Parameterization of Radiative Properties of One-Layer Broken Clouds

G.A. Titov, T.B. Zhuravieva, and V.E. Zuev
Institute of Atmospheric Optics, Tomsk, Russia

In this work, we consider a new approach to parameterization of the radiative properties of broken clouds, which allows GCM radiation codes to be improved.

Cloud models, methods of computing radiative fluxes, and the influence of effects caused by the random geometry of cloud fields on spectral fluxes of short-wave radiation and absorption by broken clouds are described in Titov 1990; Titov et al. 1995; Zuev et al. 1994a, b; and Zuev et al. 1995. At present we have mean spectral and short-wave fluxes of upward and downward solar radiation calculated for 12 atmospheric levels and 250 sets of values of input parameters. The latter were varied between the following limits:

- cloud optical depth $5 \le \tau \le 60$;
- cloud fraction $0 \le N \le 1$;
- parameter $0 \le \gamma \le 2$, where $\gamma = H / D$, H is the cloud layer thickness, D is the characteristic horizontal cloud size. Such a range of the parameter γ allows us to account for both stratus ($\gamma << 1$) and vertically elongated cumulus ($\gamma = 2$) clouds;
- solar zenith angle $0° \le \xi \le 75°$;
- underlying surface albedo varied from $A_s = 0.0$ (ocean) to $A_s = 0.8$ (new-fallen snow).

The essence of the method proposed will be explained by the example of upward fluxes $F^{\uparrow}$ of short-wave radiation. All the following will hold identically for downward fluxes of short-wave radiation $F^{\downarrow}$. Mean fluxes of upward radiation in cumulus at a height z can always be represented as

$$F_{Cu}^{\uparrow,sw}(z) = N_e^{\uparrow,sw}(z) \times F_{pp}^{\uparrow,sw}(z) + \left(1 - N_e^{\uparrow,sw}(z)\right) \times F_{cir}^{\uparrow,sw}(z) \tag{1}$$

where indices "pp" and "cir" indicate overcast cloud and clear sky, and "sw" the short-wave range (0.4-3.6 μm). The parameter $N_e^{\uparrow,sw}$, allowing an accurate consideration of the effects caused by the random cloud geometry, will be referred to as effective cloud fraction.

The task of calculating $F_{Cu}^{\uparrow,sw}(z)$ from formula (1) consists of finding convenient and reliable technique for calculating $N_e^{\uparrow,sw}$ since $F_{pp}^{\uparrow,sw}(z)$ and $F_{cir}^{\uparrow,sw}(z)$ values can be obtained based on the existing GCM radiation codes. One possible way of determining $N_e^{\uparrow,sw}$ consists of the following :

- calculate the value of effective cloud fraction with detailed step in each of the parameters:

$$N_e^{\uparrow},sw(z) = \frac{F_{Cu}^{\uparrow,sw}(z) - F_{cir}^{\uparrow,sw}(z)}{F_{pp}^{\uparrow,sw}(z) - F_{cir}^{\uparrow,sw}(z)} \tag{2}$$

- select simple interpolation formulas to calculate $N_e^{\uparrow,sw}$ for intermediate parameter values.

Such an approach to solving this task is computationally expensive, since for each fixed set of input parameters it is necessary to calculate ≈450 values of spectral fluxes (spectral resolution $\Delta v = 10 \div 20\ cm^{-1}$). These expenses can be substantially reduced if the function $N_e^{\uparrow,sw} = f\left(n_e^{vis}\right)$ is known, where he superscript "vis" indicates visible range. It is believed that this function will be fairly simple and unique, considering that the contribution of visible range to the short-wave spectral region is sufficiently large, and the effects associated with the stochastic cloud structure do not depend on wavelength.

Figure 1 presents effective cloud fraction N_e^{sw} as a function of N_e^{vis} for fluxes of upward (à) and downward (b) radiation at the top of the atmosphere, z = 16 km, and at the underlying surface, z = 0, respectively. Each point $\left(N_e^{vis}(z), N_e^{sw}(z)\right)$ on this plot corresponds to the calculation with fixed set of input parameter values. The dependence of $N_e^{sw}(z)$ on $N_e^{vis}(z)$ is fitted pretty well by functions of the form:

$$\begin{aligned} N_e^{\uparrow,sw} &= N_e^{\uparrow,vis} \times \left(0.98 + 0.02 \times N_e^{\uparrow,vis}\right), \\ N_e^{\downarrow,sw} &= N_e^{\downarrow,vis} \times \left(1.06 - 0.06 \times N_e^{\downarrow,vis}\right). \end{aligned} \tag{3}$$

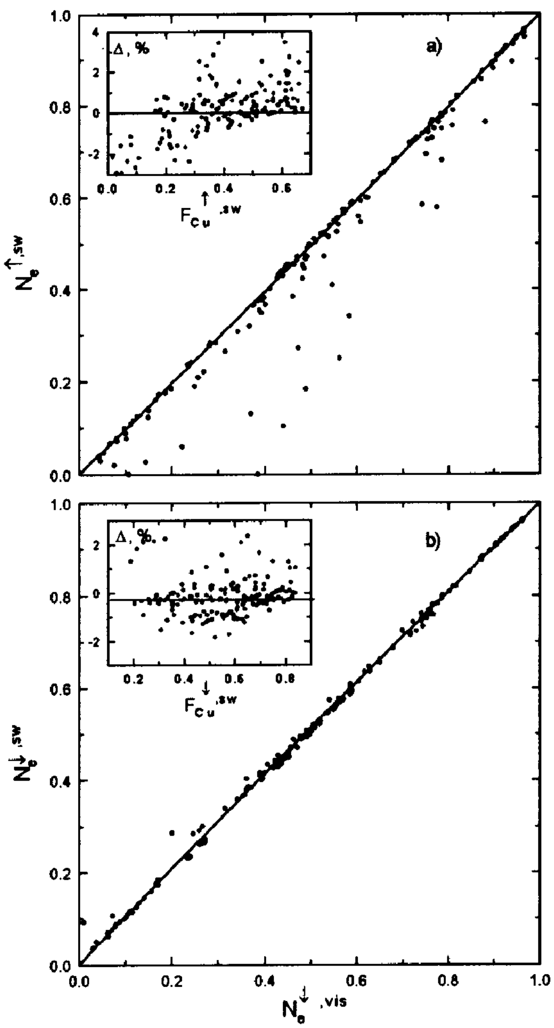

Figure 1. Dependence of $N_e^{sw}(z)$ on $N_e^{vis}(z)$ and the relative error of computing $F_{Cu}^{sw}(z)$ according to formulas (1), (3) for upward (à) and downward (b) fluxes at heights z = 16 km and z = 0 respectively.

Substantial deviations from formula (3) occur for large surface albedos $A_s > 0.4$, when $F_{pp}(z)$ and $F_{cir}(z)$ may be close in value, so that calculation of effective cloud fraction is prone to large errors. However, the large errors in calculation of N_e^{sw} do not lead to large errors when retrieving shortwave fluxes according to formulas (1) and (3), since in this case the values of $F_{pp}(z)$, $F_{cu}(z)$, and $F_{cir}(z)$ differ little from each other. Relative errors of short-wave flux calculation Δ do not exceed 4% (Figure 1).

Analysis of results shows that formulas (1) and (3) can be used to calculate $F_{Cu}^{\uparrow,sw}(z)$ and $F_{Cu}^{\uparrow,sw}(z)$ for any z. We note that to calculate $N_e^{sw}(z)$ in the undercloud atmosphere, the second formula in (3) is more appropriate since in this case the upward fluxes are determined by the value of $F_{Cu}^{\downarrow,sw}(z = 0)$. In the abovecloud atmosphere, either $F_{pp}^{\downarrow,sw}(z = 0)$ or $F_{cir}^{\downarrow,sw}(z = 0)$ value can be used instead of $F_{Cu}^{\downarrow,sw}(z)$ since the relative difference between them does not exceed 1-2%.

Since the form of the function $N_e^{sw} = f(N_e^{vis})$ is established, the task now reduces to determining N_e^{vis}. One of the possible ways of solving the task consists of using approximate methods of solution of equations for mean intensity, that allow the mean fluxes to be calculated with required accuracy. At present such methods are lacking, so we suggest that a numerical model of N_e^{vis} be developed. Computer time required for this model development is determined by the number of input parameters. In addition to parameters above, also influencing the cloud radiative characteristics are optical properties of atmospheric aerosol and cloud microstructure.

Aerosol optical depth τ_a is small, so it is possible to neglect its variability and use some mean value. Calculations showed that as τ_a grows from 0 to 0.22, the relative difference in radiative fluxes does not exceed 1-2%.

Obviously, the strongest sensitivity of N_e^{vis} to varying microstructure of clouds should be expected at their small optical depths. Table 1 presents N_e^{vis} obtained for different cloud scattering phase functions C_1, C_3, C_6 (Deirmendjian 1969) and a fixed τ. It is seen that N_e^{vis} and, hence, radiative fluxes change slightly (~1%), therefore variations of cloud microstructure can be neglected in N_e^{vis} calculation.

Table 1. Influence of cloud microstructure on N_e^{vis} with τ = 5, γ = 2, ξ = 0°, N = 0.5, and As = 0.0.

	$N_e^{\uparrow,vis}$		$N_e^{\downarrow,vis}$	
	z = 1.5 km	z = 16 km	z = 0	z = 1 km
C_1	0.436	0.435	0.433	0.431
C_3	0.440	0.438	0.437	0.434
C_6	0.435	0.434	0.435	0.424

Thus, N_e^{vis} depends on the five input parameters listed above: τ, N, γ, $\xi_\oplus$, and A_s. As an example, Figures 2 and 3 present dependencies of $N_e^{\uparrow,vis}$ on solar zenith angle, cloud fraction, and aspect ratio.

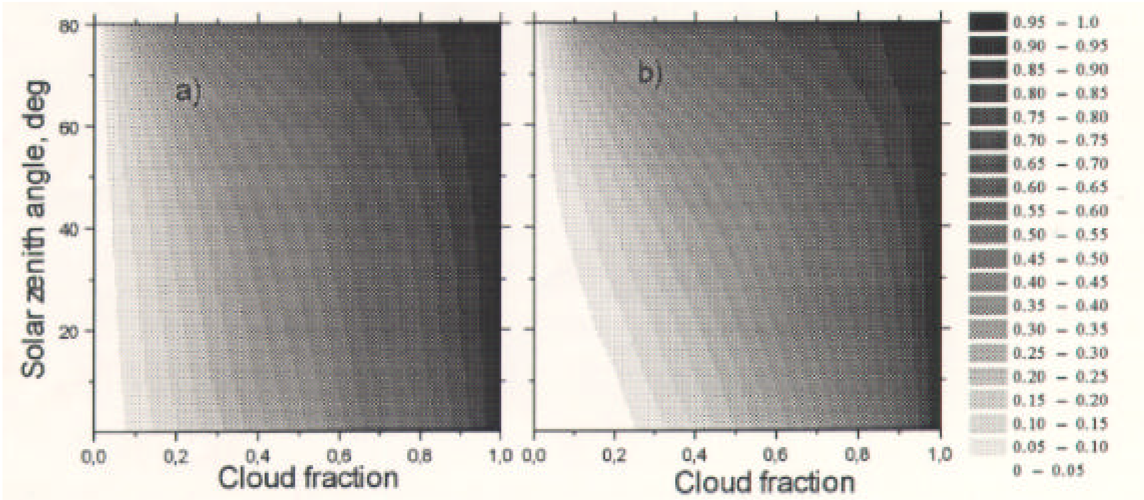

Figure 2. Influences of solar zenith angle and cloud fraction on the value of $N_e^{\uparrow,vis}(z)$ at height z = 16 km for $\gamma = 2$, $\tau = 15$, and different surface albedos: $A_s = 0.0$ (a) and $A_s = 0.4$ (b).

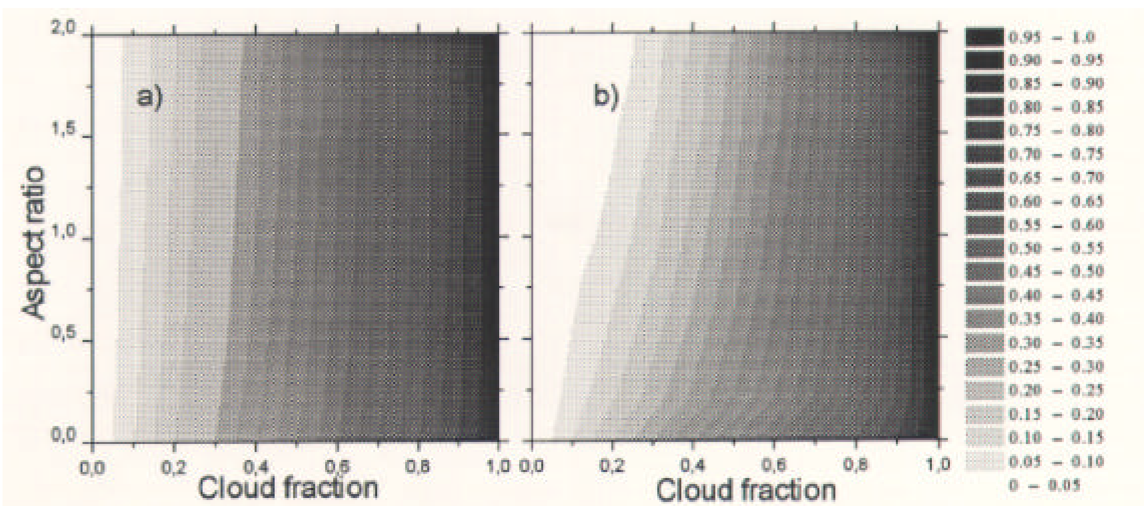

Figure 3. Dependence of $N_e^{\uparrow,vis}(z)$ on cloud fraction and aspect ratio with $\xi_\oplus = 0°$, $\tau = 15$, $A_s = 0.0$ (a) and $A_s = 0.4$ (b) at height z = 16 km.

Conclusion

New parameterization of radiation budget of broken clouds is proposed which permits sufficiently exact and fast computation of upward and downward fluxes of short-wave radiation. It is based upon simple functional dependence between N_e^{vis} N_e^{sw} that we found. The advantages of this parameterization are:

- The use of $N_e^{vis} = f(N_e^{vis})$ allows one to accurately account for the effects caused by the random cloud geometry.
- The development of the numerical model of N_e^{vis} does not require large consumptions of computer time.
- There is no need to make substantial changes to currently used GCM radiation codes.

This work was supported by the DOE's ARM Program under contract No. 350114-A-Q1.

References

Deirmendjian, D., 1969: Electromagnetic Scattering on Spherical Polydispersions, American Elservier, New York.

Titov, G.A., 1990: Statistical description of radiative transfer in clouds, *J. Atm. Sci.*, **47**, 24-38.

Titov, G.A., T.B. Zhuravleva and V.E. Zuev, 1995: Mean radiant fluxes in the near IR spectral range: algorithms for calculation (*submitted to â JGR*).

Zuev, V.E., G.A. Titov, T.B. Zhuravleva and S. Yu. Popov, 1994a: Mean Fluxes of Visible Solar Radiation in Broken Clouds, *Proceedings of the Fourth ARM Science Team Meeting, Charleston, South Carolina.*

Zuev, V.E., G.A. Titov, T.B. Zhuravleva and S. Yu. Popov, 1994b: Mean Fluxes of Near-IR Solar Radiation in Broken Clouds, *Proceedings of the Fourth ARM Science Team Meeting, Charleston, South Carolina.*

Zuev, V.E., G.A. Titov and T.B. Zhuravleva, 1995: Absorption of solar radiation in broken clouds, *Proceedings of the Fifth ARM Science Team Meeting, San Diego, California.*