"*Kodaikanal Observatory Reprint No. 22*"

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Reprinted from the "Proceedings of the Indian Academy of Sciences", Vol. LX, 1964

Reprinted from "The Proceedings of the Indian Academy of Sciences",
Vol. LX, No. 4, Sec. A, 1964

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Received August 10, 1964
(Communicated by Dr. M. K. Vainu Bappu, F.A.SC.)

ABSTRACT

The paper describes the nature of the sporadic E layer of blanketing type observed at Kodaikanal (Lat. 10°·2 N; Long. 77°·5 E; dip: 3°·5 N). It is shown that in the Indian equatorial region, the frequency of occurrence of this type of E_s is abnormally large when compared to similar latitudes in the west and that changes of large magnitudes occur in the F2 layer of the ionosphere as well as in the horizontal force of the earth's magnetic field simultaneously with the appearance of the blanketing E_s. Lunar effects have also been shown to exist both in the time of appearance of blanketing E_s and in its strength. Some evidence exists to show that blanketing E_s as well as the blanketing frequency, $f_b E_s$, have a biennial maximum. These characteristics are discussed as part of the Far East Anomaly.

1. INTRODUCTION

THE regular occurrence of equatorial type of sporadic E ($E_s - q$) in low latitudes is well known. Since 1952 when Ionospheric Vertical Soundings began at Kodaikanal, this type of E_s has been observed regularly during daytime. The nature of this layer has been studied extensively by many authors. It has been established that the region possesses a characteristic diffuseness, reflects over a wide frequency range and is transparent. Recently, it has been shown (Cohen and Bowles, 1963) that the electron density irregularities responsible for $E_s - q$ are closely associated with the equatorial electrojet. It has also been shown (Bowles *et al.*, 1963) that the irregularities are plane waves of electron density moving perpendicularly to the magnetic field and that these probably consist of plane acoustic waves. Little attention has, however, been paid to sporadic E layer observed in equatorial ionograms of types other than $E_s - q$. The more important one of these types, generally termed as blanketing E_s, appears to be of rare occurrence in the immediate vicinity of dip equator in the American zone (Kencht and McDuffie, 1961; Bowles and Cohen, 1961) but has been observed very frequently at Kodaikanal during local summer. With a view to study the nature of the blanketing E_s, 15 minute interval ionograms obtained at Kodaikanal during a 6-year period, from 1956 through 1961, were scrutinized. The blanketing E_s is found to have, in general, features which are in substantial contrast to those of $E_s - q$ in almost all respects. The appearance of the region is sporadic, shows a characteristic diurnal and seasonal variation and the layer is not transparent. A typical sequence of $h'f$ records illustrating the appearance, strengthening and subsequent disappearance of the echoes is shown in Fig. 1. Certain seasonal features of this layer have been found to be similar to temperate latitude blanketing type E_s reported at Brisbane (McNicol and Gipps, 1951) and in North America (Gerson, 1959). The appearance of the layer, on a few occasions, follows a sequence similar to that reported at Hobart, Sydney and Canberra (Heisler, 1959). It is preceded by a stratification at the base of the F1 layer and by subsequent formation of a sequential E_s which intensifies and moves downwards. More often, however, blanketing E_s formation follows an intensification of lower region of $E_s - q$. With the appearance of the blanketing E_s the equatorial E_s either weakens or completely disappears. In almost all its features, blanketing E_s observed during daytime is identical to night-time E_s. The more striking feature of the blanketing E_s, however, is its close association with a large increase in the maximum electron density of F2 layer and a reduction in the horizontal force of the earth's magnetic field.

2. Diurnal, Seasonal and Solar Cycle Characteristics

An analysis of 6 years' data on blanketing E_s (May 1956 through August 1961) indicates that it appears, following sunrise, with a forenoon peak between 0730 and 0830 hours, a minimum at about 1130 hours and a large maximum between 1700 and 1830 hours local time. From 24 summer months' data this variation is shown in Fig. 2 along with the mean diurnal variation of foF2. The layer differs in this respect from Brisbane E_s where a summer maximum occurs at 1000 hours local time; the minimum occurrence at Kodaikanal takes place at 1130 hours local time which is significant because this is the time when the electrojet strength is maximum. It is also at this time that the frequency of sudden disappearance of $E_s - q$ has been found, by a separate analysis, to be minimum and the diurnal asymmetry in N_mF2 (bite-out effect) to be maximum (Fig. 2).

The seasonal characteristics of the blanketing E_s are similar to those observed in temperate latitudes such as at Brisbane (McNicol and Gipps,

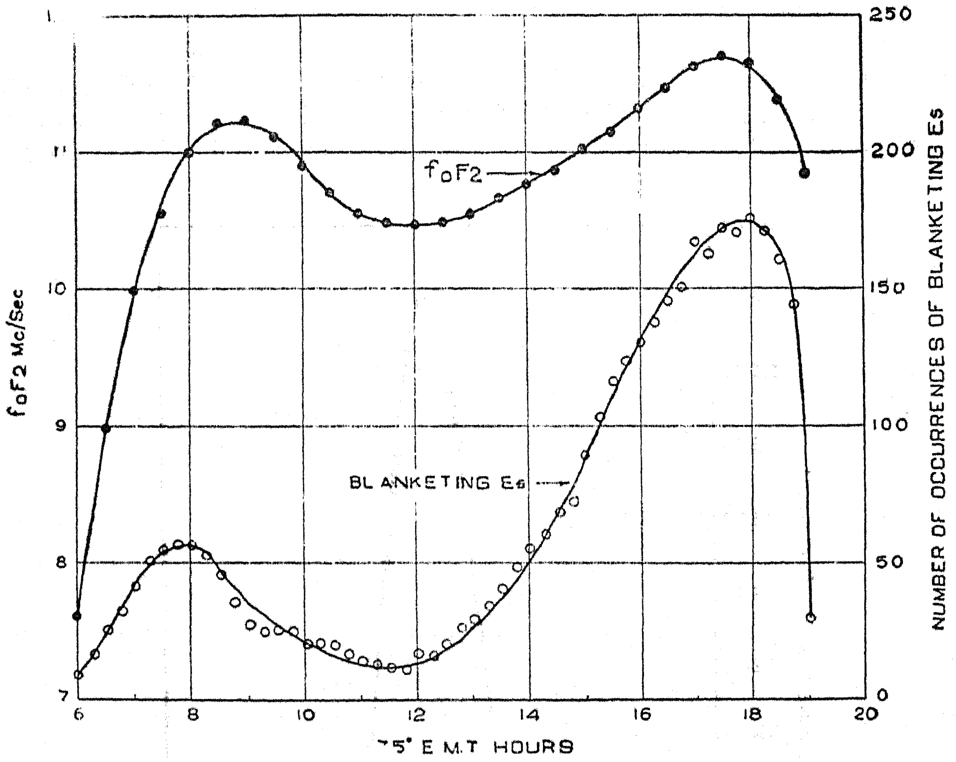

FIG. 2. Diurnal variations in daytime blanketing E_s occurrences and in foF_2.

1951), at Onna (Smith and Finney, 1961), in North America (Gerson, 1959) and in the Caribbean-Atlantic area (Dueño, 1962). The plot of total number of occurrences every month averaged over 6 years, shown in Fig. 3, indicates a predominant summer maximum with a secondary maximum during winter. Both the diurnal as well as the seasonal features suggest that electrojet inhibits the formation of the blanketing E_s. This is in accord with the recent findings (Cohen and Bowles, 1961; Knecht and McDuffie, 1961) that in the immediate vicinity of the dip equator in the American zone, the occurrence of temperate latitude type of blanketing E_s is strongly inhibited.

In the South Indian region, thunderstorms are of frequent occurrence during March, April and September. There is, however, no evidence of any enhancement of blanketing type of E_s occurrence during these months. Unlike temperate latitude E_s, the occurrence of blanketing E_s at Kodaikanal appears to increase with solar activity (Fig. 4). This variation is, however, somewhat complex with a biennial effect superimposed on a general increase with increasing sunspot number; there is some evidence of the presence of such a biennial periodicity in some modified manner even in the Caribbean-Atlantic area with more E_s activity in 1959 than in 1958 (Dueño, 1962), similar to what has been observed at Kodaikanal; for the blanketing frequency, f_bE_s, however, there is no evidence of any association with the solar activity.

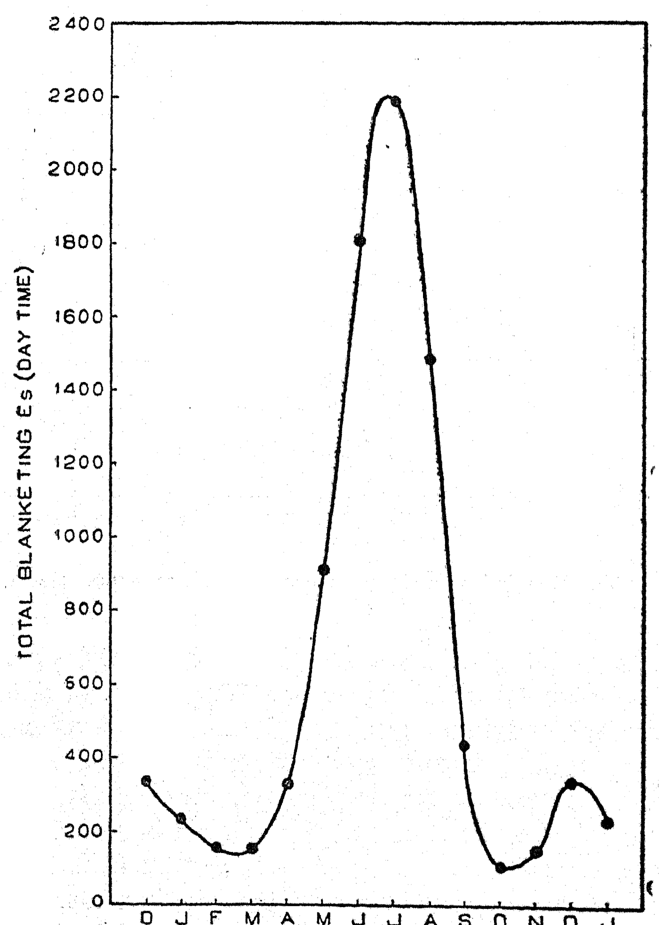

FIG. 3. Seasonal variation of daytime blanketing E_s.

3. DAYTIME BLANKETING E_s IN RELATION TO NIGHT-TIME E_s

The blanketing as well as the seasonal and solar cycle characteristics of the daytime blanketing and night-time E_s are in striking agreement. The number of occurrences of the two types of E_s every month, over a six-year period, yield a correlation co-efficient of 0·96. The close association suggests that the blanketing E_s observed during the daytime and the sporadic night-time E_s at this station arise from a common causative mechanism.

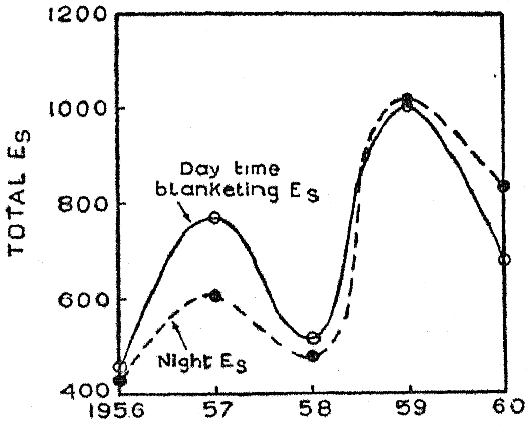

FIG. 4. Annual variations of daytime blanketing E_s and night E_s.

4. TIDAL EFFECTS IN BLANKETING E_s

Since the diurnal and seasonal characteristics indicate inverse relationship between the blanketing E_s and equatorial electrojet and since lunar tidal effects in electrojet strength are known, the possibility of finding lunar effects on blanketing E_s was investigated. The average times of occurrences of these reflections, observed during summer, for the 6-year period (1956–61) were grouped according to lunar age. The plots, Fig. 5 *a* and 5 *b*, indicate that blanketing E_s is more intense and has a tendency to appear later during the day about two days after the first and third quarters. At similar intervals after new and full moon, the layer is weaker and appears earlier. This variation is practically similar to lunar dependence in the time of final $E_s - q$ disappearance (Bhargava, 1963). It has been shown that at Kodaikanal $E_s - q$ has a tendency to disappear earlier, two to three days following the quarters, presumably due to the weakening of the solar electrojet by the lunar electrojet in the vicinity of the quarters. The presence of the lunar tidal effect in blanketing E_s reported here lends further support to the view that conditions for the appearance of blanketing E_s are favourable when the equatorial electrojet becomes weak.

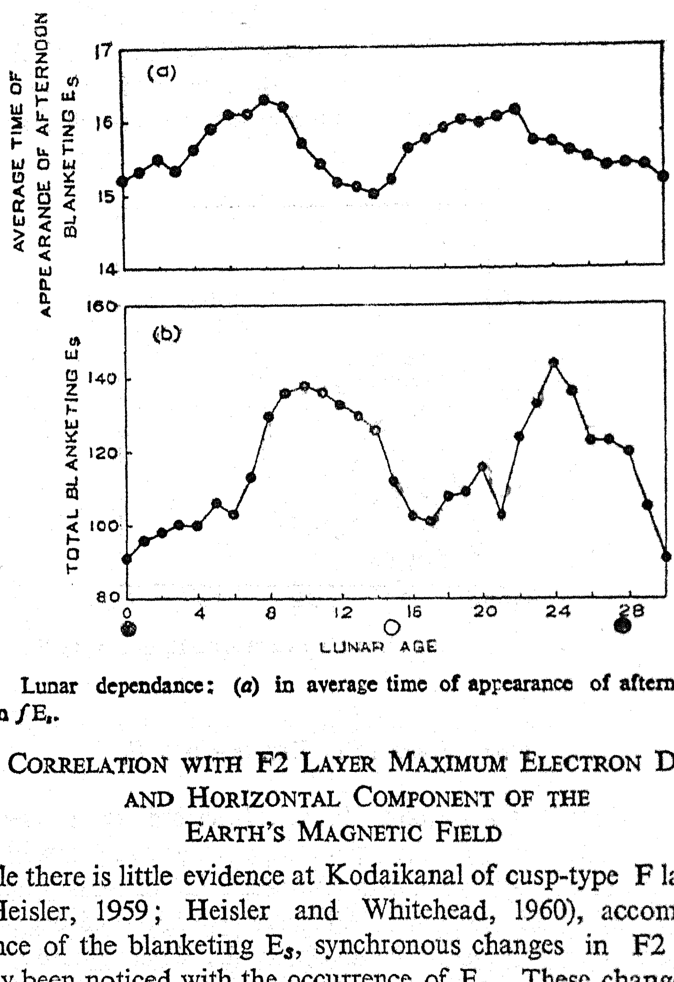

FIG. 5. Lunar dependance: (*a*) in average time of appearance of afternoon blanketing E_s and *b* in fE_s.

5. CORRELATION WITH F2 LAYER MAXIMUM ELECTRON DENSITY AND HORIZONTAL COMPONENT OF THE EARTH'S MAGNETIC FIELD

While there is little evidence at Kodaikanal of cusp-type F layer disturbances (Heisler, 1959; Heisler and Whitehead, 1960), accompanying the appearance of the blanketing E_s, synchronous changes in F2 layer have invariably been noticed with the occurrence of E_s. These changes consist of an appearance of stratification, a progressive increase in the maximum electron density and decrease in F layer semi-thickness and height of maximum electron density. In the equatorial region F layer normally undergoes some of these changes during the afternoon hours. However, the effects noticed to accompany blanketing E_s are not confined to the afternoon hours but occur during midday also when the F2 layer is thick and its maximum electron density low. The horizontal force of the earth's magnetic field undergoes a substantial reduction following blanketing E_s appearance. Thomas (1962) has found decrease of a small magnitude in geomagnetic H component at Brisbane during the occurrence of E_s echoes. The changes in the F2 layer and H component for some typical blanketing E_s events at Kodaikanal are shown in Fig. 6. In Fig. 6 *a*, the critical frequencies of F2 layer from 1000

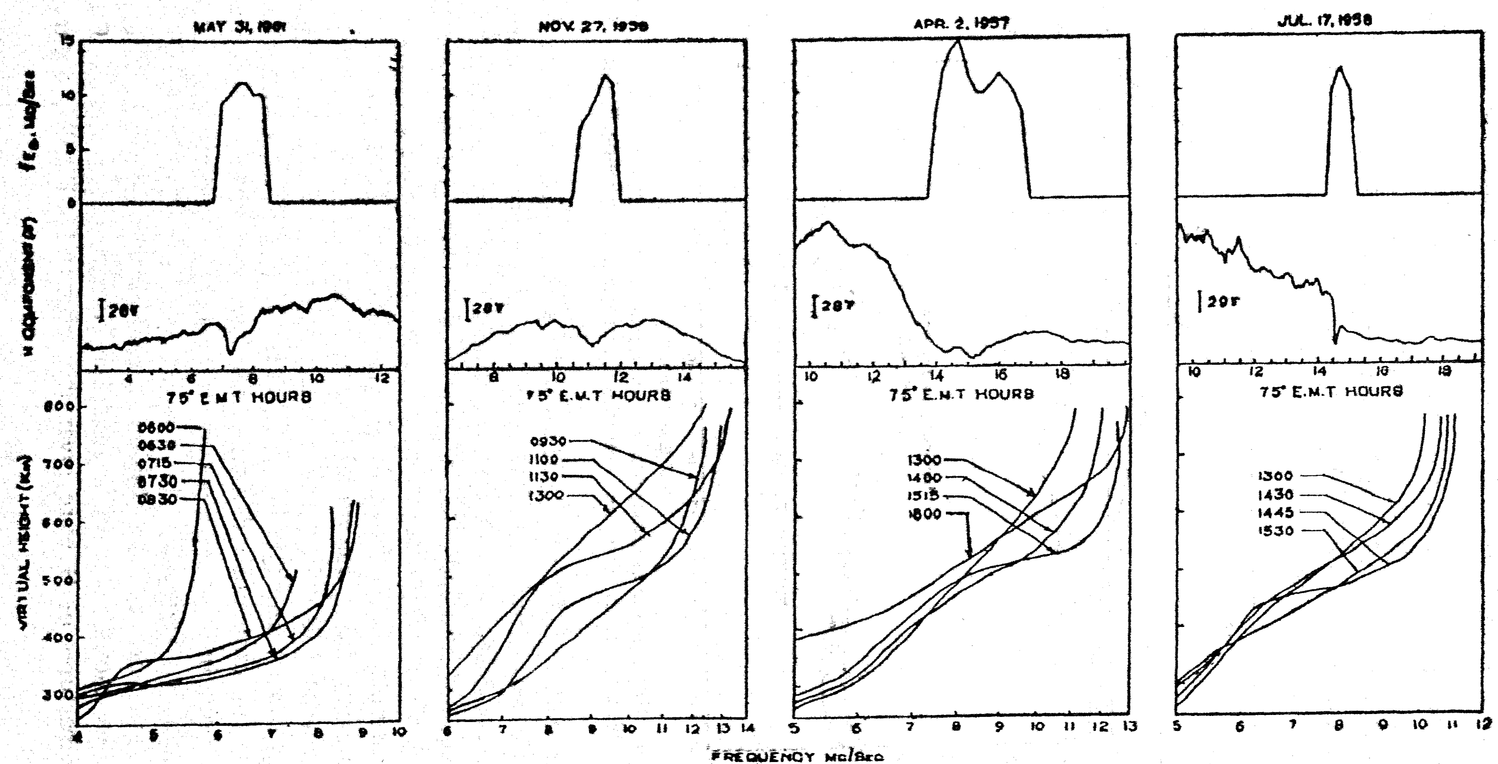

FIG. 6. Variations in foF2 and in geomagnetic H component during the appearance of blanketing E_s.

hours to midnight, averaged over seven days, when strong blanketing E_s was present, are plotted along with similar parameter averaged for an equal number of days when blanketing E_s did not appear. The days were randomly distributed during July 1957. A large positive departure during blanketing E_s events is obvious in the critical frequencies. The difference, Δ foF2,

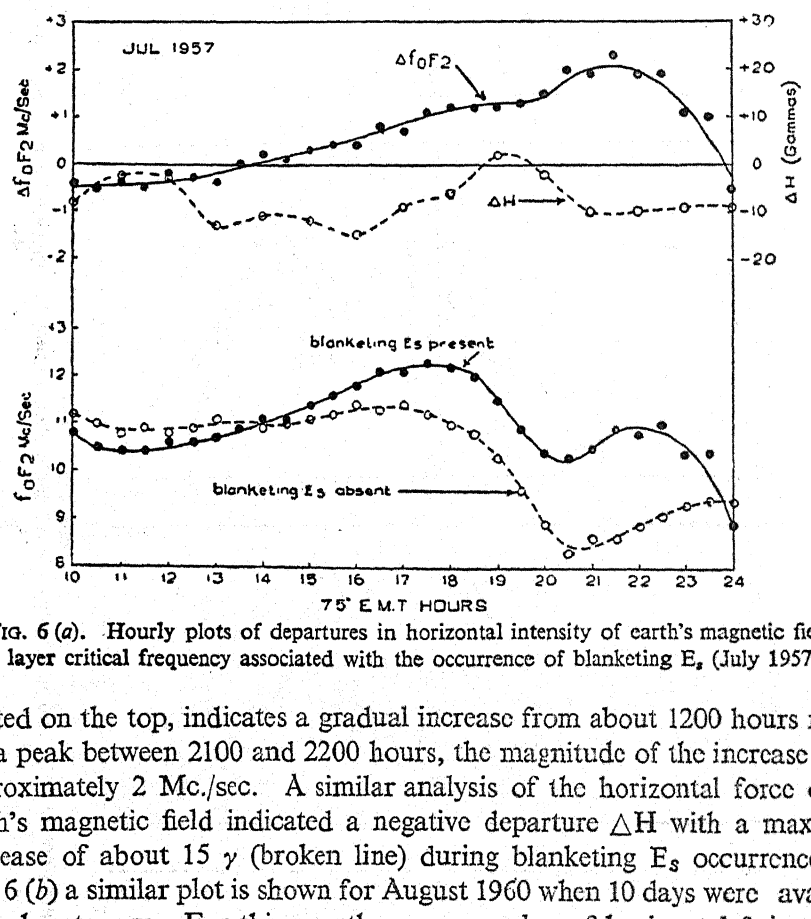

FIG. 6 (*a*). Hourly plots of departures in horizontal intensity of earth's magnetic field and in F2 layer critical frequency associated with the occurrence of blanketing E_s (July 1957).

plotted on the top, indicates a gradual increase from about 1200 hours reaching a peak between 2100 and 2200 hours, the magnitude of the increase being approximately 2 Mc./sec. A similar analysis of the horizontal force of the earth's magnetic field indicated a negative departure ΔH with a maximum decrease of about 15 γ (broken line) during blanketing E_s occurrence. In Fig. 6 (*b*) a similar plot is shown for August 1960 when 10 days were available in each category. For this month, average value of horizontal force of the earth's magnetic field indicates a gradual decrease in H, the departure being about 70 gammas. In Fig. 6 *c* for August 1958, five days when blanketing E_s was present were utilized along with five days when these echoes were absent. To obtain this plot, a superposed epoch method was used, reckoning the time when blanketing E_s echoes were first observed in 15-minute interval ionograms as 'zero' epoch. Similar variations were worked out for several other summer months. In all cases large positive departures in foF2 and negative departures in H were invariably observed. Finally, a superposed epoch analysis was carried out using 190 blanketing E_s events during a 6-year period (1956–61) when times of appearance and subsequent disappearance of the blanketing E_s echoes were distinct and were confined to daylight hours. From the observed foF2 and H values at half-hour intervals for a 6-hour

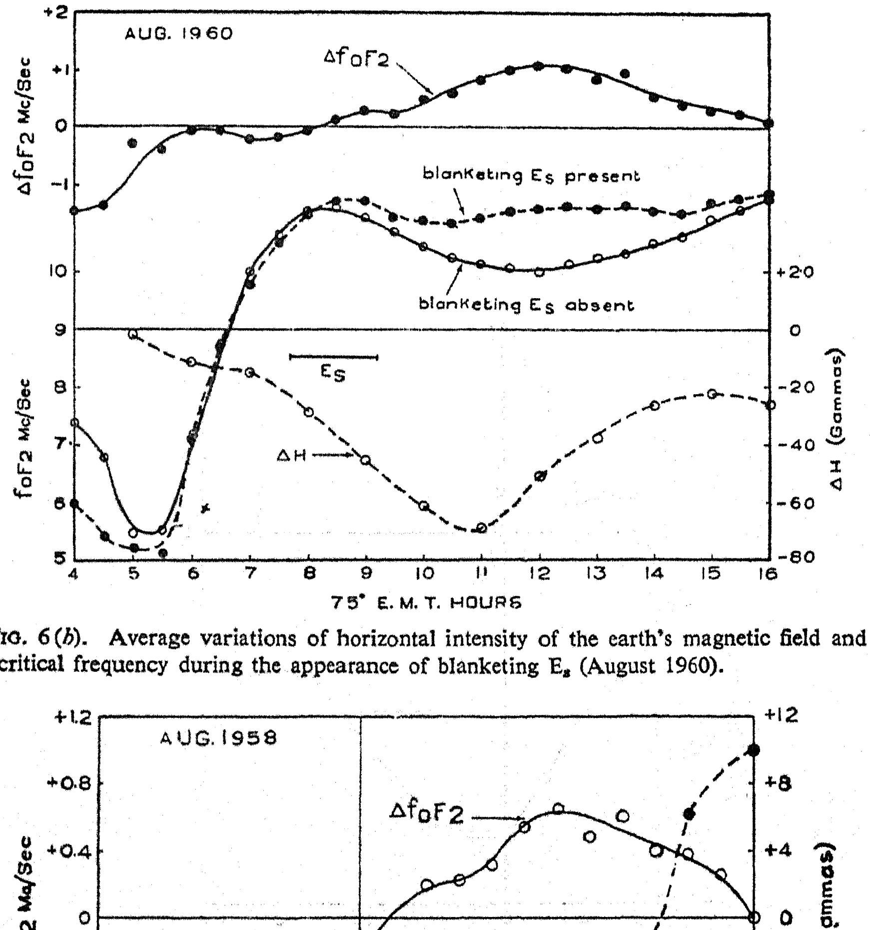

FIG. 6(*b*). Average variations of horizontal intensity of the earth's magnetic field and F2 layer critical frequency during the appearance of blanketing E_s (August 1960).

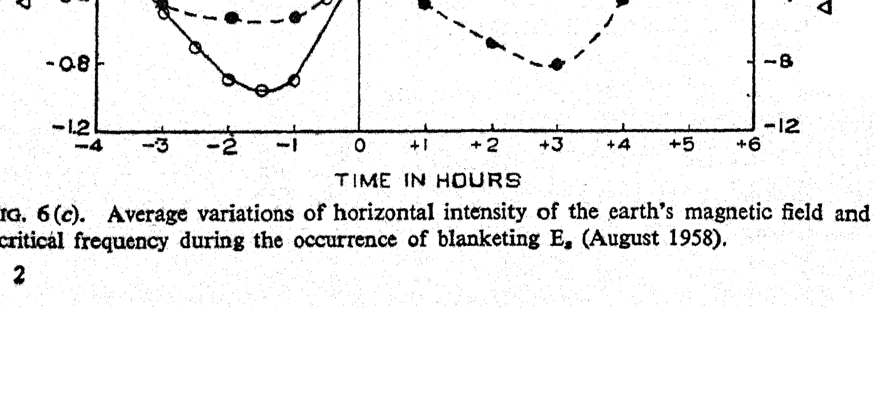

FIG. 6(*c*). Average variations of horizontal intensity of the earth's magnetic field and F2 layer critical frequency during the occurrence of blanketing E_s (August 1958).

period (2 hours prior to blanketing E_s appearance to 4 hours after its appearance) monthly mean values of the foF2 and H respectively were subtracted and the departures △foF2 and △H were grouped together. The average variations for the 190 events are plotted in Fig. 6 *d*. In general, the F2

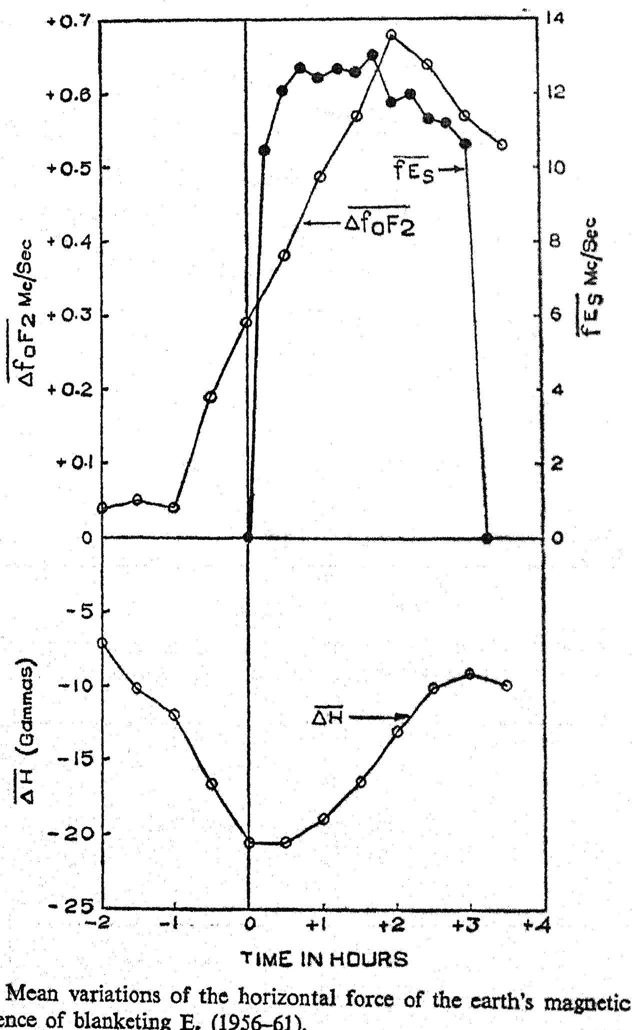

FIG. 6 (*d*). Mean variations of the horizontal force of the earth's magnetic field and foF2 during the incidence of blanketing E_s (1956–61).

layer increase begins, on an average, an hour before the appearance of blanketing E_s and the horizontal force begins to decrease more than two hours earlier to the appearance of the blanketing E_s echoes. Fig. 6 *d* also indicates that after the blanketing E_s echoes cease, foF2 and H do not return to normal until after an hour or more. The departures in foF2 as well as in H are much smaller than those for individual months (Figs. 6 *a*, *b* and *c*) because, for the overall variation, the departures were obtained from monthly means; for individual months the differences were obtained between figures for days when blanketing E_s was present and those for days when it did not appear. The magnitude of mean maximum increase in foF2 is of the order of 0·7 Mc./sec. (Fig. 6 *d*) while for individual months it is about 2 Mc./sec. in the late evening hours (Fig. 6 *a*) and about 1 Mc./sec. shortly after local noon (Fig. 6 *b*). Similarly, while the curve of Fig. 6 *d* yields a maximum decrease from monthly mean of about 20 γ in H on days when blanketing E_s was present, for individual months the maximum departures in H from days when the echoes were absent are as large as 70γ (Fig. 6 *b*). The magnitude of these variations is far in excess of the magnitude of normal day-to-day variations both in foF2 and in H.

The existence of large semi-diurnal lunar variations in foF2 and H at low latitudes are well known. The amplitude of semi-diurnal variation in foF2 at this station ranges from 0·06 Mc./sec. at 0800 hours to 0·3 Mc./sec. at 1600 hours local time. The amplitude of semi-diurnal variation in H is slightly over 3 γ; the phase of semi-diurnal lunar variation in the intensity of blanketing E_s, reported in Section 3, and the phases of semi-diurnal variation in foF2 and H at this station are such that an increase in the intensity of blanketing E_s would be expected at the lunar phase at which foF2 is maximum and H minimum. However, the magnitude of the observed variations both in foF2 and H, accompanying the blanketing E_s events, are far too large to be accounted for by the lunar tide.

6. Blanketing E_s as a Far East Anomaly

The occurrence of a Far East Anomaly in many geophysical parameters has been shown to exist by many authors in recent years. The magnetic field of the earth is strongest between longitudes 80° E. and 105° E. Longitudinal inequalities have been shown in the equatorial electrojet by Rastogi (1962) who found that the electrojet is strongest in the American zone and weakest in the Indian equatorial region. The width of the electrojet is also, perhaps, largest in the west and narrowest in the Far East (Bhargava, 1964). Similar anomalies have been reported in the S.C. amplitudes and in semi-diurnal lunar tide (Rastogi, 1963). In the occurrence of sporadic E, significant differences exist between the Far East and similar latitudes in the western hemisphere. From VHF oblique incidence measurements Smith and Finney (1960) found that sporadic E was three to five times more frequent in the Far East than in the Caribbean. Longitudinal effects also exist in the equatorial E_s ionization ($E_s - q$) (Kotadia, 1962) as well as in the temperate latitude E_s (Smith, 1957). Several F2 layer characteristics in the South Asia region differ from those in the American zone (Narasinga Rao, 1963). Lyon, Skinner and Wright (1960) have shown that the incidence of Spread F is much smaller and Spread F belt is narrower in the American zone than in the Asian zone.

The incidence of blanketing E_s around longitude of 77°·5 E. also appears to be a part of the Far East Anomaly. It has been noticed that blanketing frequency greater than 5 Mc./sec. was observed at Kodaikanal in 97 of the 7688 hourly ionograms during the 11-month period July 1957 through May 1958. This is much larger than the occurrence in similar magnetic latitude in the American zone, the corresponding figure for the similar period for Huancayo being only 3 (Knecht and Schlitt, 1961). From Fig. 5 of their analysis pertaining to the chain of 5 vertical sounding stations in the American zone it is noticed that in a location with magnetic dip equal to dip at Kodaikanal (3°·5 N.) the total number of hourly soundings with f_bE_s, >5 Mc./sec. could be expected to be approximately 40. It, therefore, appears that the occurrence of $f_bE_s > 5$ Mc. is larger in the Indian equatorial region by a factor of 2 or more.

7. ORIGIN OF EQUATORIAL BLANKETING E_s

It has been suggested that concentration of electrons for sharp gradients in electron density, sufficient to give rise to observed E_s in temperate latitudes, could be due to drift motions caused by horizontal wind shears acting on E region ionization in the presence of the earth's magnetic field. According to Hines (1960) the wind shears are caused by "internal atmospheric gravity waves" which have their origin in the large energy regions of the lower troposphere. Gossard (1962) has examined the problem of vertical flow of energy out of the lower troposphere and has found that a window can exist at periods of about 10 minutes to 2 hours through which large amounts of energy sometimes flow out of the troposphere.

Recently, Stacey and Westcott (1962) have suggested that equatorial stratospheric fluctuations extend to ionospheric heights. From a spectral analysis of mean monthly values of horizontal component of the earth's magnetic field for three stations, Huancayo in the American zone, Alibag in the Asian zone and Apia in the Far East, they found spectral peaks at a period of about 26 months at Alibag and Apia. London and Matsushita (1963) subsequently found only a 6-monthly periodicity in quiet-day horizontal force at Huancayo and observed that, to the extent ionospheric oscillations are related to the stratospheric wind fluctuations, one should find pronounced 26-month period at all low latitudes. However, 26-month period spectral peaks were not found at Huancayo. It will, therefore, appear that the extension of stratospheric fluctuations to ionospheric heights is pronounced only in the East and the Far East.

At Kodaikanal the daytime blanketing E_s as well as night E_s is purely a summer phenomenon similar to temperate latitude E_s. The solar cycle variation of blanketing E_s is complex. In addition, there is some evidence of variation of a period of about two years. This variation is observed not only in fE_s but also in the night E_s, blanketing frequency (f_bE_s) and in spread F. For instance, the total number of half-hourly ionograms in which f_bE_s was greater than 5 Mc./sec. during the months of June, July and August during daytime for the period 1957 through 1963, given in Table I, show increased occurrence during alternate years.

TABLE I

Year	1957	1958	1959	1960	1961	1962	1963
Number of ionograms with $f_bE_s >$ 5 Mc./sec.	64	51	77	66	72	49	69

Similar biennial periodicity appears to exist in Spread F occurrence also at this station. These features suggest that the occurrence of blanketing E_s is closely associated with stratospheric wind oscillations. The fact that E_s occurrence is strong in the Far East and is a local summer phenomenon supports the suggestion (Smith and Finney, 1960) that Indian and East Asian monsoon which is markedly strong in the Far East during and following summer intensifies sporadic E in some manner.

In the diurnal variation of blanketing E_s it is found that immediately preceding local noon when the jet and Sq current intensities are maximum, as manifested in H variation, occurrence of blanketing E_s is inhibited. It has been shown earlier that during the formation of this type of E_s, F region becomes lower, thinner and denser. The horizontal force of the earth's field undergoes a reduction at the same time and the equatorial sporadic E either weakens or disappears. These changes are in contrast to normal behaviour at Kodaikanal around local noon when the F region is thick due to vertical electrodynamic drift of ionization, the horizontal force is maximum and $E_s - q$ strength is also maximum. The longitudinal variation in the strength of the electrojet indicates that it is strongest in the American equatorial region and weakest in the Indian region. At the same time the occurrence of blanketing E_s is much more frequent in the Indian region in the vicinity of dip equator whereas its occurrence is considerably reduced in the American zone (Cohen and Bowles; Knecht and McDuffie, 1962). It is, therefore, concluded that almost all ionospheric and geomagnetic features which are observed under the influence of electrojet are suppressed during blanketing E_s events and that an electric current, probably directed westward, is introduced during its occurrence. The observed longitudinal anomaly in the incidence of this type of E_s in Asia and the Far East possibly arises from the peculiar land-water distribution on the earth's surface and from geomagnetic influence through irregular distribution of the earth's magnetic field. As suggested by Rawer (1962), peculiar meteorological factors in different parts of the earth also appear to influence the formation of sporadic E ionization through wind shears.

8. Acknowledgement

The authors wish to express their thanks to Dr. M. K. Vainu Bappu for his interest in this investigation.

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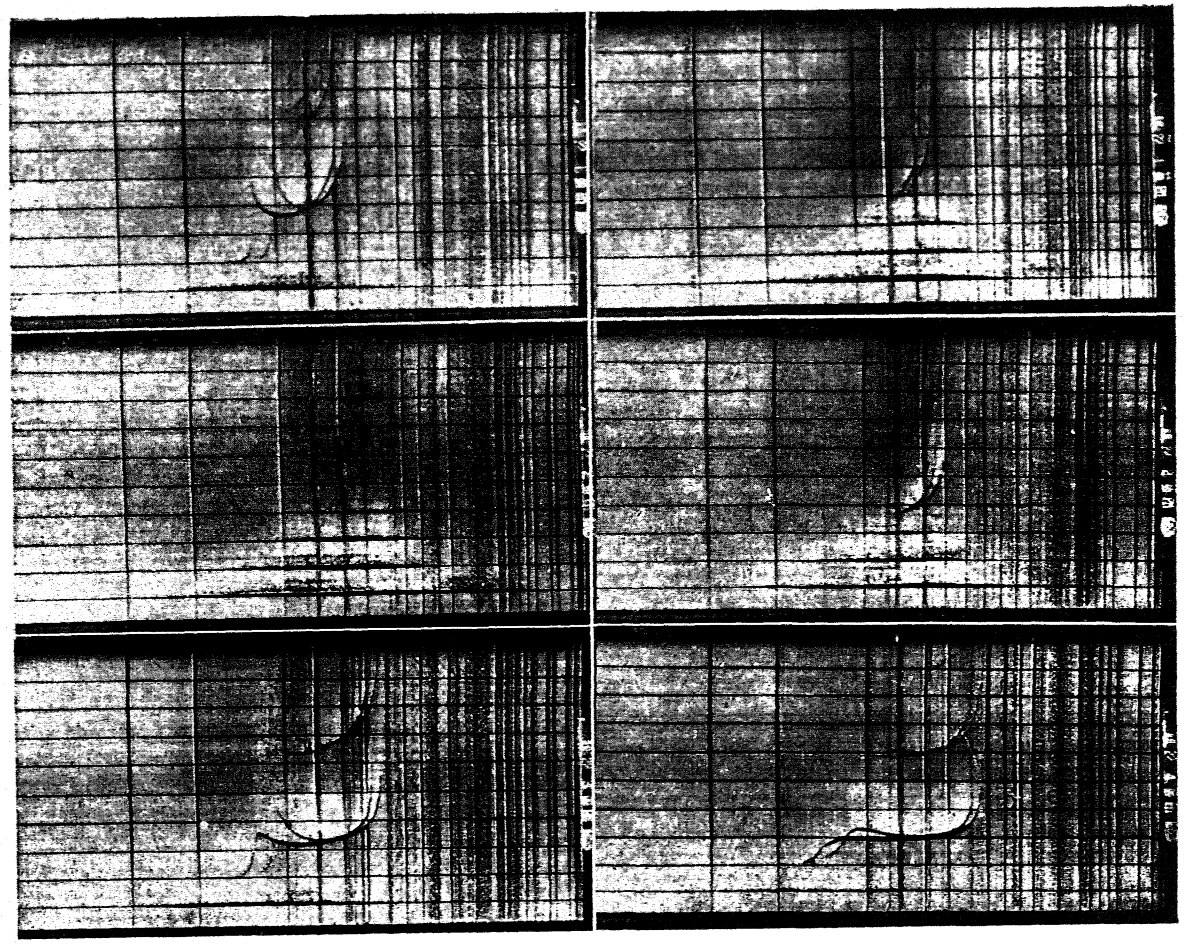

FIG. 1. A sequence of ionograms of July 22, 1963, illustrating the appearance, strengthening and subsequent disappearance of blanketing E_s.