NOTES AND CORRESPONDENCE

Comments on "Ice Multiplication in Clouds"

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In a recent issue of this JOURNAL, Hobbs (1969) reported on simultaneous observations of ice particle and ice nucleus concentrations in natural clouds. He found many more ice particles than nuclei and that the ratio of their concentrations (particles/nuclei) decreased with decreasing cloud top temperature. Using a different method which required a different type of instrumentation, we have found this same relation.

Our work measured ice nuclei which were in the precipitation, not in the air. This is a fundamental difference between the two approaches and permits redefining the ratio of interest. The ratio used by Hobbs can also be thought of as the ratio of ice particles per unit mass divided by the number of nuclei per unit mass. This is the ratio that is examined here.

The number of snow particles per unit mass was determined by measurements of particle size obtained by photography and the size/mass relationships of Nayaka and Terada (1934; see Fletcher, 1962, p. 275). The ice nuclei content of the snow was determined by the method of Vali (1968) in which the freezing of an array of millimeter-sized drops is observed as their temperature is lowered. Based on the premise that the fraction of the unfrozen drops which freeze in a particular temperature interval represents the fraction of all the drops which have nuclei effective in that interval, one can write $N(\theta)=-(1/V)\ln F(\theta)$, where $N(\theta)$ is the number of nuclei per gram of water effective at temperature θ or warmer, V the drop volume, and $F(\theta)$ the array of drops which are unfrozen at θ. (See Vali's paper for the derivation of this equation.) The other parameter which must be known is cloud top temperature and this was estimated from rawinsonde observations.

Snow samples and photographs were taken at Snoqualmie Pass, Wash. (elevation 915 m), 65 km east of Seattle, and rawinsondes were released 49 km southwest of the observation point.

During the early months of 1969, observations of this type were made and Table 1 gives a synopsis of them. The ratio is plotted vs temperature in Fig. 1 along with that of Hobbs. We feel that similarity is substantial, especially considering the greatly differing techniques.

At least one other possible explanation of this high ratio should be added to the multiplication process. That is the effect of higher level (colder) clouds on seeding the lower level ones. In the higher clouds, all nuclei effective at temperatures warmer than, say, −30C, will form ice particles. If the particles fall into a lower cloud whose top temperature is −20C, all (assuming no particles are lost due to evaporation) these crystals will be included in the ice crystal concentration, but the number of nuclei will be assumed to be only those effective at −20C or warmer. Those nuclei effective between −20 and −30C will not be included because of the choice of cloud top temperature. Hence, more crystals than nuclei are indicated. In all the cases presented here, the vapor densities with respect to ice were calculated for each sounding, the results indicating the possibility of higher clouds, usually in the −30C region.

TABLE 1. Synopsis of data for determing R (nuclei per gram × mass of crystal)$^{-1}$.

Date (1969)	Time (PST)	Crystal type	Crystal mass (mg)	Cloud top temperature (°C)	Nuclei per gram	Ratio
29 Jan.	0959–1058	Bullets	4.6×10^{-3}	−20	7100	30
29 Jan.	1058–1153	Bullets	4.6×10^{-3}	−20	3900	56
31 Jan.	2020–2052	Graupel	2×10^{-1}	−16	360	1.4
4 Feb.	1205–1459	Graupel	1×10^{-1}	− 8	3.4	3000
4 Feb.	1459–1703	Rimed stellars and needles	1.7×10^{-1}	−10	10	590
4 Feb.	1705–1903	Rimed stellars and needles	2.3×10^{-1}	−11	10	435
4 Feb.	1903–2200	Rimed spatials and stellars	2.6×10^{-1}	−12	20	190
7 Feb.	1400–1410	Rimed irregular particles	3×10^{-2}	−30	10^{6}	3.3×10^{-2}
5 Mar.	1010–1030	Graupel	1.1×10^{-1}	−23	2×10^{4}	0.45

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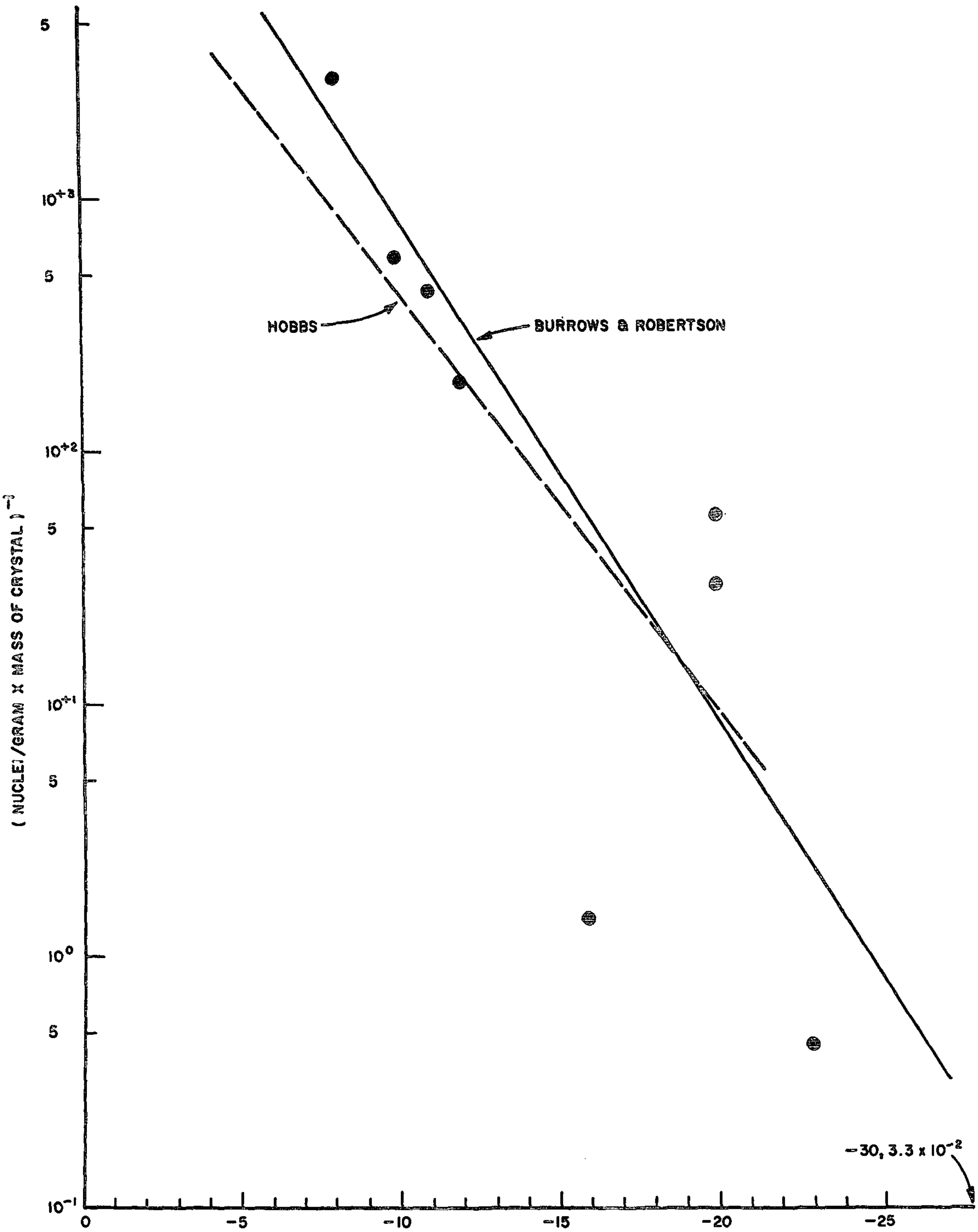

FIG. 1. Ratio of ice crystals per unit mass to ice nuclei per unit mass vs temperature (°C) shown with Hobb's results.

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