9.9 **RANGE AND VELOCITY AMBIGUITY MITIGATION ON THE WSR-88D: PERFORMANCE OF THE STAGGERED PRT ALGORITHM**

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1. INTRODUCTION

It is well known that for Doppler radars transmitting uniformly spaced pulses there is a coupling between the unambiguous range (r_a) and unambiguous velocity (v_a) given by $r_a v_a = c\lambda/8$, where c is the speed of light and λ is the radar wavelength. As shown by this relation, r_a or v_a can only be increased at the expense of a proportional decrease of the other. Because range and velocity ambiguity problems are coupled, this is a fundamental limitation: trying to overcome one tends to worsen the other.

The Radar Operations Center of the National Weather Service has sponsored the National Severe Storms Laboratory (NSSL) and the National Center for Atmospheric Research (NCAR) to develop methods for mitigating the effects of velocity and range ambiguities on the WSR-88D. NSSL has recommended a staggered pulse repetition time (PRT) algorithm for the second stage of deployment of range and velocity ambiguity mitigation techniques on the Open Radar Data Acquisition (ORDA) subsystem (Sachidananda et al. 2000). The algorithm is based on alternating PRTs and can replace the “batch mode” at intermediate elevation angles of the antenna beam. This paper shows the performance of the staggered PRT algorithm on weather data collected with NSSL’s KOUN radar in Norman, OK. Comparisons with existing “legacy” algorithms demonstrate the ability of the staggered PRT algorithm to effectively mitigate range and velocity ambiguities in future enhancements of the NEXRAD radar network.

2. WSR-88D RANGE AND VELOCITY AMBIGUITY MITIGATION

The possibility of range overlay and velocity aliasing in the WSR-88D has been well recognized, especially when observing widespread severe phenomena involving large wind speeds. Accordingly, several mechanisms have been provided to alleviate ambiguity problems. Of interest here are those methods lying in the signal processing domain and which are currently implemented in the WSR-88D RDA subsystem.

At the lowest elevation angles (< 2.5 deg), the WSR-88D typically performs two scans at each elevation angle. Each set of scans at the same elevation is usually referred to as a “split cut”. The first scan uses a long PRT and produces power estimates (reflectivity) up to r_a = 460 km. Doppler velocity estimates from this scan are useless due to their low maximum unambiguous velocity (about 9 m s^{-1}). The other scan at the same elevation angle uses a short PRT (r_a = 148 km) and produces (range folded) unambiguous velocities in the range up to v_a = 28 m s^{-1}. Signal processing algorithms in the WSR-88D’s RDA use the long-PRT power data to place velocity estimates from the short-PRT scan to the proper range location for the strongest trip only. However, this algorithm fails in regions where the strongest overlaid power in the short-PRT scan is within 5 dB of the sum of the weaker overlaid powers; note that trips with weaker overlaid powers are never recovered. Base data displays characterize this failure by encoding those range bins with unrecoverable overlaid powers using a purple color, often referred to as the “purple haze”.

At intermediate elevation angles, where clutter rejection requirements are less stringent, it is not necessary to run two scans at the same elevation angle. In these cases, the WSR-88D reduces the time by running just one scan in the “batch mode” whereby long-PRT and short-PRT batches of pulses are interlaced. Analogously to the split cut processing, powers obtained from pulses at the long PRT (r_a > 233 km) are used to unfold velocities from the short-PRT batch (v_a = 28 m s^{-1}). Unfortunately, as indicated above, not all overlaid powers can be recovered. As a result, it is typical to have significant areas of the velocity field obscured by the purple haze during the observation of weather phenomena.

At high elevation angles the occurrence of ambiguities is unlikely since storm tops do not exceed heights of about 18 km. Therefore, the system can safely operate at shorter PRTs providing larger Doppler velocity aliasing intervals without the risk of range overlays.

As will be shown later, even after applying the technique described above, Doppler velocities and spectrum widths in the WSR-88D can become severely obscured with purple haze. Over the last decade, two techniques have emerged as viable candidates to address the mitigation of range and velocity ambiguities in the WSR-88D (Zrnić and Cook 2002). These are: systematic phase coding and staggered PRT. The two techniques are complementary given that they offer advantages at specific elevation angles; hence, they can be simultaneously incorporated into the same volume coverage pattern (VCP). SZ phase coding has been selected as the first of these to be implemented in the upcoming ORDA (Torres 2005). Staggered PRT is

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currently being evaluated for implementation in subsequent updates of the network.

3. THE STAGGERED PRT ALGORITHM

The staggered PRT technique was first proposed in the context of weather surveillance radars by Sirmans et al. (1976). With this technique, transmitter pulses are spaced at alternating PRTs, T_1 and T_2, and pulse-pair autocorrelation estimates are made independently for each PRT. These estimates are suitably combined so that the effective maximum unambiguous velocity can be extended to $v_a = m\lambda/4T_1 = n\lambda/4T_2$, where the stagger PRT ratio is given by $T_1/T_2 = m/n$ (m and n are integers) and λ is the transmitter wavelength. In addition, the maximum unambiguous range is $r_a = cT_1/2$, corresponding to the shorter PRT (c is the speed of light). At the core of this technique is the generalized velocity dealiasing algorithm (Torres et al. 2004); to determine the Nyquist interval of the true velocity, it uses the fact that Doppler velocities obtained from the short and long PRTs alias in different ways.

The implementation of the staggered PRT technique on weather radars had been disqualified mainly due to the difficulties in designing efficient ground clutter filters. Recently, Sachidananda and Zrnic (2002) proposed an efficient clutter filter for staggered pairs that achieves clutter suppressions on par with those obtained for uniformly spaced samples.

The recommended algorithm incorporates both the generalized velocity dealiasing algorithm and the efficient ground clutter filter alluded above.

4. REPLACING THE BATCH MODE

Factors needing consideration in designing a staggered PRT algorithm that can potentially replace the current batch mode include: (1) system limits, (2) range coverage, (3) design considerations, and (4) errors of estimates.

The staggered PRTs must be chosen such that maximum and minimum PRT limits are not exceeded. The minimum PRTs in the system are governed by the transmitter maximum duty cycle; the maximum PRT might be limited by the sampling rate and the allocated memory storage in the signal processor. Additionally, range coverage provided by the chosen PRTs should meet NEXRAD requirements (different for reflectivity and velocity/spectrum width). However, NEXRAD requirements of range coverage can be relaxed by assuming the maximum height of storms as 18 km (Fig. 1). Next, a PRT ratio of 2/3 is preferred for optimum performance of both the generalized velocity dealiasing algorithm and the spectral ground clutter filter. Also, the acquisition time which is dictated by the antenna rotation rate, must be maintained. This means that same or shorter dwell times must be used. Finally, the number of pulses in the dwell time must be sufficient to produce estimates with acceptable errors.

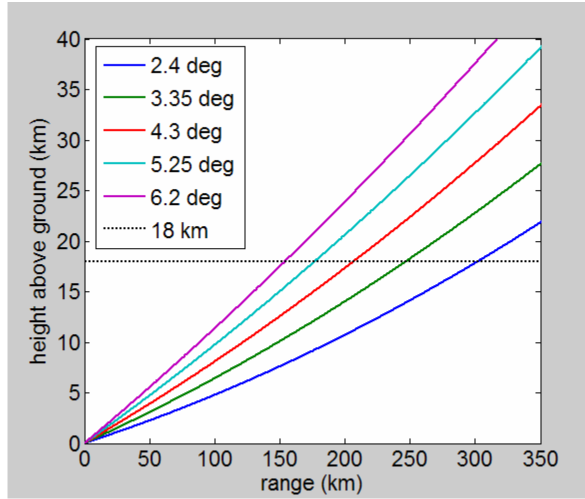

Fig. 1. Required maximum range coverage for different antenna beam elevation angles assuming maximum height of storm tops at 18 km (~59000 ft). Depicted antenna elevation angles are typically processed using the WSR-88D batch mode.

5. EXPERIMENTAL RESULTS

Staggered PRT time-series data was collected on March 3, 2004 at 20:25 UTC using NSSL's KOUN radar in Norman, OK. An experimental VCP was designed to compare the performance of the range and velocity ambiguity mitigation algorithms with the legacy "split cut" and "batch" processing modes. This custom VCP covers the lower three elevation angles and consists of groups of three scan types at each elevation angle. Each group contains a legacy WSR-88D scan (split cut or batch), a phase-coded scan, and a staggered PRT scan.

To compare the batch mode with the staggered PRT technique we focus on the scans at 2.5 deg of elevation. The two PRTs in the batch mode are T_{surv} = 3.11 ms (r_a = 466 km), and T_{dopp} = 0.98 ms (r_a = 175 km), with alternating batches of 6 and 41 samples respectively. The staggered PRTs are T_1 = 1.23 ms (r_a = 184 km) and T_2 = 1.84 ms (r_a = 276 km) giving a PRT ratio of 2/3. The number of staggered pairs in the dwell time is M_p = 20 (yielding approximately the same dwell time as with the batch mode). The maximum unambiguous velocities are v_a = 28.8 m s^{-1} and v_a = 45.1 m s^{-1} for the batch mode and staggered PRT techniques, respectively.

Figures 2 and 3 show the reflectivity and Doppler velocity PPI displays corresponding to the batch mode. Figures 4 and 5 do the same for the staggered PRT. There is excellent agreement between the reflectivity fields obtained with the batch mode and staggered PRT. However, as expected, Doppler velocity displays obtained with legacy-type processing are obscured by the purple haze (overlaid echoes) and also show significant amount of velocity aliasing. On the other hand, the staggered PRT algorithm successfully recovers all velocities with no aliasing.

Additional cases with varied weather situations will be shown at the conference.

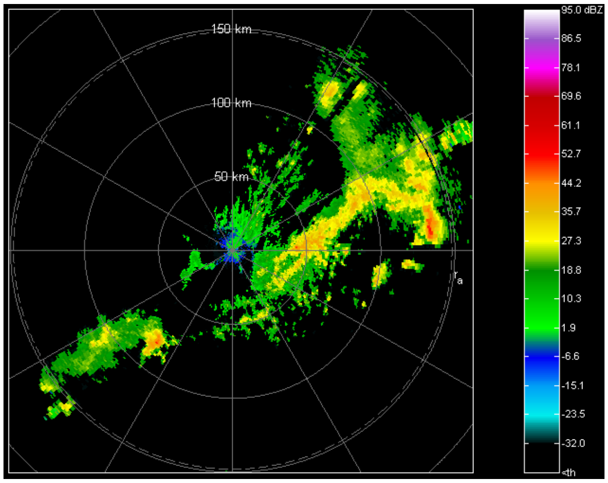

Fig. 2. Reflectivity field corresponding to the Batch mode (2.5 deg elevation). Range rings are 50 km apart.

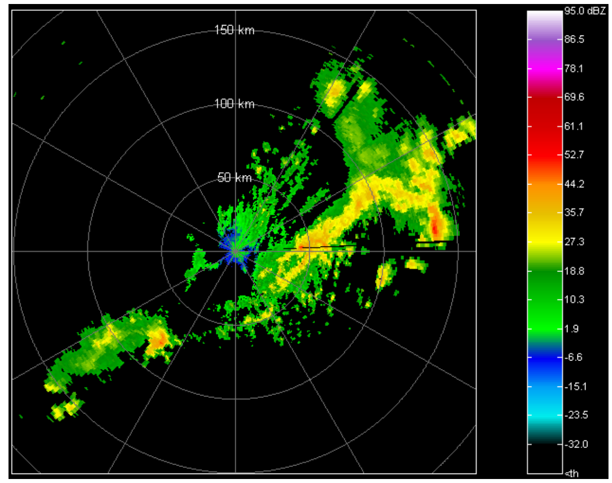

Fig. 4. Reflectivity field corresponding to the Staggered PRT algorithm (2.5 deg elevation).

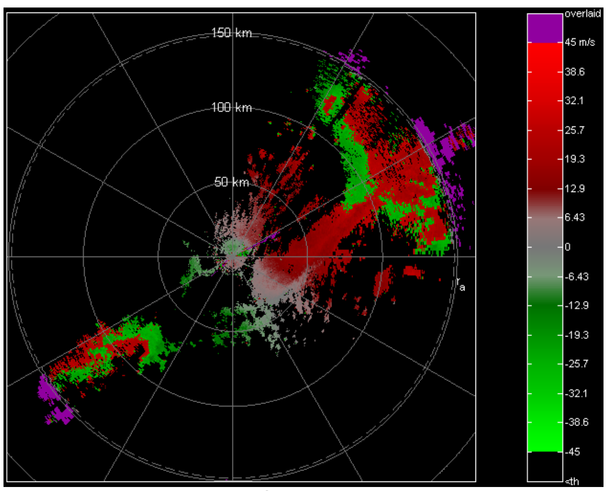

Fig. 3. Doppler velocity field corresponding to the Batch mode. Displays encode positive velocities (away from the radar) with red; more intense colors correspond to larger Doppler velocities. Purple indicates a non-recoverable overlaid return.

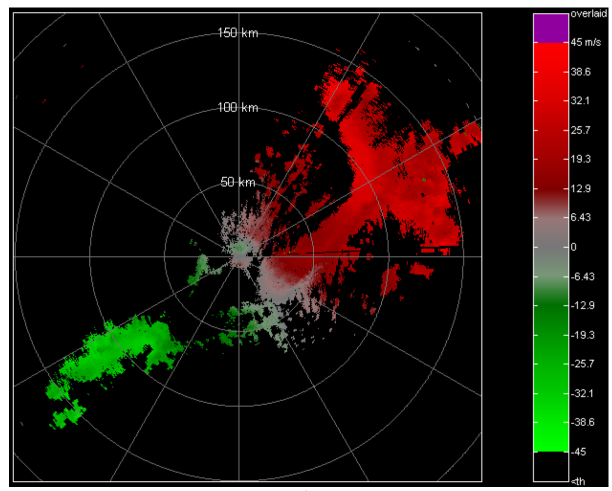

Fig. 5. Doppler velocity field corresponding to the Staggered PRT algorithm.

6. CONCLUSIONS

This work demonstrates the performance of the staggered PRT algorithm as proposed for its first implementation on the WSR-88D. Using NSSL's WSR-88D research radar and an experimental VCP, time series data were collected for comparing performance of the staggered PRT algorithm and the one obtained with current RDA techniques. The recommended algorithm was tailored to allow insertion into the ORDA signal processing pipeline and includes a spectral, map-based ground clutter filter. Preliminary tests indicate that the computational complexity of this method is well within the expected capabilities of the forthcoming ORDA. The results demonstrate that the staggered PRT algorithm mitigates range and velocity ambiguities more efficiently than legacy algorithms and therefore would be a very significant improvement in future enhancements of the national network of weather surveillance radars.

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