An Economical Net Radiometer

By V. E. SUOMI, Department of Meteorology, The University of Wisconsin, and P. M. KUHN, Office of Meteorological Research, U.S. Weather Bureau

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Abstract

A net radiometer of moderate accuracy but of simple construction and very low cost is described. The value of net radiation is obtained from the difference of fourth power temperatures of the upper and lower radiating surfaces. Conduction losses are held to a low value by employing a good insulating material and ventilation losses above and below are kept to a low value by two layers of thin polyethylene film. Field tests, calibration data, and applications are described.

1. Introduction

The net radiation normal to the earth's surface is the difference between the total upward radiation flux and the total downward radiation flux. Net radiation is important to many meteorological problems because it is a measure of the energy available at the earth-atmosphere interface. The energy exchange at the earth's surface represents the major input to the giant heat engine which circulates the atmosphere.

A number of instruments which measure net radiation are already available (ALBRECHT, 1933; GIER and DUNKLE, 1951; SUOMI, FRANSILLA, and ISLITZER, 1954). Most of them, however, are fairly expensive. As a result there are only a few stations over the entire earth which make net radiation observations. It is not possible to study the effects of a variable heat input on subsequent weather from these isolated measurements. There are far too few to give anything even approaching a representative sample. The purpose of this paper is to describe a net radiometer of moderate accuracy but very low cost. The low cost and simple construction will make it possible to obtain many more observations of net radiation over land and ocean. The errors due to the performance of the instrument can be more than offset by far better sampling.

2. Simplified theory of the instrument

The following symbols will be employed:

- $R_s\downarrow$ vertical component of sun and sky insolation (short wave)
- $R_s\uparrow$ vertical component of insolation reflected from the ground
- L_s fractional loss in transmission through the polyethylene films due to absorption, scattering, and reflection for short wave radiation
- $R_l\downarrow$ downward flux of long wave radiation
- $R_l\uparrow$ upward flux of long wave radiation
- L_l fractional loss in transmission through the polyethylene films due to absorption, scattering, and reflection for long wave radiation
- ε long wave emissivity of polyethylene film
- T_p Absolute temperature of polyethylene film
- a absorptivity of blackened aluminium foil sensor

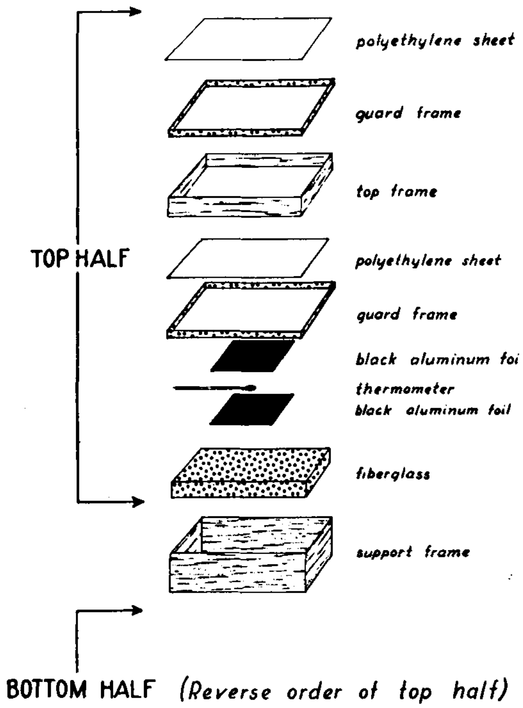

Fig. 1. Exploded view of the Net Radiometer.

K thermal conductivity of insulation

G_1, G_2 effective convective heat transfer of air films, top and bottom

T_t Absolute temperature of top blackened aluminium foil

T_b Absolute temperature of bottom blackened aluminium foil

Fig. 1 shows an "exploded" view of the instrument. The blackened aluminium foil sensing element is supported by a block of light rigid material of low heat capacity and thermal conductivity such as fiberglass insulation. Two sheets of 0.50 mil thick polyethylene film, an insulating guard, and a wooden box framework form a wind screen. The upper and lower surfaces are assembled in reverse order.

When the instrument is oriented above and horizontal to the earth's surface, and equilibrium is reached, the energy balance of the upper surface in sunlight is

$$a[R_s{\downarrow}(1-L_s)+R_l{\downarrow}(1-L_l)+\varepsilon\sigma T_p^4]=$$
$$=a\sigma T_t^4+G_1(T_t-T_p)+K(T_t-T_b) \quad (1)$$

The energy balance for the lower surface is

$$a[R_s{\uparrow}(1-L_s)+R_l{\uparrow}(1-L_l)+\varepsilon\sigma T_p^4]=$$
$$=a\sigma T_b^4+G_2(T_b-T_p)-K(T_t-T_b) \quad (2)$$

In each equation the terms on the left represent the most important heat gains by the blackened surface. The terms on the right are, in order, the losses due to radiation, convection and conduction. When four inches of insulation such as OWENS-CORNING type PF-612, two and one-half pound density, rigid fiberglass is used, the conduction terms comprise only about 10 per cent of the energy exchange. It is possible to evaluate the magnitude of the convection term using the dimensionless numbers of NUSSELT, GRASHOF, and PRANDTL. This was done following the method of DE GRAAF and VAN DER HELD, 1953. The value of this term should be greatest when the air film is heated from below as the upper blackened surface is in the presence of sunlight. The value varies between 10 and 20 per cent of the total energy exchange. Thus the remaining radiation term is the most important mode of heat loss from the sensor surface.

Fig. 2 shows the per cent transmission of 1.0 mil polyethylene film in the range of from 2 to 15 microns. The polyethylene absorption bands are located in the same region of the spectrum as the water vapor bands, but are much narrower. Polyethylene films of this thickness absorb only about 1 per cent of the incident solar radiation but the scatter due to the milky color of the film is several times this value. The combined effects of fractional transmission of short wave energy, absorption of long wave energy and re-radiation from the polyethylene film was determined experimentally by holding two large sheets of polyethylene film above a ventilated net radiometer (SUOMI, FRANSILLA, and ISLITZER, 1954) and noting the change in observed net radiation. This loss is about 10 per cent of the incident radiation.

Fig. 2. Per cent transmission of 1.0 mil polyethylene after U.S. Department of Commerce Publication 111438, 1955.

The loss due to incomplete transmission is about 10 per cent of the left hand side of (1) and (2), while the convection and conduction is about 20 per cent of the right hand side of these equations. Since these terms are proportional to the incident radiation, we can rewrite equations (1) and (2), taking these approximations into account, take their difference, and obtain

$$R_{Net} = A\sigma(T_t^4 - T_b^4) + k(T_t - T_b) + \text{error} \quad (3)$$

where $A = 1.25; k = .0025$

Figs. 3 and 4 show a comparison between a ventilated radiometer (SUOMI, FRANSILLA, and ISLITZER, 1954) of good accuracy and the radiometer just described when the temperature of the upper and lower blackened surfaces, measured with mercury thermometers or thermocouples and averaged for one hour are substituted in (3). If equations (1) and (2) were used the agreement between the two sets of observations would be even better.

At low sun angles the flat, milky polyethylene film will cause the cosine response of the instrument to be poor. For example, at zenith angles of 25°, the ratio of the net radiation measured with the ventilated radiometer over that measured with the economical net radiometer is 1.1 whereas at 65° the value is 1.2 and at 80° it averages 1.37. However, at most latitudes the error in the *total daily* radiation will be small. During the night with diffuse radiation, the cosine error is not as important, and the ratio averages 1.2 for all angles.

3. Discussion

Equations (1) and (2) contain *four* unknown radiation currents but the *two* equations only allow the evaluation of the total downward and total upward radiation flux, and, of course, their sum and difference. If a second radiometer whose sensors are painted *white* is used in addition to the black surfaced radiometer, and the ratio of the black and white paints' short wave absorptivities and ratio of the black and white paints' long wave absorptivities are known, two more equations with no additional unknowns can be written. This is enough additional information to separate $R_s\downarrow$, $R_l\downarrow$,

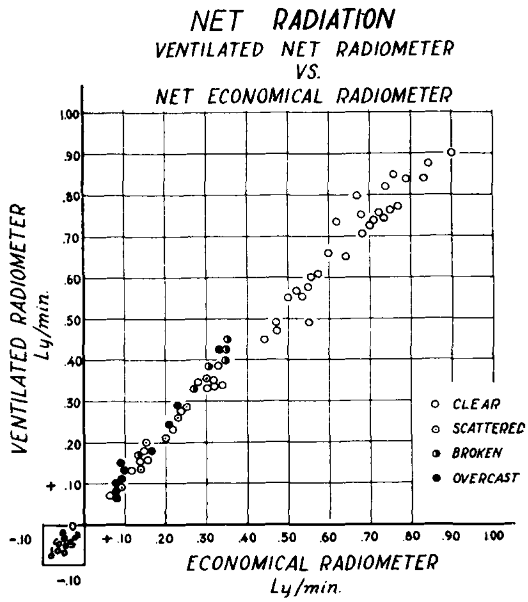

Fig. 3. Hourly net radiation comparison between Economical Net Radiometer and Ventilated Net Radiometer.

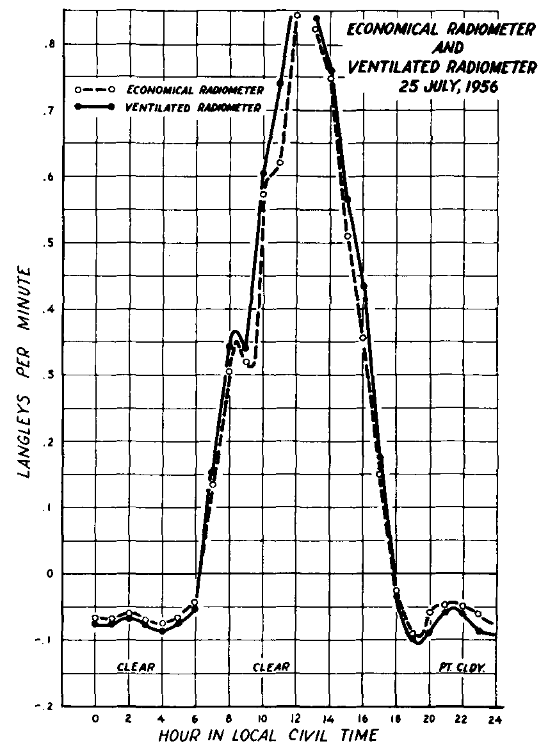

Fig. 4. Scattergram of net radiation measurements using economical net radiometer and ventilated net radiometer.

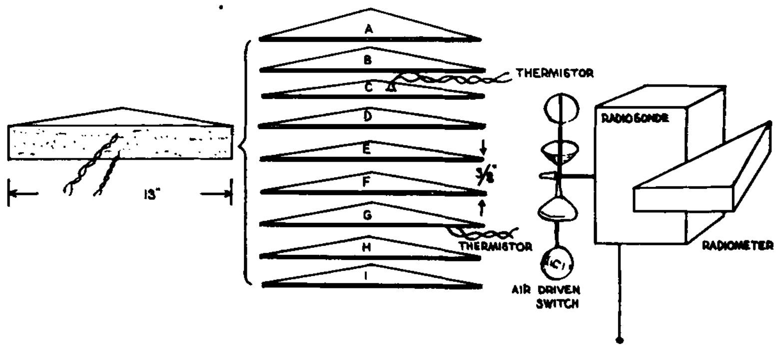

Fig. 5. Balloon-borne economical net radiometer.

$R^s\uparrow$, and $R_l\uparrow$. This application and tests of its validity will be given in another paper.

If one uses thermistors to measure the temperature of the upper and lower blackened surfaces of such a radiometer it is possible to telemeter this information in a manner similar to that used to transmit air temperature in the ordinary radiosonde. By employing very light weight material for insulation and framework, the net radiometer can be made light enough to be carried aloft by a radiosonde balloon. Fig. 5 shows such an instrument which weighs only 125 grams. In order to telemeter air temperature, humidity, and upper and lower surface temperatures it is necessary to add a sequencing switch. The figure illustrates the instrument with such a wind-driven switch. This instrument makes it possible to obtain measured values of the vertical profile of net radiation. Tests of this instrument are under way.

It is possible to compute minimum surface temperatures given the net radiation at sunset and the soil thermal properties. Therefore, the economical net radiometer can be useful in frost forecasting.

PENMAN, 1948, and others have shown that evaporation from a growing field crop is highly correlated to net radiation. Irrigation control from net radiation data is thus feasible.

4. Conclusion

We have described a very low cost net radiometer of moderate accuracy. This accuracy is, however, quite sufficient for many meteorological applications.

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