Uplifting of the equatorial electrojet currents by the meteoric dust

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Abstract

In a magnetized plasma, assuming an effective collision cross section by an equivalent number of neutral dust particles, the Hall and the Pederson conductivities are obtained. Using the measured values of electron densities in the ionospheric E-Region heights between 90 ant 120 km, by the rocket flights, 20.05-20.07 over Thumba, India and the neutral density model calculations as given by the MSIS-E-90 for geographical latitude = 0, and longitude = 80, the Cowling conductivity values are calculated. These conductivity profiles are compared with the current profiles observed on the rocket flights. We see that the conductivity maxima and current density maxima can be matched by assuming neutral dust particles in the ionosphere. The justifications for this modelling i.e., the equatorial electrojet conductivities including the dust particles and comparison with the alternative theory which is given by Ronchi et. al. (1990) are given at the end.

INTRODUCTION

The " Equatorial Electrojet " is about 600 km. wide in the North-South direction around the magnetic dip equator where an enhanced current flows in the East-West direction. The daily variations of magnetic fields on the ground level are mainly due to dynamo currents in this region of the Earth ionosphere. The successful theory is based on a combination of the Hall (σ_H) and the Pederson (σ_P) conductivities which arise in a magnetised but collisional plasma in the height region of 90-120 km. The electric fields are expected to be due to winds and to global dynamo effects in both the ionosphere and the magnetosphere (Forbes, 1981). Sugiura and Cain (1966) assumed a slab geometry in a magnetoplasma and studied the current flow pattern. In a cartesian system, where the Z-axis points towards North, and Y-axis upward towards the zenith of an ionosphere of finite thickness then the X-axis will be in the East-West direction in which the equatorial current flows. The model predicts that if there is a component of an electric field, **E**, perpendicular to the magnetic field, **B**, and when the Hall current is restricted, then the Cowling conductivity σ_C can be enhanced considerably. Even otherwise a polarisation field can be set up. It is known that the meridional currents in the electrojet region modifies this electric field (Sugiura and Porus 1968). In the model given above the polarisation field E_p is related by, $E_p = (\sigma_P/\sigma_H).E$, where E is the primary East-West electric field. When solved the electrojet current j is found to be $j = \sigma_C$ E. This σ_C is responsible for the flow of large currents in the East-West direction. Here we use an additional subscript T to denote the theoretical value and e to denote the value observed. Since then several modifications are suggested (Sugiura and Poros, 1969, and Richmond 1991).

In normal circustances, the j and ÿC should show the height profiles. But in situ rocket observations of currents show the vertical profiles of j which deviate significantly from σ_{CT} (Praksh, et. al.1972, Subbraya et.al. 1972, Muralikrishna 1975, Pfaff et. al. 1997, and Prakash and Subbraya 1999). The j profiles show peaks at the height of 105km., which differ in heights from the theoretical estimate by 4-5 km. The observation can be accounted by assuming that the primary electric field E has a gradient, mainly positive upward with respect to the height which we believe unlikely. Therefore we expect that σ_P , σ_H and σ_C are different from the theoretical estimates and need suitable modelling. In this context, we would like to point out that electron collisional frequencies estimated at heights above 90 km calculated from the radio frequency experiments are lower from those computed using the standard atmosphere model by factor ≈ 1 at 100kms, ≈ 3 at 110 kms and ≈ 10at 130 km.(Thrane and Piggot, 1966).

The metallic ions, Fe^+ , Mg^+ and Ca^+, are known to be integral components in the E region of the ionosphere. Near 105 km. height the peak densities are of the order $\sim 10^4$ (Hunten 1981, Carter and Forbes, 1999). Hunten et. al.(1981) suggest that a maximum deposition of dust and smoke particles due to meteor occurs in the height region of 70-90 km. McNeil, Lai and Murad (1996) model a distribution of magnesium ions in the ionosphere, assuming that the main source function for these particles are the meteor ablation. It is also suggested that the extremely low effective conductivity of the mesospheric dusty plasma can explain the existence of vertical electric fields observed in the lower mesosphere, in the vicinity of noctilucent clouds and polar mesosphere solar summer echoes (Zadorozhny 2001). Observations of persistence of Leonid meteor trails by Drummond et.al. (2001) suggest that dusts certainly play a significant role in the ionospheric dynamics. The period of rocket measurements electron densities and currents in the equatorial region are in the August month which has meteor shower in its entire period. Therefore, we expect a significant number of dust particles of different sizes populating the ionosphere.

We assume that the dust particles are neutral. We ignore their charges. The polarisation electric field which is proportional to the electric field in the East-West direction, is calculated by inhibiting the Hall current. For convenience, we assume that the magnetic field is along the Z-axis of the right handed co-ordinate system and the

X-axis is pointing towards the vertical. The Y-axis coincides with the East-West direction. The medium is homogeneous and uniform. By using fluid equations of motions for ions and electrons, we recalculate the direct, the Pederson and Hall conductivities in Section 2 . In Section 3 we discuss the modification of currents by dusts in the ionosphere. The possible changes introduced by them are also presented.

The conductivity calculations

The fluid equations of motion in CGS electrostatic units for electrons and singly charged ions given by

$$\rho_j \frac{d\vec{V}_j}{dt} = -\vec{\nabla} P_j + q_j(\vec{E} + \frac{\vec{V}_j x \vec{B}}{c}) - \rho_j \nu_j \vec{V}_j \qquad (1)$$

are solved assuming a steady state, i.e. by equating the Eq. (1) to zero. Here $\rho_j = m_j n_j$, V_j, P_j, and q_j represent respectively the mass-density, mass, number density, velocity, 3pressure, and charge-density of the j-th component, where j = e denotes electrons, and j = i is for the ions. The subscript d is for the dust particles. ∇ is the gradient operator. The term ν_j is the collision frequency of the j - th component with neutrals. E and B are the electric and magnetic fields permeating the medium. c is the velocity of light in vacuum.

In the steady state, the velocity components are found to be,

$$v_{jx} = \frac{q_j \nu_j}{m_j(\nu_j^2 + \Omega_j^2)} E_x + \frac{q_j \Omega_j}{m_j(\nu_j^2 + \Omega_j^2)} E_y \qquad (2)$$

$$v_{jy} = \frac{q_j \nu_j}{m_j(\nu_j^2 + \Omega_j^2)} E_y - \frac{q_j \Omega_j}{m_j(\nu_j^2 + \Omega_j^2)} E_x \qquad (3)$$

$$v_{jz} = \frac{q_j}{\nu_j m_j} E_z \qquad (4)$$

Here Ω is the gyro-frequency of the particle shown by the subscript. We also neglect P_j dependent terms. The current components are given by

$j_x = \Sigma_j n_j e v_{jx}$ and

$j_y = \Sigma_j n_j e v_{jy}$.

These currents, following Sugiura and Cain (1966) are written as

$j_x = \sigma_P E_x - \sigma_H E_y$ and (5)

and,

$j_y = \sigma_P E_y + \sigma_H E_x$ (6)

where the Hall Conductivity, σ_H and the Pederson conductivity σ_P respectively are given by,

$$\sigma_H = \frac{n_i e^2 \Omega_i}{m_i(\nu_i^2 + \Omega_i^2)} - \frac{n_e e^2 \Omega_e}{m_e(\nu_e^2 + \Omega_e^2)} \qquad (7)$$

$$\sigma_P = \frac{n_i e^2 \nu_i}{m_i(\nu_i^2 + \Omega_i^2)} + \frac{n_e e^2 \nu_e}{m_e(\nu_e^2 + \Omega_e^2)} \qquad (8)$$

For a given slab we set $j_x = 0$ which gives $E_x = (\sigma_H/\sigma_P)E_y$. This when substituted in Eq.(6) gives,

$$j_y = \left(\sigma_P + \frac{\sigma_H^2}{\sigma_P}\right) E_y = \sigma_C E_y \qquad (9)$$

where we define the Cowling conductivity σ_C. The study of behavior of σ_C is the main part of the present paper.

Computations and discussions

The effective conductivity σ_C depends on the collision frequencies. Since the conduction currents are mainly due to electrons, we assume that the collision frequencies for ions are those between the ions and neutrals i.e., $\nu_I = \nu_{In}$. Following Chapman, we assume that the collision frequencies for electrons are given by,

$$\nu_e = \nu_{en} + \nu_{Ie} + \nu_{ed} \qquad (10)$$

where as we retain $\nu_I = \nu_{In}$ without any loss of generality. Please note the presence of an additional term the ν_{ed} due to the electron-dust collisions. The standard formulae, i.e.,

$$\nu_{ei} = \left[34.0 + 4.18 \log(T^3 n_e^{-1})\right] n_e T^{-3/2} \qquad (11)$$

and

$$\nu_{en} = 5.4x10^{-10} n_n T^{1/2} \qquad (12)$$

$$\nu_i = \nu_{in} = 2.6x10^{-9}(n_e + n_n) W^{-1/2} \qquad (13)$$

are used in computation of collision frequencies. Here n_n is the number density of neutrals, T is the temperature and W is the mean molecular number. The collision frequencies ν_{ie} , ν_{en} , ν_{in} and ν_{ed} depend on the densities of electrons, ions and dusts, and their respective thermal velocities. For the calculation of collision frequencies of electrons with dusts we do the following assumptions. For a given dust particle of size d and their number density n_d, the collision frequency is given by $\pi d^2 n_d v_{eT}$, where v_{eT} is the thermal velocity of electrons. In fact this should be summed over different sizes of dust particles. Meteor ablation is important for the dusts of micron sizes which enter the atmosphere with velocity ≈15 kms^{-1} (Kornblum 1969). The concentration of dust particles is greater in the height region 80-90 km. Hunten et. al., (1980) show that for a fixed mass input by meteors at altitudes ≥ 90km particles radii r_0 vary as r_0^{-4} . The information of dust-size distributions and the number densities are lacking. Therefore we assume that the total collision frequencies of electrons with dusts vary with height as,

$$\nu_{ed} = \nu(0).e^{-h/10} \qquad (14)$$

where $\nu(0)$ is the collision frequency at the height of 90 km and h is in steps of1 km. We set $\nu(0) \approx 8.0\times10^{5}$ which is comparable to the electron neutral collission frequencies. This is equivalent to the number density ≈ 10^{5} for dust particles of uniform diameter of 10 microns.

Table 1: The atmospheric model and the observed electron and current densities .

h (km)	W	T (^{o}K)	n_n x10^{13}	n_{e1} x10^{4}	j_1 amp/km^{2}	n_{e2} x10^{4}	j_2 amp/km^{2}	n_{e3}	j_3 amp/km^{2}
	MSIS-E-90 Model			Rocket 20.06		Rocket 20.07		Rocket 20.05	
91.00	29.10	92.60	6.11	2.43	1.35	0.79	1.43	1.77	5.17
92.00	29.06	190.50	5.21	3.47	2.01	1.05	1.43	2.03	5.04
93.00	29.03	188.40	4.43	4.57	2.87	1.38	1.43	2.40	4.72
94.00	28.99	186.30	3.76	5.50	3.70	1.77	2.16	2.80	4.43
95.00	28.94	184.30	3.19	6.77	4.42	2.10	3.28	3.37	4.21
96.00	28.88	182.60	2.69	7.83	5.25	2.85	4.62	3.87	4.35
97.00	28.83	181.20	2.27	8.87	6.34	3.41	5.93	4.30	4.96
98.00	28.76	180.30	1.91	9.90	7.72	4.20	7.11	5.07	6.19
99.00	28.67	179.70	1.60	10.97	8.98	5.31	8.16	5.80	8.29
100.00	28.60	179.80	1.34	11.67	9.90	6.30	9.25	6.60	10.53
101.00	28.50	180.50	1.11	12.90	11.95	7.41	10.16	7.73	12.51
102.00	28.40	181.80	0.93	14.17	14.85	8.62	10.95	9.07	14.24
103.00	28.30	183.80	0.77	15.27	16.83	10.07	11.51	11.03	15.41
104.00	28.19	186.40	0.64	15.90	18.12	11.51	12.56	12.67	16.37
105.00	28.07	189.80	0.53	16.57	18.45	13.18	14.43	14.37	17.17
106.00	27.95	193.90	0.44	16.90	18.15	14.49	16.10	15.60	17.69
107.00	27.83	198.70	0.37	17.20	17.13	15.61	16.46	16.17	17.44
108.00	27.69	204.50	0.30	17.53	15.81	16.13	15.90	16.10	16.77
109.00	27.57	211.20	0.25	17.53	14.29	17.02	15.15	15.87	15.52
110.00	27.43	219.10	0.21	17.43	12.44	17.57	13.57	15.57	14.37
111.00	27.29	228.20	0.18	17.33	10.96	18.16	11.90	15.07	13.09
112.00	27.16	238.60	0.15	17.10	9.90	18.66	10.49	14.53	11.39
113.00	27.02	250.50	0.12	16.83	8.58	19.18	8.36	14.27	10.00
114.00	26.89	263.80	0.10	16.60	7.92	19.54	5.84	14.23	9.01
115.00	26.76	278.70	0.09	16.47	7.26	19.34	4.23	14.33	7.97
116.00	26.64	295.10	0.08	16.37	6.60	19.05	3.12	14.43	7.17
117.00	26.51	312.90	0.06	16.27	5.94	18.66	1.97	14.53	6.35
118.00	26.38	332.10	0.06	16.30	5.54	18.13	1.48	14.57	5.79
119.00	26.27	352.30	0.05	16.33	4.92	17.41	1.44	14.77	5.39
120.00	26.16	373.00	0.04	16.50	4.22	17.25	1.44	14.83	5.01

The electrojet current values are from proton precession magnetometer (Sastry, 1968) and the electron density profiles are from the Langmuir and Resonance probes (Prakash and Subbaraya,1967 and Prakash et. al., 1972) launched on-board sounding rockets. Using the equations.(11-13) and the values shown in the table 1, the relevant parameters are computed. The vertical profiles of σ_C with and without dusts and the current observed are shown in the Figures. 1-3. In all these Figuress. σ_C profiles without dusts are neither similar nor follow closely the current profiles observed. They also show peaks at 102 km. which is lesser by 4-5 km. But we see that the σ_C profiles with dusts are similar to the j profiles. The peaks occur nearly at the observed heights of 105, 107 and 107 kms respectively.

In an alternative explanation, Ronchi et. al., (1990) incorporate plasma turbulence and associated electron density irregularities to model the current density profiles. We can expect that these turbulences can induce random motions thus giving rise to an additional effective collisional frequencies. But Richmond (1991) opines that the main reduction in the polarisation fields occur below the electrojet region and thus shifting the conductivity peak. But for the validity of this idea,the altitude dependence of turbulent quantities and their profiles are needed. In the present model we need the distributions of dust density and size distribution.

As seen in the present paper, we suggest that there are significant dust particles of varying sizes. These may also be sources for the metallic ions. Both have meteoric origin.

Summary and conclusion

In conclusion, the Hall, the Pederson and the Cowling conductivities recalculated using an effective electron-dust collision frequencies can account for the observed conductivities in the ionosphere. It is suggested that the dusts will modify the conductivities significantly and thus cause a difference in the height profiles between the theory and observation. The idea presented by Ronchi et. al., (1990) and in this paper depend on the change in the collision frequencies. We know that there is a presence of dust particles in significant numbers. At the same time the electron density gradient is significant for the excitation of wave turbulences. Therefore, it will be worth comparing these two alternate ideas.

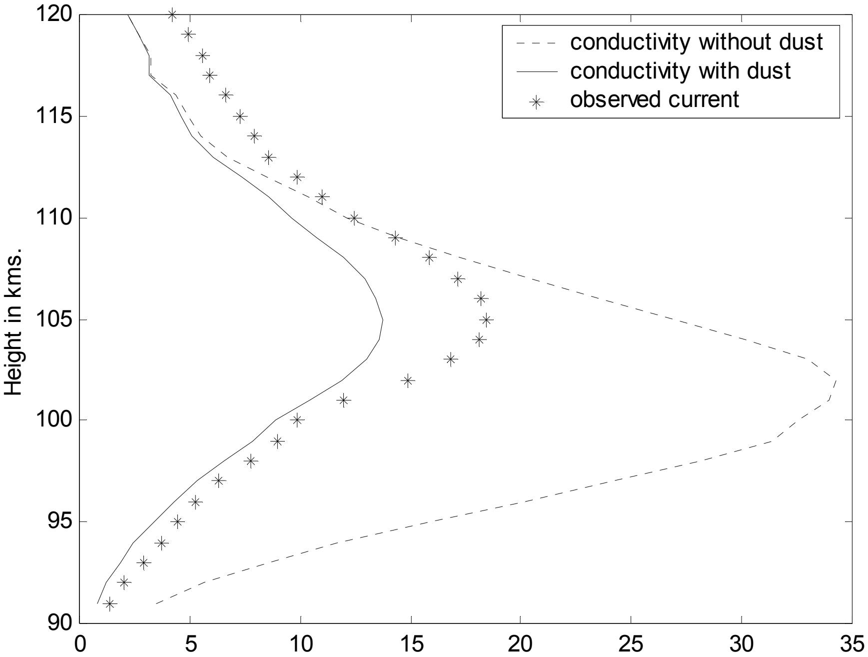

Fig.1 Variation for the flight 20.06

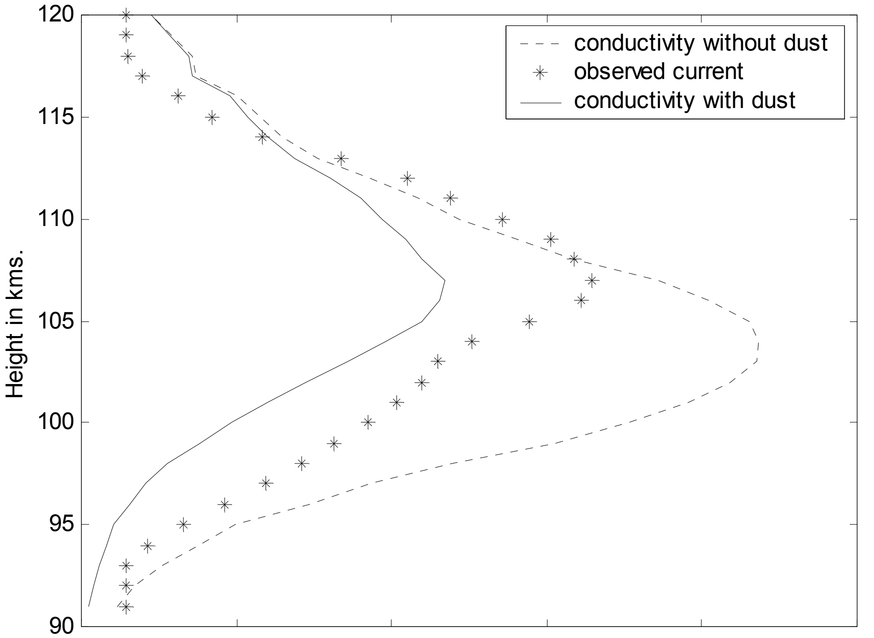

Fig. 2, Variations for the flight 20.07

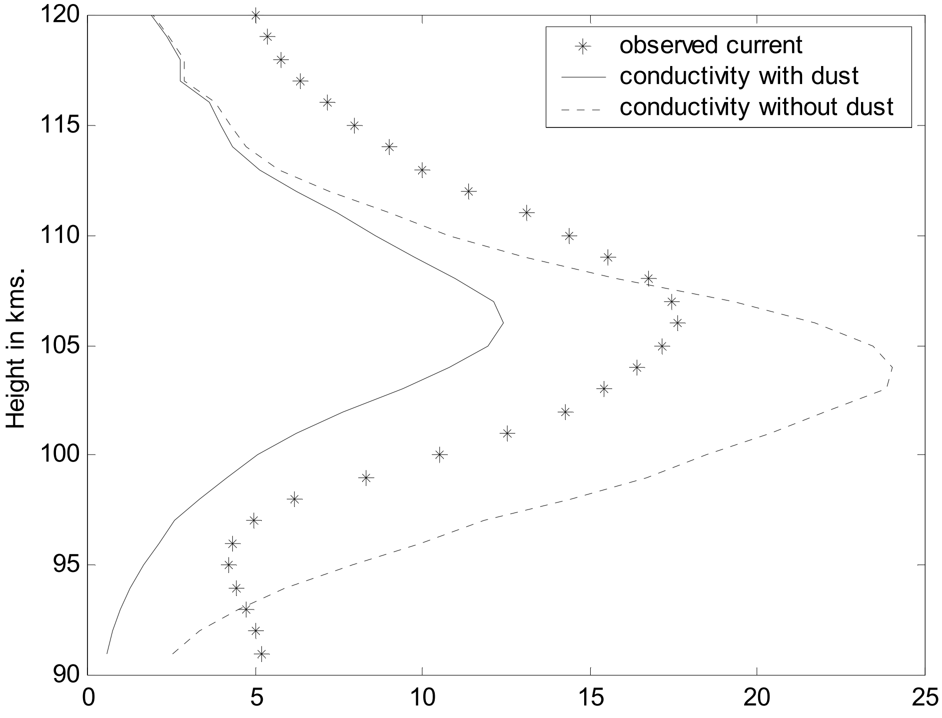

Fig.3 Variation for the flight 20.05

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