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Precipitation Monitoring Using Multi-instrument Observation System at Various Spatiotemporal Scales

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Abstract

Environmental phenomena often exhibit different characteristics depending on the scale of the observations. To detect environmental changes, determination of spatial and temporal resolution is important.

Precipitation is a very important part of climate. This includes snow, hail, rain, and even mist. Changes in the amount of precipitation falling to Earth affect our lives in many ways. Too little precipitation can result in dry soil, shallow streams, and shortages of municipal water supplies. Too much precipitation, however, can also have a negative impact on human activities and the environment.

To monitor meteorological phenomena quantitatively, we conduct research by using several kinds of sensing systems and satellite imagery. In this paper, to estimate snowfall characteristics, an automatic and multi-instrument snowfall observation system and techniques will be introduced. The instruments include a microwave radar, an optical lidar, a video camera based imaging system and a high-accuracy electrical balance.

1. INTRODUCTION

In precipitation phenomenon a droplet in the cloud develop into a raindrop, a snowflake or a hailstone and fall. We used the electric balance (HP-12k, A and D company Ltd.) for measuring rain rate *R* and the portable bistatic radar (Precipitation Occurrence Sensor System: POSS, Atmospheric Environment Service, ANDREW) for measuring radar reflectivity factor *Z* near the ground, and examined the relation between *R* and *Z* [1]. Further, we measured cloud base and optical backscatter up to altitude of 7500 m using optics lidar (Ceilometer CT25K, vaisala), and examined relation between cloud base and snow types by synchronized backscatter the time with the observational data of the ground. Moreover, we used the vertical radar (Micro rain radar: MRR: METEX) for measuring diameter distribution, radar reflectivity factor, falling velocity of precipitation particle and rain rate. Also, we used the image measurement system for examining various features of individual particles [2]. In this research, we desribe mechanism of observation system and examine the relationship of the data.

2. INSTRUMENT

Fig.1 shows outline of observation systems. These instruments except two ceilometers are all located within an area of 40×40 m.

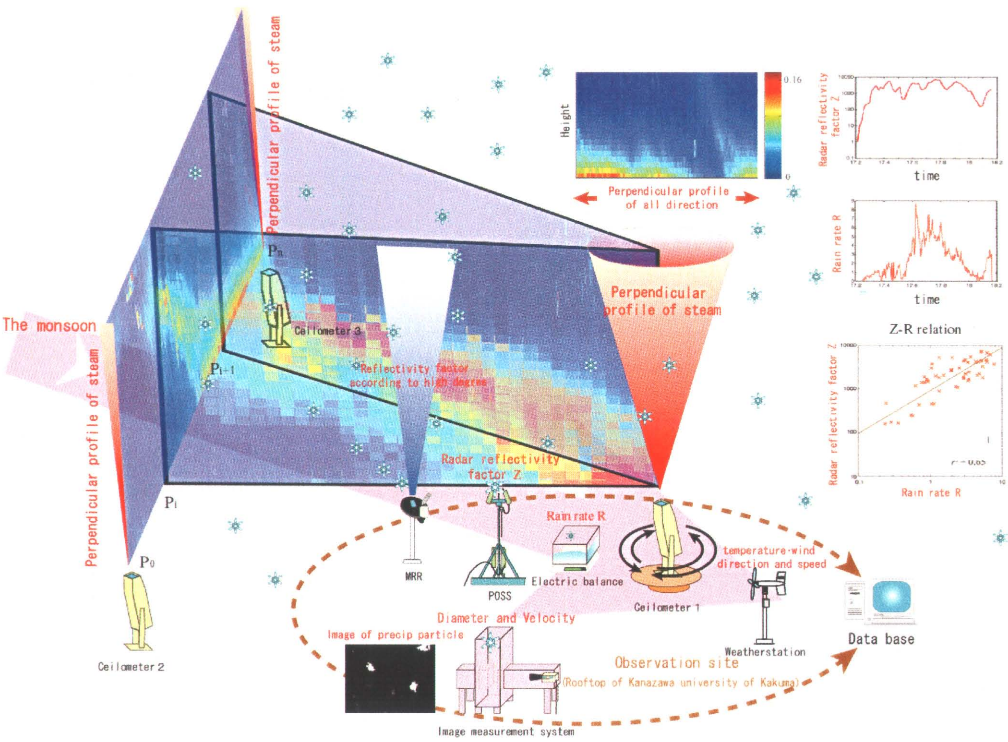


Fig.1: Outline of observation systems.

2.1 Electric balance

We use electric balance for measuring rain rate R. Precipitation accumulates into a plastic container (surface area: 1587.42 cm^2) whose weight is measured every 10 second. To prevent vibration caused by the wind the device is enclosed into an aluminum case. The rain rate R is calculated from this recorded weight data. The R is defined as the increase of the water level in mm/h water when the snow particles are relieved. The resolution of the electric balance is 0.1 g and we assume that the density of snowflakes is 0.001 g/mm^3 using previously examined data.

2.2 Portable radar

The POSS is an X-band bistatic radar. The wavelength of the radar signal is 2.85 cm and the transmitting power is 43 mW. The transmitter and the receiver are separated and the observation space is the intersection of the corresponding radar beams located about 40 cm away from the transmitter. A radar signal is scattered by the Doppler effect if a particle exists in the observation volume. The scattered signal is received by receiver and the power spectrum is obtained via a fast fourier transform (FFT).

2.3 Ceilometer

We used the optics lidar for measuring cloud base and optical backscatter value up to a height of 7500 m at 30 m resolution. Ceilometer uses a pulse diode laser, and it can send a short wavelength radar pulse that is short and strong to vertical or near vertical direction. The wavelength of transmitting signal is 905±5 nm and the transmitting power is 8.9 mW on the average. When the laser passes the atmosphere, it hits the fog, the mist, and the precipitation particle, etc., and the backscatter value is measured. The cloud base and the time distribution of backscatter value are examined by measuring the backscatter value at each distance resolution. The unit of backscatter value is $srad^{-1}$, and the data is transmitted to computer with 30 s time resolution.

Three ceilometers are set up three points in the direction of the monsoon from the northwest of Hokuriku, and movement of cloud base and backscatter value will be observed in the future. We will interpolate between the observation points in both time and spatial space for examining the distribution of backscatter value. As a result, the change of the cloud base or the snow particle groups will be analyzed.

2.4 MRR

The MRR is conventional static K-band Radar using one antenna for both receiving and transmitting. The MRR yields the FFT power spectrum of 30 points according to the distance resolution and the falling velocity of the precipitation. From this data the precipitation size distribution, the radar reflectivity factor, the rain rate and the moisture content can be calculated. As a result, the snowflake type can be determined for each observation period. The radar beam is vertical and a total of 30 resolution cells are computed.

In this research, we set the distance resolution to 30 m and the time resolution to 30 s.

2.5 Image measurement system

In order to measure the shape and velocity of a snow particle, snow particles falling through the observation space (height: 12 cm, width: 8 cm, depth: 18 cm) were photographed using two video cameras with different shutter speeds of 1/60 s and 1/4000 s. Images of snow particles appeared in the actual shape for 1/4000 s and short streaks for 1/60 s shutter speeds. Combining the two images, the same particle can be identified. A typical photograph of snow image is shown in Fig.2. Falling velocity is calculated from the difference of vertical length. Using this observation system, various features and the image of a large amount of snow particles are measured continuously over a long period.

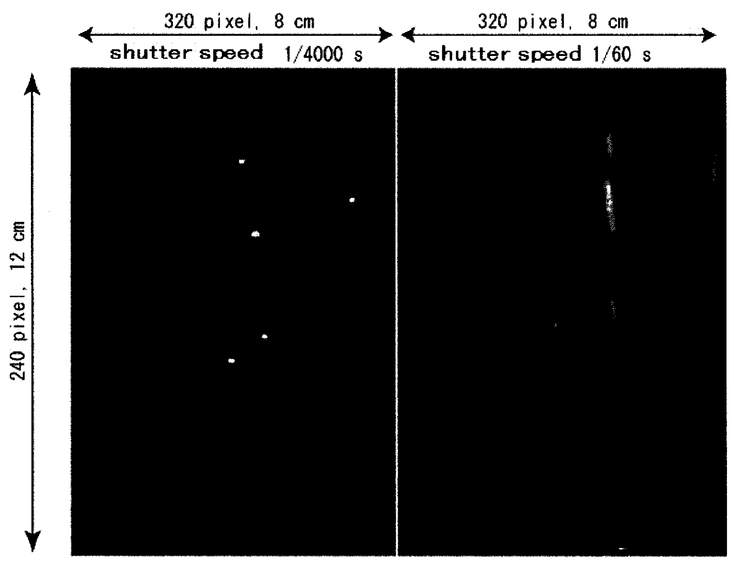


Fig.2: Typical photograph of snow image.

3. ANALYSIS

3.1 Z-R relation

In general form *Z-R* relation is written as

$$Z = BR^{\beta} \quad [\text{mm}^6/\text{m}^3] \qquad (1)$$

where Z is radar reflectivity factor, R is rain rate, B and β are coefficients.

Therefore, in this research, we use the received power measured by POSS as the radar reflectivity factor Z, and examine B and β for the *Z-R* relation. In this research, these coefficients are calculated by least square method.

3.2 Synchronizing backscatter value with the ground observation data

To synchronize the ground observational data with the backscatter values it is shifted back in time according to the height of the backscatter observation and the average falling velocity of the precipitation. The average falling velocity is calculated from the falling velocity distribution obtained by the image measurement system.

3.3 Diameter distribution and falling velocity

It has been demonstrated that the diameter distribution follows to a good extent the negative exponential law [3].

$$N(D) = N_0 e^{-\lambda D} \quad [\text{m}^{-3}\text{mm}^{-1}] \qquad (2)$$

where D is a diameter, $N(D)$ is a number of snow particles of diameter D and both N_0 and λ are coefficients. This equation states that the number concentration decreases as size increases, i.e. small particles are much more numerous than larger ones.

Similarly, the falling velocity of snowflakes follows approximately the power law

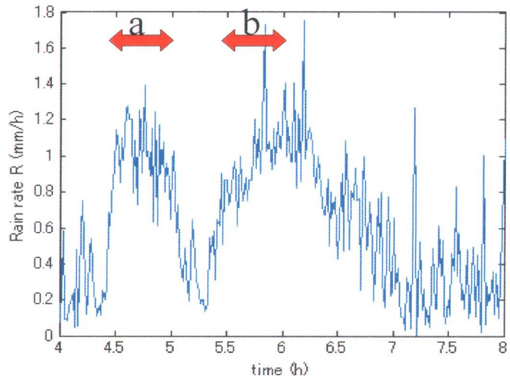
$$v = \kappa D^{\varepsilon} \quad [\text{m/s}] \qquad (3)$$

where κ and ε are coefficients [4].

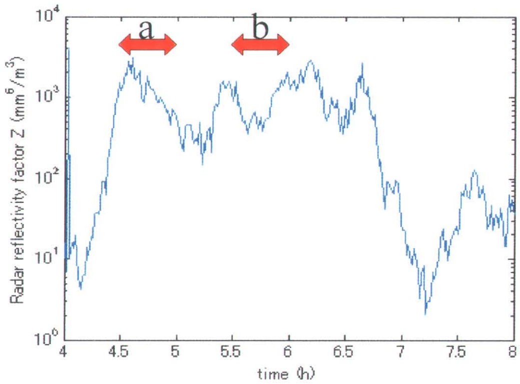
In this research, these coefficients are calculated by least square method.

4. RESULTS

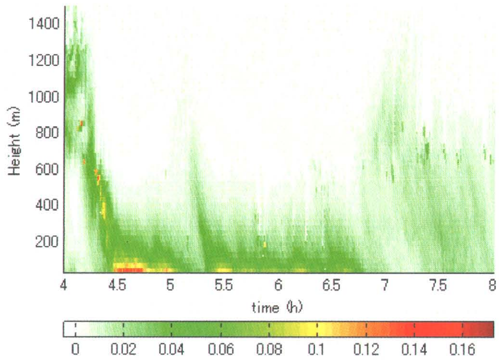
The graphs in Fig.3 present the acquired data from 4:00AM to 8:00AM on January 27th, 2004.



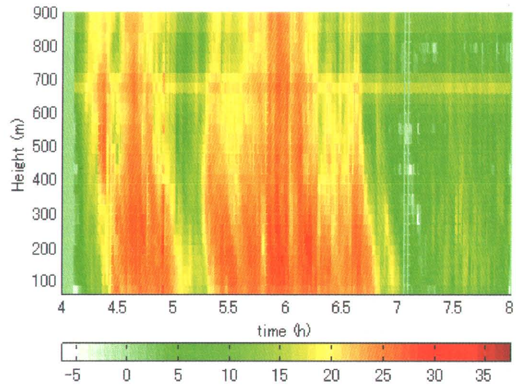
(a): Rain rate R by Electric balance.



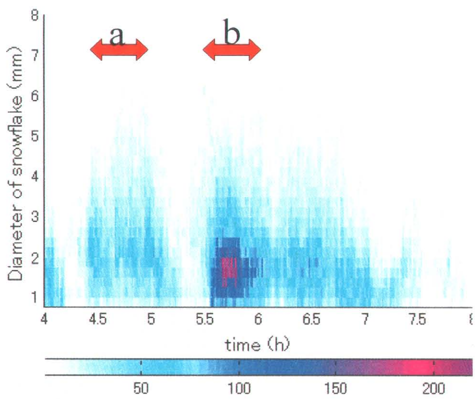
(b): Radar reflectivity factor Z by POSS.



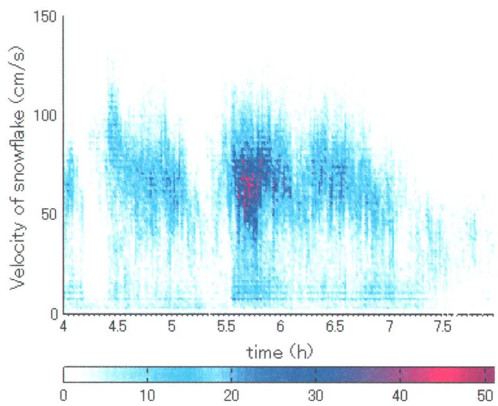
(c): Backscatter value by Ceilometer.



(d): Radar reflectivity factor by MRR.



(e): Diameter distribution of snowflakes by Image measurement system.



(f): Velocity distribution of snowflakes by Image measurement system.

Fig.3: Time series of measured data 4:00AM-8:00AM January 27, 2004.

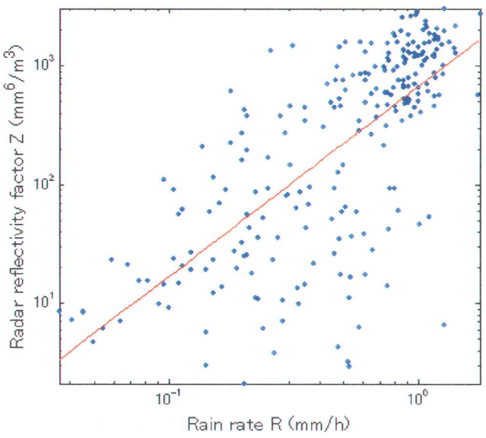


Fig.4: Z-R relation

$Z = 684R^{1.6}, \quad r^2 = 0.513$

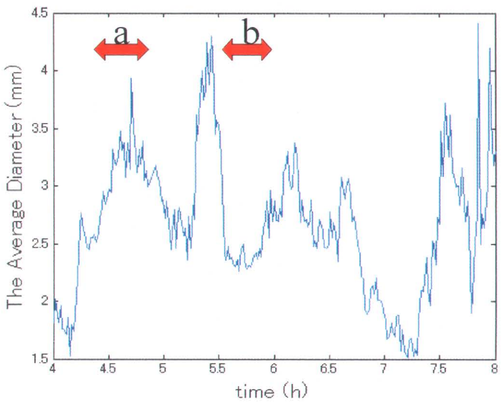


Fig.5: The average diameter

a: 4:29 AM - 4:59 AM

b: 5:36 AM - 6:06 AM

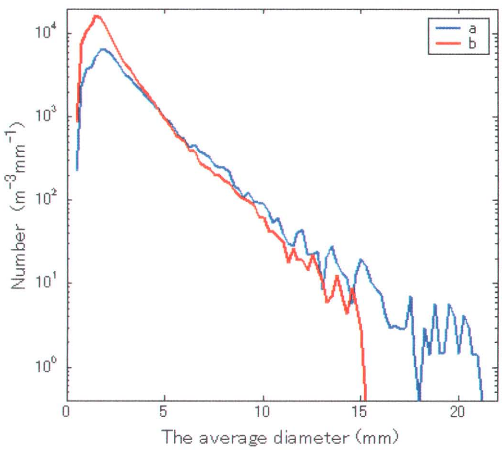
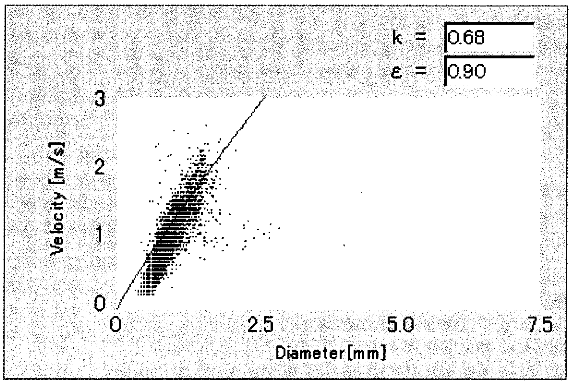


Fig.6: Diameter distribution.

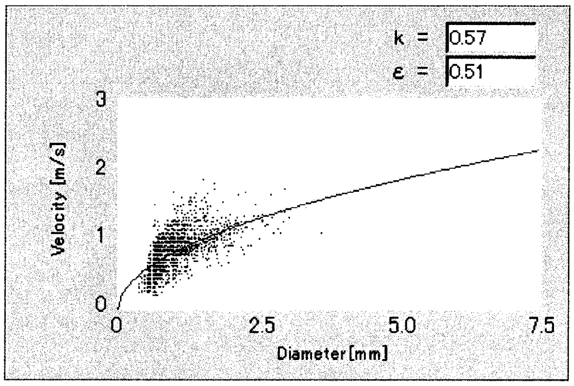
The Z-R relation is presented in Fig.4. Some correlation was seen for the observation period. The average diameter is shown in Fig.5.

During the periods **a** and **b** the rain rate *R* and the radar reflectivity factors *Z* are somewhat equal while these is a clear difference in the observed the average diameter. Fig.6 presents the number concentration of periods **a** and **b** obtained from diameter distribution data. The snowflakes of period **a** are larger than period **b**. Therefore, the radar reflectivity factor *Z* is strong when the snow particle is large.



(a) 8:30 AM - 8:37 AM

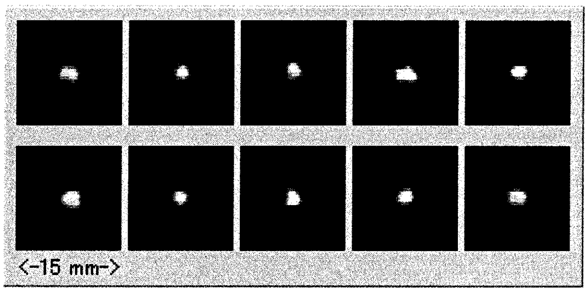
$v = 0.68D^{0.90}$



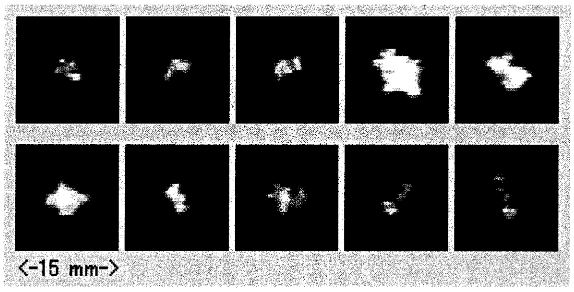
(b) 8:38 AM - 8:45 AM

$v = 0.57D^{0.51}$

Fig.7: Falling velocity versus diameter of snow particles.



(a) 8:30 AM - 8:37 AM



(b) 8:38 AM - 8:45 AM

Fig.8: Snow particle images.

Next, the data on January 31, 2005 is shown. The following Figures present the relation between diameter and falling velocity (Fig.7) and the snow particle images (Fig..8) for period a (8:30 AM –8:37 AM) and b (8:38 AM –8:45 AM). These were measured by the image measurement system. The graph of Fig.7(a) shows a characteristic of hailstone while Fig.7(b) shows of snowflake [5]. These are confirmed by actual snow particle images shown in Fig.8.

5. CONCLUSION

In this paper, we described integrated measurement system for snow particle. This system can automatically and simultaneously measure various snow and meteorological data. Using this observation system, snow phenomenon can be analyzed from various viewpoints. Simultaneous analysis of these data brings the development of the snow research.

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