Equatorial Aeronomy deals with that region of upper atmosphere over the equator where the processes of dissociation and ionization are important. This region extends from approximately 30 km above the surface of the earth to the outer limit of atmosphere at many earth radii. In this vast domain of aeronomy lies a region of relatively smaller extent known as 'ionosphere'. The term ionosphere is strictly applied to those regions where free electrons exist in such an abundance so as to affect the radio wave propagation significantly. The lower limit of ionosphere is at an altitude of nearly 50 km. The upper boundary of ionosphere is rather less sharp and merges with the magnetosphere. The ionosphere is subdivided into three regions: D-region, below
80 km altitude, E-region, between 80 and 160 km and F-region, above 160 km.

The nature of ionospheric plasma in D, E and F-regions is quite different. In the D region due to large neutral density, the collision frequencies of electrons and ions with neutrals are larger than their respective gyrofrequencies. The electrons and ions are thus controlled entirely by the collisions and for all practical purposes do not see the effect of the magnetic field below 75 km. Beyond 75 km and in the E-region, the collision frequency of electrons is smaller than their gyrofrequency whereas for ions the reverse still holds good. Thus in the E-region electrons are highly magnetised and ions are not. This region, therefore, is susceptible to charge separation. It is in this region of equatorial ionosphere that a strong current known as equatorial electrojet has been observed. This current is generally eastward during the daytime. However, on some special occasions the direction of current becomes westward for a few hours during daytime, the flow of such reversed current is termed as counter electrojet. The direction of current reverses during nighttime and becomes westward.

The present dissertation concerns with the study of ionization irregularities in the D and E-regions of the equatorial ionosphere. The irregularities are defined as spatial and temporal variations in the electron density. The study of ionization irregularities helps, to a very large
extent, in understanding the various plasma processes taking place in these regions. It has become increasingly clear by now that the study of irregularities gives very valuable information about the nature of the electric fields and the electrojet currents in the ionosphere. In addition, since the irregularities can scatter radio waves, their presence has been recently exploited for the communication at VHF frequencies. A knowledge of the properties of these irregularities would thus be very useful in planning high frequency communication links.

The electron density irregularities are produced by a number of causative mechanisms which operate in different regions of the ionosphere. An attempt has been made by the author to study the properties of irregularities produced through two such important mechanisms, viz. the cross field instability and the neutral turbulence. Since the excitation of cross field instability is closely related to the equatorial electrojet, section 1.1 is devoted to the models of equatorial electrojet. Sec. 1.2 deals with the phenomenon of counter electrojet. Observational results of ionization irregularities obtained using ground based and the rocket borne studies would be described in Sec. 1.3.

1.1 Equatorial Electrojet

The history of electrojet dates back as early as 1722 when Graham found that the compass needle executes some regular
oscillations (variations) during the day. The first explanation of these variations was given by Stewart (1882) in terms of an electric current flowing in the upper atmosphere. Stewart suggested that due to sun's heating convective currents of air are produced which can be regarded as conductors moving across magnetic lines of force. This is known as 'Stewart's atmospheric dynamo theory'. This theory got support from Schuster (1889) who proved that the major portion of the magnetic field variations has its source outside the earth. A more detailed theory was developed by him a little later (Schuster, 1908).

In 1922, a new feature of the geomagnetic field variations was brought to light at the geomagnetic observatory, Huancayo, Peru. It was found that unlike the daily ranges of the declination $D$ and the vertical component $Z$ the diurnal range of the horizontal component $H$ was abnormally large. The dynamo theory and the above mentioned observations got a new impetus with the experimental discovery of the ionosphere independently by Appleton and Barnett (1925), and Breit and Tuve (1925, 26). The verification of dynamo theory with the new discovery of ionosphere got slightly impeded when Pedersen (1927) pointed out that the conductivity of the ionosphere would be reduced due to the geomagnetic field. Preliminary calculations by Pedersen yielded a value of conductivity which was 5000 times less than the one required by Schuster's theory. The discrepancy in the conductivity values was, however,
reconciled by Cowling (1933) who found that if the medium is polarised the Hall current will be inhibited and, therefore, the conductivity would be highly enhanced. The idea of Martyn (1948) that this enhanced conductivity is good enough for the dynamo theory at all latitudes was modified by Cowling and Borger (1948) who pointed out that the enhancement of the conductivity is possible only at the equator because at other latitudes the polarisation which inhibits the Hall currents, would leak away horizontally.

Consistent with the above ideas were the observations of Egedal (1947,48) who found that the diurnal range of H at six stations, when plotted against dip latitude, exhibited a peak at the dip equator. Such enhanced diurnal variation at the dip equator was attributed by him to the electric currents flowing in a narrow zone near the dip equator. This observation was confirmed afterwards by other workers for many equatorial zones. This current was later named as "Equatorial Electrojet" by Chapman (1951).

1.1.1 Conductivities in the Ionosphere

In the lower region of the ionosphere (below 75 km) the electrical conductivity is very small as the region is characterized by

\[
\frac{\Omega_e}{\nu_{en}} \ll 1 \quad \text{and} \quad \frac{\Omega_i}{\nu_{in}} \ll 1
\]

where \( \Omega_e \) and \( \Omega_i \) are electron and ion gyrofrequencies and \( \nu_{en} \) and \( \nu_{in} \) are electron-neutral and ion-neutral collision frequencies respectively.
In most of the E-region of the ionosphere the electrical conductivities are large because the region is characterized by
\[ \frac{\Omega \epsilon}{\nu e n} \gg 1 \quad \text{and} \quad \frac{\Omega i}{\nu i n} \ll 1 \]
Under these conditions electrons are magnetised whereas the ions are not. The direction of primary electric field at equator is eastward during daytime. This field is generated due to tidal motions in the non-equatorial regions. Due to the presence of magnetic field the conductivity does not remain a scalar quantity and becomes a tensor.

In a weakly ionized plasma such as the E-region plasma, if the electric field is applied in a direction parallel to the magnetic field the resulting conductivity is known as 'direct conductivity' or 'longitudinal conductivity' and is represented by \( \sigma_0 \) where
\[ \sigma_0 = Ne^2 \left( \frac{1}{m_e \nu_e} + \frac{1}{m_i \nu_i} \right) \]
where \( N \) is the electron or ion density both being equal
\[ \epsilon \quad \text{is the electronic charge} \]
\[ m_e \quad \text{is the mass of the electron} \]
\[ m_i \quad \text{is the mass of positive ion} \]

The direct conductivity is independent of the magnetic field. If the electric field is applied in a direction perpendicular to the magnetic field, the conductivity in the
direction of the electric field is known as Pedersen conductivity and is represented by $\sigma_1$ where

$$\sigma_1 = N e^2 \left\{ \frac{v_i}{m_e (\Omega e^2 + \nu e^2)} + \frac{\nu_e}{m_i (\Omega_i^2 + \nu_i^2)} \right\}.$$  

In the above condition there is also a flow of electric current in the direction $\vec{E} \times \vec{B}$ where $\vec{B}$ is the magnetic flux vector. This current is known as Hall current and the conductivity supporting the current is known as Hall conductivity and is represented by $\sigma_2$ where

$$\sigma_2 = N e^2 \left\{ \frac{-\Omega e}{m_e (\Omega e^2 + \nu e^2)} - \frac{-\Omega i}{m_i (\Omega_i^2 + \nu_i^2)} \right\}.$$  

The general expression of the total current can be obtained if the electric field is resolved into two components viz. $E_o$ and $E_1$, parallel and perpendicular to the magnetic field respectively. The current density $J$ is given by (Baker and Martyn, 1953).

$$J = \sigma_0 \vec{E}_o + \sigma_1 \vec{E}_1 + \sigma_2 (\vec{b} \times \vec{E})$$  (1)

where $\vec{b} = \frac{\vec{B}}{B}$ is the unit vector in the direction of the magnetic field.

As pointed out earlier the inhibition of Hall current leads to an enhanced conductivity. To obtain the effective conductivity of the medium, Baker and Martyn (1953) considered the ionosphere as an ionized layer. If $x$ and $y$ represent magnetic south and east respectively, the magnetic flux $B$ dips
down at an angle $\theta$ to the $xy$ plane and the $z$ axis is
towards the vertical, then the sheet in the $xy$ plane can
be considered to be the ionosphere in the northern hemisphere.
With the assumption that the Hall current is inhibited ($j_z=0$)
the conductivity in the $x$-direction due to $x$ component of
the electric field is represented by $\sigma_{xx}$ and is given by

$$\sigma_{xx} = \frac{\sigma_0 \sigma_1}{(\sigma_0 \sin^2 \theta + \sigma_1 \cos^2 \theta)} \quad (2)$$

The conductivity in the $x$-direction due to $y$ component of
the electric field is represented by $\sigma_{xy}$ and is given by

$$\sigma_{xy} = \frac{\sigma_0 j_z \sin \theta}{(\sigma_0 \sin^2 \theta + \sigma_1 \cos^2 \theta)} \quad (3)$$

The total conductivity in $y$-direction due to $y$ component
of the electric field is represented by $\sigma_{yy}$ and is given by

$$\sigma_{yy} = \frac{\sigma_0 \sigma_1 \sin^2 \theta + (\sigma_1^2 + \sigma_2^2) \cos^2 \theta}{\sigma_0 \sin^2 \theta + \sigma_1 \cos^2 \theta} \quad (4)$$

As $\theta = 0$ at the magnetic equator the above equations reduce to
$\sigma_{xx} = \sigma_0$, $\sigma_{xy} = 0$ and $\sigma_{yy} = \sigma_1 + \frac{\sigma_2^2}{\sigma_1}$. $\sigma_{yy}$ is the
effective conductivity in the $y$-direction and is known as
cowling conductivity. Due to the inhibition of the Hall cur-
crent the effective conductivity in the $y$-direction i.e. the
cowling conductivity is enhanced. The physical explanation
of such an enhancement is simple and can be understood as the
following. The primary electric field in conjunction with the
N-S magnetic field tries to lift the plasma in upward direction.
But since the positive ions do not see the effect of the magnetic field owing to their large collision frequencies, a vertical polarization field namely the Hall field is created. The Hall field crosses with the magnetic field and makes the electrons drift in eastward direction and thus enhances the conductivity in the E-W direction.

1.1.2 Models of the Equatorial Electrojet

The first attempts for the in-situ measurement of electrojet current were made by Maynard et al. (1965) and Maynard and Cahill (1965b). Four Nike Apache rockets were launched in January, 1964 from Thumba, India by Maynard et al. (1965) under a joint NASA-INCOSPAR programme. The rockets carried the Packard and Varian (1954) type 'Proton Precession Magnetometer'. The measured values of the magnetic field were plotted against altitude. Theoretical estimates of the magnetic field over Thumba were also made using the spherical harmonic analysis of Finch and Leaton (1957). Theoretical values were then subtracted from the actual observed magnetic field in order to get the field due to electrojet current. These results yielded a value of 60-70 gammas for the electrojet field. The peak current was found to be situated around 109 km and a diffuse trail upto 130 km (Maynard and Cahill, 1965a).

A second campaign of similar measurements was started by Maynard and Cahill (1965b) who launched four Nike Apache
rockets from the USNS Croatan during March 1965. The launchings were made off the coast of Peru and were a part of NASA Mobile Launch Expedition. Payloads flown were similar to ones flown in India. The results showed that the departure field or the difference field exhibited a change of slope at 95 km and that maximum departure was about 120 gammas at 108 km. Beyond 108 km the current layer diffused upwards upto 130 km in a manner similar to that observed by them over India.

The two attempts to measure the electrojet currents over India and Peru brought very interesting results. Suguira and Cain (1966) tried to interpret these results by proposing the first model of the equatorial electrojet. Following were the main features of the model:

(a) Vertical currents were neglected \( (j_z = 0) \)

(b) Electric field in the north-south direction was neglected \( (E_x = 0) \)

(c) Primary field in the East-west direction was taken to be constant \( (E_y = \text{const}) \) with altitude

(d) Realistic magnetic field values were incorporated

(e) Height profiles of collision frequencies and electron densities were assumed.

The model was developed from the basic equations of current and layer conductivities (Equations 1 to 4). The final expression for the current in the E-W direction was found to be
\[ j_y = \sigma_{yy} \cdot E_y \]  

(5)

This model, better known as \( \sigma_{yy} \) model qualitatively explains the features of the electrojet. This model, however, gave much smaller width for the equatorial electrojet than later observed by Davis et al. (1967). The model was later proved to be self-inconsistent by Untiedt (1967). The actual equations for the current in \( x \) and \( y \) directions as obtained by them, are

\[ j_x = \sigma_{xx} E_x + \sigma_{xy} E_y \]  

(6)

\[ j_y = -\sigma_{xy} E_x + \sigma_{yy} E_y \]  

(7)

The equation (6) shows that if \( E_x \) is assumed to be zero the N-S current \( J_x \) will be finite. \( \sigma_{xy} \) is dependent of \( I \) and, therefore, of \( x \). This suggests a strong divergent current system in the N-S direction which cannot exist in a system like electrojet. In fact a meridional electric field is set up in the XZ plane which according to (7) would contribute to the electrojet currents except at the equator. The meridional field is non-zero and can yield a non-divergent meridional current system, a major part of which is in the vertical direction, therefore the first assumption that \( j_z = 0 \), everywhere is not valid.

In March 1965 there was another series of rocket launchings by NASA Mobile Launch Expedition. Nine rocket launchings were made by Davis et al. (1967) for the latitudinal survey
of the equatorial electrojet over Peru. Rubidium vapour magnetometers were on board to find out the total field. On one of the flights which was conducted during nighttime a very weak current opposite in direction to the eastward daytime electrojet was detected. The experimental results of Davis et al. (1967) showed that the equatorial electrojet had a lower maximum current density and was much more extended in latitude than indicated by Sugiura and Cain (1966). The cross-sectional current density profiles derived by Davis et al. (1967) could not be accounted for by the model. Appreciating the obvious incompatibilities between model and their results, Davis et al. (1967) proposed a modified model in which N-S current was completely inhibited in addition to the vertical current i.e. both $j_x$ and $j_z$ were assumed to be zero. Putting $j_x = j_z = 0$ in equation (6) and (7) one gets

$$j_y = \left( \sigma_{yy} + \frac{\sigma_{xy}}{\sigma_{xx}} \right) \frac{E_y}{E_y}$$

and equations 2-4 now yield

$$\sigma_{yy} + \frac{\sigma_{xy}^2}{\sigma_{xx}} = \sigma_3$$

where $\sigma_3 = \sigma_1 + \frac{j_z^2}{\sigma_1}$ is the Cowling conductivity.

In the model of Davis et al. (1967) $\sigma_3$ does not depend upon $x$ hence the assumption $j_x = 0$ does not lead to electrojet. The self inconsistencies of $\sigma_{yy}$ and Davis et al.'s model led Untiedt (1967) to propose a numerical two dimensional model.
The main features of Untiedt's model were the following:

(a) The vertical currents were not assumed to be zero \( j_z \neq 0 \)

(b) A flat earth picture was taken

(c) Similar to model all quantities were assumed to be dependent of \( x \) and \( z \) only

(d) The current function \( \psi \) was assumed to be non-divergent

(e) Winds were assumed to be stationary so that \( \frac{\partial \mathbf{B}}{\partial t} = 0 \) and the electric field is irrotational.

To solve the resulting equations following simplifying assumptions were made:

(a) \( E_y \) was assumed to be constant with the latitude and altitude. A value of 1 mv/meter was used for calculations. In actual case \( E_y \) varies with altitude as seen by Subbaraya et al. (1972) who find that the electric field increases with altitude. All currents and magnetic fields of the electrojet system are proportional to \( E_y \) hence the model can be scaled to represent different conditions by simply changing \( E_y \).
(b) \( \frac{dT}{dx} = 3 \times 10^{-7} \) (1.72 deg/100 km.). This means magnetic inclination depends linearly on \( x \) and its dependence on \( z \) is neglected. This is justified for the electrojet as it occurs in a narrow region.

(c) \( \sigma_1 \) and \( \sigma_2 \) do not depend on the latitude 'x'.

Under the above assumptions the total current will be non-divergent but not the partial currents due to ions and electrons.

The conductivities used in Untiedt's model were calculated from the height profiles of electron density obtained by Maynard and Cahill (1965a) who used a d.c. Langmuir probe. The results of Untiedt's analysis show that:

(a) A toroidal magnetic field was obtained which points towards magnetic west in the northern hemisphere and towards magnetic east in the Southern hemisphere. In z direction the field was maximum at 125 km whereas in x direction the maxima occurred at a distance of 325 km.

(b) The meridional currents of 80 amp/km flow towards the equator below 125 km and away from the equator above 125 km. At the equator the direction of current is vertically up with a maxima at 123 km where the current density is \( 5 \times 10^{-7} \) amp/m².
(c) The reduction in electrojet current as one goes away from the equator is much less than predicted by \( \tilde{\sigma}_{yy} \) model. The height of the peak of the electrojet shifts only from 105 km to 100 km as one moves from \( x = 0 \) (equator) to \( x = 500 \) km. At the equator current densities are slightly more than the ones obtained in \( \tilde{\sigma}_{yy} \) model. A comparison of current and \( \tilde{\sigma}_{z} \) profile shows that Cowling conductivity represents the electrojet fairly well in the neighbourhood of the equator.

(d) The \( H \) value at the ground due to ionospheric currents is 92.5 \( \gamma \) at the equator. The ratio of \( H \) at equator to \( H \) outside equatorial zone is 2.4 against a higher value of 3.2 given by \( \tilde{\sigma}_{yy} \) model.

A minor improvement in Untiedt's model (1967) was made by Suguiria and Poros (1969). They used a spherical harmonic expansion for the geomagnetic field and have given model electrojet for six different longitudes. This model is different from Untiedt's model in the following ways:

(a) The magnetic field used is more realistic.
(b) Spherical earth geometry and spherical polar coordinates are used.
In this model the ratio of vertical polarization field to the primary electric field was found to be $2.5$ at 100 km altitude. The same ratio was $2.8$ in case of $T_{yy}$ model. This shows that meridional currents reduce the vertical electric field but only to a very small extent.

Kato (1973) pointed out that the general belief regarding the equatorial electrojet that it is driven entirely by an electrostatic field namely the Hall field may not always be true. In presence of the N-S magnetic field $B$ and an E-W wind $W$ which can be generated due to tidal motions, the dynamo action creates a charge separation. This charge separation is responsible for the polarization, which is such that, the total field $E_{pol} + W \times B \approx 0$. If the cancellation is complete there is no contribution to the vertical electric field due to the horizontal wind motion and electrojet current does not get affected by winds. Kato (1973) has shown that when more realistic curved field lines are considered (instead of approximate horizontal lines) the effect of horizontal winds is such that the cancellation is not complete and hence there is a net vertical field due to wind motion. Thus the vertical Hall field which drives the electrojet would be modified with this vertical field due to wind motion.

The effect of neutral winds on the equatorial electrojet was considered in detail later by Richmond (1973) who developed a numerical model of equatorial electrojet. In this model the geomagnetic field lines were assumed to be perfect.
conductors i.e. $\sigma_0$ was assumed to be infinite. The results of currents and the ground level variations ($\Delta H$) of infinite $\sigma_0$ model were found to be same as in finite $\sigma_0$ model. In addition, the assumption of infinite $\sigma_0$ simplifies the computations to a great extent and provides additional conceptual insight into the physical mechanism of electrojet. It was emphasized in the model that the electric field and current at any given point is strongly dependent on the conditions prevailing all along the geomagnetic field line and is almost independent of conditions prevailing in the neighbouring field lines. The effect of height varying E-W and N-S winds has also been taken into account in this model. It is found that E-W winds do not affect the electrojet current upto $\pm 1^\circ$. Beyond $\pm 1^\circ$ these E-W winds significantly affect the eastward current and the ground level variations ($\Delta H$). The inclusion of N-S winds did not have much effect on the eastward current but resulted in generation of cross-equatorial currents.

1.2 Counter Electrojet

The history of the counter electrojet dates back to the year 1940 when Bartels and Johnston (1940) while studying the geomagnetic tides in horizontal intensity at Huancayo observed that on some of the magnetically quiet days the variation of $H$ was abnormal and exhibited a large depression during daytime. Bartels and Johnston attributed these depressions to large fluctuations in the lunar component $L$ which they thought
could exceed even the solar quiet day component $\text{Sq}$ at the time of such large depressions. The next important observation in the series of counter electrojet phenomenon, as has become evident now, was made by Matsushita (1957) who found that at Huancayo on some days the equatorial $E_s$ or $E_{s-q}$ which was quite normal up to 1330 Hrs (L.T.) suddenly vanished at 1345 Hrs (L.T.) and then reappeared after a gap ranging between half an hour to a few hours. Since the main objective of Matsushita was to study the lunar effects on $E_{s-q}$, no attempt was made by him to correlate drifts or magnetic field with the observed phenomenon.

Gouin (1962) reported some abnormal behaviour of the horizontal component of the geomagnetic field $H$, over Addis Ababa which is an equatorial station under the direct influence of the equatorial electrojet. The normal behaviour of $H$ for Addis Ababa or for that matter any other equatorial station is a gradual start with a small dip before sunrise, then a maximum around local noon and thereafter, a steady fall, with slight positive asymmetry, to nighttime level. The maximum during noon lies somewhere between 100 and 200 gammas above the nighttime level. Gouin found that on three days in the month of January, 1962 the $H$ curves were very much deviated from the normal one and had large depressions during daytime. These depressions in $H$ were reflected in the vertical component $z$, and the declination $D$ also. There was, however, no trace of any such depression before and after these three days.
Gouin interpreted these depressions in terms of amplified lunar effects.

It was around the same time that Cohen et al. (1962) found that the disappearance of $E_s$-q during daytime as observed by Matsushita (1957) is very well correlated with the sudden decrease in $H$ observed by Bartels and Johnston (1940) and Gouin (1962). Since the decrease in $H$ is connected with the electrojet current Cohen et al. (1962) were the first to establish a close association between $E_s$ irregularities and the equatorial electrojet.

In support of the conjectures of Bartels and Johnston (1940) and Gouin (1962), Onwumechilli (1964) found that the lunar component $L$ gets modified each hour on the same day and that the 'Big L' days do exist. In addition to big L days Onwumechilli found instances when $L$ was completely reversed and attributed such large fluctuations in $L$ to modifications in the oscillations of the upper atmosphere. To check whether there is a real lunar control of these depressions Rao and Raja Rao (1963) examined the Trivandrum magnetograms for the period during which Gouin had observed depressions for Addis Ababa. Since Trivandrum is only two hours of longitudes away from Addis Ababa, Rao and Raja Rao expected that if these depressions are due to lunar effects some effect should be reflected in Trivandrum magnetograms also; but to their dismay Trivandrum magnetograms did not show any such effect. Rao and Raja Rao, therefore, concluded that these depressions could not be due to
lunar effects alone. While studying the properties of blanket­
ing type of sporadic E over an equatorial station, Kodaikanal
(dip 3.4°N), India, Bhargava and Subrahmanyan (1964) found
that at the time of appearance of $E_{S-q}$ all geomagnetic and
ionospheric features which are observed under the influence of
electrojet are suppressed. They found that just before the
local noon the horizontal component of geomagnetic field
showed a large departure and the $E_{S-q}$ was either absent or
was very weak. But in addition to the disappearance of $E_{S-q}$
at the time of depression in $H$, which was found earlier by
Cohen et al. (1962), Bhargava and Subrahmanyan (1964) found
that, at the same time, i.e. just before the local noon when
depression in $H$ was seen, the height of maximum F-region ioni-
zation decreases, the extent of F-region gets reduced, i.e.
thinning of the F-layer and, the region becomes denser. Based
on all the features such as depression in $H$ and disappearance
of $E_{S-q}$ etc., Bhargava and Subrahmanyan (1964) concluded that
there should be a westward electric current in the ionosphere
at the time when blanketing $E_S$ is observed.

An extensive study of such depressions was later car-
rried out by Gouin and Mayaud (1967) who found that the occur-
rence of such depressions was more during morning and evening
hours and that the occurrence during noon was rare. Since the
occurrence was confined to same local time on a number of con-
secutive days the lunar origin of such depressions was ruled
out. Gouin and Mayaud (1967) were convinced that these depres-
sions were limited to equatorial zone only like the 'equatorial
electrojet' and since the variations in H were not related to $S_R$, variations in the declination, they christened the phenomenon "Counter Electrojet". Later, Hutton and Oyinloye (1970) observed the disappearance of $E_{\text{S}}$ during the periods of counter electrojet at Nigerian stations Zaria and Ibadan.

Using a VHF backscatter radar Balsley and Woodman (1971) measured the horizontal electron drift in the E-region during the period of counter electrojet. Their results showed that during counter electrojet the drift velocity reduced to zero but did not reverse. On the other hand Rastogi (1971) using three spaced receiver's technique found that horizontal drifts in the E-region, and the vertical drifts in the F-region over Thumba reversed during the period of counter electrojet. Later on it was shown by Rastogi (1973) that even for Huancayo $E_{\text{S}}$ disappeared when electron drift velocity as measured by VHF doppler spectra indicated very small velocity or even reversed E-region drift and downward F-region drift. If these reversals in the drifts are true the direction of primary electric field and, therefore, the direction of main electrojet must have got reversed during such periods. If the electrojet current gets reversed it should be reflected in the magnetic field above the ionospheric height. Kane (1973a) using the POGO satellite data of Cain and Sweeney (1973) observed one such case where the electrojet signatures (as shown by the magnetic fields in the higher regions) were reversed during a period when counter electrojet was observed at ground.
About the extent of the counter electrojet Rastogi (1972) showed that it can be seen at two stations separated by a few hundred km in the N-S or a few thousand km in the E-W direction. The decreased \( h_{\text{max}} F_2 \) which was first observed by Bhargava and Subrahmanyan (1964) during the depression in \( H \) was later studied in detail by Rastogi (1974). Rastogi (1974) showed that during the period of counter electrojet the height of maximum ionization in \( F_2 \) region, \( h_{\text{max}} F_2 \), decreases. A new term 'partial counter electrojet' was introduced by Rastogi (1974) who observed the cases where the depression was seen around afternoon hours but the minimum value of the field was much above the nighttime level.

Osborne (1964) suggested that the strength of the electrojet can be estimated from the difference of \( H \) values of an equatorial station and a station just outside the influence of electrojet. On magnetically quiet days the identification of counter electrojet is easy and can be made by locating a depression below the night level in \( \bigtriangleup (H_{\text{eq.}} - H_{\text{low lat.}}) \) curve. This method of defining the strength of electrojet currents would be in error depending upon the relationship between the low latitude \( S_q \) variations and equatorial magnetic field variations. Nevertheless this method seems to be quite good in establishing the presence of counter electrojet. On disturbed days, however, the method is not so straightforward and involves the removal of \( D_{ST} \) and \( DS \) effects completely. Kane (1973b) has defined an index \( S_{d_1} \) to test whether it is a counterelectrojet or not.
If $S_{dI}^{(\text{equator})}$ goes below the baseline it is termed as counter electrojet day.

Recently a VHF backscatter radar operating at 54.95 MHz was used to study the irregularities present at Thumba, India during the period of counter electrojet (Muralikrishna 1975). On most of the counter electrojet days the backscatter signal was absent indicating thereby the absence of 3-meter irregularities. On a few occasions, however, weak return echoes were detected. It was found that radar echoes appeared only when the reversed currents had become sufficiently strong and when sufficient time had elapsed after the onset of the reversal. The return echoes lasted for longer periods and were much stronger when observed during decay phase of the counter electrojet currents as compared to those observed during the development phase. A comparative study of number of counter electrojet occurrences with solar $A_p$ index revealed that quiet days were more favourable for the occurrence of counter electrojet.

1.3 D and E-region Irregularities

1.3.1 Observational Results of Ionization Irregularities from Ground Based Studies

1.3.1.1 Studies with Ionosonde

Sir Edward Appleton while studying the ionograms for non-equatorial region found that there were some abnormalities
in the E-region trace (Appleton, 1930). The occurrence of such abnormalities was so unpredictable that the name 'sporadic E' was attributed to them. The name sporadic E or Es adopted by the international community is a misnomer as these irregularities are more or less a regular feature in different latitudinal zones. At the equator the name 'q-type' or E\textsubscript{s-q} is used to designate these irregularities.

On an ionogram the E\textsubscript{s-q} appears either as a dense layer or a patchy structure at E-region heights in 100-120 km region. At times when the layer is so dense that the reflection from the higher regions are not possible, it is known as 'blanketing type' of sporadic E or simply E\textsubscript{s-b}. The blanket- ing frequency f\textsubscript{b}\textsubscript{s} is the lowest frequency at which echoes from higher layers are received through E\textsubscript{s} layer. When there is a complete blanketing the observations of F-region are prevented by this layer but at other times the layer could be partially transmitting over a small frequency range.

An indication whether the layer is thick or thin can be had by observing the retardation near the maximum frequency on the E\textsubscript{s} traces. The presence of retardation near the maximum frequency indicates that the layer is thick whereas the thin layers is characterised by no retardation.

The important parameters most frequently used to describe the sporadic E are the critical frequencies of E\textsubscript{s} layers, f\textsubscript{o}\textsubscript{E}\textsubscript{s} and f\textsubscript{x}\textsubscript{E}\textsubscript{s} (both ordinary and extraordinary),
blanketing frequency $f_E^s$ and the virtual height $h_E^s$. When the usual 'cusp' type reflections are not seen on the ionogram the frequency $f_t^E$, which is the top frequency at which the reflections are observed, is used.

1.3.1.2 Studies with VHF Forward and Backscatter Radar

a) Electrojet Irregularities

The studies of ionization irregularities started with the work of Booker and Gordon (1950) who applied the theory of scattering of radiowaves, by turbulent medium, to the tropospheric heights. Bailey et al. (1952) made the calculations of such scattering at higher levels (E-region altitudes) and then performed an experiment to check the validity of the theory. In accordance with their calculations Bailey et al. (1952) were able to receive high frequency signals between two mid-latitude stations separated by about 1245 km. Although the high frequency signals (49.8 MHz) were received irrespective of the time of observation, season and the status of the geomagnetic field their intensity was slightly dependent on these factors. These observations were later interpreted in terms of scattering caused by irregularities in the E-region altitudes.

Bowles and Cohen (1957) operated a chain of 50 MHz VHF forward scatter radars near the magnetic equator in South America. The results of these observations showed that the propagation of VHF signals was associated with sporadic-E and
was well correlated with the time variations and height of the equatorial electrojet. It was later experimentally established by Bowles et al. (1960) that plane wave electron density irregularities were acting as scattering centres for the VHF radar echoes. These plane waves were found to be moving in the general direction of the electron flow which is towards west during daytime. Bowles et al. (1960) predicted that the irregularities should be highly field aligned, i.e. the scale sizes of the irregularities along the field lines must be much larger than across them. This proposed field aligned nature of irregularities was later confirmed by Egan (1960) who used an obliquely looking radar at Huancayo, Peru (0°31' N dip) and found that the echoes were highly aspect sensitive and could only be observed when radar beam was looking at right angles to the magnetic field which is in N-S direction over Huancayo.

Another valuable information regarding the region of generation of these irregularities was presented by Cohen and Bowles (1963) who used the VHF forward scatter radar over a transequatorial path and showed that the irregularities are generated between 95 to 110 km. This range of 95 to 110 km agreed well with the limits of equatorial electrojet given earlier by Singer et al. (1951). In addition to the region of occurrence, Cohen and Bowles (1963) found a positive correlation between the radar echo intensity and the variation
in the horizontal component of the geomagnetic field. Bowles et al. (1963) found that the apparent radar echo cross-section increases with the elevation angle.

As the operating frequency of the radar decides the scale size under study Bowles et al. (1963) used two different frequencies (148 MHz and 50 MHz) to have an idea of the behaviour of two different scale sizes; their results showed that threshold needed at 148 MHz was higher than the one needed at 50 MHz but nevertheless they had similar characteristic spectra. Upto this time the irregularities observed by VHF scatter radar were thought to be generated due to the two stream instability mechanism (Farley, 1963). But around the same time it was pointed out by Bowles et al. (1963) that at times when the threshold of two stream instability is not reached, a vertically pointing radar detects echoes which did not have the above mentioned characteristic spectra. The large scale blobs of irregularities were also found to be moving in westward direction. These observations, however, could not be reconciled with the Farley's two stream instability theory. A detailed study of these irregularities (at 50 MHz) was made by Balsley (1967) who classified the irregularities into two types namely 'type I' and 'type II' and suggested that two separate mechanisms must be operating in the electrojet which give rise to these types of irregularities. Balsley identified the two-stream instability as the generating mechanism for type I echoes. But the rocket studies of Prakash et al. (1971c) show
that the threshold requirement for two stream instability is not met in case of type I echoes. Regarding the generating mechanism of type II echoes it has become clear from the rocket studies (Prakash, et al. 1971c) that these echoes are due to small scale irregularities which are generated through cross-field instability mechanism.

The velocities of both type I and type II irregularities were derived by Balsley (1967) from the doppler shift in the returned radar signal. Using the following simple formula one can compute the velocity of irregularities if the doppler shift is known.

\[ \Delta f = \frac{2 V_d f \sin \theta}{c} \]

where \( f \) is the transmitter frequency,
\( \Delta f \) is the doppler shift in the received signal,
\( V_d \) is the drift velocity of irregularities,
\( \theta \) is the angle which the direction of antenna beam makes with the vertical, and
\( c \) is the velocity of light.

The doppler shift in case of type I irregularities is always around -120 Hz when the radar beam is pointed westwards during daytime. This doppler shift was found to be independent of antenna elevation angle. As the radar beam is pointed westwards during these observations, a negative doppler shift of 120 Hz indicates that the irregularities are moving in westward
direction with a velocity of $\approx 360$ meters/sec, a velocity which is close to ion-acoustic velocity in that region. Such a fixed doppler shift is usually observed at a time during which the electrojet is supposed to be quite strong.

The doppler shift for type II irregularities is always much smaller than type I indicating that type II are moving with relatively slower speeds. Type II irregularities are usually present at all times except when electron drift velocity may be expected to be near zero. Another important point made by Balsley (1967) was that the power of the return signal was proportional to the square of the drift velocity of irregularities.

In case where both type I and type II echoes are present the individual contribution from two types can be estimated on the basis of signatures of these echoes. This method of spectral decomposition was given by Cohen (1973). Balsley (1967) studied the variation of observed drift velocity with the antenna elevation angle; the results of observed drift velocities showed a very good agreement with the theoretically predicted value of horizontal velocity.

In order to know the lower scale sizes upto which the spectrum of type I and type II irregularities extends Balsley and Farley (1971) made radar studies at three different frequencies viz. 16.25 MHz, 49.92 MHz and 146.25 MHz. These studies showed that at higher radar frequencies the strength of type II echoes decreased much more rapidly than type I; the
decrease being so large that at 146.25 MHz type II signals were not at all observed. The velocities of type I and type II irregularities were found to be independent of radar frequency. It was also pointed out by these studies that the dependence of type I scattering cross-section on electrojet strength was more at higher radar frequencies.

A detailed study of small and large scale structures of the irregularities was carried out later by Farley and Balsley (1973) using the Range Time Intensity (RTI) diagrams. The technique of RTI diagrams has been described by Balsley (1969). Using a vertically pointing radar beam which was 1° wide, Farley and Balsley (1973) could get the spatial resolution of the order of 300 meters. Such observations showed that structures of 300 to 1000 meters scalesize were present and were moving, sometimes, vertically upwards and, sometimes, downwards with a velocity lying between 50-75 m/s. The velocities could not be conclusively determined with RTI diagrams, but their being in the range was indicated by doppler shift radar measurements. At another occasion they used radar of wider beam width (≈30°) and pointed it towards 45° west. The resolution achieved in this case was about 1.5 to 2.0 km. The results of RTI diagrams showed that irregularities of few km scale size had life times of the order of 10-30 seconds and were moving in westward direction. Since their pulse width was very small (=10μs) such features could be seen, otherwise usually when one averages the signal for about a minute or so, or uses wider radar
pulses, the echo would appear to come from all directions. These studies were in agreement with the earlier rocket observations of Prakash et al. (1970) wherein it was found that the irregularities have scalesizes of a few km. in the vertical direction. The region of occurrence, amplitude, shape and spectrum of the irregularities with scalesizes from a few km down to one meter have been given in a comprehensive review by Prakash et al. (1973).

As the radar observations showed that type II irregularities were present even when the drift velocity was less than the ion-acoustic velocity, it was suggested by Farley and Balsley (1973) that small scale irregularities must be generated indirectly through some non-linear processes wherein energy is fed from larger scale sizes to smaller ones. The large scale irregularities, whose presence was first pointed out by Prakash et al. (1970) and later confirmed by RTI diagrams, when grown sufficiently could significantly alter the local conditions so as to make them suitable for invoking the nonlinear feed back of energy to generate smaller scalesize irregularities. Such a mode - mode coupling was proposed by Sudan et al. (1973) and would be described in Chapter II. Balsley and Farley (1973) carried out another set of measurements with improved altitude and time resolution. If the spatial resolution of radar measurements is comparable to the size of large scale structures the turbulent model is expected to yield highly variable Doppler structures. In the earlier measurement of Farley and Balsley (1973) due to poor spatial and temporal
resolution, these features were obscured and spectrum was found to be fairly narrow and symmetrical about zero Doppler shift with practically no structures. With the improved altitude resolution the Doppler shift which represented the vertical velocity was found to vary rapidly with altitude to the extent that the direction could be reversed two times in a bare distance of 5 km. With the improved time resolution it was possible to study the evolution of Doppler shift in time at a given altitude. It was found by Balsley and Farley (1973) that at a given altitude the Doppler shift could be markedly change in about 2.5 seconds and could even reverse sense in about 5 seconds. Although these resolutions were orders of magnitude better than the earlier ones but were certainly not the ones which one would like to have. A new signal processing and data display technique named as the modified range time intensity (MRTI) display was developed by Fejer et al. (1975). With the help of MRTI technique the structures could be studied with a altitude resolution of 1 km, and a large dynamic range of 60 db could be covered. This system was very much suited for nighttime observations. Using this technique Fejer et al. (1975) studied the vertical structure of the VHF backscattering region in the electrojet. During daytime echoes were observed from a region extending from 93 to 113 km, during the evening they were obtained from two split regions around 100 and 120 km whereas during nighttime echoes were obtained from an extended region of 93 to 130 km. The results of Fejer et al. (1975) confirm the earlier rocket results of Prakash et al.
(1971c) that type II irregularities are produced through cross-field instability mechanism. The author also gets similar results from the rocket data at Thumba. The results obtained by the author would be described and discussed in chapter IV and VI respectively.

Using a 54.95 MHz VHF backscatter radar from Thumba, India, Muralikrishna (1975) reported the nature of irregularities around morning and evening reversals of electric field. It was found that just before the morning reversal the observed Doppler shift exhibits a pronounced peak at $+120$ Hz which corresponds to a eastward velocity of 360 meters/sec. showing that before morning reversal type I echoes are present. During reversal or transition no radar echo was observed. After the morning reversal type II echoes were observed. In addition, it was found that scattering region was higher during times close to the reversal periods. The observations around the evening reversal showed that just before the reversal spectra are generally broad and also the Doppler shift is such that irregularities are moving with low drift velocities of the order of a few tens of meters per second in the east-west direction. During the reversal there was no radar signal. After the evening reversal also type II irregularities are present but the Doppler shift is negative suggesting that after evening reversal irregularities are moving from west to east.
b) Irregularities due to Neutral Turbulence

The theory of scattering of radio waves by turbulent medium was proposed in 1950 by Booker and Gordon (1950). Bailey et al. (1952) calculated the scattering of 50 MHz signal from E-region altitudes for a path length of a few thousand kilometers on the basis of the theory of Booker and Gordon (1950), and then conducted an experiment to verify the theory. The results were remarkable as the signals were transmitted exactly in the fashion as originally thought of. The fading characteristics of these signals followed a Rayleigh distribution. Some theoretical work on the scattering of radio waves by turbulent medium was done by Villars and Weisskopf (1955). Gallet (1955) proposed a mechanism by which the neutral turbulence could produce electron density fluctuations. Since the mechanism could produce only very weak irregularities Gallet proposed an amplification mechanism of the weak irregularities. Some of these theoretical ideas would be described in chapter II.

As far as experimental results are concerned, to the best of author's knowledge, there are only two attempts which have been made using VHF backscatter radar. The first one was by Crane (1970) and was limited only to stratospheric heights. Although Crane (1970) used a very powerful radar he was unable to get the return echoes of power greater than noise level. Recently Woodman and Guillen (1974) made the observations of irregularities produced by neutral turbulence mechanism. They
used an antenna which had a collecting area of $8.4 \times 10^4 \text{ m}^2$. The peak power of the radar was 1 MW, pulsewidth was $33\mu\text{s}$ and bandwidth was 30 KHz which enabled them to have a height resolution of 5 km. The pulse repetition rate was 700 microseconds. Since the operating frequency was 50 MHz, Woodman and Guillen (1974) could have studied only 3 meter irregularities. But from the subsequent analysis of the received signal they derived the information about degree of turbulence at 3 meters as well as about large scale sizes wherein 3 meter fluctuations were used as tracers.

Woodman and Guillen (1974) found that below 85 km. altitude there were two regions from which the echoes of sufficient strength were coming. The first one was the stratosphere with which we are not concerned here. The second one was the mesospheric region of 55-85 km. For the region of 55-85 km. a continuous plot of received power versus time was obtained. The behaviour of 3 meter scalesizes was found to be highly variable and echoes were observed only during daytime and were always absent during nighttime. Although their spatial resolution was only 5 km, they claimed that from their results they had an indication that well defined layers, narrower than 5 km, were present, sometimes, for even several hours together and produced echoes which were 10-15 db stronger than the background.
1.3.2 Observational Results of Ionization Irregularities from Rocket Borne Studies

The study of vertical structure of irregularities and their motion with the ground based backscatter radar, both at Jicamarca and Thumba has given very interesting results. As the generation of irregularities depends on the properties of the ambient medium the ground based techniques cannot be employed to study the properties of the ambient medium. With the advent of rockets and satellites for research investigation a new dimension was added to the scope of these studies and irregularities could be studied directly using the in-situ probes.

The in-situ measurements of ionisation irregularities in the equatorial ionosphere were carried out extensively from Thumba, India using rocket borne Langmuir probes, resonance probes and proton precession magnetometers. All the rocket results which were obtained without the involvement of the author would be discussed in the following. The recent work i.e. from the last five years or so in which the author was fully involved would be described in chapters IV, V and VI. Before describing the rocket results the principle of Resonance probe and Proton precession magnetometer would be briefly discussed.

A novel technique based on the mutual admittance of the two antennas (one of the them as an exciter and the other as a
receiver) was developed by Prakash et al. (1972). This system has many practical advantages over the system earlier flown by Heikkila et al. (1968). In this technique a R.F. signal of varying frequency is applied to the exciter and a part of induction current from it is received by the receiving antenna. As the applied signal is varied in frequency the received signal shows amplitude variations due to varying response of the medium and several plasma resonances can be detected. The strongest and most easily recognisable resonance is at the upper hybrid frequency $f_T$ which is given by the relation

$$f_T^2 = f_N^2 + f_H^2$$

where $f_N$ is the plasma frequency and $f_H$ is the gyro-frequency of the electrons in the medium. As the value of $f_H$ is accurately known the value of $f_N$ can be easily determined.

The electron density $N$ can be calculated from the relation

$$N = 1.24 \times 10^4 f_N^2$$

where $N$ and $f_N$ are expressed in cm$^{-3}$ and MHz, respectively.

For the experimental set up two stainless steel cylinders concentric with the rocket body and insulated from it were used as exciters. One was placed near the fins of the rocket (far exciter) and the other was placed near the telemetry antenna (near exciter). During alternate cycles a voltage of about 0.7 volts R.M.S. was applied to the far exciter and 0.35 volts to the near exciter. The receiving antenna is the front portion of the nose cone and is used to measure the R.F.
current flowing into it. This current is estimated by measuring the voltage across a resistance of 1 K. This resistance is much less than the impedance of the medium and the impedance of the stray capacitance of the receiving antenna. A sweep frequency exciter with a frequency sweep from 6.5 MHz to 0.5 MHz in about 1.5 second duration is used along with a double conversion type superheterodyne receiver with controlled gain and synchronized with the exciter frequency. The transmitter output is maintained at a constant level by means of an AGC system. The receiver uses two kinds of AGC systems to cover a wide dynamic range. A fast AGC system acts on transient variation, and a slow AGC system acts on average level of the received signal. The R.F. system developed by Prakash et al. (1972) is more suitable for ionospheric studies over the one by Häikäila et al. (1968) in the following sense.

(i) Since no booms are used as exciters the arrangement is simple and takes less space. In an experiment where proton precession magnetometers are flown, the space is so limited that booms cannot be flown.

(ii) The booms will also reduce the reliability and performance of the rocket and also the data of ionization irregularities would be more noisy.

(iii) Since the exciter and the receiving antenna systems are symmetric with respect to the rocket axis, it eliminates any possible spin dependent effects on the resonances.
(iv) The arrangement of sensors and their geometry is such that the induction field from the exciter does not reach the receiver directly but first goes out into the plasma and then comes back to the receiver. The effective distance achieved this way is much larger than that in other systems resulting in very sharp resonances.

The measured electron density represents the actual value in the ambient medium unperturbed by the rocket motion. The point has been confirmed by comparison of the data from the far and near exciter when used on alternate cycles.

The proton-precession magnetometer used for the rocket flight consists of a proton sensor, a programming unit, a polarizing unit and a low noise high gain amplifier (Sastry, 1968). This magnetometer is based on Packard and Varian type flown earlier by Cahill and Van Allen (1956). When the rocket borne magnetometer traverses the electrojet region it measures the resultant of the geomagnetic field and the field due to electrojet currents. A theoretically predicted base value (in absence of electrojet currents) is selected and departure $\Delta F$ of the measured field from this base value is calculated. $\Delta F$ values are plotted against altitude to obtain the 'difference curves'. The current density profiles are derived from the slopes of these difference curves under certain assumptions regarding the nature and extent of electrojet currents. The effect of currents induced in the conducting earth is also taken into account during this conversion (Sastry, 1970).
Using the rocket borne Langmuir probe Prakash et al. (1968) obtained the electron density profile and electron temperatures for evening twilight hours. The presence of \( E_2 \) layer was confirmed at 130 and 136 km during the ascent and descent respectively. During this first attempt audio frequency fluctuations in the electron density were recorded in the frequency range of 880 Hz ± 15%. The amplitude of the fluctuations varied with height indicating that the nature of the spectra was changing. These fluctuations were proposed to be generated due to ion acoustic waves which in turn were possibly produced by winds and electric fields. Subbaraya (1968) has reviewed the progress of in-situ measurements till that time. Prakash et al. (1969a) made another rocket launch during the evening twilight of 2nd February 1968. In this flight the fluctuations were measured in a frequency range of 70-1000 Hz and the output was termed 'plasma noise'. In the lower ionosphere the plasma noise was observed between 85 to 105 km whereas in upper part it was observed between 142 and 173 km. In the lower region the fluctuations in the range of 85-92 km were guessed to be due to turbulence whereas the ones between 92-105 km were thought to be generated due to combined effect of turbulence and other nonlocalized forces. The fluctuations in the region of 155-173 km which was around the apogee of the rocket were thought to be produced by the rocket itself when it is subsonic. The fluctuations in the height region of 142-155 km were thought of as the genuine ones and produced by non-localized forces. The nature of observed noise suggested that it could be produced due to ion cyclotron waves.
The detailed analysis of the evening twilight flight was reported later by Prakash et al. (1969b). The spectral index n was obtained using a power law of the type $E(k) = Ak^n$ where $E(k)$ is the energy contained in the wavenumber k, A is a constant and n is the spectral index. For the evening flight the spectral index value was $\sim -3.5$ at lower heights (97-106 km) and was $\sim -2.0$ at about 150 km. This increase in n is contrary to what would be expected if irregularities were produced by neutral turbulence mechanism. Such an increased value of n was suggestive of some other agency responsible for the production of the irregularities at higher heights. Below 95 km it was suggested that irregularities are produced by neutral turbulence mechanism whereas between 97-106 two different spectra (one due to neutral turbulence with $n = -1.6$) are superposed over each other. The possibility of Farley's two stream instability (Farley 1963) was ruled out because the theory needs a threshold of electrojet current strength and the flight under consideration was made during evening twilight when electrojet currents are weak. The Reid's theory (Reid 1968) of cross-field instability was also not considered very seriously as it predicts that for a given value of E field there is a minimum wavelength which one can observe. For all reasonable values of electric fields this limit was much higher than the actual observed scale sizes. It was strongly suggested that electric field plays a very important part in generating the observed irregularities.
A little later on 29th August 1968 at 2300 Hrs. IST, Prakash et al. (1970) launched another Nike Apache rocket which yielded invaluable information about the ionization irregularities in the equatorial ionosphere. Two important points were brought out in that communication; the first one was about the shape of the electron density profile which had electron densities of $10^3$ and $10^4$ cm$^{-3}$ in the height range of 95-120 km and had a deep valley in 120-140 km region. The electron density in the valley was of the order of few hundred electrons per c.c. Secondly this flight showed the presence of three types of structures.

(i) Large scale structures in the electron density were obtained in 95-120 km region. The vertical scale sizes were about a few km whereas the horizontal extent could be of the order of 50 km. The electron density in these structures varied by a factor lying between 4 and 25.

(ii) The irregularities of scale sizes lying between 30 and 300 meter could be seen directly on the probe current. The results of 30-300 irregularities showed that these irregularities were observed only in regions of negative density gradient (i.e. electron density decreases with increase in height). This gave the first experimental observation about the fact that these irregularities are produced by cross-field instability mechanism. During nighttime the Hall polarisation field is acting vertically downwards and hence over Thumba where magnetic field is in the N-S direction a negative density
gradient would be needed at night to excite the cross-field instability mechanism. These scale sizes could be explained in terms of the available theories of cross-field instability [Reid (1968) Tsuda et al. (1966, 69)].

(iii) Small scale irregularities in scalesize range of 1-15 meter were observed to coexist with 30-300 scalesize.

The data of 1-15 meter irregularities was spectrum analysed in the 95-125 km region by passing the output of plasma noise amplifier through six band pass filters. These six outputs represented six different scalesize ranges. By assuming a power law as mentioned earlier the spectral index 'n' was evaluated. The spectral index value for 1-15 meter scalesize range were all lying between -2 and -4 (for regions between 95 and 120 km). Such small scale sizes, could not be explained on the basis of cross-field instability mechanism. It was suggested in this paper that even if a separate mechanism were to be involved the cross-field instability mechanism could still promote or inhibit the production of irregularities because the observation of irregularities largely depends upon the orientation of the electric field and the electron density gradient.

Prakash et al. (1971a) showed on the basis of four rocket flights that the irregularities generated due to cross-field instability mechanism are observed only in positive density gradient regions during daytime and in negative density
gradient regions during nighttime. This was due to the reversal of the direction of vertical Hall field. The amplitude of irregularities in 30-300 meter scale sizes was reported to be between 5 and 20%. Whereas the amplitude of 1-15 meter scale sizes was at best a few percent. An attempt was made to calculate the minimum scale size which can be excited directly by the cross-field instability. The results showed that in order to explain the observed amplitudes of scale sizes between 15 to 30 meter one would need electric fields which are an order of magnitude larger than the estimated fields available at that time. Based on the Gallet's (1955) theory, that neutral turbulence can produce ionization irregularities in presence of electron density gradients, Prakash et al. (1971b) attempted to compare the percentage amplitude of irregularities (obtained during evening and nighttime flights) at E region heights with the theoretically calculated ones. It was found that the amplitude of irregularities around 90 km during evening flights was larger than expected from turbulence and electron density gradients. The amplitudes observed during nighttime flight at 87 km were less than theoretical values indicating that in addition to turbulence there must be some other mechanism operating below 90 km during evening whereas at night, turbulence can account for the observed amplitudes around 90 km. This work has been reviewed by Gupta (1970).

Prakash et al. (1971c) flew two rockets which had Langmuir probe as well as Proton precession magnetometers on
board. The flights were conducted during noon hour which is supposed to be the time when the electrojet currents peak. The electron density was obtained from Langmuir probe and the current was obtained from magnetometer data. Using the relation \( J = N_e V \) the velocity of streaming electrons was obtained. It was found that the streaming instability which operates at the peak of electrojet (\( \approx 105 \) km) does not need the threshold on the drift velocity of electrons as required by Farley's two stream theory (Farley, 1963). The spectrum of these irregularities was flat. The region of occurrence, spectrum and scalesize range (1-15 m) suggest that the streaming instabilities observed by Prakash et al. were same as type I irregularity observed by Balsley (1967).

Later rocket flights from Thumba have provided more information of the characteristic features of these irregularities. Based on these observations Prakash et al. (1973) have classified the irregularities observed by rockets as following:

1. Type L - Large scalesize irregularities with vertical scalesizes greater than a few km. Generation mechanism: Unknown.

2. Type M_0 - Medium scalesize irregularities with vertical scalesizes of 30-300 meters. Generation mechanism: Cross-field instability.

4. Type Mu - Medium scale size irregularities with vertical scalesizes between 30 and 300 meters. Generation mechanism: Unknown.

5. Type Sc - Small scale size irregularities with vertical scalesizes between 1 and 15 meters. Generation mechanism: Multi-linear cross-field instability mechanism.

6. Type Sn - Small scale size irregularities with vertical scalesizes between 1 and 15 meters. Generation mechanism: Neutral turbulence.

7. Type Ss - Small scale size irregularities with vertical scalesizes between 1 and 15 meters. Generation mechanism: Streaming instability.

8. Type R - Small scale size irregularities with vertical scalesizes between a few cm and one meter. Generation mechanism: Rocket motion.