9R.7 ON THE USE OF POLARIMETRIC RADARS FOR STUDIES OF CLOUDS: NUMERICAL SIMULATIONS AND S-BAND RADAR OBSERVATIONS

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Uncertainties in parameterizing clouds have been identified as an important source of error in climate model outputs. These problems are linked to insufficient data and the complex behaviors of clouds. Progress in reducing these uncertainties is being made as more data are collected and analyzed. In particular, polarimetric radars are capable of estimating microphysical cloud properties in addition to macrophysical features. Angular resolution is a major concern for cloud observations as well as many other measurements using radar. In this study, the prospect of enhancing the angular resolution of weather radar is examined by the application of advanced signal processing algorithms. Comparative results will be presented between the S-band polarimetric radar (KOUN) operated by the National Severe Storms Laboratory in Norman, Oklahoma and numerical simulations.

1. INTRODUCTION

Generally, NEXRAD radars scan continuously in azimuth with extremely fine angular sampling (up to 200 points / degree sampled in clear-air VCP 32). Groups of these samples are then processed to produce moment estimates with an angular sampling on the order of the beamwidth of the antenna ($\sim 1^\circ$). Since the radars are continuously moving, the moment estimates represent averaged values of scatterers smeared by the antenna beam. Thus, the NEXRAD radars sample the atmosphere at a higher angular rate than the beamwidth and, if the spreading effects of the antenna beam could be removed, it would be possible to retrieve higher angular resolution moments of the scattering field. This is a classic deconvolution problem.

Retrieving the true field (deconvolution) is a challenging process with barriers such as noise and non-stationary scatterers. In general, the noise is enhanced at angular frequencies where the beam energy is small in the deconvolution process and evolving scatterers decorrelate the received signal, broaden the power spectrum, and compress the autocorrelation function. For example, it is generally assumed that the received signal has a Gaussian power spectral density and the additive noise is an identically independently distributed complex Gaussian process. Then, the correlation of the received signal at lag mT_s given in Doviak and Zrnić (1993) is

$$R(mT_s) = Se^{-8(\pi\sigma_v mT_s/\lambda)^2} e^{-j4\pi\bar{v}mT_s/\lambda} + N\delta_m, \quad (1)$$

where the average signal power is S, the velocity spectrum width is σ_v, the wavelength is λ, the true radial velocity is $\bar{v}$, and the noise power is N. For typical NEXRAD values such as a sampling time T_s of 1 ms, λ of 10 cm, and σ_v from 1 to 4 m/s, the normalized correlation value (plotted in Figure 1) drops

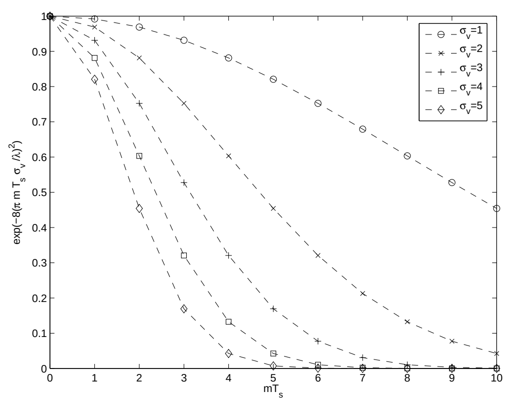

Figure 1: Correlation values of different σ_v for T_s equal 1 ms, λ equal 10 cm, and σ_v from 1 to 4 m/s.

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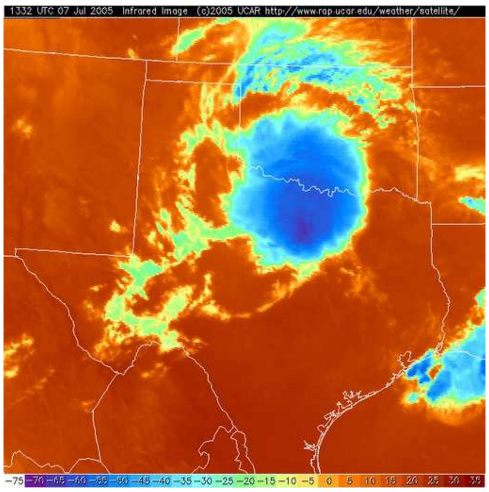


Figure 2: Infrared satellite image of environment at 1332 UTC on 7 July 2005 (www.rap.ucar.edu).

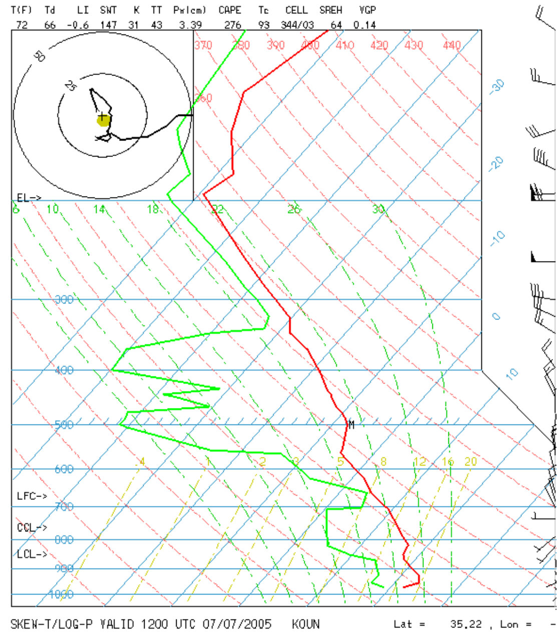


Figure 3: Upper-air rawinsonde sounding of OUN at 1200 UTC on 7 July 2005 (weather.uwyo.edu).

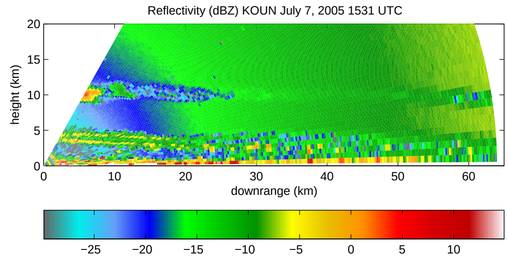
below 0.5 after only 5 time sample pulses. Furthermore, when σ_v increases, the correlation coefficient between samples decreases with increasing lag at a faster rate. The significance of the decorrelation rate, even without the effects of noise, was examined by Koivunen and Kostinski (1999) who noted that the feasibility of improving better estimates of power decreases with larger decorrelation rate because the condition number of the correlation matrix becomes extremely large and computers are unable to handle extremely large condition number.

When the decorrelation rate is low, it is possible to construct a whitening filter to improve resolution, as theorized by Torres and Zrnić (2003), and implemented by Ivić et al. (2003) on oversampled range echoes. In their work, the important time interval is range time. When the range gates are separated by less than data samples are 250 m, the range sampling time is less than 1 μs and the correlation coefficient calculated using equation (1) is approximately unity for typical values used with NEXRAD.

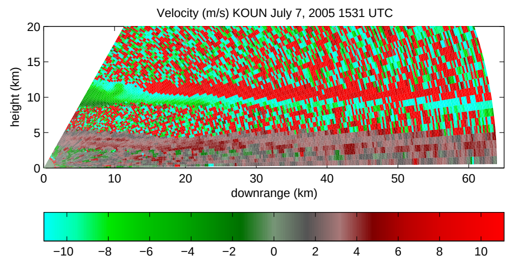
When the sample time scale is on the order of the sample time (ms), it is necessary to examine values other than direct voltages, which decorrelate quickly due to turbulence. For example, it is expected that amplitude would decorrelate less quickly. Assuming the scatters are uniformly positioned within the resolution volume, the instantaneous power is the result of particles within the enclosed volume during a snapshot. The rate at which this changes depends on velocity and spectrum width, whereas the average power is the incoherent integration of the scattered power by scatterers uniformly distributed in the resolution volume. Since the atmosphere is a fluid, the distribution of scatterers in the radar resolution volume is not expected to change substatianly within a few time samples, thus the expected decorrelation value of averaged amplitude (or approximately average power) should decrease at a slower rate compared to the voltage, which has a decorrelation value that depends on spectral width and velocity. Thus, the decreased decorrelation rate will facilitate the possible deconvolution process. In addition, the benefit of using power is that its estimate improves with larger σ_v because the data between samples are less correlated.

2. EXPERIMENT

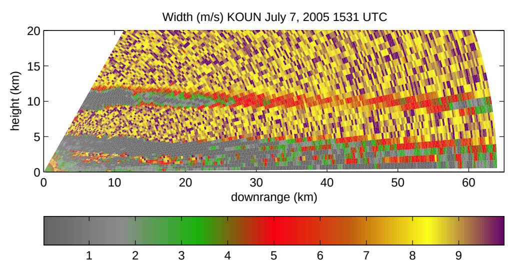
A data set was collected on July 7, 2005, at approximately 1532 UTC in Norman, Oklahoma using the polarimetric KOUN S-band radar. The main scatterers are mid-level and high-level clouds surrounding a low pressure system center on the



(a)



(b)



(c)

Figure 4: Spectral moments calculated using autocovariance processing. (a) Reflecitivity. (b) Velocity. (c) Width.

Texas-Oklahoma border. The 1200 UTC rawinsonde sounding is shown in Figure 3 (as well as a satellite image of the nearby environment in Figure 2). The upper-air data indicate a saturated level at an altitude of 3-5 km and another at 9-12 km. The relative humidity reached a maximum value of 96 % at 3640 m in the lower layer and 74 % in the upper layer at 9130 m. From the sounding, the lower level is analyzed to be composed of liquid particle scatterers because the air temperature within this level is above freezing. By a similar approach, the upper level is analyzed to be composed of only ice particles because the air temperature is much below 0°C and its source of updraft is believed to be the low pressure center so there has been sufficient time for all the particles to freeze.

The parameters of the radar include a pulse repetition time (PRT) of 2240 μs, 256 samples/degree are collected, and a pulse width of 1.57 μs. The samples are collected using an range height indicator (RHI) scan from an elevation angle of 0.5° to 60.5°. Figure 4 provides estimates of the reflectivity, radial velocity, and spectrum width. The clutter echoes were attenuated by zeroing the fifth scale of the lowpass coefficients obtained by filtering the angular time series data with a 26-length complex wavelet filter (Zhang et al., 1999).

The correlation functions for voltages and amplitude of an arbitrary gate at 25 km range were estimated for many different elevation angles. The results of several interesting regions are plotted in Figure 5. The correlation values were calculated by taking a window of 1024 points (elevation samples) and then applying the unbiased correlation estimate to the data. All the calculated correlation values were then normalized with the lag-0 value for the respective elevation angle. Figure 5 contains plots of the correlation values for clutter, noise, lower cloud layer, and upper cloud layer, respectively. In the clutter region, both the correlation value of the amplitude and voltage are approximately the same. In the noise region, the correlation value of the voltage is a spike at lag-0 and near zero at other lags while the correlation value of the amplitude is a spike at lag-0 and 0.8 at other lags. In the cloud regions, the amplitude correlation is both smoother and its spread from lag-0 is wider than the voltage correlation. As expected, the correlation results show that the amplitude does not decorrelate as quickly as the voltage. The difference is due to turbulence, which directly affects the phase of the voltage signals but does not have this effect on the amplitude. As a result, there is promise in applying deconvolution methods to the amplitude signals.

3. FUTURE PLANS

It appears that the process of retrieving the true reflectivity field by removing the effects of the beam pattern is possible by processing the amplitude rather than the voltage. The results are due to lower variability and higher decorrelation time of the amplitude. In the immediate future, a more in depth study, which includes simulations of the observations and implementation of several competing deconvolution techniques, is planned.

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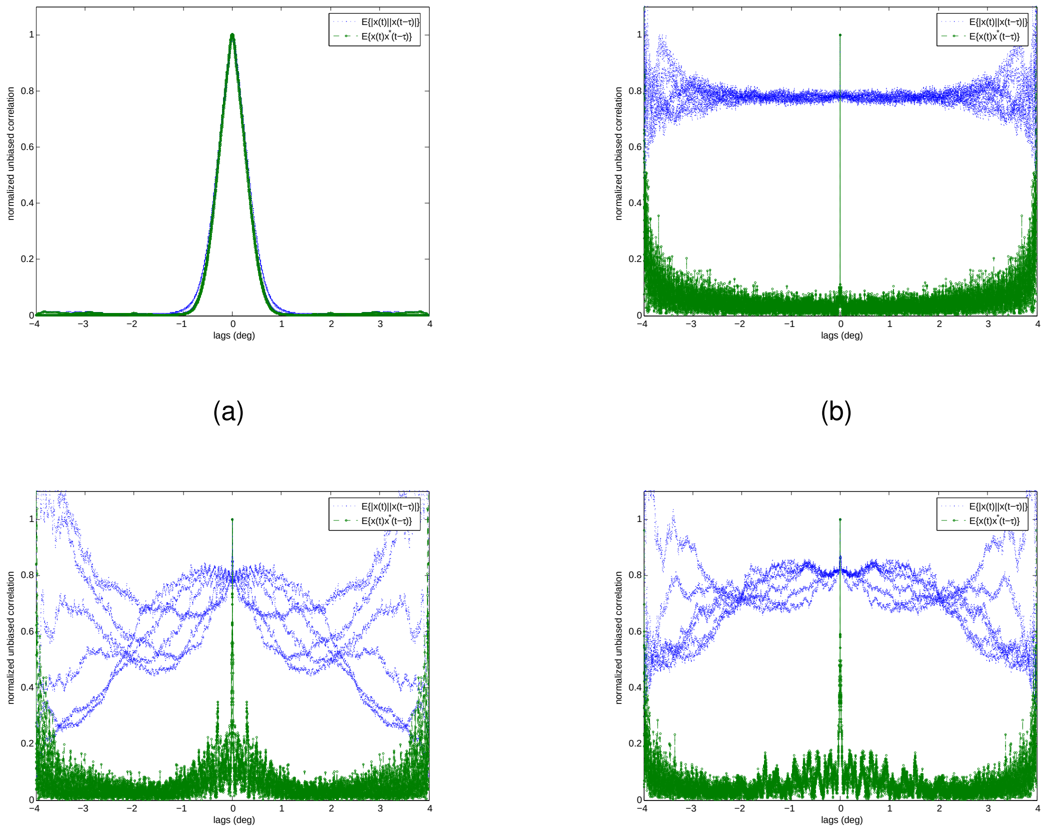

(a) (b) (c) (d)

Figure 5: Normalized correlation values of amplitude and voltages for different scattering types. (a) Clutter. (b) Noise. (c) Lower cloud layer. (d) Upper cloud layer.

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