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雑誌名	Science reports of the Tohoku University. Ser. 5, Geophysics
巻	1
号	1
ページ	1-4
発行年	1949-02
URL	http://hdl.handle.net/10097/44407

THE TOTAL SOLAR RADIATION DURING THE ANNULAR ECLIPSE ON MAY 9, 1948

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(Received October 1, 1948)

§1. INTRODUCTION

The observation of the total solar radiation during the annular eclipse on May 9, 1948 was carried out at Wakkanai, Hokkaido, Japan. Our observing station was selected in the court of the Wakkanai Branch of the Physical Institute of Radio Waves (Long. $141^{\circ}41'.1$ E, Lat. $45^{\circ}23'$ N). As the prevailing cyclone was passing by near Saghalien on May 9, the weather was rainy with strong wind from early morning. But dense clouds began to break and the weather to recover rapidly from about $10^{h}20^{m}$, and miraculously it was nearly fine during the eclipse, and then from the time when the eclipse was nearly over, the sun was covered again by dense clouds. So we could at all events carry out the observation of the total solar radiation. It was however regretted that the sun was covered by clouds at the times of first and fourth contacts and also at times during the eclipse and most regrettably at the time of minimum intensity. Thus our observation was not so satisfactory one. Nevertheless some result was obtained by analysing the result of observation.

§2. DESCRIPTION OF APPARATUS.

For measuring the intensity of radiation two actinometers of Moll-Gorczyński type, which were constructed at the Physical Institute of Tohoku University, were used. The thermopile was made of 14 elements of constantan and manganin. A cylinder fitted with diaphragms, which is same size as that attached to Abbot's silver disk pyrheliometer, was attached to each actinometer to protect the thermopile against disturbing influences. The thermopile of one actinometer was fur-

ther covered by thin glass to protect it against the strong wind of about 6 m/s blowing during the eclipse. The other thermopile was not covered by glass. Fortunately, inspite of the strong wind, the obtained record by the actinometer without glass cover was not so much inflicted fluctuation by wind, it was used for later analysis, and the record by the actinometer with glass cover was used only for reference.

Two Yokokawa's moving coil galvanometers with accessories and suitable resistances were employed for recording the actinometric measurements. To register time mark on the recording paper, the galvanometer circuit was opened in one minute at each 15 minutes interval. At the same time the actinometer was connected to millivoltmeter and the voltage produced by the radiation at that time was

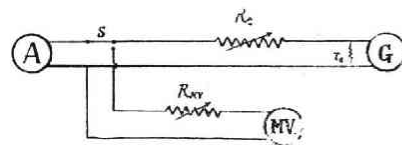


Fig. 1

shown in Fig. 1

read directly for reference. The circuit of one actinometer is

§3. OBSERVATIONS

The obtained records of the galvanometer deflection by the solar radiation during the eclipse were shown in Fig. 2. The lower continuous curve indicate the galvanometer deflection with the actinometer covered with glass. The upper discontinuous curves are those with the actinometer without glass cover. These discontinuous curves were obtained by changing the circuit resistance in accordance with the variation of the intensity of the solar radiation.

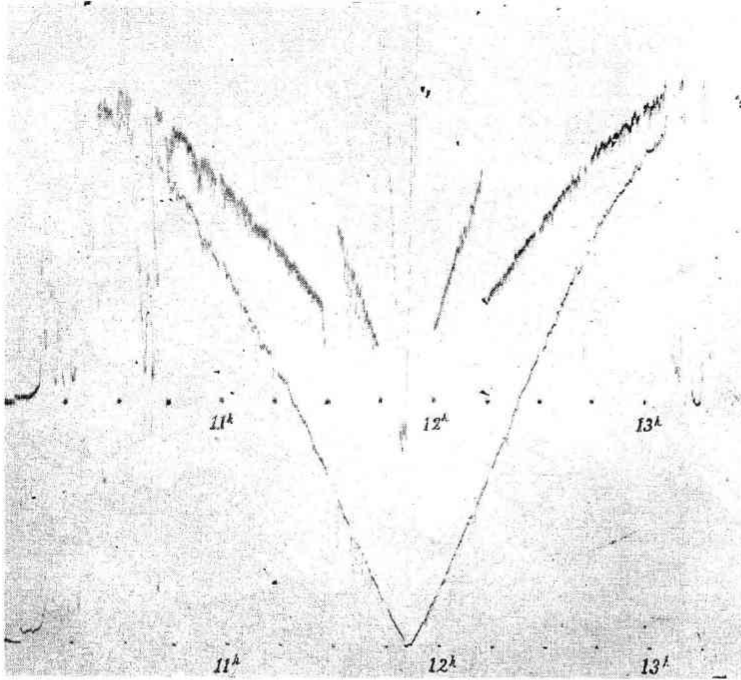


Fig. 2

TABLE I

Hour	Intensity of Radiation	Hour	Intensity of Radiation	Hour	Intensity of Radiation
10 ^h 30 ^m	1.1953	11 ^h 25	0.4588	12 ^h 20 ^m	0.4902
32.5	1.1852	27.5	0.4054	22.5	0.5374
35	1.1708	30	0.3564	25	0.5836
37.5	1.1521	32.5	0.3085	27.5	0.6315
40	1.1355	35	0.2611	30	0.6787
42.5	1.1134	37.5	0.2159	32.5	0.7223
45	1.0906	40	0.1681	35	0.7660
47.5	1.0596	42.5	0.1222	37.5	0.8113
50	1.0237	45	0.1823	40	0.8423
52.5	0.9881	47.5	0.0441	42.5	0.9039
55	0.9474	50	0.0104	45	0.9323
10 57.5	0.9108	52.5	0.0052	47.5	0.9655
11 0	0.8682	55	0.0355	50	1.0103
2.5	0.8275	11 57.5	0.0757	52.5	1.0391
5	0.7877	12 0	0.1082	55	1.0800
7.5	0.7492	2.5	0.1432	12 57.5	1.1025
10	0.7089	5	0.1948	13 0	1.1287
12.5	0.6681	7.5	0.2487	2.5	1.1502
15	0.6261	10	0.2921	5	1.1705
17.5	0.5825	12.5	0.3453	7.5	1.1858
20	0.5483	15	0.3904	13 ^h 10 ^m	1.2011
11 ^h 22.5 ^m	0.5057	12 ^h 17.5 ^m	0.4408		

Effects of cloud condition already stated are evidently seen on curves. Also effects of wind are seen on the curves, which are evidently stronger on the upper curve. Of course these two effects are to some extent distinguished; the effects of cloud are to decrease the intensity at times, whereas the

effects of wind are to oscillate the intensity curves irregularly as a whole.

It is to be noted that the upper curves show negative deflection from 11^h 50.3^m to 11^h 52.5^m. This means that at these times net radiation was not from the sun to the actinometer, but from the actinometer to the atmosphere and to the surrounding tube. As far as we use the actinometer of Moll-Gorczyński type, it is not surprising that these phenomena should happen, because the thermopile itself is emitting heat radiation. In our case probably covering of the sun by clouds during these times strengthened negative deflection to some extent.

Now original curves were smoothed by plotting the high points concerning the fluctuations due to clouds, and by drawing mean curves concerning the fluctuations due to wind. Further, discontinuous curve were converted to a continuous curve by reducing the circuit resistances to the standard value. Then the intensities of direct solar radiation are obtained by multiplying the constant of the actinometer which is 0.07776, to the smoothed galvanometer deflection. These values are shown in Table I. It is to be remembered that the correction for the radiation from the thermopile is not

considered in the above values. Of course this correction is negligible when the intensity of solar radiation is strong, but when the intensity is weak we cannot neglect this correction. It will be discussed later.

§4. CALCULATION OF LIMB DARKENING OF THE SOLAR DISK.

From our observation it is possible to calculate limb darkening of the solar disk. The intensity of solar radiation J is the function of the sun's zenith distance z , i.e.,

$$J = J_0 p^{\sec z},$$

where J_0 is the solar constant and p is Linke's coefficient of transmission. To calculate the limb darkening we must know the reduced intensities in which $z = \text{constant}$, and for the purpose we must determine p . Unfortunately the sun was covered by clouds just before and after the eclipse, so we were obliged to determine p from the value of J at 13^h 00^m when the sky was perfectly clear again. The obtained value of p is 0.70. It was assumed that p did not change appreciably during the eclipse and 13^h 00^m. Then the value of solar intensity was reduced to those at which $\sec z$ take the value at the time of minimum intensity. In Table 2 are shown the reduced values of the

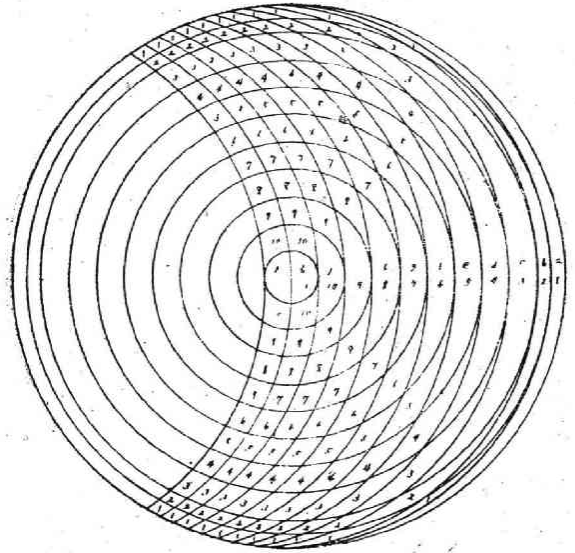


Fig. 3

solar intensity necessary for the later calculation, corresponding to the series of sickle-shaped strips, which is shown in Table 2. We shall denote these increments by the same letters as the strips. The increment a is

entirely due to radiation from zone 1; the increment b to radiation from zones 1 and 2; etc.

Let us indicate by x_n the average intensity of the radiation with which a unit of disk-surface, belonging to

zone n , supplies our thermopile. Then the increment h , for instance, will be composed as follows:

$$h = \theta_1 x_1 + \theta_2 x_2 + \dots + \theta_7 x_7$$

θ_1, θ_2 etc., being the surfaces of the parts which the corresponding zones contribute to the strip h . Following Julius, these surfaces were determined by cutting out and weighing the pieces of each strip. So the unit of area, adopted for measuring the surfaces, corresponds to a piece of our drawing paper weighing 1 mg. Table 3 contains all the values of θ , and the values of the increments of the radiation as read on the eclipse curve.

Julius had started from the first equation:

$$a = \theta_1 x_1$$

TABLE 2

Hour	Reduced Intensity	Increment of Intensity	Hour	Reduced Intensity	Increment of Intensity
	g-cal/cm ² min	g-cal/cm ² min		g-cal/cm ² min	g-cal/cm ² min
11 ^h 53.10 ^m	0.0109	0.0272	12 ^h 17.22 ^m	0.4384	0.0866
55. 3 ^h	0.0381	0.0686	21. 61	0.5250	0.0860
59. 6 ^h	0.1067	0.0780	25. 99	0.6110	0.0840
12 ^h 4.07 ^m	0.1847	0.0827	30. 38	0.6950	0.0826
8. 45	0.2374	0.0848	34. 76	0.7776	0.0799
12. 84	0.3522	0.0862	39. 15	0.8575	

solar intensity necessary for the later calculation. It is not essentially necessary for the calculation to add correction due to radiation from the thermopile, because the correction is to add nearly constant value to the solar intensities. We followed the method of Julius⁽¹⁾ in calculating limb darkening. On a homogeneous piece of paper a circle of 40cm in diameter, representing the sun, was drawn, and divided in the manner shown by Fig. 3. There are concentric zones, the width of which is 1/10 of the sun's radius, excepting the strips a and b , for which it is 1/20. There are also arcs representing the moon's limb in a series of positions. On our radiation curve we read the successive increments of the radia-

TABLE 3.

Increments	Areas (unit: mg)											
a=...	540											
b=272	166	369										
c=686	94	274	705									
d=780	48	92	394	535								
e=827	38	62	188	349	426							
f=848	34	47	129	186	303	352						
g=862	33	42	104	135	176	259	297					
h=866	32	38	90	111	132	162	221	243				
i=860	31	36	82	96	113	124	144	188	192			
j=840	31	35	76	87	97	105	116	129	154	143		
k=826	32	35	76	85	94	99	104	109	112	121	88	
l=799	32	36	76	83	91	95	100	104	108	117	84	

seen from Fig. 4 that all results are similar at the central part of the solar disk, but that our intensity curve decreases faster than that of Julius at the margin of the solar disk.

which gave him x_1 ; then from the second equation, he obtained x_2 , and so on. But in our case, as already stated, the sun was covered by thin cumulus cloud at the time of minimum intensity, so we could not determine increment a strictly, and we started our calculation from the second equation. In such case it is so troublesome to solve the simultaneous equations rigorously, that we gave up the usual manner of solution. Our way of solution was as follows: several pairs of x_1 and x_2 , which satisfy the second equation, were selected, then from the third equation x_3 was determined, and so on. By these method several series of $x_1 x_2 \dots$ were obtained, and among them one set of $x_1 x_2 \dots$ which satisfied all the equations with smallest error was selected. The results are shown in the second column of Table 4. The third column shows the same values converted into percentages of the intensity prevailing in the centre of the disk. The results are also shown in Fig. 4. For reference the results of Julius (1905) at the eclipse on August 30, 1905 and April 17, 1912 are shown in Fig. 4. It is

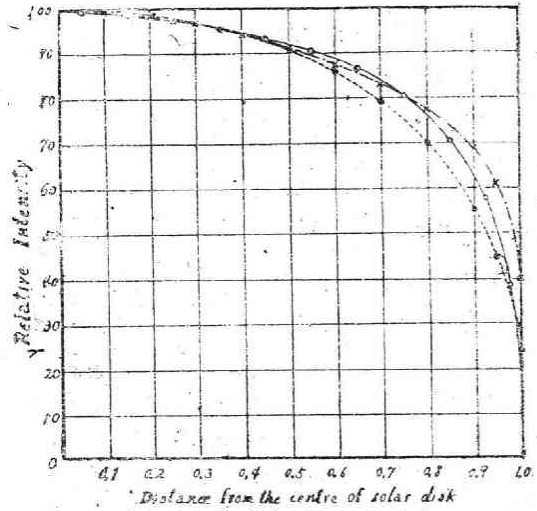


Fig. 4

- G. Yamamoto (1948)
-●..... W.H. Julius (1905)
- - - × - - - W.H. Julius (1912)

§5 ESTIMATION OF CORRECTION FOR THE RADIATION FROM THE THERMO-PILE

According to Brunt (3), the net outgoing heat radiation R from horizontal surface of temperature T⁰A. to the atmosphere is given by

$$R = \sigma T^4 (1 - a - b\sqrt{e})$$

where a, b are constants, σ is Stefan's const., and e is vapour pressure. When e is expressed in mb (whose value was 7.0 mb during the eclipse), a=0.52, b=0.065 by Dines' observation.

TABLE 4

Distance of Zone from Center of Disk	Average Radiating Power per Unit of Zone-Surface		
	Found directly from the Equations	Reduced to Value 100 at Center	Found by Graphical Interpolation
0.975	$x_1=0.38$	38.5	38.5
0.925	$x_2=0.5662$	58.0	57.8
0.85	$x_3=0.7(23)$	71.9	70.5
0.75	$x_4=0.8093$	82.9	81.0
0.65	$x_5=0.8521$	87.3	87.0
0.55	$x_6=0.8783$	89.9	90.8
0.45	$x_7=0.8954$	91.7	93.5
0.35	$x_8=0.9327$	95.6	96.0
0.25	$x_9=0.9535$	97.6	97.5
0.15	$x_{10}=0.9701$	99.4	99.0
0.05	$x_{11}=0.9755$	99.9	99.9

Then

$$R = 0.280 \sigma T^4.$$

But in our case the tube of semi-aperture angle $\alpha = 10^\circ$ is attached to thermopile. Now if we assume that the heat radiation to a direction θ (where θ is zenith distance) is proportional to $\cos\theta$, then the net outgoing radiation R' from the thermopile to the atmosphere of semi-aperture angle α is given by

$$R' = R \sin^2 \alpha.$$

On our tube, $\sin^2 \alpha = 0.032$. Hence

$$R' = 0.00896 \sigma T^4.$$

Unfortunately T was not measured, but surface temperature of the earth near the observing place was measured, which could serve in place of T without so much error. At the time of minimum intensity, for example, earth temperature was 284.5°A . Hence

$$R' = 0.00482.$$

Next, the heat exchange from the thermopile and the tube must be considered. Assuming the temperature of the tube to be T_t , and neglecting the aperture of the tube, the net radiation from the thermopile to the tube R'' is

$$R'' = \sigma(T^4 - T_t^4).$$

Here the reflecting powers of the thermopile and of the inner surface of the tube were assumed to be zero.

T_t is also unknown to us, but we shall proceed the discussion at all events. At the time of minimum intensity the sun was covered by clouds, so the radiation from the sun would be nearly zero. Then the negative intensity

which amounted to $-0.00778 \text{ g.cal/cm}^2\text{.min.}$ must be balanced by the radiation from the thermopile, i.e.,

$$-0.00778 + R' + R'' = 0.$$

$$\text{Hence } R'' = 0.00296.$$

Then from the equation of the definition of R'' , assuming $T = 284.5^\circ\text{A}$

$$\Delta T = T - T_t = 0.39$$

Thus it is supposed that temperature of the tube might be a little lower than that of thermopile at the time of minimum intensity. We think these explanation of apparent negative intensity which occurred actually is not so unreasonable.

§ CONCLUSION

We observed the intensity of the total solar radiation during the solar eclipse on May 9, 1948, at Wakkanai, Hokkaido.

The limb darkening of the solar disk was calculated from our intensity curve. Our result is somewhat different from both results, which had been obtained during the eclipse in 1905 and 1912 by W.H. Julius, at the margin of the solar disk.

Unfortunately, the sun was covered by clouds at the time of minimum intensity, we could not investigate the intensity distribution at the extreme limb of the solar disk which is one of the interesting problem at present.

Reference.

- (1) W. H. Julius: *Astrophys. Journ.*, Vol. 23-24, 1906
- (2) W. H. Julius: *Astrophys. Journ.* Vol. 37, 1913
- (3) Brunt: *Physical and Dynamical Meteorology*. Cambridge Univ. Press. p.122

ABSORPTION COEFFICIENT OF WATER VAPOUR IN THE FAR INFRA-RED REGION

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(Received October 1, 1948)

§1. INTRODUCTION.

Absorption spectrum of water vapour consists of several bands which cover almost whole of the infra-red region with transparent re-

gions between bands. In the far infra-red region beyond $\lambda = 15\mu$ lies a pure rotational band, which is the strongest band of all, and in which maximum absorption takes place at about $\lambda = 80\mu$. Between $\lambda = 8$ and 20μ there is