Study of the Cloud Albedo Related to Microphysical Properties of Clouds

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ABSTRACT
The aim of this paper is to show the dependence of the cloud albedo on the microphysical parameters of cloud, like cloud droplets number concentration (CDNC), cloud droplet effective radius and the cloud optical depth. The optical properties of clouds, especially cloud albedo are also computed in connection to the changes in liquid water content (L) and the cloud geometrical thickness.

Keywords: cloud albedo**,** cloud microphysics, cloud optical depth

1. INTRODUCTION
The clouds, by macro and microphysical features represent the key of climate change understanding. The properties of different types of clouds in various climatic conditions can be used in parameterization of clouds in regional and global climate models, because the radiative effect of clouds in both the solar and thermal regions of the electromagnetic spectrum has an important role in the radiative budget of the Earth-Atmosphere system. The microphysics of clouds is influenced on natural or anthropogenic aerosol. Aerosols alter warm, ice and mixed-phase cloud formation processes by increasing droplet number concentrations and ice particle concentrations and thereby cause an indirect radiative forcing associated with the changes in cloud microphysical and their optical properties.
Cloud droplet nucleation involves aerosol particles that can be activated to CCN (cloud condensation nuclei) and according to, for example, Twomey [18] and Penner et al [16], this process is strongly dependent on aerosol characteristics. There are two general methods that have been used to relate changes in CDNC (Cloud Drops Number Concentration) to changes in aerosol concentrations ([18], [12], [3], [7], [1, 2]). In addition, several studies prove that, during the cloud-aerosol interaction, cloud geometrical thickness can change ([6], [11]), so the predicted CDNC may change combining the effects of changes in droplet concentrations and changes in geometrical thickness of clouds [8]. In this paper the both theoretical consideration about the cloud albedo, the cloud parameters like cloud droplet effective radius and the cloud optical depth for visible spectral interval and the results obtained for microphysical properties of clouds were presented in Section 2. In Section 3, using the properties of clouds emphasized in Section 2, we calculated the cloud albedo as a function of CDNC in connection to the changes in liquid water content (L) and the cloud geometrical thickness. Section 4 summarizes the results obtained.

2. CLOUD ALBEDO
Cloud albedo is a measure of the reflectivity of a cloud- high albedo values mean that the cloud blocks more solar radiation. Values of the albedo varies from less than 10% to more than 90% from the incident solar radiation.

2.1. Theoretical considerations
The cloud microphysical parameters that we have investigated are: liquid water content (*L*), cloud droplet number concentration (*N*), effective radius (r_{eff}) cloud optical depth (τ) and cloud albedo (*A*).

The cloud albedo, *A*, was computed taking into account the two-stream approximation of a nonabsorbing, horizontally homogeneous cloud (Lacis and Hansen, 1974, [13]):

$$A = \frac{\sqrt{3}(1-g)\tau}{2+\sqrt{3}(1-g)\tau} \tag{1}$$

where τ is the optical depth of the cloud, and g denotes the asymmetry factor.
The effective radius r_{eff} is defined by the ratio between the third moment of the size spectrum and its second moment (Hansen and Travis, 1974, [9]):

$$r_{eff} = \frac{\int_0^\infty N(r) r^3 dr}{\int_0^\infty N(r) r^2 dr} \quad (2)$$

where r is the radius of the cloud droplet and $N(r)$ is the number concentration of cloud droplets.
Han et al. (1998) [8] reported that for most continental clouds and all optically thick clouds (τ > 15) over most the world, cloud albedo increases with decreasing r_{eff} , and for optically thin clouds (τ < 15) over oceans and tropical rain forest areas, cloud albedo decreases with decreasing r_{eff} in which case τ varies with square power of r_{eff} .

$$\tau = \pi \, r_{eff}^2 \, Q_{ext} \, N \, \Delta z_c \quad (3)$$

where N is the cloud droplet number concentration, Δz_c is geometrical thickness, r_{eff} effective radius of the cloud's droplets and Q_{ext} - extinction efficiency. For cloud droplets with radius much more than the wavelength of the visible light, Q_{ext} can be approximated by a constant Q_{ext} ≈ 2. For the asymmetry factor, we have considered the values of 0.865 for visible portion of electromagnetic spectrum. These are currently used values by the general circulation model of the LMD (Laboratoire de Meteorologie Dynamique). The liquid water content (g/m^3), cloud droplet number concentration (cm^{-3}) and the effective radius (μm) are related by the following equation:

$$L = \frac{4}{3} \pi r_{eff}^3 \rho N \quad (4)$$

where ρ is the water density. Consequently, the cloud optical thickness is:

$$\tau = 2\pi \Delta z_c \left(\frac{3L}{4\pi\rho} \right)^{\frac{2}{3}} N^{\frac{1}{3}} \quad (5)$$

The equations (1) and (5) may be used to compute the cloud albedo.

2.2. Results obtained for cloud microphysics

The experimental microphysical properties of five types of clouds are presented in Table1 (Hess et al. [10]). We have used these properties to calculate or to validate our results obtained, using a column (one-dimensional) model. We also used like initial input data, the geometrical thickness of different types of clouds obtained from measurements [4, 5].

2.2.1. Effective radius

The effective radius can be parameterised as a "1/3" power law of the ratio between the cloud liquid water content and the cloud droplet number concentration, with some pre-factors which are dependent of spectral dispersion of droplet size distribution ([14], [15]).

$$r_{eff} = PF \cdot \left(\frac{L}{N_{CDNC}} \right)^{\frac{1}{3}} \quad (6)$$

where the pre-factor PF has been computed as:

$$PF = 62.04 \cdot \frac{\left(1 + 2d^2\right)^{2/3}}{\left(1 + d^2\right)^{1/3}} \quad (7)$$

Here d signifies the spectral dispersion ($d = \frac{\sigma}{\bar{r}}$) of droplet size distribution. In liquid water clouds, the effective radius, r_{eff} can be used to express the cloud optical thickness, the single scattering albedo and the asymmetry factor.

We have assumed that the spectral dispersion of the aerosol number size distribution characterizes the N size distributions and we have considered the values of the spectral dispersion corresponding to the accumulation mode for the various aerosol types which lead to all the clouds, without the Cumulus continental polluted clouds when we added the nucleation type.

Table 1. Cloud types and their microphysical properties

Cloud type	**name**	$r_{\text{mod}}(\mu m)$	$r_{eff}(\mu m)$	$N(cm^{-3})$	$L(g \cdot m^{-3})$
Stratus (continental)	StCO	4,70	7.33	250	0.28
Stratus(maritime)	StMA	6.75	11.30	80	0.30
Cumulus (cont.,clean)	CuCC	4,80	5.77	400	0.26
Cumulus(cont., polluted)	CuCP	3.53	4.00	1300	0.30
Cumulus (maritime)	CuMA	10.40	12.68	65	0.44

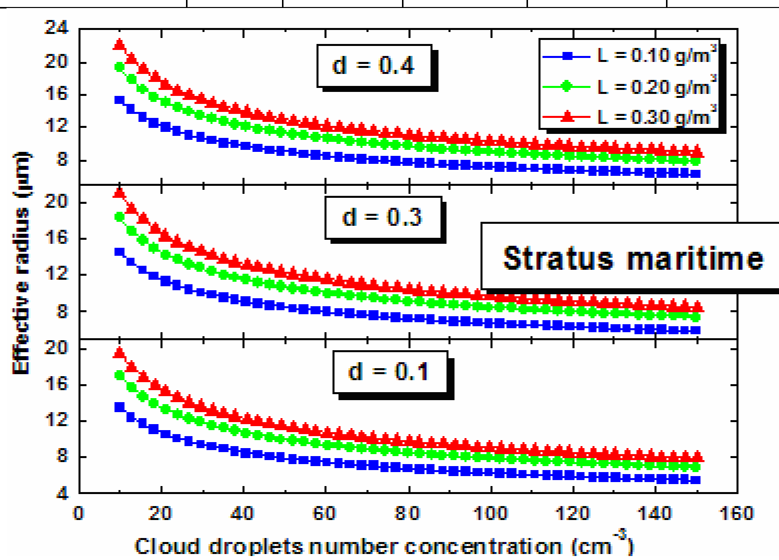


Figure 1. Cloud droplet effective radius as a function of CDNC for stratus maritime clouds.

Figure 1 shows the effective radius dependence of N for three different values of liquid water content, in case of the stratus maritime clouds and when the dispersion has the values: 0.1, 0.3 and 0.4. Results show the strong dependences between the effective radius, liquid water content, and spectral dispersion.

In case of the same values of *N*, one can observe the increase in *d* determines an increase in r_{eff}. The same result was observed for all the clouds (not shown here). An increase in *d* may also act to negate the effect of increased *N* on r_{eff} and on cloud reflectivity [14].

For the stratus maritime case results show, for the *N*=80 cm^{-3} and liquid water content of 0.3 g/m^3, effective radius is 11.3 µm like from measurements (Table 1) for *d*=0.3. An increase of liquid water content leads to higher values for effective radius, depending on the CDNC values. The values are similar with those measured by Han et al. [8]. The dependences are similar in the case of continental clouds; one observed the smaller values of r_{eff} for higher concentrations of CDNC. The most likely values for effective radius for continental clouds lie in the range 2 ÷ 4µm. The values are similar with those measured by Han et al. [8] and simulated by Boucher and Lohmann [3] with ECHAM and LMD GCM models.

2.2.2. Cloud optical depth

In order to investigate the dependence of optical depth τ on cloud droplet number concentration the equation (5) was used. We have considered in computations of cloud parameters the values of liquid water from Table1, tacking into account only non-precipitating clouds. In addition we have assumed all CCN become cloud droplets [15].

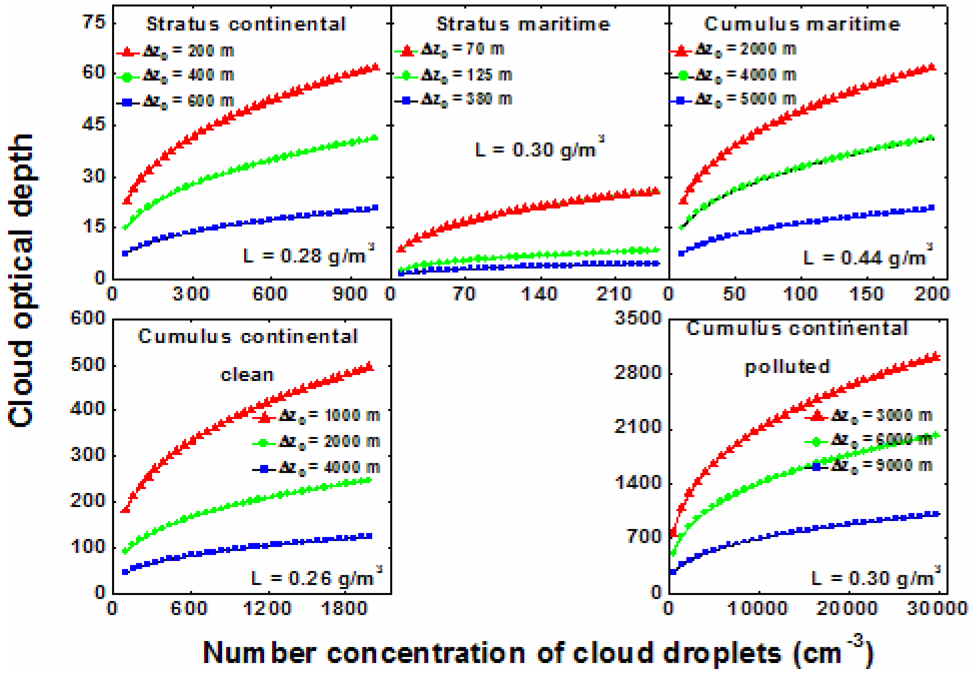
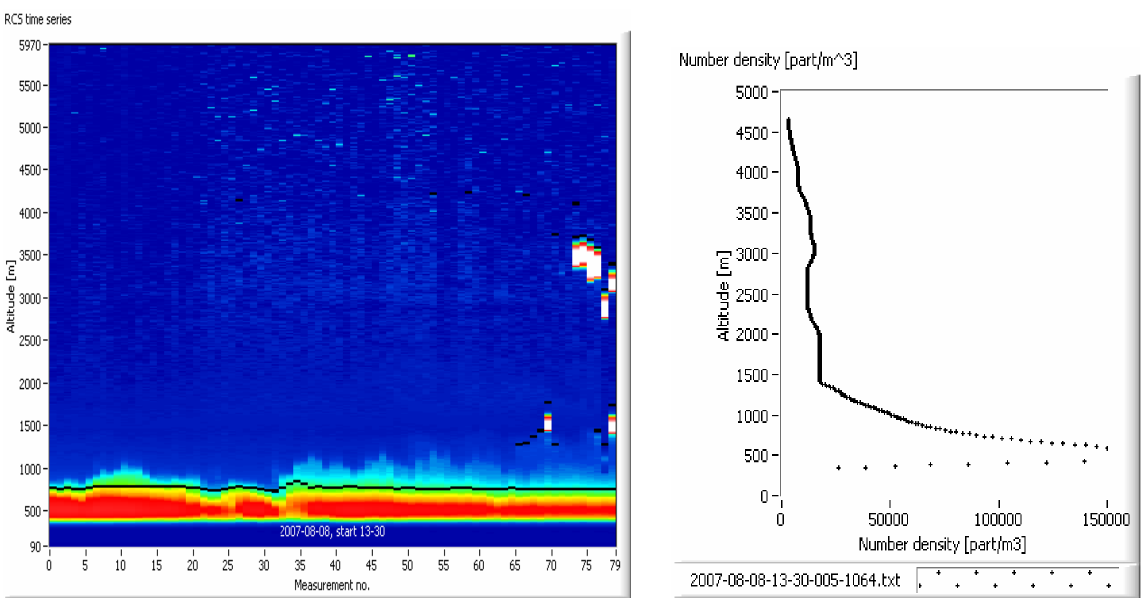


Figure 2. Cloud optical depth *versus* cloud droplets number concentration of the five types of clouds (Table 1) with their geometrical thickness and liquid water content.

Figure 2 shows the dependence of τ of cloud droplets number concentration (CDNC) in the case of the five clouds (Table 1) with particular geometrical thickness. Regarding the dependence of τ of cloud geometrical thickness for a fixed value of L one can observe an increase of cloud optical depth with the decrease of cloud geometrical thickness. We also note the dependence of τ on the type of clouds with the highest values for cumulus polluted.



a. b.

Figure 3. Range Corrected Signal (a.u.) temporal evolution - on August 8th 2007, 13:00 UTC, 1064nmsounding wavelength (a) and aerosol concentration profile (b).

We checked if it possible to use the LIDAR to determine the optical properties of clouds starting from the aerosol concentration profiles *a priori* formation the clouds. We chose the LIDAR measurements on 08 August 2007 (Figure 3a). One can observe two cloud layers: 1st layer has the cloud base at 1360m and cloud top at 1660m; 2nd layer has the cloud base at 3170m and cloud top at 3720m. Therefore the cloud geometrical thickness values are: $\Delta z_1 = 300m$ for stratus continental StCO and $\Delta z_2 = 550m$ altostratus continental AstCO. From the aerosol concentration profile (Figure 3b) were computed the values of aerosol concentration for the two layers.
Then, accounting continental air mass and lognormal size distribution of aerosol we computed using parameterization Abdul-Razzak [1,2] the CCN (Cloud Condensation Nuclei). The computed cloud optical depth values are 50 and 60 respectively, closed to values for stratus continental clouds.

3. THE DEPENDENCE OF CLOUD ALBEDO TO MACRO AND MICROPHYSICAL PROPERTIES OF CLOUD

The cloud albedo, *A*, was computed taking into account the two-stream approximation of a no-absorbing, horizontally homogeneous cloud (eq.1).

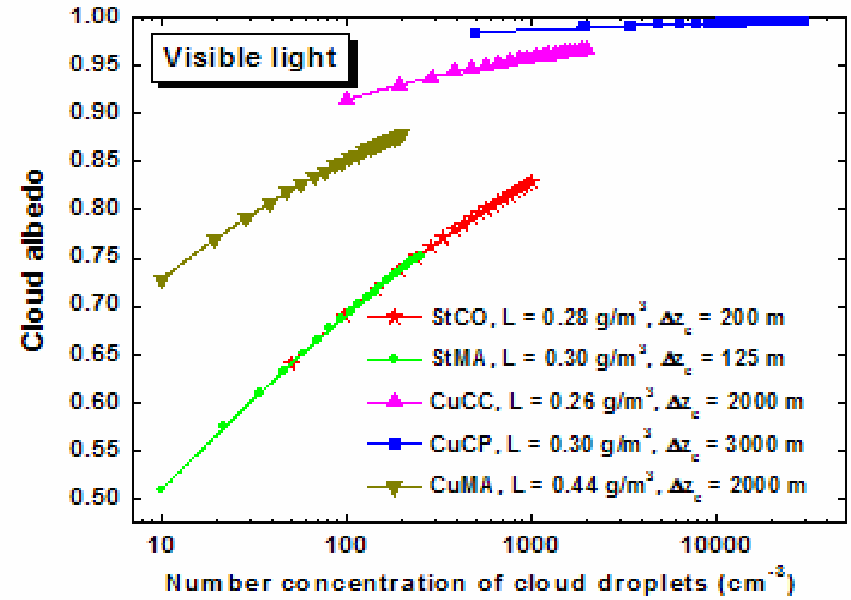


Figure 4.The Dependence of cloud albedo on CDNC for the five clouds from Table 1.

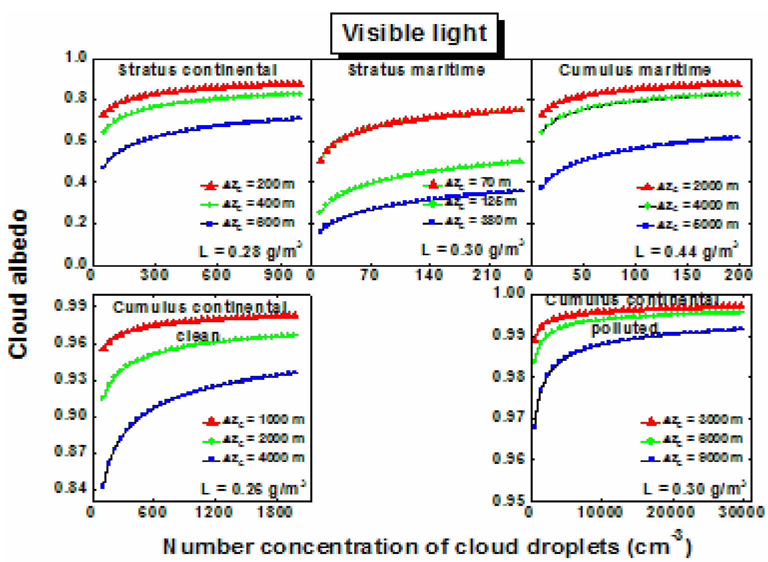


Figure 5. The dependence of cloud albedo on cloud geometrical thickness and CDNC

Figure 4 presents the cloud albedo dependence on cloud droplet number concentration for the five type clouds with for the fixed values of cloud geometrical thickness, for the visible spectrum The variation of cloud albedo with cloud droplets number concentration and the cloud geometrical thickness is shown in figure 5.
One can observe the influence of the type of clouds, so the type of aerosols, in the cloud albedo values. The albedo increases with the increase of CDNC and decreases when the geometrical thickness increases, like in the case of cloud optical depth. The largest differences are between maritime and continental clouds. The explanation is related to air masses type and composition. In continental polluted clouds where the droplets are smaller and CDNC larger, the albedo values are larger than in maritime clouds [17].

4. SUMMARY

Present work provide estimates for cloud albedo and for different cloud types as a function of increase in cloud droplet number concentration as result of increase in aerosol number concentration.
The study shows that cloud radiative properties are sensitive to cloud microphysical properties such as droplet concentrations and effective radius and macro physical aspects as the geometrical thickness. Thus, one note the dependence of τ on the both geometrical thickness and the type of clouds.
The investigated influence of cloud geometrical thickness on the cloud albedo shows large different values for various values of the geometrical thickness. That means that dynamical processes in cloud are important in calculating of albedo.
The albedo increases with the increase of CDNC and decreases when geometrical thickness increases. Therefore, in polluted clouds where the droplets are smaller and CDNC larger, the albedo values are larger than in maritime clouds.

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