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# Can lower E-region dust particles be responsible for counter electrojet?

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**Resumen**

La ablación de meteoritos deja un gran número de partículas de polvo de tamaños que van de los nanómetros a los micrómetros en la región mesosférica alta. Estas partículas de polvo pueden afectar las conductividades de la región E ecuatorial de muchas maneras. La mayoría de ellas permanecen eléctricamente neutras y pueden afectar las frecuencias de colisión del electrón y del protón, especialmente en la región E inferior, y eventualmente alterar la conductividad eléctrica de esta región. Esto puede subir el máximo de la conductividad de Cowling por varios kilómetros haciéndolo coincidir con el máximo de la corriente del electrojet observado. Las partículas de polvo cargadas en la capa E inferior pueden reducir considerablemente la densidad de corriente del electrojet en la región al capturar un número importante de electrones libres de dicha región. Una evidencia clara de esto es la gran diferencia entre las concentraciones de iones positivos y electrones observada en esta región por sondas in situ. Algunas veces se ha visto que la concentración de iones positivos es un orden de magnitud más grande que la de los electrones en la región mesosférica alta. Las observaciones mediante cohetes también han mostrado la presencia en esta región de capas de polvo cargadas positivamente en la parte superior y negativamente en la parte inferior. Estas capas de polvo pueden invertir el campo de polarización vertical localmente y aun producir el fenómeno de contra electojet. En este trabajo se presentan los cálculos del modelo de densidad de corriente del electrojet tomando en cuenta estos efectos debidos a las partículas de polvo.

**Palabras clave:** Polvo meteorítico, plasma polvoso, electrojet, contra electrojet, conductividad de Cowling.

**Abstract**

Ablation of meteors leaves a large number of dust particles of sizes ranging from nanometers to several micrometers in the upper mesospheric region. These dust particles can affect the equatorial E-region conductivities in several ways. Most of them remain electrically neutral and can affect the electron and ion collision frequencies, especially in the lower E-region, and thereby alter the electrical conductivity of this region. This can lift the Cowling conductivity maximum by a few kilometers making it coincide with the observed electrojet current maximum. Charged dust particles in the lower E-region can considerably reduce the electrojet current density in this region, by capturing a large number of free electrons from this region. A clear evidence for this is the large difference between the electron and positive ion number densities observed in this region by in situ probes. Positive ion densities, at times, are seen to be an order of magnitude higher than the electron number densities in the upper mesospheric region. Rocket observations have also shown the presence of dust layers in this region charged positively on top and negatively at the bottom. Such dust layers can reverse the vertical polarization field locally and can even produce the phenomenon of counter electrojet. Model calculations of the electrojet current density taking into account these effects of dust particles are presented here.

**Key words:** Meteoric dust, dusty plasma, electrojet, counter electrojet, cowling conductivity.

## Introduction

It is now well known that dust particles play an important role in laboratory and space plasmas (see Merlino and Goree, 2004). Ablation of meteors that enter the atmosphere with velocities ≈15 kms$^{-1}$ is the most important source of these dust particles (Kornblum, 1969) in the earth's atmosphere. Charged dust particles were experimentally detected, for the first time, in the high latitude and were found to be partly responsible for the observed anomalous PMSE (Polar Mesospheric Summer Echoes) events in the back scatter radar, and electron bite outs measured by rockets (Havnes *et al*, 1996). In some parts of the dust layers it was found that the negative charge density on dusts was so large that the number of free electrons was significantly reduced there, since the dust acted as a sink for electrons, thus causing electron bite outs. The number of charged dust particles is reported to be 5 to 10 percent of the total dust number density (Gelinas *et al*., 2005; Lynch *et al*., 2005). One should note here that the size and number density of dust particles in the atmosphere could vary by orders of magnitude from one day to another. Though the dust particles of higher mass diffuse more rapidly to lower altitudes, rather continuous influx of meteorites and micrometeorites can still maintain dust particles of larger mass at higher altitudes. Visconti (1973) estimated the relative dust concentration as a function of height and time for dust particles of different sizes assuming an initial deposit height of 110km. They found that a dust concentration of 100 at 110km reduced to about 10 after 72hours at 90km altitude, indicating that dust particles may take a few days to diffuse from 110km to 90km. This also indicates that at deposit altitudes of 105 to 110km the number density of dust particles can be several times more than those observed at lower altitudes if they are supposed to reach lower altitudes by diffusion. Reliable information on the number density and size distribution of dust particles at deposit altitudes is still lacking.

Kulkarni and Muralikrishna (2005) showed that, these neutral dust particles, when exist in sufficient numbers, can modify the collision frequencies, and thereby affect the conductivity parameters in the electrojet region. Muralikrishna and Kulkarni (2006), under simplifying assumptions using a realistic model for the meteoric dust estimated the effect of charged dust particles on the Cowling conductivity profile. A quantitative analysis of the effect of charged dust particles on the electrojet currents needs precise information on the height distribution as well as the size distribution of the dust particles. This information is still lacking. Possible effects of a dust layer on the electrojet currents are examined here assuming a dust model in the lower E-region altitudes.

## Theoretical formulation

A simplified way of looking at the electrojet currents is that the Pedersen current due to the polarization field $E_p$ is nullified by the Hall current due to the primary east-west electric field $E_0$, giving the relation (see Muralikrishna and Kulkarni, 2006):

$$J_X = \left[\sigma_P + \frac{\sigma^2_H}{\sigma_P}\right]E_0 \tag{1}$$

$$J_X = \sigma_C E_0 \tag{2}$$

were $\sigma_C = \left[\sigma_P + \frac{\sigma^2_H}{\sigma_P}\right]$ (3)

$\sigma_C$ is the Cowling conductivity here. The Hall Conductivity, $\sigma_H$ and the Pederson conductivity, $\sigma_C$ are given by

$$\sigma_H = \frac{n_i e^2 \Omega_i}{m_i(\upsilon_i^2 + \Omega_i^2)} - \frac{n_e e^2 \Omega_e}{m_e(\upsilon_e^2 + \Omega_e^2)} \tag{4}$$

$$\sigma_H = \frac{n_i e^2 \upsilon_i}{m_i(\upsilon_i^2 + \Omega_i^2)} - \frac{n_e e^2 \upsilon_e}{m_e(\upsilon_e^2 + \Omega_e^2)} \tag{5}$$

The standard formulae for the collision frequencies are:

$$\upsilon_{en} = 5.4 \text{ x } 10^{-10} N_n T^{\frac{1}{2}} \tag{6}$$

$$\upsilon_{in} = 2.6 \text{ x } 10^{-9} N_n A^{-1/2} \tag{7}$$

Here $N_n$ denotes number density of neutral particles in the atmosphere, A denotes the mean molecular weight, and T the neutral temperature. The collision frequencies $\upsilon_{en}$, and $\upsilon_{in}$ depend on the number densities of the neutral atmospheric molecules and the temperature. This is a rather simplified picture of what really happens in the electrojet region. It is known that the presence of meridional currents in this region can modify this simple image (Sugiura and Porus 1969). Several modifications have later been suggested to this simple picture (see Richmond 1991).

Fig. 1 shows the height profiles of the ratio $\sigma_H/\sigma_P$ (that is a measure of the vertical Hall polarization field as seen from equation (2) estimated from MSISE-90 atmospheric model and the ambient electron density measured using rocket-borne experiment (also given in the fig.) conducted from the equatorial station Thumba, India (Subbaraya *et al*., 1972; Muralikrishna, 1975). Also given in the fig. is the electrojet current intensity estimated from in situ observation. Fig. 1 represents the electrojet currents under normal conditions, when there is no effect of neutral or charged dust particles.

Kulkarni and Muralikrishna (2005) examined the effect of neutral dust particles on the electrojet currents. Under simplifying assumptions they estimated the effect of neutral dust particles on the conductivity parameters. In the absence of reliable information on the height distribution of dust particles, Kulkarni and Muralikrishna (2005) assumed electron-dust and ion-dust collision frequencies exponentially decreasing with altitude starting from 91km upward. They estimated the Cowling conductivity profile using the atmospheric model MSIS-E-90 and compared it with the profile estimated without considering the effect of neutral dust particles. The values of electrojet currents are from proton precession magnetometers and the electron density profiles are from the Langmuir and resonance probes launched on-board sounding rockets (Subbaraya *et al*., 1972 and Prakash *et al.,* 1972).

Fig. 2 shows the height variation of the electrojet current intensity, and the Cowling conductivity without and with dust. The Cowling conductivities are estimated assuming that the electron dust collision frequency varies exponentially with height as,

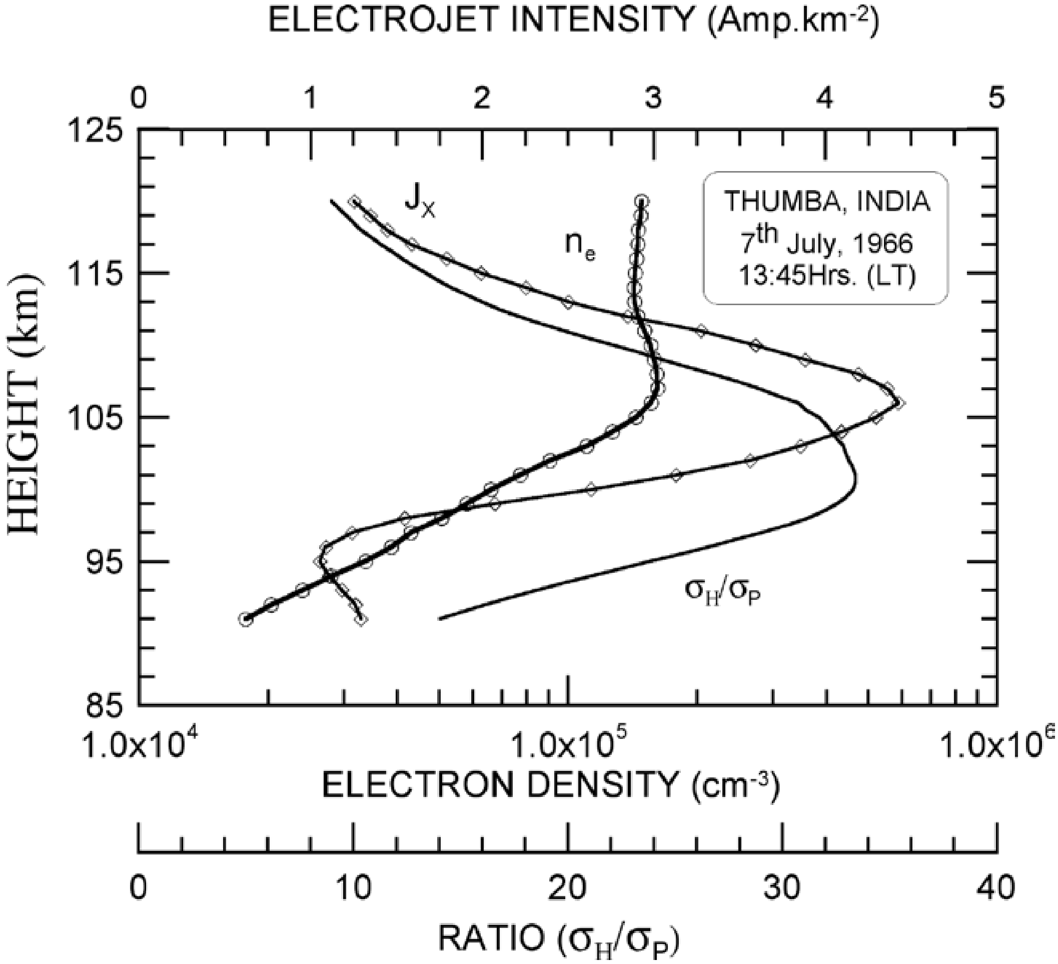


Fig. 1. Height profiles of the electron density and Electrojet current intensity estimated from in situ measurements made from Thumba, India at 13:45 LT on Jul. 7, 1966, compared with the model estimate of the ratio of Hall to Pedersen conductivity profile.

$$\upsilon_{ed} = \upsilon_{ed}(0)e^{-h} \tag{8}$$

and the ion dust collision frequency varies as,

$$\upsilon_{id} = \upsilon_{id}(0)e^{-\frac{h}{H}} \tag{9}$$

where $\upsilon_{ed}(0)$ and $\upsilon_{id}(0)$ are respectively the electron-dust and ion-dust collision frequencies at 91km height decreasing exponentially with height above 91km (Kulkarni and Muralikrishna, 2005). For dust particles of uniform diameter of 10 micron and number density $\approx 10^5$ $cm^{-3}$, the estimated values of these parameters are $\upsilon_{ed}(0) \approx 4.6 \times 10^5\ s^{-1}$ and $\upsilon_{id}(0) \approx 2.9 \times 10^4\ s^{-1}$.

The calculated conductivity without dusts shows a peak at about 103 kms. Using the same electron density parameters, in the presence of dusts the conductivity peak occurs at about 107 kms. This way Kulkarni and Muralikrishna (2005) could explain the height difference of 4 to 5km observed between the observed current profiles and model conductivity profiles (Prakash *et al*., 1972; Subbaraya *et al*., 1972; Muralikrishna, 1975; Pfaff *et al*., 1997; and Prakash and Subbaraya, 1999). The current profiles showed peaks at 105 - 107 km height whereas the model calculations showed the conductivity peaks at 100 - 103km. Such a mismatch of about 5km in the peaks of the electrojet currents estimated from atmospheric models and in situ observations was also reported by Richmond (1973) from rocket experiments conducted from the equatorial region off the coast of Peru.

## Effect of charged dust particles

*Normal Electrojet*

Muralikrishna and Kulkarni (2006) reported on the effect of negatively charged dust particles on the electrojet intensity. The role of the charged dust particles is to reduce the electron number density. During days of

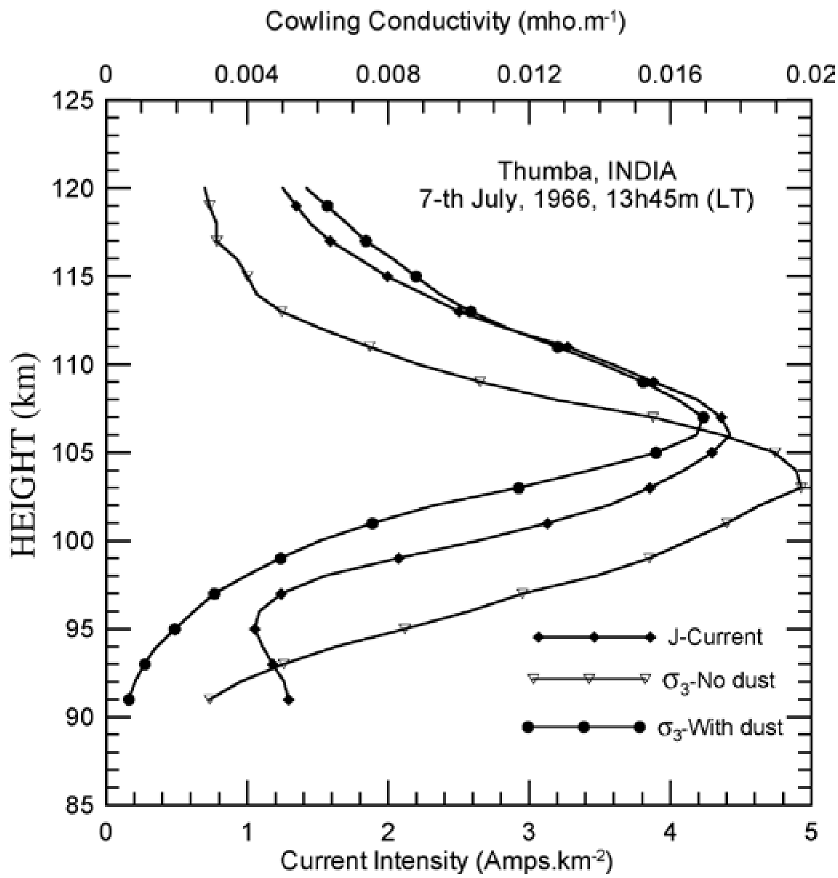


Fig. 2. Height profiles the electrojet current intensity and Cowling conductivity with and without the effect of neutral dust particles) showing the height difference between the maxima in the current intensity and in the Cowling Conductivity.

meteor showers one can expect dust particles of a wide spectrum of sizes ranging from a few nanometers to a few microns or even bigger in sufficient numbers as to attract all the electrons in the height region below the electrojet peak. This can cause a reduction or even reversal in the normal electrojet current in this height region, through the suppression of the Hall conductivity of electrons. If the charged dust layer exhibits a double polarity, positive on top and negative at bottom (Gelinas *et al.*, 1998), the nature of the Hall polarization field and the vertical structure of the electrojet current can become complex. If this results in the reversal of the vertical Hall polarization field in the region of the dust layer, one can even expect the reversed currents to be sufficiently large as to cause the phenomenon of counter electrojet as identified in the ground magnetograms. Using simplifying assumptions Muralikrishna and Kulkarni (2006) studied the effect of charged dust particles on the normal electrojet currents.

In the height region above the electrojet peak, where the dust particles are practically absent the polarization field $E_p$ enhances the east-west electrojet current as explained through the equations 1 to 3. In this region the Hall drifts of both free electrons and positive ions are in the $\mathbf{E_p x B}$ direction, that of electrons being much larger than that of the ions thereby causing a net Hall current in the $\mathbf{-E_p x B}$ direction. But in the region below the electrojet peak, where the charged dust particles remove a large number of free electrons from the ambient plasma the picture is different. Though the net current density is due to the Pedersen and Hall drifts of electrons and positive ions, the number densities of electrons and positive ions are not equal in this region. The relative contributions of electrons and positive ions to this net current depend very much on their relative number densities. The acquisition of electrons by the dust particles depends on their number density and size distribution. In the extreme case when all the free electrons are attached to the dust particles, the net Hall current is determined by the Hall drift of positive ions only and will be opposite to that of the normal electrojet currents. Though this represents a small fraction of the total Hall current, its effect is to reduce the normal current in the lower electrojet region or even to cause a reversal in it.

To make a quantitative estimate of the effect of a charged dust layer on the electrojet currents Muralikrishna and Kulkarni (2006) assumed a dust layer with uniform dust size of 1 micrometer diameter. The maximum number density of the dust particles is assumed to be $5 \times 10^4 . cm^{-3}$ at the assumed dust deposit height of 103km (below the electrojet peak) decreasing exponentially to zero at 93km. The floating potential of a dust particle of 1 micrometer diameter as estimated from the relation $V_s = -2.5kT_e/e$ is about –0.016Volts which is more than 6 times the electronic charge. Still bigger dust particles, when get fully charged may remove a large number of free electrons from the ambient plasma and a much smaller number density of such dust particles are needed to produce the same effect on the electrojet currents. Assuming that about 10% of these dust particles get negatively charged (Gelinas *et al.*, 2005) one can see that the number of electrons captured by the dust particles is more than $3 \times 10^4$ per cubic centimeter at the dust deposit height of 103 km. This, in fact, is close to the number density of free electrons in the bottom side of the E-region, under normal conditions. It should be noted here that the earlier measurements reported by Gelinas *et al.* (1998) correspond to the mesospheric heights and not to the height region of 93 – 103 km being considered here. In fact the nanometer dust particles reported earlier are known to be produced by the ablation of larger dust particles of meteoric origin. In the height region of 93 – 103km considered here the dust particles that may get charged are definitely much bigger ones. In the absence of reliable measurements, it is assumed here that about 10% of these dust particles may also be charged.

Height profiles of the Cowling conductivity with and without the presence of a dust layer, estimated for the electrojet conditions shown in fig. 1, are estimated using the above dust model and are presented in Fig. 3. Decrease in the Cowling conductivity that is a measure of the electrojet current intensity, in the region of the dust layer (93 – 103km) can be clearly seen from this fig. Depending on the actual dust density, diameter and distribution this decrease in the Cowling conductivity can be more or less than that shown in Fig. 3. Such a decrease in the electrojet currents, if exists, must leave its signature in the ground level geomagnetic variations. Muralikrishna and Kulkarni (2006) from a study of the geomagnetic field variations reported a large decrease in the daily range of variation of the horizontal component of the geomagnetic field associated with the days of the intense Leonid meteor shower.

*Counter Electrojet*

In the model approach discussed above the only physical effect considered is that of the capture of free electrons by the dust particles. The effect of the charged dust layer on the height profile of the vertical polarization field is neglected. Under these assumptions the intensity of the reversed currents is limited to that caused by the ion Hall current, which is rather insignificant. The presence of a charged dust layer with significant thickness can distort the vertical polarization field and can even create height regions where the vertical polarization field is reversed from its normally upward direction. This in turn

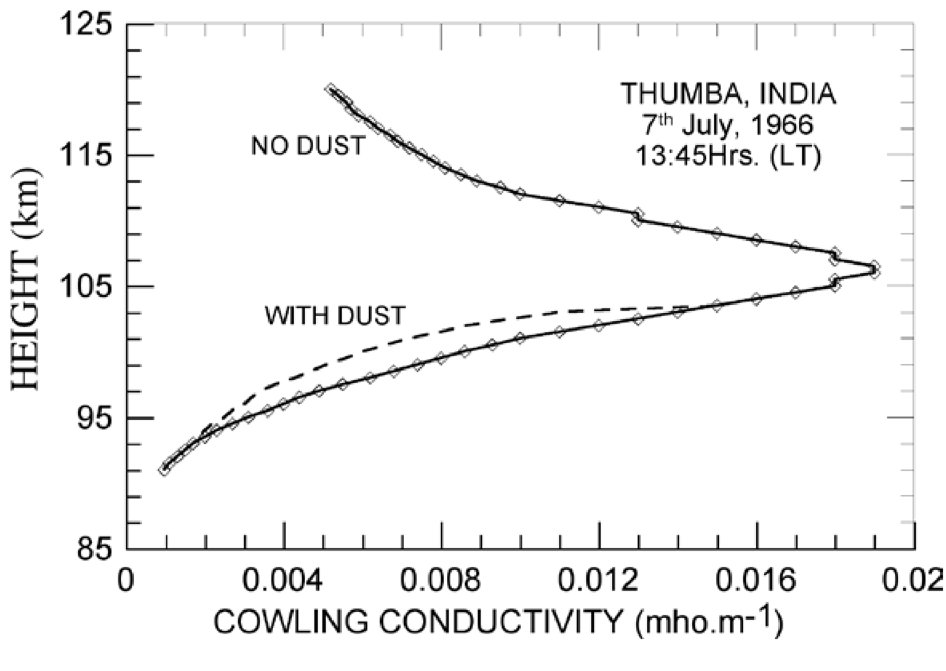


Fig. 3. Height profiles of the Cowling conductivity estimated with and without the effect of charged dust particles.

can cause a reversal in the electrojet currents in those height regions. In addition to an improved knowledge on the size and number density distribution of the meteoric dust, a detailed theoretical approach is needed to make any quantitative estimate of the effect of charged dust particles on producing counter electrojet.

Fig. 4 shows how the presence of a rather thick dust layer can alter the vertical profile of the Hall polarization field. Under normal electrojet conditions (in the absence of the effect of a dust layer) the primary field $\mathbf{E_0}$ drives a vertical $\mathbf{E_0XB}$ Hall drift. The electrons with higher mobility move faster and get accumulated on top of the electrojet boundary while the positive ions remain closer to the bottom boundary, thus causing the development of the Hall polarization field $\mathbf{E_p}$ directed upward (see Fig. 4). The presence of a dust layer with charged dust particles that are much heavier than both electrons and positive ions affects the development of $\mathbf{E_p}$ and causes a distortion in this field as shown in the Fig. 4. The negative charges in the dust layer, being very heavy compared to the free electrons do not participate in the vertically upward $\mathbf{E_0XB}$ Hall drift of electrons and ions caused by the primary electric field $\mathbf{E_0}$. The free electrons as well as positive ions move upward faster than the negatively charged dust particles creating the accumulation of positive charges on the upper boundary of the dust layer and negative charges (of the dusts particles) on the lower boundary. The polarization field inside the dust layer $\mathbf{E'_p}$ is thus directed downward. This produces a distortion in the normal vertical polarization field $\mathbf{E_p}$ that can even result in the reversal of this field below the electrojet peak, and thereby in the reversal of the electrojet currents in this region.

What is given here is a rather simple picture of the effect of charged dust particles. The real situation can be much more complex. The dust model assumed here may seem to be unrealistic, since there is no direct evidence for the presence of micron sized particles in such large numbers. Also one may argue that such large dust particles, even if arrive at the higher altitudes, may diffuse down to lower altitudes very quickly. But when there is a continuous flux of particles on top of the atmosphere this quick diffusion will not reduce the dust number at a given altitude. The continued presence of Sodium layer in the mesosphere is a clear proof of this (Visconti, 1973). Apart from all these considerations some of the established facts about the phenomenon of counter electrojet are in support of the present hypothesis that negatively charged dust particles can play a very significant role in distorting the electrojet currents especially below its maximum (see Muralikrishna and Kulkarni, 2006).

A coordinated measurement with multiple experiment payloads alone can resolve this complicated problem.

## Conclusions

- The reduction in the number density of free electrons in the height region dominated by negatively charged dust particles can cause a reduction or even a reversal in the normal electrojet currents.
- Meteoric dust precipitation can last several days and this can explain the observation, at times, of counter electrojet on consecutive days.
- Observation of counter electrojet in the morning or afternoon hours when the normal electrojet currents are rather week also supports the present hypothesis.

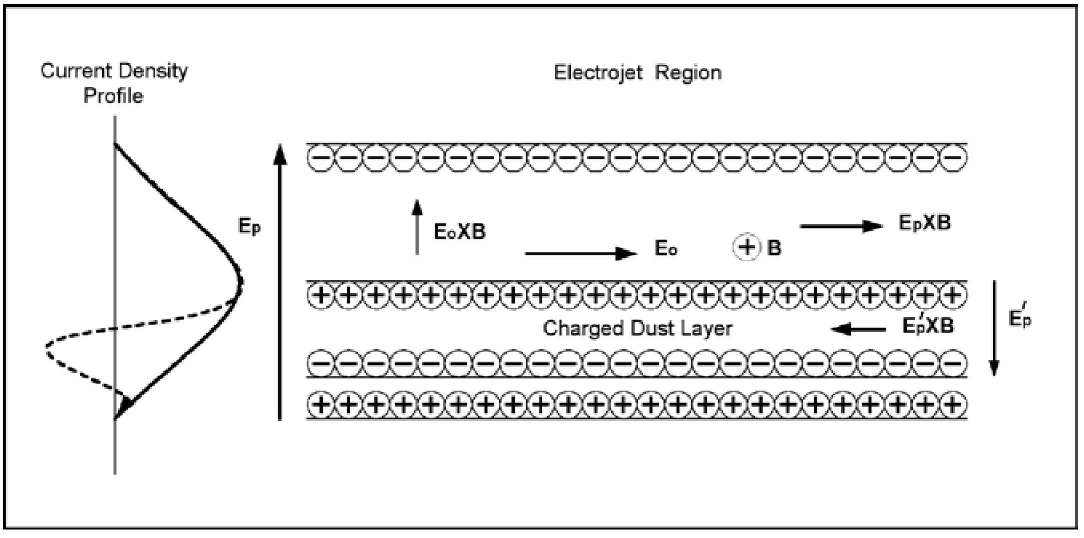


Fig. 4. Illustration of the effect of a charged dust layer on the height profile of the normal electrojet current flow. The current flow is reversed below the peak due to a reversal in the polarization electric field Ep in this region.

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