NOTES AND CORRESPONDENCE

Influence of Ice Crystal Aspect Ratio on the Evolution of Ice Size Spectra during Vapor Depositional Growth

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ABSTRACT

The relationship among aspect ratio, initial size, and the evolution of the size spectrum is explored for ice crystals growing by vapor deposition. Ice crystal evolution is modeled based on the growth of spheroids, and the ice size spectrum is predicted using a model that is Lagrangian in crystal size and aspect ratio. A dependence of crystal aspect ratio on initial size is discerned: more exaggerated shapes are shown to result when the initial crystals are small, whereas more isometric shapes are found to result from initially large crystals. This result is due to the nature of the vapor gradients in the vicinity of the crystal surface. The more rapid growth of the smaller crystals is shown to produce a period during which the size distribution narrows, followed by a broadening led by the initially smallest crystals. The degree of broadening is shown to depend strongly on the primary habit and hence temperature.

1. Introduction and motivation

The shape, or habit, of ice crystals growing by vapor deposition has long been known to depend on such ambient characteristics as temperature and supersaturation (e.g., Nakaya 1954; Hallett and Mason 1958). The primary habits of ice crystals can be defined in terms of the aspect ratio \( f = c/a \) (for plates; \( f < 1 \)) or \( f > 1 \) (for columns), where \( c \) is the crystal semidimension along the \( c \) axis (normal to the basal faces) and \( a \) is the semidimension along the \( a \) axis (toward a corner of the hexagon) (Pruppacher and Klett 1997, p. 41). The primary habit depends on temperature, whereas secondary habits, driven by morphological instability and air motions, vary with the supersaturation (Kobayashi 1961).

Simulations of atmospheric processes have revealed significant sensitivities to crystal habit. Early studies of ice crystal growth have shown that it is possible to capture the relative change in the \( a \) and \( c \) axes, along with mass, as a function of temperature for relatively simple shapes (e.g., Jayaweera 1971; Cotton 1970; Koenig 1971; Lamb and Hobbs 1971; Takahashi et al. 1991). Some recent observations have caused Jensen et al. (2008) to ponder the physical mechanisms behind the large ice crystals found near the tropical tropopause at low water vapor concentrations. Their calculations indicate that pronounced crystal habits (large deviations from \( f = 1 \)) are required to produce large crystals at low water vapor concentrations. Studies such as these underscore the fact that crystals, unlike water droplets, can change shape and grow to large sizes in relatively short periods of time, even in environments of modest supersaturation. It is important to realize that a feedback exists linking habit changes to ice growth rates: The nonspherical shape causes stronger vapor gradients near the areas of largest curvature (corners and edges), leading to stronger growth and more pronounced habits. Chen and Lamb (1994) showed that this feedback can be captured with the capacitance growth model (e.g., Pruppacher and Klett 1997, p. 547) using spheroids and a mass-redistribution hypothesis that provides the link in the feedback. It is worth pointing out that the classical capacitance model cannot evolve faceted crystals because it has the wrong surface boundary condition for faceted growth (e.g., Nelson and Baker 1996). Although this is the case, the capacitance model still produces relatively accurate estimates of vapor growth and aspect ratio evolution, at least at water saturation (e.g., Chen and Lamb 1994).
Furthermore, the capacitance model overestimates the growth rates at low ice supersaturations (e.g., Wood et al. 2001), but first-order corrections for surface-kinetic resistance can be employed to improve the performance of the capacitance model (e.g., Lamb and Chen 1995; Sheridan 2008; Harrington et al. 2009).

Although many numerical simulations of ice crystal growth in cold clouds have been performed, few have focused on predicting aspect ratios or on the consequences of using the capacitance model for evolution of ice size distributions. Some early cloud modeling studies (e.g., Cotton 1972) predicted both the \( a \) and \( c \) dimensions using laboratory-measured growth rates for the crystal faces. More recent studies (e.g., Chen and Lamb 1999; Hashino and Tripoli 2007) evolve the \( a \) and \( c \) dimensions following the theoretical approach of Chen and Lamb (1994). Chen and Lamb’s (1994) parameterization is advantageous because it allows crystal shapes to evolve naturally. However, this parameterization is computationally expensive and so the \( a \) and \( c \) axes are not usually predicted in dynamic cloud models. For instance, most “bulk” microphysical cloud models predict only a single average size (e.g., Ferrier 1994; Walko et al. 1995) based on predictive equations for ice water mass and concentration. Even most bin microphysical models carry information on only one dimension of the crystal (e.g., Reisin et al. 1996). Many times, the crystals are assumed to be spherical (e.g., Morrison et al. 2005; Fridlind et al. 2007), even in some detailed studies (e.g., Passarelli 1978) or in less computationally demanding parcel models (Lin et al. 2002; Lebo et al. 2008). When nonspherical crystals are assumed, they are usually treated simply, and only a maximum dimension is predicted (e.g., Mitchell 1988; Wu et al. 2000). The only dynamic cloud model of which we are aware that evolves both the \( a \) and \( c \) axes is that of Hashino and Tripoli (2007). Even though crystal geometry and mass growth vary greatly with temperature, few studies have been done that isolate the influence of vapor growth and habit on the evolution of ice size spectra, possibly because early studies were focused primarily on precipitation processes (e.g., Cotton 1972; Passarelli 1978; Leighton 1980; Mitchell 1988). All of the earlier studies nevertheless recognized the importance of vapor diffusion for the growth of small ice crystals. For example, Mitchell (1988) showed that vapor diffusion causes broadening of the ice crystal size spectrum, which maximizes in the dendritic growth regime. Harrington et al. (1995) attempted to parameterize such influences for bulk models and showed that different habits lead to different crystal distributions in time. However, both of these studies parameterized the shape of the ice size distribution, and both studies used relatively simple habit formulations based on observed mass–dimensional relationships.

All of the above modeling studies use the capacitance model for ice crystal growth (e.g., Pruppacher and Klett 1997, p. 547), but the consequences of using this model have not been fully explored. For instance, many of the above studies show dependencies of the capacitance model on crystal shape, but the implications of using this model for the evolution of the ice size spectrum have not been examined in detail. In this note, we explore how aspect ratio and initial crystal size influence the evolution of vapor-grown size spectra in the Chen and Lamb (1994) adaptive habit parameterization. The salient features of the model are briefly discussed in section 2. How habit evolution depends on initial size is examined in section 3, and the implications of the initial-size dependence for broadening of the ice size spectrum are discussed in section 4.

2. Adaptive parameterization of crystal habit

In order for crystal shapes to evolve in a numerical model, the vapor diffusing toward a crystal must be calculated in a physically appropriate way over the crystal basal and prism faces. Primary habit evolution is determined by the relative magnitudes of the deposition coefficients, \( \alpha_a \) and \( \alpha_c \), for growth along the \( a \) and \( c \) axes, respectively. These deposition coefficients represent the efficiency of molecular incorporation into the ice lattice. Values of the deposition coefficient range between 0 (no molecules are incorporated) and 1 (all molecules are incorporated) for each crystalline face. The single-particle growth model of Chen and Lamb (1994) controls the distribution of mass deposition onto the crystal faces through the inherent growth ratio:

\[
\Gamma(T) = \frac{\alpha_c}{\alpha_a}. \tag{1}
\]

Chen and Lamb (1994) developed \( \Gamma(T) \) from data consistent with the observed evolution of the primary habits: plates from \( 0^\circ \) to \( -4^\circ \)C, columns from \( -4^\circ \) to \( -9^\circ \)C, plates from \( -9^\circ \) to \( -22^\circ \)C, and columns below \( -22^\circ \)C (see their Fig. 3).

The complications associated with crystal habit are simplified by representing columnar and platelike crystals as prolate (\( \phi = c/a > 1 \)) and oblate (\( \phi < 1 \)) spheroids, respectively. The connection between ice crystal mass growth and primary habit evolution is parameterized by simultaneously solving the following equations for the crystal volume and aspect ratio:

\[
\frac{dV}{dt} = \frac{4\pi C_s}{\rho_{dep}} \left[ \frac{R_T}{\varepsilon D_v} + \frac{L_\varepsilon}{TK_v} \left( \frac{L_\varepsilon}{TR_v} - 1 \right) \right], \quad \text{and} \quad \frac{d\phi}{dt} = \Gamma(T). \tag{2}
\]
\[
d\ln(V) = \left(\frac{\Gamma - 1}{\Gamma + 2}\right)d\ln(V),
\]

where \(V\) is the spheroid volume, \(C\) is the crystal capacitance, \(s_i\) is the ice supersaturation, \(\rho_{dep}\) is the effective deposition density, \(R_g\) is the vapor gas constant, \(T\) is temperature, \(L_s\) is the enthalpy of sublimation, \(e_i\) is the ice equilibrium vapor pressure, \(D_v^e\) is the effective vapor diffusivity, and \(K_T^e\) is the effective thermal diffusivity (see Pruppacher and Klett 1997, 506–509). It is important to note that Eq. (3) is a direct consequence of the “mass growth hypothesis” of Chen and Lamb [1994, their Eq. (12)], which controls the distribution of mass onto each axis during growth. The change in aspect ratio is embodied in this equation. Modifications for surface kinetic resistance (e.g., Harrington et al. 2009) have not been included because ice supersaturations in our cases range between 12% and 20%, indicating that ice vapor growth is diffusion-limited. These relatively high ice supersaturations are advantageous because the capacitance model is most accurate in the diffusion-limited regime (e.g., Chen and Lamb 1994; Wood et al. 2001).
The crystal capacitance $C$ in Eq. (2) can be written as a product of a shape factor and the semimaximum dimension, so $C = a f_{ob}$ for a plate and $C = c f_{pr}$ for a column. Spheroidal geometry enables us to calculate the capacitance analytically using the electrostatic analogy developed by Maxwell (1878), where

$$
\begin{align*}
\text{oblate ($\phi < 1$):} \quad C &= a f_{ob} = a \frac{\epsilon_{ob}}{\arcsin \epsilon_{ob}}, \quad \text{eccentricity } \epsilon_{ob} = \sqrt{1 - \phi^2}; \\
\text{sphere ($\phi = 1$):} \quad C &= a = c; \quad \text{and} \\
\text{prolate ($\phi > 1$):} \quad C &= c f_{pr} = c \frac{\epsilon_{pr}}{\ln \phi (1 + \epsilon_{pr})}, \quad \text{eccentricity } \epsilon_{pr} = \sqrt{1 - \phi^{-2}}. 
\end{align*}
$$

(4)

FIG. 2. Time dependence of (a) spherical volume equivalent radius, (b) aspect ratio, and (c) semimajor dimension. Crystals began as spheres with radii of 1 (dashed) and 10 (solid) μm. The environment is at liquid water saturation with $T = -30^\circ$C. Growth is computed using the capacitance of a prolate spheroidal (thick gray curves) and a hexagonal column (thin black curves). An inherent growth ratio of $\Gamma = 1.25$ is assumed.
To illustrate the influence of the choice of capacitance on our results, we also use the capacitance for hexagonal crystals from Westbrook et al. [2008, their Eq. (3)] in our simulations. The capacitance represents the simultaneous influences of crystal shape and size on the vapor field surrounding the crystal. As with nonspherical conductors in electric fields, nonspherical crystals distort the vapor fields such that gradients are greatest where surface curvature is largest (see Marshall and Langleben 1954, their Fig. 12 and discussion). Therefore, we expect $C$ to be larger for nonspherical crystals than for spheres of the same volume, which is the case (Fig. 1a) despite the fact that the shape factor decreases with the degree of deviation from spherical ($\phi = 1$, Fig. 1b). In other words, as crystal habits become more pronounced (Fig. 1c), contributions to $C$ from the shape factor decrease, while the contributions from the semimaximum dimension dominate. The most extreme aspect ratios (largest and smallest $\phi$) have the greatest curvature at the ends along the maximum dimension (insets of Fig. 1a), producing a stronger vapor gradient and a larger growth rate. This behavior is distinctly different from water drops, which retain the same “shape” as they grow.

Figures 1a and 1b also show the capacitance and shape factors from the recent work of Westbrook et al. (2008). While there exist differences in the shape factors, the dependence on $\phi$ is similar. Moreover, the capacitance is nearly the same (within 10%) for hexagonal crystals and spheroids.

Although more extreme habits have larger growth rates, those habits frequently evolve from particles that were initially spherical (i.e., frozen water drops). Moreover, Eqs. (2) and (3) suggest that habit and ice size spectrum evolution may depend on the initial crystal size because changes in volume influence subsequent changes in aspect ratio in a nonlinear fashion.

To examine the influence of habit and initial crystal size on the ice size spectrum, we employ two methods: We first examine the evolution of a single crystal, then a population of crystals. In the single-particle model, we solve Eqs. (2) and (3) together using the method described in Chen (1992): Eq. (2) is integrated analytically over a 1-s time step assuming an equivalent volume sphere and a constant shape factor. The mass increase in one time step is then distributed over the crystal following Eq. (3). Chen (1992) and our own tests show that this method is accurate to within less than 1% for growth over 20 min.

The second method uses the Lagrangian microphysical parcel model of Lebo et al. (2008) as modified to include habit evolution following Chen and Lamb (1994). The model simultaneously solves ordinary differential equations for a moving atmospheric parcel and the growth of distributions of liquid drops and ice crystals.

Differential equations for vertical motion, temperature $T$, pressure $p$, relative humidity $\text{RH}$, height $z$, mass conservation, $n_l$ equations for liquid drops, and $n_i$ equations for crystal volume and aspect ratio [Eqs. (2) and (3)] are solved using the variable-order differential equation (VODE; Brown et al. 1989) package (for details, see Lebo et al. 2008). Since the model is Lagrangian in size and aspect ratio, the ice size spectrum is allowed to evolve naturally. Liquid drops are not included in the current simulations because ice is our primary interest. For simplicity, interparcel mixing and sedimentation are ignored. Ice nucleation is treated simply: An initial gamma distribution of ice crystals is instantaneously nucleated at cloud base. For numerical stability, a short time step ($0.1 \text{s}$) is used.

3. Growth dependence on initial size

The initial size of the crystal influences habit evolution and is most easily demonstrated with the single-particle
method. Figure 2a shows the evolution of the spherical volume equivalent radius of two crystals as they grow according to Eqs. (2) and (3). The crystals begin as spheres with radii of 1 (dashed) and 10 (solid) μm and grow as prolate spheroids with \( G = 1.25 \) (Sheridan 2008) in air with \( T = -30^\circ\text{C} \) at liquid saturation. The evolution of the aspect ratio and the semimajor axis (c) are shown in Figs. 2b and 2c, respectively. We also show the impact of using the capacitance of a hexagonal crystal in comparison to that of a spheroid. Because the capacitances are relatively similar (see Fig. 1a), the simulation results are nearly the same.

The crystal evolution displayed in Fig. 2 shows that the initially smaller crystal \((r = 1 \mu m)\) becomes the larger and exhibits a more pronounced habit in time. To understand this behavior, we recast the derivative \(dV\) in Eq. (3):

\[
\frac{dV}{dt} = \frac{d^2V}{dt^2} + \frac{d}{dt}\left(\frac{dV}{dt}\right)
\]

**Fig. 4.** (a) Initial particle spectrum for the baseline case. The first 120 bins, indicated in increments of 10, contain 99% of the crystal concentration (100 L\(^{-1}\)). (b) The baseline case spectrum from (a), indicated by a solid line, along with three other size spectra used to initialize the simulations.
The dependence on the far right comes from the depositional growth of a sphere, which varies with $dV/V \sim 1/r^2$ [see Eq. (2)]. This analysis shows that the relative change in volume $dV/V$, and consequently the relative change in aspect ratio $d\phi/\phi$, is larger for the initially smaller of the two crystals. Physically, one can interpret this result as follows (Fig. 3): new volume due to vapor growth is added to the crystal faces disproportionately, as determined by $\Gamma$. Initially smaller crystals experience a larger relative increase in volume as compared to initially larger crystals. Since this volume is added preferentially to one set of faces, one should expect a larger change in aspect ratio for the smaller crystal. As the initially smaller crystal becomes increasingly prolate (Figs. 2 and 3), its growth rate accelerates because of the influence of the aspect ratio on the capacitance [see Eq. (2) and Fig. 1a], producing more extreme crystal shapes (larger or smaller aspect ratios) in time. This result suggests that the ice distribution evolution may depend on the initial ice sizes.

4. Effect of habit on size spectra

The effects of crystal size and habit on the evolution of ice size spectra were investigated with the Lagrangian microphysical parcel model. Our simulations used $\Gamma = 1.25$, a value derived for colder, cirruslike conditions (Sheridan 2008). The parcel model was initialized with cloud base at 7 km, a temperature of $-30^\circ$C, a pressure of 300 mb, and a slight subsaturation (1%) with respect to ice. The vertical velocity was fixed at 75 cm s$^{-1}$ throughout the simulation. As the parcel rises, the ice saturation ratio $S_i$ increases until the parcel becomes saturated ($S_i = 1$). At this time, a gamma distribution of 100 L$^{-1}$ spherical ice crystals with radii ranging from 1 to 20 $\mu$m is instantaneously nucleated. This method of forming ice is intentionally simple to avoid complicating feedbacks between nucleation and vapor growth, allowing us to focus on vapor growth. This simplification limits our results since the formation of real ice size spectra depends on the particular nucleation rate equations, which depend on the type and size of ice nuclei (heterogeneous nucleation) and the size and solute concentration of supercooled droplets (homogeneous freezing). Nevertheless, as our results below illustrate, the effects that we demonstrate only depend on the existence of a spectrum of sizes regardless of the formation mechanism.

Figure 4a displays the initial spectrum with the Lagrangian bins (hereafter referred to as bins) labeled 1 to 120 in 10-bin increments. This distribution is used for most of our simulations and is designated as our baseline case. Distribution shape, as well as initial size, is expected...
to impact our results, so we also run simulations with four other initial spherical ice distributions (Fig. 4b). Two of the distributions have smaller modal radii (1.8 and 1.45 μm), while one has a larger modal radius (7.2 μm). The distribution with the smallest modal radius is shifted to smaller sizes with the smallest ice sphere having a radius of 0.5 μm instead of 1 μm.

As the ice crystals ascend with the air parcel, they grow and change shape. The variation of the size spectrum can be characterized by calculating the standard deviation as a function of height above cloud base using

$$\sigma = \sqrt{\frac{\sum (r_j - \overline{r})^2}{(N - 1)}}$$

where $r_j$ is the spherical volume equivalent radius of the crystals in bin $j$, $N$ is the total number of bins that contain crystals, and $\overline{r}$ is the concentration-mean spherical volume equivalent radius of the population.

The standard deviation for our baseline case, shown in Fig. 5, initially decreases to a minimum just above cloud base before permanently increasing, indicating a period of spectral narrowing prior to broadening. This result is perhaps counterintuitive, but it can be understood by referring to the explanation given in section 3: This narrowing is caused by the relatively large growth of the smallest crystals in the distribution. For instance, Fig. 6a shows the calculated spectra near cloud base and cloud top (1 km). Note that bin 1, which contains the initially

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**FIG. 6.** Evolution with altitude of the ice size spectrum for the baseline case. (a) The spectrum of spherical volume equivalent radii and (b) the aspect ratio spectrum. Each spectrum is shown near cloud base and at 1 km. Initially smallest crystals in bin 1 are indicated, and they are seen to overtake the larger crystals located in bin 100; the initially larger crystals in bin 100 become the smallest, with the smallest aspect ratio, with time.
smallest crystals, and bin 100, which contains the initially largest crystals, reverse position in time: The initially smallest crystals eventually overtake the larger crystals in size, causing the spectrum to narrow first and then broaden. The physical reason for this phenomenon is the nonlinear response of crystal growth to initial size, as explained in the previous section, and shown in Fig. 6b: The aspect ratio of the initially smallest crystals changes rapidly, leading to a larger capacitance (Fig. 1a) and hence faster growth.

The simulations above used an initial spectrum of very small crystals. Because initially larger spheres produce less-pronounced habits and slower growth rates (Fig. 2), it is expected that it would take longer for a spectrum of large crystals to narrow and broaden as compared to the spectrum of small crystals. Simulations with the initially larger crystals (dotted curve in Fig. 5) confirm this expectation. There is no broadening for this range of altitudes. Note also that the predicted narrowing followed by broadening does not depend on the capacitance used. As Fig. 7 shows, using the capacitance of a hexagonal crystal (gray curves, $\Gamma = 1.25$, and 0.75) instead of the capacitance of a spheroid leads to a quantitatively different, but qualitatively similar, ice spectrum evolution.

The above result indicates that the degree of broadening depends not only on the deviation of $\Gamma$ from 1 but also on the primary habit. For a given altitude and deviation from $\Gamma = 1$ (e.g., $\Gamma = 1 \pm 0.25$, Fig. 7), a distribution of prolate spheroids has a larger standard deviation than does one of oblate spheroids. Physically, as the conceptual diagram in Fig. 7 shows, oblate spheroids grow in a two-dimensional fashion, whereas prolate spheroids grow in a one-dimensional fashion.

Spectral narrowing followed by broadening depends on the deviation of $\Gamma$ from unity. Figure 7 shows the standard deviations of the size spectra with height for different values of $\Gamma$ (1, 1 \pm 0.1, and 1 \pm 0.25) and for the baseline case. The standard deviation for spherical crystals ($\Gamma = 1$) decreases monotonically with height, and the spectrum becomes essentially monodisperse. In contrast, the standard deviation for the nonspherical crystals ($\Gamma = 1 \pm 0.1$ and $1 \pm 0.25$) decreases to a minimum at low altitudes followed by broadening, as discussed above. The only exception is $\Gamma = 0.9$, which produces almost no broadening for this range of altitudes. Note also that the predicted narrowing followed by broadening does not depend on the capacitance used. As Fig. 7 shows, using the capacitance of a hexagonal crystal (gray curves, $\Gamma = 1.25$, and 0.75) instead of the capacitance of a spheroid leads to a quantitatively different, but qualitatively similar, ice spectrum evolution.
mass deposited at the plate edges, whereas prolate spheroids grow roughly along a single dimension with mass deposited mainly at the tips. For the same amount of added mass, one would expect a much greater change in the length of the column as compared to that of a plate. Consequently, the change in aspect ratio is larger for prolate as compared to oblate spheroids. This result implies enhanced mass growth rates for prolate spheroids (e.g., larger capacitance; Fig. 1c), which is borne out by data (cf. Chen and Lamb 1994).

The development of the primary crystal habits depends on temperature, which is explicitly controlled in the model by $\Gamma$ (dotted curve in Fig. 8). A temperature dependence to spectral broadening of vapor grown ice crystals should therefore be expected. To examine this possibility, the model was run so that the size spectra evolve for 30 min at fixed temperatures ranging from $-3^\circ$ to $-30^\circ$C at liquid saturation. Figure 8 depicts the standard deviations of the resulting spectra of spherical volume equivalent radii. For temperatures with large deviations in $\Gamma$ from unity ($-6^\circ$, $-15^\circ$, and $-23^\circ$C), the standard deviations are the greatest, as expected from the results presented above. Conversely, at the transitions between the platelike and columnar regimes ($-4.5^\circ$, $-9.5^\circ$, and $-20.5^\circ$C), the standard deviations decrease to local minima. At the transition temperatures, the ice crystals are nearly isometric with approximately spherical growth rates and so the standard deviations approach those computed for spherical crystals. In fact, the standard deviation can fall below that produced by spherical growth because the smallest crystals in the distribution grow faster than the average sphere, which causes more rapid narrowing of the spectrum when $\Gamma$ is near 1. Populations can exhibit properties distinct from those of individual members. Fukuta and Takahashi (1999) have noted that the fall speeds of the compact crystals produced at the transition temperatures are relatively high, making them prime candidates for early initiation of the riming process. It therefore seems likely that if the temperature-dependent spectral broadening by vapor diffusional growth demonstrated here is real, it could have consequences for the microphysical evolution of mixed-phase and ice clouds.

5. Final remarks

The results presented here provide new insight into the influence of initial size and habit on crystals growing by vapor deposition. Because of the large relative change in volume during growth, initially small crystals develop more pronounced habits than do initially larger crystals. Using the Chen and Lamb (1994) parameterization to

![Figure 8. Temperature dependence of (right axis) the inherent growth ratio according to Chen and Lamb (1994) (dotted line) and (left axis) the spectral standard deviations of spherical volume equivalent radii for spherical (dashed) and nonspherical growth (solid). Ice particles were grown at constant temperature for 30 min at water saturation. Regions with the most extreme habits ($-6^\circ$, $-15^\circ$, and $-23^\circ$C) have the largest standard deviations. Transition temperatures between the platelike and columnar regimes ($-4.5^\circ$, $-9.5^\circ$, and $-20.5^\circ$C) have standard deviation minima that approach that of spherical growth.](image-url)
simulate changes in habit, we found that the capacitance (and the growth rate) of initially small crystals increases by a relatively larger amount than for initially large crystals. The larger relative growth rates of the initially smaller crystals are due to more extreme changes in the aspect ratio with time. This phenomenon is found to alter the evolution of the crystal size spectrum: Our results suggest the existence of a period of spectral narrowing prior to broadening associated with the relatively large growth rates of the initially smaller crystals. We show that habit-induced broadening depends on temperature, with the greatest broadening occurring where the least extreme broadening is found. Prolate spheroids (e.g., columns) produce the broadest size spectra for a given supersaturation because deposition occurs primarily along a single dimension. All of these results are consequences of the capacitance model and the “mass distribution hypotesis” as formulated by Chen and Lamb (1994). Because this model predicts an initial-size dependence to the mass and aspect ratio evolution of ice crystals, laboratory studies should be used to examine the validity of the approach.

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