THE TOTAL RADIATION RECEIVED ON A HORIZONTAL SURFACE FROM THE SUN AND SKY AT MADISON, WIS., APRIL, 1911, TO MARCH, 1916.

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[Dated: Washington, May 25, 1916.]

A Callendar recording pyrheliometer[1] belonging to the University of Wisconsin was installed at the Weather Bureau Office in North Hall on April 3, 1911. The receiver is exposed on a small wooden platform on top of the instrument shelter. It is 12 feet above the roof, 71 feet above the ground, and 1,009 feet, or 308 meters, above sea level. There are no obstructions of importance between the receiver and the sky in any direction except between S. 61° W. and S. 67° W., where the dome of University Hall rises to a height of about 11 degrees and the top of the flagstaff to a height of 15 degrees. From about October 21 to November 25, and from about January 18 to February 21 the sun passes behind this dome; and for about a week preceding the first period and following the second period it passes behind the flagstaff.[2]

Considerable trouble was experienced with the Callendar register originally installed, and on July 17, 1912, it was replaced by a later type of this instrument belonging to the Weather Bureau. The record cylinder of the original register made a revolution in 24 hours. The cylinder of the new register makes a revolution in 16 hours. The time scale is 0.8 inch to the hour, and the vertical rulings on the sheet are for 10-minute intervals.[3]

The Callendar certificate for receiver No. 9864, in use at Madison, gives 0.0552 gram-calorie per minute per square centimeter as the change in radiation intensity that is represented by a lateral movement of the register pen of 0.4 cm. The longitudinal lines on the new record sheets are 0.1 inch apart. A lateral movement of the pen from one of these lines to the next, or 0.1 inch, therefore, should represent a change in radiation intensity of 0.03505 gram-calorie per minute per square centimeter. Comparisons with the Marvin pyrheliometer, which are summarized in Table 1, give a somewhat lower value than the above, except when the sun is near the horizon. These low-sun comparisons are too few in number to be given much weight, however.

TABLE 1.—*Comparisons of Marvin and Callendar pyrheliometers at Madison, Wis.*

Date.	Sun's alt.	*f.*	Sun's alt.	*f.*	Sun's alt.	*f.*	Sun's alt.	*f.*	Sun's alt.	*f.*	Sun's alt.	*f.*
1913.	°	*Gr.-cal.*	°	*Gr.-cal.*	°	*Gr.-cal.*	°	*Gr.-cal.*	°	*Gr.-cal.*	°	*Gr.-cal.*
Apr. 29					29.4	0.0325						
May 6	62.8	0.0347			32.7	.0350						
7	63.0	.0333										
9	63.8	.0345	43.2	0.0354								
10					31.3	.0336						
10					29.0	.0354						
1914.												
Nov. 10					28.0	0.0363						
1915.												
Mar. 26			37.9	0.0340	28.0	0.0352						
26			48.8	.0326								
26			40.8	.0345			21.0	0.0350				
27					28.9	.0369						
27			35.3	.0366								
30			38.4	.0330	29.4	.0353			15.1	0.0406		
30			49.0	.0326								
30			40.0	.0360	29.4	.0369					13.8	0.0487
July 21	57.0	0.0342	39.4	0.0327	27.4	0.332						
21	63.0	.0338										
21	59.7	.0359										
22	55.4	.0369	43.9	.0325	28.2	.0335						
Means	60.7	0.0348	41.7	0.0340	29.5	0.0349	21.0	0.0350	15.4	0.0406	13.8	0.0487

NOTE.—*f* is the value of 0.1 inch, or one scale division on the Callendar record sheet, in gram-calories per minute per square centimeter of horizontal surface.

[1] For description of the Callendar pyrheliometer and the method by which it is compared with the Marvin pyrheliometer see the MONTHLY WEATHER REVIEW for August, 1914, 42:474-481.

[2] Some further details relative to pyrheliometric exposures at Madison, Wis., will be found in the MONTHLY WEATHER REVIEW, January, 1916, 44:2.

[3] See the MONTHLY WEATHER REVIEW, August, 1914, 42:477, figure 5.

The orientation of this receiver is such that a line connecting the centers of the black pair of grids lies north and south. This tends to make the intensities recorded near noon higher than they should be, and those recorded when the sun is near the horizon lower than they should be, especially during the fall and winter months.[4]

As has been pointed out by one of us,[5] it is probable that the factors obtained by comparing the Callendar pyrheliometer with the Marvin are too small by about 2 per cent for reducing records obtained when the sky is cloudless, and by nearly 1 per cent when the sky is half covered with clouds. This is because diffuse radiation from the sky is not included when the comparisons are made, and it is known that the bright grids absorb a greater proportion of short-wave than of long-wave radiation. The factor given by the Callendar certificate for receiver No. 9864 is therefore very nearly correct for average sky conditions at Madison, and it has been used in reducing all records. The reductions have been made at Madison by Mr. Miller.

In figure 1 the circles in connection with the upper curve show the maximum daily amounts of radiation that have been observed in the respective decades during the 5-year period April, 1911, to March, 1916, inclusive. This curve may therefore be considered the curve of *possible radiation* for Madison, since it represents the daily amounts that would be received throughout the year if the sky were cloudless and free from haze and smoke. During the summer months this curve is very closely in accord with a similar curve for Washington, which is drawn as a broken line in the figure. During the winter months it is markedly lower than the curve for Washington, and slightly lower than a similar curve for Mount Weather, Va.,[6] as the latitude of the stations would lead us to expect.

The circles in connection with the lower curve of figure 1 represent the 5-year means of the total daily radiation for the respective decades, after smoothing them by the formula $M=\frac{1}{3}(a+b+c)$, where b is the mean for the decade for which the smoothed mean, M, is to be computed, and a and c are the means for the preceding and following decades, respectively. During the spring months these mean values coincide quite closely with similar means for Washington, which are represented by a broken line in the figure. During the fall and winter they are considerably lower than the Washington means. Reference to the MONTHLY WEATHER REVIEW for March, 1915, **43**:101, figure 1, will show that the decade means for Mount Weather and Washington are quite closely in accord.

It may also be stated that during the 10 months (July, 1915, to April, 1916, inclusive) a Callendar recording pyrheliometer has been in operation at Lincoln, Nebr., the decade maxima of daily radiation at that station have generally fallen between those for Washington and Madison, as the latitude of Lincoln would lead us to expect. The decade means coincide closely with those for Washington, except during the first three months of 1916, and from August 10 to September 10, 1915, when they show an excess.

Reference to this REVIEW for September, 1915, **43**:446, Table 2, will show that during the fall months, when the radiation recorded at Madison is markedly deficient as compared with Washington, the maximum noon radiation intensity as measured by the Marvin pyrheliometer is also low. Furthermore, about 10 per cent more clouds have been recorded at Madison than at Washington, which would further reduce the daily averages of radiation

[4] *Miller, Eric R.* Internal reflection as a source of error in the Callendar bolometric sunshine receiver. MONTHLY WEATHER REVIEW, June, 1915, 43: 264.

[5] This REVIEW, August, 1914, 42: 476-480.

[6] See the REVIEW, August, 1914, 42: 484, figure 8.

Column 3 of Table 2 gives the proportional deficiency of maximum daily amounts of radiation in the fall as compared with the maximum amounts in the spring when the sun has the same declination. Column 4 gives similar data with reference to the daily means. These latter show a greater seasonal variation than was found at Washington. The last column of Table 2 gives the percentage of possible radiation obtained at Madison at different seasons of the year. During the warm months the percentage is slightly less than at Washington, and during the cold months it is slightly greater.

Radiation deficiency during crop season, 1915.

With reference to the records from year to year, the most remarkable feature is the deficiency in radiation during the crop-growing season of 1915. From May 1 to August 10, inclusive, which was a period of excessive cloudiness, the deficiency in radiation was 7,253 gram-calories per square centimeter, or 14 per cent of the average, while from May 1 to September 30, inclusive, it was 7,595 gram-calories, or 11 per cent of the average. From May 1 to August 31, inclusive, the average daily temperature deficiency for the State of Wisconsin was 4.5 degrees (F.)[7]

Of the remaining years, the last half of 1912 received relatively a small amount of radiation. The distinguishing feature of this period, however, and also of the year 1913, is the low value of the maximum daily radiation, or the radiation received on cloudless days. These low values may doubtless be attributed to the haziness of the upper layers of the atmosphere following the eruption of Katmai volcano in Alaska in June, 1912. The diminished intensity of direct solar radiation during this period, as shown by measurements with the Marvin pyrheliometer, has been referred to in a previous paper.[8]

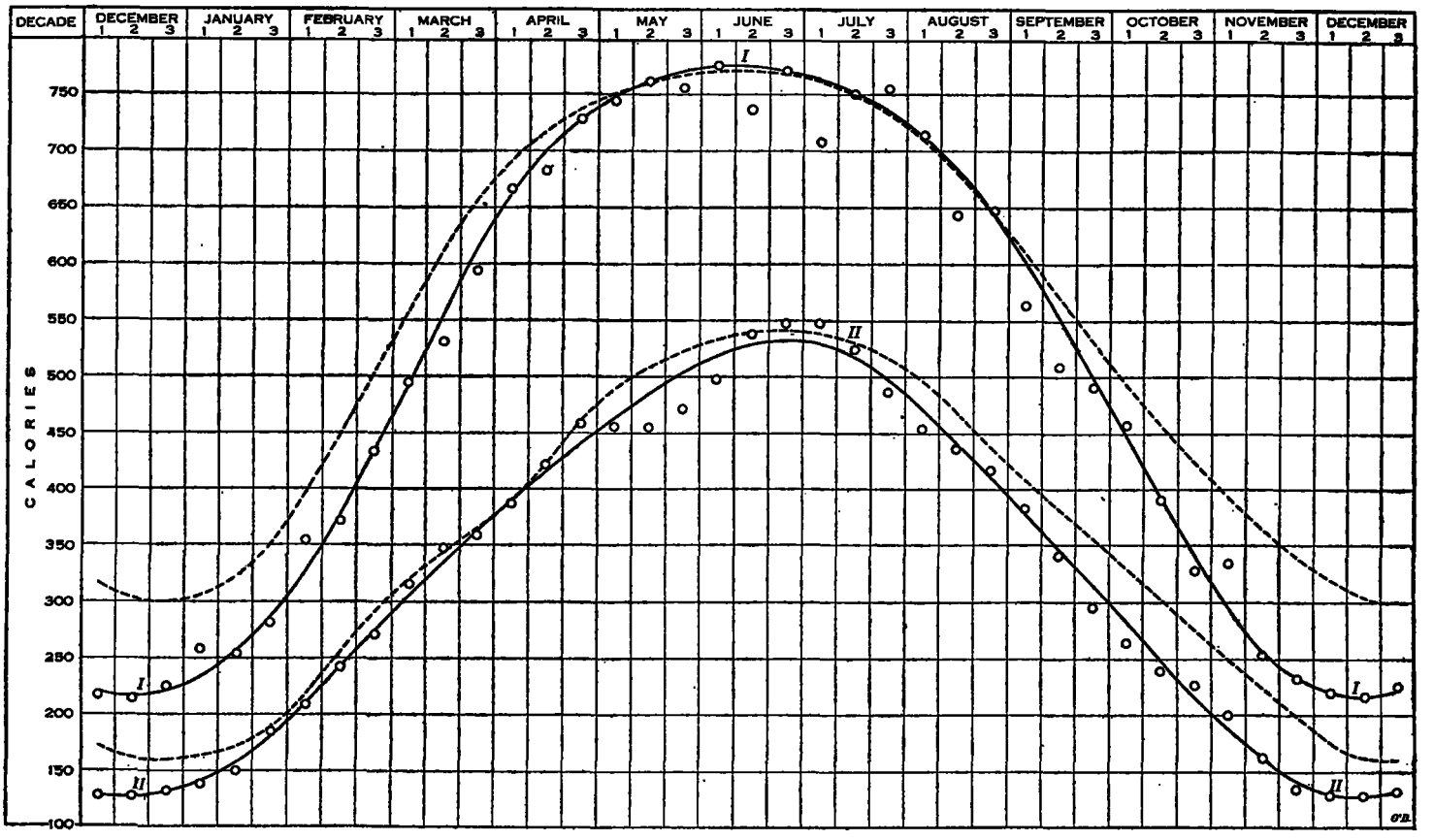

FIG. 1. Maximum (I) and mean (II) daily amounts of solar and sky radiation in gram-calories per square centimeter of horizontal surface. Solid lines, Madison, Wis.; broken lines, Washington, D. C.

TABLE 2.—*Seasonal relations of radiation intensities at Madison, Wis.*

Dates.	Solar declination.	Ratios: Max./Max.	Ratios: Mean/Mean	Dates.	Ratios, Mean/Max.
	°				
Oct. 27 / Feb. 15	−13	0.88	0.86	Feb. 15 Mar. 21	0.65 0.59
Autumnal equinox / Vernal equinox	± 0	0.88	0.93	Apr. 15 June 21 Aug. 27	0.59 0.69 0.63
Aug. 27 / Apr. 15	+10	0.90	0.97	Sept. 21 Oct. 27 Dec. 21	0.63 0.63 0.59

[7] See "Condensed Climatological Summary," this REVIEW, May to August, inclusive, 1915.

[8] This REVIEW, January, 1916, 44:8.