VI. Conclusions

1. Summary of New Results

Starting from the assumptions of TLK and steady state conditions, we have derived 3 models for analyzing ice crystal growth in the atmosphere in terms of elementary processes. These models are all based on the assumption that the flux of vapor to the crystal surface is uniform and thereby all differ fundamentally from the standard models used heretofore by the atmospheric sciences community, in which the vapor density is assumed uniform at the surface. In the new models the surface impedance to growth is calculated self-consistently in terms of local environmental conditions, again differing sharply from the standard models in which this impedance is either ignored or assigned a uniform, externally prescribed value.

Beginning with a model for uncoupled surface and vapor diffusion to a growing spherically shaped ice crystal, we have built a model which applies to cylindrically shaped ice crystals with coupled surface and vapor diffusion in the presence of gaseous impurities. This model is expected to apply to a wide range of environmental conditions and surface parameters provided that there exist many ledges on each crystal face. When there is only a single ledge on the face, the growth rate will depend on whether the ledge is part of a continuous spiral, or a circular island. A model for each ledge shape was described, and the predictions from the spiral case were shown to be consistent with the (limited) experimental data. This is shown schematically in Figure 6.1. Some of the predictions from our analysis of the stability of uniform growth (hollowing conditions) were shown to be consistent with the observed data, but again, the available evidence is very limited.

To summarize:

- The differences between the growth rates predicted by the capacitance models and those predicted by the uniform flux model depend on the magnitude of the surface impedances \(1/\sigma^{ac}\).
- Comparison of the constant flux model with experiment leads to the prediction that the surface impedances appear to be growth rate controlling factors for crystal dimensions \(\approx 30\mu\) and \(\sigma = 20\%\) or less.
- During uniform growth, the aspect ratio may be predicted from the uniform flux model. For corner growth, the aspect ratio is expected to approach \(\alpha^c/\alpha^u\).
Figure 6.1: proposed ice crystal growth models as a function of supersaturation or crystal size

- The uniform flux model allows prediction of the conditions necessary for hollowing.
- The surface supersaturation is not always greatest at the corners.
- The pseudo-coupled and single turn spiral ledge models are expected to be the best choices for atmospheric ice growth calculations.
- More experimental work is needed on ice growth in air, in pure vapor, and in the presence of controlled concentrations of impurities.

2. Future Work

Although a lot of work has been done to try to understand ice crystal growth over the past 60 years, this dissertation makes it clear just how little we really do know about this important topic. It is hoped that the appearance of these models will
encourage others to construct experiments which may be used to refine, or reject
them. In particular, the following information is desperately needed: the surface
diffusion constant for water on ice, the adsorption energies for water on ice, and
most of all, the growth rate and regime for stable uniform growth as a function of
size, supersaturation, temperature and air pressure.

In addition, more theoretical work should be done. An incomplete list includes;
studies of ventilation and other types of non-diffusive vapor transport, surface dif­
fusion on terraces with a high coverage of mobile molecules, temperature conduc­
tion into a growing/evaporating crystal, and vapor diffusion to hexagonal shaped
crystals.

A greater understanding of ice crystal growth in the atmosphere would aid us in the
understanding of clouds, climate and crystal growth in general.