PROCEEDINGS OF ISAP '92, SAPPORO, JAPAN

EVOLUTION OF RAINDROP SIZE DISTRIBUTION OBSERVED BY A VHF DOPPLER RADAR

Toru SATO, Mitsuru SATO, Hideaki CHOTOKU, and Iwane KIMURA
Department of Electrical Engineering II, Kyoto University
Sakyo-ku, Kyoto 606-01, Japan

Haruhiko ISHIDA and Toshio HARIMAYA
Department of Geophysics, Hokkaido University
Kita-10 Nishi-8, Kita-ku, Sapporo 060, Japan

1 Introduction

Evolution of the raindrop size distribution (DSD) during the falling process of the drops has recently been studied extensively via computer simulation[1, 2]. Observational evidence for such studies, however, has been limited to those obtained by a small number of aircraft measurements, because most of radars do not provide data with sufficient height resolution and/or accuracy in DSD.

VHF Doppler radars, which were originally developed for observations of clear-air turbulence echoes, have a large advantage in determining DSD, since they can directly determine the relative motion of rain drops to the background air[3]. We have developed an automated algorithm for deriving DSD from the data taken by the Kyoto University MU (Middle and Upper atmosphere) radar[4]. Although this analysis assumes an exponential distribution function, it fits most of the observed Doppler spectra fairly well.

On the other hand, DSD measured on the ground is usually much better represented by a gamma distribution[5]. In order to study the evolution process of the rain drops, we have extended the analysis procedure so that the observed Doppler spectrum can be fitted with a gamma distribution. Here we present the outline of the extended analysis technique and compare preliminary results of the analysis with the DSD measured on the ground.

2 Observation

The MU radar operates at 46.5 MHz with an active phased array antenna which consists of 475 Yagi antennas and the equivalent number of solidstate transmit/receive modules. Total peak output power is 1 MW. The antenna beam is switched between the vertical and the north, east, south and west directions with 10° zenith angle alternately from pulse to pulse at an inter-pulse period of 400 μsec. Observed height range is 1.8–10 km with a height resolution of 150 m. Doppler echo power spectra are computed for each range gate and averaged for 64 sec.

Here we analyze the data of a rain event lasted for about 10 hours on July 4, 1991, which is the most pronounced one during the Bai-U (rainy season) observation campaign carried out jointly by Kyoto University and Hokkaido University in June-July, 1991 at Shigaraki, Shiga prefecture, Japan.

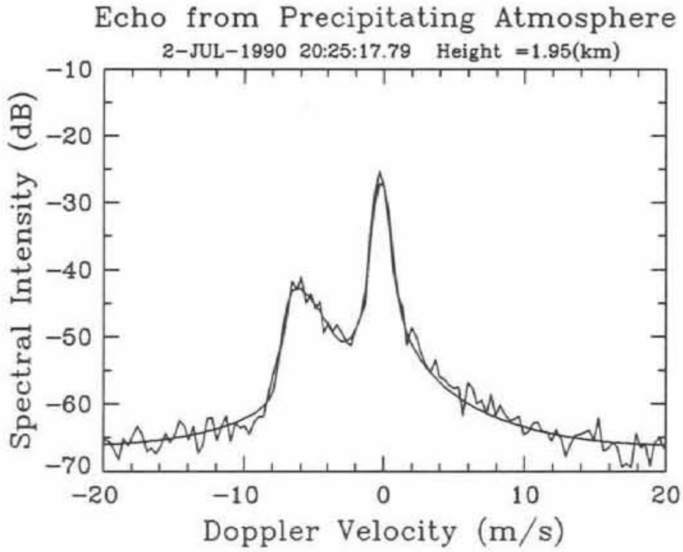

Fig. 1. Example of the Doppler echo power spectrum observed with the MU radar. The smooth curve shows the theoretically fitted spectrum.

3 Data Analysis

The unique feature of using a VHF Doppler radar is that the echo from precipitation has a comparable magnitude with that from the atmospheric turbulence[3]. It is thus possible to estimate the parameters governing the atmospheric motion, such as the mean wind velocity vector and the variance of the velocity fluctuations inside the scattering volume, simultaneously with the DSD parameters. Figure 1 shows an example of the echo power spectrum measured by the MU radar under precipitating condition.

The DSD function we use is expressed as

$$N(D) = \begin{cases} N(D) = N_0 D^{\mu} \exp(-\Lambda D) & (0 \leq D \leq D_{\max}) \\ 0 & (D_{\max} < D) \end{cases} , \tag{1}$$

where D (cm) is the diameter of raindrops, N_0 (cm^{-4}) is the number density of drops, μ and Λ (cm^{-1}) are the exponents of the DSD, and $D_{\max}$ (cm) is the maximum size of the drops.

The theoretical echo power spectrum is given as a function of the Doppler velocity v by

$$S(v) = P_0 S_0(v) + S_{\rm p}(v) * S_0(v) + P_{\rm n} , \tag{2}$$

where P_0 is the echo power of the turbulence component, $S_0(v) = \exp[(v - v_0)^2/2\sigma^2]$ is the wind velocity distribution determined by the mean line-of-sight velocity v_0 and the standard deviation σ, $S_{\rm p}(v)$ is the precipitation component computed from Eq. (1), and $P_{\rm n}$ is the background noise level. The convolution operation $*$ takes care of the distortion of the DSD due to random wind velocity fluctuations.

The theoretical spectrum expressed by Eq. (2) is then fitted to the observed spectra by adjusting these eight parameters using a nonlinear least-squares-fitting (NLLSQ) procedure[4]. The total wind velocity vector is computed from the line-of-sight velocity v_0 of different beam directions. Since it is not easy to find a good initial guess for μ that is needed in applying the NLLSQ procedure, a direct search method is employed for μ by changing its value at a step of 0.5, applying the NLLSQ using the remaining seven

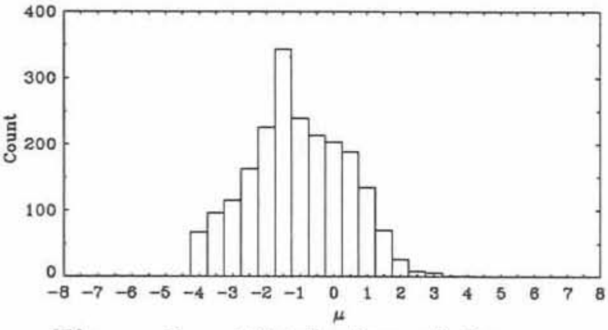

Fig. 2. Distribution of the μ observed by the MU radar at 1.8–4.2 km height.

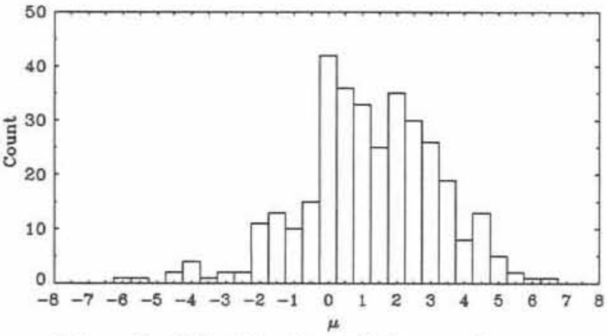

Fig. 3. Distribution of the μ observed on the ground.

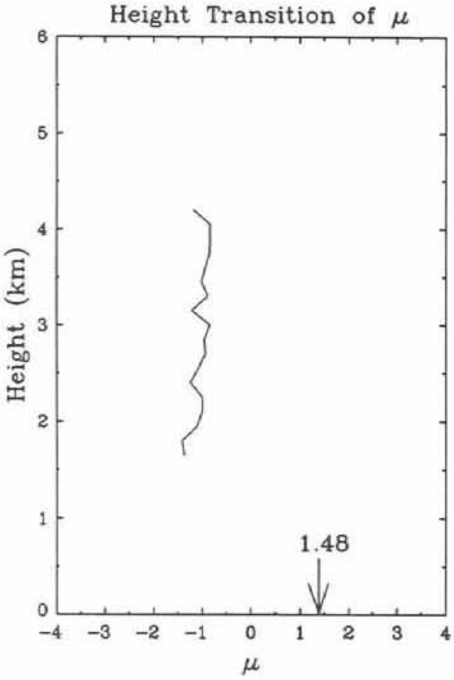

Fig. 4. Mean height profile of the μ observed by the MU radar. The arrow on the bottom of the figure shows the mean value on the ground.

parameters as variables for each value of μ. The smooth curve in Fig. 1 is the theoretical spectrum thus obtained.

4 Results

Figure 2 shows the distribution of the μ value thus derived from the MU radar data for 14:00–18:30 JST, July 4, 1991. In order to study the mean DSD under a steady condition, a few short periods in which convective activities were detected in the vertical wind velocity were removed from this data. The mean value of the μ is -1.03. The obtained distribution, although slightly dominated by negative values, suggests that the exponential DSD function ($\mu = 0$) employed in previous studies are not far from the observed DSD.

Figure 3 shows the corresponding distribution of μ observed by an optical spectrometer located on the ground at the MU radar site. The average value is 1.48. Apparently, most cases of observed DSD are represented by positive values of μ, which means that the number of larger drops decreases faster than the exponential distribution.

The mean height profile of the μ value is given in Figure 4. It is found that the profile tends to be more negative as the height decreases to the minimum observable height of 1.8 km. Since a negative μ value means that the DSD is dominated by small drops, this profile suggests the generation of rain at these height regions. The rainfall rate across each height calculated from the obtained DSD indeed shows the increasing rainfall rate as the height decreases.

The abrupt change from the negative μ value at 1.8 km height to a positive value at the ground is explained by an evolution of the DSD due to the effects of coalescence and breakup. Recent numerical simulations have shown that the DSD changes from an exponential distribution to an equilibrium state dominated by some diameter within 100–200 sec, which is the time raindrops take to fall from a height of about 1 km to the ground[1].

5 Conclusion

We have extended the analysis procedure of the precipitation data observed by a VHF Doppler radar so that it can deduce all of the parameters which determine the gamma distribution. Comparison of such analysis with the DSD observed on the ground showed a clear difference between the minimum height observed by the radar and the ground level. As demonstrated by the present results, this technique will serve as a powerful tool in studying the evolution process of the DSD.

References

[1] P. S. Brown, Reversals in evolving raindrop size distributions due to the effects of coalescence and breakup, *J. Atmos. Sci.*, Vol. 47, No. 6, pp.746–754, 1990.

[2] R. List and G. M. McFarquhar, The evolution of three-peak raindrop size distributions in one-dimensional shaft models. Part I: Single-pulse rain, *J. Atmos. Sci.*, Vol. 47, No. 24, pp.2996–3006, 1990.

[3] S. Fukao, K. Wakasugi, T. Sato, S. Morimoto, T. Tsuda, I. Hirota, I. Kimura and S. Kato, Direct measurement of air and precipitation particle motion by very high frequency Doppler radar, *Nature*, Vol. 316, No. 6030, pp. 712–714, 1985.

[4] T. Sato, H. Doji, H. Iwai, I. Kimura, S. Fukao, M. Yamamoto, T. Tsuda and S. Kato, Computer processing for deriving drop-size distributions and vertical air velocities from VHF Doppler radar spectra, *Radio Sci.*, Vol. 25, No. 5, pp. 961–973, 1990.

[5] T. Kozu, Estimation of raindrop size distribution from spaceborne radar measurement, Ph. D thesis, Kyoto University, 1991.