APPLICATION OF A MONOPULSE ARRAY SYSTEM TO WEATHER OBSERVATIONS FOR DETECTING WIND SHEAR AT SUB-BEAMWIDTH RESOLUTION

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1. INTRODUCTION

Application of monopulse processing to weather radar has the potential to provide greater details on the circulation and shear of wind fields at sub-beamwidth resolutions, which are very important for, e.g., tornado detection.

For either the azimuthal or elevation plane, a monopulse system uses two identical beams, whose outputs are summed (even-mode) and subtracted (odd-mode). The antenna segments forming these beams are physically separated and the amplitude and phase of Doppler returns from these sub-apertures should show correlation. As a result, the radar reflectivity and Doppler velocity could be estimated at a sub-beamwidth resolution. The phased array radar of the National Weather Radar Testbed (NWRT) located at Norman, Oklahoma provides an ideal platform for implementing and evaluating the application of a monopulse system to weather observations

A sophisticated radar simulator developed at the University of Oklahoma (Cheong et al., 2007) is modified to emulate the monopulse antenna system at the NWRT, with one transmitted beam and four spatially separated, quadrant-receivers. The emulator incorporates randomly distributed scatters which are advected to the times of radar pulses by time-dependent flows simulated by the ARPS (Advanced Regional Prediction System) model (Xue et al., 2000, 2001, 2003) at up to 100 m spatial resolutions. The returns from these scatters are integrated over the radar sampling volumes using realistic beam patterns. Radar reflectivity (Z) is calculated from model simulated hydrometeors.

In this study the evaluation of the monopulse system has been conducted on the condition that there is an airplane which is the hard target, and then statistical analyses will be performed on the data simulated by the enhanced emulator in monopulse mode, using very-high-resolution ARPS output of several types of weather conditions.

2. METHODOLOGY

The main idea of a monopulse system is to estimate the correlation of the "sum" and "difference" channels using two identical beams, whose outputs are summed (even-mode) and subtracted (odd-mode). In simulation we have one transmitter and four receivers for the monopulse system, whose beam width are 1.75°and 2.5°, respectively (Zhang and Doviak, 2007a). The centers of these receivers are separated with 1.22 m in x-z coordinate and the beam is directed in y direction as Figure 1.

The emulator can emulate volume scattering from atmosphere field using many point scatters, which are, for example, distributed targets of hydrometeors and hard targets of airplane. The characteristics of these point scatters like their motion and reflectivity are determined by the input meteorological fields. In this study the forecasts of ARPS are used and the parameters of the forecasts are shown in Table 1. The meteorological fields at every scatter are interpolated in time and space. Coherently summed electromagnetic signals, which are backscattered from each of the point targets, can generate the time-series signal at the receiving antennas.

In the monopulse system, the "sum" channel is generated by summing all the signals from the four receivers in time, on the other hand, the "difference" channel is by extracting the signal each other in azimuth and elevation (Zhang and Doviak, 2007b). That is, the "sum"

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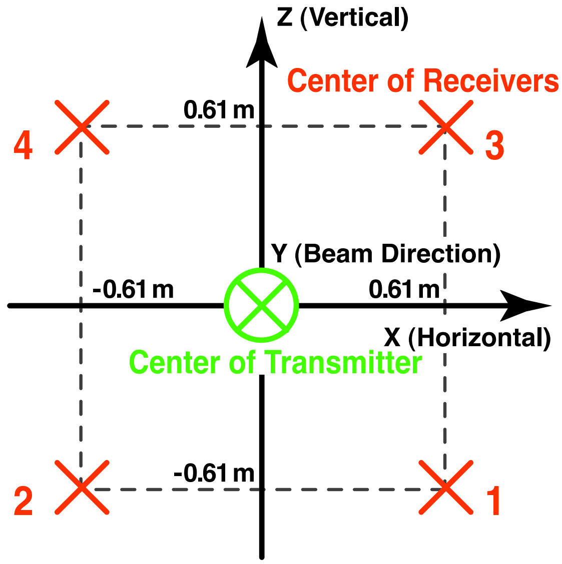

Figure 1: Diagram of transmitting and receiving antennas. The number of each receivers are also shown.

(S_{sum}) and "difference" (S_{diff}) channels in the time domain are expressed by the signal from the four receivers S_n as:

$$S_{\text{sum}}(t) = \sum_{n=1}^{4} S_n(t) \tag{1}$$

$$S_{\text{diff}}(t) = \left(\sum_{n=1,3} S_n(t)\right) - \left(\sum_{n=2,4} S_n(t)\right) \tag{2}$$
$$\text{(in Azimuth)}$$
$$= \left(\sum_{n=3,4} S_n(t)\right) - \left(\sum_{n=1,2} S_n(t)\right) \tag{3}$$
$$\text{(in Elevation)}.$$

These signal are Fourier-transformed into the frequency domain. Then the monopulse ratio (DoS) are calculated as

$$DoS = \frac{S_{\text{diff}}(f)}{S_{\text{sum}}(f)}. \tag{4}$$

The angle (θ) from the center of the transmit beam is related to the monopulse ratio,

$$\theta = \sin^{-1}\left(\frac{2\pi D}{\lambda}\tan^{-1}\left[\text{Im}(DoS)\right]\right), \tag{5}$$

where Im denotes the imaginary part, D is the distance between the receivers, and λ is the wavelength, and the Doppler velocity (V_r) is related to the index number of the monopulse ratio as

$$V_r(n) = \frac{2V_a}{N_{\text{fft}}} \times (n - 1 - \frac{V_a}{2}), \tag{6}$$

Table 1: Parameters for the ARPS forecasts.

Domain Size	64.3 × 64.3 km in 100 m grid 43 points vertically stretched up to 16 km height
Output	Pressure, Potential temperature, Mixing ratio of rain, 3-D wind (every 1 min)

where V_a is the aliasing velocity, N_{fft} is the number of FFT, n is the index number, respectively. Therefore, the Doppler velocity corresponds to the velocity at the specified location (θ).

3. PRELIMINARY RESULTS / WIND SHEAR CONDITION

We have conducted the simulation about a supercell and emulated the radar IQ signals in the region on the north side of a supercell, where there is a strong wind shear in height, not horizontally. Figure 2 shows three-dimensional wind field and radar reflectivity distribution at a specific height. The center of a supercell is located around 20 and 29 km in zonal and meridional directions, respectively. In the emulated region, as shown in black rectangles, horizontal wind is almost constant horizontally and the horizontal change of radar reflectivity is small. In this emulation the azimuth and elevation angles are 30°and 3°, respectively, the number of pulses is 256, the pulse reputation time (PRT) is 0.5 ms, and the aliased velocity is approximately 47 m/s.

In figure 3 the profiles of 'true' wind, which comes from the ARPS forecasts, 'estimated' wind through the monopulse array system and pulse-pair technique are shown. The estimation of radial velocity through the pulse-pair system is based on the condition that the power spectra of the "sum" channel is well strong. Note that only one estimation of radial velocity can be derived through the pulse-pair technique, but a profile of radial velocity can be obtained through the monopulse system and the estimation works well below 2.8°in elevation. Above 2.8°the returning signal from the scatters is weak (not shown in figure) and therefore there is no estimation.

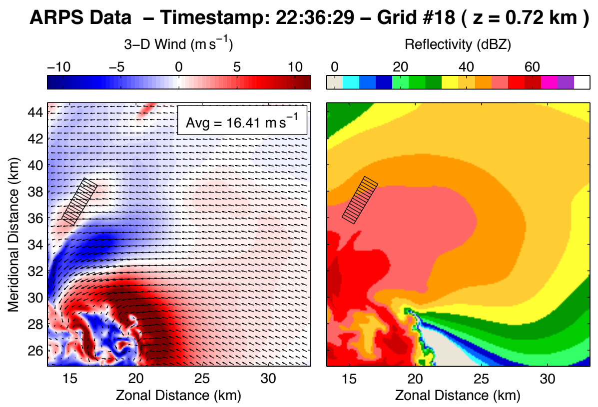

Figure 2: Three-dimensional wind field and radar reflectivity of ARPS forecasts at a height of approximately 700 m. Black rectanges denote volumes of a radar beam. A radar is located approximately 30 km southwest from the radar volume.

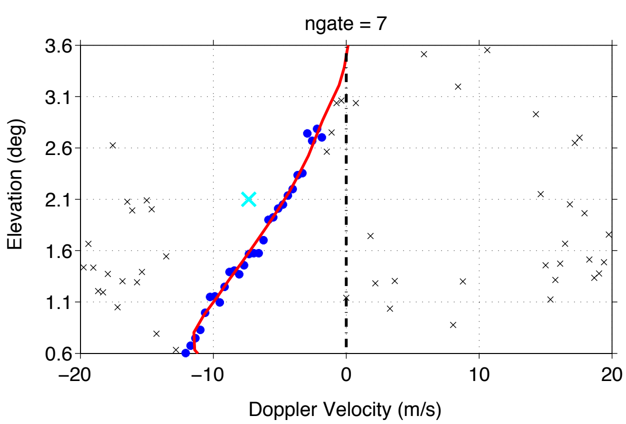

Figure 3: Doppler velocity distributions in elevation at the seventh gate. Red line show the 'true' wind profile of ARPS forecasts. Cyan cross denotes the estimated radial wind through the pulse-pair system. Black crosses come from the monopulse system and blue dots show the 'estimated' radial wind through the monopulse system.

4. CONCLUSION

A monopulse system is simulated using the radar emulator developed at the OU. Only one estimation of the Doppler velocity can be obtained through the conventional pulse-pair processing. The elevation (height) profile of radial velocity can be estimated in the case of the vertical shear region. Moreover, the estimation through the monopulse system works well while the returning power is strong, which indicates that the accuracy of the estimation depends on the signal-to-noise ratio.

The monopulse system can be applied for various meteorological and radar-processing conditions like different wind shear, signal-to-noise ratio, number of pulses, PRT, and so on. The statistical evaluation for the monopulse system is needed.

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