PARAMETRIZATION OF THE LONG-WAVE RADIATIVE HEAT INFLUX IN THE ATMOSPHERIC SURFACE LAYER

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A simple formula is proposed for calculation on the long–wave radiative heat influx near the Earth's surface. The radiative heat influx depends on the temperature at a given height, the underlying surface temperature, and the derivative of the transmission function of the layer located between the investigated layer and the Earth's surface. The validity of this simple formula is checked for different atmospheric stratifications by comparison with the results of exact calculations.

To compute the rates of temperature variation associated with the long–wave radiative heat influx the following expression is widely used:[1]

$$\frac{\partial T(z)}{\partial z}=-\frac{1}{c_p\rho(z)}\frac{\partial F}{\partial z}=-\frac{\rho_\omega(z)}{c_p\rho(z)}f\left[p(z)\right]\left\{B[T(\omega_\infty)]\frac{\partial P[\omega_\infty-\omega(z)]}{\partial\omega(z)}-\int\limits_{B[T(\omega)]}^{B[T(\omega_\infty)]}\frac{\partial P(\omega(z)-\mu]}{\partial\omega(z)}\,\mathrm{d}B[T(\mu)]-\int\limits_{B[T_s=B[T_0)]}^{B[T(\omega)]}\frac{\partial P(\mu-\omega(z)]}{\partial\omega(z)}\,\mathrm{d}B[T(\mu)\right\} \quad (1)$$

Here F is the total effective radiation flux, P is the transmission function for the total diffuse radiation, $B = \sigma T^4$ is the blackbody radiation flux, σ is the Stefan–Boltzmann constant, z is the height, $\omega(z) = \int\limits_0^z f\,[p(z)]\,p_\omega(z)\,\mathrm{d}z$ is the effective absorbing mass, $f\,[p(z)]$ is the function which takes into account the effect of pressure on the absorption, ρ and ρ_ω are the air and the absorbing gas densities, respectively, u is the effective absorbing mass of the entire atmospheric column, C_p is the specific heat capacity of air at constant pressure, μ is the integration variable, and T_s is the surface temperature. Formula (1) was obtained for the cloudless atmosphere and the Earth's surface as a blackbody under the assumption of continuous temperature at the air–surface interface.

Various modifications of expression (1) are employed to compute $\frac{\partial T}{\partial t}$. These values are obtained by means of integration by parts.[2,3] The results of computations of the radiative heat influx using the integral transmission function agree fairly well with exact calculations performed for the entire IR range, which was divided into spectral intervals with corresponding spectral transmission functions (see, e.g., Ref. 4).

The sum of the first two terms in the right side of Eq. (1) describes the contribution of heat exchange between the given layer and the atmospheric layers located above it to the radiative heat influx while the last term describes the configuration of heat exchange between this layer and layers of air located below and the underlying surface.

Figure 1 shows a diagram of different terms of Eq. (1) in the form of areas in the $\left(B\,[T(\omega)], \frac{\partial P(\omega)}{\partial\omega}\right)$ coordinates in calculating $\frac{\partial T}{\partial t}$ in the surface layer. In particular, the case of air temperature lapse is considered. The shape and size of these areas and their signs provide the opportunity to represent the total radiative heat influx approximately by the hatched area A. In general, proposed approximation may be expressed analytically in the following way:

$$\frac{\partial T(z)}{\partial t}=\frac{\sigma\rho_\omega(z)f[p(z)]}{c_p\,\rho(z)}\frac{\partial P[\omega(z)}{\partial\omega(z)}\left\{T_s^4-T^4[\omega(z)]\right\} \quad (2)$$

It should be noted that analogous relation was proposed earlier.[5] In the formula given in Ref. 5 the temperature at a certain height z_1 close to the Earth's surface was used instead of the temperature at the given height. This fact, of course, introduces an uncertainty in the formula, because it is not clear which height is taken to be z_1. The estimates of the accuracy of the proposed formula for certain z_1 were not given in Ref. 5. As calculations show, if z_1 is taken to be 0.1 m, i.e., the lowest height of temperature measurements for atmospheric stratifications considered below, then the relative error in computations of the radiative heat influx in the surface layer under conditions of high temperature lapse rates is several times greater than the error of calculations from Eq. (2), and is about 20–35%. Under conditions of low temperature lapse rates the error in computations of $\frac{\partial T}{\partial t}$ from the formula given in Ref. 5 becomes extremely gross and at certain atmospheric heights is about 1000%, so that the formula given in Ref. 5 is inapplicable for estimating even the order of magnitude of $\frac{\partial T}{\partial t}$.

The mean error in computations from the more complicated formulas proposed by A.S. Ginzburg and E.M. Feigel'son,[2] is about 30%. However, their formulas are based on the assumptions which are valid for free atmosphere and their accuracy was estimated correspondingly for the troposphere (with vertical spatial resolution of 1–4 km).

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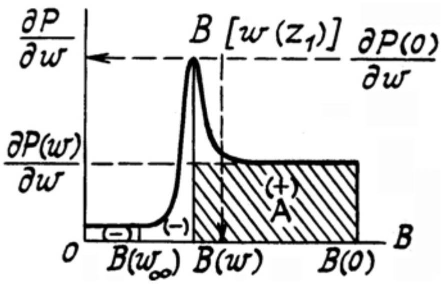

FIG. 1. A diagram of the long-wave radiative heat influx.

To estimate the radiative heat influx from formula (2), no data are needed on vertical profiles of the temperature and the absorbing gas above and below the considered height. As is well known, in atmospheric physics the simplified parametric formulae are often used to decrease the number of variables on which the unknown variable depends rather then to reduce the computational time, because not all the observations made provide all the data necessary for the exact computations.

The physical meaning of Eq. (2) is that the radiative heat influx in the atmospheric surface layer is determined mainly by heat exchange with the Earth's surface. If we assume that the layers located above and below considered layer are isothermal and introduce a temperature discontinuity at the air–surface interface, expression (1) is transformed into expression (2).

We estimated the accuracy of Eq. (2) by comparing it with the results of calculations from Eq. (1) for the values of $\frac{\partial P(\omega)}{\partial \omega}$ taken for the water vapor from Refs. 6 and 7. These values were recommended for use exactly in the surface layer. The vertical profiles of temperature and humidity for our computations ere taken from the KÉNÉKS–70 and KÉNÉKS–71 experiments,[8–10] which corresponded to cloudless conditions. The KÉNÉKS–70 observations were performed in the south-eastern part of the Kara–Kum desert in fall, while the KÉNÉKS–71 observations – in Western Kazakhstan steppe in summer. As demonstrated in Ref. 11, in the surface layer the contribution of aerosol in long-wave radiative heat influx under conditions of cloudless sky over a thoroughly superheated underlying surface is less than 1%. The contribution of carbon dioxide to heating is significantly less than that of water vapor (about 20%).

TABLE I

z, m	4.07.71		16.07.71				17.07.71	11.10.71
	10.30	14.30	10.30	14.30	18. 30	22.30	0.30	22.30
0. 1	– 4.5	– 3.4	–13.6	– 2.6	– 4.5	– 86.4	–174	584
0.25	–12.3	– 8. 1	–20. 1	–10.7	12.0	133	–408	247
0.5	–11.0	–10. 1	–10.6	–10.7	–15.4	– 86.6	– ∞	178
1.0	– 7.9	– 1.3	–10.8	–11.8	– 8.9	– 748	348	125
2.0	– 1.2	– 6.0	– 5.8	– 3.2	– 6.3	31.9	174	92.9
4.0	– 0.4	– 3.0	– 4.9	– 0.9	– 6. 1	87.5	202	– 18.2
8.0	7. 1	– 0.9	– 3.0	– 2.9	– 2.7	14.4	166	– 1.8
11.1	2.9	– 0.6	– 2.0	– 2.3	– 2.8	– 27. 1	96.7	0.8
25.0	3.9	0.5	5.6	8.4	1.9	– 100	– 41.0	– 30.7
50.0	11.4	0.9	5.3	4.3	–16. 1	– 67.7	– 50.0	13.8
100.0	21.0	6.7	14.4	10.5	16.8	– 123	– 108.0	– 61.9
$T_s - T_2$	11.2	20.1	13.1	20.6	– 12.9	– 0.4	– 0.5	– 2.4

Computations of $\varepsilon_{ex}=\frac{\partial T}{\partial t}$ from Eq. (1) followed the algorithm described in Ref. 12.

Estimates of the accuracy of formula (2) are given in Table I, in which the relative error in the calculation of $\varepsilon_{appr}=\frac{\partial T}{\partial t}$ from the approximate formula are given in per cents, i.e., the ratios for various temperature and humidity profiles. The table gives also the date and the local standard time of measuring (for example, 22.30 denotes 22 h 30 min LST). The last row of the table lists the differences between the surface temperature and the air temperature at the height 2 m in degree Kelvin.

Figure 2 shows the temperature profiles that have been used for the lower layer.

As seen from this table, formula (2) may be used for approximate estimates of the radiative heat influx in the surface layer under conditions of high temperature lapse rates. The error in estimating $\frac{\partial T}{\partial t}$ was essentially no greater than 15-20%, and substantially less than 10% within 2–25 m altitude range. In the case of a temperature inversion and low temperature lapse rates along with nonmonotonic character of the height dependence of temperature (the temperature inversion with the temperature minimum near the Earth's surface) formula (2) becomes inapplicable.

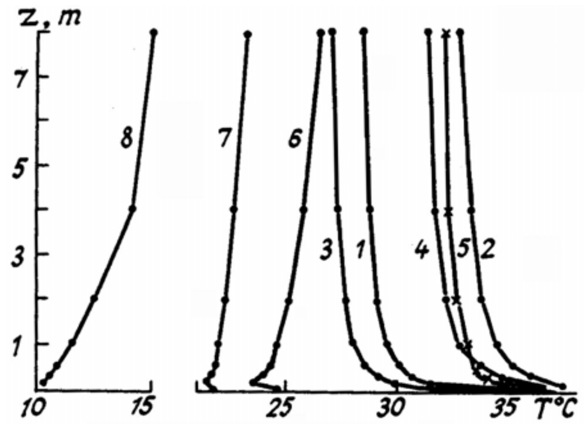

FIG. 2. Temperature profiles near the Earth's surface used for heat Influx calculations:
1) 4.07.71, 10.30; *2)* 4.07.71, 14.30; *3)* 16.07.71, 10.30; *4)* 16.07.71, 18.30; *5)* 16.07.71, 18.30; *6)* 16.07.71, 22.30; *7)* 17.07.71, 00.30; *8)* 11.10.70, 22.30.

Note in conclusion that in Ref. 13, in which the radiative heat influx to the entire layer of temperature inversion has been discussed, a regression formula has been derived that directly relates this influx with the temperature difference at the layer boundaries.

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