Indian Journal of Radio & Space Physics
Vol. 7, April 1978, pp. 84-89

Interplanetary Magnetic Field & Equatorial Ionosphere

R G RASTOGI
Physical Research Laboratory, Ahmedabad 380 009
and
H W KROEHL
National Geophysical & Solar-Terrestrial Data Center, NOAA, Boulder, Colorado 80302

Received 15 *July* 1977; *revised received* 2 *January* 1978

Large variations in the geomagnetic field near the dip equator are examined in relation to the variations of the equatorial q-type Es, E-region drifts and the interplanetary magnetic field. It is shown that the decrease of equatorial electrojet current is associated with the sudden increase of northward component (B_z) of the interplanetary magnetic field. It is suggested that the ambiguities in the interpretations of DP_2 events can be easily removed if the corresponding ionospheric data are also utilized in the analysis. The index ΔH at equatorial electrojet station minus ΔH at non-electrojet station provides a very reliable index for studying the variations of the equatorial electrojet currents even during geomagnetically disturbed conditions. This index is closely correlated with the auroral indices AU and AL; positive change in the auroral electrojet indices is associated with a decrease of the equatorial electrojet current even in minor details.

1. Introduction

Extensive studies have been done on the relation between the interplanetary magnetic field (IMF) and the polar ionosphere. The events at high latitudes are at times very complex due to field-aligned currents connecting magnetospheric current variations with ionospheric current variations. Relatively very little attention has been paid to the possible effects of the interplanetary magnetic field on the equatorial ionosphere. The equatorial ionosphere has a special advantage that it is free from field-aligned currents. However, the region close to the magnetic equator is very sensitive to the changes of the electric field on account of high electrical conductivity of the medium as a result of special configuration of the magnetic and electric fields above the equator. The two outstanding features of the equatorial ionosphere are the intense currents flowing during daytime and the generation of cross-field instabilities which are detected as Es-q by normal ionospheric sounders and as type-II irregularity by Doppler shift record of vhf backscatter radars.

An association between the geomagnetic field variations at polar and equatorial latitudes was shown by Onwumechilli *et al.*[1] who found that on moderately disturbed days the quiet-day daily variation in the polar region is enhanced whereas the quiet-day variation along the dip equator is suppressed. Further, the eastward current in the sub-auroral zone in the afternoon sector appears to enhance the equatorial electrojet.

Nishida *et al.*[2] pointed out a new type of quasi-periodic fluctuations in the geomagnetic field with the time scale of about 1 hr which are observed almost simultaneously from pole to the equator. These disturbances, now known as DP_2 fluctuations were found to show a very high degree of correlation with the southward component of the interplanetary magnetic field.[3]

Rastogi[4] showed that the q-type of equatorial sporadic E-layer (Es-q) at the equatorial station disappeared simultaneously with the occurrence of DP_2 depression in the equatorial geomagnetic field. This was attributed to the reversal of equatorial electric field temporarily from eastward to westward during DP_2 events. Rastogi and Chandra[5] showed a linear relationship between the equatorial ionospheric drift at Thumba and the B_z component of IMF, thereby demonstrating a close association of equatorial electric field with the interplanetary magnetic field. Rastogi and Patel[6] showed that the sudden reversals of the equatorial electric field during daytime or nighttime have been associated with the sudden reversals of the IMF from southward to northward direction.

Recently, there has arisen some controversy on the interpretation of DP_2 event. Firstly, Kawasaki and Akasofu[7] showed that many of the DP_2 variations are coherent with the polar substorm (DP_1) variations and are just the manifestations of the magnetospheric substorms and the DP_2 mode is not a new and distinct variation. Secondly, Matsushita and Balsley[8] have questioned the estimation of DP_2 in terms of B_y component made by Nishida[3]. According to Nishida[3] the D_{st} due to ring current causes a large decrease in the level of H minima and the DP_2 is an increase of H from that level caused by an eastward current. According to Matsushita and Balsley[8] both these ideas were not borne out by the observations of E-region drift at Jicamarca. The main problem is in defining the direction of electric currents in the equatorial region during DP_2 events.

Rastogi[9] has clearly demonstrated that Es-q over the magnetic equator is due to the cross-field instability at the base of the E-region when the Hall polarization field is upward, i.e. in the same direction as that of the plasma density gradient. During counter-electrojet periods when the geomagnetic H field is below the base level, the horizontal electric field is reversed to a westward direction causing the Hall polarization field to be downward causing the inhibition of the cross-field instability and the disappearance of Es-q. The growth or the decay rate of cross-field instability in the E-region was found to be of the order of a fraction of a minute.[10] Thus the disappearance of Es-q is a very sure index to identify the direction of electric field at the base of E-layer over the equator.

From a series of ionograms taken every five minutes, Rastogi[11] showed that the disappearance of Es-q is correlated remarkably well with a depression from the base level of the H field at an equatorial station minus that at a non-equatorial station at the same longitude. This index, as per definition, removes the effect of any ring current, symmetrical or asymmetrical, from the geomagnetic field data and gives a pure ionospheric current parameter. Recently, Rastogi *et al.*[12] showed that the index ΔH [H (Huancayo)$-H$ (Fuquene)] [hereafter referred to simply as ΔH (H-F) for brevity] is correlated with the disappearance of vhf backscatter echoes from the E-region to a time resolution of better than one minute. Thus it has been shown that the negative value of ΔH (H-F), or the disappearance of Es-q in Huancayo ionograms, or the absence of E-region echo on vhf backscatter radar at Jicamarca at any time of the day, indicates the existence of net westward electric field in the E-region of the ionosphere over the equator.

With this condition the ionospheric, geomagnetic and interplanetary magnetic field data for 13-14 Dec. 1966 have been reanalyzed here. This is an excellent example to study the ionospheric-magnetospheric-interplanetary coupling because of the availability of excellent simultaneous records of different disciplines.

2. Results

First we examine the general condition of the interplanetary magnetic field around these days. Fig. 1 shows the mean hourly values of IMF magnitude (B), latitude (θ) and longitude (ϕ) from 6 to 22

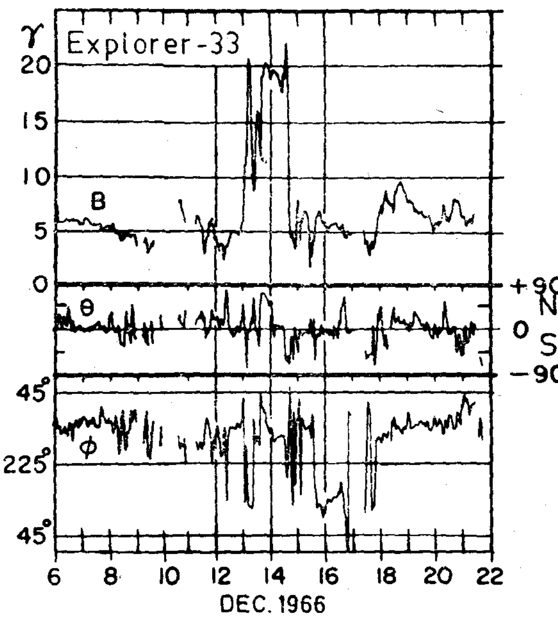

Fig. 1—Hourly mean values of interplanetary magnetic field magnitude (B), latitude (θ) and longitude (ϕ) from 6 to 22 Dec. 1966

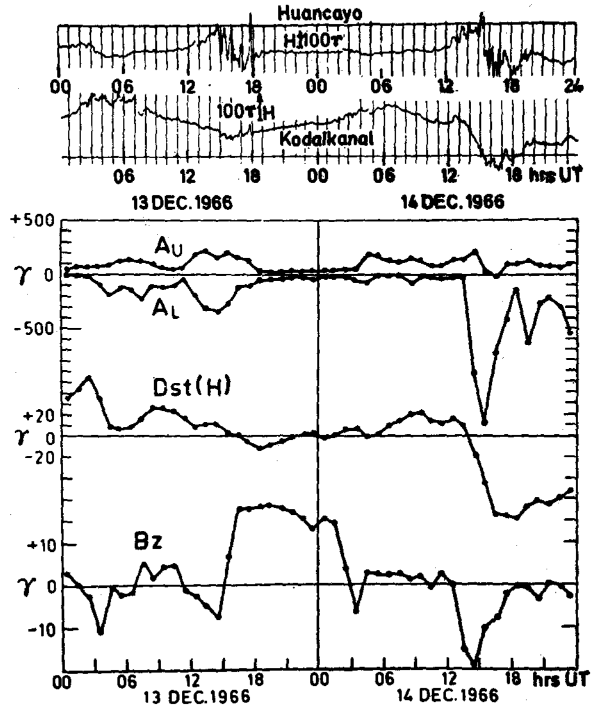

Fig. 2—Variations of interplanetary magnetic field component perpendicular to the ecliptic (B_z), equatorial D_{st} (H) value, the auroral indices AL and AU and the geomagnetic H field at the equatorial electrojet stations Huancayo and Kodaikanal on 13 and 14 Dec. 1966

Dec. 1966. Normally the magnitude of B remains between 5 and 10 γ but for the period 13 and 14 Dec. the magnitude is abnormally high being of the order of 20 γ. These large B values make any change of θ very strong, for example a change of θ from -90 deg. to $+$ 90 deg. would mean a change of B_z by 40 γ.

Fig. 2 shows the comparison of the hourly values of the north-south component of IMF, the equatorial D_{st} (H) values and the auroral indices AL and AU. In the same diagram the H magnetograms at Huancayo and Kodaikanal have also been reproduced to show the changes in the geomagnetic H field near the dip equator associated with the change in the IMF. The dates 13 and 14 Dec. 1966 were classified as "international disturbed days" of the month, the A_p values being 20 and 48 on these days, respectively. These days were preceded by a very quiet period, A_p values on 11 and 12 Dec. being 3 and 2, respectively. The magnitude (B) of IMF increased suddenly on 13 Dec. around 0100 hrs UT but the B_z had a major increase between 1500 hrs UT on 13 and 0200 hrs UT on 14 Dec. The D_{st} (H) values during this period were very low suggesting the absence of any ring current. The sudden increase of B did not produce any geomagnetic disturbance because B_z was mostly positive, i.e. the field was northward. However, very large fluctuations in the H field at Huancayo were observed between 1400 and 1800 hrs UT on 13 Dec. The field at Kodaikanal showed similar but greatly reduced fluctuations as this period happened to be local nighttime there. This active period was associated with mild activity of both eastward and westward auroral electrojets.

On 14 Dec. there occurred a SC-type geomagnetic storm at 1227 hrs UT. This was triggered by the southward turning of IMF field around that time. The D_{st} (H) value showed a sharp decrease after 1400 hrs UT suggesting the starting of the main phase of the geomagnetic storm. The H field at Kodaikanal started decreasing rapidly after 1300 hrs

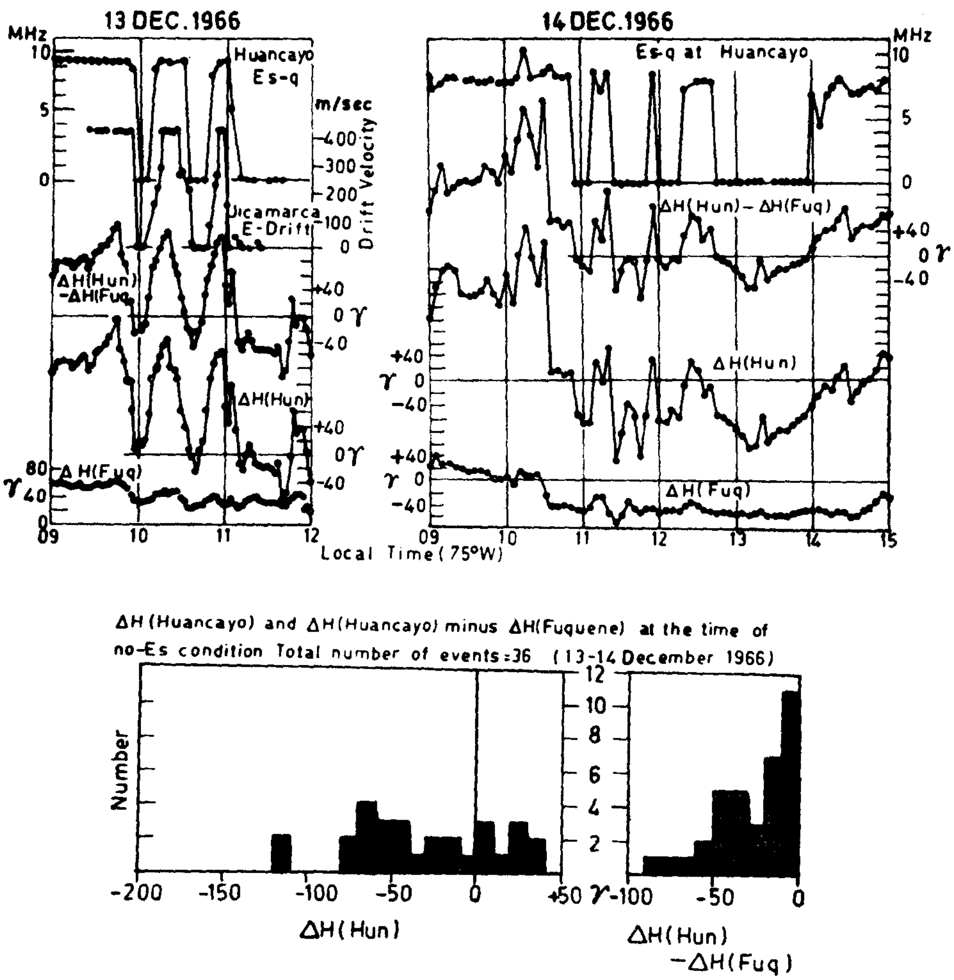

Fig. 3—Variations of ΔH at Huancayo, ΔH at Fuquene, ΔH (H-F) with the Es-q on 13 and 14 Dec. 1966 [Also shown are the histograms of ΔH (Huancayo) and ΔH (Huancayo) minus ΔH (Fuquene) at the times of Es-q disappearances.]

UT and reached the minimum value between 1600 and 1700 hrs UT. The H field at Huancayo on the other hand continued to increase from 1300 to 1630 hrs UT by which time there was a very rapid decrease of more than 200 γ. The AL index decreased by about 1400 γ between 1430 and 1630 hrs UT showing an intense westward polar electrojet. The AU index too decreased during this period by about 200 γ suggesting a significant reduction in eastward current in the auroral zone.

Now let us examine the ionospheric characteristics at Huancayo. In an earlier paper, Rastogi[13] has described the disappearances of Es-q during these days. Fig. 3 shows the variations of ΔH at Huancayo, ΔH at Fuquene, ΔH (H-F), the variations of Es-q on 13 and 14 Dec. 1966 and the E-region drift at Jicamarca on 13 Dec. 1966. In the same diagram are also shown the histograms of ΔH (Huancayo) and of ΔH (H-F) during Es-q disappearance.

From the histogram it is seen that ΔH at Huancayo could be positive as well as negative when the Es-q was absent in the ionograms. Thus the ΔH at the equatorial station is not the definite index to indicate the absence of Es-q. The histogram of ΔH (H-F) during periods of absence of Es-q is always negative. There is not a single case of Es-q absence when ΔH (H-F) was positive. Thus this index is a definite indication for the disappearance of Es-q and thereby indicates that the electric field at ~ 100 km was reversed to a westward direction. On 13 Dec. when E-region drifts were available, the changes of drift velocity varied remarkably similar to the variation of ΔH (H-F). It is to be noted that the drifts during the periods of Es-q disappearance were indicated as zero, and no reversed drift direction is indicated. This is because during these periods of reversed electric field there were no irregularities to scatter the vhf radio waves and the drift velocity was indicated as zero. We thus conclude that a positive value of ΔH (H-F) indicates an eastward electric field while a negative value indicates a westward electric field in the E-region over the equator in those longitudes. The variations of ring current would similarly affect the individual values of ΔH (Huancayo) and of ΔH (Fuquene) and would be almost cancelled in ΔH (H-F).

Now let us compare the variations of ΔH (H-F) with the variations of different parameters of the IMF on 13 Dec. 1966 as shown in Fig. 4. These values are shown every 2·5 min for the periods 1400-1700 hrs LT and 1900-2200 hrs UT. There were large changes of the latitude θ from southward to northward at about 1 33, 1503 and 1540 hrs LT. There was a large decrease of magnitude B around

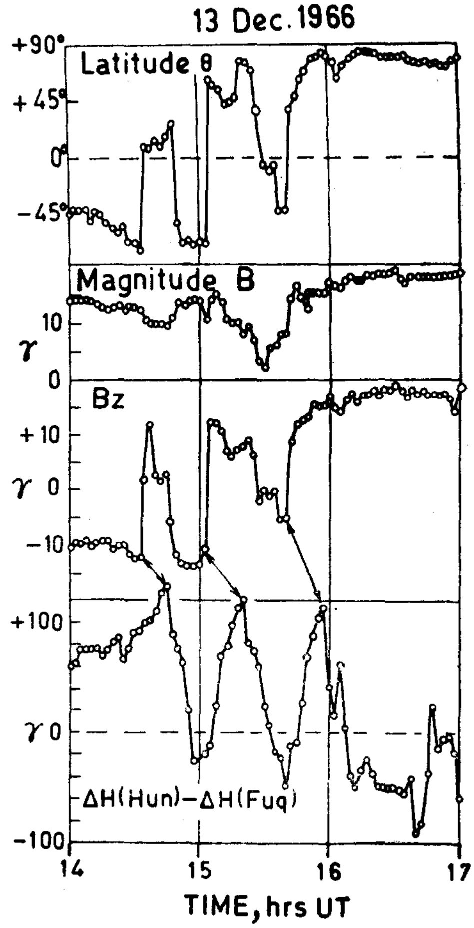

Fig. 4—Variations of the interplanetary magnetic field parameters, latitude θ, magnitude B and the component perpendicular to the ecliptic B_z on 13 Dec. 1966 during large fluctuations in the H field at Huancayo

1530 hrs LT. Since solar ecliptic and solar magnetospheric coordinates are nearly the same for Dec., the component of B perpendicular to ecliptic was calculated and these B_z components have also been plotted. B_z showed sudden increases at 1433, 1503 and 1540 hrs LT. The curve ΔH (H-F) shows remarkable coherence with the B_z curve with a lag of 18 min. The changes are noticed earlier at satellite (Explorer 33) than at ground because the satellite was in the sunward side of the earth at about 40 earth radii. These changes confirm the earlier suggestion by Rastogi and Patel[6] that a sudden change of B_z component from negative to positive causes a decrease or even the reversal of the electric field in the equatorial ionosphere.

It is also suggested that if instead of using ΔH at Huancayo only, the value of ΔH(H-F) is examined and if the ionospheric soundings are available at the time of DP_2 events, there is no ambiguity possible in deciding the base line for the ΔH variation and thereby the interpretation of DP_2 events in terms of B_z changes can be correctly made. As far as this

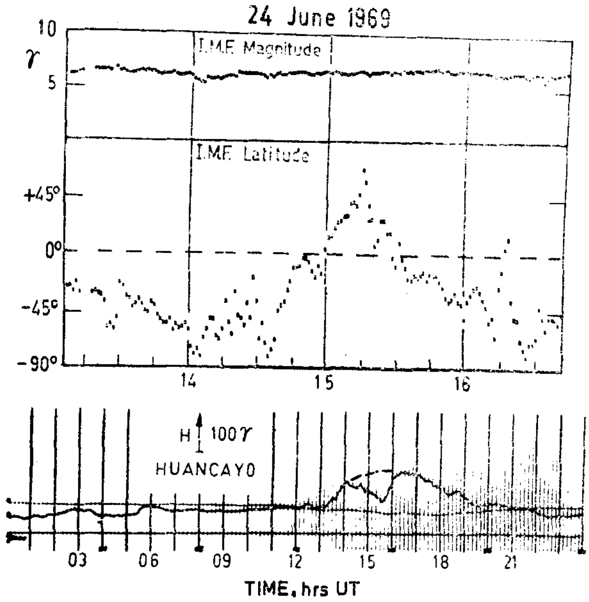

Fig. 5—Variations of interplanetary magnetic field magnitude and latitude during a decrease of the magnetic horizontal field at the equatorial station Huancayo

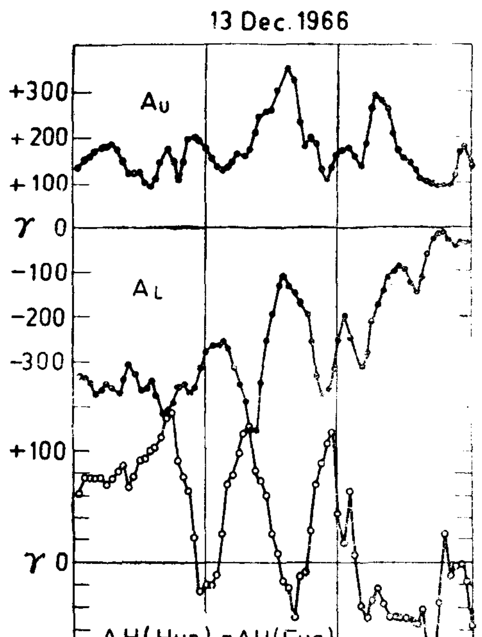

Fig. 6—Variations of the auroral activity indices AL and AU and of ΔH (H-F) on 13 Dec. 1966 (Note a close relationship between the changes in AL and ΔH)

event is concerned the conclusion of Matsushita and Balsley[8] is correct, namely that for the DP_2 event at Huancayo, the decrease of ΔH and not the increase of ΔH, as suggested by Nishida,[3] is the significant factor.

The possibilities of ambiguous interpretations of the same event by two different authors[3,8] have been due to different events chosen by them which had more than one fluctuation, and one can always identify different portions of the fluctuations to a particular change of B_z. Hence it was decided to use a clean event such that only one wave is seen in the magnetogram. One such event is shown in Fig. 5 for 24 June 1969. The H field started increasing at 1300 hrs UT (0800 hrs LT) and showed a decrease between 1400 and 1600 hrs UT (0900-1100 hrs LT). The IMF magnitude during the period 1300-1700 hrs UT remained almost constant but the IMF latitude showed a change from about −90 deg at 1430 hrs UT to about + 60 deg at 1515 hrs UT and again to − 45 deg at about 1600 hrs UT. This slow increase of B_z component is unambiguously the cause of the decrease of the equatorial electrojet currents at Huancayo. Kelley *et al.*[14] described the simultaneous measurements of the electric field in the auroral zone near College, Alaska and at the magnetic equator over Jicamarca, Peru, during the great event of 8-9 Aug. 1972. Changes in the westward electric field at College were faithfully followed by changes in the eastward electric field at Jicamarca after a few minutes. Rastogi[15] has shown that the reversals of the westward field at College and of the eastward field at Jicamarca at 0700 hrs UT on 9 Aug. 1973 were associated with the reversal of the equatorial electrojet current in the Indian zone which was then at midday longitudes. A close relation existed between the changes of electric field at Jicamarca and the changes in ΔH at Kodaikanal. Thus a possible link between the equatorial ionosphere and the magnetosphere during geomagnetically disturbed period was suggested through the auroral electrojet.

In order to check possible associations between the changes of equatorial electrojet current and the auroral electrojet current during these events, the 2·5 min values of the auroral-activity indices AL and AU are compared with the corresponding values of ΔH (H-F) in Fig. 6. A 1-2-1 smoothing process was applied to the 2·5 min values of AU and AL indices. A remarkable similarity is seen in the variations of ΔH (H-F) values and those of AU and AL indices. An increase of equatorial electrojet current is associated with the gradual increase of AU and decrease of | AL |. Examining similar cases on 14 Dec. 1966 and 24 June 1969, it was found that a northward excursion of B_z from southward caused a decrease in the magnitude of the westward electrojet (| AL |) for all cases and an increase of eastward electrojet (AU), for 80 % of the cases. Thus it is seen from these cases that the coupling of the interplanetary magnetic field with the equatorial electrojet current is manifested through the auroral electrojet current system.

Acknowledgement

This forms a part of the investigations under the Arthur L Day Grant No. 30 of the U S Academy of Sciences. Special thanks are due to Dr Alan H Shapley for his keen interest during the course of investigations. The research work at the Physical Research Laboratory (PRL) is supported by the Department of Space, Government of India, New Delhi.

References

1. Onwumechilli A, Kawasaki K & Akasofu S I, *Planet. Space Sci.*, **21** (1973), 1.
2. Nishida A, Iwasaki N & Nagata T *Annls Géophys.*, **22** (1966), 478.
3. Nishida A, *J. geophys. Res.*, 73 (1968), 5549.
4. Rastogi R G, *Proc. Indian Acad. Sci.*, 77 (1973), 130.
5. Rastogi R G & Chandra H, *J. atmos. terr. Phys.*, **36** (1974), 327.
6. Rastogi R G & Patel V L, *Proc. Indian Acad. Sci.*, **82** (1975), 121.
7. Kawasaki K & Akasofu S I, *Planet. Space Sci.*, **20** (1972), 1163.
8. Matsushita S & Balsley B B, *Planet. Space Sci.*, **20** (1972), 1259.
9. Rastogi R G, *Nature, Lond.*, **237** (1972), 73.
10. Rastogi R G, Deshpande M R & Sen A, *Geophys. Res. Lett.*, **2** (1975), 496.
11. Rastogi R G, *Geophys. Res. Lett.*, **2** (1975), 142.
12. Rastogi R G, Fejer B G & Woodman R F, *Indian J. Radio Space Phys.*, **6** (1977), 39.
13. Rastogi R G, *Annls Géophys.*, **28** (1972), 717.
14. Kelley M C, Gonzales C, Mozer F S & Woodman R F, Paper No. 8-3, *Conference digest, Fifth international symposium on equatorial aeronomy*, Townsville, Australia, 25-31, Aug. 1976.
15. Rastogi R G, *Proc. Indian Acad. Sci.*, **86A** (1977), 409.