Observations of Ice Crystal and Ice Nuclei Concentrations in Stable Cap Clouds

A. H. AUER, JR., D. L. VEAL AND J. D. MARWITZ

Natural Resources Research Institute, University of Wyoming, Laramie

3 April 1969 and 8 August 1969

1. Introduction

As early as the autumn of 1967, it was realized that a close scrutiny of the prevailing ice crystal and ice nuclei climatologies within the cap cloud should be initiated in order to study the apparent discrepancy in the concentration of ice crystals and ice nuclei. The isolated cap cloud was selected for study at that time because it is perhaps the simplest of the orographic clouds and, therefore, the possibility exists for investigating some of the important cloud processes. The isolated cap cloud offers an ideal opportunity to study the ice crystal-ice nuclei concentration ratio because of the small vertical temperature gradient through the cloud (typically 3–6C).

The observations reviewed in this note were being readied into final form when Hobbs (1969) presented similar findings. Our observations, taken from a much more stable environment and more numerous in quantity, agree, at least qualitatively, with those of Hobbs.

2. Procedures

Ice crystal replication was accomplished through the use of a Formvar-type continuous ice crystal replicator and hand slides. An estimation of the ice crystal concentration followed the procedure outlined in Hindman and Rinker (1967). The crystals were then classified according to Magono and Lee (1966). Prior comparisons with an independent set of ice crystal data revealed that the ice crystal types growing in specific temperature regimes as suggested by Magono and Lee can be satisfactorily explained in terms of the diagram of Magono and Lee relating ice crystal shape to temperature and humidity.

An NCAR ice nucleus counter, after having been modified to account for the comparison discrepancies with a cold-box mixing chamber, as first pointed but by Steele *et al.* (1967), was used to obtain simultaneous ice nuclei concentration measurements and ice nuclei-temperature spectra. While the NCAR ice nucleus counter performs most efficiently between −10 and −30C (Auer and Veal, 1968), the ice nuclei concentrations at temperatures slightly warmer than −10C can be reasonably extrapolated.

On all occasions, the altitudes of cloud base were visually observed to the nearest 100 feet by comparison to the mountain topography, cloud top altitudes being determined by means of vertical triangulation. Frequently, supporting aircraft observations confirmed these measurements of cloud base and top altitudes. A radiosonde launched approximately 10 mi upwind of the Elk Mountain cap cloud was used to provide estimates of cloud base temperature and cloud top temperature. Wet-bulb temperatures taken at the Elk Mountain Observatory within the cap cloud routinely agreed to within ±1C of the moist adiabatic lapse rate from cloud base, giving credence to the estimate of the clouds vertical temperature gradient.

At each observational period, the total ice crystal concentration was subdivided into specific crystal type concentrations. The corresponding ice crystal temperature spectrum was examined and only those nuclei bounded by the crystal activating temperature limits used in comparison with the observed ice crystal concentration spawned by that temperature limit. For example, if the cap cloud temperature gradient ranged between −8C and −12C, the total ice crystal concentration would be subdivided into these crystals forming within the −8C to −10C limit (column family) and those crystals forming in the −10C to −12C limit (hexagonal plate family). Correspondingly, the available ice nuclei concentration as determined from the ice nuclei-temperature spectrum for the temperature limits between −8 and to −10C and −10 to −12C, respectively, would be delineated. The ratio between the ice

TABLE 1. Summary of data presented in Fig. 1.

Temperature habitat (°C)	Crystal family*	Average ratio of crystal to nuclei concentration	Range	Number of samples
− 4 to − 8	Needle, sheath	1.8×10^3	2.5×10^2–4.6×10^3	6
− 8 to −10	Column, bullet, etc.	6.1×10^3	3.5×10^2–2.0×10^4	19
−10 to −13	Hexagonal plate	3.3×10^3	6.8×10–7.0×10^3	19
−13 to −17	Dendrite	6.6×10^2	3.5×10^2–1.9×10^3	11
−17 to −20	Hexagonal plate	7.0×10^2	1.2×10–2.0×10^3	15
−20 to −25	Column, bullet, etc.	1.3×10^2	9.5–6.8×10^2	11
<−25	Column, side planes, irregular, etc.	1.7×10	4.7–2.4×10	7

* After Magono and Lee, 1966.

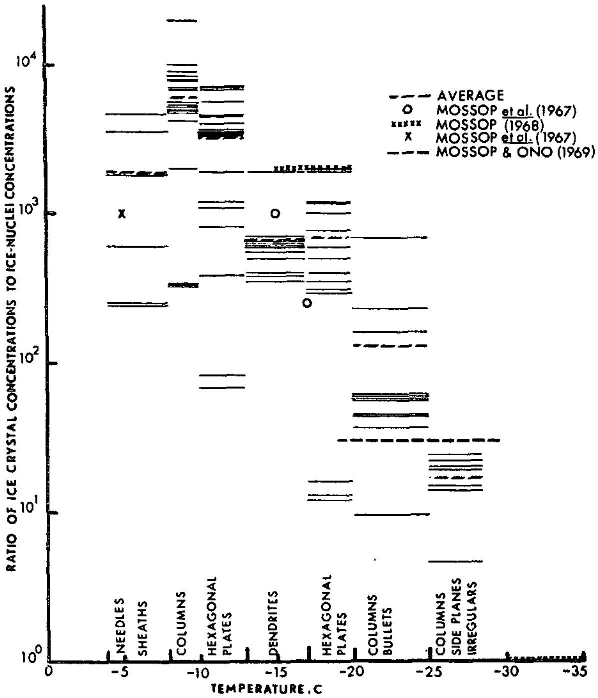

FIG. 1. Summary of observed ratios of ice crystal to ice nuclei concentrations in cap clouds vs temperature.

crystal concentrations and the ice nuclei concentrations would be computed for these respective temperature limits.

3. Discussion

The data presented in Table 1 and Fig. 1 are a summary of 88 observations from the stable orographic cap cloud. Fig. 1 presents the relationship between the ratio of ice crystal concentration to corresponding ice nucleus concentration as a function of crystal types (i.e., specific temperature habitats as demonstrated by Magono and Lee) for the crystal types observed within the cap cloud. Thus, for any particular crystal family, this ratio is plotted as a straight line connecting the limits of the temperature which spawned that crystal family. It can be seen from Fig. 1 that there is a temperature dependence of the ratio of ice crystals to ice nuclei. In the region of column crystal growth (-8C to -10C), the ratio averages near 6×10^3, while decreasing to the value of only 1.7×10 at temperatures <-25C.

Inasmuch as the diffusional growth times for the observed crystals within the cap cloud are on the order of 300 sec (Marwitz and Auer, 1968), it appears that the time constant of the responsible "multiplication process" is $\leq$ 300 sec.

Comparative singular observations by Mossop *et al.* (1967, 1968) and Mossop and Ono (1969) for various cloud types are also presented in Fig. 1; it is seen that these values are all found to agree satisfactorily with the observations from the cap cloud.

4. Conclusions

In summary, it appears from the ice crystal concentration and ice nuclei concentration data available from the cap clouds occurring over Elk Mountain that there is a temperature dependence (i.e., crystal type dependence) for the ratio of ice crystals to ice nuclei concentrations. Furthermore, from the observations of other researchers, it appears that the ratio for other cloud systems may also follow a similar trend of the data presented in Fig. 1.

The time constant of the responsible "multiplication process" is less than 300 sec.

At this time, it is not possible from our limited observations of the ice crystal climatology within the cap cloud to suggest any new mechanisms not already premised (e.g., Koenig, 1968) which would explain the increased number of ice crystals which occur in concentrations greater than the responsible ice nuclei. Further study is being directed toward this end. In addition, corresponding work on the ratio of ice crystals and ice nuclei concentrations during seeded conditions is also underway to determine if the results similar to MacCready and Baughman (1968) will be applicable, and if a similar temperature dependence will again exist in the ice crystal ice nuclei concentration ratio.

Acknowledgments. This research was made possible by the U. S. Department of the Interior, Bureau of Reclamation Office of Atmospheric Water Resources, under Contract No. 14-06-D-6002 (1 July 1966) to the Natural Resources Research Institute, University of Wyoming

REFERENCES

Auer, Jr., A. H., and D. L. Veal, 1968: Characteristics of the cloud within the NCAR ice nucleus counter. *J. Rech. Atmos.*, **1-2**, 155–165.

Hindman, II, E. E., and R. L. Rinker, 1967: Continuous snowfall replicator. *J. Appl. Meteor.*, **6**, 126–133.

Hobbs, P. V., 1969: Ice multiplication in clouds. *J. Atmos. Sci.*, **26**, 315–318.

Koenig, L. R., 1968: Some observations suggesting ice multiplication in the atmosphere. *J. Atmos. Sci.*, **25**, 460–463.

MacCready, P. B., Jr., and R. Baughman, 1968: The glaciation of an AgI-seeded cumulus cloud. *J. Appl. Meteor.*, **7**, 132–135.

Magono, C., and C. W. Lee, 1966: Meteorological classification of natural snow crystals. *J. Fac. Sci., Hokkaido Univ. Series* 7, **2**, 321–335.

Marwitz, J. D., and A. H. Auer, Jr., 1968: Ice crystal growth by diffusion and accretion. *Proc. Intern. Conf. Cloud Physics*, Toronto, 249–254.

Mossop, S. C., 1968: Comparison between concentration of ice crystals in cloud and the concentration of ice nuclei. *J. Rech. Atmos.*, **3**, 119–124.

——, and A. Ono, 1969: Measurement of ice crystal concentration in clouds. *J. Atmos. Sci.*, **26**, 130–137.

——, —— and J. Hefferman, 1967: Studies of ice crystals in natural clouds. *J. Rech. Atmos.*, **3**, 45–64.

——, R. E. Ruskin and D. J. Hefferman, 1968: Glaciation of a cumulus at approximately -4°C. *J. Atmos. Sci.*, **25**, 889–899.

Steele, R. L., C. P. Edwards, L. O. Grant and G. Langer, 1967: A calibration of the NCAR accoustical ice nucleus counter. *J. Appl. Meteor.*, **6**, 1097–1107.