Development of the NCAR/ARM Multiple Antenna Wind Profiler (MAPR)

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Introduction

The National Center for Atmospheric Research (NCAR)/ Atmospheric Radiation Measurement (ARM) Multiple Antenna Profiler (MAPR) (Figure 1) is being developed to test the application of spaced antenna (SA) measurement techniques in the boundary layer. SA wind measurement has advantages over Doppler beam swinging (DBS) techniques, which include the following:

- better time resolution - 30 seconds or 1 second depending on conditions, while DBS typically provides 30-minute resolution.

Figure 1. MAPR antenna and radioacoustic sounding system (RASS) deployed in the ARM Cloud and Radiation Testbed (CART) site, near Dexter, Kansas during BLX-96. (For a color version of this figure, please see *http: // www.arm.gov/ docs/ documents/ technical/conf_9803/cohn(1)-98.pdf*.)

- flux and turbulence measurement potential - turbulent kinetic energy, eddy dissipation rate, momentum, heat and moisture flux are theoretically possible.

Fluxes of latent and sensible heat and momentum are of first-order importance in cloud forcing for single-column modeling studies and for both initializing and evaluating ARM's modeling efforts. MAPR measurements will also have other benefits, allowing detailed observation of mesoscale events.

Good MAPR performance to date has been limited to conditions of strong clear air backscatter or precipitation. In weaker signal-to-noise ratio (SNR) conditions, system noise and ground clutter play a role. We describe efforts to expand the range of atmospheric conditions in which MAPR may be used. In particular, we address ways to increase the system sensitivity and reduce the effects of ground clutter. We primarily consider correlation-based SA techniques because of their simplicity, but spectral and structure function-based techniques are also discussed.

Effects of Antenna Diameter, D

One option, which could address issues of both sensitivity and ground clutter, is using a larger diameter antenna. The current MAPR antenna consists of four 1-m by 1-m receiving antennas arranged within a 2-m by 2-m square (D=2 m). The entire square is used as the transmitting antenna. This arrangement provides a transmitted beamwidth of approximately 9^{o} and received beamwidths of 19^{o}. Similar antenna panels that measure 1.5-m by 1.5-m are now available. Used in the same square configuration (D=3 m), this would provide transmitted and received beamwidths of 6^{o} and 13^{o}.

- **Gain**: The increased gain of the larger antenna is calculated (in dB) as $40\log(D_2/D_1)$ where D_1 and D_2 are the old and new antenna diameters (the 4^{th} power comes from antenna area, which is proportional to D^2 and the increase in gain being the 2-way gain). This gives a 7-dB increase in gain by switching from a 2-m antenna to a 3-m antenna. But the increase in the SNR of the received signal is only 3.5 dB because the larger antenna has a narrower beamwidth, which contains fewer atmospheric scatterers. This increase is in the ratio of signal to *random* (uncorrelated) noise, and is not related to any effect on ground clutter.

- **Ground clutter**: The effect of a larger antenna on ground clutter cannot be as easily evaluated. Most ground clutter comes from energy directed towards the horizon, partly from diffraction over the top of a clutter shield attached to the radar. The narrower beamwidth produced by the larger antenna would reduce sidelobes near the horizon and would improve the ratio of signal to clutter, improving performance.

Two features of the correlation functions used to determine wind speed are the slope-at-zero-lag (SZL) and the lag at which the auto and cross correlations have the same value (τ_i). Lataitis et al. (1995), Holloway et al. (1997) and Cohn et al. (1997) describe these techniques. Figure 2 shows auto correlations (C_{11}, centered at zero lag) and cross correlations (C_{12}) for three levels of turbulent strength. The slope at zero lag and τ_i are both independent of turbulence strength. We consider the effect of D on $C_{12}(0)$ and $C_{12}(\tau_i)$.

- **Effect on $C_{12}(0)$**: The SZL method makes use of the derivative with respect to lag of the cross-correlation of signals from a pair of receivers, evaluated at zero lag. We can use the value of the cross-correlation at 0 lag as an indicator for the measurement quality because it is harder to accurately find the wind when the correlation is small (analogous to a small SNR). Making use of equations in Doviak et al. (1996) we can show that $C_{12}(0)$ depends only on the transmitted and received beamwidths. It is independent of the wind speed or turbulence strength. For the current MAPR wavelength and antenna diameter we should always have $C_{12}(0)=$ 0.576. Cohn et al. (1998) show that increasing the antenna diameter, but keeping the same MAPR configuration (with the receiver spacing also D/2), results in no net change of $C_{12}(0)$. This would not be true for arbitrary receiver positions. So there is no net effect on $C_{12}(0)$ from increasing D.

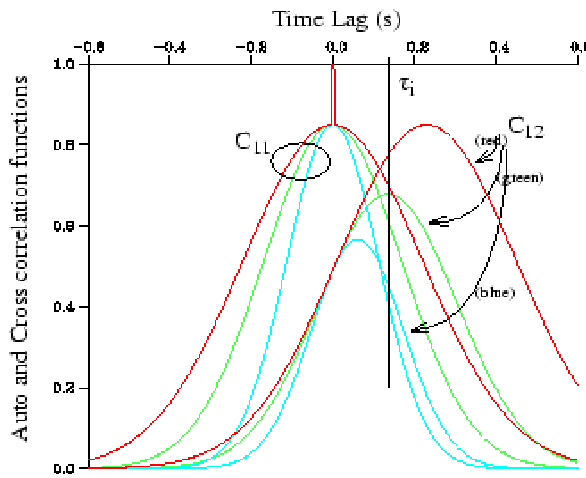

Figure 2. Theoretical auto correlations (C_{11}) and cross correlations (C_{12}) for three levels of turbulent strength σ_t. These curves assume parameters of the MAPR and a wind directed along the receiver pair baseline of 2 m s^{-1}. Turbulence strength is indicated by σ_t or spectral broadening: no turbulence (red), 0.1-m s^{-1} (green), and 0.2 m s^{-1} (blue). (For a color version of this figure, please see *http://www.arm.gov/docs/documents/technical/conf_9803/cohn(1)-98.pdf*.)

- **Effect on $C_{12}(\tau_i)$**: Antenna size has a strong effect on the correlation at the lag of intercept. Figure 3 shows the correlation as a function of D for several values of wind and turbulence. The figure demonstrates that increasing the antenna size from 2 m to 3 m would make measurements at low wind speed or strong turbulence more difficult using the intercept method. This figure also shows that, even for a 2-m antenna, the method is a poor choice if the baseline wind component, v_x, is small.

Increased Average Power

Increasing the average transmitted power would improve the signal strength, and the SNR for a fixed integration time. There would be no improvement in ground clutter rejection because the antenna patterns would not change. There are two ways we can increase the average power.

- **More powerful transmitter**: Newer, more powerful transmitters are now used in commercial UHF profilers. These would improve the SNR by about 3 dB.

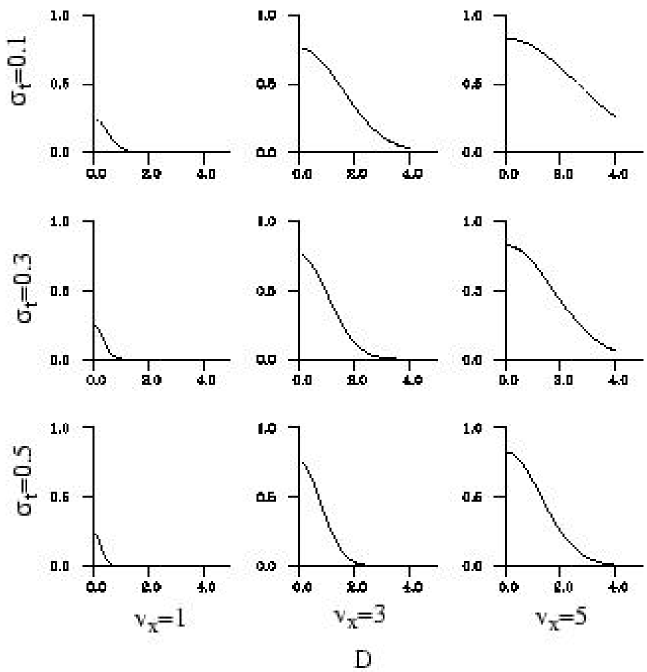

Figure 3. The value of the cross correlation at its lag of intercept with the auto correlation, $C_{12}(\tau_i)$, vs. antenna diameter D (between 0 and 4 m). Plots show the effect of varying the wind parallel to the receiving antenna baseline, v_x, from 1, 3, and 5-m s^{-1} (left to right) and varying σ_t from 0.4, 0.6, and 0.8-m s^{-1} (top to bottom). For all plots, the wind speed perpendicular to the baseline v_y is 3-m s^{-1}.

- **Pulse coding**: A common technique to increase the average power without sacrificing spatial resolution is pulse coding (Carter et al. 1995). Newer, available transmitters also have a higher duty cycle (12% rather than 5%) allowing increased average power. Implementing pulse coding with a newer transmitter could provide an 11-dB improvement, and with the current transmitter there would be a 4-dB benefit.

Clutter Screen and Antenna Design

- **Clutter screen improvements**: Ground clutter is a problem common to DBS and SA wind profilers. An antenna test range has been constructed at NCAR's Marshall Field Site to test a variety of clutter shields and edge treatments for profiler antennas. Early results using corrugated edges show promise, but quantitative results are not yet available.

- **Antenna design**: A new antenna design is being proposed by the National Oceanic and Atmospheric Administration (NOAA) Environmental Technology Laboratory with significantly smaller sidelobe energy near the horizon. Using this antenna would also improve the signal-to-clutter ratio. Once constructed, this antenna will be tested at Marshall.

Signal Processing Considerations

- **Spectral methods**: Time-domain SA methods (correlation analysis) are relatively simple, however spectral domain (Fourier transform) methods have other advantages. These include a method proposed by Doviak et al. (1996), a method known as full spectral analysis (FSA) and its variations, and a method derived by Muschinski (1998). Although most SA methods are nearly equivalent in theory, each implementation has its own advantages. Spectral methods offer the possibility to remove clutter occurring at a velocity well removed from that of the radial wind. A disadvantage of most spectral methods is the need to measure spectral width, which is difficult.

- **Zero-lag techniques**: Both correlation and spectral methods have "lag-zero" techniques. Their advantage is that at zero or small lag turbulence is not a factor – because there is no time for eddies to reorganize the refractive index structure and so there is no decorrelation due to turbulence. Muschinski's method can be shown to be a spectral equivalent of SZL.

- **A structure function method**: Praskov et al. (1998) introduces a SA method to measure wind using turbulence structure functions. This has some common features with zero-lag techniques and is being investigated further.

Acknowledgements

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