major magnetic storm of April 1981, Radio Sci., 19, 731-739, 1984.
- Aarons, J., and H. E. Whitney, Recent observations of equatorial and high latitude scintillations, Propagation effects in space/earth path, AGARD Conf. Proc., 284, 31.7-31.17, 1980.
- Aarons, J., J. P. Mullen, J. P. Koster, R. F. da Silva, J. R. Medeiros, R. T. Medeiros, A. Bushby, J. Pantoja, L. Lanat, and M. R. Paulson, Seasonal and geomagnetic control of equatorial scintillation in two longitude sectors, J. Atmos. Terr. Phys., 42, 861-866, 1980.

- Abdu, M. A., R. T. Medeiros, J. H. A. Sobral, and J. A. Bittencourt, Spread F plasma bubble vertical rise velocities determined from spaced ionosonde observations, J. Geophys. Res., 88, 9197-9204, 1983.
- Abdu, M. A., I. J. Kantor, I. S. Batista, and E. R. de Paula, East-west plasma bubble irregularity motion determined from spaced VHF polarimeters: Implications on velocity shear in the zonal F region bulk plasma motion, Radio Sci., 20, 111-122, 1985.
- Anderson, D. N., and M. Mendillo, Ionospheric conditions affecting the evolution of equatorial plasma depletions, Geophys. Res. Lett., 10, 541-544, 1983.
- Basu, S., and S. Basu, Equatorial scintillation-A review, J. Atmos. Terr. Phys., 43, 473-489, 1981.
- Das Gupta, A., S. Basu, J. Aarons, J. A. Klobuchar, S. Basu, and A. Bushby, VHF amplitude scintillation and associated electron content depletions as observed at Arequipa, Peru, J. Atmos. Terr. Phys., 45, 15-26, 1983.
- Fejer, B. G., D. T. Farley, C. A. Gonzales, R. T. Woodman, and C. Calderon, F region east-west drifts at Jicamarca, J. Geophys. Res., 86, 215-218, 1981.
- Gonzales, C. A., M. C. Kelley, R. A. Behnke, J. F. Vickrey, R. Wand, and H. Holt, On the latitudinal variations of the ionospheric electric field during magnetospheric disturbances, J. Geophys. Res., 88, 9135-9144, 1983.
- Hanson, W. B., and D. K. Bamgboye, The measured motions inside equatorial plasma bubbles, J. Geophys. Res., 89, 8997-9008, 1984.
- Kelley, M. C., G. Haerendel, H. Kappler, A. Valenzuela, B. B. Balsley, D. A. Carter, W. L. Ecklund, C. W. Carlson, B. Hansler, and R. Torbert, Evidence for Rayleigh-Taylor type instability regions during equatorial spread F, Geophys. Res. Lett., 3, 448-450, 1976.
- Klobuchar, J. A., and J. Aarons, Studies of equatorial irregularity patches using SIRIO VHF transmissions, Alta Freq., 49, 345-349, 1980.
- Klobuchar, J. A., J. Aarons, E. Weber, L. Lucena, and M. Mendillo, Total electron content changes associated with equatorial irregularity plumes, paper presented at National Radio Science Meetings, Union Radio Sci. Int., Boulder, Colo., Nov. 6-9, 1978.
- Kudeki, E., B. G. Fejer, D. T. Farley, and H. M. Ierick, Interferometer studies of equatorial F-region irregularities and drifts, Geophys. Res. Lett., 8, 377-380, 1981.

- Lee, M. C., A. Das Gupta, J. A. Klobuchar, S. Basu, and S. Basu, Depolarization of VHF geostationary signals near the equatorial anomaly crest, Radio Sci., 17, 399-409, 1982.
- McClure, J. P., W. B. Hanson, and J. F. Hoffman, Plasma Bubble and irregularities in the equatorial ionosphere, J. Geophys. Res., 82, 2650-2656, 1977.
- Mendillo, M., and J. Baumgardner, Airglow characteristics of equatorial plasma depletions, J. Geophys. Res., 87, 7641-7652, 1982.
- Ossakow, S. L., and P. K. Chaturvedi, Morphological studies of rising equatorial spread F bubbles, J. Geophys. Res., 83, 2085-2090, 1978.
- Rastogi, R. G., J. P. Mullen, and E. Mackenzie, Effects of geomagnetic activity on equatorial radio VHF scintillation and spread F, J. Geophys. Res., 86, 3661-3664, 1981.
- Sobral, J. H. A., M. A. Abdu, and Y. Sahai, Equatorial plasma bubble eastward velocity characteristics from scanning airglow photometer measurements over Cachoeira Paulista, J. Atmos. Terr. Phys., in press, 1985.
- Tsunoda, R. T., Time evolution and dynamics of equatorial backscatter plumes, 1, Growth phase, J. Geophys. Res., 86, 139-149, 1981.
- Weber, E. J., J. Buchau, R. H. Eather, and S. B. Mende, North-south aligned equatorial airglow depletions, J. Geophys. Res., 83, 712-716, 1978.
- Woodman, R. F., and C. La Hoz, Radar observations of F region equatorial irregularities, J. Geophys. Res., 81, 5447-5466, 1976.
- Yeh, K. C., J. P. Mullen, J. R. Medeiros, R. F. da Silva, and R. T. de Medeiros, Ionospheric scintillation observations at Natal, J. Geophys. Res., 86, 7527-7532, 1981.

M. A. Abdu, I. S. Batista, I. J. Kantor, E. R. de Paula, and J. H. A. Sobral, Instituto de Pesquisas Espaciais, Conselho Nacional de Desenvolvimento Científico e Tecnológico, 12200 São José dos Campos, São Paulo, Brazil.

(Received February 18, 1985;
revised May 29, 1985;
accepted June 13, 1985.)

Fig. 1. An example of a TEC depletion event registered on a VHF beacon from SIRIO on the night of January 3-4, 1983. The features on the Faraday rotation angle marked a-f on the São José dos Campos (S.J.C.) records and a'-f' on the Cachoeira Paulista (C.P.) records represent plasma bubble structures used in the zonal velocity determinations (see the text for further details).

Fig. 2. Zonal velocities of plasma bubble structures representing the average conditions of summer 1982-1983, measured on a VHF beacon from SIRIO marked by open circles. The curve through solid triangles represents the average summer 1981-1982 zonal plasma bubble velocities measured on a VHF beacon from the GOES-3 satellite. Note that SIRIO was eastward and GOES 3 was westward of the magnetic meridians of S.J.C. and C.P. The data statistics are shown at the top of the figure. (Eastward is positive in the figure.)

Fig. 3. Scintillation amplitudes (solid line) and their occurrence percentages (dashed line) at 136 MHz plotted as functions of local time for three groups representing three different levels of magnetic activity.

Fig. 4. Postmidnight-morning plasma bubble and VHF scintillation events following magnetic disturbances. Note that the velocity is eastward before 0330 LT on December 21, 1982, and westward after 0330 LT on December 22, 1982. S.J.C. station is located west of C.P. station.

Fig. 5. Another example of plasma depletion events during a magnetically disturbed period. Note that the velocities were eastward before ~0330 and not clearly marked afterward owing to the reversal in the plasma flow westward at these times.

Fig. 6. Zonal velocities of plasma bubble structures as a function of local time plotted for different levels of magnetic disturbances, during the summer of 1982-1983. The data statistics for the disturbed days are shown at the top of the figure.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Abdu et al.: Brief Report

Abdu et al.: Brief Report

Abdu et al.: Brief Report

Abdu et al.: Brief Report

Abdu et al.: Brief Report

Abdu et al.: Brief Report

Abdu et al.: Brief Report

Abdu et al.: Brief Report

MFN= 002445

01 SID/SCD

02 3023

03 INPE-3023 - PRE/461

04 CEA

05 S

06 as

10 Abdu, Mangalathyil Ali

10 Batista, Inez Stacuarini

10 Sobral, José Humberto Andrade

10 Paula, Eurico Rodrigues de

10 Kantor, Ivan J

12 Equatorial ionospheric plasma bubble irregularity occurrence and zonal velocities under quiet and disturbed conditions, from polarimeter observations

14 9921-9928

30 Journal of Geophysical Research

31 90

32 A10

40 En

41 En

42 <E>

58 DAE

59 903108

61 <PI>

64 <1985>

68 PRE

76 AERONOMIA

83 Amplitude scintillation and Faraday rotation angle fluctuations of satellite VHF beacons registered by electronic polarimeters operated at two stations spaced 110 km apart in the magnetic east-west direction namely Cachoeira Paulista, 22 degree 41 degree S, 45 degree W, dip angle of -26 degree, and São José dos Campos, 23 degree 12'S, 45 degree 51'W, dip angle of -26 degree, in Brazil are analyzed for equinoctial and summer months of 1982-1983 to determine the irregularity patch occurrence characteristics and their zonal velocities under varying levels of magnetic disturbances. The scintillation patch occurrences and total electron content fluctuations representing plasma depletion structures decrease during premidnight hours and are enhanced in the postmidnight period. The occurrences often extend to morning hours, with increasing magnetic activity index. While the night events are associated with eastward irregularity patch motion, the morning events have westward velocities (the reversal) occurring around 0400 LT, reflecting the morning velocity reversal in the F region bulk plasma motion reported earlier from Jicamarca radar measurements. The westward plasma bubble motions reported here represent the first observation of this kind. Another important finding from the present investigation is a clear tendency for the zonal plasma motion, namely, the equatorial meridional electric field, to become enhanced mainly in the premidnight hours immediately following strong magnetic activity.

87 disturbios magnéticos

87 bolhas de plasma

87 equador magnético

87 polarímetros

87 observação

88 magnetic disturbances

88 plasma bubble
88 magnetic equator
88 polarimeters
88 observation
91 8510

EQUATORIAL IONOSPHERIC PLASMA BUBBLE IRREGULARITY OCCURRENCE AND ZONAL VELOCITIES UNDER QUIET AND DISTURBED CONDITIONS, FROM POLARIMETER OBSERVATIONS

M. A. Abdu, I. S. Batista, J. H. A. Sobral, E. R. de Paula, and I. J. Kantor

Instituto de Pesquisas Espaciais, Conselho Nacional de Desenvolvimento Científico e Tecnológico
São José dos Campos, São Paulo, Brazil

Abstract. Amplitude scintillation and Faraday rotation angle fluctuations of satellite VHF beacons registered by electronic polarimeters operated at two stations spaced 110 km apart in the magnetic east-west direction namely, Cachoeira Paulista, 22°41'S, 45°W, dip angle of -26°, and São José dos Campos, 23°12'S, 45°51'W, dip angle of -26°, in Brazil are analyzed for equinoctial and summer months of 1982-1983 to determine the irregularity patch occurrence characteristics and their zonal velocities under varying levels of magnetic disturbances. The scintillation patch occurrences and total electron content fluctuations representing plasma depletion structures decrease during premidnight hours and are enhanced in the postmidnight period. The occurrences often extend to morning hours, with increasing magnetic activity index. While the night events are associated with eastward irregularity patch motion, the morning events have westward velocities (the reversal) occurring around 0400 LT, reflecting the morning velocity reversal in the F region bulk plasma motion reported earlier from Jicamarca radar measurements. The westward plasma bubble motions reported here represent the first observation of this kind. Another important finding from the present investigation is a clear tendency for the zonal plasma motion, namely, the equatorial meridional electric field, to become enhanced mainly in the premidnight hours immediately following strong magnetic activity.

1. Introduction

Equatorial ionospheric total electron content (TEC) undergoes significant fluctuations produced by the dynamics of the flux-tube-aligned plasma-depleted regions that often characterize nighttime irregularity events. Different characteristics of these depleted regions (or plasma bubbles), such as their development, structure, dynamics, and morphology, have been the subjects of extensive investigations in recent years (see, for example, McClure et al. [1977], Woodman and La Hoz [1976], Tsunoda [1981], Basu and Basu [1981], Kelley et al. [1976], Weber et al. [1978], Sobral et al. [1980], and Abdu et al. [1983, 1985]). The field-aligned depletions develop from the bottomside F layer and often rise up to over 1000 km with vertical rise velocities up to hundreds of meters per second. A mature bubble structure, having dimensions from tens to hundreds of kilometers transverse to the magnetic field line, thus extends several degrees to either side of the magnetic equator and drifts in zonal directions

with velocities approaching the velocity of the ambient plasma. Signatures of these depletions and their associated irregularities in Faraday rotation angle (representative of the TEC of the ionosphere) and amplitude of the geostationary satellite VHF beacon have been investigated in recent years using VHF electronic polarimeters and scintillation receivers operated at equatorial and low-latitude sites [Klobuchar et al., 1978; Klobuchar and Aarons, 1980; Yeh et al., 1981; Das Gupta et al., 1983; Abdu et al., 1985]. The observations from low-latitude regions located in the equatorial anomaly region, such as Ascension Island, Calcutta, and São José dos Campos, have, in particular, revealed strong Faraday rotation fluctuations in the presence of amplitude scintillation and range spread F in ionograms. In fact, the polarimeter measurements by Abdu et al. [1985] at São José dos Campos (23°12'S, 45°51'W, dip angle of -26°) and Cachoeira Paulista (22°41'S, 45°W, dip angle of -26°), located near the equatorial anomaly crest region, have shown both the fast fluctuations in the Faraday rotation angle having periods of the order of seconds, characteristic of the depolarization effect discussed by Das Gupta et al. [1983] and Lee et al., [1982] as well as slower fluctuations (rather, TEC fluctuations) having periods of the order of a few minutes. The latter class of fluctuations arose from TEC modulation by plasma bubble substructures having field line perpendicular dimensions of the order of a few tens of kilometers [Abdu et al., 1985]. Thus the correlation times of the TEC fluctuations between the two polarimeter sites, located exactly in the magnetic east-west direction, were used to deduce plasma bubble structure zonal velocities. The measurements by Abdu et al. [1985] made use of the VHF (~136 MHz) beacon from the GOES 3 satellite (having subionospheric points at 350 km of -21.4° latitude and -50.3° longitude for reception at São José dos Campos) that had a propagation path westward of the polarimeter location meridian, and the zonal velocities present by them represented the average summer 1981-1982 conditions. We have carried out similar measurements of TEC fluctuations and amplitude scintillations, during the equinoctial and summer months of 1982-1983, on a VHF beacon from the satellite SIRIO (having subionospheric points at 350 km of -21.5° latitude and -43.5° longitude and thus representing a propagation path eastward of the polarimeters). In the present paper the results from these measurements are analyzed to determine the statistical behavior of the zonal velocities and that of the associated scintillation-producing irregularity occurrences, under different levels of magnetic disturbances. One of the important highlights of the present results is our detection and measurement of westward velocities of plasma bubbles when they occur during morning hours

Copyright 1985 by the American Geophysical Union.

Paper number 5A8536.
0148-0227/85/005A-8536\$02.00

Fig. 1. An example of a TEC depletion event registered on a VHF beacon from SIRIO on the night of January 3-4, 1983. The features on the Faraday rotation angle marked a-f on the São José dos Campos (S.J.C.) records and a'-f' on the Cachoeira Paulista (C.P.) records represent plasma bubble structures used in the zonal velocity determinations (see the text for further details).

under enhanced magnetic disturbance conditions (see also Aarons and Das Gupta [1984]). Further, the zonal plasma bubble velocities which represent the equatorial meridional electric field are seen to undergo significant fluctuations during magnetically active periods.

2. Experimental Results

On the basis of the observed strong correlation of the nighttime TEC fluctuations (slow or fast) with amplitude scintillation and range spread F events, Abdu et al. [1985] interpreted the eastward velocities obtained from their polarimeter data as representing the velocities of plasma bubble substructures whose sizes typically range from 50 to 100 km. An example of TEC fluctuations events recorded in the postsunset hours at São José dos Campos and Cachoeira Paulista is shown in Figure 1. The features marked aa', bb', etc., represent well-defined correlation time differences (Δt) between the two stations. A careful examination will show that the correlation time increases toward later local times, suggesting a corresponding decrease in the drift velocities if we assume a "frozen in" hypothesis for the plasma bubble structures. We have analyzed a large number of such events observed on the geostationary satellite SIRIO simultaneously at the two locations, during the period from December

1982 to January 1983. The velocities were calculated using the Δt and the subionospheric separation for the two locations for a mean F layer peak height of 400 km (the variation in this distance is very small for a large range of the F_2 peak heights). The mean zonal velocities obtained from this analysis representing the summer 1982-1983 conditions are presented in Figure 2 (the curve marked by open circles). All the velocities obtained during a given 1-hour interval have been used to obtain the mean value plotted at the middle of that interval. The standard deviations in these values are also shown. For comparison we have shown in the same figure the 1981-1982 summer average velocities obtained using GOES 3. Good agreement is evident between the two sets of results. The mean eastward velocities show a peak around 2000-2100 LT and a steady decrease from then on to reach zero around 0400 LT and a reversal to westward after that time. This local time variation pattern (including the velocity reversal time around 0400 LT) is in excellent agreement with that of the F region ambient plasma zonal velocities measured by the Jicamarca radar as reported by Fejer et al. [1981] (also B. G. Fejer et al., unpublished manuscript, 1985). The local time pattern in the eastward velocity region of our results is also in good agreement with that of the scintillation patch velocities obtained from closely spaced (248 m) receivers at 255 MHz by Yeh

Fig. 2. Zonal velocities of plasma bubble structures representing the average conditions of summer 1982-1983, measured on a VHF beacon from SIRIO marked by open circles. The curve through solid triangles represents the average summer 1981-1982 zonal plasma bubble velocities measured on a VHF beacon from the GOES-3 satellite. Note that SIRIO was eastward and GOES 3 was westward of the magnetic meridians of S.J.C. and C.P. The data statistics are shown at the top of the figure. (Eastward is positive in the figure.)

et al. [1981] over Natal in Brazil and those obtained using a similar technique by Aarons and Whitney [1980] over Ancon, Peru. The airglow depletion patch velocities reported by Mendillo and Baumgardner [1982] over Ascension Island and by Sobral et al. [1985] over Cachoeira Paulista also showed a similar local time pattern. There are, however, important differences among the magnitudes of the velocities in these different results, whose possible implications for the F region bulk plasma velocity shears have been discussed by Abdu et al. [1985].

2.1. Magnetic Disturbance Effects on Irregularity Occurrences

Amplitude scintillation events occur simultaneously with the Faraday rotation angle fluctuation (fast or slow) registered by the polarimeters and in many cases continue well after these fluctuations subside. We have analyzed these scintillation events during the months of October, November, and December 1982 and January and February 1983 (predominantly summer months) to determine statistically possible magnetic control on their local time occurrence pattern. Occurrence per-

centages and mean scintillation amplitudes (in decibels) were determined by dividing the data for this period into three groups representing magnetic activity levels with the 3-hour Kp index having values of (≤ 2), ($> 2, \leq 4$), and (> 4). The local time variations of occurrence percentages and scintillation levels for these three groups are presented in Figure 3. In general, the amplitude of scintillations follows the percentage of their occurrence. For $Kp \leq 2$ and $2 < Kp \leq 4$ the two parameters presented almost similar trends dominated by a premidnight peak between 2100 and 0000 LT. For $Kp > 4$ the local time pattern undergoes significant alterations presenting a pronounced postmidnight enhancement primarily with reference to the premidnight inhibition of these events. Similar results have been reported for equatorial stations of Natal and Huancaño by Aarons et al. [1980] and by Rastogi et al. [1981]. A case by case study of individual event responses to magnetospheric disturbances would have been more interesting in that a detailed picture of the global coupling of the related phenomena could be explored. One important obstacle for realizing such a study is the nonavailability of an auroral activity index for the southern hemisphere. However, even a preliminary analysis using the 3-hour Kp values of some individual events presented below would show significantly different and more detailed response behavior from that represented by the statistical picture given above.

Figure 4 presents two individual plasma bubble and VHF scintillation events during postmidnight-morning hours of two consecutive nights, on December 21 and 22 1982, that occurred during a magnetically disturbed epoch (from December 17 to 22 there were continuous disturbances of moderate to severe intensity). The 3-hour magnetic activity index Kp was ≥ 4 on both nights just prior to these events. Plasma bubble structures and scintillation-producing irregularities occurred from 0100 to 0310 LT on December 21. The velocities of the structures were clearly eastward as indicated by the features marked a, b, and a', b' on the TEC curves for São José dos Campos and Cachoeira Paulista, respectively. The eastward bubble velocity is 120 m s^{-1} . On December 22 the magnetic activity was significantly higher ($Kp=7^-$) in the postmidnight period till 0300 LT than it was on the preceding night. VHF scintillation was registered from 0340 LT till 0700 LT, and significant TEC depletions were observed till about 0500 LT, after which the weaker TEC fluctuations were superimposed over the steep slope of the morning sunrise increase in TEC. The most interesting aspect of this event is that the TEC depletions have westward velocities. The velocities have been determined to be 90 m s^{-1} . It appears that these depletions and scintillation irregularities were generated in the ionosphere east of Cachoeira Paulista, where the ambient F region zonal velocity had reversed from its nighttime eastward direction to the morning westward direction. The plasma bubble irregularities, therefore, might have been carried westward by the ambient plasma. This observation shows that the presence of eastward neutral wind is not a necessary condition for plasma bubble generation, at least in the early morning hours.

Another example of a morning bubble event

Fig. 3. Scintillation amplitudes (solid line) and their occurrence percentages (dashed line) at 136 MHz plotted as functions of local time for three groups representing three different levels of magnetic activity.

associated with magnetic disturbance is presented in Figure 5. In this figure the eastward bubble velocity is evident only till a little after 0300 LT. At later hours the bubble structure features become less correlated at the two locations owing to the velocity reversal in the ambient plasma occurring near 0400 LT. However, the reversal time does not seem to be clearly defined on this morning, and hence the TEC structures at these times did not have correlations clear enough to permit determination of westward velocities.

2.2. Magnetic Disturbance Effects on Plasma Bubble Zonal Velocities

Magnetic storm effects on the plasma bubble zonal velocities were investigated by dividing the velocity data into three groups representing 12-hour sums of $K_p < 7$, $7 < K_p < 15$, and $K_p > 15$. Further, two criteria were used, namely, the K_p values occurring simultaneously with the events (criterion 1) and the K_p values occurring in the 12-hour interval immediately preceding the night of the events (criterion 2). The results of these analyses are presented in Figure 6. The standard deviations in the velocities for the

quietest nights (12-hours K_p sum of < 7) shown in this figure are significantly less than those in Figure 2, which represented all the nights of measurement. In other words, a clear reduction of the geophysical noise in the zonal plasma velocities, namely, in the meridional electric field component, is observed under magnetically quiet conditions. From Figure 6 we could see that the plasma zonal velocities do not undergo changes (except, perhaps, near 2000–2100 LT) when changes in simultaneous K_p values (criterion 1) are considered. In the plot using criterion 2 there appears to be a clear tendency for eastward velocities to increase on the nights immediately following magnetic disturbances. This increase seems to be dominant during the premidnight hours and has a striking resemblance to the statistical results of Gonzales et al. [1983] showing a perceptible enhancement, within a similar local time interval (see their Figure 3), in the downward meridional electric field component measured by Jicamarca incoherent scatter radar during magnetically very active periods. Another important feature of Figure 6 is the extension of the bubble occurrences to morning hours, permitting determination of the plasma velocities that are westward at these hours. Such morning bubble

Fig. 4. Postmidnight-morning plasma bubble and VHF scintillation events following magnetic disturbances. Note that the velocity is eastward before 0330 LT on December 21, 1982, and westward after 0330 LT on December 22, 1982. S.J.C. station is located west of C.P. station.

occurrences represent, however, magnetically disturbed conditions.

3. Discussion and Conclusions

Observations on geostationary satellite VHF beacons using an east-west spaced polarimeter system over low-latitude locations in Brazil have permitted determination of the zonal velocity component of plasma-depleted regions in the

equatorial ionosphere. Possible influence of bubble vertical rise velocities in the observed Δt has been discussed by Abdu et al. [1985]. As has been shown by radar measurements, the vertical velocity could be large during the growth phase of a bubble [Tsunoda, 1981]. Hanson and Bangboye [1984] have measured, using the Atmosphere Explorer E satellite ion drift meter, large vertical as well as horizontal ions velocities in the meridional plane inside the plasma bubbles. Although a

Fig. 5. Another example of plasma depletion events during a magnetically disturbed period. Note that the velocities were eastward before ~0330 and not clearly marked afterward owing to the reversal in the plasma flow westward at these times.

Fig. 6. Zonal velocities of plasma bubble structures as a function of local time plotted for different levels of magnetic disturbances, during the summer of 1982-1983. The data statistics for the disturbed days are shown at the top of the figure.

close relationship is expected between these bubble ion velocities and the plasma bubble velocities measured by radar, many details of this relationship do not seem to be clearly established. Our present measurements, however, refer more to the end of the growth phase of a bubble, when the vertically extended bubble structure is associated with relatively small rise velocities [Hanson and Bangboye, 1984; Tsunoda, 1981], with the bubble dynamics dominated by zonal velocities approaching the velocity of the ambient plasma [Ossakow and Chaturvedi, 1978; Tsunoda et al., 1981]. The reason for this situation is that our low-latitude polarimeters detect mature flux-tube-aligned bubble structures whose vertical extension reaches up to or beyond the apex of the field line (around 700 km) that meets the low-latitude F layer peak subionospheric point. This reasoning is amply substantiated by the results in Figure 2 that show the velocities measured by GOES 3 that has a propagation path westward of the magnetic meridian of the polarimeters and those measured from SIRIO that has an eastern propagation path, and as has been explained by Abdu et al. [1985], the good agreement between the mean velocities measured on these two paths clearly rules out any significant influence of vertical bubble movements in the deduced zonal velocities. It is worth pointing out further that the velocity measured by the present technique represents the real (and not an apparent) zonal

velocity of the plasma bubble structures, since we are deducing it from the observed correlation time for TEC structures (having field line perpendicular dimensions of a few tens of kilometers [Abdu et al., 1985] that have retained their integrity in the longitudinal distance of 110 km that separates the two polarimeters. It is reasonable to consider further that a bubble with a given percentage depletion will produce the maximum effect on the TEC when that bubble occurs at the F layer peak (rather than at other heights) such that our measured velocities should represent a height averaged value near the F layer peak. According to the theoretical and experimental results on the ambient plasma and plasma bubble zonal velocity height variation (see, for example, Anderson and Mendillo [1983], Kudeki et al. [1981], and Tsunoda et al. [1981]), these velocities should correspond closely to the peak value of the height distribution. The local time variation pattern of the velocities obtained by us is in excellent agreement with those obtained from other observations, from Jicamarca radar, from VHF scintillations on closely spaced receivers, and from airglow depletion patches. However, our low-latitude zonal velocities are found to be, in general, significantly higher than the equatorial values obtained by other workers, which suggests the existence of a latitudinal variation in the plasma zonal velocities. Possible implications of such a latitudinal velocity gradient for the vertical shears in plasma flow over the equator have been discussed by Abdu et al. [1985].

The VHF scintillation-producing irregularities occurring during the TEC depletion events have a peak occurrence rate from ~2100 to 0000 LT during quiet to moderate magnetic disturbance conditions. For severely disturbed conditions (defined here as being represented by $Kp > 4$) the irregularity strength and occurrence rates get inhibited during premidnight hours and get relatively enhanced during postmidnight to morning hours. Individual events, under the disturbed conditions, are seen occurring well into the morning hours, and in many cases (such as the case of December 22, 1982, shown in Figure 4) they follow closely large increases in the 3-hour magnetic activity index Kp . The velocities of these plasma bubble are eastward when they occur before around 0300 LT and westward when they occur at later hours in the morning, reflecting the bulk plasma zonal flow pattern at these times. Analysis of zonal velocities in search of their possible response to magnetic disturbances seems to suggest that there is a clear tendency toward higher eastward plasma bubble velocities on nights immediately following severe magnetic disturbances. One could speculate over the different, but interrelated, geophysical processes, such as changes in magnetospheric convection fields, auroral zone conductivity variations from substorm-induced particle precipitation events, enhancements in the disturbance dynamo action, etc., as responsible, to different degrees, for the meridional electric field enhancements observed in our low-latitude data. An intermediate (and perhaps additional) mechanism, though it could be related to the different magnetospherically induced sources, might be the possible increases in the F layer peak heights

(causing corresponding increases in the effective plasma bubble and associated irregularity heights) often observed under magnetically disturbed conditions over low latitudes. In the presence of a shear flow in the F region plasma zonal motion (see, for example, Tsunoda et al. [1981], Kudeki et al. [1981], and Abdu et al. [1985]), an increase in the mean (or effective) height of the plasma bubble irregularities considered here as tracers of the ambient plasma could result in an increase in their zonal velocities as well. Clear identification of the likely sources for the observed magnetospheric disturbance effects in the zonal plasma velocities should be sought on the basis of a case by case investigation of a large set of events, with simultaneous interplanetary, magnetospheric, and high-latitude ionospheric data. We plan to undertake such a detailed investigation in the immediate future.

Acknowledgments. The authors are thankful to our technical staff, particularly to Sinval Domingos and Francisco de Paula Vitor Mesquita, for good maintenance of our polarimeter operations at São José dos Campos and Cachoeira Paulista. The polarimeter at São José dos Campos was kindly loaned to us by Aldo Vieira da Rosa (from the University of Campinas), to whom we express our profound thanks. This work was partially supported by the Fundo Nacional de Desenvolvimento Científico e Tecnológico under contract FINEP-537/CT.

The Editor thanks J. P. McClure and Santimay Basu for their assistance in evaluating this paper.

References

- Aarons, J., and A. Das Gupta, Equatorial scintillations during the major magnetic storm of April 1981, *Radio Sci.*, **19**, 731-739, 1984.
- Aarons, J., and H. E. Whitney, Recent observations of equatorial and high latitude scintillations, Propagation effects in space/earth path, *AGARD Conf. Proc.*, **284**, 31.7-31.17, 1980.
- Aarons, J., J. P. Mullen, J. P. Koster, R. F. da Silva, J. R. Medeiros, R. T. Medeiros, A. Bushby, J. Pantoja, L. Lanat, and M. R. Paulson, Seasonal and geomagnetic control of equatorial scintillation in two longitude sectors, *J. Atmos. Terr. Phys.*, **42**, 861-866, 1980.
- Abdu, M. A., R. T. Medeiros, J. H. A. Sobral, and J. A. Bittencourt, Spread F plasma bubble vertical rise velocities determined from spaced ionosonde observations, *J. Geophys. Res.*, **88**, 9197-9204, 1983.
- Abdu, M. A., I. J. Kantor, I. S. Batista, and E. R. de Paula, East-west plasma bubble irregularity motion determined from spaced VHF polarimeters: Implications on velocity shear in the zonal F region bulk plasma motion, *Radio Sci.*, **20**, 111-122, 1985.
- Anderson, D. N., and M. Mendillo, Ionospheric conditions affecting the evolution of equatorial plasma depletions, *Geophys. Res. Lett.*, **10**, 541-544, 1983.
- Basu, S., and S. Basu, Equatorial scintillation-A review, *J. Atmos. Terr. Phys.*, **43**, 473-489, 1981.
- Das Gupta, A., S. Basu, J. Aarons, J. A. Klobuchar, S. Basu, and A. Bushby, VHF amplitude scintillation and associated electron content depletions as observed at Arequipa, Peru, *J. Atmos. Terr. Phys.*, **45**, 15-26, 1983.
- Fejer, B. G., D. T. Farley, C. A. Gonzales, R. T. Woodman, and C. Calderon, F region east-west drifts at Jicamarca, *J. Geophys. Res.*, **86**, 215-218, 1981.
- Gonzales, C. A., M. C. Kelley, R. A. Behnke, J. F. Vickrey, R. Wand, and H. Holt, On the latitudinal variations of the ionospheric electric field during magnetospheric disturbances, *J. Geophys. Res.*, **88**, 9135-9144, 1983.
- Hanson, W. B., and D. K. Bangboye, The measured motions inside equatorial plasma bubbles, *J. Geophys. Res.*, **89**, 8997-9008, 1984.
- Kelley, M. C., G. Haerendel, H. Kappler, A. Valenzuela, B. B. Balsley, D. A. Carter, W. L. Ecklund, C. W. Carlson, B. Hansler, and R. Torbert, Evidence for Rayleigh-Taylor type instability regions during equatorial spread F, *Geophys. Res. Lett.*, **3**, 448-450, 1976.
- Klobuchar, J. A., and J. Aarons, Studies of equatorial irregularity patches using SIRIO VHF transmissions, *Alta Freq.*, **49**, 345-349, 1980.
- Klobuchar, J. A., J. Aarons, E. Weber, L. Lucena, and M. Mendillo, Total electron content changes associated with equatorial irregularity plumes, paper presented at National Radio Science Meetings, Union Radio Sci. Int., Boulder, Colo., Nov. 6-9, 1978.
- Kudeki, E., B. G. Fejer, D. T. Farley, and H. M. Terkic, Interferometer studies of equatorial F-region irregularities and drifts, *Geophys. Res. Lett.*, **8**, 377-380, 1981.
- Lee, M. C., A. Das Gupta, J. A. Klobuchar, S. Basu, and S. Basu, Depolarization of VHF geostationary signals near the equatorial anomaly crest, *Radio Sci.*, **17**, 399-409, 1982.
- McClure, J. P., W. B. Hanson, and J. F. Hoffman, Plasma Bubble and irregularities in the equatorial ionosphere, *J. Geophys. Res.*, **82**, 2650-2656, 1977.
- Mendillo, M., and J. Baumgardner, Airglow characteristics of equatorial plasma depletions, *J. Geophys. Res.*, **87**, 7641-7652, 1982.
- Ossakow, S. L., and P. K. Chaturvedi, Morphological studies of rising equatorial spread F bubbles, *J. Geophys. Res.*, **83**, 2085-2090, 1978.
- Rastogi, R. G., J. P. Mullen, and E. Mackenzie, Effects of geomagnetic activity on equatorial radio VHF scintillation and spread F, *J. Geophys. Res.*, **86**, 3661-3664, 1981.
- Sobral, J. H. A., M. A. Abdu, and Y. Sahai, Equatorial plasma bubble eastward velocity characteristics from scanning airglow photometer measurements over Cachoeira Paulista, *J. Atmos. Terr. Phys.*, in press, 1985.
- Tsunoda, R. T., Time evolution and dynamics of equatorial backscatter plumes, 1, Growth phase, *J. Geophys. Res.*, **86**, 139-149, 1981.
- Weber, E. J., J. Buchau, R. H. Eather, and S. B. Mende, North-south aligned equatorial airglow depletions, *J. Geophys. Res.*, **83**, 712-716, 1978.
- Woodman, R. F., and C. La Hoz, Radar observations of F region equatorial irregularities, *J. Geophys. Res.*, **81**, 5447-5466, 1976.

Yeh, K. C., J. P. Mullen, J. R. Medeiros, R. F. da Silva, and R. T. de Medeiros, Ionospheric scintillation observations at Natal, J. Geophys. Res., 86, 7527-7532, 1981.

quisas Espaciais, Conselho Nacional de Desenvolvimento Científico e Tecnológico, 12200 São José dos Campos, São Paulo, Brazil.

M. A. Abdu, I. S. Batista, I. J. Kantor, E. R. de Paula, and J. H. A. Sobral, Instituto de Pes-

(Received February 18, 1985;
revised May 29, 1985;
accepted June 13, 1985.)