12B.5

RANGE AMBIGUITY MITIGATION FOR NEXRAD USING SZ PHASE CODING

Charles L. Frush
NCAR/ATD/Remote Sensing Facility
Boulder, Colorado 80307
and
R. J. Doviak
NOAA/NSSL
Norman, Oklahoma 73069

Introduction

A search for better methods to reduce range velocity ambiguity in the WSR-88D radar has resulted in the development of a set of systematic phase code sequences known as SZ codes by the National Severe Storms Laboratory in Norman, OK (Sachidananda et al., 1998). A testbed WSR-88D (KOUN) located in Norman, Oklahoma and operated by NSSL was equipped by the National Center for Atmospheric Research with the necessary hardware to transmit SZ phase coded pulse sequences and to record I, Q time series data (i.e., Archive-1). The KOUN radar was used in May 1997 to record echoes from a distant squall line and a closer isolated thunderstorm that produced range overlaid echoes. (See figure 1.) This data set has been used to evaluate the performance of the SZ phase coding method for separating echoes from adjacent trips. Processing the data with different filtering strategies results in separation performance which differ depending on whether the emphasis is on best separation, or best velocity estimates. This suggests that adaptive processing, with processing parameters depending on the characteristics of the received echoes, and the desired product will yield the best results.

1. Background

Under the condition of overlaid multiple trip echoes, the present WSR-88D signal processing yields highly censored data. In the case analyzed here, about 90% of the data in a sector was censored. By phase coding the transmit pulse with the SZ(8/64) code, and processing the time-series data with a newly developed algorithm to separate the trip-1 and trip-2 echoes, we have unraveled the velocity fields from the respective storms. Doppler velocity fields of overlaid echoes can be separated even when the weaker echo field is 30-40 dB below the stronger one. Using the developed algorithms to process SZ coded data, it appears that almost all of the regions previously censored by the existing WSR-88D signal processor have recoverable velocities. Reflectivity is more difficult to separate. By using a wider SZ filtering notch, better separation is obtained, but at the expense of larger standard errors in the estimates of Z and V.

Corresponding author address: Charles L. Frush, National Center for Atmospheric Research, Boulder, CO 80307
e-mail: frush@ucar.edu

When the spectrum width of the competing echo is very narrow, accurate reflectivity estimates can be obtained even for weak signals that would be masked by 40 dB stronger competing echoes, if a separation algorithm was not used. The use of the SZ echo separation algorithm effectively removes the effects of trip-1 ground clutter on most trip-2 power estimates.

2. How SZ phase coding works

The SZ(8/64) code minimizes the correlation of adjacent-trip return echoes using a 32-pulse repeating sequence. In this weather signal separation scheme, a chosen echo (i.e., a 2nd trip echo) spectrum is first "whitened", by creating eight spectral replicas evenly spaced in the radar's Doppler frequency unambiguous interval. This is achieved by "cohering" the phase coded signal for the competing (1st trip) echo. When cohered, the competing echo appears as a single spectrum. Normal (i.e., pulse pair) processing is used to estimate the Doppler velocity of this cohered but unwanted echo. This velocity estimate is then used to center a notch filter (typically 25%, 50%, or 75%) on the unwanted echo. When this stronger echo is filtered, the weaker second trip spectrum (spread into eight replicas, with four replicas now removed), can be reconstructed from the remaining replicas. Then the resulting signal is re-cohered for the 2nd trip causing any residue of the competing (1st trip) signal to be whitened. This process is illustrated in Figs. 2 and 3.

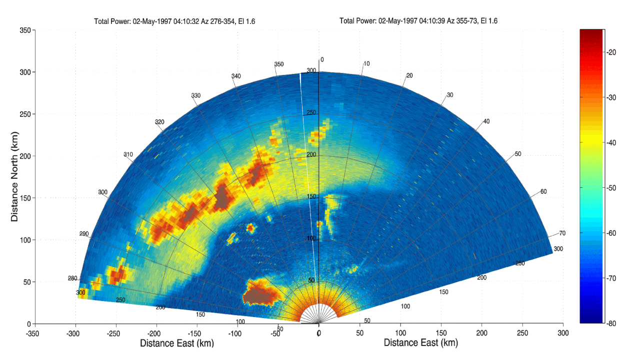

Fig. 1. Received power from long PRT 1.6 elevation scan using VCP21 on KOUN WSR-88D Testbed (Norman, OK) 2 May 1997.

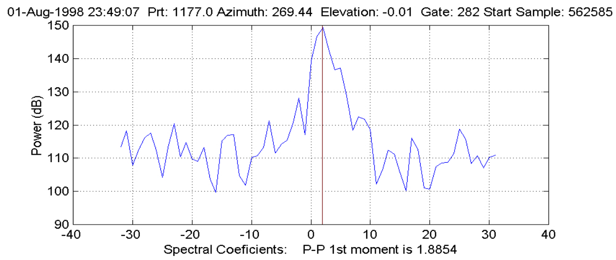

Fig. 2a. Spectrum for gate 282 after an SZ coded signal is decoded for trip-1. The eight replicas of the Trip-2 spectrum are masked by the stronger trip-1 spectrum. The vertical line marks the value of the lag-1 Pulse Pair estimate for this signal, when decoded for trip-1.

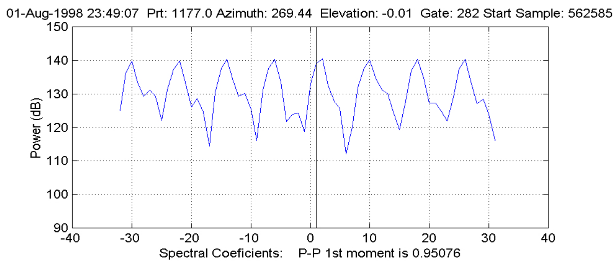

Fig. 2b. Spectrum for same gate, but with the signal decoded for trip-2. Evident are the spectral replicas of the trip-1 signal. The weaker trip-2 spectrum is almost completely masked by the stronger trip-1 replicated spectra.

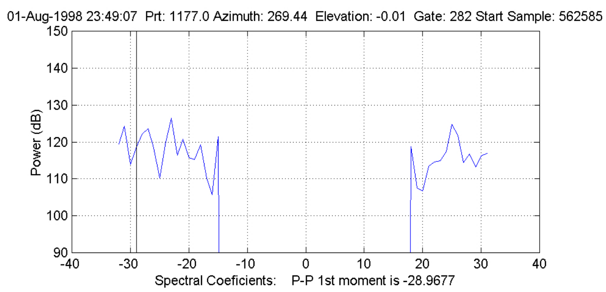

Fig. 3a. Same spectrum as in Fig. 2, with SZ notch filter removing 50% of the spectral coefficients centered around the PP mean velocity of the trip-1 decoded echo.

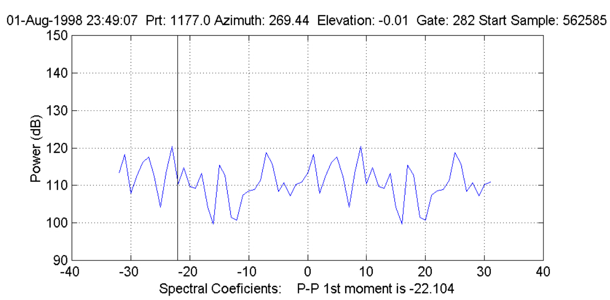

Fig 3b. The spectrum after substituting transformed replicas of the remaining spectral coefficients into the notch is shown here. The four remaining unfiltered trip-2 spectral replicas, (plus the spectral skirt of the cohered trip-1 echo), are transformed to make 4 more replicas to fill in the notch.

The data in Fig. 1 include echoes from clear boundary layer air, and a strong distant squall line which appears as a 2nd trip echo when the radar is operating at short PRT. In large areas, the 2nd trip echos are stronger than the 1st trip clear air returns. The NCAR/NSSL team developed algorithms used for decoding, filtering, and reconstruction appear to provide separation of trip-1 and trip-2 velocity data with very little ambiguity. Using this separation technique which selectively coheres the desired trip and removes much of the competing echo power, a good separation of 1st and 2nd trip echo power is usually obtained, except where the spectrum width of one of the echoes is either very wide, or otherwise “unusual”. We observe instances where the spectrum width of a competing echo is very large, is bimodal, or has a non-Gaussian shape, and in some of these instances, the residual power of the out-of-trip echo leaks into the currently processed trip at a level that may be only slightly less than it's unfiltered value. For most of the data analyzed, however, for which the spectrum widths and shapes are more typical, the competing echo power is suppressed by more than 20 dB. To the extent we can verify, the results match the expected performance from theoretical simulations.

The example shown in Figs. 2 and 3 illustrates how this method works on a trip-1 weather signal, with relatively narrow spectrum width, which overlays a weaker trip-2 signal. Figures 2a and 2b show the result of simply cohering the returned signal for trip-1 and trip-2. The filtering process that removes much of a competing trip echo power is illustrated in Figures 3a and 3b. The lag-1 Pulse Pair mean velocity of the signal, (cohered for the stronger of the overlaid echoes), is used to locate the center of a notch filter which removes 50% (in this example) of the spectral coefficients. In most cases this essentially eliminates the stronger echo power.

Next, the missing spectral coefficients are recreated by replicating the remaining spectral coefficients (Fig. 3b) which, in most cases, principally contain power of the weaker signal. The phases of the remaining complex spectral coefficients are required to assign the correct phase to the reconstructed spectral coefficient. If the spectrum in Fig. 3b is now transformed back into the time domain, and re-cohered for

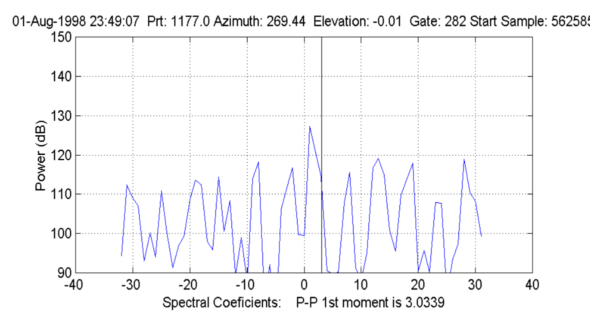

Fig. 3c. Filtered and reconstructed trip-2 spectrum after re-cohering for trip-2. Now, with most of the trip-1 energy removed, a weak trip-2 narrow weather spectra can be seen. (The trip-2 PP mean velocity estimate is slightly more positive than this peak, due to other weaker components of this spectrum.)

trip-2, the weak trip-2 echo spectrum can be seen now, since it is no longer overwhelmed by the power in trip-1 (Fig 3c).

3. Hardware requirements

In order to use the SZ phase code method to reduce range ambiguities, the radar must be fully coherent. This precludes the use of a magnetron output device in the radar transmitter. A microwave phase shifter is needed that is capable of being set to the desired phase angle settings required by the code. For the SZ(8/64) code, sixteen equally spaced phase angles are required. For good separation performance, it is important that the phase shifter produce waveforms that are highly repeatable, (e.g. angle errors less than 1 degree).

4. Test Results

The NCAR component of the Range/Velocity mitigation work has focused on acquiring and analyzing time series of I & Q samples from actual weather signals. We will show some of these results, but do not have much room here. See Figs. 4 , 5, and 6 for an example from S-Pol in Florida. More information can be found on the web at: http://www.atd.ucar.edu/atd_technical_info.html

5. Summary

The new SZ(8/64) code performed well on all cases studied. The method works best when the spectrum width of the weather echo is less than about 1/4th of the Doppler unambiguous interval. When the ratio of power in trip-1 and trip-2 becomes larger than 30 to 40 dB, the velocity estimates of the weaker echo will be noisy, or unusable. In this set of data, most of the trip-2 received power values were within 20 dB of the value in the corresponding gate for trip-1 which is substantially below this limit.

Within the limitations of a single radar for gathering data, we are highly encouraged by the results. They suggest that perhaps data lost due to ambiguity can be reduced by about a factor of ten, compared to the existing WSR-88D processing methods. It does require about 100 times more signal processing power, but this level of processing power seems attainable and affordable in the near future.

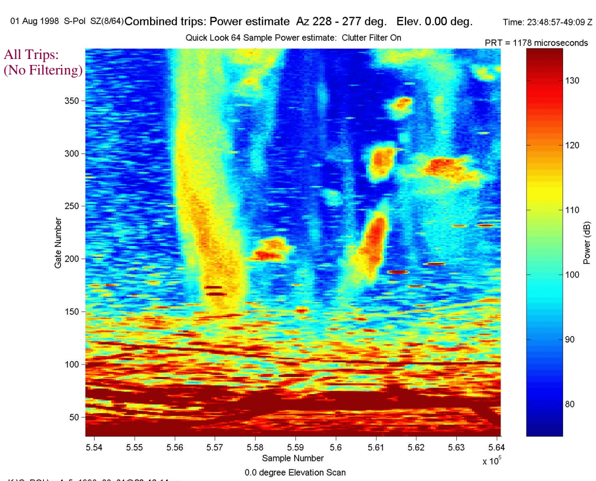

Figure 4. **Combined echoes from all trips from a zero degree elevation test scan using the NCAR S-Pol research radar.**

6. Acknowledgments

The authors would like to thank our NOAA/NSSL colleagues D. Zrnic, and M. Sachidananda for their theoretical work. We thank our NCAR colleagues Frank Pratte, Joe Van Andel, and Don Ferraro for their work on Archive 1 (I/Q) data acquisition at KOUN and S-Pol.

7. References

Frush, C., 1998: NEXRAD Range-Velocity: Exploring selected mitigation techniques. Second year report, prepared for the WSR-88D Operational Support Facility, Norman, OK, Dec. 1.

Sachidananda, M., D. S. Zrnic, R. J. Doviak, and S. Torres, 1998: Signal Design and Processing Techniques for WSR-88D Ambiguity Resolution, Part 2. National Severe Storms Laboratory, Norman, OK. 73069. June, 105 pp.

Siggia, A., 1983: Processing Phase-coded radar signals with adaptive digital filters. *21st Conference on Radar Meteor.*, Amer. Meteor. Soc., Boston, MA, 163-166.

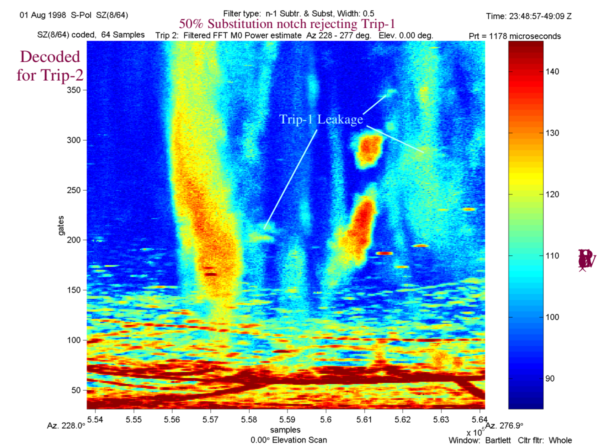

Figure 5. **Same S-Pol scan as Fig. 4, decoded and filtered for trip-2.**

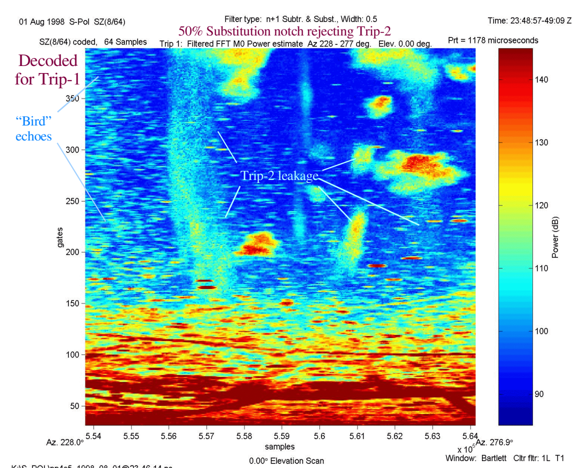

Figure 6. **S-Pol low elevation scan decoded and filtered for trip-1.**