Microphysical Consequences of the Spatial Distribution of Ice Nucleation in the Mixed Phase Clouds

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1. Mixed Phase Cloud Mystery

Long-lived, stratiform, mixed-phase clouds are frequently observed in the Arctic and mid-latitudes [Ref.1-3]. Two main properties and corresponding questions:
1. They can exist for days, even though thermodynamically unstable.
So why they can exist for such a long time? (Steady state?)
2. Ice particles precipitate from those clouds nearly all the time.
So where do the ice particles come from? Source of ice nuclei (IN) exists [Ref. 3]:
• Cloud top: entrainment
• Cloud base: convection
• Whole cloud: stochastic ice nucleation by low efficiency IN or contact nucleation?

2. Previous Minimalist Model

We assume the mixed-phase cloud is in a steady state with uniform and time-independent temperature and droplet concentration. Water vapor in the mixed phase cloud is saturated with respect to liquid water and supersaturated with respect to ice. Ice particles are generated based on stochastic ice nucleation of abundant, low efficiency IN. Updraft velocity can increase ice particle resident times, thus increasing their sizes. Considering the growth and sedimentation of ice particles, we derived a power-law relationship between ice water content (w_i) and ice number concentration (n_i):

$$w_i = \frac{G n_i^{2.5}}{n_i'^{1.5}} \qquad (1)$$

where n_i' is the volume ice nucleation rate with the units of [#/(m^{3}s)], G is the prefactor $G = \frac{4}{3}\pi\rho_i(kCDs_i)^{1.5}$ [Ref. 4].

3. Results and Questions

Blue: n_i'=0.4 #/(m^{3}s)
Red: n_i'= 2 #/(m^{3}s)
Best fitted lines shift: 5.77-4.75=1.03
Based on Equation 1: $1.5\log_{10}(5)$=1.05

Equation 1 predicts the 2.5 power law relationship between w_i and n_i from LES. In addition, Equation 1 also captures the best fitted line shift due the change of n_i'.

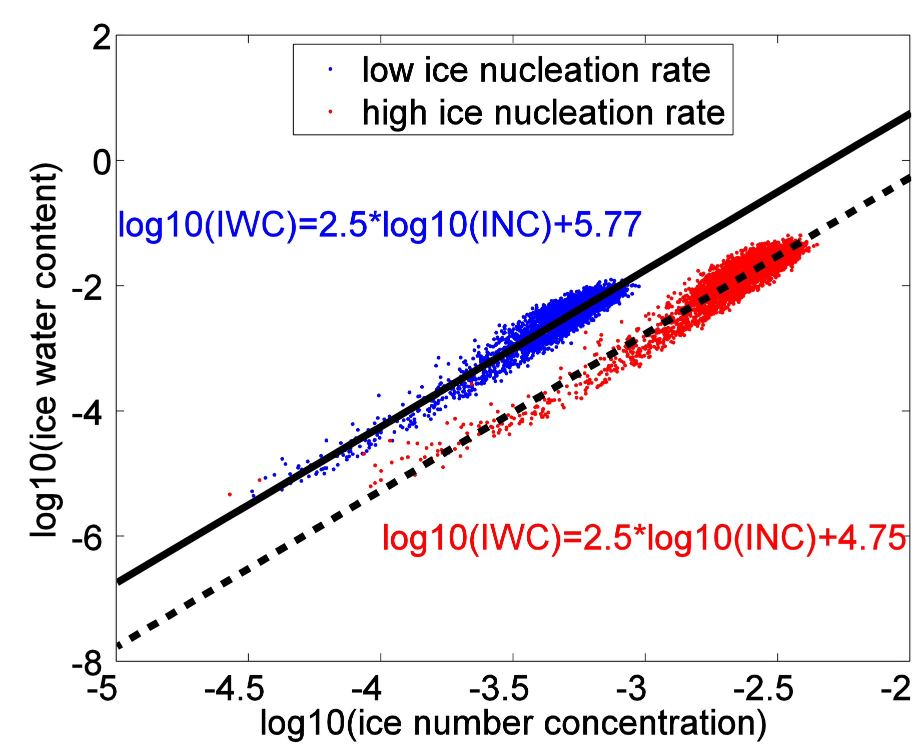

Fig.1. w_i and n_i from LES cloud model for two different n_i'. Lines are best fitted 2.5 slope lines.

However, there are still two questions:
1. Equation 1 didn't capture the intersection of the best fitted lines in Figure 1.
2. Interpreting why data from a 3D LES cloud model follow the 2.5 power law relationship predicted by a simple 1D analytical model.

Why is the 2.5 power law relationship between w_i and n_i so general?
Does it depend on the source of ice nucleation?

4. New Minimalist Model

	Thermodynamic Properties	Microphysical Properties	Dynamic Properties	Relationship between w_i and n_i	Prefactor G
Old Model	Uniform and time independent T and s_i	Uniform and time independent n_w and n_i'	Updraft decreases linearly with height	$w_i = \frac{G n_i^{2.5}}{n_i'^{1.5}}$ (1)	$G = \frac{4}{3}\pi\rho_i(kCDs_i)^{1.5}$
New Model			No updraft or downdraft	$w_i = \frac{G' n_i^{2.5}}{n_i'^{1.5}}$ (2)	$G' = \frac{8}{15}\pi\rho_i(2CDs_i)^{1.5}$

T is temperature, s_i is supersaturation over ice, n_w is the cloud droplet concentration, n_i' is the volume ice nucleation rate, w_i is ice water content, C is ice particle shape factor, D is modified diffusion coefficient, ρ_i is the ice particle's density. k is a constant from the radius-terminal velocity parametric equation: $v_i = kr_i^b$ [Ref.5].

5. Lagrangian Ice Particle Tracking in Time Dependent Field

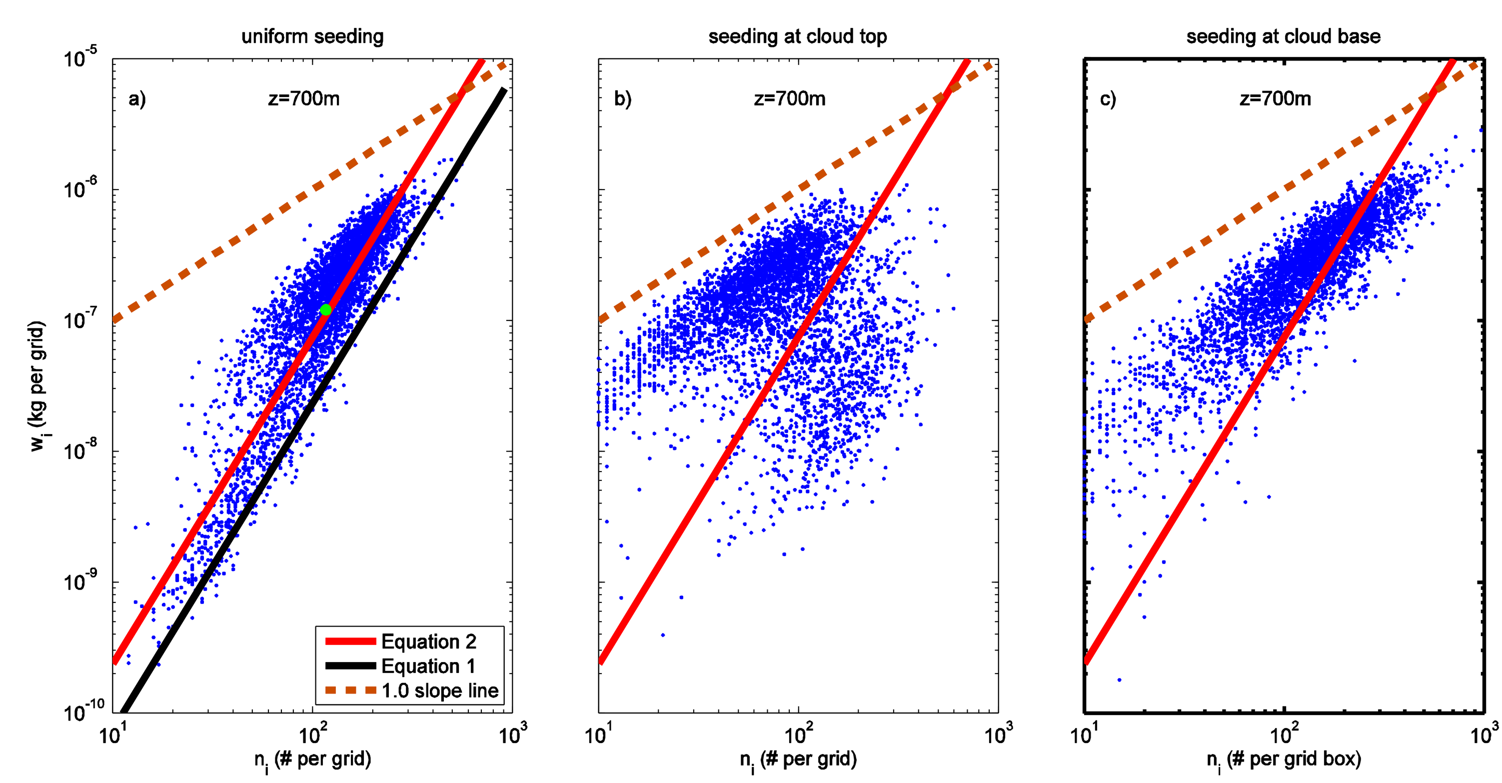

Fig.2. The $w_i - n_i$ relationship in a mixed phase cloud with Lagrangian ice particle tracking in a LES time-dependent field, for three different seeding locations: a) uniform seeding; b) seeding at cloud top; c) seeding at cloud base. Black line: calculated from Eq. 1 based on the old model; Red line: from Eq. 2 based on the new model. The brown dashed line has slope 1.0 for comparison and the green dot in subplot a) represents the average of $\log(w_i)$ and $\log(n_i)$ for the blue points.

Microphysical properties in mixed phase cloud are sensitive to the spatial distribution of ice nucleation. Eq. 2 not only captures 2.5 slope but also the mean values, thus can be used to predict n_i'.

6. Applications

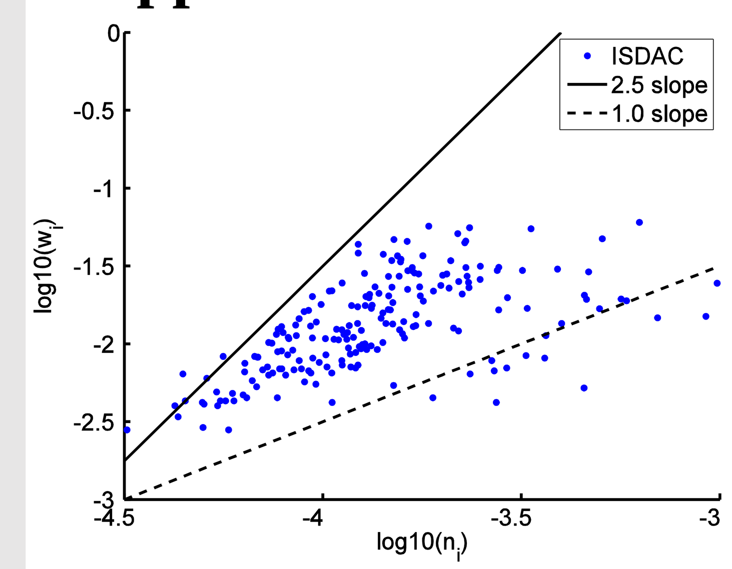

Fig.3. w_i and n_i relationship from ISDAC Flight 31.

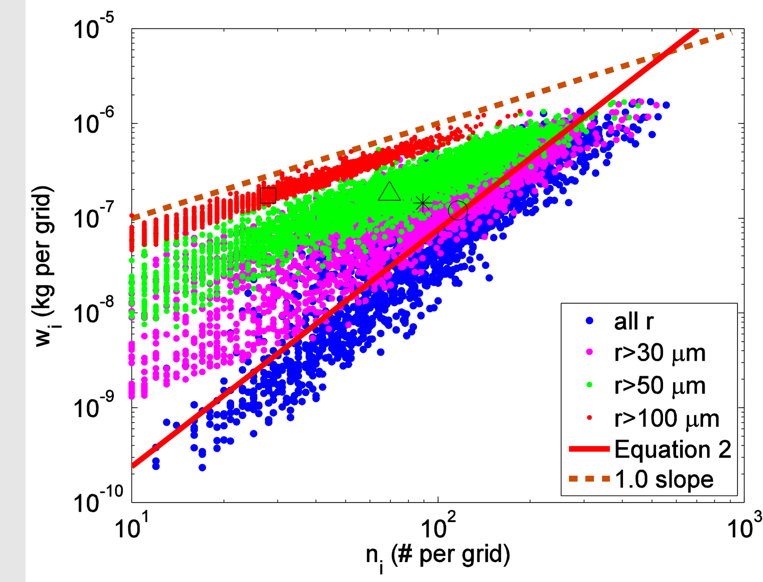

Fig.4. w_i and n_i relationship for variance threshold radii. Data here is from the Lagrangian tracking method.

Based on Eq. 2, we estimate $n_i' \approx 0.006$ m^{-3}s^{-1} for ISDAC Flight 31. This value is underestimated by one to two orders of magnitude due to the instrument capabilities.

7. Acknowledgement

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