

PARAMETERIZATION OF CIRRUS CLOUD FORMATION IN LARGE SCALE MODELS: HOMOGENEOUS NUCLEATION

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The effect of aerosols on clouds and climate is one of the major uncertainties in anthropogenic climate change assessment and prediction. Cirrus clouds are one of the most poorly understood systems, yet they can strongly impact climate. Cirrus are thought to have a net warming effect because of their low emission temperatures and small thickness (Liou, 1986). They also play a role in regulating the ocean temperature and affect the water vapor budget of the upper troposphere and lower stratosphere (Hartmann *et al.*, 2001). Concerns have been raised on the effect of aircraft emissions and long-range transport of pollution changing the properties of upper tropospheric clouds, i.e., cirrus and anvils, placing this type of clouds in the potentially warming components of the climate system (Lin *et al.*, 2002).

Introducing ice formation microphysics in large scale simulations requires a physically-based link between the ice crystal size distribution, the precursor aerosol, and the dynamics of cloud formation. To address the need for improved ice cloud physics in large scale models, we have developed a physically-based parameterization for cirrus cloud formation (Barahona and Nenes, *in press*), which is robust, computationally efficient, and links chemical effects (e.g., water activity and uptake effects) with ice formation via homogenous freezing. This was accomplished by tracing back the growth of ice crystals to their point of freezing, in a given ice saturation profile, connecting their size to their freezing probability. Using this approach, an expression for the crystal size distribution is derived, the integration of which yields the number concentration and size

distribution of ice crystals. In its final form, the parameterization expression for crystal concentration, N_c , formed in the cirrus cloud is given by,

$$f_c \approx \frac{\rho_a [k(T)]^{1/2}}{\rho_i \beta N_o} \left[\frac{2\alpha V S_{i,\max}}{\pi \bar{\Gamma}(S_{i,\max} - 1)} \right]^{3/2}$$
$$N_c = N_o e^{-f_c} (1 - e^{-f_c})$$

where N_o is the concentration of deliquesced aerosol particles; all other symbols are defined in *Barahona and Nenes (in press)*.

The parameterization is evaluated against the predictions of a detailed numerical parcel model also developed by *Barahona and Nenes (in press)*. The parcel model equations were integrated using a novel Lagrangian particle tracking scheme; the evolution of the ice crystal size distribution is described by the superposition and growth of monodisperse crystal populations generated by the freezing of single classes (of same size and composition) of supercooled droplets. The relative error of the parameterization in its final form is $1 \pm 28\%$, which is remarkable given the simplicity of the final expression obtained for N_c , the broad set of conditions tested, and the complexity of the original parcel equations.

The prediction skill of the parameterization is robust across a wide range of parameters (e.g., deposition coefficient, aerosol characteristics) of atmospheric relevance. The parameterization successfully reproduces the effect of the aerosol number on ice crystal number concentration with a simple framework that explicitly links the

variables that control the freezing time scale of the particles.

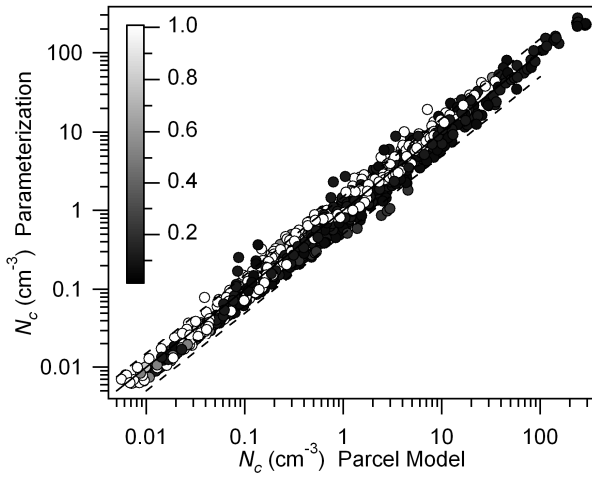


Figure 1. Ice crystal number concentration calculated by the parcel model and the parameterization. Gray scale represents the value of deposition coefficient used in the calculations; dashed lines represent the $\pm 50\%$ difference.

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