ACCURACY OF THE AIRBORNE ECONOMICAL RADIOMETER

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[Manuscript received March 30, 1961; revised May 31, 1961]

ABSTRACT

Further data are presented to indicate the accuracy of the airborne economical radiometer (frequently termed radiometersonde when used in a modified radiosonde system) in the measurement of infrared radiation, in view of its recent widespread use. Three aspects are discussed. The first deals with a nocturnal ground comparison of the economical radiometer with a Suomi ventilated radiometer. The second covers an analysis of random errors in the net radiation obtained with the economical radiometer in the radiometersonde system. And, finally, an experimental in-flight verification of the correctness of the conductivity term in the equations for the economical radiometer is discussed.

1. INSTRUMENT COMPARISON

A comparison of the Suomi ventilated radiometer [1] and the airborne economical radiometer [2, 3] was carried out 1.5 meters above homogeneous terrain during July 1961 at Madison, Wis. Consecutive nocturnal readings of both instruments taken at a sample rate of one each minute, resulted in 203 readings. The net radiation range observed was from 0.0091 to 0.1224 langley per minute. Recently Tanner et al. [4] discussed the accuracy of the economical radiometer in daytime measurements of total radiation.

The statistical results of the frequency distribution of the difference in net radiation observed with the airborne economical radiometer and the Suomi radiometer are presented in figure 1. The class interval for figure 1 is 0.0010 langley per minute. The mean difference between net radiation observed with the airborne radiometer and the ventilated net radiometer is 0.001059 langley per minute with an r.m.s. deviation of 0.001974 langley per minute.

The mean scale factor of the airborne radiometer to the ventilated radiometer is 1.01029 with an r.m.s. deviation of 0.02017. The reproducibility of the airborne radiometer readings during nighttime conditions is apparent from the results.

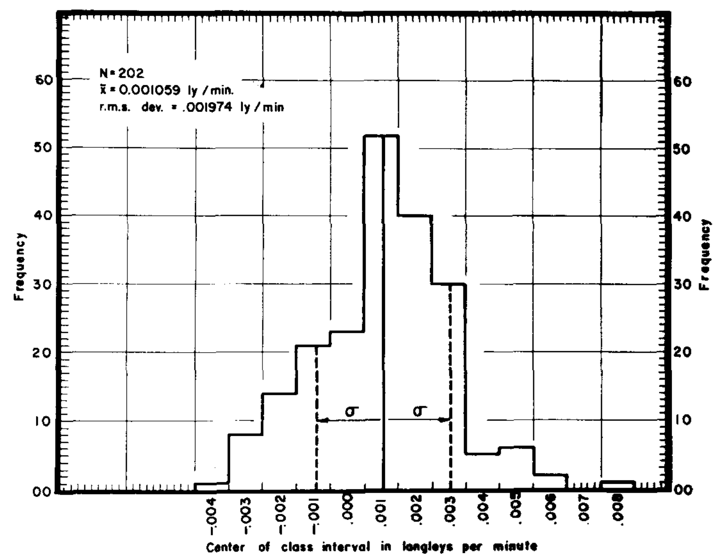

FIGURE 1.—Frequency distribution of the difference in net radiation observed with airborne economical radiometer (radiometersonde) and the Suomi ventilated radiometer.

2. ERROR ANALYSIS

In a consideration of the effects of various possible random and systematic errors in the measurement of the downward- or upward-propagating radiation stream with the radiometersonde in balloon ascents, two sources of error are suggested by the general equation of Suomi and Kuhn [2, 3]. They are random errors in conduction and black body radiation resulting from temperature measurement errors and systematic errors in conduction due to variations in the vertical dimensions of the instrument. We consider, first, errors in the temperature measuring system of the top and bottom sensing surfaces of the radiometer. The expression for net radiation obtained from equation (1) of Suomi, Staley, and Kuhn [3] may be written:

$$R_N=\sigma[T_b^4-T_t^4]+2\left[a\left\{\frac{T_b+T_t}{2}\right\}+b\right][T_b-T_t] -\left[c\left\{\frac{T_a+T_b}{2}\right\}+d\right][T_a-T_b] +\left[c\left\{\frac{T_a+T_t}{2}\right\}+d\right][T_a-T_t]+K\lambda\frac{d[T_t-T_b]}{dt} \quad (1)$$

where R_N is net radiation in langley per minute; σ is 0.817×10^{-10} ly. min.$^{-1}$ °K.$^{-4}$; T_t is observed top sensor temperature, (°K.); T_a is observed air sensor temperature, (°K.); T_b is observed bottom sensor temperature, (°K.); t is time in seconds; K is constant (1.45); and λ is constant product of effective specific heat and effective mass/cm.^{2} of the point-thermistor-Mylar sensor surface experimentally found from speed of response to be 7×10^{-3} cal./cm.^{2} deg.; a is 0.000005489 langley/minute °C.; b is 0.001804 langley/minute; c is 0.000010979 langley/minute °C.; and d is 0.003608222 langley/minute.

The last term on the right side of equation (1) is identically zero when the radiometer is tested on the ground.

Differentiating equation (1) we obtain

$$dR_N=[4\sigma T_b^3+(2a+c)T_b+2b+d]dT_b$$
$$+[-4\sigma T_t^3-(2a+c)T_t-2b-d]dT_t. \quad (2)$$

The variance of the net radiation may be expressed as:

$$\text{VAR}\ [R_N]=k_1^2\ \text{VAR}\ [T_b]+k_2^2\ \text{VAR}\ [T_t] \quad (3)$$

where k_1 is equal to the first term in brackets on the right side of equation (2) and k_2 is equal to the second bracketed term. T_b and T_t are independent of one another, but a standard error of 0.2° C. is assumed for each. The 0.2° C. for the r.m.s. deviation was obtained after careful checks of the highest accuracy obtainable in reading the radiometersonde recorder chart and after extended measurements of the normal noise in the recorder system. This random error, of course, does not include the fixed bias error of the radiosonde receiver-recorder system, but the latter effect is of the second order.

Two cases were solved for equation (3): one in which the top and bottom radiometer temperatures were −70.0° C. and −40.0° C., respectively, typical of the high troposphere or low stratosphere, and in the other in which these temperatures were 0.0° C. and 15.0° C., typical of the lower troposphere. Computation gave a standard error of 0.0027 langley per minute in the first case and 0.0041 langley per minute in the second. The former produces an r.m.s. fluctuation of about 1 percent in the upper tropospheric net radiation value. We can also express the variance as the rate of temperature change in a 50-mb. layer of the atmosphere (see equation (1) in Kuhn, Suomi, and Darkow [5]). Since

$$\frac{\partial T}{\partial t}\ (\text{°C./day})=\left[\frac{1440\ g}{c_p\Delta p}\right][R_{N_{upper}}-R_{N_{lower}}], \quad (4)$$

the variance of the left and right sides of this equation becomes

$$\text{VAR}\ [\partial T/\partial t]=\left[\frac{1440\ g}{c_p\Delta p}\right][2]\ [\text{VAR}\ (R_N)] \quad (5)$$

where $\partial T/\partial t$ is the rate of temperature change due to the divergence of the net radiation in the vertical, g is the acceleration of gravity, c_p is the specific heat of air at constant pressure, Δp is the pressure thickness of the layer considered, and R_N is the net radiation.

TABLE 1.—*Standard error of net radiation, and of the daily rate of radiational temperature change for 50-mb. and 100-mb. atmospheric layers.*

	Net radiation	$\partial T/\partial t$ (50-mb. layer)	$\partial T/\partial t$ (100-mb. layer)
Case I	0.0027 ly./min.	0.45° C./day	0.23° C./day
Case II	0.0041 ly./min.	0.68° C./day	0.34° C./day

Solving equation (5) for the two cases cited above yields standard errors in the daily rate of radiational temperature change for 50-mb. atmospheric layers of 0.45°C. and 0.68°C., respectively. For a 100-mb. layer cases I and II give standard errors of 0.23°C. and 0.34°C. per day, respectively. These results, of course, involve no smoothing, which would tend to reduce the standard error. The 50-mb. layer results give a median error of 0.50°C. for all ascent levels, to be compared with an earlier estimate of 0.60°C. [5]. The results described in this section are summarized in table 1.

3. CONDUCTIVITY TERM

In July 1958, a special balloon ascent was made carrying a "disc" type radiometersonde as well as the conventional radiometersonde. Details of this flight over Madison, Wis. were reported in [6]. The importance of the "disc" radiometersonde in this simultaneous ascent becomes apparent from figure 2. Since it is exposed to the same

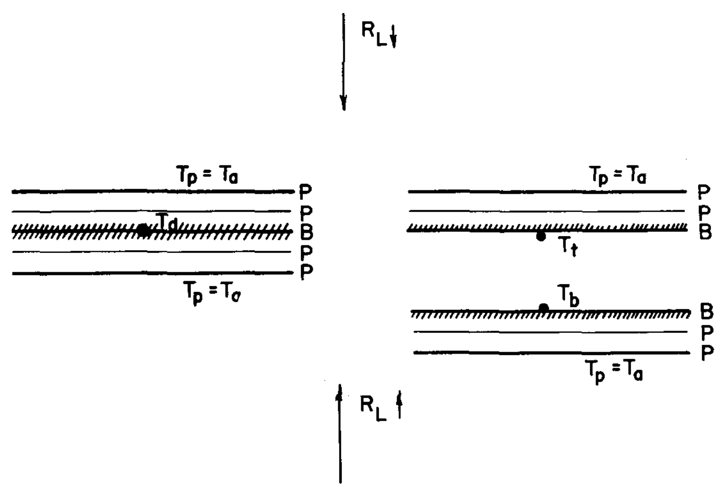

FIGURE 2.—Cross section of the disc airborne economical radiometer (left) and standard airborne economical radiometer (right). Cross hatching indicates blackened aluminum sensing surface; R_L is infrared radiation current; black dots are temperature sensors; subscripted T's refer to polyethylene, air, top, and bottom temperatures; upper case P's to polyethylene ventilation shields.

TABLE 2.—*Comparison of total radiation computed from equation (7) for standard radiometersonde and from equation (6) for "disc" radiometersonde*

Pressure (mb.)	R_{tot} (stand.)	R_{tot} (disc)	R_{tot} (disc) − R_{tot} (stand.)
900	1.130	1.165	−0.035
500	0.830	0.800	0.030
485	0.797	0.765	−0.032
350	0.600	0.566	−0.034
300	0.525	0.490	−0.035
250	0.440	0.433	−0.007
100	0.340	0.338	−0.002
90	0.345	0.340	−0.005
82	0.346	0.345	−0.001
72	0.347	0.351	0.004

streams of upward and downward propagating infrared radiation, it is clear that in the solution of the radiative balance equation for the "disc" radiometersonde there is no internal conduction term. Furthermore, in those instances when the upper and lower polyethylene (air) temperatures are equal to the disc temperature there can be no conduction between the outer polyethylene ventilation shield and the blackened "disc" surface.

If, then, the total radiation is measured both with the "disc" radiometer and the standard radiometersonde, the accuracy of the measurement of the internal conduction, top polyethylene to top sensing surface and bottom polyethylene to bottom sensing surface can be checked.

The total radiation measured by the "disc" radiometersonde is given by,

$$R_{tot}=2\sigma T_d^4-2\left[c\left(\frac{T_a+T_d}{2}\right)+d\right][T_a-T_d]+\left[\frac{K\lambda}{2}\frac{dT_d}{dt}\right] \quad (6)$$

where T_d is the observed "disc" temperature and the constants are defined as in equation (1). The total radiation measured by the standard radiometersonde is given by,

$$R_{tot}=\sigma(T_t^4+T_b^4)-\left[c\left(\frac{T_a+T_t}{2}\right)+d\right][T_a-T_t]$$
$$-\left[c\left(\frac{T_a+T_b}{2}\right)+d\right][T_a-T_b]+[K\lambda d(T_t+T_b)/dt] \quad (7)$$

where all terms are defined as in equation (1). Considering only those levels of the ascent where T_a-T_d in equation (6) is equal to or less than -1.2°C., we have computed R_{tot} from equations (6) and (7) and compare them in table 2.

The data of the last column of table 2, the deviation of the disc from the standard radiometer, display a mean value of -0.0117 langley per minute. The r.m.s. deviation is 0.0206 langley per minute. The mean deviation of the total radiation measured by the two instruments is approximately 2 percent. Since the same absorptivity for the blackened sensing surfaces is used in both instruments and since the same run polyethylene was used in both instruments it is evident that there is no lateral conduction loss. For if there were lateral losses the total radiation measured by the standard radiometersonde would be at best equal to that of the disc for a symmetric temperature profile (i.e., the air temperature is the mean of the observed top and bottom radiometer temperatures). Thus it is believed that the small discrepancy (2 percent) in the observed total radiation values springs in part from the baseline calibration and in part from the fact that T_a-T_d in equation (6) was -1.2° C.

In view of the importance assigned to atmospheric measurements of infrared radiation with the radiometersonde, it is believed that all indications to date suggest its continued use. Studies such as atmospheric flux emissivity, tropopause radiation, satellite radiation comparisons, and others are currently underway.

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