P4R.11

SPACED ANTENNA MEASUREMENTS OF CROSS BEAM VELOCITY IN SEVERE STORMS

K.-M. Hardwick,[1] S.J. Frasier, A.L. Pazmany
Microwave Remote Sensing Laboratory
Department of Electrical Engineering
University of Massachusetts, Amherst, Massachusetts
H.B. Bluestein, M.M. French
School of Meteorology
University of Oklahoma, Norman, OK

1. INTRODUCTION

Spaced antenna (SA) techniques have been employed by the MST radar and wind profiling communities for some time [, Briggs et al., 1950, Briggs, 1984, Doviak et al., 1996, Holloway et al., 1997]. In SA, the auto- and cross-correlations of echoes from closely spaced and co-aligned antennas are used to determine the advection velocity (along the baseline separating the antennas) of the scatterers illuminated. In MST and wind profiling applications, the antennas are almost always vertically pointed and stationary, and are used to obtain horizontal winds at various heights. The source of the scattering is Bragg scattering from refractive index turbulence.

We have recently applied the SA concept to a scanning dual-polarized X-band radar as a means to obtain the cross-beam (or transverse) velocity in addition to the standard Doppler (or radial) velocity. The technique employs antennas of orthogonal polarizations and is therefore called a dual-polarization spaced-antenna (DPSA). The use of dual-polarization allows for simultaneous transmission and reception on both antennas but relies on strong correlation between the polarizations and is therefore limited to Rayleigh scattering from hydrometeors. In this paper we describe the initial application of this technique using observations of a supercell storm collected in Howard, KS on June 4, 2005. We also present simultaneous measurements of reflectivity and Doppler velocity.

Initial results are promising but are far from perfect. The technique, as implemented to date, requires a large signal-to-noise ratio, and appears sensitive to the requirement of polarization correlation coefficient. The following sections describe the DPSA implementation and its application.

2. HARDWARE IMPLEMENTATION

Fig. 1. Dual-polarization spaced-antenna (rectangular box) mounted on the mobile X-Pol radar positioner.

The spaced antenna consists of two 0.76X m diameter flat-plat waveguide array antennas oriented at right angles to each other (see figure 2). Along the diagonal between them, a polarizing grid serves to reflect the signal from one antenna while transmitting the other (assuming the antennas are oriented to yield orthogonal polarizations). The projection of the two antenna apertures along the beam yield partial overlap, which is a practical requirement for SA techniques. The antenna phase centers are spaced approximately 0.17 m.

The transmitted power is 25 kw, equally split between polarizations (hybrid or "slant-45" transmission is used). The transmitted pulse has a width of 1 μs and therefor a transmitted bandwidth of about 1 MHz. The center frequency is 9.41 GHz.

Magnetron limitations restricted our duty cycle to .1 percent. Under this restriction and with a static triggering system, we implemented a staggered pulse to maximize our unambiguous velocity and range. Our unambiguous range was 60 km and our unambiguous velocity was ±18 m/s which can be unfolded in post-processing to ±36 m/s.

The positioner is capable of being run at very slow speeds. In the collection of spaced antenna data it was run at one of four speeds: 0.29, 0.57, 0.90 and 1.13

---

[1] Kery-Michael Hardwick, Univ. of Massachusetts, Dept. of Electrical Engineering, Amherst, MA; e-mail: hardwick@mirsl.ecs.umass.edu

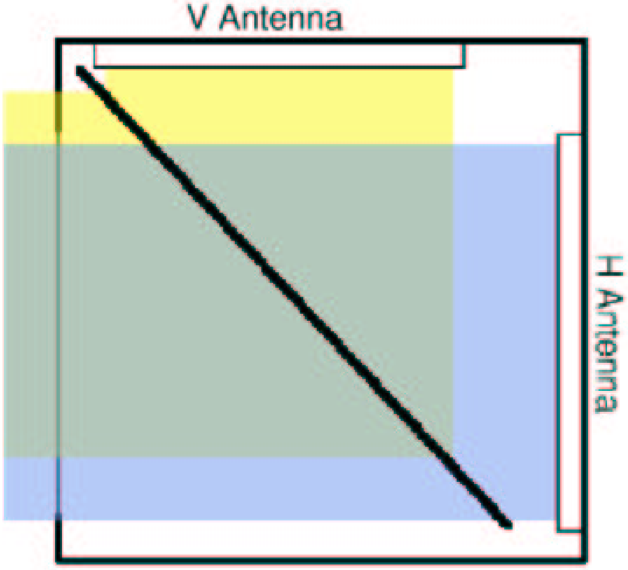

Fig. 2. Cross section of DPSA. Diagonal line indicates polarizing grid. Radiating aperture is to the left.

TABLE 1
Scan Rate, Number of Available Averages and Azimuthal Resolution

RPMs	Degrees/sec	Available Averages	$\Delta\phi$
0.29	1.74°	670	1.04°
0.57	3.42°	341	2.05°
0.90	5.40°	216	3.24°
1.13	6.78°	172	4.07°

RPMs. In the early post-procesing we've concentrated on the slowest speed, 0.29 RPMs, because this yields the greatest number of independent samples.

The spaced antenna has a beamwidth of 3.5°. So, constraining the number of available averages to remain within one beamwidth and using an average PRF of 1 kHz presents us with the results of Table 1, where $\Delta\phi$ is the azimuthal resolution between resulting cross-beam velocity estimates. In calculating this table, keep in mind, that the number of available averages is reduced by two-thirds due to the staggered pulse employed by the radar.

This table illustrates the trade off between scan time and number of averages. A faster scan allows for a faster volume scan, but it degrades the azimuthal resolution and the available number of averages for calculating cross-beam velocity. One can see that the fastest speeds azimuthal resolution exceeds the antennas beamwidth. This rules out 1.13 RPMs as a useable speed in the calculating of cross-beam velocities.

3. ALGOTITHM FOR CROSS-BEAM VELOCITY

We employ the Full-Correlation Analysis (FCA) technique[, Briggs, 1984] in which we estimate the parameters of the auto- and cross-correlations assuming they are of Gaussian form. The key parameters to estimate are the width of the auto-correlation, τ_c, the lag of the peak of the cross-correlation, τ_p, and the amplitude of the cross-correlation relative to the auto-correlation, $\exp(-\eta)$.

$$\rho_{12}(\Delta x, \tau) = \frac{|R_{12}(\Delta x, \tau)|}{\sqrt{|R_{11}(0)||R_{22}(0)|}} \quad (1)$$

$$= \exp(-\eta)\exp(-\frac{(\tau-\tau_p)^2}{2\tau_c^2}) \quad (2)$$

The parameters of this fitted cross-correlation function are then used to calculate the cross-beam velocity, v_x, according to [, Holloway et al., 1997] Under the assumption that the point scatterers are undergoing a laminar flow within the resolution volume and zero turbulence then the cross-beam velocity can be calculated according to

$$v_x = \frac{\Delta x \tau_p}{4\eta\tau_c^2 + 2\tau_p^2} \quad (3)$$

where Δx is the spacing of the antennas. We note that several other algorithms exist for estimating v_x as noted by [, Holloway et al., 1997] and others.

4. DATA PROCESSING

The staggered pulse sequence used allowed us to calculate the correlation functions at 13 different time lags: -3.0, -2.583, -1.958, -1.042, -0.625, -0.417, 0, 0.417, 0.625, 1.042, 1.958, 2.583 and 3.0 ms. These are the points used in generating the Gaussian fits. But, care must be used in which points were used because the higher time lags ($|\tau_c| > 1.042$ ms) showed more erratic behaviour. This erratic behaviour could degrade the accuracy of the Gaussian fit algorithm and so these points are not included in the fit. Also, zero lag was not used in the fits to the auto-correlations due to the spike caused by noise correlating with noise at zero time lag. Figure 2 illustrates the auto- and cross-correlation functions with their associated Gaussian fit. These data were averaged 175 points in time and 5 points in space.

Because of the concern for adequate independent samples, different temporal and spatial averaging schemes were employed to evaluate their effect on cross-beam velocity measurements. It was found that averaging five points in space, resulting in 720 m range resolution, yielded good results. But as for averaging

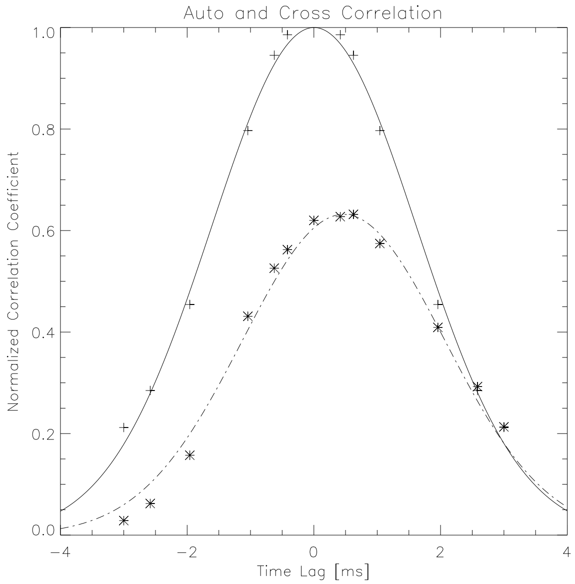

Fig. 3. Auto- and cross-correlation estimates for a single range bin. Curves are Gaussian fits to the available points.

in time, it was found that averaging any more than 200 points didn't improve the results but, rather, usually degraded them. This is expected to be due to the non-stationarity of the field as the beam scans through a spatially and temporally varying wind field. This implies that slower scans rates are desireable (as one would expect); however, this must be traded against the need to obtain a meaningful two dimensional image of the wind field (which suggests faster scan rates). Other means of obtaining independent samples such as frequency hopping may be in order.

Figure 4 displays reflectivity, unfolded Doppler, SNR and cross-beam velocity measurements from data collected on a supercell at Howard, KS on June 4, 2005. To ensure a strong signal for the cross-beam calculations, the SA velocity estimates were thresholded on a 20 dB SNR.

5. DISCUSSION

There are several observations to note about the cross-beam velocity. The first is a field of reasonably stable values in an area of strong SNR within 10 km of the radar. The second is that the cross-beam velocity field has a value of about 20 m/s in an area where the radial velocity traverses 0 m/s. This indicates that the storm is passing perpendicular to the radar beam at this point, so one would expect a strong transverse velocity here. The results agree with this understanding. The measured value of the cross-beam velocities corresponds well with the Doppler velocities which are about 20 m/s in areas where the storm appears to be moving primarily in a radial direction.

The SA field breaks apart as range increases and begins to produce unrealistically high velocities (over ±100 m/s). At more distant ranges the velocities appear to oscillate from high positive to high negative velocities. Despite reasonable SNR (20 dB or more), these velocities are indicative of very small values of τ_p, such that the peak of the cross-correlation oscillates about zero. The cause of the shift of τ_p toward zero may include factors beyond what is commonly considered in the standard SA literature. Namely, the finite polarization correlation coefficient cannot be measured directly with the existing spaced antenna due to the offset phase centers.

It is also possible that the inherent spatial variability of the wind field over the fairly short dwell times available is influencing estimates of the cross-correlation function. Also, note that the post-processing of the data can not distinguish between the motion of a scatterer or the motion of the beam. This results in a stationary obstacle being attributed a velocity as the beam sweeps over it. It is unsure exactly how the motion of the beam interferes with the measured cross-beam velocity. These are current lines of investigation.

6. SUMMARY

In this paper we have presented the preliminary results of our cross-beam measurements of a supercell over Howard, Kansas. The results so far are promising, but improvement is needed.

We have found that more is limiting our averaging than just the beamwidth of the antenna. It is our assumption that this cross-beam velocity algorithm is very sensitive to changes within the illuminated volume that results in a quick decorrelation of the signals. Therefore it is necessary to get the needed number of time averages not within a beamwidth but rather within a correlation time of the supercell itself.

Also, it is believed that there are unaccounted influences on the cross-beam velocity estimates that have not been treated, to date, in the standard SA techniques. Further effort is needed to understand fully the influences of finite polarization correlation and of scanning.

ACKNOWLEDGEMENT

This work was supported by grants from the National Science Foundation. The authors acknowledge P.-S. Tsai, J. Vight and C. Baldi for their efforts in development and fielding of the spaced antenna.

REFERENCES

[Briggs, 1984] Briggs, B. H. (1984). The analysis of spaced sensor records by correlation techniques. In Vincent, R. A., ed-

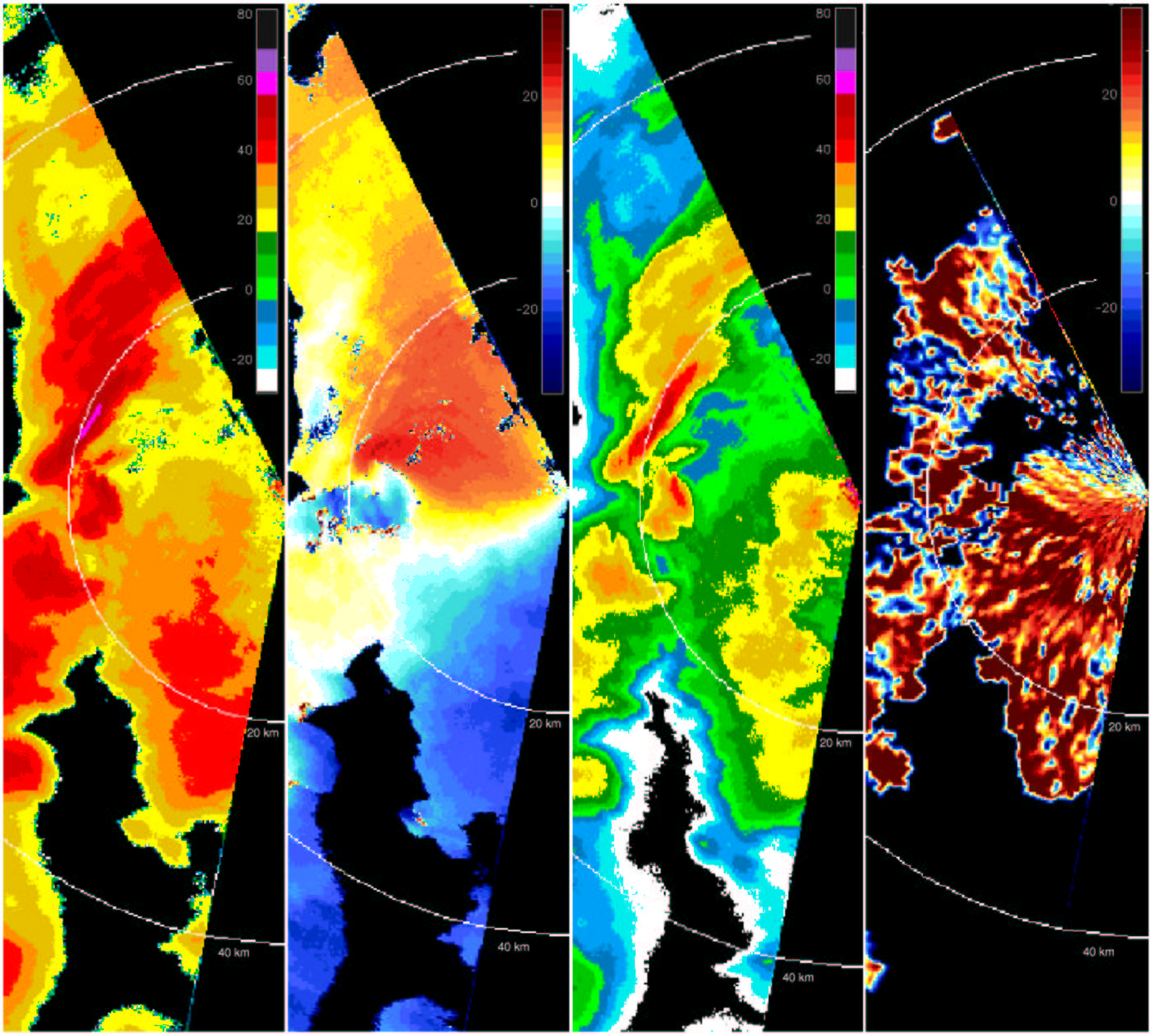

Fig. 4. Left to Right: Reflectivity [dBZ], Doppler velocity [m/s], SNR [dB] and DPSA winds [m/s] obtained from a supercell storm near Howard, KS on 4 June 2005. DPSA wind estimates are conditioned on SNR > 20 dB. Clockwise cross-beam velocities are positive while counter-clockwise velocities are negative.

itor, *Middle Atmosphere Program: Handbook for MAP*, volume 13, pages 166–186. Univ. of Ill., Urbana.

[Briggs et al., 1950] Briggs, B. H., Phillips, G. J., and Shinn, D. H. (1950). The analysis of observations on spaced receivers of the fading of radio signals. *Proc. Phys. Soc. London, B*, 63:106–121.

[Doviak et al., 1996] Doviak, R. J., Lataitis, R. J., and Holloway, C. L. (1996). Cross correlations and cross spectra for spaced antenna wind profilers part i: Theoretical analysis. *Radio Sci.*, 31:157–180.

[Holloway et al., 1997] Holloway, C. L., Doviak, R. J., Cohn, S. A., Lataitis, R. J., and Baelen, J. S. V. (1997). Cross correlations and cross spectra for spaced antenna wind profilers part ii: Algorithms to estimate wind and turbulence. *Radio Sci.*, 32:967–982.