ESTIMATION OF VERTICAL PROFILES OF RAINDROP SIZE DISTRIBUTION USING VHF RADAR

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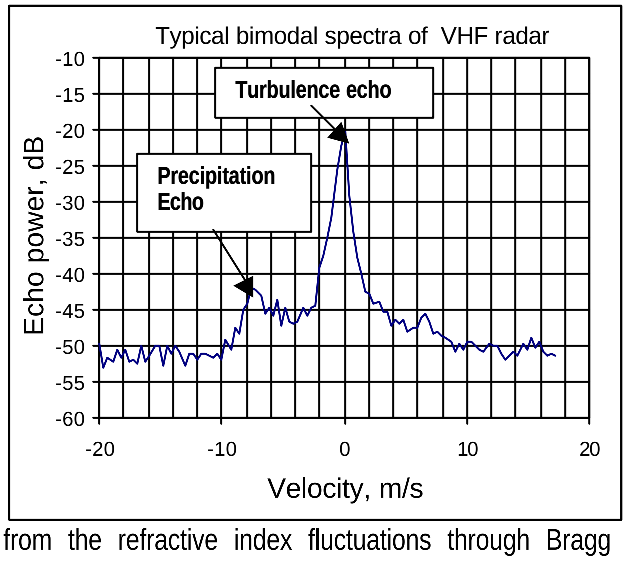
1. Introduction

In recent years, use of the (VHF/UHF) wind profiler technique for vertical profile of raindrop size distribution (DSD) measurements has proliferated. This is because, with the help of vertically pointing Doppler radar, one can directly determine the fall-velocity spectrum of the hydrometeors. If the velocity can be related to the size of the falling droplets, then the drop size distributions can be estimated using Doppler radar. Fukao et al., [1985] and Wakasugi et al. [1986] demonstrated that the VHF Doppler radars are capable of simultaneously detecting two distinct echoes, one from the clear-air turbulence and the other from hydrometeors. Sato et al. [1990] developed a computer algorithm to find the initial guess involved in the process of fitting a curve directly from the original spectra. We have also development of a non-linear least-squares algorithm to derive DSD from the radar data.

2. Experiment and Data-base

The instruments in Gadanki is rather unique; a 53-MHz VHF MST radar, an L-band Lower Atmospheric Wind Profiler (LAWP), a disdrometer, a Optical Rain Gauge (ORG) and a meteorological instruments are set up to obtain more knowledge on vertical properties of DSD and rain structure in south India. Data collected at Gadanki (13.5^{o}N, 79.2^{o}E), India using Indian MST radar (detailed system description of the Indian MST radar can be found in Rao et al. [1995]) and disdrometer are utilized for the first time in tropical India to estimate vertical profile of DSD parameters.

3. DSD estimation from VHF wind profiler



Wind profilers are recognized as a useful tool to estimate DSD aloft because they have a capability to measure both precipitation and atmospheric turbulence spectra simultaneously, which allows us to relax the DSD estimation error caused by the precipitation Doppler smearing caused by the turbulence. For moderate to heavy rainfall, VHF radar employed to obtain the “double peak” in Doppler spectra caused by the precipitation and turbulence echoes, allowing the estimation of those spectral parameters. Figures 1 depicts the Doppler spectra obtained with the vertical beam from a height of 3.9 km observed on 23 October 1997. The figure clearly shows the existence of two Spectral peaks in the Doppler spectra. The peak at the zero Doppler frequency shifts is coming from the refractive index fluctuations through Bragg scattering and the other peak in the positive side of the Doppler spectrum is coming from the hydrometeors through Rayleigh scattering. It can be used to obtain the information of vertical precipitation structures such as particle phase change and precipitation profile below 2 km or so where the VHF radar measurement is in a "blind" range.The model function of the turbulence and precipitation are described in the next section.

3. Gamma and Moment method for DSD Model

Gamma model given by Eq. 1 has been used most often.

$N(D) = N_o D^{\mu} \exp(-\Lambda D)$ (1)

Where D is the drop diameter. N_o, Λ, μ are the parameters of the gamma model.

Let W(v) be the window function in FFT, P_n be the noise power density, and "*" be the operator for the convolution, the model function of wind profiler precipitation spectrum is

$S(v) = [S_t(v) + S_p(v) * S_o(v) + P_n] * W(v)$ (2)

Where $S_t(v)$ is the atmospheric echo and $S_p(v)$ is the precipitation echo and $S_o(v)$ is the normalized gaussian atmospheric echo spectrum.Eq. (2) is an observation equation containing P_o, w, σ, P_n, No, Λ, μ as 7 unknown parameters which can be estimated from observed spectra. Note that μ can be treated as a fixed parameter without significant degradation in the estimation accuracy of rain parameters as we see later in this paper.

It not necessary to use (N_o, Λ, μ) as the parameter set. In general, it may be important to choose a parameter set in which the parameter elements are independent as much as possible. It should be noted that the precipitation Doppler spectrum is weighted with $D^6|dv(D)/dD|^{-1}$ and small raindrops would not contribute much to form the spectrum shape. Therefore, DSD parameters, which affect much to the DSD shape at larger raindrop regions, would be effective to improve the fitting performance. If we use (N_o, Λ, μ), Λ is relatively sensitive to the large drop region, and N_o to the small drop region. In order to study the relation between the choice of DSD parameters and the performance of the least-square fitting, we propose a different parameterization, which treats the moments of DSD as a DSD parameter. The xth moment, M_x, is expressed as

$M_x = N_o \Gamma(\mu + x + 1) / \Lambda^{(\mu + x + 1)}$ (3)

As we see from Eq. (3), by fixing μ and using M_x and M_y, DSD parameters (N_o, Λ) can be expressed by (M_x, M_y). There are several ways to express DSD using the moments, in this study, we keep Λ and use M_y as a parameter related to the magnitude of DSD. M_x is used to obtain Λ by combing this with M_y. Actual DSD expression is made by using the normalized moments, m_x and m_y,

$m_x = M_x/\Gamma(\mu+x+1), m_y = M_y/\Gamma(\mu+y+1)$ (4)

$N(D) = M_y \Lambda^{(\mu + y + 1)} D^{\mu} \exp(-\Lambda D)$ (5)

Where Λ is given by

$\Lambda = (m_x / m_y)^{1/(y - x)}$ (6)

Since the measurable rain echo spectra with the wind profiler are convolution of atmospheric and precipitation spectra. We need a deconvolution technique in which stabilization often becomes a problem. Thus, most algorithms for this purpose developed so far are parametric ones employing least-square fitting techniques that are generally robust to errors in both measurement and model assumption. Since the least-square problem for this purpose is generally a non-linear one, we need an iteration technique to solve the problem, in which care must be taken to possible divergence and "wrong" convergence. To evaluate the performance of such a technique, we also consider the goodness of fitting of DSD. For radar rainfall measurement, however, the accuracy of estimating "moments" of DSD is more important than that of DSD itself. In addition, the parameterization of DSD that has not been re-examined well may be important to improve the performance of the DSD estimation technique. However, in this presentation we derived the vertical profiles of DSD using Indian MST Radar for the stratiform precipitation observed on 23 October 1997.

4. Estimation of Vertical Profiles of DSD from MST radar Doppler Spectra

To obtain quantitative information from the Doppler radars, absolute calibration is essential. This could be achieved by comparing the precipitation echo power with Z-factors obtained from the disdrometer data. On October

23, 1997 VHF radar echo power (normalized at 1-km range) due precipitation can be related well with the Z-factor of disdrometer and a correction factor of 45 dB was determined.

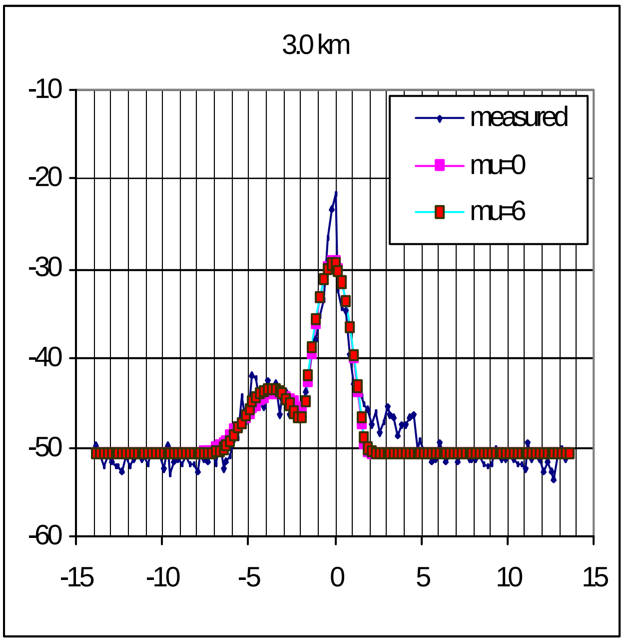


Fig.2 :VHF radar measured and fitted for m =0 & 6

In this presentation, we utilized VHF radar precipitation data collected at Gadanki, India to estimate vertical profile of DSD parameters. The parametric "moments" method is also utilized for retrieving the DSD parameters from VHF profiler data obtained on 23 October 1997. Figure 2 shows an typical an example of the MST radar spectrum fitting with the assumption μ =0 and μ = 6. From the figure it can be noticed that the fitted and measured spectra for precipitation is reasonable good compared with the turbulence. The systematic difference of 10 – 20 dB in turbulence may be due to the non-gaussain targets in the vertical incidence. Figure 3 shows the DSD estimated from VHF radar and disdrometer on 23 October 1997. From the figure it can be observed that the DSD estimates show fairly good agreement with the theoretical values. The agreement between the two instruments is good. The observational results are agreeing with the theoretical values.

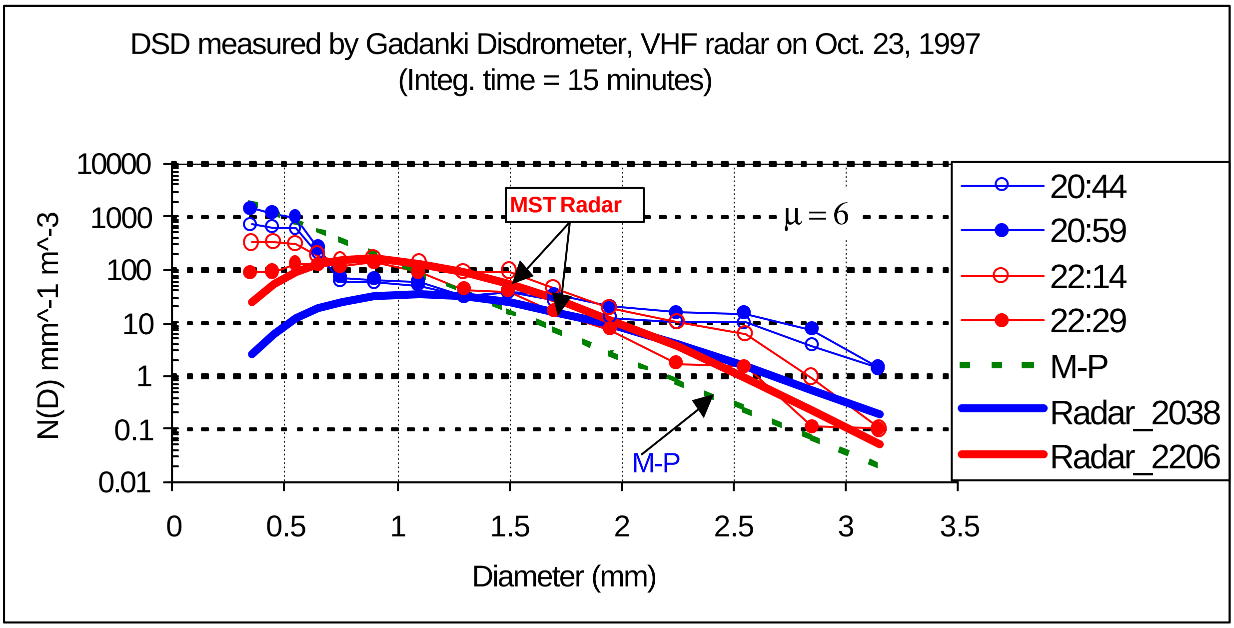


Fig.3: Comparison of DSD measured by the Indian MST radar and ground-based disdrometer.

Figure 4 shows the time series of the dBZ and dBR measured from disdrometer and estimated from VHF radar on 23 October 1997. The MST radar estimated vertical profiles of the DSDs show good agreement with Marshall-Palmer distribution and derived from the ground based disdrometer.

5. Results

In order to study the evolution process of the raindrops in the atmosphere we have developed an algorithm based on Non-linear least squares fitting method. Stabilized Gauss-Newton method is used to obtain the solution to the non-linear least squared problem. The parametric “moments” method is also utilized for retrieving the DSD parameters from VHF profiler. The observed DSD parameters show good agreement with the theoretical values. However, to test the accuracy of the algorithm we need to test more VHF radar precipitation data during different weather conditions. This study will be completed soon. VHF radar Data collected on 23 October 1997 is used for the first time to estimate vertical DSD parameters. However, we are planning to classify the precipitation storms using VHF radar and disdrometer data.

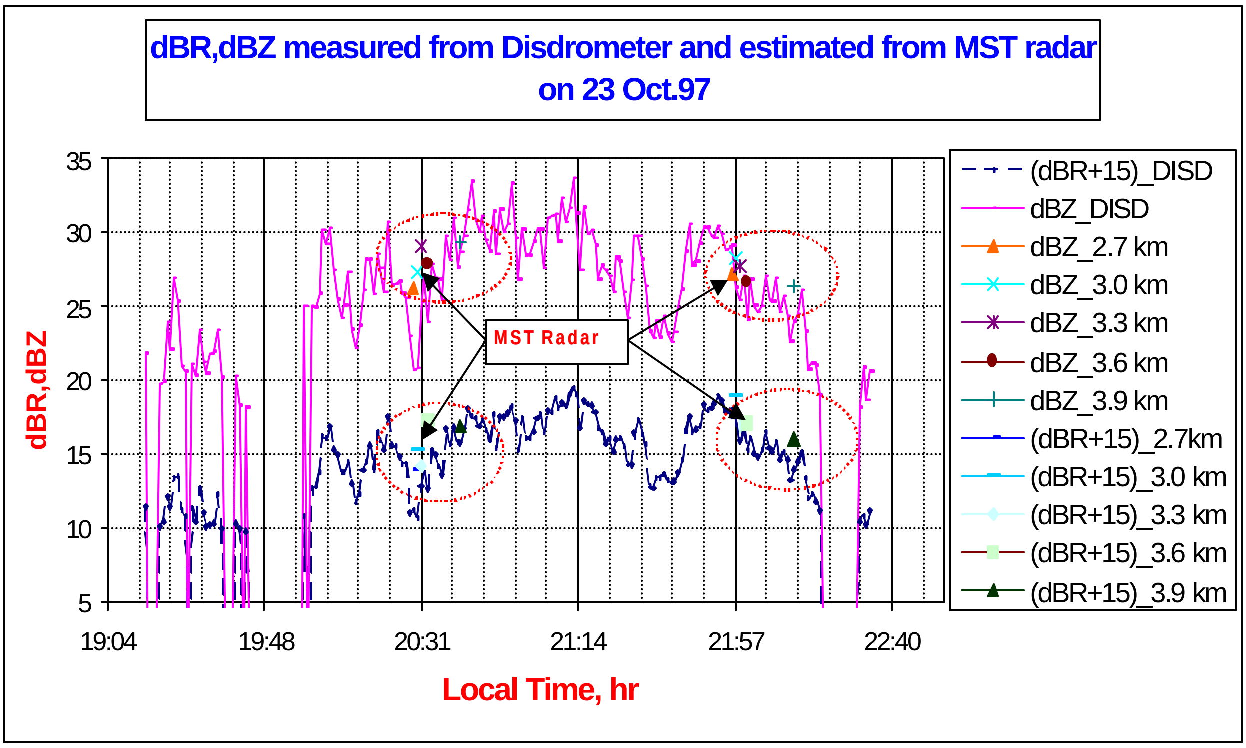


Fig. 4: Time series of the dBZ and dBR measured from Disdrometer and estimated from VHF radar on 23 October 1997.

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References

Battan, L.J. Radar Observation of the Atmosphere, 324 pp., University of Chicago Press, Chicago, 1973.

Fukao, S., K.Wakasugi, T.Sato, S.Morimoto, T.Tsuda, I.Hirota, I.Kimura and S.Kato, Direct measurement of air and precipitation particle motion by VHF Doppler radar, Nature, **316**, 712-714, 1985.

Gunn, R., and G.D.Kinzer, The terminal velocity of fall for water droplets in stagnant air, J. Meteorol. **6**, 243-248, 1949.

Kozu, T., Estimation of raindrop size distribution from spaceborne radar measurement, Dr.Eng. disseration submitted to Kyoto University, 1991

Marshall, J.S., and W.M.Palmer, The distribution of raindrops with size, J.Meteorol., **5**, 165-166, 1948.

Rao, P.B., A.R. Jain, P. Kishore, P. Balamuralidhar, S.H. Damle, and G. Viswanathan, Indian MST radar 1: System description and sample vector wind measurements in ST mode, *Radio Sci., 30*, 1125-1138, 1995.

Sato,T., 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., **25**, 961-973, 1990.

Wakasugi, K., A.Mizutani, M.Matsuo, S.Fukao, and S.Kato, A direct method for deriving drop-size distribution and vertical air velocities from VHF Doppler radar spectra, J. Atmos. Oceanic Technol., **3**, 623-629, 1986.