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The Rainfall Measurement using Dual-polarization Doppler Weather Radar

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Abstract. In order to play a part in evaluation and manage of water resource for weather radar, the quantitative rainfall measurement of dual polarization doppler weather radar is developed. And based on the observed values of ombrometer, the differences of the measured values derived from different methods are analysed. The results show: The rainfall using K_{DP} to calculate, i.e. $R(K_{DP})$ method, is proximal to the data of ombrometer; $R(Z_H)$ and $R(Z_H, Z_{DR})$ method is underestimate rainfall obviously; $R(Z_{DR}, K_{DP})$ method is overestimate rainfall. With further analysis, rainfall measured by dual-polarization radar, especially from $R(K_{DP})$ method, has higher precision, and provide the spatial distribution of the rainfall and the position of strong center well.

Introduction

The quantitative measurement of rainfall is always important development direction for the weather radar. And the doppler weather radar network has performed a significant role in the flood monitoring and forecasting. But when the precipitation is quantitatively measured using the reflectivity factor (Z) by the conventional doppler weather radar, it is apparent that the Z-R relations changed as the raindrop size distribution (RSD) and has poor universality and stability, and is in low accuracy because of assuming the raindrops are spherical and ignoring the influence of real nonspherical raindrops. Dual polarization doppler weather radar can provide the polarization parameters, and improve the precision of quantitative measurement of precipitation by obtained more precipitation information, and this has proved by theory and practice [1]. America is updating WSR-88D radar network using dual polarization technology, and China is stepping up the research [1-3].

Here using the data of the dual polarization doppler weather radar which working at S band, and the comparison with the ombrometer is made and the precision of the estimated rainfall is analysed.

The quantitative Rainfall measurement

Based on the work of Ulbrich et al. , the Gamma distribution of raindrop size of the nonspherical particles can be given as [4]

$$N(D_e) = N_0 D_e^{\mu} \exp\left[-(3.67+\mu)D_e / D_0\right] \tag{1}$$

Where N_0 is concentration parameter, μ is the shape parameter, D_e is equivalent diameter and D_0 is the median volume diameter.

Consider the Rayleigh scattering of the nonspherical particles, and the subscript ***H*** and ***V*** is used to identify the horizontal polarization and vertical polarization states, the reflectivity factors can be written as

$$Z_{H,V} = \frac{\lambda^4}{\pi^5 |U|^2} \int_0^{D_{e\max}} \sigma_{H,V}(D_e) N(D_e) dD_e \tag{2}$$

Where $N(D_e)dD_e$ is the concentration of the drops in the size interval D_e to $D_e + dD_e$, $\sigma_{H,V}$ is the backscattering cross section under horizontal or vertical ploarization, $|U|^2$ is determined by the negative refraction index of the raindrops, and $D_{e\max}$ is the maximum equivalent diameter.

Substituting Eq. (1) into Eq. (2) , $Z_{H,V}$ becomes

$$Z_{H,V} = \frac{\lambda^4 N_0}{\pi^5 |U|^2} \int_0^{D_{e\max}} \sigma_{H,V}(D_e) D_e^{\mu} e^{-(3.67+\mu)D_e/D_0} dD_e \tag{3}$$

From Eq. (3), we find that Z_H/N_0 is the function of D_0. The differential reflectivity Z_{DR} can be expressed as $Z_{DR}=Z_H/Z_V$ [5], thus Z_{DR} also is the function of D_0. And D_0 can be previously estimated using Z_{DR}, then it can compute N_0 with Z_H, and this way, we can set up the relational expression of Z_{DR} and Z_H with raindrop size distribution.

In the other hand, to dual polarization radar working in S-band, based on the definition of specific differential phase K_{DP} and relationship between the forward scattered value and D_e [5,6], we can give

$$K_{DP} = \frac{8.1\lambda}{\pi} \mathrm{Re} \int D_e^{4.5} N(D_e) dD_e \tag{4}$$

From Eq. (4), we can use raindrop size distribution to express Z_H, Z_{DR} and K_{DP}. Based the relation between rainfall rate and raindrop size distribution, the formulas of rainfall rate with dual polarization parameters can be set up. Here a group of formulas from Joint Polarization Experiment are shown as follows [7]

$$Z_H = 300R^{1.4} \tag{5}$$

$$R(Z_H, Z_{DR}) = 1.42 \times 10^{-2} Z_H^{0.77} Z_{DR}^{-1.67} \tag{6}$$

$$R(K_{DP}) = 45.3 K_{DP}^{0.786} \tag{7}$$

$$R(Z_{DR}, K_{DP}) = 136 K_{DP}^{0.968} Z_{DR}^{-2.86} \tag{8}$$

Where rainfall rate R is in units of mm/h, Z_H is in mm^6/m^3, and K_{DP} is in deg/km.

In these formulas of computed rainfall, it is believed that $R(Z)$ has lower precision, because it only uses the reflectivity factor Z to quantitatively measure rainfall, and is much influenced by raindrop size distribution, and results in that rainfall is overestimated in light rain and is underestimated in heavy rain [8]; $R(Z_H, Z_{DR})$ can improve precision, because it use two parameters, the reflectivity factor Z_H and difference reflectivity factor Z_{DR} [9]; $R(Z_{DR}, K_{DP})$ combined the difference reflectivity factor Z_{DR} with specific differential phase K_{DP}, and can adapt the change of the raindrop size distribution well; $R(K_{DP})$ has higher precision, especially in heavy rain, because specific differential phase K_{DP} isn't sensitive to the change of the raindrop size distribution [10].

Results analysis

On July 6th~7th 2009, Jiangshu was influenced by the warm and humid air and the cold air jointly, and heavy rain hit most parts of it, and there was rainstorm along the Yangtze river and North Jiangsu area. Nine countys had reached a level of rainstorm (95mm maximum) during July 6th 5:00 to 7th 5:00. Jiangshu automatic meteorological stations had statistics: rainfall of more than 100mm in 12 stations; rainfall of more than 50mm in 99 stations; and the highest rainfall reached 127.5mm. Heavy rain continued until 11:00 in Nanjing, and dumped more than 50mm of rain, partial more than 100mm of rain.

Here have selected raining regions in three time intervals between 9 a.m. and 10 a.m. on 7th July 2009 in the rainfall process. Two square areas as seen in Fig. 1 are selected as the research region. Based on the observed value of ombrometer, rainfall is computed by radar data of the selected region in accordance with Eq. (5)-(8), and the results are analysed.

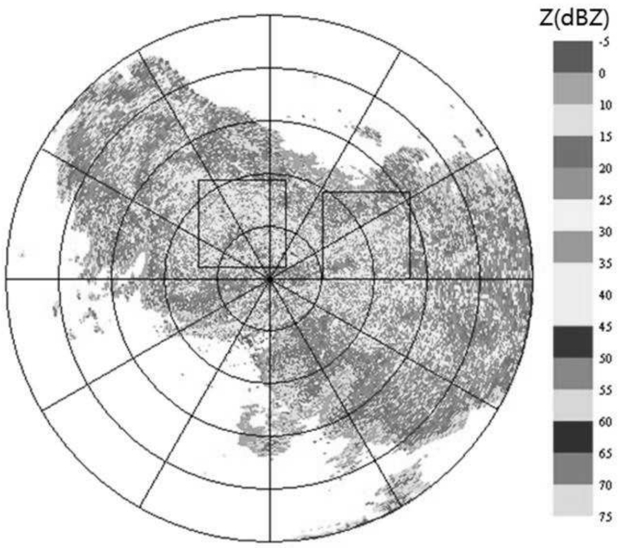


Fig. 1 Radar echo and research region

Scatter diagram of rainfall. In order to directly comparing different computing methods, the scatter diagrams between the results of different methods and the observed value of ombrometer are given as shown in Fig. 2. In the figure, the abscissa represents the observed values of ombrometer, the ordinate represents the computed values of different methods, and all units are mm. Maximum scales of two coordinates are same. There is diagonal of 45° in the figure, and that the computed value is in the diagonal indicates that it is the same as the observed value of ombrometer.

From Fig. 2(a) and 2(b), we can get that most of the samples computed by $R(Z)$, $R(Z_H, Z_{DR})$ spread under the diagonal, and further from the diagonal. The results of the two methods are greatly lower than that of ombrometer, and rainfall is much underestimated. Fig. 2(d) indicates that almost all of the samples by $R(Z_{DR}, K_{DP})$ spread above the diagonal, and are much higher than that of ombrometer, and rainfall is vastly overestimated. Only the samples from $R(K_{DP})$ plotted in Fig. 2(c) distribute relative balance, that is to say, the result of $R(K_{DP})$ is the best among the four methods.

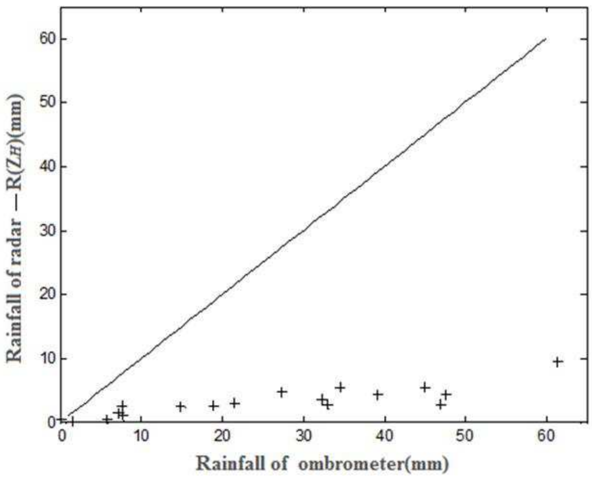
It can also be seen from Figure 2(c) that when rainfall of ombrometer is less than 10mm, there are more samples from $R(K_{DP})$ distributing above the diagonal, and having bigger deviation; but otherwise, the samples from $R(K_{DP})$ distribute on the sides of the diagonal, and the result improves apparently.

Error of different methods. In order to know the performance of different methods, bias(B), standard deviation (SD) and root-mean-square error(RMSE) between the results of different methods and the observed values of ombrometer are computed respectively. Standard deviation indicates the dispersion of every data deviated from mean value. RMSE indicates the dispersion of all samples. Table 1 shows the error between the computed results of different methods and the observed value of ombrometer.

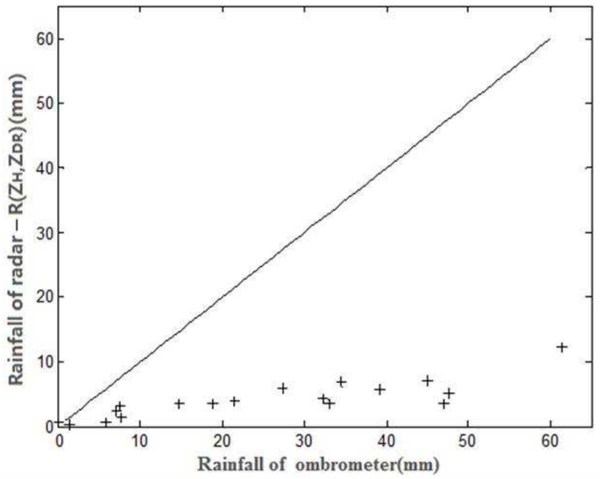
Table1 Error of different computed methods

Methods	B[mm]	SD[mm]	RMSE[mm]
$R(Z_H)$	-13.42	11.92	17.95
$R(Z_H, Z_{DR})$	-13.07	11.68	17.53
$R(K_{DP})$	3.18	8.84	9.40
$R(Z_{DR}, K_{DP})$	26.95	20.20	33.68

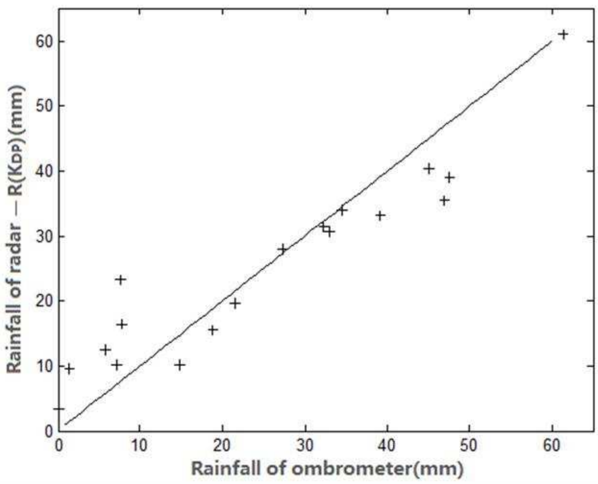
From Table 1, among the four methods, $R(K_{DP})$ has the least value of bias, standard deviation and root-mean-square error, and its precision is the best. The biases of $R(Z_H)$ and $R(Z_H,Z_{DR})$ are more than -13mm, and the rainfall is much underestimated. The mean error of $R(Z_{DR},K_{DP})$ reaches up to 27mm, and the rainfall is much overestimated.



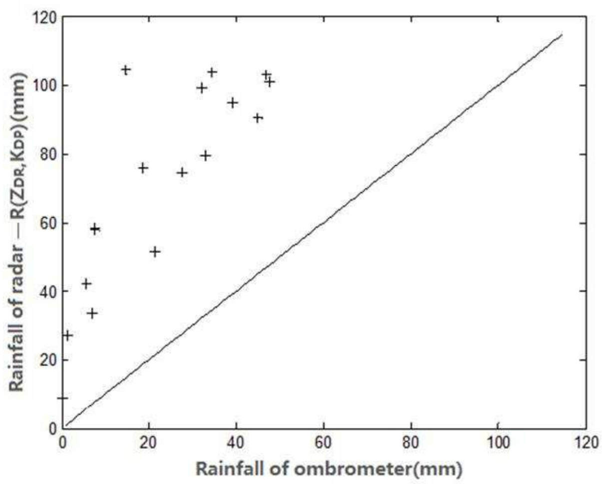
(a) $R(Z_H)$



(b) $R(Z_H, Z_{DR})$



(c) $R(K_{DP})$



(d) $R(Z_{DR}, K_{DP})$

Fig. 2 Radar echoes and research region

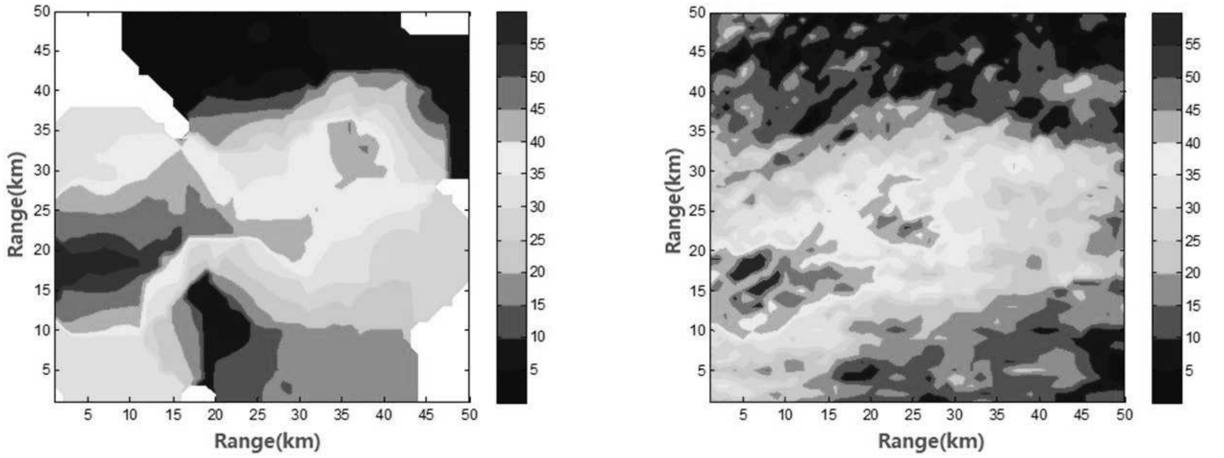
Based on Fig. 2, all samples are partitioned according to ≤10mm and >10mm. Only $R(K_{DP})$ is used to computed rainfall and the bias, standard deviation and root-mean-square error of rainfall between radar and ombrometer. Table 2 gives the results of partition statistics. From the table, $R(K_{DP})$ has higher precision when the rainfall is greater than 10mm. Thus it is beneficial to classify the rainfall for using suitable computed method to provide more precise data.

Table 2 Error of partition statistics

I[mm]	B[mm]	SD[mm]	RMSE[mm]
I≤10	9.00	9.19	12.86
I >10	0.66	6.14	6.17

Comparison of Region distribution. The measured values of radar have been analysed from the view of single sample earlier. Yet in order to judge the rationality of region rainfall distribution, the region rainfall distribution computed by $R(K_{DP})$ is compared with the interpolation rainfall distribution of ombrometer. The result is given in Fig. 3. The abscissa and ordinate represent two side of the square region respectively in the figure, and square region size is 50km×50km.

Rainfall profile of ombrometer distributes discontinuously in local region. Ombrometer is inadequate and its distribution is nonuniform, and part region appear date lack. It can be seen from Fig. 3 that strong center of ombrometer is in accordance with that of radar in the rainfall chart.



(a) Rainfall of ombrometer (b) Rainfall of radar

Fig. 3 Comparison of region distribution

Summary

Rainfall measured by dual-polarization radar has provided the spatial distribution of the rainfall and the position of strong center well. Among the four methods for calculated rainfall, $R(K_{DP})$ has the best precision, and its effect is better when rainfall is greater than 10mm.

To measure region rainfall using the dual-polarization radar can improve efficiency and accuracy to estimate hydrometry of reservoir area and is in favor of developing water resource allocate and the disaster prevention and mitigation.

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