NOTES AND CORRESPONDENCE

On Contact Nucleation

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Increasing interest has recently been shown by experimental workers in a form of ice crystal formation which they have termed "contact nucleation." Briefly, the classical theory (see, for example, Fletcher, 1962) envisages two possible ice-nucleation processes. Either ice crystals form directly by deposition from the vapor onto a foreign nucleus without intervention of the liquid phase, in which case the process is called sublimation or deposition, or else liquid water is first condensed upon the nucleus and ice is then produced by a process of freezing. It is worth noting that sublimation is often thought of as limited to environments at less than water saturation, but this is not necessarily so. Similarly, freezing is not necessarily limited to environments at water saturation or above if the nucleating particle contains a soluble as well as an insoluble component (Fletcher, 1968).

One is led to expect that any particle has a characteristic threshold for activity by each of these processes, this threshold being dependent upon details of the environmental conditions and being determined by the nature and size of the nucleating particle and by the distribution of active sites on its surface (Fletcher, 1969).

Experiments, however, many of them not yet fully reported in the literature, suggest that a nominally dry and unactivated particle may often cause freezing of a droplet when impacted upon it at a temperature which may be considerably higher than the characteristic temperature for nucleation by this class of particle by either freezing or direct vapor deposition. This is the phenomenon referred to as "contact nucleation," and it is the purpose of the present note to suggest two ways in which it can be accounted for.

If, as now seems likely, the activity spectrum of the particles in an aerosol or aqueous suspension is determined not only by particle size and composition but also by the distribution of active sites, then it is clear that any process which modifies the properties of these sites may greatly affect the nucleation activity. It has been suggested by the author that these sites may be tiny surface pits or re-entrant corners on growth steps, though it is also possible that they are associated with small extended regions of chemical or electrical inhomogeneity. In either case it is clear, if such a particle is immersed in water, that the active sites will be etched differentially relative to the rest of the crystal surface. While this might in some cases increase their activity, it is more generally likely that it will be reduced.

If a dry particle is brought into contact with supercooled liquid water, then the nucleation of freezing may well proceed at a faster rate than does the etching process. In this case contact nucleation is simply a variation of ordinary freezing behavior, with the active sites in their pristine state. It is impossible to say much more about this until the nature of the active sites has been more fully explored. It can, however, be quite generally stated that nucleation activity should be a function of particle history and, particularly, of the history of its immersion in liquid water.

Of more practical importance, perhaps, is the behavior of commerical silver iodide smoke particles, which consist of a hygroscopic mixture of AgI with KI or NaI. The simple theory of the equilibrium nucleation behavior of such smokes has been given before (Fletcher, 1968) though it is now recognized that this should be supplemented by the consideration of active sites (Fletcher, 1969). Briefly, in a cloudy environment with very small supersaturation relative to water, the smoke particles become tiny subcritical solution droplets with a mole fraction of soluble material of order 0.1. While each such droplet contains a small undissolved particle of AgI, the nucleation threshold for this particle is considerably depressed, by as much as 10C by the effect of the solute.

Suppose now that such a solution droplet, with diameter of order 0.01 μ, collides with a cloud droplet of diameter 10 μ. The immediate effect is to dilute the solution by a factor of 10^9 and to eliminate the freezing-point depression. Again there is a competition between the rate of nucleation of freezing and the rate of dissolution of the AgI particle, but, for an appropriate supercooling, the former will prevail. It is thus clear that "contact nucleation" may again produce a striking increase in the nucleation efficiency of the aerosol.

It is apparent that these effects may be of considerable importance in assessing the activity of smokes used in cloud seeding programs. It is hoped, by thus drawing attention to them, that research not only on the nature of active sites but also on the kinetics of some of the relevant collision and dissolution processes can be encouraged.

REFERENCES

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The Dynamics of Updraft Vaults in Hailstorms as Inferred from the Entraining Jet Model

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ABSTRACT

The one-dimensional steady-state entraining jet model of cumulonimbus by Squires and Turner was applied to the updraft vaults of 11 hailstorms which occurred in Nebraska and Alberta during July 1968. The initial conditions of cloud base temperature, height, updraft speed and radius were directly observed from an aircraft flying in the updrafts at cloud base. Environmental soundings of temperature and mixing ratio were obtained for each storm from nearby radiosonde observations.

The storm tops as estimated from the radar were within ±1.4 km of the model tops. The radii of the echo free vaults were within ±1 km of the model radii in the lower half of the storm. The significance of the other parameters predicted by the model are discussed.

1. Introduction

The entraining jet model of cumulonimbus by Squires and Turner (1962) considers many of the processes which act within the updraft regions of hailstorms. This model is based on a steady-state, fully turbulent, condensing plume which entrains environmental air according to the simple law that the inflow velocity at any height is proportional to the upward velocity of the plume. With this model, the velocity and radius of the updraft region as well as other properties follow from the dynamics. The set of four differential equations includes the conservation of air mass, momentum, energy and water mass. The processes considered by the set of equations are condensation, buoyancy, entrainment, water load and linear conversion from liquid to ice between −15 and −40C. The input parameters (initial conditions) required are cloud base height, temperature, updraft velocity and radius. Experience indicates that one cannot reliably predict hailstorm cloud base heights to ±500 ft on the High Plains using only radiosonde observations. Generally, observed cloud base temperatures agree quite closely with radiosonde observations, if one knows the cloud base height. However, mixing ratios required to produce the observed cloud base heights often are greater than any shown by radiosonde data. Therefore, the required cloud base observations were obtained by flying an instrumented aircraft at cloud base in the same manner as outlined by Auer and Sand (1966) and Auer and Marwitz (1968). In addition, the model requires the environmental temperature and mixing ratio above cloud base as boundary conditions. These were obtained from nearby representative radiosondes.

The radar observations of echo free vaults (EFV's) in hailstorms presented by Browning (1965), Browning and Donaldson (1963) and Chisholm (1968) have been shown to be updraft vaults by Marwitz *et al.* (1969). This was accomplished by flying an instrumented aircraft in the organized cloud base updraft fields (Auer *et al.*, 1970) and noting that these updraft fields were at the base of the EFV's.

Even though these updraft vaults are continuously undergoing evolutionary changes, it still appears that one can assume that they are a quasi-steady-state phenomenon during a 10–20 min period. This assumption is supported by observations of constant cloud base updrafts plus radar observations of the integrity of the EFV's during a 10–20 min period. Based on model