An Arithmetic to Enhance the Detecting Ability of Dual-polarization Weather Radar for Weak Echoes

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Abstract. Because the dual-polarization weather radar transmitted power in each polarimetric channel two times or 3 dB lower than in the “legacy” single polarization channel, which can cause the decrease of sensitivity. It means that the weakest signals just above the noise level are lost in the polarimetric system. Some important weather features in weak signal may become harder to identify with the polarimetric radar. In order to mitigate this systematic problem, this paper estimate the echo power based on coherent summation of two channel signals to enhance the detecting ability for dual-polarization weather radar. And also do some experiment by using IQ data of dual-polarization weather radar and analysis according to the coherent summation arithmetic. The result shows that using coherent summation arithmetic can enhance the detecting sensitivity by 3.77dB for dual-polarization weather radar and increase the detecting ability for weak echoes. In this way, the radar echoes can be more accurate and abundant.

1 Introduction

Currently, the dual-polarization Doppler weather radar use polarimetric configuration with simultaneous transmission and reception in domestic and international\textsuperscript{[1,2]}. This means the output of transmitter was divided into horizontal polarization and vertical polarization by power divider and polarization apparatus. Thus the power of each channel is 50\% of the whole power and the polarization echoes were processed simultaneous by two channel receivers. Compared with conventional Doppler weather radar, the ability of detecting cloud and precipitation is significantly improved. It also can improve the accuracy of radar observation precipitation intensity and the ability of identifying precipitation particles\textsuperscript{[3]}.

But compared to the ‘legacy’ single polarization weather radar, the echo power which received by two polarization channels reduce two times or 3dB. So it is difficult to find and confirm some important weather process in the weak echoes\textsuperscript{[4]}.

In fact, the weak echo is a broad concept\textsuperscript{[5]}. It can be indicated some echoes that radar does not detected for various reasons. This belongs to the weak echo in the narrow sense. It can also refer to those echoes detected by radar but have low SNR. This belongs to the weak echo in the broad sense such as drizzle or snow.

The main purpose to enhance dual-polarization weather radar’s detection capability is detecting those echoes which not detected before. Meanwhile it also trying to make the detected echoes more accurate. Therefore, this paper is to find a method to enhance dual-polarization weather radar’s detection capability. In this way, the dual-polarization weather radar will have a strong ability to detect more weak echoes and make the echo information more accurate and more abundant\textsuperscript{[6]}.
2 The principle about Coherent Summation of Signals algorithm

Echoes from clouds and precipitation have high correlation coefficients, such as $\rho_{hv}>0.95$. This condition justifies the coherent summation of signals [7] in the horizontal (H) and vertical (V) channels to increase the detection capability. The coherent sum of voltages $E_{sum}$ in the H and V channels is:

$$E_{sum} = e_h + e_v = s_h + n_h + s_v + n_v$$  \hspace{1cm} (1)

Where $s$ and $n$ are weather and noise voltages correspondingly in the channels marked with the superscripts. The mean power of the sum signal is:

$$P_{sum} = (e_h + e_v)(e_h^* + e_v^*) = S_h + S_v + \langle s_h s_v \rangle + \langle s_h n_v \rangle + \langle n_h s_v \rangle + \langle n_h n_v \rangle$$  \hspace{1cm} (2)

Where $S_h$ and $S_v$ are the powers of weather signal in the respective channels, the brackets define ensemble (or time) averages, the asterisk denotes complex conjugate, and we used the fact that the weather signal and noise voltages are zero mean and are uncorrelated. The latter equation can be written as:

$$P_{sum} = S_h + S_v + 2(S_h S_v)^{\frac{1}{2}}\rho_{hv}\cos(\phi_{dp}) + N_h + N_v$$  \hspace{1cm} (3)

$N_{h,v}$ are the noise powers in the H and V channels respectively and $\phi_{dp}$ is the differential phase, which is one of the measurable on the DP system. Due to high coherency between signals in H and V channels, we can set $\rho_{hv} = 1$. By digitally multiplying signal in H channel by $\exp(j\phi_{dp})$ before coherent summation, the SNR, for the coherently summed signal can be written as:

$$SNR_{sum} = \frac{S_h + S_v + 2(S_h S_v)^{\frac{1}{2}}}{N_h + N_v}$$  \hspace{1cm} (4)

For equal noise powers ($N_h = N_v = N$) and SNR in each channel defined in power units as $SNR_h = S_h/N_h, SNR_v = S_v/N_v$, $SNR_{sum}$ can be written in terms of the scatterer’s differential reflectivity.

If $Z_{dr} \approx 1$, then $SNR_{sum}$ can be written as [8]:

$$SNR_{sum} = \frac{1}{2} SNR_h \left( 1 + Z_{dr}^{\frac{1}{2}} \right)^2 \text{ or } SNR_{sum} = \frac{1}{2} SNR_v \left( 1 + Z_{dr}^{\frac{1}{2}} \right)^2$$  \hspace{1cm} (5)

In this situation, $SNR_{sum} \approx 2SNR_h \approx 2SNR_v$. As a result, the SNR of signal can be increased about 2 times, which is 3dB.
If $Z_{dr} < 1$, then $SNR_{sum} = \frac{1}{2} SNR \left( 1 + Z_{dr} \right)^2$. In this case, $SNR_{sum} < 2SNR_v$.

If $Z_{dr} > 1$, then $SNR_{sum} = \frac{1}{2} SNR \left( 1 + Z_{dr} \right)^2$. In this case, $SNR_{sum} < 2SNR_h$.

In summary, the algorithm about coherent summation of signals can improve the sensitivity degradation problems in some extent which caused by simultaneous transmission and reception system.

3 Experimental Analysis

The data in the experiment are all IQ data collected by X-band dual-polarization Doppler weather radar in 8:24 pm, May 11, 2014. At that time, there is a large range of layered precipitation, along with partial convective precipitation.

![Figure 1. The echoes power estimation comparison between traditional SNR method and coherent summation method. (a) echoes power image of traditional SNR method; (b) echoes power image of coherent summation method; (c) color code of echoes power.](image)

![Figure 2. (a) marking the blue for same data, white for increasing data and the purple for decreasing; (b) color code.](image)
Table 1. The comparison of sum echoes and weak echoes for the two methods.

<table>
<thead>
<tr>
<th></th>
<th>traditional SNR method</th>
<th>coherent summation method</th>
</tr>
</thead>
<tbody>
<tr>
<td>total echoes data</td>
<td>36691200</td>
<td>36691200</td>
</tr>
<tr>
<td>detected echoes data</td>
<td>417640</td>
<td>435334</td>
</tr>
<tr>
<td>detected weak echoes data</td>
<td>0</td>
<td>13795</td>
</tr>
</tbody>
</table>

Fig. 1 is the echo power map estimated by two methods. Display the extra part between the improved echo and the original echo in white color, the reduction in purple color, the same in blue color, as Fig. 2 (a) shows. Obviously, the echoes increase at the edge of the echo (white part), and the reduction also exists, the reduction maybe noise, which is mistaken as echo by SNR method, because the reduced points almost are stray and relatively isolated.

After statistic analysis of added point and reduced point in Fig. 2(a), it is clear relevant summation of more than SNR method to detect the echo 18448 points, reducing 754 points (points are mentioned in the text refers to the range bin). As can be seen from Table 1, weak echoes detected by SNR method is 0, but there are 13795 points detected by the coherent summation method. This illustrates the correlation summation method can enhance the dual-polarization weather radar’s ability to detect weak echoes.

![Graph](image)

Figure 3. (a) the detected echo points by two method variation with SNR; (b) the average of echoes power by two method variation with SNR; (c) the gain of SNR improvement variation with SNR.

As it can be seen from the point of Fig. 3 (a), when the SNR (0dB < SNR < 5dB) is low, there is a big difference between the two methods to detect the weak echoes. But when the SNR (SNR > 5dB) is strong even greater, the number of echoes detected by two methods is almost exactly the same.

In Fig. 3 (b), when echoes SNR greater than 5dB, the difference between the improving actual value and theoretical value of SNR maintained at about 0.41 dB; when the echoes SNR is less than 5 dB, the difference of the two value between 0.07 dB and 0.41 dB. Further analysis found that the difference is caused by the change of the noise power. That is coherent summation method in improving the echo power, at the same time it also has a certain improvement effect on noise power. Through the analysis of the above can be concluded that the coherent summation method can improve the dual-polarization radar detection sensitivity, enhance the capacity of radar detection for weak echoes, meanwhile the noise was suppressed.
4 Conclusions

Before the improvement of dual-polarization radar, undetected echo does exist. But the noise causes the echo intensity less than the noise determination threshold value, the echo is determined to be noise, and can not be showed on the reflection figure. After signal processing using the coherent summation method which is actually power calculating and noise suppression related processing, the small echo can be detected even below the noise threshold. Intuitively, the echo information on the echocardiogram is richer. Coherent summation method processes the signal of horizontal and vertical channels, making radar sensitivity improve 3.77dB. In this way, the radar can detect more weak echoes.

References


