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MEASUREMENTS OF SOLAR RADIATION INTENSITY AND DETERMINATIONS OF ITS DEPLETION BY THE ATMOSPHERE WITH BIBLIOGRAPHY OF PYRHELIOMETRIC MEASUREMENTS

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In Procès-verbaux des séances de la Section de Météorologie, Union Géodésique et Géophysique Internationale, Annexe VI, Deuxième Assemblee Générale, the president of the section, Sir Napier Shaw, has given an excellent summary of pyrheliometric measurements of solar radiation intensity made in all parts of the world. The summary was prepared in response to a resolution of the section at its meeting in Rome in 1922.

Sir Napier expresses radiation intensities in units of power (kilowatts per square dekameter) for the reason, as he states, that "The kilowatt is the unit that engineers use to represent electrical power; solar energy is thereby brought into the same category as the energy which men buy or sell."

There are two kinds of solar radiation measurements to be considered, as follows:

(1) The total radiation received on a unit of horizontal surface from the sun and sky, and

(2) The intensity of solar radiation at normal incidence.

THE VERTICAL COMPONENT OF SOLAR RADIATION

Measurements of the total radiation as in (1) above are best made with recording instruments, and the records are continued during cloudy and rainy weather as well as when the sky is free from clouds. Table 1 gives a list of the stations at which continuous records of this character have been obtained. Figures 1 and 2 give the annual march of the daily totals for the different stations expressed in kilowatt hours per square dekameter.[1]

For all stations in the United States except Mount Weather, the data from which the curves are constructed is in the form of weekly means of the daily totals; for Mount Weather and Lourenco Marques the means are for decades; for all other stations they are monthly means. The weekly and decade means have been smoothed by the well-known smoothing formula

$$\frac{a+2b+c}{4}.$$

The sources of the data are given in Table 2.

TABLE 1.—*Stations which obtain records of the total radiation received on a horizontal surface from the sun and sky*

Station	Latitude	Longitude	Altitude	Period	Instruments
	° ′	° ′	*Meters*		
(1) Lincoln, Nebr.	40 50 N.	96 41 W.	381	July, 1915-December, 1925.	Callendar.
(2) Madison, Wis.	43 05 N.	89 23 W.	308	April, 1911-December, 1925.	Do.
(3) Chicago, Ill. (University Station.)	41 47 N.	87 35 W.	210	September, 1923-April, 1927.	Weather Bureau thermo-electric.
(4) Mount Weather, Va.	39 04 N.	77 53 W.	540	May, 1912-September, 1914.	Callendar.
(5) Washington, D. C.	38 56 N.	77 05 W.	137	November, 1914-October, 1922.	Do.
				November, 1922-December, 1925	Weather Bureau thermo-electric.
(6) New York, N.Y. (Central Park Observatory.)	40 46 N.	73 58 W.	48	April, 1924-April, 1927.	Do.
(7) Habana, Cuba	23 09 N.	82 21 W.	40	March, 1925-May, 1926.	Do.
(8) Toronto, Canada	43 40 N.	79 24 W.	116		Callendar.
(9) Rothamsted, England.	51 48 N.	0 22 W.	128	1922-1924	Do.
(10) South Kensington, England.	51 30 N.	0 10 W.	37	1913-1920	Do.
(11) Davos Platz, Switzerland.	46 48 N.	9 49 E.	1, 600	November, 1920-October, 1921.	Ångström.
(12) Arosa, Switzerland.[1]	46 47 N.	9 40 E.	1, 860	1921-1925	Mi.; S. I.
(13) Lindenberg, Germany.[1]	52 13 N.	14 07 E.	106	1919	Robitzsch.
(14) Stockholm, Sweden.	59 21 N.	18 04 E.	44	July, 1922-June, 1923.	Ångström.
(15) Sloutzk (Pavlovsk), Russia.	59 41 N.	30 29 E.	40	1913-1919	Crova-Sawinoff.
(16) Lourenço Marques, Port; South Africa.	25 58 S.	32 26 E.	459	1915-1919	Callendar.
(17) Johannesburg, South Africa.	26 11 S.	28 04 E.	1, 806	1908-June, 1910.	Do.

[1] Measurements of direct solar radiation only.

TABLE 2.—*Sources of data given in Figures 1 and 2*

(1) LINCOLN.
    KIMBALL, HERBERT H. 1916–1925. Solar and sky radiation measurements. Mo. Wea. Rev., **44**:178. Monthly thereafter. Washington.

(2) MADISON.
    KIMBALL, HERBERT H. & MILLER, ERIC R. 1916. The total radiation received on a horizontal surface from the sun and sky at Madison, Wis. Mo. Wea. Rev., **44**:180.
    KIMBALL, HERBERT H. 1916–1925. Solar and sky radiation measurements. Mo. Wea. Rev. **44**:179. Monthly thereafter. Washington.

(3) CHICAGO.
    KIMBALL, HERBERT H. 1923–1927. Solar and sky radiation measurements. Mo. Wea. Rev. **51**:533. Monthly thereafter. Washington.

(4) MOUNT WEATHER.
    KIMBALL, HERBERT H. 1914. The total radiation received on a horizontal surface from the sun and sky at Mount Weather, Va. Mo. Wea. Rev. **42**:474. Washington.

(5) WASHINGTON.
    KIMBALL, HERBERT H. 1915–1925. The total radiation received on a horizontal surface at Washington, D. C. Mo. Wea. Rev. **43**:100–111. Monthly there-thereafter. Washington.

(6) NEW YORK.
    KIMBALL, HERBERT H. 1924–1927. Solar and sky radiation measurements. Mo. Wea. Rev. **52**:225. Monthly thereafter. Washington.

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[1] One gram-calorie per square centimeter equals 1.161 kilowatt hours per square dekameter.

(7) HABANA.
THEYE, CARLOS. Ms. tables.

(8) TORONTO.
SHAW, SIR NAPIER. 1926. Radiation in relation to meteorology. Procès-verbaux. Deuxème Assemblée Générale, Union Géodésique et Géophysique Internationale, Section de météorologie, p. 94. Rome.

(9) ROTHAMSTED.
SHAW, SIR NAPIER. 1926. Radiation in relation to meteorology. Proces-verbaux. Deuxième Assemblée Générale, Union Géodésique et Géophysique Internationale, Section de météorologie, p. 94. Rome.

(10) SOUTH KENSINGTON.
Great Britian. Meteorological Office, 1913–1920. British meteorological and magnetic year book, Part III (2), Geophysical Journal. London.

(11) DAVOS.
DORNO, C. 1922. Fortschritte in Strahlungmessungen. Met. Zeit. 1922, **39**:311, Tabelle 2. Braunschweig.

(12) AROSA.
GÖTZ, F. W. PAUL. 1926. Das Strahlungsklima von Arosa. Berlin.

(13) LINDENBERG.
ROBITZSCH, M. 1920–21. Einige Ergebnisse von Strahlungsregistrierungen, die im Jahre 1919 in Lindenberg gewonnen wurden. Beiträge zur Physik der freien Atmosphäre. Band IX, pp. 91–98. Leipzig.

(14) STOCKHOLM.
ÅNGSTRÖM, ANDERS. 1924. Solar and terrestrial radiation, Qr. Jr. Roy. Meteor. Soc., 1924, **50**:123, Table 1. London.

(15) SLOUTZK (PAVLOVSK).
RUSSIA. OBSERVATOIRE GÉOPHYSIQUE CENTRAL. 1926. Bulletin de la Commission Actinométrique permanent de l'observatoire géophysique central. 1925, No. 1–2, 1926, No. 1. Leningrad.
KALITIN, N. N. 1925. Die Wärmesummen der Sonnenstrahlung für Pavlovsk. Met. Zeit., **40**:355, Tabelle 2. Braunschweig.

(16) LOURENCO MARQUES. Provincia de Mocambique. Servicos de Marinha. 1916–1921. Relatonio do Observatorio Campos Rodriges em Lourenco Marques. Anno de 1915–1919. Lourenco Marques.

(17) JOHANNESBURG.
TRANSVAAL. METEOROLOGICAL DEP'T. 1907–1910. Annual Reports, Transvaal Observatory. Pretoria.

In Figure 1 the effect of latitude is shown by a comparison of the curves for Madison and Toronto with that for Habana, and the effect of altitude from a comparison of curves for Washington and Mount Weather. The curves for Chicago and New York show the screening effect of city smoke, especially during the cold months. The instruments in use at these American stations, except that for Toronto, have been standardized at the United States Weather Bureau by the method illustrated in the MONTHLY WEATHER REVIEW for May, 1923, 51: 242.

Since Figure 2 contains curves for stations in both the northern and southern hemispheres, in order to synchronize corresponding seasons of the year it is necessary to follow a different sequence of months for the two hemispheres, as shown. While we have no assurance that the instruments of different types in use at the different stations (see Table 1) record solar energy on precisely the same scale, the curves are generally in good accord. Thus, while Stockholm is farther north than the stations on the British Isles, it undoubtedly has clearer skies; therefore, the marked similarity between the curves for Stockholm, South Kensington, and Rothamsted is not surprising. The curves for Johannesburg and Lourenco Marques are in good agreement with that for Habana, but there is not the difference between the first two named that the difference in their elevations would lead us to expect. On the other hand, the curve for Davos Platz is so high as to indicate unusually clear skies.

For Sloutzk (Pavlovsk), Russia, two curves are given. One includes direct solar radiation only, the other both direct solar and diffuse sky radiation. The curves for Arosa and Lindenberg include only the direct solar radiation, that for Arosa as received upon a horizontal surface, and that for Lindenberg as received on a surface at right angles to the incident solar rays.

A comparison of the two curves for Sloutzk, and also that for Arosa with the curve for near-by Davos, indicates the very considerable part of the total solar thermal energy that is received diffusely from the sky, amounting in many months to 50 per cent. On the other hand, the curve for Lindenberg shows nearly as much energy received from the sun on a surface normal to its rays as the total energy received on a horizontal surface from the sun and sky at Davos, which is at a lower latitude and higher altitude.

For Stockholm Ångström (**1**) [2] found the ratios given in Table 3 between the total radiation and the sky radiation received on a horizontal surface.

TABLE 3.—*Ratio of sky radiation to the total radiation at Stockholm, expressed as a percentage—July, 1922–June, 1923*

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Per cent	79	74	42	35	33	35	26	36	45	54	77	97

From a summary published by me in the MONTHLY WEATHER REVIEW for October, 1924, 52: 475, Table 1, the relations given in Table 4 are found.

TABLE 4.—*Ratio of the sky radiation to the total radiation, as received on a horizontal surface with a cloudless sky, expressed as a percentage*

Station	Solar zenith distance												
	7.5°	25°	30°	48.3°	55°	60°	66.5°	70.7°	73.6°	75.7°	77.4°	78.7°	85°
Washington, D. C.:													
Winter	----	----	----	12	----	16	20	23	25	29	32	37	----
Spring	----	10	----	13	----	17	20	24	28	32	35	40	----
Summer	----	19	----	21	----	24	27	31	34	37	38	40	----
Year	----	16	----	17	----	20	23	25	29	33	36	38	----
Lincoln	----	15	----	16	----	19	21	24	27	30	33	36	----
Madison	----	16	----	16	----	24	25	26	34	36	----	----	----
Flint Island	----	19	----	----	----	----	----	----	----	----	----	----	----
Hump Mountain	----	----	----	8	----	10	12	13	15	16	18	19	----
Mount Whitney	----	8	----	----	----	----	----	----	----	----	----	----	----
Mount Wilson [1]	14	14	14	16	20	20	24	27	----	32	----	38	55

[1] Measurements made in 1913.

Ångström (**1**) has found that the total radiation income Q_s during the day may be expressed by the formula $Q_s = Q_0\ (0.25 + 0.75S)$, where Q_0 is the radiation income which corresponds to a cloudless sky, and S is the duration of sunshine expressed as a percentage of the possible duration. My own (**2**) studies of measurements made at Washington, Madison, and Lincoln give for this equation $Q_s = Q_0\ (0.22 + 0.78S)$.

The only difference between these two equations is in the term that represents the percentage of clear-sky radiation that penetrates a continuous cloud layer.

The average annual amounts of solar thermal energy received on a horizontal surface at the different stations is given in Table 5.

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[2] *The bold-face figures in parentheses refer to references at the end of the paper.*

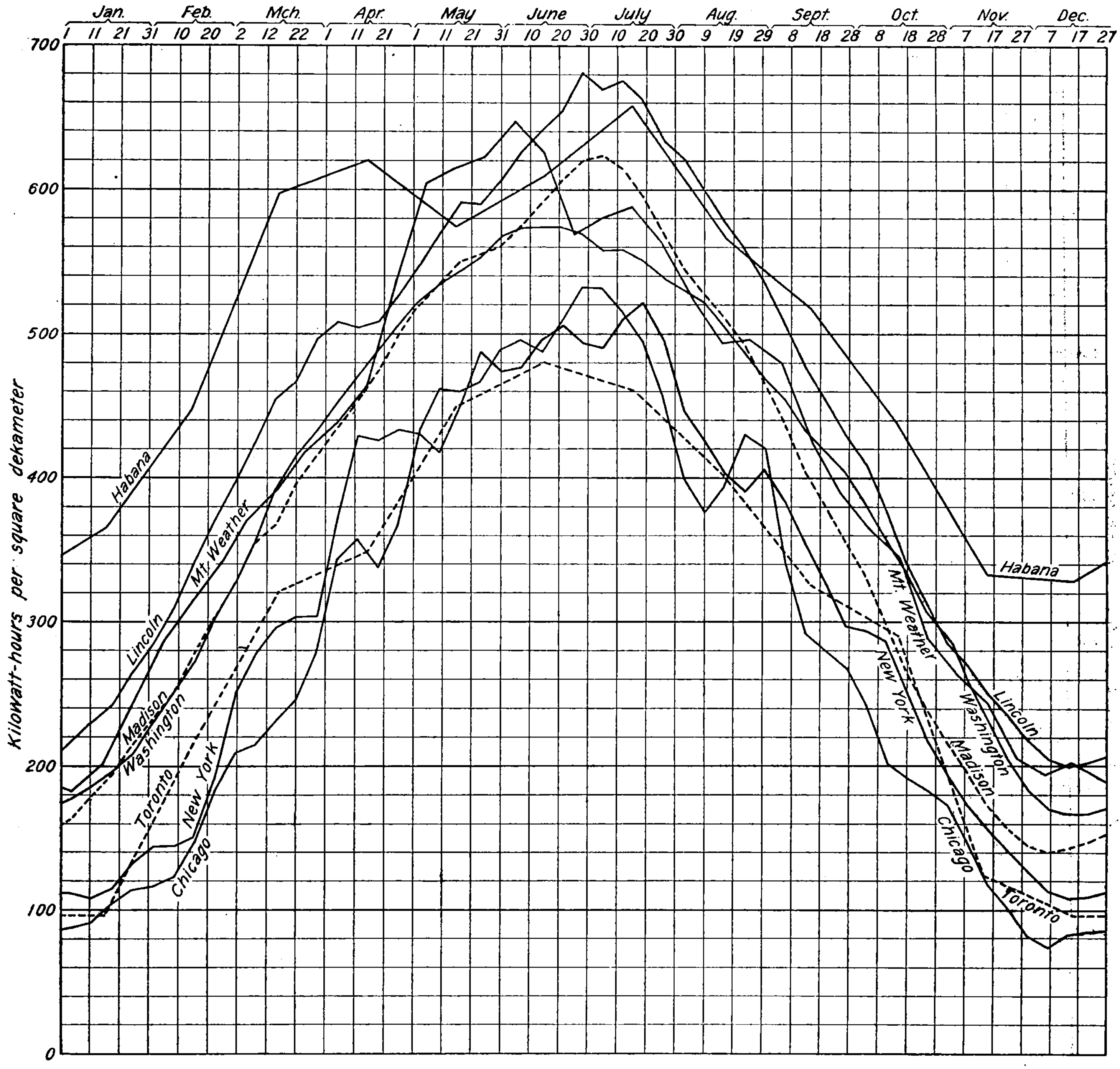

FIG. 1.—Annual march of daily totals of radiation received on a horizontal surface directly from the sun and diffusely from the sky (Western Hemisphere)

TABLE 5.—*Average annual amounts of solar thermal energy received on a square dekameter of horizontal surface*

Stations	Kilowatt-hours	Stations	Kilowatt-hours
Habana	184, 488	Lourenco Marques	169, 462
Lincoln	160, 906	Johannesburg	175, 696
Mount Weather	148, 824	Davos Platz	174, 043
Washington	145, 493	Rothamsted	83, 133
Madison	139, 523	South Kensington	78, 569
Toronto	106, 460	Stockholm	79, 267
New York	97, 856	Sloutzk	70, 296
Chicago	89, 424		

INTENSITY OF SOLAR RADIATION AT NORMAL INCIDENCE

Measurements of the intensity of solar radiation at normal incidence, (2) above, are usually made only when the sun is unobscured by clouds. They may be used to determine the total heat energy received directly from the sun with the sky cloudless, on either a horizontal surface, a surface normal to the incident rays, or a vertical or sloping surface facing in any desired direction (3), (4). However, such determinations have not the meteorological significance that attaches to continuous records under all sorts of weather conditions.

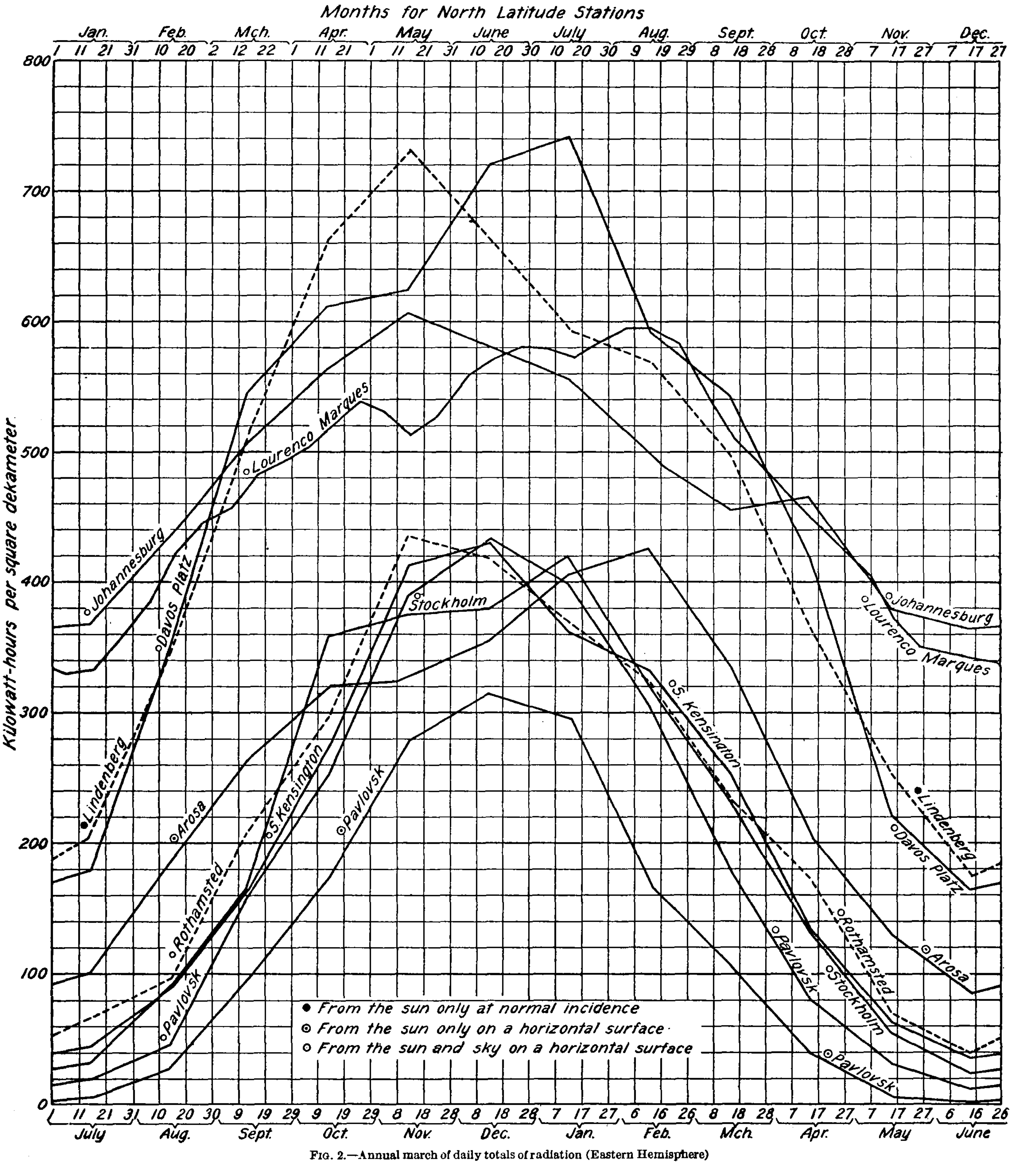

FIG. 2.—Annual march of daily totals of radiation (Eastern Hemisphere)

In this paper these measurements will be used in conjunction with the mean value of the solar constant, as determined by the Astrophysical Observatory of the Smithsonian Institution, in a study of the atmospheric transmission of solar radiation, or its complement, atmospheric depletion.

Table 6 gives a list of stations at which pyrheliometric measurements of the intensity of solar radiation have been made, the length of the period of observation at each station, and the kind of instrument employed. For this latter the following abbreviations have been employed:

Å = Ångström electrical compensation pyrheliometer.

A. P. O. = Astrophysical Observatory copper box pyrheliometer.

Ma. = Marvin electrical resistance pyrheliometer.

Mi. = Michelson bimetallic pyrheliometer.

S. I. = Smithsonian silver-disk pyrheliometer.

M. G. = Gorczyński pyrheliometer employing a Moll thermopile.

Table 7 summarizes the pyrheliometric measurements made at the various stations. In this table the following abbreviations have been employed:

m = the air mass = the length of the path of the solar rays in the earth's atmosphere, the length with zenithal sun being unity.

A_m = the solar thermal energy after passing through air mass m.

A_2 = the solar thermal energy after having passed through air mass $m = 2$.

a = atmospheric transmission coefficient.

a_{1-2} = atmospheric transmission coefficient determined from solar thermal energy measurements made with the sun in the zenith, $m = 1$, and also with $m = 2$; or, $a_{1-2} = \frac{A_2}{A_1}$. Likewise, $a_{2-3} = \frac{A_3}{A_2}$, and $a_{0-1} = \frac{A_1}{A_0}$, where A_0, the solar constant, is assumed to be 1.937 gram-calories per minute per square centimeter, and the value of A_1 has been reduced to that for the mean distance between the sun and the earth. In general, the subscripts to "a" indicate the range of values of A upon which the value of "a" is based.

In Table 7 the values of A_m are usually the means of pyrheliometric readings made near noon, and the corresponding values of m have been computed from the zenith distance of the sun at noon on the middle day of the month, as derived from the latitude of the place and the solar declination.

The value of A_2 given in the table, and the values of A_1, and A_3 which enter into the determination of the values of a_{0-1}, a_{1-2}, and a_{2-3}, have been obtained by interpolation or extrapolation from measured values. In winter, except in the Tropics, the extrapolated values of A_1 are subject to considerable error.

In many cases it has been necessary for the writer to plot logarithms of original pyrheliometric readings against air mass to obtain the desired value of A. In the case of values for Cordoba, La Quiaca, and La Confianza in Argentina, this was not possible, as the original readings are not accessible to me. I have therefore made use of the published values of A_1 and "a," and from these have computed A_2.

Values of A in the table are expressed in gram-calories per minute per square centimeter of normal surface. They have not been reduced to mean distance between the earth and sun.

The A. P. O., the S. I., and the Ma. pyrheliometers have been intercompared to permit of bringing their readings into conformity with the Smithsonian pyrheliometric scale of 1913 (5). The Mi. pyrheliometer is a secondary intrument that is standardized by comparison with a standard instrument, most frequently the Ångström. It has been shown (6) that the ratio

$$\frac{\text{Smithsonian scale}}{\text{Ångström scale}} = 1.0325,$$

approximately. Therefore, in compiling Table 7, whenever it seemed reasonably certain that radiation intensities had been recorded on the Angström scale they have been multiplied by 1.0325 to reduce them to the Smithsonian scale. That such reduction has been made is indicated by a reference to an appropriate footnote at the end of Table 6.

This reduction has been made for the purpose of bringing the intensities into accord with the scale on which Smithsonian solar constant values are expressed in so far as this is possible.

TABLE 6.—*List of pyrheliometric stations*

Station	Latitude	Longitude	Altitude	Period	Instrument
	° ′	° ′	*Meters*		
(1) Abisko, Sweden	68 21 N.	18 49 E.	390	July 2-Sept. 13, 1913; July 1-Aug. 21, 1914.	Å.[1]
(2) Agra, Switzerland	45 48 N.	9 00 E.	550	October, 1922-September, 1923.	Mi.
(3) Algäu (Riezlern), Austria.	47 22 N.	10 10 E.	1,150	May, 1922-May, 1924.	Mi., S. I.
(4) Apia, Samoa	13 48 S.	171 46 W.	2	1925-1927	M. G.
(5) Arequipa, Peru	16 22 S.	63 05 W.	2,451	August, 1912-March, 1915.	S. I.
(6) Arosa, Switzerland.	46 17 N.	9 40 E.	1,860	October, 1921-March, 1925.	S. I., Mi.
(7) Bangkok, Siam	13 44 N.	100 30 E.	10	May 5-21, 1923	Mi.[1]
(8) Bassour, Algeria	36 13 N.	2 52 E.	1,160	August-November, 1911.	A. P. O.
(9) Batavia, Java	6 11 S.	106 50 E.	8	1915 and 1917-1919.	S. I. and Mi.
(10) Calama, Chili (Mt. Montezuma).	22 28 S.	68 56 W.	2,250	July, 1918-July, 1920.	S. I.
	22 38 S.	68 56 W.	2,700	August, 1920-April 1926.	S. I.
(11) Cape Horn, Chili.	55 31 S.	70 25 W.	12	September, 1882 - September, 1883.	Pouillet.
(12) Cheyenne, Wyo	41 08 N.	104 48 W.	1,856	August 29-September 3, 1910.	S. I.
(13) Cordoba, Argentina.	31 25 S.	64 12 W.	438	February, 1912-June, 1914.	S. I.
(14) Corleto, Italy	44 36 N.	10 51 E.	58	Agust-September, 1898.	Å.[1]
(15) Davos, Switzerland.	46 48 N.	9 49 E.	1,600	1912-1918 (reduced to S. I. scale, 1913).	Å and Mi.
(16) Ellijay, N. C	35 11 N.	85 15 W.	683	May 8-13, 1916	S. I.
(17) Eskdalemuir, Scotland.	55 19 N.	3 12 W.	244	1909-1921	Å.[1]
(18) Etna, Mount (Casa Cantoniera)	37 45 N.	15 00 E.	2,950 1,885	Aug. 18-23, 1908.	Å.[1]
(19) Feldberg, Germany.	47 52 N.	8 02 E.	1,300	Oct. 19, 1921-March, 1925.	Mi., S. I.
(20) Flagstaff, Ariz	35 12 N.	111 37 W.	2,105	Sept. 25-30, 1910.	S. I.
(21) Flint Island	10 05 S.	152 10 W.	-------	Dec. 29, 1907	S. I.
(22) Florence, Italy	43 46 N.	11 13 E.	73	June, 1915-December, 1917.	Å.[1]
(23) Frankfort on the Main, Germany.	50 07 N.	8 38 E.	820	July, 1919-March, 1922.	Mi.[1]
(24) Fresno, Calif	36 43 N.	119 49 W.	110	Mar., 14, 1920	S. I.
(25) Fuji, Japan	35 22 N.	138 44 E.	3,726	July 29, 1909	Å.[1]
(26) Gornergrat, Switzerland.	45 59 N.	7 47 E.	3,136	June 25-July 12, 1903.	Å.[1]
(27) Hald, Denmark	56 23 N.	9 19 E.	78	1902-1903	Å.[1]
(28) Helwan (Cairo), Egypt.	29 52 N.	31 20 E.	116	February, 1914-December, 1923.	Å.[1]
(29) Hump Mountain, N. C.	36 08 N.	82 00 W.	1,500	June, 1917-March, 1918.	S. I.
(30) Innsbruck, Austria.	47 16 N.	11 23 E.	580	January-June, 1908.	Å.[1]
(31) Johannesburg, South Africa.	26 11 S.	28 04 E.	1,806	April, 1907-June, 1911.	Å[1].
(32) Jungfraujoch, Switzerland.	46 32 N.	7 58 E.	3,457	Sept. 23-Oct. 3, 1923.	Å, Mi.
(33) Karlsruhe, Germany.	49 01 N.	8 25 E.	128	Sept. 6, 1921-Mar. 31, 1925.	Mi., S. I.
(34) Katharinenburg, Russia.	56 50 N.	60 39 E.	290	1896-1898	Chwolson.
(35) Kew Observatory, England.	51 28 N.	0 18 W.	6	1911-1921	Å.[1]
(36) Kief, Russia	50 24 N.	30 28 E.	183	1888	Crova.
(37) Kolberg, Germany	54 11 N.	15 33 E.	2	April, 1914-April, 1915.	Å, Mi.[1]
(38) La Confianza, Argentina.	22 08 S.	65 45 W.	4,483	August-September, 1913.	S. I.
(39) La Jolla, Calif	32 50 N.	117 15 W.	30	Mar. 2-4, 1920	S. I.
(40) La Quiaca, Argentina.	22 08 S.	65 45 W.	3,492	September, 1912-October, 1913.	S. I.

[1] Radiation intensities as recorded have been reduced to the Smithsonian pyrheliometric scale of 1913 by multiplying by 1,0325.

TABLE 6.—*List of pyrheliometric stations*—Continued

Station	Latitude	Longitude	Altitude	Period	Instrument
	° ′	° ′	*Meters*		
(41) Lausanne, Switzerland.	46 31 N.	6 38 E.	515	1896–1902	Crova.
(42) Leningrad (St. Petersburg), Russia.	59 56 N.	30 15 E.	5	1895–1904	Chwolson.
(43) Lincoln, Nebr.	40 50 N.	96 41 W.	373	July, 1915–December, 1925.	Ma.
(44) Lindenberg, Germany.	52 13 N.	14 07 E.	106	1919	Mi. and Robitzsch.
(45) Madison, Wis.	43 05 N.	89 23 W.	297	July, 1910–December, 1925.	Ma.
(46) Madrid, Spain	40 24 N.	3 41 E.	655	September, 1910–August, 1924.	Å.[1]
(47) Medford, Oregon	42 20 N.	122 49 W.	468	Mar. 28–Apr. 5, 1920.	S. I
(48) Modena, Italy	44 39 N.	10 56 E.	51	March–November, 1900; July–September, 1901; January, 1902–June, 1903.	Å.[1]
(49) Mont Blanc, France.	45 49 N.	6 52 E.	4,810	August and September, 1904.	Crova actinograph.
(50) Monte Cimone, Italy.	44 12 N.	10 42 E.	2,165	August, 1899; August, 1900; July–September, 1901, July–August, 1902; July–September, 1903; July–August, 1904; July–August, 1905.	Violle and A.[1]
(51) Monte Rosa, Italy	45 55 N.	7 56 E.	4,560	August, September, 1905, 1906, 1907.	Å.[1]
(52) Montpellier, France	43 36 N.	3 53 E.	43	1883–1900	Crova.
(53) Moscow, Russia	55 45 N.	37 34 E.	156	May–August, 1921.	Michelson compared with Å.[1]
(54) Mount Czarnohora, Poland (Eastern Carpathians):					
Worchta	48 18 N.	24 34 E.	770	August, 1924	Å, S. I.
Jablonica	48 19 N.	24 29 E.	840	do	Å, S. I.
Pożyżewska	48 10 N.	24 33 E.	1,372	September, 1909.	Å, S. I.
			1,406	July, August, 1924.	Å, Mi, S. I.
Chomiak	48 22 N.	24 30 E.	1,544	August, 1924	Å, S. I.
Pożyżewska	48 09 N.	24 32 E.	1,882	do	Å, S. I.
Howerla	48 10 N.	24 30 E.	2,058	do	Å, Mi, S. I.
(55) Mount Weather, Va.	39 04 N.	77 53 W.	540	September, 1907–September, 1914.	Ma.
(56) Mount Whitney, Calif.	36 35 N.	118 17 W.	4,420	August, 1908, September, 1909, September, 1910.	A. P. O.
(57) Mount Wilson, Calif.	34 13 N.	118 04 W.	1,737	1905–1920	A. P. O.
(58) Naples, Italy	40 52 N.	14 15 E.	149	December, 1913–January, 1915.	Å.[1]
(59) Nijni-Oltchedaeff, Russia.	48 38 N.	27 40 E.	197	1912–1914	Å.[1]
(60) Numazu, Japan	35 06 N.	138 51 E.	10	July 29, 1909	Å.[1]
(61) Nyköping, Sweden.	58 45 N.	17 01 E.	18	March, 1918–May, 1919.	Å.[1]
(62) Pangerango, Java	6 50 S.	106 50 E.	3,030	June - July, 1915; July–August, 1919.	Mi.[1]
(63) Paris (Parc St. Maur), France.	48 49 N.	2 29 E.	50	1907–1923	Å.[1]
(64) Pavlovsk (Sloutzk, Russia).	59 41 N.	30 29 E.	40	September, 1892–December, 1919; January, 1925–April, 1926.	Crova - Sawinoff, Mi.
(65) Phoenix, Ariz.	33 28 N.	112 00 W.	350	Oct. 3–8, 1910	S. I.
(66) Pomona, Calif.	34 03 N.	117 45 W.	265	Feb. 26–28, 1920.	S. I.
(67) Potsdam, Germany.	52 23 N.	13 04 E.	106	March, 1907–December, 1915.	Mi, Å, S. I.
(68) Red Bluff, Calif.	40 10 N.	122 15 W.	110	Mar. 23–25, 1920.	S. I.
(69) St. Blasien, Germany.	47 46 N.	8 08 E.	790	June, 1919–March, 1920; 1921–1925.	Mi., S. I.
(70) Santa Fe, N. Mex.	35 41 N.	105 57 W.	2,138	September, 1910; October, 1912–March, 1922.	Ma.
Twin Mountain.	35 39 N.	105 55 W.	2,438	Oct. 25, 1912	S. I.
Lake Peak	35 48 N.	105 45 W.	3,720	Oct. 29, 1912	S. I.
(71) Sestola, Italy	44 15 N.	10 46 E.	1,092	July–September, 1899; July–August, 1900; July–September, 1921.	Å and Violle.[1]
(72) Simla, India	31 07 N.	77 08 E.	2,204	October, 1906–December, 1915.	Å.[1]
(73) Smeroe, Java	8 09 S.	112 55 E.	3,670	Apr. 30, 1915, and Aug. 25, 1918.	Mi.[1]
(74) Sonnblick, Austria	47 03 N.	12 56 E.	3,106	June 19–July 17, 1902.	Å.[1]
(75) Tashkent, Russia	41 20 N.	69 18 E.	-------	January–April, 1926.	Mi.
Teneriffe, Canary Islands:					
(76) Pic de Teyde	28 12 N.	16 42 W.	3,683	June 25–27, 1896.	Å.[1]
(77) Alta Vista	28 12 N.	16 42 W.	3,252	June 21–July 3, 1896.	Å.[1]
(78) Izana	28 19 N.	16 30 W.	2,367	April–December, 1916.	S. I.
(79) Cañadas	28 13 N.	16 34 W.	2,100	May, 1912 – June, 1915.	S. I.
(80) Guimar	28 18 N.	16 28 W.	360	July 2–3, 1896	Å.[1]
(81) Théodosie, Russia	45 02 N.	35 24 E.	-------	January, 1925 – April, 1926.	Mi.
(82) Tjisoeroepan, Java	6 50 S.	109 30 E.	1,200	July, 1918	Mi.[1]
(83) Trapp, Va.	39 04 N.	77 52 W.	220	Aug. 30–Sept. 2, 1909.	A. P. O.
(84) Treurenberg, Spitzbergen.	79 55 N.	16 52 E.	9	September, 1899; April–July, 1900.	Å.[1]
(85) Upsala, Sweden	59 51 N.	17 32 E.	40	1901	Å.[1]
(86) Ursanova, Poland	52 02 N.	21 00 E.	100	June–August, 1909.	Å.[1]
(87) Wahnsdorf, Germany.	51 07 N.	13 41 E.	260	August, 1917–August, 1918	Mi.
(88) Warsaw, Poland	52 15 N.	21 02 E.	120	1910–1918	Å and others.[1]
(89) Washington, D. C.	38 56 N.	77 05 W.	127	October, 1914–December, 1925.	Ma.
(90) Zakopane, Austria	49 18 N.	19 58 E.	899	August–September, 1903.	Å.[1]
MISCELLANEOUS					
(91) Atlantic Ocean	38 N.	10 W.	-------	Mar. 8, 1923	Mi.[1]
(92) Mediterranean Sea	36 N.	50 E.	-------	Mar. 13, 1923	Mi.[1]
	32 N.	32 E.	-------	Aug. 5, 1923	Mi.[1]
	34 N.	24 E.	-------	Aug. 7, 1923	Mi.[1]
	38 N.	16 E.	-------	Aug. 9, 1923	Mi.[1]
(93) Suez Canal	39 N.	33 E.	-------	Mar. 18, 1923	Mi.[1]
(94) Red Sea	22 N.	38 E.	-------	Mar. 20, 1923	Mi.[1]
	18 N.	40 E.	-------	July 31, 1923	Mi.[1]
	22 N.	38 E.	-------	Aug. 1, 1923	Mi.[1]
(95) Gulf of Aden	12 N.	44 E.	-------	Mar. 23, 1923	Mi.[1]
	11 N.	47 E.	-------	July 28, 1923	Mi.[1]
(96) Indian Ocean	10 N.	65 E.	-------	Mar. 28, 1923	Mi.[1]
	4 N.	61 E.	-------	July 22, 1923	Mi.[1]
(97) Gulf of Siam	3 N.	101 E.	-------	Apr. 10, 1923	Mi.[1]
OBSERVATIONS FROM BALLOONS					
(98) Omaha, Nebr.	41 16 N.	95 56 W.	22,000	July 11, 1914	S. I. registering.
(99) Griesheim, Germany.	51 07 N.	8 41 E.	7,505	Oct. 19, 1913	Å.[1]

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[1] Radiation intensities as recorded have been reduced to the Smithsonian pyrheliometric scale of 1913 by multiplying by 1.0325.

TABLE 7.—*Monthly means of solar radiation and atmospheric transmission*

Stations	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
La Confianza (38):												
A_2	-----	-----	-----	-----	-----	-----	-----	1.59	-----	-----	-----	-----
a_{1-2}	-----	-----	-----	-----	-----	-----	-----	.928	-----	-----	-----	-----
a_{0-1}	-----	-----	-----	-----	-----	-----	-----	.899	-----	-----	-----	-----
La Quiaca (40):												
A_2	1.44	1.41	1.41	1.48	1.53	1.54	1.57	1.51	1.51	1.49	-----	-----
a_{1-2}	.879	.869	.887	.900	.912	.911	.916	.908	.900	.891	-----	-----
a_{0-1}	.818	.818	.813	.855	.886	.903	.916	.882	.874	.855	-----	-----
Calama (10):												
A_2	1.43	1.42	1.40	1.41	1.44	1.43	1.41	1.45	1.46	1.47	1.43	1.45
a_{2-3}	.894	.894	.887	.898	.912	.908	.902	.902	.902	.900	.894	.890
a_{0-1}	.790	.799	.795	.815	.827	.834	.824	.842	.837	.832	.811	.816
Mount Montezuma:												
A_2	1.47	1.43	1.45	1.46	1.48	1.48	1.47	1.47	1.49	1.51	1.51	1.49
a_{2-3}	.901	.891	.902	.910	.918	.920	.921	.916	.915	.912	.909	.900
a_{0-1}	.813	.815	.825	.845	.859	.859	.862	.855	.857	.857	.846	.832
Arequipa (5):												
A_2	1.30	1.33	1.33	1.31	1.33	1.35	1.33	1.32	1.31	1.32	1.33	1.32
a_{1-2}	.832	.880	.878	.870	.880	.883	.865	.865	.850	.845	.843	.835
a_{0-1}	.778	.759	.775	.783	.796	.818	.820	.808	.806	.801	.795	.792
Cordoba (13):												
A_2	1.15	1.18	1.16	1.25	1.25	1.24	1.21	1.26	1.19	1.18	1.22	1.21
a_{1-2}	.800	.824	.825	.853	.863	.863	.852	.860	.825	.820	.835	.831
a_{0-1}	.720	.720	.722	.763	.770	.770	.756	.778	.748	.741	.736	.728
Cape Horn (11):												
A_m	1.48	1.37	0.99	1.09	0.88	0.96	0.93	0.88	1.39	1.36	1.25	1.37
m	1.28	1.36	1.75	2.50	3.51	5.54	3.30	3.10	1.62	1.50	1.33	1.22
Mount Whitney (56):												
A_2	-----	-----	-----	-----	-----	-----	-----	1.56	-----	-----	-----	-----
a_{2-3}	-----	-----	-----	-----	-----	-----	-----	.927	-----	-----	-----	-----
a_{0-1}	-----	-----	-----	-----	-----	-----	-----	.893	-----	-----	-----	-----
Mount Wilson (57):												
A_2	-----	-----	-----	-----	1.33	1.35	1.33	1.33	1.38	1.42	1.46	-----
a_{1-4}	-----	-----	-----	-----	.881	.893	.888	.891	.895	.903	.915	-----
a_{0-1}	-----	-----	-----	-----	.795	.795	.795	.792	.795	.796	.796	-----
Hump Mountain (29):												
A_2	1.52	1.43	1.46	-----	-----	1.29	1.12	1.24	1.36	1.38	1.41	1.46
a_{1-2}	.918	.905	.917	-----	-----	-----	-----	.857	.902	.898	.900	.916
a_{0-1}	.828	.799	.813	-----	-----	-----	-----	.765	.786	.788	.814	.814
Santa Fe (70):												
A_2	1.51	1.46	1.43	1.34	1.30	1.24	1.22	1.25	1.32	1.38	1.45	1.49
a_{2-3}	.913	.897	.903	.873	.908	.871	.885	.880	.886	.899	.912	.893
a_{0-1}	.825	.822	.814	.801	.803	.783	.766	.767	.798	.811	.813	.834
Lake Peak:												
A_2	-----	-----	-----	-----	-----	-----	-----	-----	-----	1.34	-----	-----
a_{2-3}	-----	-----	-----	-----	-----	-----	-----	-----	-----	.847	-----	-----
a_{0-1}	-----	-----	-----	-----	-----	-----	-----	-----	-----	.802	-----	-----
Twin Mountain:												
A_2	-----	-----	-----	-----	-----	-----	-----	-----	-----	1.38	-----	-----
a_{2-3}	-----	-----	-----	-----	-----	-----	-----	-----	-----	.848	-----	-----
a_{0-1}	-----	-----	-----	-----	-----	-----	-----	-----	-----	.808	-----	-----
Flagstaff (20):												
A_2	-----	-----	-----	-----	-----	-----	-----	-----	1.40	-----	-----	-----
a_{1-4}	-----	-----	-----	-----	-----	-----	-----	-----	.884	-----	-----	-----
a_{0-1}	-----	-----	-----	-----	-----	-----	-----	-----	.817	-----	-----	-----
Cheyenne (12):												
A_2	-----	-----	-----	-----	-----	-----	-----	1.26	-----	-----	-----	-----
a_{1-4}	-----	-----	-----	-----	-----	-----	-----	.859	-----	-----	-----	-----
a_{0-1}	-----	-----	-----	-----	-----	-----	-----	.765	-----	-----	-----	-----
Phoenix (65):												
A_2	-----	-----	-----	-----	-----	-----	-----	-----	-----	1.27	-----	-----
a_{1-4}	-----	-----	-----	-----	-----	-----	-----	-----	-----	.875	-----	-----
a_{0-1}	-----	-----	-----	-----	-----	-----	-----	-----	-----	.753	-----	-----
La Jolla (39):												
A_2	-----	-----	1.32	-----	-----	-----	-----	-----	-----	-----	-----	-----
a_{2-3}	-----	-----	.871	-----	-----	-----	-----	-----	-----	-----	-----	-----
a_{0-1}	-----	-----	.782	-----	-----	-----	-----	-----	-----	-----	-----	-----
Pomona (66):												
A_2	-----	1.30	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
a_{2-3}	-----	.850	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
a_{0-1}	-----	.805	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Fresno (24):												
A_2	-----	-----	1.34	-----	-----	-----	-----	-----	-----	-----	-----	-----
a_{2-3}	-----	-----	.869	-----	-----	-----	-----	-----	-----	-----	-----	-----
a_{0-1}	-----	-----	.776	-----	-----	-----	-----	-----	-----	-----	-----	-----
Red Bluff (68):												
A_2	-----	-----	1.32	-----	-----	-----	-----	-----	-----	-----	-----	-----
a_{2-3}	-----	-----	.845	-----	-----	-----	-----	-----	-----	-----	-----	-----
a_{0-1}	-----	-----	.772	-----	-----	-----	-----	-----	-----	-----	-----	-----
Medford (47):												
A_2	-----	-----	1.24	-----	-----	-----	-----	-----	-----	-----	-----	-----
$a_{1.5-2.5}$	-----	-----	.857	-----	-----	-----	-----	-----	-----	-----	-----	-----
a_{0-1}	-----	-----	.778	-----	-----	-----	-----	-----	-----	-----	-----	-----
Lincoln, Nebr.(43).												
A_2	1.35	1.37	1.28	1.20	1.13	1.09	1.07	1.07	1.17	1.27	1.36	1.37
a_{2-3}	.874	.870	.844	.821	.842	.837	.829	.841	.849	.866	.875	-----
a_{0-1}	.772	.793	.789	.750	.734	.719	.706	.682	.725	.752	.784	-----
Madison, Wis.,(45):												
A_2	1.36	1.37	1.31	1.22	1.09	1.09	1.04	1.09	1.16	1.19	1.30	-----
a_{1-2}	.893	.883	.870	.865	.801	.833	.798	.831	.879	.868	.890	-----
a_{0-1}	.776	.782	.779	.734	.718	.704	.680	.692	.720	.706	.736	-----
Washington, D. C. (89):												
A_2	1.22	1.17	1.14	1.07	0.99	0.89	0.91	0.95	1.04	1.11	1.17	1.22
a_{2-3}	.825	.829	.826	.823	.816	.800	.849	.839	.829	.838	.841	.842
a_{0-1}	.742	.744	.731	.702	.676	.643	.626	.646	.688	.719	.702	.726
Mount Weather, Va. (55):												
A_2	1.34	1.25	1.23	1.17	0.99	1.03	0.99	1.05	1.14	1.13	1.26	1.30
a_{2-3}	.861	.847	.833	.788	.775	.820	.777	.826	.830	.819	.866	.860
a_{0-1}	.778	.743	.755	.774	.675	.670	.680	.673	.71	.707	.734	.755

TABLE 7.—*Monthly means of solar radiation and atmospheric transmission*—Continued

Stations	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Trapp, Va. (83):												
A_2	-----	-----	-----	-----	-----	-----	-----	-----	1.07	-----	-----	-----
$a_{1.5-2.5}$	-----	-----	-----	-----	-----	-----	-----	-----	.750	-----	-----	-----
a_{0-1}	-----	-----	-----	-----	-----	-----	-----	-----	.748	-----	-----	-----
Ellijay, N. C.(16):												
A_2	-----	-----	-----	-----	1.21	-----	-----	-----	-----	-----	-----	-----
a_{1-2}	-----	-----	-----	-----	.846	-----	-----	-----	-----	-----	-----	-----
a_{0-1}	-----	-----	-----	-----	.754	-----	-----	-----	-----	-----	-----	-----
Teneriffe:												
Pic de Teyde (76)—												
A_2	-----	-----	-----	-----	-----	1.53	-----	-----	-----	-----	-----	-----
a_{1-2}	-----	-----	-----	-----	-----	.911	-----	-----	-----	-----	-----	-----
a_{0-1}	-----	-----	-----	-----	-----	.897	-----	-----	-----	-----	-----	-----
Alta Vista (77):												
A_2	-----	-----	-----	-----	-----	1.51	-----	-----	-----	-----	-----	-----
a_{1-2}	-----	-----	-----	-----	-----	.905	-----	-----	-----	-----	-----	-----
a_{0-1}	-----	-----	-----	-----	-----	.887	-----	-----	-----	-----	-----	-----
Izana (78):												
A_m	-----	-----	-----	1.61	1.62	1.61	1.54	1.55	1.57	1.59	1.59	1.65
m	-----	-----	-----	1.04	1.02	1.01	1.01	1.04	1.12	1.25	1.45	1.61
Cañadas (79):												
A_2	1.47	1.51	1.49	1.45	1.41	1.39	1.37	1.37	1.42	1.42	1.44	1.51
a_{1-2}	.875	.896	.897	.904	.887	.886	.879	.875	.888	.877	.883	.891
a_{0-1}	.839	.849	.851	.863	.840	.837	.853	.836	.834	.830	.822	.845
Gulmar (80):												
A_2	-----	-----	-----	-----	-----	-----	1.22	-----	-----	-----	-----	-----
a_{1-2}	-----	-----	-----	-----	-----	-----	.841	-----	-----	-----	-----	-----
a_{0-1}	-----	-----	-----	-----	-----	-----	.771	-----	-----	-----	-----	-----
Madrid, Spain, (46):												
A_m	1.23	1.26	1.34	1.36	1.33	1.30	1.29	1.26	1.28	1.27	1.23	1.16
m	2.08	1.68	1.34	1.16	1.07	1.05	1.06	1.12	1.26	1.53	1.94	2.25
Monte Rosa, Italy, (51):												
A_2	-----	-----	-----	-----	-----	-----	-----	-----	1.56	-----	-----	-----
a_{1-2}	-----	-----	-----	-----	-----	-----	-----	-----	.908	-----	-----	-----
a_{0-1}	-----	-----	-----	-----	-----	-----	-----	-----	.900	-----	-----	-----
Monte Cimone (50):												
A_2	-----	-----	-----	-----	-----	-----	-----	1.26	-----	-----	-----	-----
a_{1-2}	-----	-----	-----	-----	-----	-----	-----	.871	-----	-----	-----	-----
a_{0-1}	-----	-----	-----	-----	-----	-----	-----	.764	-----	-----	-----	-----
A_m	-----	-----	-----	-----	-----	-----	1.44	1.42	1.60	-----	-----	-----
m	-----	-----	-----	-----	-----	-----	1.22	1.28	1.50	-----	-----	-----
Sestola (71):												
A_m	-----	-----	-----	-----	-----	-----	1.38	1.37	1.32	-----	-----	-----
m	-----	-----	-----	-----	-----	-----	1.20	1.24	1.30	-----	-----	-----
Etna (Mount) (18):												
A_2	-----	-----	-----	-----	-----	-----	-----	1.43	-----	-----	-----	-----
a_{1-2}	-----	-----	-----	-----	-----	-----	-----	.920	-----	-----	-----	-----
a_{0-1}	-----	-----	-----	-----	-----	-----	-----	.823	-----	-----	-----	-----
Casa Cantoniera:												
A_2	-----	-----	-----	-----	-----	-----	-----	1.37	-----	-----	-----	-----
a_{1-2}	-----	-----	-----	-----	-----	-----	-----	.906	-----	-----	-----	-----
a_{0-1}	-----	-----	-----	-----	-----	-----	-----	.800	-----	-----	-----	-----
Florence (22):												
A_m	1.04	1.12	1.29	1.21	1.21	1.21	1.20	1.15	1.14	1.11	1.03	1.01
m	2.33	1.77	1.42	1.19	1.10	1.06	1.08	1.15	1.32	1.65	2.14	2.56
Corleto (14):												
A_m	-----	-----	-----	-----	-----	-----	-----	1.28	1.27	-----	-----	-----
m	-----	-----	-----	-----	-----	-----	-----	1.17	1.27	-----	-----	-----
Modena (48):												
A_m	1.10	1.01	1.23	1.18	1.24	1.16	1.19	1.23	1.14	1.22	1.15	1.05
m	2.41	1.86	1.45	1.22	1.11	1.07	1.09	1.17	1.33	1.68	2.21	2.65
A_2	-----	-----	-----	-----	-----	-----	1.01	0.95	-----	-----	-----	-----
a_{1-2}	-----	-----	-----	-----	-----	-----	.814	.770	-----	-----	-----	-----
a_{0-1}	-----	-----	-----	-----	-----	-----	.662	.651	-----	-----	-----	-----
Naples (58):												
A_2	1.17	1.21	1.16	1.19	1.02	1.04	1.07	1.01	1.20	1.22	1.25	1.24
a_{2-3}	.878	.857	.815	.860	.826	.828	.830	.828	.855	.867	.864	.855
a_{0-1}	.678	.763	.729	.733	.657	.684	.692	.664	.754	.733	.750	.743
Montpellier (52):												
A_m	1.05	1.09	1.12	1.16	1.14	1.14	1.13	1.12	1.12	1.09	1.05	1.01
m	2.32	1.81	1.42	1.20	1.09	1.06	1.08	1.15	1.31	1.64	2.13	2.54
Paris (63):												
A_m	0.87	1.00	1.12	1.16	1.14	1.14	1.14	1.12	1.10	1.04	0.94	0.84
m	2.86	2.10	1.57	1.28	1.15	1.10	1.12	1.22	1.44	1.86	2.60	3.24
A_{max}	1.37	1.38	1.48	1.48	1.47	1.47	1.46	1.41	1.46	1.43	1.33	1.24
m	2.52	2.31	1.48	1.28	1.24	1.14	1.18	1.27	1.37	1.78	2.23	3.53
Mont Blanc (49):												
A_m	-----	-----	-----	-----	-----	-----	-----	-----	1.66	-----	-----	-----
m	-----	-----	-----	-----	-----	-----	-----	-----	1.39	-----	-----	-----
Jungfraujoch (32):												
A_2	-----	-----	-----	-----	-----	-----	-----	-----	1.56	-----	-----	-----
a_{2-3}	-----	-----	-----	-----	-----	-----	-----	-----	.931	-----	-----	-----
a_{0-1}	-----	-----	-----	-----	-----	-----	-----	-----	.877	-----	-----	-----
Davos (15):												
A_2	1.49	1.45	1.37	1.34	1.26	1.20	1.21	1.29	1.34	1.39	1.43	1.43
a_{2-3}	.901	.876	.861	.880	.889	.920	.937	.882	.881	.887	.874	.915
a_{0-1}	.825	.832	.818	.816	.795	.780	.749	.777	.794	.820	.822	.784
Gornergrat (26):												
A_2	-----	-----	-----	-----	-----	1.30	-----	-----	-----	-----	-----	-----
a_{2-3}	-----	-----	-----	-----	-----	.855	-----	-----	-----	-----	-----	-----
a_{0-1}	-----	-----	-----	-----	-----	.856	-----	-----	-----	-----	-----	-----
Agra (2):												
A_2	1.39	1.46	1.25	1.20	1.10	1.06	0.95	1.09	1.21	1.30	1.35	1.37
a_{2-3}	.892	.907	.857	.848	.825	.828	.818	.821	.847	.892	.880	.912
$_{0-1}$	.779	.808	.747	.773	.734	.705	.653	.692	.743	.748	.776	.769
Arosa (6):												
A_2	1.52	1.52	1.47	1.43	1.35	1.33	1.34	1.36	1.41	1.45	1.48	1.54
a_{2-3}	.921	.921	.905	.895	.881	.880	.888	.904	.908	.917	.939	-----
a_{0-1}	.830	.837	.844	.827	.808	.805	.795	.809	.815	.810	.802	-----
Lausanne (41):												
A_m	0.79	0.85	0.90	0.91	0.86	0.85	.086	0.88	0.86	0.86	0.82	0.75
m	2.59	1.97	1.50	1.25	1.12	1.09	1.10	1.19	1.38	1.76	2.36	2.87

TABLE 7.—*Monthly means of solar radiation and atmospheric transmission*—Continued

Stations	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Sonnblick (Alta Vista) (74):												
A_2	----	----	----	----	----	1.44	----	----	----	----	----	----
a_{2-3}	----	----	----	----	----	.912	----	----	----	----	----	----
a_{0-1}	----	----	----	----	----	.890	----	----	----	----	----	----
Innsbruck (30):												
A_m	1.09	1.20	1.20	1.24	1.27	1.28	----	----	----	----	----	----
m	2.69	2.02	1.52	1.26	1.13	1.09	----	----	----	----	----	----
Algau (3):												
A_2	1.40	1.33	1.27	1.25	1.20	1.13	1.13	1.21	1.28	1.30	1.31	1.36
a_{2-3}	.900	.895	.866	.808	.825	.805	.858	.851	.855	.877	.878	.868
a_{0-1}	.775	.756	.767	.791	.771	.767	.736	.751	.795	.758	.752	.755
Frankfort on the Main (23):												
A_2	1.50	1.28	1.16	1.12	1.09	1.01	1.01	1.10	1.23	1.41	1.42	(1)
a_{2-3}	.893	.919	.826	.792	.782	.748	.748	.748	.783	.879	.920	(1)
a_{0-1}	.841	.707	.731	.737	.737	.722	.722	.779	.819	.829	.799	(1)
Kolberg (37):												
A_2	----	----	1.31	1.21	1.12	1.08	0.91	1.01	1.17	1.30	----	----
a_{2-3}	----	----	.828	.795	.860	.816	.824	.848	.864	.791	----	----
a_{0-1}	----	----	.783	.793	.768	.713	.699	.674	.668	.786	----	----
A_m	0.88	1.20	----	----	----	----	----	----	----	----	0.99	0.82
m	3.85	2.57	----	----	----	----	----	----	----	----	3.36	4.54
Lindenberg (44):												
A_{max}	0.60	0.85	1.05	1.21	1.25	1.15	1.08	1.05	1.02	0.91	0.71	0.51
m	3.43	2.47	1.70	1.35	1.19	1.14	1.17	1.27	1.53	2.07	3.02	3.96
Potsdam (67):												
A_2	1.27	1.25	1.14	1.16	1.08	1.06	0.98	0.96	1.11	1.14	1.21	1.20
a_{2-3}	.874	.865	.859	.814	.767	.808	.801	.772	.818	.822	.904	.866
a_{0-1}	.728	.731	.681	.747	.742	.701	.658	.660	.709	.714	.670	.690
St. Blasien (69):												
A_2	1.37	1.31	1.26	1.11	1.06	1.06	1.06	1.13	1.13	1.24	1.22	1.32
a_{2-3}	.893	.886	.849	.810	.814	.794	.814	.835	.879	.828	.909	.896
a_{0-1}	.760	.731	.731	.754	.739	.714	.699	.719	.704	.764	.686	.740
Wahnsdorf (87):												
A_2	Mean for the year, 0.96											
a_{2-3}	Mean for the year, 0.688											
Feldberg (19):												
A_2	1.28	1.24	1.15	1.08	1.15	1.04	1.14	1.21	1.25	1.32	1.34	1.32
a_{2-3}	.859	.868	.862	.850	.839	.829	.871	.864	.881	.890	.902	.886
a_{0-1}	.740	.751	.690	.702	.718	.688	.720	.762	.746	.758	.752	.735
Karlsruhe (33):												
A_2	0.92	1.07	1.17	1.01	0.98	0.95	0.87	0.85	1.02	0.95	0.98	1.00
a_{2-3}	.891	.813	.863	.802	.779	.811	.775	.755	.775	.852	.838	.850
a_{0-1}	----	.665	.696	.666	.697	.672	.637	.598	.709	.584	.590	----
Eskdaelmuir (17):												
A_m	0.92	1.06	1.16	1.16	1.25	1.23	1.28	1.21	1.21	1.16	0.95	0.85
m	4.14	2.70	1.83	1.43	1.24	1.18	1.20	1.33	1.63	2.29	3.55	4.98
Kew Observatory (35):												
A_m	0.70	0.77	0.99	1.01	1.04	1.08	1.02	1.06	0.98	0.87	0.75	0.67
m	3.28	2.31	1.69	1.33	1.18	1.13	1.15	1.26	1.50	2.02	2.90	3.77
Hald (27):												
A_m	0.72	0.88	0.87	----	1.08	1.10	1.32	1.33	1.20	1.22	0.80	0.92
m	4.48	2.82	1.89	----	1.26	1.19	1.22	1.36	1.67	2.39	3.80	5.46
Ursanova (86):												
A_2	----	----	----	----	----	1.01	1.06	1.08	----	----	----	----
a_{2-3}	----	----	----	----	----	.786	.807	.807	----	----	----	----
a_{0-1}	----	----	----	----	----	.687	.701	.713	----	----	----	----
Warsaw (88):												
A_m	0.87	1.02	1.15	1.22	1.22	1.19	1.19	1.19	1.19	1.09	0.94	0.78
m	3.39	2.36	1.70	1.37	1.20	1.14	1.17	1.28	1.52	2.06	2.90	3.82
Zakopane (90):												
A_m	----	----	----	----	----	----	----	1.21	1.24	----	----	----
m	----	----	----	----	----	----	----	1.24	1.44	----	----	----
Mount Czarnohora (54):												
Worchta—												
A_2	----	----	----	----	----	----	----	1.30	----	----	----	----
a_{1-2}	----	----	----	----	----	----	----	.929	----	----	----	----
a_{0-1}	----	----	----	----	----	----	----	.739	----	----	----	----
Jablonica—												
A_2	----	----	----	----	----	----	----	1.33	----	----	----	----
a_{1-3}	----	----	----	----	----	----	----	.902	----	----	----	----
a_{0-1}	----	----	----	----	----	----	----	.792	----	----	----	----
Pożyżewska—												
A_2	----	----	----	----	----	----	1.26	1.26	1.22	1.29	----	----
a_{1-3}	----	----	----	----	----	----	.841	.841	.820	.884	----	----
a_{0-1}	----	----	----	----	----	----	.811	.789	.757	.770	----	----
Chomiak—												
A_2	----	----	----	----	----	----	----	1.25	----	----	----	----
a_{1-3}	----	----	----	----	----	----	----	.848	----	----	----	----
a_{0-1}	----	----	----	----	----	----	----	.782	----	----	----	----
Pożyżewska—												
A_2	----	----	----	----	----	----	----	1.42	----	----	----	----
a_{1-3}	----	----	----	----	----	----	----	.930	----	----	----	----
a_{0-1}	----	----	----	----	----	----	----	.810	----	----	----	----
Howerla—												
A_2	----	----	----	----	----	----	----	1.50	----	----	----	----
a_{1-3}	----	----	----	----	----	----	----	.920	----	----	----	----
a_{0-1}	----	----	----	----	----	----	----	.852	----	----	----	----
Katharinenburg (34):												
A_m	----	1.27	1.40	1.41	1.37	1.26	1.26	1.33	1.27	1.26	1.24	----
m	----	3.26	1.96	1.46	1.25	1.20	1.22	1.37	1.71	2.90	3.59	----
$A_m=(2.45)$	----	1.41	1.33	1.25	1.13	1.03	0.99	1.11	1.17	1.31	1.40	----
Kief (36):												
A_m	----	----	1.28	----	1.32	1.22	----	1.27	1.25	1.17	1.11	1.13
m	----	----	1.68	----	1.18	1.12	----	1.31	1.47	2.24	3.19	3.49
Leningrad (42):												
A_m	0.97	1.14	1.33	1.35	1.35	1.31	1.28	1.26	1.27	1.18	0.99	0.70
m	6.10	3.37	2.10	1.55	1.32	1.25	1.28	1.44	1.82	2.75	4.90	8.10
Moscow (53):												
A_m	----	----	----	----	1.31	1.27	1.30	1.28	----	----	----	----
$a_{1\cdot2\text{-}3\cdot5}$	----	----	----	----	----	0.82	0.80	0.82	----	----	----	----
m	----	----	----	----	1.20	1.18	1.21	1.34	----	----	----	----
Nijni-Oltchedaeff (59):												
A_m	1.05	1.29	1.25	1.26	1.25	1.19	1.12	1.17	1.22	1.07	1.03	0.94
m	2.84	2.10	1.56	1.28	1.15	1.11	1.12	1.22	1.43	1.86	2.56	3.20
Pavlovsk (Sloutzk) (64):												
A_2	----	----	1.32	1.31	----	1.22	1.18	1.16	1.29	----	----	----
a_{2-3}	----	----	.883	.853	----	.860	.855	.872	.864	----	----	----
a_{0-1}	----	----	.749	.792	----	.749	.756	.751	.778	----	----	----
A_m	0.87	1.10	1.23	1.29	1.32	1.33	1.29	1.23	1.18	1.13	0.96	0.81
m	5.95	3.34	2.08	1.54	1.31	1.24	1.27	1.44	1.82	2.72	4.80	7.80
Tashkent (75):												
A_m	1.38	1.43	1.39	1.39	----	----	----	----	----	----	----	----
m	2.14	1.71	1.37	1.18	----	----	----	----	----	----	----	----
Théodosie (81):												
A_m	1.16	1.22	1.24	1.14	1.20	1.23	1.22	1.23	1.22	1.17	1.14	----
m	2.45	1.88	1.44	1.24	1.12	1.08	1.09	1.17	1.34	1.70	2.24	----
Treurenberg (84):												
A_2	----	----	----	1.36	1.30	1.32	1.36	----	1.32	----	----	----
a_{2-3}	----	----	----	.877	.879	.851	.894	----	.905	----	----	----
Abisko (1):												
A_2	----	----	----	----	----	----	1.17	1.16	1.11	----	----	----
a_{2-3}	----	----	----	----	----	----	.841	.840	.870	----	----	----
a_{0-1}	----	----	----	----	----	----	.725	.727	.646	----	----	----
Nyköping (61):												
A_2	----	----	1.29	1.29	1.20	1.26	----	----	1.24	----	----	----
a_{2-3}	----	----	.862	.866	.899	.891	----	----	.898	----	----	----
a_{0-1}	----	----	.766	.771	.772	.756	----	----	.756	----	----	----
A_m	0.89	1.12	----	----	----	----	1.30	1.29	----	1.23	0.96	0.62
m	5.25	4.08	----	----	----	----	1.49	1.45	----	2.20	4.52	9.07
Upsala (85):												
A_2	----	1.29	1.30	1.28	1.21	1.17	1.19	1.20	1.24	1.31	----	----
A_5	1.03	----	----	----	----	----	----	----	----	----	1.03	----
a_{2-3}	----	.902	.889	.879	.875	.870	.873	.893	.876	.899	----	----
a_{0-1}	----	----	.741	.770	.745	.743	.735	.715	.747	----	----	----
Helwan (28):												
A_2	1.31	1.28	1.22	1.16	1.13	1.12	1.13	1.15	1.17	1.19	1.23	1.27
$a_{1\cdot5\text{-}1\cdot9}$	.872	.864	.844	.826	.818	.811	.836	.834	.844	.848	.857	.861
a_{0-1}	.748	.742	.738	.730	.732	.738	.724	.728	.725	.719	.722	.737
Bassour (8):												
A_2	----	----	----	----	----	----	----	1.19	1.24	1.34	1.37	----
a_{2-3}	----	----	----	----	----	----	----	.855	.846	.883	.902	----
a_{0-1}	----	----	----	----	----	----	----	.752	.754	.778	.772	----
Johannesburg (31):												
A_{max}	1.60	1.54	1.49	1.54	1.37	1.29	1.36	1.34	1.29	1.54	1.56	1.61
m	1.01	1.03	1.09	1.24	1.42	1.54	1.48	1.30	1.15	1.05	1.02	1.01
Simla (72):												
A_m	1.49	1.48	1.50	1.47	1.42	1.29	1.29	1.38	1.43	1.47	1.49	1.50
m	1.62	1.39	1.19	1.07	1.03	1.02	1.02	1.05	1.13	1.30	1.54	1.72
Batavia (9):												
A_2	1.13	1.13	1.03	1.13	0.98	0.99	0.93	0.86	0.89	0.79	1.05	1.08
a_{2-3}	.750	.857	.917	.737	.806	.825	.798	.790	.871	.881	.702	.727
a_{0-1}	.686	.665	.697	.711	.677	.686	.704	.643	.630	.600	.711	.714
Pangerango (62):												
A_2	----	----	----	----	----	1.41	1.50	1.45	----	----	----	----
a_{2-3}	----	----	----	----	----	.860	.891	.890	----	----	----	----
a_{0-1}	----	----	----	----	----	.874	.919	.876	----	----	----	----
Smeroe (73):												
A_2	----	----	----	1.27	----	----	----	1.53	----	----	----	----
a_{1-3}	----	----	----	.754	----	----	----	.887	----	----	----	----
a_{0-1}	----	----	----	.904	----	----	----	.925	----	----	----	----
Tjisoeroepan (82):												
A_2	----	----	----	----	----	----	1.30	----	----	----	----	----
a_{2-3}	----	----	----	----	----	----	.861	----	----	----	----	----
a_{0-1}	----	----	----	----	----	----	.801	----	----	----	----	----
Bangkok (7):												
A_m	----	----	----	----	1.22	----	----	----	----	----	----	----
m	----	----	----	----	1.01	----	----	----	----	----	----	----
Fuji (25):												
A_2	----	----	----	----	----	----	1.49	----	----	----	----	----
a_{2-3}	----	----	----	----	----	----	.926	----	----	----	----	----
a_{0-1}	----	----	----	----	----	----	.862	----	----	----	----	----
Numazu (60):												
A_2	----	----	----	----	----	----	1.12	----	----	----	----	----
a_{2-3}	----	----	----	----	----	----	.877	----	----	----	----	----
a_{0-1}	----	----	----	----	----	----	.792	----	----	----	----	----

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[1] December and January combined.

Table 7.—*Monthly means of solar radiation and atmospheric transmission*—Continued

OBESERVATIONS AT SEA

Stations	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Atlantic Ocean (91):												
A_m			1.44									
m			1.38									
Mediterranean (92):												
A_m			1.42					1.35				
m			1.28					1.06				
Suez Canal (93):												
A_m			1.26									
m			1.15									
Red Sea (94):												
A_m			1.28				1.21	1.21				
m			1.09				1.00	1.00				
Gulf of Aden (95):												
A_m			1.41				1.16					
m			1.03				1.02					
Indian Ocean (96):												
A_m			1.41				1.24					
m			1.01				1.04					
Gulf of Siam (97):												
A_m				1.28								
m				1.01								

	Nov.-Feb.	Mar., Apr., Sept., Oct.	May-Aug.	Dec.
Oceania:				
Apia (4)—				
A_2	1.098	0.976	0.975	
a_{2-3}	.846	.848	.817	
a_{0-1}	.653	.617	.632	
Flint Island (21)—				
A_1				1.29
a_{0-1}				.664

MEASUREMENTS FROM BALLOONS

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Omaha (98):												
A_m							1.78					
m							1.06					
Griesheim (99):												
A_m										1.72		
m										2.04		

Table 8.—*Sources of pyrheliometric data*

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Table 8 gives the sources of the data summarized in Table 7.

It will be noted that in Tables 6 and 7 each station is given a number, and that in Tables 6 and 8 the arrangement is alphabetical. In Table 7 the arrangement is geographical, beginning with South America, and then passing in succession to North American, the Canary Islands, southern, central, and northern Europe, Africa, India, Java, Siam, Japan, observations at sea, Oceania, and observations from balloons.

ATMOSPHERIC TRANSMISSION

The data of Table 7 have been summarized in convenient form for studying atmospheric transmission of solar radiation, or its complement, atmospheric depletion. The latter is due to four principal causes, as follows:

(1) Scattering by the gas molecules of dry pure air.

(2) Scattering by the water vapor in the atmosphere.

(3) Absorption by the gases of the atmosphere, principally by water vapor.

(4) Scattering and absorption by the dust particles suspended in the atmosphere.

Fowle (**7**) has shown that on high mountains above the dust of the lower levels atmospheric transmission by dry air, $a_{a\lambda}$, agrees closely with the theoretical equation developed by King (8) from Rayleigh's classical equations (**9**) as follows:

$$a_{a\lambda}=e-^{k},\ \text{where } k = \frac{32}{3}\left[\pi^3(n-1)^2\frac{H}{N_0\lambda^4}+bH\right]\frac{P}{P_0}+D \qquad (1)$$

n = index of refraction of air.

$$(n-1)10^7=2875.16+13.412/\lambda^2 10^{-8}+0.3777/\lambda^4 10^{-16}$$

H = height of the homogeneous atmosphere, = 799,000 cm.

P = observed pressure in cm. of mercury.

λ = wave length of light in cm.

N_0 = molecules per cm.^{3} ($P_0=76.0$ cm., $t=0$°C.) $=2.705\times 10^{19}$

b = energy absorbed by the permanent gases and converted into heat.

D = depletion from atmospheric dust and haze, which probably does not vary greatly with λ, and becomes almost negligible at high altitudes.

Assuming b and D each equal to 0.0 and $P=P_0$, $a_{a\lambda}$ has been computed by equation (1) for 39 values of λ between 0.3415 μ and 2.442 μ, corresponding to prismatic deviations of the Smithsonian u. v. glass prism between +240′ and −40′, at intervals of 10′, except that between +120′ and +20′ the interval is 5′. The relative intensities of radiation for these wave lengths before depletion by the atmosphere, $e_{0\lambda}$, have been taken from Fowle's values (**10**) with interpolation where necessary. Let m = the air mass, approximately the secant of the sun's zenith distance, and a' the transmission coefficient for the total solar radiation through dry pure air. Then

$$e_{m\lambda}=e_{0\lambda}a^{m}{}_{a\lambda},\ \text{and} \qquad (2)$$

$$(a')^{m}=\frac{\Sigma e_{0\lambda}a^{m}{}_{a\lambda}}{\Sigma e_{0\lambda}} \qquad (3)$$

Both the numerator and the denominator of (3) must include corrections for both ultra-violet and infre-red radiation (**11**) beyond the limits of the wave-lengths considered.[3] The magnitude of these corrections appears to be known only approximately.

To take account of the scattering of solar radiation by atmospheric moisture, I have also used Fowle's (**10**) values of $a_{w\lambda}$. The equation for a' then becomes

$$(a')^{m}=\frac{\Sigma e_{0\lambda}(a_{a\lambda}a^{w}{}_{w\lambda})^{m}}{\Sigma e_{0\lambda}} \qquad (4)$$

where w is the depth of water in centimeters that would be obtained if all the moisture in the atmosphere were precipitated. If $w=0$, equation (4) is identical with (3).

At stations of the Astrophysical Observatory of the Smithsonian Institution the value of w is determined spectrobolometrically. At other stations it is necessary to use Hann's equation, $w=2.3\ \mathrm{e}\ 10^{\frac{-\mathrm{h}}{22000}}$ where e is the surface vapor pressure in centimeters, and h is altitude in meters above sea level. Fowle states (**12**) that this equation can be relied upon only when the mean values of e for a considerable period are used.

In Figure 3, the values computed from (3) for values of $m=1$, 2, 3, 4, and $40.0/76.0=0.526$, have been plotted as ordinates on the scale of their logarithms to the base 10. The abscissas have been numbered for an air pressure of 76 cm. Evidently, however, if $P<P_0$, unit air mass will fall on the abscissa corresponding to the value of P/P_0. Thus, if $P=40.0$ cm., unit air mass falls at 0.526, 2 m. at 1.052, etc.

Similarly, the values computed from (4) for $m=1.0$ 2.0, 3.0, and 4.0, and values of $w=0.5$, 1.0, 2.0, 3.0, and 4.0 cm., give curves 2–6, Figure 3. Values have also been computed for $m=0.526$, but the form of the equation shows that for this value of m the precipitable water, w, represented by the curves is $\frac{P}{P_0}w$, where w is its value for

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[3] As this paper goes to the printer I have received a copy of "Smithsonian Solar Radiation Researches," by C. G. Abbot (Sonderdruck aus "Gerlands Beitrage zur Geophysik," Bd. XVI, Heft 4, pp. 344–353, Leipsic, 1927). In it are given new determinations for these corrections that are much larger than those heretofore published. Their use would probably lead to lower transmission coefficients than are indicated by the curves of Figure 3.

$P=P_0$. Thus, for $P=40$ cm., on curves 2–6, $w=0.263$, 0.526, 1.052, 1.578, and 2.104, respectively.

From computed values of $(e_{0\lambda}a_{a\lambda}a^{w}_{w\lambda})^m$, $(a')^m$, and curves given by Fowle (**10**), I have determined the proportion of incoming radiation absorbed by quantities of water vapor represented by wm, where w has the same value as in curves 2–6. These computed values of water vapor absorption have been plotted on curve 12, Figure 3; and after increasing them by 0.5 at all air masses to take account of absorption by the permanent gases of the atmosphere (**13**) have been deducted from the value of $(a')^m$ to give values of $(a'')^m$ as plotted on Figure 3 in curves 7–11. They give the proportion of solar radiation that is transmitted by pure air containing the amounts of water vapor indicated.

The curves of Figure 3 do not take into account the depletion of solar radiation by the haze and dust in the atmosphere represented by the term D in equation (1). Undoubtedly this depletion results from both scattering and absorption; but since we do not know the relative amounts scattered and absorbed, the total is usually attributed to scattering and is here designated D'_m.

From the data in Table 7 and with the aid of Figure 3 we may determine with considerable accuracy the amount of depletion of solar radiation by the scattering and absorption of dry air, aqueous vapor, and haze and dust of the atmosphere. This has been done for a few typical stations, and the results are given in Table 9. Columns 3 and 4 give the scattering and absorption, E_m, by pure dry air; columns 5 and 6, the scattering and absorption, E_w, by water vapor; columns 9 and 10, the total depletion, $1-a_m$, as determined from the data in Table 7; columns 7 and 8, the depletion designated D'_m above, which is the difference between the total depletion of columns 9 and 10 and the sums of the depletions given in columns 3 and 5, and 4 and 6, respectively. The subscript figures affixed to E, E_w, D', and a in the heading of Table 9, indicate the values of m between which depletions were computed.

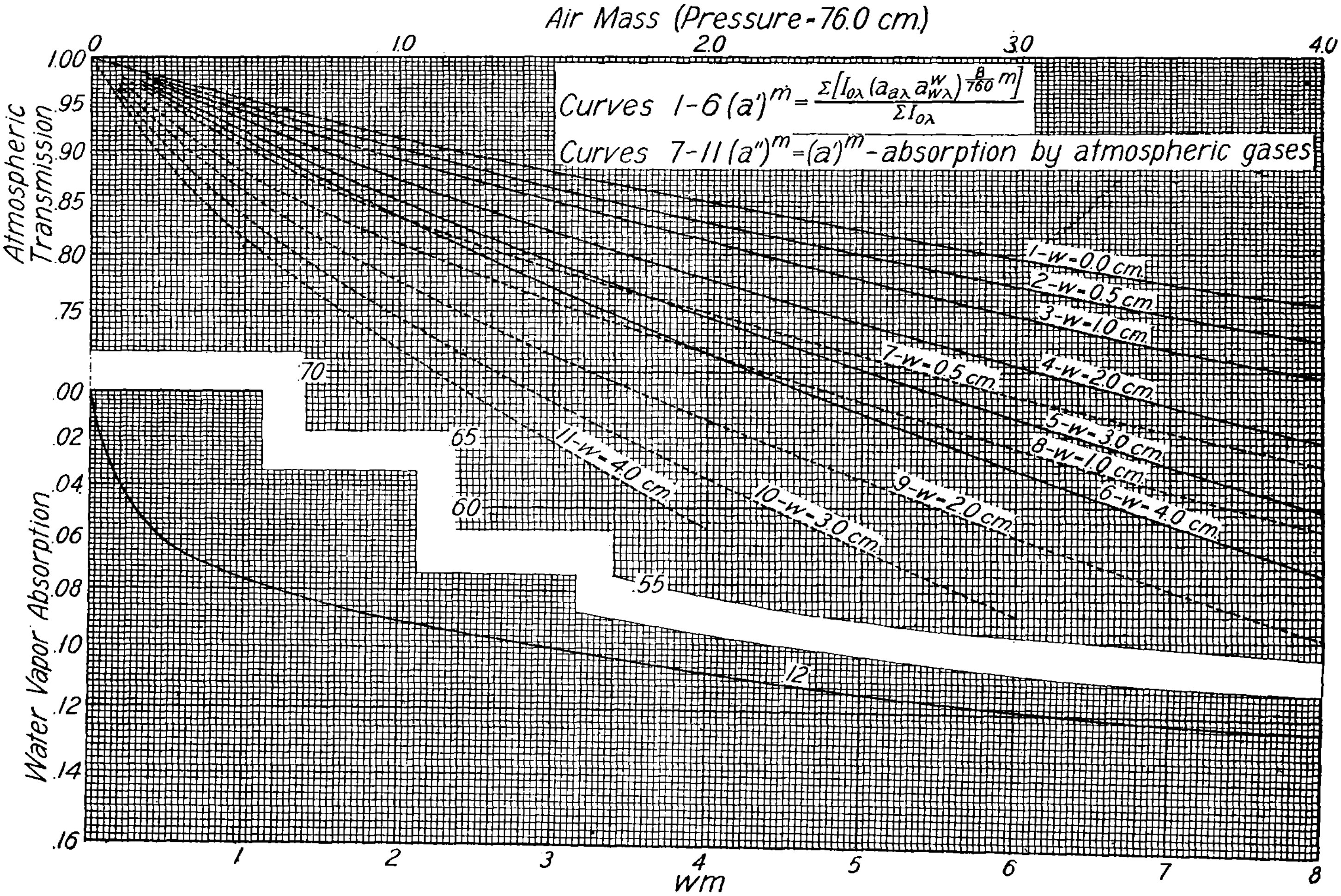

FIG. 3.—Atmospheric transmission of solar radiation through pure moist air

Linke (**14**) calls the ration $T_m=\frac{1-a_m}{E_m}$ the *atmospheric turbidity factor*, and Götz (**15**) and Milch (**16**) have made extensive use of this factor in recent publications. I have given values of T_{0-1} and T_{0-2} in the last two columns of Table 9.

An inspection of Table 9 shows but little depletion from water vapor or from dust on high mountains, which is in accord with the results obtained by Fowle (**17**). There is also less depletion from dust and haze on island stations than on continents. At Samoa it is less during the wet summer months than during the dry winter months. It has been shown (**18**) that haze at sea consists principally of minute salt crystals.

Table 9.—*Atmospheric depletion of solar radiation*

Station	Season	Dry air		Water vapor		Dust		Total		Turbidity factor	
		$E_{0\text{-}1}$	$E_{0\text{-}2}$	$E_{w0\text{-}1}$	$E_{w0\text{-}2}$	$D'_{0\text{-}1}$	$D'_{0\text{-}2}$	$1\text{-}a_{0\text{-}1}$	$1\text{-}a_{0\text{-}2}$	$T_{0\text{-}1}$	$T_{0\text{-}2}$
Apia	Winter	0.094	0.155	0.197	0.277	0.077	0.062	0.368	0.494	3.91	3.19
	Summer	.094	.155	.205	.287	.048	.005	.347	.447	3.69	2.88
Washington	Winter	.094	.155	.081	.101	.087	.141	.262	.397	2.79	2.56
	Summer	.094	.155	.165	.230	.103	.127	.362	.512	3.85	3.30
Mount Wilson	Summer	.079	.135	.106	.127	.021	.026	.206	.288	2.61	2.13
Mount Montezuma.	Winter	.070	.125	.048	.071	.021	.021	.139	.217	1.99	1.74
	Summer	.070	.125	.092	.127	.020	.016	.182	.268	2.60	2.14
Mount Whitney	Summer	.059	.106	.022	.040	.026	.034	.107	.180	1.81	1.70
Jungfraujoch	Summer	.066	.118	.037	.058	.020	.011	.123	.187	1.86	1.58
Monte Rosa	Summer	.057	.105	.027	.045	.010	.037	.100	.187	1.75	1.78
La Quiaca	Winter	.065	.117	.047	.068	−.012	.038	.100	.223	1.54	1.91
	Summer	.065	.117	.097	.125	.022	.003	.184	.245	2.83	2.09
Pic de Teyde	Summer	.064	.115	.062	.081	−.023	−.011	.103	.185	1.61	1.61
Guimar	Summer	.090	.152	.141	.190	−.002	.007	.229	.349	2.54	2.30
Fuji	Summer	.063	.114	-----	-----	-----	-----	.138	.205	2.19	1.80
Numazu	Summer	.094	.155	-----	-----	-----	-----	.208	.403	2.21	2.60
Helwan	Winter	.094	.155	-----	-----	-----	-----	.258	.355	2.74	2.29
	Summer	.094	.155	-----	-----	-----	-----	.270	.399	2.87	2.57
Treurenberg	Summer	.094	.155	.091	.119	-----	.021	-----	.295	-----	1.90

The total depletion of solar radiation by atmospheric scattering is approximately $(1-a'_m)+D'_m$, and from it we may compute the intensity of the diffuse radiation to be expected at the surface of the earth with a cloudless sky. In this computation it is necessary to make allowance for the fact that only a small proportion of the diffuse sky radiation is received at the earth's surface at normal incidence, and also for the fact that the intensity of the radiation is not the same from all parts of the sky. Upon the assumption that photometric measurements of the brightness of different parts of the sky (**19**) give the variations in sky radiation intensity with sufficient accuracy, I find that at Washington the intensity of diffuse sky radiation on a horizontal surface as computed from the atmospheric scattering of radiation is 1 to 2 per cent greater than the measured amount.

Abbot (**20**) computed the excess of the solar constant value over the sum of the measured intensity of direct solar radiation, diffuse sky radiation on a horizontal surface, and the computed absorption of solar radiation by the atmosphere. He found that, expressed in percentages, on Mount Whitney the excess was only 0.43; on Mount Wilson, 2.0; and at Bassour, on September 5, 6, and 7, 1912, about three months after the eruption of Katmai Volcano in Alaska, the excess was 14 per cent. Here, again, scattering and absorption by the gases of the atmosphere accounted for nearly all the depletion in solar radiation as it passed through the atmosphere, except at Bassour during the prevailence of the dust cloud from Katmai Volcano.

Abbot (**21**) has shown that pyrheliometric measurements made on high mountains where there is little dust will show the nature of variations in the value of the solar constant. Therefore, the value to meteorologists of careful measurements of solar radiation intensity is apparent. It must be emphasized, however, that instrumental readings should be given in units of some known pyrheliometric scale, such as the Ångstrom scale, or the Smithsonian pyrheliometric scale of 1913. The relation between these two scales appears to be well known (**6**), so that radiation intensities expressed in one are readily reduced to the other.

THE RELATION BETWEEN SOLAR RADIATION AND AIR TEMPERATURE

Ångström (**22**) has shown the relation that exists between radiation and temperature. Briefly, the diurnal march of both radiation and temperature may be expressed by a Fourier series, the first constant of which gives the annual mean, and the constant of the first harmonic the annual amplitude.

For Washington, the equation for the mean daily radiation receipt on a horizontal surface from the sun and sky is

$$Q_m = 335.4 + 171.4\cos(\Theta_x + 13.1°) - 20.0\cos(2\Theta_x + 3.4°),$$

where $\Theta = 0$ on July 5. After depletion by reflection, by processes of evaporation, and by re-radiation from the heated surface of the earth, the radiation available for heating the atmosphere is expressed by the equation

$$Q_T = 32.2 + 106.4\cos(\Theta_x + 10.0°) - 22.3\cos(2\Theta_x - 33.0°)$$

The corresponding equation for the mean daily temperature is

$$T_m = 12.8 + 12.3\cos(\Theta - 15.5°) + 0.3\cos(2\Theta_x + 45.9°).$$

In case of continuous snow cover from December to February, inclusive, the radiation equation becomes

$$Q_s = 10.9 + 132.3\cos(\Theta_x - 0.3°) - 37.6\cos(2\Theta_x - 49.4°);$$

and the temperature equation becomes

$$T_s = 10.0 + 15.3\ \cos(\Theta_x - 15.5°).$$

Similarly, we obtain for continuous sunshine

$$T_{co} = 19.4 + 16.7\cos(\Theta_x - 15.5°).$$

From the above it appears that a continuous snow cover during the winter months would lower the midwinter temperature nearly 6° C., while continuous sunshine would raise min-summer temperatures 11° C.

Such equations are of value not only in climatological, but also in thermodynamical studies.

For example, Ångström found the annual term for Q_T at Stockholm to be minus. Therefore to maintain uniform temperatures from year to year heat must be conveyed through horizontal atmospheric convection from low latitudes to high latitudes.

It becomes apparent that several factors besides the incoming radiation require careful measurement, such as the albedo of the surface of the earth, the rate of evaporation from the surface of the earth, and the intensity of the outgoing radiation at all seasons of the year and hours of the day. Ångström (**23**), (**24**) is now making valuable contributions along these lines.

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TORNADOES IN VIRGINIA, 1814–1925

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The compilation of a record of tornadoes and the construction of a tornado map is a difficult and unsatisfactory task. Not only are the necessary data widely scattered, but when assemblage from all available sources has been completed many interesting and often essential details are lacking. The phenomena involved are exceedingly transient, and the destructive results are quickly healed by man and nature. Therefore, unless the affected area is soon visited by a competent observer, much of the interesting detail and many of the unusual features are permanently lost, or survive only in the memory of the local inhabitants, always an uncertain index of what occurred.

Another difficulty is in interpretating correctly the character and motions of the destructive winds. Thunderstorm squalls may do considerable local damage leading to the belief that they were tornadic, yet they lack the gyratory motion of tornadic winds and can not be classed as such. Trained observers can readily detect the difference from the position and attitude of the débris, but unless a storm causes great property damage or casualties the area is rarely visited by such observers. In the following account an earnest effort has been made to exclude all storms that did not exhibit the phenomena characteristic of tornadoes.

The record for the earlier years is necessarily meager and brief due to uncertain and difficult means of communication, smaller population, and absence of a suitable agency for the collection and recording of weather data. The record is believed to be fairly complete since 1870, although probably a number of mild tornadoes in country districts have not been recorded.

In the preparation of the data all available sources have been utilized. Files of old newspapers have been consulted and clues have been profitably followed up by personal correspondence. The records of the Weather Bureau office in Richmond have been placed at the writer's disposal by Mr. E. A. Evans, in charge of that office. A number of accounts have appeared in the MONTHLY WEATHER REVIEW, and Mr. H. C. Hunter, of the Weather Bureau, has kindly assisted in making available from the files in Washington the record of a number of occurrences. The reports by Mr. J. P. Finley published in 1882 and 1885 by the United States Signal Service have supplied information concerning a number of Virginia tornadoes, and Mr. Finley has kindly supplemented this with details regarding 22 more recent occurrences. The annual reports of the Chief of the Weather Bureau, particularly for the years 1896 and 1897, have also yielded valuable data.

Table 1 gives all obtainable data for the 63 tornadoes recorded in Virginia to January 1, 1925. The order is chronological. The numbers in the first column are those of the tornado tracks the location and relative length of which are shown in Figure 1.