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SOME DIRECTIONAL OBSERVATIONS OF ATMOSPHERICS ON 1000 METRES DURING SUNSET TIME

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ABSTRACT. The theory of sunrise and sunset maxima in the number and strength of atmospherics, as given by Khastgir, is elaborated in this paper A simple method, based on this theory, is worked out for the location of a thunderstorm centre which gives rise to atmospherics, by observing the time of occurrence of the atmospherics maximum, when the distant thunderstorm prevails over a length of time covering the time of sunrise or sunset. The results of some directional observations of atmospherics taken in May-June 1946 with a cathode-ray tube direction-finder are also given in the paper The positions of the observed maxima with reference to ground sunset enabled determinations of the locations and distances of the thunderstorm centres active during the period The results indicated that most of the thunderstorm areas were on the eastern side of Dacca, in Burma and a few on the western side The distances were found to range from about 190 to 1750 Km.

INTRODUCTION

It was long known that there were anomalies observed in the number and in the intensity of *distant* atmospherics during the sunrise and the sunset periods. Eccles (1918) reported observation of a sunset minimum and this was confirmed by other investigators. Espenschied, Anderson and Bailey's (1926) observations, however, indicated an increase of atmospherics during the sunrise and sunset times. Potter's (1931, 1932) work on atmospherics received in frequency channels from 5 MC/S to 20 MC/S, also revealed intensity maxima during the periods of sunrise and sunset. Double peaks were also observed by him about the time of sunrise on some occasions. The preliminary investigations on distant atmospherics received in medium frequencies by Khastgir and Kameswar Rao (1940) and Khastgir and Ray (1940) in this laboratory showed an unmistakable maximum during the sunset time. Later observations on very high radio frequencies by Khastgir and Innas Ali (1942) and on medium frequencies by Khastgir and Basak (1942) showed in many cases maxima in the region of ground sunrise and sunset times. Usually one maximum (and sometimes two maxima) was observed some minutes *before* the ground sunrise time. One maximum was also observed some minutes *after* the ground sunset time. Occasionally there was indication of a maximum at the time of the ground sunset. The effect of sunset on atmospherics was also reported in a paper by Subba Rao (1941). Venkata Rao Telang's (1941) records of the atmospheric electric field also indicated anomalies during the sunset time.

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Potter (1931) attempted a general explanation of the sunrise and sunset effects observed and also of the double peak; but this explanation does not seem to be at all satisfactory in view of the present knowledge of the ionosphere. For very long waves, Namba (1933) gave an explanation of the sunset and sunrise effects on atmospherics. According to his view, the reflexion at the ionized layer is *metallic* before sunset and *dielectric* after sunset; and the sunset and sunrise effects are due to the transition in the reflection characteristics of the layer. A general explanation of the phenomenon was also offered by Khastgir (1942). The object of the present paper is to elaborate this explanation into a theory and to show that on this theory a simple method can be devised for the location of a thunderstorm centre which gives rise to atmospherics by observing the time of occurrence of the maximum in the strength of the atmospherics, when the distant thunderstorm prevails over a length of time covering the sunrise or sunset time. The results of some directional observations of atmospherics about the sunset time are also given in the paper.

THEORY OF ATMOSPHERICS MAXIMA DURING SUNRISE AND SUNSET PERIODS

A lightning stroke gives rise to damped pulses of electromagnetic waves. When a lightning takes place on the earth's surface or somewhere within the troposphere, the electromagnetic pulses arrive at the receiver situated at some distance after reflexion from the ionospheric layer. In the small hours of the morning, it is evident, the intensity of downcoming wave, originally coming from the distant source of atmospherics, increases gradually with the slowly decreasing ionization in the E-layer, till on the incidence of the solar rays, at sunrise, there is a great increase in the ionization causing a large fall in the intensity owing to a larger absorption in the layer and also to a greater deviation of the rays due to higher electron concentration. This causes a maximum in the strength of the atmospherics about the time of sunrise. Before sunset, again, the intensity of the downcoming waves gradually increases due to a continuous decrease in ionospheric absorption till at the instant of the withdrawal of the solar rays at sunset the intensity suddenly falls. This is because when the ionizing solar rays are withdrawn, there is a perceptible decrease in the E-layer ionization and the downcoming waves are much less deviated and necessarily fail to reach the receiving point. This gives a maximum in the strength of the atmospherics about sunset time. Subsequently, however, the smaller ionospheric absorption asserts itself causing at first a slow decrease of intensity and ultimately an increase.

The work on the early morning increase of E-layer ionization by Mitra (1938) has shown that the ionization begins to increase *not* when the early morning solar rays strike the E-layer by grazing the earth's surface *but* when the rays strike the layer by grazing the surface of the ozonosphere at a height of 35 Km. from the earth. The sun's rays, in order to produce ionization in the E-layer should therefore pass over the ozone region, so as not to have the radiations of the shorter wavelengths absorbed by the ozone. Keeping this conclusion in view, the time of occurrence of the increase of ionization in the E-layer by sun's rays at dawn or of the decrease of ionization when the solar rays are withdrawn at dusk, can be found with reference to the ground sunrise and sunset times. This would correspond to the time of occurrence of the atmospherics maximum observed about the time of sunrise or sunset. The double peaks which were usually observed on higher frequencies before the ground sunrise can be explained in terms of the two layers E and F. It is known that the F-layer ionization also indicates a rapid increase in value about the sunrise (in the layer) and also a sharp fall about the sunset (in the layer).

POSITION OF THE SUNRISE AND SUNSET MAXIMA AND THE LOCATION OF THUNDERSTORM CENTRES

For simplicity in treatment, let us first consider the *particular case*, when the source of the atmospheric disturbance and the receiving point are in the east-west plane. Let S and R represent the source of atmospherics and R the receiving point. The damped electromagnetic pulses from the source of the atmospherics would reach the receiving point after reflexion at A in

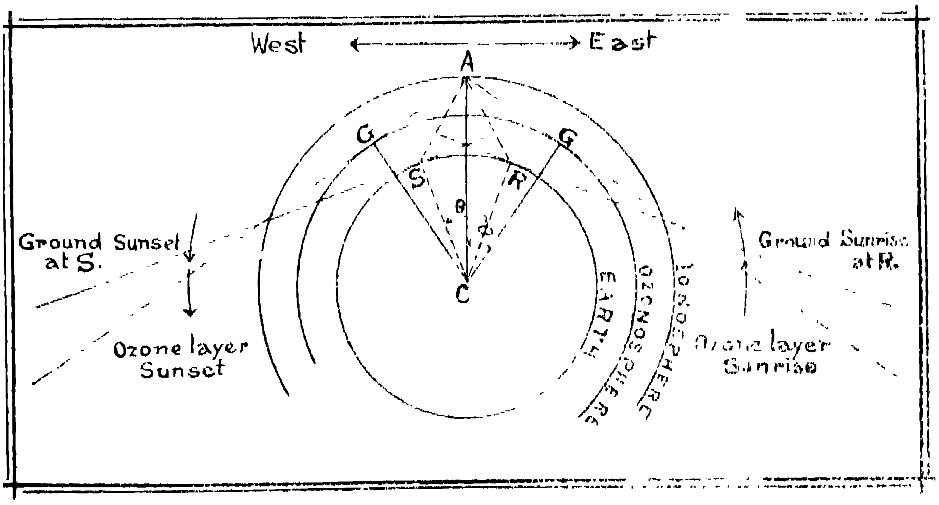

FIG. 1

the ionospheric layer. It is evident from fig. 1 that the ionization in the region A would begin to increase only when the sun's rays would pass over the tangent from A to the top of the ozone layer. The ground sunrise or sunset at the receiving point is of course easily determined by drawing a tangent plane on the earth's surface at the receiving site R. From A where the ionospheric reflexion takes place, let us now draw a tangent AG touching the ozone layer at G. Denoting the angular distance between the noise source and the receiving point by θ and the angle ACG by ϕ, it can be easily seen that the instant when the sun's rays would begin to produce ionization in the region A by grazing the top of the ozone layer it would be earlier or later than the ground sunrise at R, according as $\phi >$ or $< \frac{\theta}{2}$. This is true whether R is to the east or west of S. It is also evident that the difference between the instant of ground sunrise at the receiving point and the instant when the ionization begins to increase in the region A would be given by

$$\Delta T = (4\phi \mp 2\theta) \text{ minutes} \tag{1}$$

The signs of the difference and summation refer respectively to the cases when the receiving point R is to the east and to the west of the noise source S.

Similar arguments would apply to the case of the sunset. It should be noted that the sunset maximum would appear *after* the ground sunset, provided $\phi > \frac{\theta}{2}$, whereas under the same condition the sunrise maximum would appear *before* the ground sunrise. The difference between the instant of ground sunset at the receiving point and the time of occurrence of sunset maximum would be given by the same formula. It should be noted that the signs of difference and summation would in the case of sunset refer respectively to the cases when the receiving point R is to the west and to the east of the noise source S.

We shall now consider the *general case* where the source of the atmospheric disturbance and the receiving point lie in any plane, as in Fig. 2.

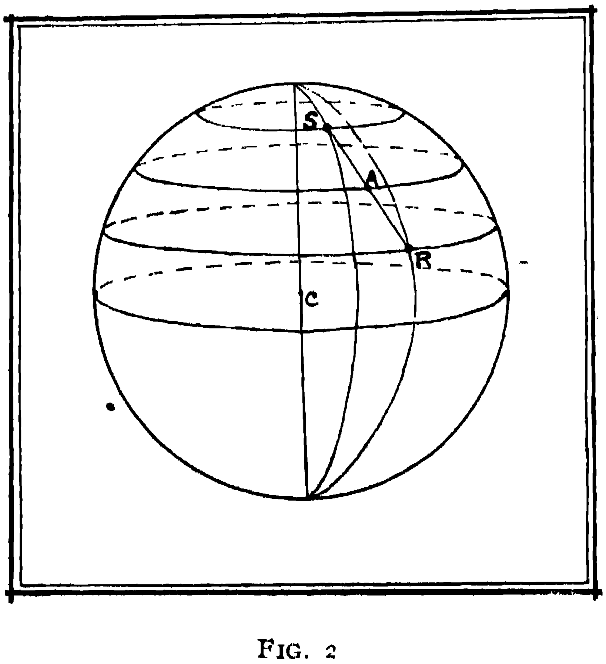

FIG. 2

Let SR make an angle with the north-south line at the receiving point R. The point at which reflexion at the ionosphere takes place is now directly above a small circle corresponding to the latitude of A ; In Fig. 1 the tangent plane drawn from A to the ozonosphere touches it at G. The straight line GC drawn from this point G to the centre C of the small circle makes now an angle with CA, given by

$$\cos\phi = \frac{R\cos\frac{\lambda_s+\lambda_r}{2}+H_o}{R\cos\frac{\lambda_s+\lambda_r}{2}+H_i}$$

where λ_s and λ_r are the latitudes of the source of atmospherics and the receiving point, H_o and H_i the heights of the ozone layer and the E-layer respectively and R the radius of the earth. We are assuming here that the sun follows a path in a plane parallel to the equatorial plane. The assumption does not materially alter the calculation with which we are concerned. Approximately, however, when the source of atmospherics is not too distant, we can write

$$\cos\phi = \frac{R\cos\lambda_r + H_o}{R\cos\lambda_s + H_i} \qquad (2)$$

Again if l_s and l_r are the longitudes of the source S of atmospherics and the receiving point R, the difference between the instant of ground sunrise (or sunset) and the instant when the ionization begins to increase (or decrease) in the region A would be given by

$$\Delta T = 4\phi \mp 2(l_s - l_r) \text{ minutes} \qquad \ldots \quad (3)$$

Further, we have

$$\tan\alpha = \frac{\lambda_r \sim \lambda_s}{l_r \sim l_s} \qquad (4)$$

where α is the direction of arrival of the atmospherics at the receiving point with respect to north-south.

Thus if for the receiving point the latitude λ_r and longitude l_r are known, it is possible to find the latitude λ_s and longitude l_s of the thunderstorm centre from (2), (3) and (4), if the time of occurrence of the sunrise (or sunset) maximum relative to ground sunrise (or sunset) and the direction of arrival of the atmospherics are known. The angular distance of the thunderstorm centre from the receiving point can then be obtained from the formula :

$$\widehat{SCR} = \cos^{-1}[\sin\lambda_s . \sin\lambda_r + \cos\lambda_s . \cos\lambda_r . \cos(l_s - l_r)] \qquad \ldots \quad (5)$$

The actual distance is easily determined by multiplying the angular distance by the radius of the earth.

For Dacca as the receiving point

and taking the following data :

Radius of the earth

Reflexion height in the E-layer from the earth's sur

Ozone layer height

we get $\phi = 7^{\circ}$

With this value of ϕ and with the observed valt
centres can be easily calculated.

TIME OF OCCURRENCE OF SUNRISE MAXIMA OF ATMOSPHERIC PARTICULAR CASES

East-West direction For the east-west directioi
evident $\lambda_s = \lambda_r$. So long as the source of atmospherics is
receiving point *i.e.*, $l_s > l_r$, and the distance is within tl $) = 2\phi$, the atmospherics maximum is expected to appear *before* ground sunrise and *after* ground sunset. Within this limit, the greater is the distance between the receiving point and the noise source, the smaller is the difference in time between ground sunrise (or sunset) and the time of occurrence of the atmospherics maximum. When the distance is such that $2(l_s - l_r) = 4\phi$, a maximum is expected at the ground sunrise (or sunset). When the distance exceeds this limit, the atmospherics maximum appears *after* the ground sunrise and *before* the ground sunset.

When the source of atmospherics is to the *west* of the receiving point $l_s < l_r$, and the distance is within the limit $(l_r - l_s) = 2\phi$, the maximum would appear *after* the ground sunrise and *before* the ground sunset. Within this limit, the greater is the distance between the noise source and the receiving point, the smaller is the difference in time between ground sunrise (or sunset) and the time of occurrence of the maximum. In the same way, again, when $2(l_r - l_s) = 4\phi$, a maximum would appear at the ground sunrise (or sunset). When the distance exceeds this limit the maximum would appear *before* the ground sunrise and *after* ground sunset.

North-South direction.—For the N-S direction *i.e.*, it is evident $l_s = l_r$. Thus the atmospherics maximum is always expected at 4ϕ min. before ground sunrise or 4ϕ min. after ground set.

SUCCESSIVE REFLEXIONS FROM THE IONOSPHERE

Successive reflexions from the ionosphere would, however, cause atmospherics maxima to appear one after another at regular intervals of time. For this, the location of thunderstorm centre requires careful consideration. Let

S and R denote respectively the source of atmospherics and the receiving point in the E-W plane. For a single ionospheric reflexion, A is the point where such reflexion takes place (Fig. 3). For double reflexion, X and Y are the points where reflexion occurs. For a single reflexion, the difference of time between ground sunrise (or sunset) and the time of occurrence of maximum is given by

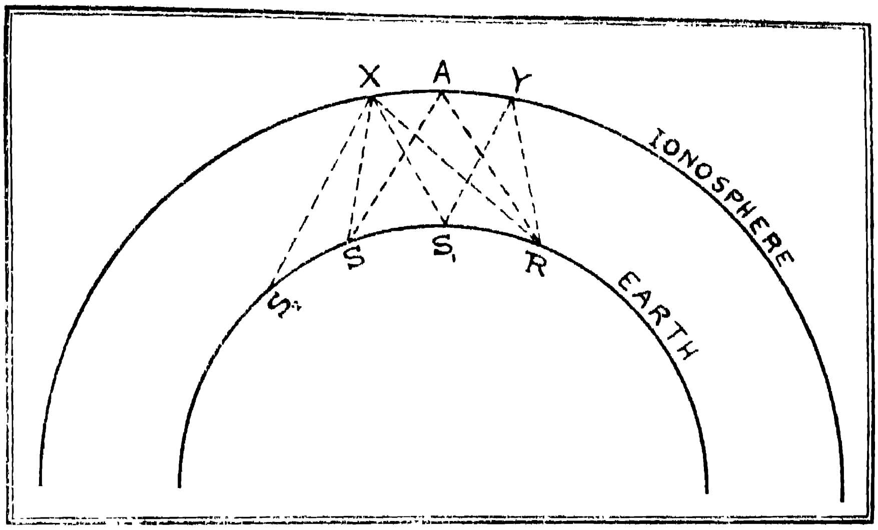

FIG. 3

$$\Delta T = 4\phi - 2\theta,$$

where θ is the angular distance between S and R.

In the case of successive double reflexion, for the *second* reflexion at Y, $(\Delta T)_2 = 4\phi - \theta$, the 'virtual' source being at S_1, whereas, for the *first* reflexion at X, $(\Delta T)_1 = 4\phi - 3\theta$, the virtual source being at S_2. The difference of $(\Delta T)_2$ and $(\Delta T)_1 = 2\theta$ min. Thus if single as well as successive double reflexions occur simultaneously between S and R, three maxima will appear successively at $(\Delta T) = 4\phi - \theta$, $4\phi - 2\theta$ and $4\phi - 3\theta$, the successive intervals of time being θ min.

In locating thunderstorms centres from directional observations of distant atmospherics, the above considerations are of importance.

THE D/F EQUIPMENT AND EXPERIMENTAL PROCEDURE

The D/F equipment

Briefly the D/F equipment consisted of the following :—

(1) A pair of 'crossed' loop, 6 ft. sq. with 10 turns of S.W. No. 7/22 stranded copper wire. The plane of one aerial was in the N-S direction and that of the other in the E-W direction. Each was tuned to 1000 metres.

(2) The two loop aerials were connected to two similar H/F amplifier units. The circuit diagram of each is shown in Fig. 4.

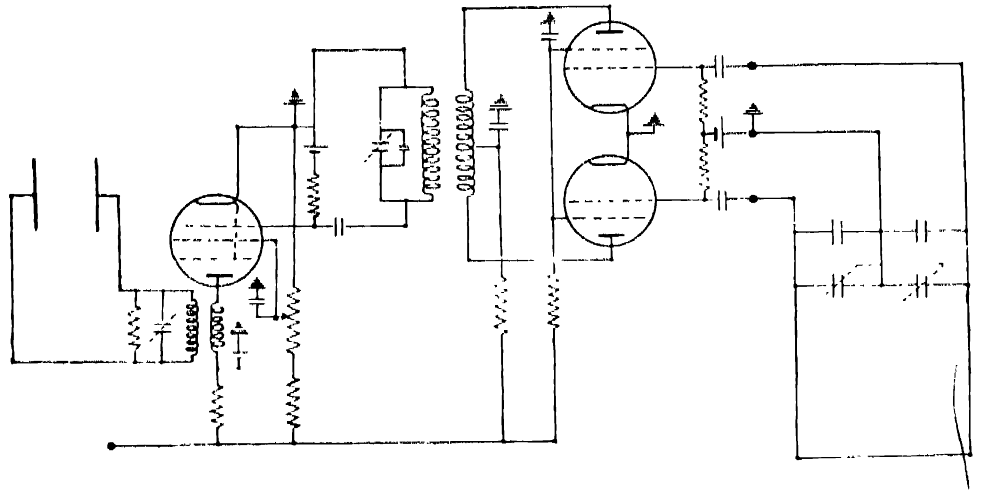

FIG. 4

(3) *The Oscilloscope.*—To a pair of the deflecting plates was connected the output of one amplifier and to the other pair was connected the output of the other amplifier.

When the atmospheric pulse was received by the aerial-system, currents were induced into the two aerials each tuned to 1000 metres. The voltages developed across the tuning condensers were then amplified and the amplified voltages applied across the two pairs of deflecting plates in rectangular directions yielded a straight line on the oscillograph screen. The inclination of the straight line gave the direction of arrival of the atmospherics for which the particular straight line response was obtained. In the experimental arrangement, the straight line sweep on the oscillograph screen in the vertical direction indicated 0° representing N-S. The orientation of the line in the clock-wise direction indicated increasing angles towards the E-W. The directions were obtained on a transparent scale held in contact with the surface of the oscillograph screen.

(4) *Balanced Oscillator.*—For proper adjustment of the D/F equipment, an oscillator producing oscillations corresponding to 1000 metres with 'pairs' of balanced 'bleeder' resistances in the output circuit was employed. With equal voltages obtained from the pair of bleeder resistances and applied across the tuning condensers of the two loop aerials, the linear response on the oscillograph screen was noted and by adjusting the gain of one or the other of the amplifiers, the straight line response was made to point exactly in the direction of 45°. The 45° alignment was made each time before a set of directional observations of atmospherics was taken.

EXPERIMENTAL PROCEDURE

Each day when sunset observations were decided upon, it was arranged to take continuous observations of the directions and magnitudes of the linear responses for 10 mins. before and 30 to

40 mins. after the ground sunset for the day. On the transparent scale was marked straight lines in ink showing directions at intervals of 10° round the centre which coincided with the undeviated central spot on the oscillograph screen. The number of atmospherics recorded in 2' mins. was then counted for each direction. The sum of the magnitudes of the linear responses for the same 2' mins. was also found for each direction. This measured what may be called the *atmospherics activity*, during the period of 2' mins. The number and the 'activity' of the atmospherics were then separately plotted against time for the different directions. From the time of occurrence of the observed maxima with reference to the ground sunset time, the locations of the source of atmospherics was found in the way already explained.

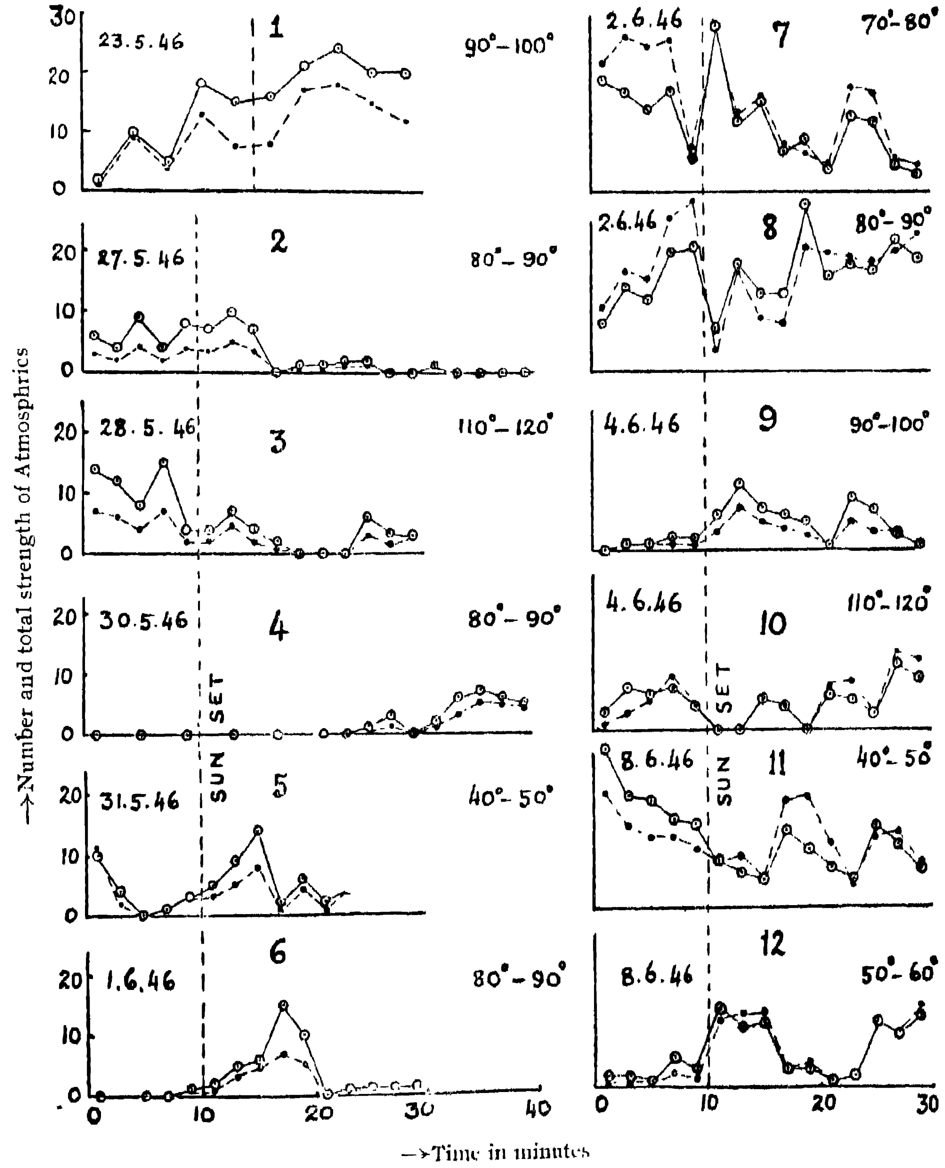

FIG. 5

EXPERIMENTAL RESULTS

Some typical directional observations out of a large number taken during the course of about a month in May-June, 1946, are given here. The twelve sets of observations for atmospherics coming from different directions are illustrated in Fig. 5. The graphs clearly show the maxima in *number* and *activity* of the atmospherics during sunset period. *Usually* the positions of the maxima coincide for atmospherics number and activity. Due to comparatively long period of observations after the sunset and only a short period before it, the maxima after senset were observed more than those before sunset. It is evident from theoretical considerations that the maximum after ground sunset *usually* denotes the arrival of the atmospherics after ionospheric reflexion from a thunderstorm centre on the eastern side of the receiving point and similarly the maximum before sunset usually indicates the arrival of the atmospherics from the western side of the receiving point, except for *very distant* atmospherics which are too feeble to be recorded on the oscillograph.

One distinct case of successive double reflexion simultaneously occurring with the usual single reflexion between the source of atmospherics and receiving point is shown in curve No. 10, where there are three successive peaks at regular intervals. The location of the source of atmospherics is in such cases obtained with reference to the middle peak. It is likely that the curves Nos. 9 and 11 represent two other similar cases where possibly the farthest of the three successive peaks was not observed.

LOCATIONS AND DISTANCES OF THUNDERSTORM CENTRES

In Table I are entered the locations and distances of thunderstorm centres for the twelve cases as calculated from the observed times of occurrence of the atmospherics maximum after or before the ground sunset time. The interval of time is taken as positive or negative according as the maximum occurred after or before the ground sunset.

TABLE I

T (min)	Location of Thunder-storm centres	Distance	Remarks
1. (*a*) + 7.5	100°.65 E 22°.8 N	1034 Km.	
(*b*) − 5.0	78°.9 E 22°.7 N	1190 Km	
(*c*) − 10.5	81°.65 E 22°.9 N	900.7 Km	
2. (*a*) + 3	102°.9 E 24°.8 N	1278 Km.	

TABLE I (*contd.*)

	(*b*)− 5	78°.9 24°.7	E N	1179 Km	
3.	(*a*)+15	96°.9 20°.7	E N	756.1 Km.	
	(*b*)+ 3	102°.9 17°.9	E N	1156 Km.	
	(*c*)− 3	77°.9 17°.9	E N	1456 Km.	
4.	(*a*)+25	91°.4 23°.8	E N	1809.0 Km	
	(*b*) +17	95°.9 24°.2	E N	978.2 Km	
5.	(*a*)+ 9	99°.9 14°.2	E N	1456 Km	
	(*b*)+ 5	101°.9 12°.2	E N	1764 Km	
6.	+ 7	100°.9 24°.6	E N	1068 Km	
7.	(*a*)+13	97°.9 25°.7	E N	705 Km	
	(*b*)+ 5	101°.9 26°.8	E N	1208 Km	
	(*c*)+ 1	103°.9 20°.1	E N	1431 Km.	
8.	(*a*)+ 9	99°.9 24°.5	E N	98[illegible].9 Km	
	(*b*)+ 3	102°.9 24°.8	E N	1276 Km	
9.	(*a*) .. (*b*)+13 (*c*)+ 3	97°.9 23°.0	E N	773.9 Km	Multiple reflexion
10.	(*a*)+17 (*b*)+11 (*c*)+ 5	98°.9 23°.3	E N	867.4 Km.	Multiple reflexion
11.	(*a*) ... (*b*)+15 (*c*)+ 7	96°.9 30°.2	E N	967.4 Km.	Multiple reflexion
12	(*a*)+15	96°.9 28°.3	E N	834.1 Km.	
	(*b*)+ 5	101°.9 31°.8	E N	1445 Km.	
	(*c*)− 3	77°.9 32°.5	E N	1575 Km	

CONCLUSION

The thunderstorm centres on the eastern side of Dacca were mostly in Burma near the Shan States. Few records showed that the atmospherics originated in the western side of Dacca were mostly from Central India. The thunderstorm centres as found from the twelve sets of atmospherics records ranged from 189 to 1764 Km.

ACKNOWLEDGEMENT

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REFERENCES

Eccles, (1918), Handbook of Wireless Telegraphy and Telephony, 176.
Espenschied, Anderson and Bailey, (1926), *Proc. I R.E.*, **14**, 7.
Khastgir, (1942), *Science and Culture*, **11**, 233.
Khastgir and Basak, (1942), *Current Science*, **11**, 392.
Khastgir and Kameswar Rao, (1940), *Proc. I.R.E.*, **28**, 511
Khastgir and Innas Ali, (1942), *Ind. J. Physics*, **16**, Part 6, 399.
Khastgir and Majumdar, (1942), *Science and Culture*, **11**, 235.
Khastgir and Ray, (1940), *Science and Culture*, **5**, 772.
Mitra, (1938), *Science and Culture*, **3**, 496
Namba, (1933), *Proc. I.R.E.*, **21**, 238.
Potter, (1931), *Proc. I.R.E*, **12**, 1731
,, (1932), *Proc. I.R.E.*, **20**, 1512.
Subba Rao, (1941), *Proc. Nat Acad. Science* (*India*), **14**, No. 2, Sec. B.
Venkata Rao Telang, (1941), *Proc. Ind. Science Congress*, Paper No. 20, Physics Section.