FURTHER STUDIES OF F-REGION AT ALLAHABAD *

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Plates III, IV and V.

ABSTRACT. Results of measurement of virtual height of the F-region carried out (mostly at night) during 1937-38 session on several wave frequencies are described. It is found that the nature of the equivalent height change varies in a marked manner from day to day. Sometimes the virtual height shows three maxima during a single night. A good correlation has been found to exist between the hour of occurrence of minimum virtual height of the F-region and the hour at which the barometer at ground level reads maximum pressure. Occasionally echoes from ionized regions above the normal F-layer have been obtained. Occurrence of complex echoes is found to be associated with variation of one or other of the terrestrial magnetic elements. It is seen that contrary to the results obtained by many investigators the F_1-region exists till about 10 o'clock at night.

INTRODUCTION.

The paper presents the results of some of the ionospheric investigations carried out at Allahabad during the 1937-38 session. The work was started with a view to predict maximum usable frequencies for broadcasting over various distances and to make a thorough study of the electron density and equivalent height variations in the F_2-region. Our experience during the 1936-37 session had shown that the critical penetration frequency of the F_2-region was always below 11 Mc/sec., so, keeping in mind the long time variation in the electron density of the ionospheric regions owing to the increased sun spot activity, we constructed a transmitter which enabled us to transmit pulses up to 13·6 Mc/sec., but we found that the 13·6 Mc/sec. waves were reflected by the region even up to 10 or 11 o'clock at night. Thus the measurement of ionization density was possible only during a limited period at night. Under such circumstances it was not possible for us to predict maximum usable frequencies for the major portion of day and we confined our attention only to the measurement of virtual height. Off and on we also measured the critical penetration frequency differences between the ordinary and the extra-ordinary waves.

* Communicated by Prof. M. N. Saha, F.R.S.

The data collected in our laboratory from experimental transmissions on 4 Mc/sec. had shown the utility of such waves for regular broadcasting purposes in India. The All-India Radio also realised this fact and started broadcasts on 60 and 90 metre bands. The International Tele-communications Conference held at Cairo also came to similar conclusions and set apart such bands for broadcasting exclusively in the tropical and sub-tropical countries. In view of the importance of these waves, the virtual height measurements were generally carried out on such and a number of other wave lengths. The data presented here are based on automatic (P′, t) records and auxiliary visual observations. The day-time observations were confined only to few holidays, since on other days the disturbance level was very high. Experiments were also made to develop an automatic (P′, f) recording apparatus. In these experiments the transmitter and receiver were kept in tune mannually. §1 gives a brief description of our apparatus while §2 contains our experimental results along with their discussion.

§1. APPARATUS.

The method used is that of Breit and Tuve.[1] The transmitter generates short wave-trains of radio-frequency 50 times per second. These waves fall on the receiver which is lying just on the side of the transmitter, both directly and after reflection from the upper ionized strata. The output from the receiver is fed to the vertically deflecting plates of an oscillograph the horizontally deflecting plates of which are connected to a timebase synchronized with the frequency of the pulses.

The transmitter consists of a simple Hartley circuit. Modulation is effected by means of a valve in series with the oscillator. Normally the grid of the oscillator is kept so negative that no plate current flows through the oscillator and the modulator, but by the application of short unidirectional pulses generated by a thyratron and its associated circuit, the grid potential of the modulator is reduced to zero for short periods fifty times per second. It is during these periods that the transmitter oscillates and radiates the desired wave trains.

§2. EXPERIMENTAL RESULTS AND THEIR DISCUSSION.

(*a*) *Diurnal variation of Virtual Height.*—The (P′, t) records were usually taken throughout a month on several frequencies so that for any particular frequency eight or ten records distributed over the entire month were available. The graphs represent monthly average values of virtual height at the particular frequency mentioned. Generally an average of more than four values has been taken. In December, however, very few records could be taken so curves for the virtual height variation for a particular day and night have been given. The October data were also meagre. The rest of the curves are fairly good averages.

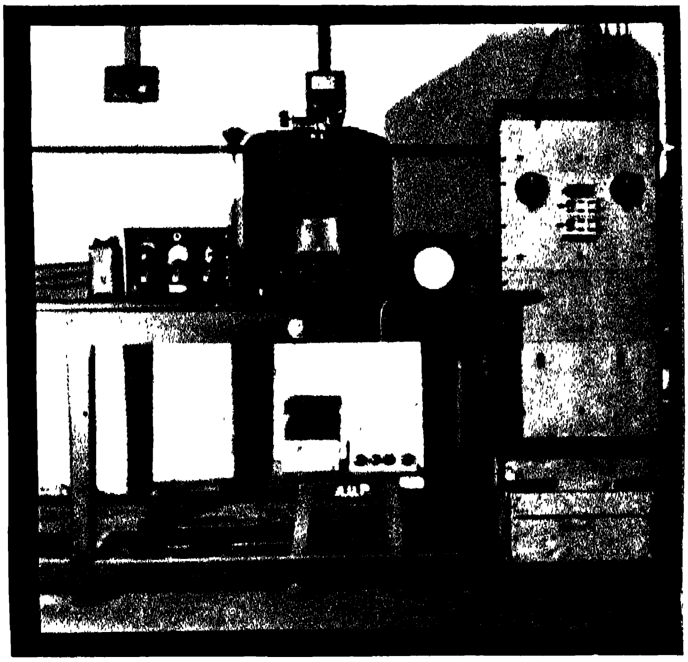


Fig. 1.

Apparatus.

Figures 2, 3 and 4 show all these curves. Marked variations in the nature of equivalent height changes are noticed from day to day. Sometimes we find that during a single night there are three maxima in virtual height, while at others there are only two and yet on certain nights the virtual height remains constant almost throughout the night. We have reported elsewhere[3] the existence of similar maxima and minima in the electron density of the night F-region and it would have been interesting to correlate the two variations, but unfortunately we could not get electron density data during this period. It is therefore difficult to say if there is any relation between virtual height variations and the increase in electron density. It is still more difficult to explain the nature of these virtual height variations mentioned above, for they depend on the complicated meteorology of the upper atmosphere about which so little is known. We cannot say if these changes accompany some sort of atmospheric oscillation or are the result of some other cause unknown to us. Some of our records clearly show that increase in electron density of the night F-region takes place several times during the course of a single night. Figure 7 taken on December 10-11, 1937, at a frequency of 2·9 Mc/sec. shows that the waves ceased to be reflected at 0020 but they reappear-

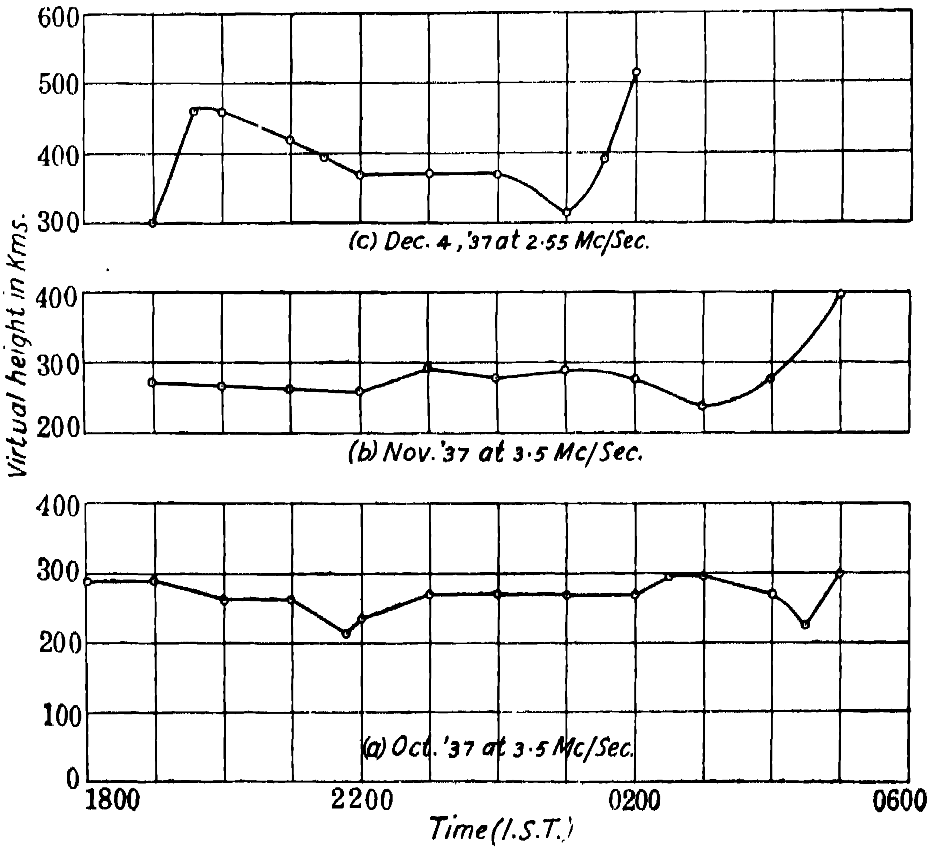


Fig 2. Showing mean virtual height of the F-region for the months and at the frequencies shown

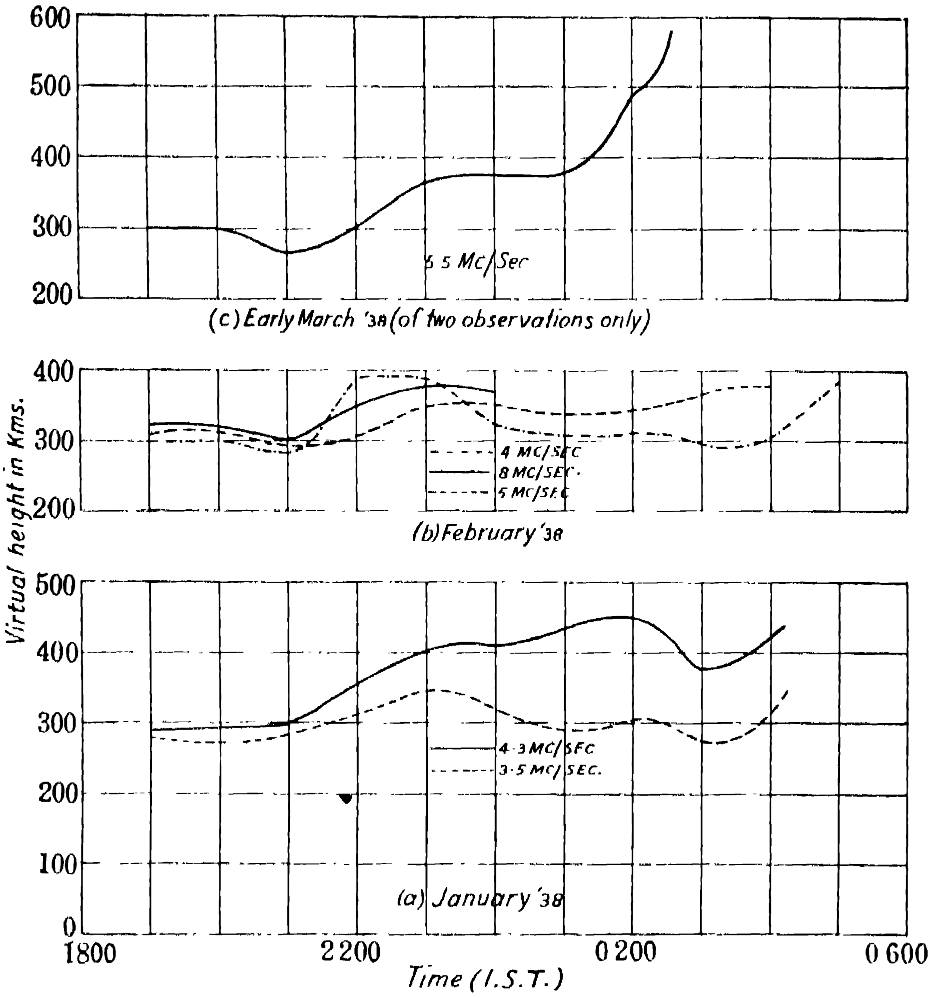


Fig 3 Mean virtual height of F_2-region for the months and at the frequencies shown

ed twice during the night before they began to be continuously reflected by increased ionization due to the incidence of the rays of the Sun in the morning. It unmistakably points out that between the hours 0130 and 0150, and 0245 and 0350, there was an increase in the electron density of the F-region which cannot be attributed to ionization due to ultra-violet light of the Sun. For understanding these short-time variations, as well as to gain an insight into the nature of variation of ionization density with height, it is very necessary that (P′, f) curves should be determined as frequently as possible and the mean hourly values of maximum electron density, minimum virtual height and virtual heights on a number of other frequencies published, just as the data for earth's magnetic field are published.

Now variations in virtual height can occur either due to change in the electron density in the lower layers which have a retarding influence on the

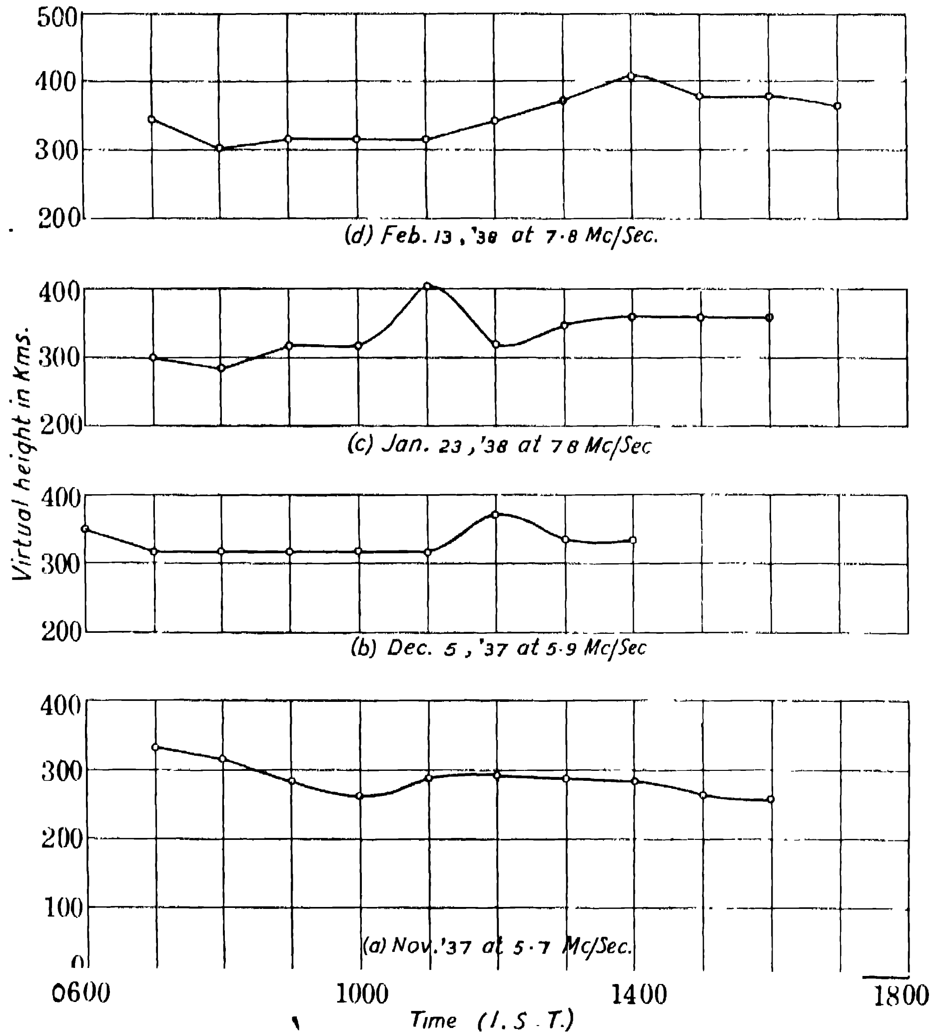


Fig 4. Showing day virtual height of the F_2-region on the dates and frequencies given (a) gives mean virtual height

waves that pass through them, or due to changes in the real height of the layer. Figure 3 clearly shows that the variations in virtual height of the night F-region are similar in nature even when frequencies vary from 4 to 8 Mc/sec. This strongly suggests that the variations in the virtual height of the region are due to changes in the actual height of the layer itself. The conclusive proof of the movement of the layer can, however, be obtained only if the temporal rate of change of optical path which can be measured by Appleton's method[3] is found to be equal to the temporal rate of change of equivalent path.

(*b*) *Seasonal Variation of Virtual Height.*

Two curves showing the seasonal variation of the virtual height during the period of observation have also been drawn. Figure 5 (*a*) shows equivalent heights as observed at seven o'clock in the evening on different days while Figure 5(*b*) gives the same for midnight. The curves also give an insight into the general difference in the values of the virtual height in the evening and at midnight. It is obvious that in general the virtual height at midnight is greater than that in the evening hours. This fact also shows that this difference in virtual height is to be expected on account of change in actual height, for otherwise we should expect greater retardation of the waves in the lower regions in the evening hours than that at midnight and hence a greater virtual height at the former hour.

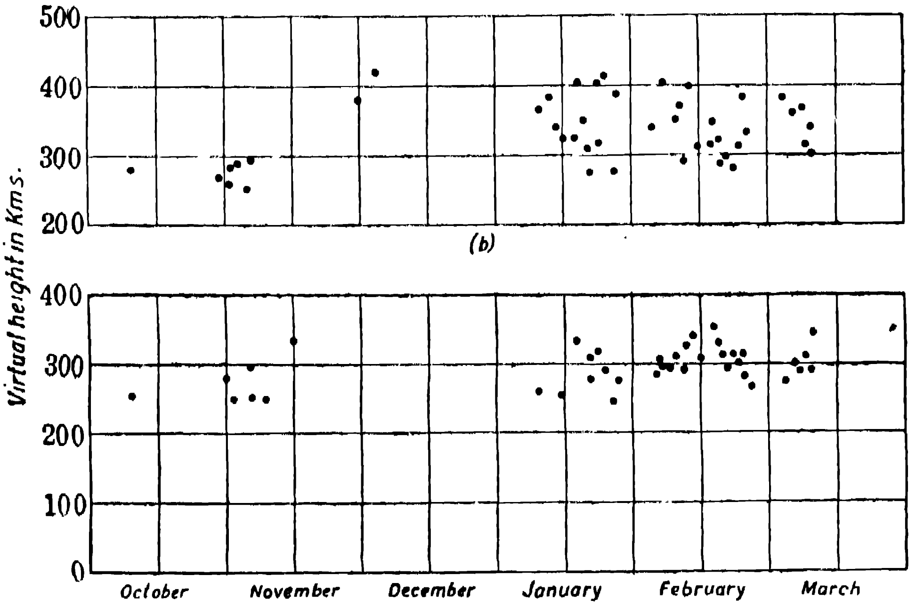


Fig 5 Showing seasonal variation of the virtual height of the F-region at (a) 1900 and (b) midnight

(*c*) *Correlation of Barometric Pressure and Virtual Height*

Correlations of atmospheric pressure with ionospheric phenomena are not new. Ranzi [4] found correlation between increase in the E region ionization after sunset and barometric depressions observed at the place of observation or north of it. Colwell [5] claims that under suitable conditions, the variations in the [illegible]al strength of a broadcasting station may be used to indicate the presence of cyclonic [illegible] anticyclonic regions with an accuracy of about ninety per cent for weather forecasting purposes. Martyn and Pulley [6] in Australia have found a strong correlation between E-layer average electron density at night and the ground level barometric pressure observed next morning. The latter authors have also found a correlation between the noon ionization density of the E-region and barometric pressure observed as before. They also pointed out that similar correlations have not been reported from the northern hemisphere. Taking up the suggestion of these Australian investigators, Best, Farmer and Ratcliffe [7] tried to look up for this correlation in England, but their report shows that they did not find any such correlation.

Figures 2 and 3, especially figure 3(*b*), clearly show that in the evening between 2000 and 2200 there occurs a minimum in the virtual height of the F-region. We attempted to find out if any relationships exist between this minimum equivalent height and the maximum barometric pressure observed at ground level during the same night. The result is given in figure 6(*b*). 6(*a*) shows correlation between the time of occurrence of this minimum in virtual

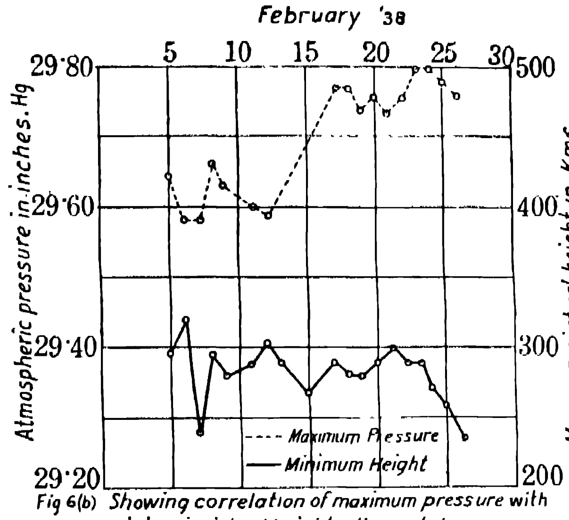
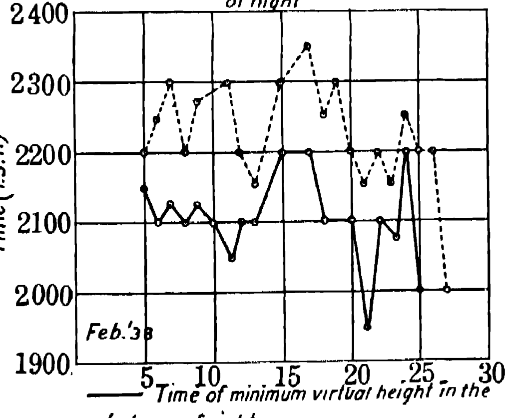


Fig 6(b) Showing correlation of maximum pressure with minimum virtual height in the early hours of night



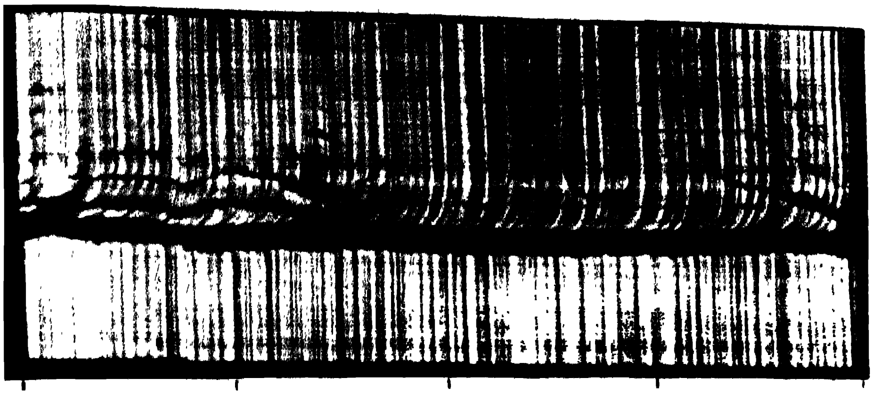
—— *Time of minimum virtual height in the early hours of night*

------ *Time of maximum pressure in the early hours of night as recorded at the Allahabad Meteorological observatory*

Fig 6(a) Showing Correlation of the time of minimum virtual height with that of maximum pressure in the early hours of night height of the F-region and the time at which barometer at ground level was observed to read maximum pressure during night. The atmospheric pressure at Allahabad shows two maxima, one at about 10 or 11 o'clock in the night and the other at about the same time during the day. The observations reported in figure 6 refer to February, 1938. A glance at figure 6(*b*) shows that the relationship between minimum virtual height and maximum barometric pressure is none too good. If the two phenomena are directly connected, we should find days of greater pressure indicating lower minimum virtual height and *vice versa*. Such a variation, although to some extent seen in figure 6(*b*), is not always to be found. Figure 6(*a*), on the other hand, shows a very good correlation between the time of the minimum virtual height and the time of maximum pressure. The days on which the minimum virtual height occurs early, the maximum pressure also is seen to take place early. There is, however, no fixed time difference between the times of occurrence of the two phenomena. This and the rather poor relationship shown in figure 6(*b*) may be due to the fact that atmospheric oscillation is not the only process taking part in these changes but there are other processes also at work which we are ignoring. It may appear that the minimum virtual height may be due to reduction in the retardation suffered by the waves in the lower part of their path or to contraction due to cooling with the advance of night. We, however, think that if this is so, then instead of a minimum we should observe a continuous fall in the virtual height, for reduction in retardation and contraction due to cooling are expected to increase with the advance of night. It seems that perhaps the semidiurnal pressure variation and this minimum in virtual height are products of the same cause, possibly some sort of atmospheric oscillation. Further study of such correlations is expected to throw light on the vexed meteorological problem of semidiurnal pressure variation.

(*d*) *Complex Echoes and Formation of High Layers.*

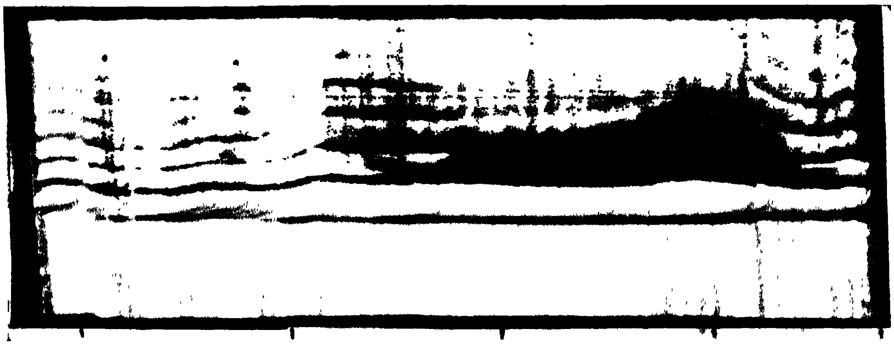
Such echoes we have described and discussed in a number of previous communications.[8] We have ascribed them to partial reflection occurring at irregularly moving electron clouds and at other high layers different from the normal stratification. The occurrence of such reflections is, in general, associated with magnetic storms.[*] Kirby, Smith and Gilliland[9] report that during the first phase of an ionosphere storm, the regions extending from E-layer upwards get literally torn up into small irregularly moving electron clouds, the normal stratification being destroyed. They, however, think that this first turbulent phase of the storm is observable only in the auroral zone latitudes. Our observations of transient irregular echoes on the other hand clearly suggest the existence of a torn-up ionosphere and we think that such conditions prevail



1900 2200 0100 0400 0700

Time (I. S. T.)

Fig. 7.



1900 2200 0100 0400 0625

Time (I. S. T.)

Fig. 8.

even at Allahabad. There is, however, a great difference in the intensity of the effect at the two latitudes. In the auroral zone the ionosphere gets disturbed and torn up down to the level of E-region and even lower when complete cessation of echoes occurs, but at Allahabad we notice such disturbance generally above the F-layer and the normal stratification of the ionosphere is not destroyed, for reflections from the normal F-region are received inspite of the irregular complex reflections. It is due to the fact that perhaps the ionizing and disturbing agency is unable to reach such low heights in lower latitudes.

Besides the irregular transient reflections taking place from ionization clouds, we also observe echoes from abnormal layers lasting for several hours. The virtual height from which such reflections take place changes even by 200 kms. during the course of a few hours. Figure 8 shows that at 2300 a reflection appeared from an equivalent height of about 650 kms. which at 2335 got reduced to only about 520 kms. Formation of such high layers and their movement has also been observed by Leiv Harang at Tromsø. Sometimes we have also observed that these abnormal layers instead of moving downwards move upwards with similar velocities. This upward movement we can ascribe to heating of the regions that generally takes place during the second phase of an ionosphere storm and which extends to latitudes far south of the auroral zone, but we have still to see as to what amount of increase in temperature will impart such high velocities to the upmoving layer. As for the downward movement of the layer, it is difficult to believe that the layer moves as a whole with such tremendous velocities as thought by some investigators. It seems that the ionizing agency moves lower down so that we are able to obtain reflections beginning from a greater height and ending at a lower one. Thus instead of the movement of the layer it appears to us that the ionizing agency travels down causing ionization in the lower heights.

In table I we have given the periods at night during which complex echoes were received along with the frequency at which observations were made. Table II gives a comparative statement of such echoes with reflections from E-layer and magnetic character of days as reported from the Colaba Observatory, Bombay. We observe that with the occurrence of complex echoes, the horizontal force may increase or decrease; the vertical force may remain quiet or it may be the only element of the earth's field to get disturbed. There are also occasions when all the three elements get simultaneously disturbed. Sometimes complexity occurs at the same time when the earth's field gets disturbed, while at other times the former takes place earlier. As it is now almost certain that the occurrence of complex echoes and disturbances in terrestrial magnetic field are due to irregularities in the upper ionized strata, and as our observations have shown that complex echoes are observed with different effects on the earth's magnetic field, it seems that every time when complex echoes are seen, the nature of the disturbance in the upper ionized regions is not the same.

TABLE I.

Date.	Frequency in Mc/sec. at which observations were made.	Time during which complex echoes appeared.
29-10-37	3·5	2330-2400
30-10-37	3·5	0000-0120
	3·5	1900-1940
18-1-38	2·8	0030-0520
	2·8	2030-2300
21-1-38	3·4	1930-2000
	3·4	2100 2400
27-1-38	3·5	0250-0320
9-2-38	6·0	0100-320
	6·0	0515-0650
13-2-38	5·4	2100-2400
14-2-38	5·4	0000-0050
15-2-38	5 4	2050-2400
18-2-38	7·8	2130-2350
19-2-38	5·4	2030-2400
20-23-8	5·4	0000-0155
	3·9	2020-2400
21-2-38	3·9	0000-0100
	3·9	2110-2400
22-2-38	3·9	0000-0100
23-2.38	5·5	1945-2030
	5·5	2148-2400
24-2-38	5·5	0000-0200
	5·5	0340-0430
	5·5	2230-2330
25 2-38	5·5	2235-2400
26-2-38	5·5	0000-0550
	3·5	2120-2400
27-2-38	3·5	0000-0145

TABLE II.

Date.	Ionospheric behaviour: Reflections from E-layer.	Ionospheric behaviour: Complex echoes.	Magnetic character as reported by the Colaba Observatory, Bombay.	REMARKS.
29-10-37		C	Quiet	Complex echoes observed for about two hours.
1-12-37	E		Small	
10-12-37	E		Small	
10-1-38			Quiet	
12-1-38			Small	
13-1-38			Small	
15-1-38			Small	
17-1-38	E	C	Very great	At about 0245, the time of appearance of complex echoes, a sudden decrease in the vertical forces was noted and a similar increase in the horizontal force was also observed. The latter, however, remained disturbed throughout the night. The decrease in declination was observed at 0330.
18-1-38	E		Small	Reflections from E were present before disturbance in H. F. and V. F. was observed, but that in D took place afterwards.
20-1-38			Small	
21-1-38		C	Moderate	Sudden rise in H. F. during the existence of complex echoes.
22-1-38	E		Very great	Great disturbances in all the three elements lasting for several hours were noted in the magnetic elements; but when the peculiar disturbances in virtual height of the E-layer took place, the magnetic disturbances were over.
24-1-38			Small	Virtual height curve quite regular.
26-1-38	E		Moderate	Disturbance in H. F. and V. F. over several hours before the appearance of sporadic E-reflections in the early morning.
27-1-38	E		Small	

TABLE II (*contd.*).

Date.	Ionospheric behaviour. Reflection from E layer.	Ionospheric behaviour. Complex echoes.	Magnetic character as reported by the Colaba Observatory, Bombay.	REMARKS.
5-2-38	...	...	Quiet ...	Nothing unusual in virtual height curve.
6-2-38	...	...	Moderate ..	Increase in ionization of the F-region noted between 0015-0400, time coincides with disturbance in H. F.
7-2-38	...	...	Small	(P', t) curve quite regular.
8-2-38	...	C	Great ..	Strong complex echoes appeared in the last phase of the storm when H. F. began to increase after undergoing a decrease.
9-2-38	...	C	Small ..	Weak complexity. Time does not coincide with magnetic disturbance.
10-2-38	...	...	Small .	(P', t) curve regular.
11-2-38	...	...	Small ...	(P', t) curve regular.
12-2-38	...	C	Small .	Weak complexity. Time of beginning coincides with the time of disturbances in V. F., H. F. and D., but complexity continues for 2 hours afterwards.
13-2-38	...	C	Small ..	Weak complexity, but no time correlation.
15-2-38	...	C	Quiet ...	Sufficiently strong complexity observed.
17-2-38	...	...	Quiet ..	... ..
18-2-38	...	C	Quiet ...	Some small rise in H. F., a little before complexity appeared.
19-2-38	...	C	Quiet ...	Strong complex echoes observed. Examination of the magnetograms showed that H. F. was very quiet, but there were some disturbances in V. F.
20-2-38	...	C	Quiet ...	.....
21-2-38	...	C	Quiet ...	......
22-2-38	...	C	Quiet ...	.....
23-2-38	...	C	Small ...	Complex echoes appeared four times during the night; at the beginning of complexity small increase in H. F. noted.
24-2-38	...	C	Quiet ...	Complexity for less than an hour and just at that time a small rise in H. F. was noticed, otherwise the day was very quiet.
25-2-38	...	C	Small ..	Complexity found during the disturbed period as well as afterwards. It begins with deflections in H. F. and V. F.
26-2-38	E	C	Small ...	......

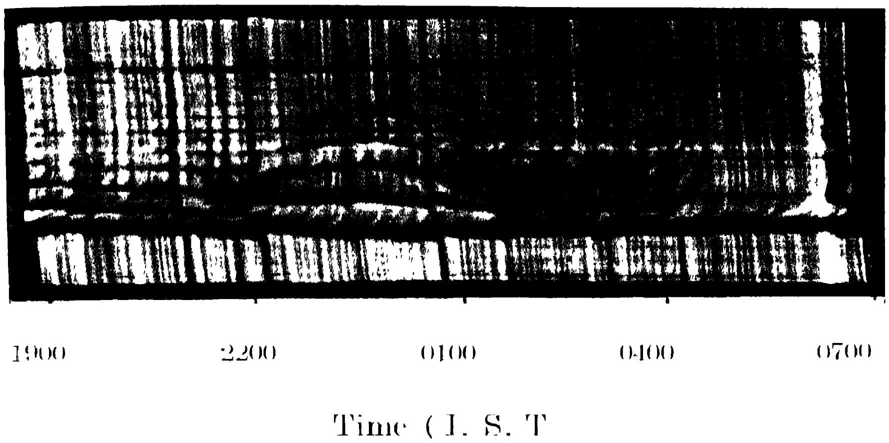

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Fig. 9.

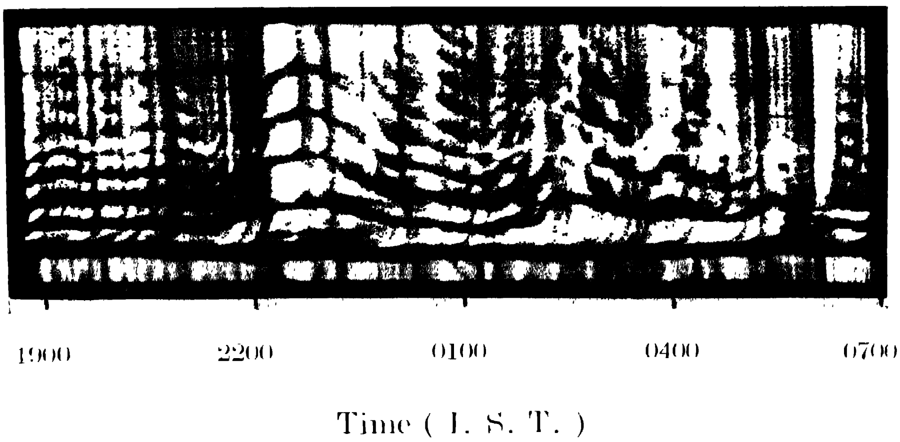
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Fig. 10.

(e) Reflections from E-layer.

Table III gives the periods during which reflections from the E-layer were received with the frequency of the waves used in the experiments. The observations were generally carried out during night, hence the table gives such periods only during night-hours.

TABLE III.

Date.	Frequency in Mc/sec. at which observations were made.	Time during which reflections from the layer appeared.
30-10-37	3·5	1815-1830
...	3·5	2110-2230
9-11-37	8·0	2100-2145
1-12-37	2·9	1820-2400
2-12-37	2·9	0000-0020
10-12-37	2·9	1930-2000
12-1-38	2·9	1810-1920
13-1-38	2·8	1815-1910
17-1-38	2·8	1940-2040
18-1-38	2·8	0030-0245
...	2·8	0455·0630
22-1-38	3·5	2200-2330
23-1-38	3·5	0510-0620
26-1-38	3·5	1845-1930
27-1-38	3·5	0130-0240
28-1-38	3·5	0120-0230
21-2-38	3·9	1800-2000
26-2-38	3·5	1815-2310
...	3·5	0000-0620

(f) Existence of F_1-region after Sun-set.

In a previous communication[2] we have reported that our ionization measurements showed us separate existence of F_1-region till about 10 o'clock at night instead of till sun-set as reported by other investigators. The present investigations also gave us a similar evidence. Figuee 9 obtained on January 27-28, 1938, at a frequency of 3.5 Mc/sec. clearly shows that from the beginning of the record at 1850 three multiple reflections from a virtual height varying from 270 to 225 kms. were received, but at 2150 suddenly there appeared reflections from an equivalent height of about 360 kms. also simultaneous with previous reflections. For a period of about 20 minutes echoes from both the heights were seen but afterwards only the higher layer reflections remained. It seems that in the beginning the waves were reflected from the F_1-region, then for about 20 minutes the x-wave was reflected from the F_1-region while the o-wave was returned from the F_2-region. Afterwards the reflections took place from the F_2-region alone. Although this is not a conclusive proof that the two regions coalesced at the time of disappearance of reflections from the lower height, for it only means that the electron density in the region fell below that required to reflect the waves having a frequency of 3·5 Mc/sec., yet it points out that the F_1-region existed at least till this hour.

(g) *Some Abnormalities.*

Sometimes, especially in the early morning hours, we have observed broad, diffuse and weak reflections coming from an equivalent height of 1000-1500 kms. On several occasions these reflections persisted for short periods even after echoes from the normal F-layer appeared.

We have also observed that during the early part of night, weak reflections persisted after the waves had penetrated the region. These would disappear if the frequency was raised by about ·5 Mc/sec. and would not show penetration phenomena.

Several times we have seen that near the penetration frequency a single pulse instead of breaking up into only two components gets separated into three and even four components which disappear one by one as the frequency of the waves is raised.

(h) *Note on Figure 10.*

In a previous section we have mentioned Colwell's claim of predicting weather conditions from the knowledge of radio broadcast reception. Figure 10 taken on January 22-23, 1938, shows possibilities of similar predictions from direct ionospheric studies. We observe that unusual disturbances occurred in the virtual height of the F-region on this night and the abnormal E appeared twice. These disturbances were connected with a severe western disturbance and the weather on the following day was found to be extremely bad. The conditions of broadcast reception during this period were found to be very poor.

ACKNOWLEDGMENTS.

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