A STUDY OF BLANKETING SPORADIC E IN THE INDIAN EQUATORIAL REGION

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(Kodaikanal Observatory, Kodaikanal)

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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, 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. Lunar effects have also been shown to exist both in the time of appearance of blanketing E, and in its strength. Some evidence exists to show that blanketing E, as well as the blanketing frequency, f, E, 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 - q) in low latitudes is well known. Since 1952 when Ionospheric Vertical Soundings began at Kodaikanal, this type of E 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 - 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 - q. The more important one of these types, generally termed as blanketing E, 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 \(E_z\), 15 minute interval ionograms obtained at Kodaikanal during a 6-year period, from 1956 through 1961, were scrutinized. The blanketing \(E_z\) 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 \(h\) 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 (Mc Nicol 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 (Mc Nicol and Gipps,
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 $E_2$ activity in 1959 than in 1958 (Duebo, 1962), similar to what has been observed at Kodaikanal; for the blanketing frequency, $f_bE_2$, however, there is no evidence of any association with the solar activity.

![Graph showing seasonal variation of daytime blanketing $E_2$.](image)

**Fig. 3.** Seasonal variation of daytime blanketing $E_2$.

### 3. Daytime Blanketing $E_2$ in Relation to Night-Time $E_2$

The blanketing as well as the seasonal and solar cycle characteristics of the daytime blanketing and night-time $E_2$ 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 nighttime \(E_s\) at this station arise from a common causative mechanism.

![Graph showing annual variations of daytime blanketing \(E_s\) and night \(E_s\).]

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 an 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. 5a and 5b, 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.
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. 6a, the critical frequencies of F2 layer from 1000
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, $\Delta$ foF2,

![Graph showing 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 $\Delta H$ with a maximum
decrease of about 15 $\gamma$ (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$_5$ events during a 6-year period (1956-61) when times of appearance and subsequent disappearance of the blanketing E$_5$ echoes were distinct and were confined to daylight hours. From the observed foF2 and H values at half-hour intervals for a 6-hour

![Graph](image)

**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$_5$ (August 1960).

![Graph](image)

**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$_5$ (August 1958).
period (2 hours prior to blanketing \( E_s \) appearance to 4 hours after its appearance) monthly mean values of the \( f_{oF2} \) and \( H \) respectively were subtracted and the departures \( \Delta f_{oF2} \) and \( \Delta H \) were grouped together. The average variations for the 190 events are plotted in Fig. 6d. In general, the \( F2 \)

![Graph showing variations in \( f_{oF2} \) and \( H \) 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. 6d also indicates that after the blanketing \( E_s \) echoes cease, \( f_{oF2} \) and \( H \) do not return to normal until after an hour or more. The departures in \( f_{oF2} \) 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 $\gamma$ 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 70$\gamma$ (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 $\gamma$; 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 equa-
torial $E_z$ ionization ($E_z - q$) (Kotedia, 1962) as well as in the temperate latitude $E_z$ (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 $E_z$ 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 Kodai-kanal 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 Schilt, 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 Kodai-kanal (3°.5 N) the total number of hourly soundings with $f_0E_z > 5$ Mc./sec. could be expected to be approximately 40. It, therefore, appears that the occurrence of $f_0E_z > 5$ Mc. is larger in the Indian equatorial region by a factor of 2 or more.

7. ORIGIN OF EQUATORIAL BLANKETING $E_z$

It has been suggested that concentration of electrons for sharp gradients in electron density, sufficient to give rise to observed $E_z$ 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 oscilla-
tions 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 $f_{E_s}$ 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**

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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 monsoons 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 $E_g$ 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 $E_g$ 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 $E_g$ 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

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9. References

Study of Blanketing Sporadic E in Indian Equatorial Region

Fig. 1. A sequence of ionograms of July 22, 1923, illustrating the appearance, strengthening and subsequent disappearance of blanketing Eₜ.