About Determination of the Cloud Optical Depth from the Data of the Cloud-Radiation-Aerosol Experiments (1994, 1996) at IAPh, Russia

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Introduction

Cloudiness is one of major factors that determines the formation of a climate and its change. Because of the complexity of direct measurements of cloud optical parameters, it is preferable to use estimates from ground observations. The optical depth of clouds, τ_{cl}, is one of the main parameters influencing the radiation, coming to the earth's surface. At present, the estimations of cloud optical depth are based usually on the measurements of solar radiation fluxes in cloudy atmosphere with wide-angle (field of view α=180°) and narrow-angle zenith radiometers (α is less than 10°) (Anikine 1991; Anikine et al. 1992; Tarasova and Chubarova 1994; Ershov et al. 1988). The optical depth, τ, is determined from comparison of the measured and calculated ratios of fluxes (intensities) of solar radiation in cloudy and at clear-sky conditions:

$$C = I_{cl} / I_o$$

Using the parameter C eliminates a systematic error of measurements and influence of clear atmosphere characteristics on the results of the comparison of measurements and calculations. Semi-spherical fluxes of radiation were calculated in a two-stream approximation of the radiative transfer theory (Sobolev 1956). Intensities were calculated using the asymptotic Sobolev's formula for the brightness coefficient of scattering layer. For a more detailed estimate of the influence of the approximations used on the results of calculations, a series of model computations of the transmittance of a cloudy layer in various conditions was fulfilled by a Monte Carlo method (Marchuk and Mikhailov 1976).

Results of Calculations

The calculations by a Monte Carlo method were carried out for various albedo of a surface (À), for single-layer and multi-layer cloudiness, and for ice and water particles with effective size r_{eff} from 6 mcm up to 72 mcm. Molecular atmosphere, overcloud, intercloud and undercloud aerosol characteristics were also taken into consideration. The dependencies of C upon the optical depth of cloud with r_{eff} = 6 mcm and a single scattering albedo ω = 1; 0.9999; 0.999 are shown in Figure 1 for α =10° and 180°, solar zenith angle β = 60°, and wavelength λ=0.37 ìcì. The cloud base height is equal to 1 km. The optical depth, τ_a, of the undercloud aerosol layer was assumed to be equal to 0.08 and overcloud - to 0.12. It follows from Figure 1 that the unambiguous dependence, C, upon τ_{cl} exists for wide-angle instruments (α = 180°). For α = 10°, the dependence, C, upon τ_{cl} is possible to use only for τ_{cl} > 6, i.e., when direct solar radiation is rather small compared to diffuse. For big values of τ_{cl} and significant absorption (ω = 0.999), curves in Figure 1 are split, which lead to inaccuracy in retrieval of the optical depth without knowledge of cloud single scattering albedo.

Figure 2 illustrates the influence of the cloud particle phase functions on the determination of the τ_{cl} in the case of one-layer cloudiness located at a height of 1 km. Relations between C and τ_{cl} are compared in Figure 3 for one-layer and two-layer cloudiness. The top layer (ice clouds with r_{eff} = 72 mcm) is located at a 6-km height, bottom (water clouds with r_{eff} = 6 mcm) at a height of 1 km. One-layer cloudiness with r_{eff} = 6 mcm is placed at a height of 1 km and with r_{eff} = 72 mcm at a height of 6 km. Total τ_{cl} of two layers is

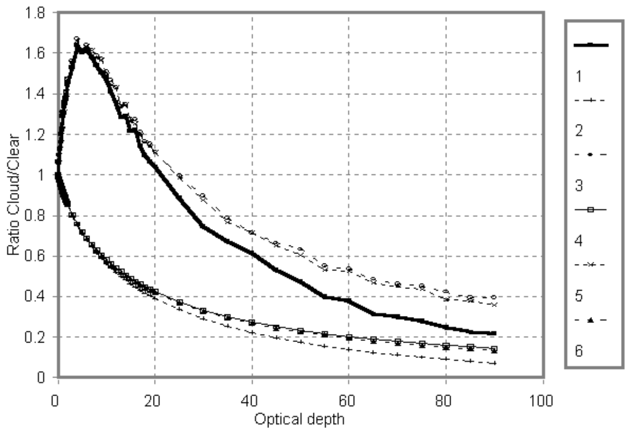

Figure 1. Calculations of the parameter C as a function of the cloud optical depth τ_{cl} for wavelength λ = 0.37 mcm and effective radius of cloud particles r_{eff} = 6 mcm:

1 - α=10°, ω= 0.9999; 2 - α=180°, ω= 0.9999;
3 - α=10°, ω= 0.999; 4 - α=180°, ω= 0.999;
5 - α=10°, ω= 1; 6 - α=180°, ω= 1.

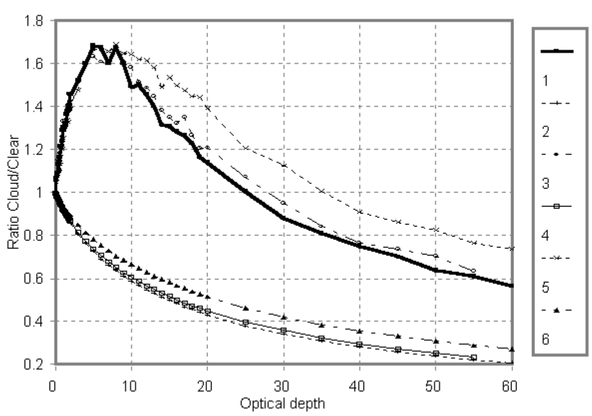

Figure 2. Calculations of the parameter C as a function of the cloud optical depth τ_{cl} for wavelength λ = 0.37 mcm and single scattering albedo ω= 1:

1 - α=10°, r_{eff} = 6 mcm; 2 - α=180°, r_{eff} = 6 mcm;
3 - α=10°, r_{eff} = 15 mcm; 4 - α=180°, r_{eff} = 15 mcm;
5 - α=10°, r_{eff} = 72 mcm; 6 - α=180°, r_{eff} = 72 mcm.

approximately equal to τ_{cl} of one-layer. All above-presented results of calculations are obtained for the constant aerosol optical thickness, τ_a = 0.2. However, τ_a can essentially affect C for big τ_{cl} because of a weak sensitivity of C, in this case to τ_{cl} (Tarasova and Chubarova 1994). The effect of the aerosol optical depth on dependencies of C upon τ_{cl} is shown in Figure 4. Errors in estimations of τ_{cl} can reach 50% for great τ_{cl}. Surface albedo A also strongly influences the dependence C upon τ_{cl}. Since our

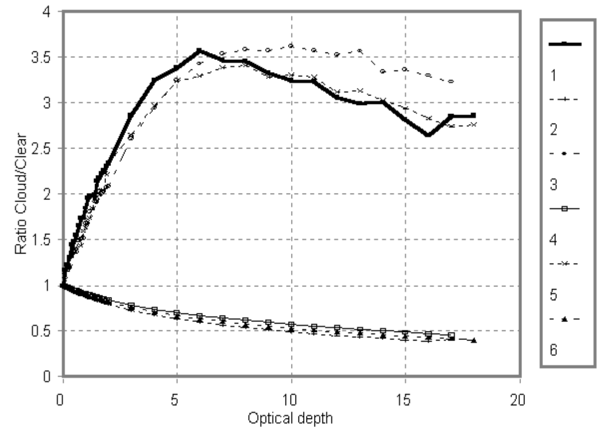

Figure 3. Influence of multilayer clouds on retrieving τ_{cl} for λ = 0.53 mcm and ω= 1:

1 - α=10°, r_{eff} = 6 mcm and 72 mcm;
2 - α=180°, r_{eff} = 6 mcm and 72 mcm;
3 - α=10°, r_{eff} = 72 mcm; 4 - α=180°, r_{eff} = 72 mcm;
5 - α=10°, r_{eff} = 6 mcm; 6 - α=180°,r_{eff} = 6 mcm.

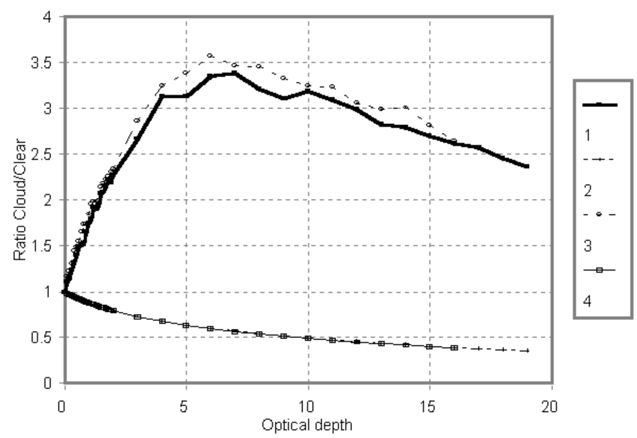

Figure 4. Influence of the optical depth of undercloud aerosol τ_a on retrieving τ_{cl} for λ = 0.53 mcm, ω= 1, and r_{eff} = 6 mcm:

1 - α=10°, τ_a = 0.16; 2 - α=180°, τ_a = 0.16;
3 - α=10°, τ_a = 0.08; 4 - α=180°, τ_a = 0.08.

experiments on the study of the radiative properties of cloudiness were held mainly in the summer and fall seasons, we have calculated dependencies C(τ_{cl}) for A = 0.1, 0.2, 0.3. They are shown in Figure 5.

Results of Measurements

The measurements were carried out in September and October 1994 and June and July 1996 at the Zvenigorod

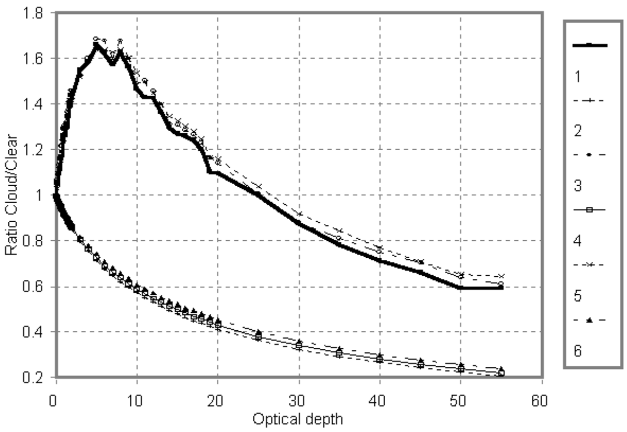

Figure 5. Influence of surface albedo A on retrieving τ_{cl} for λ = 0.37 mcm, r_{eff} = 6 mcm, and ω= 1:

1 - α=10°, A= 0.1;	2 - α=180°, A= 0.1;
3 - α=10°, A= 0.2;	4 - α=180°, A= 0.2;
5 - α=10°, A= 0.3;	6 - α=180°, A= 0.3.

Scientific Station of IAPh. The cloudy and clear-sky brightness was measured at three wavelengths: λ = 0.37 mcm, 0.53 mcm, and 0.74 mcm by photometers with 2 degrees field of view, directed to Zenith. A continuous record of the results of the measurements was conducted. The solar radiation fluxes (Eppley's pyranometers), water content, number of clouds, and cloud base height were measured in parallel with cloud brightness. A continuous record of the measurement data was conducted. The temporal course of τ_{cl} retrieved from different experimental data is shown in Figure 6. The optical depth obtained from cloud water content data was calculated assuming the specific mass extinction coefficient to be equal to 2500 cm^2/g, that corresponds to narrow cloud particle's size distribution.

There is good agreement between the different methods of receiving τ_{cl} from our measurements of fluxes to Eppley's pyranometer and photometers with narrow-angle aperture among themselves. However, the τ_{cl} received from the water content of clouds have too large an error (more that 100%).

Conclusions

The estimations of the effects of the surface albedo, cloud particle's phase functions and single scattering albedo on the accuracy of the evaluation of the cloud optical depth were made. The analysis showed that the discussed methods of retrieving the cloud optical depth can be used for the interpretation of the data of the field experiments on investigation of the cloud influence on the downward radiative fluxes. Optical depths obtained by different methods are in a rather good agreement.

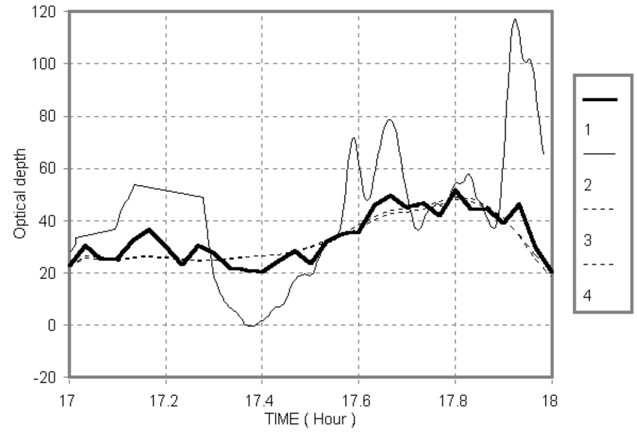

Figure 6. Example of time series of optical depth τ_{cl} from the experimental data.

1 - from spectral zenith brightness measurements;
2 - from cloud water content measurements;
3 - from measurements with help of Eppley's pyranometer and formulae from (Tarasova and Chubarova 1994);
4 - the same measurements and formula from (Sobolev 1956).

Acknowledgments

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