A Preliminary Study on Detection Accuracy of Solid-State Weather Radar

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Abstract: Solid-state transmitters are always used in miniaturized weather radars because of their high reliability and maintainability. This paper has finished some preliminary research about the detection accuracy of solid-state weather radar. Reflectivity data from Doppler weather radar, which is considered very accurate, is used as the criterion for evaluating solid-state's data quality. Comparison and statistics show that the observations of solid-state radar are consistent with the Doppler weather radar, especially in heavy rainfall. Results from the analysis indicate that solid-state weather radar has high detection accuracy in practical application.

1 INTRODUCTION

Weather radar plays a key role in modern meteorological observations, especially in severe weather monitoring and early warning. In recent years, many domestic and foreign scholars have made a lot of analysis on Doppler weather radar's detection data which has been proved to have higher forecast accuracy on small-scale severe weather than other detection means (Doviak, 1993; Whiton, 1998; Douglas et al, 2007; Jameson, 2010; CONG Fang and LIU Liping, 2011; DONG Gaohong and LIU liping, 2012). However, the new generation weather radar of China mainly uses a klystron or other high power microwave vacuum tube as the transmitter, which has a huge volume and restricted lifetime. With the improvement in microwave semiconductor power devices, conventional radar transmitters will be gradually replaced by solid-state transmitters. Solid-state transmitters have many notable advantages, including longer life, higher reliability, smaller size and weight, and lower cost (Masakazu Wada et al, 2010). All these advantages explain the extensive use of solid-state transmitters in airborne, vehicle-mounted and other mobile weather radars, and have become the development direction of ground-based weather radar. (Fumihiko Mizutani, 2008). For the peak power of solid-state transmitters is limited, we generally transmit long pulses to get a higher average power. The higher average power can guarantee a greater detection distance and increased sensitivity; pulse compression processing at the receiving end can improve range resolution (Mudukutore and Chandrasekar, 1998; OHora and Bech, 2005; Fritz OHora, 2007; Hoon Lee, 2011). The weighting method is put forward to suppress the range side-lobes that generated by compressed Linear Frequency Modulated (LFM) signals(Keeler et al, 1995; Cho, 2006), and combined-pulses transmission mode can solve the close-range blind zone problem that caused by long pulses.

This paper conducts preliminary research with regard to the detection accuracy of solid-state weather radar. It takes Doppler weather radar's detection data as the criterion and carries out a series of studies to evaluate the data quality and usability of solid-state weather radar.

2 COMBINED-PULSES TRANSMISSION MODE

Under the condition of low peak-power transmission, solid-state weather radar attains improved detection capability by lengthening the pulse duration (GU Zhiqiang et al, 2001; HE Jianxin et al, 2003). But transmitting long pulses will expand the close-range blind zone (Given a pulse width of 100μs, the blind zone of solid-state weather radar would exceed 15km), which is urgent to be addressed in the practical application.

The transmission mode of combined-pulses was implemented by sending short pulses and long pulses successively a specific order (HE Jianxin et al, 2013). The data from short pulse returns fills the close-range blind zone, which was imposed by using long pulses. Distant targets can still be obtained using the long pulse echoes. Parameters of the new transmission mode are shown as follows: τ_S, τ_L for different pulse lengths, PRT_S, PRT_L for the pulse repetition time in the corresponding pulse durations, N_S, N_L, for the coherent integration times of each given-length pulse, and schematic diagram is Fig. 1.

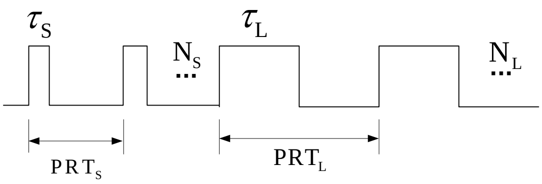

Fig. 1 Combined-pulses transmission mode in diagram

Where $\tau_S<\tau_L$, $PRT_S \le PRT_L$. Optimizing parameters produce significant improvement in the performance of the weather radar (HOU Xiaolin et al, 2012).

3 FIELD EXPERIMENT

Taking Doppler radar as criterion, a comparison experiment is designed to test the data accuracy of solid-state radar. The X-band solid-state weather radar and X-band Doppler weather radar are located on the rooftop of the same building with a distance of 53m apart and a height difference of 2m. The parameters of two weather radars are listed in Tab. 1:

Tab. 1 the experimental parameters of two weather radars

Parameter	X-band solid-state weather radar	X-band Doppler weather radar
Wavelength (cm)	3.1819	3.2
Antenna gain (dB)	39	44
Transmission power (kW)	0.05	75
Sensitivity (dBm)	-107	-110
Bandwidth (MHz)	2.0	1.5
Pulse length(μs)	10+100	0.833
Antenna beamwidth (°)	1.5	1.0
Pulse repetition frequency (Hz)	(600，2500)	(300，1500)
Range resolution(m)	75	125

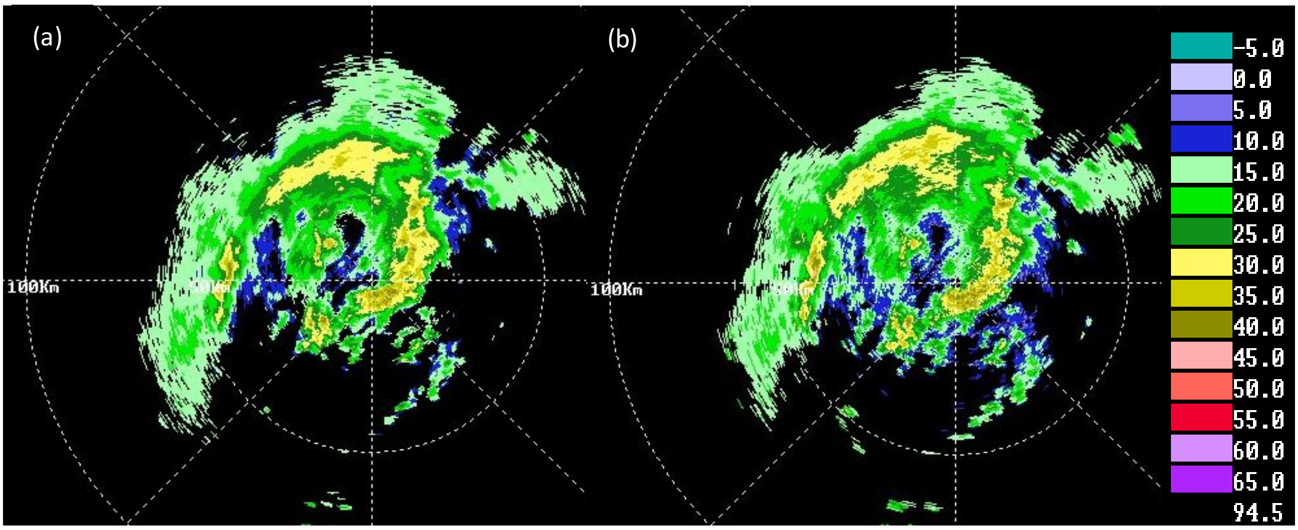

Fig. 2 The comparison of echo intensity in heavy precipitation at 16:59 BT 4 July 2013

(a) Solid-State Weather Radar (b) Doppler Weather Radar

Fig. 2 offers a comparison of Plan Position Indicator (PPI) images obtained from two weather radars in the same heavy rainfall process. The two PPI images were

collected 1 min apart so changes in the rain field should be minimal. As seen in Fig. 2, the echo from solid-state radar has similar shape and size to Doppler radar after unified the different range resolution of two radars to 375m. Solid-state weather radar coupled with combined-pulses transmission mode, help reduce the close-range blind zone and achieve complete information in distance.

However, the comparison of PPI images simply presents the two weather radars have similar detection capability. At the same time, it's necessary to develop qualitative analysis of echo data to investigate the detection accuracy of solid-state radar.

4 COMPARISON AND ANALYSIS

The detection data of Doppler weather radar, which is proved comparatively accuracy in precipitation monitoring, will be used as the criterion for evaluating the data accuracy of solid-state weather radar (YANG Jinhong et al, 2008; SHI Rui et al, 2010; HU Mingbao et al, 2012).

4.1 Comparison of echo area

Overlapping the PPI images of Fig. 2 (a) and (b) can compare the echo size of two weather radars. In Fig. 3, red indicates that the difference between two radars' reflectivity intensity does not exceed 5dBz, and blue indicates the difference exceeds 5dBz or only one radar gets the effective data. As shown, two radars' echo area is basically the same, but the different detection sensitivity makes Doppler radar obtained more weak targets than solid-state radar in the echo edge.

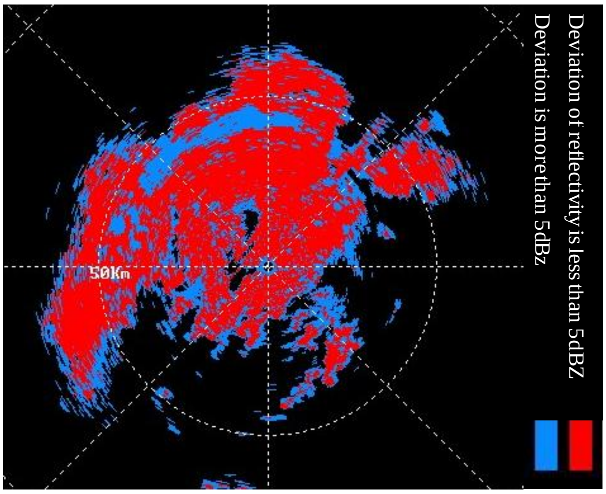

Fig. 3 Comparison of echo area

Detection accuracy in Tab. 2 will refer to the ratio of the number of red points to the total number of two radars' detection points. As presented in Tab. 2, the values of reflectivity factor are divided into several groups to discuss about the detection accuracy of solid-state weather radar.

Tab. 2 Statistics of detection accuracy from solid-state weather radar

Reflectivity factor /dBz	The number of red points (the deviation of two radars' reflectivity factor is less than 5dBz)	The total number of two radars' detection points	Rate of detection accuracy/%
0-10	28	905	3.01%
10-15	541	2670	20.26%
15-20	3689	6707	55.00%
20-30	6659	8135	81.86%
30-40	2707	2993	90.45%
40-50	128	136	94.12%

Statistics suggest that the detection accuracy of solid-state radar increases rapidly with the reflectivity factor increasing. When detecting the weak weather targets (the value of reflectivity factor is less than 15dBz), the solid-state radar presented poor detection accuracy. The table also explains the Fig. 3, that is, the echo area obtained from two weather radars has large overlap in the strong echo areas, and has detection deviation in weak target areas. The analysis of detection accuracy means that the data from solid-state weather radar has high reliability in the strong rain field.

4.2 The consistency and accuracy of detection data

Fig. 4 shows the scatter diagram of weather echo in the Fig. 2. The vertical axis represents the reflectivity factor of solid-state weather radar, while the horizontal axis represents the reflectivity factor of Doppler weather radar, and the red line indicates diagonal. Scatter diagram can intuitively reflect the data consistency of two radars. As shown in Fig. 4, a great number of scattered points distribute near the diagonal which means the two weather radars are in good agreement. With the echo intensity increasing, scattered points are more concentrated around the diagonal. But for the different transmitting mechanism, some deviations can be observed only in a small number of areas. In general, the values of reflectivity factor from two weather radars quite agree with each other, when comparing the detection data in the same precipitation process.

We choose the overlapping echo region for deviation analysis. Equation (1) and (2) calculate the mean and standard deviation of the disparity between two radars' reflectivity factor, where Z_1 and Z_2 are the reflectivity factor obtained from solid-state weather radar and Doppler weather radar respectively and n is the number of effective pixels in the overlapping region. Dz means the average value of the reflectivity factor deviation. σz represents the dispersion degree of deviation. In other words, the greater standard deviation leads to the less concentration of the difference (XIAO Yanjiao et al, 2007).

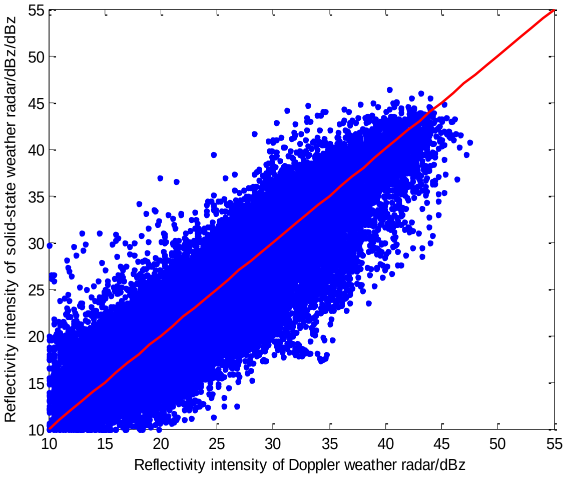

Fig. 4 Scatter diagram of reflectivity intensity

$$D_z = \frac{1}{n}\sum_{i=1}^{n}(Z_{1i} - Z_{2i}) \quad (1)$$

$$\sigma_z = \sqrt{\frac{1}{n-1}[\sum_{i=1}^{n}(Z_{1i} - Z_{2i})^2 - nD_z^{\ 2}]} \quad (2)$$

Tab. 3 shows the result of deviation analysis. With the value of echo intensity increasing, the standard deviation of two radars' reflectivity factor was found to reduce significantly. This indicates that the two radars detection data is closer in the region of strong echo.

Tab. 3 Deviation analysis

Ranges of reflectivity factor from two radars	>=10dBz	>=20dBz	>=30dBz	>=40dBz
Dz	0.3013	0.2795	-0.0807	0.4106
σz	3.6291	3.6144	3.0083	1.6724

The analysis results show that the data accuracy of solid-state radar is proportional to the echo intensity of weather targets. Data from solid-state weather radar agrees quite well with that detected by Doppler weather radar. That's to say solid-state weather radar does have high detection accuracy in heavy rain process.

5 CONCLUSION

Reflectivity data from Doppler weather radar is first used as the criterion for evaluating the detection accuracy of solid-state radar in adjacent position. The result of statistics and comparison indicates that the observations obtained from two weather radars are in good agreement when the heavy precipitation occurred. But limited time of tests is far from the requirement for assessing the radar system good or bad. It will take the analysis of massive data sets on different types of weather to draw this conclusion. This paper primarily proves that the detection data of solid-state weather radar is highly accurate and so lays the foundation for the detection performance evaluation in the next step. As the research of solid-state weather radar continues in meteorological field, it can be predicted the solid-state weather radar will be wildly applied for the severe weather monitoring and warning in the near future.

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