CLIMATE OF MINNESOTA

Part XI - The Availability and Dependability of Solar Radiation at St. Paul, Minnesota

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Climate of Minnesota Part XI

The Availability and Dependability of Solar Radiation at St. Paul, Minnesota

Introduction

The climatology of solar radiation, that is, the areal and temporal distribution of solar radiation, is an important but frequently overlooked aspect of solar energy technology. It should be of general interest to anyone interested in the environment and of particular interest to those concerned with the design of solar energy collector and storage systems. It is apparent that the *availability* and *dependability* of solar radiation will dictate the feasibility of a particular system. Such information should be at hand for any designer and planner.

A study of the areal and temporal distribution of solar radiation within the North Central region is available (3). The only Minnesota station in that study was the National Weather Service Station at St. Cloud. Because the measurement of radiation at St. Cloud was terminated in 1972, this study is based on data from the St. Paul station, the only one currently in operation in Minnesota that has a record of sufficient longevity for a study of this kind.

The objective of this study is to provide more detailed information on radiation reception within the state, with particular emphasis upon the dependability of solar radiation. The study is divided into five parts:

1. Climatological parameters of importance to solar collector technology.
2. Weekly radiation reception probabilities.
3. Duration and frequency of runs of low radiation days.
4. Frequency of runs of high radiation days.
5. The relationship between air temperature and solar radiation.

Instrumentation and Site Description

The instrumentation used in this study is part of the microclimate research station on the St. Paul campus of the University of Minnesota. The station is located at 44°59′ N, 93°11′ W, and is 296 m MSL. The station site provides an unobstructed view of the sky hemisphere.

The microclimate research station is located within an area devoted to small agricultural test plots. The general area is best described as a modified rural environment, since there has been a gradual encroachment of private residences and university buildings. The central business districts of St. Paul and Minneapolis are

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approximately 8.3 km SE and 6.7 km WSW, respectively, of the microclimate station.

The solar radiometers used were 50-junction pyranometers with their output recorded on a circular chart single-pen recorder with a built-in mechanical integrator. The calibration of the pyranometers was checked against a similar instrument held in reserve for this purpose. The recorder was serviced on a regular basis. An observer was at the station at least once per day, and the pyranometer bulb was cleaned as required.

The pyranometers used were sensitive to both direct and diffuse radiation. The recorded values are of the total daily short-wave (solar) radiation received on a horizontal surface.

The units of solar radiation used in this bulletin are calories per square centimeter per day (cal $cm^{-2}day^{-1}$). With respect to other comparable units (5) 1 cal cm^{-2} day^{-1}

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=697.5 watts $meter^{-2}$=697.5 w m^{-2}.
=4.185 joules $centimeter^{-2}$ day^{-1}=
4.185 joules cm^{-2} day^{-1}.
=3.685 British thermal units $foot^{-2}$
day^{-1}= 3.685 Btu ft^{-2} day^{-1}.

Data Correction Procedures

Due to the occasional malfunctioning of equipment or the occurrence of heavy frost or ice on the radiometer dome, there were days or portions of days for which no data were available. This was not acceptable if the runs of days with high and low radiation values were to be determined. Therefore, it was necessary to estimate the missing portion of the record. This was done by one of two procedures: the albedo method or the regression method.

If at all possible, the reflected solar radiation, monitored by an adjoining and similar instrument to that which measured the incoming solar radiation at the St. Paul station, was used to determine the missing data. In this method the incoming and reflected (outgoing) solar radiation for several days before and several days after the missing day were compared to determine the mean albedo. Then the incoming solar radiation of the missing day was calculated using the reflected radiation measurement and the mean albedo.

When just a portion of the day was missing the reflected radiation trace on the daily chart was used to reconstruct the incoming radiation trace. This portion of the record was then hand integrated and added to that part of the daily record for which the measurement was available.

On those few occasions when the reflected radiation measurement was not available the regression method was used. In this case the value for the missing day was estimated using a weekly linear regression equation and the measured sunshine value at the Minneapolis-St. Paul National Weather Service station. This gave the estimated value for radiation at St. Cloud, which was then adjusted for the 125 km distance between St. Cloud and St. Paul. The regression equations were obtained from a publication by Baker and Haines (2).

The North Central Region study (3) computer program written to calculate the extremes, means, and probabilities of solar radiation reception was used for this study, while the program for the frequency of runs of high and low radiation values was prepared especially for this study. It should be noted that any run of either high or low radiation values which began in one month and continued into the succeeding month was counted only within the month in which the run began.

The basic time units used in this study are the calendar month and the climatological week. Week 1 is the week of March 1-7, and week 52 is February 21-27. Week 53, which includes February 28-29, was omitted from consideration. The advantage of the climatological week over the calendar week is that the day and week number remain the same regardless of whether there is a leap-year.

Results

1. CLIMATOLOGICAL PARAMETERS

Data contained in Table 1 are presented as an aid for design and planning purposes relative to solar radiation and its capture by various types of collectors.

The phototemperature and nyctotemperature, items 7 and 9 in Table 1, are estimates of the day and night temperatures, respectively. The phototemperature is defined by Went (7) as the mean daily temperature plus ¼ of the daily range and the nyctotemperature as the mean daily temperature less ¼ of the daily range. The daily range is, of course, the difference between the maximum and the minimum. This estimation method is necessary, since at most stations only the daily maximum and minimum temperatures are recorded.

Liu and Jordan (6) estimated the day temperature by the formula T (day) = 0.7 T (mean) + 0.3 T (maximum). In a comparison of the Liu and Jordan and the Went methods against the true mean temperature for the day at the St. Paul microclimate station, it was found that both provide good estimates. On the average the two were within 1.5°F of the true temperature. The Liu and Jordan method consistently underestimated the mean daytime temperature while the Went method overestimated it.

The Liu and Jordan method was not used here, since calculated day and night temperatures for a number of Minnesota stations have already been determined (4) using the Went method (7).

The inclusion of heating degree days (HDD), item 12 in Table 1, as a useful climatic parameter is due to the high correlation often found between cumulative HDD and fuel requirements of homes and industrial plants (1). A higher correlation between the two exists in the Minneapolis-St. Paul area than in western Minnesota due to the greater wind movement in the west. This is because the wind removes heat faster than the temperature differential between the inside and outside of buildings indicates.

Mean monthly HDD for a number of Minnesota stations and a map of the average annual total HDD are available in a bulletin by Baker and Strub (4).

Cooling degree days (CDD), item 13 in Table 1, are similar to HDD except they serve as a method to estimate summer-time energy requirements, principally for air conditioning. The assumption, of course, is that when the mean air temperature exceeds 65°F, air conditioning is required, and the energy is consumed in direct proportion to the difference between the mean air temperature and 65°F. Just as the wind factor can decrease the correlation between HDD and fuel requirements, so, too, can atmospheric humidity alter the relationship between CDD and energy requirements. "It isn't the heat, it's the humidity" is a common phrase that expresses this fact.

2. SOLAR RADIATION MEANS, EXTREMES AND PROBABILITIES

Table 2 contains the weekly probabilities of solar radiation reception at 10 percent increment levels from 10 to 90 percent. The number of daily observations used in the calculations is shown in the column immediately after the weekly period for which each set of data was calculated. Also shown are the maximum, minimum, and mean radiation values measured in each climatological week during the record period. The sixth column (standard of mean) is the standard deviation of the mean for each week of the year. It is the unbiased estimate of the standard deviation divided by the square root of the number of observations for that particular week.

An earlier study has indicated that a solar radiation record of at least six years in duration is required for a stable frequency distribution (3). The 15-year St. Paul record, 1963-1977, is, therefore, of sufficient duration to provide an adequate sample of expected radiation values and their distribution during the course of a year.

The mean is a particularly useful statistic as long as the data it represents are symmetrically distributed. However, daily radiation values in the North Central region are not normally distributed throughout the year (3). The mean remains the center of gravity of the data, but no longer are 50 percent of the values higher and 50 percent of the values lower than the mean. In Minnesota the distribution of solar radiation data is negatively skewed, particularly in the summer. Therefore, the mean is less than the median due to the influence of a few low values, and it no longer separates the data into two equal parts. In such cases the median is the preferred statistic for it does divide the data into two equal parts.

Figure 1 shows the potential and actual amounts of radiation received on a horizontal surface at St. Paul. In the absence of an atmosphere, it is the extraterrestrial radiation that would be received. However, the atmosphere absorbs and scatters radiation so that even when clouds are absent the amount received is on the average about 30 percent less then the potential or extraterrestrial radiation. As shown in Figure 1, the maximum daily radiation received (assumed to be clear day) can differ by 40 cal cm^{-2} or even more from week to week. This is due principally to the varying amount of water vapor and dust in the atmosphere. Thus, depending upon the time of year, clear-day values can vary from the maximum clear-day value by 5-10 percent in the summer to as much as 20 percent in the winter. The presence of clouds further diminishes the radiation received due mainly to reflection from the tops of the clouds and only slightly due to the absorption of radiation by the clouds themselves.

The skewness of the radiation data referred to earlier is evident in Figure 1. For example, even though the maximum values measured are between 750-775 cal cm^{-2} day^{-1} in June, the median or 50 percent value is approximately 575 cal cm^{-2} day^{-1}, or about 200 cal cm^{-2} day^{-1} greater than the expected mean if the data were normally distributed. However, skewness of the data nearly disappears in winter. This can be seen both in Figure 1 and Table 2 which show that the maximum weekly December values are only about double the 50 percent probable (median) values. In addition, the mean and median values are nearly equal indicating an approximately normal distribution.

3. FREQUENCY AND DURATION OF LOW RADIATION VALUES

The ideal energy source has at least two important features. One is that it is continuous, and another is that it remains above a certain minimum value. It is apparent that in regard to its receipt at the surface of the earth solar energy fails in both respects.

The discontinuous feature arises, of course, from the rotation of the earth about its axis producing the day-night effect. And as long as radiation is captured at the

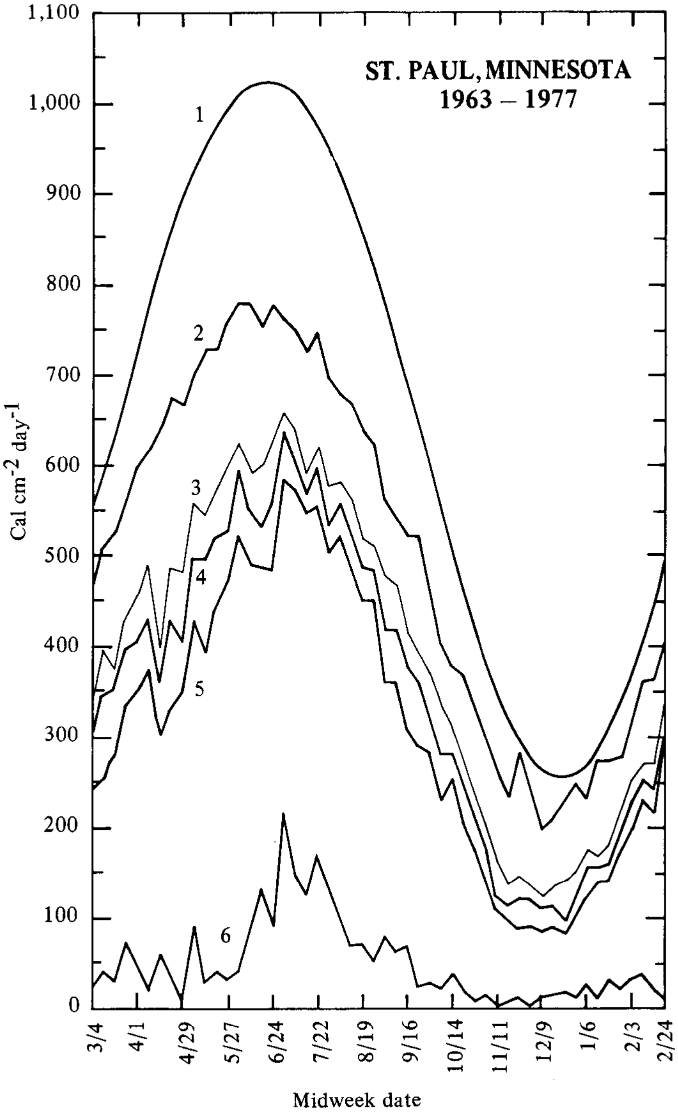

Figure 1. The total daily solar radiation received on a horizontal surface under six different conditions. Curve 1 is the extraterrestrial radiation at 45° N. Curves 2-6 represent values measured at St. Paul, 1963-1977; Curve 2 shows the maximum and curve 6 the minimum values during each week; and curves 3, 4, and 5 show the least amount of radiation that occurred with probabilities of 40, 50, and 60 percent, respectively, each week of the year.

surface of the earth this will remain a problem. Both Table 3 and Tables 4-26 are, therefore, directed to the other problem, which is selected threshold values of low radiation and the frequency at which they occurred.

The minimum or threshold value of radiation that is required for a solar collector to be effective depends upon environmental conditions and collector technology. Since collector design and engineering can be expected to improve with time, there can be no fixed threshold value with regard to minimum solar radiation amounts. Therefore, the next best idea is to present the radiation amounts at various incremental levels. The reader can select the threshold radiation that is appropriate for any set of circumstances.

The data shown in Tables 3-37 are based upon the 14-year period (1963-1976) rather than the 15-year period (1963-1977) used in Table 2.

Tables 4-16 show the frequency at which below-threshold runs of various lengths have occurred each year. A number such as 0.25 means that a particular run will be expected to occur once every four years. Several threshold levels have been included so that the user can choose the threshold value most closely related to the solar collector in use. These tables should aid in determining the size of the reservoir, or if indeed solar energy can be successfully used as an energy source for certain purposes. For example, is solar radiation sufficiently dependable when a run of three days in which it never exceeds 100 cal cm^{-2} day^{-1} has occurred with a frequency of 0.36 in January, 0.36 in February, 0.29 in September, 0.64 in October, 1.50 in November, and 1.93 in December? This means that in December almost two runs of three or more days duration are expected each year. In addition, on one occasion during the 14-year study period there were 12 consecutive December days when radiation never exceeded 100 cal cm^{-2} day^{-1} as shown in Table 7.

Tables 17-26 are presented to show what the probabilities are for receiving various amounts of radiation on a day succeeding one in which the total daily radiation failed to exceed a particular threshold value. For example, if the radiation did not exceed 100 cal cm^{-2} on a given November day, then there is a 50 percent probability that it will not exceed 100 cal cm^{-2} day^{-1} on the following day (Table 20), and the probability that any November day will not exceed 100 cal cm^{-2} day^{-1} is 39 percent (Table 3). This demonstrates the day-to-day persistence inherent in solar radiation values and certain other meteorological parameters, but care should be taken because it does not occur in all seasons or at all threshold values. This persistence means that there is a tendency for low radiation days and high radiation days to occur in groups, which has important ramifications with respect to the storage capabilities of a solar system.

4. RUNS OF HIGH RADIATION VALUES

Just as there is interest in the consecutive occurrence of daily radiation values below a certain threshold, there may also be interest in the runs of high radiation values. For this reason Tables 27-36 are presented. They show the frequency that runs of high radiation amounts have occurred at St. Paul for the period 1963-1976. From Table 27 it is evident that there was only one run in 14 years (probability of 0.07 per year or 7 percent) of three consecutive days in which the daily total equalled at least 750 cal cm^{-2}. A run of just two consecutive days with 750 cal cm^{-2} or more never occurred in the 14-year period.

With the threshold lowered to 700 cal cm^{-2} or more (Table 28), it can be seen that a run of six consecutive days (an annual probability of 0.07) occurred once in June. When the threshold value is lowered to at least 600 cal cm^{-2} day^{-1} (Table 30), a single run of 10 consecutive days is found in June (annual probability of 0.07).

It is apparent from studying Tables 27-36 that the highest probabilities and longest runs almost invariably occur in June. Since the summer solstice occurs on June 22, it may appear that June is the month of maximum mean radiation. But this is not the case as shown in Table 1, for the mean June radiation is 529 cal cm^{-2} day^{-1} compared to the mean July reception of 546 cal cm^{-2} day^{-1}. Table 3 also shows that there are more June than July days below 600 cal cm^{-2}.

Nevertheless, Tables 27-36 seem to show that June ordinarily receives more high radiation days than July in contrast to what is shown in Tables 1 and 3. This apparent paradox can be explained by the way in which the runs were counted. For example, those that began in June but continued into July were counted in June, the month in which they began. Thus, runs that began late in June, at the time of peak radiation, apparently have a relatively high probability of continuing if they extend into July, a month of less precipitation and cloud cover and greater sunshine than June.

5. RELATIONSHIP OF SOLAR RADIATION TO PHOTOTEMPERATURE

The relationship between daily air temperatures and daily solar radiation totals was studied for two reasons. First, the ambient air temperature affects the efficiency of a solar collector. Secondly, the air temperature also serves as a measure of the total energy need. As a result, it was deemed of value to determine if the variation between the two parameters was direct, indirect, or even random.

The phototemperature is an estimate of the mean air temperature during daylight hours when a solar collector is in use. Because the daytime temperature is normally not measured directly it has to be estimated, and, as noted earlier, it was calculated by the Went method (7). Went termed the daytime temperature estimate the phototemperature.

Results of the comparison between total daily radiation and the phototemperature (mean daytime temperature) are shown in Table 37. Quite a remarkable changeover is found during the course of the year. During the months of December-March, 61 percent or more of the days which have radiation greater than the median radiation for the month also have daytime temperatures that are lower than the 33rd percentile of the days for that month. Days with daytime temperatures which ranked below the 33rd percentile for a particular month were defined as low-temperature days. Thus, a third of the days each month are low-temperature days. With little fear of contradiction it can be stated, therefore, that during the winter a high radiation day is a low-temperature day. For the April-October period the reverse is more likely to be the case with a high radiation day associated with a high temperature day. November is apparently a transition month for the chances are about even that a high radiation day will be a low temperature day.

Climatologically the patterns noted are to be expected because in winter the cloudy days are ordinarily warmer than the clear days. This is because the sun's radiation is relatively insignificant in warming the earth in the presence of a highly reflective snow covered surface. Thus, even during the daytime clouds are effective in reducing the earth's heat loss. In addition, clouds, particularly the low-level clouds, are more often associated with the influx of warmer air from the south. In summer the reverse is usually the case with the cloudy days being the cool ones, since the clouds now serve to reduce the incoming radiation.

These results indicate that relatively high radiation amounts are available during the coldest winter days when solar radiation is needed the most. That the winter days with low radiation reception tend to be mild, could be of importance to the size of the energy storage facilities. This is because the runs of low radiation days will generally occur on relatively mild days when the heating demand is not so great.

Table 1. Minneapolis-St. Paul climatological data useful in the application of solar radiation data.*

	J	F	M	A	M	J	J	A	S	O	N	D	Mean, Total or Extreme
1. Mean solar radiation, cal cm^{-2} day^{-1}	155	243	318	379	468	527	546	460	337	234	135	113	326
2. Mean clear-day solar radiation, cal cm^{-2} day^{-1}	219	337	474	590	690	727	682	593	495	347	233	186	464
3. Mean extraterrestrial solar radiation, cal cm^{-2} day^{-1}	301	435	624	817	958	1,018	985	865	689	495	335	261	649
4. Ratio of 1 to 3, percent	52	56	51	46	49	52	55	53	49	47	40	43	50
5. Extreme maximum temperature, °F	58	59	83	92	95	100	104	102	98	89	75	63	104
6. Mean maximum temperature, °F	21	26	37	56	68	77	82	81	71	61	41	27	54
7. Phototemperature, °F	17	22	32	50	63	72	77	75	66	56	36	23	49
8. Mean temperature, °F	12	17	28	45	57	67	72	70	60	50	32	19	44
9. Nyctotemperature, °F	7	12	24	40	51	62	67	65	54	44	28	15	39
10. Mean minimum temperature, °F	3	7	20	35	46	57	61	60	49	39	24	11	34
11. Extreme minimum temperature, °F	−34	−28	−32	2	18	34	43	39	26	15	−17	−24	−34
12. Heating degree day normals	1,649	1,366	1,147	612	286	75	14	26	195	496	993	1,451	8,310
13. Cooling degree day normals	0	0	0	0	23	111	206	163	18	6	0	0	527

*Items 1 and 2 are for the period 1963-1976; items 6, 7, 8, 9, 10, 12, and 13 are for the period 1941-1970; and items 5 and 11 are for the period 1891-1976.

Table 2. Solar radiation received on a horizontal surface, cal cm^{-2} day^{-1}, St. Paul, Minnesota, 1963-1977.

WEEK	NUMBER OF OBSERVATIONS	MINIMUM RADIATION	MAXIMUM RADIATION	MEAN RADIATION	STD OF MEAN	PROBABILITY IN PERCENT OF RECEIVING AT LEAST THE INDICATED AMOUNT 90	80	70	60	50 (MEDIAN)	40	30	20	10
03/01 - 03/07	105	22.0	465.0	271.2	12.6	87.5	121.0	175.5	239.0	301.0	335.0	374.5	407.0	414.0
03/08 - 03/14	105	41.0	509.0	306.2	13.3	103.0	169.0	210.0	246.0	326.5	390.0	417.0	442.0	457.5
03/15 - 03/21	105	29.0	524.0	319.4	14.3	96.0	155.0	219.5	282.0	351.0	375.0	439.0	472.0	490.5
03/22 - 03/28	105	49.0	560.0	352.6	13.8	124.0	195.0	282.0	340.0	395.0	431.0	454.5	479.0	508.0
03/29 - 04/04	105	50.0	598.0	357.8	16.6	89.0	166.0	239.0	329.0	391.5	447.0	496.5	519.0	552.0
04/05 - 04/11	105	20.0	616.0	395.4	16.5	125.5	208.0	264.5	388.0	450.0	492.0	535.5	558.0	566.0
04/12 - 04/18	105	60.0	643.0	344.7	16.9	82.5	162.0	225.5	304.0	356.0	400.0	468.0	531.0	560.5
04/19 - 04/25	105	25.0	675.0	398.9	19.3	109.5	174.0	248.5	337.0	437.5	500.0	562.0	605.0	625.5
04/26 - 05/02	105	8.0	666.0	404.6	19.2	116.5	184.0	287.5	363.0	420.0	493.0	556.5	612.0	634.5
05/03 - 05/09	105	91.0	703.0	476.3	17.2	213.5	273.0	386.5	432.0	500.5	575.0	619.0	653.0	669.5
05/10 - 05/16	105	31.0	727.0	446.7	20.0	141.0	199.0	312.5	412.0	502.0	558.0	620.5	646.0	668.5
05/17 - 05/23	105	40.0	729.0	472.3	18.1	212.5	266.0	368.0	429.0	518.0	575.0	610.5	638.0	687.0
05/24 - 05/30	105	33.0	758.0	489.4	19.6	178.0	290.0	375.0	485.0	542.0	591.0	630.5	673.0	713.5
05/31 - 06/06	105	40.0	780.0	528.6	17.3	249.5	327.0	444.0	537.0	596.0	626.0	651.5	682.0	707.5
06/07 - 06/13	105	92.0	777.0	515.7	17.0	227.5	366.0	446.5	509.0	553.5	595.0	638.0	679.0	703.0
06/14 - 06/20	105	133.0	755.0	519.4	15.5	276.5	352.0	443.0	489.0	530.5	600.0	640.0	668.0	705.5
06/21 - 06/27	105	91.0	777.0	523.4	17.4	225.0	351.0	441.0	488.0	575.5	632.0	653.0	676.0	710.0
06/28 - 07/04	105	216.0	761.0	583.7	13.0	378.0	459.0	511.0	583.0	635.5	654.0	680.0	702.0	713.5
07/05 - 07/11	105	146.0	747.0	554.5	14.7	306.0	448.0	523.5	568.0	606.0	636.0	649.5	672.0	695.0
07/12 - 07/18	105	125.0	726.0	533.0	14.0	260.0	423.0	502.5	544.0	569.5	600.0	628.5	644.0	670.5
07/19 - 07/25	105	173.0	748.0	560.7	12.3	375.5	447.0	519.5	553.0	600.5	625.0	642.0	656.0	687.0
07/26 - 08/01	105	135.0	695.0	498.8	13.5	300.5	368.0	435.0	492.0	529.5	575.0	600.0	618.0	643.5
08/02 - 08/08	105	91.0	677.0	513.7	12.9	327.0	398.0	478.0	518.0	557.5	576.0	598.5	622.0	646.5
08/09 - 08/15	105	69.0	669.0	490.8	13.1	266.5	383.0	448.5	492.0	526.0	565.0	586.0	602.0	618.0
08/16 - 08/22	105	70.0	640.0	443.8	14.1	204.5	299.0	385.5	444.0	483.5	514.0	553.0	568.0	596.0
08/23 - 08/29	105	53.0	624.0	416.1	15.4	162.0	258.0	346.0	430.0	481.0	511.0	525.0	553.0	574.5
08/30 - 09/05	105	79.0	562.0	398.0	12.4	201.5	276.0	335.0	358.0	417.5	474.0	497.0	518.0	539.0
09/06 - 09/12	105	63.0	541.0	362.8	14.1	131.5	175.0	280.0	361.0	409.0	460.0	479.5	494.0	510.5
09/13 - 09/19	105	68.0	522.0	325.8	14.7	103.0	141.0	204.5	290.0	375.0	414.0	455.0	470.0	494.5
09/20 - 09/26	105	25.0	522.0	290.8	14.7	73.5	101.0	157.0	279.0	334.0	386.0	416.5	435.0	458.5
09/27 - 10/03	105	27.0	457.0	297.5	11.7	110.5	186.0	224.0	282.0	326.0	370.0	395.0	409.0	421.5
10/04 - 10/10	105	21.0	400.0	249.6	11.9	65.0	105.0	168.5	224.0	271.0	327.0	360.5	369.0	380.5
10/11 - 10/17	105	38.0	378.0	246.3	10.5	69.5	114.0	178.0	258.0	286.0	313.0	325.5	337.0	350.0
10/18 - 10/24	105	18.0	366.0	214.7	10.1	66.0	95.0	134.5	204.0	246.5	270.0	289.0	314.0	330.0
10/25 - 10/31	105	9.0	332.0	190.3	8.9	37.5	89.0	131.5	177.0	210.5	240.0	254.0	277.0	294.0
11/01 - 11/07	105	15.0	299.0	163.4	8.3	40.5	70.0	95.5	142.0	175.5	208.0	228.5	252.0	265.0
11/08 - 11/14	105	1.0	264.0	136.2	7.6	29.0	64.0	73.5	108.0	123.5	162.0	202.0	222.0	240.5
11/15 - 11/21	105	7.0	233.0	121.3	6.4	39.5	57.0	70.0	96.0	114.0	137.0	158.5	201.0	211.5
11/22 - 11/28	105	13.0	281.0	120.4	6.4	30.5	51.0	71.0	88.0	119.5	145.0	171.0	185.0	200.0
11/29 - 12/05	105	1.0	235.0	117.3	5.7	37.0	61.0	78.0	91.0	116.5	135.0	155.5	178.0	190.5
12/06 - 12/12	105	14.0	197.0	110.2	5.3	34.5	56.0	72.0	85.0	110.0	124.0	154.5	170.0	180.0
12/13 - 12/19	105	16.0	209.0	111.1	5.4	37.0	50.0	65.5	90.0	113.0	135.0	148.0	167.0	184.0
12/20 - 12/26	105	19.0	229.0	113.4	5.5	43.0	56.0	70.0	82.0	98.0	139.0	159.5	173.0	186.0
12/27 - 01/02	105	13.0	273.0	124.7	5.7	45.0	66.0	80.5	100.0	126.0	151.0	163.0	180.0	195.0
01/03 - 01/09	105	26.0	236.0	142.4	5.4	56.5	89.0	104.0	134.0	153.5	173.0	184.0	194.0	201.5
01/10 - 01/16	105	10.0	273.0	149.0	5.5	71.5	94.0	118.5	138.0	154.5	167.0	186.0	199.0	218.5
01/17 - 01/23	105	31.0	272.0	153.7	6.2	56.5	84.0	111.5	138.0	159.0	183.0	198.0	214.0	230.0
01/24 - 01/30	105	20.0	276.0	178.8	6.7	66.5	97.0	149.5	173.0	190.0	215.0	232.0	244.0	254.0
01/31 - 02/06	105	32.0	312.0	265.3	7.8	82.5	109.0	169.5	208.0	239.0	254.0	263.5	277.0	288.0
02/07 - 02/13	105	36.0	360.0	229.9	7.6	98.5	155.0	202.0	231.0	250.5	268.0	283.0	296.0	311.0
02/14 - 02/20	105	20.0	363.0	237.8	8.7	107.5	151.0	185.5	215.0	239.5	270.0	307.5	329.0	343.5
02/21 - 02/27	105	7.0	417.0	286.6	9.0	129.0	213.0	260.5	293.0	312.5	337.0	347.0	360.0	380.0

Table 3. Cumulative frequency in percent of the number of days each month equal to or less than the indicated threshold value for the period 1963-1976.

Month	Number of days	Threshold values, cal cm^{-2} day^{-1}																			
		25	50	75	100	125	150	175	200	225	250	275	300	350	400	450	500	550	600	700	800
Jan.	434	1	8	14	26	34	43	57	75	86	94	100	100	100	100	100	100	100	100	100	100
Feb..	396	1	2	4	10	16	19	23	28	37	45	57	70	89	99	100	100	100	100	100	100
Mar.	434	0	3	5	9	13	18	21	25	30	33	37	41	49	62	79	92	99	100	100	100
Apr.	420	1	1	5	10	14	17	20	23	27	32	35	37	42	52	57	66	76	90	100	100
May	434	0	1	2	4	5	7	10	13	17	20	22	24	30	36	43	49	57	67	92	100
June	420	0	0	0	1	1	3	4	6	7	9	11	13	19	25	31	40	47	55	86	100
July	434	0	0	0	0	0	1	3	3	5	6	6	8	11	15	22	29	41	54	92	100
Aug.	434	0	0	1	2	3	5	7	9	11	12	14	17	22	29	35	48	64	85	100	100
Sept.	420	0	2	4	9	14	17	21	24	27	28	31	35	42	54	71	88	99	100	100	100
Oct.	434	3	6	12	18	24	28	32	35	41	47	56	65	85	98	100	100	100	100	100	100
Nov.	420	5	17	28	39	48	56	65	75	88	94	99	100	100	100	100	100	100	100	100	100
Dec.	434	3	17	32	47	56	67	82	97	99	100	100	100	100	100	100	100	100	100	100	100

Table 4. Frequency per year of runs with incident solar radiation ≤25 cal cm^{-2} day^{-1} at St. Paul.

Month	Number of days in run											
	1	2	3	4	5	6	7	8	9	10	11-20	21-40
Jan.	0.21	0										
Feb.	0.14	0										
Mar.	0.07	0										
Apr.*	0.29	0										
Sept.	0.07	0										
Oct.	0.43	0.21	0									
Nov.	1.29	0.14	0									
Dec.	0.64	0.14	0									

*May-August are omitted because no runs occurred.

Table 5. Frequency per year of runs with incident solar radiation ≤50 cal cm^{-2} day^{-1} at St. Paul.

Month	Number of days in run											
	1	2	3	4	5	6	7	8	9	10	11-20	21-40
Jan.	1.64	0.29	0	0.07	0							
Feb.	0.43	0										
Mar.	0.64	0.07	0									
Apr.	0.43	0										
May.	0.21	0										
June*	0.07	0										
Sept.	0.29	0	0.07	0								
Oct.	0.79	1.21	0.14	0.07	0.07	0						
Nov.	2.71	0.64	0.21	0								
Dec.	2.14	0.57	0.29	0.14	0	0.07	0					

*July and August are omitted because no runs occurred.

Table 6. Frequency per year of runs with incident solar radiation ≤75 cal cm $^{-2}$ day^{-1} at St. Paul.

Month	Number of days in run											
	1	2	3	4	5	6	7	8	9	10	11-20	21-40
Jan.	2.79	0.50	0.07	0.14	0							
Feb.	0.86	0.14	0									
Mar.	1.14	0.14	0									
Apr.	1.50	0.07	0									
May	0.36	0.14	0									
June*	0.07	0										
Aug.	0.29	0										

Table 6. (Continued)

Month	Number of days in run 1	2	3	4	5	6	7	8	9	10	11-20	21-40
Sept.	0.79	0.14	0.07	0								
Oct.	1.93	0.29	0.14	0.14	0.14	0						
Nov.	2.50	1.43	0.57	0.07	0	0	0.07	0				
Dec.	3.57	0.86	0.43	0.43	0.14	0	0.14	0				

*July is omitted because no runs occurred.

Table 7. Frequency per year of runs with incident solar radiation ≤100 cal cm^{-2} day^{-1} at St. Paul.

Month	Number of days in run 1	2	3	4	5	6	7	8	9	10	11-20	21-40
Jan.	4.36	1.0	0.07	0.14	0.07	0	0	0.07	0	0	0.07	0
Feb.	1.57	0.14	0.36	0								
Mar.	1.64	0.36	0.07	0								
Apr.	2.86	0.07	0.07	0								
May	0.71	0.07	0.07	0								
June*	0.21	0										
Aug.	0.36	0.07	0.07	0								
Sept.	1.29	0.21	0.14	0.14	0							
Oct.	2.07	0.86	0.36	0.14	0.14	0						
Nov.	2.86	1.29	0.93	0.29	0.07	0.14	0.07	0				
Dec.	3.71	1.07	0.71	0.36	0.50	0.14	0.07	0	0.07	0	0	0.07

*July is omitted because no runs occurred.

Table 8. Frequency per year of runs with incident solar radiation ≤125 cal cm^{-2} day^{-1} at St. Paul.

Month	Number of days in run 1	2	3	4	5	6	7	8	9	10	11-20	21-40
Jan.	4.36	1.57	0.36	0.14	0.07	0.07	0	0.07	0			
Feb.	1.86	0.50	0.36	0.07	0.07	0						
Mar.	1.79	0.64	0.14	0.07	0							
Apr.	2.50	0.43	0.29	0								
May	0.71	0.21	0.07	0								
June	0.43	0										
July	0.07	0										
Aug.	0.64	0.07	0.07	0								
Sept.	1.57	0.50	0.07	0.21	0	0.07	0					
Oct.	2.29	0.86	0.50	0.36	0.14	0	0	0	0	0	0.07	0
Nov.	2.50	1.36	1.21	0.50	0.21	0.14	0.07	0				
Dec.	2.50	1.07	0.86	0.43	0.50	0.36	0.14	0.14	0	0.07	0.07	0

Table 9. Frequency per year of runs with incident solar radiation ≤150 cal cm^{-2} day^{-1} at St. Paul.

Month	Number of days in run 1	2	3	4	5	6	7	8	9	10	11-20	21-40
Jan.	4.07	1.71	0.79	0.29	0.07	0	0.07	0.07	0.07	0		
Feb.	2.29	0.43	0.36	0.21	0	0.07	0					
Mar.	2.14	1.07	0.29	0.07	0							
Apr.	2.57	0.57	0.36	0.07	0							
May	1.00	0.36	0.14	0								
June	0.57	0.14	0									
July	0.36	0										
Aug.	1.00	0.14	0	0.07	0							
Sept.	1.93	0.64	0.14	0.29	0	0.07	0					
Oct.	2.57	1.00	0.36	0.57	0.07	0.14	0					
Nov.	2.36	1.43	1.07	0.43	0.29	0.29	0.07	0.21	0			
Dec.	1.71	1.14	0.71	0.57	0.43	0.36	0.21	0.21	0.07	0.21	0.14	0

Table 10. Frequency per year of runs with incident solar radiation ≤175 cal cm^{-2} day^{-1} at St. Paul.

Month	Number of days in run 1	2	3	4	5	6	7	8	9	10	11-20	21-40
Jan.	3.57	1.57	0.64	0.64	0.29	0	0.07	0.14	0.07	0	0.14	0
Feb.	2.50	0.71	0.36	0.07	0.21	0.07	0					
Mar.	2.36	1.36	0.36	0.07	0							
Apr.	2.43	0.86	0.36	0.14	0							
May	1.29	0.50	0.21	0								
June	0.93	0.07	0.07	0								
July	0.79	0										
Aug.	1.21	0.29	0	0	0.07	0						
Sept.	2.14	0.79	0.29	0.36	0	0.07	0					
Oct.	2.64	1.00	0.43	0.64	0.14	0.21	0					
Nov.*	1.43	1.07	0.93	0.36	0.43	0.29	0.21	0.14	0	0	0.21	0.07

* December is omitted because at least 70 percent of the daily totals ≤175 cal cm^{-2}.

Table 11. Frequency per year of runs with incident solar radiation ≤200 cal cm^{-2} day^{-1} at St. Paul.

Month	Number of days in run 1	2	3	4	5	6	7	8	9	10	11-20	21-40
Jan.	1.36	1.21	0.43	0.43	0.14	0.14	0.07	0.14	0	0.21	0.14	0
Feb.	2.86	0.71	0.43	0.14	0.21	0.14	0					
Mar.	2.50	1.57	0.36	0.14	0	0	0.07	0				
Apr.	2.71	1.00	0.36	0.21	0							
May	1.86	0.71	0.21	0								
June	1.21	0.14	0.14	0								
July	1.00	0										
Aug.	1.36	0.36	0	0.07	0.07	0						
Sept.	2.36	1.00	0.29	0.36	0	0.07	0					
Oct.*	2.79	1.21	0.36	0.57	0.14	0.29	0	0	0.07	0		

*November and December are omitted because at least 70 percent of the daily totals ≤200 cal cm^{-2}.

Table 12. Frequency per year of runs with incident solar radiation ≤225 cal cm^{-2} day^{-1} at St. Paul.

Month	Number of days in run 1	2	3	4	5	6	7	8	9	10	11-20	21-40
Feb.*	2.79	1.21	0.64	0.21	0.29	0.07	0	0	0.07	0		
Mar.	2.86	1.86	0.50	0.14	0	0	0.07	0				
Apr.	2.36	1.43	0.50	0.29	0							
May	1.93	1.07	0.21	0.07	0							
June	1.43	0.14	0.14	0								
July	1.29	0.07	0									
Aug.	1.36	0.50	0.14	0.07	0.07	0						
Sept.	2.21	0.93	0.43	0.50	0	0	0	0	0	0.07	0	
Oct.*	2.57	1.36	0.29	0.57	0.21	0.14	0.07	0.07	0	0	0.14	0

*January, November, and December are omitted because at least 70 percent of the daily totals ≤225 cal cm^{-2}.

Table 13. Frequency per year of runs with incident solar radiation ≤ 250 cal cm^{-2} day^{-1} at St. Paul.

Month	Number of days in run											
	1	2	3	4	5	6	7	8	9	10	11-20	21-40
Feb.*	2.57	1.21	0.64	0.57	0.21	0.14	0	0.14	0.07	0		
Mar.	3.07	1.71	0.50	0.21	0.07	0	0.07	0				
Apr.	2.50	1.07	0.93	0.29	0.14	0						
May	2.14	1.00	0.50	0.07	0							
June	1.93	0.14	0.14	0								
July	1.64	0.07	0									
Aug.	1.64	0.57	0.14	0.07	0							
Sept.	2.14	1.14	0.29	0.64	0	0	0	0	0	0	0.07	0
Oct.*	2.21	1.07	0.57	0.64	0.36	0.14	0.07	0.07	0	0.07	0.14	0

*January, November and December are omitted because at least 70 percent of the daily totals ≤ 250 cal cm^{-2}.

Table 14. Frequency per year of runs with incident solar radiation ≤ 300 cal cm^{-2} day^{-1} at St. Paul.

Month	Number of days in run											
	1	2	3	4	5	6	7	8	9	10	11-20	21-40
Feb.*	1.43	0.79	0.50	0.57	0.50	0	0.14	0	0	0	0.07	0
Mar.	3.00	1.64	0.57	0.36	0.07	0.21	0.14	0				
Apr.	2.57	1.07	1.07	0.36	0.29	0						
May	2.43	1.29	0.36	0.14	0.14	0						
June	2.57	0.43	0.07	0.07	0							
July	2.21	0.07	0									
Aug.	1.79	0.93	0.21	0.07	0.07	0.07	0					
Sept.	2.29	1.36	0.50	0.79	0.07	0	0	0	0	0	0.07	0
Oct.*	1.71	1.00	0.36	0.43	0.21	0.07	0.07	0.14	0.14	0		

*January, November, and December are omitted because at least 70 percent of the daily totals ≤ 300 cal cm^{-2}.

Table 15. Frequency per year of runs with incident solar radiation ≤ 400 cal cm^{-2} day^{-1} at St. Paul.

Month	Number of days in run											
	1	2	3	4	5	6	7	8	9	10	11-20	21-40
Mar.*	2.29	1.07	1.00	0.79	0.36	0.14	0.29	0.07	0.07	0	0.07	0
Apr.	2.50	1.29	0.71	0.50	0.43	0.21	0	0.07	0.07	0	0.07	0
May	2.36	1.29	0.36	0.57	0.07	0.14	0.07	0.07	0			
June	3.07	1.00	0.36	0.14	0.14	0						
July	2.79	0.57	0.14	0.07	0							
Aug.	2.50	1.14	0.57	0.21	0.14	0.14	0.07	0				
Sept.*	1.43	1.43	1.00	0.57	0.21	0.07	0.07	0	0.07	0.07	0.07	0

*January, February, and October-December are omitted because at least 70 percent of the daily totals ≤ 400 cal cm^{-2}.

Table 16. Frequency per year of runs with incident solar radiation ≤ 500 cal cm^{-2} day^{-1} at St. Paul.

Month	Number of days in run											
	1	2	3	4	5	6	7	8	9	10	11-20	21-40
Apr.*	1.64	0.86	0.79	0.79	0.57	0.29	0.21	0.14	0.07	0	0.14	0
May	2.71	1.14	0.93	0.43	0.21	0.07	0.14	0.21	0			
June	2.93	1.93	0.36	0.36	0.07	0	0	0	0.07	0.07	0.07	0
July	3.86	0.79	0.86	0.14	0.07	0						
Aug.*	2.71	1.43	0.93	0.43	0.07	0.43	0.07	0.07	0.07	0	0.14	0

*January-March and September-December are omitted because at least 70 percent of the daily totals ≤ 500 cal cm^{-2}.

Table 17. Percent probability of receiving no more than the indicated value of total daily solar radiation given that no more than 25 cal cm^{-2} was received on the previous day.

Month	Solar radiation, cal cm^{-2} day^{-1}											
	25	50	75	100	150	200	250	300	400	500	600	700	800
Jan.	0	0	33	33	33	66	100						
Feb.	0	0	0	0	0	50	100						
Mar.	0	0	0	0	0	0	0	100					
Apr.*	0	0	0	0	25	25	75	75	75	75	75	100	
Sept.	0	0	0	0	0	0	0	0	100				
Oct.	30	40	50	50	60	60	60	100					
Nov.	8	37	45	54	79	87	95	100					
Dec.	15	30	46	61	84	100							

*May-August are omitted because there were no days with radiation ≤25 cal cm^{-2}.

Table 18. Percent probability of receiving no more than the indicated value of total daily solar radiation given that no more than 50 cal cm^{-2} was received on the previous day.

Month	Solar radiation, cal cm^{-2} day^{-1}											
	25	50	75	100	150	200	250	300	400	500	600	700	800
Jan.	3	18	24	36	63	81	96	100					
Feb.	0	14	28	42	57	71	85	100					
Mar.	0	8	8	25	41	50	50	83	83	100			
Apr.	0	0	0	0	16	50	50	50	66	66	83	100	
May	0	0	33	66	66	66	66	100					
June*	0	0	0	0	0	0	0	0	0	100			
Sept.	0	28	28	42	57	57	57	57	85	100			
Oct.	26	34	47	52	69	73	82	95	100				
Nov.	8	27	48	55	77	88	95	100					
Dec.	8	37	56	64	82	100							

*July and August are omitted because there were no days with radiation ≤50 cal cm^{-2}.

Table 19. Percent probability of receiving no more than the indicated value of total daily solar radiation given that no more than 75 cal cm^{-2} was received on the previous day.

Month	Solar radiation, cal cm^{-2} day^{-1}											
	25	50	75	100	150	200	250	300	400	500	600	700	800
Jan.	3	13	21	36	59	81	90	100					
Feb.	0	11	16	33	44	50	66	83	100				
Mar.	0	13	13	26	47	56	56	86	86	100			
Apr.	0	0	0	4	14	23	33	33	47	52	90	100	
May	0	9	27	36	54	63	63	72	81	81	90	100	
June*	0	0	0	0	0	0	0	0	0	0	100		
Aug.	0	0	0	0	0	0	50	75	75	100			
Sept.	5	16	22	38	55	55	61	66	83	100			
Oct.	12	18	29	35	50	56	64	81	100				
Nov.	7	24	43	52	72	86	97	100					
Dec.	5	25	45	60	76	98	100						

*July is omitted because there were no days with radiation ≤75 cal cm^{-2}.

Table 20. Percent probability of receiving no more than the indicated value of total daily solar radiation given that no more than 100 cal cm^{-2} was received on the previous day.

Month	Solar radiation, cal cm^{-2} day^{-1}											
	25	50	75	100	150	200	250	300	400	500	600	700	800
Jan.	1	11	20	29	49	83	95	100					
Feb.	0	9	12	29	46	48	68	85	100				
Mar.	0	12	12	23	53	61	64	82	87	100			
Apr.	0	0	2	4	21	29	43	48	60	68	92	100	
May	0	5	16	22	38	44	50	55	77	77	88	100	
June*	0	0	0	0	0	33	33	33	66	66	100		
Aug.	0	0	22	33	33	33	66	77	77	88	100		
Sept.	2	7	15	34	47	57	63	68	86	100			
Oct.	9	16	24	37	51	55	62	75	98	100			
Nov.	6	21	39	50	68	84	97	100					
Dec.	3	21	39	54	72	98	100						

*July is omitted because there were no days with radiation ≤100 cal cm^{-2}.

Table 21. Percent probability of receiving no more than the indicated value of total daily solar radiation given that no more than 150 cal cm^{-2} was received on the previous day.

Month	Solar radiation, cal cm^{-2} day^{-1}												
	25	50	75	100	150	200	250	300	400	500	600	700	800
Jan.	1	9	17	27	45	80	95	100					
Feb.	0	5	6	20	36	44	58	83	100				
Mar.	0	8	10	15	37	44	49	65	75	93	100		
Apr.	1	1	7	12	29	39	50	56	66	73	95	100	
May	0	5	14	20	31	40	48	54	71	77	85	97	100
June	0	0	0	0	16	33	33	33	50	75	91	100	
July	0	0	0	0	0	0	25	25	50	50	75	100	
Aug.	0	0	9	22	22	22	40	45	63	77	95	100	
Sept.	1	5	10	21	41	46	53	57	76	98	100		
Oct.	6	11	20	33	47	54	66	79	99	100			
Nov.	5	19	34	45	64	82	97	100					
Dec.	3	19	38	52	71	98	100						

Table 22. Percent probability of receiving no more than the indicated value of total daily solar radiation given that no more than 200 cal cm^{-2} was received on the previous day.

Month	Solar radiation, cal cm^{-2} day^{-1}												
	25	50	75	100	150	200	250	300	400	500	600	700	800
Jan.	0	8	15	28	46	80	96	100					
Feb.	0	4	6	16	33	41	54	80	96	100			
Mar.	0	6	9	12	33	41	46	57	73	91	100		
April	1	1	7	13	26	37	47	54	65	70	93	100	
May	0	5	11	16	23	30	40	43	61	71	85	98	100
June	0	0	0	0	10	21	21	21	50	64	78	89	100
July	0	0	0	0	0	0	7	7	30	38	61	100	
Aug.	0	0	5	13	22	33	50	52	66	77	97	100	
Sept.	1	4	9	18	34	42	48	53	73	98	100		
Oct.	6	11	20	33	45	52	66	79	99	100			
Nov.	6	18	32	44	61	81	97	100					
Dec.	3	17	32	47	66	97	100						

Table 23. Percent probability of receiving no more than the indicated value of total daily solar radiation given that no more than 250 cal cm^{-2} was received on the previous day.

Month	Solar radiation, cal cm^{-2} day^{-1}											
	25	50	75	100	150	200	250	300	400	500	600	700	800
Jan.	0	8	14	27	44	77	95	100					
Feb.	0	3	5	14	28	39	55	77	100				
Mar.	0	5	8	13	30	37	45	56	73	92	100		
Apr.	1	1	5	13	26	36	47	53	66	72	93	100	
May	0	3	9	12	20	29	38	44	60	70	85	97	100
June	0	0	0	0	7	15	15	15	44	60	76	89	100
July	0	0	0	0	0	0	4	4	24	32	60	100	
Aug.	0	0	3	11	17	25	36	44	57	74	96	100	
Sept.	0	3	7	16	33	44	50	54	74	96	100		
Oct.	5	9	17	28	43	51	63	79	98	100			
Nov.	5	17	29	40	58	77	95	100					
Dec.	2	16	32	47	66	97	100						

Table 24. Percent probability of receiving no more than the indicated value of total daily solar radiation given that no more than 300 cal cm^{-2} was received on the previous day.

Month	Solar radiation, cal cm^{-2} day^{-1}											
	25	50	75	100	150	200	250	300	400	500	600	700	800
Jan.	0	7	14	25	42	74	94	100					
Feb.	0	2	4	12	23	33	50	77	99	100			
Mar.	0	4	7	11	27	34	42	52	72	92	100		
Apr.	1	1	6	13	26	35	45	50	64	71	92	100	
May	0	2	7	10	17	26	35	42	57	70	85	98	100
June	0	0	0	1	6	15	17	20	41	50	74	89	100
July	0	0	0	0	0	0	3	3	18	30	63	96	100
Aug.	0	0	4	11	15	25	35	42	57	78	97	100	
Sept.	0	2	6	15	30	40	45	51	74	95	100		
Oct.	4	8	15	23	37	45	58	76	98	100			
Nov.	5	16	27	38	56	74	93	100					
Dec.	2	16	32	47	66	97	100						

Table 25. Percent probability of receiving no more than the indicated value of total daily solar radiation given that no more than 350 cal cm^{-2} was received on the previous day.

Month	Solar radiation, cal cm^{-2} day^{-1}											
	25	50	75	100	150	200	250	300	400	500	600	700	800
Jan.	0	7	14	25	42	74	94	100					
Feb.	0	1	4	10	19	29	47	74	99	100			
Mar.	0	4	6	12	26	33	40	49	68	91	100		
Apr.	1	1	7	14	27	36	46	50	66	73	93	100	
May	0	2	6	9	16	25	34	40	54	66	83	98	100
June	0	0	0	2	6	12	13	19	35	50	69	90	100
July	0	0	0	0	0	0	4	8	28	39	67	95	100
Aug.	0	0	3	8	13	23	30	36	49	71	94	100	
Sept.	0	2	6	15	28	36	42	47	71	93	100		
Oct.	3	6	13	20	31	39	52	71	98	100			
Nov.	5	16	27	38	56	74	93	100					
Dec.	2	16	32	47	66	97	100						

Table 26. Percent probability of receiving no more than the indicated value of total daily solar radiation given that no more than 400 cal cm^{-2} was received on the previous day.

Month	Solar radiation, cal cm^{-2} day^{-1}												
	25	50	75	100	150	200	250	300	400	500	600	700	800
Jan.	0	7	14	25	42	74	94	100					
Feb.	0	1	4	10	19	28	45	70	99	100			
Mar.	0	3	6	12	25	32	39	47	67	91	100		
Apr.	0	0	5	12	23	30	40	45	62	72	93	100	
May	0	1	5	7	14	23	33	40	54	66	82	98	100
June	0	0	0	1	6	14	14	20	35	49	69	91	100
July	0	0	0	0	1	3	7	10	24	35	70	93	100
Aug.	0	0	2	6	11	19	26	33	47	68	90	100	
Sept.	0	2	6	12	24	32	38	45	67	93	100		
Oct.	2	6	12	18	29	36	48	66	98	100			
Nov.	5	16	27	38	56	74	93	100					
Dec.	2	16	32	47	66	97	100						

Table 27. Frequency per year of runs with incident solar radiation ≥750 cal cm^{-2} day^{-1} at St. Paul.

Month	Number of days in run											
	1	2	3	4	5	6	7	8	9	10	11-20	21-40
May*	0.14	0										
June	0.36	0	0.07	0								
July*	0.14	0										

*January-April and August-December are omitted because no runs occurred.

Table 28. Frequency per year of runs with incident solar radiation ≥700 cal cm^{-2} day^{-1} at St. Paul.

Month	Number of days in run											
	1	2	3	4	5	6	7	8	9	10	11-20	21-40
May*	1.00	0.29	0.21	0.07	0							
June	2.29	0.50	0.21	0	0	0.07	0					
July*	1.21	0.36	0	0.07	0							

*January-April and August-December are omitted because no runs occurred.

Table 29. Frequency per year of runs with incident solar radiation ≥650 cal cm^{-2} day^{-1} at St. Paul.

Month	Number of days in run											
	1	2	3	4	5	6	7	8	9	10	11-20	21-40
Apr.*	0.29	0.21	0									
May	2.07	0.71	0.64	0.21	0							
June	2.29	1.36	0.43	0.29	0.21	0.07	0.14	0				
July	2.50	1.07	0.29	0.29	0.07	0						
Aug.*	0.50	0.14	0									

*January-March and September-December are omitted because no runs occurred.

Table 30. Frequency per year of runs with incident solar radiation $\geq$600 cal cm^{-2} day^{-1} at St. Paul.

Month	Number of days in run 1	2	3	4	5	6	7	8	9	10	11-20	21-40
Apr.*	0.93	0.71	0	0.21	0							
May	2.07	1.14	0.79	0.36	0.29	0.14	0					
June	2.79	1.50	0.79	0.29	0.07	0.36	0.21	0	0	0.07	0	
July	2.64	0.86	1.43	0.43	0.21	0.21	0.14	0				
Aug.*	2.14	0.71	0.29	0								

*January-March and September-December are omitted because no runs occurred.

Table 31. Frequency per year of runs with incident solar radiation $\geq$550 cal cm^{-2} day^{-1} at St. Paul.

Month	Number of days in run 1	2	3	4	5	6	7	8	9	10	11-20	21-40
Mar.*	0.21	0.07	0									
Apr.	2.57	1.36	0.14	0.21	0.07	0.07	0	0.07	0			
May	2.50	1.36	0.50	0.43	0.21	0.29	0	0.07	0.14	0		
June	2.43	1.43	0.79	0.36	0.21	0.36	0.14	0.07	0	0.14	0.14	0
July	2.21	1.29	0.93	0.64	0.36	0.29	0.21	0.07	0.14	0.07	0	
Aug.	3.07	1.21	0.64	0.36	0.21	0.14	0					
Sept.*	0.07	0.07	0									

*January-February and October-December are omitted because no runs occurred.

Table 32. Frequency per year of runs with incident solar radiation $\geq$500 cal cm^{-2} day^{-1} at St. Paul.

Month	Number of days in run 1	2	3	4	5	6	7	8	9	10	11-20	21-40
Mar.*	1.93	0.21	0.14	0								
Apr.	2.64	1.79	0.50	0.21	0.29	0.07	0	0.07	0			
May	2.64	1.36	0.57	0.43	0.43	0.36	0.14	0.07	0.14	0		
June	2.43	1.14	0.64	0.64	0.14	0.29	0.29	0.07	0	0.21	0.21	0
July	1.43	1.57	0.64	0.14	0.50	0.14	0.43	0.43	0.14	0.21	0.07	0
Aug.	2.07	1.36	0.86	0.57	0.64	0.43	0					
Sept.*	1.36	0.50	0.07	0.14	0							

*January-February and October-December are omitted because no runs occurred.

Table 33. Frequency per year of runs with incident solar radiation $\geq$450 cal cm^{-2} day^{-1} at St. Paul.

Month	Number of days in run 1	2	3	4	5	6	7	8	9	10	11-20	21-40
Mar.*	2.64	0.93	0.36	0.07	0.21	0						
Apr.	2.36	1.86	0.64	0.36	0.36	0.29	0	0.07	0			
May	2.29	1.57	0.57	0.36	0.57	0.36	0.07	0	0.21	0	0.14	0
June	1.57	0.71	0.50	0.43	0.36	0.36	0.36	0.14	0.07	0.14	0.49	0.07
July	0.86	1.07	0.50	0.21	0.36	0.14	0.43	0.36	0.21	0.21	0.21	0
Aug.	1.86	1.00	0.57	0.71	0.64	0.36	0.14	0.14	0.07	0.14	0.07	0
Sept.	1.71	1.00	0.43	0.07	0.29	0.07	0.07	0				
Oct.*	0.07	0										

*January-February and November-December are omitted because no runs occurred.

Table 34. Frequency per year of runs with incident solar radiation ≥400 cal cm^{-2} day^{-1} at St. Paul.

Month	Number of days in run										
	1	2	3	4	5	6	7	8	9	10	11-20	21-40
Feb.*	0.07	0.07	0									
Mar	3.00	1.43	1.00	0.43	0.29	0.07	0					
Apr.	1.71	1.86	0.86	0.29	0.43	0.50	0	0.07	0	0	0.07	0
May	1.86	0.93	0.29	0.36	0.43	0.29	0.29	0	0.21	0.14	0.42	0
June	1.29	0.71	0.43	0.57	0.21	0	0.29	0.21	0.14	0.21	0.71	0.07
July	0.50	0.57	0.21	0.07	0.36	0.21	0.21	0.43	0.29	0.21	0.36	0.07
Aug.	1.21	0.79	0.36	0.43	0.43	0.36	0.14	0.29	0.14	0.21	0.21	0
Sept.	1.71	1.57	0.93	0.36	0.36	0.07	0.14	0				
Oct.*	0.36	0	0.14	0								

*January and November-December are omitted because no runs occurred.

Table 35. Frequency per year of runs with incident solar radiation ≥350 cal cm^{-2} day^{-1} at St. Paul.

Month	Number of days in run										
	1	2	3	4	5	6	7	8	9	10	11-20	21-40
Feb.*	1.29	0.57	0	0.14	0							
Mar.	2.71	1.64	0.71	0.71	0.36	0.36	0.07	0	0.07	0		
Apr.	1.50	1.29	1.07	0.29	0.43	0.50	0.21	0.07	0.07	0	0.14	0
May	1.57	1.00	0.36	0.29	0.21	0.57	0.21	0.07	0.14	0.21	0.43	0.07
June	0.64	0.64	0.36	0.29	0.29	0.07	0.21	0.21	0.14	0.21	0.57	0.36
July	0.57	0.21	0.14	0.07	0.21	0.07	0.07	0.29	0.21	0.14	0.43	0.36
Aug.	0.93	0.93	0.14	0.43	0.36	0.21	0.07	0.07	0.21	0.14	0.36	0
Sept.	1.64	0.50	1.14	0.43	0.36	0.36	0.14	0.29	0.07	0	0.14	0
Oct.*	1.43	0.57	0.07	0.14	0	0.07	0					

*January and November-December are omitted because no runs occurred.

Table 36. Frequency per year of runs with incident solar radiation ≥300 cal cm^{-2} day^{-1} at St. Paul.

Month	Number of days in run										
	1	2	3	4	5	6	7	8	9	10	11-20	21-40
Feb.*	2.36	1.07	0.50	0.07	0.50	0.07	0	0	0	0.07	0	
Mar.	2.00	1.43	0.86	0.50	0.36	0.29	0.29	0.07	0.14	0.14	0.07	0
Apr.	1.21	1.21	1.00	0.21	0.36	0.71	0.21	0	0.07	0.07	0.36	0
May	1.07	0.86	0.50	0.14	0.29	0.36	0.14	0.07	0.14	0.14	0.50	0.21
June	0.43	0.50	0.21	0.29	0.14	0.13	0.07	0.14	0.14	0.14	0.57	0.50
July	0.36	0.14	0.07	0	0.21	0	0.14	0.07	0.29	0.07	0.57	0.43
Aug.	0.43	0.43	0.14	0.36	0.29	0.36	0.14	0.07	0.21	0.14	0.29	0.07
Sept.	1.36	0.64	0.93	0.29	0.36	0.50	0.29	0.21	0.07	0.07	0.14	0
Oct.*	2.21	1.50	0.43	0.36	0	0.14	0.07	0				

*January and November-December are omitted because no runs occurred.

Table 37. Relationship between total daily radiation and daytime temperature at St. Paul, 1963-1976

Month	Radiation threshold value (R),[1] cal cm^{-2}	Temperature threshold value (T),[2] of °F	Percent of days greater than R but less than T	Percent of days greater than R and greater than T
Jan.	150	10	77	44
Feb.	250	15	61	34
Mar.	350	30	66	39
Apr.	400	45	35	55
May	500	60	35	61
June	550	70	45	57
July	550	75	46	61
Aug.	500	70	31	59
Sept.	350	60	40	66
Oct.	250	50	42	59
Nov.	150	30	47	41
Dec.	100	20	75	39

[1]The radiation class limit closest to the median radiation value for a particular month.

[2]The temperature class limit closest to the 33rd percentile phototemperature for a particular month; the lowest third of the days with respect to daytime temperatures.

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