# Is Spectral Processing Important for Future WSR-88D Radar?

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## Abstract:

Processing speed and memory capacity are reaching a point where future weather radar systems will be able to exploit the power of full spectral processing. This work focuses on data from the polarimetric KOUN radar at NSSL and will study the validity of the Gaussian Doppler spectrum for different regions of storms. Many processing algorithms, such as those used to estimate reflectivity, velocity and dual-polarization parameters, assume a Gaussian-shaped spectrum. It is our hypothesis that the Gaussian Doppler spectrum will be valid for only relatively homogenous parts of the complex structure of storms. Radar data are in time-series (time domain) form (Level I) and it is necessary to convert them to the frequency domain using a Fourier transform. The processing must be performed on each gate of the radar. For this investigation we need to determine how close the actual Doppler spectra are to the Gaussian form and relate a goodness-of-fit measure to different regions of the supercell storm of May 8, 2003.

## I. Introduction and Motivation

Currently, technology is being used to improve the quality of life of every citizen, and meteorology can also plays a significant role. Weather events, such as tornados, can put people's lives in danger. A tornado is a violently rotating narrow column of air, averaging approximately 100 meters in diameter, which extends to the ground from the interior of a cumulonimbus cloud. It appears as a condensation funnel pendant from cloud base and/or a swirling cloud of dust and debris rising from the ground [*Doswell*, *2001*]. In this work, we study the validity of using a Gaussian distributed Doppler spectrum for characterizing the velocity within a tornado. The tornado which was studied for this investigation was a Type I Supercell Storm (Fig 1).

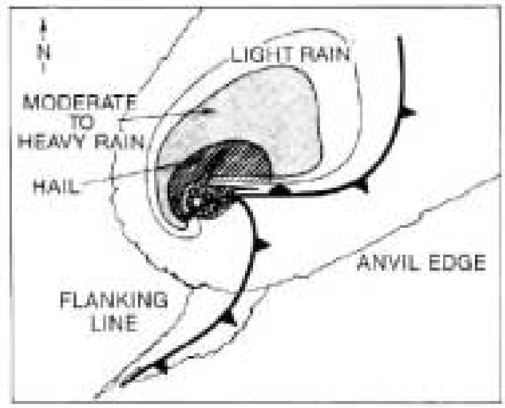


Fig 1. Supercell tornado [*Met*, *TAMU*].

The time that we will focus on to investigate the tornado, the storm was in its mature stage (stage 3) [*Doswell*, *2001*]. This tornado, as with many of this category, spawns other tornados of lesser intensity called tornados families. In an effort to improve warning lead time, the National Weather Service (NWS) and the National Severe Storm Laboratory (NSSL) are involved in the development of sophisticated Doppler radars. These radars use microwaves which have the capacity to penetrate clouds and rains [*Doviack and Zrnić*, *1993*]. In World War II, it was learned that an electromagnetic pulse could be sent, and scattered by an object, which could then be detected by a receiving device. Then, in 1940, the Pulsed Doppler technique called MTI (moving target indicator) was developed. But it was not until 1953 that radar was used for meteorological applications by Browne and Barrat in Cambridge University, England. In order to improve severe weather warnings, in 1988 the Weather Surveillance Radar 88 Doppler (WSR 88D) was deployed. In 1997, the installation of 165 of these radars was completed covering all the regions of the United States in an effort to improve the weather service. The Doppler radar is the only remote sensing instrument that can detect tracers of winds and measure its radial speed in clear air and within a strong rain region [*Doviak et al., 2000*]. Charles A. Doswell III wrote "on both mesocyclone and the tornado scales, a sufficient number of observations must be gathered to allow for the generalization of the results" [*Doswell, 2001*]. For this research, it is desired to find how close the Actual Doppler Spectra (ADS) is to the Gaussian form [*Janssen and Van Der Spek, 1985*] and relate this measurement for different regions of the storm. In other words, we intend to test the Gaussian Doppler Spectrum assumption as a function of location within various formations of storms.

## II. Experimental Design

### A. Description of KOUN Radar

The KOUN radar (Fig 2) is an experimental WSR 88D that was installed in March of 2002 at NSSL and has been upgraded to allow polarization diversity [*CIMMS*]. This radar transmits each electromagnetic pulse with an orientation of 45 degrees to the horizontal surface. In addition, this radar can independently send and receive pulses in the vertical and horizontal plane (polarimetric). It is one of only a few radars in the world that provides data in time series (Level I) format. The data obtained from this radar can be used to assist in flood warnings, for example. Moreover, this radar offers new ways to detect tornadoes. It is possible that information of the structure of a tornado can be obtained from these data sets that could be used to provide warnings sooner. KOUN was designed to emulate the elevation angles, scanning rates, and volume coverage patterns used by standard WSR-88D radars.

Figure 2. KOUN Radar at NSSL [*CIMMS*]

**B. Measurement Procedures**

As mentioned earlier, the data of the radar are obtained in time series (Level I) format and it is therefore, necessary to convert it to the frequency domain (Level II) using a Fourier transform. As is typically the case, we have opted to use the so-called periodogram to estimate the Doppler Spectrum. When obtaining the periodogram, the Fast Fourier Transform is typically used [*Stoica and Moses, 1997*].

$$\hat{S}(w) = \frac{1}{N}\left|\sum_{t=1}^{N} y(t)e^{-iwt}\right|^2$$

*N = number of all data*
*y (t) = time series data*
*w = frequency (rad/sec)*

When obtaining the ADS, we need to know the area of the observed region occupied by the storm. This is obtained by calculating the reflectivity (Fig 3) and radial velocity (Fig 4) for all azimuth angles and ranges. This plan position indicator (PPI) display is used to localize the storm and relate the Doppler spectral shape to different regions of the storm.

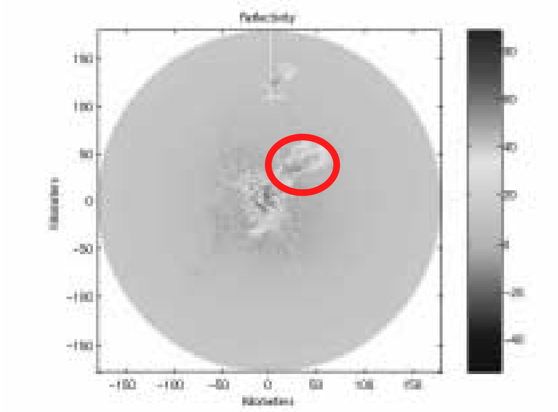



Figure 3. Reflectivity of all data that started at May 8, 2003. The circle indicates the storm location.

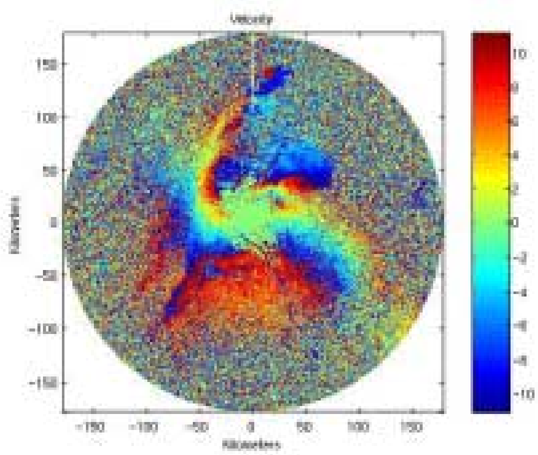



Figure 4. Velocity of the complete data that started at May 8, 2003.

We calculate the Doppler Spectra and compare to the Gaussian Model Fit (GMF) using the estimated moments. The error is calculated using the Mean-Square Error (MSE).

$$MSE = \frac{1}{N}\sum_{i=1}^{N}\left|S(v_i)-\hat{S}(v_i)\right|^2$$

*$S(v_i)$ = Gaussian Model Fit*
*$\hat{S}(v_i)$ = Actual Doppler Spectra*

## C. Data Reduction

We would like to isolate the storm. Therefore, it is necessary to choose range gates of 0 to 313. The reduced (zoomed) plot is obtained as shown below.

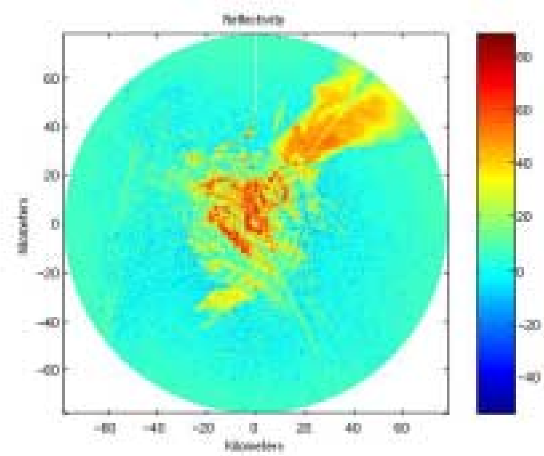



Figure 5. Reflectivity plot of the storm from range gates 0 to 313.

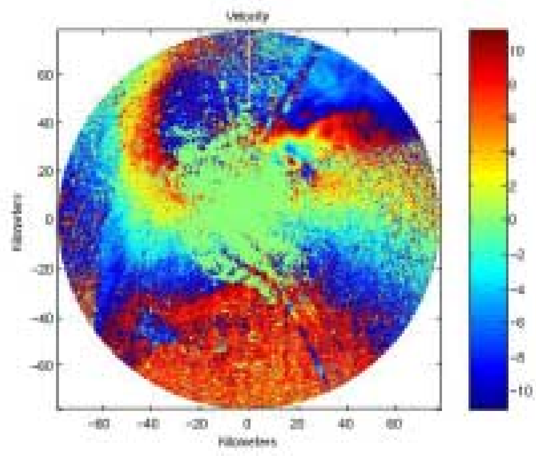


Figure 6. Velocity plot of the storm from range gates 0 to 313.

## D. Correction or Improvement

We need a preliminary analysis tool to compare the ADS to the GMF. This comparison is shown in Fig. 7a. Notice the similarities between the two curves. However, side lobe problems hamper the comparison. Therefore, a hamming window was used to improve the spectral estimate which is shown in Fig 7b.

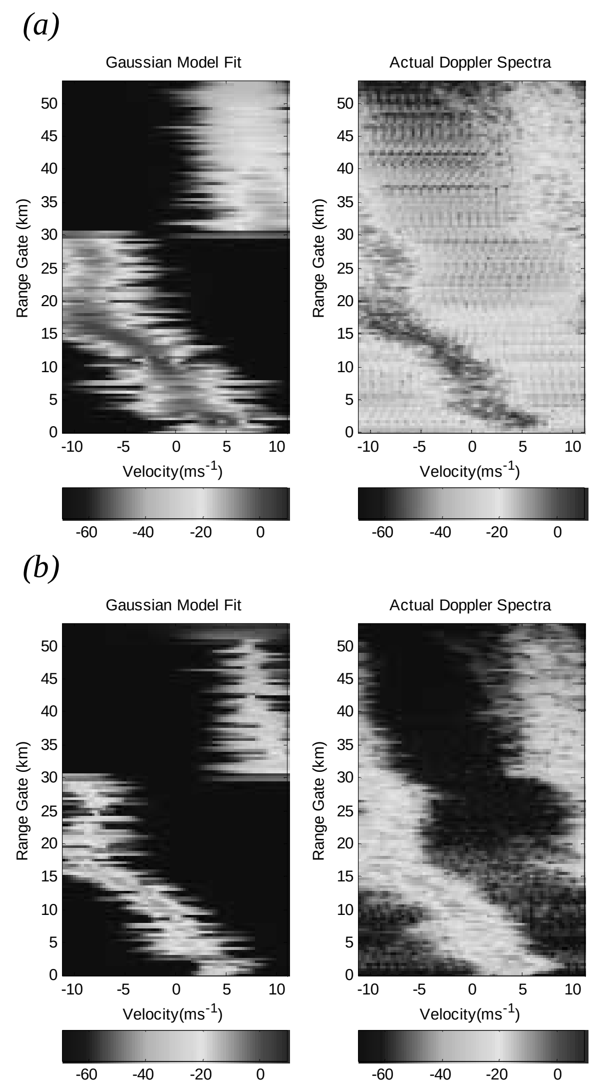



Figure 7. Without Hamming (a); with Hamming (b). Left is the GMF and the right is the ADS.

In order to obtain precise location of the storm, we have chosen range gates 100-313. We have also eliminated regions of strong ground clutter.

### E. Results and Interpretation

After eliminating ground clutter, we obtained the MSE of the area of the storm which is shown in Fig 8. According to Fig 8, a high MSE exists in and near the tornado and a low MSE exists in the outflow region of the storm.

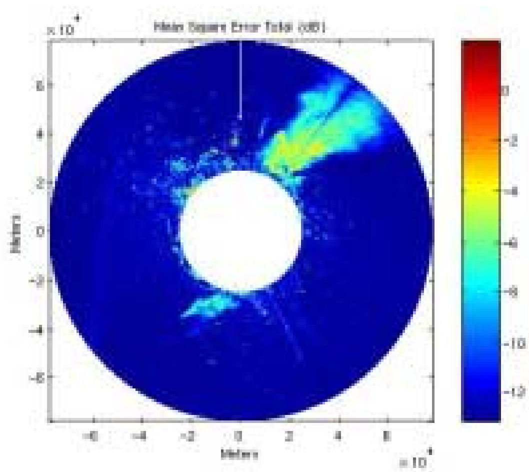



Figure 8. Mean Square Error (dB) after eliminating ground clutter.

We would now like to verify if the MSE is representative of the actual spectrum. For this purpose, we chose comparative areas of greater and smaller MSE. For example, we selected azimuth angles of 32.4º and 34.9º which are areas of the tornado and have greater MSE. The ADS for these azimuths do not follow a Gaussian form as seen in Figs 9 and 10. In contrast, azimuths 39.9º and 47.9º with gates greater than 250 show remarkable comparison in that the ADS have a quite good Gaussian form. Other examples of small MSE are shown in Figures 11 and 12.

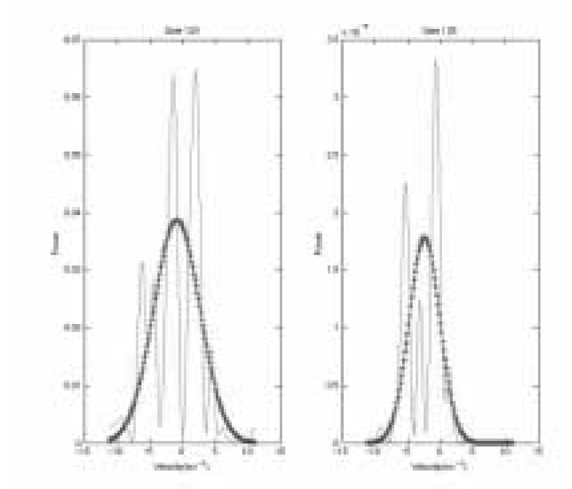


Figure 9. Azimuth 32.4º; gates 120 and 125. MSE = .001 - .1

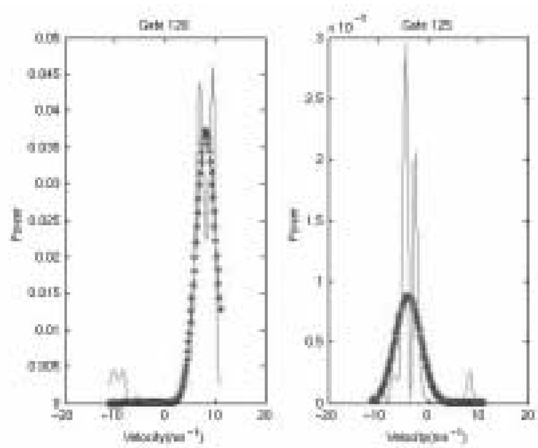



Figure 10. Azimuth 34.9º; gates 120 and 125. MSE = .001 - .1

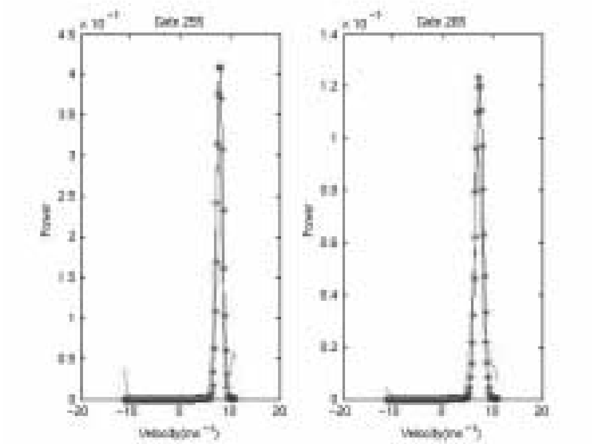


Figure 11. Azimuth 39.9º; gates 255 and 265. MSE = .00001 - .001

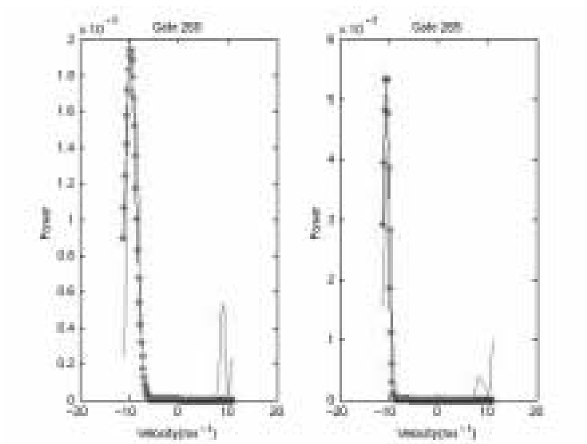
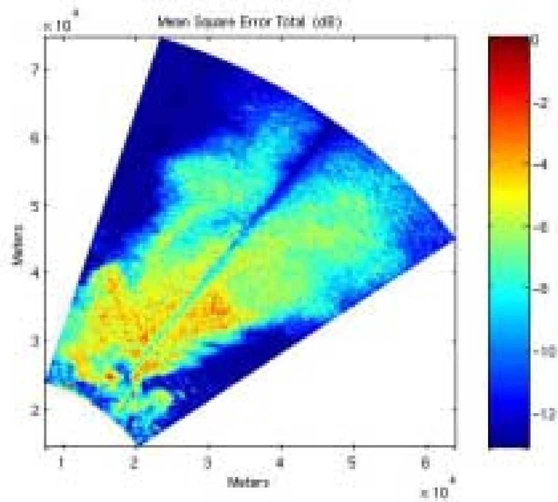


Figure 12. Azimuth 47.9º; gates 255, 260 and 265. MSE = .00001 - .001

## III. Discussion of Results

### A. Regions of Gaussian Assumption Validity

The area where the Gaussian assumption is valid is the outflow region (light rain) of the storm as illustrated in Figure 14. This is the region of smaller MSE that is found in the weather event, and is characterized by light rain and general homogeneity. The region of high vorticity near the updraft is obviously inhomogeneous. Therefore, the Gaussian shape is less valid in these regions. Also in this region significant turbulence exists, which is produced by the inflow of dry environmental air and wind shear near the updraft.



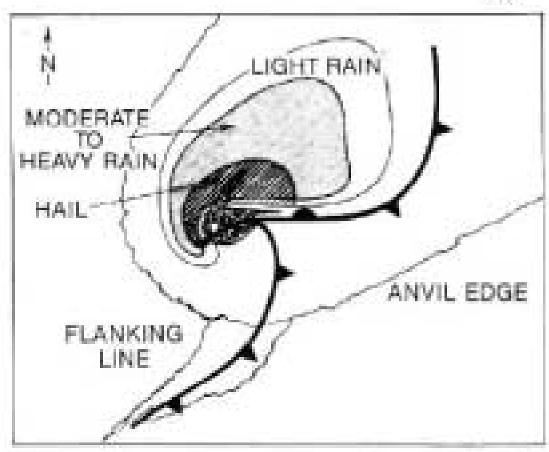



Figure 14. The region of MSE of the storm in comparison with the structure of a supercell storm

## IV. Conclusions

From the beginning of the research, we thought that the homogeneous part of the storm would exhibit a Gaussian-shaped Doppler spectrum. When finishing this investigation, we have found that the area of the storm that has a Gaussian form is the outflow region which is the homogeneous part of this storm. This Gaussian area coincides with little or moderate precipitation. The MSE relation verifies this hypothesis. In addition, it was discovered that the largest MSE was in the updraft region of the storm. This is the region that contains moderate to heavy precipitation and hail and happens in or near the storm tower.

Nevertheless it is difficult to generalize since our results were obtained from a single storm. It would be far better to compare it with other storms to verify if the results are general. Also, it is necessary to verify if our analysis method of comparison is the most beneficial. However, we can affirm that for this particular storm the Gaussian part with low MSE is the outflow region.

With this study, it has been verified that spectral processing is important for the future of the WSR 88D radar. More information and parameters that can be used to obtain better knowledge of different storm classes will offer the community a more reliable level of security and warning.

## V. Acknowledgment

I would like to thank the REU program of National Weather Service and its director Daphne Zaras [NSF 0097651] and CASA [EEC-0313747] by the opportunity of participating in the summer internship 2005. I want to give a special recognition to Dr. Robert Palmer (OU) due to his dedication and help in the development of the research. The cooperation of Khoi Le, Dr. Boon Leng Cheong and all persons of the School Of Meteorology of the University of Oklahoma is gratefully acknowledged. This opportunity was a great experience given my lack at English language ability. However, with the help of my mentor I could do the work.

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