5.9 DEVELOPMENT OF ADVANCED TECHNIQUES ON NOAA's WSR-88D RESEARCH RADAR

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1. INTRODUCTION

Evolutionary changes to the WSR-88D envisioned for the next 10 years are explored and tested on the NOAA research and development radar (hereafter designated as KOUN). These include a) new frontiers in weather observations such as the utility of polarimetric measurements for discriminating and quantifying precipitation, b) demonstrating algorithms and novel procedures for weather forecasting and warning, c) gaining additional insights in weather phenomena, and d) serving as a test bed for technological innovations pertinent to the WSR-88D. Herein we address item a) and c).

This radar has unique capabilities. It served as a proof of concept for the Open Radar Data Acquisition (ORDA) system of the WSR-88D network. Thus, the KOUN has a powerful signal processor, a versatile control of transmitter phase from pulse to pulse, as well as control of spacing between transmitted pulses. Moreover, the radar has two modes of dual polarization capability. One termed Simultaneous transmission and reception of Horizontally and Vertically polarized waves (SHV) does what its name says. The other termed Linear Depolarization Ratio mode consists of transmitting horizontally polarized waves and receiving both horizontally and vertically polarized waves. Also, sampling of returned signals can be done at a rate five or ten times higher than the reciprocal of pulse length. On top, there is capability to collect time series data so that various enhancing schemes can be tested post facto. Such after-the-fact investigations provide significant insight and allow comparisons to help guide our choice of the evolutionary path that will happen over the next few years. Already a large archive of time series data exists and these are being processed and evaluated off line (http://cimms.ou.edu/rvamb/Mitigation_R_V_Ambiguities.htm) to either validate a new technology or choose the best solution among competing approaches. Significant system enhancements will be achieved once the chosen technologies, discussed next, are introduced to the network.

2. SYSTEM ENHANCEMENTS

Herein we discuss main improvements in radar technology which are under investigation.

a) Range and velocity ambiguities /software and hardware enhancements

Mitigation of range and velocity ambiguities has been one of the highest priorities for the WSR-88D system. An interim solution just implemented on the network consists of three successive scans at the lowest elevations with different PRT in each scan. The velocities and powers from these scans are combined to increase the unambiguous velocity and minimize obscuration by range overlaid echoes.

Meanwhile, researchers at NSSL have devised a systematic phase code for transmitted pulses so that overlaid echo returns can be separated. The weaker echo, up to 40 dB bellow the stronger one, can be recovered. This technique has been tested with the KOUN radar on several storms (http://cimms.ou.edu/rvamb/SZ/SZ-2_Algorithm.htm) and is scheduled to be implemented on the network in 2006. Examples of results with clutter filtering and recovery of overlaid echoes demonstrate large increase in clear area (Fig. 1).

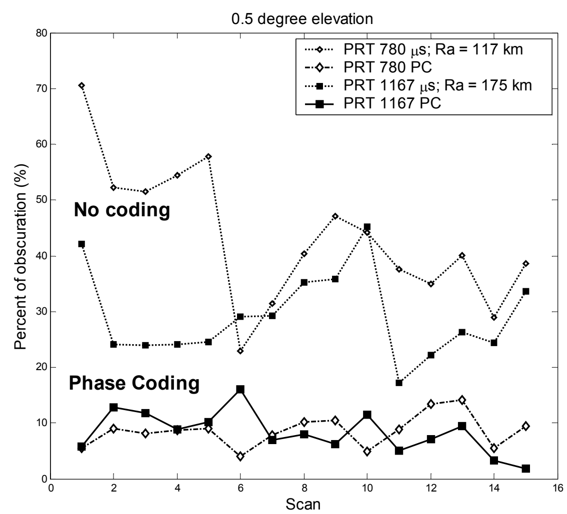
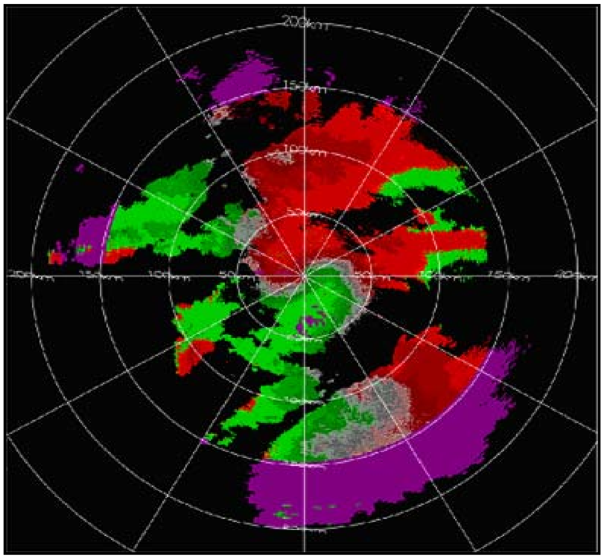
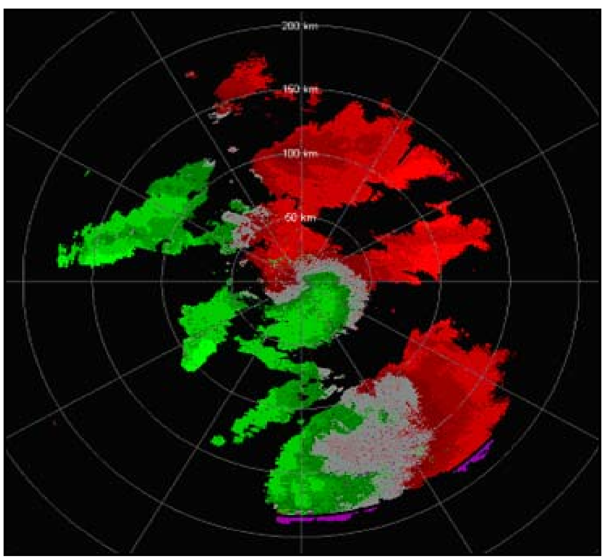


Fig. 1 Percent of obscured area in cases of no phase coding and systematic phase coding. Data are from Oct 11, 2002.

Moreover, staggered PRT has also been tested and recommended (see Fig 2) for higher elevation scans (http://cimms.ou.edu/rvamb/Staggered/Stag_Algorithm.htm). Until recently, the drawback of staggered PRT was difficulty in clutter filtering. This was overcome, however, by NOAA scientists who developed spectral ground clutter filter for staggered PRT sequences. Thus in the very near future the volume coverage pattern on the WSR-88D will likely consist of phase coded sequences at the lowest elevation scans and staggered PRT sequences at the higher elevations. Further on, we envision adaptive (weather dependent) selection of staggered PRT and phase coded sequence so that ambiguities will all but disappear.



(a)



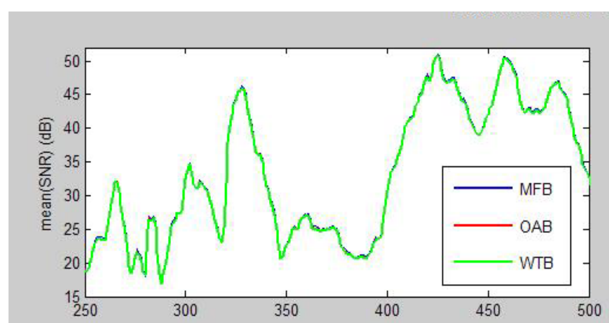
(b)

Fig. 2 (a) Velocity field obtained with the KTLX (Oklahoma City operational NWS) radar on April 6, 2003. Elevation is 2.5 deg and purple areas indicate presence of overlaid echoes. Red colors are for receding radial velocities and gray are for velocities near zero. (b) Same as in (a) except the data is obtained with the KOUN radar (about 20 km SW of KTLX) in a staggered PRT mode. Notice aliased velocities in (a) no aliased velocities in (b) and a much smaller purple area in (b).

The example in Fig. 2 compares (a) velocity field from an operational WSR-88D (uniform PRT interlaced with a long PRT for detecting overlaid echoes - so called batch mode) with (b) the fields obtained from the KOUN radar using staggered PRT. The unambiguous velocity of the operational WSR-88D in this case is 25.4 m s^{-1} and the extended unambiguous velocity of KOUN is 45.2 m s^{-1}.

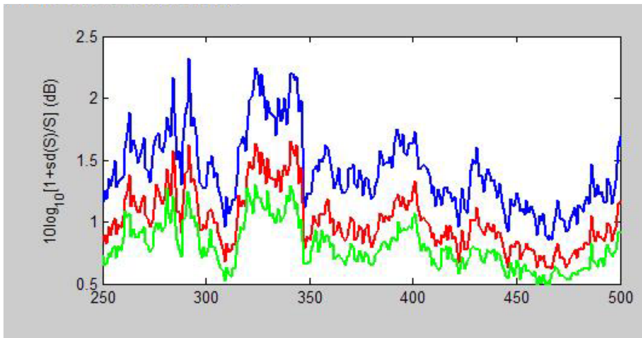
b) Reduction of errors and faster volume coverage

Rapid update of observation and maintaining small errors of estimates are conflicting requirements in weather radars. Recently, a new method for estimation of spectral moments has been proposed and successfully tested. The scheme operates on oversampled echoes in range; that is, samples of in-phase and quadrature phase components are taken at a rate several times larger than the reciprocal of the transmitted pulse length. The spectral moments are estimated by suitably combining weighted averages of these oversampled signals (in range) with usual processing of samples (spaced at pulse repetition time) at a fixed range location. The weights in range are derived from a whitening transformation, hence, the oversampled signals become uncorrelated and consequently the variance of the estimates decreases significantly. Because the estimates' errors are inversely proportional to the volume scanning times, it follows that storms can be surveyed much faster than is possible with current processing methods, or equivalently, for the current volume scanning time, accuracy of the estimates can be greatly improved. This massive improvement is achievable at large Signal-to-Noise Ratios (SNR). Extensions of the method so that the estimates do not degrade at low SNR have also been developed. After full deployment of the ORDA (sometime in 2007) these new techniques will become part of the signal processing algorithms. An example of mean values and variances of power obtained with conventional pulse pair processing and with advanced processing of oversampled signals is in Fig. 3. Note that SDs (green) for whitening are bellow 1 dB for most data, and these are spaced 250 m. The WSR-88D requirement is the same but for data averaged over 1 km!



(a)

Fig. 3 (a) Mean values of signal to noise ratio along range (in increments are 250 m). Blue curve is obtained with standard processing (matched filter), red is for oversampling and averaging, and green is for oversampling with whitening and then averaging. Antenna was stationary (200 records, 64 samples each).



(b)

Fig. 3 (b) Similar to (a) but plotted standard deviations of estimates (dB). Oversampling factor is 5.

c) Dual polarization

In 2003 the Joint POLarization Experiment (JPOLE) was conducted in central Oklahoma to test the practicality and operational utility of polarimetric WSR-88D radar (http://cimms.ou.edu/~schuur/jpole/). The experiment lasted one year and provided a large dataset that demonstrates advantages of dual-polarization. Notable are significant improvements in point and areal rainfall estimates (1.7 and 3.7 times smaller rms errors than for estimates from reflectivity factor) and measurements of heavy precipitation. Also, confirmed was the unique classification capability to identify non-meteorological echoes (ground clutter/anomalous propagation, insects, birds, and chaff) and superior hail detection. Other achievements are discrimination between rain and snow, very precise identification of the melting zone, and even detection of tornadoes. Yet, there are problems such as determination of hail size, presence of icing conditions, or separation of dry aggregated snow from light rain that challenge radar polarimetry.

The highly successful operational validation of the polarimetric method was followed by a cost-benefit study which suggests that 17,838 million $ (in 2003 $) would be saved over twenty years if the network acquires the polarimetric capability. And this is a conservative estimate as the study considers gains in water management and reduction in flood damages but excludes mitigation of effects from snow storms. With such clear justification, a decision has been made (by NWS, FAA, and AWS) to initiate the upgrade and start the retrofit in about 2008.

NSSL continues to collect dual polarization data to further advance hydrometeor classification and quantitative measurements of precipitation, specifically snow fall. Calibration procedures for precise measurement of polarimetric variables are being developed, often with the aid of data itself. A method to calibrate differential reflectivity is under investigation. Scatterers of opportunity, such as ground clutter or leading edges of precipitation are suitable for measurements of system differential phase.

d) Full spectral analysis

Extraction of weather information from Doppler spectra has the following advantages over processing of auto- and cross-covariances (as currently done on weather surveillance radars). It is possible to identify and remove artifacts caused by point scatterers, biological scatterers (will be shown), extraneous interference, and noise. Significant portion of noise can be filtered so that spectral moments are more accurate at low SNR. Spectral and cross-spectral processing can improve the quality of polarimetric variables. Phase coding schemes require spectral processing. The most sophisticated version to process staggered PRT data calls for spectral analysis on unequally spaced sequences; such processing is effective in reducing ground clutter and in reconstructing velocities (sometimes even if two echoes are overlaid). Potentially, the most significant impact may be the possibility for early tornado detection; there is no proof yet that tornado spectral signatures would be seen before significant shear is noticeable between adjacent radials. Nonetheless, we expect that at distant range the azimuthal shear will disappear before the wide spectrum (characteristic of tornadoes) is overwhelmed by contributions of air motions from the very large resolution volume.

e) Synthesis of improvements

Combined application of items a) through d) will amount to a quantum leap in data quality and utility of weather radar, but not without a peril. Although each improvement is relatively simple the whole is much more complex than the sum of parts. Thus, each part has to fit harmoniously without inadvertent damage to other functions. This can be easily tested on existing time series data. Furthermore, the signal processor must keep up with real time throughput which would increase by an order of magnitude when oversampling and dual polarization are implemented.

3. CONCLUDING REMARKS

The evolutionary and revolutionary advancements of the WSR-88D are well defined and will be implemented on the WSR-88D network by about 2010. We have outlined the significant ones which are being tested on time series data obtained with the KOUN research and development radar. Thereafter, much effort will be expended on automatic interpretation of radar data to pinpoint storm initiation, to detect weather hazards, and to quantify precipitation as well. Better radar observations might help solve the enigma of tornado genesis; search for definite precursors is ongoing and if successful it would increase lead time for tornado detection.

Forthcoming are other sophisticated uses of radar data, such as retrieval of near ground humidity or measurements of winds in not precipitating clouds and clear air. Possibly the greatest benefit to short term (up to couple of hours) prognosis of spatially small but intense convective hazards might ensue from skillful assimilation of polarimetric weather radar data into numerical prediction models. We submit that predicting flash floods in small hydrologic basins requires coupling of such numerical model with a distributed hydrologic model.