19.2 RANGE AND VELOCITY AMBIGUITY MITIGATION ON THE WSR-88D: PERFORMANCE OF THE SZ-2 PHASE CODING 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. In a joint effort, NSSL and NCAR have recently recommended an algorithm for the initial deployment of range and velocity ambiguity mitigation techniques on the Open Radar Data Acquisition (ORDA) subsystem. The algorithm, referred to as SZ-2, is based on systematic phase coding that uses the SZ(8/64) code and will replace the Doppler half of split cuts at the lowest elevation angles of the antenna beam. This paper shows the performance of the SZ-2 algorithm on weather data collected with NSSL's KOUN radar in Norman, OK. Comparisons with existing "legacy" algorithms demonstrate the ability of the SZ-2 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, 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. 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 RDA use the long-PRT power data to place velocity estimates from the short-PRT scan to the proper range location. However, this algorithm fails in regions where the overlaid powers in the short-PRT scan are within 5 dB of each other; it also fails to restore the weaker power if it is outside this range. Base data displays characterize this failure by encoding those range bins with overlaid powers using a purple color, normally 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. 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.

3. THE SZ-2 PHASE CODING ALGORITHM

As will be shown in the next section, even after applying the described techniques, 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

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phase coding has been selected as the first of these to be implemented in the upcoming ORDA.

3.1. *SZ systematic phase coding*

Sachidananda and Zrnić (1999) proposed the SZ phase code as a better alternative to random codes. SZ phase coding is similar to random phase coding except that the transmitted pulses are phase-modulated with a systematic code consisting of M phases that repeat periodically. These codes exhibit properties that make them attractive for the separation (in the spectral domain) of overlaid signals. If the received signal is cohered for a given trip, the spectra of all out-of-trip echoes consist of evenly spaced replicas of their corresponding coherent spectra. Hence, out-of-trip echoes do not bias the mean Doppler velocity estimate of the coherent signal. Once the velocity is recovered for the strong-trip, the coherent signal is notched out such that the two least contaminated replicas of the out-of-trip (i.e., the weak trip) echo remain. These two replicas are enough to reconstruct (or "recohere") the weak-trip echo and recover its mean Doppler velocity. From the family of SZ(n/M) codes, the SZ(8/64) code gives the best performance in terms of recovery of overlaid trips (Sachidananda et al. 1998).

3.2. *The algorithm*

Recovery of strong and weak trip signals can proceed in a stand-alone manner (referred to as the SZ-1 algorithm) or with the aid of an extra scan (at the same elevation angle) using a long PRT (referred to as the SZ-2 algorithm). Although the latter requires an additional scan (similarly to the split cuts described above), long-PRT data provides non-overlaid power information that is essential in the determination of the location and strength of overlaid trips during the short-PRT scan. Having the long-PRT information available makes the SZ-2 algorithm computationally simpler and more effective than its stand-alone counterpart. Whereas the long-PRT data provides the reflectivity and spectrum widths free of range ambiguities, the short-PRT data is used to compute Doppler velocities associated with the two strongest overlaid signals and the spectrum width associated with the strongest signal.

The proposed SZ-2 algorithm uses the GMAP spectral clutter filter available in the ORDA (Siggia, and Passarelli 2004) and can handle ground clutter or AP clutter in any of the possible trips. Lastly, the algorithm incorporates a set of censoring rules to maintain data quality under situations that preclude the recovery of one or more overlaid echoes.

4. EXPERIMENTAL RESULTS

SZ phase coded data was collected using NSSL's KOUN radar in Norman, OK. An experimental VCP was designed to compare the performance of the SZ-2 algorithm with the legacy split cut processing. The VCP covers the lower elevation angles and consists of groups of five scans at each elevation angle. Each group contains a non-phase-coded long-PRT scan, phase-coded and non-phase-coded medium-PRT scans, and phase-coded and non-phase-coded short-PRT scans.

The case in Fig. 1 was obtained on October 8, 2002 at 15:11 GMT. KOUN operated with the experimental VCP described above. The long, medium, and short PRTs are T_{long} = 3.107 ms (r_a = 466 km), T_{medium} = 1.17 ms (r_a = 175 km), and T_{short} = 0.78 ms (r_a = 117 km). The number of pulses in the dwell time is M = 15 for the long PRT and M = 64 for the medium and short PRTs. The corresponding maximum unambiguous velocities are v_a = 23.75 m s^{-1} and v_a = 35.52 m s^{-1} for the medium and short PRTs, respectively.

Figure 1 shows the reflectivity PPI display from the first scan that uses a long PRT at an elevation angle of 0.5 deg. Figures 2 and 3 contain the Doppler velocity PPI displays obtained using legacy and SZ-2 processing for the medium and short PRTs at the same elevation angle. As expected, Doppler velocity displays obtained with legacy-type processing are significantly obscured by the purple haze which indicates the presence of unresolvable overlaid echoes. On the other hand, the SZ-2 algorithm successfully recovers velocities of the two strongest overlaid echoes.

An additional limitation observed in these figures is that all NEXRAD radars currently display velocities only up to 230 km; with the SZ-2 algorithm velocities can be displayed up to about 460 km. Whereas velocity estimates agree quite well in places where both legacy and SZ-2 processing show valid data, estimates obtained with the SZ-2 algorithm can exhibit larger errors in places of low SNR and/or strong overlay and therefore are censored.

In general, range and velocity ambiguity mitigation schemes work better with longer PRTs because overlaid echoes are more likely to occur with shorter PRTs. This is evident when comparing Figures 2.b and 3.b. Using the short PRT provides the largest maximum unambiguous velocity but also leads to cases with triple overlay from which only two trips can be resolved. Using the medium PRT leads to a smaller v_a but at most two trips are overlaid at any given range location.

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

5. CONCLUSIONS

This work demonstrated the performance of the SZ-2 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 SZ-2 algorithm and the one obtained with the current RDA techniques. The recommended algorithm was tailored to allow insertion into the ORDA signal processing pipeline and includes the GMAP 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 SZ-2 algorithm mitigates range and velocity ambiguities more efficiently than legacy algorithms and therefore will be a very significant improvement in future enhancements of the national network of weather surveillance radars.

6. REFERENCES

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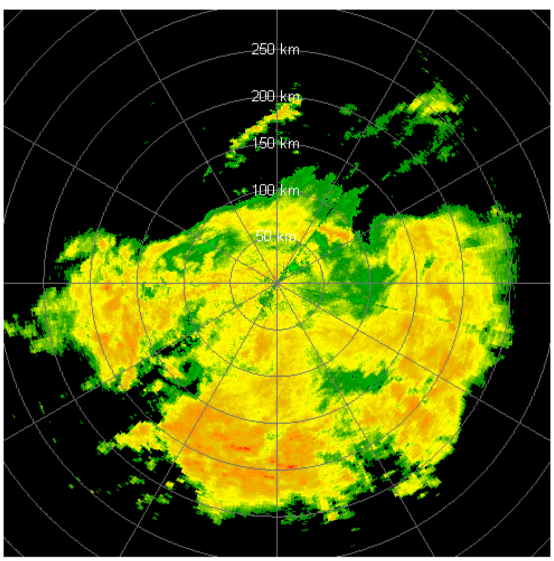
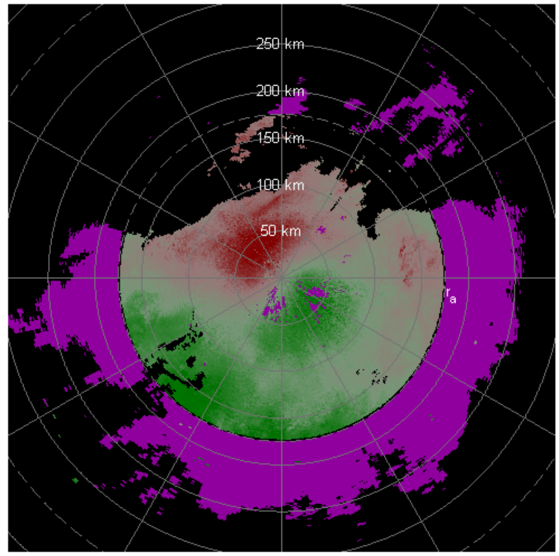
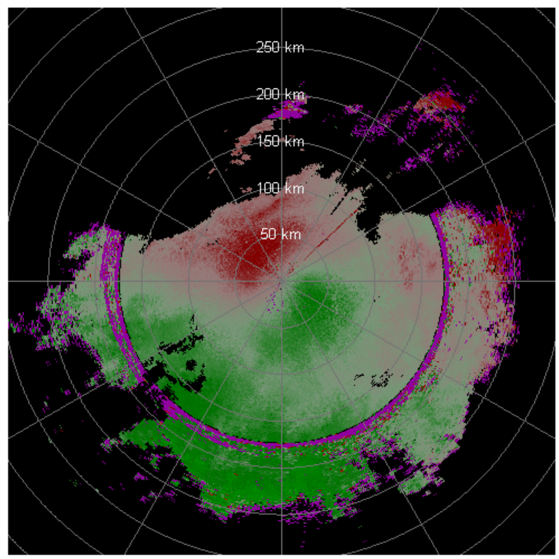


Fig. 1. Reflectivity field corresponding to the long PRT. Range rings are 50 km apart.

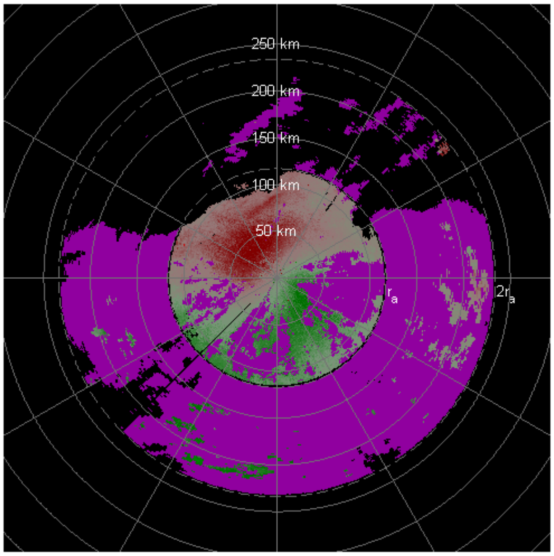


(a)

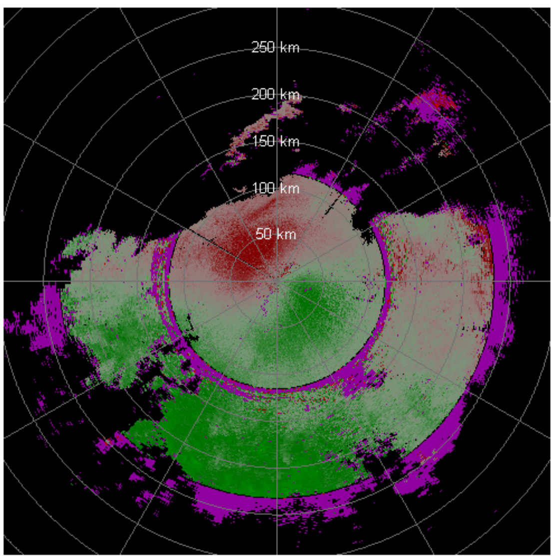


(b)

Fig. 2. Doppler velocity fields corresponding to the medium PRT using (a) legacy processing and (b) the SZ-2 algorithm. 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.



(a)



(b)

Fig. 3. Doppler velocity fields corresponding to the short PRT using (a) legacy processing and (b) the SZ-2 algorithm.