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1.2.5 MEASUREMENTS OF PRECIPITATING ATMOSPHERE BY THE MU RADAR

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INTRODUCTION

Although MST radars make it possible to study the dynamics of the middle atmosphere (BALSLEY and GAGE, 1980), simultaneous observations of the troposphere are also important, since various dynamical processes in the middle atmosphere originate with meteorological phenomena in that region.

Sensitive VHF Doppler radars have the capability to detect echoes from precipitation particles as well as refractive index irregularities. We have used the middle and upper (MU) atmosphere radar at Shigaraki, Japan for tropospheric observations of precipitating atmosphere (FUKAO et al., 1985a). We have detected precipitation motions simultaneously with the ambient air motion (FUKAO et al., 1985b), and shown the capabilities of the MU radar in investigating mesoscale structures of meteorological phenomena such as air and precipitation motions within a cold frontal system (WAKASUGI et al., 1985a). More recently, a direct method for deducing the drop size distribution of precipitation particles was developed using Doppler spectra of the MU radar (WAKASUGI et al., 1985b). This method is free from errors inherent in conventional measurements using microwave Doppler spectra.

In the present paper, we will discuss the capabilities of the MU radar for studies of the precipitating atmosphere. Meteorological microwave radar (i.e., non-MST radar) data are also utilized for monitoring vertical and horizontal structures of precipitation.

DOPPLER SPECTRA FROM THE PRECIPITATING ATMOSPHERE

Figure 1 shows typical altitude variations of Doppler spectra obtained in the vertical direction during periods with and without perceivable precipitation on the surface (FUKAO et al., 1985b). The rainfall rates at Kinose, 6.9 km north of the MU radar, provided by the Japan Meteorological Agency, is 1 and 0 mm h^{-1} in the respective periods. The rain is considered to be a weak stratiform type.

Of the two spectral components in Figure 1(a), the minor one with large positive (downward) Doppler shift does not exist while no precipitation is observed, whereas the major one with near zero Doppler shift persistently appears irrespective of the precipitation.

The vertical speed of the minor component is about 7 ms^{-1} above 5 km, while it is less than 2 ms^{-1} above 6 km. The fairly large change with altitude near 5-6 km is quite certain because the minor component is clearly separated from the major one below 8.5 km. The minor component merges in the major one above 9 km. The half-power spectral width varies by more than 3 times in the vicinity of 5-6 km, and is roughly constant elsewhere, i.e., 0.8 and 2.7 ms^{-1} above and below the melting layer, respectively. These features, which are consistent with those of precipitation particles observed with meteorological Doppler radars (DOVIAK and ZRNIC', 1984), indicates that the minor component of the MU radar echo originates from precipitation particles, i.e., snowflakes above the melting layer and raindrops below it.

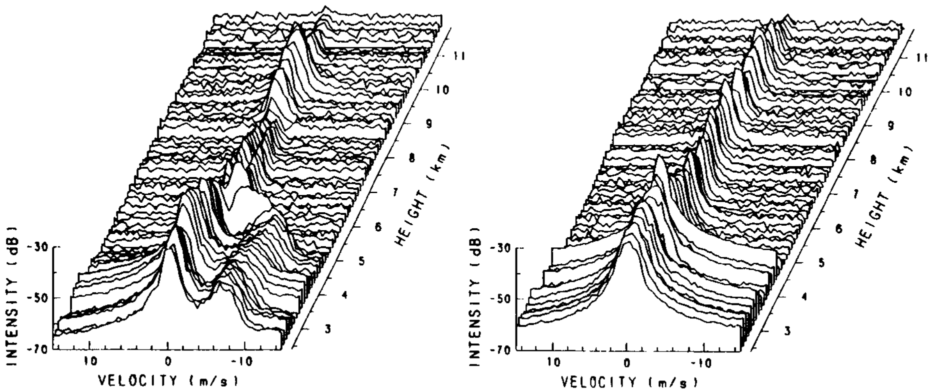

Figure 1. Doppler spectra versus altitude obtained in the vertical direction. The observational periods are (a) 0845-0851 LT and (b) 0750-0756 LT on 22 August 1984. The power is in decibels with an arbitrary reference level. Downward motions are positive in this figure.

RADAR OBSERVATION OF A COLD FRONT

The three-dimensional motions of both air and precipitation particles can be deduced when two off-vertical beams are used in addition to the vertical one. Therefore, a modified VAD technique is used for the present observations (WAKASUGI et al., 1985a).

The observations were made on 19-20 June 1984, during a period of a cold front moving southeastward. Figure 1 shows the horizontal radar reflectivity patterns observed with the Miyama microwave radar (5260 MHz). Several rainbands, which moved with the front, were several tens kilometers wide. These rainbands can be attributed to wide cold-frontal rainbands as described by HOBBS et al. (1980).

Figure 3 shows a time-altitude section of airflow perpendicular to the front. The horizontal component is the relative speed of the front which is assumed to move, on average, at a speed of 5.5 ms^{-1} toward 150° azimuth (see Figure 2). For the vertical component, the figure shows that upward motions are predominant during most of the observation. A relatively strong updraft is observed around 17, 21 LT on June 19 before the frontal passage. A deep strong updraft, associated with the leading edge of the cold front, begins at 03 LT on June 20 at the lowest level of data. The lifted air then ascends and reaches above an altitude of 10 km at 05 LT. Upward velocities in the region are 2.0

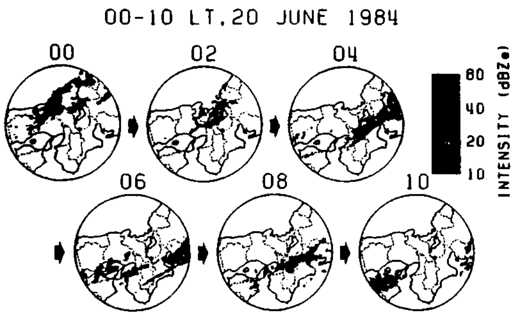

Figure 2. Radar reflectivity patterns with the Miyama radar. The dot is the location of the MU radar at Shigaraki. The circle diameter is 400 km.

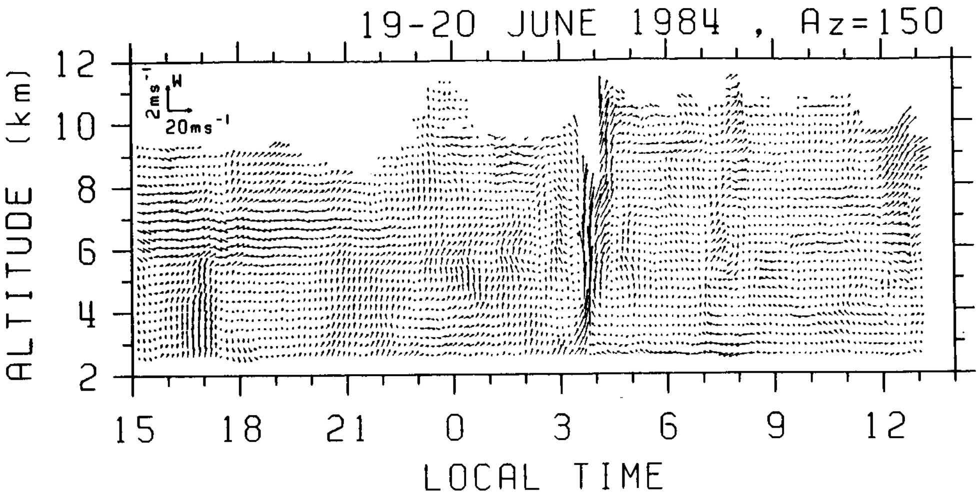

Figure 3. Vertical and transverse airflow relative to a cold front. Time resolution is ten minutes. The vertical and horizontal speed scales are indicated in the upper right-hand corner.

ms^{-1}. For the horizontal component, the figure shows that air flows into the cold front region at low levels both from ahead and behind the front.

DROP SIZE ESTIMATION FROM DOPPLER SPECTRA

Measurements of the size distribution of precipitation are important in studies of the growth of precipitation and cloud modeling. In this section, we will show a direct method in deriving parameters of N(D) from the VHF Doppler radar spectra (WAKASUGI et al., 1985b).

In the presence of the mean (up- or downdraft) velocity w, the Doppler spectrum S_o can then be written as $S_o(V) = P_1S_1(v-w)*S_2(v) + P_2S_2(v-w)$ where upward speeds are positive. P_1 and P_2 are the echo powers associated with precipitation and refractive index irregularities. The asterisk denotes the convolution operation between S_1 and S_2. We have assumed that S_1 is of Gaussian form, and S_2 of exponential drop size distribution with parameter N_o and Λ.

Figure 4 shows examples of the 10-min average Doppler spectra obtained with the vertical beam during the frontal passage. Although the exponential function well approximates the size distributions during the observation, least squares fit errors sometimes decrease when a truncated N(D) was used. Figure 4 also shows the temporal variations of the estimated parameters N_o, Λ and the liquid water content M. Temporal variations are characterized by a sudden decrease of N_o and Λ with the passage of the front at 0400 LT. This corresponds to narrow size distribution of particles changing into much broader distribution. However, the Doppler spectra of the precipitation before the passage is wider than that observed after the passage. This is attributed to the broadening due to turbulence and confirms that the information of spectral broadening of the air component is essential to estimate precipitation particle parameters accurately (HAUSER and AMAYENC, 1981).

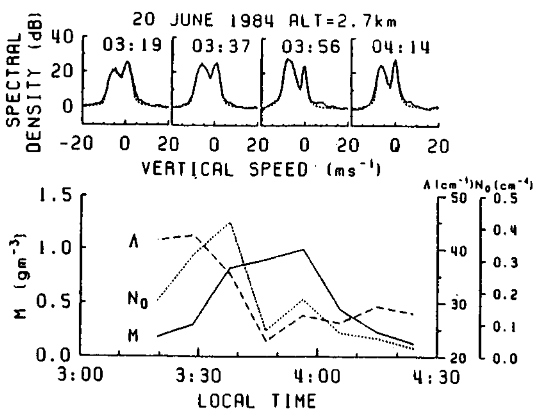

Figure 4. Temporal variations of observed spectra and the estimated parameters N_o, Λ and M during the frontal passage. Upward motions are positive.

RADAR CALIBRATION USING PRECIPITATION ECHO

Finally, we will proceed to the calibration of radar sensitivity. A direct calibration of the MST-type radars is difficult because the large aperture antenna of MST radars can only be pointed to a limited number of directions near the zenith. For the present observation, we have used the radar reflectivity factor Z obtained by the Miyama meteorological radar to calibrate the MU radar sensitivity.

The MU radar reflectivity factor is first calculated with an unknown constant which is proportional to the sensitivity, and then, this constant is determined by equalizing the two reflectivity factors. This method can be used for the calibration of other MST radars especially when the microwave radar is reliably calibrated, and both radars illuminate the same precipitating volume. However, the resolution volume of the Miyama radar is about 500 times larger than that of the MU radar over Shigaraki. Therefore, we conclude that the accuracy is expected to within 5 decibels for our case. The MU radar reflectivity factor is also estimated from the signal-to-noise ratio of the precipitation component following the procedure proposed by VANZANDT et al.(1978). The estimates generally coincide with that of the Miyama radar.

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