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ABSTRACT

The pre-sunrise phenomenon of a rapid drop in the maximum ionic density of F-layer followed by an increase in the semi-thickness and height of the layer and stratification is described. The phenomenon, which is found to occur prominently during periods of low or moderate solar activity and during winter months, is discussed in relation to the distortion of the overhead Sq. current system and vertical drift of ionization.

1. INTRODUCTION

VERTICAL soundings of the ionosphere using a N.B.S. type C-3 Ionosonde were started at Kodaikanal (Latitude 10° 14′ N., Longitude 77° 28′ E.) early in 1952. The early morning phenomenon of F-layer stratification was observed soon after and was reported, on the basis of preliminary observations, by one of the present authors (1952). Similar observations have been made by Bandyopadhyaya (1959) at Haringhata near Calcutta and have been discussed for possible bearing on the E-layer cusps observed there. Round-the-clock observations at Kodaikanal were commenced in September 1955 and intensive observations were made during the 3-hour period preceding sunrise in order to determine the nature of the stratification which was frequently observed during periods of low solar activity and during winter.

2. EFFECT OF VERTICAL DRIFT ON ELECTRON DENSITY

The basic continuity equation of electron density N in a simple solar-controlled region is

$$\frac{\partial N}{\partial t} = q(t) - \alpha N^{p} - \text{div.}\ (Nv) \qquad (1)$$

where $q(t)$ represents the ion production term and αN^p is the electron dissipation rate, p being the exponent to indicate whether the dissipation process is one of recombination ($p = 2$) or of attachment ($p = 1$). The term div. (Nv) represents the electron transport rate.

If we restrict our attention to the peak of the layer, Equation (1) reduces to

$$\frac{\partial N}{\partial t} = q(t) - \alpha N^p - N_m \frac{\partial v}{\partial z}. \tag{2}$$

Martyn (1947 *a*, *b*, 1948) had indicated that vertical movements may cause important perturbations in an ionized region. Appleton and Lyon (1955) have discussed the effects of vertical drift in distorting the electron density profile of a Chapman-like region. They have shown that the fractional change in the level of maximum electron density $\delta h\,(N_m)$ and in its magnitude δN_m due to vertical drift are given by

$$\left.\begin{aligned} \delta h\,(N_m) &= \frac{v}{2\alpha N_m} && \text{(recombination)} \\ \delta h\,(N_m) &= \frac{v}{\beta} && \text{(attachment)} \end{aligned}\right\} \tag{3}$$

$$\left.\begin{aligned} \frac{\delta N_m}{N_m} &= -\frac{1}{2\alpha N_m} \cdot \frac{\partial v}{\partial h} - \frac{1}{4H^2}\left(\frac{v}{2\alpha N_m}\right)^2 && \text{(recombination)} \\ \frac{\delta N_m}{N_m} &= -\frac{1}{\beta} \cdot \frac{\partial v}{\partial h} - \frac{1}{2H^2}\left(\frac{v}{\beta}\right)^2 && \text{(attachment)} \end{aligned}\right\} \tag{4}$$

where α and β are recombination and attachment coefficients respectively, v is the vertical drift velocity reckoned positive upwards, $(\partial v/\partial h)$ is its vertical gradient and H is the scale height of the ionized constituent. Equations (3) and (4) indicate that the influence of vertical drift on N_m and its height is determined by drift characteristics and by the quantity $(1/2\alpha N)$ or $(1/\beta)$.

3. CHANGES IN F-LAYER BEFORE SUNRISE

As stated previously, the early morning hours of winter months, particularly during periods of low solar activity, are characterised by rapid changes of maximum ionic density, height and layer shape. A typical sequence of ionograms observed between 0430 and 0630 hours on the morning of January 4, 1960, is given in Fig. 1 (Plate VII). The layer is normal till about 0430 hours. Shortly afterwards, the ionic density begins to drop and the virtual height registers an increase. Around 0600 hours the critical frequency of

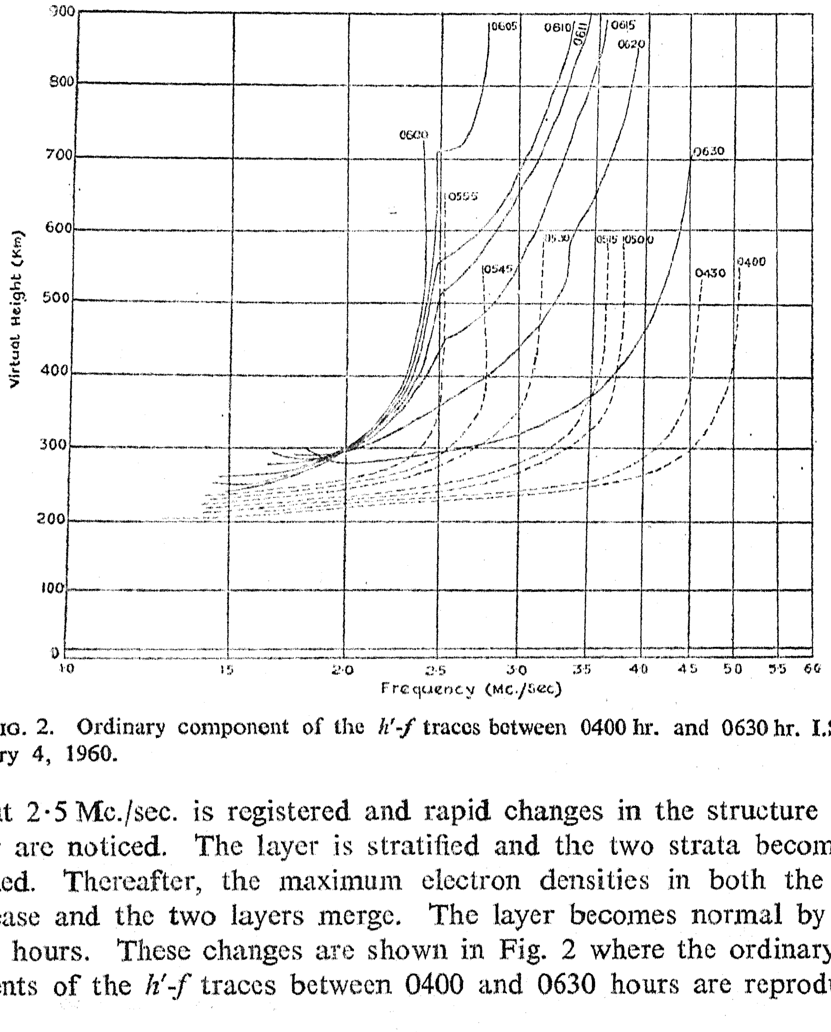

FIG. 2. Ordinary component of the *h'-f* traces between 0400 hr. and 0630 hr. I.S.T. on January 4, 1960.

about 2·5 Mc./sec. is registered and rapid changes in the structure of the layer are noticed. The layer is stratified and the two strata become well defined. Thereafter, the maximum electron densities in both the layers increase and the two layers merge. The layer becomes normal by about 0630 hours. These changes are shown in Fig. 2 where the ordinary components of the *h'-f* traces between 0400 and 0630 hours are reproduced.

4. THE DISTRIBUTION OF ELECTRON DENSITY AS A FUNCTION OF TRUE HEIGHT

In order to examine the variations of electron densities at several levels, the *h'-f* records during the interval 0330 hours to 0630 hours for two typical days, January 12, 1956 and January 4, 1960, were reduced to $(N, h)_t$ profiles using Tables of Coefficients given by Schmerling and Ventrice (1959). The profiles for January 12, 1956 and January 4, 1960, are given in Fig. 3 *a* and Fig. 3 *b* respectively. From the $(N, h)_t$ profiles for one of these days, *viz.*, January 4, 1960, the height variations of constant ionization levels were deduced and the resulting curves are presented in Fig. 4. It will be seen

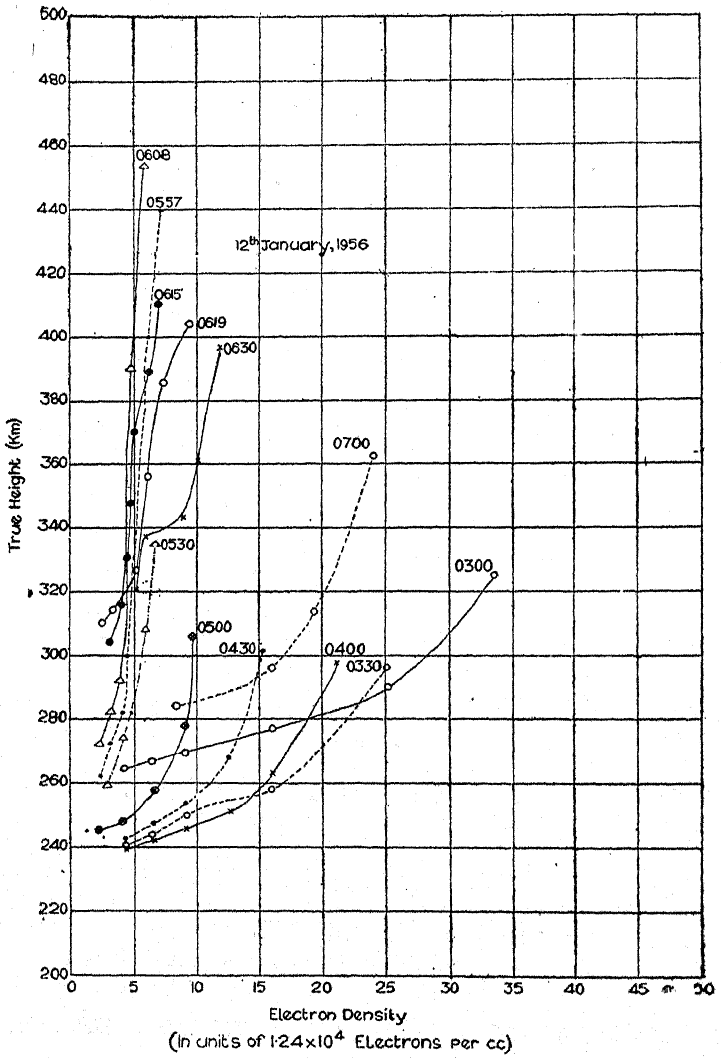

FIG. 3 (*a*). (N, h)$_t$ profiles between 0300 hr. and 0700 hr. I.S.T., deduced from h'-f records of January 12, 1956.

from the curves of Fig. 3 *a* and Fig. 3 *b* that considerable variations in height and thickness occur near the layer peak from 0430 hours and these variations are maximum around 0600 hours. Fig. 4 shows some interesting features. Perturbations in the heights at different ionization levels take place. At 0600 hours when the layer gets stratified, the variations in height appear to be maximum. It is also noticed that the layer appears to rise as a whole with a velocity of about 100 km./hr. Simultaneously, the critical

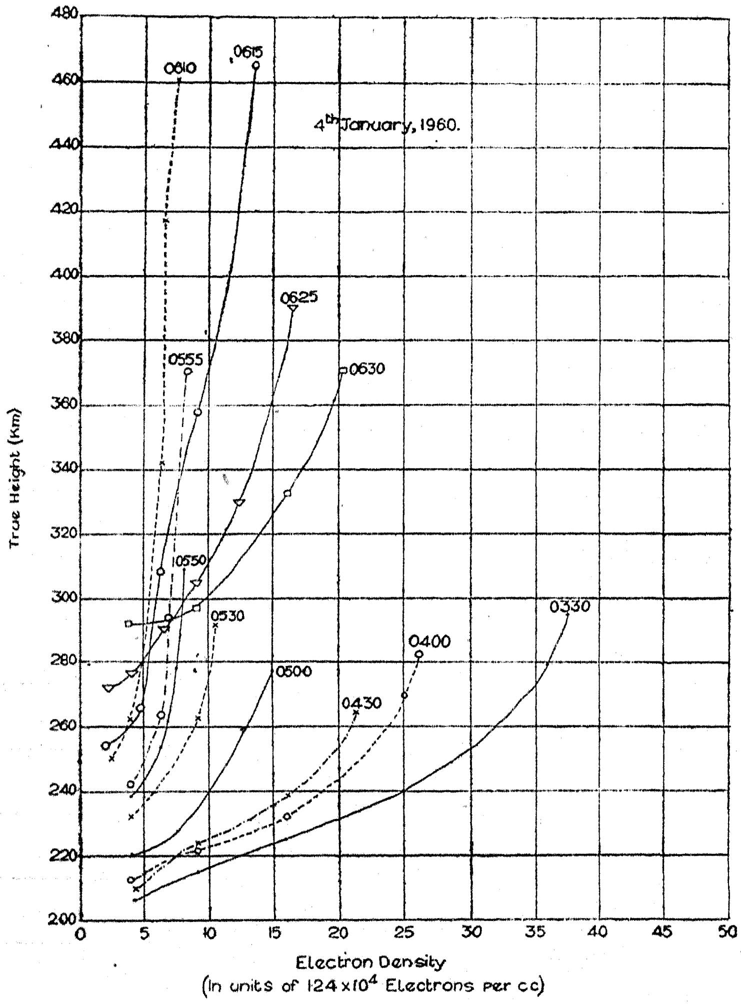

FIG. 3 (*b*). (N, h)$_t$ profiles between 0330 hr. and 0630 hr. I.S.T., deduced from h'-f records of January 4, 1960.

frequency drops to a low value of about 2·5 Mc./sec. at the time of stratification.

5. DISCUSSION

(i) *Changes in the layer shape due to vertical movements.*—As mentioned earlier, the effect of vertical drift velocity is to perturb the ionized layer, the electron density changes being represented by the continuity equation (1). It will be further seen from the Appleton and Lyon equation (4) that irrespective of its sign, the effect of drift velocity v will be to spread out the ionization. The rise or fall in height of peak ionic density will depend upon the

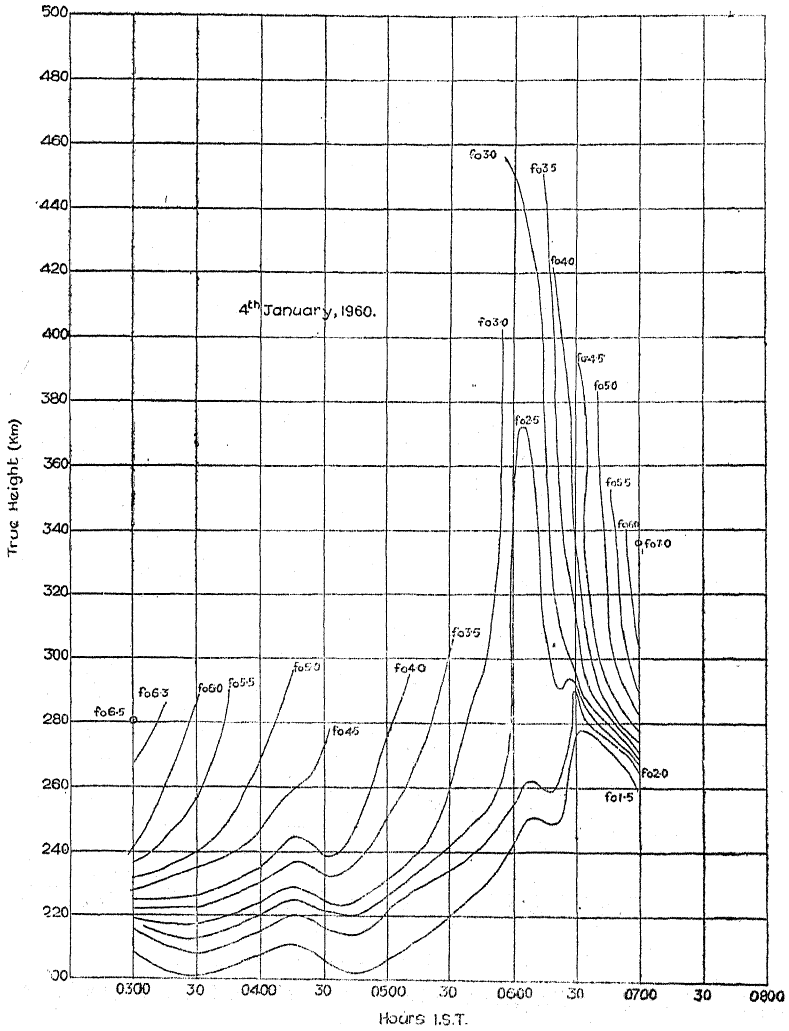

FIG. 4. Height variations of constant ionization levels of January 4, 1960, during pre-sunrise F-region "splitting".

sign of v, equation (3). The magnitude and sign of the gradient of drift velocity will determine the overall effect of distortion on peak ionic density.

Using the electron density-height profiles the time variation of the heights of peak ionic density was obtained. It was found that the peak rises rapidly from 270 km. at about 0430 hours to over 450 km. at 0600 hours.

According to Martyn (1955), the effect of height gradient of electron loss ($\partial\alpha/\partial z$) is to move the level of Z_m upwards. It can be seen from the constant ionization levels (Fig. 4) that just before sunrise, the level of Z_m is very much lifted up, indicating thereby, that the magnitude of $(\partial\alpha/\partial z)$ is very much increased.

Following Martyn, we shall write

$$\alpha = \alpha_0 e^{-z/a} \tag{5}$$

Differentiating the above, we get

$$\frac{\partial\alpha}{\partial z} = -\frac{\alpha}{a}. \tag{6}$$

If the magnitude of $(\partial\alpha/\partial z)$ is large, the value of "a" should be small. This can be examined in a different way. Following Marasigan (1958), we may write that at the point of inflexion

$$\frac{\partial}{\partial z}(\alpha N^p) = 0. \tag{7}$$

Differentiating (7) we get

$$\frac{\partial\alpha}{\partial z} = -\frac{\alpha}{N^p}\cdot\frac{\partial}{\partial z}(N^p). \tag{8}$$

From (6) and (8) we get

$$a = \frac{N}{p\left(\frac{\partial N}{\partial z}\right)}$$

$$= \frac{N}{\left(\frac{\partial N}{\partial z}\right)} \quad (p = 1, \text{ attachment process}).$$

It is an observed fact that just before sunrise the magnitude of N is very much reduced while $(\partial N/\partial z)$ is much increased, thereby indicating a small value for "a" just before splitting. It appears, therefore, that the large upward shift in the level of maximum ionization is followed by splitting of the layer due to large value of height gradient of loss coefficient $(\partial\alpha/\partial z)$.

(ii) *Magnitudes of vertical drift velocity v and its gradient* $(\partial v/\partial z)$.—Using the relation $\delta h(N_m) = (v/\beta)$ where β is the attachment coefficient, values of v were computed at 10 minutes intervals on January 4, 1960. Substituting these values of v in the continuity equation, the magnitude and sign of $(\partial v/\partial z)$ at the height of maximum ionization at the same intervals were also computed. These values are given in Tables I *a* and I *b*.

TABLE I (*a*)

Time I.S.T.	Magnitude of drift velocity gradient $(\partial v/\partial z)$ on January 4, 1960, in sec.$^{-1}$ at 10-minute interval
	$10^{-5}\times$
0400	−14·9
10	−13·5
20	−11·5
30	−13·1
40	−19·4
50	−18·4
0500	−16·8
10	−15·2
20	−13·5
30	−11·7
40	− 9·5
50	− 6·1
0600	− 2·9

It will be seen that starting from about 0440 hours v was positive and its magnitude increased rapidly. At the same time $(\partial v/\partial z)$ approached zero, starting from a negative value, thereby indicating that the second term of the right side of the equation

$$\frac{\delta N_m}{N_m} = -\frac{1}{\beta}\cdot\frac{\partial v}{\partial z} - \frac{1}{2H^2}\left(\frac{v}{\beta}\right)^2$$

was predominant in determining the electron density changes at the peak.

(iii) *Distortion of the Sq. current system and the associated movements.*—Martyn and others (1952) have indicated that the morphology of the F-region may be profoundly affected by the events in the E-region because

TABLE I (*b*)

Time I.S.T.	Magnitude of drift velocity v in units of 10^3 m. sec.$^{-1}$ on January 4, 1960, at 10-minute interval
0400	$-1 \cdot 95$
10	$-1 \cdot 45$
20	$-0 \cdot 80$
30	$+0 \cdot 60$
40	$+0 \cdot 95$
50	$+1 \cdot 27$
0500	$+1 \cdot 42$
10	$+1 \cdot 50$
20	$+1 \cdot 66$
30	$+2 \cdot 00$
40	$+2 \cdot 60$
50	$+4 \cdot 40$
0600	$+3 \cdot 52$

the electric fields would be communicated to F-region along the lines of magnetic force. This is supported by the experiments of Maple, Bowen and Singer (1952) and more recently by those of Van Allen and Cahill (1958) which indicate that the E-region is the seat of strong electric currents and that these currents are responsible for the diurnal quiet-day Sq. variations of the magnetic elements. Any change in the horizontal intensity at low latitude stations, therefore, indicates a distortion of the Sq. current intensity, the magnetic field being related to the electric field by

$$\Delta H = 2\Pi I = 2\Pi K \Delta E. \tag{9}$$

Further, the magnitude of the drift velocity v is determined by the east-west component of the Sq. current and the strength of the horizontal component of the earth's field.

In order to examine the relationship between the abnormal rise in the peak of electron density in the pre-dawn period and any distortion in the Sq. current intensity, the following analysis was undertaken. Thirty days in January, 1960, for which complete data were available were grouped into two categories depending upon whether the F-layer critical frequency immediately preceding sunrise was below or above an arbitrarily chosen value of 3·0 Mc./sec. There were nine days of the first category and twenty-one days of the second. The departures ΔfoF2 from mean values for these days were derived at half hour intervals between 0300 and 0700 hours I.S.T. Likewise, the departure ΔH in gammas in horizontal force recorded at Kodaikanal were also obtained for the two groups of days at half hour intervals. These departures $\Delta \mathrm{foF}_2$ and ΔH are plotted in Fig. 5. It can be seen at once that on nine days when foF_2 is negative, ΔH is also negative, the maximum dip in ΔfoF2 occurring at about 0600 hours, about an hour and a half later than the dip in ΔH. It is interesting to note that it is just about 0430 hours when the maximum dip occurs in H, that the height-changes in F-layer begin to take place (Figs. 4 and 5) presumably due to distortion of the Sq. current intensity in the dynamo region. The maximum departure in foF2 occurs after an interval of about an hour and a half which is very close to the relaxation time $[\tau = (1/2\alpha \mathrm{N}_m)]$ where α is the effective loss coefficient taking into account the vertical drift

$$\left(\alpha_{\text{eff.}} = \alpha_0 + \frac{1}{\mathrm{N}_m} \cdot \frac{\partial v}{\partial h}\right).$$

It, therefore, appears that the abnormal rise of the layer in the pre-dawn period is associated with the additional movement in the region caused by the distortion in the Sq. current intensity.

(iv) *Influence of solar activity on the occurrence of the pre-sunrise phenomenon.*—The pre-dawn increase in the height of the F-layer and the associated splitting were rarely seen during 1957–59, a period of high solar activity. It is known that the rate of ion production is in general proportional to the intensity of solar ionizing radiation. The magnitude of the first two terms on the right side of the continuity equation (1) will be large as compared to the last term and the effect of the transport term div. (Nv) is likely to be small. Further, at sunspot maximum there may exist (Allen, 1953) a high resistance to movements due to electric or magnetic damping by the higher electric conductivity. The contribution of the movements to the rate of change of ionization becomes progressively smaller with increasing solar activity while the residual overnight ionization densities are comparatively

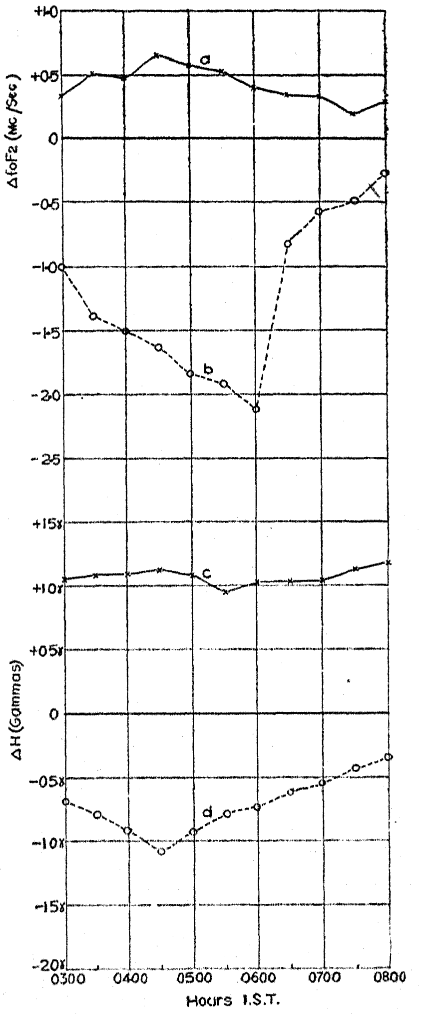

FIG. 5. Upper curves: Variation of Δ foF2 for January 1960: (*a*) for 21 days when pre-sunrise minimum of foF2 was >3·0 Mc./sec. and (*b*) for 9 days when the parameter was found to be < 3·0 Mc./sec.

Lower curves: Variation of ΔH at Kodaikanal for January 1960, averaged for the same days as in the upper curves (*a*) and (*b*).

much larger. The conditions favourable for bifurcation are, therefore, not fulfilled during the periods of high solar activity.

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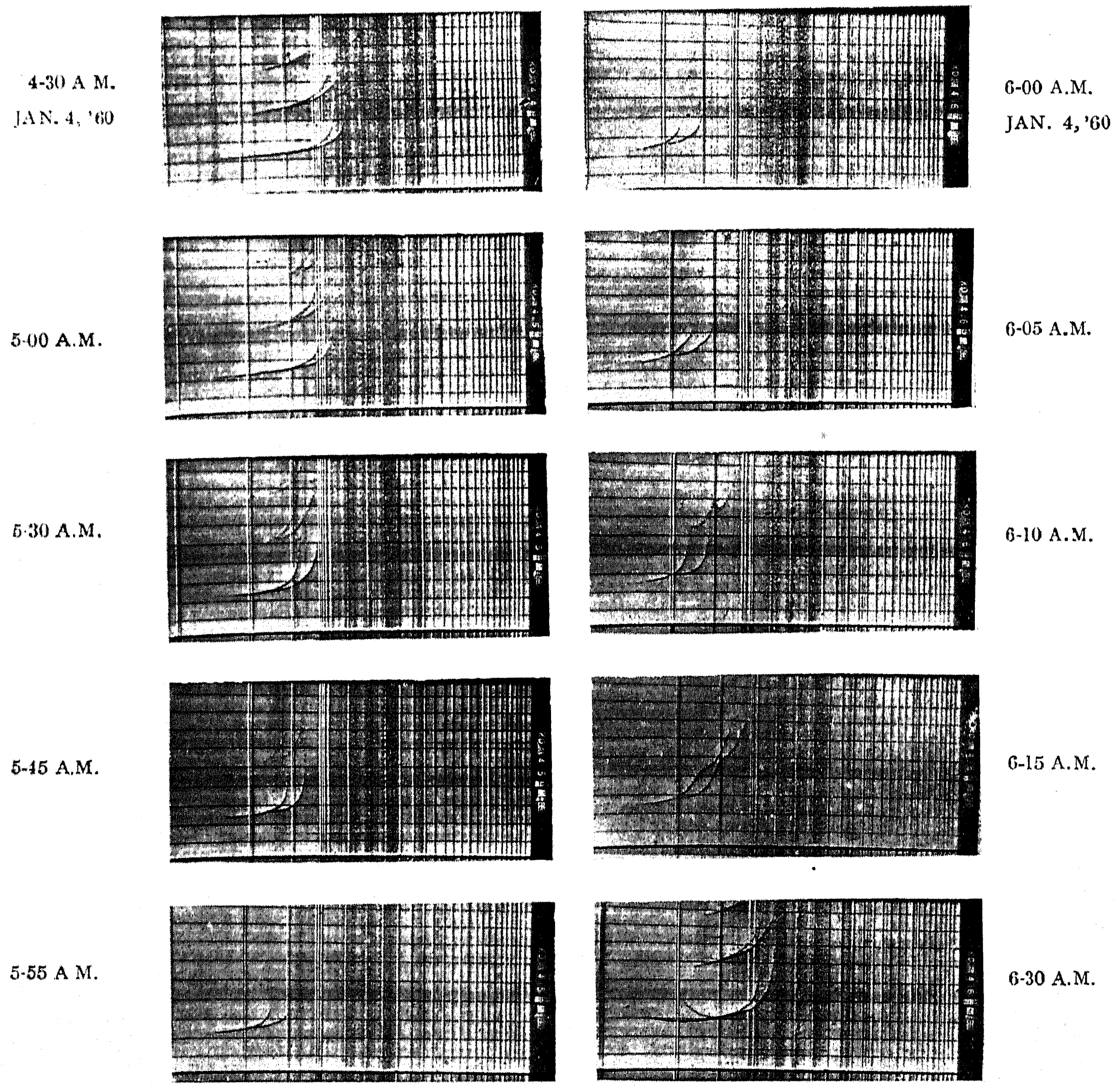

FIG. 1. A sequence of ionograms (January 4, 1960) illustrating the development of pre-sunrise F layer "splitting".