PART I

Studies on Equatorial Sporadic E
CHAPTER I.

INTRODUCTION

In 1930 Sir Edward Appleton, using the pulse sounding technique at Slough, detected abnormal echoes during night-time from E region levels and termed them as 'abnormal E' echoes. Later, sporadic E or $E_g$ was the name given to these abnormal echoes appearing on the ionogram as these echoes show features different from the normal E-region echoes.

A 'sporadic E' reflection is defined as any abnormal reflection characterized by one or more of the following criteria (Thomas & Smith 1959).

1) Random time of occurrence.
2) Partial transparency.
3) Variation of penetration frequency with transmitter power as deduced from F-region reflections.
4) Uniform apparent reflection height, regardless of frequency.

Extensive studies on sporadic E, using ionograms from different stations, revealed that it can be classified mainly into three types depending upon the latitude zone of its occurrence. These are (a) Auroral zone sporadic E,
(b) temperate zone sporadic E and (c) equatorial sporadic E.

Auroral Zone Sporadic E.

The auroral zone sporadic E is predominantly a night-time phenomenon with a maximum near midnight (Ratcliffe 1962, Bailey et al., 1955) and with very little apparent seasonal variation. It starts near 60°N geomagnetic latitude and has a maximum at 69°N (Matsushita 1952).

Some of the types of sporadic E are unique to this zone; first of these, is the 'a-type' with virtual height commonly increasing with frequency. Knecht (1956) has related these to overhead auroras. In this zone, ionograms often show a night E region echo with a large group retardation and a critical frequency of 1-2 MHz (King 1962). This is often classified as auroral Es. Another type of auroral Es is the slant type where the virtual range increases linearly with frequency (Olesen and Ryhner, 1958; Whale 1951; Smith and Knecht 1957).

Auroral sporadic E is attributed either to the precipitation of energetic particles or to the intense current streams, called auroral electrojet, which flows in these regions (Smith 1966). Farley's (1963) two-stream plasma instability theory appears to be the most promising
of theories, to explain the production of these auroral zone Es irregularities (Whitehead 1971).

Temperate Zone Sporadic E.

The temperate zone, for the purposes of sporadic E, is defined as the part of the earth's surface which is not within 30° of the two poles nor within 5° of the magnetic equator (Smith 1962).

The temperate zone sporadic E appears both during day and night hours. The most striking temporal feature of sporadic E in this zone is its seasonal variation. There is a very distinct summer maximum peaking in the months of June and July. A less well defined and much smaller maximum shows up around December. The diurnal behaviour of sporadic E shows quite a distinct maximum before noon and frequently a second maximum in the evening after sunset.

In this latitude zone a type of sporadic E appears frequently on the ionograms which is called as blanketing type. In this type, a strong sporadic E echo appears which obscures F layer echoes. The minimum frequency at which the F-region reflection is obtained or in other words, the frequency at which the Es layer begins to be transparent, is
called the blanketing frequency of Es ($f_{bE_s}$). Incidence of this type of sporadic E sharply diminishes at latitudes close to the magnetic equator (Knecht and MacDuffie 1962).

The simultaneous observations of midlatitude sporadic E by rockets and ionosondes have revealed that the blanketing frequency of Es layer gives the maximum electron concentrations in the Es layers within an error of about 10% on the average (Reddy and Rao 1968, Reddy 1968). Further Reddy and Rao (1968) observed that the 'top frequency' and critical frequency of Es layer give electron concentration values exceeding the rocket-observed maximum electron concentration by 40-100% during daytime and by several hundred percent during night time.

Many mechanisms have been suggested for temperate zone blanketing sporadic E, but out of these, wind shear theory offered satisfactory explanation for the blanketing type of Es (Axford 1961, 1963; Axford and Cunnold 1966; Whitehead 1960, 1961). A horizontal wind shear leads to vertical movement of ions and electrons which gives rise to the formation of thin layers of ionization. The probability of the layer appearing depends on the horizontal component of the earth's magnetic field.
Equatorial Sporadic E.

Equatorial sporadic E, as observed on the ionograms, is broadly classified into two types, namely q type (Esq) and slant type (Es-s).

(a) In Esq, the scatter echoes occur around 100 Km altitude and do not show any increase in altitude with increase in the exploring frequency.

(b) In Es-s, the scatter echoes occur around 100 Km and the height range increases with increase in frequency.

On some occasion blanketing type of sporadic E has been observed on Trivandrum (dip 8$^\circ$N) ionograms mostly during afternoon periods (Reddy and Devasia 1971).

Sporadic E is not sporadic in its occurrence as far as the equatorial regions are concerned. It is mainly a daytime phenomenon occurring almost every day in the morning hours and disappearing in the evening hours with no significant seasonal variation. Rangarajan (1954) reported that at Kodaikanal (dip 8$^\circ$N) it occurs 93% of the half hourly ionograms during day time. Bandyopadhyay and Montes (1963) from an analysis of Huancayo (dip 2$^\circ$N) ionograms found that Es is present 95% of the time during day
time. Equatorial sporadic E exhibits a diurnal variation very similar to that of the equatorial electrojet. On some occasions sporadic E occurs, at equatorial latitudes, in the late evening and night hours also. The night time occurrence of Es is very much less compared to the day time occurrence.

It is well known that the daily amplitude of the geomagnetic horizontal field \( H \), and hence the intensity of current in 100 \( \text{Km} \) region, is large at the magnetic equator. Matsushita (1951, 1953) has shown that this enhancement in \( H \) field occurs in a narrow zone centred around the magnetic equator. This intense band of current is called equatorial electrojet. Analysing Es data from the stations at and near the magnetic equator Matsushita (1951) concluded that the equatorial Es (Esq) appears in the same narrow zone as that in which the equatorial electrojet flows. A good correlation between \( f_{0E_{sq}} \) (the 'ordinary' critical frequency of \( E_{sq} \)) and the daily amplitude of \( H \), hence jet intensity, at the same stations was observed. A correlation coefficient of 0.93 was obtained between the monthly median values of \( f_{0E_{sq}} \) averaged for the hours 0900 to 1500 and the daily amplitude of \( H \) averaged on ten quiet days in each month at
Huancayo for equinoctial months of 1953-56 and a correlation coefficient of 0.66 in southern solstitial months for the same period. Thus, Matsushita (1951, 1953, 1962) concluded, in general, that the Esq has a close correlation with the H field, hence the equatorial electrojet.

Olahen and Bowles (1963) observed, with the help of the back scatter radar at 50 Mc/s, that the intensity of the equatorial sporadic E echoes shows a remarkable association with the current strength in the equatorial electrojet. As the electrojet current builds up, the strength of the associated radar echo is noted to rise markedly, presumably due to the increase in the strength of the irregularities.

**ELECTROJET.**

An intense band of current, called equatorial electrojet (Chapman 1951), flows over the magnetic dip equator where the dip angle goes to zero. In this region earth's magnetic field is horizontal while the electric field and principal current flow are horizontal and perpendicular to this magnetic field. This typical orientation of the fields leads to various geomagnetic and
ionospheric phenomena which are unique to this region. The crossed electric and magnetic fields generate a Hall current which flows perpendicular to both the fields. Flow of this current sets up a vertical polarisation field due to the difference between the electron and ion mobilities, effectively opposing the Hall current. Cowling found that, if the Hall polarisation inhibits the flow of Hall current, the effective conductivity of the medium parallel to the electric field is greater than Pedersen conductivity. This enhanced conductivity around 100 Km levels near the equator results in a flow of strong day-time band of current parallel to the electric field within a narrow belt of a few degrees of geomagnetic latitude which is named by Chapman as 'equatorial electrojet'.

The electrojet effect on the ground magnetic field is most pronounced in the American zone, less so in African zone and least in Indian zone (Rastogi 1962).

The extent of this strong band of current in the N-S direction has been estimated from the analysis of the ground based magnetograms, distributed all over the world (Forbush & Casaverde 1961; Onwumechilli 1959; Ogbuchi and Onwumechilli 1963 and 1964). The width of the electrojet
is reported to depend on solar activity. Onwumechilli (1959) using ground based magnetometer data, found a width \((440 \pm 20)\) Km for electrojet in Nigeria in December 1956 whereas \((406 \pm 20)\) Km (Ogbuehi and Onwumechilli 1964) in May-July 1962. This difference is attributed to the solar activity changes. Ogbuehi and Onwumechilli (1964) observed jet width to increase in northern summer, when the sun is over the electrojet. Forbush from the study of geomagnetic variation during IGY over South America, assuming a uniform current density, has deduced an electrojet width of 660 Km. (Knecht and McDuffie 1962). The width in the Indian zone during IGY period has been reported by Yacob and Khanna (1963) to be 290 Km.

**Width of the Equatorial E**

Equatorial \(E_s\) (\(E_{sq}\)) is closely associated with the equatorial electrojet and appears in the same narrow zone as that in which the equatorial electrojet flows. In view of this association many estimates have been made on the width of the electrojet current by determining the width of the equatorial belt in which \(E_{sq}\) occurs.

During IGY period Knecht and Mac Duffie (1962) using \(E_{sq}\) data, obtained from a chain of closed space stations in the vicinity of the magnetic equator in Peru and Bolivia, found the electrojet width to be 700 Km. Kotadia (1962) inferred from \(E_{sq}\) and horizontal field data that the boundary
of the equatorial electrojet extends up to 7° magnetic dip in high sunspot years as compared to 5° magnetic dip in low sunspot years, i.e., the meridional half width changes from about 250 km to 350 km.

Lunar effect on $E_s$.

The lunar effect in ionosphere is its tidal effect which gives periodic oscillation of ionospheric parameters with respect to lunar time.

The existence of lunar tidal variation in $E_s$ was first found by Matsushita (1952, 1953). Lunar tidal variations in $f_{E_s}$ (top frequency of $E_s$) and $h'_{E_s}$ (virtual height of $E_s$) have been investigated by Matsushita using published $E_s$ data for five stations of different latitudes, including equatorial station Huancayo. He established that the occurrence frequencies of large value of $f_{E_s}$ and of weak or nonexistent $E_s$ clearly depend on lunar time and also that values of $f_{E_s}$ indicate semi-diurnal lunar variations. The result indicated that low values of $f_{E_s}$ or nonexistent $E_s$ often occur at about 0200 and about 1400 hours lunar time.
Wright and Skinner (1959) also arrived at the same lunar variation of $f_{E_s}$ for Ibadan with a seasonal variation.

Matsushita gave a qualitative explanation of his results. The lunar component in the ground magnetic field variation has been attributed to the flow of lunar electrojet current at E-region levels superposed on the solar electrojet current. The manner of superposition of these two currents depends on the lunar age and time.

At new and full moon, a westward lunar electrojet flows in the magnetic equatorial zone at 0000-0300 and 1200-1500 hour lunar time. Thus the day time eastward electrojet current is reduced due to the superposition of the westward lunar electrojet current at these times. Matsushita (1952, 1953) attributed the weakening or disappearance of $E_s$ near lunar midnight and noon to this reduced jet current at those times.

**Lunar influence on the first appearance of $E_{sq}$**

Knecht (1959) studied the variability of time of first appearance of sporadic $E$ in the morning hours for Huancayo. He divided the 12 month period into three seasons, and for each season tabulated the time of first appearance of $E_{sq}$ on each day. The days were then grouped
together according to their approximate lunar age, and the averages were computed. Khecht observed a lunar dependence in the equinox and December solstice curves with $E_{s-q}$ tending to occur earlier during time’s of new and full moon. Khecht has put forward an explanation to his observations, based on the work of Chapman and Bartles (1940) which shows that during new and full moon, the contribution of the current system attributed to the lunar tidal force is such that it adds to eastward flowing solar associated current ($S_q$) during the early morning hours (0600-1000) where as during the first and third quarter, the lunar contribution weakens the eastward flowing current during the early morning hours. Thus, if $E_{s-q}$ depends on the strength of the eastward current it should appear earlier during new and full moon and later at the first and third quarters. Bandyopadhyay and Montes (1963) also arrived at the same conclusion. They pointed out that the final disappearance is remarkably steady and does not show any lunar influence. Bhargava (1963) analysing Kodaikanal data mentioned that during winter, $E_{s-q}$ appeared about 34 minutes earlier around new and full moon.
Association with Magnetic activity.

A positive correlation between magnetic activity and sporadic E is known to exist in the auroral zone. In the temperate zone clear evidence of magnetic dependence has not been established. Equatorial sporadic E is found to be affected by magnetic activity. Skinner and Wright (1957) found from Ibadan data that $f_{E_s}$, at noon, decreased from a mean value of 15 MHz on quiet days to 12 MHz on disturbed days and low $f_{E_s}$ occurred simultaneously with reduced horizontal and vertical magnetic fields. Analysing Indian and American equatorial zone sporadic E data, Rao (1964) reported that in both the annual and seasonal variations on quiet days, values of $f_{E_s}$ are always higher at Indian stations compared to that at American zone. Disturbed day values of $f_{E_s}$ have been found to be lower than the quiet day values.

Bhargava and Subrahmanyan (1961) found $E_{eq}$ to disappear for several hours during the main phase of the magnetic storm. On the other hand Bandyopadhyay and Montes (1963) found that occurrence of $E_{eq}$ is not affected by magnetic activity.
Disappearance of $E_s$.

Equatorial $E_s$ which persists, usually, during the day-time, occasionally disappears suddenly around afternoon periods. The period of disappearance usually extends from 15 minutes to few hours. Matsushita (1957) first studied such disappearances and found a lunar influence. He found that the sudden disappearance time mostly lies between 0000 and 0300 or between 1200 and 1500 hours lunar time. This relation, he found, more conspicuous during the December-Solstice month's than during the June-Solstice months. These lunar times correspond to westward lunar electrojet flow and as such, the normal eastward jet current would be weakened during these times. Matsushita suggested that this reduction in the eastward current is responsible for the disappearance of equatorial sporadic $E$.

Bhargava and Subrahmanyan (1961) analysing Kodaikanal data of the period June 1957 to May '60 found that during the main phase of most of the storms, when the horizontal magnetic field was considerably subnormal, $E_s$ disappeared suddenly.

They attributed this to the westward magnetospheric ring current during the storm period preventing favourable
conditions for the inhibition of the Hall currents at equatorial stations. This in turn appears to cause a considerable drop in the 'effective' conductivity in the dynamo region and results in weakening of the electrojet currents; the weakening of the electrojet current leads to the observed disappearance of $E_s$ for several hours during main phase of the storm.

Bandyopadhyay and Montes (1963) analysing Huancayo sporadic E data for sudden disappearances of sporadic E for the period 1958-61 observed, in general, a lunar dependence. They also reported that 82% of disappearances of $E_s$ in 1958 were associated with troughs in the horizontal magnetic field (H) trace on the ground magnetograms.

**Nature of equatorial $E_s$ irregularities.**

Extensive work on the nature of the equatorial electron density irregularities is being done since last decade at Jicamarca Radar Observatory in Peru. Cohen et al (1962) gave an experimental information as to the origin of the scattered echoes appearing at virtual heights greater than 100 Km on the ionograms, using a pair of orthogonal log-periodic antenna arrays with Huancayo ionosonde. One was polarized north-south and had a broad beam pattern in the east west plane; the other was polarized east-west and
had a narrow beam pattern in the east-west plane. Ionograms obtained separately with these antenna patterns showed that equatorial (E_{eq}) echoes were not affected by the changing beam pattern whereas slant E_s (E_{s-s}) echoes weakened considerably when narrow east-west antenna pattern were used. Thus the equatorial sporadic E trace as seen on the ionograms, they concluded, results from essentially overhead scattering while equatorial slant sporadic E (E_{s-s}) trace must result from scattering by irregularities east-west of the ionosonde. Hence the irregularities contributing to the scattering are those in a thin horizontal, east-west band situated at E-region heights. Further Cohen et al. (1962) assuming that these irregularities are embedded in the equatorial E layer, satisfactorily explained the echo pattern (E_{ss}) on the ionogram resulting from east-west band of irregularities. Egan (1960) concluded from his direction-of-arrival measurements by backscatter sounder that the irregularities detected in the equatorial E region were aligned with the earth's magnetic field. It was observed that the spatial correlation of electron density irregularities extended for much longer distances along the magnetic field lines than across them (Bowles et al., 1960). Bowles and Cohen, (1962) also showed that these irregularities are of
length 200 meters or greater, measured along the magnetic field lines, with at least one transverse dimension of the order of 6 meters or less.

Radar echoes from magnetic field aligned irregularities in the electrojet are 'aspect sensitive' (Bowles et al., 1963a) which describes the fact that such echoes can be obtained only when the path of propagation lies nearly perpendicular to the lines of force of the earth's magnetic field. Bowles et al., (1960, 1963a) have studied the spectrum of equatorial echoes (at 50 Mc/s) as a function of the direction of the propagation path. They observed that (a) after spectrum obtained at 30° zenith angle to the east and to the west of the station are essentially mirror images of each other, (b) no mean Doppler shift was obtained when a narrow-beam antenna pointed towards the zenith is used (c) except for echoes originating within about 15° of the zenith, and except for times when the echoes are of relatively low intensity, the spectral maximum always comes at a Doppler shift of 120 c/s (± 10 c/s) in the 50 Mc/s measurements. This Doppler shift of 120 c/s corresponds to a line-of-sight velocity component of 360 meters per second.
Bowles et al., suggested a model consistent with the above results in which the irregularities are composed of plane wave fronts (longitudinal waves), the wave normals of which are distributed in a plane normal to the magnetic field. In this model these plane wave irregularities move with acoustic velocities.

Farley (1963) has shown theoretically, that these plane wave irregularities arise from a two-stream instability in the electrojet plasma. The plane waves are, in this theory, ion acoustic waves, moving at the acoustic velocity of the medium.

Certain characteristics of the VHF radar echoes from the irregularities could not be explained by Farley's linear theory of two-stream instability, as the formation of those electrojet irregularities that scatter vertically. These irregularities are supposed to be the horizontal wave fronts and clearly associated with equatorial electrojet and responsible for the day time VHF forward scatter and for radar echoes obtained from the electrojet at vertical incidence. Another question was raised by the unexplained observation of certain electrojet irregularities moving at speeds slower than the acoustic velocity predicted by the
theory, observed by Bowles et al. (1963a) on VHF (50 Mc/s) radar echoes from the electrojet.

Dougherty and Farley (1967) gave a qualitative theory to account for such irregularity characteristics. They proposed that the waves that are generated by the two-stream instability will grow until they are limited by nonlinear effects. These effects will cause coupling between waves, which will, in turn, generate new waves which cannot be accounted for in the linear theory. Later Balsley (1969) made a series of observations with VHF radar (~50MHz) at Jicamarca and arrived at the conclusion that there exist distinctively two types of irregularities. The one which is associated with two-stream instability and the other which is not generated by two-stream instability. He showed that the latter type of irregularities can exist even when two-stream instability is not present. Balsley (1969) classified the irregularities (for convenience) as type I, which are generated directly by the two-stream instability and type II which are non-two-stream type. The main features of the type II irregularities obtained from radar spectra are summarized below.
1) The mean motion of the irregularities is in the same direction as the electron drift. Superposed upon this mean drift, the irregularitites have a random, fairly isotropic motion in the vertical.

2) Type II irregularities can exist independently of the type I.

3) An increase or decrease in the echo power of either type of echo is accompanied by a similar change in the other.

4) The power returned from the type II irregularities increases with increasing drift velocity.

5) Type II irregularities have been found to appear at night time also when electron drift velocity is eastward.

6) Type II irregularities exist even at low electron drift velocities.

Recently Balsley and Farley (1971) using three different radar frequencies 16.25, 49.92 and 146.25 MHz have shown that the strength of the type II irregularities decreases with decreasing wavelength. The type I irregularities can be obtained right up to radar frequency of 148 MHz indicating the presence of irregularities down to
a scale size of 1 meter. The type II echoes have been attributed to 'cross field instability mechanism'. In this mechanism, the electron density gradient plays an important role. According to this mechanism, instabilities will grow in a plasma with crossed magnetic and electric fields and an electron density gradient, in appropriate directions.

Rocket observation of Satyaprakash et al. (1971a, 1971b) from Thumba (dip 6°S) show the presence of irregularities in E-region both during night and day time. Their observations show presence of irregularities in electron density with amplitude 5 to 20%, in scale size range of 30-300 meters, and with amplitudes 1 to 20% in the scale size range 1-15 meters. In their night time flight at 2300 hour IST (29 August 1968) irregularities were seen to be present in regions of negative electron density gradient. (Satyaprakash et al. 1971a) Irregularities were obtained even at 120 km where the estimated electron drift velocity was of the order of 70 m/sec. These irregularities have been attributed to the crossfield instability mechanism.
CHAPTER II

STUDY OF SLOW DISAPPEARANCE OF EQUATORIAL E_

Sporadic E at equatorial latitudes (E_{sq}) is mainly a daytime phenomenon. As seen on the ionograms it appears, in general, in the morning around 0700 hours local time and persists throughout the day, disappearing around 1700 hours local time. However, on some occasions, E_{sq} disappears suddenly in the afternoon period. Matsushita (1957) studied the sudden disappearance of E_{sq} at Huancayo (dip 2°N) in relation to the lunar time. He found that on many occasions the time of sudden disappearance of E_{sq} was around local lunar midnight or local lunar noon. He interpreted this disappearance related to lunar time in terms of the lunar electrojet. Around lunar midnight and noon, the lunar electrojet current flows in westward direction at the E-region levels, opposing the normal eastward electrojet current. The sudden disappearance of E_{sq} was attributed to this decrease in eastward electrojet current. Bhargava and Subramanian (1961) analysing the Kodaikanal (Long 77°29'E, dip 3.5°N) data found that during the main phase of the magnetic storm, when the horizontal field has decreased, E_{sq} disappeared suddenly. Rastogi et al. (1971) from a study of the ionospheric and magnetic data at stations close to the magnetic equator in the Indian zone, showed that the disappearance of E_s during the depressions in horizontal magnetic field during daytime is associated with the reversal of ionospheric drift.
In the following sections, the results of the studies on the sudden disappearance of $E_{sq}$ at Trivandrum and Kodaikanal are presented.

Analysis of Sudden Disappearance of $E_{q}$ ($SD_{E_{q}}$).

The ionograms analysed in the present investigation correspond to Trivandrum (same as Thumba) (Long 76°52'E, dip 0.6°S) and Kodaikanal (Long 77°29'E, dip 3.5°N). These were taken at quarter hour intervals using CRPL ionosonde ($C_{4}$). The output power of the ionosonde transmitter was about 8 KW, which was maintained reasonably constant throughout the period of investigation. The transmitting and receiving aerials are crossed delta aerials, erected 45° to the magnetic North-South. The height of the aerial pole is 70 feet above the ground and each horizontal arm is extended to 120 feet for Trivandrum ionosonde. The length of the horizontal arm has been increased over the normal $C_{4}$ ionosonde aerial (60 feet) for better performance of the system at the lower frequencies.

The presence of $E_{q}$ at equatorial latitudes is shown on the ionograms as diffuse echoes. When these diffuse echoes are absent and a clear E-region trace is
seen during the daytime, it is taken as the disappearance of $E_{sq}$. The ionograms obtained during 0600 to 1700 hours L.T. corresponding to Trivandrum and Kodaikanal have been examined for the sudden disappearance of $E_{sq}$ for the period of two years 1969 and 1970.

In the present investigation, the disappearance of $E_{sq}$ before the normal disappearance time (around 1700 hours local time) is taken to represent the sudden disappearance event. This disappearance is found to occur, in general, rather suddenly, without showing any considerable weakening of the echoes before the disappearance. However, on few occasions, it is noticed that the disappearance of $E_{sq}$ is gradual, preceded by weaker $E_{sq}$ echoes for the duration of about half an hour. Hereafter this sudden disappearance of $E_{sq}$ will be denoted as SDE$_q$ event. The time at which the SDE$_q$ occurs is taken as the time of start of the event. The duration of the event, in case $E_{sq}$ reappeared again, is determined by noting the time of ionogram preceding the ionogram on which $E_{sq}$ has reappeared.

In figure 1 ionograms are presented showing the sequence of the SDE$_q$ event. These ionograms correspond to Trivandrum, on 8th January 1970. Ionogram a' and b' show
FIG. 1 IONOGRAM TAKEN AT TRIVANDRUM SHOWING SDE event
FIG. 1 (CONT'D)
FIG. 1 (CONT'D)
the normal presence of $E_{sq}$ at 1110 and 1140 hours L.T.
The ionogram at 1155 shows the sudden disappearance of $E_{sq}$. It can be seen that in this ionogram, both the ordinary and extra-ordinary traces of E region are clear and the critical frequencies of these can be determined. Clear E region traces continue upto 1640 hours. It may be noted that the foE (ordinary critical frequency of the E-region) is about 2.8 MHz at 1155 hours and decreases to about 1.7 MHz at 1640 L.T. $E_{sq}$ reappears again at 1655 and is also present in the ionogram at 1710 L.T. The total duration of the SDE$_g$ event in this case is 4 hours and 45 minutes, from 1155 to 1640 hours.

With a view to seeing the dependence of SDE$_g$ event on magnetic activity, if any, the days of SDE$_g$ event have been grouped according to the daily sum of planetary magnetic indices ($\xi K_p$) for the two year period 1969 and 1970. This is shown in the histogram (fig. 2a). It can be seen from the histogram that the number of occurrences of SDE$_g$ event shows a broad maximum between $\xi K_p$ equal to 6 and 26. There are considerable number of occurrences of SDE$_g$ event on days which are extremely magnetically quiet as well as on days which are extremely magnetically disturbed ($\xi K_p \geq 34$).
FIG. 2a. MONTHLY OCCURRENCES OF THE SDEs EVENT DURING 1969 & 1970 FOR TRIVANDRUM

FIG. 2b. MONTHLY OCCURRENCES OF THE SDEs EVENT DURING 1969 & 1970 FOR TRIVANDRUM
This shows that the $SDE_S$ event occurs both on magnetically quiet and disturbed days. In the following analysis, days with $\Sigma K_p \leq 18$ are taken as relatively magnetically quiet days and days with $\Sigma K_p \geq 18$ are taken as disturbed days. Out of the total number of 90 occurrences of $SDE_S$ event during the period 1969 and 1970, 47 cases of $SDE_S$ event occurred on magnetically quiet days ($\Sigma K_p \leq 18$).

The number of occurrences of the $SDE_S$ event, in each month during the two year period, have been counted. In figure 2b the number of occurrences in each month for Trivandrum are plotted against the corresponding month. In this figure the days of $SDE_S$ event with $\Sigma K_p \leq 18$ have been shown by unshaded portion. It can be seen from this figure, that except in the month of July, the $SDE_S$ event occurred in every month. Three maxima are seen, occurring in January, May and September with one in January as the highest for both total number of days and quiet days. Bhargava (1963) found from an analysis of Kodaikanal ionograms for the period September 1955 to August 1960, that the sudden disappearance of $E_{sq}$ occurs most frequently in local summer, with a minimum in equinox and secondary maximum in winter. Bandyopadhyaya and Montes (1963)
observed from Huancayo data for the year 1958 and 1960-61
two maximum in the disappearance of $E_s$ occurring in solstices
with the maximum in December solstice as higher. The present
analysis shows similar features except for another maximum
in September.

The time of start of SDE$_s$ event as well as its
duration are noted examining the quarter hour ionograms for
the two year period (1969-70) for Trivandrum. With a view
to seeing the local time dependence of the SDE$_s$ event, the
starting times are grouped according to the local time. A
histogram showing the number of occurrences of the starting
time of SDE$_s$ event against the local time is presented in
figure 3a, for Trivandrum. The unshaded portions correspond
to magnetically quiet days. It can be seen that the event
occurs mainly in the afternoon period. The maximum occurrence
of the starting time is between 1400 and 1500 hours local
time for both magnetically quiet and disturbed days. This
agrees well with the observation of Bandyopadhyaya and
Montes (1963) from Huancayo data that the afternoon sudden
disappearance of $E_s$ is maximum around 1430 hours L.T. It
can be noted from figure that all the disappearances before
1100 L.T. occurred on magnetically disturbed days.
FIG. 3a. Shows number of SDEs event against local time for Trivandrum.

FIG. 3b. Shows number of SDEs event against lunar time for Trivandrum.
To study the lunar dependence of the $SDE_g$ event, the starting times are converted to lunar times. The number of occurrences of the event are grouped according to the lunar hour and is shown, as a histogram in figure 3b, for the years 1969 and 1970. The unshaded portions show days with $S_{K_p} \leq 18$. It can be seen that the event occurs at all the lunar hours. A broad maximum is shown in the interval 1200 to 1800 hours lunar time. From the figure, it is clear that the event occurs not only around the lunar midnight and noon but also at other lunar hours. As the time of westward flow of lunar electrojet current is around lunar midnight and noon (Matsushita 1957) the occurrences of the $SDE_g$ event at other lunar times cannot be attributed to the effect of lunar electrojet.

Magnetograms for Trivandrum and Kodaikanal have been analysed with a view to seeing if there are any abnormal changes in the horizontal magnetic field (H) variations on the days of $SDE_g$ event. The method of analysis and the results, are presented in the following.
Association of SDEs event with Magnetic field Changes.

Method of analysis of magnetograms and results:

The values of the range $\Delta H$, of the horizontal magnetic field $H$, at quarter hour intervals, are obtained for a particular day from the magnetograms in the following manner. $\Delta H$ at any time 't' on a particular day is given by

$$\Delta H(t) = H(t) - H_B$$

where $H(t)$ is the observed value of the $H$ field at time $t$ and $H_B$ is the base value of the field for that day. $H_B$ represents the value of the field when the overhead currents are minimum. This condition is achieved during midnight hours as the conductivity of the dynamo region will be minimum during those hours due to low electron density. So $H_B$ is obtained for each day by averaging the $H$ values corresponding to 2300 (of previous day), 0000, 0100, 0200 hours of the same day. The deviation in the $H$ value during the period 2300 to 0200 hours from their average is found to be, in general, about 5 Y on magnetically quiet days ($\Sigma K_p \leq 18$). So the uncertainty in $\Delta H$ would be about the same.
As shown above, the \( \Delta H \) values at quarter hour intervals for all SDE\(_s\) event days which are not magnetically disturbed, are estimated \( (\Sigma K_p \leq 18) \).

The quiet day average \( \Delta H \) values for a month \( (\overline{\Delta H}_q) \) were obtained by taking the average of \( \Delta H \) for the five international quiet days of the month. On any of these five quiet days if there was an SDE\(_s\) event, that day was not included in the averaging.

The values of \( \overline{\Delta H}_q \) thus obtained are subtracted from the corresponding \( \Delta H \) values for each day in the month. The difference \( (\Delta H - \overline{\Delta H}_q) \) on a particular day in the month, represents the deviation in \( \Delta H \) from its average quiet day behaviour.

The difference \( (\Delta H - \overline{\Delta H}_q) \) has been plotted for all the days on which SDE\(_s\) event occurred. Figure 4 shows a typical plot of \( (\Delta H - \overline{\Delta H}_q) \) on a SDE\(_s\) event day (January 8, 1970) for Trivandrum and Kodaikanal. The duration of the disappearance of \( E_{sq} \) was 4 hours and 45 minutes. The time of starting of the SDE\(_s\) event and its duration are marked in the figure. It is seen from this figure, that \( (\Delta H - \overline{\Delta H}_q) \) shows similar features for Trivandrum and Kodaikanal. \( (\Delta H - \overline{\Delta H}_q) \) goes negative around 1000 hours and again becomes
Fig. 4. Diurnal variation of \((\Delta H_8 - \overline{\Delta H_8})\) for Trivandrum and Kodaikanal. Arrow marks show the duration of SDE events.
positive after 1600 hours. The maximum depression in 
$(\Delta H - \Delta H_q)$ at Trivandrum is about $85^\circ$ reached around 1305 hours. The SDE$_S$ event occurred at 1155 L.T. when the 
$(\Delta H - \Delta H_q)$ is negative. $E_0$ reappeared again when $(\Delta H - \Delta H_q)$ has reversed to positive value. It may be noted that throughout the duration of SDE$_S$ event, $(\Delta H - \Delta H_q)$ remained negative. This shows that during the SDE$_S$ event the range $\Delta H$ goes below the average quiet day value of the range $\Delta H_q$.

The times of occurrence and duration of the SDE$_S$ event are shown in table 1 for January 1970 for both Trivandrum and Kodaikanal.

<table>
<thead>
<tr>
<th>Date</th>
<th>Time of Disappearance</th>
<th>Duration in Hour</th>
<th>Time of maximum Field Depression</th>
<th>$(\Delta H - \Delta H_q)$ loss of data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan'70</td>
<td>KOD</td>
<td><strong>TVM</strong></td>
<td>KOD</td>
<td>TVM</td>
</tr>
<tr>
<td>7</td>
<td>1125</td>
<td>1140</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>8</td>
<td>1155</td>
<td>1155</td>
<td>4.75</td>
<td>4.75</td>
</tr>
<tr>
<td>9</td>
<td>1440</td>
<td>1425</td>
<td>1.50</td>
<td>1.75</td>
</tr>
<tr>
<td>10</td>
<td>1355</td>
<td>1355</td>
<td>2.50</td>
<td>2.50</td>
</tr>
<tr>
<td>13</td>
<td>1425</td>
<td>1425</td>
<td>1.75</td>
<td>1.75</td>
</tr>
<tr>
<td>14</td>
<td>1540</td>
<td>1525</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>24</td>
<td>c</td>
<td>1425</td>
<td>c</td>
<td>2.5</td>
</tr>
<tr>
<td>28</td>
<td>1425</td>
<td>1425</td>
<td>1.75</td>
<td>1.75</td>
</tr>
<tr>
<td>29</td>
<td>1340</td>
<td>1340</td>
<td>1.50</td>
<td>1.50</td>
</tr>
</tbody>
</table>

* Kodaikanal
** Trivandrum
- Loss of data
The maximum negative value of \( (\Delta H - \Delta H_q) \) during the event and its time of occurrence are also shown in the same table. It can be seen that there are large depressions in \( \Delta H \) from the quiet day average value \( \Delta H_q \). The duration of the event varies from 15 minutes to 4 hours 45 minutes. It is interesting to note that when the duration of the event is 4 hours 45 minutes, there is a very large depression of 75\( \gamma \) and 82\( \gamma \) at Kodaikanal and Trivandrum respectively. It can also be seen from the table that the SDE\( _s \) event occurs, in general, simultaneously at Kodaikanal and Trivandrum and also that the duration is same for both the stations. This indicates that the SDE\( _s \) event is not a local phenomenon confined to one station. It extends at least upto 3\( ^\circ \) in geomagnetic latitude from the magnetic equator. From the above, it can be concluded that the SDE\( _s \) event is associated with large depressions in the \( \Delta H \) compared to the average quiet day range \( \Delta H_q \).

To investigate the behaviour of the range \( \Delta H \) on days of SDE\( _s \) event, which are magnetically quiet \( (K_p \leq 18) \), \( \Delta H \) for those days have been plotted. Figures 5 to 9 show some typical plots of \( \Delta H \) versus local time. The SDE\( _s \) event is marked in the figure along with the duration of the
event. Also the times of morning onset of $E_{sq}$ on those days have been indicated in the figures. Figures 5 and 6 show $\Delta H$ variations at Trivandrum and Figures 7, 8 and 9 show those at Kodaikanal. $\Delta H$ values, for all the $SDE_{s}$ event days with $\Sigma K_p \leq 18$, at the time of start of $SDE_{s}$ event as well $\Delta H$ values at the time of reappearance of $E_{s}$ have been tabulated in table number 19 of the next chapter (Chapter No.3).

The essential features in these figures can be summarised as follows:

1. The $\Delta H$ values at the time of starting of the $SDE_{s}$ event are, in general, above the nighttime value ($\Delta H=0$), except on one day (9.1-70) where the $\Delta H$ is around the nighttime value.

2. In cases when $E_{s}$ reappeared again, the $\Delta H$ values at the time of reappearance show both positive and negative values.

3. During the $SDE_{s}$ event, $\Delta H$ obtained negative values in most of the cases.

4. The $\Delta H$ values at the times of morning appearance, starting of $SDE_{s}$ event and reappearance are not the same.
FIG. 5 $\Delta H$ VARIATION ON THE DAYS OF SDE$$_3$ EVENT

TRIVANDRUM
8.1.70

9.1.70
FIG. 8 ΔH VARIATION ON THE DAYS SDEs EVENTS

KODAIKANAL
21-5-70

5-6-70
FIG. 9. $\Delta H$ VARIATION ON THE DAY OF SDEs EVENT
Disturbed day $\Delta H$ values ($\Sigma K_p > 18$), on the days of SDE$_g$ event, have also been plotted and shown in the figure 10, for two days. It may be mentioned here that the base values $H_p$ for disturbed days are obtained by averaging the night-time $H$ values (2300 to 0200 hours as described earlier) of a nearest quiet day. On 2.9.70, which is a moderately disturbed day ($\Sigma K_p = 24$), it can be seen that the behaviour of $\Delta H$ is similar to that on quiet days. On 23.10.70, $\Sigma K_p$ is high, equal to 32. Disappearance of $E_{eq}$ on this day lasted for a short duration of 30 minutes. A small depression is shown during this period. After the reappearance of $E_{eq}$ at 1500 hours there is large depression in $\Delta H$. It may also be noted that the morning on-set of $E_{eq}$ occurred when $\Delta H$ was negative. It is quite likely that on this day, the magnetospheric contribution to $\Delta H$ is large resulting in negative $\Delta H$ values during morning and afternoon periods. As such, the $\Delta H$ variations do not completely represent the currents in the dynamo region. So, the presence or disappearance of $E_{eq}$ cannot be directly related to the $\Delta H$ variations on disturbed days unless magnetospheric contribution is taken into account.
FIG. 10. MAGNETICALLY DISTURBED DAY $\Delta H$
VARIATION ON THE DAYS OF SDEs EVENT

KODAIKANAL
2.9.70
$Kp_0 = 24$

23.10.70
$Kp = 32$

LOCAL TIME

$\Delta H$, IN $Y$
Cohen, Bowles and Calvert (1962), from back scatter observations at Jicamarca, found that the strength of the back scattered signal from \( E_{sq} \) is associated with the \( H \) field. Later Bandyopadhyaya and Montes (1963) examined the disappearance of \( E_{sq} \) using Huancayo (dip 2°N) ionograms. They found that the disappearance of \( E_{sq} \), as seen on the ionograms, is associated with a trough in the \( H \) field. They also observed that in most of the cases, \( E_{sq} \) disappeared when the \( H \) field is less than the value of \( H \) at the time of first appearance in the morning. The present findings for magnetically quiet days are in general agreement with their observations. In the present study, it is found that in most of the cases, the field value at the time of disappearance is not the same as that at the time of onset of \( E_{sq} \) in the morning. It is also observed that in most of the cases, at the time of disappearance, the field value is above the nighttime value. This means that the overhead eastward current in the dynamo region responsible for \( H \) variations is not reversed in direction at the time of disappearance. Also it may be noted that though sudden disappearance of \( E_{sq} \) is always associated with a decrease in the field, it is found that the converse is not true. This was also observed by
Bandyopadhyaya and Montes (1963). It is likely that all the depressions in the field are not due to changes in the electrojet current and some of them may be due to magnetospheric contributions. However, as the $E_{sq}$ irregularities are associated with the electrojet region, the field changes during the SDE$_g$ events can be attributed to the changes in the electrojet current.

The magnetic field depressions during the SDE$_g$ event are examined in detail in the next chapter and quantitative estimates of the electric field and electron velocity in the dynamo region are presented.
CHAPTER III

ESTIMATION OF THE ELECTRIC FIELD AND ELECTRON VELOCITY AT E-REGION LEVELS

The enhancement in the horizontal magnetic field during day-time over the night-time value at equatorial latitudes is mainly due to the currents flowing at the E region levels. An eastward current would give rise to an enhancement in the horizontal magnetic field at equatorial stations. So, in general, a decrease in the field superposed on the normal enhancement can be attributed to a decrease in the eastward current flowing at the E region levels. Some of the low latitude field depressions are related to the high latitude positive bays (Akasofu 1968). In such cases, low latitude field depressions are explained as due to the westward return current of the high latitude bays. It can be seen that this westward return current would result in a net decrease in the normal eastward current flowing at that time. Equivalently this can be taken to correspond to a decrease in the eastward electric field responsible for the current.
Around lunar midnight or noon the westward lunar electrojet current would cause a net decrease in the normal eastward current. This reduction in the net eastward current would result in a depression in the ground magnetic field during those times, namely, around lunar midnight and noon. In the present analysis, only the field depressions which are associated with the SDE\(_{s}\) events are analysed. As mentioned in the previous chapter, the field depressions during these times can be taken to be predominantly due to change in the electrojet currents. It may also be noted here, that only the field variations on relatively magnetic quiet days (daily sum of \(K_p\) index \(< 18\)) on which SDE\(_{s}\) events occurred, have been analysed in the following.

The electrojet current depends upon the electrical conductivity and the electric field in the E-region. The conductivity is a function of electron density and collision frequencies between charged and neutral particles. It may be expected that there will not be any abrupt change in the collision frequencies leading to change in conductivity during SDE\(_{s}\) event.

In general, a change in the normal eastward electrojet current strength could be due to 1) a change in the
electron density leading to a corresponding change in the electric conductivity or 2) a change in the electric field responsible for the current or both. In the following, these alternatives are examined in detail.

Variation of $f_0E$ during SDE$_g$ events.

The E region critical frequency ($f_0E$) cannot be scaled when $E_{sq}$ is present on the ionograms. At such times, the $f_{\text{min}}F$ (the minimum frequency at which the F region echo appears on the ionogram) values are noted when the F region trace on the ionogram shows group retardation towards the low frequency end of the trace. These $f_{\text{min}}F$ values can be taken to be approximately same as the $f_0E$ values at these times. During the SDE$_g$ events, as the E region trace will be clear, $f_0E$ values are scaled from the ionograms. The diurnal behaviour of $f_0E$ on four SDE$_g$ event days in the month of January 1970 is plotted in Figure 11. In this figure, the crosses indicate the $f_0E$ values when $E_s$ is present and the circles during the SDE$_g$ event. It can be readily seen from these four plots of diurnal behaviour, that $f_0E$ shows a smooth diurnal variation with a broad peak around noon. There is no abnormal variation of $f_0E$ during the SDE$_g$
Fig. 11 shows diurnal variation of $f$ on SDEs event days. Crosses indicate $f$ values in presence of E4, and circles during SDEs event.
event. In Figure 12, the diurnal behaviour of $f_0 E$ on days without SDE$_s$ event in January 1970 is shown. It can be noted that these plots show similar behaviour as shown in Figure 11 for SDE$_s$ days. Thus, it appears, that there is no appreciable change in $f_0 E$ or equivalently the E-region maximum electron density, during the SDE$_s$ events. If it is assumed that there is no considerable change in electron density profile during SDE$_s$ events compared to normal times, it can be taken that there would be no appreciable change in the E-region conductivity due to electron density, during SDE$_s$ events from its normal value.

It is quite likely that the changes in the magnetic field associated with the SDE$_s$ events are due to the changes in the electric field responsible for the currents flowing at the E-region levels. So, it is necessary to make an estimate of this electric field at the E-region levels. In the following, the method of estimation of the east-west electric field and hence electron drift velocity ($V$) is described and results are presented.
FIG. 12. SHOWS DIURNAL BEHAVIOUR OF $S^e$ ON DAYS WITHOUT SDE$^e$ EVENT.

Local Time

$S^e$ IN MWZ

10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Estimation of east-west electric field and electron velocity from $\Delta H$.

Method of estimation.

For magnetically quiet days ($\Sigma K_p \leq 18$), the observed daily range of horizontal magnetic field $\Delta H$ at the ground consists predominantly of contributions due to overhead currents in the dynamo region and the induced earth currents. It is taken that the overhead current contribution is two-thirds of the total range $\Delta H$ (Chapman 1951). The overhead current intensity responsible for this part of $\Delta H$ is estimated following the method of Chapman (1951). In this, a horizontal band of current situated at a height of $h$ is assumed with a width of $2W$ meters and uniform intensity of $J$ emu/meter. This current is given by

$$J = \frac{\Delta H^1}{2 \tan^{-1} \frac{2v}{1 + u^2 - \gamma^2}}$$

(1)

where $\Delta H^1 = \frac{2}{3} \Delta H$

$v = W/h$, $u = x/h$, $x$ is the distance in meters of the station from the equator along the meridian, $W$ is the half-width of the electrojet in...
N-S direction, \( W \) is taken to be equal to \( 300 \times 10^3 \) meters for the Indian Zone (Yacob and Khanna 1963). This intensity \( J \) in amp/meter can also be expressed approximately as

\[
J = \left\{ \int_{h_1}^{h_2} N e V \, dh \right\} \left( \frac{1}{h_2^3} \right) \left( \frac{\delta}{\psi} \right) E_y \, dh
\]

where \( I \) is current density in amp/meter\(^2\),

\[
\frac{\delta}{\psi} = \text{Cowling Conductivity}
\]

\( N = \text{electron density/meter}^3 \)

\( e = \text{electron charge} \)

\( V = \text{electron drift velocity in meter/sec} \)

\( E_y = \text{eastward electric field in volts/meter} \)

\( h_1 \) and \( h_2 \) are the lower and upper limits of the height respectively over which the integration is carried out.

In other words, the total height integrated current density \( \int_{h_1}^{h_2} I \, dh \) is taken to be equivalent to a sheet current of intensity \( J \) situated at a height \( 'h' \). This height is taken to be the height of \( \sqrt{3} \) maximum.

Assuming that \( E_y \) does not change with height in the height range \( h_1 \) to \( h_2 \), \( E_y \) can be expressed as

\[
E_y = \frac{J}{\int_{h_1}^{h_2} \frac{1}{h_2^3} \, dh}
\]

(3)
From this the velocity \( V \) is estimated by using the relation

\[
V = \frac{\sqrt{3} E_y}{N.e}
\]  

(4)

at the height of maximum of \( \sqrt{3} \) \( \left( \sqrt{3} \text{ and } N \text{ to be taken at the height of } \sqrt{3} \text{ maximum in equation 4.} \right) \)

ESTIMATION OF CONDUCTIVITY.

In the ionosphere, equal numbers of positive ions and electrons are embedded in the neutral gas in which, if electric field \( E \) is applied there will be a flow of current. In the presence of the geomagnetic field ionospheric conductivity becomes anisotropic.

In the general case \( \overrightarrow{E} \), the applied electric field, may be resolved into components \( \overrightarrow{E_0} \) and \( \overrightarrow{E_1} \) respectively parallel and perpendicular to \( \overrightarrow{B} \), the intensity of the uniform magnetic field. If \( \hat{h} \) is a unit vector parallel to \( \overrightarrow{B} \) the current density \( \overrightarrow{I} \) is given by

\[
\overrightarrow{I} = \zeta_0 \overrightarrow{E_0} + \zeta_1 \overrightarrow{E_1} + \zeta_2 (\hat{h} \times \overrightarrow{E})
\]

where \( \zeta_0 \), which is termed as 'longitudinal conductivity', is along the direction parallel to the magnetic field and is independent of \( B \); the conductivity \( \zeta_1 \), called the 'Pedersen conductivity', is along the direction parallel to that
component of the electric field which is normal to the magnetic field; \( \frac{\sqrt{2}}{2} \), the Hall conductivity is along the direction perpendicular to both, the electric and the magnetic field.

At the magnetic equator earth's magnetic field is horizontal (and northward) while the electric field and principal current flow are along east-west direction. Because of the Hall drift the ions and electrons tend to move in the vertical direction. This sets up a vertical polarization field \( E_p \) due to the disparity between the electron and ion mobilities, effectively opposing the Hall current. This vertical polarization field crossing with magnetic field produces additional drift in the east-west direction, thus increasing the conductivity of the medium in this direction. This enhanced conductivity in the E-region results in a flow of strong day time band of current parallel to the electric field, within a narrow belt of few degrees of geomagnetic latitude around the magnetic equator.

Taking a rectangular co-ordinate system and choosing x-y plane as the ionized sheet plane, and the magnetic field dipping downwards at an angle \( \alpha \) to the plane, and the x and y axes coinciding with the magnetic south and east
respectively, and then if z-direction be considered as pointing upwards, the components of conductivity tensor can be expressed as

\[ \begin{align*}
\mathcal{\Omega}_{xx} &= \frac{\mu_0 \eta I}{\mu_0 \sin^2 \phi + (\omega z)^2 \cos^2 \phi} \\
\mathcal{\Omega}_{xy} &= \frac{\mu_0 \eta I}{\mu_0 \sin^2 \phi + (\omega z)^2 \cos^2 \phi} \\
\mathcal{\Omega}_{yy} &= \frac{\mu_0 \eta I}{\mu_0 \sin^2 \phi + (\omega z)^2 \cos^2 \phi}
\end{align*} \]

At the magnetic equator \( \phi = 0 \) the components of conductivity are

\[ \begin{align*}
\mathcal{\Omega}_{xx} &= \mu_0 \eta I \\
\mathcal{\Omega}_{xy} &= 0 \\
\mathcal{\Omega}_{yy} &= \mu_0 \eta I + \frac{\mu_0 \eta I}{\omega^2 + \omega z^2} \cos^2 \phi \\
\mathcal{\Omega}_{zz} &= \mu_0 \eta I + \frac{\mu_0 \eta I}{\omega^2 + \omega z^2} \cos^2 \phi
\end{align*} \]

The following expressions as given by Chapman (1956) for \( \mathcal{\Omega}_1 \) and \( \mathcal{\Omega}_2 \) have been used for the computation of \( \mathcal{\Omega}_3 \).

\[ \begin{align*}
\mathcal{\Omega}_1 &= \text{Pedersen conductivity} \\
&= N e^2 \left[ \frac{\nu_e}{m_e (\nu_e^2 + w_e^2)} + \frac{\nu_i}{m_i (\nu_i^2 + w_i^2)} \right]
\end{align*} \]
\[ \omega_2 = \text{Hall conductivity} \]
\[
= \frac{N e^2}{m_e \left( \frac{w_e^2}{w_e^2 + w_i^2} \right)} - \frac{w_i}{m_i \left( \frac{w_i^2}{w_e^2 + w_i^2} \right)}
\]

where

- \( m_{e,i} \) = electron or ion mass
- \( \nu_{e,i} \) = electron or ion collision frequency
- \( w_{e,i} \) = electron or ion cyclotron frequency

and

\[
\nu_e = \nu_{en} + \nu_{ei}
\]

Collision frequency models.

For the estimation of conductivity, two different collision frequency models have been used.

One of the models adopted is the model given by Chapman (1956). This is given as

\[
\nu_{ei} = \left[ 34 + 4.18 \log \left( \frac{T^2 N^{-1}}{\nu e} \right) \right] N T^{-3/2}
\]
\[
\nu_{en} = 5.4 \times 10^{-10} N_n T^{1/2}
\]

and

\[
\nu_i = \nu_{in} = 2.6 \times 10^{-3} (N + N_n) W^{-1/2}
\]
where $N_n$, $T$, and $W$ are the neutral particle density, the
temperature, and the mean molecular weight of the ions
(which is assumed to be equal to that of the neutral parti­
cles) respectively, and $N$ is the electron density.

The other model for $\nu_{en}$ and $\nu_{ei}$ given by Thrane
and Piggott (1966) has been used.

\[
\nu_{en} = 1.5 \nu_M = 1.5 u \left[ 1.11 \times 10^{-7} n (N_2) + \right.
\left. 7 \times 10^{-8} n (O_2) \right]
\]

where $n (N_2)$ and $n (O_2)$ are the number densities of $N_2$ and
$O_2$ respectively, $u$ is the electron energy $(KT)$ in ev

\[
\nu_{ei} = \left[ 30 + 3.6 \ln \frac{T_e}{T_i} - \frac{T_i}{N} \right] N. T_e^{-3/2}
\]

where $T_e$ and $T_i$ are the electron and ion temperatures and
$N$ is the ion number density which is taken to be equal to
the electron number density. For the height range of 80 to
150 km it is taken that $T_e = T_i = T$ (neutral gas temperature).

And $\nu_{in}$ is computed using the expression given by Banks
(1966). Considering the species $[O^+, O], [N_2^+, N_2]$ and
$[O_2^+, O_2]$ the expression $\nu_{in}$ can be written as
\[ \nu_{\text{in}} = 4.7 \times 10^{-13} n (O) \bar{T}^{1/2} (10.5 - 0.67 \log_{10} \bar{T})^2 + 3.6 \times 10^{-13} n (N_2) \bar{T}^{1/2} (14.2 - 0.96 \log_{10} \bar{T})^2 + 8.2 \times 10^{-10} n (O_2) \]

where \( \bar{T} = T_i + T_e = 2T \)

In the case of ion-neutral (\( \nu_{\text{in}} \)) collisions, involving particles of like masses, the use of reduced mass in place of mass, while arriving at the collision frequency expression by momentum transfer considerations, effectively leads to doubling of the collision frequency arrived at from mean free path considerations. Collision frequencies obtained from mean free path considerations are used in the conductivity formulae given above. So \( \nu_{\text{in}} \) values obtained by this model are divided by two before using in the conductivity expressions.

For computing the collision frequencies by above mentioned models, neutral densities, temperature and mean molecular weight have been taken from appropriate CIRA (1965) model.
Electron density profile.

The electron density profile has been obtained from the resonance probe data of 28th January 1971, 1040 hours (IST) flight from Thumba (Satyaprakash 1971). The electron density profile (fig 15) from this probe shows a maximum electron density of about $1.7 \times 10^{11}/m^3$ at 110 Km, the electron density falling by about 10% to a minimum at 120 Km, above which the electron density steadily increases until rocket apogee of about 155 Km. The maximum electron density of $1.7 \times 10^{11}/m^3$ at 110 Km very well agrees with the $f_E$ value ($f_{\min}$) observed during the rocket flight on the ground based ionosonde.

The electron density profiles at different times of the day are obtained from the above rocket electron density profile assuming that the shape of the electron density-height profile does not appreciably change in the height range of concern. The ratio of the peak density of the rocket electron density profile and the peak density at a given time (obtained from $f_E$ values) is found out. The rocket electron density profile is multiplied by this ratio and the resulting profile is assumed to correspond to the given time.
Collision frequency results.

Collision frequencies \( \nu_0 \) and \( \nu_1 \) in the height range 80 to 150 \( \text{Km} \) by the two different models, as mentioned earlier, are given in the table 2 and also shown in the Figures 13 and 14. \( \nu_1 \) values obtained from Chapman's model as well as Bank's model are almost same. There is no appreciable difference between the two values in the height range of 80 to 150 \( \text{Km} \). At 100 \( \text{Km} \) the collision frequency value (\( \nu_1 \)) is about \( 5 \times 10^3/\text{sec} \).

The electron collision frequency obtained from Chapman's model and Piggott and Thrane's model shows an appreciable difference. Values obtained from Chapman's model are higher than the Piggott and Thrane's values. For example at 100 \( \text{Km} \), \( \nu_e \) from Chapman's model is \( 8.5 \times 10^4/\text{sec} \) and from Piggott and Thrane's model, it is \( 2.96 \times 10^4/\text{sec} \).

Gyrofrequencies.

Gyrofrequencies of ion (\( w_i \)) and electron (\( w_e \)) for the height range of 80 to 150 \( \text{Km} \) have been computed with the help of the magnetic field values obtained from spherical harmonic analysis. The gyrofrequencies are tabulated in table number 2.
COLLISION FREQUENCIES USING CHAPMAN'S MODEL

COLLISION FREQUENCIES $(S_{e,c})$

Figure 13.
COLLISION FREQUENCIES (SEC\(^{-1}\))

Fig 14.
<table>
<thead>
<tr>
<th>Altitude (Km)</th>
<th>Angular Gyrofrequency (ION (W_i))</th>
<th>Collision frequency (Chapman's model)</th>
<th>Collision frequency (Peter Bank's Piggot and Thrane's model)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>$1.25 \times 10^2$</td>
<td>$6.61 \times 10^6$</td>
<td>$1.83 \times 10^5$</td>
</tr>
<tr>
<td>85</td>
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Conductivity results.

The conductivities \( \bar{\bar{\Omega}}_1 \), \( \bar{\bar{\Omega}}_2 \) and hence \( \frac{\bar{\bar{\Omega}}_2}{\bar{\bar{\Omega}}_1} \) and \( \bar{\bar{\Omega}}_3 \) values in the height range of 80-to 150 Km have been computed with the use of the collision frequency models described earlier and are shown in Figures 15 and 16. Collision frequency model I corresponds to Chapman's model and model II represents Piggot and Thrane's and Bank's models. The following are the main features of the results shown in Figures 15 and 16.

1) The ratio \( \frac{\bar{\bar{\Omega}}_2}{\bar{\bar{\Omega}}_1} \), (which effectively gives the vertical polarization field when multiplied by primary east-west electric field) by the model I is 28.5 at 98 Km while model II gives a much higher value and is 48.7 at 95 Km.

2) The Cowling conductivity \( \bar{\bar{\Omega}}_3 \) reaches a maximum value of \( 15.63 \times 10^{-14} \) emu at 102 Km by collision frequency model I whereas by the model II it is \( 19.75 \times 10^{-14} \) emu at 98 Km.

3) For both the collision frequency models, the \( \bar{\bar{\Omega}}_3 \) maximum occurs at a lower height than the height of maximum of E region electron density (110 Km). The height integrated
FIG. 15. COMPUTED $\sigma_2/\sigma_1$ AND $\sigma_3$ PROFILE USING CHAPMAN'S COLLISION FREQUENCY MODEL FOR $\nu_e + \nu_l$.

ELECTRON DENSITY PROFILE OF 28th JAN 1971.

1040 HRS 1ST FLIGHT USED.
FIG. 6. COMPUTED $\sigma_2/\sigma_1$ AND $\sigma_3$ PROFILE USING COLLISION FREQUENCY MODELS OF PIGGOTT & THRANE FOR $\nu_2$ AND PETER BANK FOR $\nu_1$. ELECTRON DENSITY PROFILE OF 28th JAN 1971.
1040 HRS 1ST FLIGHT USED.
effective conductivity \( \int_{10^{-7}}^{150} \frac{\mu_3}{dh} \) by model I is \( 2.56 \times 10^{-7} \) emu while from model II is \( 3.19 \times 10^{-7} \) emu.

4) In both the models \( \mu_3 \) maximum is reached at a greater height than the height \( \mu_2/\mu_1 \) maximum.

There is a considerable difference in the \( \mu_2/\mu_1 \) values obtained by using collision frequency model I and II. Piggott and Thrane's electron collision frequency values (model II) are less than the values obtained from Chapman's model (model I) whereas \( \nu_2 \) values for both the models are of the same order. From the expressions of \( \mu_1 \) and \( \mu_2 \) it can be seen that higher value of \( V_e \) will result in a higher value of \( \mu_1 \) whereas there will be no appreciable effect on \( \mu_2 \). As such the ratio \( \mu_2/\mu_1 \) obtained from the model I can be expected to be less than the one obtained using model II.

The difference in the height of maximum of \( \mu_3 \) by the model I and II which is of the order of 4 Kms, can again be attributed to the different collision frequency models used.

It is interesting to compare the conductivity profiles
obtained in the present investigation with those obtained by Suguira and Cain (1966). Suguira and Cain using Chapman collision frequency models reported that $\bar{n}_3$ attains a peak value of $0.71 \times 10^{-13}$ emu at 102 km for Indian Zone ($80^\circ$E longitude). It may be noted that they had used a mean electron density profile obtained from rocket experiments over Wallops Island, a high latitude station. The peak electron density of this profile is much less than the one used in the present investigation. The higher value of $\bar{n}_3$ obtained in the present investigation using Chapman collision frequency models (model I) is due to the higher electron density (obtained from rocket data at Thumba) used in the computations. As has been already noted, the Cowling conductivity $\bar{j}_3$ obtained by using collision frequency model II is higher than those obtained by using model I. The difference is about 30%. In the following estimates of $E_y$ and $V$, the conductivities obtained by using model II are used as this is more recent model.

Computation of East-west electric field ($E_y$) and electron drift velocity ($V$).

Having computed $\bar{n}_3$ and height integrated $\bar{j}_3$, east-west electric field ($E_y$) and east-west electron drift velocity ($V$) at the height of max $\bar{n}_3$ can be obtained, for
any hour of the day, with the help of expressions 3 and 4 knowing $\Delta H$ and $f_0E$ values for that particular hour of the day.

In the following, an example of estimation of $E_Y$ and $V$ is given. Let $\Delta H$ at ground be 150 $\mu$ and $f_0E$ value say 4 Mc/s. then by using the relation (defined earlier)

$$J = \frac{\left(\frac{2}{3} \Delta H\right)}{2 \tan^{-1} \frac{2}{1 + u^2 - v^2}}$$

and substituting proper values of $v$ & $u$, for the station, $J$, the current intensity in emu/m corresponding to $\Delta H$ of 150 $\mu$ comes out to be $349 \times 10^{-1}$. Then $E_Y$ can be estimated from the relation

$$E_Y = \frac{J}{\int J^3 \, dh}$$

which comes out to be $1.08 \times 10^{-3}$ volts/meter after converting in to proper units. After having determined $E_Y$ (electric field), the electron drift velocity is estimated from the relation (defined earlier)
The electron density is determined assuming that the shape of the rocket electron density-height profile which has been used for conductivity computations, does not appreciably change in the height range of concern with time, then the peak density of the rocket electron density data is $1.7 \times 10^{11}/m^3$ is scaled down to the observed $f_{oE}$ value, in this case 4 Mc/s, which corresponds to $1.98 \times 10^{11}/m^3$. Then the value of $N$ is read at 98 km which is the height of maximum $\mu_3$ and is $1.28 \times 10^{11}/m^3$. The following values are obtained for the above example.

\[
V = \frac{\mu_3 E_y}{N e} \text{ at the height of maximum } \mu_3.
\]

\[
\mu_3 \text{ (at 98 km)} = 19.75 \times 10^{-14} \text{ emu}
\]
\[
= 1.975 \times 10^{-2} \text{ mho/m}
\]

\[
N = 1.28 \times 10^{11}/m^3
\]

\[
e = 1.6 \times 10^{-19} \text{ coulomb (amp/sec)}
\]

\[
E_y = 1.08 \times 10^{-3} \text{ volts/m}
\]

\[
V = 1.04 \times 10^3 \text{ m/sec}.
\]
As it is found (Chapter II), in general, that the H field variation at Thumba and Kodaikanal are similar, Kodaikanal $\Delta H$ values have been used for the quantitative estimates of $E_y$ and $V$ in the following analysis.

Electric field ($E_y$) and Electron drift velocity on SDE$_g$ event days.

The E-region east-west electric field ($E_y$) and the electron drift velocity ($V$) for all the SDE$_g$ event days with $(\Sigma K_p \leq 18)$ during the period January 1969 to December 1970 have been estimated by the method described above. These parameters have not been computed for disturbed days ($\Sigma K_p > 18$) because the $\Delta H$ obtained from ground magnetograms on disturbed days may have a significant component other than ionospheric (E-region) origin. In such a case the currents estimated from $\Delta H$ on disturbed days will not completely represent the currents at E-region levels.

Figures 17 to 20 show the day-time variation of $E_y$ and $V$ on SDE$_g$ event days with $\Sigma K_p \leq 18$. In these figures, positive values of $E_y$ and $V$ represent eastward field and westward velocity respectively and negative values of $E_y$ and $V$
First Day Time Variation of Electron Content, Line Height, and Electron Drift Velocity
DAY-TIME VARIATION OF EAST-WEST ELECTRIC FIELD AND ELECTRON DRIFT VELOCITY.

FIG. 19: 1969
Fig. 20 Day time variation of E-region eastward electric field and electron drift velocity.
1970

Fig. 2: Day-time variation of E-region eastward electric field and electron drift velocity.
1970

Electron Drift Vel. m/sec

Local Time

FINDLAY: TIME VARIATION OF E-REGION EASTWARD ELECTRIC FIELD AND ELECTRON DRIFT VELOCITY.
Figs. 1-7 show the variation of the region eastward electric field and electron drift velocity over time.
represent westward field and eastward velocity respectively. The time of first appearance of $E_s$ in the morning is shown by an arrow mark. The duration of the SDE$_s$ event is shown by broken lines bounded by vertical lines for both $E_y$ and $V$. On some days when it was not possible to determine the time of morning appearance due to lack of clarity in the ionograms, the morning appearance time is not indicated on the figures.

It can be seen from these figures that $E_y$ and $V$ show similar diurnal variations and attain their peak values, in general, earlier than local noon. Around the peak, the electron velocity attains values higher than 600 m/sec and $E_y$ greater than 0.6 mV/meter. On some days, the rate of increase of $E_y$ and $V$ in the morning is slow and on these days the peak values are also lower.

During the afternoon, $E_y$ and $V$ fall off reaching low values and on some days show reversal in direction in the late afternoon period. After about 1600 hours $E_y$ and $V$, in general, start increasing again.

Figure 25 shows $E_y$ for two quiet days without SDE$_s$ event. The $E_y$ variation on these days can be compared with those on SDE$_s$ event days. The eastward electric field, shown
FIG 25. DAY-TIME VARIATION OF QUIET DAY EAST-WARD ELECTRIC FIELD WITHOUT SDEEs EVENT
in Figure 35, shows broad peak near noon, similar to the feature shown on SDE\textsubscript{S} days. But it can readily be seen from the Figure 35 that the eastward electric field after the noon peak, does not fall off rapidly as can be seen on the SDE\textsubscript{S} event days. The eastward electric field, during the afternoon period, reached a minimum value of 0.35 mV/meter as shown in the Figure 3K.

It is interesting to compare the electron drift velocity variations shown here, with that of back scatter radar results at Jicamarca on electron drift velocity (Balsley and Woodman 1971). In this technique, the data are obtained by determining the mean Doppler shift of oblique radar returns from electron density irregularities embedded in the electrojet region. It is taken that these irregularities drift with the electrons so that the measured drift velocity of the irregularity is equal to the electron drift velocity itself.

The east-west drift velocity in the E-region thus deduced by Balsley and Woodman (1971) on some days attains values higher than 500 m/sec. These data also show an increase in the drift velocity in the evening period before
sunset. It can readily be seen, these results of electron drift velocity, are in general agreement with those obtained in the present investigation.

From an examination of the Figures 17 to 24, it can be seen that values of $E_y$ and $V$ at the time of first appearance of $E_{sq}$ are different for different days. It is interesting to note on 21st December 1970 (figure 24a), 17th December 1970, 12th and 15th December 1969 (figure 24a), when $E_y$ and $V$ build up slowly in the morning hours and reach relatively low peak values, $E_{sq}$ appears late in the morning.

It can be seen from Figures 17 to 24 that the SDE$_s$ event starts when $E_y$ and $V$ are decreasing. The values of $E_y$ and $V$ at the start of SDE$_s$ event are, in general, significantly different from the values at the time of morning occurrence of $E_{sq}$. The reappearance of $E_s$ after SDE$_s$ event occurs sometimes during the rising portion and sometimes during the falling portion of the $E_y$ and $V$ curves. On five occasions, 7th January, 16th August, 11th September of 1969 and 24th January, 19th May of 1970, $E_s$ reappeared when $E_y$ is significantly westwards.
FIG. 26a. SHOWS SLOW BUILD UP OF EY ON THE DAYS WHEN Esq. APPEARED LATE IN THE MORNING. ARROW INDICATES TIME OF FIRST APPEARANCE OF Esq.
On 5-12-70, as shown in the Figure 24, it can be seen that E-region electric field ($E_y$) and $V$ were very low during the day time. $E_{sq}$ echoes on this day were found to be very weak on the Trivandrum ionograms. On this day $E_{sq}$ disappeared first around 1000 hours L.T. for about 15 minutes and then reappeared on the ionogram. Again $E_{sq}$ disappeared around 1130 hours LT and reappeared around 1200 hours LT. It is interesting to note that there is small depression in the electric field at the times corresponding to the $E_{sq}$ disappearance.

The values of $\Delta H$, $E_y$, and $V$ at the time of start of SDE$_g$ event and reappearance of $E_g$ are presented in table 3 for all the SDE$_g$ event days during the years 1969 and 1970. It has been observed that the type of $E_g$ after reappearance is blanketing type on some occasions. As such, the type of $E_g$ after reappearance is also noted in the table. In the table, blanketing type of $E_g$ is denoted as $E_g B$ and the equatorial type $E_g$ as $E_{sq}$. On occasions when $E_{sq}$ is followed by $E_g B$ in the next ionograms, it is indicated as $E_{sq} + E_g B$. 
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Positive $E_y$ and $V$ represent eastward field and westward velocity respectively; negative $E_y$ and $V$ represent westward field and eastward velocity respectively.
It can be seen from the table that $E_y$ at the time of start of SDE$_s$ event is always positive and less than 0.3 mV/meter. The velocities at this time also show wide variation and are less than 300 m/sec. At the time of reappearance of $E_s$, the values of $E_y$ and $V$ are not, in general, the same as those at the time of start of SDE$_s$ event. However on some days, these are about the same. Referring back to Figures 17 to 24 and table 3, it can be seen that when $E_{sq}$ reappeared again during the rising portion of the $E_y$ and $V$ curves, it is $E_{sq}$ type. It is interesting to note that when $E_s$ reappeared as $E_{sb}$, the values of $E_y$ and $V$ are less than those at the times of start of SDE$_s$ event. On occasions where $E_s$ reappeared when $E_y$ is westward and $V$ is eastward, it is blanketing type $E_s$, except on one occasion (24th January 1970). The figure in the next page shows an example of reappearance of sporadic $E_s$, type SDE$_s$ event, as blanketing type of $E_s$ on 19 May 1970.

With a view to study the morning occurrence of $E_{sq}$, $H$, $E_y$ and $V$ at the time of morning appearance are evaluated for 5 magnetically quiet days in each month of the year 1970. These are tabulated and shown in table 4. The local time of morning appearance is also noted in this table. In this table the values of these parameters at the time of morning
1355 LT
$E_{sq}$ at 100 km.

1425 LT
Disappearance of $E_{sq}$.

1630 LT
Reappearance of $E_{as}$ blanketing type.

VIRTUAL HEIGHT IN KM.

MPFZ
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appearance on SDE$_3$ days are also included. There is considerable variability in the time of occurrence even in the same month. Only in the month of September this is less, the difference in time between the earliest and latest occurrence being 30 minutes. Bhargava (1963), Bandyopadhyay and Montes (1963) and Knecht (1959) found from an analysis of $E_{sq}$ data at stations in the electrojet region, that there is a considerable lunar influence on the morning occurrence of $E_{sq}$. It has been found that during new and full moon periods $E_{sq}$ appears earlier. In the present investigation, the analysis has been done in terms of $\Delta H$, $E_y$ and $V$ as the $E_{sq}$ is mainly due to the electrojet currents.

Using the values of $\Delta H$, $E_y$ and $V$ presented in tables 3 and 4, histogram for all these parameters are shown in Figure 26b to study the dependence of $E_{sq}$ occurrence on the value of these parameters. $\Delta H$ shows a peak at 5-10 mV range. The most probable value for $E_y$ is in the range 0.075 to 0.125 mV/meter, and for $V$ it is in the range 75-125 m/sec. There are no morning occurrences of $E_{sq}$ when $E_y$ and $V$ are less than 0.025 mV/meter and 25 m/sec respectively as can be seen from the histograms. It is interesting to note here that
FIG. 26. b
SHOWS DEPENDENCE OF FIRST APPEARANCE OF $E_{sq}$
ON $\Delta H$, $E_Y$ & $V$
Satyaprakash et al. (1971b) from data of electron density and current density in the E region by rocket experiments at Thumba found that electron density irregularities are present when the electron velocity is of the order of 70 m/sec.

Summary of the results.

The results of analysis of $E_y$ and $V$ for sudden disappearance of $E_{sq}$ as well as for the morning occurrences are summarised in the following.

1. $E_y$ and $V$ show similar diurnal variations and attain peak values higher than 0.6 mV/meter and 600 m/sec respectively before local noon.

2. On days, when the morning increase in $E_y$ and $V$ is slow, $E_{sq}$ appears late in the morning.

3. Sudden disappearance of $E_{sq}$ occurs only when $E_y$ and $V$ are decreasing in the afternoon and not when $E_y$ and $V$ are increasing.

4. Sudden disappearance of $E_{sq}$ occurs when $E_y$ is less than 0.3 mV/meter. This corresponds to $V$ less than 300 m/sec.
5. $E_{sq}$ reappeared as blanketing $E_g$ when $E_y$ and $V$ are reversed to west and east respectively.

6. The morning onset of $E_{sq}$ occurs when $E_y$ and $V$ are above .025 mV/meter and 25 m/sec respectively. The most probable values of $E_y$ and $V$ at the morning occurrence are in the range .025 to .075 mV/meter and 25-75 m/sec respectively. The most probable value of $\Delta H$ at this time is in the range 5 to 10Y.

Uncertainties involved in the estimation of $E_y$ and $V$.

Before discussing the implication of the results obtained in this investigation, it is necessary to discuss the uncertainties involved in the estimation of $E_y$ and $V$.

The uncertainties in the estimation of $E_y$ and $V$ may arise due to the following.

1. Uncertainty in the estimation of $\Delta H$.

2. Uncertainty in the estimation of the current intensity $J$.

3. Uncertainty in the estimation of $\frac{h_2}{\sqrt{3}}$ and $\frac{h_1}{\sqrt{3}}$ dh.
As has already been mentioned in the previous chapter, the uncertainty involved in the estimation of $\Delta H$ is about 5%. This could be still less for international magnetic quiet days which are also included in the analysis of morning appearance of $E_{sq}$. In the estimation of $J$, the height of the current sheet and its half width are assumed to be 98 Km and 300 Km. It can be seen from the expression for $J$, (equation 1) that a change in the half width $w$, results in a change of about the same percentage. It has also been assumed in calculating $J$, that the current intensity is uniform in the band.

$\frac{E}{2}$ depends upon the collision frequencies and the electron density. It was estimated that a 20 percent increase in $\nu_e$ results in a decrease of about 5 percent in $\frac{E}{2}$ at the height of its maximum. The corresponding change in $\int_{h_1}^{h_2} \nu_t \frac{1}{\nu_3} \, dh$ is about 20 percent. An increase of 20 percent in $\nu_2$ results in an increase of about 15 percent in $\nu_3$ and 17 percent in $\int_{h_1}^{h_2} \frac{1}{\nu_3} \, dh$. So it can be seen that a change in $\nu_2$ affects the conductivity $\frac{E}{2}$ more than a change in $\nu_e$.

In the expression for $E_y$, $\int_{h_1}^{h_2} \frac{1}{\nu_3} \, dh$ is involved whereas as for velocity $V$, the ratio $\frac{E_y}{\nu_3} \int_{h_1}^{h_2} \frac{1}{\nu_3} \, dh$ is involved.
It can be seen that uncertainty in $V$ due to uncertainty in the collision frequencies would be small.

For the electron density profile used in these estimation, the rocket profile has been adjusted to the peak E-region electron density determined from $f_0E$. As $f_0E$ (or $f_{\text{min}}F$) can be scaled to an accuracy of $\pm 1$ MHz, the uncertainty in the electron density profile may be considered to be small provided the shape of the profile remained same.

From the above discussion of the uncertainty involved in the estimates of $E_y$ and $V$, it can be seen that it is difficult to fix any quantitative limit on the uncertainties in these two estimated quantities. However, it seems reasonable to assume that the uncertainty involved in these estimates may be about 30 percent.

Discussion.

It is clear from the evidence presented in this chapter that the electric field $E_y$ showed always a considerable decrease during the sudden disappearance of $E_{sq}$. The electric field $E_y$ according to the dynamo theory is a wind generated electric field. As such, the decrease in $E_y$ could
possibly be attributed to a change in the wind pattern in the
equatorial region or to a change in the global wind pattern.
To determine which of these is responsible, it is necessary
to analyse the equatorial $E_s$ data spread over a wide range
of longitudes. In the present work, this is not attempted.

It has been found that the sudden disappearance of
$E_{sq}$ occurred when $V$ is less than 300 meter/sec or equivalently
when $E_y$ is less than 0.3 mV/meter. This means that $E_{sq}$ was
present on the ionograms even when $E_y$ and $V$ are less than
0.3 mV/meter and 300 m/sec. It may also be noted that no
disappearance of $E_{sq}$ has been observed when $E_y$ is above
.3 mV/m. The analysis of the morning appearance of $E_s$ showed
that $E_{sq}$ is most likely to appear when $V$ is in the range
25-75 m/sec and correspondingly $E_y$ in the range .025 mV/meter
to .075 mV/meter. Allowing for the uncertainties in these
estimates, it can be said that $E_{sq}$ appears when velocity is,
in general, above 100 m/sec or equivalently $E_y$ is above
0.1 mV/meter. The wide variations in these values both for
the appearance and disappearance on different days indicates
that there are other factors influencing the sporadic $E$ than
$E_y$ and $V$.

These results in the present investigation are
examined in the light of the current theories of equatorial
sporadic $E$ in the next chapter.
Equatorial sporadic E irregularities are small scale irregularities situated at E-region levels. Various investigators (Cohen et al., 1962, Matsushita 1951) have shown that the equatorial sporadic E is intimately related with the electrojet current strength. Observations (Egan 1960, Cohen et al., 1962) have shown that the E-region irregularities are magnetic field aligned. The theories that have been proposed, to explain the E_s irregularities are based on the relation between the equatorial sporadic E and the electrojet current strength.

In the last decade, two theories have received great attention. These are the two stream instability and the gradient instability theories.

Two Stream Instability.

A plasma consisting of two or more interpenetrating streams of charged particles, with the mean velocity of the particles in the two streams differing sufficiently, will
become unstable. In such a plasma, longitudinal waves will grow. Particles with velocities close to the phase velocity of the wave interact with the wave. If particles decelerated by the wave are more than the particles accelerated, the wave gains energy and grows. Many investigators (e.g., Buneman, 1959; Jackson 1960, Bernstein and Kulsrud 1960, Penrose 1960, Fried and Gould, 1961) have worked out the theory of this instability for a highly ionized, collisionless plasma. In a collisionless plasma with no imposed magnetic field and with equal ion and electron temperatures if the mean velocity of the electrons relative to the ions is greater than, approximately, their thermal velocity, the plasma will become unstable. The spontaneously created waves will travel at approximately the ion acoustic velocity. Parley (1963) has developed this instability theory taking into account both the effect of collisions of the ions and electrons with neutrals and the presence of uniform magnetic field. He has applied the results of this theory to the ionospheric case and found, that the ionization density irregularities arise spontaneously in regions in which a sufficiently strong current flows normal to the magnetic field lines. Parley had shown that when the velocity of the streaming electrons
exceeds the ion acoustic velocity, the waves will grow.
Thus there is a threshold velocity for the electrons equal to the ion acoustic velocity for the growth of the instabilities. At E region levels the ion acoustic velocity is approximately 350 m/sec. Balsley and Parley (1971) showed that, in fact, the component of the electron drift velocity in the direction of the wave (instability) vector must be about 30 percent greater than the acoustic velocity to excite the instability at 105 Km, independent of the wavelength of the irregularity. At this threshold, the phase velocity is equal to the acoustic velocity. It may also be noted here that according to the linear theory of two stream instability it is not possible to generate instabilities with wave vector perpendicular to the electron stream velocity. As the electron streaming velocity is in the westward direction in equatorial day time E region, instabilities with wave vectors in the vertical direction cannot be generated.

Back Scatter observations (Bowles et al 1963a; Balsley 1969) at Jicamarca have shown that there are two types of irregularities giving rise to back scatter radar returns. These types have been classified as Type I and
Type II. Most of the observed features of the Type I irregularities can be explained by two stream instability mechanism (Balsley and Farley 1971). Type II irregularities show phase velocity much smaller than the ion acoustic velocity, sometimes as small as 50 m/sec and less. The phase velocity of these irregularities was found to be linearly related to the electric field ($E_y$) in the E-region. The Type I echoes are found to be aspect sensitive whereas the Type II do not show this feature (Balsley 1969).

Balsley and Farley (1971) investigated the diurnal variation of the Doppler Spectrum at three operating radar frequencies, namely, 16 MHz, 50 MHz and 146 MHz. They found that in the morning, when the electrojet is weak, Type II echoes appear with small mean Doppler velocities. The velocities increase as the electrojet becomes stronger. When the electrojet is strong, the Type I echoes appear and dominate. Type I echoes dominate at higher operating frequencies and at 146 MHz, type II echoes are not present. It has been observed that when the two stream instability threshold is crossed, type I echoes are received at all the three operating frequencies more or less simultaneously, but smaller electron drift velocities led to type II echoes at only lower
operating radar frequencies. Balsley and Parley (1971) have shown that the observed features of the type I irregularities are in good agreement with the predictions of the two stream instability theory, and concluded that these are caused by the two stream mechanism. They also concluded that the type II are not caused by a two stream instability.

It is worthwhile to discuss the results of the present investigation described in Chapters II and III. It is not possible to distinguish between type I (two stream) and type II (non-two stream) irregularities from the $E_s$ echoes appearing on the ionograms. But ionograms observations show that the $E_s$ irregularities are present in the morning and afternoon periods when the electrojet is weak. The estimates of electron velocity presented in the last chapter showed that the electron velocity $V$ reaches high values of about 600 m/sec around noon time. This is clearly much above the ion acoustic velocity ($\sim 350$ m/sec) at $E$ region levels. So, these results reveal that conditions required for the two stream instability mechanism for the generation of the irregularities exist around noon (ie) when the electrojet is strong. However, in the morning when $E_{sq}$ is present, the electron streaming velocity $V$ is, as estimated in Chapter III,
sometimes as low as 25 m/sec. The most probable value is in the range 25-75 m/sec for the morning occurrence of $E_{sq}$. In the afternoon, before the disappearance of $E_{sq}$, the estimated velocities are less than 300 m/sec. These values are much less than the ion acoustic velocity in the region. As such, conditions favourable for the two stream instability mechanism do not exist at these times. These conclusions agree very well with the Jicamarca observations.

Another type of instability mechanism which has been investigated in recent years is the gradient instability mechanism or the crossfield instability mechanism. This can give rise to growth of irregularities in a partially ionized plasma containing a magnetic field and gradient of electron density under the influence of electric field. Balsley and Farley (1971) from their observations on type II irregularities stated that these are more likely to be caused by the gradient instability. Many authors (Knox, 1964, Tsuda et al 1966, Reid 1968, Whitehead 1970, Kato 1972) have investigated this mechanism as applied to the ionospheric case. Reid (1968) using nighttime electron density profile, has shown that the instabilities can grow in the
valley region above the height of E region maximum under the influence of westward electric field at equatorial latitudes. He had also shown that below the height of maximum where the electron density increases with height, an eastward electric field is required for the growth of the instabilities. Reid, in his analysis, had not taken into account the large vertical polarisation field present in the E region at the equator. With a view to investigate whether this mechanism can give rise to irregularities when electrojet is weak, this instability mechanism is examined in the following, using daytime electron density profile and taking into consideration the vertical polarisation field. The linearised treatment of Reid is followed in this analysis.

Theoretical Considerations.

The coordinate system used here is shown below. The magnetic field is along the positive Y axis and the density gradient $\nabla n_0$ is along the X-axis. As we are considering the problem only at the magnetic equator, X-axis is along the vertical. The steady electric
field $B_0$ is in the $XZ$ plane. The positive $Z$ axis is along the magnetic west direction. We consider in this investigation only sinusoidal perturbations in the density travelling along the east-west direction ($Z$ - axis) with wave number $k_z (= 2 \pi / \Lambda_z)$. 
The continuity equation for the electrons and ions can be written as

$$\frac{\partial n}{\partial t} = q - \lambda n^2 - \nabla n \mathbf{v}^+$$  \hspace{1cm} (1)

where $n$ represents the number density of electrons and ions.

$q$ is the production term of both electrons and ions

$\lambda$ is the recombination coefficient.

$\mathbf{v}^\pm$ is the velocity of ions and electrons the upper superscript ($+$) for ions and the lower ($-$) for electrons.

In the following, superscripts $'+$ and $'-'$ will be used to represent ions and electrons respectively and single equation will be written to represent both, with double signs where necessary; the upper sign represents the ions and the lower the electrons. The components of the particle flux $\mathbf{F}^\pm$ along the three directions can be written as:

$$F^\pm_x = -D^\pm_p \frac{\partial n}{\partial x} + D^\pm_H \frac{\partial n}{\partial z} + \mu_p^\pm n E_x - \mu_H^\pm n E_z$$  \hspace{1cm} (2)
\[ \mathbf{F}_y = -D_{D}^{\pm} \frac{\partial n}{\partial y} + \Lambda_{D}^{\pm} n \mathbf{E}_y \] (3)

\[ \mathbf{F}_z = -D_{D}^{\pm} \frac{\partial n}{\partial z} + \frac{D_{H}}{\partial x} \frac{\partial n}{\partial x} + \Lambda_{D}^{\pm} n \mathbf{E}_x + \Lambda_{H}^{\pm} n \mathbf{E}_x \] (4)

where \( D_{D}^{\pm} \), \( D_{P}^{\pm} \) and \( D_{H}^{\pm} \) are longitudinal, Pedersen and Hall diffusion coefficient and \( \Lambda_{D}^{\pm} \), \( \Lambda_{P}^{\pm} \) and \( \Lambda_{H}^{\pm} \) longitudinal, Pedersen and Hall mobilities. These are given by

\[ D_{D}^{\pm} = \frac{K \tau}{m} \mathbf{\nu}^{\pm} \]

\[ D_{P}^{\pm} = \frac{D_{D}^{\pm} (\mathbf{\nu}^{\pm})^2}{(\mathbf{\nu}^{\pm})^2 + (\mathbf{\omega}^{\pm})^2} \]

\[ D_{H}^{\pm} = \frac{D_{D}^{\pm} \mathbf{\omega}^{\pm} \mathbf{\nu}^{\pm}}{(\mathbf{\nu}^{\pm})^2 + (\mathbf{\omega}^{\pm})^2} \]

\[ \Lambda_{D}^{\pm} = \frac{e \tau}{m} \mathbf{\nu}^{\pm} \]

\[ \Lambda_{P}^{\pm} = \frac{\Lambda_{D}^{\pm} (\mathbf{\nu}^{\pm})^2}{(\mathbf{\nu}^{\pm})^2 + (\mathbf{\omega}^{\pm})^2} \]
\[ \mathcal{M}_H^{\pm} = \frac{\lambda_{10}^\pm (\nu^\pm \omega^\pm)}{(\nu^-)^2 + (\omega^-)^2} \]

\( \nu^\pm \) and \( \omega^\pm \) are the collision and gyro frequencies respectively, \( m^\pm \) is the mass, \( k \) is the Boltzmann constant and \( T \) is the temperature (taken to be same for ions and electrons).

Assuming that the density and the electric field consist of a steady state component and a small perturbation, we can write,

\[ n = n_0 + n_1 \quad (6) \]

and \[ E = E_0 + E_1 \quad (7) \]

Where \( n_0 \) and \( E_0 \) represent the steady components and \( n_1 \) and \( E_1 \) represent the perturbations. Substituting (2), (3), (4), (6) and (7) in (1) and cancelling the steady state terms and neglecting the terms involving the products of perturbations, we get
As horizontal variations in the densities can be neglected, the derivatives with respect to y can be dropped. Adopting sinusoidal forms for the perturbed quantities, with wavenumber $K_z$ and angular frequency $\omega$, we can write

$$n_1 = n_1(x) \exp \left\{ -i(\omega t - K_z z) \right\} \quad (9)$$

and

$$E_1 = -\nabla \left\{ V_1(x) \exp \left\{ -i(\omega t - K_z z) \right\} \right\} \quad (10)$$

where $E_1$ has been assumed to be derivable from scalar potential $V_1(x)$. $\omega$ is a complex quantity and the sign
of the imaginary part of $\omega$ determines whether the perturbation grows or decays. We further assume that

$$n_1(x) = N \exp \left( -\frac{x}{H} \right)$$

and

$$V_1(x) = V \exp \left( -\frac{x}{H} \right)$$

where

$$\frac{1}{H} = -\frac{1}{n_0} \left( \frac{\partial n_0}{\partial x} \right) = \text{scale height of the density.}$$

Substituting these, in (8) we get a pair of algebraic equations,

$$N (-i\omega + A^+ + iB^+) + Vn_0(C^- + iD^+) = 0$$

where

$$A^\pm = D_\pm \frac{2}{\partial p} K_Z + A_1^\pm \pm E_{ox} A_Z^\pm + E_{oz} A_3^\pm$$

$$B^\pm = K_Z \left[ \pm \frac{\partial}{\partial p} E_{oz} + \frac{\partial}{\partial H} E_{ox} \pm B_1^\pm \right]$$

$$C^\pm = \pm \frac{\partial}{\partial p} K_Z^2 + C_1^\pm$$

$$D^\pm = K_Z D_1^\pm$$
and

\[ A_1^+ = 2\alpha n_o + H^{-1} \frac{d}{dx} (D'_p) - D'_p H^{-2} \]
\[ A_2^+ = (-M_p H^{-1} + \frac{d}{dx} (M'_p H^{-1}) \]
\[ A_3^+ = [\mu^+_H H^{-1} - \frac{d}{dx} (\mu'_H H^{-1})] \]
\[ B_1^+ = \frac{d}{dx} (D'_H H^{-1}) \]
\[ C_1^+ = \pm H^{-1} \frac{d}{dx} (\mu'_H H^{-1}) \mp 2\mu'_p H^{-2} \]
\[ D_1^+ = [-\mu'_H H^{-1} + \frac{d}{dx} (\mu'_H H^{-1})] \]

For a non-trivial solution of equation (13), the determinant should vanish. This condition leads to the following expression for the imaginary part of \( \omega \).

\[ \omega^i = \frac{(C^- - C^+) (A^- C^+ - B^- D^+ - A^+ C^- + B^+ D^-)}{(C^- - C^+)^2 + (D^- - D^+)^2} \]

\[ + \frac{(D^- - D^+) (B^- C^+ + A^- D^+ - A^+ D^- - B^+ C^-)}{(C^- - C^+)^2 + (D^- - D^+)^2} \]

(18)
If $\omega$ is numerically positive, the perturbation grows exponentially and if it is negative, the perturbation decays exponentially. At the equator, during daytime, the horizontal electric field will be directed towards east. There will be a polarization field in the vertical direction directed upwards. This vertical polarization field is given by

$$E_ox = E_oz \frac{(M^- - M^+)}{(M^- - M^+)} = -M.E_oz$$

Thus for equatorial conditions, $E_ox$ in equations (14) and (15) can be replaced by ($-M.E_oz$). Substituting these in (18) and rearranging the terms we get

$$\omega = \frac{2}{(-KzCz + C_3)} \left\{ \frac{K_4}{E_oz} + \frac{2}{Kz} K_2 + E_oz (K_4 + L_1) \right\} + L_2 \left\{ K_3 + Kz E_oz \right\} +$$

$$- \frac{2}{Kz D_2} \left\{ \frac{2}{Kz} (P_1 E_oz + P_2 + P_3) + E_oz (R_1 + R_2 + R_3) \right\}$$

$$\omega_i = \frac{\left( \frac{2}{(-KzCz + C_3)} + \frac{1}{Kz D_2} \right)}{2 \left( \frac{2}{2} \right)}$$
where \( c_2 = A_p^+ + A_p^- \), \( c_3 = c_1^- - c_1^+ \)

\[ D_2 = D_1 - D_1^+ \]

\[ K_1 = D_p A_p^+ + D_p A_p^- \]

\[ K_2 = D_p C_1 - D_p C_1 + A_p^+ A_1 + A_p^- A_1 \]

\[ K_3 = A_1 C_1 - A_1 C_1 \]

\[ K_4 = A_3 A_p^+ + A_3 A_p^- + M (A_p A_2 - A_p A_2) \]

\[ K_5 = C_1 A_3 - C_1 A_3 + M (C_1 A_2 + C_1 A_2) \]

\[ L_1 = D_1 A_p^+ + D_1 A_p^- + M (D_1 A_p H - D_1 A_p H) \]

\[ L_2 = D_1 D_1 + D_1 D_1 \]

\[ P_1 = -M (A_p H A_p - A_p H A_p) \]

\[ P_2 = B_1 A_p^+ + B_1 A_p^- \]

\[ P_3 = D_p D_1 - D_p D_1 \]

\[ R_1 = C_1 (-A_p^- - M A_p H) + C_1 (-A_p^+ + M A_p H) \]
It is found that $C_3$ is negligible compared to $K_z C_2$ for wavelengths ($\frac{2\pi}{K_z}$) up to 200 meters. For $A_z = 200$ meters, at 90 Km altitude, $K_z^2 C_2 \approx 6.7 \times 10^1$ and $C_3 \approx 2.2 \times 10^2$. At greater heights $C_3$ will become still smaller in comparison with $K_z C_2$. As such $C_3$ is neglected in comparison with $K_z C_2$. Thus, the expression for $\omega_1$ becomes

$$
\omega_1 = \frac{-C_2 \left[ K_1 K_z + K_z K_2 + E_{oz} (K_4 + L_1) + D_2\right] + K_3 + K_5 E_{oz}}{K_z^2 C_2 + D_2}^{\frac{2}{2}}
$$

The denominator in the equation (20) contains only square terms. So, the sign of $\omega_1$ depends upon the numerator. By rearranging the terms in the equation (20) the minimum electric field required for the growth of the instability for a particular $K_z$ (making the numerator of equation 20 positive), is obtained as
\[
E_{oz} \text{ (minimum)} = \frac{D_2 \left[ K_z^2 (P_2 + P_3) + R_3 \right]}{C_2 \left[ K_z^2 (K_4 + L_1) + K_5 \right] - D_2 \left[ K_z^2 P_1 + R_1 + R_2 \right]}
\]

As stated earlier if, \( \omega_1 \) is numerically positive, the perturbation grows exponentially. The inverse of \( \omega_1 \) gives the time \( t \) required for e-fold growth of the perturbation. The real part of \( \omega \) is related to the phase velocity of the perturbation by

\[
\omega_r = \Omega K_z
\]

Expression for \( \omega \) can be obtained adopting the same procedure as for \( \omega_1 \). The velocity \( \mathbf{v} \) is thus given by

\[
\begin{align*}
\omega_r &= \Omega K_z \\
D_2 \left[ K_z^4 + K_z^2 \left( K_2 + E_{oz} (K_4 + L_1) + L_2 \right) \right] &+ K_3 + K_5 E_{oz} \] \\
+ K_z^2 C_2 \left[ K_z^2 (P_1 E_{oz} + P_2 + P_3) + E_{oz} (R_1 + R_2) + R_3 \right] \\
\] \\
&= \frac{K_z^2 C_2^2 + D_2^2}{K_z^2 C_2^2 + D_2^2} \quad (22)
\end{align*}
\]

Results.

The collision frequency model II (shown in figure 14 chapter III) and the rocket electron density profile at
1040 L.T. (shown in figure 15 chapter III) have been used in these calculations. For $\lambda$, the recombination coefficient, a value of $3 \times 10^{-13}$ (mks units) and its variation with height is neglected in the height range of interest (85 Km to 140 Km).

The minimum electric field required for the growth of the instability for different wavelengths, as a function of height as estimated using equation (21) and shown in Figure 27. The wave lengths $\lambda \ (= 2 \pi / k \lambda)$ used for this are 10, 40, 80, 120 and 200 meters. The calculations have been made at 5 Km. height intervals, starting from 85 Km to 145 Km. It can be seen that an eastward electric field is necessary for the growth in the height region 85 Km. to 110 Km. It may be noted that the electron density gradient is positive in this height range. Above ~15 Km. the electron density continues to increase with height very very slowly. As such electron density gradient will be very small and the electric field required for the growth of the instabilities will be very high. So, the discussion is confined here to heights below 115 Km. which is the region of interest in the present study. It can be seen from Figure 27 that minimum electric field ($E_{oz \min}$) required for the growth shows a significant variation with instability wavelength. At longer wavelengths
MINIMUM EASTWARD ELECTRIC FIELD (EOZ) IN mV/m

HEIGHT IN km.

Fig. 27
the field required is smaller compared to that at shorter wavelengths. At 95 km altitude, $E_{oz}(\text{min})$ for $\lambda = 10$ is 0.34 mV/meter (eastward) and for $\lambda = 200$ meters, $E_{oz}(\text{min})$ is 0.009 mV/meter (eastward). It can be seen from Figure 27 that $E_{oz}(\text{min})$ shows a minimum at about 95 km altitude for all the wavelengths considered. This is due to the fact that the vertical polarization electric field $(\sigma_2 / \gamma_1 \cdot E_{cz})$ reaches its maximum around this altitude (Figure 16 of Chapter III).

The growthtime $\tau (\approx \frac{1}{\omega_i^2})$ is plotted against altitude for $E_{oz} = 0.4$ mV/meter (eastward) and $\lambda = 40, 80$ and 200 meters and shown in Figure 28a. It can be seen that the growth times are minimum in the height range 90 to 100 km. In fact, there is not much variation in the growth times in the altitude range 90 to 100 km. Also, all the three wavelengths show essentially same growthtimes in the altitude range 90 to 100 km. The growthtimes are about 1.2 seconds in this height range. Below 90 km, the growth times increase rapidly with decreasing height and with decreasing wave length. For $\lambda = 40$ meters, at 85 km altitude, $\tau$ is about 300 seconds.

Growthtime $\tau$ as a function of electric field for $\lambda = 40$ and 80 meters at 95 km altitude is shown in Figure 28b.
$E_{0z}(eastward) = 0.4 \text{ mV/meter}$
The growthtimes, as can be seen from this figure, decrease with increasing electric field, increase being rapid at lower electric fields.

The phase velocity $\mathbf{v}$ of the wave has been estimated using equation (22). It is shown as a function of height for $E_{oz} = 0.4$ mV/meter (eastward) and $\Lambda = 80$ meters in Figure (29a). As can be noted from the Figure, the phase velocity decreases with decreasing altitude, the decrease being rapid at lower heights. The velocity $\mathbf{v}$ is shown as a function of electric field in Figure 29b. It can be seen that the velocity increases with the electric field, the increase being rapid at higher values of electric field. In the same figure is shown with dotted line, the velocity as a function of wavelength at 95 km. altitude for $E_{oz} = 0.4$ mV/meter (eastward). It is interesting to note that in the wavelength range 10 to 200 meters, $\mathbf{v}$ does not show any significant variation with wavelength. The velocity is about 260m/sec. at 95 km. for $E_{oz} = 0.4$ mV/meter (eastward). This means that there is practically no dispersion in the wave propagation at least for the wavelength range considered.

To investigate the effect of the magnitude of the electron density gradient, the instability parameters are
HEIGHT IN km.

PHASE VELOCITY IN m/Sec.
Fig. 29a

EOZ = A \times 0.3
\lambda = 80

EOZ (eastward) IN m/Sec/meter

PHASE VELOCITY IN m/Sec. AT 95 km
Fig. 29b
estimated, changing the electron density gradient to an arbitrary value. Keeping the electron density at 115 Km. same as the rocket electron density data used previously, the gradient is made half and twice of the original value and the minimum electric field ($E_{oz}$ min) required for the growth been estimated for both these cases. $E_{oz}$ min values are shown in the table below for different wavelengths at 95 Km. altitude.

<table>
<thead>
<tr>
<th>$\lambda$ meter</th>
<th>$\pm \nabla n_o$</th>
<th>$\nabla n_o$</th>
<th>$2 \nabla n_o$</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.72</td>
<td>0.35</td>
<td>0.18</td>
</tr>
<tr>
<td>40</td>
<td>0.07</td>
<td>0.03</td>
<td>0.018</td>
</tr>
<tr>
<td>80</td>
<td>0.038</td>
<td>0.014</td>
<td>0.01</td>
</tr>
<tr>
<td>120</td>
<td>0.032</td>
<td>0.01</td>
<td>0.009</td>
</tr>
<tr>
<td>200</td>
<td>0.029</td>
<td>0.009</td>
<td>0.009</td>
</tr>
</tbody>
</table>

The dependence of $E_{oz}$ min on the gradient can be seen from this table. $E_{oz}$ min shows a decrease with increasing electron density gradient. It can be seen from the table that the effect is more pronounced at shorter wave lengths.

For a positive electron density gradient an eastward electric field is required for the growth.
Summary of results.

1. The minimum electric field required for the growth of the instability is minimum at about 95 Kn. altitude. At longer wavelengths of the instability, \( E_{\text{oz}}(\text{min}) \) is smaller compared to that at shorter wavelengths. \( E_{\text{oz}}(\text{min}) \) varies with the electron density gradient being higher for smaller electron density gradient.

2. The growth time of the instability does not vary with the wavelength in the height region 90 to 100 Kn. times. The growth times are found to be small, in the order of few seconds.

3. The phase velocity of propagation does not show appreciable variation with wavelength. It increases with increasing electric field.

Discussion:

In the present investigation, it has been shown by quantitative estimates, that the crossfield instability mechanism can give rise to instabilities at E region levels at the magnetic equator under suitable conditions. It has been shown that under the influence of an eastward electric field, in the underside of the E region, growth of electron
density instabilities takes place. An eastward electric field exists at E region levels in the daytime equatorial region. Reid (1968) using nighttime electron density data has shown that the crossfield instability grows in the underside of E region for an eastward electric field and above the E region maximum for a westward electric field. Reid has not included explicitly the vertical polarisation field in his calculations. Using an arbitrary electron density distribution, Whitehead (1971) has shown that the crossfield instabilities can grow at equatorial latitudes. The results of the present investigation are in general conformity with those reported by Reid (1968) and Whitehead (1971). It may be noted here, that a daytime electron density profile obtained by rocket measurement has been used in the quantitative estimates and also the vertical polarisation field has been taken into consideration.

In Chapter III, estimates of the electric fields have been made corresponding to Sporadic E conditions. It was noted that the morning onset of Sporadic E takes place in general when $E_y$ is in the range $0.075$ to $0.125$ mV/meter (eastward). Occurrences have also been noted when $E_y$ is above these ranges. A few occurrences have been noted when $E_y$ is in the range $0.025$ to $0.075$ mV/meter (eastward). The electron drift velocity corresponding to these $E_y$ values is
much less than the ion acoustic velocity (~360 m/sec) and as such two stream instability mechanism cannot take place at these times. It can be readily seen that these $v_y$ values at the onset times are sufficient to enable the growth of the crossfield instabilities. As the cross field instability mechanism depends upon the electron density gradient also, the instabilities may grow at different $v_y$ values on different days as the electron density gradient is likely to vary from day to day.

In the afternoon time, before the sudden disappearance of $E_g$ it was noted in the last chapter that $E_{sq}$ was present even when the $v_y$ values are less than 0.3 mV/meter (eastward). The presence of $E_{sq}$ even at low values of $v_y$ in the afternoon can again be attributed to the crossfield instabilities.

In the last chapter, it was observed that when $v_y$ became westward and attained values of about 0.1 mV/meter in the late afternoon after the SDE event, $E_{sq}$ did not appear except in one case. As has already been pointed out, if the field is westward crossfield instabilities arise only in the region where the electron density gradient is negative. This means these instabilities do not occur below the $E$ region.
maximum when \( E_y \) is westwards. Instabilities may occur above the \( E \) region maximum if a sufficient negative gradient of electron density exists which is likely in the evening period. However, ionosonde cannot, in general, record the echoes coming from this region of negative electron density gradient. This explains the reason why \( E_{sq} \) was not noticed in general when \( E_y \) became westwards.

It has been mentioned in the previous chapter that after the disappearance of \( E_{sc} \), \( E_s \) reappeared, on some occasions, as blanketing type (\( E_sB \)). It was found that \( E_s \) reappeared as \( E_sB \) when \( E_y \) was westward or the value of \( E_y \) was less than those at the time of disappearance of \( E_{sq} \). The appearance of \( E_sB \) cannot be explained by the corssfield instability theory. Blanketing type of \( E_s \) at equatorial latitudes may be generated by some other mechanism.

It is interesting to examine the results of theoretical estimates made in this chapter with that of back scatter radar observations reported by Balslev and Farley (1971). They observed the type II irregularities on radar frequencies 16 MHz and 50 MHz. For back scatter observations, these operating frequencies correspond to irregularity wavelengths of about 9 and 3 meters for 16 MHz and 50 MHz respectively.
From Figure 27, it can be seen that for the growth of irregularity of wavelength 9 meters the minimum electric field required is about 0.4 mV/meter (eastward). However, for the growth of 3 meter wavelength an electric field much higher than 1 mV/meter (eastward) is required which is unrealistic. It needs to be pointed out here that the estimates made in this chapter are based on linear theory of the instability mechanism. Non-linear mode coupling of longer wavelength instabilities can give rise to lower wavelengths (Balsley and Farley 1971). Assuming this, a qualitative comparison, can be made between the results of 15 MHz and 50 MHz back scatter experiment and the present theoretical estimates. Balsley and Farley (1971) observed that the phase velocity of the type II irregularities does not vary with the operating frequency or equivalently the irregularity wavelength. This observation agrees well with the conclusion arrived here from the theoretical estimates that the phase velocity of the irregularities is independent of their wavelength. Balsley (1969) reported that the phase velocity of the irregularities varies linearly with the electric field. This again agrees very well with the results of the theoretical estimates presented here. It may be again pointed out here, that these comparisons are made
based on linear theory of the instability. For a quantitative comparison, estimates based on non-linear theory of the instability mechanism have to be made.

In conclusion, it can be said that the type II irregularities observed on back scatter radar and the $E_{\text{sq}}$ irregularities observed on the ionosonde when electron drift velocity is smaller than the ion acoustic velocity, can be attributed to the corssfield instability mechanism.
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