The role of post sunset vertical drifts at the equator in predicting the onset of VHF scintillations during high and low sunspot activity years

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Abstract. The day-to-day variability in the occurrence of ionospheric scintillations that are of serious concern in the trans-ionospheric communications, makes their prediction still a challenging problem. This paper reports a systematic study in quantitatively identifying the precursors responsible, such as pre-reversal ExB drift velocity, geo-magnetic activity index (Kp) and the Equatorial Ionization Anomaly (EIA) gradient, for the onset of VHF scintillations over a low latitude station, Waltair (20°N dip), during high (2001) and low (2004) sunspot activity years. The percentage occurrences of VHF scintillations over Waltair show a good correlation with the monthly mean post sunset vertical drift velocities at the equator, both during the high and low sunspot activity years. During the days on which intense (>10 dB) scintillations occur, the ionization anomaly gradient (dN/dL), measured from ionosonde data of an equatorial (Trivandrum, 0.9°N dip) and an off equatorial station (Waltair, 20°N dip) shows an enhancement in the gradient prior to the onset of scintillations. However, this enhancement is not seen on days when the scintillations are weak (< 10dB) or absent. The day-to-day post sunset enhancement in the ExB drift is found to decrease with increasing Kp-index and this decrease is more prominent in equinoxes, less in winter and insignificant in summer months. On a day-to-day basis, it is found that the threshold value of upward drift velocity at the equator should be ≥ 30 m/s for the onset of strong scintillations over Waltair for magnetically quiet days with average Kp ≤ 2 (6 hrs prior to the local sunset) during the high sunspot year, 2001. This threshold value of the upward drift reduces to 20 m/s with the decrease in the sunspot activity during 2004. Further, these conditions for the onset of intense scintillations is well defined in equinoxes, less in winter and least in summer solstices.

Index Terms. Equatorial ionosphere, ExB drift, equatorial ionization anomaly, ionospheric irregularities.

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1. Introduction

The equatorial and low latitude ionosphere is the region where the most significant postsunset ionospheric dynamics play a great role in the generation of Equatorial Spread-F (ESF) irregularities causing scintillations on the trans-ionospheric radio communication signals. The processes responsible for the generation, growth and dynamics of ESF irregularities have been widely reported in several earlier studies carried out with different experimental techniques (Calvert and Cohen, 1961; Woodman and LaHoz, 1976; Aarons et al, 1980). Measurement of scintillations is the most simple, efficient and inexpensive diagnostic tool for probing the characteristics of the ESF irregularities, which are of serious concern in the recent times under the space weather and related studies.

Several earlier studies (Woodman and LaHoz, 1976; Yeh and Liu, 1982; Basu and Basu, 1985) on the general morphological features of scintillations revealed that the occurrence of scintillations is controlled by local time, season, solar cycle, latitude, longitude and geo-magnetic activity. But, the day-to-day randomness in the occurrence of scintillations makes their prediction still a challenging problem. However, there are some favorable conditions identified that are responsible for the generation of ESF irregularities. These are (i) a sharp gradient at the bottom side of the F-layer, anti-parallel to the gravity (Kelly, 1989), (ii) the pre-reversal enhancement (PRE) in upward ExB drift and associated uplifting of the F-layer (Risheth, 1978; Fejer et al, 1999; Whalen, 2002), (iii) a simultaneous decay of the E-region conductivity at both ends of the field line (Tsunoda, 1985, Stephen et al, 2002) and (iv) trans-equatorial component of the thermospheric winds and the associated symmetry in the Equatorial Ionization Anomaly (EIA) (Maruyamma and Matuura, 1984; Maruyama, 1988; Mandillo et al, 1992, 2001).

The height of the nighttime equatorial F-layer, which is the most important parameter in controlling the generation or inhibition of ESF (Farley et al, 1970; Ossakow et al, 1979; Rastogi, 1980; Kelly and Maruyama, 1992), that is largely driven by the equatorial vertical plasma drift (ExB) velocity. The rapid post sunset enhancement of zonal electric field lead to a large vertical plasma drift (ExB), thereby lifting the F-layer to higher altitudes resulting in a condition conducive for the generation of ESF.

Recent investigations by Basu et al, (1996); Fejer et al, (1999), Fagundes et al, (1999), Anderson et al, (2004) led to a question of whether the post sunset enhancement in upward

ExB drift over the equator is the necessary and sufficient condition, or, simply the necessary condition for creating favorable conditions for the generation of ESF. Fejer et al, (1999) have reported that when the drift velocities are large enough, the necessary seeding mechanism for the generation of strong Spread-F always appears to be present. Fugundes et al, (1999) from their 5-day experimental campaign, reported that, on one of the nights with a strong upward drift of F-layer associated with the presence of a gravity wave at mesospheric altitudes resulted in strong plasma bubble irregularities. On another night when the upward drift was even stronger without any gravity wave activity, the bubble irregularities were much weaker. Anderson et al, (2004) have reported that there appears to be a threshold value of ExB drift (≈ 20 m/s) for the occurrence of UHF scintillations with S4 > 0.5. Fejer et al, (1999); Whalen et al, (2002); Lee et al, (2005) have shown that the pre-reversal enhancement in the ExB drift velocities are reduced with increasing magnetic activity as measured by a 6-hour average Kp-index thereby reducing the occurrence and/or intensity of the scintillations. They have also shown that, the diminution in the vertical drifts with increasing Kp is significant during equinoxes and winter months, but is insignificant during summer months.

This paper reports the results of a systematic study carried out on the role of the pre-reversal enhancement in the upward ExB drift and the geo-magnetic activity index (Kp) for the development/inhibition of ESF irregularities and quantitatively describes the precursors for the occurrence/absence of scintillations on night-by-night basis during the high and low sunspot years of 2001 and 2004 respectively.

2. Observations and approach

Two digital ionospheric sounders have been operated simultaneously, one at an equatorial station Trivandrum (8.47°N, 76.91°E, 0.9°N dip) and another at an off equatorial station Waltair (17.7°N, 83.3°E, 20°N dip) and the ionograms are recorded at every 15 minute intervals during the relatively high and low sunspot years, 2001 and 2004 respectively. During the same periods, amplitude scintillations at VHF (244 MHz) have also been recorded from a geostationary satellite FLEETSAT (73°E) at Waltair.

The pre-reversal enhancement (PRE) in the upward ExB drift is derived by measuring the true height of a given electron density value in the bottom side F-layer and measuring the height rise in a given time interval at the magnetic equator (Anderson et al, 2004). In the present study, the height of the 4 MHz return signal is taken as the true height (since the difference between true height and virtual height is very small at this low frequency), which corresponds to the altitudes where the electron density is approximately 2 x 10^5 el/cm^2. The virtual height of the 4 MHz return signal (h'F) on the ionograms of the equatorial station Trivandrum is scaled at every 15 minutes interval, and the computed dh'F/dt during the post sunset hours is considered as the pre-reversal enhancement in upward ExB drift (herein after is called as PRE ExB drift). The principal causes for the height rise after sunset are (i) the rapid post sunset enhancement of zonal electric field that leads to large vertical plasma drift (ExB) velocities, thereby lifting the F-layer to a greater altitudes, (ii) decay of bottom side ionization due to chemical recombinations in the absence of production by solar ionizing radiations after sunset and (iii) Presence of equator ward meridional neutral wind that transports the ionization along the field lines, there by lifting the F-layer to higher altitudes. At the magnetic equator, the effect of meridional wind is unimportant because the geo-magnetic field lines are horizontal. The height rise due to chemical losses is of the order of 5 m/s, and is negligible when compared to large vertical drift velocities due to the pre-reversal enhancement (PRE) in the zonal electric field (Krishna Murthy et al,1990; Basu et al, 1996, Anderson et al, 2004). Hence, the method adopted in computing the PRE ExB drift used in the present study is thus justified.

3. Results

3.1 PRE ExB drifts and the occurrence of VHF scintillations

With a view to examine the seasonal variation of post sunset vertical drift of the equatorial F-region and its control over the occurrence of VHF scintillations, the PRE ExB drift velocities are derived from the ionosonde data recorded at an equatorial station Trivandrum (0.9°N dip). The monthly mean drift velocity is computed by taking the maximum dh'F/dt between local sunset (1800 hrs local time) and the onset time of the Spread-F on each day, and is averaged for a month. The percentage occurrence of VHF scintillations at

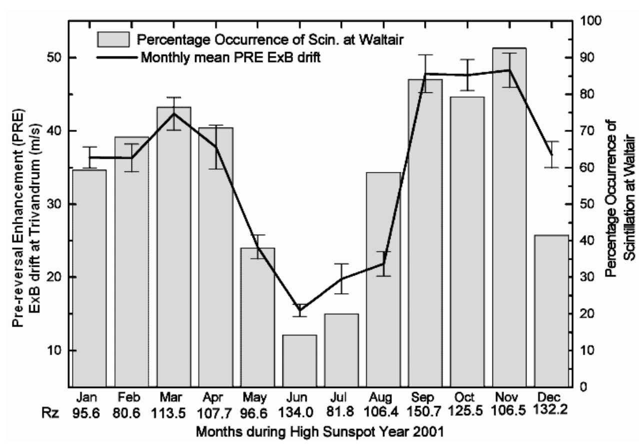

Fig. 1. The correspondence between the monthly mean PRE ExB drift velocities (solid line) and percentage occurrence of VHF scintillations (vertical bars) during a high sunspot year 2001.

the off equatorial station, Waltair (20°N dip) is computed as the ratio of the number of days on which post sunset (1800 – 2200 hrs local time) scintillations occurred to the total number of days for which data is available. In Fig. 1, is shown the monthly mean PRE ExB drift (solid line with error bars) and the percentage occurrence of VHF scintillations (vertical bars) at Waltair for each month during a high sunspot year, 2001. During this year, the monthly mean sunspot number (Rz) varies from a minimum of 80.6 during February 2001 to a maximum of 150.7 during September 2001. The drift velocities are shown on the left hand side of the y-axis and the percentage occurrence of scintillations is shown on the right hand side of the y-axis.

From the figure, it is seen that the percentage occurrence of VHF scintillations show a good correspondence with the monthly mean PRE ExB drift velocities and also exhibits a clear seasonal variation with prominent equinoxial maxima followed by winter and with a minimum in summer. The mean vertical drift velocities exhibit peak values during equinoxial months (March, April, September and October) and also during a winter month of November 2001. During the month of November 2001, the percentage occurrence of scintillations (93 %) as well as the corresponding mean PRE ExB drift velocity is maximum (48.27 m/s). On the other hand, both the mean vertical drift and the percentage occurrence of scintillations are much reduced during the summer months of May, June, July and August with minimum values of 15.47 m/s and 13 % respectively during June 2001. These results are consistent with the results of Fejer et al, (1999), who reported that the largest and smallest vertical drift velocities do occur during equinoxes and June solstices, respectively.

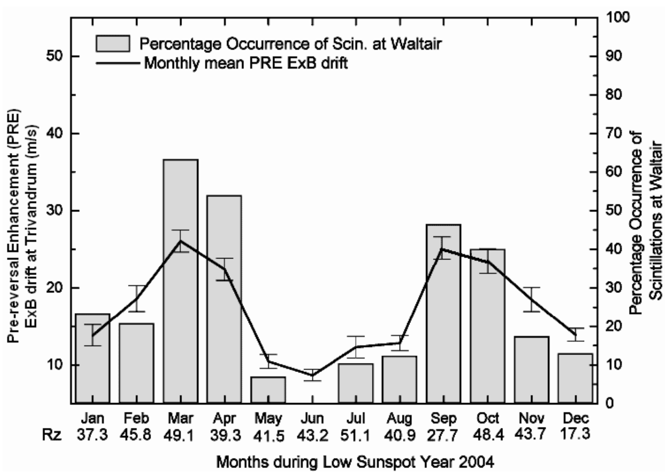

Fig. 2. The correspondence between the monthly mean PRE ExB drift velocities (solid line) and percentage occurrence of VHF scintillations (vertical bars) during a high sunspot year 2004.

Fig. 2, shows the association of the mean PRE ExB drift velocities with the percentage occurrence of VHF scintillations during a low sunspot year, 2004. During this period, the monthly mean sunspot number (Rz) varies between a minimum of 17.3 during December 2004 and a maximum of 51.1 during July 2004. It is seen from this figure, that both the mean vertical drift velocities as well as the percentage occurrences of scintillations are reduced significantly as the sunspot number decreased from the years 2001 (Fig. 1) to 2004 (Fig. 2). However, the seasonal variation in both the vertical drifts and the percentage occurrences still show maxima during the equinoxes, less in winter and a minimum in summer months. The percentage occurrence of VHF scintillations observed at an off equatorial station Waltair, also shows a good correspondence with the monthly mean PRE ExB drift measured at an equatorial station Trivandrum. Thus, Figs. 1 and 2 suggest that the PRE ExB drift at the equator is one of the most important parameters that control the scintillation activity at off equatorial stations like Waltair (20^oN dip) during both the solar cycle epochs.

It may be seen from Fig. 2, that although the monthly mean sunspot numbers (Rz) of summer solstice months of May (41.5), June (43.2), July (51.1) and August (40.9) are higher than those of equinoxial months of April (39.3) and September (27.7), the percentage occurrence of scintillations are much higher during equinoxes than during summer months, suggesting that the seasonal control on the occurrence of scintillations is more dominant than the sunspot number control during this low sunspot activity year, 2004.

3.2 The PRE ExB drift and the equatorial ionization anomaly gradient

With a view to examine the effect of post sunset vertical (ExB) drift on the strength of the Equatorial Ionization Anomaly (EIA) and its impact on the occurrence as well as the intensity of scintillations, we have measured the anomaly gradient (dN/dL) from the ionosonde data of an equatorial station, Trivandrum (TVM), and an off equatorial station, Waltair (WLT). The peak electron density of the F-layer (NmF_2) at every 15 minute intervals is computed from the foF_2 data of both the stations and the gradient (dN/dL), which is defined as (NmF_2 at WLT - NmF2 at TVM) / (Geog.lat of WLT – Geog.lat of TVM), is evaluated for each 15-minute intervals. While computing the dN/dL, the local time difference due to the longitudinal difference in the locations of the two stations is corrected to Indian Standard Time (IST).

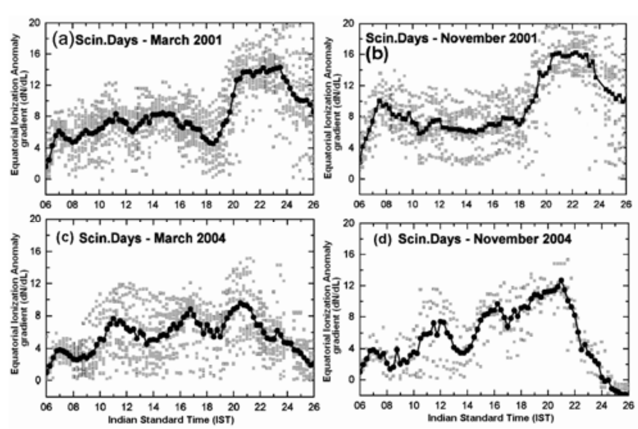

Fig. 3. The diurnal variations of the Equatorial Ionization Anomaly gradients (dN/dL) for the days on which strong (≥ 10 dB) scintillations have occurred during (a) March 2001, (b) November 2001, (c) March 2004 and (d) November 2004.

In Fig. 3, is presented the diurnal variation of the anomaly gradients for the days on which strong (≥ 10 dB) scintillations have occurred, wherein, Figs. 3(a) and 3(b) correspond to March and November months of the high sunspot year, 2001, and Figs. 3(c) and 3(d) correspond to March and November months respectively of the low sunspot year, 2004. It is clearly seen from these figures, that the anomaly gradients show significant enhancements that starts at the post sunset hours (around 1800 hrs IST) for the days on which intense scintillation activity is present over Waltair during both high (Figs. 3(a) and 3(b)) and low (Figs. 3(c) and 3(d)) sunspot activity periods. The enhancement in the anomaly gradient (dN/dL) is significantly higher during the high sunspot periods than during the low sunspot periods. This is due to the larger post sunset vertical drifts observed during the high sunspot year 2001 than during the low sunspot year 2004 as may be seen from Figs.1 and 2 presented in the previous section. Also, it is noticed form Fig. 3 that the post sunset enhancement in the anomaly gradient (dN/dL) is higher in November 2001 (Fig. 3(b)) than during March 2001 (Fig. 3(a)), which is evidently due to larger PRE ExB drift velocities observed during November than during March (Fig. 1). The enhancement in the anomaly gradient during the post sunset hours suggests that the fully developed PRE ExB drift, during the nights on which scintillation activity is present, lifts the equatorial F-layer to higher altitudes, and reenergizes the equatorial fountain by depleting the ionization near the equator, while simultaneously increasing the ionization at off equatorial stations.

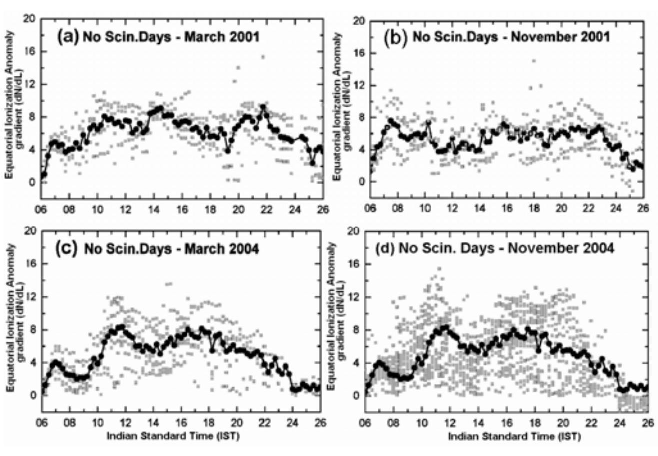

Fig. 4. The diurnal variations of the Equatorial Ionization Anomaly gradients (dN/dL) for the days on which scintillations are weak (< 10 dB) or absent during (a) March 2001, (b) November 2001, (c) March 2004 and (d) November 2004.

In Fig. 4, is shown the diurnal variation of the anomaly gradients (dN/dL) for the days on which scintillations are weak (< 10 dB) or absent. Figs. 4(a) and 4(b) correspond to March and November months of high sunspot year (2001), and Figs. 4(c) and 4(d) correspond to March and November months of low sunspot year (2004) respectively. The post sunset enhancements in the anomaly gradients are not seen in this figure, indicating that the PRE ExB drift velocities are not high enough to lift the equatorial F-layer to higher altitudes depriving the equatorial fountain to energize. Thus, Figs. 3 and 4, clearly show the control of the PRE ExB drift velocities over the equator on the Equatorial Ionization Anomaly and the subsequent occurrence of VHF scintillations at the off equatorial stations.

It is interesting to note from the Figs. 3, that the daytime maximum in the anomaly gradient is slightly higher (around 1615 hrs IST in Fig. 3(c)) during the low sunspot period of March 2004 than during high sunspot period March 2001 (Fig. 3(a)). During the winter month of November also, the daytime maximum in the gradient is higher (around 1530 – 1600 hrs IST in Fig. 3(d)) in low sunspot year, 2004 than in high sunspot year 2001 (Fig. 3(b)). It is known that, the Equatorial Ionization Anomaly (EIA) centered at the equator and extends to a larger latitudinal width during high sunspot activity periods than during the low sunspot activity periods. That means, during the low sunspot activity periods, the anomaly crests are moves closure to the equator, while during the high sunspot activity periods the crests move away from the equator. Hence, during the low sunspot activity periods, a station like Waltair with 20^{o}N (which lies between the magnetic equator and the anomaly crest region) experiences larger ionization than during high sunspot activity periods. As a result, the daytime anomaly gradient (dN/dL) between the stations Trivandrum and Waltair is larger in low sunspot activity period than in high sunspot activity periods as may be seen from Fig. 3. However, during the post sunset hours, the anomaly gradient is mostly controlled by the PRE ExB drift, which is larger during high sunspot periods. Hence, the post sunset enhancement in the anomaly gradient (dN/dL) is larger during the high sunspot periods than in low sunspot periods. Raghava Rao et al,(1988) (and references therein) have reported that, the anomaly peaks become more pronounced around 1200 – 1400 hrs LT during solar minimum, but, during solar maximum, the anomaly peaks become more pronounced around 1900-2100 hrs LT and were some times found to survive beyond the midnight up to 0300 hrs LT. The present results also show similar features, with higher daytime anomaly gradients during low sunspot periods and higher post sunset anomaly gradients during high sunspot periods.

3.3 PRE ExB drift velocity, geo-magnetic index (Kp) and the occurrence of VHF scintillations

The results shown in Figs. 1 to 4, clearly indicate that the PRE ExB drift is the most important parameter that controls the scintillation activity. To examine the day-to-day randomness in the occurrence of scintillations, a quantitative study is made in describing the role of PRE ExB drift and the geo-magnetic activity index (Kp) on the occurrence or inhibition of scintillations. In Fig. 5, is presented the PRE ExB drift velocities measured over the equator on each day during the high sunspot year, 2001 as a function of the corresponding geomagnetic activity index (Kp). Fig. 5(a)

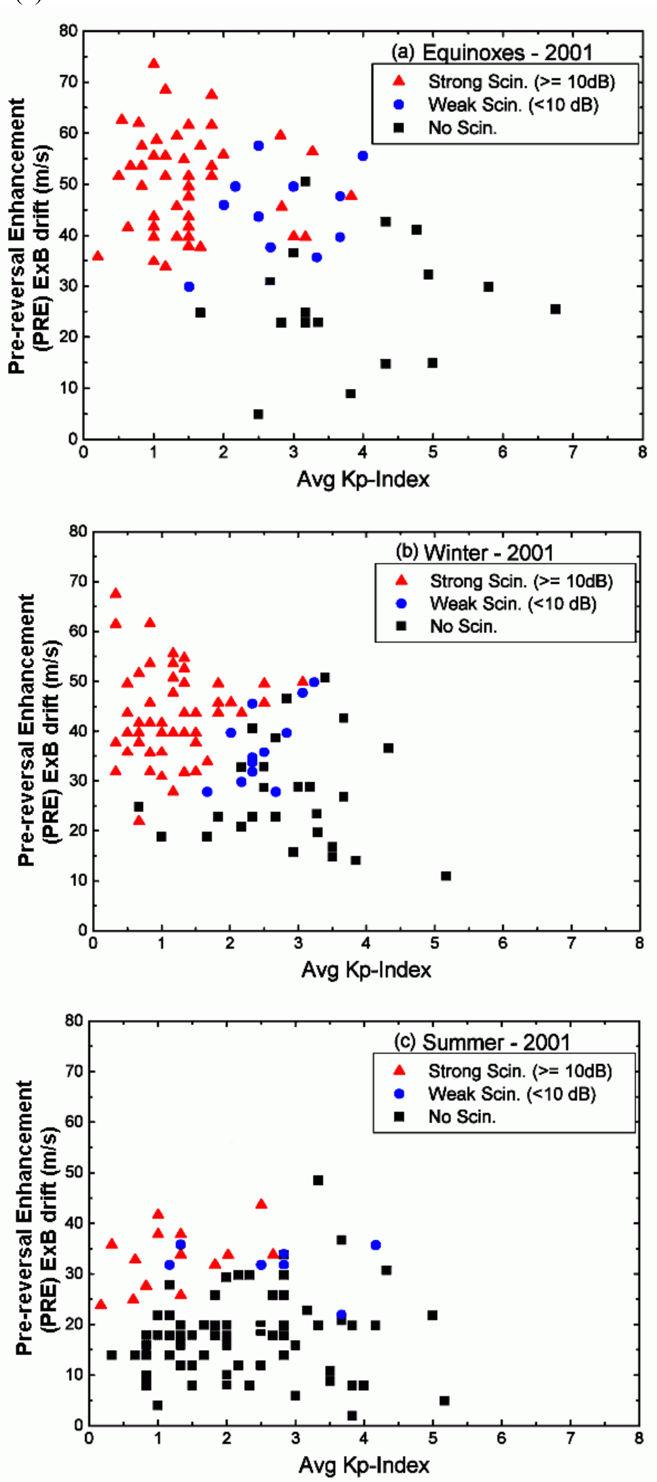

Fig. 5. The Pre-reversal enhancement (PRE) ExB drift velocities as a function of the 6-hour average Kp, observed for each day during (a) eqinoxes, (b) winter and (c) summer solstice months of high sunspot activity year, 2001.

corresponds to equinoxial months (March, April, September and October), Fig. 5(b) corresponds to winter months (January, February, November and December) and Fig.5(c) corresponds to summer months (May, June, July and August). The Kp-index shown on the x-axis is the 6-hour mean Kp-index value prior to the local sunset (0600 – 1200 hrs UT

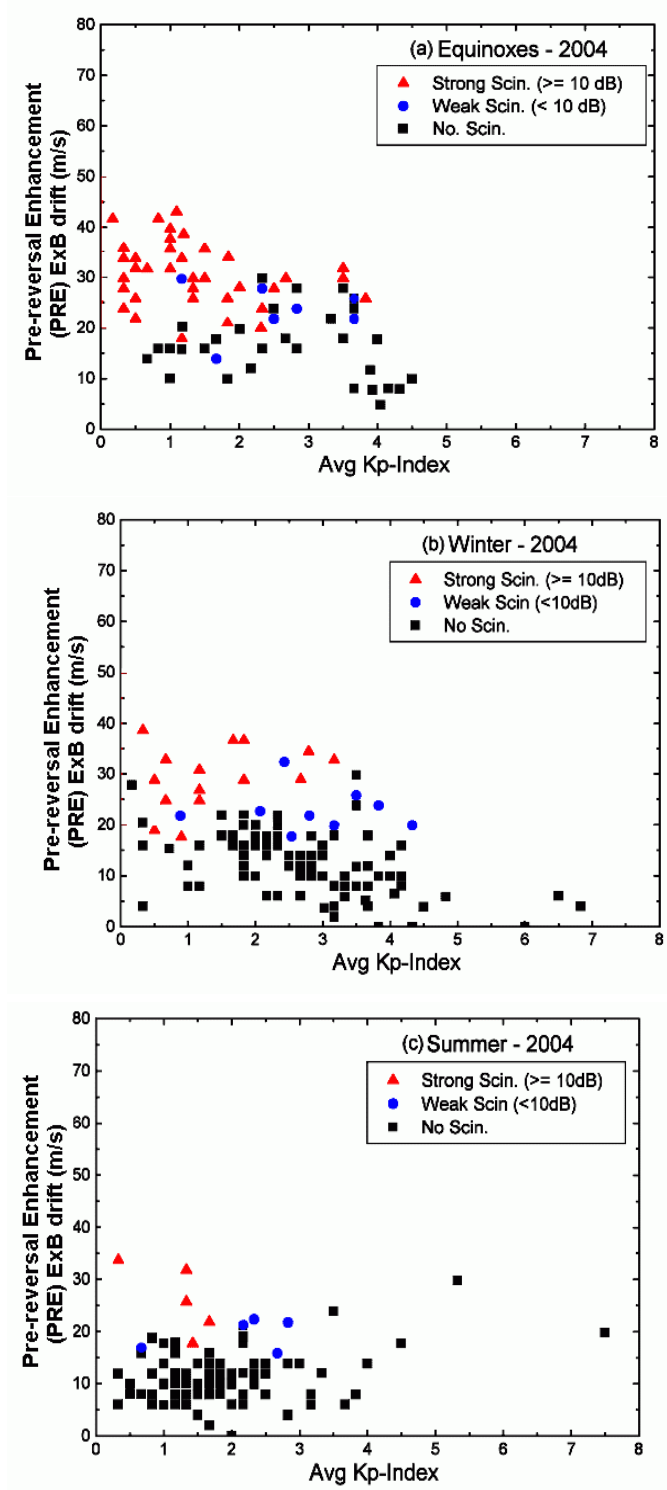

Fig. 6. The Pre-reversal enhancement (PRE) ExB velocities drift as a function of the 6-hour average Kp, observed for each day during (a) eqinoxes, (b) winter and (c) summer solstice months of low sunspot activity year, 2004.

which corresponds to 1230 – 1730 hrs IST). The red color triangles indicate the PRE ExB drift velocities for the days on which strong (≥10 dB) post sunset scintillations have occurred. The blue color circles represent the weak (< 10 dB) scintillation days and the black squares represent the days on which there are no scintillation occurrence. From these figures, it can be seen that, for the magnetically quiet days (average Kp≤2) strong post sunset scintillations are found to occur whenever the PRE ExB drift is ≥ 30 m/s. Also, during the days on which the PRE ExB drift is greater than 30 m/s but the average Kp lies between 2 and 4, there is an equal probability in the occurrence of strong, weak or no scintillation events to occur. However, when the PRE ExB drift is less than 30 m/s and/or the average Kp is greater than 4, the scintillation occurrences are very rarely seen. This suggests that there exists a threshold value of 30 m/s for the vertical drift to trigger the ESF irregularities causing intense (≥ 10 dB) scintillations for the days on which the 6-hour average Kp-index prior to the sunset is less than 2. However, for the days on which the average Kp lies between 2 and 4, there is an equal probability for strong, weak and no scintillation events to occur even though the vertical drift velocity exceeds the threshold value of 30 m/s.

In Figs. 5(a) and 5(b), during equinoxial and winter months respectively, it is also observed that the vertical ExB drift velocities decrease with increasing Kp and this feature is more pronounced during equinoxial months (Fig. 5(a)). However, this decrease in drift with increasing Kp is not seen during summer months (Fig. 5(c)).

Similarly, Fig. 6 shows the drift velocities for each of the days as a function of average Kp-index during the low sunspot year 2004. From the plots of this figure (a, b & c), it is noticed that, here also exists a threshold value of 20 m/s of the PRE ExB drift velocity to cause strong (≥ 10 dB) scintillations during the magnetically quiet days (average Kp ≤ 2). But, for the days on which the average Kp between 2 and 4, the strong, weak and no scintillation events are distributed with nearly equal probability even though the PRE ExB drift velocity exceeds the threshold value of 20 m/s. It is interesting to note here that the threshold PRE ExB drift for the generation of irregularities decreases from 30 m/s during the high sunspot activity year 2001 to 20 m/s during the low sunspot year 2004.

Also during the low sunspot year, it is seen that the post sunset upward drift velocities decrease with increasing magnetic activity (Kp-index), more significantly during equinoxes (Fig. 6(a)) followed by winter months (Fig. 6(b)). However, during summer months, this decrease of drift velocities with increasing Kp-index is not visible.

In this study a total of 259 days, on which simultaneous data of PRE ExB drift measured from Trivandrum and VHF scintillations recorded at Waltair, is considered during the high sunspot year, 2001. Out of these 259 days, on 114 nights (53 during equinoxes, 47 during winter and 14 during summer months) strong (≥ 10 dB) post sunset scintillations are observed. During the equinoxial months (Fig. 5(a)), all the 53 strong scintillations events have occurred only when the PRE ExB drift ≥ 30 m/s. However, there are 2 scintillation events (out of 47 nights) during winter (Fig. 5(b)) and 4 scintillation events (out of 14 nights) during summer (Fig. 5(c)) occurred even though the PRE ExB drift is less than 30 m/s. Thus, these results indicate that the necessary condition for the onset of strong post sunset scintillations during the high sunspot year 2001 is well defined during equinoxes, less in winter and least in summer months.

During the low sunspot year of 2004, only on 57 nights (37 in equinoxes, 15 in winter and 5 in summer), strong (≥ 10 dB) post sunset scintillations have occurred out of the available 268 days of observations. Out of the 37 nights of strong scintillation activity during the equinoxial months (Fig. 6(a)), 36 scintillation events occurred when the PRE ExB drift ≥ 20 m/s, and only on one night strong scintillation activity is observed even though the PRE ExB drift is less than 20 m/s. During the winter months (Fig. 6(b)), there are 2 scintillation events (out of 15 nights) occurred even though the PRE ExB drift is less than 20 m/s. These numbers indicate that the necessary condition for the occurrence of intense post sunset scintillations during the low sunspot year 2004 is also well defined during equinoxial months than during the winter months.

4. Discussion

During the early evening hours, the E-region ionization is quickly eroded due to the recombination of electrons and ions in the absence of production by solar ionizing radiations from the sun. Therefore, soon after the local sunset the F-region ambient ionization is relatively high with sharp gradients at the bottom side of the F-layer which become anti-parallel to the gravity (Kelly, 1989). Further, the rapid post sunset enhancement in the zonal electric field leads to large vertical ExB drifts, thereby lifting the F-layer to greater altitudes where the recombination effects are negligible and collisions are rare resulting in a condition conducive for the development of plasma irregularities. Through the Generalized Rayleigh-Taylor Instability (GRT) mechanism, the irregularities are then developed into plasma-depleted bubbles and are uplifted to higher altitudes. As the plasma-depleted bubble rises from the bottom side of the F-layer, they are elongated along the field lines to off equatorial latitudes and extend upto a north-south dimension of the order of 2000 km (Aarons et al, 1980).

Further, the large post sunset vertical drifts resurges the equatorial fountain effect by depleting the ionization near the magnetic equator, and simultaneously increasing the ionization at off equatorial stations. Thus, the ambient ionization near off equatorial stations like Waltair (20^{o}N dip) becomes higher than that at the equatorial stations like Trivandrum, giving rise to large ionization anomaly gradients (dN/dL) during the post sunset hours as may be seen from Figs. 3 and 4. Further, as the plasma-depleted bubbles are surrounded by larger amounts of ionization, result in steep gradients at the bubble walls causing more intense scintillations at off equatorial stations like Waltair which closer to crest region. Figs. 3 and 4 further confirm that, the significant enhancement in the anomaly gradient is accompanied by the intense (≥ 10 dB) scintillation activity observed over Waltair. Valladares et al, (2004), from a chain of GPS receiver network in the American sector, have also reported that, the anomaly peak-to-trough ratios show larger values around post sunset hours during the days of intense scintillation activity.

In the present study, it has been observed that the PRE ExB drift at the equator is the most crucial parameter that controls the development of irregularities causing intense VHF scintillations. Our studies reveal that there exists a threshold value of PRE ExB upward drift velocity of 30 m/s (Fig. 5) during high sunspot year, 2001 for the strong scintillations to occur. Also, it is observed that this threshold value decreases to 20 m/s (Fig. 6) during the low sunspot year, 2004. Fejer et al,(1999) from Jicamarca radar observation of a total of 200 events during evening and nighttime periods from April 1968 to March 1992, have reported that, when the drift velocities are large enough, the necessary seeding mechanisms for the generation of strong Spread-F always appear to be present. The threshold drift velocity for the generation of strong early night irregularities increases/decreases linearly with solar flux. Basu et al, (1996) have also reported from their campaign observations during September 25 to October 7 of 1994 in the south American sector, that the pre-reversal enhancement in upward drift, even though of only 20 m/s during solar minimum period, is a necessary condition for the development of scintillation activity. Recently, Anderson et al, (2004) have reported that there appears to be a threshold value of the ExB drift ≈ 20 m/s for the occurrence of UHF scintillations with S4-index > 0.5. Hence, the results obtained from the present study are consistent with most of the results reported earlier.

Further, Fejer et al,(1999) have shown that the extended magnetic activity during equinox solar maximum conditions generally causes large reductions in the amplitude of the pre-reversal enhancements, which inhibit the occurrence of Spread-F. Whalen, (2002) has shown that each level of Spread-F decreases as a linear function of Kp averaged in the 6 hours preceding the observations during March, April, September, and October, and November-February; however, during May-August the Spread-F levels are small and are independent of Kp. The disturbance dynamo electric fields which are driven by the enhanced energy deposition into the high-latitude ionosphere during the magnetically disturbed periods, causes large reduction of the evening upward drifts at the equator thereby inhibiting the generation of ESF irregularities. Fejer et al,(1999) have also shown that, this decrease of the evening upward drifts during the magnetically disturbed days is more pronounced during equinoxial solar maximum periods. Whalen (2002) have also reported that the suppression of irregularities results from the decrease of maximum pre-reversal eastward electric fields by the geomagnetic activity represented by Kp averaged over 6 hours is greatest in the equinoxial months, less in the December solstice months, and nil in the June solstice months during the solar maximum periods. Hence, the results obtained from our studies presented in Figs. 5 and 6 are in good agreement with the results reported earlier by Fejer et al,(1999) and Whalen (2002). Further, the present results also show that the influence of the 6-hour average Kp-index preceding the sunset on the maximum PRE ExB drift and thereby on the suppression of ESF irregularities is significant even during the relatively low sunspot year 2004.

5. Summary

A detailed study carried out to determine any possible quantitative relationship that exists between the pre-reversal enhancement in the vertical ExB drift at the equator (Trivandrum) and its role in the occurrence of VHF scintillations at off equatorial station (Waltir), we have analyzed a total of 259 nights of data during the high sunspot activity year, 2001 and 268 nights of data during the relatively low sunspot year, 2004. The percentage occurrences of VHF scintillations show a good correspondence with the monthly mean PRE ExB vertical drift velocities at the equator and both the parameters show a clear seasonal behavior with equinoxial maxima followed by winter and a summer minima during both high and low sunspot activity years.

The ionization anomaly gradient (dN/dL) between the equatorial station Trivandrum (0.9^{o}N dip) and an off equatorial station Waltair (20^o N dip) shows a significant enhancement during post sunset hours for the days on which intense scintillation activity is present, suggesting the re-energization of Equatorial Ionization Anomaly (secondary fountain effect) owing to the enhancement in the upward ExB drift creating favorable conditions for the generation of irregularities that elongate along the geomagnetic field lines and appear as intense (≥ 10 dB) scintillation at off equatorial stations like Waltair.

Further, the PRE ExB drift velocities are found to decrease with increasing geomagnetic activity as measured by the 6-hour average Kp-index, preceding the local sunset, during both high (2001) and low (2004) sunspot years. Also, this decrease is more prominent in equinox, less in winter and insignificant in summer months.

During the high sunspot year of 2001, it is found that there is a threshold value of ≥30 m/s for the PRE ExB drift velocity to give rise to a subsequent occurrence of intense (≥ 10 dB) scintillations for the days on which the 6-hour average Kp-index preceding the sunset is less than 2. However, this threshold value of the drift reduces to 20 m/s during the low sunspot year 2004. Hence the necessary condition for the occurrence of intense (≥ 10 dB) scintillations at off-equatorial stations like Waltair (20^{o}N dip) is that the pre-reversal enhancement in the ExB drift at the equator should be ≥ 30 m/s with an average Kp ≤ 2 during high sunspot year, 2001 and the PRE ExB drift ≥ 20 m/s with an average Kp ≤ 2 during low sunspot year 2004. Further, during the high sunspot activity year 2001, these conditions are well defined in the equinoxial months than in winter and summer months.

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