Introduction

Recent observations by MAGSAT orbiting the dawn-dusk meridian have reconfirmed the existence of the strong eastward electrojet current system in the equatorial ionosphere. Maeda et al (1982) have reported a systematic change in the eastward (Y or D) component of the magnetic field on the dusk side dip equator which they have attributed to a meridianal current system which closes itself through north-south currents at the base of the vertical currents and through the field aligned currents, basically in the dusk-meridian. Here we report a systematic change in all the three components of the field near the dip equator and propose a new model for the vertical currents which will account for not only the Y-but also the X-component (north) of the field. It is already known from the ground (Matsushita & Campbell 1967), as well as space (Onwumechilli and Agu, 1981) observations that the height-integrated electrojet intensity varies with local time. Naturally this does not satisfy the vanishing of the divergence of the current density. We propose a vertical current density propotional to the eastward gradient (∇_yy) of the horizontal electrojet currents to be flowing at all local times. As to the vertical extent of the currents we do not speculate much. They may connect themselves with a possible F-layer current (Dahau and Ramanelli, 1979) or with the field aligned currents. We also present a numerical calculation of the fields generated by such a vertical current system. The horizontal jet curmnets together with the associated vertical currents can account for the MAGSAT observations as well as the simultaneous ground data collected from the observatories situated near the dip equator in the Indian subcontinent.

Data Reduction : We have chosen a quiet period : Nov. 21-23, 1979 and have restricted our studies near the dip equator and the longitude zone of 60°E to 113°E. The main field is removed from the MAGSAT data contained in the NASA-supplied tape labelled as CRONFIN. The field model used is MGST (4/81) of Langel et al (1981); the maximum degree and order of the terms in the model is 13. The CRONFIN data contain 16 measured values per second along the satellite path whereas the available orbit data are only one per minuite. Numerical inter-polation method is employed to get the orbit data for the intermediate periods. To save computer time we have read every eigth data point from the tape. The residual field after subtracting the main field was averaged over a five-second interval (which means averaging over about 3 km) in order to minimise the random error involved in the interpolation of the orbit data. Correction due to the ring currents was performed as described by Langel et al (1981).

Results and Discussion :

In fig 1 we have plotted a few latitudinal profiles of the residual fields (without ring current correction)=in different longitudinal zone in the dawn meridian. Although the overall feautures are the same, there are still variations of a few gammas between the values at a given latitude but different longitudes. Since the Y component (east) is not much affected by the ring currents and the ionospheric currents in the dawn sector are presumed to be small, it is clear that the contributions from the crustal anomaly fields are not negligible and need to be corrected. It so happens that the crossover point between the morning and the evening passes in any longitudinal zone is very near to the dip equator as shown in Fig.2. Therefore, subtracting the morning values from the evening pass values at a particular latitude will eliminate the crustal anomaly field to some extent, atleast in the neighbourhood of the crossover point. The resulting field components which can be assumed to be arsing from the ionospheric currents, have been shown in Figs. 3 a,b.

Supporting ground data from the three observatories (Trivandrum, Kodikanal and Annamalainagar with dip latitudes - 0.5°, 1.5° and 2.9° respectively) in the approximate longitude zone of 77°E to 79°E have been subjected to the same ring current correction as that of the satellite data. The field components at 18.00 hrs local time minus those at 6.00 hrs local time and averaged over the three days Nov. 21-23, 1979, have been shown in Fig. 4. The D-variation (east-west component of the field) is negligibly small and therefore has not been shown.

Strictly speaking the ring current corrections for the ground data should have been done from a global analysis of ground based data only. Since such an analysis is not available for the period concerned we have assumed that the ring current potential at the gouund level is the same as that at the satellite level.

Although fields in figs. 3 a,b have been plotted as a function of geographic latitude, rather than dip-latitude, it is clear that X-component is fairly symmetrical about the dip equator. On the otherhand, Y-component exhibits certain amount of asymmetry. The dusk meridian results of Maeda et al (1981) do not show this asymmetry There are two distinct features evident from the results derived from these MAGSAT fields : Inspite of the large scatter in the data, X and Z components (Gig. 3 a,b) are consistent with the west-east electrojet flowing below the satellite height (360 to 500 km). According to standard electrojet models (Yacob, 1965 ; Matsushita & Campbell, 1967 ; Dahau & Romanelli, 1979) the current density is almost constant up to about 300 km in the N-S direction from the dip equator and then falls off very sharply with the latitude. Latitudinal profiles of X and Z at the MAGSAT height are rather flatter than those at the ground level. This is only expected for the simple reason that the satellite height from the jet level is about 2.6 times (~260 km) greater than the jet height from the ground (~100 km).

2. The next point of interest is the observation of small but finite Y - field at the satellite height. The sign of Y (positive in the southern and negative in the northern side of the dip equator) is not compatible with the Sq currents. This indicates the existence of a vertical current system at the equatorial ionosphere as conjectured by Maeda et al (1982).

It must be remembered that the observed fields are the combi effect of the ionospheric jet as well as its induced image-current system below the ground level. Moreover, if we postulate a vertical current system in order to explain the Y-field at the MAGSAT height, a fraction of the observed X-field also must be due to these currents. Let us examine the numerical values of certain relevant parameters in order to check the internal consistency of this hypothesis.

The fraction of the total observed field due to the induced currents is somewhat dependent on the latitudinal extent of the electrojet and the depth of the image currents. Following the results of Yacob (1963, 1977) and Duhau Romanelli (1979) we assume that the electrojet,with half width of about 300 km in the N-S direction, is approximately at 105 km altitude; and the induced currents flow at a depth of about 506 km below the ground. Following this model it can be shown that at the dip equator the ratio of the field due to the image current to the field due to the jet current is approximately .44 on the ground and about .38 at the satellite height respectively. Therefore, out of 20γ field (for X) observed at Trivandrum (fig 4) approximately 13.8γ can be attributed to be due to the jet current and 6.2γ to be due to the image current respectively. This current system, then should yield - 10γ at the satellite height whereas the image contribution should be + 3.7γ. The observed - 15γ field at the satellite height, thus, demands that the contribution of the vertical currents density to X must be of the order of -8γ with its contribution of about 5 to 6γ to Y - field

Vertical Current Model.

The ground observation shows that the electrojet currents are predominantly in the west east direction at all local times. However, the jet intensity is a sharply varying function of local time. This is demonstrated in fig.5 where we have ploted the local variation of the horizontal component H, normalised by its peak value and averaged over the three days (Nov. 21-23, 1979) for an equatorial station TRV (dip latitude = - 0.5°, geographic longitude = 76° 57'E).

Onwumechilli and Agu (1981) also concluded from the POGC satellite data that the strenth of the jet in the mid-morning and mid-afternoon is weaker than its noon value although its latitudinal width is more or less uniform.

These observations, together with MAGSAT results analysed above prompt us to believe that a vertical current density exists at all local times which is related to the gradient of the horizontal jet currents, i.e.

$$J_z(x,y) \propto \frac{\partial}{\partial y} \dot{j}_y(x,y)$$

where Y is parallel to the equatorial jet direction and Z is the vertical direction respectively. Jz is the vertical current density (in units of amp/square km) and $\dot{j}_y$ is the height integrated horizontal current intensity (in units of amp/km) respectively. We perform a numerical calculation of the contribution of this vertical current system to the Y component of the field at the MAGSAT height. Local time variation of J_z is derived from the gradient of normalised H shown in fig 5. We assume the vertical current starts from 100 km height and extends upto an arbitrarily great height, say, 9000 km. If the peak value of $\dot{J}_y$ be 300 amp/km and if the latitudinal extent of horizontal jet current be ± 300 km., the resulting vertical current will produce 5 γ for Y in the evening sector at the MAGSAT height. The corresponding contribution to X is about 6 γ. The contribution of these vertical currents to the ground fields are one order of magnitude less. on the other hand if the vertical extent of the currents, J_z is just below the satellite height, peak $\dot{J}_y$ has to be more intense (600 amp/km) to produce the same field. Even if the electrojet half width is slightly wider, say , 350 km, still the required current density is very high (510 amp/km). Such high intensity for the jet has not been observed on the ground. Therefore, we believe the vertical extent of the current to be much greater than the MAGSAT height. In the dawn side of the ionosphere the horizontal currents j_y as well as their gradient are much weaker than their dusk side values as can be seen from fig. 5. Therefore the dusk-dawn difference of the field values as plotted in fig. 3 do indeed represent the dusk values, as we have claimed earlier in this paper.

Vertical extent of J_z

Although the vertical current model satisfactorily explains both the MAGSAT data and the corresponding ground data, one must find and outlet for these currents. It is possible that these vertical currents connect themselves with the F-layer dynamo fields, the existence of which has been conjectured by many authors in the past (Duhau and Romanelli, 1979,). They may also find a return path in the field aligned currents at the top of the ionosphere. The theoretical estimates of the field aligned currents which flow between the two hemispheres are of the order of 5×10^{-9} cm/m^2 (Taxeda, 1982). The main difficulty in postulating a vertical current density at the equator is that J_z is assumed to be zero in all dynamo calculations for the horizontal current systems. For the electrojet, 300 amp/km height - integrated currents over a vertical height of about 10 km (width of the E layer) means a current density of 30 amp/Sq.km. In contrast, the vertical current density in our model turns out to be of the order of .03 amp/sq km which is three orders of magnitude less than the horizontal current density. Therefore, the vertical current model does not interfere with the dynamo calculation where it can still be regarded as zero.

Acknowledgments

This work has been carried out with the MAGSAT data made available by NASA to the Indian MAGSAT team. The author is thankful to Dr. Anil Seth for his help in the development of the computer software for reading the MAGSAT tapes.

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Figure Caption

Fig - 1 Geographic Latitudinal profile of the north (X), east (Y) and the vertical (Z) components of the residual fields for a few dawn passes of the MAGSAT on Nov. 21-23, 1979. Dip equatorial crossings are approximately in the longitude (geographic) zone of (a) 114°E, (b) 91°E, (c) 68°E, (d) 100°E (e) 77°E respectively.

Fig. - 2 Two typical consecutive morning and two consecutive evening orbit positions of MAGSAT. The evening passes cross the morning passes in the latitude-longitude plane at a point slightly north of the dip equator. The radial co-ordinates near the cross over points are indicated by the arrows.

Fig. - 3 a,b The latitudinal (geographic)profile of the three components of the magnetic fields at the MAGSAT height arising from the dusk side ionospheric currents:

(a) the solid line represents the negative of X-component and the dashed line plots the Y-component respectively.

(b) It shows the Z-component of the field. The northern latitudes are positive. The average position of the dip-equator is indicated by an arrow.

Fig. - 4 The ionospheric contribution to the X and Z components of the magnetic field at 18-00 local time as observed at the ground observatories. The data have been averaged over three days Nov. 21-23, 1979.

Fig. - 5 Local time variation of the ionospheric contribution to the X component of the field at TRV (dip latitude = -0.5°) normalised by its peak value near the local noon.

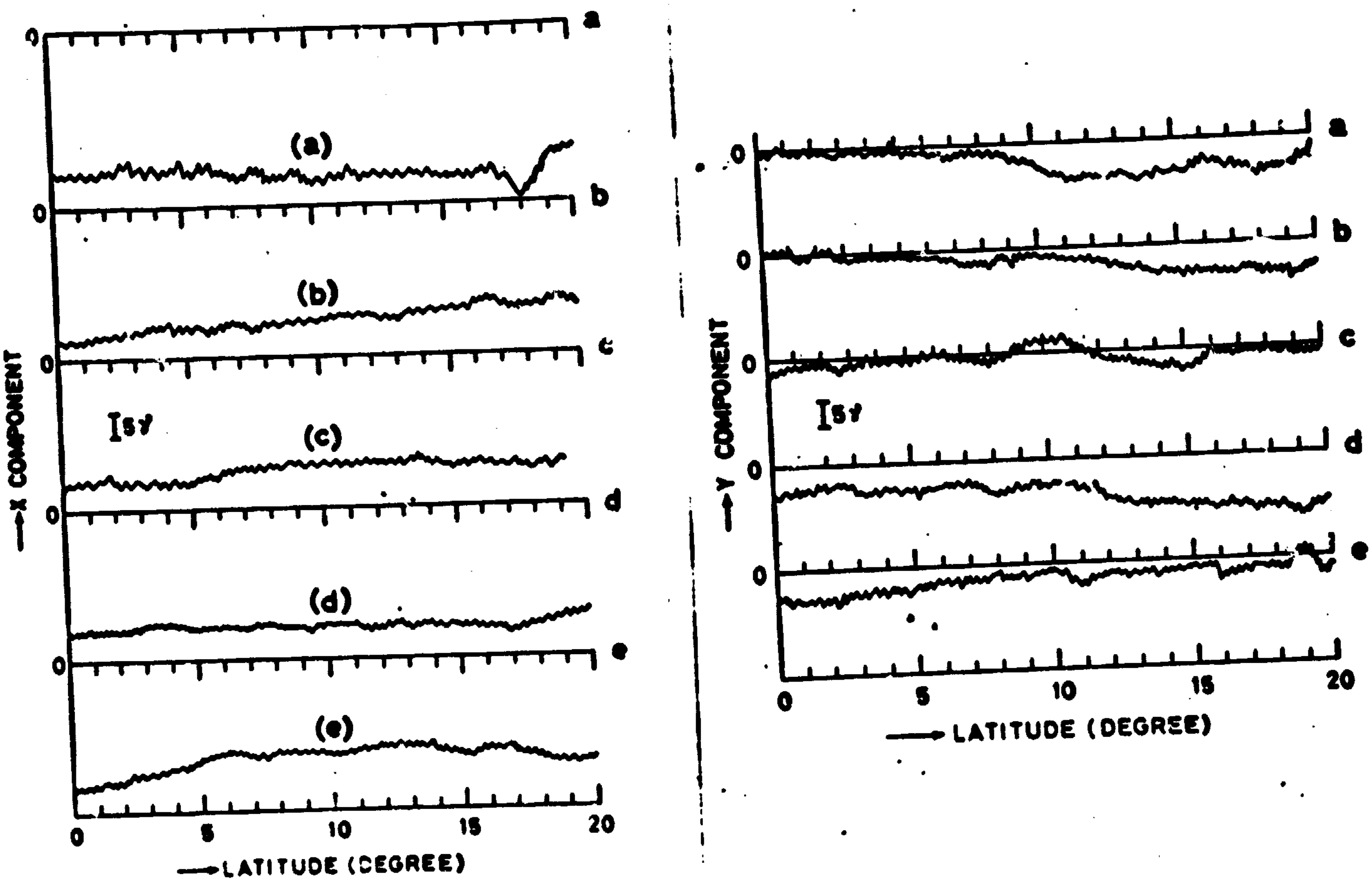
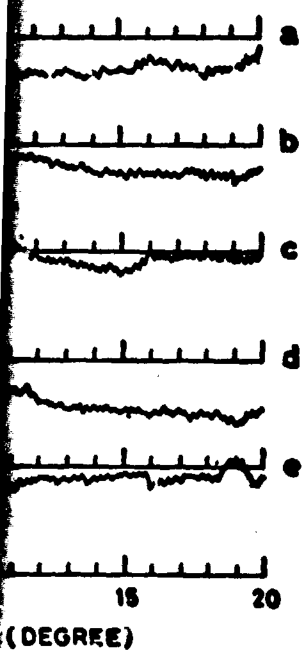
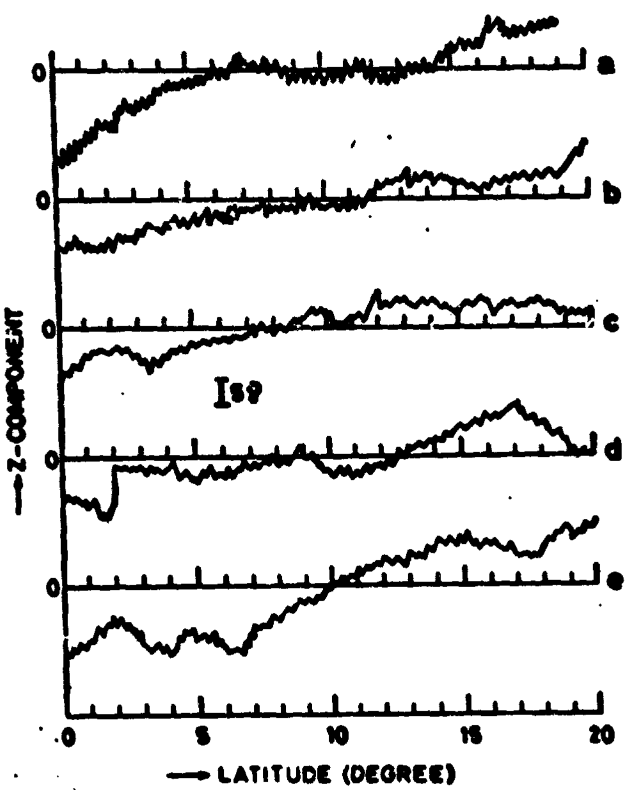


FIG. 1

FOLDOUT FRAME


a
b
c
d
e
15
20
(DEGREE)


0
a
b
c
d
e
Z-COMPONENT
0
5
10
15
20
LATITUDE (DEGREE)

. 1

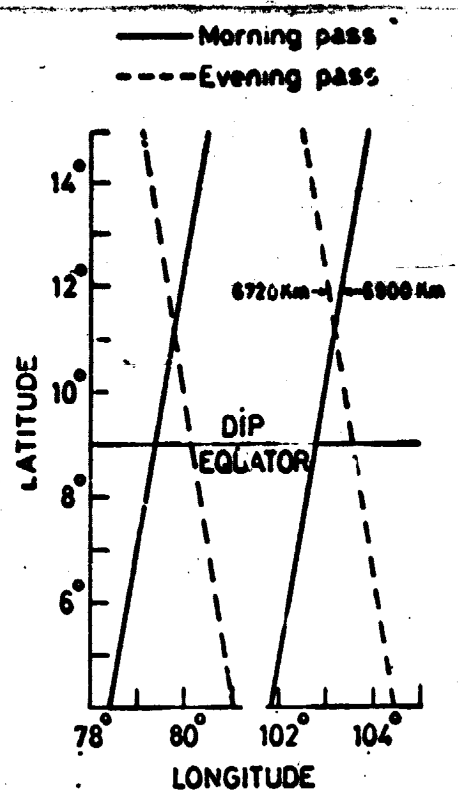


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FIG. 2

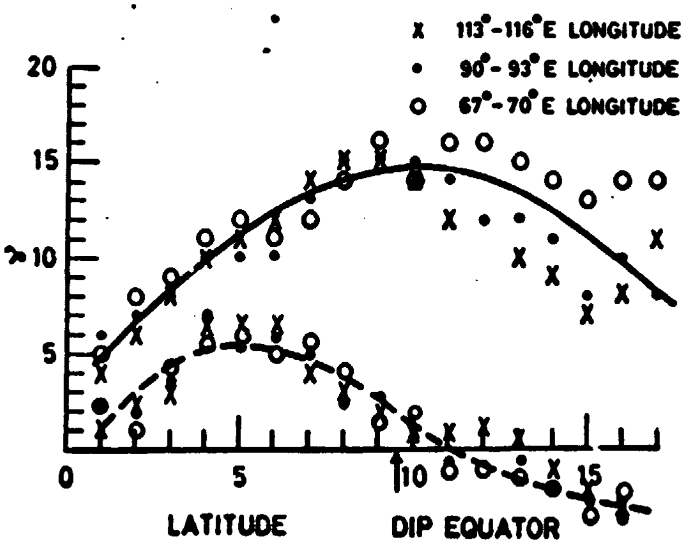

FIG. 3(a)

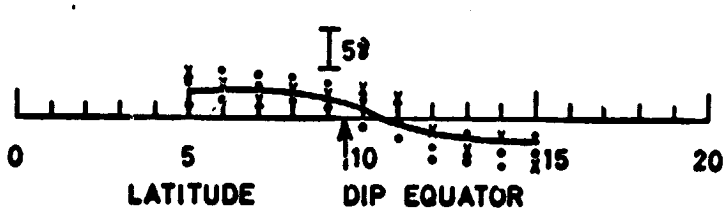

FIG. 3(b)

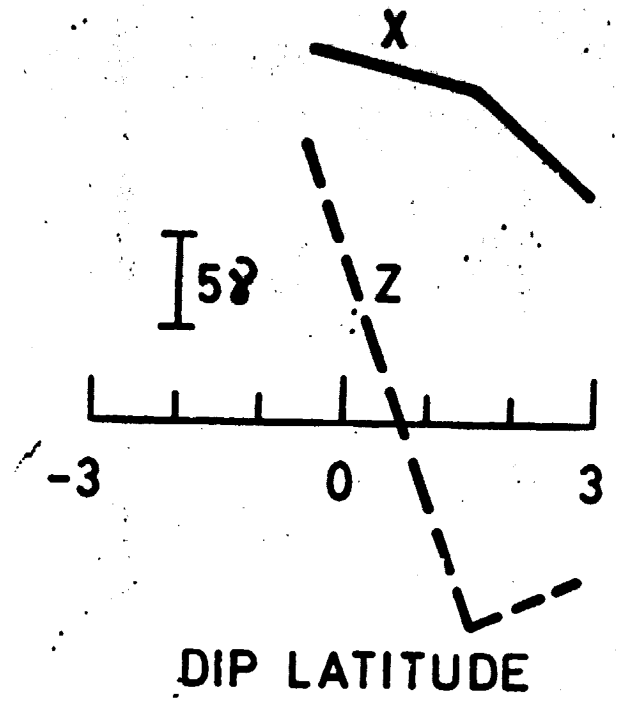
X
5γ
Z
-3
0
3
DIP LATITUDE

FIG. 4

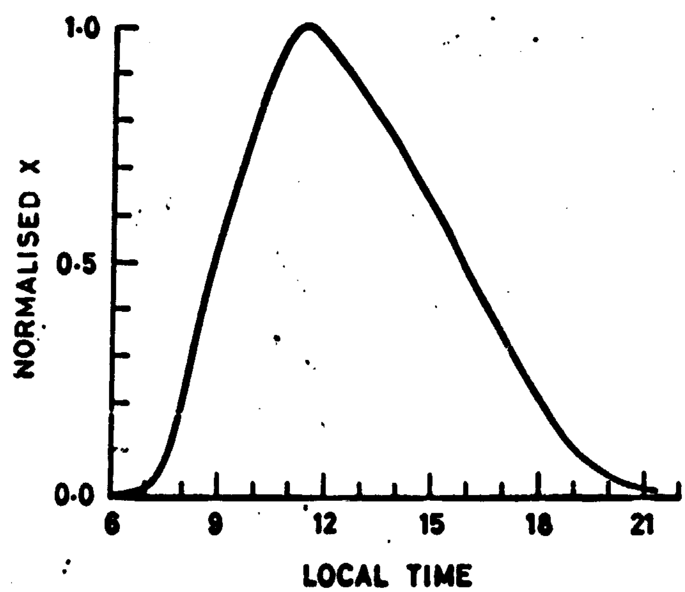
1.0
0.5
0.0
NORMALISED X
6
9
12
15
18
21
LOCAL TIME

FIG. 5

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EQUATORIAL IONOSPHERIC CURRENTS DERIVED FROM MAGSAT DATA

Manashi Roy

Indian Institute of Geomagnetism
Colaba, Bombay - 400 005.
India.

Abstract

The MAGSAT data on the three components of the geomagnetic field are subjected to ring current correction and crustal anomaly elimination near the dip equator. The evidence of a strong west east electrojet current below the satellite height (~350 km) is confirmed. Strong evidence of east west component of the field suggests the existance of a vertical current originating at the jet level and extending upwards. A model calculation shows that such a current system can explain the satellite data as well as the ground data.

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