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RESEARCH TRANSLATION

Separate Measurement of Upward and Downward Radiation Fluxes

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SEPARATE MEASUREMENT OF UPWARD AND DOWNWARD RADIATION FLUXES

Translation of

O razdel'nom izmerenii voskhodiashchego i
niskhodiashchego potokov radiatsii

by

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An instrument (double pyrgeometer) designed for separate measurement of upward and downward radiation fluxes is described. The radiation receivers are standard Yanishevsky balancemeters exposed to forced air.

In a number of situations, in particular in studying fog structure, combatting frosts, studying the mechanism of drought formation, etc., one must measure upward and downward radiation fluxes separately [5]. Below, we describe the use of standard instruments for that purpose.

The instruments most widely used for measuring effective nocturnal radiation and the daytime radiation balance are the Yanishevsky thermoelectric pyrgeometer and balancemeter [9]. Experience in the use of balancemeters in a broad network of stations has shown that these instruments, which are portable and quite reliable in the field, have a number of advantages over other instruments of this type. Therefore, we used them for the separate measurement of upward and downward radiation fluxes. The instrument described below is sensitive enough to detect the difference between these fluxes at two levels under conditions where the absorption or emission of radiant energy in an examined layer is sufficiently high.

Let us note that the pyrgeometer is the Yanishevsky balancemeter [9] mounted above a screen blackened on the top and shiny on the bottom. In such a pyrgeometer, the screen can become overheated with respect to the ambient air and, consequently, give erroneous results for daytime.

The double pyrgeometer, which we used for simultaneous separate measurement of upward and downward radiation fluxes, consists of two balancemeters situated one above the other [7] with a black body between.

This black body consists of two sheets of thin copper foil, between which is glued a copper wire thermistor in the form of a flat bifilar coil, and the black body is coated on both sides with Holland black. The temperature of the black body was checked and recorded periodically.

A schematic of the instrument is given in fig. 1a. Here 1 is the upper and 2 the lower balancemeter, 3 is a flat, horizontal ventilating shaft at whose outlet the balancemeters are mounted, 4 is the blower motor energized by a stabilized dc source. The motor can develop 7000 rpm, a speed sufficient to ventilate the balancemeters and the intervening black body (3 mm apart) at a rate of 9 m/sec. The ventilation rate may be regulated by changing the voltage to the motor. The instrument can be calibrated by the "sun-and-shadow" or by the black-body method [4].

The instrument is similar to the Courvoisier balancemeter [10], but there are several differences. The temperature difference between the body of the instrument and the receiving surfaces is measured in the Courvoisier instrument. It is assumed that the ventilation of the instrument keeps its temperature equal to that of the ambient air, however, in the case of strong irradiation this condition is not fulfilled and the instrument readings are not reliable [10].

The temperature differences of the top surfaces and bottom surfaces of the balancemeters are measured in our instrument. The bottom surfaces receive the black-body radiation which, owing to intensive airflow and small heat capacity, have the temperature of the ambient air. The length of the ventilating shaft is several times greater than the thickness of the stream of air that ventilates the black body and the balancemeters. This insures thermal stability of the airstream and precludes the development of large temperature gradients inside the instrument.

The pyrgeometer concept [1-3] is based on determination of the heat exchange between the receiving plates of the instrument and the air, expressed by Newton's formula

$$q = \alpha(T_b - T_{air}) = \alpha\theta \tag{1}$$

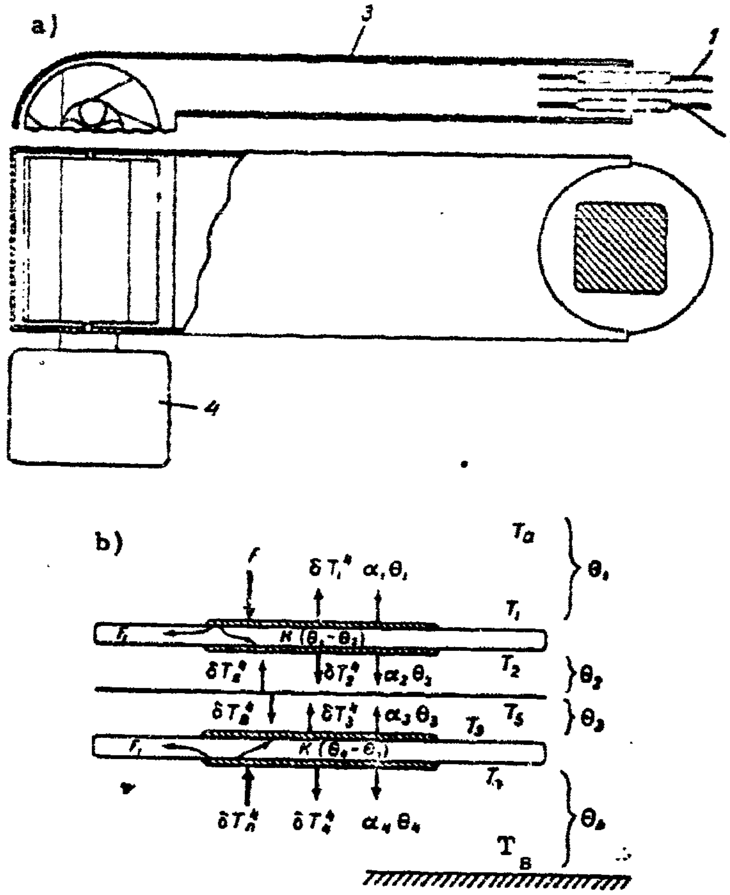

Figure 1. Diagram of the double balancemeter system with forced airflow (a) and of the heat fluxes at the receiving surfaces of the instrument (b).

where q is the amount of heat emitted or received by a unit surface of a body in a unit time, α is the heat-transfer coefficient, T_b is the temperature of the body, T_{air} is the air temperature at a specified distance from the body, and θ is the mean temperature difference.

The heat-transfer coefficient α is a complex function of a number of parameters, including the geometric contours of the body, the mean temperature difference, and the wind speed. The airstream ventilating the receiving surfaces must be strong enough [2] to exclude convection (over the receiving surfaces) from the heat-transfer conditions.

Let us examine the heat balance of the receiving surfaces of the plates of the double pyrgeometer. In the general case, the receiving surfaces of the upper balancemeter have the temperatures T_1 and T_2, the lower T_3 and T_4, the black body between them T_5, the air high above the balancemeters T_a, while the surface below the instrument and the layers of air adjacent to it have the temperature T_s (fig. lb).

During the day, when there is solar radiation, the upper plate of the upper balancemeter receives heat by absorption F of the total radiation and the counterradiation of the atmosphere; heat is lost by radiation σT_1^4, heat exchange with the ambient air $\alpha_1 \Theta_1$, heat conduction to the lower plate $k(\Theta_1 - \Theta_2)$ and to other parts of the upper balancemeter F_1. In these expressions, σ is the Stefan-Boltzmann constant, α_1 is the coefficient of heat exchange between the upper plate and the air, and k is thermal conductivity. The subscripts to the letters here and in what follows give the number of the receiving surface. Here

$$\Theta_1 = T_1 - T_a; \quad \Theta_2 = T_2 - T_5.$$

The lower plate of the lower balancemeter receives heat by radiation of the underlying surface [earth] E_e and from reflected short-wave radiation R_{sw}; it loses heat by conduction to the inner plate $k(\Theta_4 - \Theta_3)$ and to other parts of this balancemeter F_1, and by heat exchange with the air flowing beneath the instrument $\alpha_4 \Theta_4$. Here

$$\Theta_3 = T_3 - T_5; \quad \Theta_4 = T_4 - T_s.$$

We shall disregard the radiation of the layer of air between the underlying surface and the instrument. The heat exchange conditions for the inner surfaces of the balancemeters are evident from fig. lb.

The heat balance equations for the upper and lower receiving surfaces are written as follows for the case of thermal equilibrium:

For the upper balancemeter

$$F + F_1 - \sigma T_1^4 - \alpha_1 \Theta_1 - k(\Theta_1 - \Theta_2) = 0. \qquad (2)$$

$$\sigma T_5^4 - \sigma T_2^4 - \alpha_2 \Theta_2 + k(\Theta_1 - \Theta_2) = 0. \qquad (3)$$

For the lower balancemeter

$$\sigma T_5^4 - \sigma T_3^4 - \alpha_3\Theta_3 + k(\Theta_4 - \Theta_3) = 0, \tag{4}$$

$$E_e + R_{sw} - F_1 - \sigma T_4^4 - \alpha_4\Theta_4 - k(\Theta_4 - \Theta_3) = 0. \tag{5}$$

The dimensions of the black body separating the balancemeters may be found from the condition that its temperature variation with time is determined by influx and efflux of heat on its surfaces

$$\frac{\partial T_5}{dt} = \frac{S}{cM}(\sigma T_2^4 + \sigma T_3^4 - 2\sigma T_5^4 + \alpha_2\Theta_2 + \alpha_3\Theta_3), \tag{6}$$

where c is the heat capacity, M the mass, and S the surface area of the black body.

It may be assumed that when the ventilating airflow is strong and steady, the inner surfaces of the balancemeters that face the black body, as well as the black body itself, have a temperature close to that of the ventilating air, i.e.,

$$T_2 \approx T_3 \approx T_5 \approx T_{air}. \tag{7}$$

Condition (7) is fulfilled at a ventilation rate of 3 m/sec, if there is no wind.

From (2), (3), (4), and (5), it follows that the balance equations of the upper balancemeter B_u and the lower balancemeter B_ℓ may be written

$$B_u = F - \sigma T_1^4 - \alpha_u\Theta_u, \tag{8}$$

$$B_\ell = E_e + R_{sw} - \sigma T_4^4 - \alpha_\ell\Theta_\ell. \tag{9}$$

Here

$$\alpha_u\Theta_u = \alpha_1\Theta_1 + \alpha_2\Theta_2 + F_1 \tag{10}$$

and

$$\alpha_\ell\Theta_\ell = \alpha_3\Theta_3 + \alpha_4\Theta_4 + F_1 \tag{11}$$

are the complex characteristics of the heat exchange conditions of the upper $\alpha_u\Theta_u$ and lower $\alpha_\ell\Theta_\ell$ balancemeters. The effect of the differences between them on the measurement results can be taken into account in part by calibration, on the assumption that there are no structural differences between the two balancemeters. We shall disregard the differences between the internal total heat conduction of the two balancemeters. We assume that the heat transfer of the inner surfaces is the same for the two balancemeters, that the radiant fluxes reaching these surfaces from the black body are equal, and that the heat exchange between the air and the upper and lower surfaces of the balancemeters is identical. These assumptions are made for all current balancemeters.

From (8) and (9) it is clear that the readings of the upper balancemeter characterize the downward flux of radiation F, while the readings of the lower balancemeter characterize the upward flux $E_e + R_{sw}$, measured with respect to the radiant flux of a single black body with a temperature close to the air temperature. The vertical profile of upward and downward radiation fluxes were obtained concurrently from readings of the upper and lower balancemeters made in turn at different heights. From the deviation of the effective radiation, measured with this instrument, one can detect layers of radiational change in temperature of a particular sign, which is very important, e. g., in studying the development of fog [8], in studying the structure of the atmospheric surface boundary layer, et al.

This version of the double pyrgeometer was shown at the All-Union Comparison of Balancemeters held in Tashkent in September 1963, where it was tested under conditions of high temperature, clear sky, weak winds, and calm. The radiation fluxes were measured during the comparison of the various balancemeters. Three readings per minute were taken during each of the twenty eight 30-min measurement series. The comparison showed that at night the radiation fluxes were determined satisfactorily by all the instruments compared.

Naturally, the greatest discrepancy was noted during the day. Our instrument showed quite stable readings during the day. For example, the soil radiation values recorded with our instrument varied monotonically with the change in the temperature of the soil surface beneath the instrument, and the atmospheric counterradiation varied monotonically with the change in the height of the sun above the horizon.

The reliability of the radiation-flux measurements is a function of the reliability of the calibration. We calibrated the instrument by the sun-and-shadow method, using short-wave radiation. The results are presented in table 1.

Table 1

Conversion Factors for the Double Pyrgeometer when Calibrating by Short-Wave Radiation under Various Conditions (10^{-4} cal/cm^2 min per scale division).

	9/12	[1963] 9/12	9/12	9/27	10/1	10/3	11/26
	in tube		with forced air				
Upper balancemeter	140	157	169	149	162	152	147
Lower balancemeter.	140	155	158	143	157	156	140
Ventilating rate, m/sec	0	with correction factor 1.12	9	4	9	4	4

From table 1 it is evident that an increase in the ventilation rate is accompanied by an increase in the conversion factor. However, an increase in the ventilation rate improves the operation of the receiving surfaces.

The results of measurements with the various instruments were compared. The systematic difference between the readings of our instrument and the Main Geophysical Observatory (MGO) radiometer with a germanium filter [6] is due to the difference in calibration techniques. The MGO instrument was calibrated with a black body. When the conversion factor for our instrument is correlated with the conversion factor for the MGO instrument, using the comparisons made in Tashkent, the factor for our upper balancemeter increases by 17.4%, the lower balancemeter by 42.6%, i.e., when the factor obtained for a ventilation rate of 4 m/sec with still air around the instrument is used.

Next, we made a series of closely spaced soundings to a height of 10 m, by raising the instrument with a pulley along a mast and making frequent measurements at various heights. The results show that our instrument can determine the characteristics of the diurnal variation of atmospheric counterradiation and the radiation of the underlying surface.

From what has been said, it is clear that the instrument described in this paper can be used to measure the upward and downward radiation fluxes relative to the radiant flux from a black body. Forced-air ventilation improves the operation of the instrument. The instrument is made of standard parts manufactured by our industry; it is simple and convenient to operate.

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