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Short Communication

First observational evidence for the connection between the meteoric activity and occurrence of equatorial counter electrojet

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ABSTRACT

This paper presents the first direct observational evidence for the possible role of meteoric activity in the generation of the equatorial Counter Electrojets (CEJ), an enigmatic daytime electrodynamical process over the geomagnetic equatorial upper atmosphere. The investigation carried out using the data from Proton Precession Magnetometer and Meteor Wind Radar over a geomagnetic dip equatorial station, Trivandrum (8.5°N, 77°E, 0.5°N dip lat.) in India, revealed that the occurrence of the afternoon CEJ events during a month is directly proportional to the average monthly meteor counts over this location. The observation is found to be very consistent during the considered period of study, i.e the years 2006 and 2007. The study vindicates that the meteor showers play a major role in setting up the background condition conducive for the generation of CEJ by reducing the strength of the upward polarization field.

1. Introduction

As is well known, the Equatorial Electrojet (EEJ) is an intense eastward current system that flows over the dip equator, during daytime, at an altitude region of 90–120 km, centered at around 105 km in a narrow latitude region of $\pm 3°$. However, in situ rocket observations of EEJ currents over the dip equatorial stations in India and Peru showed that vertical profiles of the EEJ current deviate significantly from that of Cowling conductivity (Prakash et al., 1972; Subbaraya et al., 1972; Richmond, 1973; Pfaff et. al., 1997). Nevertheless, the current profiles consistently show peaks around 105 km, which differ from the theoretically estimated values (using model atmosphere parameters) by 4–5 km. As is known, on certain geomagnetically quiet days the EEJ current shows a reversal in its direction, especially during the afternoon hours manifesting the Counter Electrojet (CEJ). The CEJ has been studied extensively across the globe ever since its discovery in 1967 (Gouin and Mayaud, 1967), but still remain as an enigmatic phenomenon since it is a multi factors problem. Some of the reported features of the CEJ are (i) its unpredictable occurrence (ii) the average frequency and intensity are larger in the afternoon hours than in morning hours (iii) the frequency of occurrence increases substantially with decreasing solar activity, (iv) periodic occurrence during the winter months of northern hemispheric Stratospheric Sudden Warming (SSW) events etc. A number of studies have been conducted in the past, on the seasonal and solar cycle dependence of the occurrence of CEJs (Marriot et al., 1979) and their association with the disappearance of sporadic E layer (Rastogi et al., 1971).

Different mechanisms have been proposed for explaining the occurrence of the CEJ. For example, Somayajulu et al. (1993) have suggested that CEJ can be produced due to the changes in the wind fields in the ionospheric dynamo region caused by the interaction of certain tidal modes with the background mean flow. Later on, it was shown that the amplitudes and the phases of the tidal components at Mesospheric Lower Thermosphere (MLT) altitude were substantially different on CEJ days (Sridharan et al., 2002). Another mechanism suggested was the presence of an additional current system in the altitude region of 98 km, when it intensifies in the opposite direction of EEJ produces the CEJ (Bhargava et al., 1980). The existence of such a current system was inferred later on by using the ground based geomagnetic data (Alex and Mukherjee, 2001). In addition to this, the role of height varying vertical winds for reversing the polarization electric field and the occurrence of CEJ was put forward (Richmond, 1973; Fambitakoye et al., 1976; Reddy and Devasia, 1981). Similarly, the gravity wave associated vertical winds were also proposed as a suitable forcing for the reversal of the polarization field and hence the EEJ (Raghavarao and Anandarao 1980; 1987). Though they could simulate the reversal of EEJ current, it necessitated the existence of vertical winds of large magnitudes (~20–30 m/s) which was not experimentally confirmed. Recently, Vineeth et al. (2007a) showed that associated with CEJ; there exists a strong localized cooling in the mesopause region over the dip equator. They suggested that the gravity wave

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associated vertical winds [originally proposed by Raghavarao and Anandarao (1980)] can reduce the downward diffusion of [O] from lower thermosphere, thereby reducing the exothermic OH chemistry, leading to the decrease in mesopause temperature (The [O] is produced in the lower thermosphere, and brought to mesosphere through downward diffusion or mean advection, where it reacts with the prevailing O_2 molecules to produce [O_3]. This [O_3] reacts exothermically with H producing the OH radicals). At EEJ altitudes such vertical winds can push the ion layer to higher altitude and reverse the upward electric field, thereby generating the CEJ. The observational evidence for such an enhanced gravity wave activity at mesopause altitude during the CEJ events has been reported recently by Vineeth et al. (2012).

Apart from these local effects, the contributions of global wind and current systems to the occurrence of CEJs have also been brought out by certain researchers in the past (Stening et al., 1996; Gurubaran, 2002). One such study is the relation of CEJ occurrence with the prevailing phase of the stratospheric quasi biennial oscillation reported by Chen et al. (1995). Further, in a study dealing with the occurrence of CEJ during the winter months, Stening et al. (1996) have suggested an association of SSW for the occurrence of CEJ events. Recently, Vineeth et al. (2007b, 2009) have shown that the CEJ occurs in a periodic manner during the SSW years. They found that the group of CEJs occur in a quasi periodicity of 16-day, which corresponds to a Planetary Wave (PW) that is amplified during the winter months of the SSW years, adding one more dimension to the causative forcing for the CEJ. As is well known, the SSW is known to be caused by the interaction of vertically propagating PWs with the polar vortex, leading to its splitting or displacement. Therefore, the polar stratospheric temperature may exhibit fluctuations corresponding to the PW periodicity before the SSW occurs.

In addition to these, short-term CEJ have been observed during the disturbed periods associated with the energy deposition at high latitudes. The disturbance ionospheric dynamo is believed to be one of the causes for the existence of CEJ (Fejer et al., 1999; Yizengaw et al., 2011). The high energy deposition in the polar region can alter the ionospheric dynamo by changing the neutral wind speed. It is a well known fact that the Co-rotating Interactive Region (CIR) driven storms are accompanied by enhanced convection and continuous energy deposition into high-latitude ionosphere, which in turn enhances the equatorward neutral wind speed. The changes is neutral wind can alter the ionospheric dynamo (Blanc and Richmond, 1980), which in turn manifest as the CEJ over the dip equator.

The rapid decrease in the penetrating electric field of magnetospheric origin during the northward turning IMF condition is also another possible source of CEJ (Kikuchi et al., 1996, 2000). Kikuchi et al. (2003) suggested that the decrease of the penetrating electric field is associated with region 1 field-aligned currents (R1 FACs) under the condition of a well-developed shielding electric field due to the region 2 field-aligned currents (R2 FACs). They suggested that the rapid decrease in equatorward penetrating electric field associated with abrupt drop off in R1 FAC (under the condition of well developed shielding electric field due to the northward turning of IMF Bz) leads to the dayside reversal of equatorial electric field. In fact, the R2 FAC is suggested to be one of the predominate contributor for the westward electric field at the dayside dip equator (Kikuchi et al., 2000).

Though exhaustive studies have been conducted to explore the causative mechanisms for CEJ and many theories have been put forward for explaining the occurrence CEJ as briefed above, the relative role of the each mechanism still remains inexplicable. However, it is worth mentioning here that the recent developments in this field clearly vindicate that the waves (both gravity waves and planetary waves) and tides of lower atmospheric origin play a definitive role in the generation of CEJ (Vineeth et al., 2007a; 2009; 2012). Further, it is also clear that the background conditions like the strength of the electric field and direction of the zonal wind at MLT heights also play a major role in the occurrence of CEJ (Vineeth et al., 2012). The preferential occurrence of CEJ during the solsticial months as reported earlier clearly indicates the role of background conditions, such as the weakened EEJ current. If the strength of the EEJ is weak on a particular day it facilitates easy occurrence of the CEJ since the exiting electric field would be very weak on that day.

The modeling studies in the past have suggested that the meteoric dust particles also play a major role in the development of CEJ (Kulkarni and Muralikrishna, 2005; Muralikrishna and Kulkarni, 2008) by setting up the background conditions, conducive for the development of CEJ. They showed that strong dust layer produced by meteoric ablation in the lower E region can lead to the total re-orientation of the polarization electric field in the EEJ zone. Such a dust layer can get negatively charged by attracting the electrons and cause a polarization electric field in the downward direction leading to another current with a westward motion in the bottom-side E region. If this polarization field is strong enough it can lead to the reversal of the EEJ current. However, it must be mentioned that no direct observational evidence has been brought out so far to support such a connection between the meteoric ablation and the occurrence of CEJ.

In this context, the present study is an attempt to find out the connection between meteoric activity and the occurrence of afternoon CEJ, if any, using two years of continuous meteoric and magnetic field observation from Trivandrum (8.5°N, 77°E, 0.5°N dip lat.), a dip equatorial station in India. In order to correlate between the meteor counts and occurrence of CEJ, a monthly averaging method is considered since the meteoric activity is a continuous process and the dust particle deposition depends on the nature of the shower and a dust layer deposited can be present for a few days together. Therefore, the effect of same meteor counts on different days having different solar and dynamical conditions may produce entirely different effects since the occurrence of quiet time CEJ depends upon many other factors as discussed earlier. As a result of this, one should not expect one-to-one relation between the occurrence of CEJ and meteor counts on a day-to-day basis. The analysis of monthly mean meteor counts and number of afternoon CEJs occurred on those particular months revealed that there exists an excellent correlation of 0.94 between the two during the considered period of study. This paper is aimed at reporting this unique observation and discusses the plausible reasons for this in context of the modeling studies done in the past.

2. Data base

The EEJ induced magnetic field at the surface was measured using a Proton Precession Magnetometer (PPM) from Trivandrum. Though PPM gives only the total field, the magnetic field component is essentially horizontal over the dip equator. The meteor counts and neutral winds at MLT region were obtained from co-located SKiYMET Radar. The details of this radar have been described elsewhere (Hocking et al., 2004). The diurnal variation of the EEJ induced magnetic fields were visually scanned through and occurrence of geomagnetically quiet CEJs in the afternoon period were separated out for two consecutive years, 2006 and 2007, where continuous, uninterrupted measurements on meteors counts and magnetic fields were available. Only afternoon CEJs, which occurred between 13:00 and 17:00 IST (Indian Standard Time) have been considered in this paper. To check the association of CEJ occurrence with the meteor activity, the day-mean meteor