CHAPTER IV

A STUDY OF THE NOON CRITICAL FREQUENCIES

OF THE E AND F1 LAYERS OF THE IONOSPHERE
A Study of the Noon Critical Frequencies of the E and F1 Layers of the Ionosphere.

The E and F1 layers of the ionosphere experience regular changes during the day, with season and with solar activity. The average daily and seasonal changes in the ionisation of these layers are in approximate accord with the simple relation of Chapman's theory of ionized layer formation (Kirby and Judson 1935; Gilliland 1935; Appleton 1937; Best, Farmer and Ratcliffe 1938; Hulburt 1939). Noon ionisation of these layers is found to rise and fall with sunspot number and the ionisation can be expressed by a simple linear relation (Hulburt 1940; Phillips 1947; National Bureau of Standards 1948). Examining the E and F1 layer data more critically, the E layer was found to be more regular than F1. The seasonal variation of F1 noon critical frequencies at many places did not follow the \( \cos^2 \theta \) law strictly. Lejay and Ardillon (1950) pointed that the seasonal variation of F1 was very different from that of E. Further, the influence of the solar cycle on \( f_0F1 \) was found to be greater at higher latitudes.

Regular ionospheric soundings were started at Ahmedabad in January 1953. The coordinates of the station are
The station is situated near the northern peak of F2 layer ionisation and hence the ionosphere at Ahmedabad has presented some interesting features. It was found that the F1 layer critical frequencies in the summer of 1953 had decreased below those in March-April 1953, and that another maximum of $f_0F1$ appeared in the months of September and October. The E layer critical frequencies, on the other hand, showed a single maximum in local summer and a minimum in local winter. The variation of $f_0E$ and $f_0F1$ at Ahmedabad during the last three years is shown in Fig. 1. The two maxima of $f_0F1$ in March-April and in September-October are most conspicuous in 1954, the year of least solar activity. This behaviour of $f_0F1$ is analogous to that of $f_0F2$ at Ahmedabad and at stations in middle latitudes.
The seasonal variation of noon $f_0E$ and $f_0F1$ at other stations at about the same latitudes as Ahmedabad viz. Mauii (20.8°N), Rarotonga (21.3°S) Yamagawa (31.2°N) and Puertorico (18.5°N) during the years 1952-1954 are shown in Fig. 2. At all the places $f_0E$ shows a single maximum in local summer and a minimum in local winter. The inverse relationship between the North and the South hemisphere is seen in the curves for the E layer. On the other hand $f_0F1$ shows minima in solsticles and maxima in equinoctial months. There is no inverse correlation between the stations of the Northern and Southern hemispheres.

Fig. 2.
With a view to examine whether the summer minimum in $f_0 F_1$ could be attributed to thermal expansion of the $F_1$ layer, the actual heights and semi-thicknesses of the layer were calculated from the $F$- records at Ahmedabad by Ratcliffe's method (1954). These are shown in Fig. 3. It is seen that the semi-thickness of the layer is maximum at noon the variation being nearly symmetrical at about noon. The heights of $h_0 F_1$ and of maximum electron density ($h_m F_1$) are lowest at about 11 hr. In Fig. 4 are shown the seasonal variations of the semi-thickness and of the total electron content in a vertical column up to the level of
maximum electron density of the F1 layer \( n_{F1} \). Both the electron content and the thickness varied in a similar way to \( f_{0}F1 \). The behaviour of the ionisation of the E and F1 layers at various other ionospheric stations are given below. Only the noon critical frequency of E and F1 layers were studied.

First the variations of \( f_{0}E \) and of \( f_{0}F1 \) with solar activity were examined. The noon critical frequencies of E and F1 can be expressed by a relation of the form

\[
f_{0} = a (1 + bR_{Z})
\]

where \( a \) and \( b \) are constants depending on the layer, the position of the station, season and hour of the day and \( R_{Z} \) is the Zurich sunspot number. Figs. 5, 6, 7 and 8 show mass plots of monthly mean noon critical frequencies of E and F1 against the corresponding sunspot number \( f_{0} \) for the stations, Slough, Canberra, Huancayo and Rarotonga respectively. It will be
seen that $f_0E$ and $f_0F_1$ vary with $R_2$ approximately linearly. From Fig. 5 it is clear that the slope of the straight line for $F_1$ at Slough is a minimum in the winter months of November, December, January and February and a maximum in the summer months of May, June, July and August. The slope of $E$ layer critical frequency does not show any such seasonal variation. In the case of Canberra, (Fig. 6) the slope of the line is maximum in November, December, January and February (Southern Summer), and the minimum in May, June, July and August (Southern winter). At Huancayo, the slope of line for $F_1$ remains practically constant, whereas that of the $E$ layer seems to be a maximum in local summer and a minimum in local winter. An interesting fact observed about Rarotonga is that the slope of the straight line for $f_0F_1$ in any month is greater than that for any other stations studied.

In Fig. 9 are plotted the seasonal variations of $b(E)$ and $b(F_1)$ for a few typical stations. $b(E)$ at any place seems to be practically constant throughout the year except at Huancayo and Trinidad. $b(F_1)$ on other hand has a systematic seasonal variation. There does not seem any correspondence between the seasonal variation of $b(F_1)$ and the cosine of the solar zenith distance ($\cos \chi$), but $b(F_1)$ is maximum during local summer and minimum during local winter at any station. $b(F_1)$ at Huancayo is practically constant throughout the year. It may be remembered that the sunspot cycle variation of $f_0F_2$ is different in summer and
winter (Characteristics of the Ionosphere in England), being less in summer than in winter which is just opposite to the effect on $f_0 F_1$. A similar effect on $f_0 F_2$ at Washington has been found by Benington (1953). He pointed out that the sunspot cycle effect was less in the months of minimum $f_0 F_2$ than in the months of maximum $f_0 F_2$ and called this a saturation effect in $f_0 F_2$ during period of minimum $f_0 F_2$.

In Fig. 10 are plotted the annual mean values of $b(E)$ and $b(F1)$ against geographical latitude. $b(E)$ is practically constant or decreases slightly at high latitudes. $b(F1)$ varies appreciably with latitude with two sharp maxima at 20-30° latitudes and a minimum at the equator. This means...
that the effect of sunspot activity on $f_0F1$ is maximum at middle latitudes. The two peaks in Fig. 10 occur at Rarotonga (21°S) in the South and at Okinawa (26°N) in the North.

Referring again to Figs. 5 to 8, the intercepts of the lines on $R_2 = 0$ i.e. the value of the constant $a$, gives
the critical frequencies of the layer for zero sunspot number. It was found that the values of \( a(E) \) and \( a(F1) \) were nearly the same as the monthly mean noon values of \( f_0E \) and \( f_0F1 \) (11-13 hours L.M.T.) during the sunspot minimum year 1954. In Fig.11 are shown the seasonal variations of \( a(E) \) and \( a(F1) \) for a few stations.

Fig. 11.
To give an idea of the latitudinal variation of these factors near the equatorial zone the noon critical frequencies of some additional equatorial stations have been included though these do not have long period observations. These stations are marked with asterisks. For comparison, the seasonal variation of $\cos \chi$ is also shown in the figure. It will be seen that $a(E)$ at any station follows faithfully the corresponding $\cos \chi$ curve, but that $a(F1)$ behaves differently.

At high latitudes $a(F1)$ follows the $\cos \chi$ variation, but at the middle altitudes $a(F1)$ has two pronounced maxima during the year, whereas $\cos \chi$ shows only one flat hump. At equatorial stations where $\cos \chi$ shows the maximum twice in a year, the maxima of $a(F1)$ do not correspond to those of $\cos \chi$. The maxima in $a(F1)$ appear in the equinoctial months irrespective of the geographic position of the station. This shows that besides the usual $\cos \chi$ effect on the ionisation of $F1$, there exists another perturbing influence causing maxima in the equinoctial months.

In Fig. 12 the annual mean values of $a(E)$ and $a(F1)$ are plotted against latitude. Both show maxima at the equator and decrease with increasing latitudes.

In order to ascertain whether $a(F1)$ shows a maximum at the equator in all the months of the year, the mean values of $a(F1)$ for March, April, September and October are plotted in Fig. 13.
It is seen that $a(F_1)$ shows a single maximum at the equator even in the equinoxes, when seasonal maxima of $a(F_1)$ are observed at stations in low and middle latitudes. It is concluded therefore, that $a(F_1)$, i.e. $F_1$ layer critical
frequency for zero sunspot period, is maximum at the equator in all the months of the year. This does not agree with the conclusions of Miss Ghosh (1955) that F1 experiences a geomagnetic control analogous to that of the F2 layer both in high sunspot and low sunspot years. It may be noted that she had taken 1951 as a representative of the low sunspot year. Sato (1955) did not find any trough in the latitudinal distribution of noon critical frequencies of F1 layer during 1953, a period of less solar activity than 1951. The appearance of pronounced maxima of b(F1) at middle latitudes and single maximum of a(F1) at the equator suggests that as the sunspot activity increases, there is proportionately a greater increase of f0F1 in middle latitudes. It must be remembered that f0F2 showed maxima at middle latitudes during the low sunspot year of 1954. So F1 differs from F2 in its latitudinal distribution in minimum sunspot years.

According to Chapman’s simple theory of layer formation the seasonal variation of noon critical frequencies of a layer should follow the \( \cos^4 \chi \) law. However, the exponent of \( \cos \chi \) has been found to be variable both in E and F1. The constant \( K \) of the equation \( f_0 = K \cos^N \chi \) can be obtained by plotting the monthly mean noon critical frequencies (more exactly \( a(E) \) of \( a(F1) \)) against the corresponding \( \cos \chi \) on double logarithmic graph paper. Such an evaluation of \( N(E) \) and \( N(F1) \) was made either from the values of \( a \), or of noon critical frequencies where the former was
not available. Fig. 14 shows the variation of $N$ with latitude for the E layer. It is seen that there are minima of $N(E)$ at latitudes of about 35°. There appear to be similar minima in $N(F1)$ also, though the scatter is much greater in this case. (Fig.15). $N(F1)$ for equatorial stations could not be evaluated as the maximum value of $f_0F1$ does not occur at noon when $\cos X$ is a maximum.
Recently, Beynon and Brown (1956) have reported two maxima in the exponent \( n \) \( [(fE)^n = K \cos \lambda] \) of the seasonal variation of E layer noon critical frequencies. These correspond to the two minima of the exponent \( N \) in our analysis. Beynon explained these maxima in terms of vertical drifts in the E layer due to the \( S_q \) current system flowing in the ionosphere. Curiously, however, in the case F1 layer, the minima of the exponent \( N \) derived from the seasonal variation and the maxima of the factor \( b \) derived from solar cycle variation do not occur at the same latitude; the latter appears about ten degrees nearer to the equator. The peaks of \( b(F1) \) at about twenty-five degrees and the minima of \( N(F1) \) at about thirty-five degrees may be due to the shift of the \( S_q \) current focus by ten degrees towards the equator in high sunspot years.

**Summary**

1. **Solar cycle variation**:

   (i) The noon critical frequencies of E and F1 layers vary with Zurich sunspot numbers approximately according to the law \( f_0 = a(1 + bR_z) \).

   (ii) The factor \( b \) for the E layer of a station is the same for the different months of the year.

   (iii) The factor \( b \) for the F1 layer of a station is maximum in local summer and minimum in local winter.
(iv) The factor $b(E)$ is almost same for any latitude.

(v) The factor $b(F_1)$ is maximum in middle latitudes (20-30°) with a depression at equator.

(vi) The factor $a(E)$ follows the solar zenith distance at the place, for any latitude.

(vii) The factor $a(F_1)$ follows the solar cos variation only at high latitudes. It has two maxima in the equinoctial months for stations in middle and equatorial latitudes.

(viii) The annual mean values of the factors $a(E)$ or $a(F_1)$ show maxima at the equator.

2. Seasonal Variation

The seasonal variation of $a(E)$ and $a(F_1)$ can be put in the form

$$f_0 = K \cos^N \chi$$

and the exponents $N$ for the $E$ and $F_1$ layers show minima in middle latitudes (30-40°).

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