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SIMULTANEOUS PYRHELIOMETRIC MEASUREMENTS AT DIFFERENT HEIGHTS ON MOUNT WASHINGTON, N. H.

By I. F. HAND,[1] J. H. CONOVER,[2] and W. A. BOLAND[1]

The transmission of solar radiation through the 4,668-foot layer of atmosphere between the top of Mount Washington, N. H., and the Glen House, 4 miles to the east, was observed on October 2 and 3, 1942, by means of simultaneous pyrheliometric measurements at different points.

The standard Smithsonian silver-disk pyrheliometer No. 1-bis of the U. S. Weather Bureau was read at the base of Mount Washington by Boland, and Smithsonian silver-disk pyrheliometer No. 63 of the Harvard Blue Hill Meteorological Observatory was read at the top by Conover. The senior author used a Clark vacuum pyrheliometer with a portable potentiometer, taking readings early in the morning at the base, followed by two series at the Half-way House in mid-morning, and taking noon readings at the summit; during the afternoon of October 2 this itinerary was reversed. Observations were made in 22-minute series, at 45-minute intervals from beginning to beginning, throughout the day. Both Smithsonian pyrheliometers recently had been compared against Smithsonian standards at the Astrophysical Observatory of the Smithsonian Institution in Washington. Factors previously determined for the Clark vacuum pyrheliometer were used in the reductions of the observations, and the fact that there is less than one percent difference between the values of the readings with this instrument and those made with the silver-disk pyrheliometers indicates that all instruments were in excellent agreement.

Mount Washington is the highest peak in northeastern United States; it is in the White Mountains, N. H., at latitude 44°16′ N., longitude 71°18′ W., and altitude 6,288 feet. The Half-way House is 2 miles to the northeast at an elevation of 3,860 feet, while the Glen House, 4 miles east-northeast, has an elevation of 1,620 feet. Although a slightly greater differential might have been obtained by taking the base readings at another point, the horizontal distance from the top would then have been too great, and it is conceivable that the base station might have been in a different type of air mass from the top.

It was agreed that a dry, cool air mass of cP origin would be best for the purpose of observations. The arrival of an air mass of this type can generally be forecast several days in advance; it provides a greater probability of clear weather than most other types; and it usually brings rather pure, dust-free air, with excellent visibility.

The best examples of cPk air in the New England region are provided by air masses which originate in the Hudson Bay region; fresh outbreaks of this type of air are generally most common during the latter part of the winter season, when transportation of delicate apparatus would be impracticable, and therefore it was decided to utilize a cPk air mass or more northwesterly or westerly origin, such as occurs frequently in New England during the autumn.

The air-mass originally chosen for the observations approached New England from an almost due westerly direction, but moved and dissipated much more rapidly than expected. The essential weather characteristics required were consequently lacking; but the preliminary cPk surge fortunately was immediately followed by a secondary outbreak of cPk air of apparently direct north-northwesterly origin, which, while it did not originate in the Hudson Bay region, was nevertheless greatly strengthened in that region during the simultaneous dissipation of the original air-mass over the middle Atlantic region. The secondary outbreak, which was prevalent over New England during October 2 and 3 provided almost ideal conditions. It was preceded by a rather complex system of two cold-front passages, both recorded fairly prominently on the October 1 autographic records of the Mount Washington station.

The air immediately following the passage of such a well-developed cold-front system is usually extremely pure and clear, but such a post-frontal zone also frequently is affected by considerable turbulence, which quite often produces extensive formations of stratocumulus clouds. The latter condition becomes generally less prominent with moderating temperature conditions, and is also much rarer under conditions of rapidly increasing pressures, which occur only during periods of persistent rapid synoptic movement. In all these respects the weather developed favorably; according to the observers on Mount Washington, October 2 was the clearest day of the year. The islands off Portland, Maine, were clearly visible during the early morning; also Whiteface Mountain in New York State, 130 miles to the west-northwest. The maximum visibility was 170 miles to the northwest, the most distance object ever visible in any direction.

The observations are given in table 1. The observed values of Q, the direct solar radiation at normal incidence in gram-calories per square centimeter per minute, were corrected to mean solar distance by the values of the radius vector in the *American Ephemeris;* the corrections are very small (since at this time of the year the sun is nearly at its mean distance) and amount to only a few thousandths of a calorie. The so-called "air mass"—not to be confused with the synoptic air mass—was computed from the formula

$$M=\frac{(B-e)\,R}{76.0\times 58.36\sin Z}$$

where B is the barometric pressure in centimeters, e the vapor pressure, 76.0 the normal sea-level pressure, and Z the zenith distance of the sun. The atmospheric transmission coefficient was computed from

$$a^m=\sqrt{\frac{Q_1}{Q_0}}$$

[1] U. S. Weather Bureau. [2] Harvard Blue Hill Observatory.

where Qc is the corrected pyrheliometric reading, and $Q_0 = 1.94$, the value of the "solar constant" as determined by Abbot and his colleagues at the Astrophysical Observatory of the Smithsonian Institution.

The average percentage difference between the readings of the Clark and the two Smithsonian pyrheliometers, when read at the same level, was less than one-tenth of 1 percent, while the maximum percentage difference of any one series was 0.9 percent. According to Abbot, Smithsonian pyrheliometers may be read within one-quarter of one percent by experienced observers, as all three on this expedition were. With such close agreement between the Clark and both Smithsonian pyrheliometers, we may safely assume that all readings are correct within one percent.

The Smithsonian readings are made with the shutter alternately open and closed for 2 minutes, while the Clark readings are instantaneous and made every minute. Had the sky been less clear, we should have expected greater differences between the readings of the two types of pyrheliometers owing to the above differences in manner of reading the instruments. The fact that the Smithsonian and Clark readings were reduced independently by different observers by the use of factors previously determined is evidence of the constancy and calibration of the pyrheliometers.

It is interesting to note that the atmospheric transmission coefficients for the Glen House and the Half-way House are within 1 percent of each other, while, with a single exception, the transmission coefficients at the summit are appreciably higher than either the Half-way House or the base. The temperatures on the 2d ranged from 0° C. at 8:36 a. m. E. W. T. to 12.9° C. at 3:17 p. m. at the base; and from −4.4° C. at 8:36 a. m. to −1.1° C. at 2:32 p. m. at the Summit. On the 3d the temperatures at the base ranged from −2.2° C. at 8:36 a. m. E. W. T. to 12.4° C. shortly after noon; at the Summit they ranged from +0.6° C. to +1.7° C. On the 2d, convection undoubtedly played an important part in raising the haze layer from the base to the area between the Half-way House and the summit, as well shown by the gradually decreasing values of the ratios in columns 11 to 14 of table 1.

Figure 1 shows the plot of the morning observations. The extrapolation of the readings on the morning of the 2d, if carried out to zero air mass, give a value well within 1 percent of the solar constant, 1.94. (See fig. 2.)

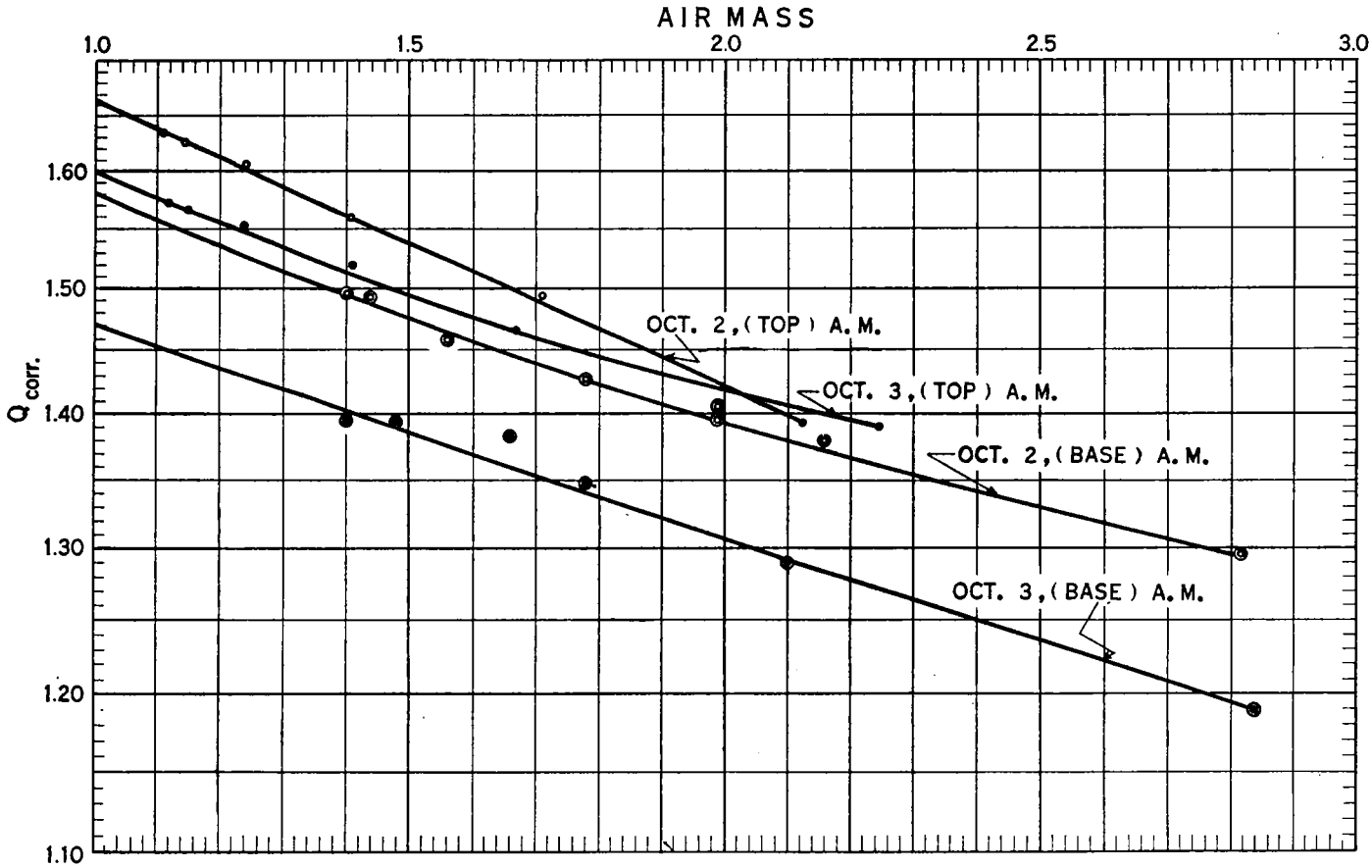

FIGURE 1.—Pyrheliometric observations of October 2 and 3, 1942, a. m.

The station pressure at Mount Washington on October 2 rose from 805.5 mb. at 7 a. m. to 807.8 mb. at 3 p. m. On the following day the pressure remained stationary at 811 mb. all the morning. The relative humidity on October 2 was 39 percent at 7 a. m., 48 percent at 8 a. m., and gradually dropped to 20 percent at noon followed by a gradual rise to 69 percent at 4 p. m. On the 3d the relative humidity values varied from 35 percent at 7 a. m. to 72 percent at noon. The vapor-pressures at Mount Washington on October 2 at 8 a. m. and solar noon were 1.24 and 1.52 mb. and for the same times on October 3, 1.68 and 1.78 mb. respectively.

The noon readings on Mount Washington on the 2d were the highest ever obtained by the Weather Bureau, with the exception of a few 20 years ago at Santa Fe', N. Mex., and those obtained on the top of Mount Evans at an

elevation of 14,260 feet, in 1938 (Mo. WEA. REV., Sept. 1939, 67:331–338). The most outstanding feature of the observations was the transparency of the atmosphere between the base station and the summit of Mount Washington.

Although the Half-way House is, as the name implies, almost exactly half-way in altitude between the base and the summit, the readings at the Half-way House were only 2 to 3 percent higher on the 2d. than the readings at the base, while the readings at the summit ranged from 7 to 11 percent higher than those at the base. On the 3d the readings at the Half-way House were only 4 percent higher than those at the base while the readings on the summit ranged from 11 to 14 percent higher than those at the base. This seems to indicate that the air layer between the Half-way House and the Summit was decidedly hazier than the layer below the Half-way House. During the forenoon of the 3d there was an obvious sharp temperature inversion between the Half-way House and the summit, and on both days there was an appreciable difference in clearness between the upper and lower parts of the Mountain.

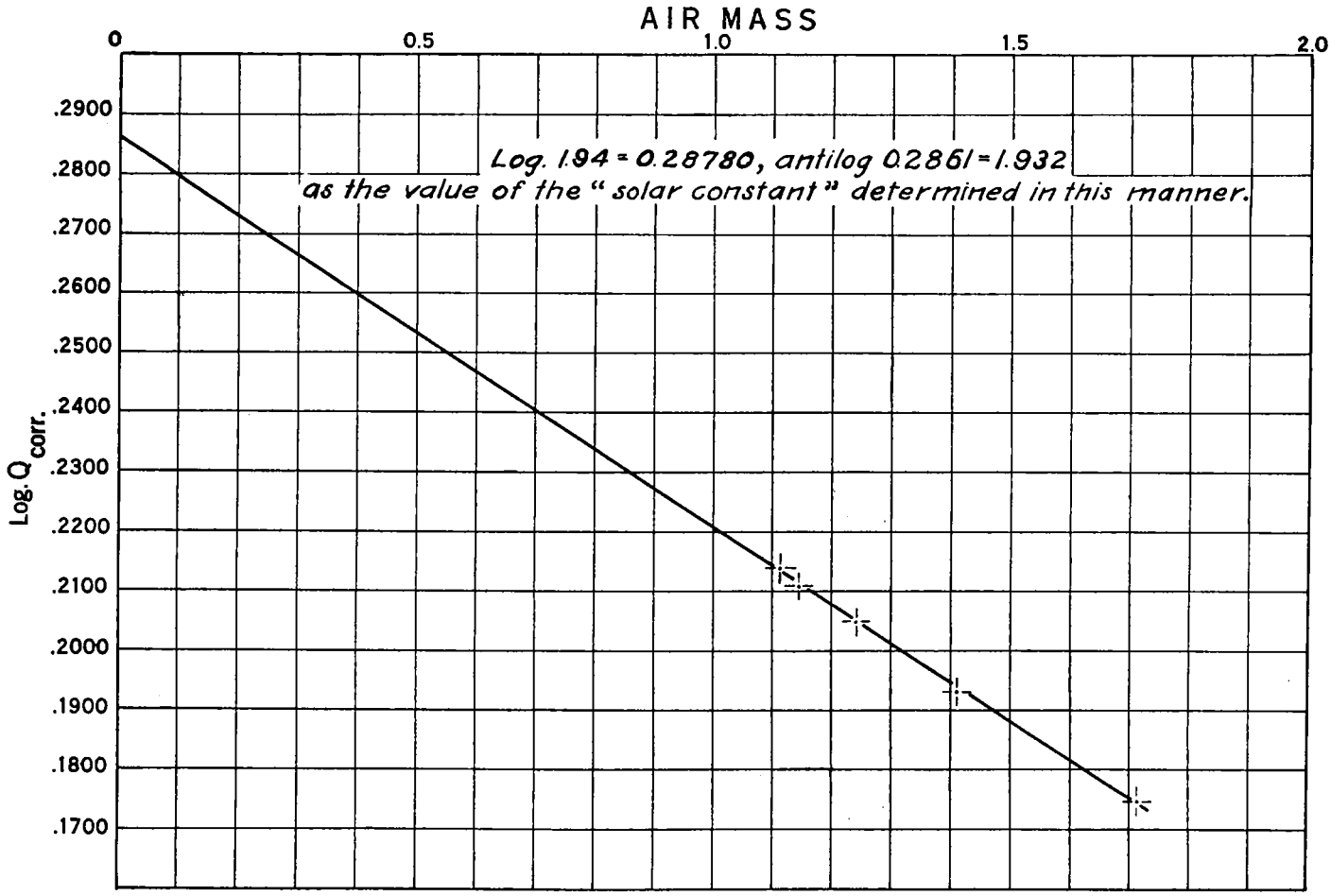

FIGURE 2.—Pyrheliometric observations of October 2, 1942, extrapolated to zero air mass.

ACKNOWLEDGMENTS

The authors wish to express their sincere thanks to Mrs. Hand and Mrs. Conover for aid in recording data; to Mr. Noyes of the Mount Washington Summit Road Co., and to Messrs. Lafayette Gosselin and Victor Clark, and their associates for the respective courtesies they accorded the observers.

TABLE 1.—*Pyrheliometric readings, Mount Washington, N. H., and vicinity*

1942 Eastern war time	Hour angle of sun	Mount Washington			Half-way House		Glen House			S_1/S_u	C/S_1	S_1/C	C/S	Atmospheric transmission coefficients		
		Air mass	Q^1_0	Q^2_0	Air mass	Q^2_0	Air mass	Q^2_0	Q^3_0					Q_1	Q_2	Q_3
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Oct. 2	*h m*															
8:36 a. m.	3 59	2.34	1.364				2.95									
8:40 a. m.	3 55	2.25	1.394				2.86									
8:44 a. m.	3 51	2.17	1.391				2.77									
8:48 a. m.	3 47	2.10	1.422				2.69									
Means		2.215	1.393				2.82		1.292				0.927	0.861		0.866
9:17 a. m.	3 18	1.77	1.488				2.23									
9:21 a. m.	3 14	1.73	1.492				2.18									
9:25 a. m.	3 10	1.69	1.500				2.14									
9:29 a. m.	3 06	1.66	1.501				2.09									
Means		1.712	1.495				2.16		1.380				.923	.859		.854
9:36 a. m.	2 59						2.02	1.397								
9:40 a. m.	2 55						1.99	1.388								
9:44 a. m.	2 51						1.96	1.397								
Means							1.99	1.394	1.405		*1.008	.992			0.847	
10:02 a. m.	2 33	1.44	1.555				1.83	1.419								
10:06 a. m.	2 29	1.42	1.546				1.80	1.423								
10:10 a. m.	2 25	1.40	1.572				1.77	1.426								
10:14 a. m.	2 21	1.38	1.565				1.74	1.437								
Means		1.410	1.560				1.78	1.426	1.423	0.914	*.998	1.002		.857	.841	
10:47 a. m.	1 48	1.26	1.609		1.46		1.58	1.449								
10:51 a. m.	1 44	1.25	1.602		1.44		1.56	1.459								
10:55 a. m.	1 40	1.23	1.601		1.43		1.55	1.461								
10:59 a. m.	1 36	1.22	1.602		1.41		1.54	1.466								
Means		1.240	1.606		1.44	1.495	1.56	1.459		.908		.976	.931	.859	.833	.834
11:36 a. m.	0 59	1.15	1.634				1.44	1.493								
11:40 a. m.	0 55	1.15	1.606				1.44	1.491								
11:44 a. m.	0 51	1.14	1.643				1.43	1.490								
11:48 a. m.	0 47	1.14	1.623				1.43	1.503								
Means		1.145	1.625	1.626			1.44	1.494		.919			*1.001	.856	.834	
12:17 p. m.	0 18	1.12	1.626				1.40	1.488								
12:25 p. m.	0 10	1.11	1.632				1.40	1.501								
12:29 p. m.	0 06	1.11	1.650				1.40	1.507								
12:33 p. m.	0 02	1.11	1.635				1.40	1.491								
Means		1.112	1.636	1.630			1.40	1.497		.915			*.996	.858	.831	
1:02 p. m.	0 37	1.12	1.616		1.30		1.41	1.495								
1:06 p. m.	0 41	1.12	1.622		1.30		1.41	1.484								
1:10 p. m.	0 45	1.13	1.622		1.30		1.42	1.481								
1:14 p. m.	0 49	1.13	1.629		1.31		1.42	1.484								
Means		1.12	1.624		1.30	1.520	1.42	1.486		.915		.978		.853	.829	.829
1:47 p. m.	1 12	1.17	1.622		1.36		1.50	1.441								
1:51 p. m.	1 16	1.18	1.606		1.37		1.51	1.472								
1:55 p. m.	1 20	1.19	1.605		1.38		1.53	1.465								
1:59 p. m.	1 24	1.20	1.624		1.39		1.54	1.465								
2:03 p. m.	1 28	1.21	1.628		1.40		1.56	1.470								
Means		1.19	1.617		1.38	1.486	1.53	1.463		.905		.988		.858	.832	.824
2:32 p. m.	1 57	1.29	1.592				1.63	1.442								
2:36 p. m.	2 01	1.30	1.590				1.64	1.441								
2:40 p. m.	2 05	1.31	1.589				1.66	1.427								
2:44 p. m.	2 09	1.33	1.599				1.68	1.434								
2:48 p. m.	2 13	1.35	1.578				1.70	1.439								
Means		1.32	1.590				1.66	1.437	1.445	.904	*1.006	.994		.860	.834	
3:17 p. m.	2 42	1.50	1.530				1.88	1.380								
3:21 p. m.	2 46	1.52	1.536				1.90	1.367								
3:25 p. m.	2 50	1.55	1.544				1.92	1.375								
3:29 p. m.	2 54	1.57	1.526				1.93	1.344								
3:33 p. m.	2 58	1.60	1.523				1.94	1.361								
Means		1.55	1.532				1.92	1.365	1.353	.891	*.991	1.009		.859	.833	
	h. m.															
4:02 p. m.	3 27	1.89	1.505				2.35	1.295								
4:06 p. m.	3 31	1.95	1.497				2.42	1.274								
4:10 p. m.	3 35	2.01	1.479				2.48	1.255								
4:14 p. m.	3 39	2.05	1.470				2.54	1.268								
4:18 p. m.	3 43	2.10	1.443				2.65	1.243								
Means		2.00	1.479				2.49	1.267	1.267	.857	*1.000	1.000		.873	.843	
4:47 p. m.	4 12	2.62	1.353				3.34	1.133								
4:51 p. m.	4 16	2.73	1.328				3.46	1.129								
4:55 p. m.	4 20	2.85	1.326				3.59	1.112								
4:59 p. m.	4 24	3.06	1.316				3.74	1.109								
Means		2.82	1.331				3.53	1.121	1.134	.842	*1.012	.989		.875	.856	

See footnote at end of table.

TABLE 1.—*Pyrheliometric readings, Mount Washington, N. H., and vicinity*—Continued

1942 Eastern war time	Hour angle of sun	Mount Washington			Half-way House		Glen House			S_1/S_c	C/S_1	S_1/C	C/S	Atmospheric transmission coefficients		
		Air mass	Q^1_c	Q^2_c	Air mass	Q^2_c	Air mass	Q^2_c	Q^2_c					Q_1	Q_2	Q_3
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Oct. 3	*h m*															
8:36 a. m.	3 58	2.35	1.364				2.97									
8:40 a. m.	3 54	2.29	1.369				2.89									
8:44 a. m.	3 50	2.22	1.405				2.80									
8:48 a. m.	3 46	2.15	1.423				2.72									
Means		2.25	1.390				2.84		1.190				.856	.862		.842
9:22 a. m.	3 12	1.73	1.450				2.16									
9:26 a. m.	3 08	1.69	1.466				2.12									
9:30 a. m.	3 04	1.65	1.486				2.08									
9:34 a. m.	3 00	1.62	1.473				2.04									
Means		1.67	1.468				2.10		1.290				.879	.846		.823
10:02 a. m.	2 32	1.45	1.504													
10:05 a. m.	2 29						1.83	1.347								
10:06 a. m.	2 28	1.43	1.526													
10:09 a. m.	2 25						1.80	1.345								
10;10 a. m.	2 24	1.41	1.510													
10:13 a. m.	2 21						1.77	1.358								
10:14 a. m.	2 20	1.39	1.523													
10:17 a. m.	2 17						1.75	1.356								
10:18 a. m.	2 16	1.37	1.537													
10:21 a. m.	2 13						1.73	1.346								
Means		1.41	1.520				1.78	1.350	1.340	.888	.993	*1.007		.841	.816	
10:47 a. m.	1 47	1.26	1.534		1.46		1.69	1.374								
10:51 a. m.	1 43	1.25	1.546		1.44		1.68	1.381								
10:55 a. m.	1 39	1.24	1.561		1.42		1.66	1.376								
10:59 a. m.	1 35	1.22	1.567		1.40		1.64	1.394								
11:03 a. m.	1 31	1.21	1.557		1.38		1.63	1.395								
Means		1.24	1.553		1.42	1.437	1.66	1.384		.891	1.038		.925	.836	.816	.809
11:32 a. m.	1 02	1.17	1.551				1.46	1.394								
11:36 a. m.	0 58	1.16	1.560				1.47	1.378								
11:40 a. m.	0 54	1.15	1.568				1.48	1.401								
11:44 a. m.	0 50	1.14	1.573				1.49	1.404								
11:48 a. m.	0 46	1.14	1.576				1.50	1.395								
Means		1.15	1.566				1.48	1.394		.890				.830	.800	
12:17 p. m.	0 17	1.12	1.576													
12:19 p. m.	0 15						1.40	1.404								
12:21 p. m.	0 13	1.12	1.570													
12:23 p. m.	0 11						1.40	1.393								
12:25 p. m.	0 09	1.11	1.567													
12:27 p. m.	0 07						1.40	1.382								
12:29 p. m.	0 05	1.11	1.579													
12:31 p. m.							1.40	1.404								
Means		1.12	1.573				1.40	1.396		.887				.829	.791	

(4) Observations taken by J. H. C. with Smithsonian silver-disk pyrheliometer No. 63.
(5) Observations taken by I. F. H. with Clark vacuum pyrheliometer. (Means of all observations taken during the times under (1).)
(7) Observations with Clark normal incidence pyrheliometer. (Means of all observations taken during times under (1).)
(9) Observations taken by W. A. B. with U. S. Weather Bureau Smithsonian silver-disk pyrheliometer No. 1-bis.
(10) Measurements made by I. F. H. with Clark vacuum pyrheliometer. (Means of all observations taken during times under (1).)
(11) Smithsonian normal incidence values at the Glen House divided by the Smithsonian normal incidence values at the summit.
(12) Clark normal incidence values (at whatever height the observations were taken) divided by the Smithsonian normal incidence values at the Glen House.
(13) Smithsonian normal incidence values taken at the base divided by the Clark normal incidence values.
(14) Clark normal incidence values divided by the Smithsonian normal incidence values at different levels.
(15) Atmospheric transmission coefficients for readings taken with the Smithsonian silver-disk No. 63 at the summit.
(16) Atmospheric transmission coefficients for readings with the Clark vacuum pyrheliometer.
(17) Atmospheric transmission coefficients for the U. S. Weather Bureau Smithsonian silver-disk pyrheliometer No. 1-bis at the Glen House.

*Ratios between the Clark and the Smithsonian pyrheliometers when both types were at the same level. Used as check readings to determine the accuracy of the instruments