The Use of Spectral Processing to Improve Radar Spectral Moment

GREGORY MEYMARIS*
National Center for Atmospheric Research, Boulder, Colorado

1. INTRODUCTION

The data quality of the spectral (Doppler) moments (power, radial velocity and spectrum width) continues to be an on-going problem for the NEXRAD radar products. Data contaminants that are significant include so-called hard targets like ground clutter (both normal and anomalous propagation), birds, and airplanes. Even with clutter filtering, whether the legacy clutter filters or Gaussian Model Adaptive Parameter (GMAP), Sigmet's spectral based clutter filter, clutter residue can still bias all moments. However, the new Open RDA system to be deployed on the WSR-88D fleet will allow much more flexibility for processing the so-called level 1, I&Q data. In particular, spectral-domain processing will become a viable method for calculating the moments, thus opening the door to advanced techniques, such as the NEXRAD Spectral Processing Algorithm (NSPA), described in this paper, that can improve moment estimates by isolating weather signals from contaminants, like clutter residue, airplanes, and isolated birds. Improvements to power and velocity estimates would be realized when, for example, weather and strong ground clutter echoes compete. Spectrum width estimates would be improved almost universally by using spectral processing rather than the current pulse pair estimator.

NSPA, like its predecessors NCAR Improved Moment Algorithm (NIMA) Morse et al. (2002)and NCAR Enhanced Spectra Processing Algorithm (NESPA)Cornman et al. (2002), use spectral information along a radial, to determine which spectral features weather rather than contaminants. When contaminants are identified, the algorithm attempts to calculate the spectral moments of only the weather, excluding the contaminants. In this paper, the NSPA algorithm will be described and its performance evaluated.

**Corresponding author address*:
Gregory Meymaris, RAL, NCAR
1850 Table Mesa Dr., Boulder, CO 80305
E-mail: meymaris at ucar.edu

2. Moment Estimation via Spectral Processing

All three spectral moments can be computed in the spectral domain, rather than the time domain (Doviak and Zrnić 1993; Cornman et al. 2002; Morse et al. 2002), although in this paper we will only examine the mean radial velocity estimator. There are several decisive advantages to spectral-domain processing. The first is that in the frequent cases of contamination (birds, planes, *strong* clutter, etc.), spectral-domain processing can often produce unbiased estimates of the meteorological spectral moments whereas the time-domain processing most often cannot do so. The second is that with spectral-domain processing, estimates of the quality (or confidence) of the moments can be computed and passed on (eventually) to the Open RPG for use in NEXRAD products. This would allow different users to choose the data quality level required for the products. Confidences can be based on information only available in the spectral domain (e.g. identifying multi-modal spectra, elevated noise power, and when the weather signal is overlaid with contaminants).

In spectral-domain processing, echoes are sorted by their radial velocity relative to the radar. Figure 1 shows, in blue, a simulated spectrum of weather and clutter. Since the weather is moving at roughly 15 m/sec and the clutter at 0 m/sec, the two signals are distinct. The clutter to noise ratio simulated was 60 dB which is beyond the legacy clutter filter suppression capability. The spectrum after legacy clutter filtering is shown in red. Since GMAP is the clutter filter on the Open RDA, the spectrum after GMAP is applied is shown in black. Using either clutter filter results in residual clutter power, highlighted with the green circle. In time-domain processing, the residual clutter power affects all 3 spectral moments. Reflectivity and spectrum width will both have a positive bias, and the velocity will be biased towards 0. Because in this case the two signals are distinct in the spectral domain, these biases can be mitigated using spectral processing techniques like those used in NSPA.

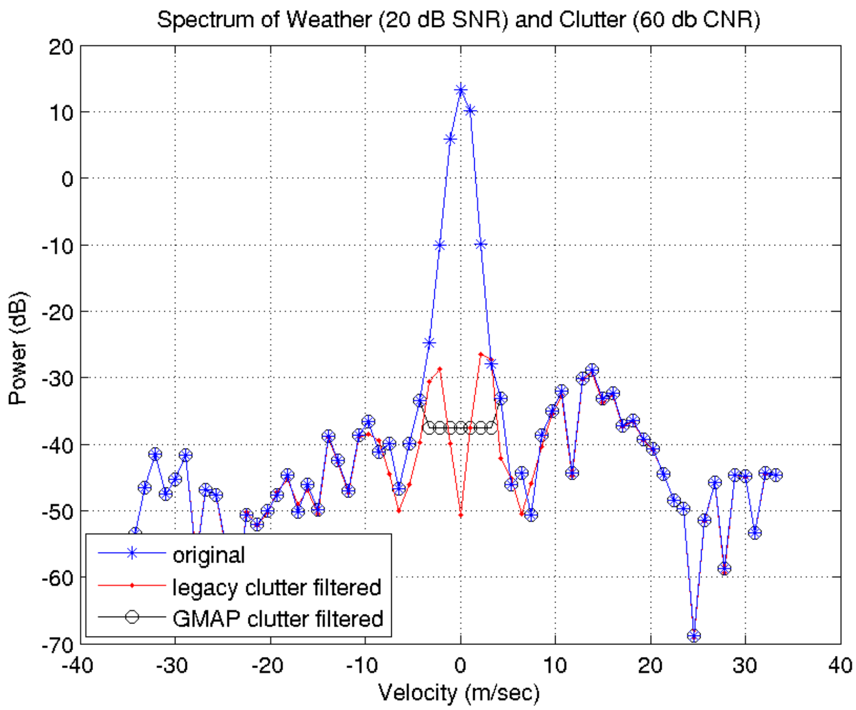

Figure 1: Simulated spectrum of a 20 dB signal to noise ratio weather spectrum centered at 15 m/sec with a 60 dB clutter to noise ratio clutter spectrum centered at 0 m/sec. The original spectrum in shown in blue, the spectrum after the high suppression legacy clutter filter is shown in red, and the spectrum after a high suppression GMAP filter is shown in black. Within the green circle is the clutter power residual after clutter filtering.

3. NPSA Algorithm Description

The basis for NIMA, NESPA and NSPA is the so-called waterfall plot such as in figure 2. The *x*-axis corresponds to radial velocity (m/sec) and the *y*-axis to range (km) from radar. The color corresponds to the range-adjusted power of the power spectrum at that velocity (Doppler frequency) and range. The dots represent the mean velocity as computed by an algorithm, in this case the pulse-pair estimator. This particular data shown was taken on April 5, 2003 at KOUN, NSSL's test bed radar. The continuous feature that begins around 35 km and continues to the top of the plot that resembles a river is part weak clear air return (from 35 km to 85 km) and part strong weather signal (from 85 km to 120 km). An important aspect of the weather (as well as clear air returns) is that it is strongly continuous in range, as is apparent in this figure.

Close examination of figure 2, in particular the ranges between 45 and 55 km, reveals that the pulse-pair algorithm 'locks on' to features that appear to be isolated peaks not related to the clear air returns. These could be, for example, isolated birds or planes. The key feature is that they are isolated or only affect a few range gates.

a. *NSPA pass 1*

To calculate the radial velocity, NSPA simply performs the following calculation:

$$v = \frac{\sum_{i \in I} (f_i \ominus f_c)(S_i - N)}{\sum_{i \in I} (S_i - N)} \oplus f_c \qquad (1)$$

where I is the range of indices in the spectral domain that the 'integral' (sum) is to take place over (in Doviak and Zrnić (1993) and Sirmans and Bumgarner (1975) I would be taken as the entire spectrum), f_i is the velocity corresponding to the i^{th} spectral bin, f_c is the velocity of the desired 'center' of integration (e.g. the peak value of the power spectrum), S_i is the value of the i^{th} power spectrum array, and N is the power of the noise. Note that $\oplus$ is $+$ using a special modular arithmetic $a \oplus b \equiv \mathrm{mod}\,(a + b + v_a, 2v_a) - v_a$ which is like modulo arithmetic except that values are force between $-v_a$ and v_a, where v_a is the Nyquist velocity. The definition of $\ominus$ is $a \ominus b = a \oplus (-b)$. Equation 1 is as defined in Doviak and Zrnić (1993). The affect of *re-centering* is that velocity aliasing of the spectrum is mitigated to a certain extent. Sirmans and Bumgarner (1975) also defines the spectral computation of mean radial velocity this way except without the re-centering, which explains why they found severe biases when the mean velocities approached the Nyquist velocity.

The main component of NSPA, then is to decide what values f_c, and N to use, and, most importantly, what indices make up I, the region of integration. Ideally, I should be the indices that the weather spectrum resides from the peak to the noise on each side of the spectral feature. For example, in figure 2 at 60 km, a reasonable range might be the indices that span $-30\,m/sec$ to $-20\,m/sec$. But because the spectra are fairly noisy, it is necessary to first average the spectrum in range. Referring again to figure 2, the spectrum are averaged in the *y*-axis dimension with a Gaussian kernel of length 7. Other choices are certainly possible, including median filtering.

The algorithm then starts at the bin of the maximum value of the power spectrum, and moves to the left, wrapping around the edge if necessary, until the spectrum values reach the noise level. The points between the 'left' cutoff and the peak are added to I. The same is now done on the right side. f_c is set to the velocity of the maximum value of the power spectrum. The mean radial velocity can now be calculated in equation 1. Note that the S_i are the *un*-averaged spectral values.

b. *NSPA Pass 2*

In the second pass, as in NESPA, NSPA looks for discontinuities and attempts to 'patch' them by redefining I. The idea is that if the velocity is discontinuous from the surrounding gates then the first pass probably locked onto the wrong feature. By redefining I based on the integration regions of the neighboring gates, the velocity of the weather should be recovered.

The technique currently used is to smooth the velocity from pass 1, along each radial, and compare that to the raw first pass velocities. Outliers are identified by looking at the magnitude of the difference ($\ominus$). When the difference exceeds a threshold, the algorithm uses the adjacent gates to determine the new region of integration and recalculates the the radial velocity using 1

4. Results

Figure 3 shows a PPI plot of range-corrected power from the same dataset as figure 2. There is a fair amount of range-folding, as is evident from the cigar shaped radial features. Figures 4 and 5 shows PPI plots of the mean velocity as estimated from pulse-pair and NSPA, respectively. The texture of the NSPA velocities are much smoother than the pulse-pair, especially in the regions corresponding to low SNR.

5. Conclusions

Advanced spectral-domain processing techniques, such as those employed by NSPA, allow better discrimination between contamination and weather echoes as well as better estimation of the meteorological spectral moments when contamination occurs. As an example, when weather is collocated with ground clutter, spectral-domain processing will result in better estimates of the meteorological spectral moments.

In the past, spectral-domain processing with the WSR-88D was not possible in the real-time environment because of limitations in the processing power of the RDA. With the impending deployment of the RVP8, the ability to perform spectral-domain processing, like NESPA, becomes practical and advantageous.

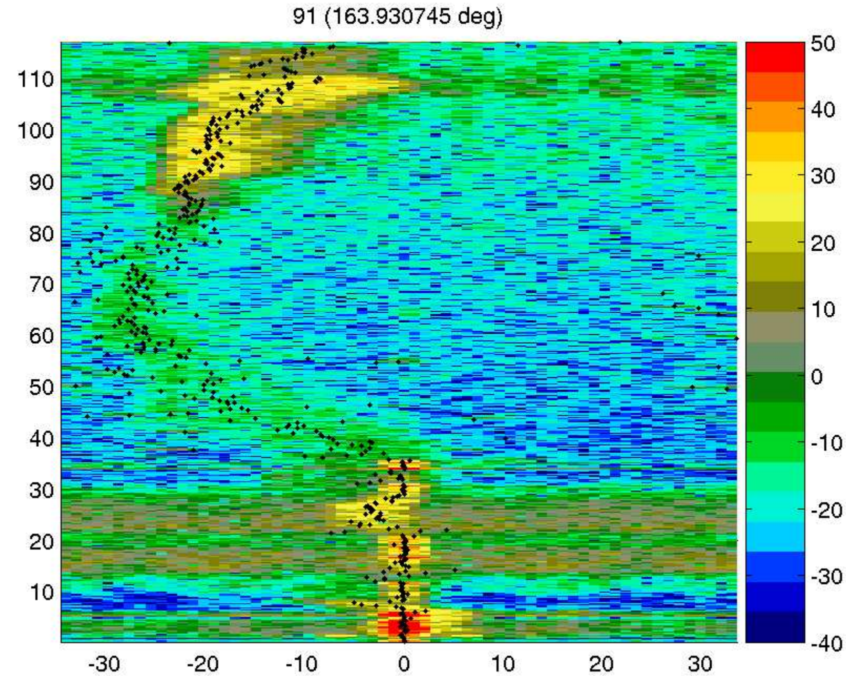

Figure 2: Waterfall plot taken of the radial at $164°$ from data taken on April 5, 2003 at KOUN. The x-axis corresponds to radial velocity (m/sec) and the y-axis to range (km) from radar. The color corresponds to the range-adjusted power of the power spectrum at that velocity (Doppler frequency) and range. The dots represent the mean velocity as computed by an algorithm, in this case the pulse-pair estimator.

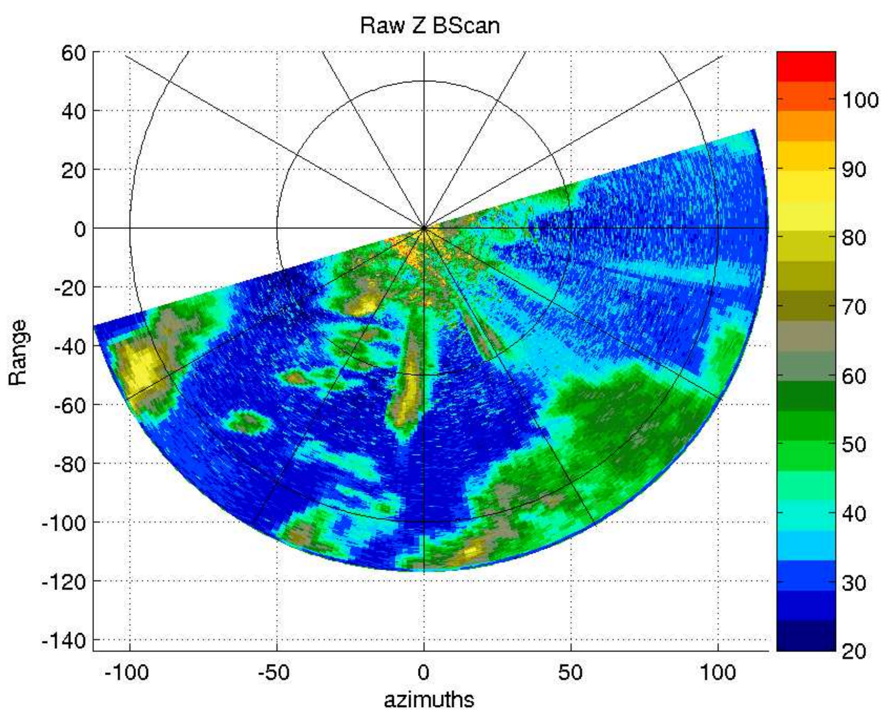

Figure 3: Un-calibrated range-corrected power PPI plot from data taken on April 5, 2003 at KOUN.

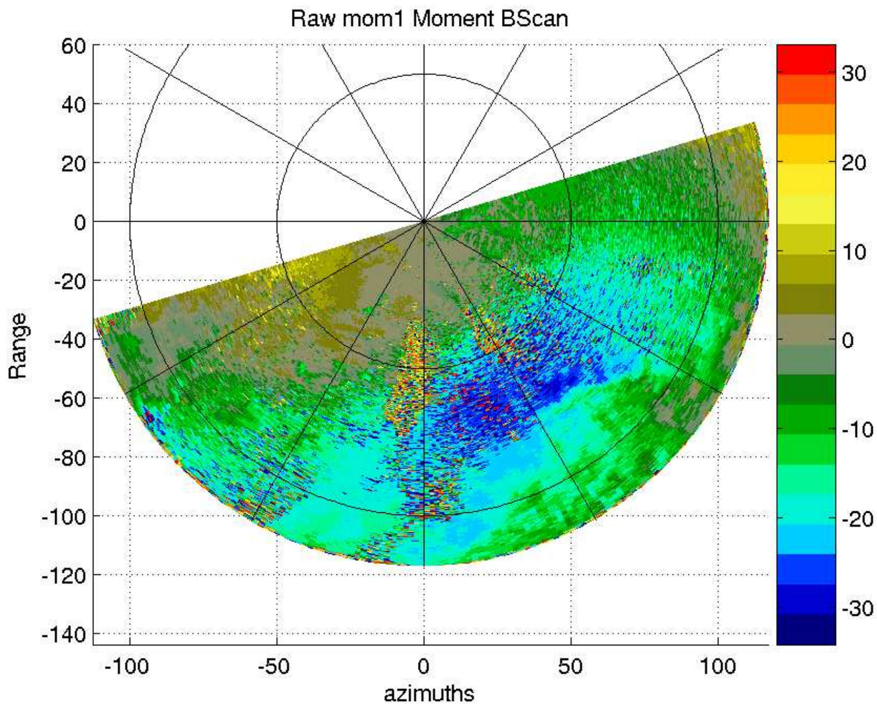

Figure 4: Pulse-pair mean radial velocity PPI plot from data taken on April 5, 2003 at KOUN.

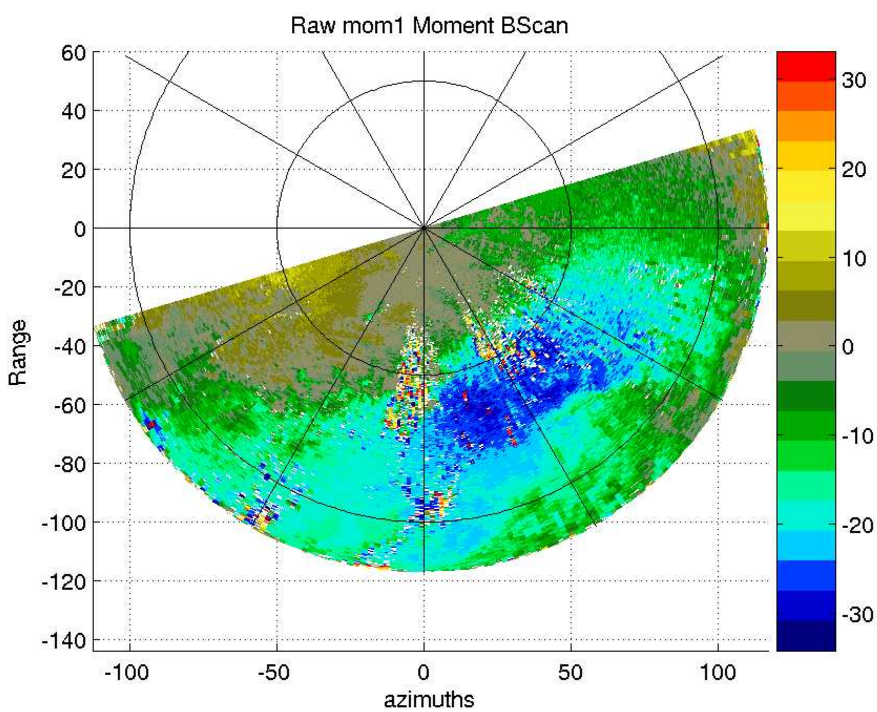

Figure 5: NSPA final mean radial velocity PPI plot from data taken on April 5, 2003 at KOUN. Note, due to a bug, that in cases of very low SNR, velocities are sometimes returned as a missing value (white).

Updates to this paper will be posted at http://www.rap.ucar.edu/staff/meymaris/IIPS07_NSPA

References

Cornman, L. B., S. Gerding, G. Meymaris, and J. Williams: 2002, Real-time estimation of atmospheric turbulence severity from in-situ aircraft measurements. 10th Conference on Aviation, Range, and Aerospace Meteorology, Portland, OR, 237–240.

Doviak, R. J. and D. S. Zrnić: 1993, *Doppler Radar and Weather Observations*, Academic Press, San Diego, California. 2nd edition.

Morse, C. S., R. K. Goodrich, and L. B. Cornman, 2002: The nima method for improved moment estimation from doppler spectra. *Journal of Atmospheric and Oceanic Technology*, **19**, 274–295.

Sirmans, D. and B. Bumgarner, 1975: Numerical comparison of five mean frequency estimators. *Journal of Applied Meteorology*, **14**, 991–1003.