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NOTES AND CORRESPONDENCE

Revised Parameterization to Predict Cloud Droplet Concentration and a Retrieval Method to Predict CCN Concentration—Supplement—

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Abstract

In our recent paper "Parameterization of the effect of cloud condensation nuclei on optical properties of a non-precipitating water layer cloud" (Kuba et al. 2003), we developed an approximation to predict the cloud droplet concentration as a function of the CCN concentration and the updraft velocity at the cloud base. This study improves on the approximation for convenience. In addition, this study proposes an approximation for higher updraft velocities than those in the previous paper.

The paper entitled "Parameterization of the effect of cloud condensation nuclei on optical properties of a non-precipitating water layer cloud" (Kuba et al. 2003) proposed a new method to predict the optical thickness, effective radius, and concentration of cloud droplets in water layer clouds using the spectrum of cloud condensation nuclei (CCN), the updraft velocity at the cloud base, and the liquid water path (LWP). A retrieval method also was proposed to predict the CCN concentration using independent observations of the updraft velocity at the cloud base, the optical thickness, and the LWP of clouds.

In that paper, equations to estimate the number of cloud droplets at 100 m above the cloud base (N_d) were expressed as a function of the CCN concentration and the updraft velocity at the cloud base (V_{base}, m s^{-1}) as follows (Eq. 5 in Kuba et al. 2003):

$$N_d = J \ln N_c(0.2\%) + K,$$

where $J = 724V_{base} - 8.07$ and $K = -2410V_{base} + 70.4$. $N_c(0.2\%)$ is the cumulative number of CCN that can be activated at 0.2% supersaturation. A critical supersaturation of 0.2% corresponds to a radius of 0.036 μm (0.048 μm) for the dry nucleus of NaCl ($(NH_4)_2SO_4$). Since this equation is not a good approximation for small $N_c(0.2\%)$, the following equation was applied for $N_c(0.2\%) < 50$ cm^{-3} (Eq. 5′ in Kuba et al. 2003):

$$N_d = (0.0782J + 0.02K)N_c(0.2\%).$$

In this study, we propose more convenient and adequate approximation than Eqs. 5 and 5′ from Fig. 12 in Kuba et al. (2003). This is expressed using the following equation for all $N_c(0.2\%)$:

$$N_d = LN_c(0.2\%)/(N_c(0.2\%) + M), \quad (1)$$

where $L = 4710V_{base}^{1.19}$ and $M = 1090V_{base} + 33.2$. The approximated curves for three updraft velocities (0.06, 0.12, and 0.24 m s^{-1}) are shown in Fig. 1a. In contrast to Ghan et al. (1993), our parameterization is a function of CCN concentration that can be activated under a certain supersaturation, instead of aerosol particles concentration. Equation 1 can be rewritten as:

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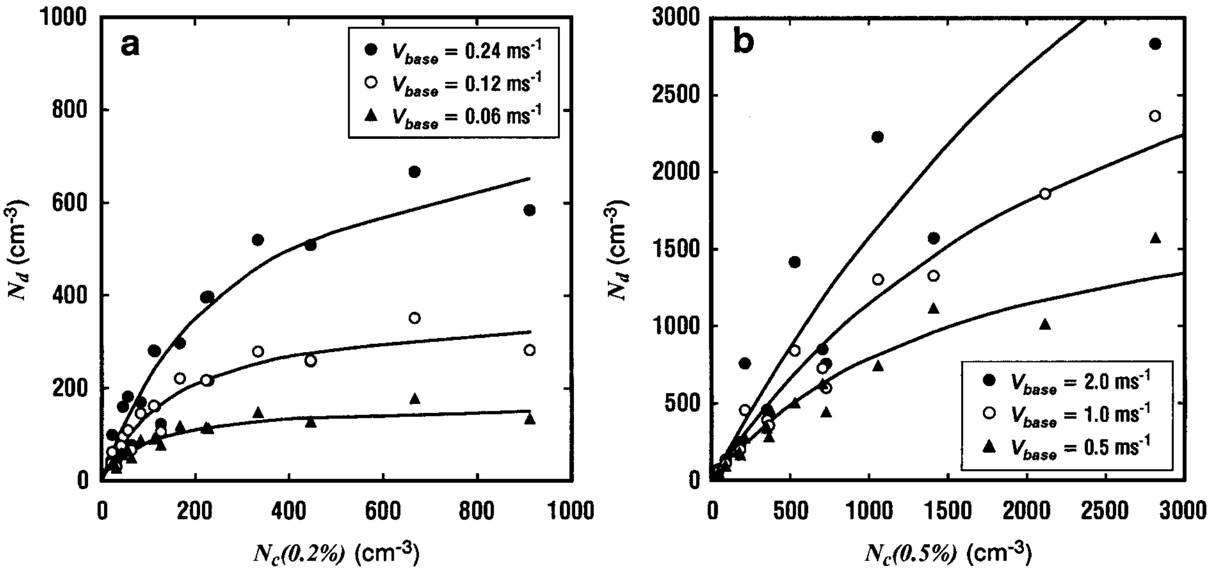

Fig. 1. a: Relationship between cloud droplet concentration at 100 m above cloud base, N_d, and the cumulative number of CCN that can be activated at 0.2% supersaturation, $N_c(0.2\%)$, for three updraft velocities: 0.06, 0.12 and 0.24 m s^{-1}.
b: Relationship between the cloud droplet concentration at 100 m above cloud base, N_d, and the cumulative number of CCN that can be activated at 0.5% supersaturation, $N_c(0.5\%)$, for three updraft velocities: 0.5, 1.0, and 2.0 m s^{-1}.

$$N_c(0.2\%) = MN_d/(L - N_d). \tag{2}$$

This parameterization leads to almost the same values as those given by the original parameterization. However, the new equation is simpler and easier to use than the original ones. Since the sensitivity of N_d to $N_c(0.2\%)$ is lower for a larger number of $N_c(0.2\%)$, the application of this retrieval method should be limited to the range of N_d, in which the sensitivity of N_d to $N_c(0.2\%)$ is large enough. The limitation of the application of Eq. 2 is as follows:

$$N_d < 75\ \text{cm}^{-3} \quad \text{for } V_{base} = 0.06\ \text{m s}^{-1},$$
$$N_d < 200\ \text{cm}^{-3} \quad \text{for } V_{base} = 0.12\ \text{m s}^{-1},$$
$$N_d < 500\ \text{cm}^{-3} \quad \text{for } V_{base} = 0.24\ \text{m s}^{-1}.$$

These equations are based on simulated data with a relatively low updraft velocity (< 0.24 m s^{-1}). In this study, we developed a new approximation to predict the cloud droplet number for a higher updraft velocity. Figure 1b shows the relationship between the cloud droplet concentration, N_d, and the cumulative number of CCN that can be activated at 0.5% supersaturation, $N_c(0.5\%)$, for three updraft velocities: 0.5, 1.0, and 2.0 m s^{-1}. A critical supersaturation of 0.5% corresponds to a radius of 0.019 μm (0.027 μm) for the dry nucleus of NaCl ($(NH_4)_2SO_4$). The deviation of the simulated values from the approximations is smaller for $N_c(0.5\%)$ than for $N_c(0.2\%)$, for the range of V_{base} assumed here. The approximation of N_d is as follows:

$$N_d = L'N_c(0.5\%)/(N_c(0.5\%) + M'), \tag{3}$$

where $L' = 4300V_{base}^{1.05}$ and $M' = 2760V_{base}^{0.755}$. Equation 3 can be rewritten as:

$$N_c(0.5\%) = M'N_d/(L' - N_d). \tag{4}$$

The limitation of the application of Eq. 4 is as follows:

$$N_d < 800\ \text{cm}^{-3} \quad \text{for } V_{base} = 0.5\ \text{m s}^{-1},$$
$$N_d < 1900\ \text{cm}^{-3} \quad \text{for } V_{base} = 1.0\ \text{m s}^{-1},$$
$$N_d < 4400\ \text{cm}^{-3} \quad \text{for } V_{base} = 2.0\ \text{m s}^{-1}.$$

These parameterizations are derived from the results of many numerical simulations based on the many size distributions of CCN and several vertical profiles of ascending velocity. They cover reasonable variety of a natural

CCN size distribution and a vertical profile of ascending velocity. Therefore, these parameterizations can help the prediction of the indirect radiative forcing of anthropogenic aerosol particles.

This study assumes that the cloud base is at an altitude of 500 m in the U.S. Standard Atmosphere 1976. The parameterizations used to predict N_d tend to underestimate N_d, when the cloud base temperature is below 284.9 K. The error is about 5% for a five-degree cooling with the updraft velocities assumed here.

We like to correct B of Eq. 1 in Kuba et al. (2003) from $B = 0.274\mathrm{LWP}^{0.05}$ to $B = 0.274\mathrm{LWP}^{0.0538}$. We also like to correct the sentence "The coefficients in the equation, C and D, are functions of the LWP." (p. 404, after Eq. 2 in Kuba et al. (2003)) to "The coefficients in the equation, C and D, are functions of Z."

References

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