Tropical Spread-F

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It is shown that the equatorial range spread-F is due to scattering of radio waves from a series of levels of large plasma density gradients, and that the equatorial frequency spread is the decay process of the range spread following the lifting of the irregularities to higher heights. The spread-F at tropical latitudes is due to the superimposition of additional off-vertical h-l traces from the patches of irregularities drifting from the equatorial region along the geomagnetic field lines. The range and frequency spread at tropical latitudes are just different manifestations of additional ionogram traces over the normal one. The occurrences of equatorial and low latitude spread are interconnected through a fountain of plasma irregularities similar to the daytime fountain of the plasma causing tropical maxima of F2 critical frequencies.

1 Introduction

Scattering of the radio waves from the region of the ionosphere was detected during the very early stages of ionospheric research. The scattering of radio waves from the F-region of the ionosphere, at low latitudes, was first detected by Booker and Wells. They described ionograms at Huancayo showing diffuse echoes from the F-region received continuously at night over a wide range of frequency and virtual height. The phenomenon was seen between 1900 and 2000 hrs LT and was preceded by a marked rise of 100 km or more in the height of the F-region. Meek was the first to use the term 'spread' echoes to describe diffuse ionograms at high latitudes. He found that during these events a main part of the echo was reasonably steady and the spread part was very variable and suggested the spread echoes to be due to reflections from non-zenith directions. Osborne described the phenomenon of spread-F echoes at the equatorial station, Singapore, to be similar in nature to that at Huancayo. He noted that on several occasions echoes from several distinct layer heights were simultaneously obtained at low frequencies although a clean single reflection was present at higher frequencies.

The characteristics of equatorial spread-F have been described by a series of papers on spread-F at Ibadan (dip 6°N). The spread-F occurrence was maximum around midnight with an indication of pre-sunrise secondary maximum. The development of spread-F at Ibadan could be categorized into two classes, viz. (i) ionograms with no signs of group retardation at all, with a number of stratifications widespread in both height and frequency, usually occurring between 1900 and 2200 hrs and (ii) ionograms with group retardation visible, but widespread particularly at higher frequencies with no stratifications, usually occurring from 2300 hrs LT onward. The layer trace was seen to double before the development of spread echoes suggesting the occurrence of reflections from a layer tilt which developed just before the occurrence of spread-F.

2 Data

Chandra and Rastogi described the characteristics of spread-F echoes at Thumba (magnetic dip 0.6°S). They clearly defined the equatorial spreading as falling into two categories, viz. (i) range spreading when the diffuseness is principally along the horizontal part of the h-l trace giving rise to the ambiguity in h-l but the critical frequencies are clearly identified, and (ii) frequency spreading when the spreading is maximum at frequencies close to the penetration frequencies causing ambiguities in the identification of f,F2 while the trace is clear and sharp at lower frequencies. The two kinds of equatorial spread-F were shown to have different temporal variations and geomagnetic storm effects. Effective studies of range and frequency types of spread-F at Huancayo have been published by Rastogi and Vyas, Rastogi, Rastogi et al. and Chandra et al.

Comparing the vertical incidence ionograms at Huancayo and the vertical drifts at Jicamarca, Rastogi showed that a strong peak in the eastward electric field to the eastward direction during any time of the night is followed by the generation of range type of spread-F configurations in the ionograms. Rastogi showed that the conditions for the start of equatorial spread-F are (i) the existence of strong plasma density gradients, (ii) the existence of eastward electric field and (iii) the continuation of the above two conditions for about an hour or so. Rastogi
suggested that the first seeding of the spread irregularities at the equatorial ionosphere in the evening hours occurs due to a gradient drift instability at any height between the E and F layers wherever a large plasma density gradient exists. Later, the irregularities extend upwards throughout the F-region due to the buoyancy effects through Rayleigh-Taylor instability mechanism.

In Fig. 1 are shown some typical ionograms of equatorial spread-F to clearly define the differences in the characteristics of spread-F at an equatorial and at non-equatorial (tropical) station. Fig. 1(a) shows the ionogram at the initial stage of the range spread-F. Note that the normal $h'f$ traces are clearly distinguishable within the diffused echoes and the critical frequencies are clearly defined. The scatter echoes are at a virtual height lower than the minimum virtual height of the normal $h'f$ trace and the scatter trace does not show any group retardation effects, i.e. the increase of virtual height with increasing frequency of the exploring radio wave. The spread echoes, instead of being uniformly scattered on the ionogram are concentrated at a number of layers. The ionogram in Fig. 1(b) is an example of intense, fully developed stage of range equatorial spread when scatter is extended over a large amount of frequency and height scale. Still, within this area a number of traces are distinctly distinguishable, each of which shows complete absence of group retardation suggesting multiple levels of scattering either at the base or within the F-layer. Fig. 1(c) shows a case of equatorial frequency spread-F. Here the height range of scattering increases uniformly with the frequency of the radio wave. At lower frequencies the scattering is too small and the minimum vertical heights are clearly seen at all frequencies. It is to be noted that the individual echoes are randomly distributed on the ionogram and do not show a tendency to fall on any definite $h'f$ trace suggesting that these echoes are due to weak scatter by irregularities within the F-layer, simply adding echoes with range higher than the minimum virtual height for any particular frequency. It will be shown later that even though the terms range and frequency spread, are used for tropical spread-F the characteristics of the spread from these two regions are different.

Probably the most extensive study of the non-equatorial spread-F has been done by the Australian scientists, especially at Brisbane. Gipps et al. have found that the diffuseness on the ionograms first appears in the form of clouds corresponding to frequencies above the critical frequencies and as the irregular clouds of ions gradually descend they produce scattering from lower heights and frequencies. The second type of spread shows apparent reflecting regions at slightly different heights and with different critical frequencies. The classifications of 'range spreading' and 'frequency spreading' were first used in a series of papers describing the spread-F at Brisbane. Range spread manifests itself as a multiplicity of discrete F-region traces, all of closely similar range frequency characteristics. In the case of frequency spread, the widening of $h'f$ traces near the critical frequency is sometimes resolved into a number of fairly distinct upward sweeping traces.

Bowman has categorized the characteristics of tropical spread-F (at Brisbane) into four broad types which are redrawn in Fig. 2. The spread-F at Brisbane makes itself manifest on ionosonde records by additional traces which are generally similar to the main $h'f$ trace but with critical frequencies which may be greater than or lesser than that of the main trace. Observation of these satellite traces at the lower frequency end of the ionograms where retardation can be neglected indicate, at certain times, ranges more than 10 km greater than the true range of the main echo. This type is classified as range spreading. At
other periods, the true range of the satellite echo is little greater than the main trace but the critical frequencies are different: this configuration is classified as frequency spread. Other ionograms exhibit diffuse traces which on critical examination suggest that these configurations are the result from satellite traces so close in true range or critical frequency that the resolution of the equipment is insufficient to separate them. It is convenient to classify spreading into further two groups 'resolved' and 'unresolved'.

3 Analysis

Now we shall interpret some of actual ionograms recorded at different tropical latitude stations. In Fig. 3 are reproduced ionograms at a tropical latitude station, Grand Bahama, showing the broad characteristics of the spread-F. The ionogram in Fig. 3(a) shows $h'$-$f$ traces with broadening only for frequencies close to $F_2$ and $F_3$ and with both $o$ and $x$ traces are well resolved; this would be classified as weak frequency spread. Fig. 3(b) shows an ionogram with no spreading at lower frequencies (less than 2 MHz) whereas there is complete spreading for frequencies in the range 3.5 to 5.3 MHz. Even within the diffused echoes it is easy to trace out some of the individual $h'$-$f$ traces. This would be classified as 'tropical frequency spread' and is different from the characteristics of equatorial frequency spread where the echoes are completely randomly distributed. Fig. 3(c) shows the ionogram which distinctly is a composite of a number of individual $h'$-$f$ traces with different minimum virtual heights and penetration frequencies. This ionogram, classified as tropical range spread, again differs from the equatorial range spread in that individual traces within the spread area do show the effects of group retardation.
Now we examine the characteristics and the development of the spread-F at a few tropical stations. To begin with in Fig. 4 are shown the ionograms at Brisbane after Fig. 4 of a paper by Bowman. The ionograms for 0200 and 0210 hrs LT show some spreading close to critical frequencies. The ionograms for 0220 and 0230 hrs LT indicate further a satellite trace to the main trace and thus spreading has extended to a lower frequency. The ionograms at 0240 and 0250 hrs LT show a number of $h'f$ traces almost parallel to each other and each of them shows group retardation effects. This type of range spread is distinctly different from the equatorial range spread shown in Fig. 1(b).

In Fig. 5 are shown two spread-F ionograms at another tropical latitude station, viz. Bogota. Fig. 5(a) represents the frequency type of spread-F. There is very little spreading below 2 MHz and there is extreme spreading between 2 and 4 MHz. It is interesting to note that, even within the spread-F, individual $h'f$ traces can be easily identified. Fig. 5(b) representing 'range spread-F' is again a mosaic of a number of individual $h'f$ traces such that both the penetration frequency as well as minimum virtual heights are not the same.

In Fig. 6 are shown the ionograms at Bogota for the period 1800 to 2130 hrs LT on 7 Dec. 1954. The ionogram for 1800 hrs LT shows clear $h'f$ trace with very distinct critical frequencies of $o$ and $x$ components. In the ionogram for 1830 hrs LT one can see some additional traces on frequencies close to the critical frequencies. At 1915 hrs LT two parallel $h'f$ traces are seen with different $hF$ and $fF2$. At 1945 and 2000 hrs LT, strong range spread can be seen with a number of individual $h'f$ traces embedded within the spread.

In Fig. 7 are shown two spread-F ionograms at another tropical latitude station, Panama. It can be seen that the spread-F at the western zone station, Panama, is also the result of number of $h'f$ traces with different $hF$ and critical frequencies, each trace showing group retardation similar to that in the first order F-layer trace.

In Fig. 8 are shown the development of tropical spread-F at Grand Bahama on 28-29 Dec. 1964. At 2300 hrs LT there are no signs of spreading on the $1 \times F$ or $2 \times F$ traces. At 2315 hrs LT extra traces are seen on $1 \times F$ trace specially near the critical frequencies while $2 \times F$ trace is still clear. At 2330 hrs LT strong range splittings with a number of multiple traces are seen on $1 \times F$ trace while the $2 \times F$ trace is still clear with critical frequencies clearly defined. At 2345 hrs LT spread traces are seen on $2 \times F$ trace too and at 0000 hrs LT, range splittings are seen on both the first as well as second order traces. It is to be noted that there is no Es trace visible and so these multiple traces cannot be interpreted in terms of M or N echoes due to reflections between Es and F layers.

During 1962, extensive ionospheric instrumentation was established in the central Pacific area. A total of twelve vertical incidence ionosondes and seventeen oblique incidence ionosondes were operated in an area of 2800 km in radius centering on the magnetic equator at 173°W longitude. Lomax has described the occurrence of spread-F at these stations on 27 Oct. 1962. Here we describe the characteristics of spread-F.
at some typical stations on one particular day. First in Fig. 9 are shown the contours of F2-region critical frequency, $f_{c}F2$, at 0600 hrs UT using the data from all the stations operating in the region. In Fig. 9 one can see the maximum of $f_{c}F2$ both in the northern and southern regions with low values of $f_{c}F2$ along the magnetic equator. From the contours shown one can identify that Canton (lat. 5° S) and Kwajalein (lat. 5° N) are equatorial stations, Palmyra (dip. lat. 7° N) occupies the region of maximum $f_{c}F2$, Samoa (dip. lat. 14° S) is just outside the F2 anomaly crest and French Frigate Shoals (dip. 24° N) is well outside the F2-region anomaly. The distribution of these stations covered time zones of an interval of 2 hr. Some selected spread-F records at these stations are reproduced in Fig. 10. The spread-F at Kwajalein was typical of equatorial range type, the diffuseness being primary at low frequency end of the ionogram. At Canton, the first sign of spread was indicated by a strong oblique echo at virtual range of 400 km at 1832 hrs LT. Fifteen minutes later, strong spreading was evident on both the main as well as on the oblique traces. This process continued to develop with time. At Palmyra, where the value of $f_{c}F2$ was large (about 13 MHz), the spread-F started with a scattered type on the oblique echo. It is to be noted that there are no Es reflections and the satellite F-trace cannot be interpreted as M or N type of echoes between F and Es layers. Later development of spread-F at Palmyra consisted of a series of parallel $h$-f traces typical of non-equatorial range spread discussed earlier in this paper. At Samoa too, the oblique returns were obtained as virtual ranges of 380 to 400 km; later multiple ranges of scattered echoes with minimum range decreasing with time was noticed. At French Frigate Shoals, the main 1 $\times$ F and 2 $\times$ F traces were always clear but strong scattered traces were observed in between. Further as seen in the ionogram for 1921 hrs LT, the scattered trace had much higher critical frequencies than that of the main trace indicating that the scattering (spread-F) was due entirely to off-vertical returns, and irregularities were not present vertically above the station. No spread was recorded at the stations Mauii, Rarotonga or Tongatapu which were well outside the F2-anomaly crests.

As the stations were spread over about 45° longitude equivalent to the 3-hr time difference, the analyses of the stations had to be simplified by interchanging the time and longitude and the problem reduced to two dimensions, viz. the local time and the distance of the station from the magnetic equator. With this assumption the onset times of spread-F at all the stations were noted and indicated in Fig. 1.2.17 of the paper by Lomax. He had also drawn a diagram [Fig. 1.2.18] giving the percentage occurrence of...
topside spread-F based on the study by Calvert and Schmid. Both these diagrams are combined in Fig. 11. The zero per cent curve for topside spread-F may be interpreted as representing the onset time of the earliest occurring case of spread-F during the period covered in the data. Higher percentage curves are believed to describe onset time versus latitude of subsequently occurring cases. As the spread-F once initiated may continue for several hours, in the time interval between the 20%, and 40%, contours, it is unlikely that any of those spread-F represented on 20%, occurrence figure will change. The same day, therefore, is represented in the 40% curves, and the 20% difference represents the onset of spread-F on an additional 20% of the days. Thus the family of occurrence curves is representative of a family of onset curves. Then it is clear from Fig. 11 that the initial onset spread-F is a strong function of the distance from the equator. The bottomside spread-F starts at the magnetic equator around 1820 hrs LT and is delayed by about 20 min at a distance of 1000 km from the equator; at a distance of 2000 km, the spread-F occurs at 1930 hrs LT, about 1 hr after its onset at the equator, and the onset is further delayed by 1 hr at a distance of 3000 km from the equator. Chandra and Rastogi have shown that the equatorial spread-F at the stations Huancayo, Ibadan, Djibouti or Kodaikanal occurs most frequently before midnight during maximum sunspot years and around midnight during minimum sunspot years. At a tropical latitude station, Ahmedabad, the spread-F is most frequent after midnight during low sunspot years. Similar results were found at Nairobi. At a low latitude station, Baguio, the peak occurrence of spread-F was around 2100 hrs LT during 1956-58 (high sunspot) and around 0100 hrs LT during the low sunspot periods 1953-55. These results based on statistical analyses of long period data indicate that spread-F is most frequent at a later hour of the night as its distance from the equator is increased.
There has been a good network of ionospheric stations in India from the magnetic equator to a latitude well beyond the peak of equatorial F2-region anomaly. During 1965 four automatic ionosondes were operating in India at Kodaikanal (equatorial station), Hyderabad (within F2-anomaly region), Ahmedabad (at the anomaly peak latitude) and at Delhi (well-outside the anomaly region). The occurrence of the spread-F were noted at these stations and in Fig. 12 the percentage occurrence of the spread echoes versus time has been shown for these stations. The peak of spread-F occurrence at Kodaikanal (geogr. lat. 10°N) during 1965 was around 0000 hrs LT while at the low latitude station Hyderabad (lat. 17°N) the peak occurrence was around 0200 hrs LT and the peak value was slightly decreased. The peak occurrence at Ahmedabad (lat. 23°N) was around 0230 hrs LT and at Delhi (lat. 28°N) it was around 0330 hrs LT. It is also to be noted that the frequency of occurrence of the spread-F decreases slightly with increasing distance from the magnetic equator besides the systematic shift of the time of occurrence.

McNicol and Bowman\textsuperscript{28} examined the ionograms at stations between the magnetic equator and the latitude 50° for the month of January 1956 for the occurrence of nighttime spread-F satellites, recorded as discrete extra traces of range greater than the main F-region echo on ionograms. These characteristics represent what is now designated as range type of non-equatorial spread-F. They found that the occurrence of range spread showed as a very irregular function of geographic latitude. However, in terms of geomagnetic latitudes the data were quite regularly distributed and the phenomenon was found to be most common between the latitudes of 20° and 45°. The irregularities data are replotted in Fig. 13 against the magnetic dip angle of the station. The latitudinal variations of noontime $f_n$F2 during the periods 1953-54 and 1957-58 (after Rastogi\textsuperscript{34}) are also included in Fig. 13 to show the F-region anomaly. It is very clear that the multiple $h'$-f traces type of spread-F is not seen at the region close to the equator and is most common around the region of F2-anomaly crest which experiences the largest share of the plasma diffusion from the equator along the lines of force. It is to be noted that the F2-anomaly is a daytime phenomenon and spread-F is a nighttime phenomenon. The comparison is not made to show the association between the two. However, a similarity between the latitudinal variations of the two phenomena indicates some similar mechanism for both, which will be explained later. The statistical studies of the spread-F data obtained from IGY stations had shown the existence of a belt of enhanced occurrence frequency around the magnetic equator\textsuperscript{30-32}. In Fig. 14 are plotted some of the phenomena which are associated with the magnetic equator, viz., the equatorial electrojet depicted by the daily range of geomagnetic $H$ field (after Onwumechiliti\textsuperscript{33}), the F2 equatorial anomaly depicted by the $f_n$F2 (after Rastogi\textsuperscript{34}), the bottomside spread after Shimazaki\textsuperscript{30} and the topside spread-F occurrence after Calvert and Schmid\textsuperscript{23}. The

![Fig. 12](image1.png)\textsuperscript{1965}

![Fig. 13](image2.png)

![Fig. 14](image3.png)
equatorial electrojet is confined to ±5° dip and is a daytime phenomenon. Another ionospheric phenomenon very similar in latitudinal variation is the occurrence of F2-type of equatorial sporadic-E layer during the daytime. The F2-anomaly shows itself by the depression of F2-layer critical frequency over the magnetic equator and two maxima at regions around 15° N and 15° S dip latitudes. The width of the F2-anomaly is much larger than that of the equatorial electrojet. Its explanation is given in terms of equatorial plasma fountain in which the plasma in the F-region over the magnetic equator is lifted upwards due to the eastward electric field and on reaching higher regions, the plasma diffuses along the lines of force giving rise to a concentration of plasma around 15° dip latitudes. It is interesting to note that the width of the spread-F belt corresponds to that of F2-region anomaly and not to the width of the electrojet. This suggests that the low latitude spread-F has in it some dynamic features similar to those of daytime equatorial plasma fountain.

Rastogi\textsuperscript{11} has stressed that the primary parameter for the post-sunset generation of spread-F in the equatorial regions is the horizontal electric field in the F-region which has to be eastward to produce the spread-F irregularities. Rastogi\textsuperscript{12} further suggested that the initial seeding of the irregularities in the equatorial ionosphere during the nighttime hours is due to the gradient drift instability mechanism. In the presence of favourable conditions these irregularities develop throughout the F-layer by Rayleigh-Taylor instability mechanism.

It is suggested here that these irregularities, when raised high up in the equatorial latitudes, diffuse northward and southward along the lines of force in a fashion similar to the diffusion of equatorial plasma along the lines of force during the daytime. Approaching a tropical latitude station, these irregularities are seen as a ripple or a wave on a regular plasma distribution and are detected as satellite traces over the normal h-f ionogram traces. This idea explains the fact that at middle latitude the spread-F is just seen at the higher frequency end and later it extends to lower frequencies. The occurrence of spread-F being delayed at increasing distance from the equator is again analogous to the occurrence of the forenoon peak of f0F2 at a later time at a station away from the equator\textsuperscript{35}.

\section*{4 Discussion}

King\textsuperscript{36} has suggested that spread-F echoes are not due to partial reflection from small irregularities but are rather due to total reflection from a large tilted surface of ionization. He also considered range spreading to be due to steps or ridges in the iso-ionic surface and the frequency spreading as the decay product of the range spreading.

Bowman\textsuperscript{37} has concluded that satellite traces are an integral part of the spread-F phenomenon. He has also shown that directions of arrival for diffuse echoes and the westward movement of the spread-F are virtually the same as has been found for nighttime TIDs\textsuperscript{19}. He suggested that the diffuse nature of some of the specular reflections may be due to scattering by small scale structures which are also present.

Bowman and Dunne\textsuperscript{38} studied the zenith and azimuth angles of the spread-F echoes using directional ionosonde at Brisbane. They detected that spread-F occurrence on some occasions was associated with tongues of ionization which extended some tens of kilometres below the normal level of the F2-layer. Departures from spatially uniform airglow emissions have been detected at low latitudes. Inter-tropical arcs of enhanced 6300 Å OI are maximum in the regions roughly coinciding with the tropical peaks of Appleton anomaly in F2-layer critical frequencies\textsuperscript{39}. Smaller scale airglow structures of 6300 Å intensity having a dimension of about 500 km have also been detected\textsuperscript{40}. Less frequently, highly structured north-south aligned ridges on fingers of enhanced 6300 Å emission have been observed.

Weber \textit{et al.}\textsuperscript{43}, have shown the existence of north-south aligned depletions in regions of decreased intensity in the 6300 Å OI airglow using an all sky imaging photometer installed in the Airborne Ionospheric Observatory at the AFGL. These depletions have east-west dimensions from 50 to 200 km with fine structures as small as 2.5 km and often larger than 1200 km north-south. Simultaneous ionosonde measurements showed that the depletions were accompanied by strong spread-F\textsuperscript{42}.

Sobral \textit{et al.}\textsuperscript{44} studying simultaneous observations of the 6300 Å OI emission intensity and the ionosonde records at low latitudes, detected wavelike structures propagating poleward at an average speed of 240 ± 70 m/sec. These disturbances had wavelengths of a few hundred kilometres and were associated with spread-F in the ionograms. They suggested that the poleward propagating airglow disturbances observed over Cachoeira Paulista could be the manifestation of vertical propagation of plasma bubbles over the magnetic equator. In a later publication, Sobral \textit{et al.}\textsuperscript{44} showed that the airglow disturbances had north-to-south and west-to-east velocity components during the pre-midnight period and almost all these disturbances were accompanied by strong range type spread-F in the ionograms. The most important result of their study was that an often observed feature of the meridional profile of the airglow intensity was the propagating disturbances superimposed on otherwise
rather slowly varying spatial gradients, and that these disturbances were caused by corresponding disturbances in the electron density rather than by the height changes in the F-region.

Thus there are ample evidences that at tropical latitudes one gets disturbances in the electron density over the smoothly varying latitudinal component, and that these move away from the equator.

One of the other manifestations of the spread-F irregularities is the scintillation of radio waves from a satellite received on the ground. Rastogi\textsuperscript{45} has shown that it is the range type of spread-F with multiple layers of scattering in the F-region which produces equatorial radio wave scintillation. Scintillations at tropical latitudes are also associated with range type of spread\textsuperscript{46}.

Using a large array of receivers, McDougall\textsuperscript{47} has studied the distribution of nighttime irregularities which produce scintillations at midlatitudes. The irregularities were found to occur preferentially near the F-region ionization peak, are aligned along the earth's magnetic field and appear to extend from top to bottom of the F-region.

5 Conclusion

The spread-F irregularities are first generated at the base of the F-region over the production of night time F-region. These irregularities are later lifted upward over the equatorial regions by the buoyancy effects associated with Rayleigh-Taylor instability mechanism. This gives rise to the following sequence of traces on an equatorial ionogram, viz. first, range spread at lower frequencies and heights close to $h_{\text{max}}$; second, filling up of a large height range and also frequency extent with spread echoes; later a transformation of range spread to frequency type of spread, and finally, the decay of spreading at equatorial regions. This process, though at its maximum over the magnetic equator, may exist to a lesser degree over a reasonably wide belt of $\pm 10$ of the equator. Having lifted up, the patches of irregularities drift north and south along the lines of earth's magnetic field in a process similar to the daytime fountain of equatorial F-layer plasma and produce extra traces in the ionograms at tropical latitudes. With the progress of time, the region of F-region irregularities widens in its latitudinal extent and at a particular tropical latitude, extends from the F2-layer peak to lower heights changing the character of tropical spread from frequency type to range type spread. Thus the spread-F phenomenon over the whole width of $\pm 20$ from the magnetic equator is a single complex series of events starting at the base of F-layer at the equator due to the eastward electric field, generally after sunset period, or during certain disturbed periods of the night when normal westward electric field is reversed eastward.

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References

3 Booker H G & Wells H W, Terr Mag & Atmos Electr (USA), 43 (1938) 249.
4 Meek J H, J Geophys Res (USA), 54 (1949) 339.
5 Osborne B W, J Atmos & Terr Phys (GB), 2 (1951) 66.
7 Wright R W, J Geophys Res (USA), 64 (1959) 2203.
8 Chandra H & Rastogi R G, Ann Geophys (France), 28 (1972) 37.
19 Singleton D G, Aust J Phys (Australia), 10 (1957) 60.
23 Calvert W & Schmid C W, J Geophys Res (USA), 69 (1964) 1839.
30 Shimazaki T, J Radio Res Lab (Japan), 6 (1939) 669.
35. Rastogi R G. *J Geophys Res* (USA), 64 (1959) 727.