Reducing Dew and Frost on the Domes of Net Pyrradiometers

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ABSTRACT

The objective of this study was to improve the accuracy of net radiation (R_n) measurements under conditions conducive to dew or frost deposition. Two nonventilated net pyrradiometers were mounted over grass during November and December 1986. A heating element was located on the supporting arm of each radiometer so that heat would be conducted to the sensing head. Heat was applied to one radiometer for a few days, followed by a period during which no heat was applied. The procedure was repeated, alternating between radiometers throughout the experiment. Heating the radiometers successfully averted the deposition of dew and frost on the domes, which produced errors in R_n as high as 54 W m^{-2}. The effect of heating alone was slightly asymmetric and resulted in a significant decrease in the mean R_n of 8 W m^{-2} relative to the unheated radiometer. This effect can be compensated for in the calibration of the radiometer.

1. Introduction

The presence of dew or frost on the domes of nonventilated net pyrradiometers reduces the transparency of the domes to longwave radiation. On a cloudless night, dew or frost on the upper dome increases the measured downward radiation since the view of the cold sky is reduced. It is speculated that dew or frost on the lower dome may result in smaller errors since the temperature difference between the lower dome and ground is less than the temperature difference between the upper dome and sky. Therefore, dew or frost on both domes would increase the downward component of the measured net radiation (R_n). The error in the measured R_n is large during the early morning when longwave radiation dominates the radiation balance and dew or frost may be present in various climatic regions. After sunrise, dew or frost also impedes the reception of shortwave radiation by the radiometer.

Accurate R_n measurements are essential in energy balance studies where radiation is the major source of energy to evaporate water. In the Bowen ratio-energy balance method (Tanner 1960), the accuracy in the latent heat flux density (LE) is dependent on errors in R_n (Blad and Rosenberg 1974; Sinclair et al. 1975). In this method, the error in calculating LE is most prominent when the Bowen ratio approaches −1 (near sunrise and sunset), resulting in unrealistic values of LE which are commonly discarded (Green et al. 1984). Accurate nighttime R_n measurements are also essential to model dew duration, a critical component in disease control.

Dew deposition frequently occurs during the growing season at the Elora Research Station, Ontario, (43°39′N, 80°25′W, 376 m elev.), where R_n is monitored throughout the year. Bootsma (1972) documented that between 15 June and 31 August 1970 surface wetness existed 46% of the time; 12% corresponded to precipitation and 34% was associated with dew. During the fall and winter, frost on the domes frequently lasts for several hours after sunrise. Although ventilated pyrradiometers (Suomi et al. 1954) avert dew and frost deposition, they are not accurate when the sensing surfaces become wet during precipitation. Since the drying time is unknown, accuracy remains uncertain for an indeterminate period following precipitation. Funk (1959) and Fritschen (1963) used heaters to maintain dome temperatures on nonventilated net pyrradiometers above the dewpoint temperature, thus preventing condensation. However, Fritschen (1963) concluded that errors resulting from heating were large relative to the errors attributed to condensation on the domes, making this approach impractical.

This study investigated the effects of 1) dew and frost on the measurement of R_n, 2) heating the net pyrradiometer on the dew and frost deposition on the domes, and 3) heating the net pyrradiometer on the measured R_n when dew or frost was not present.

2. Methods

The supporting arms of two nonventilated net pyrradiometers (Solar Radiation Instruments, model 4; S/N-106 and S/N-112) were wrapped with 24-gauge

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TABLE 1. Upper-dome temperature during calm conditions.

Power (W)	Degrees celsius above ambient
1.6	2.3
4.1	4.6
8.8	10.5

insulated constantan wire creating a heating element with a resistance of 6 Ω. The element was covered with foam insulation (3 mm thick) to reduce heat loss. Since the radiometer sensing head normally heats up during the day, it was speculated that applying additional heat symmetrically, by conduction from the arm, would not abnormally alter the response.

In calm wind conditions in the laboratory, the upper dome temperature was measured as the heating power was increased (Table 1) to estimate a reasonable operational voltage. The dome temperature was measured by pressing a 30-gauge thermocouple against the outer surface of the upper polyethylene dome. A heating level of 7.5 W was chosen which corresponded to approximately 6.5°C increase in the upper dome temperature (Table 1). The heating was later increased to 15 W.

The two radiometers were mounted approximately 1 m apart, over a grass surface at a height of 1.6 m during November and December 1986. The half-hour mean R_n was computed for each radiometer. Heat was applied to one radiometer for a few days followed by a few days when no heat was applied. This was repeated for each radiometer in sequence, throughout the experiment. The first two objectives were investigated when dew or frost was present on the unheated radiometer as indicated by visual observations before sunrise. To answer the third objective, the effect of heating alone was investigated using daytime measurements when no dew or frost was present on either radiometer.

The analysis of the effect of heat alone followed a procedure outlined by Allen and Raktoe (1981) for determining the accuracy between predicting procedures. In this analysis, the actual difference which may exist between radiometers, for any particular half-hour measurement, is the root-mean-square-error. The actual difference is decomposed into a mean difference (bias) between radiometers, a difference due to regression and a difference due to random disturbances. Mean differences occur if R_n from one radiometer consistently overestimates or underestimates R_n from the second radiometer. A regression difference exists if the slope of the paired R_n values is different from one. The random difference results from scatter between paired R_n measurements. The significance of the mean difference between R_n measurements was examined using a paired Student's t test (Snedecor and Cochran 1980).

3. Results

Heating the radiometers was effective in reducing dew and frost deposition on the domes. For example, at 0630 h on 27 November 1986, a thick layer of frost covered the lower and upper domes of the unheated radiometer (Fig. 1). At the same time, no frost was present on the heated radiometer (Fig. 2). Although applying the arbitrary 7.5 W was normally sufficient to prevent dew formation, it was not enough heating to prevent all condensation on 27 November (Fig. 2, center of upper dome). Heating was subsequently increased to 15 W for several days which averted all condensation on the domes.

Measurements of R_n are shown in Figs. 3 and 4 when frost was present on the domes of the unheated radi-

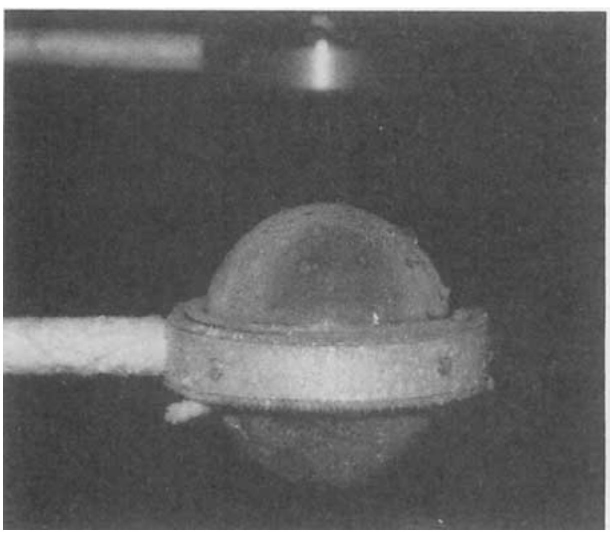

FIG. 1. Unheated net pyrradiometer S/N-106 at 0630 h on 27 November 1986.

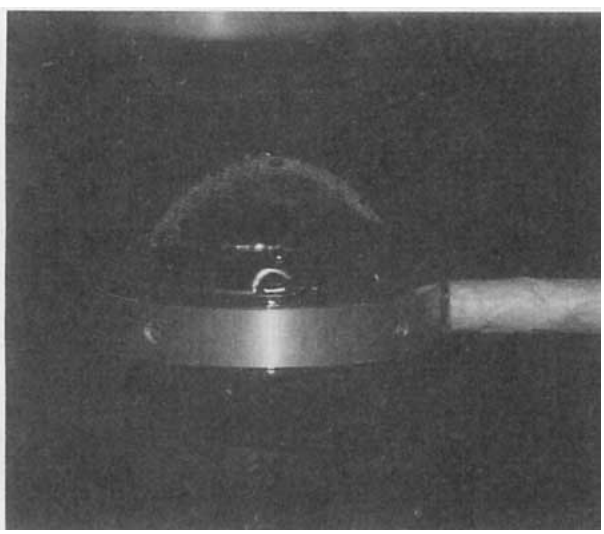

FIG. 2. Heated net pyrradiometer S/N-112 (7.5 W) at 0630 h on 27 November 1986.

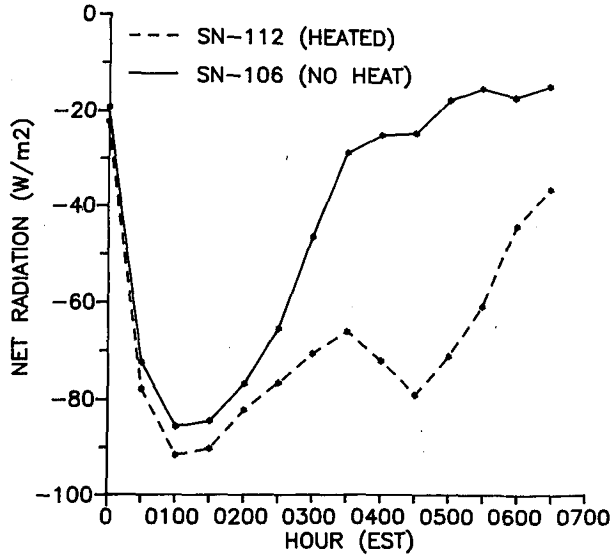

FIG. 3. Measured net radiation on 27 November 1986. Frost was present on the unheated net pyrradiometer (S/N-106) and only a small amount of dew existed on the heated net pyrradiometer (S/N-112).

ometer. On 27 November, a maximum difference between R_n measurements of 54 W m^{-2} occurred at 0430 h. This difference declined to 14 W m^{-2} at 0630 h, the time of the conditions shown in Figs. 1 and 2. A similar difference between R_n measurements occurred the morning of 3 December. During this time, the unheated radiometer indicated the R_n flux was constant at approximately 3 W m^{-2} (net downward flux) while

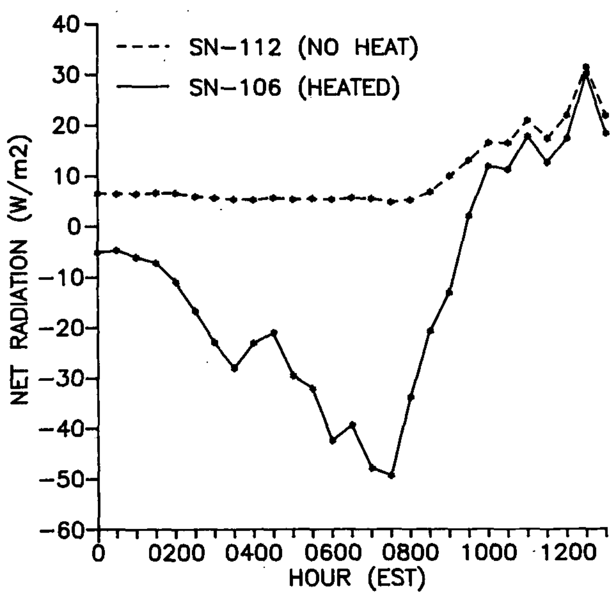

FIG. 4. Measured net radiation on 3 December 1986. Frost was present on the unheated net pyrradiometer (S/N-112) but not on the heated net pyrradiometer (S/N-106).

TABLE 2. Analysis of measured R_n differences during periods when dew or frost was not present on domes.

	No heat	S/N-112 Heated	S/N-106 Heated
Accuracy analysis			
n*	154	145	71
A	14.5 (67.0)	58.7 (96.9)	38.0 (80.5)
P	14.5 (66.9)	50.9 (93.3)	46.4 (78.8)
Mean	0.0	7.8	8.4
Regression	0.2	3.7	2.0
Random	3.9	5.0	6.0
rms	3.9	9.9	10.6
Paired t-test			
$\bar{x}$	0.0 (3.9)	7.8 (6.2)	−8.4 (6.4)
t	0.0 NS	15.0†	−93.8†

* n is the number of half-hour samples; A, mean R_n from radiometer SN-106; P, mean R_n from radiometer SN-112; ( ), standard deviation; rms, root-mean-square; $\bar{x}$, mean difference (bias) between A and P; t, Student's t-test; NS, not significant ($P > 0.05$); †, significant ($P < 0.05$).

R_n measured with the heated radiometer (15 W) decreased during the night to a minimum of −49 W m^{-2} (net upward flux) at 0730 h.

The correlations of R_n measurements between radiometers are shown in Fig. 5, when dew or frost was not present. The R_n measurements were collected between 1000 and 2000 h from 11 November to 21 December 1986. The simultaneous R_n measured by the two radiometers was highly correlated under both heated (7.5 W) and unheated conditions; the correlation coefficients were greater than 0.99.

When no heat was applied and dew or frost was not present (Fig. 5a), accuracy analysis (Allen and Raktoe 1981) indicates an actual difference of 3.9 W m^{-2} could exist between R_n measurements by the two radiometers, most of which is attributed to random disturbances (Table 2). A paired Student's t-analysis indicated that the mean difference between radiometers was not significant ($P > 0.05$). This finding permits the mean difference in R_n between radiometers to be used to indicate the effect of heating.

When heat was applied to radiometer S/N-112 (Fig. 5b), the actual difference between measured R_n by the two radiometers increased to 9.9 W m^{-2} while the mean difference increased to 7.8 W m^{-2} (Table 2). A paired Student's t-analysis of the mean difference indicated it was significant ($P < 0.05$), inferring a difference in measured R_n existed due to heating.

The analysis of the data in Fig. 5c (S/N-106 heated) was similar to the results in Fig. 5b (Table 2). The actual difference between measured R_n by the two radiometers was 10.6 W m^{-2}. The mean difference of 8.4 W m^{-2} between R_n measurements by the two radiometers was significant ($P < 0.05$).

The mean difference between measured R_n by the two radiometers was similar (approximately 8 W m^{-2})

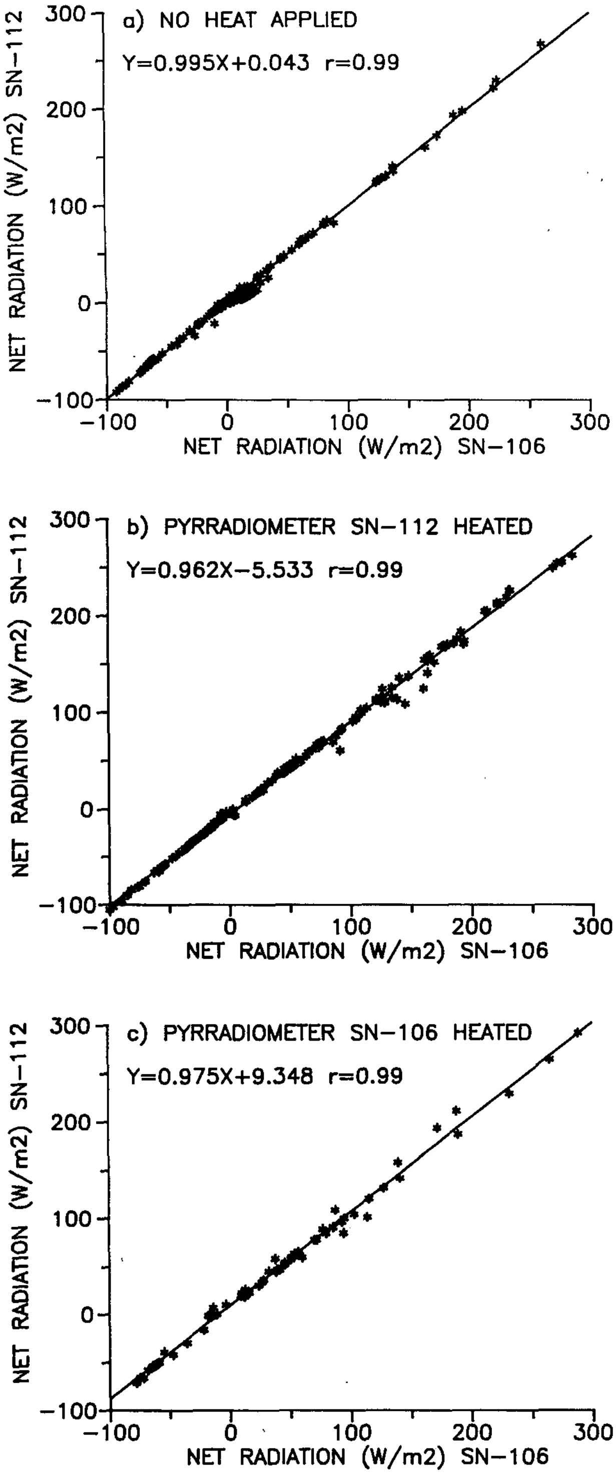

FIG. 5. Correlation of net radiation measured using net pyrradiometers S/N-112 and S/N-106 during the daytime when no dew or frost was present on the domes.

regardless of the radiometer being heated. It is speculated that the mean difference results from an asymmetric distribution of heat from the conducting arm. The decrease in R_n during heating indicates the lower sensing surface received a larger portion of the heat supplied. Smaller effects of heating were evident by an increase in the difference due to regression of 1.8 to 3.5 W m^{-2} and an increase in the difference due to random disturbances of 1.1 to 2.1 W m^{-2}.

4. Conclusions

In this study, dew and frost on the domes of the radiometers during the night and early morning resulted in an overestimate of the downward radiation by as much as 54 W m^{-2}. However, applying heat to the sensing head was shown to avert the deposition of dew and frost on the domes. The effect of this heating alone (dew or frost not present) was to introduce a mean difference in R_n of approximately 8 W m^{-2} during the daytime which can be incorporated into the calibration of the radiometer. Since heating the sensing head of the radiometers is beneficial only at night and early morning, it could also be switched off during the daytime to avoid heating effects.

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