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Seasonal and solar cycle association of zonal drifts of ionospheric plasma irregularities in the Indian equatorial region

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Abstract. Long series of simultaneous VHF scintillation observations at two stations situated in near magnetic east-west direction in the vicinity of the dip equator in the Indian region have been employed to investigate the night-time ionospheric plasma zonal drifts. The drifts are found to be predominantly easterly. On comparing the magnitudes of the drifts with those results derived earlier by HF fading technique, monitoring signals from two satellites at a station and spaced receiver experiment, their associations with the season and the degree of solar activity are discussed. On a broader scale, the annual mean sunspot number is shown to have a direct control on the derived drift, the positive relationship even on day to day basis with the solar flux is established. However, the relationship, as understood by the slope of the best fit line, in the Indian region (0.27) is found to be weaker when compared with the similar slope (0.45) in the American sector. There appears to be no geomagnetic activity control on the estimated drifts.

1 Introduction

F-region ionospheric plasma is under the continuous influence of neutral wind and electric and magnetic fields prevailing at those altitudes. Under certain conditions, the ionosphere becomes disturbed and depletions in plasma densities are experienced. These depletions are generally observed in the night-time ionosphere in low latitude regions with spatial dimensions of the order of thousands of kilometres along the geomagnetic field lines and tens of kilometres across the field lines. They are found to be associated with spread-F events on the ionogram, plumes in the radar intensity maps, large depletions in the ionospheric atomic oxygen airglow at wavelength 630 nm and strong interference in VHF beacon transmissions (Tsunoda, 1981; Sobral *et al.*, 1980; Weber *et al.*, 1982). These eastward propagating depletions are reported to be highly field aligned (Mendillo and Baumgardner, 1982).

Measurement of east-west (zonal) velocities of the F-region plasma in the equatorial region is of prime importance for understanding the ionospheric dynamics at low latitudes since these drifts are consequences of the action of the entire dynamo system (Richmond *et al.*, 1976). The zonal drifts have been estimated in low and equatorial regions using different techniques such as back scatter radar (Fejer *et al.*, 1985, 1991), airglow measurements (Sipler *et al.*, 1983; Sobral *et al.*, 1985), spaced polarimeter (Abdu *et al.*, 1985), spaced scintillation receivers (Yeh *et al.*, 1981; Spatz *et al.*, 1988; Chandra *et al.*, 1989). Monitoring of radio beacons from two geostationary satellites at a single station (Koparkar and Rastogi, 1985; Rama Rao *et al.*, 1988) and a single beacon at two different stations separated in east-west direction (Koparkar *et al.*, 1991; Pathan *et al.*, 1991) have been used successfully in deriving the zonal drifts in the past.

The association of zonal drift velocities with various geophysical parameters such as season, solar and magnetic activity have been studied using radar and optical measurements in the American sector extensively (Fejer *et al.*, 1985; Ganguly *et al.*, 1987; Sobral and Abdu, 1991). The characteristics of spread-F irregularities in the Indian and American regions are reported to be variable suggesting that the dynamics of these irregularities may also differ in the two sectors. The E-W drift velocities and their dependence on season and solar and magnetic activities based on simultaneous recordings of scintillation on the same beacon at two stations separated in an east-west direction in the Indian longitudinal sector are derived and discussed in this communication.

2 Observation and results

The 244-MHz radio beacon signals transmitted from FLEETSAT (73°E) have been continuously monitored at Trivandrum (8.40°N, 76.90°E, dip 0.6°N) and Tiruchendur (8.50°N, 78.20°E, dip 0.6°N), both stations in the southern

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tip of Indian peninsula, since 1985. These two stations are situated very close to the dip equator with a separation of 105 km in the east-west direction at 400 km sub-ionospheric crossover points. Identical receivers and strip chart recorders at 1 cm/min run rate were deployed at the two stations.

Using the data from these stations on the simultaneous amplitude scintillations of the beacon, the predominant eastward drifts were estimated for low to moderate solar activity period of July 1985 to December 1988, and the results were discussed by Koparkar *et al.* (1991) and Pathan *et al.* (1991). In estimating the drift velocity, the following were considered: (a) strikingly similar features of scintillation activity at the pair of stations and measurable time shifts, and (b) selection criterion of events that were generally recorded first at the western station (Trivandrum) and after a delay (normally few minutes) at the easterly located station (Tiruchendur). In (b), however, there were occasions when almost simultaneous occurrence at the two stations and also cases of early scintillation registration at the easterly station were observed. These were generally few in number and were not considered while estimating the hourly average easterly drifts of the ionospheric irregularities.

The years 1985–1988 fall during intervals of low to moderate solar activity and have limited scintillation occurrence activity and so the drifts derived could not be utilized completely in studies related to associations with other geophysical parameters. The databases on apparent drift velocities have been extended further by the same simple technique of working out the time shifts in the identical signatures on scintillation events at the two stations and employing the known distance between them at the sub-ionospheric points for the interval January 1989–December 1991. Thus, continuous estimates for over half a solar cycle form the basis for understanding the associations.

2.1 Seasonal variation of eastward drifts

To understand the seasonal variations in the ionospheric plasma drift the data pertaining to 1989, 1990 and 1991 only are grouped in three different seasons, E-months (March, April, September and October), D-months (January, February, November and December) and J-months (May, June, July and August). Earlier results for 1985–88 are too scanty for inclusion in the seasonal sub-divisions. Mean hourly drifts and the associated standard errors are computed and are shown in Fig. 1. The average drift values during the E-months varied between 155 to 80 m/s during the course of the night. The drifts are maximum at and around the onset of scintillation activity and found to decrease from then on until midnight after which they remain more or less steady upto the time of sunrise. During D-months (local winter) the range of drift variation is 129 to 80 m/s. Drifts are almost the same till midnight after which they decrease gradually in magnitude. In the J-months (local summer) the drifts are maximum (~123 m/s) during the onset time of activity and are seen to decrease monotonically to a minimum value of 74 m/s around the early morning hours. It may, thus, be inferred that the eastward drift velocities of the kilometre scale size irregularities which are responsible for VHF radio wave scintillations, are maximum during the E-months. However, drift velocities remain at higher levels till midnight during local winter. No substantial difference between local summer and winter during the intervals of high solar activity could be observed in the drift velocities.

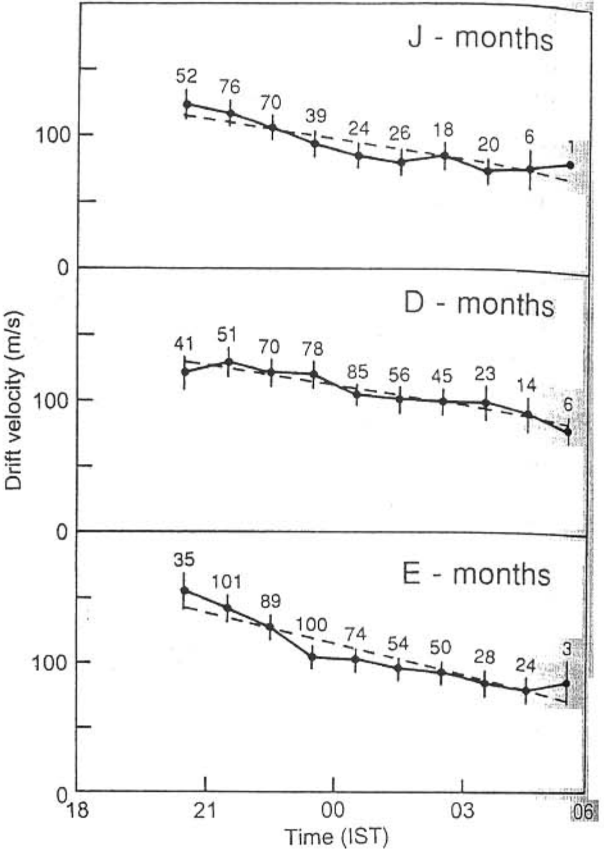

Fig. 1. Nocturnal variation of average hourly eastward zonal drifts with corresponding standard errors (*vertical bars*) during three different seasons during 1989, 1990 and 1991. The numbers over the *circles* are the drifts averaged. The *broken line* is the best fit

2.2 Effect of solar activity on drifts

To understand the association of solar activity on the F-region plasma dynamics, hourly mean drift velocities estimated for each of the years 1989, 1990 and 1991 are employed. The average sunspot numbers (R_z) for these years are 157.6, 142.6 and 145.6 respectively. The nocturnal variation of drift velocities and their standard errors for each of the years are shown in Fig. 2. The drifts for low to moderate solar activity period of 1985–88 reported by Koparkar *et al.* (1991) are also included in the figure for comparison.

On average, drift velocities have varied between 149–93 m/s, 129–75 m/s and 132–83 m/s during the course of the night in the years 1989, 1990 and 1991 respectively. The ranges of drift velocities have shown systematic

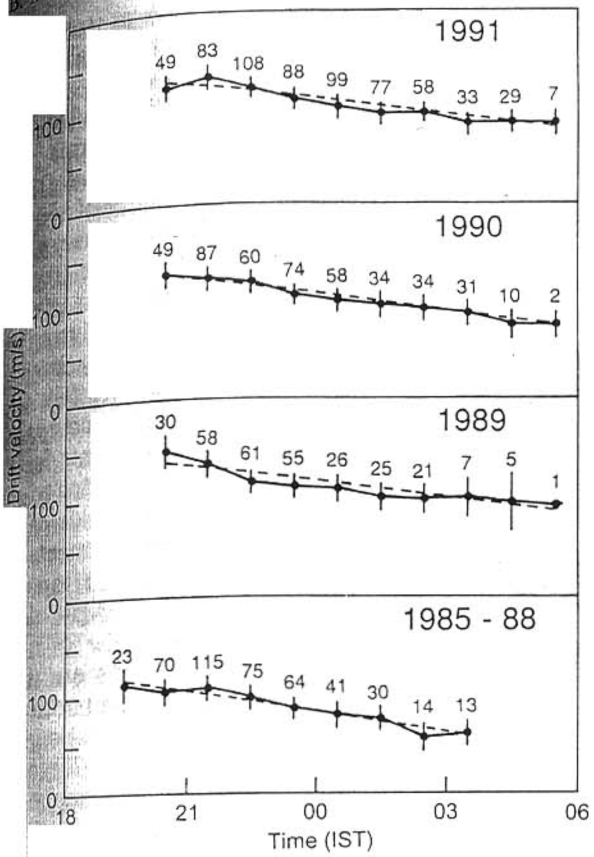

Fig. 2. Nocturnal variations of average eastward zonal drifts with associated standard errors (*vertical bars*) during the years 1989, 1990 and 1991. The results of Koparkar *et al.* (1991) for low-to-moderate solar activity period of 1985 to 1988 using the same technique are also included (other symbols as given in Fig. 1)

associations with the annual average R_z in these three years. Similar drifts for the low to moderate solar activity period 1985–88, have indicated variation from 110 to 60 m/s. By these results, it can be inferred that the nocturnal dynamics of the irregularities are strongly associated with the degree of solar activity.

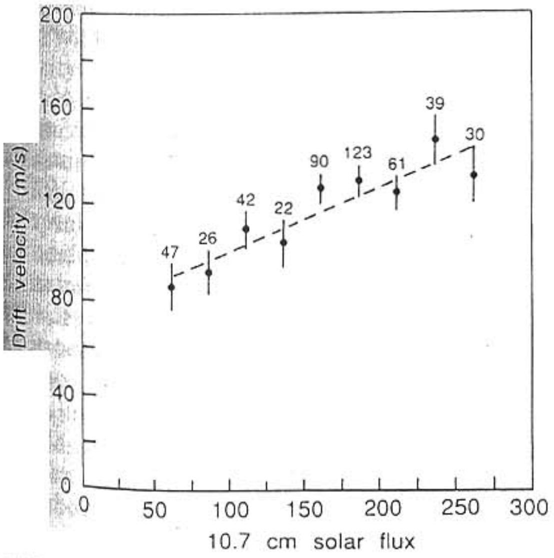

Fig. 3. Averaged peak (20–22 IST) zonal drifts against similar average 10.7 cm solar flux. The standard errors (*vertical bars*) and number of estimates used in averages are included

To examine the association on a finer time resolution, the drift velocities in the time intervals 20–22 IST (82.5° EMT) have been selected as they maximize during this period irrespective of the season. All the days of drift observations are grouped in the intervals of solar flux (S10.7 cm) ranging between 50–74, 75–99, 100–124, 125–149, 150–174, 175–199, 200–224, 225–249 and greater than 250. Average velocities (for 20–22 IST) and corresponding standard errors in these nine intervals are computed. Average drift velocities along with the average fluxes (from the range intervals) are shown in Fig. 3. The eastward maximum drift velocity is found to increase linearly with the flux having slope and intercept magnitudes of 0.27 and 73.1 respectively. However, there is considerable scatter of maximum velocities which may be due to different rates of increase with solar flux at different seasons and also due to the signatures of other controlling processes.

2.3 Association of zonal drifts with magnetic activity

To understand the association of magnetic activity on the eastward drift, the nocturnal estimates for the period 1989–1991 are arranged according to the magnitude of

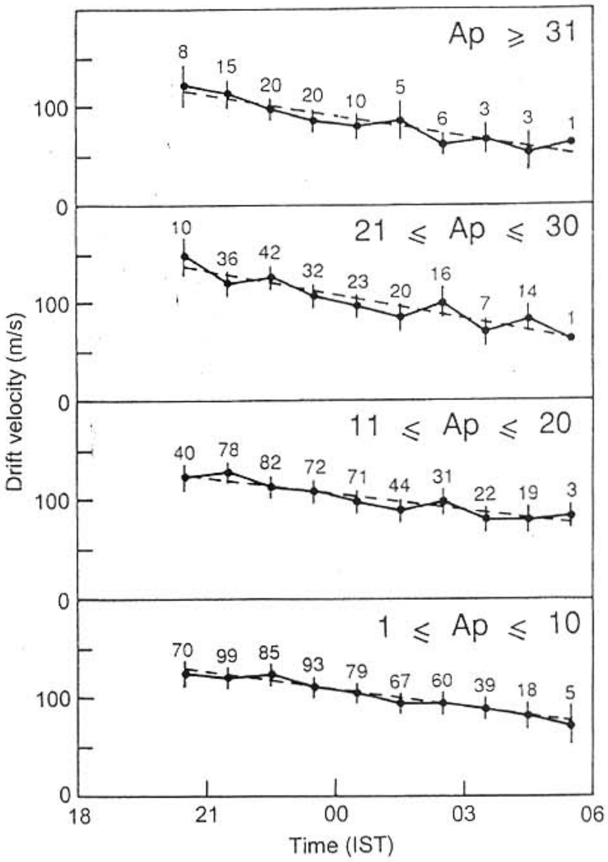

Fig. 4. Nocturnal variation of average eastward zonal drift at four levels of geomagnetic activity (A_p). The standard errors (*vertical bars*) and number of drifts used in each hourly averages are indicated over the respective circles

the A_p index on that day. Entire period of observations are divided into four groups depending on the level of magnetic activity. In the first group (group I), are included days when $A_p < 11$ and in the second (group II), days when A_p is between 11 and 20. Similarly, group III has A_p between 21 and 30 and days with A_p indices above 30 are grouped in the fourth (group IV). There are very few days in the last group as the scintillation activity is highly subdued in the Indian region on higher magnetic activity days (Rastogi *et al.*, 1990). Average drifts along with standard errors of each of the hours for the four groups are shown in Fig. 4. The drift values varied between 125 and 73 m/s on the days in group I, between 128 and 80 m/s in group II, between 148 and 61 in group III and 122 and 54 on the days in group IV. Thus, it is evident that the geomagnetic activity does not have any significant control on the drift velocities of F-region plasma irregularities mainly during the pre-midnight hours, although there are indications that the drifts during the post-midnight hours decrease with the increase in the level of magnetic activity.

3 Discussion

Investigations on plasma drifts transverse to the Earth's magnetic field, which are driven by the neutral-wind-generated E-region dynamo electric fields and by F-region polarization fields are the initial steps in understanding the dynamics of the Earth's ionosphere. These drifts are essential parameters for modelling the low-latitude thermosphere, ionosphere and protonosphere (Richmond *et al.*, 1976; Anderson *et al.*, 1989). Daily pressure variation in the ionosphere, due to solar heating, causes neutral wind to flow in the F-region and effect the motion of the charged particles. The wind blowing across the magnetic field imparts a slow transverse drift to the ions which are perpendicular to the directions both of the wind and the magnetic field (Rishbeth, 1971). The magnetospheric dynamo and ionospheric disturbance dynamo can also play a significant role in altering the plasma dynamics in the equatorial region under geomagnetically disturbed conditions (Sastri, 1988). East-west movement of ionospheric irregularities have been extensively studied using various techniques and scintillation on the VHF/UHF signal is an inexpensive and simple technique for deriving them. Using multi-satellite, multi-station and spaced-receiver scintillation observations simultaneously, Aarons *et al.* (1980) concluded that the drift velocities estimated from these different approaches were comparable. Also, they were reported to be in agreement with those derived from radar interferometers (Basu *et al.*, 1986, 1991). Thus, monitoring radio beacons from different satellites or monitoring the same beacon at two different locations situated in the east-west direction may give nearly the same estimates as those of spaced-receiver and the radar measurements.

The eastward drift velocities, determined by using the simultaneous observations of VHF scintillations presented here, are found to decrease gradually as the night progresses. The range of variation has been shown to depend on various geophysical parameters. These results match well with earlier observations, such as incoherent scatter radar (Fejer *et al.*, 1981, 1985, 1991), airglow (Biondi *et al.*, 1990; Sobral and Abdu, 1991), spaced polarimeter measurements (Abdu *et al.*, 1985) and spaced scintillation experiments (Yeh *et al.*, 1981; Rama Rao *et al.*, 1988; Koparkar *et al.*, 1991). Dabas *et al.* (1992) estimated the eastward drift to be of the order of 150 m/s using simultaneous beacons from two geostationary satellites at Chengelpet (dip 10.5°N) in the Indian region. Recently, Pathan and Rao (1994) have reported eastward zonal drifts varying in the ranges of 160–60 m/s during the course of the night from spaced-receiver experimental data from Tirunelvelli (dip 1.2°N). However, drift velocities obtained here are slightly higher when compared with values derived by HF fading measurements in the Indian region (Vyas *et al.*, 1978). This may be due to the fact that HF fading technique probes bottomside of the F-region only while the scintillation measurements respond to the plasma irregularities both in the top and bottom sides of ionosphere along the line of sight of the satellite signal.

Present measurements indicate that drifts are maximum during the equinox season and are comparable in the other two seasons. Similar indications were also given from HF fading experiment (Chandra *et al.*, 1971) in the Indian equatorial region. Using night glow measurements at Arequipa (dip 6.5°N), Biondi *et al.* (1990) reported that the zonal flow throughout the night was eastward during equinoxes and winter, increasing slightly between early night and 2200 h and then decreasing to zero in the pre-dawn period. The winter winds were found to be systematically higher by about 30 m/s than the equinoctial winds. Fejer (1991) studied the effect of season on the plasma zonal drifts using the radar observations at Jicamarca (dip 2°N) during 1970 to 1988. It was shown by him that the zonal drifts were minimum during the local summer and maximum during the local winter and this is more pronounced during the high solar activity period.

The results here have clearly indicated equinoctial maximum which suggest that the seasonal characteristics of plasma zonal drifts in the Indian region differ from those reported by Biondi *et al.* (1990) and Fejer (1991) for the American sector.

Fejer *et al.* (1981) studied the dependence of zonal plasma drifts on solar activity using the back scatter measurements at Jicamarca. The peak night-time velocities were found to vary from 130 m/s during 1970–71 (high solar activity period) to 105 m/s during low solar activity period of 1974–77, indicating that the solar activity has a finite control on the zonal drifts. The effect shown by them was more pronounced during the local summer. The eastward peak velocity at Jicamarca was reported to increase linearly with daily solar flux with the slope and intercept of 0.45 and 60.01, respectively (Fejer *et al.*, 1991). The Arecibo (dip 50°N) radar measurements also indicated a linear relationship between peak velocity and solar flux, however, the slope was less in magnitude when compared with Jicamarca measurements (Berkey *et al.*, 1990). Sobral and Abdu (1991) analyzed the airglow data at Cachoeira Paulista (dip 28°S) for January 1988 to January 1990 and found that eastward velocity at any local time of the night tends to increase with solar activity and the rate of local time decrease in drift appeared to be somewhat less with increasing solar activity. Based on the experimental data from 1983 to 1990 at Arequipa, Biondi *et al.* (1991) presented solar cycle variations of the equatorial thermospheric winds in the American longitudes. They showed some dissimilarities between the results from the years 1983 and 1988 despite both years having comparable solar EUV fluxes and more or less same degree of geomagnetic activity. Later, after a correction issued by the authors (Biondi *et al.*, 1995) for the error in the reduction of data for the years 1988–1990 when the factor was applied, the discrepancy in zonal drifts of plasma irregularities was found to be eliminated and definite control of solar activity on the zonal drifts was noticed. The simulation studies of Takeda *et al.* (1986) also suggested a positive correlation between eastward drift and solar activity. Theoretical work by Anderson *et al.* (1987) showed that the zonal winds are highly dependent on the solar activity irrespective of latitude-dependent or -independent wind models. Using the latitude-independent wind model they calculated an eastward drift velocity of about 120 m/s during low solar activity which increases to about 180 m/s during high solar activity period. With the latitude-dependent model the drift velocities are about 110 m/s and 140 m/s for low and high solar activity periods, respectively. Recently, the spaced received scintillation experimental result, at a station very close to the dip equator in the Indian region, also indicated higher drifts with less rate of decrease with local time during the higher solar activity period (Pathan and Rao, 1994).

Present estimates of zonal drifts using widely separated station data have shown a strong control of solar activity, represented by the sunspot numbers. The drift values are low during the periods of low-to-moderate solar activity (1985–88), compared with those during a high solar activity period (1989–1991). Also, there was very little change in solar activity conditions during 1989, 1990 and 1991 but this small change in activity was also reflected, to a larger extent, in the drift values during these years. The rate of local time decrease is found to be negatively correlated with the phase of solar activity. However, the peak velocity around 20–22 IST appears to be dependent on the solar flux even on day to day basis although the dependence is weaker (slope is 0.27) as against 0.45 the value obtained from Jicamarca measurements.

The variations in the minimum virtual height of the F layer, $h'f$ (minimum height of reflection of the F-layer echoes) derived from ionograms at Kodaikanal (dip 4°N), a station in the Indian equatorial region, for the years 1989–91 and 1985–88 have been shown as a function of night hours in Fig. 5. The higher height parameters during the pre-midnight hours and steeper gradients are evident during the high solar activity intervals of 1989–91. Chandra and Rastogi (1971) have shown that the electron density and peak density altitude (h_{max}) maximizes during equinoctial seasons in the Indian zone. Also, these parameters are shown to be positively related with the phase of the solar activity. Assuming that h_{max} follows $h'f$, seasonal and solar cycle associations of the drifts reported here can be understood as due to the increase in the electron density, peak electron density heights and corresponding increase in the Pedersen conductivities. In fact, Anderson and Mendillo (1983) have shown that the eastward plasma drift velocity depends on the Pedersen conductivity which is largely controlled by the electron density, ion-neutral collision and ion gyro-frequencies.

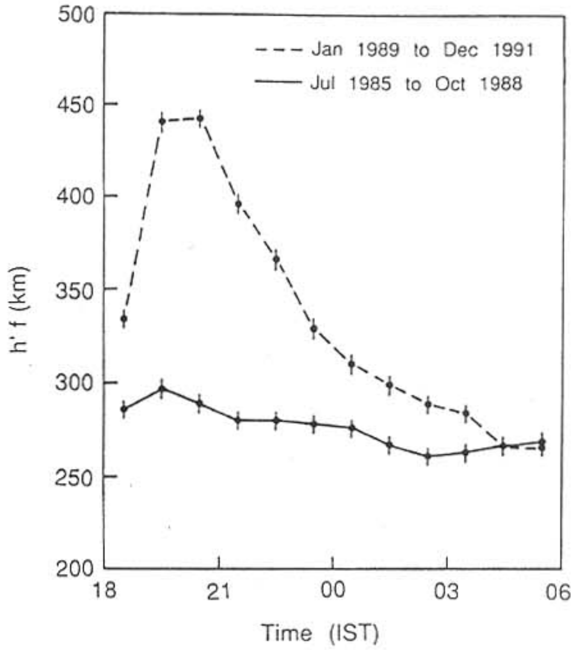

Fig. 5. Variation of virtual group height ($h'f$) as a function of time during low (1985–88) and high (1989–91) solar activity periods

Regarding geomagnetic control on drifts, the quiet time F-region electrodynamics are due to E- and F-region dynamos. Reddy *et al.* (1980) have shown that a sudden perturbation in magnetospheric potential across the polar cap often results in short-lived electric field perturbations propagating almost simultaneously from high to middle and equatorial latitudes and thus affecting the electrodynamic drifts in that region. However, Abdu *et al.* (1985) found a tendency for eastward drifts to increase on nights immediately following the magnetic disturbances. The increase was more dominant during the pre-midnight hours. Fejer *et al.* (1981) found very little effect of magnetic activity on Jicamarca drift data while Ganguly *et al.* (1987) stated that the increase in magnetic activity seems to decrease plasma zonal drifts derived by incoherent scatter radar measurements at Arecibo. Aggson *et al.* (1987) showed that the eastward drifts were not significantly correlated with magnetic activity index K_p by employing DE-2 satellite measurements. However, Rastogi *et al.* (1971) have shown that the F-region drifts decrease with increase in K_p through HF fading experimental results conducted at Thumba in the Indian equatorial region.

Using simultaneous observations of beacons transmitted from two different satellites at Bombay, Koparkar (1988) found higher drifts on magnetically disturbed days. However, the measurements were made in the period of low solar activity when the scintillation occurrence itself was minimal and thus could not be substantiated with good statistics.

Long series of drift velocities reported here indicate that the drift velocities are not significantly affected by the magnetic activity. However, it is seen that on days falling in group III ($21 < A_p < 30$) the drift velocities are higher during the early evening hours when compared to the similar time intervals of the outer groups.

4 Conclusions

As the solar flux increase substantially from solar minimum to solar maximum (S10.7 cm values vary from 67 to 300, during the interval of study), this perhaps results in the increase of pressure gradients in the vicinity of the sub-solar point, which in turn makes higher drifts at solar maximum interval. The differences between the rates of increase at different locations in the same latitudinal belt may perhaps be due to other compensating factors such as the change in ion drag from the higher F-region ionospheric plasma density and changes in the structure of thermospheric winds etc.

Differences are also observed in the seasonal characteristics of the zonal drifts derived. The Indian equatorial region shows equinoctial maximum of the drifts whereas at Jicamarca, a clear winter maximum and summer minimum of drifts were reported by Fejer (1991). The equinoctial maximum of the drifts in the Indian region are further confirmed by the HF fading experimental studies by Chandra *et al.* (1971). The seasonal characteristics are to be further probed for a plausible explanation.

Magnetic activity appears to have no significant control on the zonal drifts in the Indian equatorial region.

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