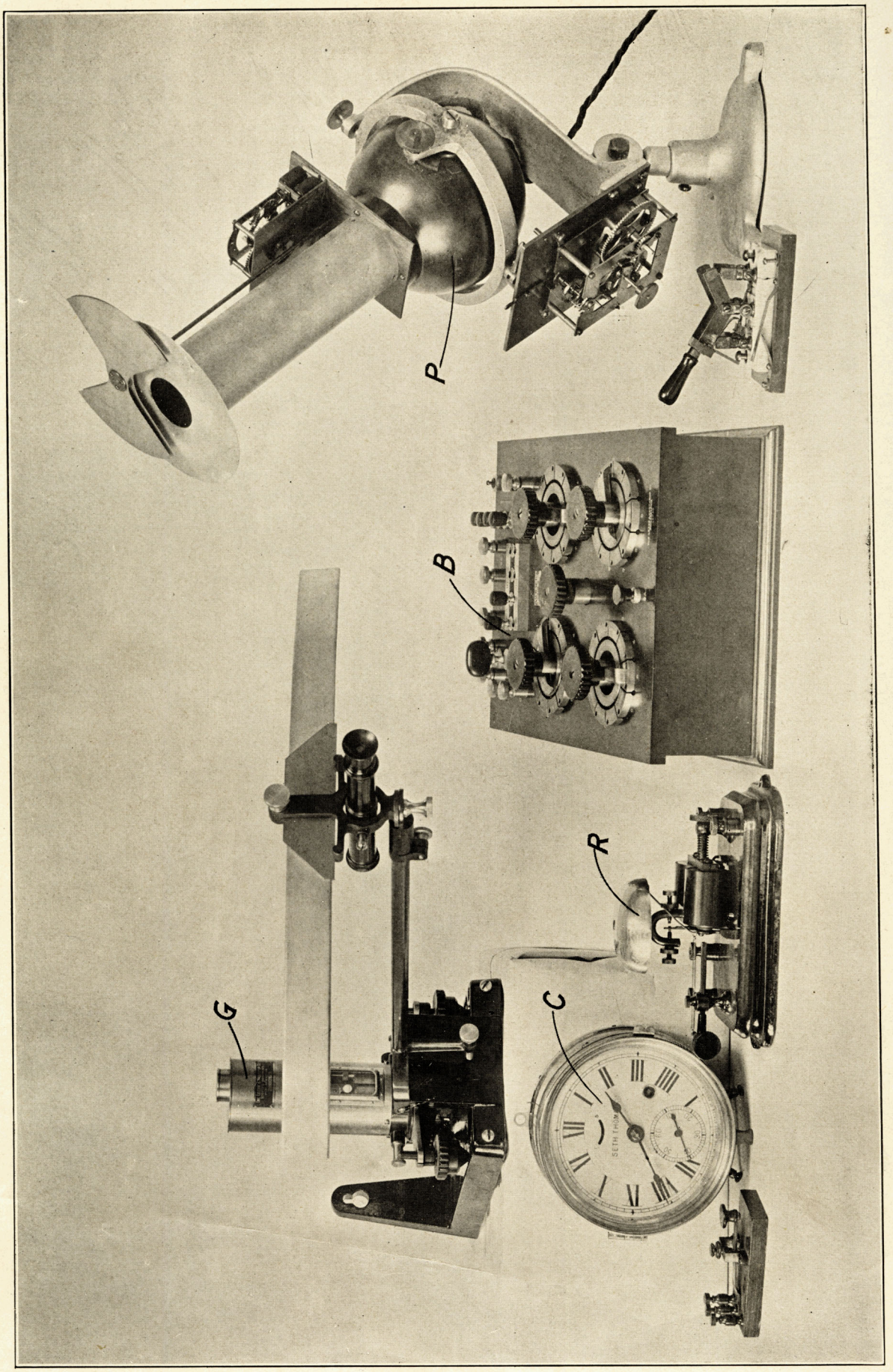

FIG. 1.—Marvin pyrheliometer and auxiliary apparatus.

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VARIATIONS IN THE TOTAL AND LUMINOUS SOLAR RADIATION WITH GEOGRAPHICAL POSITION IN THE UNITED STATES.

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[Dated: Weather Bureau, Washington, D. C., Jan. 2, 1920.]

SYNOPSIS.—The measurements of solar radiation intensity at normal incidence made at Washington, D. C., Madison, Wis., Lincoln, Nebr., and Santa Fe, N. Mex., have been utilized in determinations of the intensities for the Atlantic Coast States, the Plains States, and the Rocky Mountain plateau, at latitudes 30°, 36°, 42°, and 48° N., at hourly intervals, on the 21st day of each month. Corresponding determinations of the intensity of the radiation received on a horizontal surface, and of the total radiation per day, have been made from the vertical component of the normal intensities, and measurements by the Callendar recording pyrheliometer of the diffuse radiation received on a horizontal surface from the sky. The variations in the daily totals with altitude and with cloudiness have also been determined.

From the relation between the total solar or heat radiation and the visible or luminous radiation, determined by means of synchronous pyrheliometric and photometric measurements made at Mount Weather, Va., in 1913–14, the solar radiation intensities at normal incidence above described have been converted into illumination intensities at normal incidence, and on vertical surfaces facing S., SW., W., NW., N., NE., E., and SE. Also, the total illumination on a horizontal surface from the sun and sky has been determined for clear sky and completely overcast sky conditions.

Most of the results are shown in both tables and charts, the latter consisting of isopleths of heat or of luminous solar radiation, with hour angles of the sun as ordinates and days of the successive months as abscissas, except that the daily totals of radiation on a horizontal surface on the 21st of each month are shown by means of radiation isograms on outline maps of the United States.

The effect of surface slope on solar radiation intensities is briefly considered.

INTRODUCTION.

It is the purpose of this investigation to determine as accurately as possible with the data available, (1) the variation in direct solar radiation intensities with latitude, (2) the increase in intensity as we go westward from the Atlantic coast districts to the drier and more elevated central plains, (3) the total radiation received on a horizontal surface (direct solar, plus diffuse radiation from the sky), and (4) to reduce the total, or heat radiation as thus determined along certain parallels of latitude to luminous, or daylight intensity. There have been utilized in this investigation the radiation measurements made at Washington, D. C., since 1905; at Madison, Wis., since 1910; at Santa Fe, N. Mex., since 1912; and at Lincoln, Nebr., since 1915; and the measurements of the total solar, or heat radiation, and of luminous solar radiation or daylight illumination, made at Mount Weather, Va., during 1913 and 1914. The coordinates of these stations are as follows:

Washington, lat. 38° 56′ N.; long. 77° 05′ W.; alt. 418 ft. (127 m.).
Madison, lat. 43° 05′ N.; long. 89° 23′ W.; alt. 974 ft. (297 m.).
Lincoln, lat. 40° 50′ N.; long. 96° 41′ W.; alt. 1,225 ft. (373 m.).
Santa Fe, lat. 35° 41′ N.; long. 105° 57′ W.; alt. 7,037 ft. (2,145 m.).
Mount Weather, lat. 39° 04′ N.; long. 77° 53′ W.; alt. 1,772 ft. (540 m.).

The direct solar radiation measurements obtained at Washington prior to 1914 were made with an Ångström pyrheliometer; all others have been made with a Marvin pyrheliometer. They have been published in the Bulletin of the Mount Weather Observatory **3**:85–96, **5**:175–183, 302–303, and in the MONTHLY WEATHER REVIEW, 1914, **42**:648; 1915, **43**:112 (monthly thereafter).

THE MARVIN PYRHELIOMETER.

Figure 1, frontispiece, shows the Marvin pyrheliometer and the auxiliary apparatus employed in its standardization at the Weather Bureau. The pyrheliometer (P) consists of a silver disk, mounted inside a metal shell that is inclosed in the wooden bulb of the instrument, imbedded in which is an insulated nickel wire wound noninductively in the form of a thin disk. Its resistance is about 25 ohms. The front of the silver disk is blackened, and a beam of solar rays of known area is admitted to it through the diaphragmed tube. The bulb and tube have a clock-driven equatorial mounting, and on the tube is a mechanism for operating the shutter at the end of the tube, the circuit through the magnets of which is closed by the clock (C) at the end of each minute, thereby alternately opening or closing the shutter. A bell on the relay (R) is rung every 10 seconds by means of circuit breakers on the clock. The resistance coil of the pyrheliometer is in one arm of the Wheatstone bridge (B) and in the opposite arm are dials for varying the resistance to maintain approximately the bridge balance as the resistance of the pyrheliometric coil increases or decreases with heating or cooling. A high sensitivity galvanometer (G) is employed to measure small differences in resistance between the two arms of the bridge.

The pyrheliometers have been standardized by first carefully measuring the resistance of the coils at known temperatures, and then submitting them to the heating effect of an electric current of known strength and measuring the resulting change in resistance. There results a series of factors varying with the temperature, or resistance, of the coils, by means of which rates of change of resistance may be reduced to units of heat that have produced the observed changes of resistance, Dr. Paul D. Foote [1] of the United States Bureau of Standards has made a careful study of one of these pyrheliometers, and his results, which may be consulted for details of the methods followed, are confirmatory of the Weather Bureau determinations.

Comparisons of Marvin pyrheliometers with the Smithsonian Absolute pyrheliometer, through secondary Smithsonian Silver-disk pyrheliometers, have shown that the former read slightly the lower. For the sake of uniformity, the constants of the Marvin pyrheliometers have been increased to bring the instrumental readings into accord with the Smithsonian revised scale of pyrheliometry".[2]

[1] "Some characteristics of the Marvin pyrheliometer" Scientific papers of the Bureau of Standards, No. 323. Abstract in the MONTHLY WEATHER REVIEW for November, 1918, **46**: 499–500.

[2] "Smithsonian pyrheliometry revised," Abbot, C. G. and Aldrich, L. B. Smithsonian Misc. Col. Vol. 60, No. 18, 1913. See also Note on comparisons between pyrheliometers and on the difference between the Ångström Standard and the Smithsonian Standard, by Dr. Anders Ångström. This REVIEW, p. 798–799.

In measuring radiation intensities with the Marvin pyrheliometer the same auxiliary apparatus is employed as in the standardization of the instruments, except that a special bridge has been constructed, which has in the arm opposite that containing the pyrheliometer a single dial and a series of plugs in place of the four dials shown on the bridge in figure 1. Successive rates of increase and decrease of resistance with increase and decrease of the temperature of the coils during exposure to and shading from the sun, respectively, are measured during the 50-second intervals beginning with the 10-second signal by the relay bell, and ending with the 60-second signal.[3]

TOTAL SOLAR RADIATION.

There are six principal causes of variation in the solar radiation intensities at the surface of the earth, as follows:

(1) Variations in the amount of heat energy radiated from the sun, the intensity of which at the earth's mean solar diatance is called the solar constant. These are small, apparently nonperiodic variations, and need not be considered in this investigation.

(2) Variations in the earth's solar distance. Since the radiation intensity varies inversely as the square of this distance, we would expect it to be 7 per cent more intense with the earth in perihelion early in January than with the earth in aphelion early in July.

(3) Amount of water vapor in the atmosphere. In general, this decreases with latitude, altitude, and distance from the ocean, and increases with temperature.

(4) Dustiness or haziness of the atmosphere. This appears to be closely related to (3).

(5) The zenith distance of the sun, which is easily computed when we know the latitude of the place of observation, the sun's declination, and the apparent, or true solar time.

(6) Obviously, the radiation intensity will, in general, increase with altitude.

Generally speaking, in the northern hemisphere the water vapor content of the atmosphere increases at about the same time of year the earth's solar distance increases, so that with the sun at any given zenith distance the solar radiation intensity is much greater in winter than in summer, and in the early spring months than in the late fall. There is also a wide range in the intensities measured on different days in a given month, so that long series of measurements are necessary to establish monthly mean values. In this investigation such monthly means have been obtained from the mean of the weighted a. m. and p. m. normals that are derived from the "Monthly means" and "Departures from normal" given each month in the REVIEW from July, 1918, to June, 1919, inclusive, in my monthly summary of "Solar and sky radiation measurements," Tabl e[4] Extreme accuracy would require that a. m. and p. m. radiation intensities be considered separately, but the character of the data available does not justify such refinement.

The radiation intensities measured at Washington with the sun at different zenith distances probably represent fairly well the intensities that would be measured anywhere in the Atlantic Coast States at elevations under 500 feet with similar atmospheric conditions as regards water vapor and haziness, and with the sun at corresponding zenith distances. Similarly, the measurements obtained at Madison and Lincoln probably represent fairly well places on the Central Plains between 1,000 and 1,500 feet above sea level; and those obtained at Santa Fe likewise represent radiation intensities on the Rocky Mountain Plateau at elevations of about 7,000 feet.

VARIATION DUE TO LATITUDE.

The radiation intensity at any hour of the day varies with the sun's altitude, or complement of the sun's zenith distance.[5] In Table 1 is given the altitude of the sun for each hour of apparent or true solar time from noon to sunset, on the 21st day of each month, for north latitudes 30°, 36°, 42°, and 48°. The altitudes are, of course, the same for corresponding hour angles of the sun from the meridian before noon. Table 2 gives the corresponding azimuths[6] of the sun, which, with the altitudes of Table 1, completely define the sun's position when referred to the horizontal system of coordinate circles. If we plot the logarithms of the monthly mean radiation intensities for the different stations above referred to against the corresponding air masses, m, (approximately the secant of the sun's zenith distance) we obtain slightly curved lines from which the logarithms of radiation intensities for air masses corresponding to any altitude of the sun, as, for instance, the altitudes of Table 1, may be read off.

TABLE 1.—*Solar altitudes.*

LATITUDE 30° N.

Date.	Sun's hour angle from meridian.															
	0		1		2		3		4		5		6		7	
	°	′	°	′	°	′	°	′	°	′	°	′	°	′	°	′
Dec. 21	36	33	34	33	29	12	21	12	12	04	0	20	.....		.....	
Jan. 21	40	06	38	03	32	21	23	56	13	42	2	19	.....		.....	
Feb. 21	49	29	47	00	40	16	30	44	19	33	7	25	.....		.....	
Mar. 21	60	16	57	01	48	47	37	56	25	48	13	05	0	08	.....	
Apr. 21	70	53	67	10	56	49	44	37	31	47	18	48	5	55	.....	
May 21	80	12	73	16	61	13	48	21	35	23	22	21	9	57	.....	
June 21	83	27	75	06	62	30	49	32	36	36	23	52	11	29	−0	23
July 21	80	29	73	27	61	21	48	28	35	30	22	39	10	05	.....	
Aug. 21	71	07	67	20	56	57	44	43	31	53	18	55	6	01	.....	
Sept. 21	60	42	57	25	49	07	38	12	26	03	13	19	0	21	.....	
Oct. 21	49	17	46	49	40	06	30	35	19	26	7	19	.....		.....	
Nov. 21	40	04	38	01	32	19	23	54	13	41	2	18	.....		.....	

[3] Prof. F. H. Bigelow in Supplement No. 1 to "Treatises on the Atmospheres of the Sun and the Earth," New York, 1919. p. 1, has erroneously classified the Marvin pyrheliometer with the Ångström pyrheliometer, which makes use of the static method of observation, instead of with the Smithsonian Silver-disk pyrheliometer, which makes use of the dynamic method of observation. Reference to the above description of the instrument, and to the paper by Dr. Foote already cited, will make clear Prof. Bigelow's error. However, with reference to his statement that the former (static) system is incapable of determining the true value of the "solar constant" of radiation, we need have no concern, since the method by which Professor Bigelow undertakes to compute the value of the "solar constant" from readings of the pyrheliometer is seriously in question (See *Science* June 21, 1918, NS. 47:609 and *Nature* (London) June 5, 1919, Vol. 103, p. 261.), while the accuracy of radiation measurements by such instruments as the Ångström and the Smithsonian pyrheliometers in the hands of competent observers is generally admitted. That the measurements by the Marvin pyrheliometer are equally accurate has been shown by frequent comparisons between the later and Smithsonian Silver-disk pyrheliometer No. 1, which is the property of the Weather Bureau, and which is itself frequently compared with the secondary pyrheliometers at the Smithsonian Institution.

[4] For Santa Fe, for the months October to March, inclusive, it will be necessary to consult the REVIEW for October, 1917, to March, 1918, inclusive.

[5] We may compute the sun's altitude from the equation

$$\sin a = \sin \phi \sin \delta + \cos h \cos \phi \cos \delta,$$

where a = solar altitude, δ = solar declination, h = hour angle of the sun from the meridian of the place = apparent solar time after noon, or 12 hours minus apparent solar time before noon, and ϕ = the latitude of the place of observation. The altitudes of Table 1 are true altitudes for the center of the sun and have been obtained from "Altitude, or Position Line Tables," by Fredrick Ball, London, 1st ed., 1907, 2d ed., 1910.

[6] We may compute the sun's azimuth from the equation $\sin \alpha = \frac{\cos \delta \sin h}{\cos a}$. The azimuths of Table 2 have been computed with the aid of Ball's Altitude or Position Line Tables, already referred to.

TABLE 1.—*Solar altitudes*—Continued.

LATITUDE 36° N.

Date.	Sun's hour angle from meridian. 0	1	2	3	4	5	6	7
	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
Dec. 21	30 33	28 53	24 08	16 55	7 53	.....	.....	.....
Jan. 21	34 06	32 19	27 18	19 45	10 23	−0 11	.....	.....
Feb. 21	43 29	41 24	35 34	27 05	16 54	5 40	.....	.....
Mar. 21	54 16	51 29	44 42	35 05	24 02	12 15	0 09	.....
Apr. 21	65 53	62 22	53 47	42 55	31 08	19 02	6 58	.....
May 21	74 12	69 27	59 22	47 43	35 38	23 33	11 43	0 22
June 21	77 23	71 57	61 15	49 21	37 14	25 13	13 31	1 46
July 21	74 29	69 41	59 33	47 52	35 47	23 42	11 52	0 33
Aug. 21	66 07	62 33	53 56	43 03	31 14	19 09	7 05	.....
Sept. 21	54 42	52 03	45 03	35 24	24 18	12 30	0 25	.....
Oct. 21	43 17	41 12	35 24	26 56	16 46	5 33	.....	.....
Nov. 21	34 04	32 17	27 16	19 43	10 22	−0 12	.....	.....

LATITUDE 42° N.

Dec. 21	24 33	23 06	18 55	12 28	4 17	.....	.....	.....
Jan. 21	28 06	26 34	22 11	15 27	6 59	.....	.....	.....
Feb. 21	37 29	35 43	30 42	23 14	14 05	3 50	.....	.....
Mar. 21	48 16	46 08	40 18	31 56	22 02	11 17	0 11	.....
Apr. 21	59 53	57 09	50 06	40 40	30 05	19 01	7 55	.....
May 21	68 12	64 47	56 37	46 24	35 26	24 18	13 22	2 54
June 21	71 27	67 41	59 04	48 35	37 31	26 25	15 34	5 14
July 21	68 29	65 03	56 50	46 36	35 37	24 29	13 33	3 06
Aug. 21	60 07	57 23	50 21	40 52	30 15	19 11	8 05	.....
Sept. 21	48 42	46 31	40 42	32 18	22 21	11 35	0 28	.....
Oct. 21	37 17	35 29	30 32	23 04	13 55	3 42	.....	.....
Nov. 21	28 04	26 32	22 09	15 23	6 58	.....	.....	.....

LATITUDE 48° N.

Dec. 21	18 33	17 17	13 39	7 58	0 38	.....	.....	.....
Jan. 21	22 06	20 47	16 59	11 05	3 32	.....	.....	.....
Feb. 21	31 29	30 00	25 45	19 34	11 10	2 00	.....	.....
Mar. 21	42 16	40 31	35 40	28 29	19 47	10 10	0 12	.....
Apr. 21	53 53	51 46	46 04	38 02	28 43	18 49	8 48	.....
May 21	62 12	59 40	53 10	44 29	34 47	24 47	14 52	5 25
June 21	65 27	62 44	55 53	46 56	37 10	27 06	17 16	7 53
July 21	62 29	59 57	53 25	44 42	35 00	24 59	15 05	5 37
Aug. 21	54 07	51 59	46 16	38 12	28 53	18 59	8 58	.....
Sept. 21	42 42	40 56	36 04	28 52	20 09	10 31	0 32	.....
Oct. 21	31 17	29 48	25 34	19 23	10 59	1 49	.....	.....
Nov. 21	22 04	20 45	16 57	11 03	3 30	.....	.....	.....

TABLE 2.—*Solar azimuths.*

LATITUDE 30° N.

Date.	Declination.	Sun's hour angle from meridian. 0	1	2	3	4	5	6	7	Sunrise or sunset.
	° ′	°	°	°	°	°	°	°	°	°
Dec. 21	−23 27	0	17	32	44	54	60	.....	.....	62
Jan. 21	−19 54	0	18	34	47	57	65	.....	.....	66
Feb. 21	−10 31	0	22	40	54	65	73	.....	.....	77
Mar. 21	0 16	0	28	49	64	74	83	90	.....	91
Apr. 21	11 53	0	41	63	76	86	93	100	.....	104
May 21	20 12	0	58	77	87	95	101	108	.....	114
June 21	23 27	0	67	84	92	99	104	111	118	118
July 21	20 29	0	58	77	87	95	101	108	.....	114
Aug. 21	12 07	0	41	64	77	86	93	101	.....	104
Sept. 21	0 42	0	29	50	64	74	83	91	.....	91
Oct. 21	−10 43	0	22	40	54	65	73	.....	.....	77
Nov. 21	−19 56	0	18	34	47	57	65	.....	.....	66

LATITUDE 36° N.

Dec. 21	−23 27	0	16	30	43	54	.....	.....	.....	60
Jan. 21	−19 54	0	17	32	45	56	65	.....	.....	64
Feb. 21	−10 31	0	20	37	51	63	73	.....	.....	76
Mar. 21	0 16	0	25	45	60	72	81	90	.....	91
Apr. 21	11 53	0	33	55	71	82	91	100	.....	106
May 21	20 12	0	44	67	81	90	99	107	115	116
June 21	23 27	0	50	72	85	94	102	109	118	120
July 21	20 29	0	44	68	81	91	99	107	115	116
Aug. 21	12 07	0	33	56	72	82	91	100	.....	106
Sept. 21	0 42	0	25	45	61	72	82	91	.....	92
Oct. 21	−10 43	0	20	37	51	63	73	.....	.....	76
Nov. 21	−19 56	0	17	32	45	57	65	.....	.....	64

TABLE 2.—*Solar azimuths*—Continued.

LATITUDE 42° N.

Date.	Declination.	Sun's hour angle from meridian. 0	1	2	3	4	5	6	7	Sunrise or sunset.
	° ′	°	°	°	°	°	°	°	°	°
Dec. 21	−23 27	0	15	29	42	53	.....	.....	.....	57
Jan. 21	−19 54	0	17	30	44	55	.....	.....	.....	62
Feb. 21	−10 31	0	18	35	50	62	72	.....	.....	75
Mar. 21	0 16	0	22	41	56	69	80	90	.....	91
Apr. 21	11 53	0	28	50	66	78	89	99	.....	107
May 21	20 12	0	35	58	74	86	96	105	115	119
June 21	23 27	0	39	63	78	89	99	108	117	123
July 21	20 29	0	35	59	75	86	96	106	115	119
Aug. 21	12 07	0	28	50	66	79	89	99	.....	107
Sept. 21	0 42	0	22	41	56	69	80	91	.....	92
Oct. 21	−10 43	0	18	35	49	61	72	.....	.....	75
Nov. 21	−19 56	0	17	30	44	55	.....	.....	.....	62

LATITUDE 48° N.

Dec. 21	−23 27	0	14	28	41	52	.....	.....	.....	53
Jan. 21	−19 54	0	15	30	43	55	.....	.....	.....	58
Feb. 21	−10 31	0	17	33	47	60	72	.....	.....	73
Mar. 21	0 16	0	20	38	53	67	79	90	.....	91
Apr. 21	11 53	0	24	45	62	75	87	98	.....	109
May 21	20 12	0	28	52	68	82	93	104	114	122
June 21	23 27	0	31	55	72	85	95	106	117	127
July 21	20 29	0	29	52	69	82	93	104	115	122
Aug. 21	12 07	0	24	45	62	75	87	98	.....	109
Sept. 21	0 42	0	20	38	54	67	79	91	.....	92
Oct. 21	−10 43	0	17	33	47	60	72	.....	.....	73
Nov. 21	−19 56	0	15	30	43	55	.....	.....	.....	58

TABLE 3.—*Relation between radiation intensities and the atmospheric water vapor pressure at the earth's surface.*

e.	Washington, D. C. Q_2	ΔQ	$\frac{\Delta Q}{Q_2}$	Madison, Wis. Q_2	ΔQ	$\frac{\Delta Q}{Q_2}$	Santa Fe, N. Mex. Q_2	ΔQ	$\frac{\Delta Q}{Q_2}$
mm.	*cal.*	*cal.*	*Per cent.*	*cal.*	*cal.*	*Per cent.*	*cal.*	*cal.*	*Per cent.*
1.0	1.208	.....	.....	1.385	.....	.....	1.453	.....	.....
2.0	1.180	0.028	2.3	1.348	0.037	2.7	1.418	0.035	2.4
3.0	1.154	26	2.2	1.315	33	2.5	1.385	33	2.3
4.0	1.129	25	2.2	1.284	31	2.4	1.355	30	2.2
5.0	1.104	25	2.2	1.255	29	2.3	1.327	28	2.1
6.0	1.081	23	2.1	1.230	25	2.0	1.301	26	2.0
7.0	1.058	23	2.1	1.205	25	2.0	1.276	25	1.9
8.0	1.035	23	2.2	1.183	22	1.8	1.254	22	1.7
9.0	1.014	21	2.0	1.161	22	1.9	1.233	21	1.7
10.0	0.994	20	2.0	1.139	22	1.9	1.212	21	1.7
11.0	0.974	20	2.0	1.118	21	1.9	1.192	20	1.7
12.0	0.954	20	2.1	1.096	22	2.0	.....	.....	.....
13.0	0.936	18	1.9	1.075	21	1.9	.....	.....	.....
14.0	0.918	18	1.9	1.053	22	2.1	.....	.....	.....
15.0	0.900	18	2.0	1.032	21	2.0	.....	.....	.....
16.0	0.883	17	1.9	0.970	62	6.0	.....	.....	.....
17.0	0.867	16	1.8	0.905	65	6.7	.....	.....	.....
18.0	.....	.....	.....	0.840	65	7.2	.....	.....	.....

WATER VAPOR CORRECTION.

The radiation intensities must next be corrected for variation in the water vapor content of the atmosphere with latitude. This correction has been determined as follows:

(1) Table 3 shows the relation between radiation intensities Q_2 and the atmospheric water vapor pressure, e, at Washington, Madison, and Santa Fe, with the sun at zenith distance 60°, $m=2$. The radiation intensities have been reduced to mean solar distance of the earth. It will be seen that in general an increase of 1 mm. in the water vapor pressure decreases the radiation intensity by 2 per cent. This result is in accord with that obtained by Gorczyński and others.[7] A previous investi-

[7] Gorczyński, Ladislas. Sur La Marche Annuelle de l'intensité du rayonnement Solaire à Varsovie: Varsovie, 1906. Valeurs pyrhéliometriques, et les sommes d'insolation à Varsovie, 1901-1913. Varsovie, 1914.
Westman, J. Mesures de l'intensité de la radiation solaire faites à Upsala en 1901. Upsala. 1907. 55p. f°. (Kungl. Svenska vetenskapsakademiens handlingar. Bd. 2. No. 4. p. 26.)

gation[8] by the writer had shown that absorption of radiation by water vapor would lead us to expect a decrease of intensity of only about 1 per cent per mm. increase in e. The earlier comparisons, however, were confined to days when polarization of skylight indicated equal intensities of scattered sunlight. In this present case the greater decrease in radiation with increase in vapor pressure must be attributed to the fact that generally there is increased haziness, and, therefore, increased scattering of the sun's rays, with increase in vapor pressure, partly, perhaps, on account of the hygroscopic character of the dust and other particles in the atmosphere.

(2) From the plotted logarithms of the monthly mean radiation intensities already referred to, it is found that the atmospheric transmission coefficient[9] is diminished about 0.6 per cent for an increase in e of 1 mm. Therefore the total effect of water vapor pressure upon radiation may be expressed approximately by the equation

$$Q'_m = Q_m(0.98^{\Delta e} \times 0.994,^{m-2} \quad (1)$$

where Q_m is the monthly mean radiation intensity for air mass m at a given station and Q'_m is the intensity at another locality under similar climatic conditions, except that the value of e is Δe millimeters greater.

In Table 4 are given the monthly means of water vapor pressure for Washington, Madison, Lincoln, and Santa Fe, and for group of stations along the thirtieth, thirty-sixth, forty-second, and forty-eighth parallels of latitude.[10]

TABLE 4.—*Monthly mean water vapor pressure.*

EASTERN STATES.

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
	mm.	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*	*mm.*
Washington....	3.40	3.48	4.52	6.35	10.21	14.20	16.33	15.67	12.83	8.31	5.31	3.81
Lat. 30°.	8.08	8.90	10.59	12.82	15.98	19.56	20.83	20.72	18.62	13.86	10.54	8.67
Δe.....	+4.68	+5.43	+6.07	+6.47	+5.77	+5.36	+4.50	+5.05	+5.79	+5.55	+5.23	+4.86
Lat. 36°.	4.54	4.83	6.07	7.94	11.67	15.60	17.52	17.07	13.90	9.26	6.28	4.96
Δe.....	+1.14	+1.35	+1.55	+1.59	+1.46	+1.40	+1.19	+1.40	+1.07	+0.95	+0.97	+1.15
Lat. 42°.	2.67	2.68	3.64	5.27	8.22	11.93	13.94	13.19	10.77	7.18	4.64	3.27
Δe.....	−0.73	−0.80	−0.88	−1.08	−1.99	−2.27	−2.39	−2.48	−2.06	−1.13	−0.67	−0.54

CENTRAL STATES.

Madison.	2.29	2.18	3.53	5.18	8.52	11.87	13.31	13.12	10.76	6.67	4.27	2.79
Lincoln..	2.60	2.56	3.92	5.70	9.12	12.68	14.25	14.28	10.86	7.07	4.29	2.81
Lat. 30°.	5.10	5.61	6.87	8.84	11.51	13.81	15.86	16.15	13.69	9.67	6.81	5.51
ΔLe.....	+2.50	+3.50	+2.95	+3.14	+2.39	+1.13	+1.61	+1.87	+2.83	+2.60	+2.52	+2.70
Lat. 36°.	3.40	3.58	4.91	6.18	10.85	14.32	15.51	14.93	11.92	8.02	5.22	3.87
ΔLe.....	+0.80	+1.02	+0.99	+0.48	+1.73	+1.64	+1.26	+0.65	+1.06	+0.95	+0.93	+1.06
Lat. 42°.	1.93	2.05	3.29	5.32	8.21	12.17	14.03	13.14	9.55	6.11	3.48	2.44
Δe.....	−0.51	−0.32	−0.43	−0.12	−0.61	−0.51	−0.22	−1.14	−1.31	−0.96	−0.81	−0.36
Lat. 48°..	1.34	1.33	2.31	4.13	6.18	9.11	10.99	10.10	7.54	5.10	2.89	1.9
Δe.....	−1.10	−1.04	−1.41	−1.31	−2.64	−3.57	−3.26	−4.27	−3.32	−1.97	−1.40	−0.89

CENTRAL PLATEAU.

Santa Fe	2.13	2.44	2.64	3.12	4.19	5.51	8.08	8.05	6.15	4.17	2.87	2.21
Lat. 42°.	2.42	2.58	3.09	3.68	4.87	5.99	6.77	6.56	4.93	4.09	3.11	2.45
Lat. 42° × 0.8.....	1.94	2.06	2.47	2.94	3.90	4.79	5.42	5.25	3.94	3.27	2.49	1.96
Δe.....	−0.19	−0.38	−0.17	−0.18	−0.29	−0.72	−2.66	−2.80	−2.21	−0.90	−0.38	−0.25

[8] Some causes of variation in the polarization of skylight. Jr. Franklin Inst., Apr. 1911, p. 339.

[9] Log. a=log. Q_m−log. Q_{m-1}, where a is the atmospheric transmission coefficient and m is any air mass.

[10] These data have been taken from W. B. Bulletin W and REVIEW Supplement No. 6 for the following stations:

Lat. 30°: Gulf Coast, Galveston, Tex.; Jacksonville, Fla.; Mobile, Ala.; and New Orleans, La. Southern Plains, Abilene, Tex.; San Antonio, Tex.; Yuma, Ariz.

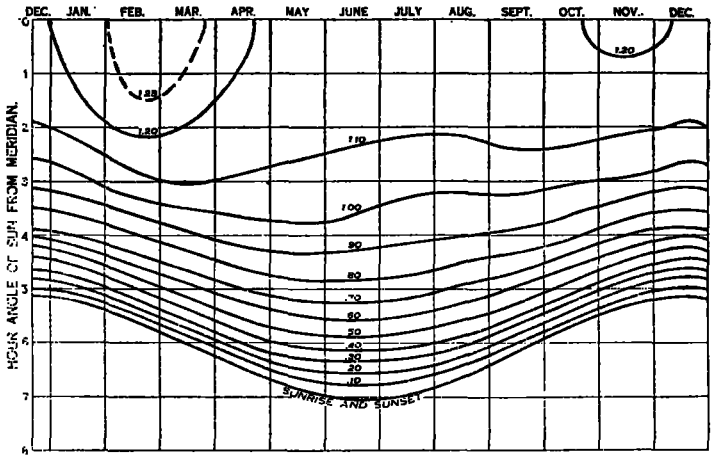
Lat. 36°: Eastern U. S., Chattanooga, Tenn.; Charlotte, N. C.; Knoxville, Tenn.; Memphis, Tenn.; Nashville, Tenn.; Norfolk, Va.; Raleigh, N. C. Central Plains, Amarillo, Tex.; Fort Smith, Ark.; Oklahoma, Okla.

Lat. 42°: Northeastern U. S., Albany, N. Y.; Boston, Mass.; Buffalo, N. Y.; Chicago, Ill.; Cleveland, Ohio; Detroit, Mich.; Erie, Pa.; New Haven, Conn.; Sandusky, Ohio; Toledo, Ohio. Central Plains, Davenport, Iowa; Des Moines, Iowa; Dubuque, Iowa; North Platte, Nebr.; Omaha, Nebr.; Valentine, Nebr.; Yankton, S. Dak. Central Plateau, Cheyenne, Wyo.; Lander, Wyo.; Pocatello, Idaho; Salt Lake City, Utah; Winnemucca, Nev.

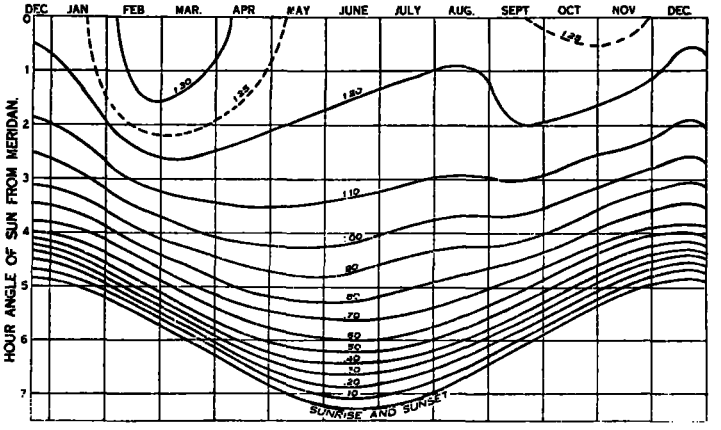
Lat. 48°: Northern Plains, Devils Lake, N. Dak.; Duluth, Minn.; Havre, Mont.; Houghton, Mich.; Moorhead, Minn.; Williston, N. Dak.

In the table, Δe for lat. 30°, on the Gulf Coast, for lat. 36°, in the States east of the Mississippi, and for lat. 42° in the northeastern States, is the average excess of the monthly mean water vapor pressure for the respective latitudes over the monthly means for Washington; and this value has been used in equation (1) to determine the water vapor correction.

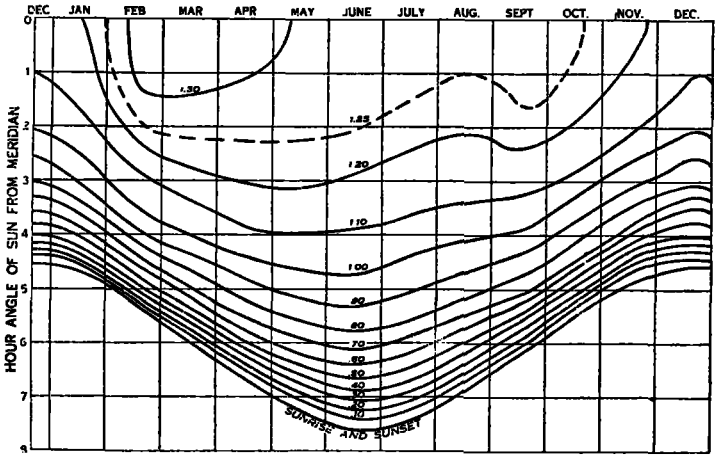
Applying the water vapor correction as above determined to the radiation intensities for latitudes 30°, 36°, and 42°, as derived from the monthly means for Wash-



(*a*), Latitude 30°N. (Gulf Coast).

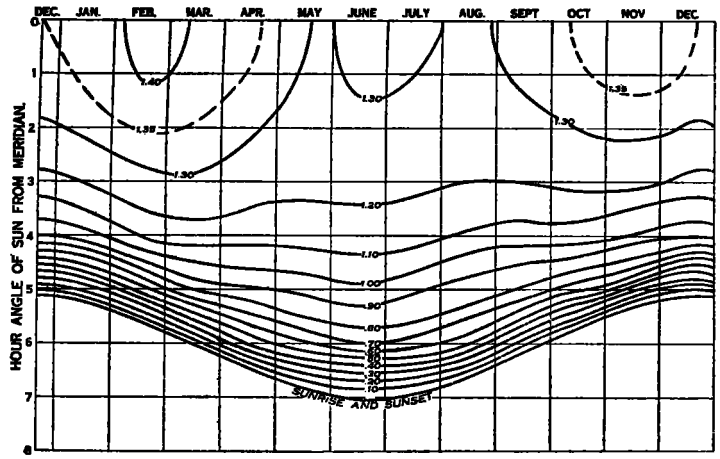


(*b*), Latitude 36°N. (Eastern States).

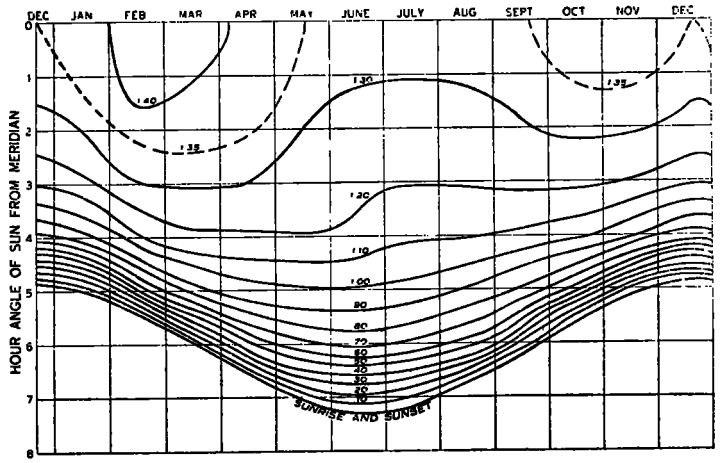


(*c*), Latitude 42°N. (Northeastern States).

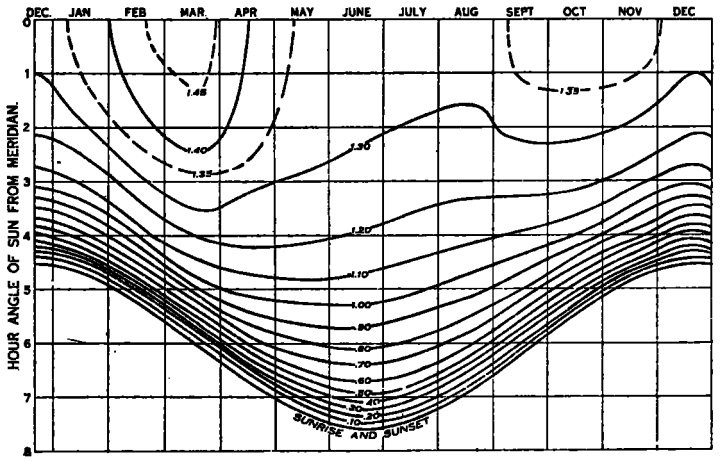
FIGURE 2.—Solar radiation intensity at normal incidence. (Gram calories per minute per square centimeter.)



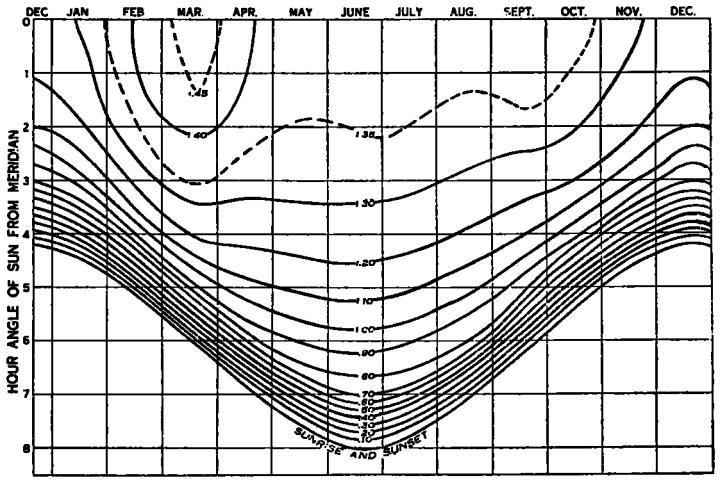
(a), Latitude 30°N. (Southern Plains).



(b), Latitude 36°N. (Central Plains).



(c), Latitude 42°N. (Central Plains).



(d), Latitude 48°N. (Northern Plains).

FIGURE 3.—Solar radiation intensity at normal incidence. (Gram calories per minute per square centimeter.)

ington, the intensities of Table 5a and figure 2 are obtained.

A comparison of radiation intensities for lat. 42° derived from Madison and Lincoln measurements indicates that the increased tendency to cloud formation, perhaps due to the presence of numerous lakes in the vicinity of Madison, depresses the radiation intensity at that station during the warm part of the year (May to November), when the lakes are free from ice. During the cold months (December to April), the effect of the lakes is not apparent. During these latter months, therefore, the mean of the radiation intensity and the vapor pressure at these two stations has been employed in determining the radiation intensity and the vapor pressure in the Plains States at lat. 42° and 48°, and the data for Lincoln for the remainder of the year. The Lincoln data have also been employed in determining the radiation intensities at lat. 36° and 30° in the Plains States. The intensities thus determined are given in Table 5b and figure 3.

TABLE 5a.—*Solar radiation intensity at normal incidence.*

(Gram-calories per minute per square centimeter of surface.)

LATITUDE 30° N. GULF COAST.

Date.	Hour angle of sun from meridian.								Percentage of possible daily total.
	0	1	2	3	4	5	6	7	
	cal.	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	
Dec. 21	1.19	1.16	1.09	0.93	0.67	0.12	.....	.....	.....
Jan. 21	1.23	1.21	1.15	0.99	0.72	0.23	.....	.....	.....
Feb. 21	1.29	1.28	1.22	1.10	0.87	0.57	.....	.....	.....
Mar. 21	1.26	1.24	1.19	1.10	0.90	0.61	0.11	.....	.....
Apr. 21	1.20	1.19	1.15	1.09	0.96	0.71	0.38	.....	.....
May 21	1.17	1.16	1.12	1.05	0.94	0.74	0.41	.....	.....
June 21	1.16	1.15	1.12	1.06	0.95	0.76	0.47	.....	.....
July 21	1.19	1.18	1.14	1.08	0.96	0.77	0.48	.....	.....
Aug. 21	1.16	1.15	1.11	1.03	0.89	0.67	0.35	.....	.....
Sept. 21	1.19	1.17	1.14	1.05	0.88	0.58	0.11	.....	.....
Oct. 21	1.20	1.18	1.13	1.01	0.80	0.49	.....	.....	.....
Nov. 21	1.22	1.19	1.12	0.98	0.71	0.22	.....	.....	.....

LATITUDE 36° N. EASTERN U. S.

Dec. 21	1.22	1.18	1.09	0.92	0.62	.....	.....	.....	46
Jan. 21	1.25	1.22	1.15	0.99	0.70	.....	.....	.....	.....
Feb. 21	1.34	1.33	1.27	1.14	0.91	0.50	.....	.....	.....
Mar. 21	1.33	1.31	1.26	1.16	0.99	0.70	0.11	.....	53
Apr. 21	1.28	1.27	1.22	1.17	1.04	0.82	0.50	.....	.....
May 21	1.23	1.22	1.19	1.12	1.02	0.85	0.59	0.11	.....
June 21	1.23	1.22	1.19	1.13	1.02	0.86	0.60	0.13	50
July 21	1.24	1.23	1.20	1.13	1.03	0.86	0.61	0.11	.....
Aug. 21	1.21	1.19	1.15	1.08	0.95	0.75	0.45	.....	.....
Sept. 21	1.25	1.24	1.20	1.12	0.95	0.67	0.11	.....	51
Oct. 21	1.26	1.24	1.18	1.06	0.84	0.48	.....	.....	.....
Nov. 21	1.26	1.23	1.16	0.99	0.70	.....	.....	.....	.....

LATITUDE 42° N. NORTHEASTERN U. S.

Dec. 21	1.14	1.10	1.01	0.81	0.41	.....	.....	.....	43
Jan. 21	1.21	1.18	1.10	0.93	0.61	.....	.....	.....	.....
Feb. 21	1.34	1.33	1.25	1.12	0.95	0.41	.....	.....	.....
Mar. 21	1.34	1.32	1.27	1.17	1.01	0.73	0.12	.....	53
Apr. 21	1.32	1.30	1.27	1.21	1.09	0.89	0.58	.....	.....
May 21	1.29	1.28	1.24	1.18	1.10	0.94	0.73	0.20	.....
June 21	1.29	1.28	1.25	1.19	1.09	0.96	0.75	0.36	53
July 21	1.29	1.28	1.24	1.18	1.11	0.95	0.75	0.20	.....
Aug. 21	1.26	1.25	1.21	1.14	1.02	0.83	0.48	.....	.....
Sept. 21	1.29	1.27	1.24	1.14	0.98	0.72	0.11	.....	51
Oct. 21	1.25	1.24	1.18	1.04	0.81	0.35	.....	.....	.....
Nov. 21	1.21	1.18	1.10	0.92	0.55	.....	.....	.....	.....

TABLE 5b.—*Solar radiation intensity at normal incidence.*

(Gram-calories per minute per square centimeter of surface.)

LATITUDE 30° N. SOUTHERN PLAINS.

Date.	Hour angle of sun from the meridian.								Percentage of possible daily total.
	0	1	2	3	4	5	6	7	
	cal.	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	
Dec. 21	1.35	1.34	1.29	1.17	0.91	0.15			
Jan. 21	1.38	1.37	1.32	1.22	0.98	0.29			
Feb. 21	1.42	1.41	1.36	1.29	1.12	0.69			
Mar. 21	1.39	1.38	1.34	1.29	1.16	0.85	0.13		
Apr. 21	1.35	1.34	1.31	1.25	1.14	0.89	0.49		
May 21	1.29	1.28	1.26	1.21	1.15	0.93	0.58		
June 21	1.32	1.31	1.29	1.24	1.15	0.98	0.71		
July 21	1.31	1.30	1.28	1.23	1.16	0.94	0.62		
Aug. 21	1.29	1.28	1.25	1.19	1.08	0.87	0.51		
Sept. 21	1.33	1.32	1.28	1.21	1.06	0.74	0.12		
Oct. 21	1.36	1.35	1.31	1.23	1.05	0.62			
Nov. 21	1.38	1.37	1.32	1.22	0.98	0.29			

LATITUDE 36° N. CENTRAL PLAINS.

Dec. 21	1.35	1.33	1.27	1.12	0.76				54
Jan. 21	1.38	1.37	1.32	1.19	0.91				
Feb. 21	1.44	1.43	1.38	1.31	1.12	0.63			
Mar. 21	1.41	1.40	1.37	1.31	1.18	0.88	0.13		59
Apr. 21	1.39	1.38	1.35	1.30	1.19	0.97	0.59		
May 21	1.31	1.30	1.28	1.22	1.13	0.96	0.80	0.13	
June 21	1.30	1.30	1.28	1.23	1.15	0.99	0.83	0.17	57
July 21	1.32	1.31	1.29	1.23	1.14	0.97	0.81	0.14	
Aug. 21	1.31	1.30	1.27	1.21	1.11	0.89	0.58		
Sept. 21	1.35	1.34	1.30	1.23	1.07	0.76	0.12		56
Oct. 21	1.37	1.36	1.32	1.23	1.03	0.56			
Nov. 21	1.38	1.36	1.31	1.19	0.90				

LATITUDE 42° N. CENTRAL PLAINS.

Dec. 21	1.32	1.30	1.22	1.05	0.52				49
Jan. 21	1.37	1.35	1.30	1.15	0.75				
Feb. 21	1.45	1.44	1.39	1.30	1.09	0.48			
Mar. 21	1.47	1.46	1.43	1.37	1.24	0.95	0.13		61
Apr. 21	1.39	1.38	1.36	1.31	1.23	1.05	0.72		
May 21	1.34	1.33	1.31	1.26	1.19	1.03	0.79	0.28	
June 21	1.34	1.33	1.31	1.27	1.19	1.06	0.84	0.51	58
July 21	1.33	1.32	1.30	1.26	1.18	1.03	0.78	0.25	
Aug. 21	1.32	1.31	1.29	1.23	1.13	0.94	0.63		
Sept. 21	1.37	1.36	1.32	1.24	1.09	0.78	0.12		59
Oct. 21	1.37	1.36	1.33	1.23	1.00	0.44			
Nov. 21	1.37	1.35	1.29	1.13	0.76				

LATITUDE 48° N. NORTHERN PLAINS.

Dec. 21	1.23	1.21	1.10	0.81	0.14				
Jan. 21	1.32	1.29	1.21	1.02	0.47				
Feb. 21	1.42	1.41	1.35	1.27	1.01	0.32			
Mar. 21	1.48	1.46	1.43	1.36	1.23	0.92	0.14		
Apr. 21	1.40	1.39	1.37	1.33	1.24	1.08	0.82		
May 21	1.36	1.35	1.33	1.30	1.22	1.09	0.87	0.52	
June 21	1.39	1.38	1.36	1.33	1.26	1.15	0.96	0.71	
July 21	1.38	1.38	1.35	1.31	1.24	1.10	0.90	0.54	
Aug. 21	1.37	1.36	1.33	1.29	1.19	1.02	0.80		
Sept. 21	1.39	1.37	1.34	1.25	1.10	0.79	0.13		
Oct. 21	1.36	1.34	1.30	1.19	0.91	0.22			
Nov. 21	1.31	1.28	1.21	1.01	0.47				

The latitude of Santa Fe (35° 41′) differs so little from 36° that the vapor pressure for that station has been employed for lat. 36° on the Plateau. For lat. 42° the vapor pressures determined at stations averaging about 5,000 feet have been reduced to the 7,000-foot level by the use of Hann's equation,[11] the factor in this case being 0.8. The resulting radiation intensities are given in Table 5c and figure 4.

[11] Smithsonian Meteorological Tables, 4th edit., 1918, p. 194.

TABLE 5c.—*Solar radiation intensities at normal incidence.*

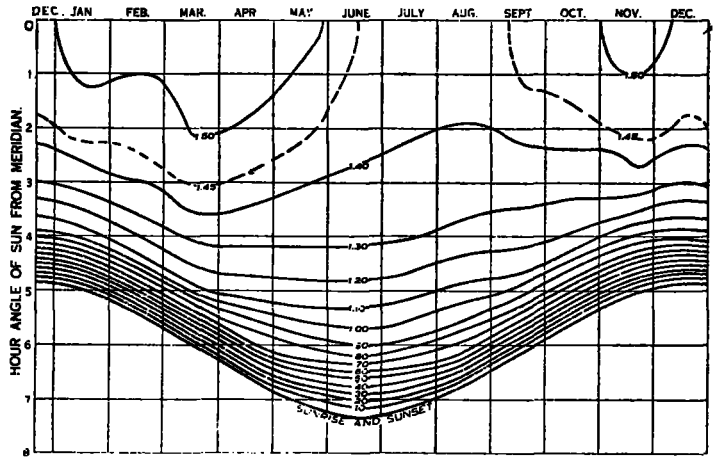
(Gram calories per minute per square centimeter of surface.)

LATITUDE 36° N. CENTRAL PLATEAU.

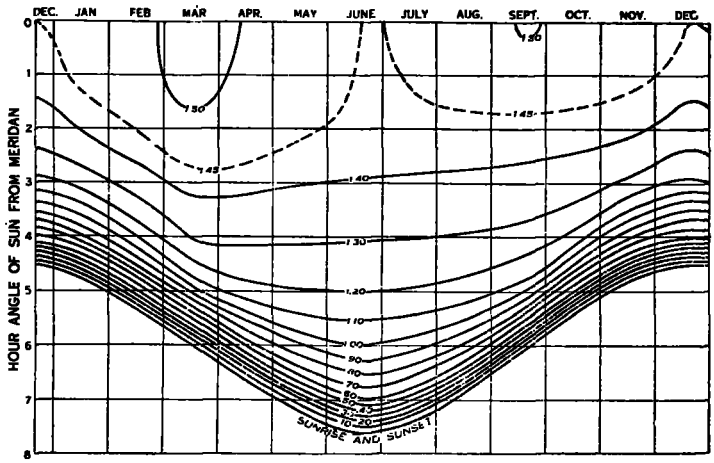
Date.	Hour angle of sun from the meridian.								Percentage of possible daily total.
	0	1	2	3	4	5	6	7	
	cal.	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	
Dec. 21	1.49	1.48	1.44	1.30	0.93				62
Jan. 21	1.52	1.51	1.47	1.37	1.07				
Feb. 21	1.51	1.50	1.47	1.40	1.24	0.70			
Mar. 21	1.54	1.54	1.51	1.46	1.36	1.11	0.16		67
Apr. 21	1.50	1.50	1.46	1.41	1.32	1.16	0.70		
May 21	1.51	1.50	1.48	1.43	1.34	1.22	1.03	0.15	
June 21	1.42	1.41	1.39	1.37	1.29	1.17	0.93	0.21	60
July 21	1.41	1.41	1.39	1.34	1.26	1.15	0.85	0.14	
Aug. 21	1.41	1.40	1.37	1.32	1.23	1.07	0.67		
Sept. 21	1.47	1.46	1.42	1.36	1.24	1.02	0.15		64
Oct. 21	1.49	1.48	1.43	1.35	1.18	0.61			
Nov. 21	1.52	1.50	1.47	1.37	1.07				

LATITUDE 42° N. CENTRAL PLATEAU.

Dec. 21	1.45	1.43	1.36	1.18	0.60				58
Jan. 21	1.49	1.47	1.42	1.27	0.87				
Feb. 21	1.49	1.49	1.45	1.36	1.19	0.49			
Mar. 21	1.53	1.52	1.49	1.44	1.35	1.08	0.15		63
Apr. 21	1.49	1.48	1.45	1.41	1.32	1.17	0.79		
May 21	1.51	1.50	1.47	1.42	1.35	1.24	1.08	0.40	
June 21	1.44	1.43	1.41	1.36	1.30	1.18	0.96	0.61	63
July 21	1.47	1.46	1.44	1.39	1.33	1.23	1.01	0.40	
Aug. 21	1.45	1.44	1.42	1.38	1.29	1.15	0.77		
Sept. 21	1.51	1.48	1.44	1.39	1.28	1.07	0.15		65
Oct. 21	1.47	1.45	1.41	1.33	1.15	0.40			
Nov. 21	1.49	1.47	1.42	1.28	0.86				



(*a*), Latitude 36°N. (Central Plateau).



(*b*), Latitude 42°N. (Central Plateau).

FIGURE 4.—Solar radiation intensity at normal incidence. (Gram calories per minute per square centimeter.)

Equation (1) is not general in its application, for if applied to Washington radiation intensities to determine intensities for the Pacific Coast States, where the monthly means of vapor pressure for latitudes 36° to 42°, inclusive, lie between 6 mm. in winter and 9.5 mm. in summer, the computed noon intensities for August and September are about 5 per cent greater than the intensities for March and April, which seems improbable. More consistent values are obtained by applying to the Atlantic coast intensities for latitudes 36° and 42°, respectively, a correction of about 0.01 Δe, or −3 per cent for January and February, −2 per cent for November, December, and March, + 2 per cent for May, + 4 per cent for September, and + 6 per cent for June, July, and August.

The daily totals of direct solar radiation received on a surface normal to the sun's rays may be obtained by plotting the intensities of Table 5 against the corresponding hour angles of the sun, integrating the areas under the curves, and multiplying the results by 2. The possible daily total is found by the equation $\Sigma I_0 = \frac{I_0 t}{R^2}$ where I_0 is the solar constant, t is the length of the day in minutes, and R is the earth's solar distance expressed in terms of its mean solar distance. In the last column of Table 5 is given the ratio between the "Daily totals," and the "Possible daily totals" as above determined, for the months of December, March, June, and September, and latitudes 36° N., and 42° N. In the Atlantic Coast States the ratio is about 50 per cent, in the Plains States about 57 per cent, and on the Plateau it is about 63 per cent.

The water vapor correction for lat. 30° as derived from equation (1) may be too large. Possibly the radiation intensities given in Table 5a for that latitude are 5 per cent too low. The percentage of error in the remainder of Table 5 must be small, however.

TABLE 6.—*Noon radiation intensities.*

(Gram-calories per minute per square centimeter of normal surface.)

Date.	Washington.			Madison.			Lincoln.			Santa Fe.		
	Mean.	Absolute max.	Max. / mean.	Mean.	Absolute max.	Max. / mean.	Mean.	Absolute max.	Max. / mean.	Mean.	Absolute max.	Max. / mean.
	cal.	*cal.*	*ratio.*	*cal.*	*cal.*	*ratio.*	*cal.*	*cal.*	*ratio.*	*cal.*	*cal.*	*ratio.*
Dec. 21	1.18	1.48	1.25	1.30	1.47	1.15	1.32	1.51	1.14	1.49	1.61	1.08
Jan. 21	1.24	1.42	1.15	1.35	1.56	1.16	1.36	1.52	1.12	1.52	1.66	1.09
Feb. 21	1.35	1.50	1.11	1.44	1.57	1.09	1.43	1.58	1.10	1.50	1.65	1.10
Mar. 21	1.34	1.48	1.10	1.51	1.60	1.06	1.42	1.56	1.10	1.54	1.66	1.08
Apr. 21	1.30	1.51	1.16	1.39	1.58	1.14	1.39	1.58	1.14	1.51	1.64	1.09
May 21	1.25	1.45	1.16	1.28	1.47	1.15	1.32	1.53	1.16	1.51	1.61	1.07
June 21	1.25	1.43	1.14	1.28	1.44	1.12	1.33	1.49	1.12	1.42	1.53	1.08
July 21	1.25	1.47	1.18	1.28	1.46	1.14	1.33	1.44	1.08	1.41	1.45	1.03
Aug. 21	1.23	1.43	1.16	1.26	1.46	1.16	1.31	1.49	1.14	1.40	1.47	1.05
Sept. 21	1.26	1.49	1.18	1.22	1.45	1.19	1.35	1.48	1.10	1.47	1.53	1.04
Oct. 21	1.25	1.45	1.16	1.22	1.46	1.20	1.36	1.53	1.12	1.49	1.57	1.05
Nov. 21	1.24	1.48	1.19	1.24	1.42	1.15	1.36	1.56	1.15	1.52	1.63	1.07
Means	.....	.....	1.16	.....	.....	1.14	.....	.....	1.12	.....	.....	1.07

Table 6, giving the monthly means and absolute maxima of noon radiation measurements, indicates that at midday on exceptionally clear days radiation intensities from 15 to 20 per cent greater than the average are to be expected in the eastern States, from 10 to 15 per cent greater in the Plains States, and from 5 to 10 per cent greater on the Rocky Mountain plateau.

INCREASE OF SOLAR RADIATION INTENSITY WITH ALTITUDE.

For a study of the increase in radiation intensity with altitude, in addition to the data contained in Tables 5 and 6, there are available measurements made by the Weather Bureau at Mount Weather, Va.,[12] between September, 1907, and September, 1914, inclusive; by the Smithsonian Institution on Hump Mountain, N. C.,[13] between June, 1917, and March, 1918, inclusive; on Mount Wilson, Calif., in 1908, 1909, 1910, and 1911; and on Mount Whitney, Calif., in 1908, 1909, and 1910;[14] by A. Ångström on Mount Whitney in 1913;[15] and by the writer at Cheyenne, Wyo., and Flagstaff and Phoenix, Ariz.,[16] in 1910, and at Ellijay, N. C., in 1915. These data are summarized in Table 7. They are probably adequate to establish monthly mean values at Mount Wilson, but are insufficient to establish such values at other points. During the time when most of the readings were made at Mount Weather the atmospheric transmission was much below the normal, due to the high dust layer resulting from the eruption of Katmai Volcano in June, 1912. On Mount Whitney readings were obtained on 18 half-day periods; at Flagstaff, 8; at Phoenix, 11; at Cheyenne, 5; and at Ellijay, 5. With the exception of Cheyenne and Mount Weather, these stations are not far from latitude 36° N. We shall therefore consider that they represent intensities at that latitude after applying a correction for the sun's zenith distance where necessary.

TABLE 7.—*Monthly averages of solar radiation intensity.*

(Gram-calories per minute per square centimeter of normal surface.)

Month.	Air mass.		Noon intensities.			
	1.0[1]	2.0	Max.	Min.	Mean.	Max. / Mean.
	cal.	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*
MOUNT WHITNEY, CALIF., LAT. 36° 35′ N.; LONG. 118° 17′ W.; ALT. 14,502 FT. (4,420 M.).						
Aug. 12-Sept. 3	.....	1.51	1.73	1.60	1.65	1.05
MOUNT WILSON, CALIF., LAT. 34° 13′ N.; LONG. 118° 4′ W.; ALT. 5,767 FT. (1,789 M.).						
May	1.52	1.34	1.57	1.46	1.51	1.04
June	1.52	1.34	1.59	1.41	1.52	1.05
July	1.50	1.34	1.59	1.37	1.49	1.07
August	1.52	1.35	1.65	1.34	1.51	1.09
September	.....	1.40	1.61	1.43	1.53	1.05
October	.....	1.44	1.62	1.40	1.53	1.06
November	.....	1.48	1.58	1.43	1.53	1.03
Mean	.....	.....	.....	.....	.....	1.06
HUMP MOUNTAIN, N. C., LAT. 36° 8′ N.; LONG. 82° 0′ W.; ALT. 4,800 FT. (1,463 M.).						
June	.....	1.29	.....	.....	.....	.....
July	.....	1.12	.....	.....	.....	.....
August	.....	1.24	.....	.....	.....	.....
September	.....	1.36	.....	.....	.....	.....
October	.....	1.38	.....	.....	.....	.....
November	.....	1.41	.....	.....	.....	.....
December	.....	1.46	.....	.....	.....	.....
January	.....	1.52	.....	.....	.....	.....
February	.....	1.44	.....	.....	.....	.....
March	.....	1.46	.....	.....	.....	.....
MOUNT WEATHER, VA., LAT. 39° 4′ N.; LONG. 77° 53′ W.; ALT. 1,772 FT. (540 M.).						
January	.....	1.34	1.37	.....	.....	.....
February	.....	1.25	1.48	.....	.....	.....
March	.....	1.23	1.48	.....	.....	.....
April	.....	1.17	1.45	.....	.....	.....
May	.....	0.99	1.50	.....	.....	.....
June	.....	1.03	1.47	.....	.....	.....
July	.....	0.99	1.48	.....	.....	.....
August	.....	1.05	1.45	.....	.....	.....
September	.....	1.14	1.50	.....	.....	.....
October	.....	1.32	1.48	.....	.....	.....
November	.....	1.26	1.43	.....	.....	.....
December	.....	1.30	1.40	.....	.....	.....

[12] See Bull. of the Mount Weather Observatory, 5:295-311, and 6:215-219; Monthly Weather Review, 1914, 42:139, 310, 520.

[13] From the manuscript of a table that will appear in Annals of the Astrophysical Observatory, Vol. IV, and kindly furnished by Assistant Secretary Abbot.

[14] Annals of the Astrophysical Observatory of the Smithsonian Institution, 3:74-99.

[15] A study of the radiation of the atmosphere. Smithsonian Misc. Col. 65: No. 3, p. 152, 1915.

[16] Some causes of the variation in the polarization of skylight. Jr. Franklin Instit., April, 1911, p. 338.

Month.	Air mass.		Noon intensities.			
	1.0[1]	2.0	Max.	Min.	Mean.	Max. / Mean.
FLAGSTAFF, ARIZ., LAT. 35° 12′ N.; LONG. 111° 37′ W.; ALT. 6,907 FT. (2,105 M.).						
	cal.	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*
Sept. 25–30	1.59	1.40	1.57	.....	1.55	.....
CHEYENNE, WYO., LAT. 41° 8′ N.; LONG. 104° 48′ W.; ALT. 6,088 FT. (2,105 M..)						
Aug. 29–Sept. 3	1.47	1.18	1.47	.....	1.43	.....
ELLIJAY, N. C., LAT. 35° 11′ N.; LONG. 83° 15′ W.; ALT. 2,240 FT. (683 M.)						
May 8–13	1.43	1.21	.....	.....	.....	.....
PHOENIX, ARIZ., LAT. 33° 28′ N.; LONG. 112° 0′ W.; ALT. 1,108 FT. (336 M.).						
Oct. 2–8	1.47	1.28	1.48	.....	1.43	.....

[1] Extrapolated.

In curves I–IV, figure 5 is plotted the percentage increase in radiation intensity along the thirty-sixth parallel from the Atlantic Coast States to the Rocky Mountain plateau. Curve I has been derived from the monthly mean intensities with the sun at zenith distance 60°; curve II, from the monthly mean noon intensities of Tables 6 and 7; curve III, from the maximum noon intensities of tables 6 and 7; and curve IV, from the maximum intensities that have been recorded at the respective stations, reduced to zenithal sun and mean solar distance of the earth. Great weight has been given to the data derived from the Washington, Lincoln, and Santa Fe data, as these stations are more representative of general conditions than are mountain stations. The data for the latter for curves I, II, and III, are generally high, indicating that the average radiation intensity on a mountain peak is higher than on a plateau of the same elevation. The intensity at Mount Wilson for curve IV is low, probably because readings have not been made there in winter when the vapor content of the atmosphere is least. A high degree of accuracy can not be claimed for the extreme readings on individual days of curve IV, and especially where they have been extrapolated to air mass 1 from about air mass 2, as has been the case with the readings for Washington, Lincoln, and Santa Fe.

Curves V, VI, VII, and VIII, figure 5, are based upon the increase in the "Daily totals of radiation" of Tables 9b and 9c for latitudes 36° and 42° N., over the corresponding totals of Table 9a. It is to be noted that for the cold season of the year, when the altitude of the sun at noon is low, curves V and VI approximate to curve I; but for the warm season of the year, when the sun is near the zenith at noon, curves VII and VIII approximate to curve II.

The intensities for Phoenix, Ariz., given in Table 7, are only slightly higher than the October intensities for the Plains States at latitude 36°, and the corresponding vapor pressures are also about equal. The few readings obtained at Ellijay, N. C., are higher than one would expect for the elevation of that station.

Curve II is comparable with the results previously obtained by the writer,[17] namely, an increase in radiation intensity of about 5 per cent per 1,000 feet between 720 and 1,720 feet elevation, and of about 0.5 per cent per 1,000 feet between 7,000 and 12,000 feet elevation. Curve IV may be compared with Abbot's [18] determination, which gave less than 1 per cent increase per 1,000 feet between Mount Wilson and Mount Whitney. The radiation intensities upon which curve IV is based, and the

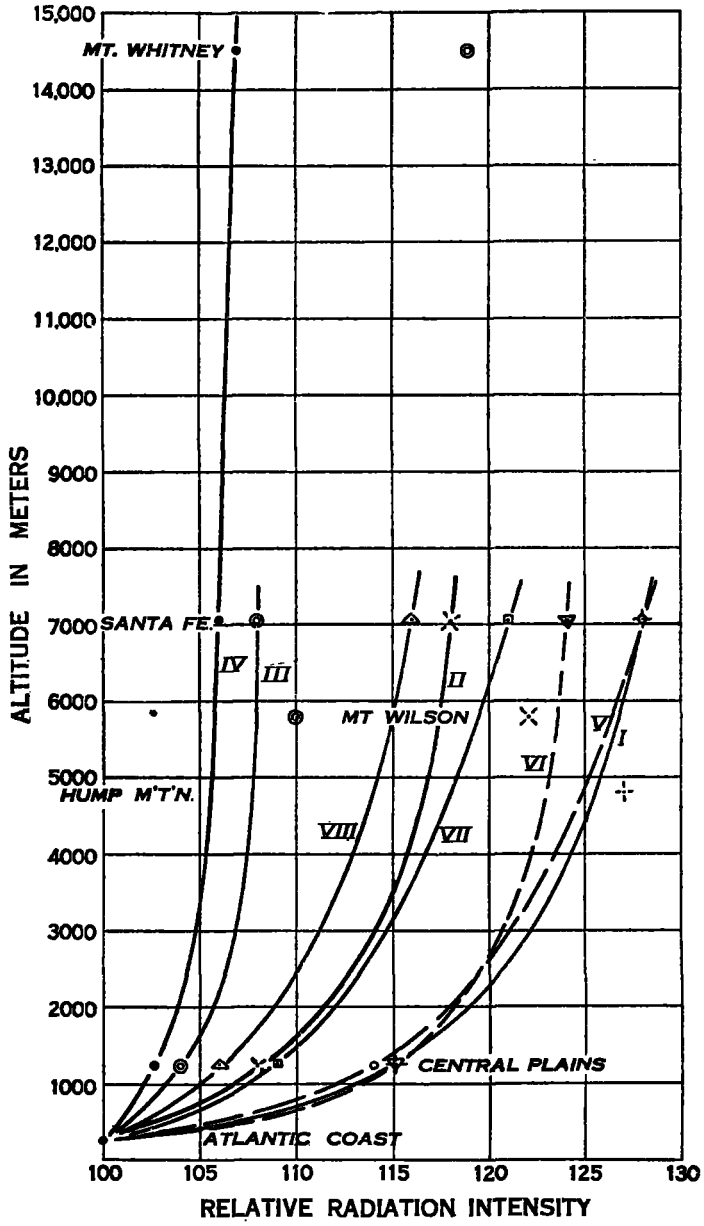


FIGURE 5.—Increase in solar radiation intensity with altitude, westward from the Atlantic Coast. Curve I (⊞), from monthly mean intensities with the sun at zenith distance 60°. Curve II (⊠), from monthly mean noon intensities. Curve III (◎), from maximum noon intensities. Curve IV (●), from absolute maximum intensities, reduced to zenithal sun and mean solar distance of the earth. Curve V (⊙), from daily totals of radiation, Oct. to Jan., incl., at Lat. 36°N. Curve VI (▽), from daily totals of radiation, Oct. to Mar., incl., at Lat. 42°N. Curve VII (⊡), from daily totals of radiation, Feb. to Sept., incl., at Lat. 36°N. Curve VIII (△), from daily totals of radiation, Apr. to Sept., incl., at Lat. 42°N.

dates when observed, are as follows: Washington, D. C., 1.65, Dec. 26, 1914; Lincoln, Nebr., 1.71, Feb. 1, 1917; Santa Fe, N. Mex., 1.75, Feb. 1, 1917; Mount Wilson, Calif., 1.70, Aug. 13, 1909; Mount Whitney, Calif., 1.77, Aug. 17, 1910. These values differ slightly from those employed by Abbot.

[17] Observations on the increase in isolation with elevation. Bull. Mt. Weather Obs. 6: 107–110.

[18] New evidences of the intensity of solar radiation outside the atmosphere. Smithsonian Misc. Col., vol. 65, No. 4, p. 53–54.

The noon radiation intensities measured at Cheyenne average 14 per cent higher than the corresponding intensities for the northeastern part of the United States at latitude 42° N., and 8 per cent higher than the corresponding intensities for the Plains States. This is slightly less increase than is shown at latitude 36°, but is closely in accord with Curve VIII, figure 5. The mean intensities at Mount Weather under normal sky conditions with the sun at zenith distance 60° average only 8 per cent higher than the corresponding Washington intensities. This is less than curve I would lead us to expect. Evidently the curves of figure 5 include the effect of decreased humidity with increase in distance from the ocean, as well as altitude effect.

TOTAL RADIATION ON A HORIZONTAL SURFACE.

The vertical component of the total radiation (direct solar plus diffuse radiation from the sky) at any hour of the day with a clear sky may be computed by the equation

$$Q_H = \frac{Q_m \sin a}{r}$$

in which Q_m is the radiation intensity at normal incidence, for different hour angles of the sun, given in Table 5; a is the corresponding altitude of the sun given in Table 1; and r is the ratio of the vertical component of direct solar radiation to the total (direct plus diffuse) radiation. The ratio r has been obtained from a great number of measurements made at Washington, Madison, and Lincoln,[19] and the results are summarized in Table 8. The ratios for Washington are also shown graphically in figure 12. At Madison but few measurements were made with the zenith distance of the sun in excess of 60°. The ratios for low sun at that station should therefore be given little weight.

TABLE 8.—*Ratio of the vertical component of direct solar radiation to the total radiation received on a horizontal surface.*

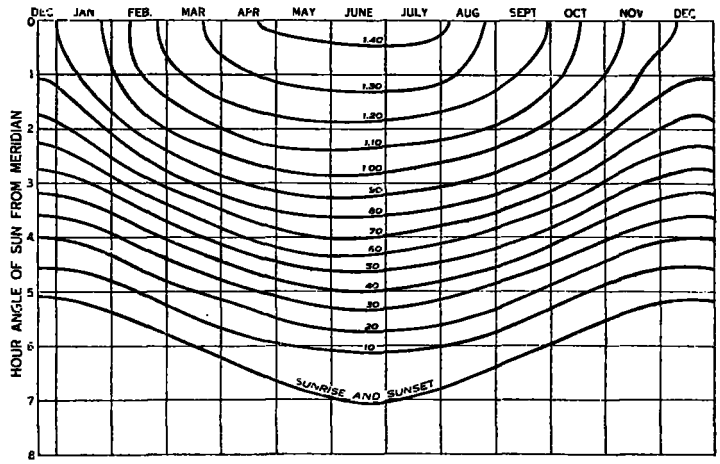
	Sun's zenith distance.									
	30°.0	48°.3	60°.0	66°.5	70°.7	73°.6	75°.7	77°.4	78°.7	79°.8
Ratios for Washington	0.84	0.83	0.815	0.79	0.76	0.73	0.71	0.69	0.68	0.67
Ratios for Lincoln....	0.85	0.84	0.81	0.79	0.76	0.73	0.70	0.67	0.65	0.63
Ratios for Madison...	0.84	0.84	0.76	0.75	0.74	0.66	0.64	.....	.....	.....

On account of the clearer skies at Lincoln we would expect the ratio r to be larger there than at Washington,[20] as it is, until the sun is 60° distant from the zenith. That the reverse is true with low sun may be due to inaccuracies in the records from the Callendar pyrheliometers. However, the ratios determined at Washington have been used in computing the total radiation on a horizontal surface for the Eastern States, and those determined at Lincoln in computations for the Plains States and the Plateau, and the results are given in Tables 9a, 9b, and 9c, and figures 6, 7, and 8. It is to be noted that a considerable error in the value of r, for zenith distances of the sun greater than 60°, will introduce comparatively small errors in the computed total radiation received on a horizontal surface during a half-day period.

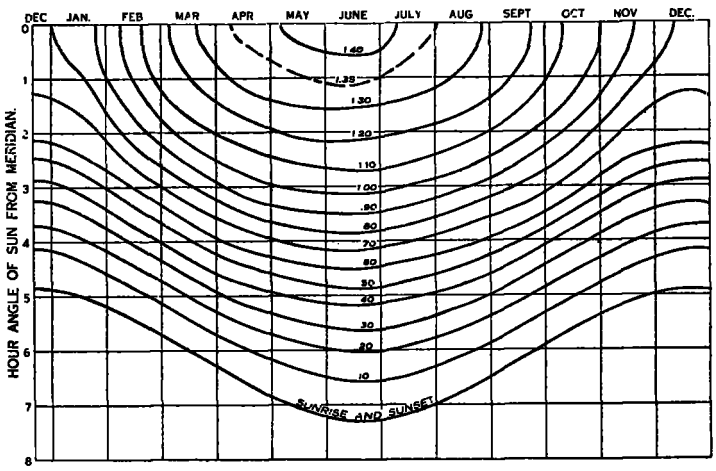
[19] For a description of the manner in which these measurements were obtained, see the MONTHLY WEATHER REVIEW, August, 1914, 42: 477–479. See also "A new instrument for measuring sky radiation," by Anders Ångström. This Review, pp. 795–797.

[20] See also "Some problems relating to the scattered radiation from the sky," by Anders Ångström. This Review, pp. 797–798.

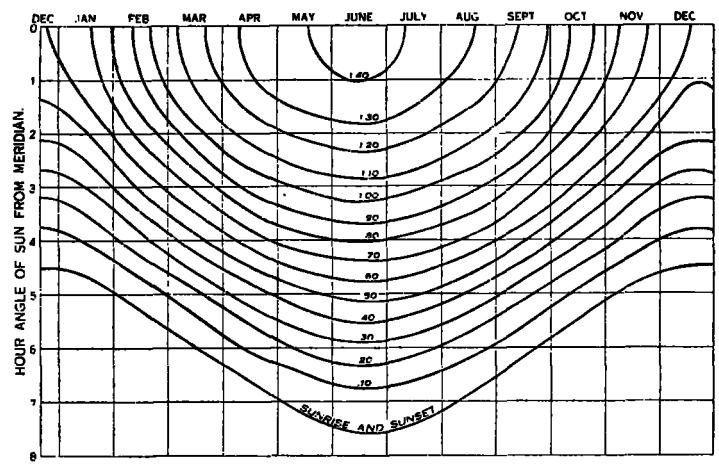
This latter is obtained by plotting the radiation intensities of Table 9 against the hour angle of the sun, and graphically integrating the area under the curve. Multiplied by 2 the results give the daily totals of the above tables.



(a), Latitude 30°N. (Gulf Coast).



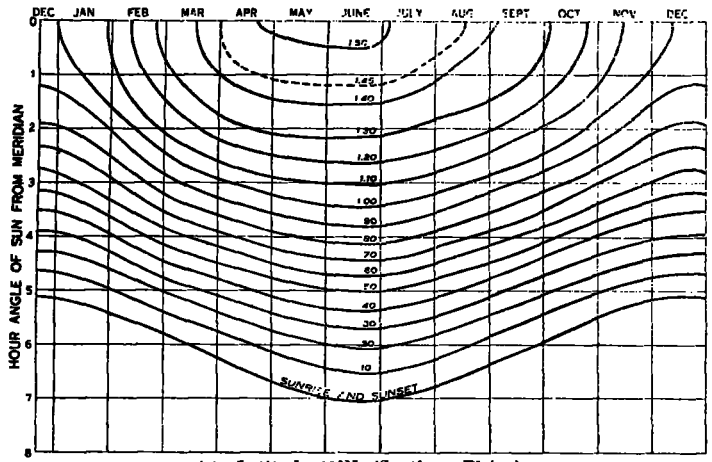
(b), Latitude 36°N. (Eastern States).



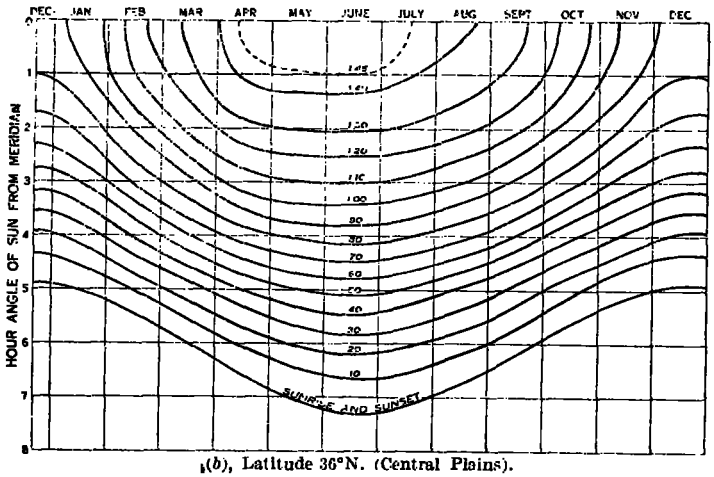
(c). Latitude 42°N. (Northeastern States).

FIGURE 6.—Total radiation intensity on a horizontal surface with a cloudless sky. (Gram calories per minute per square centimeter.)

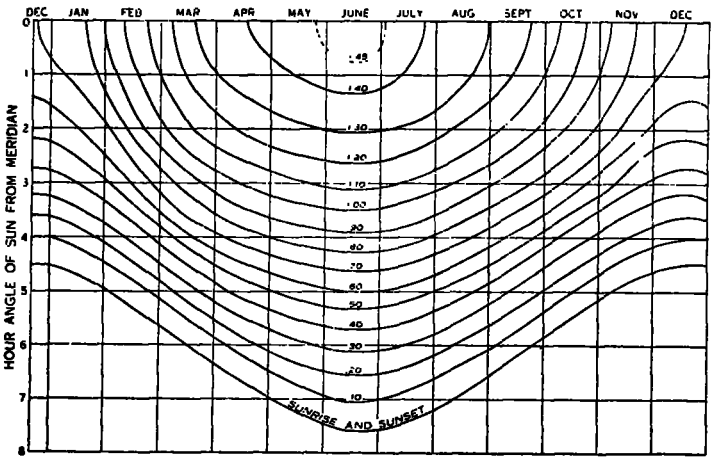
It is worthy of note that in Tables 9a and 9b the ratio of the daily total of radiation on June 21 to the daily total on Dec. 21, for latitude 30° N., is 2.09; while with an atmospheric transmission coefficient of 1.0, and



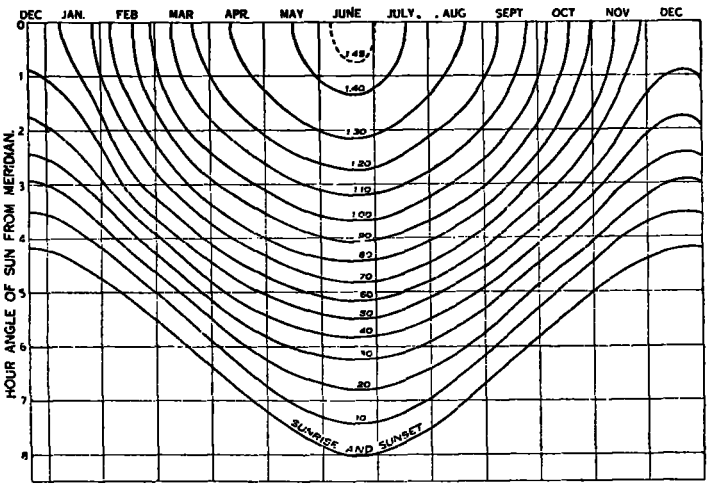
(a), Latitude 30°N. (Southern Plains).



(b), Latitude 36°N. (Central Plains).

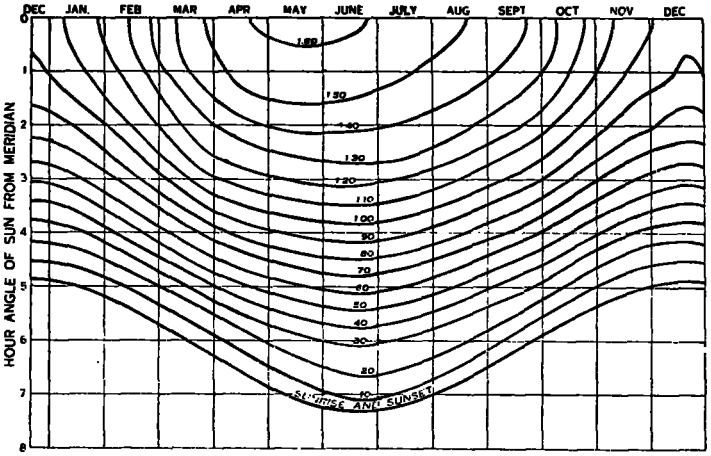


(c), Latitude 42°N (Central Plains).

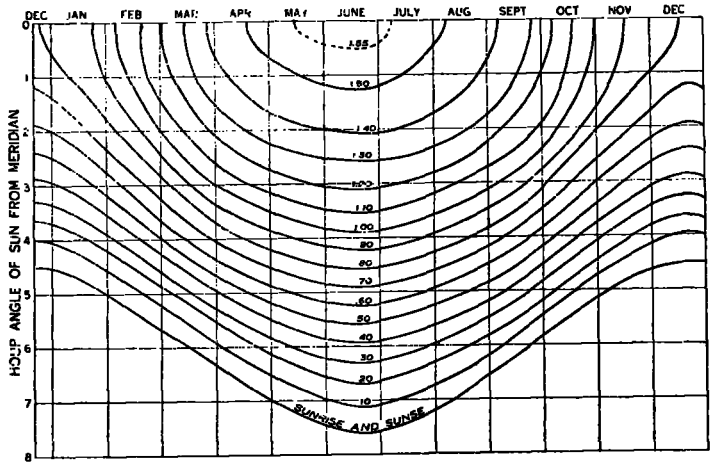


(d), Latitude 48°N. (Northern Plains.)

FIGURE 7.—Total radiation intensity on a horizontal surface with a cloudless sky. (Gram calories per minute per square centimeter.)



(a), Latitude 36°N. (Central Plateau).



(b), Latitude 42°N. (Central Plateau).

FIGURE 8.—Total radiation intensity on a horizontal surface with a cloudless sky. (Gram calories per minute per square centimeter.)

neglecting the diffuse radiation from the sky, Angot's [21] computations give 2.09 for the ratio of the maximum to the minimum heat received in a day at latitude 30° N., and 2.07 for the ratio of the total heat received in June to that received in December. At latitude 48° N., Table 9b gives for the daily totals on June 21 and December 21 the ratio 5.1, while Angot's computations as above give 4.8 for the ratio of the maximum to the minimum daily amounts and 4.7 for the ratio of the June to the December monthly totals. The ratios for Angot's computations increase rapidly with decreasing atmospheric transmission. Indeed, assuming the transmission in December to be 0.8 and in June 0.7, at latitude 30° N. the ratio for the maximum to the minimum daily radiation, and also for the June to the December monthly radiation, becomes 2.1, while at latitude 48° the corresponding ratios become 7.5 and 6.5, respectively. The fact that under these circumstances Angot's computations show a less relative radiation intensity in winter than in summer, and less at high latitudes than at low latitudes, than is shown by Table 9, is to be attributed to the increase in the ratio of diffuse radiation to direct solar radiation with decrease in the sun's altitude, as shown by Table 8. This is also shown by the computations of Schmidt [22].

[21] Angot, Alfred. Recherches théoretiques sur la distribution de la chaleur a la surface du globe. Annales du Bureau Central Météorologique de France, Année 1883, B121-169.

[22] Schmidt, Wilhelm. Strahlung und Verdunstung an freien Wasserflächen usw. Annalen der Hydrographie und Maritimen Meteorologie, März. 1915, S 121.

By drawing a smooth curve through the plotted daily totals of radiation for the different latitudes in the Eastern and in the Plains States the daily totals for the latitudes of Washington and of Lincoln, respectively, have been obtained, and are given in Table 10, in the column headed "Computed." The computed daily totals for Madison were obtained directly from the vertical component of the monthly means of direct solar radiation and the ratios of Table 8. These computed daily totals may be compared with the daily maxima and the daily normals of total radiation, given in Table 10. The daily normals have been obtained from the data published in the REVIEW in "Solar and Sky Radiation Measurements," Table 3, July, 1918, to June, 1919, inclusive. The observed daily maxima for Madison are somewhat low as compared with the computed daily totals, partly, no doubt, because in reducing the Callendar records at that station the selective absorption of the bright (platinum) grids has not been taken into account, as it has been at Washington,[23] and Lincoln, [24] and also in the computed daily totals. In order that they may be comparable with the remaining data of the table the Madison observed daily maxima and daily normals should be increased by about 2 per cent and 1 per cent, respectively. The selective absorption of the bright grids has been taken into account in computing the ratios of Table 8 for Madison.

TABLE 9a.—*Total radiation on a horizontal surface with a cloudless sky.*

(Gram calories per minute per square centimeter of surface.

LATITUDE 30° N. (GULF COAST.)

Date.	Hour angle of sun from the meridian.								Daily. Total.
	0	1	2	3	4	5	6	7	
	cal.	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal. per cm².*
Dec. 21	0.87	0.81	0.66	0.44	0.20	0.01	.....	.....	307
Jan. 21	0.96	0.92	0.77	0.51	0.24	0.03	.....	.....	352
Feb. 21	1.18	1.13	0.96	0.70	0.38	0.12	.....	.....	465
Mar. 21	1.30	1.24	1.07	0.83	0.49	0.20	0.01	.....	539
Apr. 21	1.35	1.31	1.15	0.93	0.63	0.30	0.07	.....	605
May 21	1.37	1.32	1.17	0.94	0.66	0.36	0.10	.....	625
June 21	1.37	1.32	1.18	0.97	0.70	0.39	0.13	.....	643
July 21	1.39	1.35	1.19	0.98	0.68	0.38	0.12	.....	644
Aug. 21	1.31	1.26	1.11	0.88	0.58	0.29	0.07	.....	579
Sept. 21	1.24	1.18	1.03	0.79	0.49	0.18	0.01	.....	516
Oct. 21	1.08	1.04	0.89	0.63	0.35	0.10	.....	.....	425
Nov. 21	0.96	0.89	0.74	0.51	0.24	0.03	.....	.....	345

LATITUDE 36° N. (EASTERN U. S.)

Dec. 21	0.77	0.71	0.67	0.36	0.13	.....	.....	.....	260
Jan. 21	0.86	0.80	0.66	0.43	0.20	.....	.....	.....	307
Feb. 21	1.10	1.07	0.90	0.65	0.35	0.07	.....	.....	431
Mar. 21	1.30	1.22	1.08	0.82	0.51	0.21	0.01	.....	540
Apr. 21	1.39	1.35	1.18	0.97	0.66	0.35	0.10	.....	637
May 21	1.40	1.36	1.20	1.00	0.72	0.43	0.18	0.01	672
June 21	1.43	1.38	1.24	1.04	0.75	0.46	0.20	0.02	694
July 21	1.43	1.37	1.23	1.01	0.73	0.44	0.19	0.01	683
Aug. 21	1.32	1.26	1.12	0.89	0.61	0.33	0.10	.....	596
Sept. 21	1.22	1.18	1.03	0.79	0.49	0.20	0.01	.....	517
Oct. 21	1.04	1.00	0.83	0.60	0.32	0.07	.....	.....	401
Nov. 21	0.87	0.82	0.66	0.43	0.19	.....	.....	.....	309

LATITUDE 42° N. (NORTHEASTERN U. S.)

Dec. 21	0.59	0.54	0.43	0.24	0.05	.....	.....	.....	212
Jan. 21	0.71	0.66	0.52	0.33	0.12	.....	.....	.....	239
Feb. 21	1.00	0.95	0.79	0.56	0.31	0.05	.....	.....	379
Mar. 21	1.20	1.15	1.00	0.76	0.48	0.20	0.01	.....	505
Apr. 21	1.36	1.32	1.17	0.96	0.68	0.38	0.13	.....	640
May 21	1.43	1.38	1.24	1.02	0.78	0.49	0.24	0.02	709
June 21	1.45	1.40	1.28	1.07	0.81	0.54	0.27	0.06	744
July 21	1.43	1.38	1.24	1.04	0.79	0.49	0.26	0.02	715
Aug. 21	1.30	1.26	1.12	0.91	0.66	0.35	0.11	.....	610
Sept. 21	1.17	1.11	0.98	0.75	0.47	0.20	0.01	.....	494
Oct. 21	0.93	0.88	0.74	0.52	0.28	0.05	.....	.....	352
Nov. 21	0.71	0.67	0.53	0.33	0.12	.....	.....	.....	241

[23] See the MONTHLY WEATHER REVIEW for August, 1914, 42: 476-80. Jan. 1916, 44: 4.
[24] See the MONTHLY WEATHER REVIEW for April, 1916, 44: 179.

TABLE 9b.—*Total radiation on a horizontal surface with a cloudless sky.*

(Gram-calories per minute per square centimeter of surface.)

LATITUDE 30° N. (SOUTHERN PLAINS.)

Date.	Hour angle of sun from the meridian.								Daily Total.
	0	1	2	3	4	5	6	7	
	cal.	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal. per cm².*
Dec. 21	0.97	0.93	0.78	0.54	0.28	0.01	.....	.....	363
Jan. 21	1.07	1.02	0.87	0.64	0.33	0.04	.....	.....	410
Feb. 21	1.28	1.23	1.06	0.81	0.50	0.16	.....	.....	527
Mar. 21	1.42	1.37	1.20	0.96	0.63	0.28	0.01	.....	619
Apr. 21	1.50	1.45	1.30	1.05	0.74	0.39	0.10	.....	690
May 21	1.49	1.45	1.29	1.07	0.81	0.45	0.16	.....	718
June 21	1.52	1.48	1.34	1.11	0.84	0.51	0.21	.....	759
July 21	1.52	1.47	1.32	1.10	0.81	0.46	0.17	.....	731
Aug. 21	1.43	1.38	1.24	1.00	0.70	0.37	0.10	.....	657
Sept. 21	1.36	1.31	1.15	0.91	0.59	0.25	0.01	.....	588
Oct. 21	1.22	1.17	1.01	0.78	0.46	0.14	.....	.....	500
Nov. 21	1.07	1.02	0.87	0.63	0.33	0.04	.....	.....	408

LATITUDE 36° N. (CENTRAL PLAINS.)

Dec. 21	0.85	0.80	0.66	0.45	0.17	.....	.....	.....	300
Jan. 21	0.94	0.90	0.76	0.53	0.25	.....	.....	.....	353
Feb. 21	1.19	1.14	0.97	0.75	0.45	0.13	.....	.....	483
Mar. 21	1.35	1.29	1.15	0.91	0.61	0.28	0.01	.....	591
Apr. 21	1.49	1.43	1.29	1.07	0.77	0.42	0.13	.....	702
May 21	1.48	1.44	1.29	1.07	0.80	0.48	0.24	0.02	730
June 21	1.48	1.45	1.31	1.10	0.85	0.53	0.25	0.03	748
July 21	1.49	1.45	1.31	1.08	0.81	0.49	0.26	0.02	741
Aug. 21	1.41	1.35	1.22	0.99	0.72	0.38	0.13	.....	658
Sept. 21	1.30	1.25	1.10	0.86	0.56	0.23	0.01	.....	559
Oct. 21	1.13	1.08	0.93	0.70	0.41	0.10	.....	.....	452
Nov. 21	0.94	0.90	0.75	0.53	0.25	.....	.....	.....	352

LATITUDE 42° N. (CENTRAL PLAINS.)

Dec. 21	0.69	0.65	0.53	0.34	0.10	.....	.....	.....	236
Jan. 21	0.81	0.75	0.63	0.43	0.17	.....	.....	.....	286
Feb. 21	1.07	1.02	0.88	0.65	0.37	0.08	.....	.....	423
Mar. 21	1.31	1.25	1.12	0.89	0.61	0.29	0.01	.....	580
Apr. 21	1.41	1.37	1.23	1.02	0.77	0.45	0.18	.....	688
May 21	1.46	1.41	1.28	1.08	0.83	0.52	0.25	0.03	736
June 21	1.48	1.44	1.32	1.13	0.87	0.59	0.32	0.10	786
July 21	1.46	1.41	1.28	1.10	0.83	0.53	0.25	0.04	740
Aug. 21	1.34	1.30	1.17	0.96	0.71	0.41	0.15	.....	646
Sept. 21	1.22	1.17	1.03	0.81	0.53	0.24	0.01	.....	529
Oct. 21	1.01	0.96	0.84	0.62	0.34	0.08	.....	.....	400
Nov. 21	0.80	0.75	0.63	0.42	0.17	.....	.....	.....	284

LATITUDE 48° N. (NORTHERN PLAINS.)

Dec. 21	0.52	0.49	0.37	0.19	0.02	.....	.....	.....	160
Jan. 21	0.65	0.60	0.47	0.30	0.08	.....	.....	.....	212
Feb. 21	0.92	0.87	0.75	0.57	0.30	0.04	.....	.....	359
Mar. 21	1.20	1.14	1.01	0.81	0.55	0.25	0.01	.....	527
Apr. 21	1.34	1.29	1.18	0.99	0.75	0.47	0.22	.....	670
May 21	1.41	1.38	1.26	1.08	0.84	0.58	0.31	0.08	749
June 21	1.48	1.44	1.33	1.15	0.92	0.65	0.35	0.16	809
July 21	1.44	1.41	1.29	1.10	0.86	0.58	0.32	0.08	762
Aug. 21	1.31	1.27	1.15	0.97	0.71	0.44	0.20	.....	649
Sept. 21	1.13	1.08	0.96	0.75	0.50	0.22	0.01	.....	493
Oct. 21	0.88	0.83	0.71	0.53	0.29	0.03	.....	.....	340
Nov. 21	0.63	0.59	0.48	0.29	0.08	.....	.....	.....	210

TABLE 9c.—*Total radiation on a horizontal surface with a cloudless sky.*

(Gram-calories per minute per square centimeter of surface.)

LATITUDE 36° N. (CENTRAL PLATEAU.)

Date.	Hour angle of sun from the meridian.								Daily Total.
	0	1	2	3	4	5	6	7	
	cal.	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal.*	*cal. per cm².*
Dec. 21	0.94	0.88	0.75	0.52	0.23	.....	.....	.....	340
Jan. 21	1.04	1.00	0.84	0.61	0.30	.....	.....	.....	397
Feb. 21	1.25	1.19	1.05	0.80	0.49	0.15	.....	.....	516
Mar. 21	1.48	1.42	1.27	1.02	0.70	0.34	0.01	.....	666
Apr. 21	1.60	1.56	1.39	1.15	0.84	0.50	0.15	.....	766
May 21	1.71	1.65	1.49	1.26	0.94	0.62	0.32	0.02	858
June 21	1.61	1.56	1.43	1.24	0.95	0.63	0.32	0.14	843
July 21	1.60	1.55	1.41	1.18	0.89	0.58	0.26	0.02	800
Aug. 21	1.50	1.44	1.31	1.08	0.79	0.46	0.15	.....	717
Sept. 21	1.42	1.36	1.21	0.96	0.65	0.32	0.01	.....	626
Oct. 21	1.22	1.18	1.01	0.77	0.46	0.13	.....	.....	498
Nov. 21	1.04	0.98	0.84	0.61	0.30	.....	.....	.....	393

LATITUDE 42° N. (CENTRAL PLATEAU.)

Dec. 21	0.79	0.72	0.58	0.37	0.10	.....	.....	.....	261
Jan. 21	0.87	0.83	0.70	0.47	0.20	.....	.....	.....	315
Feb. 21	1.10	1.06	0.91	0.69	0.41	0.08	.....	.....	443
Mar. 21	1.35	1.31	1.16	0.94	0.66	0.32	0.01	.....	610
Apr. 21	1.52	1.46	1.32	1.11	0.82	0.50	0.20	.....	739
May 21	1.64	1.59	1.44	1.24	0.94	0.65	0.35	0.04	848
June 21	1.58	1.52	1.41	1.22	0.97	0.67	0.37	0.13	854
July 21	1.54	1.49	1.36	1.15	0.89	0.61	0.31	0.04	769
Aug. 21	1.48	1.43	1.30	1.08	0.80	0.50	0.19	.....	727
Sept. 21	1.34	1.28	1.13	0.91	0.63	0.33	0.01	.....	596
Oct. 21	1.08	1.02	0.89	0.67	0.40	0.08	.....	.....	431
Nov. 21	0.87	0.83	0.70	0.47	0.19	.....	.....	.....	314

TABLE 10.—*Daily totals of solar and sky radiation on a horizontal surface.*

[Gram-calories per square centimeter.]

WASHINGTON, D. C.

Dates.	Computed.	Observed. Maximum.	Observed. Normal.	Ratio. Normal. / Computed.	Monthly means. Cloudiness 0-10.	Monthly means. Percentage of possible sunshine.
	cal.	*cal.*	*cal.*			
Dec. 21	237	297	157	0.662	6.5	47.3
Jan. 21	275	346	183	0.665	6.2	50.8
Feb. 21	408	464	269	0.659	5.4	56.7
Mar. 21	528	642	349	0.661	5.0	65.3
Apr. 21	641	714	429	0.669	5.4	58.9
May 21	690	734	494	0.716	5.7	60.3
June 21	718	748	524	0.730	5.3	65.4
July 21	699	667	494	0.707	5.7	59.9
Aug. 21	603	660	431	0.715	4.9	67.5
Sept. 21	508	556	370	0.728	4.6	68.5
Oct. 21	380	454	281	0.740	4.5	62.6
Nov. 21	283	354	198	0.700	4.6	65.5
Means				0.696	5.3	60.8

MADISON, WIS.

Dec. 21	227	223	130	0.573	6.5	39.2
Jan. 21	270	306	183	0.678	6.5	45.6
Feb. 21	418	424	263	0.629	6.1	53.5
Mar. 21	573	572	356	0.621	6.4	57.1
Apr. 21	673	713	423	0.629	6.5	54.0
May 21	720	758	470	0.653	6.5	57.9
June 21	766	770	535	0.698	6.0	62.9
July 21	710	788	509	0.717	5.3	69.6
Aug. 21	591	648	425	0.719	5.4	61.6
Sept. 21	491	524	322	0.656	5.6	55.8
Oct. 21	343	358	223	0.650	5.9	48.9
Nov. 21	255	258	143	0.561	6.4	41.0
Means				0.649	6.1	52.0

LINCOLN, NEBR.

Dec. 21	250	269	173	0.692	5.8	47.0
Jan. 21	299	328	232	0.776	5.1	65.0
Feb. 21	435	473	316	0.726	5.3	63.0
Mar. 21	582	602	412	0.708	5.2	64.0
Apr. 21	691	724	423	0.612	6.7	47.0
May 21	734	738	517	0.704	5.7	59.0
June 21	780	804	595	0.763	4.1	70.0
July 21	740	765	558	0.754	4.0	75.0
Aug. 21	647	650	472	0.730	4.5	66.0
Sept. 21	535	574	397	0.742	4.6	60.0
Oct. 21	411	428	294	0.715	4.7	58.0
Nov. 21	298	328	209	0.701	4.6	60.0
Means				0.719	5.1	60.0

TABLE 11.—*Relation between cloudiness and radiation—Percentage of clear sky radiation.*

OCTOBER TO MARCH.

Station.	Cloudiness. 0	1	2	3	4	5	6	7	8	9	10
Washington	100	99.0	94.3	88.5	83.3	78.5	70.9	66.0	55.3	47.3	23.2
Madison	100	100.2	98.7	94.3	91.0	85.4	82.9	74.8	66.4	59.9	33.0
Lincoln	100	100.5	97.5	92.3	87.4	82.4	78.9	70.7	61.4	53.2	29.6
Mean	100	99.9	96.8	91.7	87.2	82.1	77.6	70.5	61.0	53.5	28.9

APRIL TO SEPTEMBER.

Washington	100	99.5	96.0	89.5	84.6	80.0	73.8	66.7	56.9	47.2	26.7
Madison	100	97.1	96.9	91.6	89.4	83.6	78.6	72.4	61.3	53.6	33.7
Lincoln	100	99.0	95.9	91.5	86.8	79.1	75.2	64.9	58.3	45.1	27.8
Mean	100	98.5	96.3	90.9	86.9	80.9	75.9	68.0	58.8	48.6	29.4

YEAR.

Washington	100	99	95	89	84	79	72	66	56	47	25
Madison	100	99	98	93	90	84	81	74	64	57	33
Lincoln	100	100	97	92	87	81	77	68	60	50	29
Mean	100	99	97	91	87	81	77	69	60	51	29

TABLE 12.—*Relation between percentage of possible sunshine and radiation—Percentage of clear sky radiation.*

OCTOBER TO MARCH.

Station.	Percentage of possible sunshine. 100	94.5	84.5	74.5	64.5	54.5	44.5	34.5	24.5	14.5	5.0	0
Washington	100	94.5	90.5	85.5	76.0	68.5	60.0	59.0	53.5	43.0	33.0	21.0
Madison	100	97.0	93.0	89.0	83.0	77.0	75.0	59.0	61.0	55.0	44.0	26.0
Lincoln	100	97.0	96.0	89.0	83.0	75.5	73.5	68.0	60.0	51.0	40.0	24.0
Mean	100	96.0	93.0	88.0	81.0	74.0	70.0	62.0	58.0	50.0	39.0	24.0

APRIL TO SEPTEMBER.

Washington	100	96	90	95	76	68.5	65	60	46	40	31	19
Madison	100	97	93	86.5	78	70	63	57	49	39.5	31	21
Lincoln	100	96	92	86	79	72	65	59	52	42	29	20
Mean	100	96	92	86	78	70	64	57	49	40	30	20

YEAR.

Washington	100	95	90	85	76	68.5	62	59	50	41.5	32	20
Madison	100	97	93	88	80	74	69	58	55	47	38	23
Lincoln	100	96	94	87	81	74	69	63	56	46	35	22
Mean	100	96	92	87	79	72	67	60	54	45	35	22

RELATION BETWEEN CLOUDINESS, DURATION OF SUNSHINE, AND RADIATION INTENSITY.

From the Callendar records the average daily amount of radiation for each decade, except that for June and December the averages are for the entire month, has been determined for days on which the cloudiness was recorded as 0, 1, 2, 3, etc., to 10, respectively, and also on days for which the percentage of possible sunshine as recorded by the Marvin sunshine recorder was 100, 99–90, 89–80, etc., to 9–1, and 0, respectively. From these decade and monthly averages the seasonal and annual averages of Tables 11 and 12, which are expressed as a "Percentage of clear-sky radiation," have been derived. The seasonal differences are not important. The annual

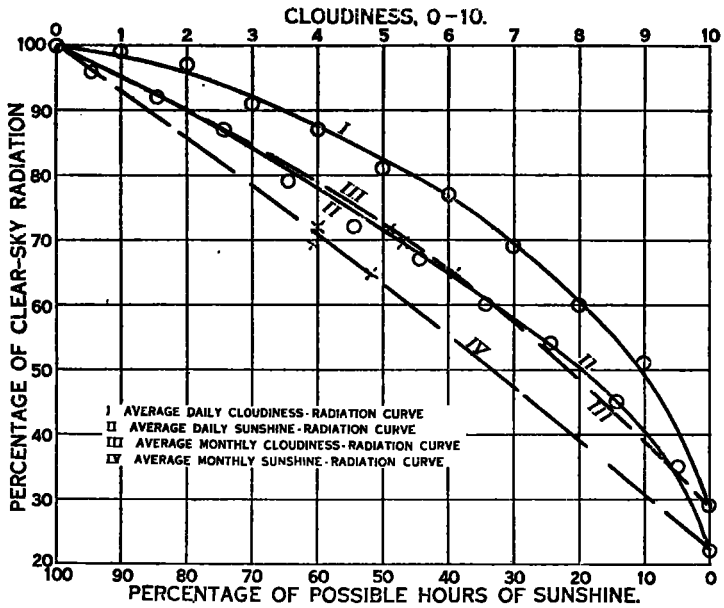


FIGURE 9.—Relation between radiation intensity and average daily and monthly cloudiness and percentage of possible sunshine, expressed as a percentage of the average intensity with a cloudless sky.

averages are shown graphically in figure 9. From this latter it is seen that with the daily cloudiness recorded 10 the radiation averages about 29 per cent of clear-sky radiation. This is a little greater than for zero percent-

age of possible sunshine, namely, 22 per cent, for the reason that the sun may sometimes shine with the sky more than 95 per cent covered with clouds. Also, 50 per cent clear-sky radiation intensity corresponds to an average cloudiness of 9, and to a percentage of possible sunshine of 20; and 50 per cent possible sunshine corresponds to 71 per cent, and 5 cloudiness to 82 per cent, of clear-sky radiation intensity. In general, the percentage of possible hours of sunshine is greater than the cloudiness would lead us to expect, the maximum difference occurring when the sky is rather more than half covered with clouds. This is no doubt partly due (1) to the fact that much recorded cloudiness is of thin clouds and (2) to the fact that the record of cloudiness is based upon the proportion of the sky that *appears* to be covered with clouds. When detached cumulus clouds or broken cloud sheets, especially of strato-cumulus, are viewed nearly edgewise near the horizon, they *appear* to cover a greater percentage of the sky than they really do; and while with the sun near the horizon, when the direct radiation is only about half the total, the sun may be shaded a considerable portion of the time, with the sun near the zenith, when direct solar radiation is more than 0.8 of the total, the sun will be but little shaded.

If we plot on figure 9 the radiation ratios $\frac{\text{normal}}{\text{computed}}$ of Table 10 as ordinates against the monthly or annual cloudiness or the precentage of possible sunshine of the same table as abscissas, it will be seen that they fall at points considerably below the corresponding radiation-cloudiness and radiation-sunshine curves, as we would expect. In fact, the radiation-ratio and sunshine data plot very nearly on the straight line connecting 100-per-cent-sunshine and 0-per-cent-sunshine radiation intensities. We may therefore use the broken-line curves through the points named to determine the percentage relation between clear-sky and actual radiation at points having a greater or less average monthly cloudiness or percentage of possible sunshine than Washington, Madison, or Lincoln.

AVERAGE DAILY TOTALS OF RADIATION.

Figure 10 has been constructed by plotting along the parallels 30° N., 36° N., 42° N., and 48° N., the daily totals of radiation given in table 9, reduced by factors derived from curves V–VIII, figure 5, to the intensities at the 1,000, 2,000, 3,000, and 5,000 foot levels, where necessary. During the cold part of the year the radiation increases rapidly from high to low latitudes, with a maximum increase of over 100 per cent from latitude 48° N. to latitude 30° N. in the Plains States. During the warm part of the year the increase is from the Atlantic coast westward to the Rocky Mountain plateau, with a maximum of 28 per cent at latitude 36° N. in May.

Figure 11, has been constructed by multiplying the plotted daily totals of figure 10 by the percentage of clear-sky radiation, as given by curve IV, figure 9, corresponding to the monthly average percentages of possible hours of sunshine at points where the parallels of 30° N., 36° N., 42., and 48° N. cross the sea level, and the 1,000, 2,000, 3,000, 5,000, and 7,000 foot contour lines. The monthly average percentages of possible hours of sunshine have been obtained from unpublished charts made up by the Climatological Division, Weather Bureau, in connection with the preparation of seasonal charts for the Atlas of American Agriculture. They are based on records by the Marvin sunshine recorder for the years 1905 to 1912, inclusive. In figure 11 the radiation increase from high to low latitude in winter, and from low to high altitude in summer, is even more marked than in figure 10. The increase from the Lakes at Lat. 42° N. to the Gulf at latitude 30° N. is 100 per cent in December and January; and in December, from latitude 48° N. to latitude 30° N. in the Plains States the increase is nearly 200 per cent. In June the increase at latitude 36° N. from the Atlantic coast to the Rocky Mountain plateau s 50 per cent.

THE EFFECT OF SLOPE UPON THE QUANTITY OF SOLAR RADIATION RECEIVED PER UNIT OF SURFACE.

Let $\phi =$ the latitude of the place, and c the angle of slope. For a south slope the angle of incidence of the solar rays with the surface for different hour angles of the sun will be the same as on a horizontal surface at latitude $\phi - c$. The possible hours of sunshine with *south* or *minus* solar declination will not be changed; but for *north* or *plus* solar declination they will be the same as for latitude $\phi - c$. For a north slope the angle of incidence of the solar rays with the surface for different hour angles of the sun will be the same as at latitude $\phi + c$. The possible hours of sunshine with *north* or *plus* solar declination will not be changed; but for *south* or *minus* declination they will be the same as for latitude $\phi + c$.

Thus, on a south slope of 7 per cent, or 4°, at latitude 35°, the angle of incidence of the solar rays will be the same as on a horizontal surface at 31° N.; and on a south slope of 35°, or 70 per cent, at latitude 35°, the angle of incidence of the solar rays will be the same as on a horizontal surface at the Equator, and from March 21 to September 21, inclusive, the hours of possible sunshine per day will likewise be the same, namely, 12 hours. On a north slope of 45°, or 100 per cent, at latitude 45° N., the angle of incidence of the solar rays will be the same as on a horizontal surface at the north pole. It will receive sunshine only between March 21 and September 21, and the possible hours of sunshine will be the same as at latitude 45°. Such a surface will therefore receive less solar radiation than a horizontal surface at the north pole.

In the case of a slope facing α' degrees in azimuth the angle of incidence of the solar rays will be the same as on a horizontal surface at a point on a great circle passing through the slope at right angles to it and as many degrees removed as the angle of the slope. We may locate this point in latitude and longitude by the solution of the right-angled spherical triangle of which c, the angle of slope, is the hypotenuse, α' is one of the angles, the side b is the difference in longitude between the point and the slope, and side a is the difference in latitude. The computation equations are $\tan b = \frac{\cos \alpha'}{\cot c}$, and $\sin a = \sin \alpha' \sin c$.

Example: At Wagon Wheel Gap, Colo., at latitude 37° 46′ N., longitude 106° 53′ W., and elevation about 10,000 feet, are four slopes, A–2, B–2, A–1, and B–1, facing south 56° east, south 45° east, north 24° west, and north 24° east, and with angular slopes of 34° 20′, 30°, 31° 20′, and 37° 30′, respectively. The points where horizontal surfaces are parallel to those slopes are as follows:

A–2, latitude 16° 52′ north, longitude 79° west.
B–2, latitude 15° 34′ north, longitude 86° 11′ west.
A–1, latitude 66° 51′ north, longitude 119° 6′ west.
B–1, latitude 72° 48′ north, longitude 92° 33′ west.

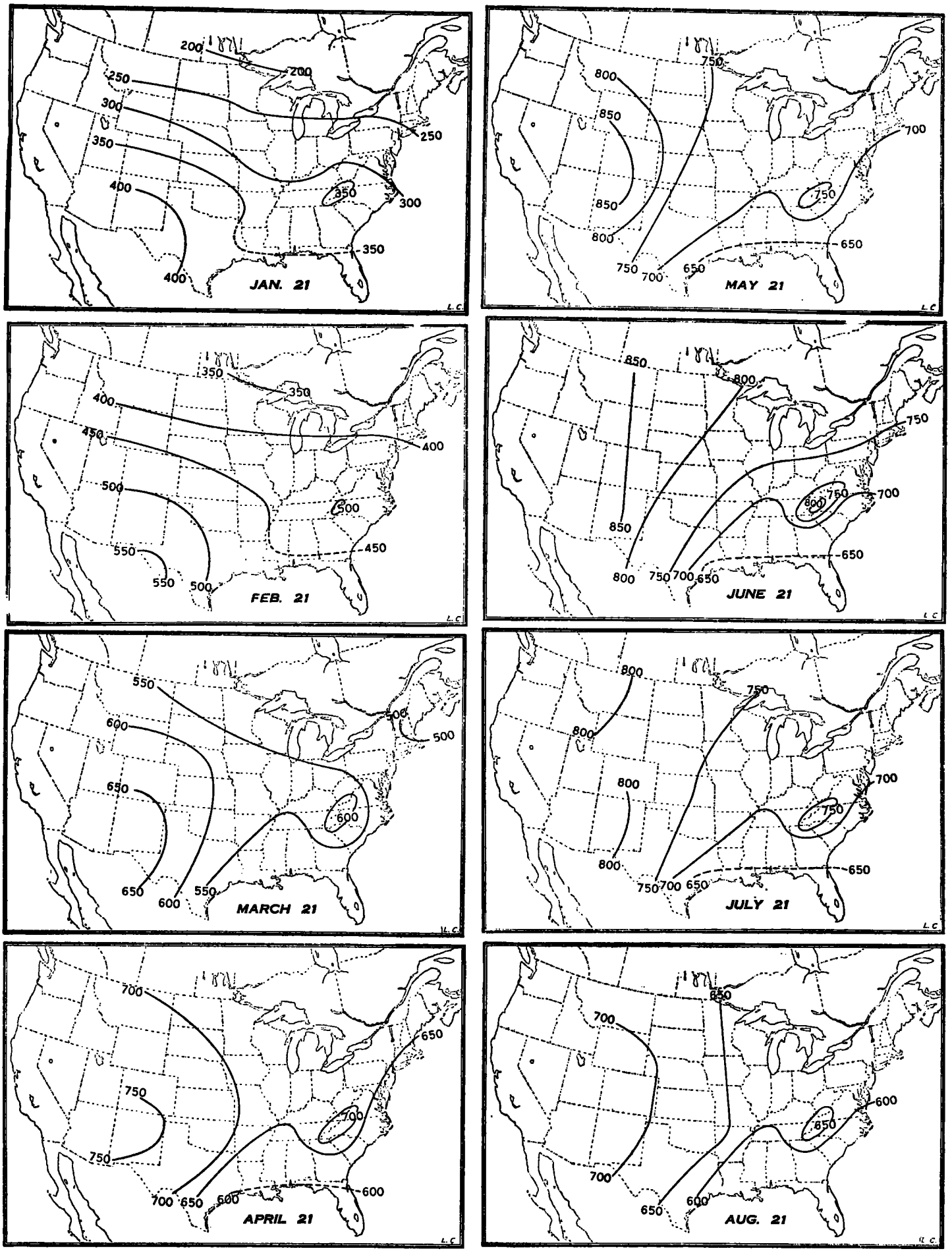


FIGURE 10.—Average daily totals of radiation received on a horizontal surface with a cloudless sky. (Gram calories ~~per minute~~ per square centimeter.)

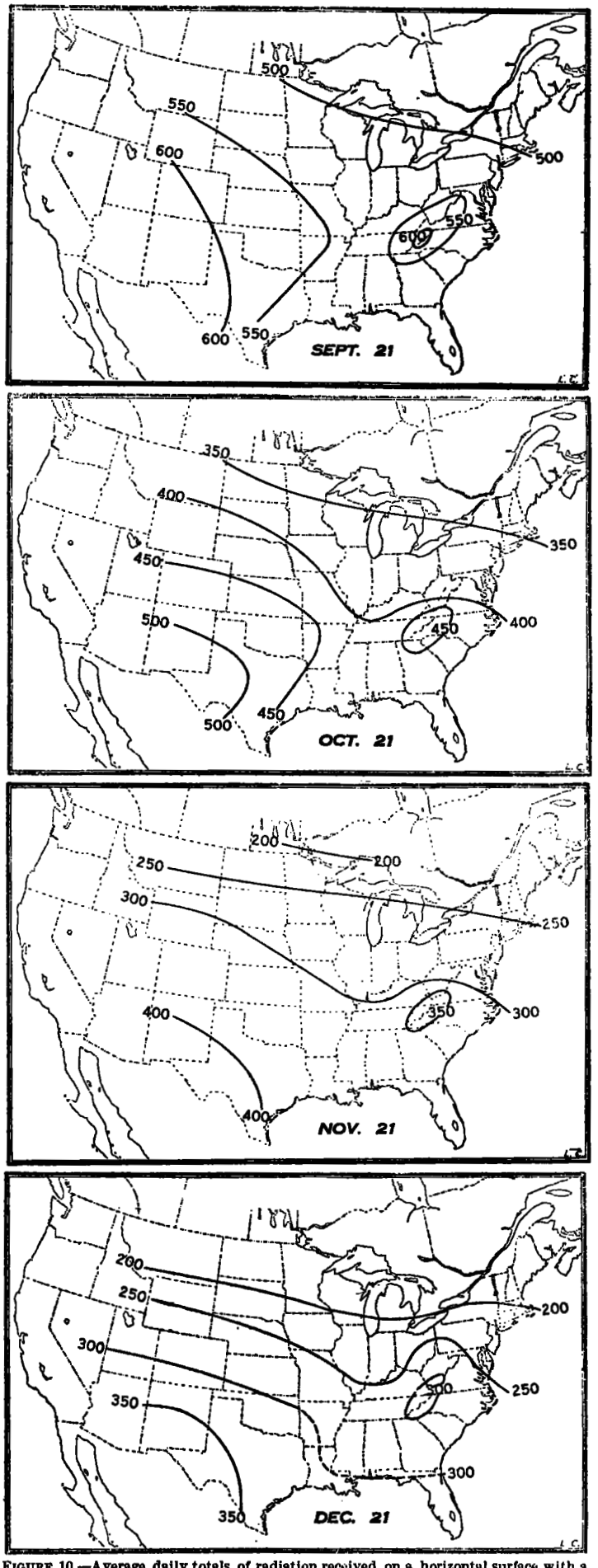


FIGURE 10.—Average daily totals of radiation received on a horizontal surface with a cloudless sky—Continued. (Gram calories per square centimeter.)

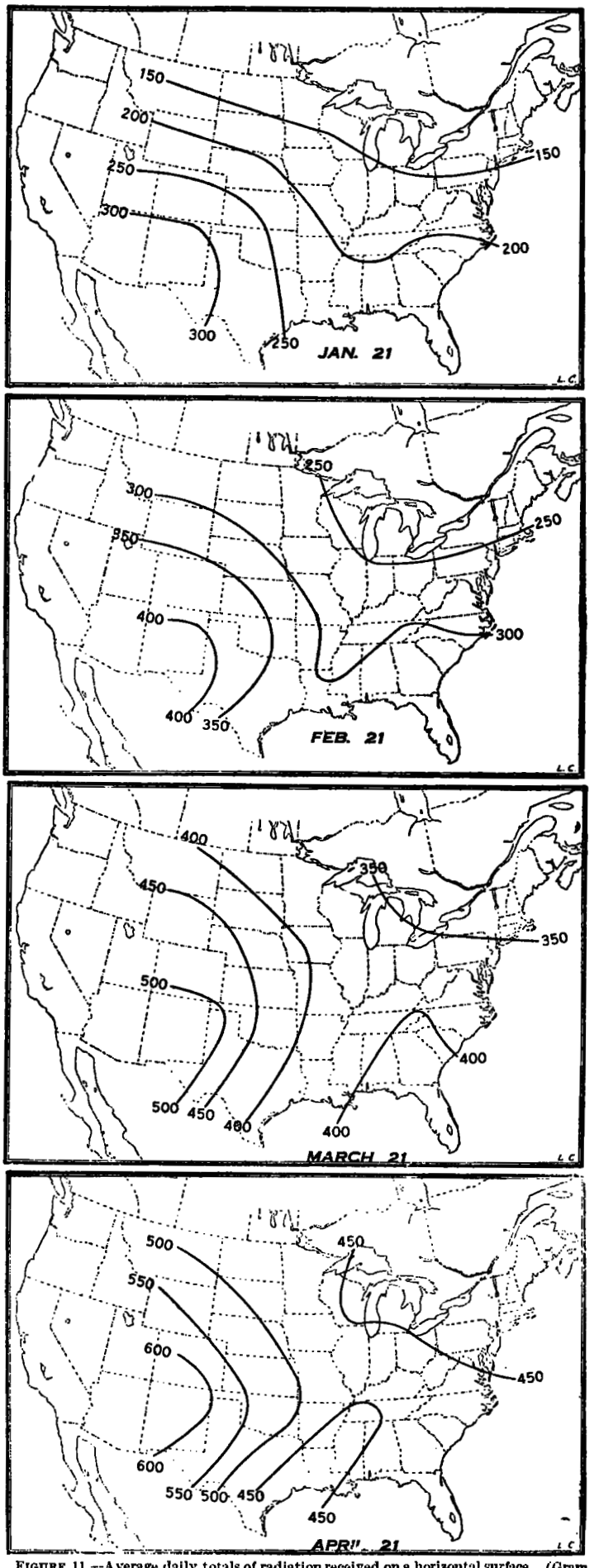


FIGURE 11.—Average daily totals of radiation received on a horizontal surface. (Gram calories per square centimeter.)

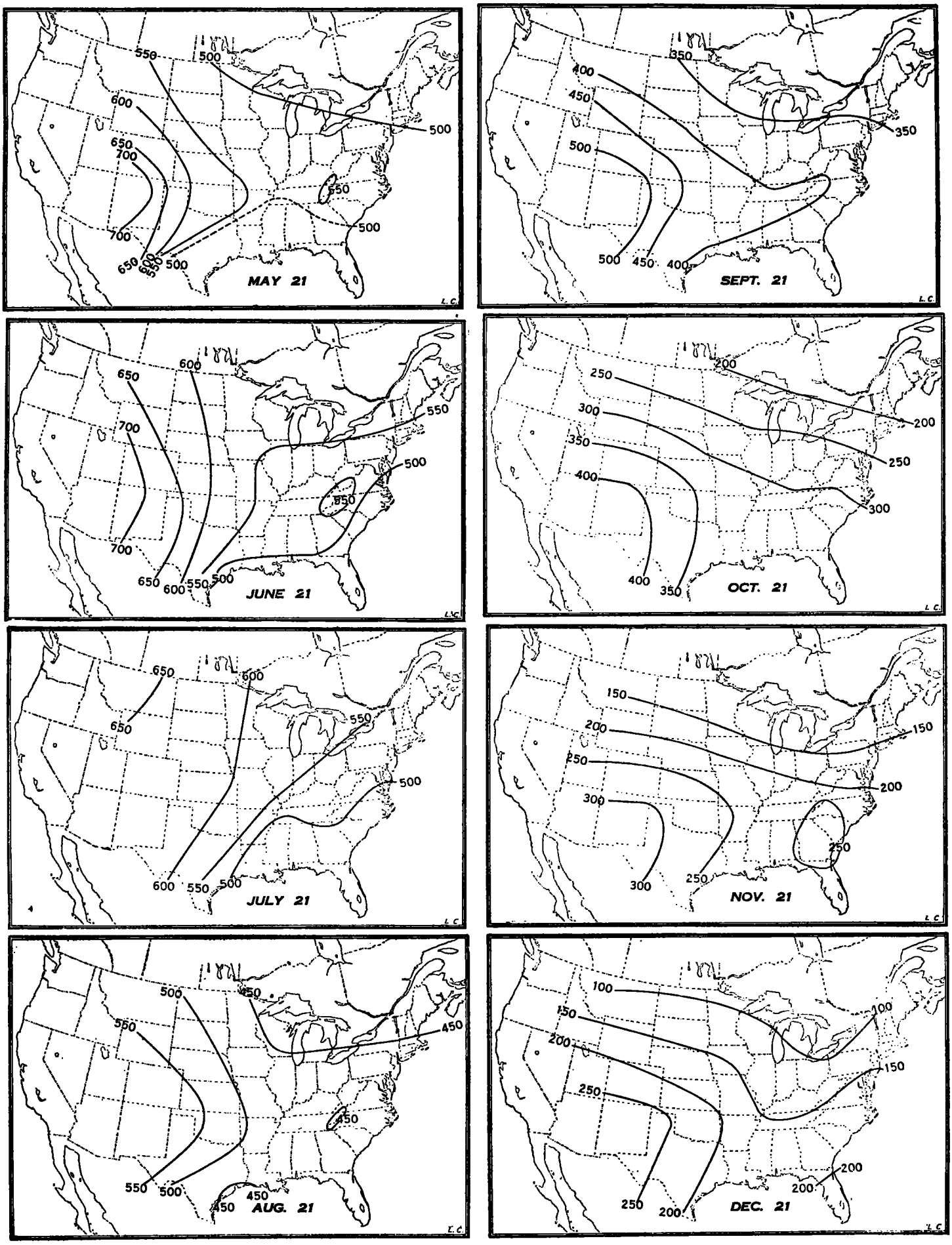


FIGURE 11.—Average daily totals of radiation received on a horizontal surface—Continued. (Gram calories per minute per square centimeter.)

The solar radiation intensities upon these slopes have been computed upon the assumption that at normal incidence the intensity is as given in Table 5c for latitude 37° 46′, increased by 1 per cent for the increased elevation at Wagon Wheel Gap. The results are given in Table 13.

On slopes A–2 and B–2, where the radiation intensity is high throughout the year, the snow that falls is evaporated many days earlier than on slopes A–1 and B–1, which receive no direct solar radiation in midwinter, and a greatly reduced amount throughout the year.

Table 13 indicates a shorter period of sunshine before noon than after noon on slope A–1, and a shorter period after noon than before noon on the other three slopes, except on slopes A–1 and B–1 from about the middle of May to the end of July.

line of equivalents. Since a high equivalent generally corresponds to a high radiation intensity, and vice versa, the range in illumination intensities will be considerably greater than the range of heat radiation intensities indicated by Table 6.

The equivalent values of Table 14 have been plotted as ordinates against the sun's altitude in degrees as abscissas. By means of the smoothed values thus obtained from the first line the "Solar radiation intensity at normal incidence" of Table 5a has been reduced to the "Solar illumination intensity at normal incidence" of Table 15a and figure 13. Similarly, by means of the smoothed values of the second line, the solar radiation intensities of Tables 5b and 5c have been reduced to the illumination intensities of Tables 15b and 15c, and figures 14 and 15. The maximum inten-

TABLE 13.—*Solar radiation intensity upon slopes at Wagon Wheel Gap, Colo. (Apparent time.)*

Slope.	Date.	A. M.								P. M.								Daily total.
		5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	
		Gr.-cal. per min. per square centimeter.																gr.-cal. per cm.²
A–2	Dec. 21				0.53	0.92	1.08	1.09	0.98	0.77	0.50	0.18						379
	Mar. 21		0.07	0.73	1.11	1.34	1.45	1.44	1.31	1.08	0.77	0.41						588
	June 21	0.12	0.51	0.84	1.12	1.29	1.40	1.39	1.27	1.28	1.07	0.80	0.17					643
B–2	Dec. 21				0.49	0.89	1.06	1.13	1.07	0.89	0.78	0.32	0.03					402
	Mar. 21		0.06	0.63	1.02	1.29	1.44	1.48	1.40	1.20	0.92	0.57	0.21					596
	June 21	0.08	0.41	0.74	1.03	1.25	1.38	1.41	1.34	1.17	0.93	0.64	0.32	0.01				641
A–1	Jan. 21							0.02	0.08	0.08	0.01							11
	Feb. 21					0.06	0.15	0.26	0.32	0.33	0.29	0.22	0.11	0.01				105
	Mar. 21			0.03	0.17	0.32	0.45	0.55	0.60	0.61	0.57	0.49	0.36	0.20	0.01			259
	June 21	0.03	0.28	0.45	0.65	0.82	0.96	1.06	1.11	1.12	1.07	0.93	0.87	0.63	0.42	0.06		608
B–1	Feb. 21				0.04	0.11	0.15	0.17	0.16	0.12	0.05							46
	Mar. 21		0.01	0.17	0.29	0.38	0.44	0.46	0.45	0.40	0.33	0.23	0.11	0.09				181
	June 21	0.15	0.43	0.61	0.74	0.84	0.90	0.93	0.93	0.88	0.80	0.71	0.59	0.45	0.30	0.11		555

LUMINOUS RADIATION.

From the simultaneous measurements of heat and luminous solar radiation intensities made at Mount Weather, Va., in 1913–14 [25] there have been derived the equivalent values given in Table 14. Measure-

TABLE 14.—*Illumination equivalent of one gram-calory per minute per square centimeter of solar heat energy, with the sun at different altitudes.*

Air mass	1.1	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5
Solar altitude	65°.0	42°.7	30.°0	23°.5	19°.3	16°.4	14°.3	12°.6	11°.3	10°.2
	Foot-candles.									
All observations	6,320	5,770	5,490	5,170	4,820	4,780	4,670	4,610	4,600	4,480
Observations on good days only	6,720	6,600	5,580	5,310	5,120	4,780	4,670	4,610	4,600	4,480

ments obtained under very smoky conditions in May, and under unusually hazy conditions in August, 1914, have been disregarded in obtaining the second line of values. With solar altitude 30°, the 26 values obtained for the illumination equivalent have varied between 4,680 and 6,370, or 14 per cent below and 17 per cent above the mean value. Twenty of these values lie between 5,090 and 5,980, or 9 per cent below and 7 per cent above the mean value given in the second

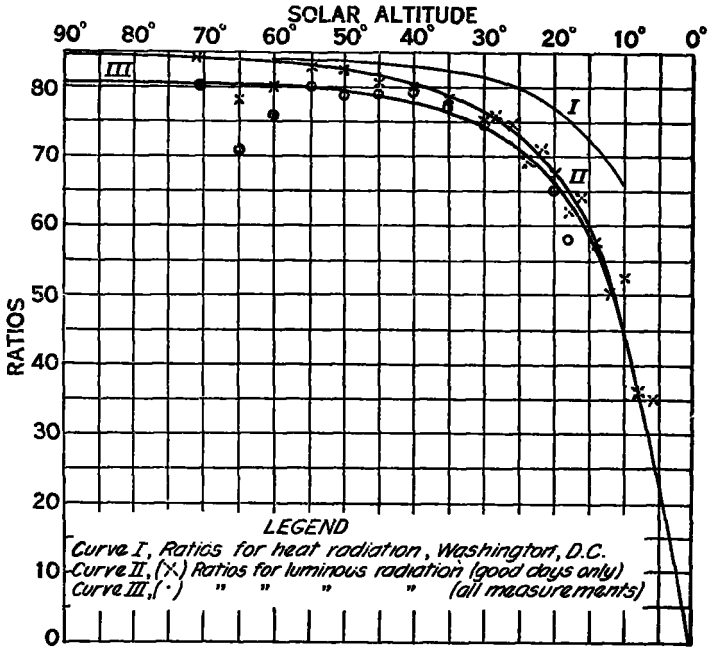
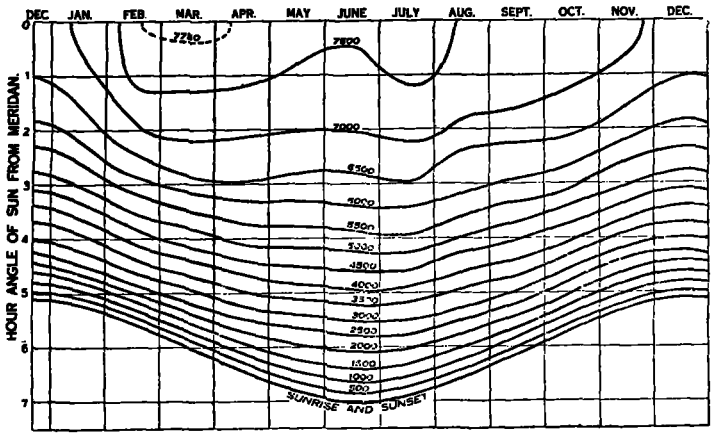


FIGURE 12.—Ratio of direct solar to total radiation (per cent), as received on a horizontal surface.

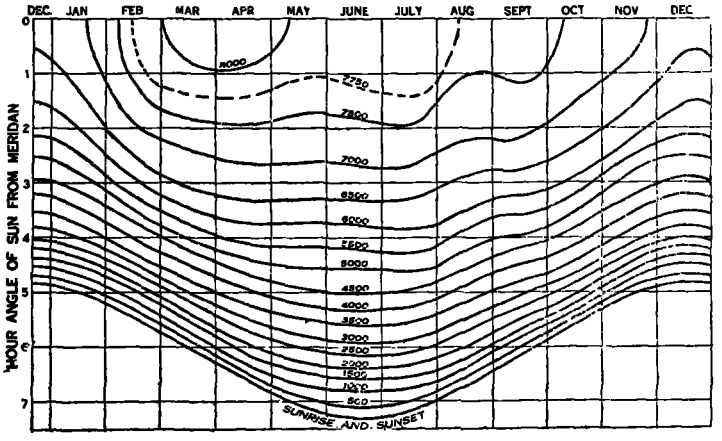
sity of 9,700 foot-candles measured at Mount Weather just before noon on June 30, 1914, is in accord with measurements made in Switzer and by Dorno [26] if we make allowance for the difference in elevation of the two points of observation.

[25] The heat measurements will be found summarized in the Bulletin of the Mount Weather Observatory, vol. 6, pp. 218–219, and in the REVIEW for 1914, vol. 42, pp. 139, 310, and 520; the illumination measurements will be found in the same volume of the REVIEW, p. 652.

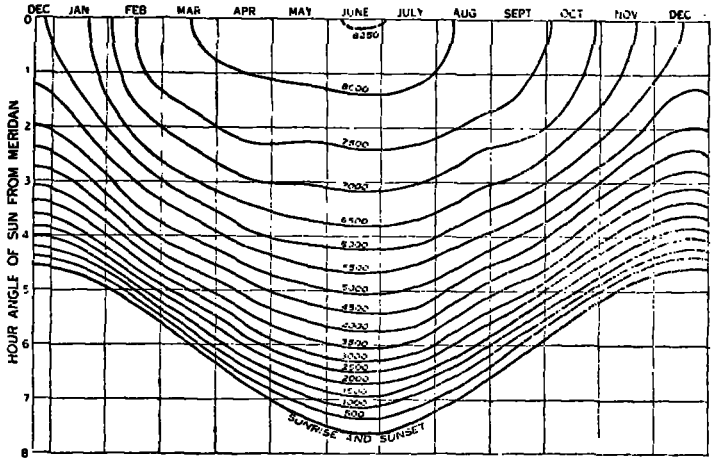
[26] Dorno, C. Physik der Sonnen-und Himmelsstrahlung. Die Wissenschaft, Braunschweig, Bd. 63, S. 46.



(a), Latitude 30°N. (Gulf Coast).



(b), Latitude 36°N. (Eastern States).

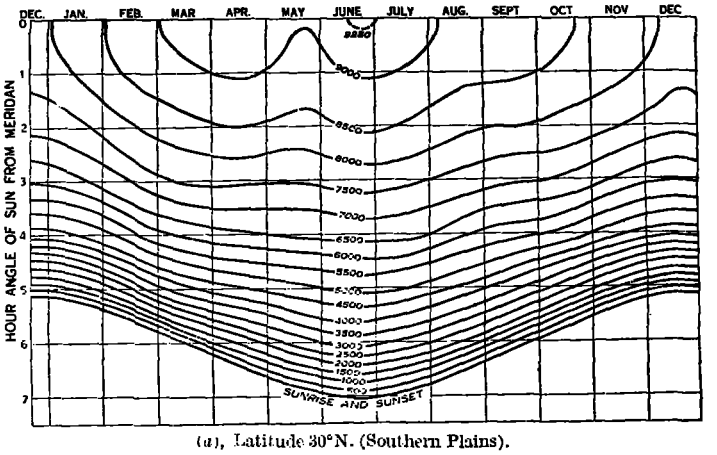


(c), Latitude 42°N. (Northeastern States).

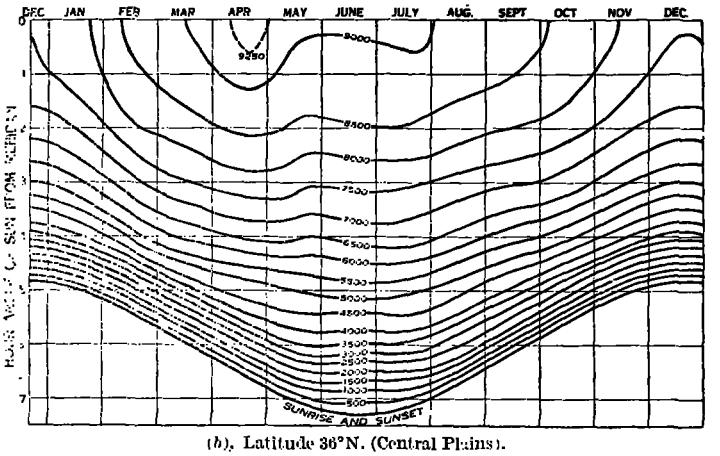
FIGURE 13.—Solar illumination intensity at normal incidence. (Foot-candles.)

From the mean of all the measurements of the illumination of a horizontal surface, (a) by the sun and sky and (b) by the sun alone, made at Mount Weather, Va., in 1913-14,[27] the ratios, expressed as percentages, of curve III, figure 12, have been obtained. Omitting the measurements obtained under unfavorable conditions in May and August, 1914, already referred to, the ratios of curve II, figure 12, have been obtained. There is also shown in figure 12

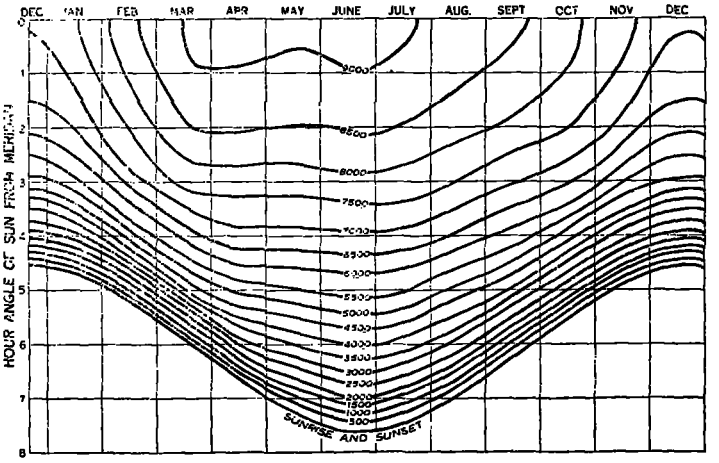
[27] The measurements (a) are summarized in the REVIEW for December, 1914, 12:651, Table 2. The measurements (b) are obtained by subtracting the sky illumination measurements summarized in Table 3, REVIEW reference just cited, from the measurements (a). In obtaining the ratios (b)/(a), here given, the original readings have been used.



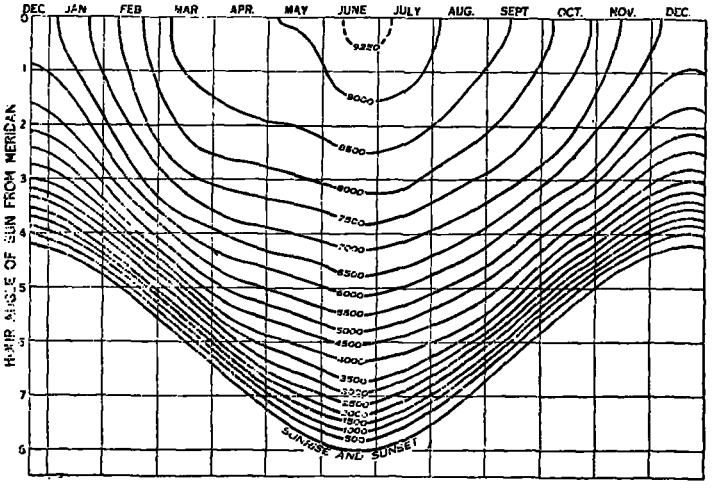
(a), Latitude 30°N. (Southern Plains).



(b), Latitude 36°N. (Central Plains).

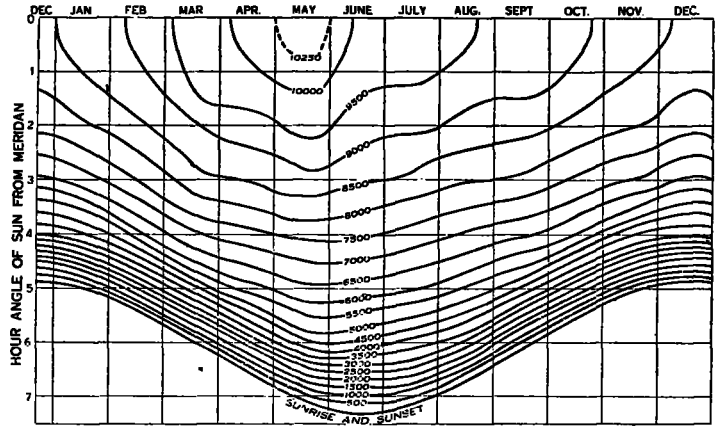


(c), Latitude 42°N. (Central Plains).

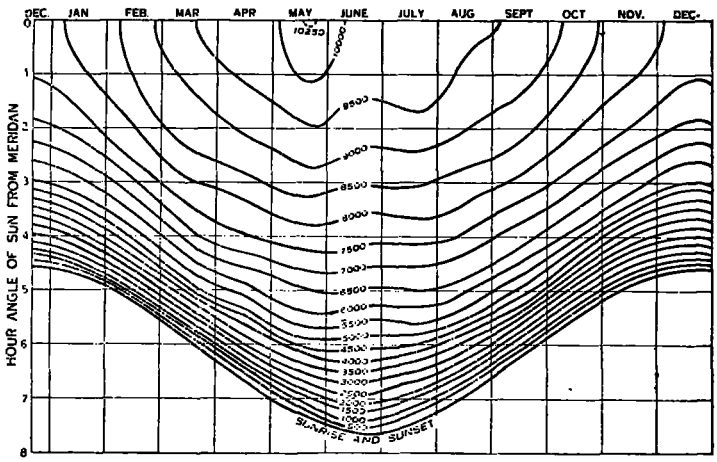


(d), Latitude 48°N. (Northern Plains).

FIGURE 14.—Solar illumination intensity at normal incidence. (Foot-candles).



(*a*), Latitude 36°N. (Central Plateau).



(*b*), Latitude 12°N. (Central Plateau).

FIGURE 15.—Solar illumination intensity at normal incidence. (Foot-candles.)

for the purpose of comparison, curve I, derived from the ratios between direct solar and the total heat radiation received on a horizontal surface at Washington, as given in Table 8. As we would expect, the ratio $\frac{\text{direct solar radiation}}{\text{total radiation}}$ is larger than the ratio $\frac{\text{direct solar illumination}}{\text{total illumination}}$, and the percentage difference increases with the zenith distance of the sun. Or, with increase in the sun's zenith distance, the percentage of the total illumination on a horizontal surface received from the sky is increasingly greater than the percentage of total heat radiation received from the same source.

TABLE 15a.—*Solar illumination intensity at normal incidence.*

LATITUDE 30° N. GULF COAST.

Date.	Sun's hour angle from the meridian.							
	0	1	2	3	4	5	6	7
	Foot-candles.	*Foot-candles.*	*Foot-candles.*	*Foot-candles.*	*Foot-candles.*	*Foot-candles.*	*Foot-candles.*	*Foot-candles.*
Dec. 21	6,760	6,510	5,900	4,690	3,060	460	.....	.....
Jan. 21	7,120	6,930	6,360	5,120	3,350	920	.....	.....
Feb. 21	7,780	7,650	7,080	6,020	4,220	2,450	.....	.....
Mar. 21	7,870	7,660	7,160	6,300	4,730	2,820	420	.....
Apr. 21	7,670	7,560	7,110	6,450	5,290	3,490	1,600	.....
May 21	7,600	7,450	7,010	6,310	5,300	3,770	1,820	.....
June 21	7,590	7,420	7,030	6,390	5,400	3,930	2,130	.....
July 21	7,750	7,590	7,150	6,490	5,420	3,930	2,140	.....
Aug. 21	7,420	7,300	6,850	6,100	4,900	3,300	1,470	.....
Sept. 21	7,450	7,240	6,860	6,020	4,640	2,680	420	.....
Oct. 21	7,220	7,040	6,540	5,520	3,960	2,100	.....	.....
Nov. 21	7,060	6,820	6,180	5,070	3,300	880	.....	.....

TABLE 15a.—*Solar illumination intensity at normal incidence*—Contd.

LATITUDE 36° N. EASTERN UNITED STATES.

Date.	Sun's hour angle from the meridian.							
	0	1	2	3	4	5	6	7
	Foot-candles.	*Foot. candles.*	*Foot-candles.*	*Foot-candles.*	*Foot-candles.*	*Foot-candles.*	*Foot-candle..*	*Foot-candles.*
Dec. 21	6,660	6,360	5,650	4,430	2,680	.....	.....	.....
Jan. 21	7,000	6,750	6,130	4,920	3,120	.....	.....	.....
Feb. 21	7,890	7,750	7,180	6,060	4,390	2,100	.....	.....
Mar. 21	8,170	7,960	7,460	6,530	5,130	3,200	420	.....
Apr. 21	8,100	7,980	7,470	6,870	5,700	4,040	2,130	.....
May 21	7,950	7,780	7,410	6,710	5,760	4,390	2,680	430
June 21	7,960	7,820	7,450	6,810	5,810	4,510	2,780	510
July 21	7,990	7,850	7,480	6,800	5,820	4,450	2,780	430
Aug. 21	7,670	7,480	7,050	6,340	5,220	3,740	1,930	.....
Sept. 21	7,680	7,550	7,120	6,320	4,930	3,070	450	.....
Oct. 21	7,420	7,220	6,660	5,620	4,040	2,010	.....	.....
Nov. 21	7,060	6,800	6,170	4,910	3,120	.....	.....	.....

LATITUDE 42° N. NORTHEASTERN UNITED STATES.

Dec. 21	5,930	5,650	4,970	3,710	1,690	.....	.....	.....
Jan. 21	6,500	6,240	5,600	4,410	2,600	.....	.....	.....
Feb. 21	7,650	7,510	6,840	5,760	4,440	1,680	.....	.....
Mar. 21	8,050	7,870	7,370	6,450	5,130	3,300	460	.....
Apr. 21	8,220	8,050	7,680	7,030	5,940	4,390	2,510	.....
May 21	8,220	8,090	7,660	7,030	6,200	4,880	3,370	800
June 21	8,270	8,140	7,780	7,150	6,220	5,080	3,560	1,500
July 21	8,220	8,090	7,660	7,040	6,270	4,940	3,480	810
Aug. 21	7,880	7,740	7,330	6,620	5,560	4,100	2,080	.....
Sept. 21	7,750	7,570	7,240	6,300	5,000	3,260	430	.....
Oct. 21	7,120	7,000	6,440	5,350	3,770	1,430	.....	.....
Nov. 21	6,490	6,240	5,600	4,360	2,350	.....	.....	.....

TABLE 15b.—*Solar illumination intensity at normal incidence.*

LATITUDE 30° N. SOUTHERN PLAINS.

Date.	Sun's Hour Angle from the Meridian.							
	0	1	2	3	4	5	6	7
	Foot-candles.	*Foot-candles.*	*Foot-candles.*	*Foot-candles.*	*Foot-candles.*	*Foot-candles.*	*Foot-candles.*	*Foot-candles.*
Dec. 21	7,860	7,700	7,150	6,010	4,190	570	.....	.....
Jan. 21	8,220	8,060	7,480	6,470	4,620	1,140	.....	.....
Feb. 21	8,900	8,710	8,110	7,220	5,680	2,970	.....	.....
Mar. 21	9,170	8,980	8,300	7,590	6,250	3,970	490	.....
Apr. 21	9,230	9,060	8,520	7,620	6,440	4,480	2,060	.....
May 21	9,040	8,810	8,340	7,540	6,650	4,860	2,590	.....
June 21	9,230	9,070	8,580	7,770	6,690	5,190	3,240	.....
July 21	9,180	8,960	8,490	7,660	6,720	4,930	2,780	.....
Aug. 21	8,810	8,650	8,120	7,270	6,090	4,380	2,140	.....
Sept. 21	8,790	8,610	8,010	7,110	5,730	3,460	460	.....
Oct. 21	8,510	8,340	7,810	6,890	5,310	2,660	.....	.....
Nov. 21	8,220	8,060	7,480	6,470	4,610	1,140	.....	.....

LATITUDE 36° N. CENTRAL PLAINS.

Dec. 21	7,560	7,340	6,760	5,510	3,290	.....	.....	.....
Jan. 21	7,920	7,770	7,210	6,060	4,100	.....	.....	.....
Feb. 21	8,740	8,580	7,990	7,140	5,500	2,630	.....	.....
Mar. 21	9,050	8,880	8,370	7,570	6,270	4,030	520	.....
Apr. 21	9,350	9,180	8,640	7,850	6,700	4,900	2,520	.....
May 21	9,050	8,850	8,410	7,580	6,540	5,070	3,060	490
June 21	9,050	8,920	8,490	7,700	6,730	5,320	3,430	660
July 21	9,120	8,920	8,490	7,640	6,610	5,130	3,710	530
Aug. 21	8,830	8,660	8,140	7,320	6,240	4,490	2,480	.....
Sept. 21	8,690	8,520	7,960	7,110	5,690	3,520	460	.....
Oct. 21	8,300	8,150	7,630	6,690	5,050	2,340	.....	.....
Nov. 21	7,920	7,710	7,150	6,050	4,040	.....	.....	.....

LATITUDE 42° N. CENTRAL PLAINS.

Dec. 21	7,040	6,850	6,150	4,850	2,120	.....	.....	.....
Jan. 21	7,540	7,320	6,790	5,540	3,200	.....	.....	.....
Feb. 21	8,500	8,350	7,780	6,860	5,170	1,940	.....	.....
Mar. 21	9,140	8,990	8,520	7,740	6,460	4,320	490	.....
Apr. 21	9,150	8,980	8,550	7,820	6,860	5,290	3,110	.....
May 21	9,100	8,920	8,500	7,760	6,890	5,480	3,700	1,110
June 21	9,180	9,020	8,590	7,920	6,970	5,750	4,060	2,120
July 21	9,030	8,870	8,450	7,770	6,830	5,490	3,670	1,120
Aug. 21	8,710	8,540	8,130	7,360	6,320	4,750	2,740	.....
Sept. 21	8,550	8,390	7,880	7,030	5,700	3,560	460	.....
Oct. 21	8,010	7,870	7,450	6,480	4,720	1,770	.....	.....
Nov. 21	7,520	7,320	6,730	5,440	3,250	.....	.....	.....

LATITUDE 48° N. NORTHERN PLAINS.

Dec. 21	6,160	5,980	5,170	3,520	530	.....	.....	.....
Jan. 21	6,890	6,630	5,950	4,630	1,890	.....	.....	.....
Feb. 21	7,990	7,780	7,280	6,440	4,600	1,250	.....	.....
Mar. 21	8,920	8,720	8,280	7,490	6,250	4,120	530	.....
Apr. 21	8,960	8,810	8,440	7,820	6,840	5,430	3,600	.....
May 21	9,040	8,880	8,500	7,930	7,030	5,820	4,160	2,170
June 21	9,340	9,190	8,800	8,220	7,350	6,370	4,740	3,070
July 21	9,180	9,090	8,640	8,000	7,150	5,900	4,320	2,260
Aug. 21	8,800	8,640	8,190	7,590	6,570	5,140	3,520	.....
Sept. 21	8,400	8,190	7,790	6,900	5,620	3,560	490	.....
Oct. 21	7,640	7,450	6,990	6,020	4,110	860	.....	.....
Nov. 21	6,840	6,580	5,950	4,590	1,890	.....	.....	.....

TABLE 15c.—*Solar illumination intensity at normal incidence.*

LATITUDE 36° N. CENTRAL PLATEAU.

Date.	Sun's Hour Angle from the Meridian.							
	0	1	2	3	4	5	6	7
	Foot-candles.	*Foot-candles.*	*Foot-candles.*	*Foot-candles.*	*Foot-candles.*	*Foot-candles.*	*Foot-candles.*	*Foot-candles.*
Dec. 21	8,340	8,170	7,660	6,400	4,020	.....	.....	.....
Jan. 21	8,720	8,560	8,030	6,960	4,820	.....	.....	.....
Feb. 21	9,170	9,000	8,510	7,630	6,090	2,930	.....	.....
Mar. 21	9,890	9,700	9,230	8,440	7,230	5,050	600	.....
Apr. 21	10,100	9,980	9,340	8,520	7,420	5,860	2,990	.....
May 21	10,390	10,220	9,720	8,880	7,760	6,450	4,720	570
June 21	9,880	9,670	9,220	8,580	7,550	6,280	4,370	820
July 21	9,740	9,600	9,150	8,320	7,310	6,100	3,880	530
Aug. 21	9,500	9,320	8,780	8,000	6,910	5,410	2,870	.....
Sept. 21	9,470	9,290	8,690	7,860	6,600	4,720	570	.....
Oct. 21	9,030	8,870	8,270	7,340	5,790	2,540	.....	.....
Nov. 21	8,720	8,490	8,030	6,960	4,820	.....	.....	.....

LATITUDE 42° N. CENTRAL PLATEAU.

Dec. 21	7,740	7,510	6,850	5,450	2,450	.....	.....	.....
Jan. 21	8,200	7,970	7,410	6,120	3,710	.....	.....	.....
Feb. 21	8,730	8,640	8,120	7,180	5,640	1,980	.....	.....
Mar. 21	9,530	9,360	8,880	8,140	7,050	4,920	570	.....
Apr. 21	9,800	9,630	9,120	8,420	7,370	5,910	3,420	.....
May 21	10,350	10,090	9,540	8,760	7,800	6,600	5,060	1,500
June 21	9,860	9,680	9,250	8,490	7,620	6,400	4,640	2,510
July 21	9,980	9,810	9,360	8,580	7,700	6,560	4,750	1,600
Aug. 21	9,570	9,390	8,950	8,250	7,210	5,820	3,350	.....
Sept. 21	9,420	9,130	8,610	7,880	6,690	4,880	570	.....
Oct. 21	8,600	8,400	7,900	7,010	5,430	1,610	.....	.....
Nov. 21	8,180	7,970	7,410	6,160	3,670	.....	.....	.....

TABLE 16a.—*Total illumination on a horizontal surface from sun and sky*

LATITUDE 30° N. GULF COAST.

Date.	Sun's Hour Angle from the Meridian.							
	0	1	2	3	4	5	6	7
	Foot-candles.	*Foot-candles.*	*Foot-candles.*	*Foot-candles.*	*Foot-candles.*	*Foot-candles.*	*Foot-candles.*	*Foot-candles.*
Dec. 21	5,240	4,840	3,910	2,510	1,210	66	.....	.....
Jan. 21	5,880	5,510	4,520	2,970	1,370	234	.....	.....
Feb. 21	7,420	7,060	5,850	4,140	2,190	717	.....	.....
Mar. 21	8,530	8,040	6,770	5,030	2,800	1,120	58	.....
Apr. 21	9,020	8,680	7,440	5,730	3,640	1,730	474	.....
May 21	9,290	8,870	7,670	5,920	4,010	2,080	606	.....
June 21	9,340	8,910	7,790	6,110	4,190	2,270	800	44
July 21	9,490	9,050	7,840	6,110	4,110	2,200	748	.....
Aug. 21	8,720	8,520	7,180	5,430	3,450	1,640	443	.....
Sept. 21	8,110	7,620	6,520	4,800	2,850	1,070	66	.....
Oct. 21	6,870	6,480	5,400	3,790	2,000	653	.....	.....
Nov. 21	5,830	5,430	4,400	2,930	1,360	222	.....	.....

LATITUDE 36° N. EASTERN UNITED STATES.

Dec. 21	4,510	4,190	3,300	2,050	864	.....	.....	.....
Jan. 21	5,170	4,810	3,880	2,510	1,110	50	.....	.....
Feb. 21	6,880	6,540	5,460	3,820	2,030	618	.....	.....
Mar. 21	8,300	7,790	6,630	4,910	2,980	1,220	60	.....
Apr. 21	9,200	8,820	7,550	5,950	3,940	2,010	660	.....
May 21	9,500	9,050	7,950	6,260	4,390	2,380	1,010	68
June 21	9,650	9,250	8,150	6,490	4,560	2,670	1,130	130
July 21	9,570	9,150	8,050	6,360	4,440	2,560	1,060	72
Aug. 21	8,730	8,280	7,130	5,490	3,620	1,870	590	.....
Sept. 21	7,850	7,460	6,370	4,780	2,920	1,190	70	.....
Oct. 21	6,460	6,090	5,020	3,540	1,850	586	.....	.....
Nov. 21	5,200	4,830	3,910	2,500	1,100	50	.....	.....

LATITUDE 42° NORTHEASTERN UNITED STATES.

Dec. 21	3,400	3,180	2,470	1,440	467	.....	.....	.....
Jan. 21	4,190	3,880	3,090	1,920	810	.....	.....	.....
Feb. 21	6,040	5,720	4,710	3,260	1,840	470	.....	.....
Mar. 21	7,560	7,170	6,120	4,550	2,800	1,220	60	.....
Apr. 21	8,880	8,450	7,390	5,860	4,020	2,180	810	.....
May 21	9,490	9,130	8,000	6,430	4,660	2,860	1,360	215
June 21	9,740	9,370	8,340	6,740	4,910	3,140	1,560	428
July 21	9,500	9,160	8,010	6,460	4,710	2,980	1,450	218
Aug. 21	8,530	8,190	7,080	5,540	3,770	2,050	667	.....
Sept. 21	7,320	6,940	6,040	4,470	2,770	1,220	70	.....
Oct. 21	5,580	5,310	4,400	3,020	1,560	390	.....	.....
Nov. 21	4,180	3,840	3,080	1,910	728	.....	.....	.....

TABLE 16b.—*Total illumination on a horizontal surface from sun and sky.*

LATITUDE 30° N. SOUTHERN PLAINS.

Date.	Sun's Hour Angle from the Meridian.							
	0	1	2	3	4	5	6	7
	Foot-candles.	*Foot-candles.*	*Foot-candles.*	*Foot-candles.*	*Foot-candles.*	*Foot-candles.*	*Foot-candles.*	*Foot-candles.*
Dec. 21	5,880	5,550	4,590	3,150	1,580	66	.....	.....
Jan. 21	6,550	6,170	5,140	3,660	1,870	290	.....	.....
Feb. 21	8,200	7,760	6,490	4,770	2,820	920	.....	.....
Mar. 21	9,520	9,060	7,640	5,840	3,710	1,550	58	.....
Apr. 21	10,360	9,940	8,570	6,550	4,380	2,170	608	.....
May 21	10,510	10,300	8,730	6,850	4,870	2,620	905	.....
June 21	10,870	10,370	9,080	7,160	5,010	2,920	1,200	44
July 21	10,680	10,180	8,900	6,980	4,880	2,680	972	.....
Aug. 21	9,890	9,520	8,170	6,270	4,160	2,130	634	.....
Sept. 21	9,160	8,720	7,350	5,490	3,410	1,370	66	.....
Oct. 21	7,830	7,410	6,230	4,570	2,630	826	.....	.....
Nov. 21	6,500	6,200	5,140	3,650	1,860	287	.....	.....

LATITUDE 36° N. CENTRAL PLAINS.

Dec. 21	5,000	4,700	3,830	2,500	1,050	.....	.....	.....
Jan. 21	5,650	5,350	4,440	3,030	1,450	50	.....	.....
Feb. 21	7,370	7,000	5,880	4,360	2,500	770	.....	.....
Mar. 21	8,890	8,390	7,160	5,510	3,540	1,550	60	.....
Apr. 21	10,170	9,710	8,400	6,690	4,520	2,390	780	.....
May 21	10,320	9,850	8,660	6,830	4,820	2,840	1,370	68
June 21	10,440	10,070	8,900	7,090	5,060	3,110	1,370	170
July 21	10,410	9,950	8,770	6,900	4,890	2,870	1,390	72
Aug. 21	9,610	9,180	7,930	6,140	4,200	2,190	760	.....
Sept. 21	8,540	8,110	6,890	5,210	3,270	1,350	70	.....
Oct. 21	6,980	6,630	5,500	4,090	2,270	680	.....	.....
Nov. 21	5,650	5,200	4,380	3,020	1,430	50	.....	.....

LATITUDE 42° N. CENTRAL PLAINS.

Dec. 21	4,030	3,780	2,980	1,870	630	.....	.....	.....
Jan. 21	4,720	4,420	3,650	2,370	995	.....	.....	.....
Feb. 21	6,480	6,170	5,180	3,790	2,110	540	.....	.....
Mar. 21	8,300	7,900	6,820	5,280	3,420	1,500	60	.....
Apr. 21	9,470	9,060	7,940	6,300	4,490	2,570	1,000	.....
May 21	10,040	9,620	8,540	6,850	5,060	3,120	1,470	300
June 21	10,320	9,930	8,880	7,230	5,310	3,400	1,750	600
July 21	9,990	9,580	8,500	6,830	5,020	3,140	1,470	300
Aug. 21	9,030	8,630	7,580	5,850	4,160	2,320	880	.....
Sept. 21	7,810	7,420	6,350	4,810	3,000	1,330	70	.....
Oct. 21	6,070	5,760	4,920	3,570	1,930	480	.....	.....
Nov. 21	4,700	4,420	3,610	2,330	1,000	.....	.....	.....

LATITUDE 48° N. NORTHERN PLAINS.

Dec. 21	2,960	2,750	2,090	1,140	90	.....	.....	.....
Jan. 21	3,680	3,420	2,710	1,680	513	.....	.....	.....
Feb. 21	5,460	5,090	4,310	3,290	1,680	318	.....	.....
Mar. 21	7,330	7,020	6,110	4,730	3,120	1,450	60	.....
Apr. 21	8,720	8,370	7,410	6,020	4,340	2,630	1,200	.....
May 21	9,550	9,170	8,200	6,810	5,090	3,360	1,600	620
June 21	10,120	9,730	8,770	7,320	5,560	3,840	2,180	990
July 21	9,710	9,430	8,360	6,890	5,190	3,420	1,830	666
Aug. 21	9,590	8,230	7,210	5,860	4,190	2,500	1,180	.....
Sept. 21	7,020	6,630	5,780	4,400	2,830	1,260	75	.....
Oct. 21	5,150	4,860	4,130	2,980	1,560	226	.....	.....
Nov. 21	3,670	3,390	2,710	1,670	510	.....	.....	.....

TABLE 16c.—*Total illumination from sun and sky on a horizontal surface.*

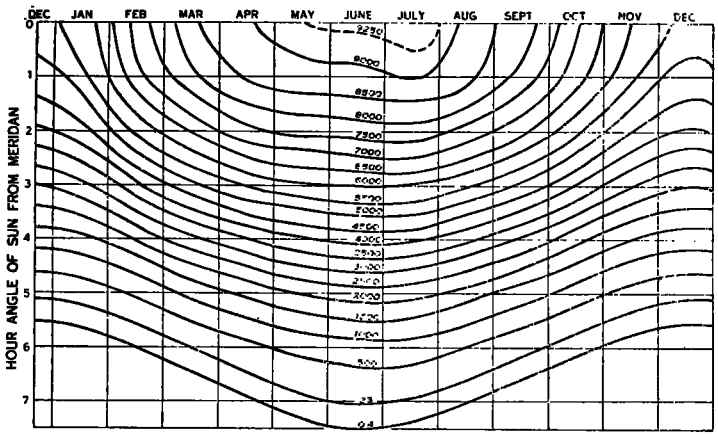
LATITUDE 36° N. CENTRAL PLATEAU.

Date.	Hour Angle of the Sun from the Meridian.							
	0	1	2	3	4	5	6	7
	Foot-candles.	*Foot-candles.*	*Foot-candles.*	*Foot-candles.*	*Foot-candles.*	*Foot-candles.*	*Foot-candles.*	*Foot-candles.*
Dec. 21	5,520	5,220	4,340	2,970	1,300	.....	.....	.....
Jan. 21	6,210	5,880	4,900	3,470	1,710	50	.....	.....
Feb. 21	7,740	7,350	6,260	4,660	2,770	853	.....	.....
Mar. 21	9,670	9,210	7,940	6,140	3,820	1,930	60	.....
Apr. 21	10,980	10,550	9,100	7,140	5,010	2,860	930	.....
May 21	11,850	11,380	10,010	8,000	5,710	3,600	1,760	68
June 21	11,510	10,700	9,670	7,900	5,730	3,670	1,930	210
July 21	11,130	10,700	9,460	7,520	5,410	3,420	1,470	72
Aug. 21	10,330	9,870	8,540	6,710	4,660	2,640	880	.....
Sept. 21	9,310	8,840	7,510	5,690	3,790	1,810	70	.....
Oct. 21	7,600	7,220	6,060	4,490	2,610	743	.....	.....
Nov. 21	6,210	5,820	4,930	3,470	1,620	50	.....	.....

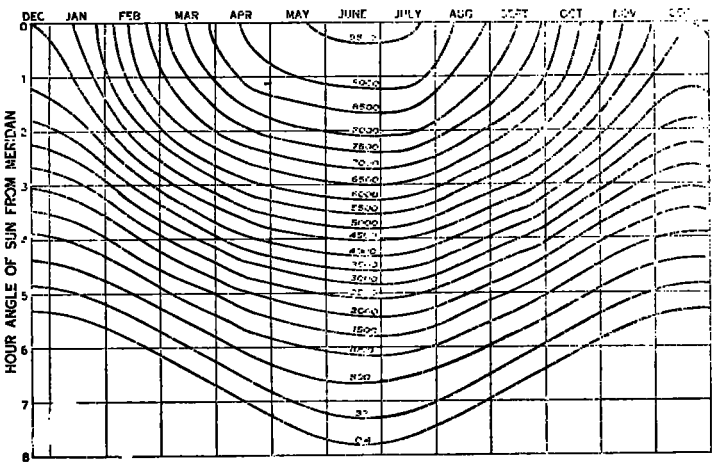
LATITUDE 42° N. CENTRAL PLATEAU.

Dec. 21	4,430	4,160	3,330	2,100	675	.....	.....	.....
Jan. 21	5,140	4,810	3,980	2,630	1,150	.....	.....	.....
Feb. 21	6,660	6,380	5,400	3,960	2,290	552	.....	.....
Mar. 21	8,650	8,330	7,120	5,570	3,770	1,810	60	.....
Apr. 21	10,120	9,710	8,470	6,790	4,820	2,880	1,100	.....
May 21	11,310	10,850	9,500	7,730	5,710	3,770	2,020	445
June 21	11,090	10,640	9,520	7,740	5,810	3,810	2,010	723
July 21	11,030	10,610	9,410	7,610	5,650	3,760	1,910	431
Aug. 21	9,930	9,510	8,340	6,670	4,740	2,850	1,080	.....
Sept. 21	8,600	8,090	6,940	5,410	3,610	1,830	70	.....
Oct. 21	6,520	6,160	5,220	3,870	2,220	435	.....	.....
Nov. 21	5,110	4,810	3,970	2,650	1,110	.....	.....	.....

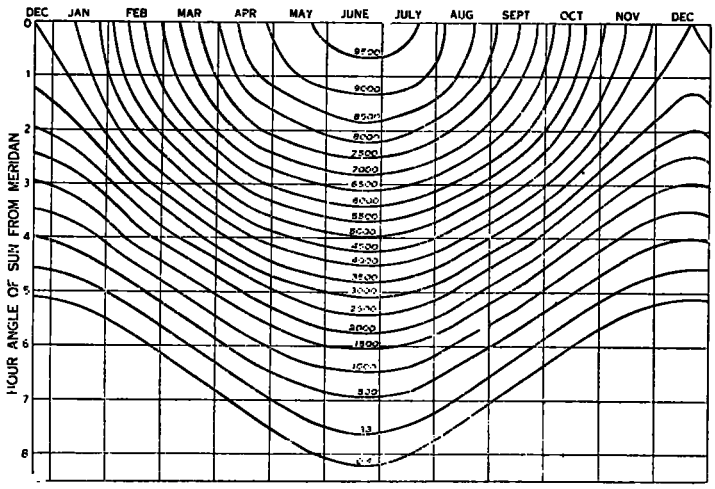
We may obtain the vertical component of direct solar illumination at any hour of the day by multiplying the solar illumination intensity at normal incidence by the sine of the solar altitude. The vertical components of the intensities of Table 15a thus obtained have been divided by the ratios of curve III, figure 12, for corresponding solar altitude, to obtain the "Total illumination on a horizontal surface" of Table 16a, and figure 16.



(a), Latitude 30°N. (Gulf Coast).



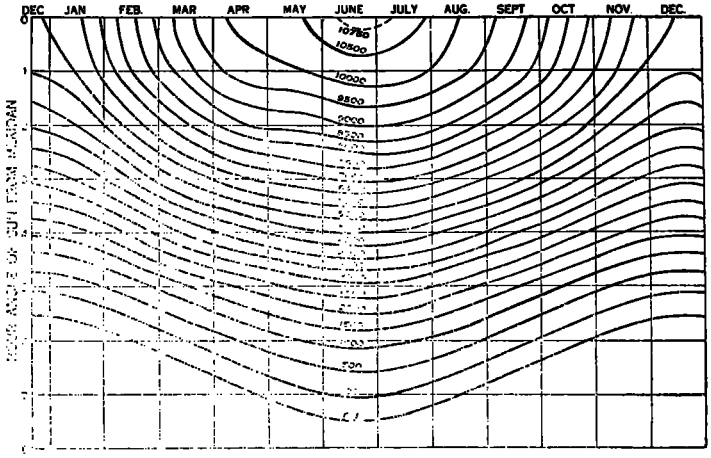
(b), Latitude 36°N. (Eastern States).



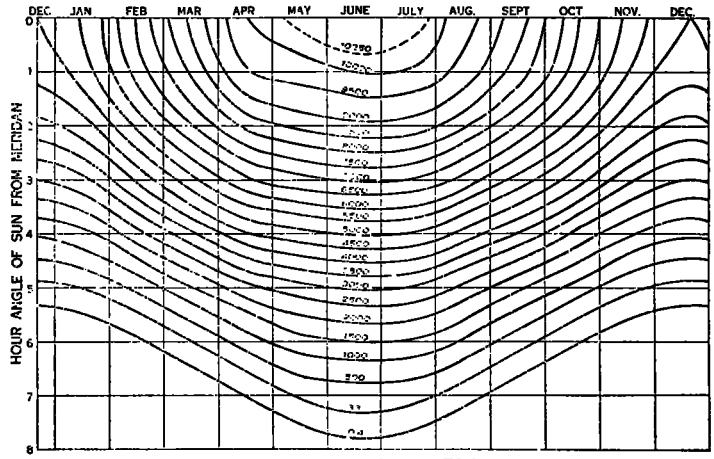
(c), Latitude 42°N. (Northeastern States).

FIGURE 16.—Total illumination on a horizontal surface. (Foot-candles.)

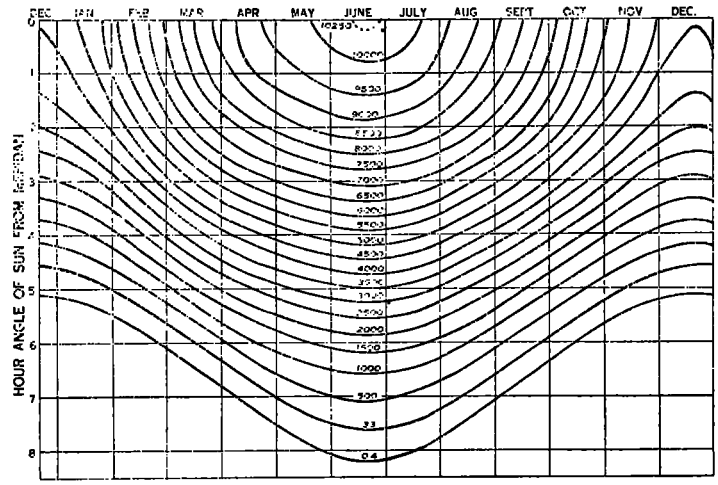
Similarly, the vertical components of the illumination intensities of Table 15b and 15c have been divided by the ratios obtained from curve II, to obtain the "Total



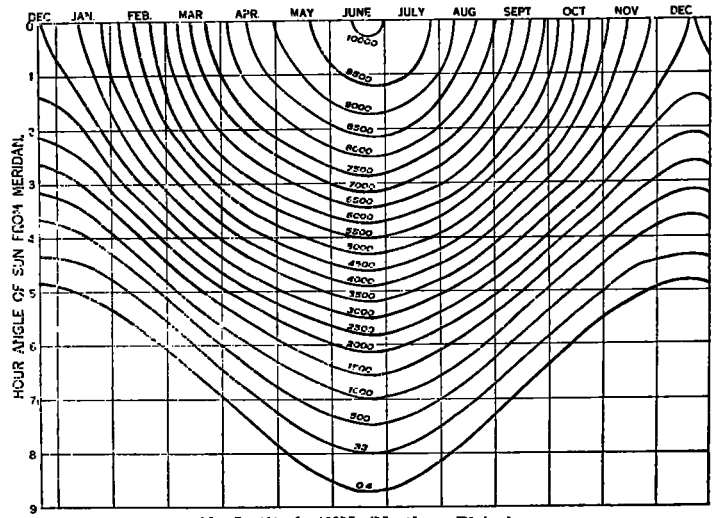
(a), Latitude 30°N. (Southern Plains).



(b), Latitude 38°N. (Central Plains).



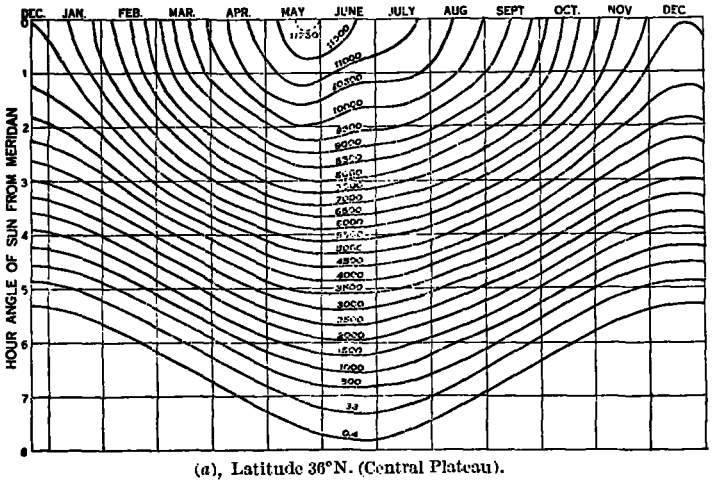
(c), Latitude 42°N. (Central Plains).



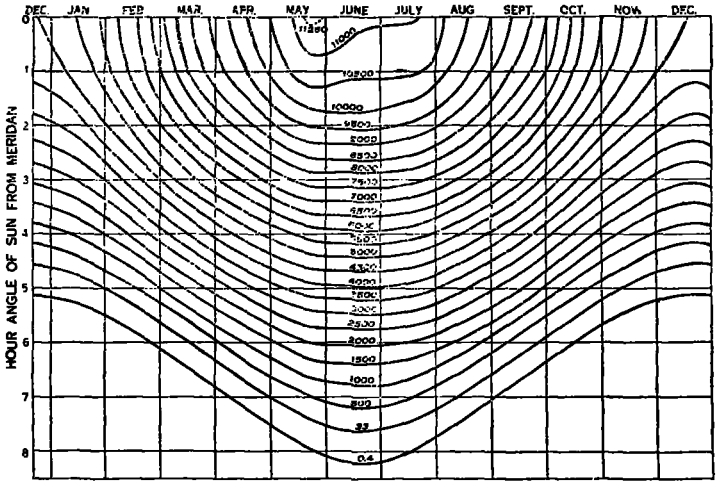
(d), Latitude 48°N. (Northern Plains).

FIGURE 17.—Total illumination on a horizontal surface. (Foot-candles.)

illumination on a horizontal surface" of Tables 16b and 16c, and figures 17 and 18. The solar altitudes have been obtained from Table 1. In figures 16, 17, and 18 the curve of illumination intensity 33 foot-candles represents the time of sunrise or sunset, and the curve of 0.4 foot-candles the time of the beginning or ending of civil twilight, respectively, these intensities corresponding to the results given in the Review for November, 1916, page 620, Table 5.



(a), Latitude 36°N. (Central Plateau).



(b), Latitude 42°N. (Central Plateau).

FIGURE 18.—Total illumination on a horizontal surface. (Foot-candles.)

In a similar manner, representing the illumination intensity at normal incidence by I_n, we may obtain its intensity upon an *east (a. m.) or west (p. m.) vertical* surface, I_e, or upon a north or south vertical surface, I_s, from the equations

$$I_e = I_n \cos a \sin \alpha$$

and $I_s = I_n \cos a \cos \alpha$

where a = solar latitude, and α = solar azimuth expressed in degrees from the meridian of the place. The values of I_e and I_s have been computed for each hour of the day on the 21st of each month at latitudes 30° N., 36° N., 42° N., and 48° N., for the southern, central, and northern plains, using for I_n the intensities of Table 15b and for a and α the values given in Tables 1 and 2, respectively. The results are shown graphically in figures 19 and 20. Since I_e and I_s are directly proportional to I_n their values for the Gulf or Atlantic Coast States, or for the Central Plateau, may easily be obtained, if desired, from the values of I_n at corresponding latitudes in Tables 15a and 15c.

The intensity of solar illumination upon surfaces facing NE., SE., SW., and NW., respectively, has also been computed, and the results are shown graphically in figures 21 and 22.

Table 17 shows the possible hours of direct solar illumination, at the time of the solstices and the equinoxes, on vertical surfaces differently oriented. During the late spring and the summer months a vertical surface facing southeast or southwest will receive the greatest number of hours of sunshine; during the remainder of the year, a surface facing south. Figures 19 to 22 show that at the time of the winter solstice the illumination is most intense on a south exposure; during most of the winter and fall months it is most intense on a southeast or southwest exposure; and during the late spring and the summer months, on an east or a west exposure.

A south exposure has a decided advantage over an east or a west exposure, in that it will be both the lighter and the warmer in winter and the cooler in summer. A detached house with its four sides facing NE., SE., SW., and NW. will have a much more equable distribution of light and heat upon all sides than one whose sides face the cardinal points of the compass. In the latitudes included in the United States each side may receive direct solar illumination for at least a short time on every day in the year, and the maximum illumination, and also the maximum heating effect, will come during the seasons when most needed.

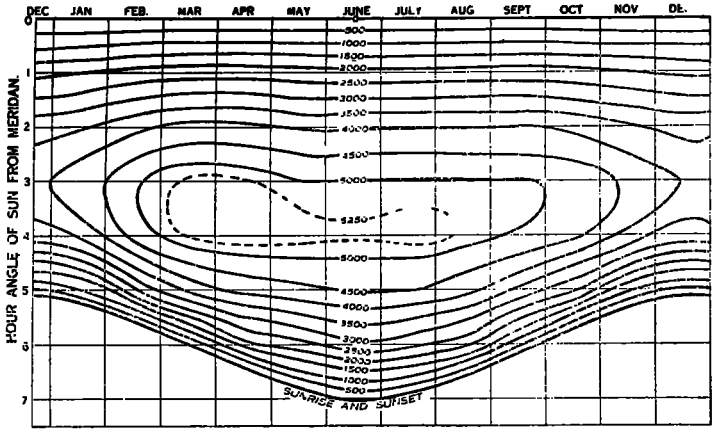
TABLE 17.—*Possible hours of direct solar illumination for vertical surfaces differently oriented.*

Surface facing.	N.	S.	E. (a.m.) W. (p.m.)	SE. or SW.	NE. (a.m.) NW. (p.m.)
	H. m.	*H. m.*	*H. m.*	*H. m.*	*H. m.*
DECEMBER 21.					
Lat. 30° N.	0 0	10 08	5 04	8 08	2 00
Lat. 36° N.	0 0	9 40	4 50	8 00	1 40
Lat. 42° N.	0 0	9 00	4 30	7 48	1 12
Lat. 48° N.	0 0	8 22	4 11	7 32	0 50
MARCH 21 OR SEPTEMBER 21.					
Lat. 30° N.	0 0	12 08	6 04	7 50	4 18
Lat. 36° N.	0 0	12 10	6 05	8 07	4 03
Lat. 42° N.	0 0	12 12	6 06	8 20	3 50
Lat. 48° N.	0 0	12 14	6 07	8 33	3 41
JUNE 21.					
Lat. 30° N.	8 40	5 24	7 02	7 30	6 34
Lat. 36° N.	7 28	7 08	7 18	8 10	6 26
Lat. 42° N.	7 08	8 08	7 38	8 52	6 24
Lat. 48° N.	7 06	8 56	8 01	9 33	6 29

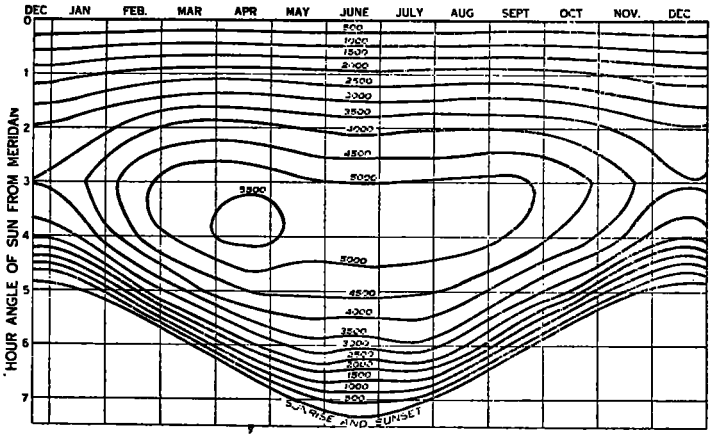
Also, the advantage of streets running from SE. to NW. and SW. to NE. instead of from E. to W. and N. to S. should not be overlooked. Both the former may receive sunshine on every day of the year. Of the latter, those running east and west, if lined by high buildings, will receive no direct sunshine at the street level from September 21 to March 21; and those running north and south will receive the direct solar rays at a time of day when the sun's azimuth, as shown by Table 2, is changing at its maximum rate.[28]

To the illumination of a vertical surface by the direct solar rays should be added the diffuse illumination from the sky, and the reflection of light from the ground and

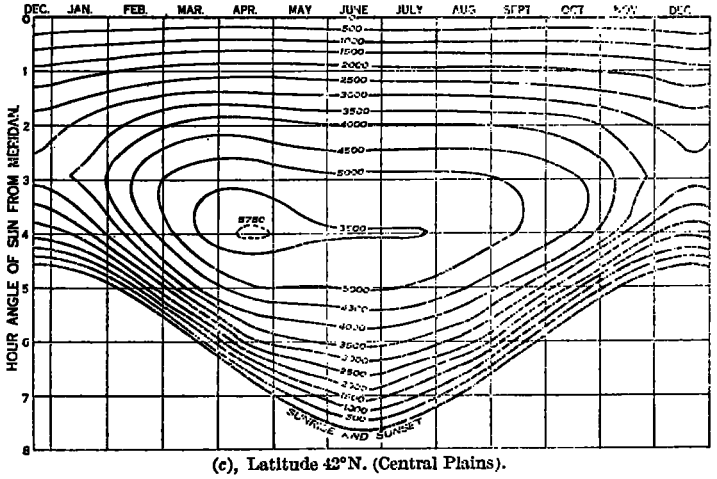
[28] See "Planning Sunlight Cities," by Herbert S. Swan and George W. Tuttle, in The American City Pamphlets, No. 167; The Civic Press, New York. The authors show that north-south streets afford the maximum daylight illumination for high attached buildings, and that detached houses on narrow lots facing on east-west streets are more uniformly lighted on both sides than would be the case if the streets were differently oriented.



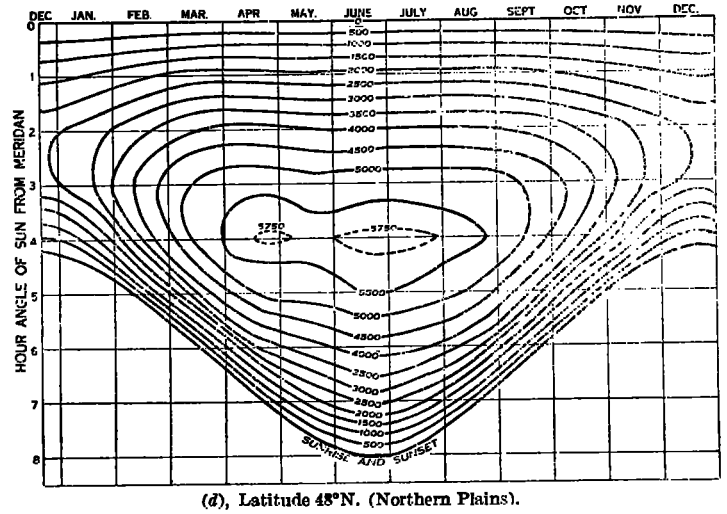
(*a*), Latitude 30°N. (Southern Plains).



(*b*), Latitude 36°N. (Central Plains).

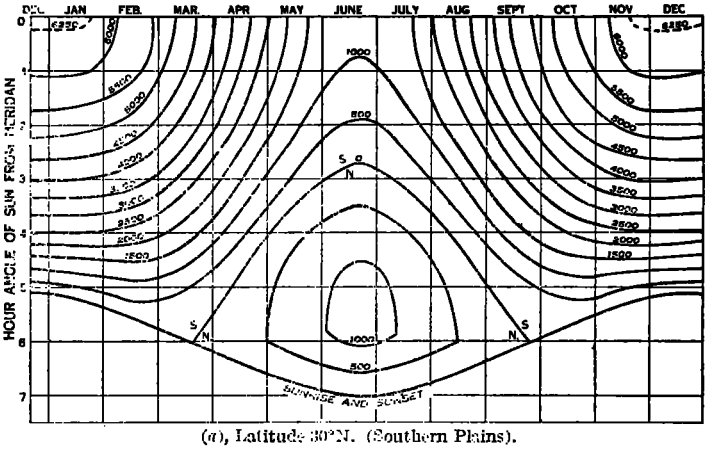


(*c*), Latitude 42°N. (Central Plains).

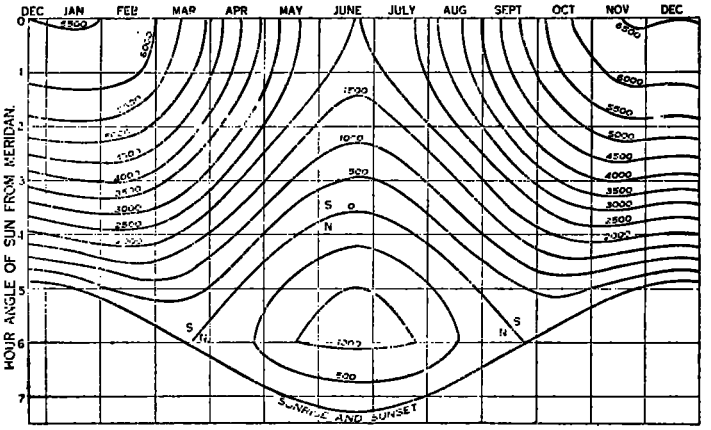


(*d*), Latitude 48°N. (Northern Plains).

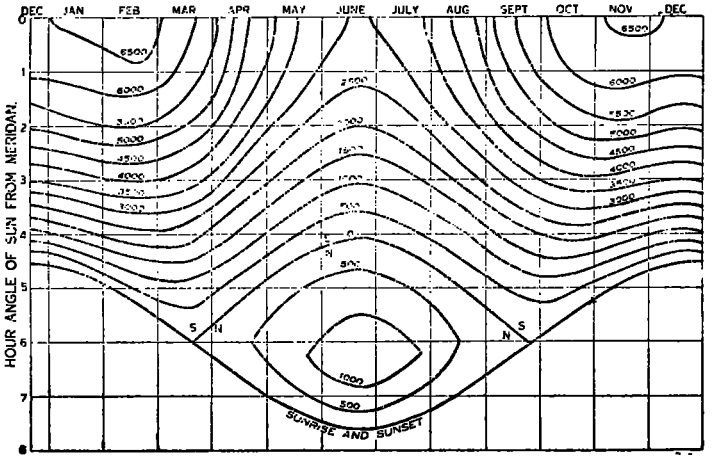
FIGURE 19.—Solar illumination on a vertical surface facing east (a. m.), or west (p. m.), (Foot-candles.)



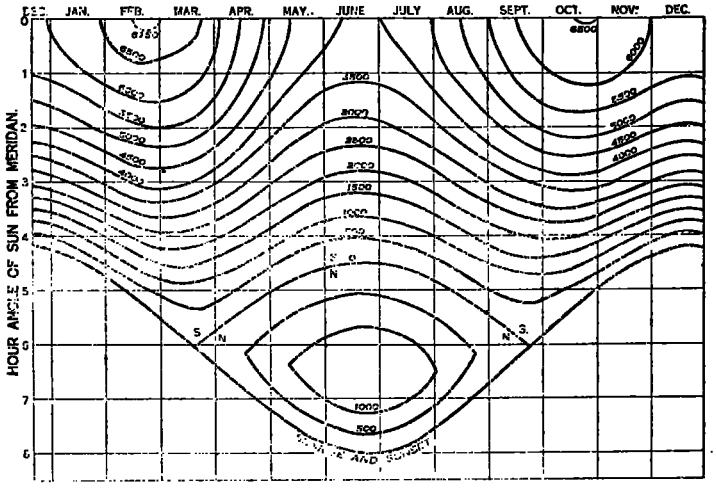
(*a*), Latitude 30°N. (Southern Plains).



(*b*), Latitude 36°N. (Central Plains).

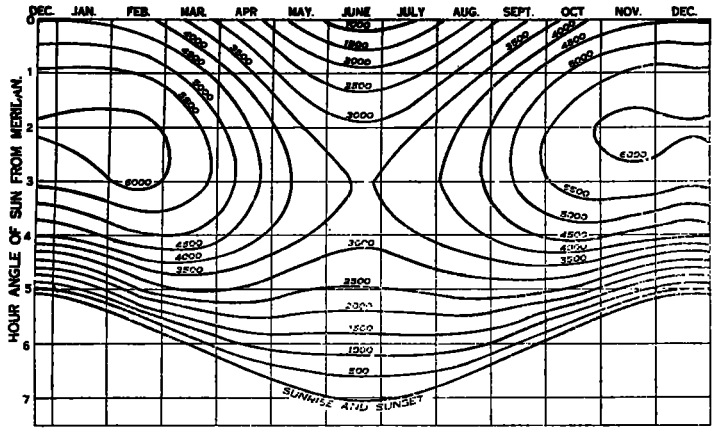


(*c*), Latitude 42° N. (Central Plains).

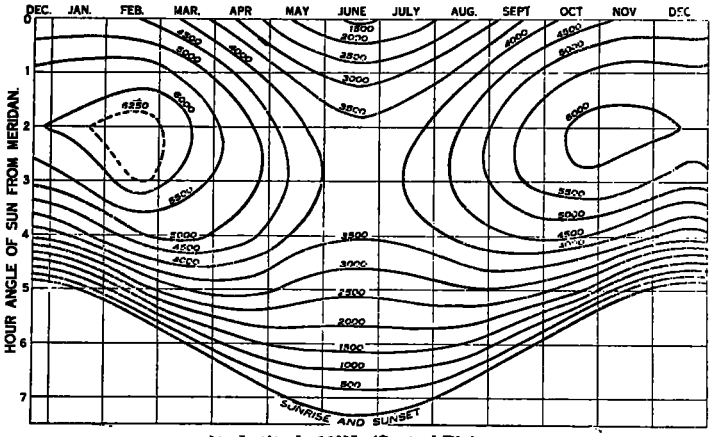


(*d*), Latitude 48°N. (Northern Plains).

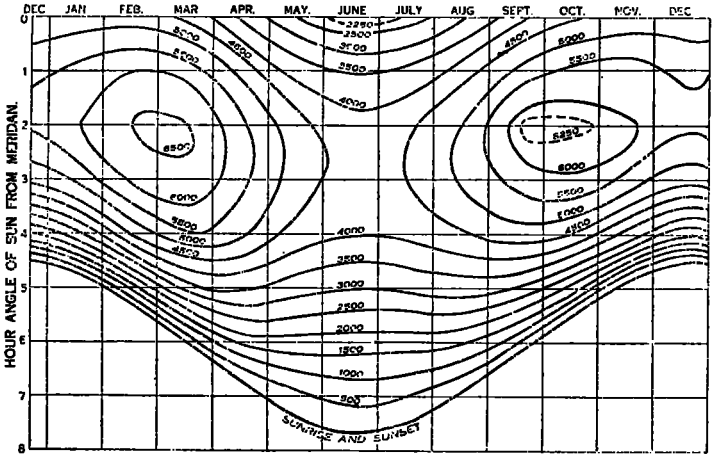
FIGURE 20.—Solar illumination on a vertical surface facing north or south. (Foot-candles.)



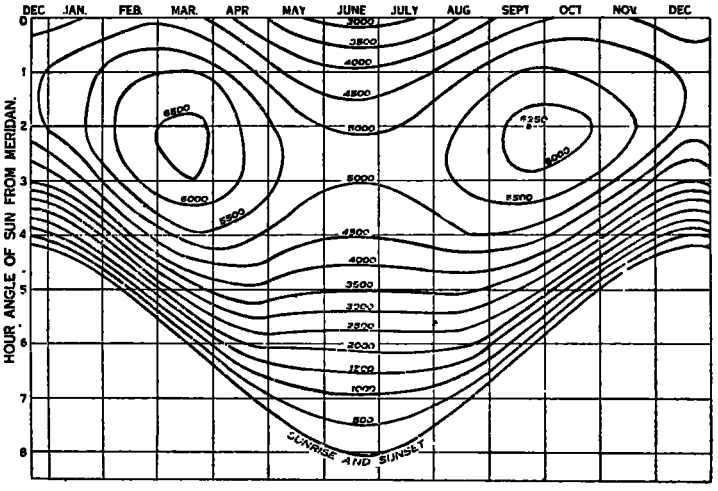
(a), Latitude 30°N. (Southern Plains).



(b), Latitude 36°N. (Central Plains).

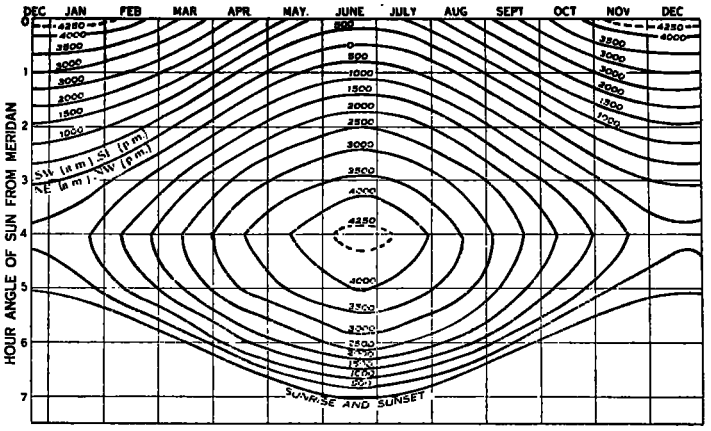


(c), Latitude 42°N. (Central Plains).

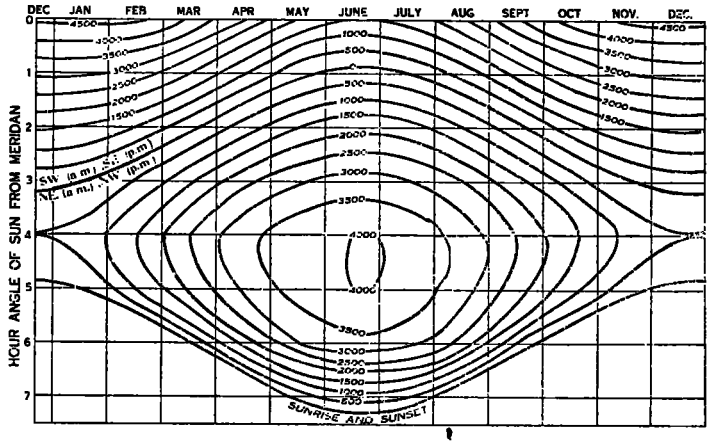


(d), Latitude 48°N. (Northern Plains).

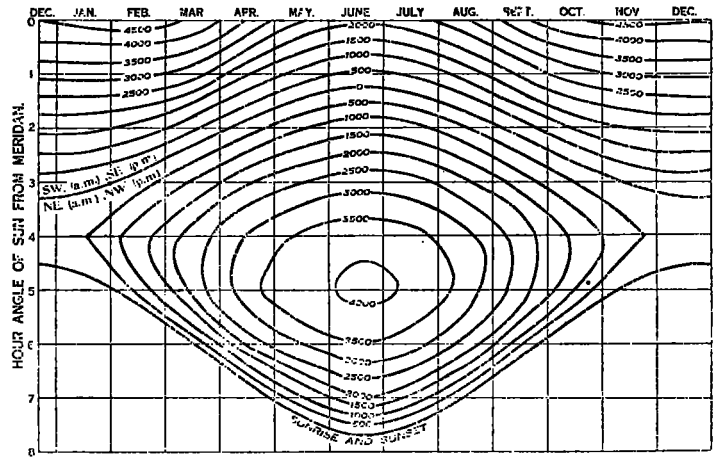
FIGURE 21.—Solar illumination on a vertical surface facing SE. (a. m.) or SW. (p. m.). (Foot-candles.)



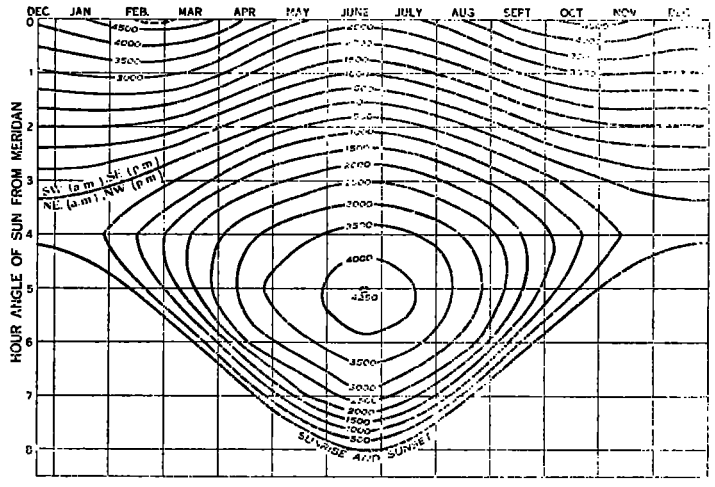
(a), Latitude 30°N. (Southern Plains).



(b), Latitude 36°N. (Central Plains).



(c), Latitude 42°N. (Central Plains).



(d), Latitude 48°N. (Northern Plains).

FIGURE 22.—Solar illumination on a vertical surface: above zero line, facing SW. (a. m.), or SE. (p. m.); below zero line, facing NE. (a. m.), or NW. (p. m.).

other objects. The latter varies greatly with the character of the reflecting surfaces. Dorno[29] states that at Davos, in Switzerland, the snow cover of winter increases the average illumination of vertical surfaces facing both toward and from the sun (Vorderlich) so that it equals the illumination of a horizontal surface (Oberlicht). With the disappearance of the snow the Vorderlicht diminishes about 25 per cent, and principally on surfaces facing northward; for with the sun at an altitude of 40°, and the ground covered with snow, he found the illumination of a vertical surface facing north to be one-fourth the illumination of a vertical surface facing south, while without the snow cover the proportion was only one-thirteenth.

From the studies of Wiener[30] and the measurements of Abbot[31] and Dorno[32], we know that the unclouded sky has its maximum brightness near the sun. With the sun near the horizon the point of minimum brightness, approximately 90° above the sun, is only about one-tenth as bright as the sky 10° from the sun which, in turn, is only one-tenth as bright as the sky 2° from the sun. With increasing solar altitude the solar distance of this point of minimum diminishes, as also does the ratio of the maximum to the minimum intensity. In general, the sky brightness increases with approach to the horizon. Therefore, we must expect the illumination of vertical surfaces by diffuse light from the sky and reflected light from the earth and other objects to exceed one-half the illumination of a horizontal surface by skylight, and under favorable conditions to equal or even exceed it.

ILLUMINATION INTENSITY WITH AN OVERCAST SKY.

From the Callendar pyrheliometer records of hourly amounts of radiation received on a horizontal surface at Washington, Madison, and Lincoln, on days when no sunshine was recorded by the Marvin sunshine recorder, the average radiation intensity per minute during each hour has been determined, tabulated by months with respect to the sun's altitude at the time of mean radiation intensity for the hour, and the monthly averages for each solar altitude reduced to illumination intensity by multiplying 6,250[33]. Plotting these monthly means of illumination intensity against the corresponding solar altitudes, the smooth curve I, figure 23, is obtained for the Plains States from the Madison and Lincoln records, which are closely in accord, and curve II, for the Atlantic Coast States from the Washington records. From the monthly minimum intensities for the different solar altitudes, Curve III is obtained for the Plains States, and Curve IV for the Atlantic Coast States. With these curves, and the solar altitudes of Table 1, we may determine the average and the minimum illumination that may be expected with an overcast sky at any hour of the day at different latitudes. Thus, at latitude 48° N., in the Plains States, on December 21, at noon, we may expect an illumination intensity on a horizontal surface of about 800 foot-candles although it may not exceed 160 foot-candles. On the Atlantic coast at latutide 36° N., at 9 a. m. on June 21, we may expect an illumination intensity of 1,260 foot-candles, although it may not exceed 300 foot-candles.

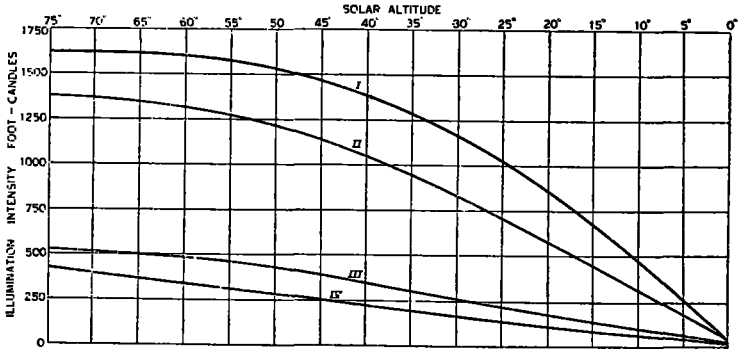


FIGURE 23.—Illumination intensity with a cloudy sky. Curve I average for Plains States. Curve II average for Atlantic Coast States. Curve III Minimum for Plains States. Curve IV Minimum for Atlantic Coast States.

As already shown[34], with a completely overcast sky, and especially with low sun, the illumination intensity may equal or even exceed half the intensity with a clear sky. Therefore the curves of mean values are of little practical use. The curves of minimum values, however, show the illumintion that may be expected when dense rain or snow clouds prevail. If, however, to the screening effect of clouds we add that of dense city smoke, the daylight illumination may be still further reduced, as has been shown by the author and others in previous papers.[35]

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[29] Ibid., p. 111.

[30] *Wiener, Dr. Chr.* Die Helligkeit des Klaren Himmels und die Beleuchtung durch Sonne, Himmel und Rückstrahlung. Abh. die Kaiserl. Leop.-Carol. Deutschen Akad. der Naturforscher. Band 73, Nr. 1, Halle, 1900, Band 91, Nr. 2, Halle, 1909.

[31] *Abbott, C. G.* Annals of the Astrophysical Observatory of the Smithsonian Institution. Vol. 3, 1913, p. 141-151. The direct and scattered radiation of the sun and stars. Astron. Jr., March, 1914, 28: 129-135.

[32] *Dorno, C.* Himmelshelligkeit, Himmelspolarisation und Sonnenintensität in Davos, 1911 bis 1918. Met. Zeit., 36, 1919, S. 109-124.

[33] See MONTHLY WEATHER REVIEW for December, 1914, 42: 651-652, for the derivation of this factor.

[34] MONTHLY WEATHER REVIEW, loc. cit.

[35] *Kimball, Herbert H.* The meteorological aspect of the smoke problem. MONTHLY WEATHER REVIEW, January, 1914, 42:29-34. Kimball, Herbert H. and Thiessen, Alfred H. City smoke and daylight illumination intensities. MONTHLY WEATHER REVIEW, May 1917, 45:205-207.