Theoretical Investigations of Radiative Heat Exchange on the Basis of Zvenigorod and Other Measurements

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Introduction

Cloudiness strongly affects the formation of the weather and climate of our planet. The mathematical apparatus for investigating cloud impacts on radiation fluxes—the equation of radiative transfer—was elaborated in a set of countries—including ours for 50 years and has been continuously developed until now. Several complex experiments were performed at Zvenigorod Scientific Station (ZSS) of the Institute of Atmospheric Physics located near Moscow. During the last experiments of 1994 and 1996, systematic measurements were conducted on the heights of the lower - z_l and upper - z_{up} cloud boundaries, water vapor content - v, liquid water content of clouds - w, optical thicknesses, vertical profiles of the temperature and humidity. The last two parameters from radiosonde sounding were not from ZSS, but at a 50-km distance from it—in the city of Dolgoprudny. Both places of measurements gave similar results if the ZSS data were used in a near-surface layer (Gorchakova and Zaitseva 1994).

For evaluation of the optical thickness of clouds, we used downward radiation in the visible region Q and the ratio (Tarasova and Chubarova 1994):

$$C = \frac{Q}{Q_o} \qquad (1)$$

where Q_o = clear-sky solar radiation. The results of the calculations for the spectral range $\Delta\lambda$ = 0.38 - 0.71 mñm are presented in Table 1 (Feigelson and Shilovtseva 1998):

Table 1. The results of calculations for the range $\Delta\lambda$ = 0.38 - 0.71 mcm.

ξ_o		30°	45°	60°	75°
Q_o (kw/m^2)	1	0.455	0.355	0.232	0.104
Q_o (kw/m^2)	2	0.456	0.365	0.244	0.114

If the sun is high (solar zenith angle ξ_o = 30°), the measured - 1, and the calculated - 2 data practically coincide; for low sun the difference is about 10%.

In Table 2 (Feigelson 1998), the satellite data are compared with the ground data. The data were obtained during the experiment in June 1994. Several examples are given.

Table 2. Comparison of the satellite data with the surface one (see explanation in text).

1	2 (°K)	3 (km)	4 (km)	5^1	5^2	5^3
$7,16^{32}$	253	6.5	0.2	50	47	
$8,16^{20}$	270	3.2	1.0	25	28	24
$15,16^{34}$	261	4.2	3.2	25		
$20,17^{13}$	268	2.8	1.1	20		
$22,16^{40}$	264	3.8	2.0	15	8	10
$24,18^{50}$	270	2.0	1.0	25	0	0
$28,17^{16}$	269	3.4	2.0			

1 Day and time of the satellite flight over ZSS.
2 The upper cloud boundary temperature from satellite.
3 Its height.
4 The height of the cloud lower boundary from surface measurements.
5^1, 5^2, 5^3 - the optical thicknesses of clouds retrieved by Tarasova and Chubarova (1994) and by Feigelson (1998).

Using all the results mentioned above and other data, we performed the study (Feigelson et al. 1997), simulated by Cess et al. (1995). The following expression was considered:

$$C_s(z) = Q_{cloud}(z) - Q_{clear}(z) \qquad (2)$$

where $Q(z) = Q\downarrow(z) - Q\uparrow(z)$ in the cloud (Q_{cloud}) or clear (Q_{clear}) atmosphere, going down $\downarrow$ or up $\uparrow$, differences of the integral solar radiation fluxes at the level z. The similar expression determining the parameter $C_l(z)$ can be written for the thermal radiation, Denote $C^* = C_s + C_l$ and $R = C_s(0)/C_s(\infty)$. We have calculated and analyzed the parameters C_s and C_l for the levels 0, z_l, z_{up}, ∞ and the differences ΔC_s, ΔC_l, ΔC^* for the intervals (0; z_l), (z_l, z_{up}), (z_{up}, ∞), (0, ∞), and also R using the ZSS experimental data.

The main result is that due to the radiation, the whole atmosphere and the cloud are heated in the same order of magnitude. The ratio R in our cases is less than Cess et al. (1995)—not 1.5, but 1.24 to 1.27 in all cases we considered.

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