5.1 Introduction:

The results of a study of the quiet day electrojet by in-situ measurements of magnetic field were presented in the previous chapter. In this chapter, the results from a unique rocket magnetometer flight conducted for the study of the equatorial electrojet during the main phase of a magnetic storm will be discussed.

It is now well known that just as the amplitude of the regular quiet time diurnal variation of geomagnetic field shows an enhancement in the equatorial region, some of the short duration disturbances also show such enhancements in this region. Ferraro and Unthank (1951), Sugiura (1953), Yamura (1954) and many others have studied the enhancement of storm time disturbance effects near the dip equator. Sugiura (1953) pointed out that the storm sudden commencements (SSC) during day time show considerable enhancements in the equatorial region. Enhancements of the amplitude of initial phase were observed by Vestine (1953) and Forbush and Vestine (1955), and the enhancement of negative SSCs was reported by Matsushita (1960). Vestine (1953) who studied the field
depression during the main phase of several storms found no enhancement in the main phase depression in the equatorial region. Obayashi (1969) has summarised the effects of extra-terrestrial origin observed in the electrojet region. He has discussed the origin of the DP2 associated fluctuations, occasionally seen in the electrojet region, during certain disturbed periods. The various storm time effects in the electrojet region have been reviewed by Bhargava (1969).

Kane (1973) has evaluated the DS component during the magnetic storm and has observed that the equatorial electrojet during the noon hours usually weakens during the main phase of a magnetic storm and sometimes during the recovery phase also. Some of the important features of disturbed day geomagnetic variations have been summarised and presented in a recent review by Kane (1976).

Taking the observed day time enhancement of disturbance variations in the equatorial region as mainly of ionospheric origin, mechanisms have been suggested by Akasofu and Chapman (1964), Closs (1967) and others to explain the augmentation of SSC and initial phase effects in the equatorial region.

The only in-situ measurement carried out so far for the study of mid latitude ionospheric currents during magnetic storm did not, according to Burrows (1976), show any modifi-
cation of the Sq currents during the storm. No results of in-situ investigation of equatorial electrojet during a magnetic storm have been reported so far except the one presented here. In this investigation, the effect of the storm on the equatorial electrojet has been studied using simultaneous measurements from a rocket-borne magnetometer and the data from a string of ground magnetometer stations spread in latitude across the electrojet region.

5.2 Details of the Experiment:

A Petrel rocket carrying a dual cell Rb. vapour magnetometer (FL. P60/20.15) was launched from Thumba, on February 13, 1972 at 1825 hrs. IST. The magnetometer sensor was mounted at an angle of 45° to the rocket spin axis. The rocket was launched at an azimuth of 266° and an elevation of 86°. As discussed in chapter 2, section 2.1.2, with this mounting and launch coordinates, the magnetometer will give good signal except during two narrow dead zones in a spin cycle. The rocket reached an apogee of about 143 km. The trajectory information was obtained using the radar skin-track data, the azimuth and elevation values from the ground tone-range system and the on-board magnetometer data.
Data from the rocket-borne magnetometer was obtained throughout the upward leg of the flight. Soon after the apogee, the data was lost due to telemetry failure. Signal appeared again just before the vehicle reentry and good data was obtained thereafter. The fore-body release mechanism used for separating the experimental payload from the second stage of the rocket did not function, which resulted in a modulation of the measured field by about ± 10 nT.

5.3 Ground Data:

The launch day, February 13, 1972 was characterised by a mild magnetic storm. The H variations recorded at Trivandrum, Kovilpatti, Kodaikanal, Tiruchirappalli and Annamalainagar stations which are under the equatorial electrojet, the records from Hyderabad and Alibag observatories which are away from the electrojet and the magnetic H variation at Sabhawala, an observatory near the Sq focus, on February 13, 1972 were examined to determine the effect of storm on the diurnal variation. Figure 5.1 shows the H variations observed at these stations on the day of launch. It is seen that the magnetic field variation was undisturbed as on quiet day until about 1600 hrs. IST. The field started decreasing rapidly after 1600 hrs and reached a minimum around 1830 hrs IST. Thereafter the field started recovering.
FIG. 5.1. The H variations recorded at the ground magnetic observatories and temporary magnetic stations, Kovilpatti and Tiruchirapalli, on Feb. 13, 1972. The launch time of the flight P60/20.15 is shown in the figure. The depression in H at the time of launch is due to the main phase of a weak magnetic storm. Hourly values of H have been used in preparing these plots.
The rapid decrease in the H field after 1600 hours IST was due to the main phase of a magnetic storm. The day was characterised with an Ap index of 22.

5.4 Discussion:

It is seen from the magnetograms of Figure 5.1 that the H variation level of the previous midnight was quiet, at all the stations. The depression from the previous midnight level in the H component at the launch time of the rocket, (1825 hrs IST) at different stations considered, is shown in table 5.1. Careful examination of the data of Figure 5.1 and table 5.1 show that the depression is not the same at all the stations.

<table>
<thead>
<tr>
<th>Station</th>
<th>Depression at 1830 hrs on February 13, 1972, in nT.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trivandrum</td>
<td>29</td>
</tr>
<tr>
<td>Kovilpatti</td>
<td>30</td>
</tr>
<tr>
<td>Kodaikanal</td>
<td>30</td>
</tr>
<tr>
<td>Tiruchirapalli</td>
<td>32</td>
</tr>
<tr>
<td>Annamalainagar</td>
<td>14*</td>
</tr>
<tr>
<td>Hyderabad</td>
<td>39</td>
</tr>
<tr>
<td>Alibag</td>
<td>40</td>
</tr>
<tr>
<td>Sabhawala</td>
<td>55</td>
</tr>
</tbody>
</table>

*The instrument did not function between 0900 to 1100 hrs IST and the Δ H at 1200 hrs IST is greater than that at Trivandrum which indicates that the magnetogram is in error.

TABLE 5.1 The depression in the horizontal component of the earth's field, below the previous midnight level at 1830 hrs IST on Feb. 13, 1972, recorded at the various ground stations in the Indian zone. The depression is due to the main phase of a mild magnetic storm.
The depression is minimum at Trivandrum and increases systematically with latitude. We will first examine how this can happen.

As the depression in the magnetic field due to the main phase of the magnetic storm is caused by the magnetospheric ring currents, the depression can be expected to be the same at low latitude stations like Trivandrum and Alibag. The magnetic storm effect has a symmetric component $D_{st}$ and an asymmetric component $DS$. The values of equatorial $D_{st}$ are evaluated periodically and published by Sugiura and Poros (1971). The $D_{st}$ is latitude dependent, and changes as $D_{st} \cos \theta$ where $\theta$ is the geomagnetic latitude of the station. $D_{st} \cos \theta$ is not very much different for the stations Trivandrum and Alibag, hence latitudinal dependence of $D_{st}$ cannot explain the observed difference in depression at these two stations.

$DS$ effect is longitude dependant and is not evaluated regularly. The longitude difference between Alibag and Trivandrum is negligible to have any difference in $DS$ effect. Therefore, the observed systematic decrease in depression with latitude must be of ionospheric origin. An estimate of this effect can be made as discussed below with the available data.
One method of evaluating the strength of the electrojet is to subtract the H variation at Alibag from that of Trivandrum. By this way the common magnetospheric effects are removed and the remainder will be mostly the ionospheric effect, specially that due to the electrojet. The $H_T - H_A$ curve for February 13, 1972 is shown in Figure 5.2a. It can be seen from this that a positive departure of about 10 nT persisted at this time at the ground, due to the electrojet flowing eastwards. To find whether such a positive variation of about 10 nT is normally expected at these hours (1830 hrs) on quiet days or not, the average of the H variation on five international quiet days for the months of January, February and March 1972 at Trivandrum was examined. This average variation is shown in Figure 5.2b. It can be seen here also; that on the average, a positive excursion of about 12 nT at 1830 hours is expected on quiet days in this season, indicating that the depression being less at Trivandrum at 1830 hrs on February 13, 1972 as compared to other stations is due to a positive contribution from the ionospheric currents. This means that the storm depression is counteracted by the normally present electrojet effect and what is actually observed at the ground is the resultant of storm depression and the positive effect of the electrojet. While the storm effect does not change appreciably with latitude, the electrojet effect falls off
a) The electrojet strength on Feb. 13, 1972, as obtained from subtracting the $H$ variation at Alibag ($H_{\text{ALI}}$), a non-electrojet station, from that at Trivandrum ($H_{\text{TRI}}$), an electrojet station. A positive $\Delta H$ of about 10 nT from the midnight levels is seen at the launch time of F1.P60/20.15.

b) The average of the $H$ variations at Trivandrum on international quiet days in the months of Jan., Feb., and March 1972. A positive $\Delta H$ of about 12 nT from the mean night level is seen here also at the launch time of F1.P60/20.15.
rapidly with latitude. This explains why the depression is minimum where the jet effect is maximum.

The evidence to show that both the storm effect and the jet effect were simultaneously present at the equatorial stations during the storm main phase comes from the rocket measurements of Flight P60/20.15. The result from this flight is shown in Figure 5.3, where the difference field $\Delta F$ is plotted against the altitude. It can be clearly seen from this figure that there is no indication of reversed currents at the time of this flight that can account for the field depression observed at Trivandrum and other low latitude stations. Further, there is an indication that the current flow, whatever its intensity be, was normal as on a normal quiet day. It can be seen from Figure 5.3 that the $\Delta F$ levels below 90 km and above 130 km are distinctly different and the first level is higher than the second, during both ascent and descent. Intensity of the current cannot be estimated correctly due to large modulation on the $\Delta F$ profile, but it can be said that the electrojet effect cannot be more than 20 nT, which is the peak to peak amplitude of the modulation. This is the electrojet effect that is expected corresponding to the ground variation of 10 nT observed at the time of the flight as discussed earlier, (Figure 5.2). Thus, the study of the data from the ground
The difference field $\Delta F = (F - F_T)$ plotted as a function of altitude. $F$ is the rocket measured field from Fl. P60/20.15 and $F_T$ is the theoretically computed field for this flight epoch.
stations and the data from in-situ measurements show that the main phase of the storm did not affect the electrojet.

5.5 Conclusions:

1. The rocket magnetometer launched during the main phase of a storm did not detect any reversed currents that could produce or could have enhanced the depression observed on the ground. This indicates that the observed depression is of magnetospheric origin.

2. There is an indication in the flight results of an east-ward electrojet at the time of the flight, whose magnetic effect is of the order of 10 nT. From an analysis of the ground station data, such an electrojet effect is expected on quiet days in this season. The magnitude of this current is sufficient to account for the systematic decrease in the depression of the magnetic field observed as the center of the electrojet is approached.