THE SPORADIC *E* LAYER AT KODAIKANAL

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ABSTRACT

An examination of the ionospheric records at Kodaikanal, which is located almost on the geomagnetic equator, reveals that the sporadic *E* layer here has some regular features not observed at other latitudes. It occurs in nearly 93 per cent of the half-hourly records during the daytime. Two main types of *Es* are observed; namely, (1) the patchy type with a well-marked diurnal variation, and (2) the blanketing type which occurs mostly during afternoons. It is found that neither meteoric activity nor thunderstorm activity has any appreciable influence on the formation of either of the two types of *Es*. No correlation is observed between *Es* and the geomagnetic field.

Introduction

Regular ionospheric observations with a multifrequency panoramic recorder were commenced early in 1952 at the Kodaikanal Observatory, which is located almost on the geomagnetic equator. The equipment used is the type C-3 automatic recorder, designed by the National Bureau of Standards, Washington, D.C. The frequency range of 1.0 to 25.0 Mc/sec is swept in an interval of 30 seconds, and records are obtained every half-hour from about sunrise to sunset. The ionospheric records here reveal that the occurrence of the "sporadic *E* layer" during the daytime is so regular that it may be regarded as a normal layer for this location. The characteristics of this *Es* layer are found to be such that neither meteoric activity nor thunderstorm activity can adequately account for its formation. There is also no correlation between *Es* activity and the geomagnetic field, and thus the problem is posed as to why the *Es* at this locality is so different from that observed at higher latitudes.

Frequency of occurrence

The most notable feature of the sporadic *E* layer at Kodaikanal is the high frequency of its occurrence during the daytime. In striking contrast with what has been observed at moderate and high latitudes, this layer is almost always present during the day. Among a total of 5,785 half-hourly records obtained during a year, covering the period $08^h\,00^m$ to $16^h\,00^m$ IST, *Es* occurred in no less than 5,372, or about 93 per cent of the total number. The percentage frequency of occasions when *Es* was observable during each of the 12 months of the year under study is shown in Table 1. The occurrence is relatively rarer during the winter months.

Table 1—*Percentage frequency of occurrence of Es in half-hourly records from* $08^h\ 00^m$ *to* $16^h\ 00^m$ *IST*

Month	Percentage frequency of occurrence
1952	
June	95
July	92
August	96
September	94
October	94
November	92
December	87
1953	
January	81
February	95
March	95
April	97
May	96

The two main types of Es

The sporadic *E* layer at Kodaikanal can be classified into two main types. The first one, more frequently and regularly observed than the other, is of the patchy type exhibiting well-spread echoes. The reflections are only partial and

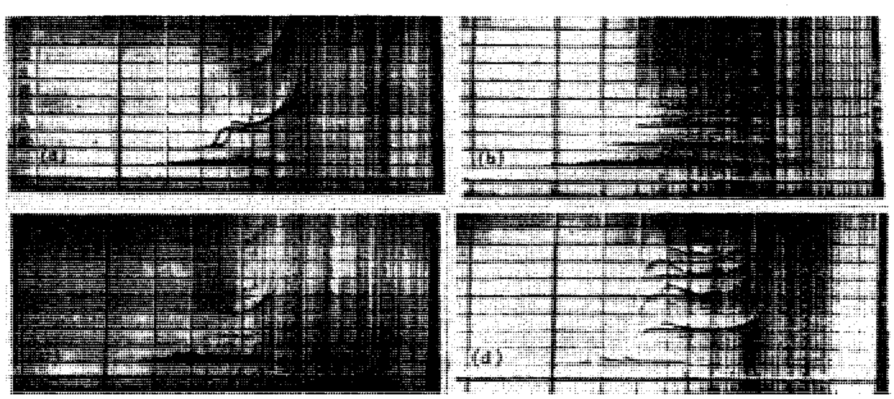

Plate I—Types of *Es* observed at Kodaikanal

hence the higher *F*1 and *F*2 regions are not occulted. This type of *Es* is shown in Plate I(*a*). The other type of *Es* is the blanketing type, illustrated in Plate I(*b*). It usually blankets the *F*1 layer, the critical frequency of which is in the range 4.0 to 4.6 Mc, but on other occasions blankets the *F*1 and *F*2 layers completely.

The first type of Es

A conspicuous feature of this type of *Es* is its diurnal variation. It forms about one to two hours after ground sunrise, and its critical frequency, *fEs* (the highest frequency for which reflections are observable), which is low in the morning, increases rapidly as the zenith angle of the sun decreases. The maximum *fEs* is reached by about noon, after which *fEs* decreases until evening, when this type of *Es* disappears. The layer forms in the morning *in situ* at the almost invariable height of 100 km, this height remaining unchanged during the day. It blankets the normal *E* layer for most of the time and, on some occasions, it is seen as a continuation of the normal *E* layer. Due to the regular occurrence of this *Es*, the normal *E* layer can seldom be perceived in the ionospheric records and consequently the characteristics of the normal *E* layer cannot be studied.

The plots of the hourly median values of *fEs* for daytime are shown in Figure

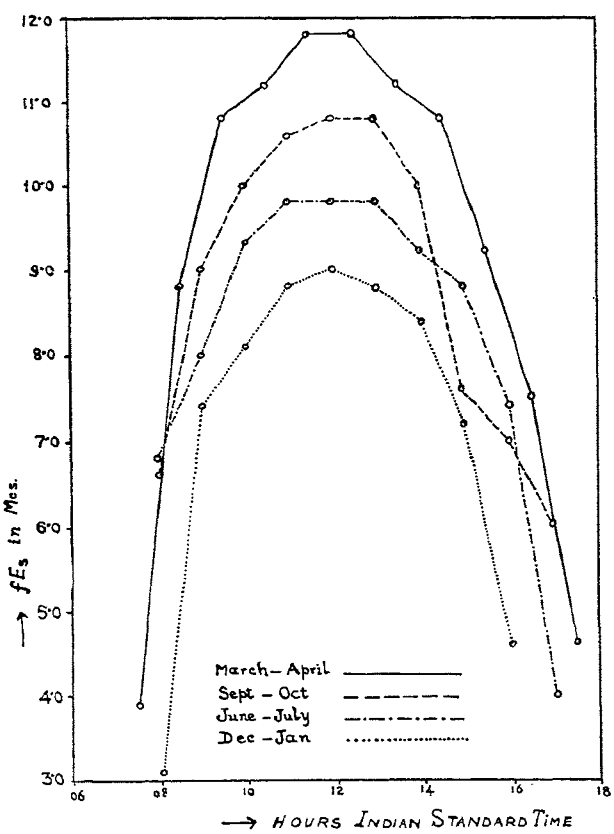

FIG. 1—Diurnal variation of *fEs* at Kodaikanal

1 for four periods of the year, representing the two equinoxes and the two solstices; namely, (*a*) March-April, (*b*) June-July, (*c*) September-October, and (*d*) December-January. All the four curves illustrate a well-marked diurnal variation of *fEs*. It is also seen that the midday ionisation of the *Es* layer as indicated by *fEs*

has an annual variation with a maximum near spring equinox and a minimum near the winter solstice. A secondary maximum occurs near the autumn equinox and a secondary minimum near the summer solstice. Figure 2 shows the variation of monthly median values of noon *fEs* during the year. These diurnal and seasonal

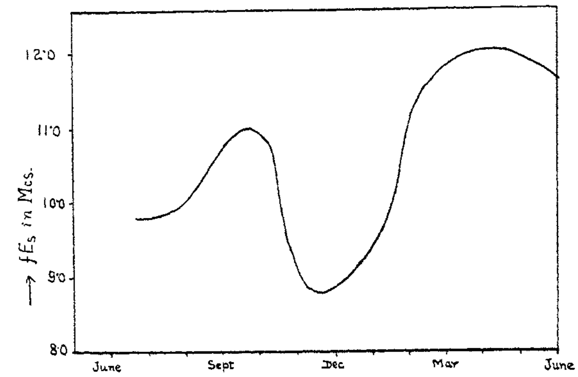

FIG. 2—Annual variation of noon *fEs*

variations of *fEs* apparently indicate some sort of solar control of the *Es* layer. This type of *Es* seems to resemble the constant-height type of *Es* observed at Brisbane by McNicol and Gipps [see 1 of "References" at end of paper].

The second type of Es

This blanketing type of *Es* occurs mostly during the afternoon hours. The duration of blanketing ranges from a few minutes to several hours. This type

TABLE 2—*Statistical data for blanketing type of Es*

Month (1)	No. days when blanketing type *Es* was observed (2)	No. half-hourly records (08^h-16^h) when blanketing was observed		No. occasions under col. 3 when there was complete blanketing
		08^h-$11^h.30$	12^h-16^h	
1952				
June	21	8	55	8
July	12	2	28	4
August	14	11	42	5
September	12	0	18	0
October	7	0	13	1
November	12	1	12	0
December	7	1	14	0
1953				
January	10	2	19	5
February	12	0	21	1
March	9	1	19	0
April	12	0	24	1
May	18	5	38	3

forms at a slightly greater height than the first type, and has a structure more continuous and better defined than the first. A notable feature is its high reflectivity, as shown by the occurrence of a number of multiple echoes. The penetration frequency varies widely from 6.0 Mc to 24.0 Mc, but the most frequent range is from 10.0 to 15.0 Mc. Table 2 gives some statistical data about this type of *Es* for the period of one year. Its occurrence seems to be truly sporadic in nature and its formation is due to some different cause. On some occasions, both the types of *Es* coexist, the blanketing one being higher, as shown in Plate I(*c*).

In addition to the two main types described above, there is a third type, which occurs rarely. This *Es* is sharply defined, with a complete absence of spread echoes, and is characterised by the presence of both ordinary and extraordinary components at the low-frequency end. Plate I(*d*) shows such a type of *Es* and is similar to Plate 7 of the atlas of ionospheric records published by the National Bureau of Standards, Washington, D.C. This unusual type of *Es* also blankets the *F*1 and *F*2 layers partially.

The origin of Es

The existence of more than one type of *Es* has been observed at other places also, and it would appear that more than one agency might be responsible for the formation of *Es*. Baral [2], in a recent study, has observed that meteoric impacts might be the main source of ionisation of the *Es* layer. The characteristics of the *Es* at Kodaikanal, however, do not lend much support to this view. In the first place, the diurnal variation of the first type of *Es* shows a pronounced midday maximum, whereas meteoric activity should be a maximum in the early hours of morning. During early morning, the occurrence of *Es* has been found to be very rare. Secondly, the blanketing type of *Es* occurs much more frequently during the latter half of the day than in the first. To study whether increased meteoric activity has any effect on *Es* ionisation, the ionospheric records during the periods of activity of the meteoric showers like the Leonids, Geminids, etc., during 1952-53, were examined. No perceptible change, either in the frequency of occurrence of *Es* or in the critical frequency of *Es*, was observed during those periods. During the periods of activity of Delta Aquarids, Perseids, Orionids, Leonids, and the Geminids of 1952, ionospheric records were available for the predawn period also (from $05^h\ 00^m$ IST) when meteoric activity may be expected to be even greater than during the daytime. These records also did not indicate any abnormal *Es* activity.

McNish [3] has found after simultaneous observations of meteor reflections obtained on both the ionosphere recorder and the meteor equipment that the meteor reflections are sharper and of much shorter duration than the typical sporadic *E* reflections seen in the ionospheric records. Also he did not find any correlation between the blanketing type of *Es* and meteoric activity. This experimental evidence supports the view that meteoric ionisation may only be short-lived. The correlation reported by other investigators [4] is probably between occurrence of this type of short-lived echoes and meteoric activity. At any rate, there appears to be no connection between either of the two types of *Es* observed at Kodaikanal and meteoric activity.

Es and thunderstorm activity

Following the hypothesis of C. T. R. Wilson that thunderstorms could cause an enhancement of the ionisation of the E region, Bhar and Syam [5] carried out an investigation to study this effect at Calcutta. Their results showed a statistical correlation between the frequency of occurrence of Es and the incidence of thunderstorms. However, Best, Farmer, and Ratcliffe [6], after a study of the effects of thunderstorm on the abnormal ionisation of the E region in southeast England, did not find any such correlation. Recently, Chatterjee [7] has found that the reflection coefficient of the sporadic E layer at Calcutta increases during a thunderstorm. The high frequency of occurrence of thunderstorms at Kodaikanal during the summer months was availed of by the author to study this effect. During the months of April and May 1953, thunderstorms occurred at Kodaikanal during the afternoon or early evening on 32 days. There was no appreciable change in the frequency of occurrence of Es on those days as compared with days without

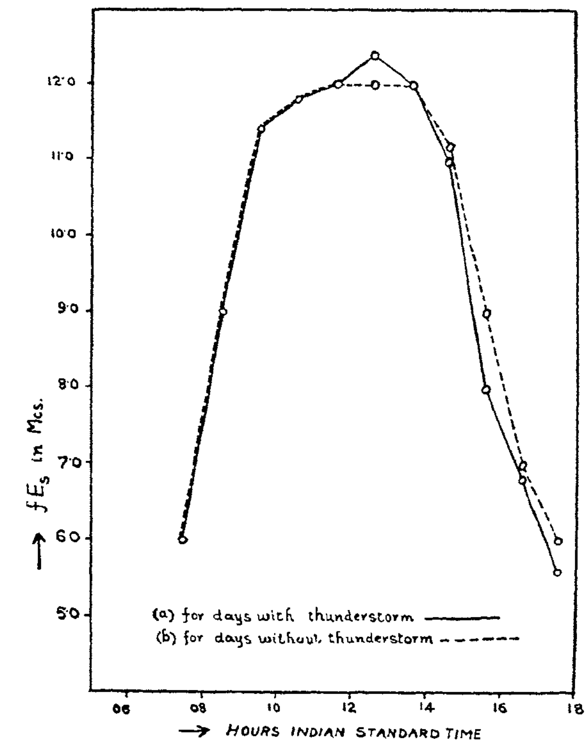

FIG. 3—Median hourly values of fEs

thunderstorm. The hourly median values of fEs (both the types of Es being taken into account) for thunderstorm days were plotted and compared with similar curves for days without thunderstorm. As shown by Figure 3, the two curves are almost similar. It is thus found that no perceptible increase of ionisation takes place on thunderstorm days. A similar result was obtained also for other months having fewer days of thunderstorm. Besides this statistical test, a few individual cases were found in which there was no *Es* layer at all in the ionospheric records when a well-developed thunderstorm was occurring at the station. Also, an examination of the occasions of intense blanketing type of *Es* did not reveal any correlation with thunderstorms. The conclusion, therefore, is drawn that, so far as Kodaikanal observations show, thunderstorms do not exert any appreciable influence on the ionisation of the *Es* layer.

Es and the geomagnetic field

The high frequency of occurrence of *Es* during the daytime at Kodaikanal and the diurnal variation of *fEs* appear to be very similar to those at Huancayo, which is also located on the geomagnetic equator. This similarity fits in with the suggestion of Baral [2] and Sadami Matsushita [8] that a narrow zone of intense *Es* might exist over the geomagnetic equator. Both these investigators have also suggested that this narrow zone of intense *Es* may have some relationship with the intense eastward current (electrojet) over the geomagnetic equator. However, if this current-system were to have a control over the formation of the *Es* layer, one ought to find some correlation between the occurrence of intense *Es* and the magnetic elements. Preliminary examination has revealed no such correlation at Kodaikanal. Accumulation of more comprehensive data on *Es* near the geomagnetic equator may help to throw further light on this question.

The origin of the *Es* region thus remains to be explained. Cosmic radiation is capable of producing ionisation in the *E* region. Hulbert [9] showed that the ionisation produced by cosmic radiation in the whole of the ionosphere is much less than that produced by solar ultraviolet radiation. Using recent values for the intensity of primary cosmic radiation and by assuming that the energy lost through absorption is entirely utilised in ionising the air molecules, a rough calculation was made to obtain the extent of ionisation. The effects of secondary radiation, which introduce complexities, have been ignored. It was found that the number of ion pairs formed at the 100-km level may be of the order of 10^4 per cc. This value of ion density is much smaller than that determined from observed values of critical frequencies of the *Es* layer; namely, 10^6 to 10^7 per cc. It would appear that cosmic radiation by itself may not be sufficient to account for the ionisation of the *Es* layer. However, the effect of cosmic radiation on the ionisation of the *E* layer seems to be worthy of further examination.

The marked diurnal variation and the seasonal variation of *fEs* at Kodaikanal suggest the possibility that solar radiation might be an important factor controlling the formation of *Es* of the first type. McNicol and Gipps [1], who found a correlation between one of the types of *Es* at Brisbane and the amount of solar radiation, have put forth a suggestion that this *Es* might be formed due to the ionisation of preexcited atoms by the radiations in the visible part of the solar spectrum. If this view is correct, the process of the formation of the *Es* layer by solar action should be a very complex one, requiring detailed investigation. Why the occurrence of daytime *Es* is so regular at Kodaikanal (and perhaps at places very near the geomagnetic equator) and not so at other places where the solar radiation may be equally effective, will have to be accounted for.

The height of the sporadic E layer of the first type at Kodaikanal is more or less constant at 100 km. Whenever the normal E layer is also present, the two layers are seen at this height as a fairly continuous trace, with no well-marked critical frequency for the E layer. This suggests the possibility that the sporadic E echoes of the first type at Kodaikanal might be due to a redistribution of ionisation within the E layer itself, by some unknown process.

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