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Influence of Interplanetary magnetic field on Equatorial Electrojet-Observations from South India

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ABSTRACT

The occurrence of equatorial Counter electrojet (CEJ) and Prompt penetration effects are studied at a newly established equatorial remote station, Vencode (VEN), Kanyakumari Dt, at the southern tip of India. The three month's dataset (Nov, Dec-2010 and Jan-2011) of VEN along with permanent Hyderabad (HYB) Magnetic Observatory are used in the present study to assess the relationship between the CEJ and prompt penetration events with interplanetary parameters (IPP): Electric field (Ey) / southward component of magnetic field (Bz) and modeled penetration fields. The influence of short-term (~30-60 minutes) and long-term (~02-04 hours) fluctuations of the equatorial ionosphere on the horizontal (H) component of earth's magnetic field at VEN are explained in terms of change in orientation of IPP. We found a strong correlation between the CEJ events with Bz orientation (north-south-north). Moderate correlation is found between the high frequency components of the derived Equatorial electric field (EEF) with Real time prompt penetration electric field model (PPEFM). The day-to-day variability in Equatorial electrojet (EEJ) strength associated with CEJ events highlight the role of equatorial ionosphere in the present study. Our results from VEN confirm the positive relation of about 70% between CEJ events with Bz polarity.

INTRODUCTION

Equatorial Electrojet

The discovery of "equatorial electrojet" (EEJ) in the daily variation of the horizontal field, H, within a narrow belt of latitudes over the equator (Egedal, 1947), was explained by Chapman (1951). The EEJ field is caused by the ionospheric current flowing along the narrow channel ($\pm 3^{\circ}$ in latitudinal range) caused by an enhanced eastward current in the E-region of the ionosphere (Gouin, 1962).

Counter Electrojet

The equatorial "counter-electrojet" (CEJ) is also a well known phenomenon, which is observed as a depression in the northward / horizontal magnetic component continue up to 2 to 3 hours, where the diurnal amplitudes are suppressed and variation is well below the night time level. This was first observed by Bartels and Johnston (1940) and named counter electrojet (CEJ) by Gouin and Mayaud (1967). Many investigations have been made on CEJ phenomena from the early studies of geomagnetism (Chapman, 1951; Onwumechill and Agu, 1980; Rangarajan and Rastogi, 1993). Gouin (1962) noticed the interesting aspect of the reversal in direction of the horizontal component around midday hours at the equatorial station Addis Ababa. Gouin and Mayaud (1967) explained this negative depression of the regular H -field due to the effect of westward flow of electrojet current. Few more instances of CEJ are found at other equatorial stations: Zaria, Northern Nigeria (Hutton and Oyinloye, 1970) and Trivandrum, India (Sastry and Jayakar, 1972). Onwumechili and Akasofu (1972) described the occurrence of the counter electrojet over a wider longitude on some occasions.

CEJ EFFECT DUE TO ORIENTATION OF INTERPLANETARY MAGNETIC FIELD (BZ)

Studies show that the westward currents manifested during the reversal of the normal equatorial electrojet, responsible for the occurrence of CEJ may also

be explained in terms of reversal of the 'IMF Bz' component; i.e., when the Bz>0, it causes amplification in the H-component in the Equatorial observatories, whereas Bz<0, causes counter electrojet event (Sizova, 2002; Francisca et al., 2013). Rastogi and Patel (1975) demonstrated that a number of events were associated with a northward turning of the IMF-Bz and compared with the recorded magnetograms at Huancayo with the high resolution interplanetary magnetic field data. Kane and Trivedi (1981) studied about a dozen CEJ events in association of Bz polarity. Marriott et al. (1979), Hanuise et al. (1983), Stening et al. (1996) explained the possible reversal of the east-west electric field 'Ey' (product of Solar wind velocity and Bz) in the electrojet region produce a CEJ event and concluded that the westward turning of 'Ey' results in a CEJ and eastward turning results in the enhancement of magnetic field during day time. Alex and Mukherjee, (2001); Sizova, (2002) discussed that the CEJ events due to the reversal of the IMF Bz-component from south to north, further Alex and Mukherjee, (2001) defined the classes of CEJ based on the occurrence time of CEJ event between 06:00 to 18:00 LT. Recent studies by Francisca et al. (2013) on Ascension Island (ASC), Huancayo (HUA), Pondicherry (PND) observatories show a significant contribution of IMF Bz polarity on CEJ phenomenon.

The investigations of CEJ phenomena offered some proposed explanations as follows:

i. flow of electric currents in westward direction (Gouin, 1962)
ii. gravity wave associated vertical winds (Richmond, 1973; Reddy and Devasia,1981;Raghavarao and Anandarao, 1980; Aanadarao and Raghavarao, 1987)
iii. influence of solar flares (Rastogi et al. 1975, 1999; Manju et al. 2009)
iv. during sub-storm recovery phase (Kikuchi et al. 2003)
v. changes in the tidal components (Rastogi, 1973; Matsushita and Balsley, 1972; Somayajulu et al. 1993; Sizova, 1995)
vi. during magnetically disturbed as well as during magnetically quiet conditions (Kikuchi et al., 2003; Rastogi, 1974a; McCreadie, 2004)
vii. contributions of the global wind and current systems (Gurubaran, 2002), localized cooling in mesopause temperature (Vineeth et al.2007b), rise in lower atmospheric temperature connected with the phenomena of Sudden Stratospheric Warming (SSW) (Matsuno, 1971; Liu and Roble, 2002; Sridharan et al, 2009)
viii. change in orientation of IMF Bz polarity (Alex and Mukherjee, 2001; Sizova, 1995 , 2002).

PROMPT PENETRATION EFFECT

In the equatorial ionosphere of the earth, the wind driven currents coupled with the earth's horizontal magnetic field produce the Equatorial electric field (EEF). The EEF is known to be highly variable from day to day, primarily as a result of solar wind electric fields penetrating from high latitudes to the equator, in addition to variabilities in the neutral winds coming from below. The interplanetary electric fields (IEF), generated by the convection movement of the solar wind across the interplanetary magnetic field (Ey) appear instantaneously in the magnetosphere and ionosphere. This short-term penetration has a significant impact on the equatorial horizontal component. This process is called Prompt penetration effect (Manoj and Maus, 2012).

INFLUENCE OF PENETRATION FIELDS ON THE EEJ

Onwumechilli and Ogbuehi, (1962), Nishida, (1968) demonstrated two variants of disturbances that are believed to be originated from the interaction between the solar wind and magnetosphere, which has a significant correlation with the magnetic activity at electrojet stations, termed as DP1 (originated from auroral electrojet) and DP2 (associated with fluctuations in north-south component of interplanetary magnetic field). DP2 magnetic fluctuations are characterized by a quasiperiodic variation with a timescale of half an hour to several hours and during these fluctuations the strength of Sq field in the electrojet region opposed by North-South component of Solar wind velocity, when Bz is turning from negative to positive direction. This results a strong negative attenuation in the horizontal component of earth's magnetic field and marks CEJ at a given longitude. The magnetic fluctuations at equatorial stations are usually correlated with simultaneous magnetic fluctuations outside the equatorial region, particularly with those at polar stations. These short period events exhibit a strong decrease in magnitude with decreasing latitude; however, it is enhanced considerably at the dip-

equator (Nishida et al. 1966; Kikuchi et al, 1996). It has been largely investigated and established that the DP2 magnetic fluctuations were enhanced in amplitude at the dayside dip-equator compared to low- latitude stations (Nishida, 1968). Recently developed models allow investigating the short-period penetration electric fields (~30 to 60 min) into the magnetic field variations on the 'H' component of equatorial observatories (Manoj and Maus, 2012). Improved understanding on these penetration electric fields suggest that the events may even occur when IMF Bz is northward (Manoj et al. 2008).

OBJECTIVES OF THE CURRENT STUDY

In the light of present understanding on different causes for the occurrence of negative attenuation at electrojet longitude, we would like to address this subject at a newly established EEJ pair (VEN-HYB) from the three months (Nov, Dec-2010 and Jan-2011) data by means of: (1) perturbations of about (02-04 hours) in the variation of IMF polarity (2) correlation of short-term penetration (30-60 minutes) effects from modeled prompt penetration electric field (PPEFM), (Manoj and Maus, 2012).

DATA

Three month's dataset (Nov, Dec-2010 and Jan-2011) from VEN (77°10′ E, dip: 0.07° N) and HYB (78°33′ E, dip: 10.18° N) have been used in the present study and their geographical locations are shown in Figure 01.

VEN is a remote site established by National Geophysical Research Institute in project mode operating since May, 2010. The historical permanent Magnetic Observatories: Ettaiyapuram (ETT, 78° 01′E, dip: 0.6°S) and Trivandrum (TRD, 76° 58′E, dip: 0.8°S) established by National Geophysical Research Institute, Hyderabad and Indian Institute of Geomagnetism, Bombay, are also used in the current study.

5 min and 1 hour averages of VEN and HYB are used to compute the EEJ strength for the above mentioned data set. EEJ variations for each day are obtained by subtracting midnight mean (23:00 –

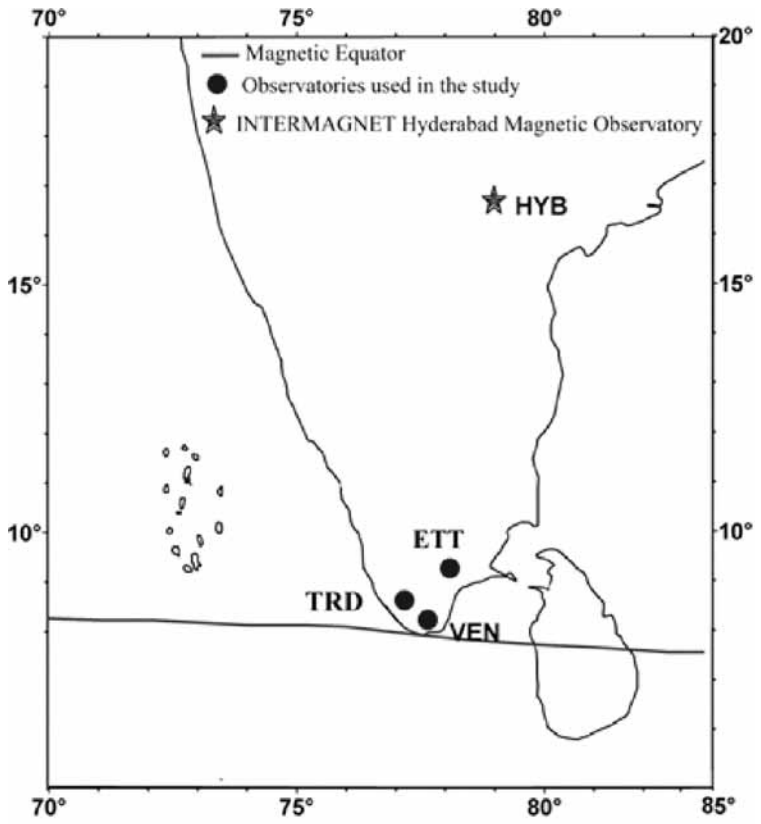

Figure 1. Map showing the locations of the Magnetic Observatories used in the study.

02:00 LT) removed variation at a low-latitude station (HYB) from midnight mean removed variation at the EEJ site (VEN). This effectively removes the Sq and Dst contribution from the EEJ sites and enhances the EEJ strength. (VEN- HYB) pair used in the present study highlights the CEJ's in association with Bz polarity.

The five minute averages of (VEN-HYB) pair are used to identify the Prompt penetration events at VEN. Equatorial electric field (EEF) was obtained from EEJ strength at (VEN) using (Anderson et al. 2004) method. The following equation used for extracting EEF in the present study.

$$EEF = ((5.2889+0.1947*(\Delta X) +0.0001*(\Delta X) \ ^2- 0.0000021*(\Delta X) \ ^3)* B/1e^6)$$

where ΔX = (VEN-HYB) H-component, B = 37074.8 nT derived from IGRF at 150 km.

The difference between observed and smoothed polynomial 3rd order fit is the residual. The residual part of the EEF is selected for the days Kp ~ 3. The 5 minute sampling interval of Real time model of the Ionospheric field (Manoj and Maus, 2012) is used to examine the relation with ground derived EEF. The IMF-Bz and Solar wind speed (V) dataset of 5 min and one hour averages are downloaded from IMP-8 satellite data from SPIDR http://spidr.ngdc.noaa.gov/spidr/). Simultaneous variation of Ey and Bz are shown in Figure 02.

As both behave in the similar manner, hence it is decided to study the relation of CEJ with 'Bz' in the present work.

Figure.3, shows the daily variation at HYB and (VEN-HYB) pair, which followed the pattern of solar daily variation. The additional field on the (H) component at VEN can be attributed to the influence of EEJ, the moving east-west currents in day time E-layer of ionosphere where as HYB shows the influence of Sq currents, plotted with one minute sampling interval.

CEJ EFFECT DUE TO BZ ORIENTATION

The EEJ strength reaches its maximum strength during its noon. However, during some days / series of days, the amplitude undergoes a sudden depression

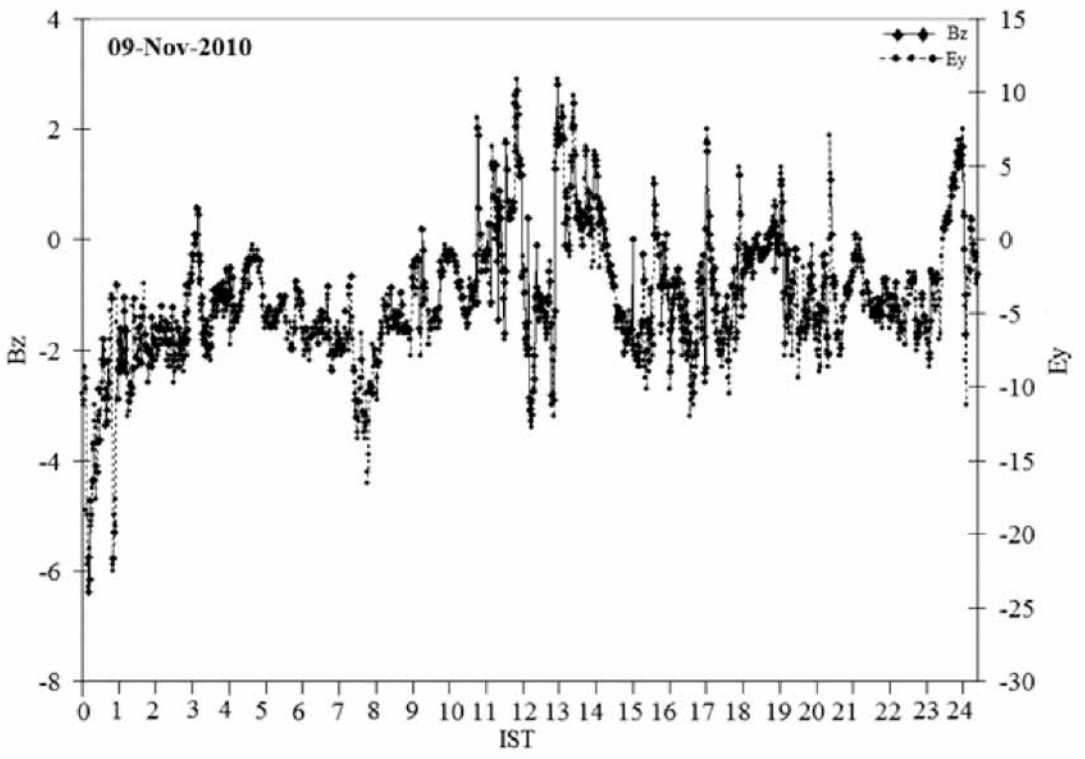

Figure 2. Similarity in variations between computed Ey (Interplanetary Electric field) and Bz (Interplanetary Magnetic field) for the day 09th Nov, 2010.

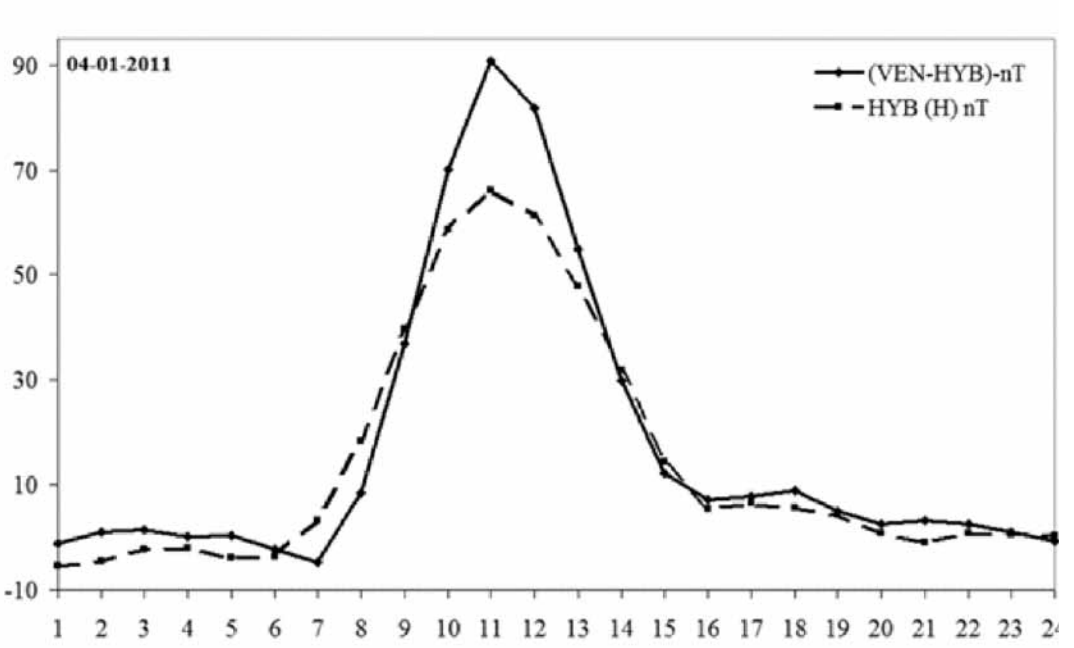

Figure 3. The EEJ strength at Vencode i.e., (VEN-HYB) horizontal component (Solid line) in comparison with non-equatorial station, Hyderabad (HYB) (Dotted line) during Jan 4th, 2011.

for 2-3 hours in 'H' component starting from 08:00 to 18:00 LT. We identified this feature at (VEN-HYB) pair and discussed few examples of variants in negative attenuations according to the time of occurrence. Three variants of CEJ are witnessed in the present study at (VEN-HYB) pair, 1) Morning counter electrojet (MCEJ; 06:00 to 09:00 LT), Afternoon Counter electrojet (ACEJ; 12:00 – 14:00 LT) and Evening Counter electrojet (ECEJ; 15:00 – 18:00 LT) along with the influence of Bz polarity. Figures 04a-04d show the occurrences of variants of CEJ's on: (a) 05th Nov-2010, strong ACEJ, (-25 nT), (b) 11th Dec-2010, MECJ, (-23 nT), (c) 07th Dec-2010, ECEJ, (-8 nT) and (d) 28th Jan-2011, a strong NCEJ (-18 nT) is recorded at (VEN-HYB) EEJ pair. Over 70 numbers of CEJ's are observed at (VEN-HYB) pair and most of the events are the result of change in orientation of Bz from south to north. From figures 04b and 04c, the noon-time values linearly increasing with (Bz>0). Figures 04a and 04d, illustrate the noon-times values are completely depressed due to Bz<0.

IDENTIFICATION OF PROMPT PENETRATION EFFECTS AT (VEN-HYB) EEJ PAIR:

Ground-based magnetic field observations provided a great opportunity for understanding the penetration electric fields with satellite derived models (PPEFM). In the present study the influence of prompt penetration fields on H component at VEN for the days Kp ~3 (i.e., 2.98 and 3.01) are studied and correlated with the real time PPEF model (Manoj and Maus , 2012). During Nov-2010, two prompt penetration events are identified, (11th and 12th Nov, 2010) which are shown in Figure 05. The times of observed correlation with the ground based EEF and the zonal fields are marked in the figure. The prompt penetration effects identified in the present study showed a good correlation with the PPEFM during the periods marked in the figure. In the same figure, there are some instances where the short-term fluctuations are not correlated with the model.

From (Fig.5), it is very clear that PPEFM was unable to reflect all the fluctuations with the real-time ground based EEF data set. The reasons for the discrepancy between the data sets need to be investigated. This correlation study highlights the significance of real-time measurements of equatorial ionosphere over the differing longitude, which leads to probe the factors influencing on the ground based data sets. Finally, the model presents an overview of the influence of equatorial ionospheric current system in response to the real-time magnetic field variations at VEN.

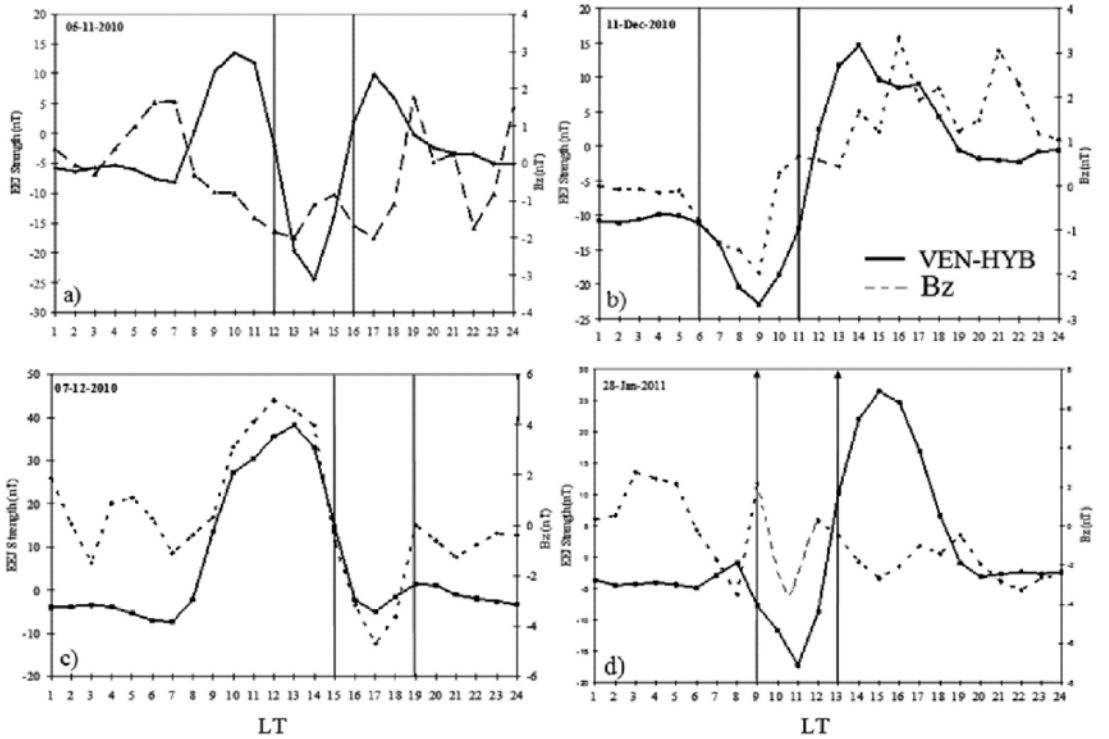

Figure 4. a) Occurrence of MECJ, NCEJ and ECEJ at (VEN-HYB) EEJ pair along with Bz during 05th Nov, 2010,; b) 07th Nov, 2010; c) 11th Dec, 2010 and d) 28th Jan, 2011. The marked portion indicates the time of occurrence of CEJ events.

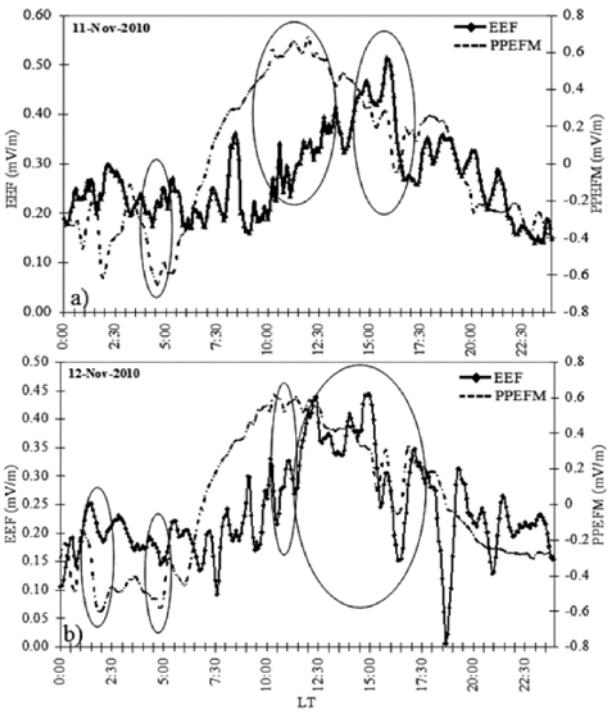

Figure 5. Observed Prompt Penetration effects at (VEN-HYB) derived EEF from H-component (Solid line) compared with the PPEFM (Dotted line) during (a) 11th Nov, 2010 and (b) 12th Nov, 2010. Marked portions indicate the correlation between the two data sets.

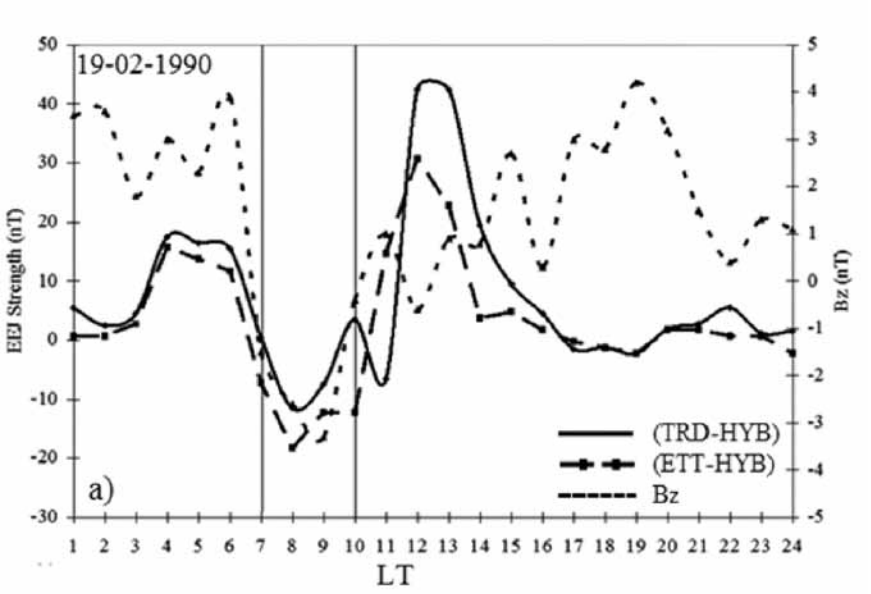

Figure 6. Represents the CEJ event at (TRD-HYB) and (ETT-HYB) on 18th Feb 1990 at 07:00 and 10:00 LT in accordance with the IMF-Bz component (North-South-North). Originally the day was selected from the work of (Sizova, 2002) for (TRD-ABG) EEJ pair.

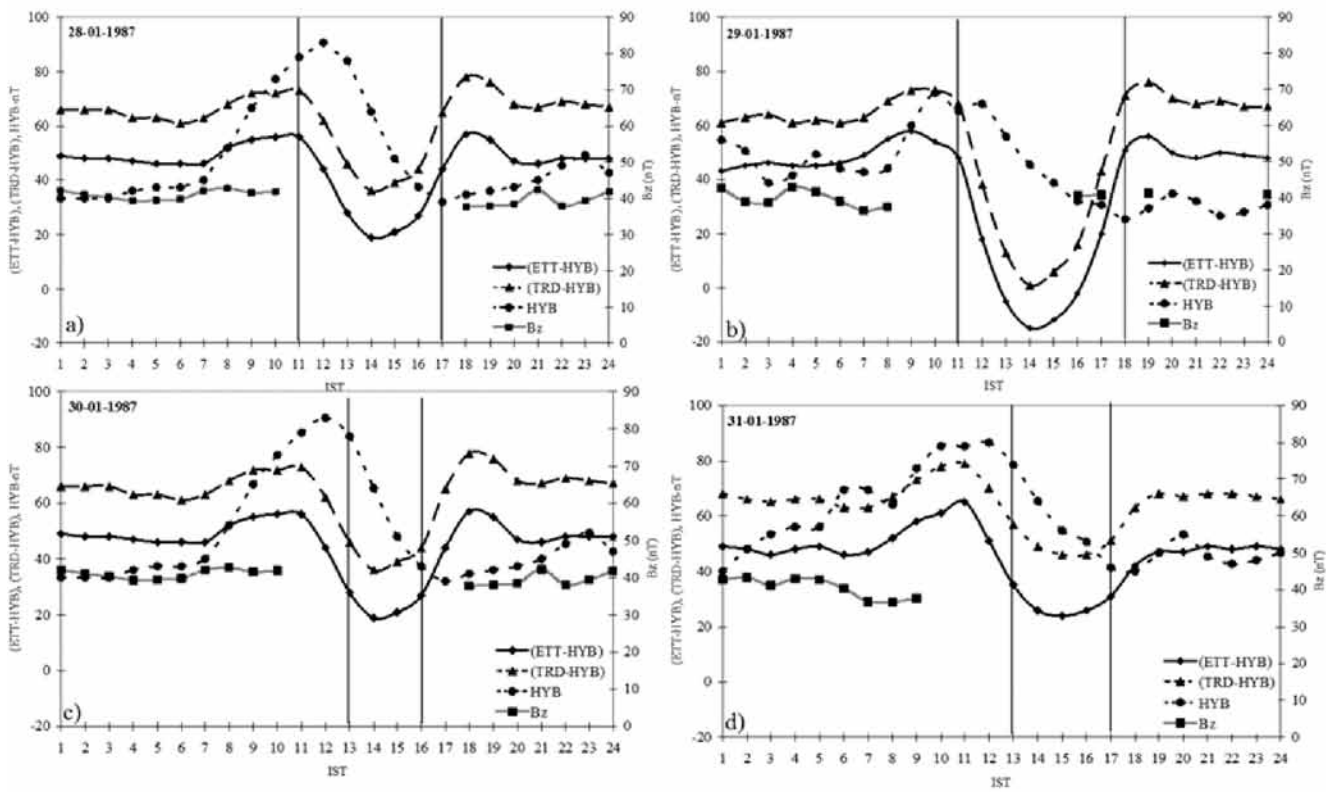

Figure 7. Observed ACEJ and ECEJ events at (ETT-HYB) and (TRD-HYB) pairs in association with Bz polarity during (a) 28th Jan 1987 (b) 29th Jan 1987 (c) 30th Jan 1987 and (d) 31st Jan 1987. The marked portion indicates the occurrence of CEJ events. Originally the days are selected from the work of (Somayajulu et al., 1993) for (TRD-ABG) EEJ pair.

DISCUSSION

To strengthen the present observations on CEJ with Bz polarity at (VEN-HYB) pair, we additionally carried out analysis on few selected days, (04th April, 1982), (28th-31st January, 1987), (2nd February, 1990), (08th April, 1993) and (07th July, 1995) from the published works of (Somayajulu et al., 1993; Sizova, 2002; Kikuchi et al., 2003) on Trivandrum–Alibag (TRD-ABG) pair. As mentioned earlier, the EEJ strength is computed from the hand scaled mean hourly averaged values from the magnetograms of TRD, ETT with reference to HYB for the above mentioned days.

Fig. 6, shows a typical MCEJ event recorded at (ETT- HYB) and (TRD-HYB) pairs during 19th Feb, 1990 (Sizova, 2002) and the occurrence of MECJ is the result of change in Bz orientation from north-south-north. The CEJ amplitude recorded at these pairs was -13 nT and -20 nT. The similar study is carried out for the days 28-31st of Jan 1987 (Somayajulu et al. 1993) and witnessed ACEJ and ECEJ events at (TRD-HYB) and (ETT-HYB) pairs shown in Figure (7a-7d).

We also studied the days 08th Apr 1993 and 16th July 1995 from the published work of (Kikuchi et al. 2003)and witnessed CEJ's with reference to Bz polarity at (ETT-HYB) and (TRD-HYB), but not shown in the present study. We observed from the data sets: ETT, TRD and VEN, the occurrence of CEJ may also happen on series of days. All the discussed observations by means of Bz orientation reinforces the analysis by (Rastogi, 1974a; Alex and Mukherjee, 2001; Sizova, 2002; Francisca et al. 2013). The gaps in the Bz data is due to loss of record (Fig.7).

Observations are summarized as follows:

1. From the figures (04a-04d); (06) and (07a-07d) the occurrence CEJ events at (VEN-HYB), (ETT-HYB) and (TRD-HYB) are due to the change in orientation of IMF-Bz from north-south-north. Debates are still going on the CEJ events with Bz polarity in the scientific community. The present analysis of CEJ events at (VEN-HYB) pair reinforces the earlier results of (Somayajulu et al. 1993; Sizova, 2002; Kikuchi et al. 2003) and recent results by (Francisca et al. 2013).
2. On an average the variability in electrojet strength is witnessed on day-to-day and for most of the days, especially during CEJ events, the strength is reduced around (08-18 LT) at (VEN-HYB) EEJ pair which strongly suggest the response of IMF-Bz polarity (north-south-north) in day time ionosphere.
3. Short-term penetration effects (~30 – 60 minutes) on horizontal component at (VEN-HYB) are investigated by using the derived EEF for the days Kp ~3 following (Anderson et al. 2004) method. The high frequency component of EEF is compared with the real time Prompt penetration electric field model (PPEFM). Observations reveal, in some instances the correlation found strong between the EEF and the model. However in some periods, the relation is moderate, shown in figures 05a and 05b, highlighting the role of other parameters / mechanisms on the equatorial ionosphere.

CONCLUSIONS

The influence of interplanetary magnetic field (IMF-Bz) polarity (south to north), leaves signatures on the horizontal magnetic field, which is assessed through a comparative study at electrojet sites VEN, ETT and TRD along with HYB. The correlation found strong between the CEJ events and Bz polarity in the new records of (VEN-HYB) pair. Correlation found moderate between the derived EEF and PPEFM during the period of study. Our results from VEN further confirm the positive relation between CEJ events with Bz polarity. Apart from Bz there are other mechanisms (winds, local Ionosphere conductivity, Sudden Stratosphere warming, etc) must be evoked.

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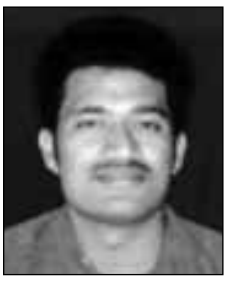

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