SNOWFALL MEASUREMENT USING LIDAR CEILOMETERS, RADARS AND SNOW GAUGES

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1. INTRODUCTION

The Hokuriku district of Japan is one of the heaviest snowfall regions in the world. Cloud streets are often observed when a cold air mass advects over a warm sea around the Japan Islands during the winter monsoon. Examination of the behavior and structure of cloud is important in the snowfall formation in areas of Japan facing the Japan Sea [1]-[3].

It has been shown that clouds are very complex in both the horizontal and vertical directions, i.e. clouds are not homogeneous. Their complex structure needs to be viewed in high spatio-temporal resolution to accurately describe the spatial structure [4], [5].

In this paper, we used two optical backscatter lidar systems (ceilometer CL-31, Vaisala) to measure water vapor in the lower atmosphere. We also used the vertical radar (Micro Rain Radar: MRR, METEX) to measure radar reflectivity factor and falling velocity of snow particle. Furthermore snowfall rate was measured by 2 high-sensitive electric balances (snow gauges).

The results of the study will lead us to deeper understanding of meteorological relationship between snowfalls and vertical water vapor distribution.

2. INSTRUMENTS AND METHODS

The instruments used in this study include two optical lidars (ceilometer), two small microwave radars and two electric balances. All the instruments were integrated into an automatic measurement system, and recorded data at short intervals over long time periods. We had two observation sites which were located at Kakuma and Takaramachi campus. The distance between two campuses is 3.1 km. Location of two sites (main and satellite site) is in the direction of the monsoon from the northwest of Hokuriku (Fig. 1). All the instruments except one lidar were set up at the main site of Kakuma campus.

2.1. Lidar

The Vaisala CL-31 lidar ceilometer is a pulsed diode laser with wavelength 905 nm and 8.9 mW average power. Backscatter profile is obtained at a resolution of 10 m and an integration time of 8 s. The operation is similar to the vertical radar, except that RF components are replaced by optical ones.

2.2. Radars

The MRR (Micro Rain Radar, METEX) is a monostatic K-band radar (peak power: 50 mW), using one antenna for both the receiver and transmitter. The radar beam is vertical and a total of 30 resolution cells are computed. Maximum measurement height is 1050 m, yielding a vertical resolution of 35 m. A X-band polarimetric radar (peak power: 200 W) of Nagoya University was also installed at Oshimizu (distance: 31.7 km from Kakuma campus, elevation angle: 1.89°), Ishikawa, from December 2008 to March 2009. This radar was operated with 12 PPI scans in 5 min and RHI scans were occasionally performed by manual operation.

2.3. Electric balances

The two balances are highly sensitive electric laboratory balances (A&D Co., Model GP-12K) that have been set up for measuring snowfall rate. Knowing the surface area where precipitation accumulates, the water equivalent intensity in mm/h can be calculated from the increase in mass.

2.4. Interpolation

We interpolated the data between the two sites in both temporal and spatial space to construct range height indicator (RHI) display of the optical backscatter power.

Since in winter monsoon season, wind usually blows from the northwest (the Japan sea) in Hokuriku, changes of cloud base and the distribution of backscatter value were first detected at the satellite site, and then they were detected at the main site (Fig. 1). In the first step, the time difference t_d between two time series data was determined by calculating the correlation factor r for arbitrary selected period.

$$r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2}\sqrt{\sum (y_i - \bar{y})^2}} \qquad (i = 1,2,\ldots,n) \tag{1}$$

where (x_i, y_i) = each pair of data for integrated from 60m to 120m.

$\bar{x}, \bar{y}$ = average for selected period,

The data of the spatial distribution is expressed as

$$D = \left(1 - \left(\frac{t - t_1}{t_d}\right)\right) D_1 + \left(\frac{t - t_1}{t_d}\right) D_2 , \qquad t_d = t_2 - t_1 \tag{2}$$

where D_1 indicates the value at the time of t_1 at the satellite site, similarly D_2 indicates the value at t_2 at main site, D is the interpolated value for time t between two sites (Fig. 2). As a result, the cloud length, width, and the separation between clouds were able to analyze. In this study, display of altitude was limited up to 1000 m because the purpose of this study is the observation in the lower atmosphere.

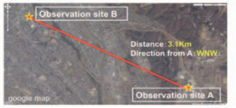

Fig. 1 Location of the observation sites.

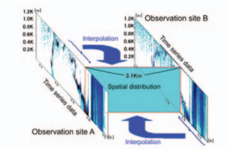

Fig. 2 Spatial interpolation using time series backscatter data of each site.

3. RESULTS AND DISCUSSION

Kanazawa was covered with snow on February 16, 2009, due to a wintry atmospheric pressure pattern.

Time series of ceilometer backscatter (a), MRR radar reflectivity (b), MRR radar velocity (c) and snowfall rate (d) are shown in Fig. 3.

Fig. 4 shows the vertical profile of radar reflectivity from 2105 to 2115. It was observed that radar reflectivity varies a little with height during 2105 to 2110, but it gradually increased during 2111-2115.

Fig. 5 shows the spatial distribution of vertical cross section for 1 min interval from 2108 to 2113 of February 16, 2009. It is possible to estimate the "group velocity" of small particles (vapor) from transitions of spatial distribution.

Fig. 6 shows the PPI display of reflectivity measured by MP radar from 2105 to 2115 of 16 February 2009. There were some masses of cloud around the altitude of 1000 m. They moved from satellite to main site as shown in Fig.5. We can detect the horizontal movements of these clouds from Fig. 6. The combination of Figs. 3, 4, 5 and 6 can give a deep understanding for snowfall characteristics and cloud movement.

4. CONCLUTION

The combination of high temporal and spatial resolution of vertically-pointing MRR and optical lidar make it well understanding of various size of particles. RHI display using two optical lidars can give the information on the cloud length, width, and the separation between clouds. Moreover, conventional weather radar gives information broad range in middle temporal and spatial resolution. Therefore combination of all these instruments and methods will be potent system for deeper understanding of meteorological relationship between snowfalls and vertical water vapor distribution.

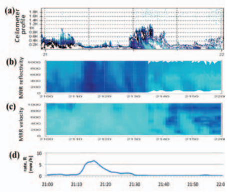

Fig. 3 Time series of atmospheric profiles and snowfall rate in February 16, 2009. (a) Ceilometer [(10000 srad km)$^{-1}$], (b) MRR radar reflectivity [dBZ], (c) MRR velocity [m/s], (d) Snowfall rate [mm/h].

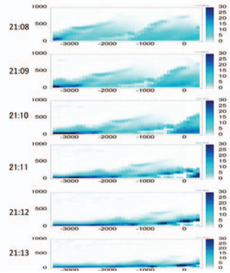

Fig. 5 RHI display of optical backscatter for 1 min interval during 2108-2113 of February 16, 2009. x-axis: distance from main site, y-axis: height.

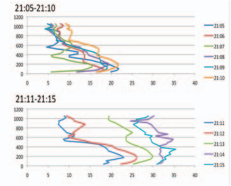

Fig. 4 Vertical profile of radar reflectivity per 1 min. Different colors indicate different time from 2105 to 2115. x-axis: reflectivity [dB], y-axis: height.

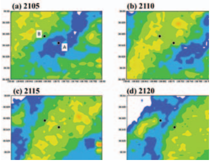

Fig. 6 PPI display of reflectivity measured by MP radar from 2105 to 2120 of February16, 2009. Here A is main site, B is satellite site.

5. REFERENCES

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