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TOTAL SOLAR AND SKY RADIATION ON MOUNT WASHINGTON, N. H.

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[Blue Hill Observatory of Harvard University ,Milton, Mass., December 1936]

When the Mount Washington Observatory [1] was reestablished in 1932, a pyrheliometer and recorder, of the standard type used by the United States Weather Bureau [2] were loaned by the Eppley Laboratory, Inc., of Newport, R. I., for the measurement of the total radiation from sun and sky on a horizontal surface.[3] The pyrheliometers which were used until March 1935, had 50 junctions.

Records were started on November 6, 1932. They were interrupted, however, by wind and lightning damage to pyrheliometer or recorder, in January 1933, and from the last of June to early in October 1933. The number of daily records for each month which could be used to compute the monthly averages in table 1 is rather small during this period, partly because no records were made on very stormy days, and partly because of other deficiencies. With occasional interruptions, as noted in table 1, observations were carried on until November 1935, when they were discontinued after the pyrheliometer had been broken in a gale.

In winter the bulb of the pyrheliometer was frequently covered with rime. This rime cover was usually removed from the bulb once or twice a day, and the time of removal noted. The removal is noticeable on the record as a sudden rise of the recorded radiation intensity, especially on clear days. It does not seem possible to take into account the loss of recorded solar radiation due to rime and frost deposits. The only possibility would be to smooth out the sharp rise in the radiation curve at the time of the rime removal. However, the time when the rime first formed is not known, and it is impossible to tell where the curve corrected for rime should begin to deviate from the recorded curve. Therefore, no corrections for rime have been applied. No attempt to prevent rime formation was made. It is doubtful if such methods as have been described by Lauscher [4] and Grundmann [5] would be of help under the severe conditions on Mount Washington.

The records were sent to Blue Hill Observatory at the end of each month. Here they were evaluated by Messrs. R. F. Baker, H. Wexler, S. Pagliuca, A. A. McKenzie, and the author. In the evaluation, each day was subdivided into intervals of 20 minutes; for these intervals the mean ordinate could be estimated without difficulty in most cases. The results are given in table 1, and figures 1 to 7. The time used is apparent time.

The highest average daily total occurred in May during 2 (1933, 1934) of the 3 years for which observations are available; while at Blue Hill, in 1933, the average daily total had its maximum in June [6] (table 2). In 1935, on the other hand, the radiation on Mount Washington was highest in June. During each year the radiation was lowest in December, as was also the case at Blue Hill in 1933. However, in January 1935, the radiation was exceptionally low, lower than for any other month. If we compare corresponding months, we see that in 1934, the radiant energy received at Mount Washington was markedly higher than in 1933 or 1935. Only the average daily total in November 1933, exceeded that of November 1934, by 39 gr cal/cm^2; and the value for January 1933,

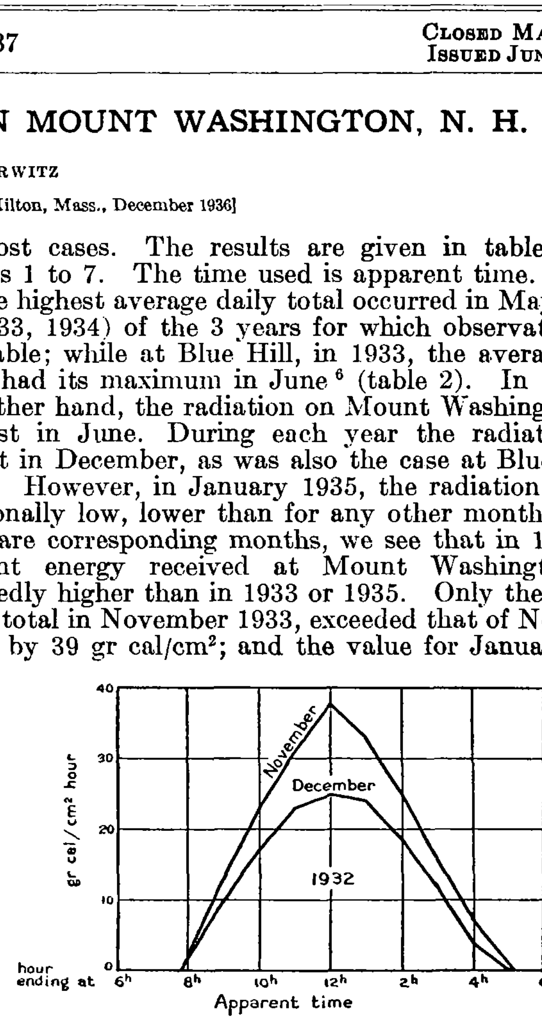

FIGURE 1. Monthly means of hourly sums of total radiation on a horizontal surface at Mount Washington, November–December, 1932

is higher than January 1934. The records for November and December 1932 show that during these 2 months the mean monthly daily total was higher than during the corresponding months in the following years for which data are available. Particularly low was the total radiation during the spring and early summer of 1935.

A comparison of the radiation received at Blue Hill and at Mount Washington during 1933 (cf. table 2) shows that through the year more energy was received at Blue Hill than at Mount Washington except in January, April, and May, when the average daily total was lower at Blue Hill than at Mount Washington. Neglecting the small difference in latitude, the influence of the higher altitude of Mount Washington which would tend to increase the radiation is evidently more than counterbalanced by the greater cloudiness and fogginess on the mountain.

Figure 1 shows that the diurnal rise to the maximum during November 1932 is much steeper than in December. During the noon hours the radiation energy was markedly greater in November than in December.

[1] For general descriptions of the Observatory see: R. S. Monahan and S. Pagliuca, The Mount Washington Observatory, Trans. Amer. Geoph. Un., 1933, p. 85; S. Pagliuca, Mount Washington Observatory, N. H., Progress Report, 1933, MONTHLY WEATHER REVIEW, Jan. 1934, 62: 16–18, 5 figs.; A. A. McKenzie, The Mount Washington Observatory, 1934–35, Bull. Am. Met'l. Soc., March 1935, 16: 90–93. The geographical position of Mount Washington is 44°16′ N. lat. and 71°18′ W. long.; its elevation is 1911 meters above sea level.

[2] Pyrheliometers and pyrheliometric measurements, Weather Bureau circular Q, Washington, D. C., 1931.

[3] The pyrheliometer, on a wooden pillar set in a pile of rocks about 20 meters from the Observatory building, is shown in the photograph reproduced in the MONTHLY WEATHER REVIEW, vol. 63, January 1934, fig. 5, opp. p. 17. There was no obstruction to the direct solar radiation, and only a negligible part of the lower sky was obscured by other buildings on the summit. The recorder was placed inside the Observatory building.

[4] F. Lauscher, Über ein Hilfsmittel zur Verhütung von Reifansatz an Sonnenscheinautographenkugeln, Met. Z., vol. 49, 1932, p. 112.

[5] W. Grundmann, Verhütung von Reifansatz an Sonnenscheinautographenkugeln und Aktinographenschalen, Met. Z., vol. 50, 1933, p. 194.

[6] B. Haurwitz, Daytime Radiation at Blue Hill Observatory in 1933, Harvard Meterological Studies, No. 1, Cambridge, 1934.

In January and March 1933 (fig. 2), the hourly radiation sums are equal, and in February only slightly smaller in the noon hours. The 11 gr cal/cm² per day by which the average daily totals in February exceeded January were received in the forenoon and late afternoon. The same is true for the radiation surplus in March. In April and May the radiation is very much higher during the noon hours. From June to September 1933 no hourly values are available.

In October and Nŏvember 1933 (fig. 3), the average radiation intensities are equal in the morning hours. Thus the greater daily total in October is to be attributed to the higher radiation during the afternoon. The hourly radiation in December 1933 is less than that of November 1933, throughout the day.

During January 1934 (fig. 4), the radiation is much lower than in February 1934. In agreement with the fact that the average daily total is higher in May than in June 1934, the average hourly radiation intensity in May is the greater except in the forenoon and the evening, when June shows slightly higher values. For the hours ending at 11h and at noon, the June values are even exceeded by April; but in the earlier forenoon, and, to a lesser degree, in the afternoon, the radiation is more intense in June than in April 1934.

Figure 5 shows that in August 1934 the mean daily radiation had its maximum in the hour from 10h to 11h, while in November 1934 it was in the hour 12h to 1h. The reason for the occurrence of the August maximum in the forenoon may be the cumulus clouds which frequently shaded the summit about noon.

In 1935, the means of the daily totals during February and March were almost equal, 172 and 177 gr cal/cm², respectively. Throughout the forenoon and in the later afternoon, past 3h, the radiation was slightly stronger in March; but from noon to 3h, February 1935 had, on the average, a higher radiation intensity (fig. 6).

According to figure 7, the radiation excess of October over November 1935, is mainly due to the radiation received during the afternoon.

It is of some interest to see how the daily totals are divided between forenoon and afternoon, table 3. It will be noted that the amount of radiation received during the forenoon is larger than during the afternoon with the exception of April 1933, and June and October 1935; while during March and May 1933, the radiation is equally divided between forenoon and afternoon. Especially remarkable is November 1933, when 62 percent of the daily total was received during the forenoon, a condition paralleled at Blue Hill with 60 percent. April, May, October, and December 1933 also show a certain parallel between a. m. versus p. m. percentages.

TABLE 1.—*Monthly, hourly and daily means of total radiation on Mount Washington, N. H. in gr cal/cm²*.

Month	Number of days[5]	Mean hourly totals during hour preceding:																Mean daily total
		5h	6h	7h	8h	9h	10	11	12	1h	2h	3h	4h	5h	6h	7h	8h	
1932																		
November	16	---	---	---	2	13	23	31	38	33	25	16	7	1	---	---	---	189
December	18	---	---	---	2	,10	17	23	25	24	19	12	4	0	---	---	---	136
1933																		
January	12	---	---	---	2	9	18	24	31	31	21	15	7	1	---	---	---	159
February	24	---	---	0	6	13	20	24	28	26	21	17	10	5	---	---	---	170
March	24	---	---	6	8	14	20	27	31	30	27	22	15	7	3	1	---	211
April	13	---	0	6	18	31	43	54	57	58	50	42	31	24	10	3	0	427
May	22	1	6	15	27	37	52	58	64	65	60	47	37	26	16	7	1	519
June[1]	14	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	484
July	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
August	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
September	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
October	19	---	---	0	7	15	23	28	33	31	28	21	13	4	0	---	---	203
November	24	---	---	0	7	15	24	27	27	24	19	12	5	1	0	---	---	161
December	25	---	---	---	1	8	14	17	18	16	13	8	3	0	---	---	---	98

[1] Time marks missing on a number of days, hence hourly values not determinable.

TABLE 1.—*Monthly, hourly and daily means of total radiation on Mount Washington, N. H. in gr cal/cm²*—Continued

Month	Number of days	Mean hourly totals during hour preceding:																Mean daily total
		5h	6h	7h	8h	9h	10	11	12	1h	2h	3h	4h	5h	6h	7h	8h	
1934																		
January	28	---	---	---	2	11	18	23	25	24	21	14	7	2	0	---	---	147
February	23	---	---	0	7	19	31	39	44	42	40	28	16	6	1	---	---	273
March[2]	27	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	[2] (295)
April	28	---	2	11	24	27	48	54	57	54	52	44	32	21	10	2	0	438
May	27	0	6	18	33	45	54	62	66	65	60	51	39	28	14	6	1	548
June	28	1	7	16	29	48	51	52	56	56	55	45	33	23	15	6	1	494
July[3]	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
August	11	0	4	16	32	48	57	65	57	52	48	40	32	18	9	2	---	480
September	26	---	1	6	17	28	38	42	45	43	40	30	22	14	7	1	---	334
October	30	---	---	2	9	19	27	32	34	33	29	22	14	6	1	---	---	228
November	26	---	---	0	2	10	18	18	20	21	15	11	6	1	---	---	---	122
December	29	---	---	---	1	6	13	16	18	18	15	10	4	1	---	---	---	102
1935																		
January	27	---	---	---	1	6	10	13	15	14	13	10	6	1	---	---	---	89
February	25	---	---	0	5	13	20	25	29	26	22	18	10	4	0	---	---	172
March	20	---	0	2	8	16	22	27	28	25	19	14	11	4	1	0	---	177
April[4]	(26)	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	341
May[4]	(22)	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	354
June	(15)	0	7	14	13	30	36	43	50	43	42	41	33	26	17	7	1	403
July[4]	(19)	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	403
August	25	---	4	14	25	36	44	46	49	50	43	35	28	20	13	5	1	413
September[4]	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
October	20	---	---	1	6	13	23	26	32	36	30	24	17	7	1	---	---	216
November	17	---	---	0	3	10	19	26	29	29	24	16	10	2	---	---	---	168

[2] This value probably should be disregarded. On Mar. 8, 1934, it was found that the glass stem inside the bulb of the pyrheliometer was broken and the broken element slanting 64° from the vertical facing a direction 70° E. of N. A new instrument was not installed until Mar. 30; the method employed for obtaining the daily totals is crude and the results liable to grave errors.

[3] Pyrheliometer struck by lightning July 1; replaced Aug. 19.

[4] Pyrheliometer and recorder burned out by lightning at end of March 1935; 10-junction pyrheliometer installed, and eye readings obtained with Eppley potentiometer bridge until new recorder was installed. Recorder again failed, probably because of atmospheric phenomena (cf. A. A. McKenzie, Some Static Electric Phenomena, Mount Washington Observatory, Bull. Amer. Met. Soc., March 1935, pp. 78–80), in July and in September 1935. During the periods when only eye readings were available, linear variation of intensity between observations was assumed; hence hourly values were not calculated, and when the interval between 2 readings was 3 hours or more, the whole day was omitted.

[5] The number given is a mean value obtained by averaging the total month by number of hours, since on some days a whole day's record was not obtained.

TABLE 2.—*Monthly means of daily totals in 1933 at Blue Hill and Mount Washington in gr cal/cm²*

	January	February	March	April	May	June	July	August	September	October	November	December
Blue Hill	154	236	318	355	511	526	479	408	333	278	206	121
Mount Washington	159	170	210	427	519	484	----	----	----	203	161	98
Blue Hill—Mount Washington	−5	+66	+108	−72	−8	+42	----	----	----	+75	+45	+23

TABLE 3.—*Total radiation at Mount Washington during forenoon and afternoon in percent of the daily total; and comparison with Blue Hill*

	January	February	March	April	May	June	July	August	September	October	November	December
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1932												
A. m.	----	----	----	----	----	----	----	----	----	----	57	57
P. m.	----	----	----	----	----	----	----	----	----	----	43	43
1933												
A. m.	53	53	50	49	50	----	----	----	----	52	62	59
P. m.	47	47	50	51	50	----	----	----	----	48	38	41
1934												
A. m.	54	51	----	51	52	53	----	58	53	54	56	53
P. m.	46	49	----	49	48	47	----	42	47	46	44	47
1935												
A. m.	51	54	58	----	----	49	----	53	----	47	52	----
P. m.	49	46	42	----	----	51	----	47	----	53	48	----
1932–35												
A. m.	53	53	54	50	51	51	----	55	53	51	57	56
P. m.	47	47	46	50	49	49	----	45	47	49	43	44
BLUE HILL												
1933												
A. m.	49	48	53	49	50	48	48	49	51	59	60	56
P. m.	51	52	47	51	50	52	52	51	49	41	40	44

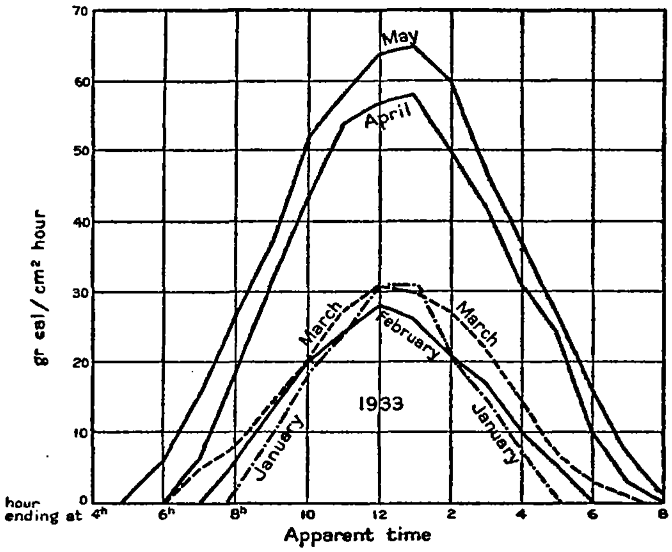

FIGURE 2. Monthly means of hourly sums of total radiation on a horizontal surface at Mount Washington, January–May, 1933.

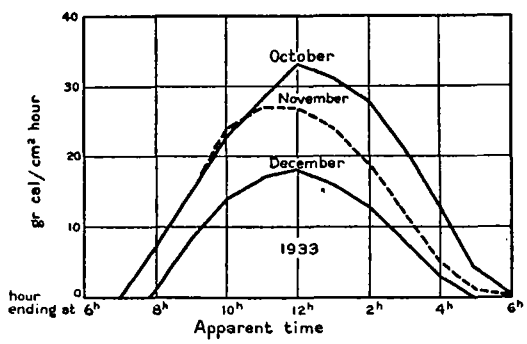

FIGURE 3. Monthly means of hourly sums of total radiation on a horizontal surface at Mount Washington, October–December, 1933.

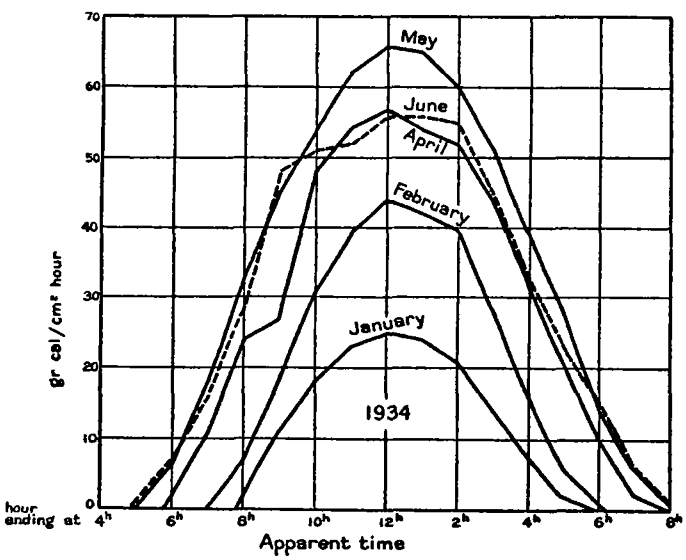

FIGURE 4.—Monthly means of hourly sums of total radiation on a horizontal surface at Mount Washington, January–February, April–June, 1934.

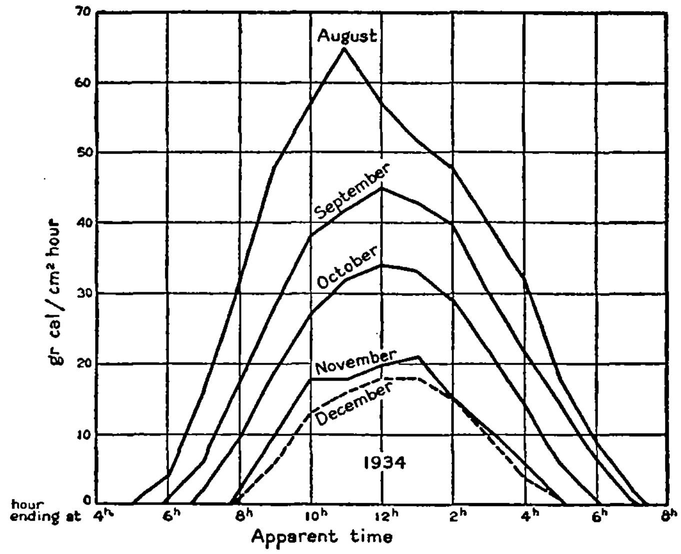

FIGURE 5. Monthly means of hourly sums of total radiation on a horizontal surface at Mount Washington, August–December, 1934.

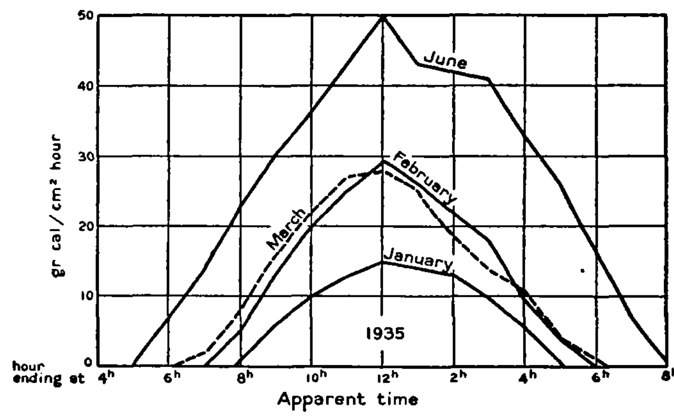

FIGURE 6. Monthly means of hourly sums of total radiation on a horizontal surface at Mount Washington, January–March, June, 1935.

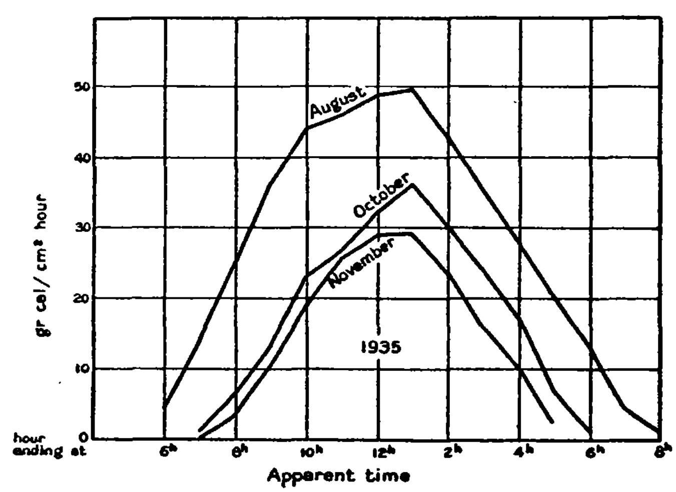

FIGURE 7. Monthly means of hourly sums of total radiation on a horizontal surface at Mount Washington, August, October, November, 1935.