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Influence of Riming on the Fall Velocity of Dendritic Snow Crystals

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Abstract

Experimental formulae of fall velocity of rimed dendritic snow crystals were quantitatively derived by the use of riming proportion. The relationship between the fall velocity and the riming proportion of crystals described here is useful in numerical modeling studies of the growth of ice particles due to the process of riming.

1. Introduction

Riming, the collision and capture of supercooled cloud drops by falling snow crystals, is one of the important process in the growth of snow particles. The rate of increase in the mass of crystals due to the riming as it moves through a cloud is dependent on the mass or size, and fall velocity. In turn, the riming on snow crystals has direct effect upon the falling motion of them (Kajikawa and Okuhara, 1997).

The purpose of this paper is to reveal quantitatively the effect of the degree of snow crystal riming to the fall velocity of dendritic snow crystals.

2. Experimental data

The present study uses the observation data of dendritic snow crystals with varying degrees of riming, that fell from storms in northern Japan (Kajikawa, 1975; Heymsfield and Kajikawa, 1987). Complete descriptions of the experimental methods are given in the previous papers (Kajikawa, 1992; Kajikawa and Okuhara, 1997).

Riming proportion R (%) is defined as the ratio of the mass of riming amount to the mass M(g) of rimed crystals, according to the similar manner of Harimaya and Sato (1989) and Mosimann et al. (1994), and is expressed as follows:

$$R = \{(M - M_0)/M\} \times 100$$
$$M_0 = 1.39 \times 10^{-3} d^{2.65}$$

where, M_0(g) is the mean mass of the same size d(cm) of unrimed dendritic crystals (Ple, P2a, and P2c; Heymsfield and Kajikawa, 1987). The classification of the crystals follows the manner of Magono and Lee (1966).

3. Fall velocity of rimed dendritic snow crystals

3.1 Relationship between the fall velocity and the mass of rimed dendritic crystals

The fall velocity V(cm/s) of rimed dendritic crystals, rimed stellar crystals (Rld), densely rimed stellar crystals (R2b), and graupellike snow of hexagonal type (R3a), is shown in Fig. 1 as a function of their mass M(g). When applying the general formula ($V = kM^n$, where k and n are constants) according to Fujiwara (1957), experimental formurae obtained by the least squares method and the range of riming proportion R are as follows:

$$\text{R1d } (R = 8.6 \sim 69\%,\ N = 71) \quad V = 425M^{0.214},\ r = 0.67$$
$$\text{R2b } (R = 49 \sim 88\%,\ N = 52) \quad V = 524M^{0.210},\ r = 0.68$$
$$\text{R3a } (R = 73 \sim 92\%,\ N = 14) \quad V = 1227M^{0.280},\ r = 0.78$$

where, N is the number of crystals and r the correlation coefficient to the relationship.

What is evident from the Fig. 1 the scatter of measured values is remarkable even in the same mass and crystal shape. It can be considered that the reason for this scatter is mainly due to the effects of riming amount.

Considering the riming proportion R, therefore, the experimental formulae of the fall velocity of rimed dendritic crystals can be expressed as follows:

$$R: <30\% \quad (\bar{R} = 20\%,\ N = 29) \quad V = 232M^{0.152},\ r = 0.57$$
$$R: 30 \sim <50\% \quad (\bar{R} = 42\%,\ N = 30) \quad V = 479M^{0.225},\ r = 0.65$$
$$R: 50 \sim <75\% \quad (\bar{R} = 63\%,\ N = 41) \quad V = 570M^{0.231},\ r = 0.70$$
$$R: \geqq 75\% \quad (\bar{R} = 82\%,\ N = 37) \quad V = 1194M^{0.288},\ r = 0.77$$

where, $\bar{R}$ is the mean value of riming proportion R.

The variation of k and n due to the riming proportion R is shown in Fig. 2, using the mean value R of riming proportion. Moreover, the empirical formula $V = 356M^{0.221}$ of the unrimed dendritic crystals (Ple, P2a and P2c; Kajikawa, 1975) was used for $R = 0\%$. The experimental formula of k and n

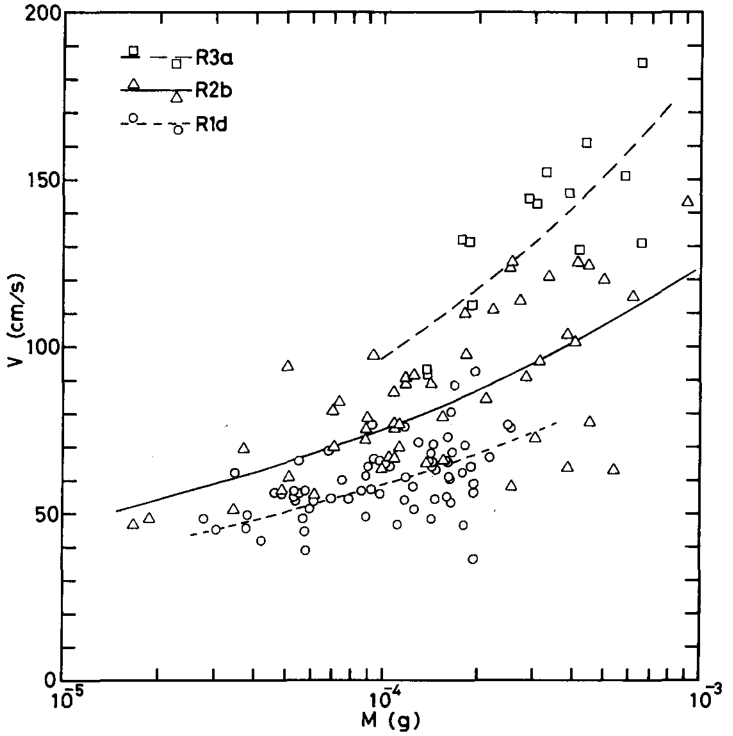

Fig. 1. The relationship between the fall velocity V and the mass M of rimed dendritic snow crystals.

can be expressed approximately as follows:

$$k=250e^{0.0160R}, \quad r=0.862$$
$$n=0.181+0.00103R, \quad r=0.698$$

3.2 Relationship between the fall velocity and the size of rimed dendritic crystals

When applying the general formula ($V=kd^n$, where k and n are constants) the experimental formulae of the fall velocity V(cm/s) obtained by the least squares method are expressed as a function of size d(cm) for rimed dendritic crystals as follows:

R1d ($R=8.6\sim69\%$, $N=71$) $V=88.1d^{0.359}$, $r=0.50$
R2b ($R=49\sim88\%$, $N=52$) $V=149d^{0.444}$, $r=0.54$
R3a ($R=73\sim92\%$, $N=14$) $V=180d^{0.232}$, $r=0.26$

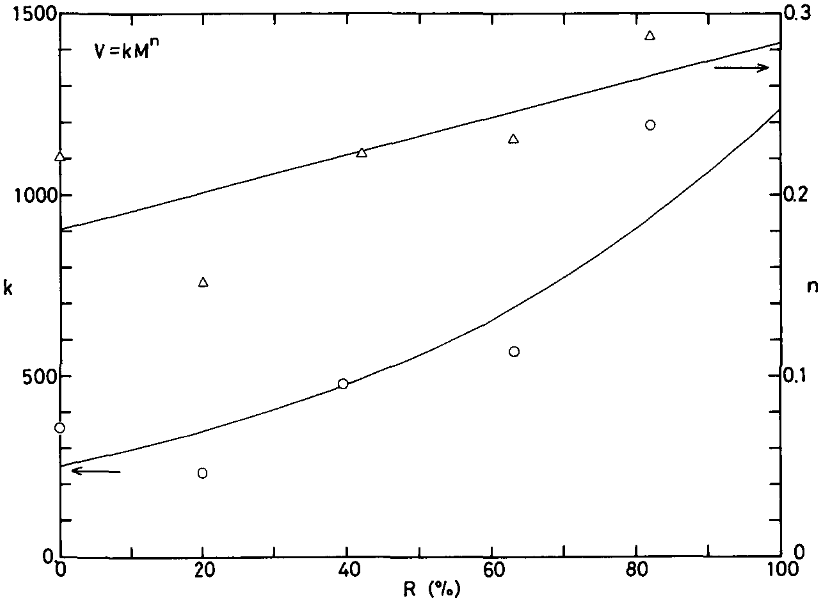

Fig. 2. The relationship between the variation of constants k and n in the general formula ($V=kM^n$) and the riming proportion R of rimed dendritic snow crystals.

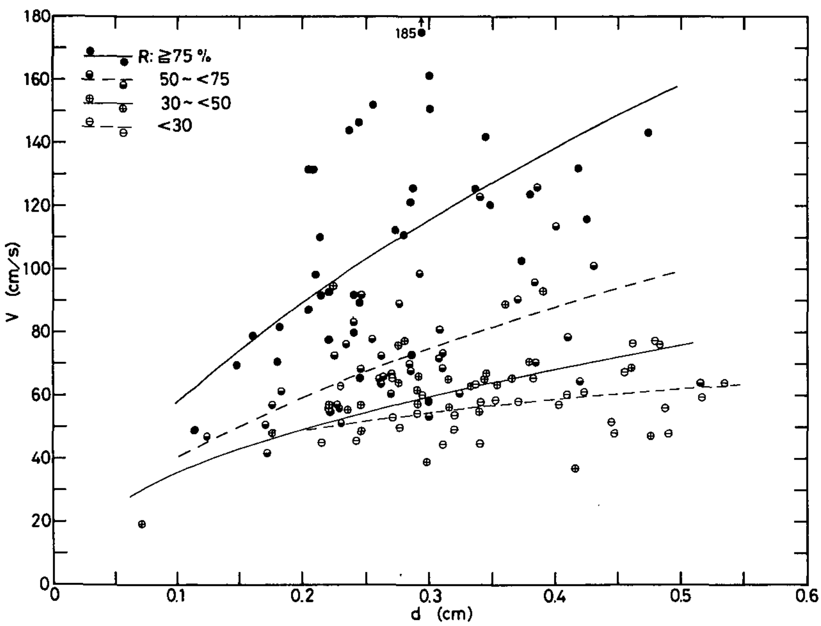

Fig. 3. The relationship between the fall velocity V and the size d of rimed dendritic snow crystals.

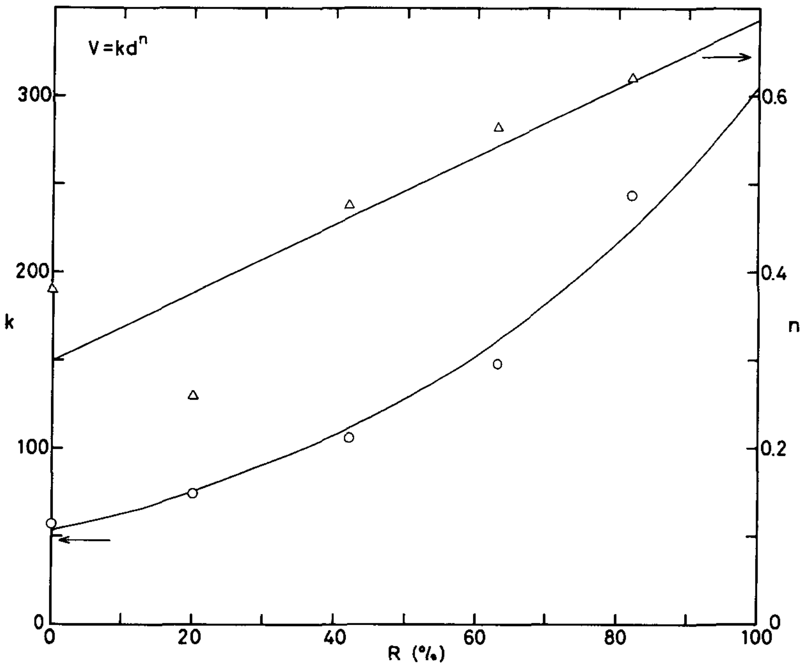

Fig. 4. The relationship between the variation of constants k and n in the general formula ($V=kd^n$) and the riming proportion R of rimed dendritic snow crystals.

Considering the riming proportion R, moreover, the fall velocity of rimed dendritic crystals is shown in Fig. 3 and the experimental formulae can be expressed as follows:

R: <30% ($\bar{R}$=20%, N=29) $V=74.5d^{0.260}$, $r=0.42$
R: 30~<50% ($\bar{R}$=42%, N=30) $V=106d^{0.476}$, $r=0.55$
R: 50~<75% ($\bar{R}$=63%, N=41) $V=148d^{0.565}$, $r=0.63$
R: ≧75% ($\bar{R}$=82%, N=37) $V=244d^{0.621}$, $r=0.59$

The variation of k and n due to the riming proportion R is shown in Fig. 4, using the mean value $\bar{R}$ of riming proportion. Moreover, the empirical formula $V=56.5d^{0.380}$ of the unrimed dendritic crystals (P1e, P2a and P2c; Heymsfield and Kajikawa, 1987) was used for $R=0\%$. The experimental formula of k and n can be expressed approximately as follows:

$$k=53.5e^{0.0174R}, \quad r=0.992$$
$$n=0.299+0.00388R, \quad r=0.867$$

4. Concluding remarks

Using the relationships described above sections, the fall velocity of rimed dendritic crystals can be described by the riming proportion and the mass or size of them. It is considered that the method described here is useful in numerical modeling studies of the growth of ice particles due to the process of riming.

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