Insolation measurements at Poona during the solar eclipse on 14 December 1955

P. JAGANNATHAN, O. CHACKO and S. P. VENKITESHWARAN

Meteorological Office, Poona

(*Received 21 February 1956*)

1. Introduction

A partial eclipse of the Sun occurred at Poona (18°32′N, 73°51′E) on 14 December 1955. The eclipse commenced at 1039 IST; at 1242 IST the Sun was eclipsed to the maximum extent of 56 per cent and the last contact occurred at 1442 IST. The eclipsed portion of the Sun at maximum phase is equivalent to a circular area with a diameter of 0·750 of that of the Sun.

At the Central Agricultural Meteorological Observatory, Poona, an Eppley pyrheliometer recording the total Sun and sky radiation was in operation. The intensity of the solar energy in the different spectral regions was measured with an Ångström pyrheliometer a few times during the day.

Thermographs recording temperature of the soil on the surface and at 3″ depth and of air in Stevenson Screens at four different heights, *viz.*, ground surface, 4 ft, 15 ft and 30 ft above ground were also in operation.

2. Radiation from the Sun and sky

Fig. 1 shows the portion of the pyrheliometer record for the day round about the period of the eclipse. The average value of the total Sun and sky radiation obtained during the four clear days, *viz.*, two days previous to the eclipse and two days after the eclipse, are indicated in broken line for the period 1000 to 1500 IST. This can be taken to indicate the total Sun and sky radiation that would have been received had the Sun not been eclipsed. The average total (Sun+Sky) radiant energy received during the period 1039 to 1442 IST on the above four days (curve 2) is 297·4 mw. hr. per square cm. The actual total energy received from the eclipsed Sun and sky during the same period is 220·6 mw. hr. per square cm. Thus there had been diminution of energy due to the eclipse of 76·8 mw. hr. per square cm during the period of 4 hours and 3 mins., *i.e.*, a reduction of 25·8 per cent.

The intensity of radiation from the Sun at the time of maximum phase was reduced to 43 per cent. Dogniaux (1954) has observed that during the partial eclipse of the Sun on 30 June 1954 at Uccle, the intensity of radiation from the Sun at maximum phase was reduced to about 14 per cent, the diameter of the equivalent circular area of the eclipse portion being 0·774 of that of the Sun.

If we assume that the energy received from the Sun is radiated with uniform intensity from the entire Sun's disc*, we can calculate the amount of depletion of solar energy at the boundary of the earth's atmosphere. The flux of solar radiation F_t reaching unit area in the horizontal at the

*This, however, is to be taken as a first approximation. It may be mentioned that intensity decreases towards the limb; at distance r from the centre of the Sun the reduction can be represented as a polynomial in $\cos\theta$ where $\theta = \sin^{-1} r/R$ (Minnaert 1952)

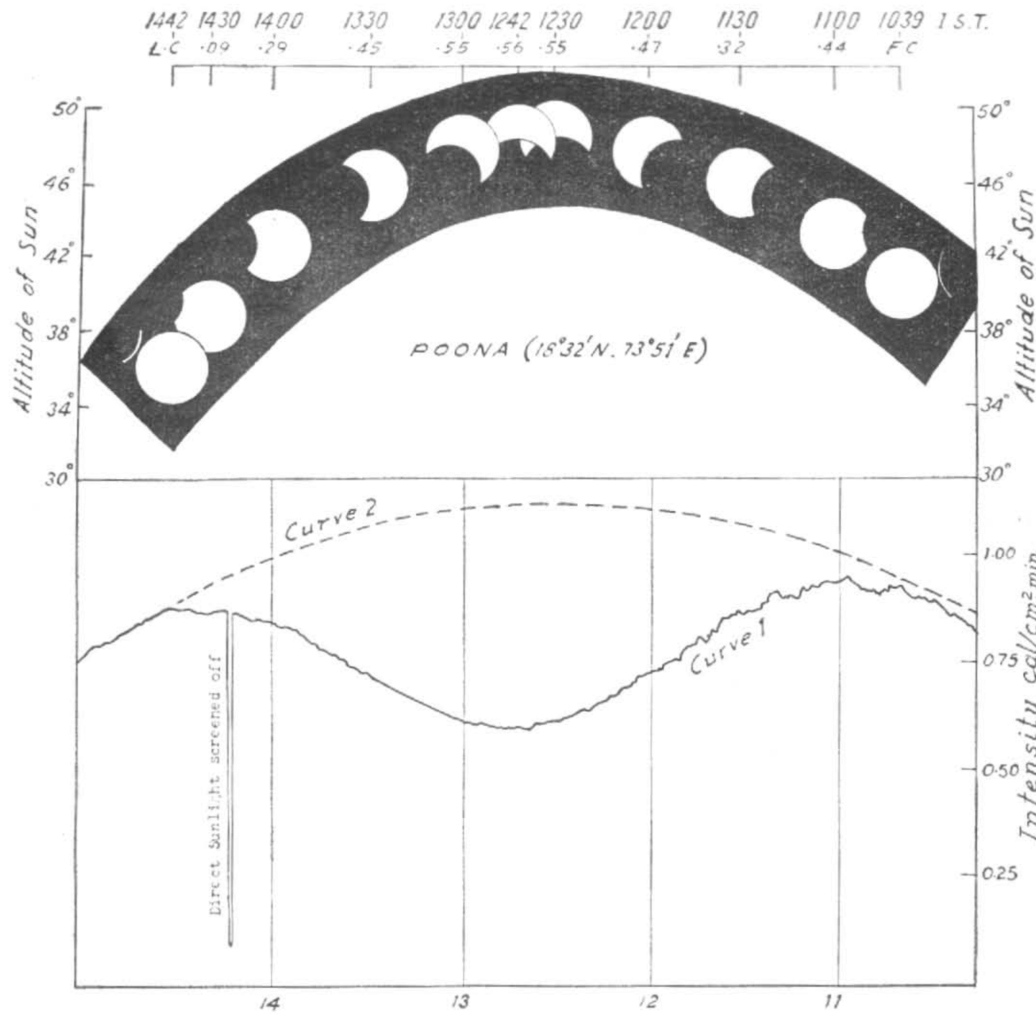

Fig. 1. Total solar radiation on horizontal surface recorded by Eppley Pyrheliometer at Poona during solar eclipse on 14 December 1955

Curve 1 on 14 December and curve 2 average for 12 to 16 December 1955

boundary of the earth's atmosphere at time t can be indicated by—

$$F_t = S\,(1 - w_t)\cos Z_t \Big/ \left(1 - e\cos\frac{2\pi d}{T}\right)^2 \quad (1)$$

where S is the Solar Constant, w_t is the proportion of the Sun obscured by the moon at time t, Z_t the zenith distance of the Sun, e the ellipticity of the earth's orbit, d the number of days from 1 January and T the periodic time in days (365·26 days). The total energy delivered during the time t_1 to t_2 can be obtained by integrating

$$\int_{t_1}^{t_2} F_t\,dt = \int_{t_1}^{t_2} S(1 - w_t)\cos Z_t\,dt \Big/ \left(1 - e\cos\frac{2\pi d}{T}\right)^2 \quad (2)$$

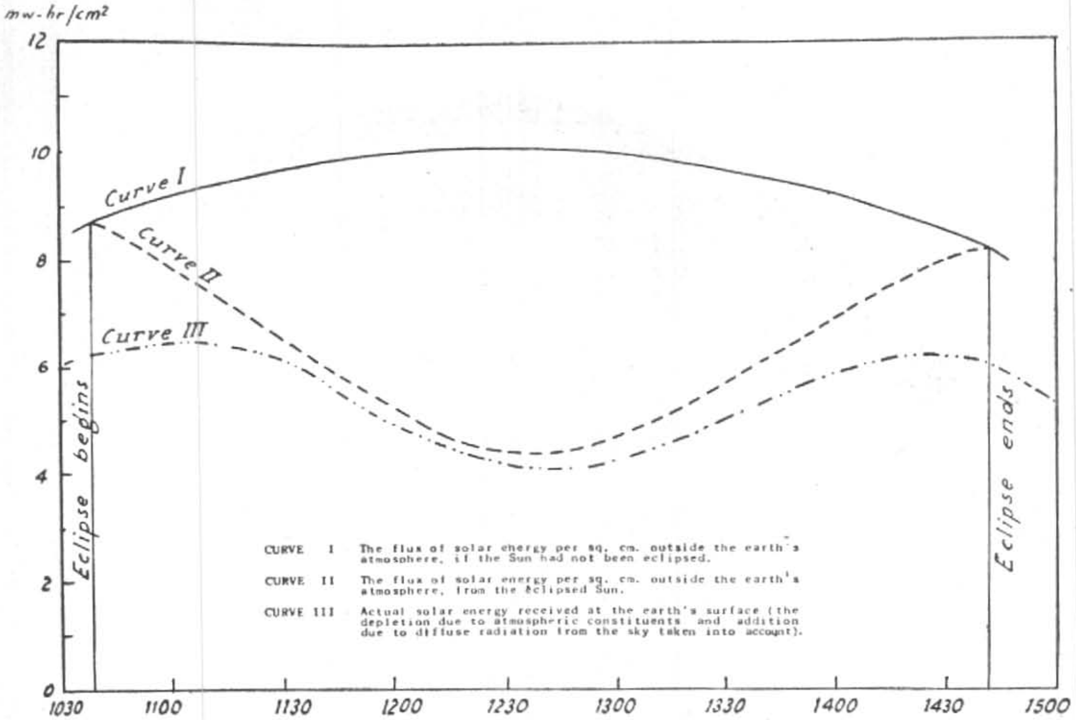

Fig. 2. Solar radiation at Poona on 14 December 1955

and the reduction in the total energy caused by the eclipse can be obtained as—

$$Q_D = \int_{t_F}^{t_L} S\, w_t \cos Z_t \, dt \Big/ \left(1 - e \cos \frac{2\pi d}{T}\right)^2 \qquad (3)$$

where t_F is the time of first contact and t_L is the time of last contact.

Curve I in Fig. 2 gives the solar energy in mw. hr per square cm outside the earth's atmosphere if the Sun had not been eclipsed and curve II gives the energy from the eclipsed Sun*. In the same figure, the solar-energy recorded by the Eppley pyrheliometer has also been given—curve III. It indicates the energy after depletion by the earth's atmosphere.

The total area between curves I, II and III and the abscissa bounded by the time ordinates t_F=1039 IST and t_L=1442 IST give the total radiation (in mw. hr) during the period 1039 to 1442 IST on 14 December 1955 from the uneclipsed and eclipsed Sun, without and with the atmosphere as given below.

	Uneclipsed Sun	Eclipsed Sun (mag. 0·44)
Without atmosphere	392·36	255·51
With atmosphere	297.40	220·60

It is seen that due to the eclipse, (*i*) the diminution in the total radiation without the atmosphere was 34·9 per cent and (*ii*) the diminution in the total radiation with the atmosphere was 25·8 per cent.

*The integral has been calculated using the values S=1·94 cal per sq. cm. per min. (or 135·3 mw. per sq. cm) and e=0·01673 (Landsberg 1945)

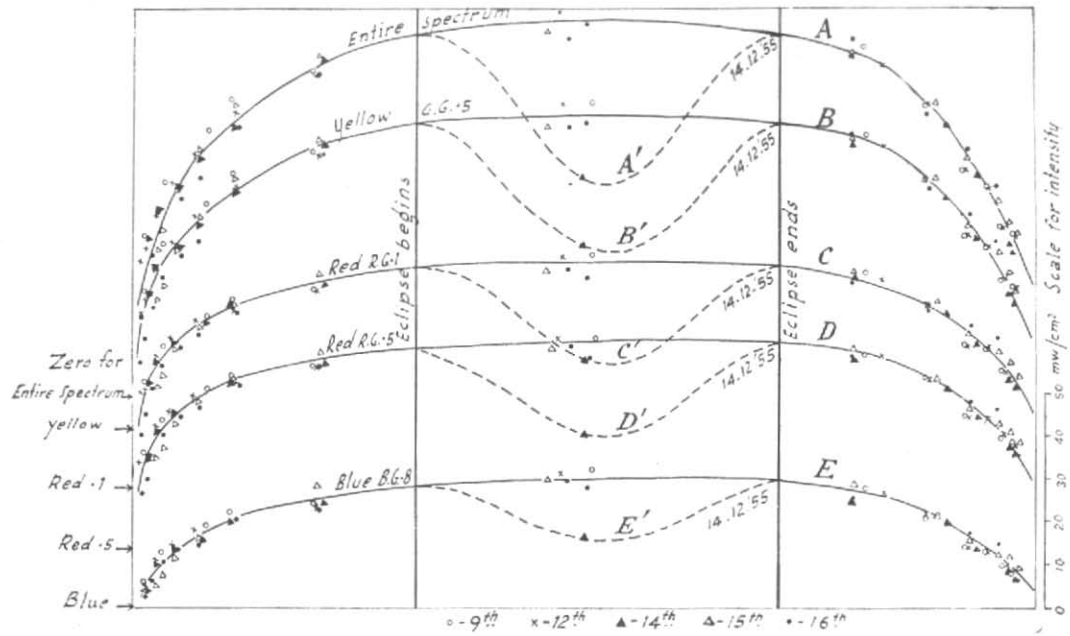

Fig. 3. Intensity of solar radiation in the different spectral regions

If there had been no eclipse, the effect of the atmosphere appears to account for a reduction of the total radiation from the Sun by 24·2 per cent during the period 1039 to 1442 IST. However, during the eclipse, the atmosphere reduces the total available radiation by 13·7 per cent only.

3. Energy distribution in various spectral regions

In Fig. 3, the diurnal variation of the intensity of the solar radiation as well as the intensity of the radiation in the different spectral regions (*viz.*, Blue, B. G. 8, 2·8 μ to 1·2 μ and 0·65 μ to 0·35 μ; Red, R. G. 5, 2·8 μ to 0·675 μ; Red, R. G. 1, 2·8μ to 0·6μ; and Yellow, G. G. 5, 2·8 μ to 0·45μ) during the 5 days, *viz.*, 9th* and 12th prior to the eclipse, 14th—the day of the eclipse and 15th and 16th after the eclipse, have been plotted. These visual observations were taken about 5 times between sunrise and 0930 IST, once about noon and about 5 times between 1530 IST and sunset. The interpolation of the values of intensity between 0930 and noon, and noon and 1530 was made as follows—The continuous record of the Eppley pyrheliometer gives the total radiation, *i.e.*, the direct radiation from the Sun plus the diffuse radiation from the sky, on a unit area exposed horizontally. The solar intensity I_t at any time can be obtained from the radiation recorded by the Eppley pyrheliometer R_t by means of the formula

$$I_t = (R_t - D_t) \sec Z_t \qquad (4)$$

where D_t is the diffuse radiation from the sky†, Z_t is the zenith angle of the Sun at the time t. The value of I_t thus obtained on the 9th, 12th, 15th and 16th along with

*Observations for 13 December 1955 were not available and the nearest days for which observations are available, have been taken

†The depletion due to the atmosphere occurs in both the instruments. The diffuse sky radiation is taken into account in the Eppley pyrheliometer and not in the Ångström instrument. To determine the value of the diffuse sky radiation only, the receiver of the Eppley pyrheliometer is screened from the direct radiation from the Sun with a circular disc 2½″ in diameter at a distance of 3 ft a number of times during the day

TABLE 1

Depression of temperature of air and soil on 14 December 1955 from the average of 4 days— 12, 13, 15 and 16 December 1955

Time (IST)		0900	1000	1030	1100	1130	1200	1230	1300	1330	1400	1430	1520	1600
			F. C. (1039)					G. P. (1242)				L. C. (1442)		
Percentage of sun covered					14	32	47	55	55	45	29	9		
Air temp. in S. screen	30 ft	·6	2·9	2·6	0·9	1·2	1·3	2·7	2·4	2·6	2·7	2·3	1·1	0·8
	15 ft	0·9	2·0	0·9	0·9	0·8	2·0	2·3	2·1	2·8	2·7	1·8	0·9	0·7
	4 ft	1·9	2·1	1·2	0·8	2·2	2·1	3·0	3·0	3·2	3·4	1·6	1·0	1·7
	Ground surface	2·2	2·6	1·5	0·6	2·6	2·4	3·4	3·4	4·3	4·1	1·9	1·9	1·7
Bare soil temp.	Ground surface	0	·3		1·3		8·8		10·9		7·2		3·8	2·7
	3″	1·6	2·3		1·3		·5		3·8		6·1		5·6	4·5

the values obtained with the Ångström pyrheliometer outside the period of eclipse have been utilised for completing the mean curve A (continuous line). The values of I_t for the 14th, along with the Ångstörm pyrheliometer value at 1230 IST on the same day have been utilised in drawing the broken curve A′.

Intensity of solar radiation with different filters were made on 14 December as on other days. There was, however, only one observation at 1230 hrs during the period of the eclipse. The value of the intensity of radiation with different filters we:e plotted as shown in curves B, B′, C, C′, D, D′, E, E′ for all the 5 days. Smooth curves were drawn to fit all the observations. The curve A′ of total radiation on 14 December 1955, was used to indicate the trend of variation in the different spectral regions during the period of eclipse. These curves show the approximate reduction in the intensity of the radiation received during the eclipse in the various spectral regions. The observations made at 1230 hrs which is practically at the time of maximum phase of the eclipse (magnitude 0·55 as against 0·56 at 1242), show the reduction in radiation as given below—

Blue (B. G. 8) ($2·8\mu$–$1·2\mu$ and $0·65\mu$–$0·35\mu$)	45·3%
Red (R.G. 5) ($2·8\mu$–$0·675\mu$)	43·6%
Red (R.G. 1) ($2·8\mu$–$0·6\mu$)	41·3%
Yellow (G.G. 5) ($2·8\mu$–$0·45\mu$)	39·9%
Entire spectrum	41·3%

4. Thermal effects on the soil surface and the atmosphere

The temperature of the soil as measured by thermographs with elements just below the bare soil surface and at 3″ depth and the temperature of air recorded in Stevenson Screens at ground surface, 4 ft, 15 ft and 30 ft above ground level have also shown certain features during the period of the eclipse. In Table 1, the reduction of temperature on 14 December 1955 from the average value for the 4 days, 2 days before and 2 days after the eclipse, are given for the various hours. They bring out the following features—

(*i*) The maximum diminution of temperature of the bare soil surface was of the order of 11°F while at 3″ depth it was about 6·0°F.

(*ii*) The soil surface experienced the maximum reduction practically synchronously with the grand phase of the eclipse, while at 3″ depth it was experienced after about 1½ hours.

(*iii*) The maximum diminution of temperature of air was about 2°F at the surface, decreasing to about 1°F at 15 ft. No definite and appreciable fall of temperature seemed to have occurred at 30 ft.

(*iv*) The maximum decrease in air temperature at and above 4 ft occurred about an hour after the grand phase of the eclipse.

REFERENCES

Dogniaux, R.	1954	Observations de la radiation Solaire durant l'eclipse de Soleil du Juin 1954, Inst. R. Met. Belgique, Publ. 13.
Landsberg, H.	1945	*Handbook of Meteorology*, p. 929, Ed. F.A. Berry, E. Bollay and N.R. Beers, Mc Graw Hill Book Co., New York.
Minnaert, M.	1952	*The Sun*, p. 99, Ed. Gerard P. Kuiper Univ. Chicago Press.