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An Attempt at Automatic Measurement of Riming Proportion

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Abstract

As the riming process is important in the mechanism of snowfall formation and in the wet removal of pollutants from the atmosphere, an attempt was made to automatically measure the riming proportion which represents the growth of snow particles by the riming process. The first method used the density of snow particles estimated by the empirical formula of fall velocity-density relation from the fall velocity automatically measured. The second method used the V/D variable, i.e., the fall velocity standardized by the diameter of snow particles, where the fall velocity is automatically measured. It was shown that the riming proportion can be measured automatically by both methods in the range of more than 50%. In the range of less than 50%, other methods must be used such as the method using the extinction of light by accreted cloud droplets.

1. Introduction

Recently, it has been pointed out that the growth of snow particles by the riming process is important in the mechanism of snowfall formation (Harimaya and Sato, 1992 ; Harimaya and Kanemura, 1995). The riming is also an important process in the wet removal of pollutants from the atmosphere (Parungo et al., 1987 ; Borys et al., 1988 ; Mitchell and Lamb, 1989 ; Collett et al., 1991).

In order to study the contribution of riming growth in the formation of snow particles, quantitative measuring methods are required to determine the ratio of

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the mass of rime to the total mass of a snow particle. Recently, Harimaya and Sato (1988, 1989) developed quantitative measuring methods to determine the amount of rime in snowflakes. Mitchell et al. (1990) then developed a method similar to that of Harimaya and Sato (1988, 1989). Recently, Mosimann, Weingartner and Waldvogel (1994) presented the same method as that of Harimaya and Sato (1988, 1989). However, these methods are slow due to the manual labor involved, and it is difficult to obtain the values of the riming proportion in time intervals shorter than 10 minutes. Therefore, these methods are not suitable for investigation of phenomena occurring in short time intervals. These methods can also not be used for long-term observations due to the manual labor required, and measurements under conditions near 0°C are difficult because snow particles melt during operation. In order to overcome these weak points, we have attempted to develop a method of automatic measurement of the riming proportion.

2. Method for measuring riming proportion

2.1 Background of measuring riming proportion

Snowfall phenomena in areas near the Japan Sea, Japan during winter can be characterized as follows. Cumulus clouds aligned parallel to the wind direction move from the sea toward the land, following the wind direction. The lines of cumulus cause the horizontal distribution of snowfall to be band-shaped, and to have each peak in coastal and inland areas. In order to study the difference in the growth process of snow particles between coastal and inland areas, observations were carried out of snow particles at Iwamizawa in the winter of 1991 and at Shinoro in the winter of 1992 (Fig. 1). Observational variables included snowfall intensity measured over one minute, the ratio of rime to total mass (riming proportion) measured by the disassembly method at 10 minutes intervals (shortest measurable interval), the size distribution and fall velocity of snow particles measured by the snowfall particle observation system (INTEC Inc., PROSPER-10) every one minute and so on.

The method for measuring riming proportion was as follows. Snowflakes were collected on a piece of board covered with a velvet cloth and one snowflake with a mean degree of riming amount was selected as representative one. This snowflake was broken down into each snow crystal by a bamboo skewer on a glass plate as carefully as possible so that it would not fracture. Then, all the snow crystals constituting one snowflake were photographed. Figure 2 shows an example of a disassembled snowflake which was collected at 0820 JST 23

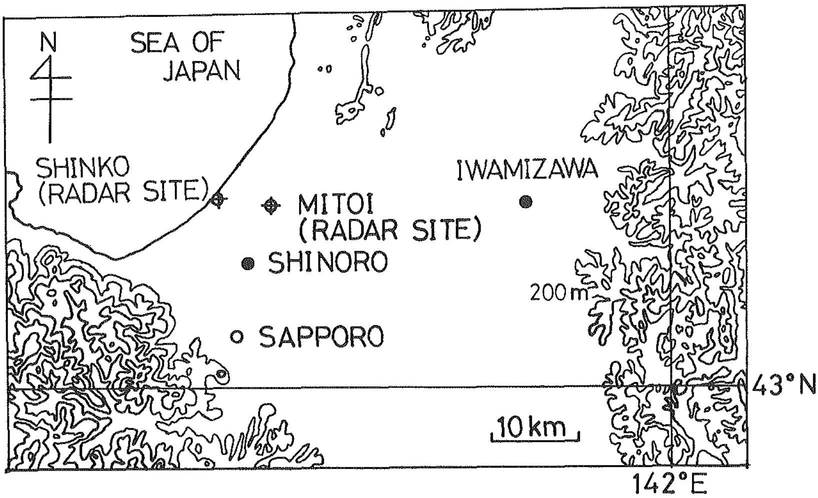

Fig. 1. Map showing the observational sites. The thick solid line represents the coastline and the thin lines are contours of elevation for every 100 meters.

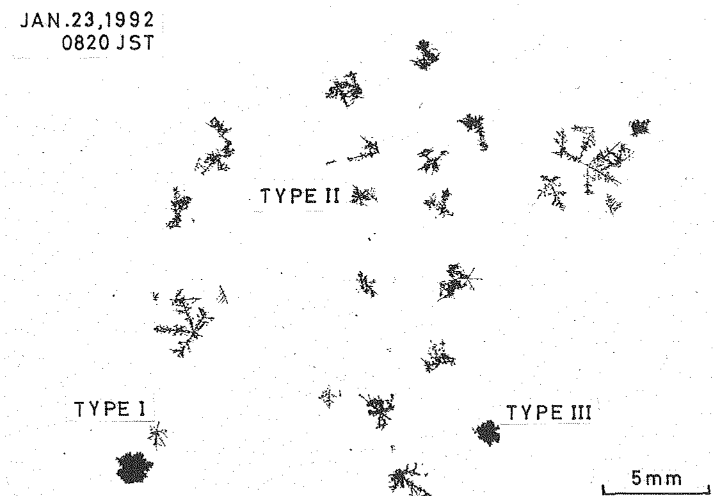

Fig. 2. All the snow crystals constituting one snowflake. Examples in each type are shown by classifications such as Type I, Type II and Type III.

January 1992. Each snow crystal was classified into three types (Type I, Type II and Type III) as seen in Fig. 2 according to the degree of riming, and graupel particles were referred to as Type IV. Then, the numbers of each type of snow crystal constituting one snowflake were determined.

Next, the riming mass of each snow crystal was determined using empirical formulas. For example, for a snow crystal of Type III with a diameter of 3 mm, the mass is obtained from the empirical formula of Type III and the riming is estimated from the mass difference between a snow crystal (Type III) and unrimed snow crystal (Type I) with a diameter of 3 mm. Then, the totals of masses and riming masses were calculated for all the snow crystals constituting one snowflake and the riming proportion was calculated as the ratio of the total riming mass to the total mass constituting one snowflake.

The size distributions of snowflakes were measured by the snowfall particle observation system shown in Fig. 3, which uses a CCD TV camera to photograph snowflakes falling in a tower with an opening of 1 m by 1 m by 2 m in height. The photographed images were converted into digital form with an image-analysis board installed on a personal computer and recorded on a disk (Muramoto et al., 1993). The data are formed to the space distributions with 0.5 mm in size width every one minute. This system is characterized by the ability to directly obtain space distributions and is different from the method in which the number distribution on a horizontal surface is converted to a space distribu-

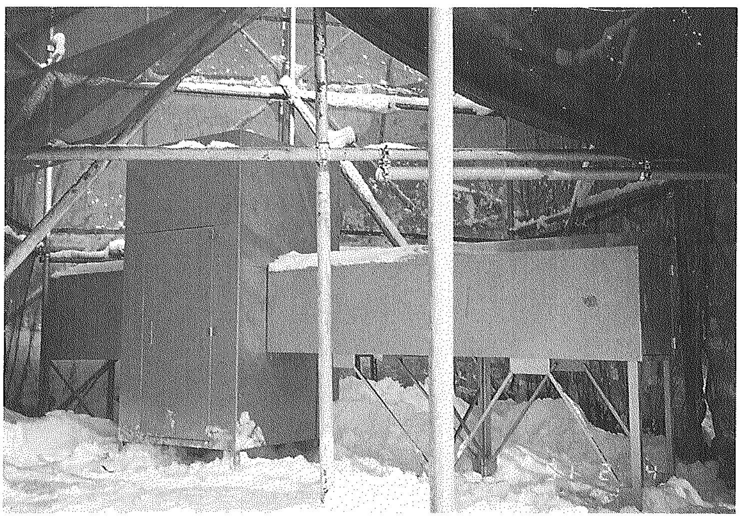

Fig. 3. Sensor unit of snowfall particle observation system.

tion using the fall velocity of a snowflake. Using this system, we can also simultaneously measure and record the fall velocity of each snowflake.

2.2 Method for measuring riming proportion using the density of a snowflake

It is known that the snowflakes with a low riming proportion have a considerable amount of open spaces and those with a high riming proportion are full of ice. Therefore, snowflakes with a high riming proportion are thought to have a high density. As Fig. 4 shows, snowflakes with a high density have a large fall velocity under the condition of an equal diameter. At first, we tried the method of measuring riming proportion by the density of a snowflake. As the fall velocity of a snowflake can be measured automatically by the snowfall particle observation system, the riming proportion can be automatically calculated.

Magono and Nakamura (1965) obtained the following equation showing the relationship between density difference and fall velocity (Fig. 5).

$$U=377\ (\sigma-\rho)^{\frac{1}{4}}, \tag{1}$$

where, U is fall velocity (cm/sec), σ is the density of a snowflake (g/cm^3) and ρ is the density of air (g/cm^3). Assuming condition of -5°C in temperature and 1013 hPa in pressure as the density of air, then the density of snowflake can be

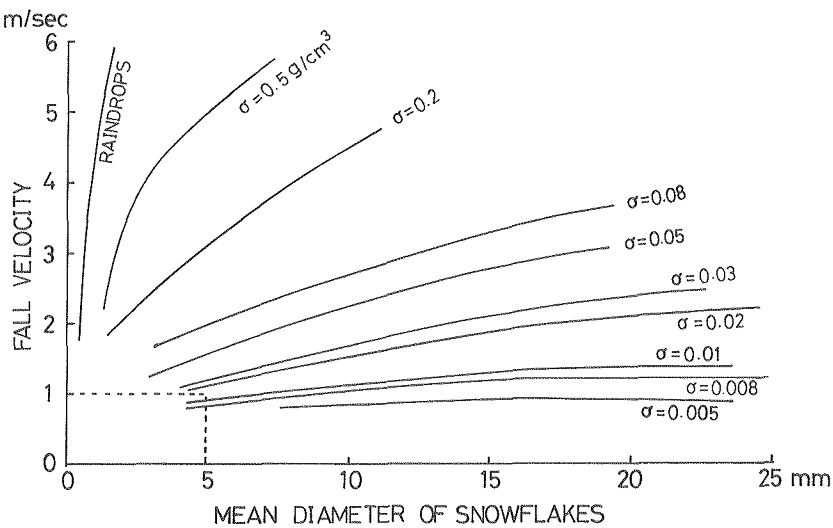

Fig. 4. Fall velocity of snowflakes with some density (Based on the data of Magono and Nakamura, 1965).

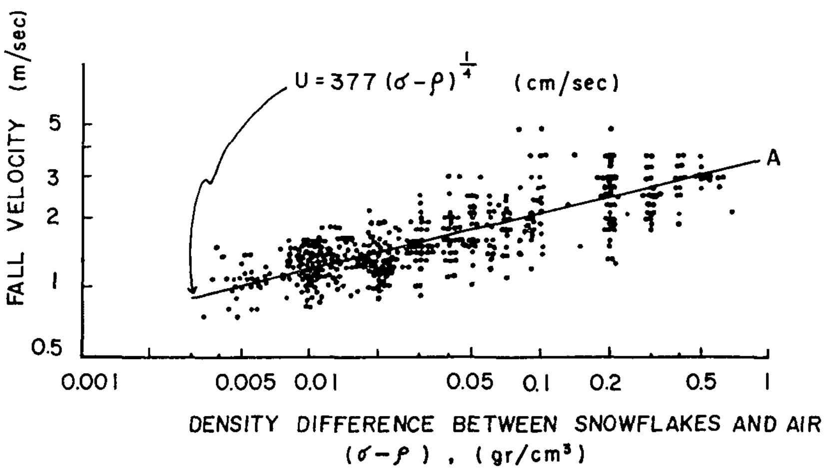

Fig. 5. Relation between density difference ($\sigma-\rho$) and fall velocity of snowflakes (after Magono and Nakamura, 1965).

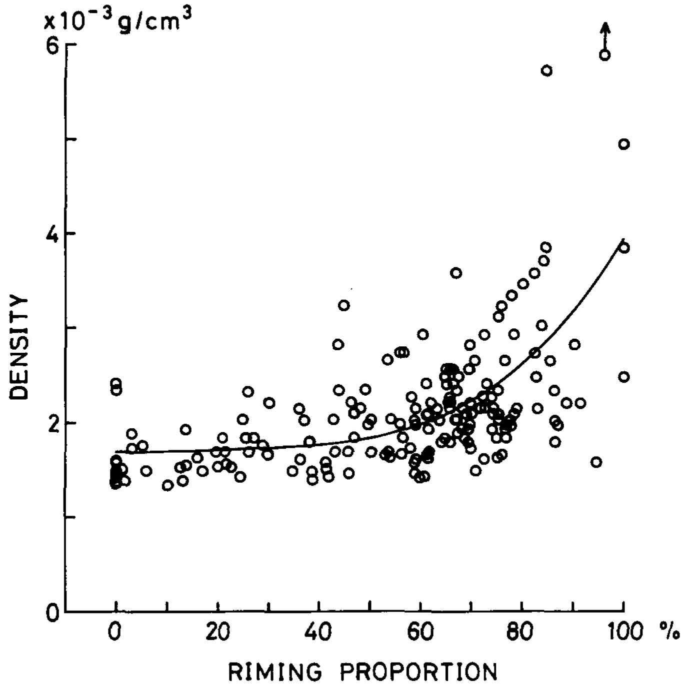

Fig. 6. Relation between riming proportion and density.

obtained from the mean fall velocity by using Equation (1). The densities are shown in Fig. 6 along with the riming proportions. As Fig. 6 shows, density tends to increase with increases in riming proportion in the range of over 50% in riming proportion, although density varies widely according to the riming proportion. The riming proportion was estimated from one snowflake, while the density was estimated from the average of many snowflakes. This is the reason for the large variation in density. A more accurate may be obtained if both values are measured for each snowflake. Thus, automatic measurement of the riming proportion is considered to be possible by this method.

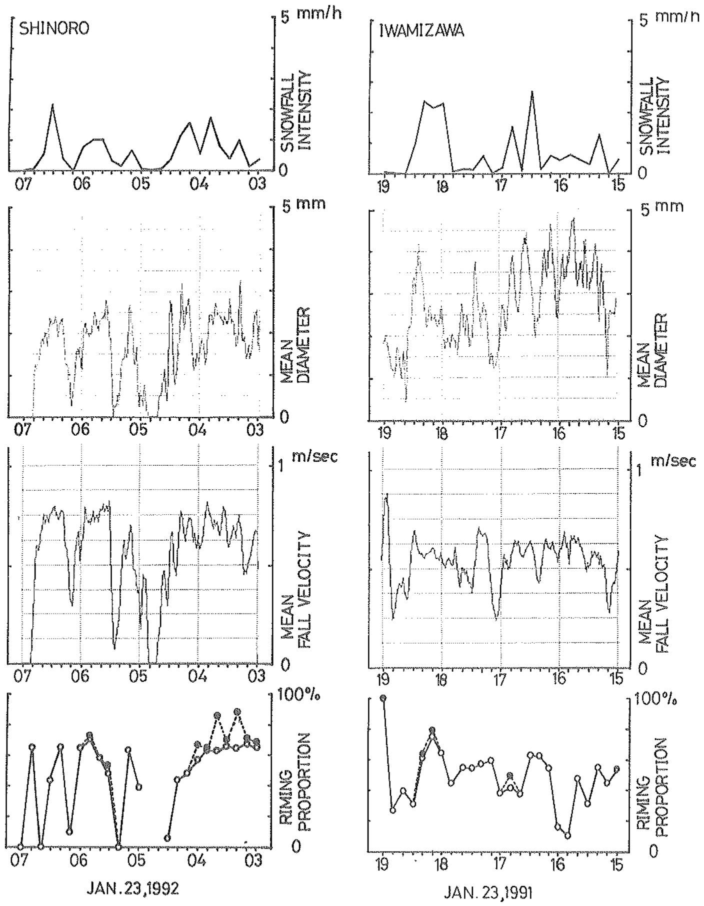

Fig. 7. Properties of snow particles in a coastal area (Shinoro) and land area (Iwamizawa).

2.3 V/D method for measuring riming proportion

Figure 7 shows the properties of snow particles in a coastal area where the riming process is important in the growth of snow particles and in a land area where the riming process is not so. The properties are shown by temporal changes in the mean diameter and mean fall velocity of snow particles, and the riming proportion at Shinoro (coastal area) and Iwamizawa (inland area) under conditions of nearly equal snowfall intensity. A comparison of the properties of the snow particles between the two areas shows the following. The left part shows that there are many cases of more than 60% in riming proportion, while right part shows that there are many cases of less than 60%. The left part which shows a high riming proportion has a high mean fall velocity in spite of a small mean diameter in comparison with the right part which shows a low riming proportion. So we define the fall velocity standardized by diameter of snow particles (V/D, V : fall velocity, D : Diameter) as a variable and examine what determines the variable.

Figure 8 shows the relation between density and V/D of snow particles. It is seen that V/D increases with increases of density. Therefore, it is attempted to adopt V/D in stead of density in Fig. 6.

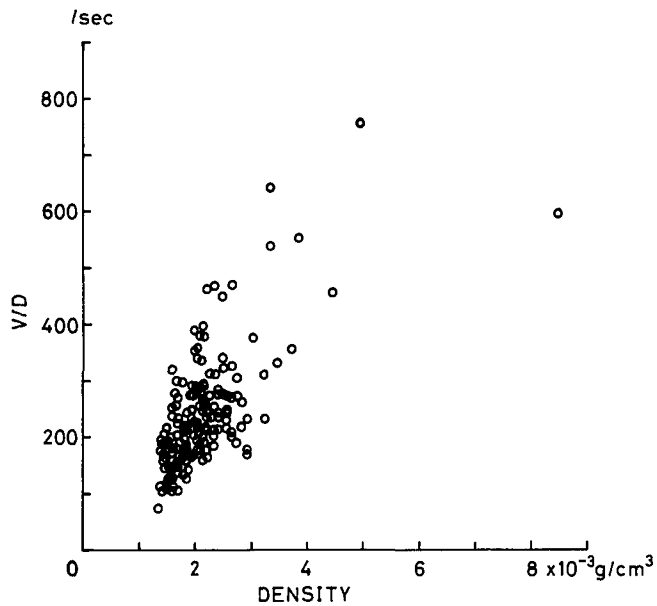

Fig. 8. Relation between density and V/D of snow particles.

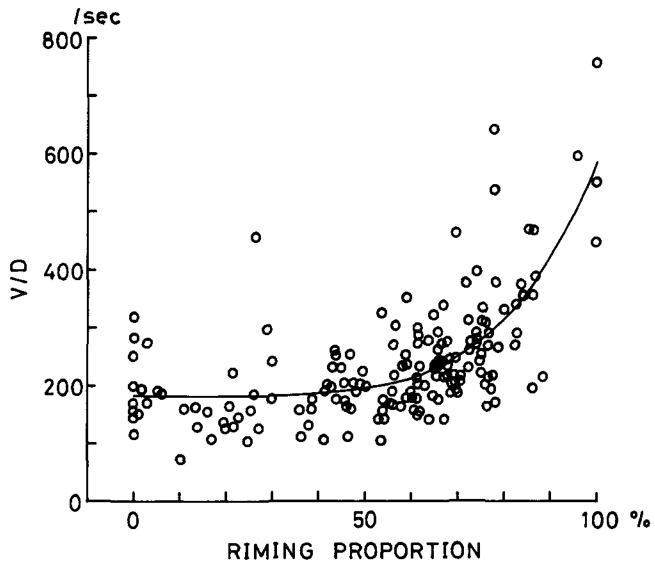

Fig. 9. Relation between riming proportion and V/D.

Figure 9 shows the relation between riming proportion and V/D. V/D tends to increase with increases of riming proportion in the range of more than 50%. The reason for the large variation in V/D is thought to because the riming proportion was estimated from one snowflake, while V/D was estimated from the average of many snowflakes. Thus, it is thought that a more accurate relation can be obtained if both values are measured for each snowflake. Thus, automatic measurement of the riming proportion is also thought to be possible by this method.

3. Conclusion

An attempt was made at automatic measurement of the riming proportion which represents the growth of snow particles by the riming process. The first method used the density of snow particles obtained by the empirical formula of the fall velocity-density relation from the fall velocity automatically measured. Examination of the relation between the density and riming proportion by the disassembly method showed that the riming proportion can be measured automatically by this method in the range of more than 50%.

The second method used the V/D variable, i.e. the fall velocity standardized by the diameter of snow particles, where the fall velocity is automatically measured. Examination of the relation between the riming proportion and the V/D variable showed that this method is also effective for automatic measurement of the riming proportion in the range of more than 50%.

Both methods can not be used in the range of less than 50% in the riming proportion. In this range, the best method is considered to be the one in which the riming proportion is estimated from the extinction of light by accreted cloud droplets. If these two method are combined, it would be possible to automatically measure the riming proportion in the full range.

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