RELATIONSHIP BETWEEN IMAGE DATA OF SNOW PARTICLES AND A Z-R RELATION

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1. Introduction

Radar measurements of precipitation are based on the relation between the radar reflectivity factor Z and precipitation rate R[1]. In order to determine the Z-R relationship for snowfall, Z and R have to be measured independently with high accuracy at short time intervals. However, few systems have been developed for measurement of snowfall rate with high degree of accuracy and temporal resolution[2].

In this paper, a new system to measure physical snowfall parameters using image processing techniques is proposed. The diameter, velocity and density of each snow particle are computed from these images. Snowfall rates calculated from image data are compared with values directly obtained using an electronic balance. During this observation, the received power was measured using a small X-band bistatic Doppler radar, called Precipitation Occurrence Sensor System(POSS), during January 1997 in Muikamachi. The relationship between X-band wave attenuation and snowfall rate is investigated and compared to the characteristics of snow particles.

2. Measurement methods

2.1 Doppler radar

To measure the scattered power from snow particles having different velocity, it was observed using a Doppler radar as shown in Fig. 1. The POSS radar is a small solid state 10.525 GHz, 43 mW Doppler radar set developed by the Canadian Atmospheric Environment Service. The transmitter and receiver are separated by only 31 cm and tilted so that each antenna axis is 70 degrees from horizontal. The intersection of the two antenna beams is the sensing volume. A Doppler shifted frequency of 71 Hz corresponds to a velocity component of 100 cm/sec. The power spectrum of the received power is recorded by computer with an RS-232C serial connection.

2.2 Image processing system

The imaging system is outlined in Fig. 2. In order to protect falling snow particles from wind, a tower was constructed. Snowflakes fell vertically into the tower even during strong winds, ensuring accurate measurement of snow particle characteristics.

To measure the diameter and terminal velocity of snow particles, images of snow particles were photographed using a CCD camera with 1/60 s shutter speed and then continuously fed into an image-analysis board installed on a personal computer. Snow particles falling through the tower have almost no horizontal movement, and have generally a spherical shape, so diameter can be approximated by their horizontal trace. As these images appeared as short streaks in vertical direction, these were used to calculate the falling velocity of snow particles. To decrease the geometrical errors generated by the depth of field, the pictures of falling snowflakes in the photographing space were taken by a zoom lens at a distance of 2.5 m. Simultaneously, snowfall rate was measured using an electronic balance.

3. Snowfall rate

Using an electronic balance, it is possible to measure the snowfall rate with high accuracy at short time intervals. In this paper, it is proposed to measure the snowfall rate using only image data to calculate the mass for every diameter or velocity of snow particles. It is assumed that snow particles are spherical and have uniform density. As a droplet (diameter D, density ρ, mass m, volume V) falls in the atmosphere (density ρ_a, viscosity coefficient ν), the down force mg is balanced by the upward forces; the buoyancy and the drag force by a viscous fluid F. That is

$$0 = mg - (V\rho_a g + F) \qquad (1)$$

where g is gravitational acceleration and V is the volume of a droplet. Because the drag force by a viscous fluid is proportional to the square of the terminal velocity v, we can write

$$\mathrm{v} = \sqrt{\frac{8g}{3C_D}\frac{(\rho-\rho_a)}{\rho_a}\left(\frac{D}{2}\right)} \cong \sqrt{\frac{8g}{3C_D}\frac{\rho}{\rho_a}\left(\frac{D}{2}\right)} \qquad (2)$$

where C_D is the drag coefficient. On the other hand, the Reynolds number Re is defined as

$$R_e = \frac{D \cdot \mathrm{v}}{\nu} \qquad (3),$$

which can be calculated using D and v. An experimental equation between Re and C_D for a sphere

$$C_D = \frac{24}{Re} + \frac{5}{\sqrt{Re}} + 0.4 \qquad (4)$$

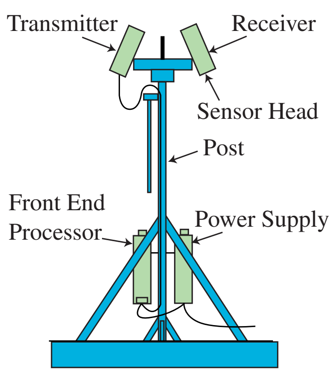

Fig. 1 POSS radar.

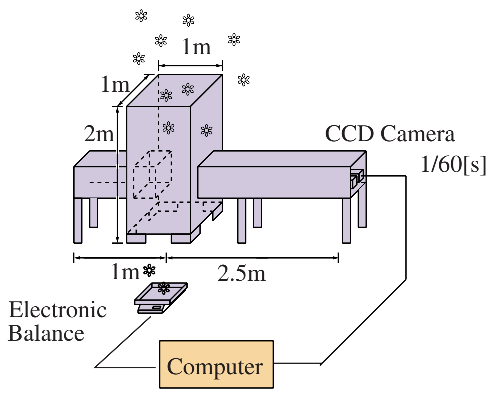

Fig. 2 Equipment for measuring snow particles.

is used in this paper. Using the diameter and falling velocity calculated by image data, it is possible to estimate the density and mass of a snow particle. Furthermore, summing the mass of each snow particle, the snowfall rate is given by

$$R = \sum_i \frac{4}{3}\pi\left(\frac{D_i}{2}\right)^3 \rho_i v_i \qquad (5).$$

4. Experimental results

To verify our method in which the density of snow particles is calculated using only image data, the snowfall rate calculated by image data is compared with that using an electronic balance. Figure 3 shows a time series of snowfall rate obtained by the two methods. It suggests that our method is useful.

It is possible to obtain the snowfall rate calculated by image data for every velocity. Because the received power spectrum of POSS is related with the velocity of snow particles, the snowfall rate and the power spectrum in every Doppler shifted frequency at steps of 16 Hz is shown in Figure 4. These were the sum of data from 9 to 10 AM on the 25 th January 1997. It seems that the histogram of the snowfall rate corresponds well with that of the power spectrum. Figure 5 shows the relation between the power of POSS and the snowfall rate at steps of 16 Hz for the same period of Fig 3. The power is proportional to the snowfall rate in any frequency. There are some different distributions in every frequency.

Using image data, it is possible to calculate the radar reflectivity Z, assuming Rayleigh scattering and discrete data[3]. It is given by

$$Z = \sum_i D_i^6 \qquad (6).$$

In this equation, there is a problem with the diameter D_i. In the case of rain, the diameter of a rain drop is unique. However, a snow particle has the cross-section diameter, which are measured by our image processing, and the melted diameter. Since it is possible to calculate the melted diameter using the mass of a snow particle, Eq. (6) using the melted diameter are obtained from our system. The relation between snowfall rate R and reflectivity Z calculated from only image data are shown in Figure 6. From 16Hz to 80Hz, the distributions are similar and the received power is proportional to snowfall rate. When it becomes bigger than 80Hz,

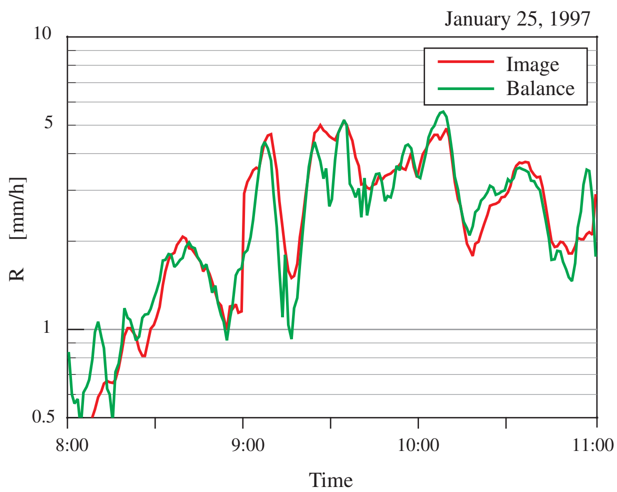

Fig. 3 Time series of snowfall rate.

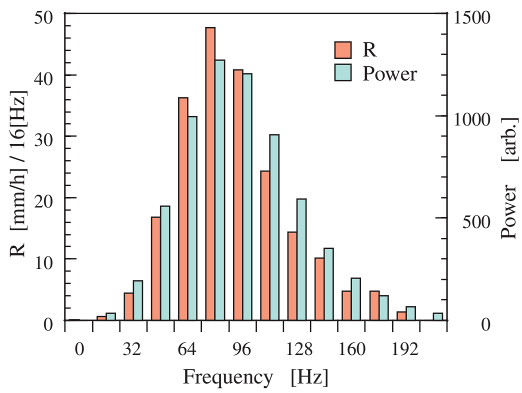

Fig. 4 Histograms of power and snowfall rate.

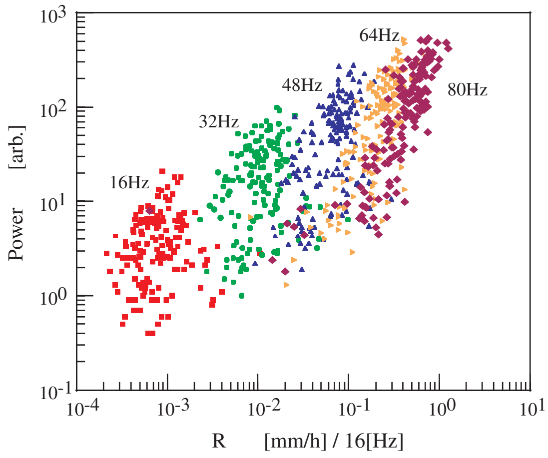

Fig. 5 POSS power and snowfall rate.

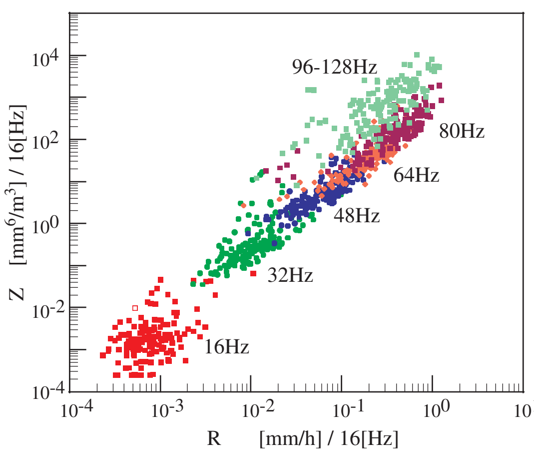

Fig. 6 Z-R relation calculated using image data.

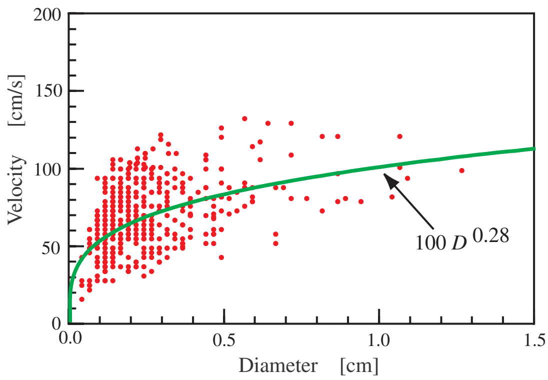

Fig. 7 Velocity distrbution.

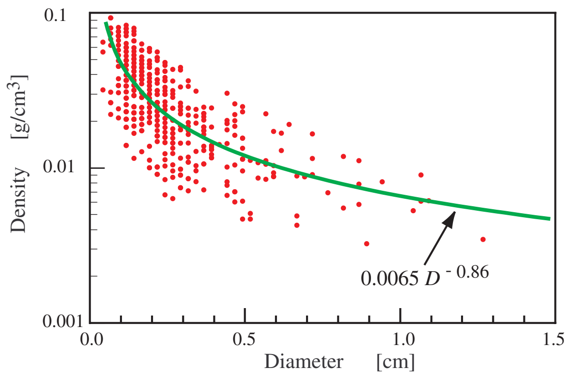

Fig. 8 Density distribution.

there are some different distributions.

Figure 7 and 8 show fall velocity and density distributions[4]. In these figures, the cross-section diameter of snow particles is used. It is suggested that the velocity of snow particles is related with density. It is considered that different distributions in every frequency(that is, velocity) as shown in Fig. 5 and 6 depend on the density of snow particles.

5. Conclusion

A new system to measure diameter, velocity and density of each snow particle using image processing techniques was developed. It was also possible to calculate snowfall rate and radar reflectivity from only image data. This snowfall rate was compared with the value directly obtained using an electronic balance and was almost equivalent. The backscatter power was simultaneously measured using a Doppler radar . It was suggested that the power spectrum is related with the density of snow particles.

References

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