NEXRAD Range-Velocity Mitigation:

SZ1 Comparison Study Report

Preparing for:
WSR-88D Operational Support Facility, Norman, Oklahoma

By:
Mike Dixon, Greg Meymaris, John Hubbert and Scott Ellis

National Center for Atmospheric Research, Boulder, Colorado
Atmospheric Technology Division (ATD)
Research Applications Program (RAP)

24 September 2004
NEXRAD Range-Velocity Mitigation:

SZ1 Comparison Study Report

Report on the study
of the comparison
between the
Sigmet SZ1 algorithm implemented on the RVP8
and the
NCAR-implemented SZ1 algorithm.

Document prepared for:

WSR-88D Radar Operations Center (ROC)
US National Weather Service
Norman, Oklahoma

By:

Michael Dixon, Greg Meymaris,
John Hubbert and Scott Ellis

National Center for Atmospheric Research (NCAR)
Boulder, Colorado *

* NCAR is operated by the University Corporation for Atmospheric Research.
* NCAR is sponsored by the National Science Foundation.
# Table of contents

**Executive Summary** ........................................................................................................... 1

1 **Introduction** .................................................................................................................... 2

2 **Goal of the study** ........................................................................................................... 2

3 **Obtaining the data for the study** ..................................................................................... 2

4 **Limitations of the data** ..................................................................................................... 3

5 **Case details** .................................................................................................................... 4

6 **Censoring** ....................................................................................................................... 5

7 **Moments computation methods** ..................................................................................... 5

8 **Histogram plots** .............................................................................................................. 6

   8.1 **Strong trip reflectivity, 2004 cases** .......................................................................... 7

   8.2 **Weak trip reflectivity, 2004 cases** ......................................................................... 9

   8.3 **Strong trip spectrum width, 2004 cases** ................................................................. 11

   8.4 **Weak trip spectrum width, 2004 cases** ................................................................ 13

   8.5 **Strong trip velocity, 2004 cases** .......................................................................... 15

   8.6 **Weak trip velocity, 2004 cases** ............................................................................. 29

9 **Summary** ........................................................................................................................ 36

10 **Conclusions** ................................................................................................................... 36

11 **Acknowledgements** ....................................................................................................... 37

12 **References** ..................................................................................................................... 37
13 Appendix A: PPI plots ............................................................................................................. 38
  13.1 All fields for case 20040328.23. .................................................................................... 38
  13.2 Reflectivity plots for all cases ....................................................................................... 47
14 Appendix B: Discussion of NCAR spectrally-based moments computations .......... 53
  14.1 The problem with NCAR-computed spectrum width ..................................................... 53
  14.2 Comparing the spectral method to the pulse-pair for velocity and width .................. 56
15 Appendix C: plots for 2003 cases ................................................................................ 58
  15.1 Strong trip reflectivity, 2003 cases ................................................................................. 58
  15.2 Weak trip reflectivity, 2003 cases ................................................................................ 60
  15.3 Strong trip spectrum width, 2003 cases ...................................................................... 62
  15.4 Weak trip spectrum width, 2003 cases ...................................................................... 64
  15.5 Strong trip velocity, 2003 cases .................................................................................. 66
  15.6 Weak trip velocity, 2003 cases .................................................................................. 72
Executive Summary

This report compares the Sigmet SZ-1 algorithm to the NCAR implemented SZ-1 algorithm which is based on Sachidanada’s (1998) SZ-1 algorithm. The algorithms are compared using phase coded experimental data collected by NCAR’s S-POL with an RVP8 receiver/processor. The experimental data consists of interleaved long- and short-PRT PPI scans which allow the SZ recovered moments (mean radial velocity as well as reflectivity and spectrum width) to be compared to long PRT moments. The moments are calculated via the playback feature of the ROC’s A1 recorder. This proved to be a difficult task. NCAR was unable to play back the experimental data through NCAR’s RVP8 due to several upgrades of RVP8 software/hardware which were incompatible with the A1 recorder. The solution was to use the ROC’s RVP8 which could run both SZ algorithms.

The compared data is not ideal: the beams are not indexed and the beam widths from the long and short PRT scans are not matched, both of which cause the compared moments to come from slightly different resolution volumes. The result of this is that scatter plots of compared moments have considerably more variance (scatter) than is to be expected. This increased variance does not, however, significantly affect the main conclusions of this study. If both clutter and weather are present in the radar returns, the mean estimates of the three used algorithms, Sigmet SZ-1, NCAR SZ-1 and long PRT, can be different due to the non-matched beams and due to the spectral moment estimation technique used by NCAR SZ-1 as opposed to the pulse pair technique by the Sigmet SZ-1 and the long PRT algorithms. These discrepancies are pointed out but again they do not affect the main conclusions of this report.

By-in-large the performance of the Sigmet and NCAR SZ-1 algorithm are very similar. There are some discrepancies but they may well be due to the non ideal data processing, phase noise of the system, minor censoring differences, or problems with moment estimation calculations rather than a significant difference in the two SZ-1 algorithms. In the NSSL’s Part 6 report (Sachidananda et al. 2002) simulations of the Sigmet SZ algorithms indicated that it produced a minus two m/s bias in weak trip velocity estimates. We found no evidence of this. We also found that the standard deviations of the estimated weak trip velocity were similar. The Sigmet algorithm did, however, produce some spurious velocity estimates. These regions from which they come are identified but the cause is unknown. The problem seems linked with low signal-to-noise ratios. We show that some of the bad velocity estimates can be eliminated with some simple image speckle filtering.

Thus, censoring and ultimate control of data quality are important reasons for the ROC to develop, implement and maintain its own SZ algorithm rather than rely on the Sigmet SZ algorithm. Programmers from the ROC, NCAR and NSSL have intimate knowledge of the SZ-1 algorithm, which importantly contains unique censoring schemes, and these organizations can easily upgrade and improve the algorithm performance when needed. If the Sigmet SZ-1 implementation is chosen, then we highly recommend that the problems described in this report are addressed, and further studies are performed to validate that implementation.
1 Introduction

This study was carried out by the National Center for Atmospheric Research (NCAR) in order to fulfill Task 5 in the FY2004 Statement of Work from the WSR-88D Radar Operations Center (ROC) to NCAR.

The study compares two implementations of the SZ-1 algorithm, one developed by Sigmet and the other by NCAR. The ‘SZ-1’ algorithm refers to that version of the SZ(8/64) algorithm which is ‘stand-alone’ in that it does not make use of long-PRT data from a previous sweep for trip sorting and censoring, but only uses the short-PRT data from the current sweep.

2 Goal of the study

As part of the work on the SZ phase coding algorithm, NCAR implemented a C version of SZ-1 based on the report by Sachidananda et. al. (1998). Engineers at the ROC took this code and embedded it into the run-time environment of the RVP8 processor from Sigmet.

Sigmet, on the other hand, developed a version of the SZ-1 algorithm which was also based on Sachidananda et. al. (1998) but with significant variations. This version also runs on the RVP8, under the Random Phase processing option.

The ROC wishes to check that the Sigmet version of the algorithm produces results that are comparable to the original Sachidananda algorithm. This study is intended to compare the results of the two algorithms and assess if there are any significant differences between them.

3 Obtaining the data for the study

During the 2003 and 2004 seasons, the NCAR SPOL radar was run at the Marshall field site just South of Boulder, Colorado. The radar antenna was controlled by S-POL. The transmitter was triggered by S-POL but the phases were controlled by the RVP8 transmitter card. Alternating PRT’s were used to simulate the NEXRAD operation, a long-PRT of around 3 milliseconds, and a short-PRT of around 1 millisecond. Data from the long-PRT scan is used as ‘truth’ in this study.

Phase-coded time series data was recorded to disk using the LIRP server and client applications developed by the ROC. The data was copied to DVDs for long-term storage.

In addition to the LIRP server and client code, the ROC also developed the capability to play back LIRP data through the RVP8. Unfortunately, Sigmet changed some implementation details on the RVP8 which means that this playback mechanism will only work with RDA releases up to and including 8.04.3. For this study version 8.04.3 was used both on IRIS and the RVP8.
Figure 3.1 Playback data flow diagram

The playback data flow is shown in Figure 3.1. The LIRP files are read by the rvp8 process running on the RVP8 host. Moments are computed and transmitted to the IRIS applications via TCP/IP. IRIS then transmits the moments (using UDP) and this data is read by the application SigmetUdp2Dsr, which writes the moments into a file message queue on a beam-by-beam basis. The Dsr2Vol application reads the beams, assembles them into a PPI and writes them into MDV files. (MDV is a volume format used internally at NCAR.)

4 Limitations of the data

There are four aspects of the data which affect how we interpret the results of the study.

- **1-byte resolution of the data fields**: the UDP stream from IRIS can be configured to be either 1 byte or 2 bytes wide. The software for reading the UDP data stream can handle both widths, but the 2-byte capability was not fully tested at the time the playback cases were run. Because of time constraints it was decided to use 1-byte data to be on the safe side. This means that the resolution of the data is 0.5-dBZ for reflectivity, approximately 0.25 m/s for velocity and approximately 0.12 m/s for spectrum width. This resolution limitation leads to a somewhat ‘blocky’ appearance in some of the histograms.

- **Beams are not indexed**: the RVP8 has the option of indexing beams. However, this feature was not activated when the cases were run (this was an oversight). This means that the azimuths for the beams in the various data sets do not agree exactly, leading to increased spread when comparing one data set against another. Furthermore, when the beams are stored in the MDV volumes, the azimuth is rounded to the closest whole degree. Therefore, there is typically a 0.5-degree error when comparing a beam from one data set with a beam from another.

- **Only reflectivity, not power is not available**: the UDP data read from IRIS included reflectivity, velocity and spectrum width. Power was not included. Although it is possible to estimate power from reflectivity, it was decided to present the results in terms of reflectivity in order to avoid introducing errors into the study.

- **Beam widths not matched between long and short PRTs**: the long PRT scan was processed with 32 pulses per beam while the short PRT scans were processed with 64 pulses per beam. The antenna scan rate was the same for both. To match the widths of
the beams between the short and long PRT scans, each beam in the long PRT scan should have consisted of 17 pulses. This will have the effect of adding variance to the errors, but it should not affect the relative performances of the algorithms.

5 Case details

The table below lists the details of each of the cases. The case name is derived from the date and hour of the data. Cases can have multiple PPI-pairs, which are designated by a letter: a, b, c or d. For most cases, the long PRT scan is followed by the short PRT scan. For case 20030713.01.a, the only reasonable pair was a short PRT followed by the long PRT scan.

<table>
<thead>
<tr>
<th>Case number</th>
<th>Date</th>
<th>Long PRT (msecs) /PRF</th>
<th>Short PRT (msecs) /PRF</th>
<th>Time of long PRT PPI</th>
<th>Time of short PRT PPI</th>
<th>Time lag from long to short (secs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20030706.23.a</td>
<td>2003/07/06</td>
<td>2.703/370</td>
<td>1.042/960</td>
<td>23:32:02</td>
<td>23:25:02</td>
<td>180</td>
</tr>
<tr>
<td>20030708.01.a</td>
<td>2003/07/08</td>
<td>2.703/370</td>
<td>1.042/960</td>
<td>00:45:00</td>
<td>00:49:20</td>
<td>260</td>
</tr>
<tr>
<td>20030708.01.b</td>
<td>2003/07/08</td>
<td>2.703/370</td>
<td>1.042/960</td>
<td>00:57:33</td>
<td>01:02:33</td>
<td>300</td>
</tr>
<tr>
<td>20040328.01.a</td>
<td>2004/03/28</td>
<td>3.125/320</td>
<td>0.800/1250</td>
<td>00:56:53</td>
<td>00:58:09</td>
<td>76</td>
</tr>
<tr>
<td>20040328.01.b</td>
<td>2004/03/28</td>
<td>3.125/320</td>
<td>0.800/1250</td>
<td>01:05:51</td>
<td>01:07:05</td>
<td>74</td>
</tr>
<tr>
<td>20040328.01.c</td>
<td>2004/03/28</td>
<td>3.125/320</td>
<td>0.800/1250</td>
<td>01:10:28</td>
<td>01:11:42</td>
<td>74</td>
</tr>
<tr>
<td>20040328.01.d</td>
<td>2004/03/28</td>
<td>3.125/320</td>
<td>0.800/1250</td>
<td>01:15:25</td>
<td>01:16:39</td>
<td>74</td>
</tr>
<tr>
<td>20040328.21.a</td>
<td>2004/03/28</td>
<td>3.125/320</td>
<td>0.800/1250</td>
<td>21:24:08</td>
<td>21:25:10</td>
<td>62</td>
</tr>
<tr>
<td>20040328.21.b</td>
<td>2004/03/28</td>
<td>3.125/320</td>
<td>0.800/1250</td>
<td>21:35:14</td>
<td>21:36:14</td>
<td>60</td>
</tr>
<tr>
<td>20040328.21.c</td>
<td>2004/03/28</td>
<td>3.125/320</td>
<td>0.800/1250</td>
<td>21:41:17</td>
<td>21:42:17</td>
<td>60</td>
</tr>
</tbody>
</table>

The data collected during 2003 used PRFs of 370 Hz and 960 Hz. It was discovered that this choice of values led to poor phase stability in the transmit phase, probably caused by the frequency differences between the SPOL clock and RVP8 transmitter card and IFD clocks. For
the 2004 data the PRFs were changed to 320 Hz and 1250 Hz to address this problem. These values are also closer to those planned for the NEXRAD RVP8.

PPI plots of the various cases appear in Appendix A.

6 Censoring

For the Sigmet SZ-1 algorithm, the censoring was set as close as possible to that which will be used for NEXRAD operations. According to the ROC, for initial operations the Sigmet LOG censoring method will be used, which is effectively signal-to-noise ratio censoring, with the following thresholds:

- dBZ: 2.5 dB
- vel: 3.5 dB
- width: 3.5 dB

When using IRIS for control, only a single threshold can be set for all fields. Therefore for this study, an SNR value of 3.0 dB was used.

For the NCAR SZ1 the censoring thresholds used were those set in the SZ1 code which the ROC incorporated into the RVP8 as a major mode. These are:

- signalToNoiseRatioThreshold: 3.0 dB
- szStrongToWeakPowerRatioThreshold: 45.0 dB
- szOutOfTripPowerRatioThreshold: 6.0 dB
- szOutOfTripPowerNReplicas: 3

These are explained in detail in the FY2003 Interim Report from NSSL and NCAR to the ROC. We note here that there is significantly more flexibility in the censoring parameters for the NCAR SZ algorithm as compared to Sigmet.

7 Moments computation methods

The RVP8 SZ-1 algorithm uses the Pulse-pair method for computing the moments for velocity and spectrum width. It is our understanding that the R1/R2 method is used for spectrum width.

The NCAR SZ-1 algorithm uses spectral methods for computing velocity and spectrum width.

In the course of the study it was found that there is an error in the NCAR code which computes spectrum width on the RVP8. The error produces histogram plots with a bi-modal distribution. The error only applies to spectra with very low SNR values. However, the width values for spectra with good SNR are still valid.

This topic is covered in detail in Appendix B.

Analysis shows that for widths of less than approximately 6 m/s, the error has minimal effect. Therefore, the spectrum width plots shown in this report restrict the NCAR spectrum widths to less than 6 m/s.
8 Histogram plots.

The various differences between the results of the algorithms are presented as 2-Dimensional histograms. These are color plots, in which the color represents the log of the count for a particular 2-D bin. The log was used because of the large range in counts. Where applicable, a white solid line indicates either the 1:1 or zero error lines, a solid black line indicates the mean for each column and the dashed white line is the computed standard deviation for each column.

The cases were divided into two groups, those from 2003 and those from 2004, so that all cases in each group have the same PRF values. The 2004 cases are presented in the body of the report, along with a discussion of the plots. The 2003 cases show similar results, and are included in Appendix C for completeness.

The 2004 cases are more representative because (a) the time between the long-PRT and short-PRT scans is less and (b) the PRFs are better chosen to reduce system phase errors.

The plots are organized into 6 sections, as follows:

<table>
<thead>
<tr>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.1 Strong trip reflectivity.</td>
</tr>
<tr>
<td>8.2 Weak trip reflectivity.</td>
</tr>
<tr>
<td>8.3 Strong trip width.</td>
</tr>
<tr>
<td>8.4 Weak trip width.</td>
</tr>
<tr>
<td>8.5 Strong trip velocity.</td>
</tr>
<tr>
<td>8.6 Weak trip velocity.</td>
</tr>
</tbody>
</table>
8.1 Strong trip reflectivity, 2004 cases

**Figure 8.1.a:** NCAR Z vs. long-PRT Z, strong trip, 2004

**Figure 8.1.b:** Sigmet Z vs. long-PRT Z, strong trip, 2004
Figures 8.1.a – 8.1.c show the comparisons between the data sets for strong trip reflectivity. The solid black line shows the mean at each bin along the x-axis (i.e. for each column), while the dotted lines show one standard deviation on each side of the mean line. The strong-trip reflectivity shows good agreement between all datasets. The spread in the comparisons to the long PRT data show more spread than the NCAR versus Sigmet plot. The facts that the beams were not indexed, the beam widths of long and short PRT scans differ, and the weather has advected and evolved during the time delay between scans contribute to the spread in the comparisons of NCAR and Sigmet to the long PRT data. The NCAR and Sigmet beams are also not indexed adding spread to Figure 8.1.c. The non-indexed beams result in azimuths that differ between data sets by an average of 0.5 degrees. This results in reflectivity differences, particularly in regions of high reflectivity variance or gradients, such as ground clutter or the edge of strong weather echoes. The non-matched beams will result in much the same problems. Most importantly, Figure 8.1.c show that on average the two SZ-1 algorithms yield nearly the same reflectivity estimate and thus there is no significant difference seen. This is expected and merely indicates the correct functioning of the software.
8.2 Weak trip reflectivity, 2004 cases

Figure 8.2.a: NCAR Z vs. long-PRT Z, weak trip, 2004

Figure 8.2.b: Sigmet Z vs. long-PRT Z, weak trip, 2004
Figures 8.2.a – 8.2.c show the comparisons between the data sets for weak trip reflectivity. Both S5-1 algorithms produce a positive bias for reflectivities less than about 30 dBZ as compared to the long-PRT ‘truth’ data set. This is expected, since some strong trip power will leak through into the weak trip. The standard deviation with the long PRT is also similar between the NCAR and Sigmet algorithms. The NCAR and Sigmet comparison (Figure 8.2.c) shows good agreement between the two algorithms. Some of the spread is again likely due to the lack of indexed beams and non-matching beam widths. At the high end of the reflectivity range, the NCAR algorithm appears to under-estimate compared to the Sigmet algorithm. However, there are very few data points in this region, and therefore the trend is not conclusive. Also, the 2003 cases (see Appendix C, Figure C.2.c) do not show same the behavior as seen in Figure 8.2.c.
8.3 Strong trip spectrum width, 2004 cases

Figure 8.3.a: NCAR W vs. long-PRT W, W < 6 m/s, strong trip, 2004.

Figure 8.3.b: Sigmet W vs. long-PRT W, W < 6 m/s, strong trip, 2004.
Figures 8.3.a – 8.3.c show the comparisons between the data sets for strong trip spectrum width. As mentioned in section 7, only width values of less than 6 m/s are included in the plots because of errors in the NCAR computation of widths for larger values. Agreement between NCAR and Sigmet widths is, in general, good. Sigmet uses a pulse pair (time domain) estimate and NCAR uses spectral estimates. Comparing Figure 8.3.c to Figure B.5, which shows a comparison between widths computed using the pulse pair and spectral moments estimation methods, shows that the two width estimates are very tightly correlated. One clear difference between the two methods is that the pulse pair method produces a large number of values which are close to 0, and are probably the result of R2 exceeding R1 where R1 and R2 are the magnitudes of the first and second lag of the autocovariance function, respectively. On the other hand, the spectral method does not produce as many values close to zero, and appears to have a lower bound of about 0.5 m/s (in this case). The agreement between the long PRT widths and both sets of short PRT widths is relatively poor but the NCAR estimates do show a bit less variance. The conclusion, however, is that the NCAR and Sigmet width estimators appear by-in-large equivalent with no outstanding discrepancies. Better matched data is required to determine whether one algorithm performs better than the other.
8.4 Weak trip spectrum width, 2004 cases

Figure 8.4.a: NCAR $W$ vs. long-PRT $W$, $W < 6$ m/s, weak trip, 2004

Figure 8.4.b: Sigmet $W$ vs. long-PRT $W$, $W < 6$ m/s, weak trip, 2004
Figures 8.4.a – 8.4.c show the comparisons between the data sets for weak trip spectrum width. The Sigmet widths are better correlated to the long PRT widths than the NCAR widths. The reason for this is unknown. Perhaps the way in which noise correction is accomplished by the two algorithms can account for some of this difference. Figure 8.4.c shows that the correlation between the NCAR and Sigmet weak trip widths is poor. The main point of this set of plots is that the estimation of weak trip spectrum widths is difficult.
8.5 Strong trip velocity, 2004 cases

Making comparisons between long- and short-PRT velocity estimates is considerably more complicated than comparing reflectivities or spectrum widths. There are two main reasons for this:

1. The short-PRT and long-PRT data obviously have different Nyquist intervals. Therefore, in order to compare the short and long PRT results it is necessary to artificially fold the short-PRT velocities using the long-PRT Nyquist. An alternative would be to try unfolding the long-PRT data, but this is prone to errors related to the unfolding procedure which could be confused with genuine errors in the original estimates. Therefore it was decided to fold the short-PRT data instead.

2. The Sigmet velocity estimates appear to include some errors, which create small but unexpected patterns in the histograms. We show later that these errors appear to occur in isolated regions in the PPI scans (often only single gates) which have perhaps eluded the Sigmet censoring methods. Low SNR seems to be linked with these errors. On the other hand the NCAR algorithm appears to produce good estimates for these gates.

Figure 8.5.a: Wrapped NCAR V vs. long-PRT V, strong trip, 2004

Figure 8.5.a shows the comparison between the wrapped NCAR velocity and the long-PRT velocity for the strong trip 2004 cases. At this point we explain some of the features in this plot since they recur in a number of later plots.

The vast majority of the data of the plot is scattered about the 1:1 line, which is shown in white. The points in this primary region are those for which the NCAR and long-PRT data agree for the most part. The non-indexed nature of the beams, the non-matched beam widths, and the time difference between the long and short PRT data sets contribute to the scatter in the plots.
The small maxima at the top left corner and bottom right corner of the plot are actually part of the primary data region along the 1:1 line since long PRT velocity aliasing folds data at Nyquist velocity values +/-8.5 m/s.

Also noticeable in Figure 8.5.a are the relative increases in frequency of data with 0 m/s velocity values corresponding to both the NCAR and long PRT data, which resemble a plus sign centered at (0,0). These points are caused by one algorithm producing estimates close to 0 m/s while the other algorithm does not. The most likely causes are the non-indexed beams, the non-matched beam widths, and the time delay between scans. Thus, there can be gates in one scan dominated by ground clutter that are not dominated by clutter for the other scan. As a hypothetical example, the long PRT scan has an azimuth centered at 90 degrees and sees a tower located at 90.4 degrees, however, the NCAR scan azimuth is centered at 89.8 degrees and does not see the tower until the next azimuth centered at 90.8 degrees.

Given an understanding of all of these features, it appears that the NCAR algorithm produces velocities which are very well correlated with the long-PRT velocities.

![wrapped V_sigmet vs long V](image)

**Figure 8.5.b:** Wrapped Sigmet V vs. long-PRT V, strong trip, 2004

Figure 8.5.b is analogous to Figure 8.5.a, but for Sigmet V. This plot has, for the most part, similar features to 8.5.a, although there are some additional artifacts, most obviously at the top and bottom of the Y axis along the V_long = 0 m/sec line. In addition, the spread of the region at the center point along the Y axis is greater than for the NCAR data. Furthermore, the data-sparse regions in the top-left and bottom-right quadrants show higher frequency values in the Sigmet plot than in the NCAR plot.

As mentioned earlier, these features appear to be related to some relatively isolated bad estimates of velocity by the Sigmet algorithm, which have escaped censoring. This topic will be addressed in detail later in this section.
Figure 8.5.c: NCAR V vs. Sigmet V, strong trip, 2004

Figure 8.5.c shows the plot comparing the NCAR V estimates with the Sigmet V estimates for the strong trip. Since both data sets have the same Nyquist velocity the data can be plotted without folding.

The dominant 1:1 diagonal feature once again shows the agreement between the two estimates for the majority of the data points. Some of the scatter can be attributed to the non-indexed beams. However, the artifacts on either side of the main diagonal, with the same slope, show the scattered errors in the Sigmet V estimates alluded to above. These anomalous estimates will be referred to as *ghosts*, and will be discussed below.
Figure 8.5.d: Error of wrapped NCAR V vs. long-PRT V, strong trip, 2004. Black line is mean error, dotted white line is SDEV of error.

Figure 8.5.e: Error of wrapped Sigmet V vs. long-PRT V, strong trip, 2004. Black line is mean error, dotted white line is SDEV of error.

Figure 8.5.d presents the same data as in Figure 8.5.a, but plots the difference of NCAR V (folded onto the long PRT Nyquist interval) and the long PRT V against the long-PRT V. This quantity is assumed to be the error in the NCAR velocity estimate. The same features of Figure...
8.5.a are visible in Figure 8.5.d, but in a different configuration. The 1:1 line in Figure 8.5.a becomes the $y = 0$ line in Figure 8.5.d, the horizontal clutter artifact becomes diagonal and the vertical clutter artifact is not affected. Figure 8.5.e shows a similar plot but for the Sigmet V data set.

The solid white line represents ‘perfect agreement’ between the two data sets, i.e., an error of 0 m/sec. The solid black line shows the mean error for different V values, and the dashed white line represents the standard deviation of the error. There appears to be a slight negative bias of up to about 0.5 m/s in the NCAR velocity estimates. This bias appears to be caused, at least in part, by the way the different algorithms are impacted by clutter. The NCAR algorithm velocities are less prone to biases from clutter in the case where clutter and weather are both present and have spectra which do not overlap, whereas both the long PRT and Sigmet velocity estimates will be quite prone to biases. This hypothesis is supported by Figure 8.5.f, which is the same plot as Figure 8.5.d, except that only data beyond 130 km are used, which is largely clutter-free. The biases are seen to be quite small in the absence of clutter. Likewise Figure 8.5.g is the same as Figure 8.5.e, except that only data beyond 130 km are used.

![Figure 8.5.f: Error of wrapped NCAR V vs. long V (no clutter), strong trip, 2004. Black line is mean error, dotted white line is SDEV of error.](image-url)
The Sigmet algorithm results in Figure 8.5.e also show a slight negative bias, though less than for the NCAR data set. The biases decrease somewhat when clutter is absent, as shown in Figure 8.5.g. The standard deviation of the error is slightly higher for the Sigmet data than the NCAR data. This is most likely due to the erroneous ghost estimates referred to above.
Figure 8.5.h: Error of wrapped NCAR V vs. P1/P2, strong trip, 2004.
Black line is mean error, dotted white line is SDEV of error.

Figure 8.5.i: Error of wrapped Sigmet V vs. P1/P2, strong trip, 2004.
Black line is mean error, dotted white line is SDEV of error.

Figures 8.5.h and 8.5.i show the error in the velocity estimates plotted against the P1/P2 ratio as estimated from the long-PRT reflectivity values. Once again, the solid white line refers to 0 m/sec error, the solid black line shows the mean error and the dotted white line is the standard
deviation of the error. These plots are analogous to those shown in the report by Sachidananda et al., (2002).

Both figures show mean errors which are close to 0, although the NCAR velocity is slightly negatively biased as in the previous plots. For the Sigmet algorithm the standard deviation of the error is again slightly larger than for the NCAR algorithm.

Figure 8.5.i also shows that the Sigmet ghost velocity estimates, which are seen here as the artifacts close to ±8 m/s, mostly occurring at P1/P2 values of between 45 and 60 dB.

In order to gain insight into the nature of the ghost velocity estimates, the plots which follow are useful. Figure 8.5.j shows the NCAR velocity vs. SNR as estimated from the Sigmet reflectivity. Similarly Figure 8.5.k shows Sigmet velocity vs. Sigmet SNR. (NCAR Z was not censored in the same manner as Sigmet Z, therefore it was decided to use the Sigmet-derived SNR for both plots.) Similarly, Figures 8.5.l and 8.5.m show NCAR V and Sigmet V plotted against range from the radar.

The two sets of plots help identify the nature of the velocity differences that might be causing the artifacts seen in the Sigmet V. The NCAR velocity plots both have a reasonably smooth appearance. By contrast, the Sigmet plots have the ghost artifacts centered on certain velocities, seemingly at multiples of about 8 m/s from 0, with the strongest centered on approximately ±26 m/sec. Furthermore, the ghosts seem to be stronger at shorter ranges, i.e., less than 50 km, and they seem to be most evident for low SNR as estimated by Sigmet.

Based on this information, PPIs were generated for one of the cases, highlighting any velocities between 24 and 28 m/s. Figure 8.5.n is a PPI plot of the Sigmet velocity for the NE quadrant out to a range of 50 km. The gates at which the magnitudes of the velocity values were between 24 and 28 m/s are highlighted. Figure 8.5.o shows the similar plot for NCAR velocity. Note how many fewer gates are highlighted in Figure 8.5.o. Figure 8.5.p shows the long-PRT velocity, which indicates most of the area is clutter.
Figure 8.5.j: Estimated Sigmet SNR vs. NCAR V, strong trip, 2004.

Figure 8.5.k: Estimated Sigmet SNR vs. Sigmet V, strong trip, 2004.
Figure 8.5.l: Range vs. NCAR V, strong trip, 2004.

Figure 8.5.m: Range vs. Sigmet V, strong trip, 2004.
Figure 8.5.n: PPI for Sigmet V, case 20040328.21.a. Velocities in the range 24 to 28 m/s are shown highlighted.

Figure 8.5.o: PPI for NCAR V, case 20040328.21.a. Velocities in the range 24 to 28 m/s are shown highlighted.
Most of the region is covered in clutter.

In order to test the hypothesis that these anomalous gates are the cause of the Sigmet ghosts, a simple de-speckling censoring algorithm was applied to the Sigmet velocity field to remove some of these anomalous gates. Figure 8.5.q is a copy of Figure 8.5.c, comparing NCAR V with Sigmet V. Figure 8.5.r is a similar plot but for the de-speckled data. It is clear that the de-speckling censoring removed some of the data which appears in the ghosts on either side of the 1:1 line. This supports the theory that it is these anomalous gates which are producing the extra features in the plots. It seems likely that the underlying commonality of the ghosts is low SNR, but the true cause of the problem is unknown.
To summarize the strong trip velocity results: The NCAR velocities appear to have a slight negative bias compared with the long PRT velocities which may largely be due to the way the algorithms handle overlaid clutter. The Sigmet velocities also appear to have a slight negative bias, but the bias is smaller than for the NCAR velocities. At isolated gates, the Sigmet algorithm appears to compute velocities which are grossly incorrect and which show up as ghosts.
in the plots above. As a result, the standard deviation of the error of the Sigmet velocities is slightly higher than for the NCAR velocities.
8.6 Weak trip velocity, 2004 cases

In this section, the recovered weak trip radial velocity for the same data sets as section 8.5 above is presented.

Figure 8.6.a: Wrapped NCAR V vs. long-PRT V, weak trip, 2004.

Figure 8.6.b: Wrapped Sigmet V vs. long-PRT V, weak trip, 2004.
Figures 8.6.a through 8.6.c show similar features as the above strong trip velocity plots. The same *ghost* artifacts are present in the Sigmet plots, indicating that the cause may be related to moments estimation rather than differences in the NCAR and Sigmet SZ1 algorithms.

Figure 8.6.d: Error of wrapped NCAR V vs. long-PRT V, weak trip, 2004. Black line is mean error, dotted white line is SDEV of error.
Figures 8.6.d and 8.6.e show the weak trip velocity error computed with respect to the long PRT data for the NCAR and Sigmet SZ1 algorithms, respectively. Similar to the strong trip velocity, the NCAR method shows a small negative bias larger in magnitude than the Sigmet bias. The standard deviations of the errors are comparable, and near 2.5 m/s.

Figure 8.6.f: Error of wrapped NCAR V vs. P1/P2, weak trip, 2004. Black line is mean error, dotted white line is SDEV of error.
Figures 8.6.f and 8.6.g show the NCAR and Sigmet wrapped velocity error as functions of P1/P2 power ratio. Again the NCAR method shows a small negative bias and the standard deviations for the two methods are comparable. The Sigmet ghost artifacts are visible at about 8 m/s, which is consistent with the observation of them at multiples close to 8 m/s and the velocity wrapping used to produce Figure 8.6.g.
Figure 8.6.h: Estimated Sigmet SNR vs. NCAR V, weak trip, 2004.

Figure 8.6.i: Estimated Sigmet SNR vs. Sigmet V, weak trip, 2004.
Figures 8.6.h and 8.6.i show the NCAR and Sigmet retrieved weak trip velocity versus Sigmet SNR and Figures 8.6.j and 8.6.k show them versus range from the radar. These plots display similar features as the corresponding strong trip plots (Figures 8.5.h – m, except f and g). The velocity artifacts at ±26 m/sec in the Sigmet data seen in the strong trip are also apparent in the weak trip, but not as strong. This may be a result of the fact that the ghosts are mostly observed in ground clutter contamination and the weak trip has far less clutter return than the strong trip. Another possibility is that ghosts are a relatively rare event and therefore requires a large number
of gates with a specific velocity to see a ‘coherent’ ghost. In fact, the random scatter that is easily seen in Figure 8.6.i may be many ghosts offset from each other. Also, a clumping of the Sigmet velocity data is apparent, especially in Figure 8.6.i. Note that in Figure 8.6.h, which shows the NCAR estimates, no such clumping appears. It is not clear whether the clumping is caused by the same problem that causes the ghosts.
9 Summary

The performance of the Sigmet and NCAR implemented SZ-1 algorithms were compared in this report. The comparison was accomplished using experimental phase coded data collected by S-Pol using Sigmet’s RVP8 receiver/processor. Two data sets were analyzed: one collected in 2003 and one collected in 2004. The differences in the data collection between these two sets of data are the PRT’s used and the time lags between the long and short PRT data. In 2003 the PRFs were 960 Hz and 370 Hz were used and the average time lag between short and long PRT scans was around 4 minutes. In 2004, 1250 Hz and 320 Hz were used and the average time lag was just over a minute. As reported in the 2003 NCAR NEXRAD Annual Report to the ROC, it is important to have both PRFs be divisible by the 10Mhz GPS system clock and the Sigmet IFD 36 MHz clock. If this condition is not met, phase errors result which can significantly affect the performance of the SZ algorithm. In 2004 the selected PRFs met these criteria and indeed the SZ performance statistics improved. Thus, in the main text of this report the 2004 data is addressed while the 2003 data is put into Appendix B.

Long and short PRT PPI scans were gathered in time series format using the ROC developed A1 time series recorder. This data was then run back through the RVP8 using the A1 recorder. In this way three sets of moments data were produced: 1) long PRT moments (no phase coding and range unambiguous), 2) short PRT Sigmet SZ-1 moments and 3) short PRT NCAR SZ-1 moments. These calculated moments were not ideal for comparisons due to several factors:

- The number of samples used was 64 for the short PRT while 32 were used for the long PRT. This means that the long PRT beams or ray sectors were about twice as wide as the short PRT beams.
- The beams were not indexed so that the beam center for each of the moments estimation algorithms (long PRT, short PRT Sigmet, short PRT NCAR) are offset. The result is that compared moments of the algorithms will not be calculated from the same spatial resolution volume.
- A clutter filter was not used. Since the long PRT beam is about twice as wide as the short PRT beams (1.5 degrees and 0.75 degrees, respectively), the long PRT data had more evident clutter signal. This is likely the cause of some of the anomalous data points observed.

One effect of these factors was the increase of variance or spread seen in comparison scatter plots. There were also small biases observed in the strong trip comparison between both the NCAR and Sigmet velocities and the long PRT velocity. This was attributed to clutter. Comparison plots made with data only from regions without clutter nearly eliminated the previously observed small biases. Despite these measurement caveats, the data provided for a good comparison between the two SZ algorithms.

10 Conclusions

It was found that the performance of the Sigmet and NCAR SZ algorithms were very similar. Simulation studies performed by Sachidanada et. al. (2002) indicated that there was a -2m/s bias in weak trip Sigmet velocity estimates. We found no evidence of this in this study. We do not know the cause of this discrepancy.
A few anomalous (large and systematic) velocity estimate errors, called ghosts, were produced by the Sigmet algorithm. Further investigation showed that many of these estimates occurred for isolated data points and that they could be, in part, eliminated by using a speckle filter on the retrieved Sigmet velocity PPI scan. The underlying cause is unknown but the key factor seems to be signal-to-noise ratios less than 10 dB. It should be noted, however, that the Sigmet algorithm does not output SNR and so we had to estimate it after the fact. The ghost problem is likely not serious but deserves further investigation. The Sigmet algorithm also produced velocities that were clumped together, especially seen in the weak trip, resembling quantization. The cause of the clumping is unknown. This problem is likely not serious also, but it needs to be resolved.

We suggest that if censoring and ultimate control of data quality are important to the ROC, then the ROC should develop, implement and maintain its own SZ algorithm rather than rely on the Sigmet SZ algorithm. Programmers from the ROC, NCAR and NSSL have intimate knowledge of the SZ-1 algorithm, which importantly contains unique censoring schemes, and these organizations can easily upgrade and improve the algorithm performance when needed. If the Sigmet SZ-1 implementation is chosen, then we highly recommend that the problems described in this report are addressed, and that further studies are performed to validate the Sigmet implementation.

Further comparisons should be conducted using the following procedures: 1) index beams should be activated on the playback feature of RVP8, 2) the beam widths of the long PRT should match the short PRT, i.e., the number of samples should be 64 and about 16 for the short and long PRTs, respectively and 3) clutter filtering should be used. These procedures should greatly reduce the spread in the scatter plots and reduce much of the anomalous data points.

11 Acknowledgements

We would like to thank the ROC staff for making their facility available to us for using the RVP8, and particularly Darcy Saxion and Rick Rhoton for their hard work in assisting us to get the software working and run the cases on the RVP8.

12 References


13 Appendix A: PPI plots

13.1 All fields for case 20040328.23.

This is the best case for comparisons, because it (a) has the best set of PRT’s for matching the transmitter to the IFDs, (b) because the time between the long and short PRT scans is short and (c) because there is good weather and overlaid echoes. Unambiguous range for the short PRT scans is 120 km.

Figure A.1: Case 20040328.23.a, long-PRT reflectivity.
Figure A.2: Case 20040328.23.a, long-PRT velocity.
Figure A.3: Case 20040328.23.a, long-PRT spectrum width.
Figure A.4: Case 20040328.23.a, NCAR SZ1 short-PRT reflectivity.
Figure A.5: Case 20040328.23.a, NCAR SZ1 short PRT velocity.
Figure A.6: Case 20040328.23.a, NCAR SZ1 short-PRT spectrum width.
Figure A.7: Case 20040328.23.a, Sigmet SZ1 short-PRT reflectivity.
Figure A.8: Case 20040328.23.a, Sigmet SZ1 short PRT velocity.
Figure A.9: Case 20040328.23.a, Sigmet SZ1 short-PRT spectrum width.
13.2 Reflectivity plots for all cases

The following are images which show the long PRT reflectivity for each of the cases.

Figure A.10: Case 20030706.23.a, long PRT dBZ.
Figure A.11: Case 20030708.01.a, long PRT dBZ.
Figure A.12: Case 20030712.23.a, long PRT dBZ.
Figure A.13: Case 20030713.22.a, long PRT dBZ.
Figure A.14: Case 20040328.01.a, long PRT dBZ.
Figure A.15: Case 20040328.23.a, long PRT dBZ.
14 Appendix B: Discussion of NCAR spectrally-based moments computations

(Note – all plots in this section are based on data from case 20040328.23.a, weak trip.)

14.1 The problem with NCAR-computed spectrum width

As mentioned in section 7, there is an error in the NCAR code on the RVP8 which computes the width and velocity using spectral methods.

The error applies to spectra with low signal-to-noise values. The noise value is estimated from the spectrum. This is done by dividing the spectrum into 8 equal parts, with one part centered on the spectral peak. A search is then made for the 2 adjacent parts which have the lowest mean power. The mean and standard deviation of the power in those two parts is then computed. For the purposes of computing velocity and width, the noise threshold is then computed as the mean plus the standard deviation.

Velocity and width computations are based on the data centered at the spectral peak. On each side of the peak a search is conducted for the first 3 consecutive points below the noise threshold. The limit of the data used in the computations is set to point just before those 3 consecutive points.

This method works well. However, an additional test was made on the SNR for the entire spectrum. If the mean signal was less than the mean noise plus 3 times the standard deviation, the spectrum was deemed to be so noisy that the entire spectrum should be used to compute the width. This was a mistake.

The problem is that this method results in a bi-modal distribution for the width. For example, see Figure B.1 below.
Figure B.1: NCAR-computed width vs. long-PRT width.

The widths in the lower lobe are correct, while those in the upper lobe are in error.

In order to investigate this thoroughly, the NCAR code was corrected and the 20040328.23.a case was run again, using native NCAR code rather than the RVP8. Both spectral and pulse-pair methods were tested. The figures below show the comparisons. Figure B.2 shows the widths from the old FFT method plotted against the improved FFT method. Figure B.3 shows the width plotted against SNR.

Figure B.2: NCAR-computed width, old FFT method vs. fixed FFT method.
These plots show that the widths with very low SNR computed with the old method are invalid, while those for higher SNR are valid. From figure B.1 it appears that the widths below 6 m/s are good, while those above 6 m/s are probably in error.

Therefore, it was concluded that in order to compare the NCAR widths with either the long-PRT widths or the Sigmet widths, a maximum value of 6 m/s should be imposed on the NCAR widths.

Similarly, Figure B.4 shows the plot for $V$ from the old NCAR method vs. the corrected method. The old method basically worked well, although there is some spread between the 2 data sets.
14.2 Comparing the spectral method to the pulse-pair for velocity and width

The investigation was carried further to compare the pulse-pair method with the spectral moments estimation method.

Figure B.5 below plots $W$ computed using the spectral method against $W$ computed using the pulse-pair $R_1/R_2$ method. The agreement for the most part is good. The main difference seems to result from how the $R_1/R_2$ method deals with cases in which $R_2$ exceeds $R_1$ and the result becomes negative. In these cases the width is set to 0.
Figure B.5: NCAR-computed width, FFT method vs. PP method.

Figure B.6 is similar to B.5, but for velocity. Once again the agreement between the two methods is good.

Figure B.6: NCAR-computed velocity, FFT method vs. PP method.
Appendix C: plots for 2003 cases

The following plots for the 2003 cases are included for completeness. They are the companion plots to those in Section 8.

15.1 Strong trip reflectivity, 2003 cases

Figure C.1.a: NCAR Z vs. long-PRT Z, strong trip, 2003

Figure C.1.b: Sigmet Z vs. long-PRT Z, strong trip, 2003
Figure C.1.c: NCAR Z vs. Sigmet Z, strong trip, 2003
15.2 Weak trip reflectivity, 2003 cases

Figure C.2.a: NCAR Z vs. long-PRT Z, weak trip, 2003

Figure C.2.b: Sigmet Z vs. long-PRT Z, weak trip, 2003
Figure C.2.c: NCAR Z vs. Sigmet Z, weak trip, 2003
15.3 Strong trip spectrum width, 2003 cases

![NCAR W vs. long-PRT W, W < 6 m/s, strong trip, 2003.](image)

Figure C.3.a: NCAR W vs. long-PRT W, W < 6 m/s, strong trip, 2003.

![Sigmet W vs. long-PRT W, W < 6 m/s, strong trip, 2003.](image)

Figure C.3.b: Sigmet W vs. long-PRT W, W < 6 m/s, strong trip, 2003.
Figure C.3.c: NCAR W vs. Sigmet W, W < 6 m/s, strong trip, 2003.
15.4 Weak trip spectrum width, 2003 cases

Figure C.4.a: NCAR W vs. long-PRT W, W < 6 m/s, weak trip, 2003

Figure C.4.b: Sigmet W vs. long-PRT W, W < 6 m/s, weak trip, 2003
Figure C.4.c: NCAR W vs. Sigmet W, W < 6 m/s, weak trip, 2003
15.5 Strong trip velocity, 2003 cases

Figure C.5.a: Wrapped NCAR V vs. long-PRT V, strong trip, 2003

Figure C.5.b: Wrapped Sigmet V vs. long-PRT V, strong trip, 2003
Figure C.5.c: NCAR V vs. Sigmet V, strong trip, 2003
Figure C.5.d: Error of wrapped NCAR $V$ vs. long-PRT $V$, strong trip, 2003.
Black line is mean error, dotted white line is SDEV of error.

Figure C.5.e: Error of wrapped Sigmet $V$ vs. long-PRT $V$, strong trip, 2003.
Black line is mean error, dotted white line is SDEV of error.
Figure C.5.f: Error of wrapped NCAR V vs. P1/P2, strong trip, 2003. Black line is mean error, dotted white line is SDEV of error.

Figure C.5.g: Error of wrapped Sigmet V vs. P1/P2, strong trip, 2003. Black line is mean error, dotted white line is SDEV of error.
Figure C.5.h: Estimated Sigmet SNR vs. NCAR V, strong trip, 2003.

Figure C.5.i: Estimated Sigmet SNR vs. Sigmet V, strong trip, 2003.
Figure C.5.j: Range vs. NCAR V, strong trip, 2003.

Figure C.5.k: Range vs. Sigmet V, strong trip, 2003.
15.6 Weak trip velocity, 2003 cases

Figure C.6.a: Wrapped NCAR V vs. long-PRT V, weak trip, 2003.

Figure C.6.b: Wrapped Sigmet V vs. long-PRT V, weak trip, 2003.
Figure C.6.c: NCAR V vs. Sigmet V, weak trip, 2003.
Figure C.6.d: Error of wrapped NCAR V vs. long-PRT V, weak trip, 2003. Black line is mean error, dotted white line is SDEV of error.

Figure C.6.e: Error of wrapped Sigmet V vs. long-PRT V, weak trip, 2003. Black line is mean error, dotted white line is SDEV of error.
Figure C.6.f: Error of wrapped NCAR V vs. P1/P2, weak trip, 2003.
Black line is mean error, dotted white line is SDEV of error.

Figure C.6.g: Error of wrapped Sigmet V vs. P1/P2, weak trip, 2003.
Black line is mean of error, dotted white line is SDEV of error.
Figure C.6.h: Estimated Sigmet SNR vs. NCAR V, weak trip, 2003.

Figure C.6.i: Estimated Sigmet SNR vs. Sigmet V, weak trip, 2003.
Figure C.6.j: Range vs. NCAR V, weak trip, 2003.

Figure C.6.k: Range vs. NCAR V, weak trip, 2003.