On the equatorial spread $F$

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Abstract. The post-sunset maximum in virtual height of the $F$ region near the magnetic equator is associated with the general rise of the whole $F$ region from the base to the height of peak ionisation with little change in the semi-thickness of the layer. This rise of $F$ region is accentuated on days with large evening peak in the vertical drift velocity or the horizontal electric field in the $F$ region. The range type of equatorial spread $F$ first occurs only if the $F$ region drift velocity remains significantly upwards after sunset but the maximum intensity of spread $F$ occurs when the drift velocities are low or even downwards. The range spread first appears at or below the base of the $F$ layer and later spreads into the $F$ layer due to downward movement of the layer and/or upward movement of the irregularity. Spread $F$ seen on VHF backscatter records corresponds to the range type of spread $F$ seen on normal ionograms. The frequency type of spread $F$ does not produce VHF echoes. A strong peak in the electric field seems to be a necessary condition for the generation of equatorial spread $F$.

Keywords. Spread-$F$; equatorial $F$-region; $F$-region irregularities.

1. Introduction

The early observations of spread $F$ at equatorial stations—Huancayo by Booker and Wells (1938) and Singapore by Osborne (1952) had suggested that the phenomenon is correlated with the marked rise in the height of the $F$ region between 1800 and 2000 LT. Similar correlations were later found between the temporal variation of the virtual height of the $F$ layer and the occurrence of spread $F$ at the other equatorial stations Kodaikanal (Bhargava 1958), Ibadan (Lyon et al. 1971) and Thumba (Chandra and Rastogi 1972).

The data from large number of stations operating during IGY had revealed a very high probability of occurrence of spread $F$ at equatorial latitudes (Shimazaki 1959; Wright 1959; Singleton 1960). It was also noted that the latitudinal plots of the percentage occurrence of spread $F$ showed significantly less scatter against dip latitude than against geomagnetic dipole or geographic latitude. The equatorial belt of spread $F$ was shown to be associated with similar belt of high value of virtual height of the $F$ layer (Lyon et al. 1960; Rao 1966). Thus it was clear that equatorial spread $F$ is closely associated with the magnetic dip equator even though there is no concentration of equatorial electrojet during the night time.

With the use of powerful VHF radar at Jicamarca, the profiles of electron density with height have been computed in the ionosphere even for regions above the peak ionisation level of the $F$ region ($h_mF_2$). Number of contour diagrams of electron density on the grid of actual height versus local time have been published by Farley (1966) and by McClure et al. (1970). The vertical drift velocities in the $F$ region,
\( V_z(F) \), have also been measured through the Doppler shift of the backscattered echoes. Woodman (1970) has described the result of these measurements over the period 1968–70. On certain days both the electron density contour and the vertical drift velocity are available (Woodman and La Hoz 1976).

The present paper compares the occurrence of spread \( F \) as seen on the VHF backscatter records at Jicamarca with the spread \( F \) configuration on the ionograms at Huancayo. Some of the data used in the present analysis have been kindly provided to the author by Dr R F Woodman. It is to be noted that the two sets of data are not from identically the same location and hence no comparison of short period variations is attempted here.

2. Variations of the \( F \) region parameters over the magnetic equator in the evening hours

The post-sunset rise of the \( F \) region has been generally inferred from the increase of the minimum virtual height of the \( F \) layer, \( h'_F \), because this parameter is easily available for most of the ionospheric stations in their data bulletins. Lyon et al (1961) compared the variations of \( h'_F \) and \( h_mF \) (true height of maximum electron density as determined by Kelso method) at Ibadan and found that the variations of \( h'_F \) are very similar to that of \( h_mF \) during the period 1700–2000 LT. As there are large longitudinal differences in the characteristics of equatorial spread \( F \), it was considered necessary to study the variation of \( F \) layer parameters in the American zone for comparison with the Jicamarca data. In figure 1 are shown the daily variations of \( h'_F \) at Huancayo as taken from routine tabulations as well as of \( h_mF \) and \( y_mF \).

![Figure 1](image)

**Figure 1.** Daily variations of minimum virtual height of \( F \) region \( (h'_F) \), height of maximum ionization density in the \( F \) region \( (h_mF) \) and the semithickness of the \( F \) region \( (y_mF) \) at Huancayo during the months of March and April 1961. Note the simultaneous increase of \( h'_F \) and \( h_mF \) during the post-sunset period without any large change in \( y_mF \) at the same time.
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(semi-thickness of the layer) as derived from full $N-h$ computations by Budden's matrix method for two months March and April 1961.

The minimum virtual height, $h'F$, shows a very flat minimum around midday hours and a flat peak around sunrise and a prominent peak after sunset. The $h'F$ starts increasing even after 1500 LT, reaches a maximum value at 1900–2000 LT and slowly decreases till about midnight, the total increase of $h'F$ being more than 100 km. The $h_mF$ shows a very sharp peak around sunrise which is due to the generation of fresh ionisation at higher heights, it again starts increasing after 1400 LT and reaches a peak between 1900 and 2000 LT. The variations of $h'F$ and $h_mF$ are very similar during the afternoon and evening hours. The semi-thickness $Y_mF$ is maximum at 1000 LT and slowly decreases from 1000 LT till the next sunrise. Thus it is to be concluded that there is a genuine uplifting of the $F$ region over the magnetic equator as a whole during the sunset period without any large change in the thickness of the layer. Rishbeth (1971) has suggested that this rise in the height of the $F$ region in the evening hours is primarily caused by an eastward electric field. Schieldge et al (1973) have suggested this occasional increase of the electric field as due to the polarization charges which tend to build up in regions where the conductivity has a strong horizontal gradient.

3. Frequency and range types of spread $F$

We next compare in figure 2 the daily variations of the occurrence of range and frequency types of spread $F$ and that of $h'F$ at Huancayo for different seasons of the year.

![Figure 2](image_url)  
**Figure 2.** Daily variations of the occurrence of 'range' and 'frequency' types of spread $F$ compared with the daily variations of $h'F$ at Huancayo for different seasons of the year. Note that the post-sunset spread $F$ associated with the large rise of $h'F$ is the range type and not the frequency type.
year. The year 1961 was chosen for these comparisons because the regular tabulations of $h'F$ were discontinued for later years. It is clearly seen that the evening increase of $h'F$ is present at Huancayo during any of the seasons.

The occurrence probability of either types of spread $F$, frequency of range type, is remarkably low during $J$-months (winter) even though the evening rise of $h'F$ is not much different during this season as compared with other seasons. Thus the seasonal variation of either types of equatorial spread $F$ is similar with a peak around December and a minimum around July. Nocturnally the frequency type of spread $F$ occurs most commonly around midnight hours. The probability of the occurrence of range type of spread $F$ increases rapidly shortly after sunset and reaches a peak around 2000 LT. From these features, it can be concluded that it is the range type and not the frequency type of spread $F$ which is directly associated with the evening rise of the $F$ region. The routine monthly ionospheric data bulletins denote the occurrence of spread $F$ based on the criterion as to what extent the spreadness makes the scaling of $f_oF_2$ uncertain. The results based on the study of spread $F$ occurrences from the routine monthly ionospheric bulletins would be highly biased in favour of frequency type of spread $F$.

In figure 3 we compare the occurrence of range spread at Huancayo with the $F$ region vertical drift velocity at Jicamarca during summer months of 1968–69. It may be mentioned that in the $F$ region the vertical drift velocity is directly related to east-west electric field, a velocity of 40 m/s upwards corresponds to an eastward electric field of about 1 mV/m. The vertical drift, $V_z(F)$, decreased steadily with time in the afternoon hours followed by a relatively sharp peak at about 1830 LT and reversed its direction downward at about 1930 LT; it remained downward throughout the night and reversed to upward direction around sunrise. The onset of range type of spread $F$ occurs when the $F$ region drifts are upward, i.e. when the electric fields are eastward but the peak occurrence frequency of the spread $F$ occurs about an hour later and by that time the $F$ region drifts get reversed downward.

![Figure 3](image-url)

**Figure 3.** Comparison of the temporal variation of the occurrence of range spread $F$ at Huancayo with the daily variation of vertical $F$ region velocity at Jicamarca. Note that the phenomenon of spread $F$ occurs for the most part when the $F$ region drifts are downwards (negative).
Figure 4. Iso-electron density contours and $F$ region vertical drift velocity at Jicamarca compared with the ionograms at Huancayo on 2-3 October 1970. Note spread $F$ started when $F$ region drift velocity was downward. VHF spread $F$ occurred in the lower half of the $F$ region and was associated with the "range" type of spread $F$ on the ionograms.
4. Spread $F$, vertical $F$ region drifts and iso-electron density contours

We now compare the characteristics of the spread $F$ at Huancayo ionograms in relation to the electron density contours and the vertical $F$ region drifts at Jicamarca. In figure 4 are shown the iso-electron density contours and vertical $F$ region drift velocity at Jicamarca on 2–3 October 1970 compared with the ionograms at Huancayo. The iso-electron density contour at the base of the $F$ region is seen to increase even during the afternoon hours but the overall increase of the height of contours up to the height $h_{\text{max}}$ started at about 1730 LT and the peak height was reached at 1930 LT. The $F$ region drift had a flat peak around midday, decreased to almost zero value around 1530 LT, and again increased to form a sharp peak at 1845 LT, reversed its direction at 1930 LT and remained negative (downward) during the whole night. The spread $F$ was seen by the VHF radar between 1900 and 2115 LT only in the lower portions of the $F$ region. The isoionic contours were clear below $h_{\text{max}}$ indicating that the $F$ region near the height of peak electron density did not have the irregularities responsible for VHF back-scattering. The ionogram at 1700 LT showed the $Es-q$, $Es-c$ and the normal $F$ region traces. At 1800 LT the $Es-q$ had disappeared, $Es-c$ had risen to 175 km, and the $F$ region had also gone up in height. At 1815 LT the cusp type $Es$ was clearly present at 200 km indicating the presence of large $N-h$ gradient at 200 km. At 1830 LT the $f_{\text{min}}$ $F$ had greatly reduced but the presence of low level ionisation was indicated by the group retardation in $F$ layer traces. At 1845 and 1900 LT high multiple echoes were recorded due to the existence of large horizontal gradients in the isoionic surfaces in the $F$ region (Rastogi 1955). The first indication of spread $F$ was seen in the lower frequency portion of the $F$ region trace at 1900 LT. At 1915 LT and 2015 LT the spread $F$ had increased in intensity. It is interesting to note that the $F$ region critical frequencies were clearly seen even in the presence of intense range spread at 2015 LT. At 2100 LT the intensity of spread $F$ had diminished and it disappeared by 2200 LT. This example shows that range spread $F$ can coexist with very clear critical frequencies. Further, the occurrence of range spread on the ionogram is closely linked with the spread echoes seen in the VHF radar.

We now compare in figure 5 the ionograms and the iso-electron density contours during the occurrence of a very strong spread $F$ on 22–23 September 1971. It is seen that $h'F$ started increasing even before the increase of the evening peak in $F$ region vertical drifts. The $F$ region continued to increase as long as the $F$ region drift was upward and the peak value of $h'F$ occurred almost at the time of the reversal of $V_z$. Examining the ionograms, one finds high multiple echoes at 1900 LT indicating large gradient in the isoionic surface which is confirmed from the contours of the electron density ($Ne$) derived from VHF data. At 1915 LT both frequency and range spread are seen on the ionograms and some portion of $h'F$ trace is also discernible indicating normal electron density variation with height. At 2000 LT the ionogram shows complete spread with no group retardation in the traces; there are a number of horizontal traces at slightly different heights. These conditions continued up to 2200 LT after which the spread $F$ gradually decreased in intensity. The VHF radar echoes indicated spread $F$ throughout the entire height of the $F$ region from 1930 to 2200 LT. It is to be noted that the onset of spread $F$ was when the $V_z$ was upwards although it continued even later when the $V_z$ had reversed downwards. Thus it is again seen
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Figure 5. Iso-electron density contours in the $F$ region over Jicamarca, the vertical $F$ region drift at Jicamarca, minimum virtual height of the $F$ region at Huancayo compared with the ionograms at Huancayo on 22 September 1971. Note the complete spread in the ionograms, with no group retardation in $\nu'F$ seen; no indication of critical frequencies can be seen and the VHF radar indicated spread over the entire $F$ region at the same time.
that the uplifting of the $F$ region and the onset of range spread are closely associated with the strong eastward electric field in the $F$ region during the post-sunset period.

5. Spread $F$ and the post-sunset increase of $F$ region drift velocity

Now, the question arises is the post-sunset increase of the $F$ region drift an essential condition for generating the spread $F$ or is it the height of the $F$ region that controls the occurrence of spread $F$? It was sought to find out two close-by days with distinctly different variations of $V_z(F)$ during the evening period and to examine the Huancayo ionograms on these two days. It was possible to find two such days in April 1971. In figure 6 are shown the variations of $V_z(F)$ at Jicamarca with $h'F$ at Huancayo together with some of the ionograms at Huancayo on 26 and 28 April 1971. The variations of the geomagnetic $H$ field at Huancayo are also shown for these days to check if the changes are associated with any geomagnetic disturbances.

The most interesting feature noticed in the diagram is that $V_z(F)$ at Jicamarca on 28 April 1971 was almost zero in the evening hours and later reversed to downward direction without showing any positive peak before changing its direction. On the other hand, on 26 April 1971, $V_z(F)$ showed a prominent sharp peak shortly after sunset and later the direction was reversed. The magnetogram traces did not show any noticeable differences which could be attributed as due to differences in $V_z(F)$ on two days. The minimum virtual height of the $F$ region ($h'F$) on 28 April 1971 showed an increase beginning 1500 LT from 200 km to the peak value of 280 km between 1800 and 2100 LT. On 26 April 1971 $h'F$ did start increasing since 1500 LT but after 1700 LT the rise was very rapid, the peak value of $h'F$ was 380 km at 1915 LT after which $h'F$ decreased slowly. Thus it is concluded that even on normal days without any large value of $V_z$ near sunset hours, the virtual height of the $F$ region goes up since the afternoon hours till a few hours after sunset. On the days with large pre-reversal peak in $V_z$, an additional upward lifting occurs when the $h'F$ is raised by more than 100 km within an hour or so.

Examining the ionograms one notices that on 28 April 1971 there was no indication of spread $F$ echoes on the first order $F$ region reflections. On 26 April 1971, there were no scatter echoes till 2045 LT. At 2115 LT no overhead scatter echoes were seen on $1 \times F$ trace but a satellite scatter trace was seen due to oblique reflection. At 2145 LT spread $F$ echoes were seen at the base of the $F$ region. By 2200 LT the spread $F$ region had decreased to the height lower than $h'F$. At 2215 LT satellite echoes were seen and by 2245 LT the spread $F$ echoes had more or less disappeared. It is to be noted that around 2100 LT on 26 April 1971 when spread $F$ was first seen on the ionogram the minimum height of the $F$ layer was about 270 km which is roughly the value of $h'F$ on 28 April 1971 between 1800 and 2100 LT. Thus it seems that a threshold value of $h'F$ only above which spread echoes can be seen to be incorrect and the post-reversal peak in the $F$ region drift velocity is an important prerequisite for the generation of the equatorial spread $F$.

In figure 7 is reproduced the figure 2 of Woodman (1970) showing the temporal variations of $F$ region vertical drift velocities over Jicamarca on a few days in the months of May and June. The shaded bands in the diagram indicate the times when spread $F$ was seen by the VHF radar. It is seen that spread $F$ was seen during the
Figure 6. Variations of $kF$ at Huancayo, geomagnetic field ($H$) at Huancayo and $F$ region vertical drift velocity at Jicamarca $V_z(F)$ compared with some of the ionograms at Huancayo on 26 and 28 April 1971. Note strong spread on 26 April 1971 when the post-sunset peak of $V_z(F)$ was present and absence of spread $F$ on 28 April 1971 when no increase of $V_z(F)$ occurred during the sunset period.
post-sunset periods on 14–15 May 1969, and on 21–22 May 1968 and on both these days $V_d(F)$ was sufficiently high around sunset periods. On 28–29 May 1968 and 28–29 May 1969, the $V_d(F)$ was very low at sunset and no spread $F$ was indicated. On 29–30 May 1969, strong $V_d(F)$ was present at sunset and spread $F$ echoes were seen after 1900 LT. On 30–31 May 1969, no evening peak of $V_d(F)$ was evident and no post-sunset spread $F$ was present. On 3–4 June 1968 and 4–5 June 1968 strong peaks in $V_d(F)$ shortly after sunset were followed by the occurrence of spread $F$.

It is thus concluded that the existence of a strong upward drift or a strong eastward electric field in the $F$ region is a necessary condition to exist for some time after sunset to initiate equatorial spread $F$.

6. Spread $F$ seen through HF ionosonde and VHF radar

We now compare the characteristics of spread $F$ on Huancayo ionograms and on VHF radar at Jicamarca. One such example for 15–16 October 1964 is reproduced in figure 8 (after McClure et al 1970). The isoelectron density contours showed increasing height after about 1700 LT with the peak around 2000–2100 LT. The VHF radar indicated spread echoes from 1945 to 2300 LT. It is interesting to note that these irregularities were seen by VHF radar only in the lower half of the $F$ region.
Figure 8. Iso-electron density contours obtained by VHF radar at Jicamarca compared with the ionograms at Huancayo on 15-16 October 1964. Note that the VHF spread $F$ echoes occurred in the lower half of the $F$ region and were associated with range type of spread $F$. No spread $F$ was seen in VHF when the ionogram showed strong frequency type of spread $F$. 
The ionograms first indicated some scatter echoes at 2000 LT on lower frequencies. At 2015 LT range type spread $F$ was quite clear and the critical frequencies were distinctly distinguishable. At 2100 LT the spread had reached to the critical frequencies and some layered structures were evident within the spread $F$. After 0000 LT the spread $F$ started to transform into frequency type i.e., the spread was absent at the lowest frequency end of the trace and increased towards the critical frequency region. At 0200 LT and 0215 LT strong frequency spread $F$ was present. The VHF radar did not show spread $F$ after midnight when the characteristics of the spread $F$ were of frequency type.

In figure 9 are shown another comparison of VHF scatter data and ionograms on 10–11 December 1964. The contours of $N_e$ show a rapid rise of $h_mF$ after about 1800 LT with the occurrence of spread $F$ after 1930 LT and ending at 2200 LT; but the spread $F$ was seen only in the lower half of the $F$ region. The ionograms did not show any spread $F$ at 1845 LT while at 1915 LT a few scatter echoes were seen at lower frequencies and the critical frequencies were quite clear. At 1930 LT spread $F$ had extended up to the critical frequencies and discrete layers of irregularity were evident. After 2200 LT the character of spread had changed into frequency type. Strong frequency spread can be seen on the ionogram at 2315 LT. The spread $F$ condition extended up to about 0230 LT. It is to be noted that the VHF radar did not indicate spread $F$ during these periods of strong frequency spread.

We show in figure 10 an example of VHF spread when the $hf$ ionosonde did not show any spread at all. The isoionic contours over Jicamarca for 25 June 1969 indicated significant rising of the $h_{max}F$ in the post-sunset period. Spread $F$ was also seen in the VHF radar between 1900 and 2200 LT. Examining the ionograms, one can see high multiple echoes from 1815 to 1900 LT indicating large gradients in the isoionic surfaces but no indication of spread $F$ can be seen on any of the ionograms at Huancayo that evening. It thus seems that even on occasions when the conventional $hf$ ionosonde does not receive any spread $F$ echoes, the VHF radar can detect scattered signals which may be identified as caused by spread $F$.

7. Discussion

The occurrence of equatorial spread $F$ during the evening hours when the $F$ region is rising rapidly had prompted many workers to associate the spread $F$ with the movement or with the height of the layer.

Osborne (1952) suggested that $h'F$ reached the maximum value at the time of sunset at the ionospheric heights when the layer disintegrates into scattered clouds. Clemesha and Wright (1966) reported that the onset of spread $F$ at Ibadan occurs at the time of peak $h'F$ and is preceded by the satellite traces. The model suggested by them assumes the presence of irregularities above a certain height in the $F$ region and the spread $F$ is seen when the $F$ layer rises above this threshold height. Rao (1966) had shown that $h'F$ at Huancayo has to cross a threshold value of about 400 km for the production of spread $F$. He used the published monthly $f_0F_2$ data bulletins and as such was unable to identify the range spread which does not affect the identification of the critical frequencies. If it is assumed that irregularities in the $F$ region are already there and the spread $F$ is seen on the ionograms only after the $F$ layer has
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Figure 9. Iso-electron density contours obtained by VHF radar at Jicamarca compared with the ionograms at Huancayo on 10-11 December 1964. Note that the VHF spread $F$ occurred in the lower half of the $F$ region and were associated with range type of spread $F$. No spread $F$ was seen in VHF when the ionograms showed strong frequency type of spread $F$. 
risen above this threshold height, then the onset of spread $F$ should start first on higher frequencies and then gradually to lower frequencies, but the case is just opposite to this. Farely et al (1970) also suggested that there is a threshold altitude above which the bottom of the $F$ layer has to rise before the irregularities are generated. Rastogi (1977) has shown that range spread as seen on the ionograms appears at heights significantly lower than the base of the $F$ region and only afterwards mixes up with the main $F$ region due to downward movements of the layer or possibly upward movement of the irregularity itself.

Booker (1956) was the first to suggest that the irregularities responsible for spread $F$ was below the base of $F$ layer. He suggested that the spread $F$ on the ionograms is due to the forward scattering of HF radio waves by a scattering screen between the $F$ region and the ground probably at the height of 180 km and such that the screen is not directly detectable with the conventional ionosondes. Cohen and Bowles (1961) studying the transequatorial forward scattering of 50 MHz signal in Peru during IGY concluded that the range spread designated by them as the equatorial spread $F$ results from scattering by thin sheets of irregularities situated at about the bottom of the $F$ layer or as much as 100 km below it although at times the scattering layer can occur up to heights of 450 km or more.

McNicol et al (1956) combined the vertical ionograms at Brisbane with range-time recordings of spaced (95 km apart) transmitters, phase-path recordings and the direction of arrival of the echoes and concluded that the range type of spread $F$ is due to the number of individual traces which are not resolved. Bowman (1960 a, b) combining the oblique sounding link and spaced loop direction finding with the vertical ionospheric soundings of Brisbane concluded that the irregularities responsible for the spread $F$ at Brisbane are ripples of considerable extent with wavelength varying from 20 to over 100 km. King (1970) has suggested that range spread is caused by total reflection of radio waves due to the passage of a step or ridge in the isoionic surface in the $F$ region. Calvert and Cohen (1961) have explained the variety of equatorial spread $F$ configurations on the basis of partial reflection from a single irregularity moving horizontally at different heights with respect to the $F$ region. Their model attributes most of the features of the spread $F$ configuration to refraction and retardation imposed on the radio waves by the ionosphere as they travel to and fro from the position of scattering.

Booker (1961) has suggested the existing of holes in the ionosphere to explain the bottomside spread $F$. Inside each hole the electron density is lower than that of the ambient ionosphere. When these holes are overhead the station, the number of penetration frequencies would be observed giving rise to number of cusps on the ionogram at the same virtual height giving rise to the frequency spread configuration on the ionograms. Holes at a distance from the station would show up at greater virtual heights and would be generally at a lower critical frequency than the ambient, giving rise to range spreading configuration on the ionograms.

Rastogi and Woodman (1977a) by comparing the ionograms at Huancayo with corresponding MRTI records of VHF radar at Jicamarca have shown that the range type of spread $F$ is very efficient for back-scattering of the VHF radio waves. On the other hand, the frequency type of spread $F$ does not produce strong echoes. Later Rastogi and Woodman (1977b) by comparing the vertical $F$ region drifts measured by the VHF back-scatter radar at Jicamarca and the vertical incidence ionograms at Huancayo, have shown that a reversal of the $F$ region vertical drifts to positive
Figure 10. Temporal variations of the isotonic density contours and vertical drifts in the $F$ region over Jicamarca after Farley et al. (1970) and some of the ionograms at Huancayo on 25 June 1969. Note complete absence of the spread $F$ on the ionograms for the period when VHF radar indicated spread $F$. 
(upward) value during any time of the night is followed by the generation of range type of spread \( F \) configuration on the ionograms with a delay of half to one hour.

Thus it is seen that the essential condition for the generation of range spread at the equatorial latitudes is firstly that the nighttime condition is not necessary but only the post-sunset period is necessary and secondly the existence of eastward electric field.

The rocket flights during the nighttime hours at equatorial latitudes have shown very large positive as well as negative electron density gradients at heights below the \( F \) region (Aikin and Blumle 1968; Prakash et al 1970; Kelley et al 1976; Morse et al 1977).

It is suggested that the range type of spread \( F \) first occurs at the base of \( F \) region during any part of the night when there exists a steep electron density gradient and provided that the horizontal electric field is eastward. The frequency spread is the later development of the range spread.

Thus it is seen that besides finding out a suitable theory for the generation of spread \( F \) irregularities, interpretation of spread \( F \) ionograms is not unique and needs detailed study using simultaneously different techniques. The recent launching of EQUION rocket from Peru is a welcome effort in this direction (Morse et al 1977).

8. Conclusions

(1) The spread \( F \) associated with the post-sunset uplifting of the \( F \) region is the 'range' type showing spread at lower frequency regions of the ionograms with clear critical frequencies. (2) The vertical drift velocity in the \( F \) region over the equator has an evening peak around 1800 LT. The onset of the 'range' spread \( F \) occurs around the period of peak upward velocity and most of the development of spread \( F \) occurs later when the \( F \) region drifts are decreasing or even downwards. (3) Spread echoes in VHF back-scatter records are seen during the period of occurrence of 'range' spread \( F \) on the ionograms. (4) The presence of frequency type of spread \( F \) on the ionograms does not cause spread in VHF echoes. (5) Range spread is absent on days with no evening peak of \( F \) region drift velocity and is present in the evenings with large peak of drift velocity. (6) The range spread occurs only at regions below or at the base of the \( F \) region and extends to within the \( F \) region gradually with time. (7) The threshold of the \( F \) region height above which only the spread \( F \) occurs seems to be untenable. The more necessary condition for the generation of range spread is the large vertical drift velocity in the evening hours.

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