CHAPTER VII

STUDIES OF SPREAD-F AT EQUATORIAL STATION HUANCAYO

7.1 Introduction and a brief review of equatorial spread-F

'Spread-F' is usually described in terms of its appearance in the conventional ionograms (h'F curves). Sometimes, the h'F curves become very diffuse, in contrast to the usual sharp traces known as the 'spread echo', 'diffuse echo', 'scattered echo' etc. When this spreading or diffuseness occurs in the F-region echoes, the condition is called spread-F or F-scatter. Scattered echoes were first observed by Mogel (1932) while monitoring the signals of high power transmitter in Germany. Booker and Wells (1938) were the first to report spread-F at an equatorial station. They invoked mechanism involving Rayleigh scattering by irregularities in the F-region.

Several morphological studies of the occurrence of spread-F have been made by Ibr (1956), Shimazaki (1959, 1962), Lyon et al (1960), Singleton (1960), Rastogi (1970) and Rastogi and Woodman (1978). Wright (1959) pointed out that between the dip latitudes 20°N and 20°S there is a belt of high occurrence of spread-F. This was further confirmed by Lyon et al (1960) and Singleton (1960). The features of spread-F based on the study of ionograms have been reported at a number of low-latitude stations namely at Huancayo (Booker and Wells 1938), Singapore (Osborne 1952), Ibadan (Lyon et al 1961), Ahmedabad (Rastogi and Kulkarni 1969), Thumba (Chandra and
Rastogi (1972b) Kodaikanal (Bhargava 1958, Sastri and Murthy 1975), Taipaei (Huang and Yeh 1970) and Nairobi (Skinner and Kelloher 1971). However, these investigations suffer drawback that they do not take into consideration the type of spread-$F$ as this is not given in the published data.

Chandra and Rastogi (1972b) separated Range and Frequency spread at Thumba. They have shown that Range spread occurring during the post-sunset period while Frequency spread occurring during pre-dawn period.

As no systematic study of equatorial Range and Frequency spread was made, attempt is made to study the range and frequency spread-$F$ at equatorial station Huancayo for the period 1957-74, covering about one and half solar cycles.

**Belt of equatorial spread-$F$:** The prominent feature in geographic distribution of spread-$F$ occurrence is existence of two areas of maximum, one is found at $\pm 20^\circ$ latitude centred over the geomagnetic equator whereas the other is confined to polar latitudes. Equatorial spread-$F$ occurs within the equatorial belt and occurs during night-time only while at high latitudes spread-$F$ occurs at all times of the day or night, although peak occurrence is during night-time (Cohen and Bowles 1961, Ponndorf 1962, Herman 1966).
Types of equatorial spread-F:-- Earlier studies were made on the basis of the spread-F index, which indicates the degree (intensity) of spread-F. Spread-F index indicates basically the frequency spread. Menicoc et al (1956) suggested division of spread-F into two classes:--

(a) If the diffuseness is pronounced along the section of the trace that sweeps upward, such that there is some ambiguity regarding the penetration of critical frequency, the spread is to be termed as 'Frequency type'.

(b) If the spread is more or less independent of frequency over a wide range of frequencies and the diffuseness is principally along the horizontal path of the trace giving rise to ambiguity in virtual height, the spread effect is classed as 'Range type'.

Seasonal and solar cycle variations of spread-F:-- The prominent feature of the equatorial spread-F is the extremely rapid commencement of spread-F which occurs around 1800 hr LT, reaches maximum around 2100-2200 hr LT, then decreases till morning hours. It has been observed that time of commencement is usually one hour to one and half hours after the ground sunset.

The seasonal variation is high in American zone with maximum in December solstice and minimum in June solstice, while in African zone the seasonal variation is small and in the Asian
zone very little seasonal variation is noticed (Chandra and Rastogi 1970b). The spread-$F$ occurrence shows a positive correlation with solar activity in the African and Indian zones while in the American zone it shows negative correlation, indicating longitudinal difference (Chandra and Rastogi 1970b).

**Spread-$F$ and $h'F$:** Occurrence frequency of spread-$F$ is closely correlated with height variation in the $F$ layer. Studies of $h'F$ rise and its relation to spread-$F$ were made by Chandra and Rastogi (1972b) at different equatorial stations during different solar activity. Their results indicate that post-sunset rise showed positive correlation at Ibadan, Djibouti, Kodaikanal and Huancayo. Skinner and Kelleher (1971) showed that spread-$F$ is coincident not only with rise of $h'F$ but also downward movement of the layer following its earlier rise. Chandra and Rastogi (1972b) showed that range spread-$F$ occurs in the pre-midnight hours and is well correlated with post-sunset $h'F$ increase while frequency spread which occurs in pre-dawn period does not show much dependence in $h'F$ variations.

**Spread-$F$ and magnetic activity:** Early observations of spread-$F$ during quiet and disturbed days indicated that spread-$F$ incident is lower on disturbed days than on quiet days during any of the seasons.
Chandra and Restogi (1972) showed that during high sunspot years spread-F index was greatly reduced on disturbed days at Kodaikanal as well as at Huancayo and the peak of spread-F index is not found to vary on either quiet or disturbed days. During low sunspot years, their results indicated that spread-F index found to be reduced on disturbed days at Kodaikanal, while at Huancayo spread-F index reaches its peak just before sunrise and the disturbed day peak was more than on quiet days.

Bowman (1974) showed that at Huancayo a good correlation was observed between days of highest Ap index and high spread-F occurrence for pre-sunrise hours. No such effect was detected for post-sunset spread-F occurrence.

Bhargava (1958) reported that spread-F occurrence is markedly reduced at night following the storm day. Sastri and Murthy (1975) tried to isolate the geomagnetic storm time variations on the spread-F occurrence, but could not isolate any significant effect on either pre-midnight or post-midnight spread-F.

**Electric field and spread-F:** The vertical motion of the F layer is directly controlled by the electric field in the D-region. This electric field communicated through the highly conducting magnetic field which acts as equipotential. During day, the electric field points eastward and F-region ionization moves westward due to resulting E x B drift. The electric field reverses just after sunset and rise in h\(^F\) is observed. This
post-sunset rise in $h'F$ is studied by various workers (Lyon et al 1961, Rao and Rao 1961, Chandra and Rastogi 1972b). Onset of time of spread-$F$ was shown to be closely associated with the rise of $h'F$. Rastogi (1978) has shown that rise of $F$-region is associated with the pre-reversal peak of $F$-region electric field. Further the spread-$F$ is absent and there is no large height rise of the $F$-region when pre-reversal peak of the electric field is absent. Thus it is seen that pre-reversal electric field plays an important role in onset of the equatorial spread-$F$.

**Topside spread-$F$:** Similar to ionospheric soundings from ground based stations, the satellite-borne ionosondes provides the ionograms of the upper half of the $F$-region. Lockwood and Petrie (1963) have described the occurrence of spread in the topside ionograms. On some occasions instead of completely diffused echoes, the topside ionogram shows sharp echoes having range much larger than the normal trace (Calvert and Schmid 1964). These traces are explained as ducted propagation involving field aligned irregularities with thickness greater than radio wave lengths.

By comparing the topside and bottomside ionograms, it was found the spread-$F$ at both the half of the $F$-region does not always occur simultaneously. Sometimes spread-$F$ is observed in both the ionograms suggesting presence of irregularities in the whole $F$-region. Sometimes bottomside does not show spread-$F$.-----------------------------
while topside indicates spread-$F$, indicating presence of irregularities in the top of the $F$ layer.

**Backscatter radar studies:** Recently backscatter technique has been used quite extensively to study the equatorial spread-$F$. The potential of the backscatter technique and specifically of the Jicamarca radar for the study of the ionospheric irregularities responsible for spread-$F$ has become evident. Its capability of giving the continuous time history of the irregularities, of giving their exact location throughout the altitude range at which they occur, and measuring at the same time the important background parameters such as electron density, density gradients and electromagnetic drifts (electric fields) have no counterpart in the classical techniques used so far their study. In this technique weak echoes scattered either by individual electron or by the irregularities are used to study the irregularities as a function of altitude and time. To study the spread-$F$ irregularities backscatter radar technique was used by Farley et al (1970), Kelleher and Skinner (1971), McClure and Woodman (1972) and Woodman and LeHoz (1976).

**Spaced receiver results on spread-$F$:** By recording simultaneously the fading of the ionospheric echoes at three spaced aerials one can compute the various properties like true drift speed $V$, random component $V_\text{c}$ and the axial ratio $r$ of the irregularities.
These parameters were studied at Thumba during spread-\(F\) and non-spread-\(F\) conditions (Misra 1973\textsuperscript{e}). His results indicated that true drift velocity is not significantly different on spread-\(F\) days, on the other hand the ratio of random to true drift was found to increase during the period of spread-\(F\). The axial ratio of irregularities was found to be about 10 at normal nights whereas during spread-\(F\) conditions it exceeded 30. These observations indicate that irregularities causing the spread-\(F\) are very highly elongated along the magnetic field lines.

Further \(E-W\) drift reversal is related to the spread-\(F\). Chandra and Rastogi (1972\textsuperscript{b}) have shown that reversal of \(E-W\) drift occurs almost at the same time as of the peak of \(h'F\). The maximum spread-\(F\) occurs about two hours after the reversal of drift during summer and winter but only half an hour later during equinoxes. Recently Chandra and Rastogi (1978) compared spaced fading records of night-time \(F\)-region echoes over Thumba on spread-\(F\) and non-spread-\(F\) days. They have shown that the fading rate is considerably low on non-spread-\(F\) days. The daytime westward drift reversed about one hour later on spread-\(F\) days than on non-spread-\(F\) days. Irregularities associated with spread-\(F\) are more closely field-aligned with higher elongation and smaller \(E-W\) size than those on non-spread-\(F\) days.

Current theories of spread-\(F\):- A number of theories of the generations of spread-\(F\) irregularities have been advanced (Herman 1966). The main mechanisms for the generation of irregularities
in the F-region can be classified as under:

(i) Amplification of irregularities by vertical motion in the presence of ionization density gradients (Martyn 1959, Calvert 1963, Simon 1963).

(ii) Gravitational Rayleigh-Taylor instability (Dungey 1956).

(iii) Coupling and transfer of irregularities from the E to F region (Dagg 1957, Cole 1971).


(v) Coupling with hydrodynamic waves (Singleton 1966).

Observations of energetic particles at the equator reported by Heikkila (1971) have possibly brought up a new mechanism for equatorial spread-F, but it does not seem to be a major source, because spread-F is a very common phenomenon, while these particle events seem, at least from the existing observations to be rather scattered.

Mechanism involving coupling between the E and F regions by equipotential magnetic field lines, is also not generally considered, due to high attenuation in the propagation of small scale electric fields (Farley 1959, 1960, Spreiter and Briggs 1961a,b).
Farley et al (1970) concluded that none of the theories which appeared under the first and second classes of generation mechanisms, could account for all the features in the radar observations of F-region irregularities. None of the theories could explain the irregularities smaller than ion Larmor radius, while the radar detection of 3 m structures showed the presence of such dimensions in the irregularity spectrum. However, an open question whether the radar observed 3 m irregularities always occur as a part of the strong long wave-length structures.

Recently the measurements of irregularities made simultaneously with rocket-borne plasma probe and ground-based radar gave an evidence of the presence of two separate irregularity structures (Kelley and Mozer 1975).

Holtet et al (1977) with the help of OGO-6 satellite made electric field measurements based on double probe technique using long cylindrical antenna. Their observations of different spectra in equatorial F-region showed that 3 m structures can appear independent of strong long wave length fields and suggested that different mechanisms are probably involved in the generation of the different types of irregularities.

More recently theoretical treatment of equatorial spread-$F$ has brought new life into the Rayleigh-Taylor instability. Dungey's early version on this mechanism (Dungey 1956) has been elaborated by Hudson and Kennel (1975), B.(1972)
and Haerendel (1974). Recently, Woodman and La Hoz (1976) found the existence of plume-like (bubbles) structures extending hundreds of kilometers in altitude and physically connecting the spread-F on the topside with the bottomside. They interpreted it as evidence of a Rayleigh-Taylor instability and explained how the bubbles or low density plasma generated at the bottomside of the F-region can extend to the top of the F-region.

Another new mechanism to explain the occurrence of spread-F in the equatorial ionosphere is the spatial resonance theory suggested by Whitehead (1971) and Beer (1974). It is envisaged as multistage process involving movement of ionization drift with atmospheric gravity waves that results in spatial resonance, consequent enhancement of ionization irregularities and eventual strong vertical layering (enhanced ionization layers one above the other) (Beer 1974). The spatial resonance cannot continue indefinitely and will cease when the charged particle density of the ionization irregularities has become so large that the system satisfies the collision-dominated Rayleigh-Taylor instability criterion. This is the second stage of the process and it is here that the instability is observed as spread-F on ionograms. The theory of spatial resonance mechanism appears to be applicable to explain the pre-midnight range spread-F (Beer 1974).

Recently Kottger (1978) examined the resonance condition for reasonable parameters of travelling ionospheric disturbances,
plasma drift and neutral wind velocities. He has shown that resonance condition can be fulfilled in equatorial region during the post-sunset hours.

7.2 Studies of spread-F at equatorial station - Huancayo

The early observations of spread-F at an equatorial station Huancayo by Booker and Wells (1938) had suggested that the phenomenon is correlated with the marked rise in the height of the F-region between 1800 and 2000 LT. Later the occurrence of spread-F at other equatorial stations Ibadan, Kodaikanal and Thumba was shown to be closely associated with the post-sunset rise in the height of the F-region (Bhargava 1958, Lyon et al 1961, Chandra and Rastogi 1972b). Solar cycle and seasonal variations of spread-F at equatorial stations were studied by Chandra and Rastogi (1970b). They had shown that a remarkable seasonal variation is seen at Huancayo, with occurrence of spread-F being maximum during December solstices and minimum during June solstices. At Djibouti, Ibadan and Kodaikanal, smaller seasonal variation with maximum in June and minimum in December was noted in the occurrence of spread-F. Spread-F occurrence showed positive correlation with sunspot number at Kodaikanal, Ibadan and Djibouti while at Huancayo it showed negative correlation with sunspot number indicating longitudinal differences. Another well known feature of the equatorial spread-F has been its marked inhibition due to magnetic activity (Lyon et al 1958, Rangaswami and
Kapasi 1963, Chandra and Rastogi 1972b). However, results at Huancayo have indicated increase in spread-$F$ due to magnetic disturbances in the post-midnight periods (Chandra and Rastogi 1972c, Bowman 1974).

Most of the earlier investigations were made from the published ionospheric data where qualifying symbol '$F$' is used in the tabulations of $f_0F_2$ to give an idea of the occurrence of spread-$F$. Examining critically, the ionograms at the equatorial station Thumba, Chandra and Rastogi (1972b) found that the equatorial spread-$F$ is basically of two types: (i) Range spread which is more common during high sunspot years, occurring in pre-midnight period and is well correlated with post-sunset increase of $h'F$ and (ii) Frequency spread which is more common in summer of low sunspot years and occurring usually in the predawn period.

Sastri and Murthy (1975) confirmed that spread-$F$ configurations at Kodaikanal during pre-midnight period were of range type and in the post-midnight period were of the frequency type. Sastri et al (1975) showed that both range and frequency spread have positive correlation with solar activity and the occurrence pattern of range and frequency spread-$F$ showed significant similarity with each other. It was felt therefore to study the occurrence of range and frequency types of spread-$F$ at Huancayo separately in view of the large longitudinal difference observed.
Method of data analysis: - The study is based on quarter-hourly readings of the occurrence of spread-F from daily F-plots which mark the presence of the range and frequency spread with different notations. Data covering the period July 1957 to June 1974 have been covered in the present study. The incidence of range and frequency spread-F was noted separately at every fifteen minutes. The data were divided into three seasonal groups of E-months (September, October, March and April), D-months (November, December, January and February) and J-months (May, June, July and August).

Results: - Seasonal, solar cycle and magnetic activity variations of the occurrence frequency of the range and frequency types of spread-F are studied. Results are already reported in literature and papers are attached at the end of this chapter. The main results are summarised here:

(1) Range spread occurs mostly in the premidnight period with maximum frequency around 2100 LT for any of the solar epoch. The frequency spread has maximum occurrence between 2300 and 0000 LT in high sunspot years and between 0000 and 0100 LT in low sunspot years. The seasonal variation in the occurrence of either types of spread-F shows minimum during J-months and maximum during D-months (refer paper 1).
(2) The occurrence of range type of spread-$F$ is inversely related to the Zurich sunspot number while that of frequency type of spread-$E$ is practically independent of sunspot number (refer paper 2).

(3) The occurrence of frequency spread-$F$ is decreased on disturbed days for $D$-months and $E$-months while during $J$-months an increase is noted in the post-midnight periods. The occurrence of range spread is decreased on disturbed days in the pre-midnight hours during $D$-and $E$-months. Post-midnight hours of $D$- and $E$-months and all hours at night during $J$-months show an increase of range spread on disturbed days which is most prominent during low sunspot years (refer paper 3).

(4) Occurrence of frequency spread as well as of the range spread in the pre-midnight period decreases with increasing $Kp$ index during $D$-months and $E$-months but increases with increasing $Kp$ index during $J$-months. However, the occurrence of range spread in the pre-sunrise period increases with increasing $Kp$ index during each season (refer paper 4).