Concept of Operations For the SZ-2 Range-folding Mitigation Technique

W. David Zittel, ROC Applications Branch

1. Overview of SZ-2.

SZ-2, a modified version of the Sachidananda/Zrnic SZ (8/64) algorithm, is used to mitigate range folding commonly referred to as "purple haze" in conjunction with a high PRF such as 8 (~1300 Hz, unambiguous range of 63 n mi, and Nyquist velocity of ~34 m s^{-1}) to mitigate velocity dealiasing errors. Remember that with a high PRF, microwave energy from previous pulses may be mixed in with microwave energy from the current pulse. Energy from previous pulses is referred to as second trip, third trip echo etc., while energy from the current pulse is referred to as first trip echo. SZ-2 examines energy from up to four trips but for simplicity we will consider echo from just the first two trips. To separate out the first trip from the second trip echo, SZ-2 uses a sequence of eight modulation phases to change the transmitted phase of each succeeding radar pulse. Each sequence is rotated 90 degrees. The resulting transmitted pulse train repeats every 32 pulses. Sixty-four pulses are used to reduce variance of the estimate. By changing the phase of succeeding pulses SZ-2 can separate first trip from second trip echo. The algorithm first determines which of the trips has the stronger echo, It subtracts (or coheres) the phase sequence for both the first and the second trip echo from the return signal time series data and computes an autocorrelation value for each. The time series data with the higher autocorrelation value contains the strong trip echo from which SZ-2 computes the Doppler moments. Next, SZ-2 converts the time series data to the frequency domain and notches out the strong trip velocity. After returning to time series data, SZ-2 coheres to the weak trip echo and computes its Doppler moments. Because of the possibility of signal contribution from third and fourth trip echo when using high PRFs, the original SZ (8/64) algorithm was modified to use a surveillance scan to assign energy to the appropriate trip, hence the designation SZ-2. (Use of a surveillance scan follows the same pattern as the WSR-88D VCPs' split cuts.)

For each bin, windowing is performed on the time series data depending on the combination of clutter and weather signal present. Where there is clutter present a Blackman window is used, where there is range-overlaid weather signal the Von Hann window is used, and where there is only weather signal the Hamming window is used. The last is defined as the "default" ORDA window. Use of the windows increases the variance of the estimates for both velocity and spectrum widths. The Blackman filter, being the strongest, increases the variance by up to 50 percent, the Von Hann and Hamming windows increases variance by about 35 percent. (The default window may be changed to rectangular filtering in the future which doesn't increase the variance.) Clutter filtering that occurs in multiple trips is discussed under limitations.

2. Operational Considerations

Because SZ-2 is intended to reduce range folding, it is best suited to weather events with wide-spread coverage (e.g., tropical cyclones or mesoscale convective systems) or that have extensive length such as squall lines. It will also prove helpful when there are both enhanced clear-air returns near the radar after sunset and precipitation events away from the radar. The number of scans and rotation rates for

the three new SZ-2 VCPs match existing VCPs and so will not increase hardware component failure rates and may be used for the same types of weather events.

2.1 Volume Coverage Patterns

SZ-2 is being fielded with three new VCPs 211, 212, and 221. These VCPs have the same elevation angles and number of scans as the baseline ORDA VCPs 11, 12, and 21. For both VCP 211 and 221 SZ-2 processing is done at 0.50 and 1.45 degrees elevation. For VCP 212 SZ-2 processing is performed at 0.50, 0.90, and 1.30 degrees. (Figure 1 illustrates the coverage patterns.) Both VCPs 211 and 221 complete their volume scan in the same length of time as VCPs 11 and 21 which is five and six minutes, respectively. VCP 212 takes about 20 seconds longer to complete than VCP 12 but should still complete in about 4.5 min.

2.2 Limitations

2.2.1 Residual Range Folding

Despite its sophisticated signal processing SZ-2 does not completely eliminate range folding. The most common occurrence will be a band of "purple haze" at the start of second trip echo. This is most likely when there is a combination of ground clutter and weather in the first trip and also weather in the second trip. A second source of residual range folding occurs when the strongest echo lies in the third or fourth trips and there is also echo in the first and/or second trip. When that happens, the weaker signals in the first and second trip will be displayed as range-folded. Generally, VCP 221 which has the longest range to the end of first trip is least contaminated by residual range folding while VCP 211 which has the shortest range to the end of first trip is most contaminated by residual range folding.

2.2.2 PRFs For Split Cuts for SZ-2 VCPs Cannot Be Changed

The WSR-88D baseline system allows users to select a different PRF in each of three azimuthally defined sectors for Doppler scans in the precipitation mode VCPs 11, 12, and 21. If the Auto PRF function is enabled, it too, may change PRFs in the Doppler scans. However, the SZ-2 VCPs are restricted to just one preconfigured PRF at the low-level elevations where SZ-2 processing is used. Elevation cuts above the lowest two (three for VCP 212) do not have that restriction and can be edited by the user or allowed to change as the Auto PRF function dictates. SZ-2 VCP 211 uses PRF 8 (unambiguous range of ~63 n mi), SZ-2 VCP 212 uses PRF 6 (unambiguous range of ~74 n mi), and SZ-2 VCP 221 uses PRF 5 (unambiguous range of ~79 n mi).

The reason for the PRF restriction is due to a requirement for 64 pulses. In the baseline WSR-88D system the rotation rate is invariable for any given scan. When a PRF changes, the number of pulses is adjusted to fit within one degree. However, the 64 pulse requirement for SZ-2 forces the use of only one PRF. Thus, to achieve PRF diversity three VCPs were created. The ability to change the rotation rate may be added to the WSR-88D system in the future.

2.2.3 "All Bins" Clutter Filtering

"All Bins" cluttering filtering works differently with SZ-2 than it does with the baseline ORDA processing. Normally, when a WSR-88D user downloads an "All Bins" clutter filtering map to the ORDA, the GMAP clutter filter is applied to each bin whether or not there is ground clutter or anomalous propagation (AP) in that bin. By contrast, the SZ-2 algorithm does not apply GMAP everywhere. Where there is truly clutter in multiple trips, SZ-2 cannot separate the first trip from the second trip signal. To work around this limitation, if the clutter map indicates there is clutter in multiple trips, SZ-2 checks the clutter to signal ratio (CSR) applied to the surveillance scan. Where the CSR exceeds 15 dB, clutter is assumed to be present in the Doppler scan. Otherwise, SZ-2 assumes there is no clutter or AP present and does not apply GMAP. Unfortunately, some clutter and AP may not be filtered out and velocities and spectrum width may be biased towards zero because the signal retains the spectral component of the stationary clutter/AP. Users are highly encouraged to avoid using the "All Bins" clutter filtering option with SZ-2 VCPs.

2.2.4 Clutter Censor Zones

Use clutter censor zones with care. For example, a bypass map used in conjunction with a clutter censor zone that starts at the beginning of second trip echo will cause the SZ-2 algorithm to invoke the same CSR test as it uses with "All Bins" clutter filtering. SZ-2 will assume there is clutter in multiple Doppler trips. Likewise, a clutter censor zone of large radial extent (as long as or longer than the unambiguous range) will appear as clutter in multiple trips to the SZ-2 algorithm with or without a bypass map. See Section 2.2.5 Clutter Filtering Strategies.

2.2.5 Clutter Filtering Strategies

Generally the bypass map is recommended as the first choice for clutter filtering because the Blackman filter, used by GMAP wherever clutter is defined, increases the variance of the Doppler estimates by 50 percent. If extra censoring is needed because of AP, consider applying a clutter censor zone that extends only to the end of first trip. Such a clutter censor zone is shown schematically in Figure 2 as Clutter Censor Zone 1. For AP at far ranges consider using a censor zone that starts at a distance beyond the start of second trip that includes the depth of the ground clutter. In Figure 2 this is shown schematically as Clutter Censor Zone 2. For instance, if VCP 211 is being used, the unambiguous range is about 63 n mi. If ground clutter extends 25 n mi from the radar, then the clutter censor zone should start about 88 n mi. If AP extends beyond the first trip, consider using an alternate SZ-2 VCP with a greater range to the end of first trip (Figure 3).

2.3 SZ-2 Processing and Spectrum Width Estimates

Early in the development of the SZ-2 algorithm it was recognized that the variance of the spectrum width estimates from weak trip echo would be unacceptably high. To get around this limitation, the spectrum width is computed, instead, from the surveillance scan. Because of the low PRF used for the surveillance scan, the Nyquist velocity is about 11 m/s. The effective maximum meaningful value for the spectrum width is constrained to about 6 m/s in weak trip echoes. By design, if the computed spectrum width in weak trip exceeds 6 m/s for a particular bin, the bin is indicated as range folded. The consequence of this limitation is that there are more bins indicated as range folded for spectrum width data than for velocity data.

2.4 SZ-2 and Multiple PRF Dealiasing Algorithm Differences

The SZ-2 algorithm differs from the Multiple PRF Dealiasing Algorithm (MPDA) in a number of fundamental ways. The SZ-2 algorithm runs in the RDA and, as such, is the first of the long-term "hardware" solutions while the MPDA, the short-term "software" solution, runs in the RPG. Unlike the MPDA which acquires up to two extra Doppler scans using different PRFs via VCP 121, the SZ-2 algorithm requires no extra scans but instead uses sophisticated processing techniques. The MPDA combines the velocity data from the extra scans to reduce range folding and mitigate velocity dealiasing errors. First, it assumes that data that are range-folded in one PRF may not be range folded in another PRF. Secondly, it uses multiple velocity estimates from the same point in space to provide "seed" values to correctly dealias the rest of the velocity field. By contrast, the SZ-2 algorithm does no special processing to mitigate velocity dealiasing errors. It uses the standard velocity dealiasing algorithm. In fast moving or rapidly changing situations, the time required to acquire the scans for the MPDA may degrade storm circulation patterns. SZ-2 requires no extra Doppler scans. However, it may have problems identifying circulations that lie at the start of second trip due to residual range folding.

2.5 Tropical Cyclone Scenario for Using SZ-2 and MPDA

Because of their range folding reduction capability the SZ-2 algorithm and the MPDA provide the best area coverage of velocity data for large weather systems such as tropical cyclones. To consider which algorithm to use, we need to consider the operational limitations of each. MPDA works well out to about 95 n mi in reducing range folding. Beyond 95 n mi (unambiguous range of its lowest PRF) its performance is inconsistent. SZ-2 works well reducing range folding at the farthest ranges from the radar but has a range folded ring at the start of the second trip. Therefore, as the eyewall of a tropical cyclone first moves into range for velocity products, SZ-2 might provide more reliable velocity data. As the eyewall approaches the band of range folding in SZ-2, MPDA would provide a clearer image of velocity data. As the eyewall approaches the radar SZ-2 might again provide a clearer image because there would be less chance of degrading the pattern due to rapid changes in the viewing angle.

2.6 Engineering Change Proposal to Combine SZ-2 and Multiple PRF Dealiasing Algorithm

The Radar Operation Center's Applications Branch has developed and tested a change to VCP 121 (used with the Multiple PRF Dealiasing Algorithm) to add SZ-2 range folding mitigation. Because the SZ-2 algorithm runs in the RDA while the MPDA runs in the ORPG the two processes can be run sequentially to eliminate nearly all range folding. An Engineering Change Proposal is being prepared to test the modified VCP 121 at a number of sites after Build 9 is fielded.

3.0 Bibliography

Ice, R. L., R. Rhoton, D. S. Saxion, C. A. Ray, N. K. Patel, D. A. Warde, A. D. Free, O. E. Boydstun, D. S. Berkowitz, J. N. Chrisman, J. C. Hubbert, C. Kessinger, M. Dixon, S. Torres, 2007: Optimizing Clutter

Filtering in the WSR-88D, 23rd International Conference on Interactive Information Processing Systems for Meteorology, Oceanography, and Hydrology.

Passarelli, R., and A. Siggia, 2004, Gaussian Model Adaptive Processing for Improved Ground Clutter Cancellation and Moment Estimation, Third European Conference on Radar Meteorology and Hydrology.

Radar Operations Center Internal Document: Quick Reference VCP Comparison Table for RPG Operators.

Sachidananda, M., D. Zrnić, R. J. Doviak, and S. Torres, 1998: Signal Design and Processing Techniques for WSR-88D Ambiguity Resolution, Part 2

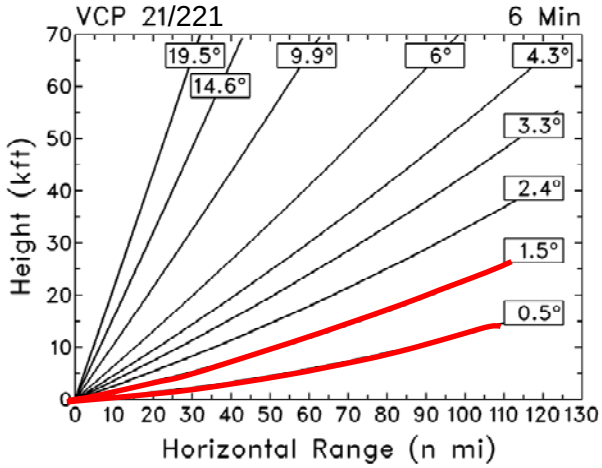
Saxion, D. S., R. Rhoton, R., G. T. McGehee, R. L. Ice, D. A. Warde, D. Sirmans, 2005: Radar Operation Center (ROC) Production Software Status for RV Ambiguity Mitigation, 21st International Conference on Interactive Information Processing Systems for Meteorology, Oceanography, and Hydrology.

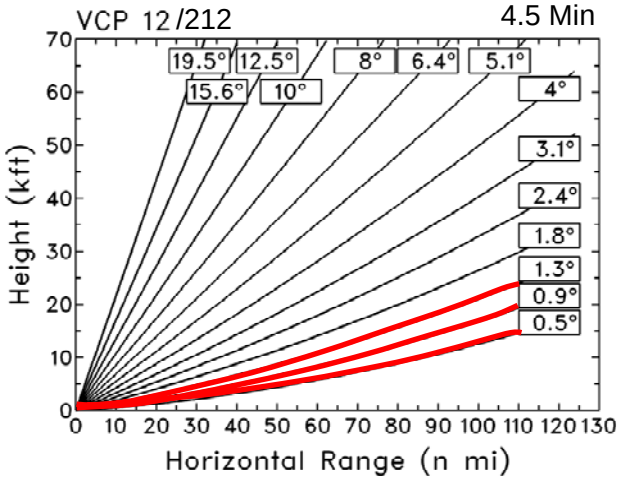
Saxion, D. S., R. D. Rhoton, R. L. Ice, G. T. McGehee, D. A. Warde, O. E. Boydstun, W. D. Zittel, S. Torres, G. Meymaris, 2007: New Science for the WSR-88D: Implementing a Major Mode On the SIGMET RVP8, 23rd International Conference on Interactive Information Processing Systems for Meteorology, Oceanography, and Hydrology.

Zrnic, D., S. Torres, J. Hubbert, G. Meymaris, S. Ellis, M. Dixon, 2006: NEXRAD Range-Velocity Ambiguity Mitigation, SZ-2 Algorithm Recommendation. WSR-88D Radar Operation Center Engineering Branch Publication.

Figure 1. This figure shows graphically (red lines) the angles where SZ-2 processing is performed for VCP 212 (lower left), VCP 211 (lower right) and VCP 221 (upper right).

Standard WSR-88D VCPs and SZ-2 VCPs have the same angles. SZ-2 processing is done only on Doppler cuts associated with a surveillance scan.





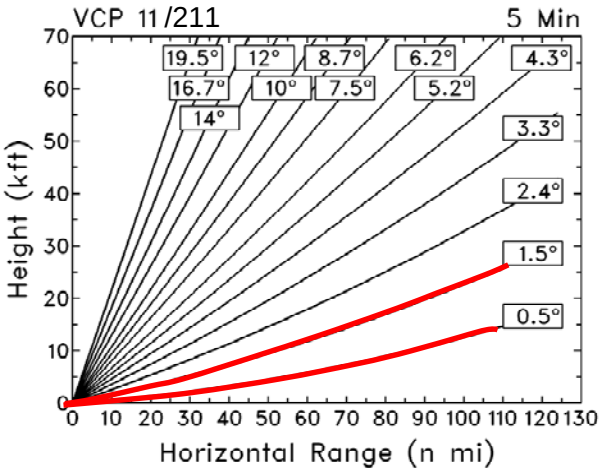


Figure 2. This figure shows schematically two configurations in VCP 211 where clutter censor zones could be used to mitigate anomalous propagation labeled as AP below (shaded light blue). Range to the end of first trip is R_a or about 63 n mi. Range of coverge is 125 n mi. The first clutter censor zone is bounded by points abcd (shaded light red) and the second clutter censor zone is bounded by points efgh (shaded pink). A bypass clutter map is applied to the area labeled as Ground Clutter (shaded light blue). Note the second clutter censor zone starts beyond the unambiguous range R_a plus the extent of the ground clutter.

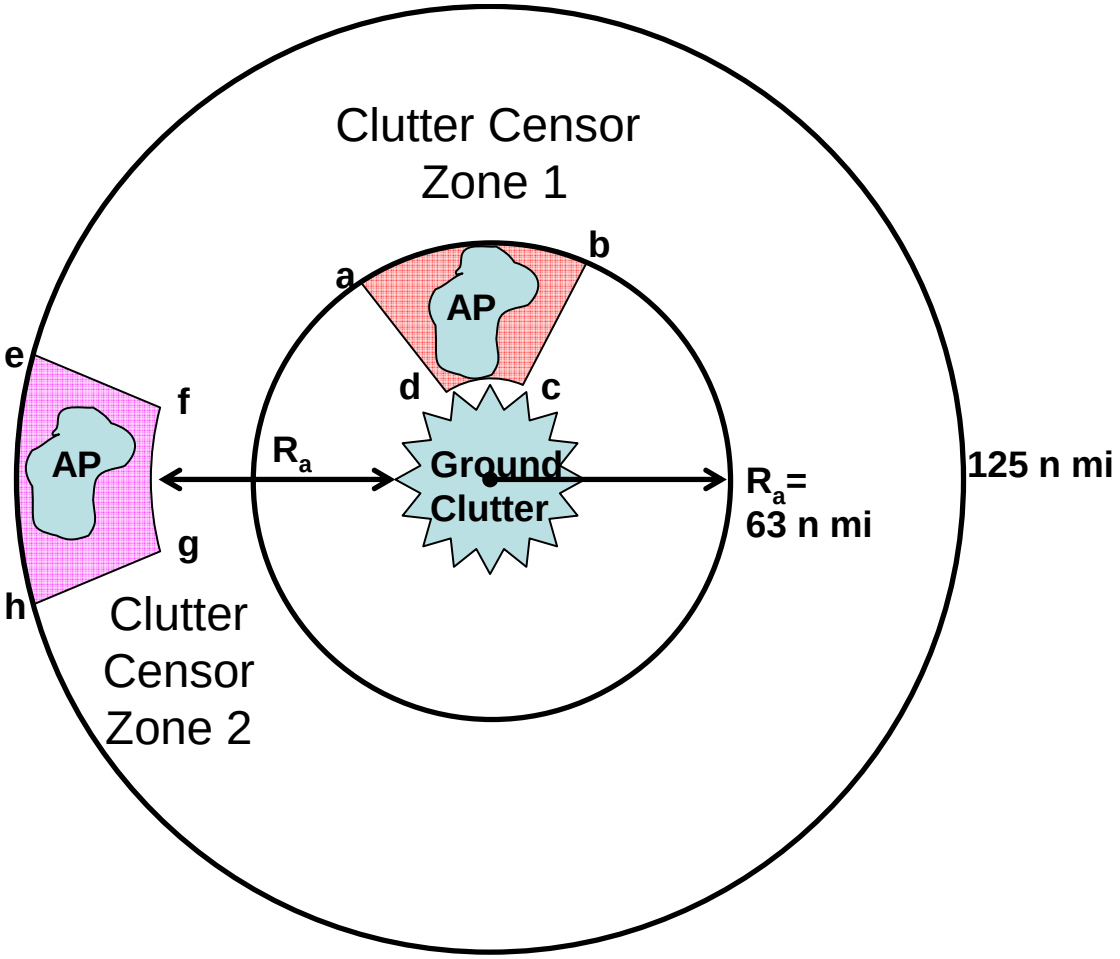
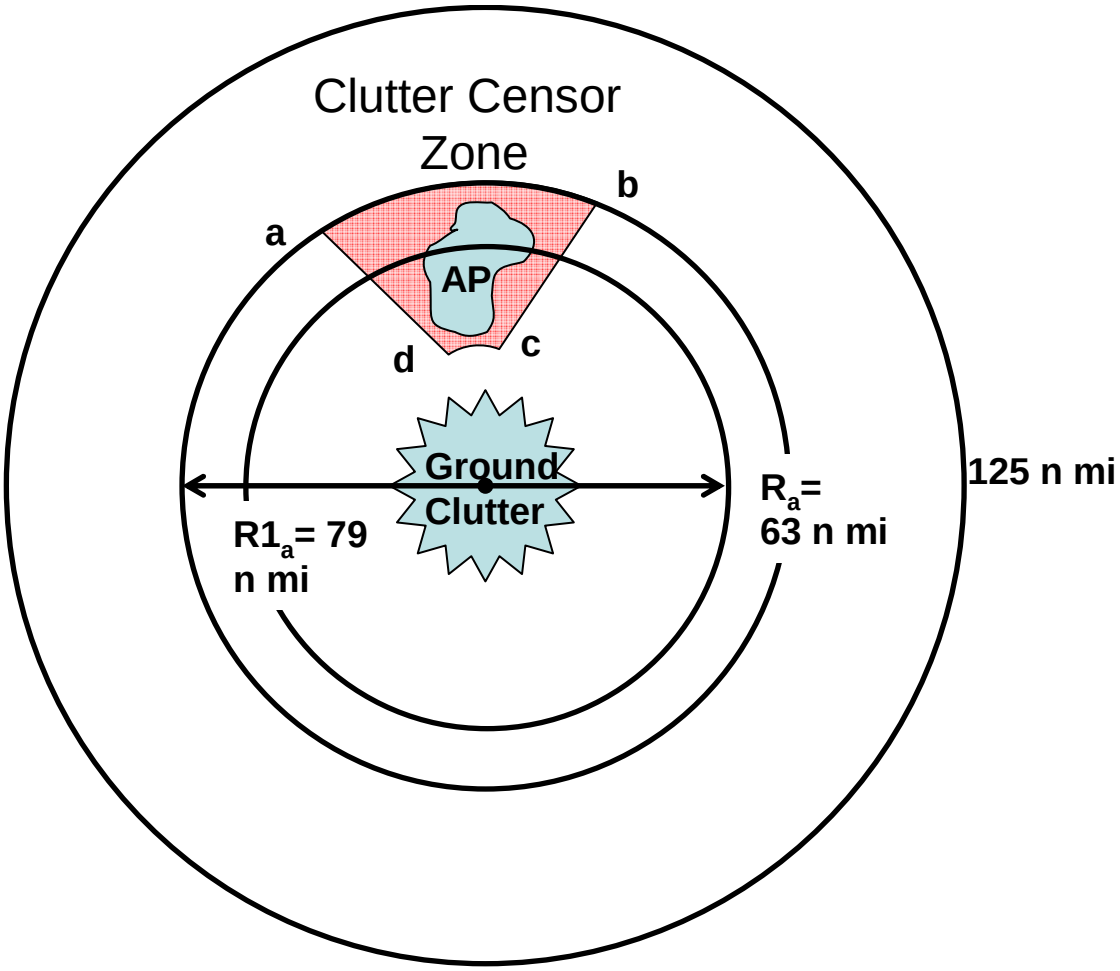



Figure 3. This figure shows schematically an area of anomalous propagation labeled AP (shaded light blue) that extends beyond VCP 211's unambiguous range of 63 n mi labeled R_a. In VCP 221 the range to then end of first trip is 79 n mi labeled $R1_a$, which lies beyond the AP region. The greater unambiguous range in VCP 221 allows the use of a clutter censor zone (defined by points abcd and shaded light red) without compromising data quality.