A Three-Year Study of Net Radiation at St. Paul, Minnesota[1]

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ABSTRACT

This study is based upon net radiation measurements made with a Suomi-type ventilated net radiometer. The average annual net radiation was 36,247 ly for the study period 1 April 1964–31 March 1967. April–October showed positive net radiation totals, November–February negative net radiation totals, and March had positive net radiation totals in two of the three years studied.

Only fourteen days with all negative net radiation and two days with all positive net radiation occurred in the three-year period. Average daily time of positive net radiation ranged from 244 min in January to 749 min in June. Although positive net radiation exceeded negative net radiation an average of 36,247 ly per year, negative or null net radiation was recorded 63% of the time.

The ratio of net radiation to incoming solar radiation varied widely during the year. However, from May–August the ratio ranged only from 0.45–0.54 for any one month during the three years and averaged 0.50.

Monthly net radiation values calculated by the method described by Sellers were within 10% or less of the measured values for all but two months. Budyko's calculated annual value of ~35,000 ly also agreed favorably with the average measured value.

1. Introduction

Radiant energy composed primarily of shortwave and longwave radiation is received at the earth's surface from the sun and the atmosphere, respectively. The earth absorbs or reflects this energy, and it also emits longwave radiation. The difference between the upward and downward radiation streams through a horizontal plane is termed net radiation. Net radiation is a measure of the energy available at the earth-atmosphere interface and thus affects the moisture and heat budgets of soil, air, vegetation and water bodies.

Published data on measured net radiation are available at only a few locations and most are of short duration. For example, Koberg (1958) measured the net radiation at Lake Mead in 1952–53, Collman (1958) and Frankenberger (1960) measured net radiation at Hamburg, Germany, in 1953–54 and 1957–58, respectively, and Budyko (1956) cited measured net radiation values for periods $\leqslant 4$ years at several locations in the Soviet Union. In addition to these measured values Budyko (1956) and Sellers (1965) have calculated values for a number of stations throughout the world.

This study presents the weekly, monthly and annual net radiation values measured at St. Paul, Minn., from 1 April 1964 through 31 March 1967. Hopefully these data will be valuable additions to the few presently available. In addition, they serve to check calculated values for this location.

2. Instrumentation and data collection

Net radiation was measured using a Suomi-type ventilated net radiometer (Suomi *et al.*, 1954) located on the St. Paul campus of the University of Minnesota (44°59′N, 93°05′W; 920 ft MSL). The radiometer was mounted 3 ft above a sod surface and was free of major interference from any nearby obstacles. The signal from the net radiometer was recorded by a Honeywell strip chart recorder. A moisture sensitive device (Norman *et al.*, 1966) caused the recorder to indicate zero net radiation when rain or snow fell on it rather than the false negative net radiation readings that ordinarily result. Measurements were made on a continuous basis except for brief periods of equipment breakdown.

The net radiometer was calibrated at least once each month by shading the net radiometer and an Eppley 50 junction pyranometer with a small black paddle held 3–4 ft from the sensing units. The calibration constant was calculated based on the shaded and unshaded values obtained with the two radiometers. The constant changed a maximum of 6% in a month, but was generally 2% or less. The net radiometer thermopile was replaced twice in the three-year period. In each case 6% of the surface area of the new thermopile was painted white as recommended by Suomi *et al.* (1954).

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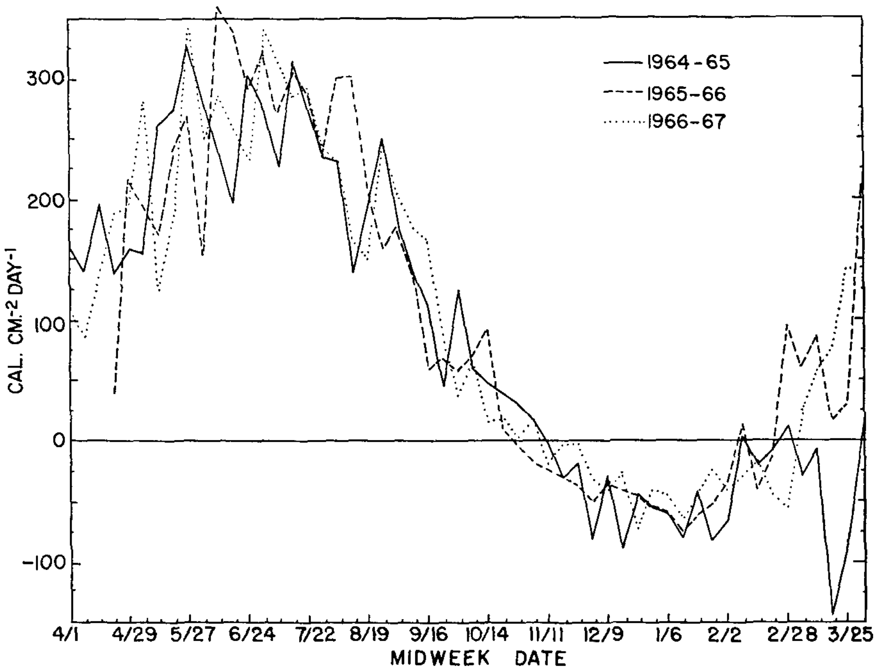

Fig. 1. Average daily net radiation measured at St. Paul, Minn., April 1964–March 1967; data for 29 March–18 April 1965 are missing.

3. Summarization of net radiation

The average daily net radiation values for each week are presented in Fig. 1. Perhaps the most striking feature of this curve is the large difference in net radiation between March 1965 and March in the other two years. March 1965 was similar to the winter months of December and January because it had a negative net radiation balance of 1773 ly compared to positive balances of 1692 ly in March 1966 and 2089 ly in March 1967. Much of the difference in the annual total net radiation between the year from April 1964–March 1965 and the following two years can be attributed to this single month.

Observations made at the associated weather station provide evidence for the high negative net radiation values during March 1965. Freezing rain and thawing followed by freezing temperatures left 4–5 inches of ice on the ground. Three snowstorms then followed on 2–3 March, 17 March, and 27–29 March. The fresh snow surface, with an albedo estimated at 90–95% [Budyko (1956); and verified with later measurements made at the associated weather station], reflected most of the incoming solar radiation. The high albedo combined with the relatively clear, cold sky which prevailed during much of this period were responsible for the large negative net radiation values during this month.

The average daily and annual net radiation values for each month are given in Table 1. The three-year average and the highest and lowest average daily values on a monthly basis are plotted in Fig. 2. The three years of data show that, in general, April–October are periods of positive net radiation with November–February having negative net radiation totals. March had positive net radiation totals in two of the three years examined. The duration of the negative net radiation period was largely a function of the persistence of snow cover. June and July received the maximum amounts of positive net radiation, while the largest negative radiation balance usually occurred in December and January.

The annual net radiation totals ranged from 33,266 ly for 1 April 1964–31 March 1965 to 38,169 ly for 1 April 1966–31 March 1967. The measured net radiation averaged 36,247 ly per year.

The average daily minutes of positive net radiation

Table 1. Measured average daily and annual net radiation totals (ly) at St. Paul, Minn., for each month from April 1964–March 1967.

Period	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Annual
1964–65	162	246	255	266	201	119	51	−14	−57	−65	−20	−56	33,266
1965–66	127	214	295	278	229	95	49	−27	−45	−58	−13	74	37,307
1966–67	137	239	263	290	200	131	21	−3	−44	−40	−34	35	38,169
Average	142	233	271	278	210	115	40	−15	−49	−54	−22	18	36,247

TABLE 2. Average daily minutes of positive net radiation, April 1964–March 1967, and average daily minutes of negative and null* net radiation, 1966.

Month	Positive net radiation 1964–65	1965–66	1966–67	Average	Negative and null net radiation Negative	Null
Apr.	638	584	609	610	758	73
May	709	776	661	715	725	54
Jun.	736	793	717	749	679	44
Jul.	726	735	725	729	668	47
Aug.	663	688	634	662	702	104
Sep.	571	622	574	589	777	89
Oct.	497	510	443	483	912	85
Nov.	374	357	406	379	792	242
Dec.	197	260	286	248	888	266
Jan.	297	211	235	244	1145	84
Feb.	421	438	345	401	887	115
Mar.	426	548	578	517	798	94
Average	521	543	518	527	811	108

* Null time is the time when radiation is neither positive nor negative and includes time of liquid precipitation. Null and negative time were recorded separately only late in the study period and the data shown are only for calendar year 1966.

for each month are shown in Table 2. The minutes of positive net radiation ranged from a high of 793 in June 1965 to a low of 211 in January 1966. June had the highest three-year average with 749 min of positive net radiation and January the lowest with only 244 min. Although positive net radiation exceeded negative net radiation on an annual basis, negative or null net radiation was recorded 63% of the time.

As a rule, each day had both positive and negative net radiation. The only exceptions during this study were fourteen days of all negative and two days of all positive net radiation. Fresh snow cover on relatively clear, cold and dry days produced days of all negative net radiation. In contrast, positive only net radiation occurred on foggy and heavily overcast winter days during periods with very little snow cover.

4. Comparison of solar and net radiation

Fig. 3 shows the three-year average daily net and incoming solar radiation for each month. The curves

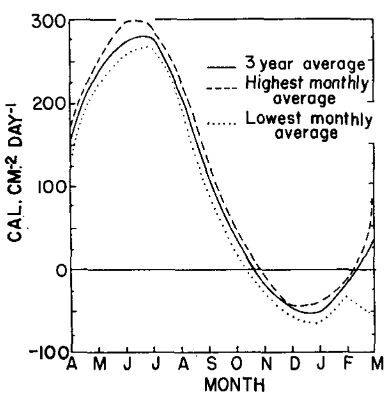

FIG. 2. Average daily net radiation measured at St. Paul, Minn., showing the average, highest and lowest values for each month, April 1964–March 1967.

are similar except for the inflection in the solar radiation curve in September and October. This inflection resulted from the combination of a low average for September 1965 (224 ly day^{-1} compared to an average of 339 ly in the other two years) and a high October 1965 average (307 ly day^{-1} compared to 240 ly for 1966 and 1967). The net radiation did not seem to have been affected by the prevailing conditions as much as the solar radiation.

From May–August, which corresponds closely to the local growing season, the ratio of net to solar radiation was nearly constant (Fig. 4). August had a slightly lower ratio than the other months. This was probably due to increased outgoing radiation from soil and plant surfaces as a result of higher soil and plant temperatures caused by inadequate moisture for evapotranspiration demands.

According to Tanner (1960), evapotranspiration in humid areas (such as eastern Minnesota) is approximately equal to net radiation. The May–August ratio of net to solar radiation averaged 0.50 and varied between 0.45–0.54 for any one month of the three-year period. A reasonable estimate of net radiation, and therefore evapotranspiration, may be obtained by applying the factor 0.5 to the more numerous solar radiation station data for the May–August period in areas with climates similar to that at St. Paul.

Ekern (1965) cited values for the ratio of net to solar

TABLE 3. Comparison between ratios of net to solar radiation obtained at St. Paul and those cited by Ekern (1965).

Station	Cover	Period	Radiation ratios Cited by Ekern	St. Paul
Davis, California	sod	June	0.56	0.50
Copenhagen, Denmark	sod	July	0.51	0.51
Copenhagen, Denmark	sod	April to September	0.44	0.46

Table 4. Comparison of average daily measured and calculated net radiation (ly) for each month from May 1965–April 1966.*

	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	Annual
Calculated	231	300	274	223	101	72	−24	−43	−65	−15	79	155	108
Measured	214	295	278	229	95	49	−27	−45	−58	−13	74	137	103
Difference	17	5	−4	−6	6	23	3	2	−7	−2	5	18	5

* Lack of necessary temperature data for calculated values limited the comparison to these 12 months.

radiation at several locations and over different types of vegetation. The values at St. Paul are similar to those measured over sod in other localities, as shown in Table 3. This would seem to imply that the ratio is a fairly conservative quantity during periods of plant growth.

At St. Paul the ratio decreased rapidly in the fall and became negative during the winter months. This decrease was caused by greater reflection of solar radiation as a result of both the lower elevation of the sun and increased albedo, particularly in the presence of snow. The ratio increased in the spring as surface conditions changed and the solar altitude increased.

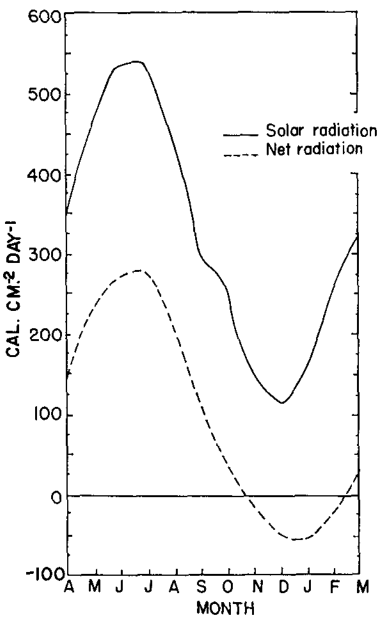

Fig. 3. Average daily net and solar radiation at St. Paul, Minn., April 1964–March 1967.

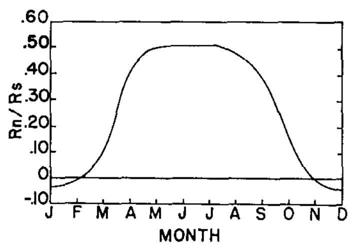

Fig. 4. Average monthly ratio of net radiation (R_n) to solar radiation (R_s) at St. Paul, Minn., measured over a sod surface, April 1964–March 1967.

5. Comparison between measured and calculated values

Because little measured net radiation data are available several methods have been developed for calculating this important meteorological and climatological parameter using meteorological data which are generally available. One such method is described by Sellers (1965), and it is interesting to see how values calculated by this method compare with measured data. Monthly net radiation values from 1 May 1965 through 30 April 1966 were calculated using a slight modification of the Sellers method (measured rather than calculated surface temperatures were used in estimating the outgoing long-wave radiation). Calculated values are compared with measured values in Table 4.

It is probable that errors introduced through inaccurate estimates of the albedoes and effective outgoing radiation are largely responsible for differences in the measured and calculated values. Calculation of the effective outgoing radiation required the amount of the precipitable water in the atmosphere, but since data for the 1965–66 period were nota vailable the mean monthly values reported by Reitan (1960) were used.

Tanner and Pelton (1960) reported that errors in carefully measured net radiation may be about 10%. Comparison of measured and calculated values showed differences of less than 10% in all months except April and October. For the entire year the calculated net radiation was 39,450 ly compared to the measured total of 37,610 ly or a difference of less than 5%.

Budyko (1956) constructed a map of the general distribution of net radiation for much of the earth. His map indicates an annual net radiation balance of approximately 35,000 ly for St. Paul, which compares favorably with the three-year average measured value of 36,247 ly obtained in this study.

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