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**Report of the Indian Expedition to Ceylon to observe
the Total Solar Eclipse of 20 June 1955**

1. Introduction

The eclipse of 20 June 1955 was one of exceptionally long duration and was of special interest to the Kodaikanal Observatory, as the path of totality passed very close to the southern tip of India.

From a general consideration of the climatic features of the regions along the path of totality of the eclipse it seemed that the so-called "dry zone" of Ceylon offered the most favourable weather conditions for observing the eclipse. This view was evidently shared by many other expeditions also, for there were in Ceylon expeditions from Britain, U.S.A., Germany, France, Switzerland, Holland and Japan.

An advance party of four members under the leadership of Dr. A. K. Das, Deputy Director General of Observatories, Astrophysical Observatory, Kodaikanal, left Kodaikanal on 17 May 1955 with nearly 5 tons of equipment and reached the eclipse camp at Hingurakgoda, Ceylon on the 19th. During Dr. Das's earlier exploratory visit, the Director of the UNESCO Fundamental

Education Centre, Hingurakgoda, Ceylon had kindly placed at the disposal of the Indian expedition the Women's Hostel of the Education Centre and the adjoining grounds. Selection of proper sites for the various instruments and their installation were carried out during the first two weeks.

The second party of three members including Dr. T. M. K. Nedungadi, Assistant Director, Kodaikanal Observatory and Mr. B. N. Bhargava, Meteorologist, arrived at the eclipse camp on 14 June 1955. Besides the above seven members, there were four other volunteers with scientific training who came to Ceylon a few days before the eclipse day and helped the expedition. Intensive rehearsals with all the optical instruments were carried out for some days prior to the eclipse day. Although adequate arrangements had been made, during Dr. Das's exploratory visit to Ceylon, for electricity supply to the camp for running the radio instruments, two petrol-driven M.G. sets, one of 2·5 KW and the other of 400 watt capacity were taken with the

We are grateful to Dr. A. K. Das, Leader of the Expedition for his detailed notes from which this article has been prepared—*Editor*

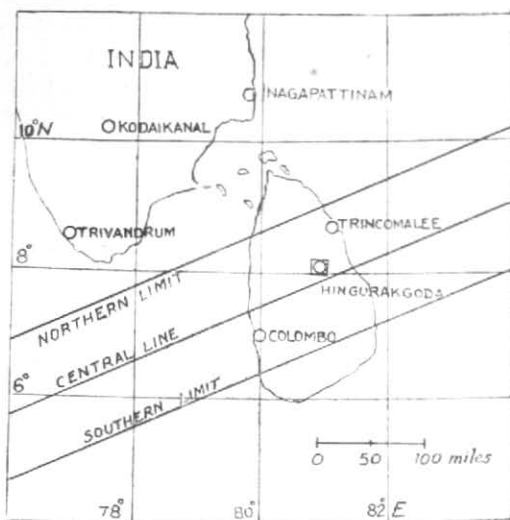


Fig. 1. Map showing belt of totality and observing sites at Hingurakgoda, Ceylon and Kodaikanal

party as a standby measure. On the eclipse day the 2.5 KW generator was kept running and ready to be put into service at a moment's notice in the event of a failure of the town electricity supply.

Fig. 1 shows the path of totality of the eclipse and the location of the expedition sites at Hingurakgoda, Ceylon. The circumstances of the eclipse at Hingurakgoda are as given below—

	<i>h</i>	<i>m</i>	<i>s</i>	(IST)
First contact	07	08	19	
Second contact	08	12	11	
Third contact	08	16	53	
Fourth contact	09	31	32	

The circumstances of the eclipse at Kodaikanal for ground level and for several heights in the ionosphere are given in Table 1.

The programme of observations of the Indian expedition at Hingurakgoda during the eclipse was divided broadly into four parts—

- (a) Optical observations
- (b) Ionospheric observations
- (c) Geomagnetic observations and
- (d) Radio-astronomical observations

TABLE 1

Height	Time (IST) of						Magni- tude
	First contact		Maximum phase		Last contact		
	<i>h</i>	<i>m</i>	<i>h</i>	<i>m</i>	<i>h</i>	<i>m</i>	
Ground level	07	08.4	08	11.9	09	25.2	0.914
100 km	07	06.8	08	10.2	09	23.6	0.912
200 km	07	05.1	08	08.5	09	22.0	0.910
300 km	07	03.5	08	06.7	09	20.3	0.908
400 km	07	01.8	08	05.0	09	18.6	0.905

Arrangements were also made to supplement the optical, ionospheric and geomagnetic observations at Hingurakgoda with intensive observations at Kodaikanal Observatory.

The various items of observation carried out at Hingurakgoda under the four broad heads are described together with the general results in the following sections.

2. Optical observations

- (i) Photographing the flash spectrum using a three-prism spectrograph of 6 feet focal length in conjunction with a coelostat and a parabolic reflector
- (ii) Photographing the spectrum of the inner corona with a low-dispersion spectrograph in conjunction with an 8" object glass of 9½ feet focal length and a Foucault siderostat
- (iii) Direct photography of the corona in red light using a camera of 10" focal length provided with an arrangement for measuring the polarisation at great distances from the sun's limb
- (iv) Direct photography of the corona in blue-violet light using a camera of 48" focal length with arrangement for measuring polarisation in the corona

- (v) A photographic polarimeter using an object glass of 24" focal length for determining the polarisation of the corona in green light at various distances from the sun's limb.

All the above instruments had devices for photographic photometry.

Because of cloudiness during the total phase of the eclipse, the Indian expedition was not able to carry out the optical observations outlined above. The other observing teams at Hingurakgoda such as the British, German, Dutch and French, as also the British, Japanese and Swiss teams at nearby Polonnaruwa, whose programmes were entirely optical, also completely failed to make any observations. An American team at Sigiria is, however, reported to have made some observations of the infra-red spectrum of the corona through relatively thin cloud.

3. Ionospheric observations

(i) *Study of F2 layer during the eclipse*—During several eclipses in the past, attempts have been made to investigate eclipse effects on F2 layer; but these have often been found erratic and controversial. Large and irregular variations in the F2 layer make it difficult to isolate eclipse effects. Fortunately, the eclipse of 20 June occurred in the early morning hours when the ionization of F2 layer is normally increasing smoothly and rapidly and the time was ideally suited for the observation of any discontinuities in the slope of the diurnal curve due to sudden masking of ionizing radiation. Observations over a period of 15 days including seven days on either side of the eclipse day have been utilized in this study. For coronal activity in green (5303 Å) line, a diagram was reconstructed from data from Climax, Colorado. Since it is known that bright coronal regions or streamers have a life time upto several months and rotate with approximately the same period as the photosphere, the

positions of active regions on the disc was estimated from available observations on the limbs by applying the solar rotation period. The state of the solar corona on the disc obtained in this manner together with the path of the moon's centre is shown in Fig. 2.

The results of the study are indicated briefly below—

A discontinuity in the F2 critical frequency curve observed 22 minutes before the commencement of the eclipse at 250 km level pointed to its possible connection with very fast corpuscular radiation of speed of about 8700 km sec⁻¹ of whose existence there is, at present, only little evidence. The reduction could also be due to masking by the moon of ionizing wave radiation from the corona at a distance of about 500,000 km from the limb of the sun. From the coronal activity on the day shown in Fig. 2 it was noticed that there was no markedly bright coronal region in the SW limb at about 7° S heliographic latitude where the moon was nearest to the sun at the time the discontinuity was observed. The origin of the discontinuity before the commencement of the eclipse, therefore, cannot be satisfactorily explained from a consideration either of corpuscular eclipse effects or of masking of coronal wave radiation.

The principal effects marked by a reduction in electronic density commenced a few minutes before the first contact and were simultaneous with the covering by the moon of the region containing an active sunspot group in the SW quadrant of the solar disc. The ion-density of the F2 layer decreased from the expected value for the day by about 33 per cent, the minimum of ionic density occurring 18 minutes after the maximum phase of the eclipse. The recovery was simultaneous with the uncovering of the active spotgroup and provided definite evidence of enhanced radiation (effective for the formation of F2 region) from the vicinity of the spotgroup.

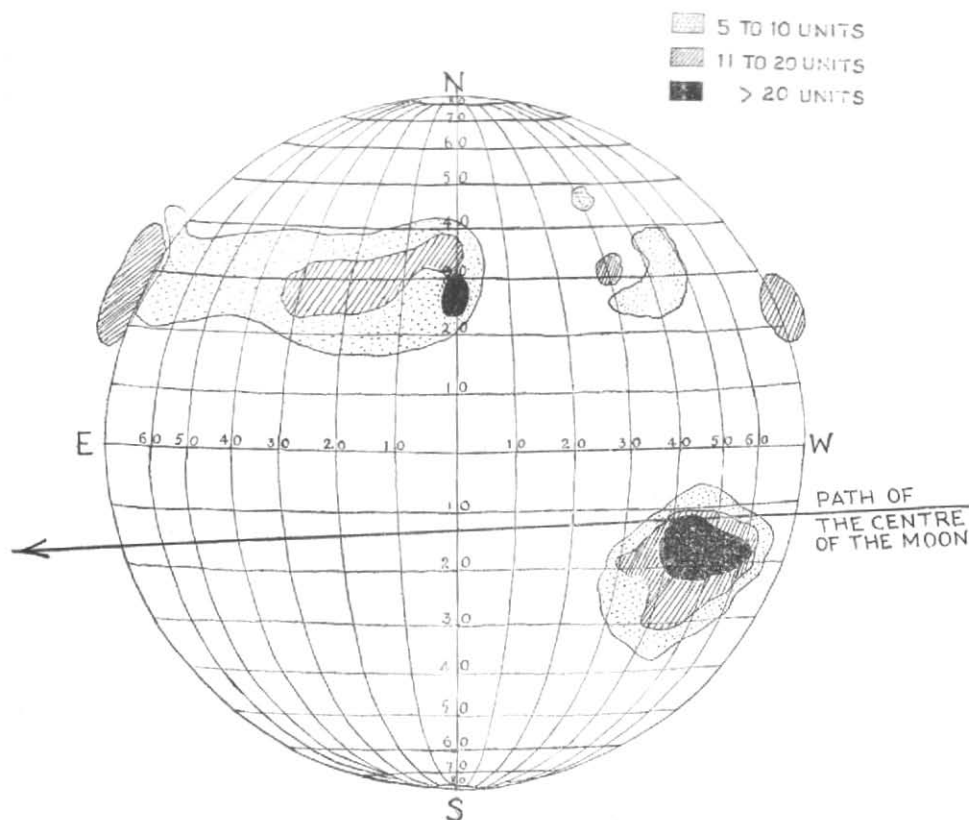


Fig. 2. Coronal activity on eclipse day and path of moon's centre

The period after the maximum phase was marked by rapid change in layer shape, formation of a new layer and vertical transport of ions in the F2 region. The pre-eclipse F2 region commenced to rise vertically 15 minutes after the maximum phase of the eclipse. A new stratification developed intermediate between F1 and F2 layers and its maximum electronic density rose sharply to almost fourfold in two hours. In Fig. 3 are shown the critical frequency of the F2 region on eclipse day and a mean curve obtained from the data of control days.

The new layer eventually replaced the pre-eclipse F2 layer which was registered upto heights of 1000 km and probably continued to exist at greater heights. These effects were similar to ionic drifts occurring

more or less regularly at distinct solar and lunar hours implying a common mechanism for vertical drifts irrespective of the cause of the stratification.

(ii) *Study of Solar Tides in the F2 region over Kodaikanal*—For some time it has been known that tidal oscillations occur in the ionosphere with large amplitudes in equatorial regions. With a view to determining the magnitude of these oscillations in the F2 layer over Kodaikanal, data collected during the eclipse observations were made use of. The values of virtual height and critical frequency at intervals of 30 minutes were used for this purpose. The variations of the two parameters, corrected for non-cyclic variations, were analysed harmonically. The results of the analyses indicate that the values of the amplitudes of the first and the

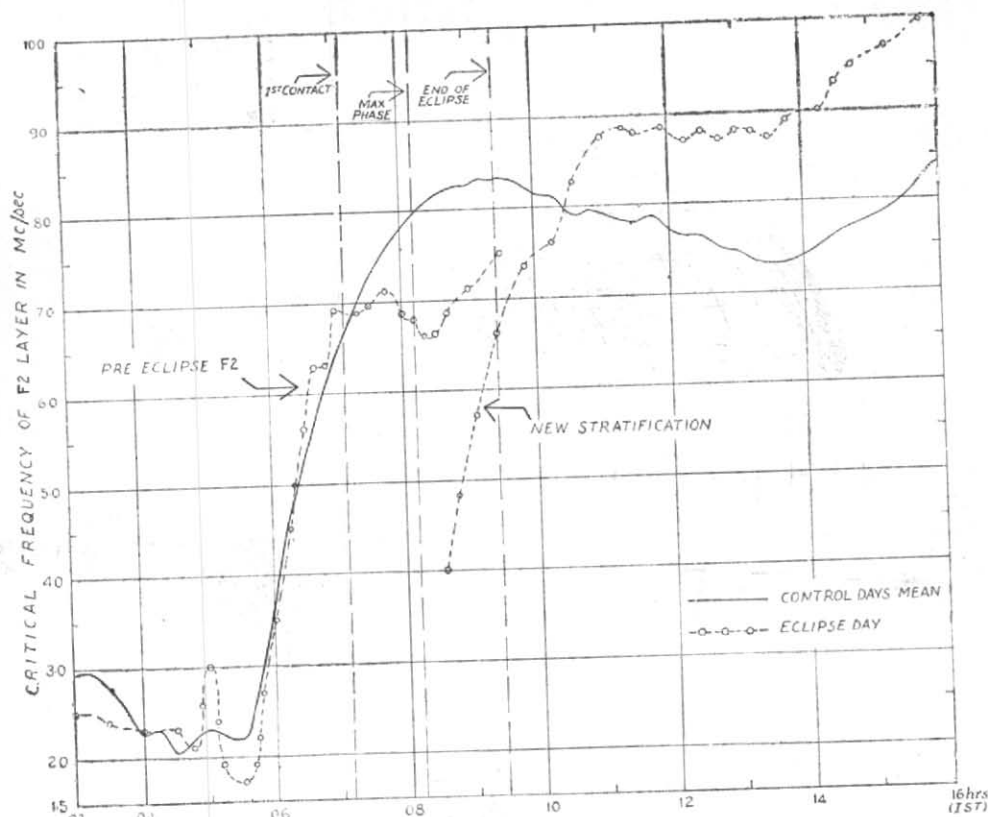


Fig. 3. F2 layer critical frequencies on eclipse day and mean control day

second harmonic coefficients in $h'F_2$ were nearly equal, the mean values being 40.3 and 46.1 km respectively. The standard deviations of the first and the second harmonic coefficients were 11.7 km and 5.85 km respectively. The time of maximum of the first harmonic varied from 6.8 to 14.1 hrs local mean time, but the time of maximum of the second harmonic varied from 0.2 to 1.5 hrs only. These indicate that the most consistent variation was the semidiurnal one. Its amplitude is of the same order as at Huancayo, Peru.

For foF_2 , the mean amplitudes of the first two harmonic coefficients were 2.79 Mc/sec and 1.75 Mc/sec respectively and the times of maximum 14.7 hrs and 8.0 hrs local mean time respectively.

(iii) *The effects of the Solar Eclipse on the lower ionospheric layers*—The behaviour of the lower ionospheric layers, namely, the F1, E and D regions during the eclipse has been studied. The data were collected from ionospheric soundings at one-minute intervals on the eclipse day. Ionospheric records at 5-minute intervals during morning hours throughout the month of June provided control data. Oblique incidence field strength records were made at Hingurakgoda, Ceylon to supplement the vertical incidence data obtained at Kodaikanal. The observed effects on the various layers are described in the following sections. From data of Kodaikanal Observatory, sunspots, calcium flocculi and H-alpha dark markings on the solar disc and K-prominences on the limb as on 20 June were plotted on the solar disc and are reproduced in Fig. 4.

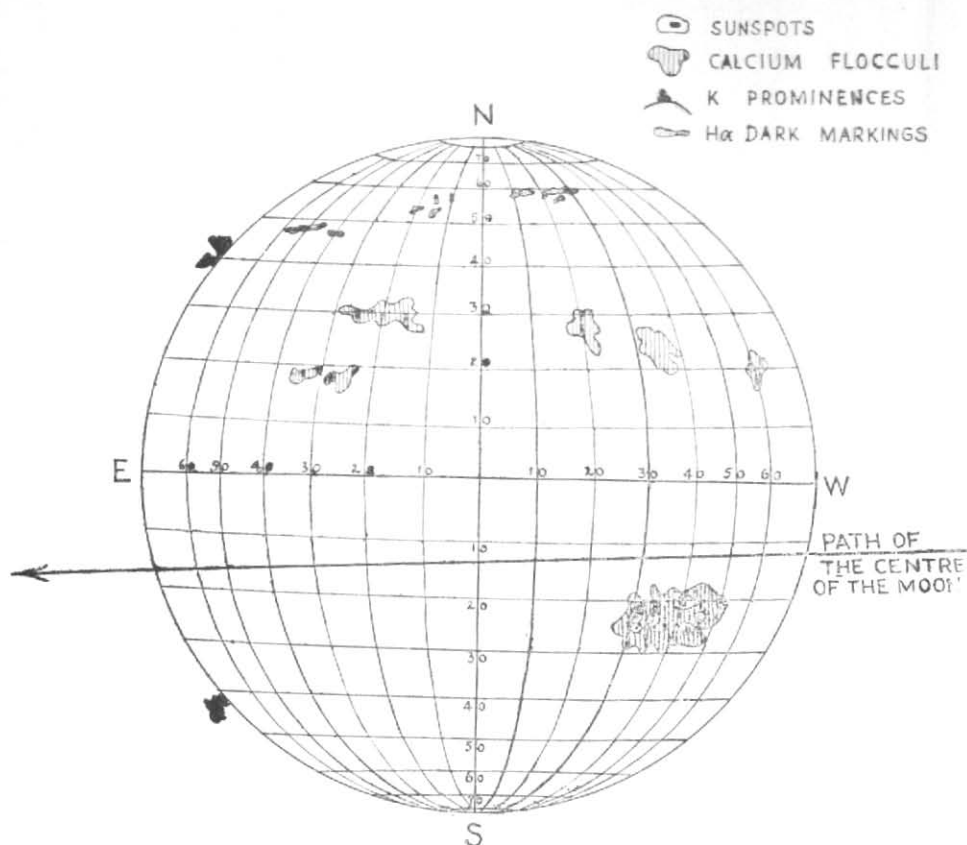


Fig. 4. The state of the sun's activity on the morning of the eclipse day as observed at Kodaikanal

The E-layer—The normal diurnal variation of the E-layer at Kodaikanal is symmetrical about local noon and follows the $(\cos \chi)^n$ law where χ is the sun's zenith angle and n at Kodaikanal is between 0.28 and 0.30. With the commencement of the eclipse the rise in electronic density in the E-layer was arrested and its critical frequency remained at 2.4 Mc/sec for about 8 minutes. Thereafter it fell steadily until 0809 hrs when it attained the lowest value of 1.82 Mc/sec. The minimum electronic density occurred almost simultaneously with the maximum phase of the eclipse at the level of 100 km. The recovery was very rapid between 0809 and 0830 hrs and the electronic density continued to rise afterwards,—more gradually until 0920 hrs. Thereafter the variation of foE followed the normal pattern, the

values of foE being higher for the day than the corresponding median values. The eclipse day and median control day variation of foE is shown in Fig. 5.

By a detailed analysis of the change in the ion-density of the E-layer during the progress of the eclipse, it is shown that the solar ultraviolet radiation responsible for the ionization of the E-layer is not distributed uniformly over the sun's disc and that an active sunspot group situated in the SW quadrant of the sun's disc on the eclipse day was a discrete source of enhanced radiation.

The F1-layer—On the eclipse day the F1-layer was sufficiently developed by 0740 IST to enable scaling of its critical frequency. The lowest value of foF1, viz., 2.5 Mc/sec was reached at 0808 IST also, coincident with the

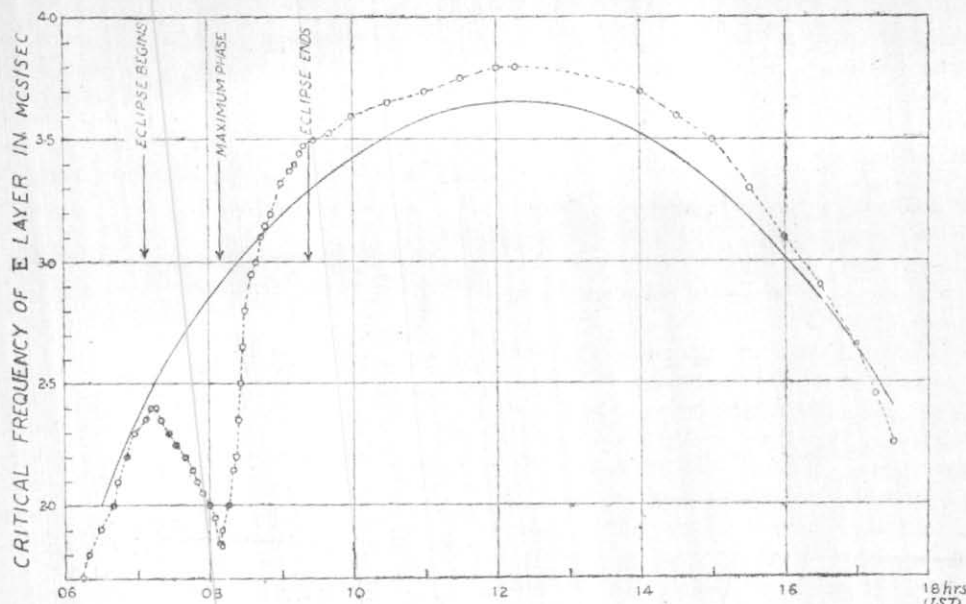


Fig. 5. Variation of critical frequency of the E-layer on eclipse day (dotted line) and mean control day (solid line)

time of maximum phase of the eclipse at the F1-layer level (200 km). Thereafter, f_oF1 rose steadily until 0821 hrs. During the next 9 minutes, the rise was very rapid at the rate of about 0.1 Mc/sec per minute. Again from 0830 hrs f_oF1 rose steadily till the end of the eclipse and followed the normal diurnal pattern for the rest of the day. The rapid rise of the ion-density for 9 minutes between 0821 and 0830 IST occurred simultaneously with the uncovering of the sunspot group in the SW quadrant of the sun's disc, thus indicating that the latter was a source of enhanced radiation. From the minimum observed value of f_oF1 it has been found that the ion-density of the F1-layer decreased by 61.9 per cent at the time of the maximum phase of the eclipse as compared to the mean control period value. Similarly, in the case of the E-layer the electron density was found to decrease by 61.1 per cent. The close agreement in the percentage reductions suggests common solar radiation responsible for the ionisation of the E and F1-layers.

The D-layer—(a) The changes in the ionisation of the D-region were studied in an indirect manner from observations of the lowest

frequency from which reflections are observable from the E-layer, ($f_{\min}E$). The $f_{\min}E$ values on the eclipse day were generally much higher than the values during control period. With the commencement of the eclipse $f_{\min}E$ values decreased progressively, but the fall was not steady and uniform. The lowest value of $f_{\min}E$, 1.45 Mc/sec was reached at 0747 hrs and another minimum of 1.5 Mc/sec at 0807 hrs which was near about the time of maximum phase in the D-layer. As in the case of E and F1 regions there was an abrupt rise of $f_{\min}E$ at the time of uncovering of the active sunspot group, again indicating the existence of a source of enhanced radiation in the vicinity of the group.

(b) At Hingurakgoda, Ceylon, ionospheric field intensity measurements were made on the eclipse day and on a number of days before and after. The equipment consisted of a Hammerlund Communication Receiver, Model SP-600-J, the A.V.C. voltage from which was fed on to a D.C. amplifier and thence to a recording milliammeter. The receiver was tuned to broadcast signals at a frequency of 770 Kc/sec radiated from the

Trichinopoly Station of All India Radio. These transmissions during the morning hours were specially arranged by the A.I.R. for the study of the strength of the received signals during the eclipse.

An analysis of the field strength records made at Hingurakgoda indicates that on the eclipse day the signal strength at 770 Kc/sec increased appreciably between about 0750 and 0830 IST, when compared with the corresponding values on the preceding and succeeding days. This increase in signal strength was apparently due to reduced absorption of the signal within the D-layer, during the course of its transmission from Trichinopoly to our receiving station at Hingurakgoda via the E or sporadic E-layer, the decreased D-layer absorption resulting from the low ion-density during the eclipse. The results of the observation of the D-layer by the field strength measurement technique are consistent with those deduced indirectly from the vertical incidence observations of D-layer at Kodaikanal.

Thus it is seen that the eclipse considerably affected the ionization in all the three layers, D, E and F1, confirming that the main source of ionization in the three layers is the ultraviolet radiation from the sun. An active sunspot group in the SW quadrant of the sun's disc was identified as the source of enhanced ionizing radiation in the D, E and F1 regions.

4. Geomagnetic observations

(i) *Study of the Geomagnetic variations during the total solar eclipse*—Geomagnetic observations were made at Hingurakgoda, Ceylon as part of the general eclipse programme of the Astrophysical Observatory, Kodaikanal. The instrumental equipment consisted of—

(1) Two Eschenhagen Magnetographs, one for recording the Horizontal Force and the other for the Vertical Force, both recording photographically with a chart speed of 15 mm per hour

(2) An 'Askania' Magnetic Field Balance for Horizontal Force with a chopper-type recorder giving a directly visible ink record

(3) Quartz Horizontal Magnetometer (QHM) with three tubes for calibrating the H.F. instruments.

(4) Zero Balance Magnetometer (BMZ) for calibrating the V.F. instruments.

All these instruments were housed in tents with sufficient spacing so as to avoid interaction between the magnet systems. Calibration experiments were performed daily for fixing independently the base-line values of each day's records. H.F. and V.F. records were available from 11 to 23 June except with the loss of H.F. record on the 18th.

From a study of the magnetograms and considering the values of the International Magnetic Character Figures, 11th, 13th and 21st were selected as control days for the study of the variation in H.F. on the eclipse day and 11th, 18th and 21st were selected as control days for studying the eclipse variation in V.F. These days were of course magnetically the calmest days.

(ii) *Results*—The analysis of H.F. data on the eclipse day indicated a decrease in H.F. during the eclipse. This is shown in Fig. 6 where the absolute values of H.F. for 10-minute intervals are plotted against time for the period 0600 to 1200 IST. The continuous-line curve shows the trends in H.F. on the eclipse day and the dashed line gives the corresponding mean values of the control days. It will be seen that the eclipse day values began to drop below the normal at about 0710 hours, almost simultaneously with the commencement of the eclipse. The maximum decrease in H.F. was registered at 0810 hours which was about a minute before the total phase. This departure works out to 18 gammas. This was followed by gradual recovery and the normal diurnal trend. The average level of H.F. remained high for the day compared to the average level on the control days.

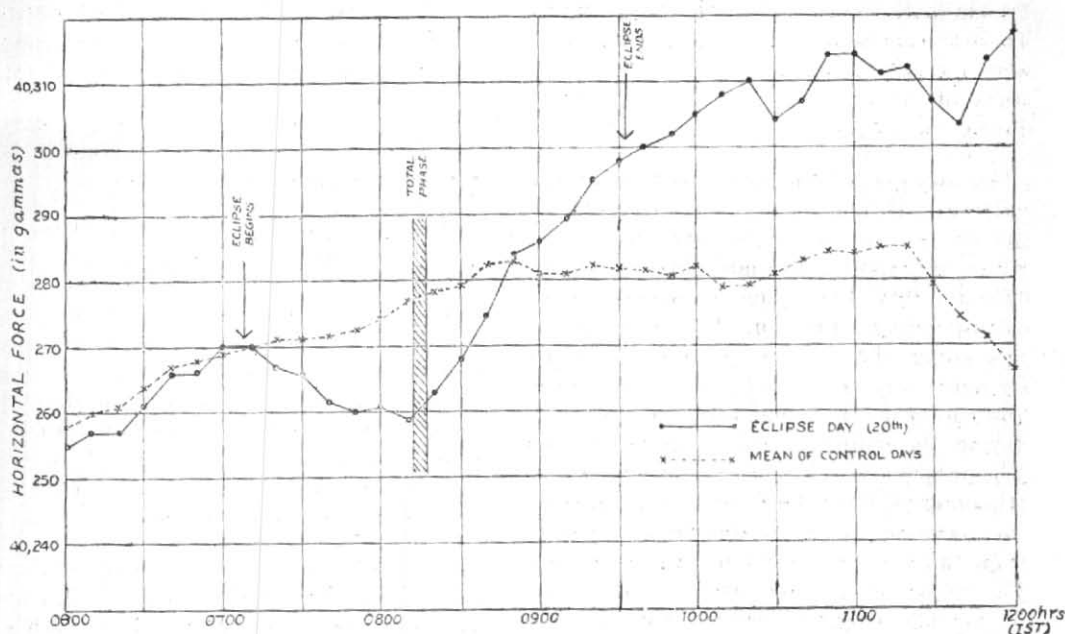


Fig. 6. Variation of the horizontal force of the earth's magnetic field at Hingurakgoda, Ceylon on eclipse day (solid line) and mean control day (dotted line)

According to Prof. S. Chapman's theoretical investigations the value of H.F. during the eclipse can be expected to deviate towards the value obtainable a few hours before dawn by about one-third the way. This fractional departure according to theory works out to 0.22-0.28 depending upon the height at which the currents which influence the Solar Daily Variation of the earth's magnetic field are assumed to flow. In the investigations conducted during the present eclipse the fractional departure works out to 0.29 which is very close to Prof. Chapman's theoretical value of 0.28, obtained on the basis that the currents producing the Solar Daily Variation were confined to the E-region of the ionosphere at a height of 96 km. Thus our value of 0.29 for the fractional departure appears to provide strong evidence in support of the view that the seat of Solar Daily Variation of the earth's field is the E-region of the ionosphere. Prof. Chapman's theory also postulates that the eclipse effect should be a maximum when the site of observation is at the centre of the area of

shadow cast in the ionized layer by the eclipse. In our case the site was almost vertically below the centre of the shadow area in the E-layer during the eclipse.

Unlike H.F., the variations in V.F. were not quite conclusive. The V.F. on the eclipse day was observed to be subnormal as compared to the average on control days even well before the commencement of the eclipse. From the beginning of the eclipse to the total phase there was indication of a further decrease; but at about the total phase of the eclipse the trend changed and the value of V.F. began to increase far above the mean of the control days. This increase continued till almost the end of the eclipse after which the curve took up the usual diurnal trend.

5. Radio-Astronomical observations

Observations of Solar Radio Noise on a wavelength of 1.5 metres—A radio-telescope for the observation of radio-emission from the sun at 200 Mc/sec was installed at Hingurakgoda. The receiver was specially constructed at Kodaikanal for the purpose and was

used in conjunction with a Yagi-type antenna with four directors and one reflector. The aerial gain was approximately 12. The registration was made on an Elliot Current Recorder of range 0 to 1 mA with a chart speed of 3" per hour. Observations were commenced a few days before the eclipse day for comparison purposes.

The variations of solar flux deduced from the records have been studied together with the distribution of activity on the disc. A diagram showing this activity (sunspots, calcium flocculi, prominences and dark markings) on 20 June is shown in Fig. 4. The sunspot group in the SW quadrant of the disc was fairly active on eclipse day, although no important flare appears to have been reported from any observatory on that day. No reduction in the received radiation was observed with the commencement of the eclipse. However, 12 minutes afterwards there was a sharp decrease in the received noise which was significantly synchronous with the occultation by the moon of this sunspot group. This decrease continued till 0745 hrs and the level thereafter remained practically constant until 0830 hrs when a gradual recovery was observed to commence. This recovery continued for the rest of the duration of the eclipse and was complete almost exactly at the time of the 4th contact.

The above observations were used for deducing the temperature corresponding to the flux of radio radiation at 1.5 metres received from the whole disc of the sun (excluding the sunspot group). Similar calculation was also made for the region of angular diameter 3.2' containing the sunspot group. In both cases it was assumed, as usual, that the source of radio radiation was a black body radiating according to the Rayleigh-Jeans formula. The temperature thus derived

was approximately 1.2×10^6 °K for the whole disc excluding the effect of the sunspot group, while the temperature obtained for the sunspot region was 5.3×10^6 °K. Now, since the temperature of the photosphere is reliably known to be of the order of 6000°K and further since the chromosphere must be opaque to radiation of 1.5 metre wavelength, it follows that the radiation recorded by our radio telescope must have originated in the tenuous solar corona. Accordingly, the above observations mean that on 20 June 1955 the general solar corona had a temperature of the order of 1.2 million degrees, while the corona above the sunspot group in the SW quadrant was much hotter, its temperature being higher than 5 million degrees.

6. Acknowledgement

Grateful thanks are due to Prof. A. W. Mailvaghanam of the Ceylon University for much useful local information supplied in advance in connection with the expedition. Sincere thanks are also due to various official and other bodies at Ceylon for rendering valuable assistance and co-operation as regards the supply of tents, their setting up, customs clearance of scientific instruments, electric supply, transport of equipments etc. Thanks are also due to Dr. Spencer Hatch, Director of UNESCO Fundamental Education Project for placing an entire hostel and its adjoining grounds at the disposal of the party and to the volunteers from the above Education Project for help in carrying out the programme of observations. The strenuous work done by the members of the team and the assistance received by the party from Mr. B. G. Narayan, Prof. W. F. Kibble, Prof. K. R. Gunjekar and Dr. R. Ananthakrishnan who had joined as volunteers are also acknowledged with thanks.