

*Application of a 2-Dimensional Velocity Dealiasing Algorithm in the WSR-88D  
Network*

Project Number: 13

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Metr 4922 Senior Seminar II (Capstone)

Date: May 7, 2010

## **Abstract**

Correct velocity dealiasing is important for providing quality radar products used by forecasters during adverse weather. The current velocity dealiasing algorithm (VDA) in the National Weather Service Weather Surveillance Radar 1988 Doppler (WSR-88D) network occasionally fails to correctly dealias velocity data in critical areas during severe weather events, which impairs the quality of timely warnings issued by forecast office personnel. Incorrect velocity dealiasing occurs in tornadic storms, especially those passing into the radar clutter region, along thunderstorm outflow boundaries, and tropical cyclones passing within the radar area of coverage.

In this study a two dimensional (2-D) VDA developed by Jing and Smith was applied to the WSR-88D and compared to the performance of the current radar product generator (RPG) VDA. The performance is evaluated qualitatively for several archived weather events including tropical cyclones, tornadic thunderstorms, and outflow boundaries. The results of the study show sufficient improvement of the velocity data for implementation of the 2-D VDA into the WSR-88D network.

## **Introduction**

Correct dealiasing of velocity data is important for providing quality velocity products. Velocity dealiasing errors are characterized by velocity estimates that are not meteorologically realistic. The errors can range in size from a few bins to an area that encompasses a large portion of the velocity field.

Forecasters use radar generated velocity data as a tool for making decisions during severe weather events. The quality of the velocity data determines usefulness of the tool; it is important that the forecaster does not lose confidence in the velocity data provided from the WSR-88D network. Currently, forecasters observe improper velocity dealiasing during severe weather events such as: (1) in circulations passing into the radar clutter region, (2) along thunderstorm outflow boundaries, and (3) in tropical cyclones.

Doppler radar measures Doppler shift in a signal returned from a scatterer and converts the shift into a velocity measurement. Paraphrasing Zhang and Wang (2006), the signal becomes aliased when the phase shift between two consecutive pulses exceeds the maximum detectible phase shift based on the radars pulse repetition frequency and wavelength. The maximum velocity that can be measured is limited to the Nyquist velocity ( $V_n$ ). Any velocities within the first Nyquist interval can be measured, but when they exceed the Nyquist velocity they are folded back within the first  $V_n$  rather than falling into one of the next intervals. The equation given for calculating the true velocity ( $V_T$ ) is given by Zhang and Wang (2006) as:

$$V_T = V_o \pm 2nV_n$$

Where  $V_o$  is the observed velocity and  $n$  is an integer representing the interval. If the  $V_T$  lies within the first Nyquist interval ( $2nV_n$ ), the integer  $n$  would be zero. As  $V_T$  increases beyond  $V_n$ , the integer  $n$  increases. In order to determine the correct  $V_T$ , a reference velocity must be determined. The reference velocity may be taken from a nearby velocity or group of velocities deemed reliable or from an external source such as a sounding. The goal generally is to find the value of  $n$  that produces the smallest difference between the reference velocity value and the velocity being dealiased.

The current VDA uses continuity checks and an environmental wind table to help determine the true velocity estimate for a bin. It was developed due to computer processing unit limitations that restricted the amount of data that could be processed in real time. The process is built upon a method described by Eilts and Smith (1990). Eilts and Smith describe a local Environment Dealiasing technique in which each data point undergoes a continuity test with the surrounding points. If there are insufficient data points for performing the continuity check, such as along the edge of a thunderstorm, an environmental wind table may be used to determine the correct velocity interval. The environmental wind table is generated through the Velocity Azimuth Display (VAD) or from sounding data (Eilts and Smith<sup>1</sup>, 1990). Though this method is effective, it is possible that weather phenomena such as an outflow boundary ahead of thunderstorms could be dealiased incorrectly once past the radar. Once the thunderstorms have passed the radar the surface winds represented by the VAD may not have the same directional components as those along the leading edge of the thunderstorms, leading to dealiasing errors along the leading edge of the thunderstorms (personal communication, Dave Zittel). Dealiasing errors also occur when tornadic storms enter the clutter region and in tropical cyclones passing near the radar.

Several other methods have been developed to dealias radar velocities. One technique was developed by James and Houze (2001). This dealiasing scheme uses spatial and temporal data provided by a Doppler radar network. The algorithm James and Houze developed studied each tilt angle of a radar scan. Taken from their publication, the method begins “at the highest elevation where clutter is minimal and gate-to-gate shear is typically low compared to the

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<sup>1</sup> Currently affiliation, Radar Operations Center

Nyquist velocity. It then dealiases each tilt in descending order until the entire radial velocity volume is corrected”.

Friedrich and Caumont (2003) developed a dealiasing scheme which is designed to correct data measured by bistatic receivers. Friedrich and Caumont modified the real-time four-dimensional Doppler dealiasing scheme (4DD), developed by James and Houze (2001), allowing monostatically and bistatically measured Doppler velocities to be dealiased at the same time. The data used were obtained from a bistatic Doppler radar network.

James and Houze applied the 4DD dealiasing scheme to the WSR-88D and found a large amount of processing time was needed to find the correct radial at the beginning of each volume (2001). The large processing time and top down approach of the algorithm make the 4DD dealiasing scheme unsuitable for the WSR-88D system in real time.

The method that was used in this study was originally developed in the Research Applications Program at the National Center for Atmospheric Research (Jing<sup>2</sup> and Wiener, 1993). The technique was described in a paper by Jing and Wiener, *Two-Dimensional Dealiasing of Doppler Velocities* (1993). Three algorithms were described; a basic 2-D algorithm, a modified 2-D algorithm, and a dealiasing algorithm that uses environmental wind data. Both versions of the 2-D algorithm use a process in which the dealiasing was done by calculating the difference between a gate and the neighboring gates, placing paired gates into a smoothness function, and applying a least squares method to find suitable velocity values which minimize the smoothness function. The third algorithm attempts to resolve isolated velocities by incorporating

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<sup>2</sup> Current affiliation, Radar Operations Center

environmental wind data. The 2-D VDA that was tested combines the third algorithm with the modified 2-D algorithm. The 2-D VDA was applied to a CP-2 radar in the summer of 1992. They found the algorithm correctly dealiased data contaminated by noise, but failed in large areas of strong wind shear such as along a gust front. The algorithm may also fail in regions connected by thin strips of incorrect data. They suggest a gust front detection algorithm and dilation-and-erosion technique may be used to improve the performance of the algorithm and conclude that further study was needed (Jing and Wiener 1993).

A new version of the previously described basic 2-D VDA was developed in the Radar Operations Center. The method described by Witt, Brown, and Jing (2009) in *Performance Of A New Velocity Dealiasing Algorithm For The WSR-88D* applies a weighting factor to a method built upon the 2-D VDA. The amount of weight applied depends on the difference with respect to near 0 and near  $2V_n$  values. The closer the difference is to 0 or  $2V_n$  the greater the weighting that was applied. The algorithm works through two phases. One phase of the 2-D VDA uses an entire elevation scan to create a reliable global wind distribution. The second phase splits the elevation scan into partitions and the 2-D VDA is used to dealias smaller features. An internally generated environmental wind table or external source is then used to dealias small isolated regions. In their study they used an internally generated environmental wind table. The 2-D VDA was tested using data from three different types of weather: 1) clear air using VCP-31, 2) thunderstorms using VCP-12, and 3) hurricanes using VCP-212. The performance was scored against the current VDA and showed the most improvement with VCP-31 though improvement was still noted with the VCP-12 and VCP-212 cases. An option mentioned by Witt, Brown, and Jing that may improve the dealiasing further, is to remove velocity data that is associated with

high spectrum width before applying the 2-D VDA. Though results of this study showed improvement the authors conclude more data needed to be evaluated in the future (Witt et.al 2009).

For our study we used the most current version of the 2-D VDA developed in the ROC (Jing and Smith). This version is similar to the one previously described and also incorporates spectrum width data. The spectrum width is used for determining a weighting factor for the corresponding velocity data. Velocities associated with high spectrum width receive a smaller weighting during the global optimization of the algorithm but no velocity data are removed (Personal communication, Zack Jing).

Our primary objective was to examine how the 2-D VDA performed on the WSR-88D system and used the results to determine if it should be implemented into the WSR-88D Network. We specifically address how the 2-D VDA performed compared to the current VDA during tropical cyclones, along outflow/gust front boundaries, and on tornadic storms.

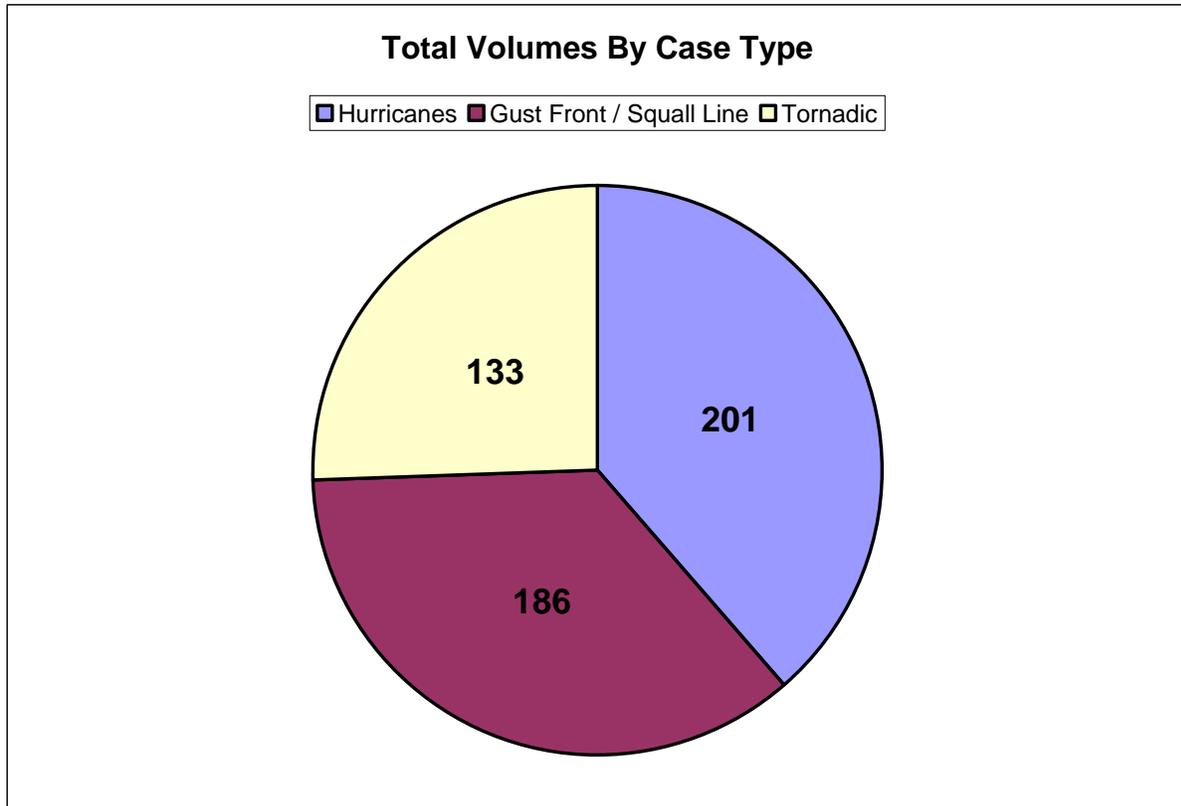
## **Details and Methods**

### **Data and Acquisition**

We studied the application of a Two Dimensional (2-D) Velocity Dealiasing Algorithm (VDA) to four different precipitation mode Volume Coverage Patterns (VCPs) within the WSR-88D network; VCP 21, VCP 212, VCP 11, and VCP 12. Witt et. al (2009) had concluded that the most improvement was with the clear air VCP 31. Radar Operations Center (ROC) personnel felt the improvements were not significant enough for the implementing the 2-D VDA into the

WSR-88D Network, we were asked specifically to evaluate precipitation VCPs. We evaluated only the 0.5 degree elevation scan, allowing us to evaluate a large number of volume scans under the time constraints. We used a base velocity product that has an azimuthal resolution of one degree and radial resolution of one quarter kilometer, which was common to all our cases.

Our data sets were made up of three different case types: hurricane, tornadic thunderstorm, and gust fronts. The original data set contained ten cases for a total of 520 volumes. Figure 1 (see p.8) shows the total amount of volumes for each type of case examined, 133 volumes from tornadic cases, 201 volumes from hurricanes cases, and 186 volumes from gust front cases. The case from KARX (La Crosse, WI) did not contain a tornadic circulation; however the storms had produced tornadoes over Iowa. We used this case because the La Crosse forecast office reported dealiasing errors as the storms moved into the area, impacting operations. Some individual cases used multiple VCPs during the event; these cases were broken into smaller cases according to VCP, yielding a total of 15 cases: 3 hurricane, 5 gust front, and 7 tornadic (Table A1).



**Figure 1: Total number of volume scans by case type.**

We ordered Level II radar data from National Climate Data Center (NCDC) and replayed the data through a non-operational Radar Product Generator (RPG) at real time rate to create the velocity products. For both algorithms we used the VAD for the environmental winds. If the vertical wind profile generated from the VAD was missing large amounts of data, a manual sounding was entered. Screen captures of the first elevation velocity products from each volume scan were collected, placed into a document, and scored.

## **Scoring**

We followed a scoring system, developed by Arthur Witt (2007) that had been used in a previous study of the 2-D VDA. The scoring method used by Witt is an adaptation of a technique originally developed by Dave Zittel (unpublished). The method assigns each scan a score of 100, and then subtracts the appropriate penalty, shown in Table A2, determined by the classification of the dealiasing error(s) (Witt 2007). To become familiar with the scoring system and develop a baseline we scored three of the cases that Witt had previously studied and scored.

We also recorded individual dealiasing errors based on conditions where the current VDA occasionally fails. These conditions are described in a set of guidelines written by Melissa Patchin (2007). Each dealiasing error is recorded based on the VCP, Pulse Repetition Frequency (PRF), Date, and Time. Properties of the error are recorded such as the location of the error with respects to unambiguous range (trip), 1<sup>st</sup> radial of the sweep, noise, mesocyclones, the leading edge encountered by the beam azimuthally, gust fronts, clutter and anomalous propagation (AP), beam blockage, and movement of the weather towards or away from the radar. The recorded characteristics of each dealiasing error help determine strengths and weaknesses of the algorithms.

## **Results and Discussion**

Figure 2 (see p.10) shows the average score for the three different classifications (Hurricane, Gust Front, and Tornadic); each category is discussed below. The 2-D VDA has 71 volumes with errors while the current VDA is much higher with at total of 252 volumes with errors (Figure A1).

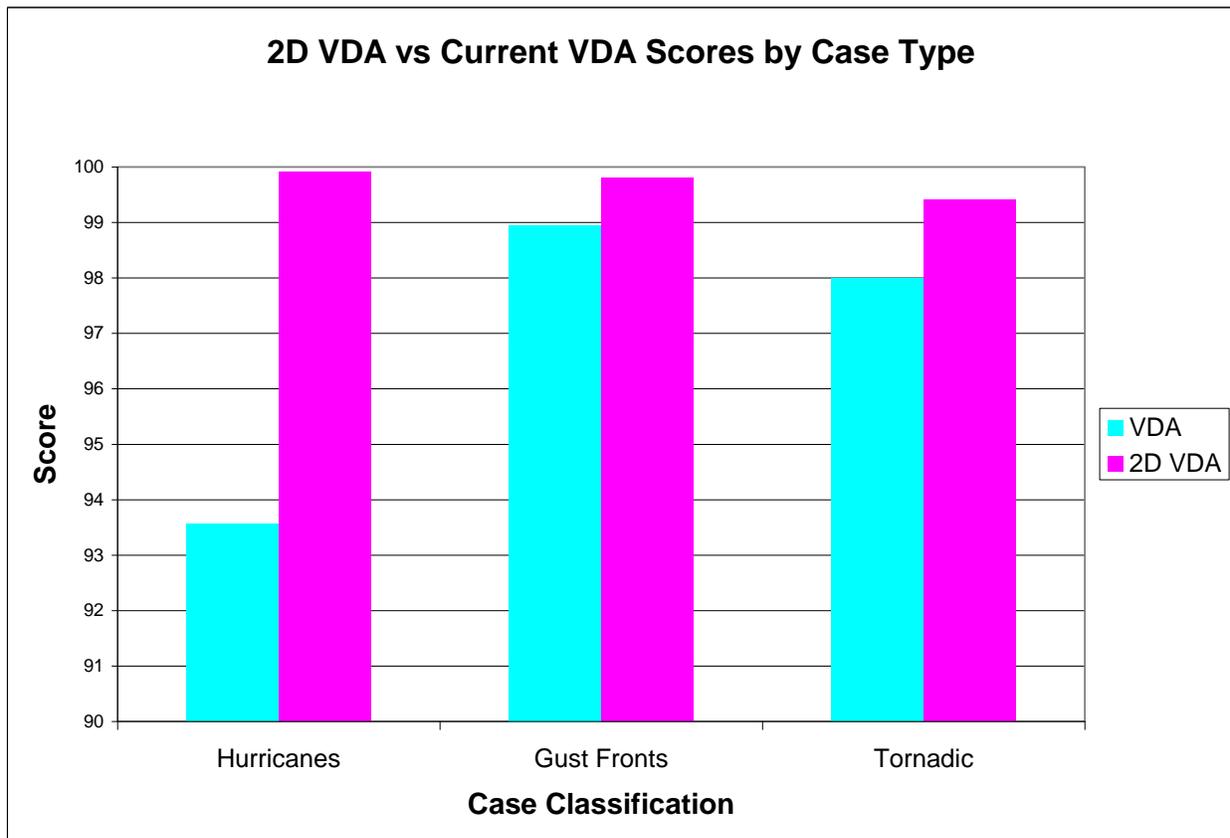


Figure 2: Average scores for all cases by case type

Table 1: Total volumes and dealiasing errors for each case type.

Case Type	Total Volumes	Total Errors VDA	Total Errors 2-D VDA
Hurricane	201	185	5
Tornadic	186	102	51
Gust Front	133	46	16

### Hurricane Cases

Figure 2 (above) shows the 2-D VDA outscored the current VDA 99.9 to 93.6 respectively.

Table 1 (above) shows the total amount of errors for each algorithm based on case type. The 2-D VDA has a significant reduction in the total amount of dealiasing errors for hurricane cases

counted over 201 volume scans, only 5 total errors for the 2-D VDA and 185 total errors for the current VDA. We examined the relevant characteristics of the dealiasing errors shown in Figure A2. The categories with the largest impacts on dealiasing errors during hurricanes are areas with noise and second trip data. The movement is marked as unknown for many of the errors largely due to the rotation of the precipitation around the radar; therefore it is neither moving towards nor away from the radar. Velocity data from 1Sep08 for the current VDA, shown in Figure A3, shows a large dealiasing error in second trip along a large portion of the eyewall. The same volume using the 2-D VDA has been properly dealiased with no obvious errors.

### **Tornadic Cases**

The tornadic cases show improvement in the score and total errors, seen in Figures 2 (see p.10) and Table 1 (see p.10). The 2-D VDA had a score of 99.4 and a total of 51 dealiasing errors, the current VDA scored a 98.0 and had 102 total errors. We examined the relevant characteristics of the dealiasing errors, see Figure A4. The number of operational impacts and total errors is lower with the 2-D VDA; however the total number of errors occurring on a mesocyclone is the same. Figure A5 shows velocity data from 25Jul09 KBUF for the VDA and 2-D VDA respectively. Both algorithms came up with different solutions, but neither algorithm dealiased all the velocities correctly.

### **Gust Front Cases**

Gust front cases showed the least improvement in the score, the 2-D VDA scored a 99.8 and the current VDA scored a 98.9, see Figure 2 (see p.10). The case from KPAH had no errors for

either algorithm over 52 volume scans, which increases the score for both dealiasing algorithms. Excluding the KPAH case drops the score of the current VDA down to 98.7 and 2-D VDA to 99.7. We still see a large reduction in errors using the 2-D VDA. There were 46 errors using the current VDA and only 16 with the 2-D VDA, shown in Table 1 (see p.10). Errors along gust fronts moving away from the radar have been common with the current VDA as discussed earlier. Figure A6 shows that there was a reduction in the total amount of dealiasing errors; however the majority of the dealiasing errors for both algorithms occurred while the gust front was moving away from the radar. The 2-D VDA dealiased most of the data correctly compared to the VDA shown in Figure A7, however a very small error still exists along the gust front with the 2-D VDA indicated by the circled area.

### **Limitations**

The 2-D VDA currently has two disadvantages. The 2-D VDA does not currently work for radars running with different PRF sectors and it takes longer to process data than the current VDA. Forecasters sometimes change the PRF in a sector to change the unambiguous range and move range folded areas away from a specific storm of interest. The current VDA processes velocity data on a radial by radial basis, while the 2-D VDA applies the first processing step to a completed volume scan. This would increase the time a forecaster has to wait for new data during critical situations.

### **Conclusions and Summary**

Overall the 2-D VDA outperformed the current VDA. All three case types scored higher on average and had fewer total dealiasing errors with the 2-D VDA. The 2-D VDA is still

susceptible to failure under conditions that the current VDA fails, specifically on mesocyclones in the clutter region and on gust fronts moving away from the radar. The 2-D VDA also has a few limitations as previously discussed and the current VDA must be retained for the Multiple PRF Dealiasing Algorithm used by VCP-121 and for future improvements that rely on the current VDA such as staggered PRT. The advantages of the 2-D VDA are the significant reduction in dealiasing errors and improved data quality. The most significant increase in data quality using the 2-D VDA is with the hurricane cases. We recommend implementing the 2-D VDA, especially hurricane events.

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## Appendices

### A1: Tables, Graphs, Radar Images

Table A1: 15 cases where evaluated. The cases were sorted by date, site, type, VCP, and number of volume scans.

Date	Site	Type	VCP	Volumes	Start Time	End Time
24-Sep-05	KLCH	Hurricane	21	62	01:03Z	06:56Z
13-Nov-05	KARX	Tornadic	12	7	00:02Z	00:27Z
13-Nov-05	KARX	Tornadic	11	39	00:45Z	03:55Z
1-Jun-07	KINX	Gust Front	12	56	08:11Z	11:59Z
19-Jun-07	KTLX	Gust Front	212	37	04:44Z	09:30Z
23-Jul-08	KBOX	Tornadic	12	17	20:23Z	21:32Z
23-Jul-08	KBOX	Tornadic	212	21	18:46Z	20:18Z
1-Sep-08	KLIX	Hurricane	212	39	12:59Z	15:58Z
13-Sep-08	KHGX	Hurricane	212	100	04:16Z	11:58Z
16-May-09	KTLX	Gust Front	11	11	02:01Z	02:50Z
16-May-09	KTLX	Gust Front	12	30	2:55Z	04:57Z
16-Jun-09	KPAH	Gust Front	212	52	15:04Z	18:55Z
25-Jul-09	KBUF	Tornadic	21	15	18:01Z	19:22Z
25-Jul-09	KBUF	Tornadic	12	7	19:28Z	19:53Z
25-Jul-09	KBUF	Tornadic	212	27	19:57Z	21:57Z

Table A2: Penalties for the different types of dealiasing errors (From Witt et al. 2009).

Description of Error	Penalty
Single gate or 2 adjacent gates	-1
Small radial spike (<3 km in length)	-2
Very small patch	-2 to -3
Small patch	-4 to -8
Large patch	-8 to -12
Swath of ~20°	-12 to -16
Swath of ~40°	-26 to -30
Swath of ~60°	-32 to -38
Swath of ~90° or larger	-40 to -50

**2D VDA v. Current VDA Comparison of Volumes With and Without Dealiasing Errors**

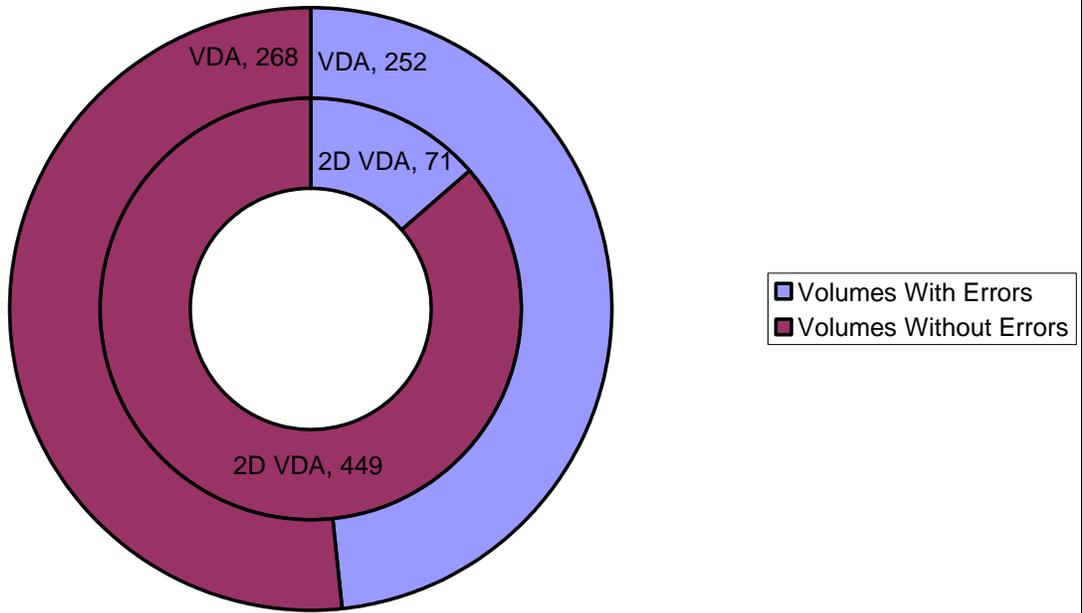


Figure A1: Volumes with and without dealiasing errors for all cases combined

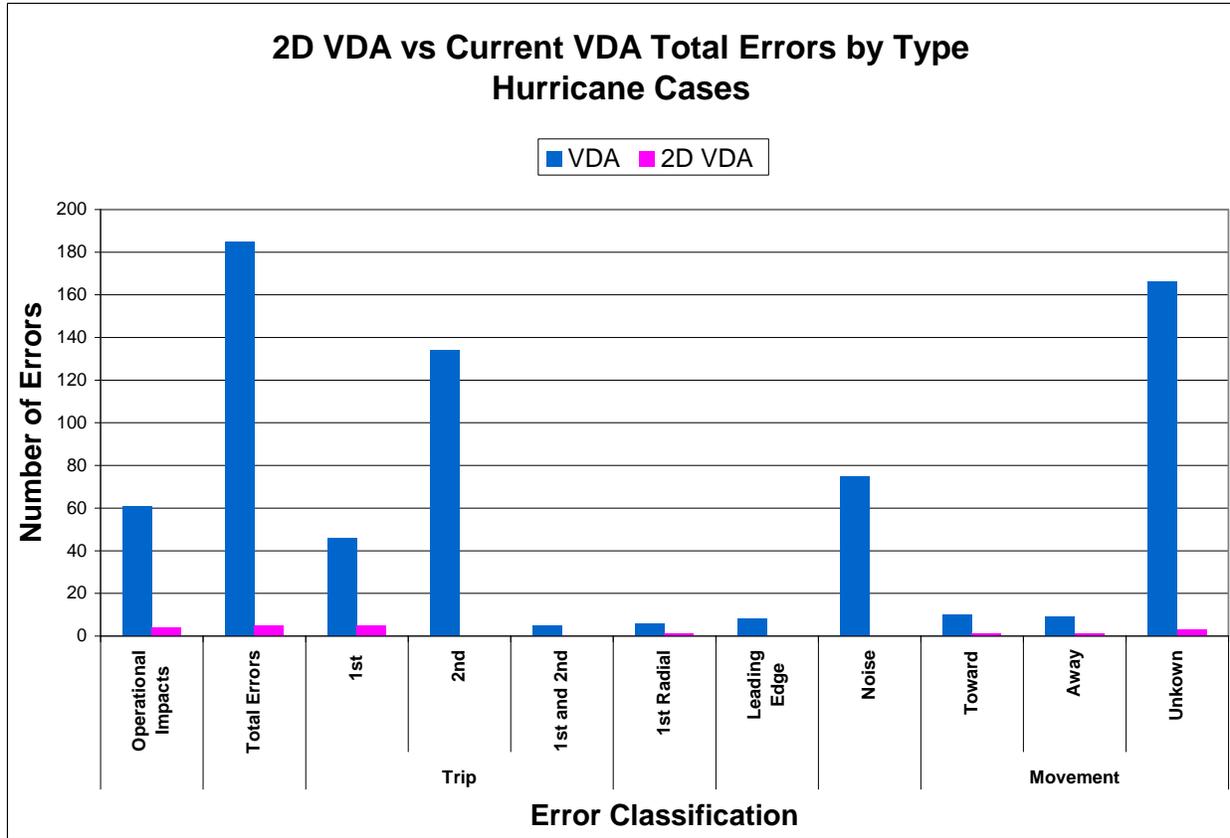


Figure A2: Total Errors for all hurricane cases combined based on classification

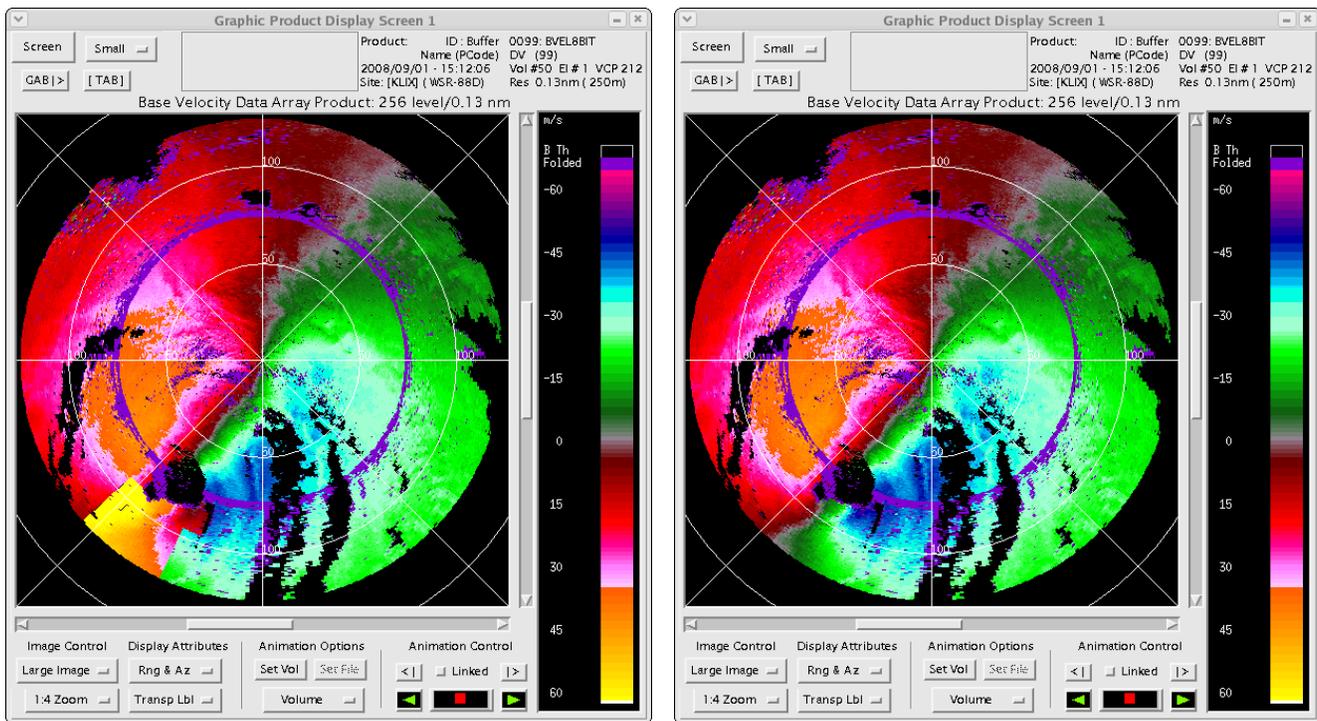


Figure A3: Velocity data from KLIX 1Sep08 at 1512Z. Dealiasing errors are visible using the current VDA (left). No dealiasing errors using the 2-D VDA (right).

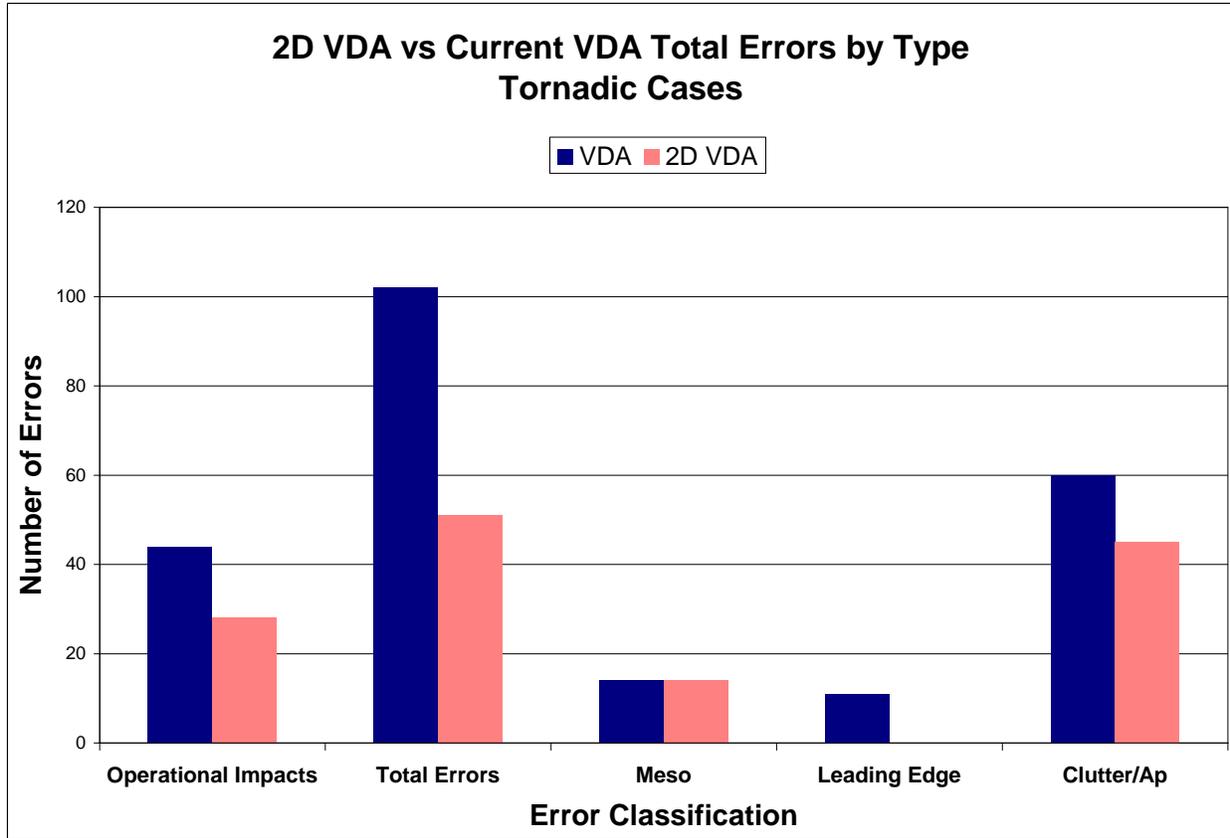


Figure A4: Total errors for all tornadic cases combined based on classification.

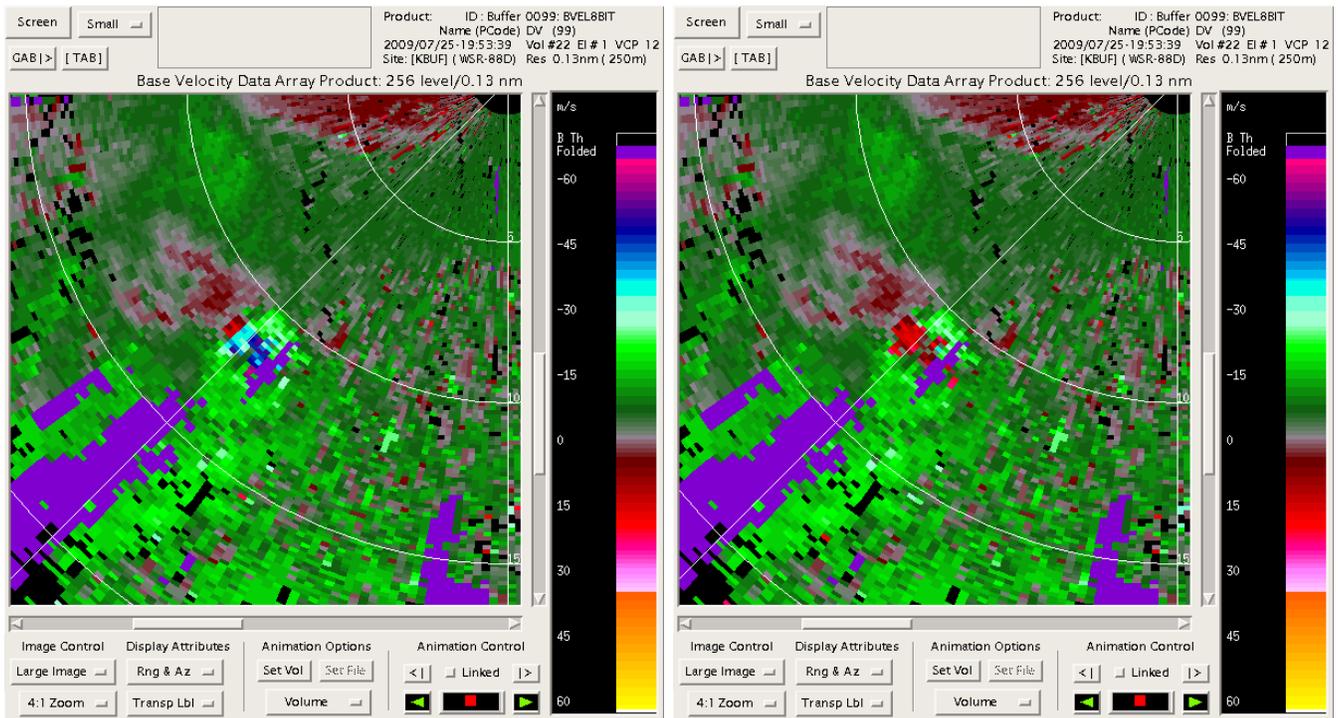


Figure A5: Velocity data from KBUF 25Jul09 at 19:53Z. Both algorithms, VDA (left) and 2-D VDA (right), fail to correctly dealias a mesocyclone in the clutter region of the radar.

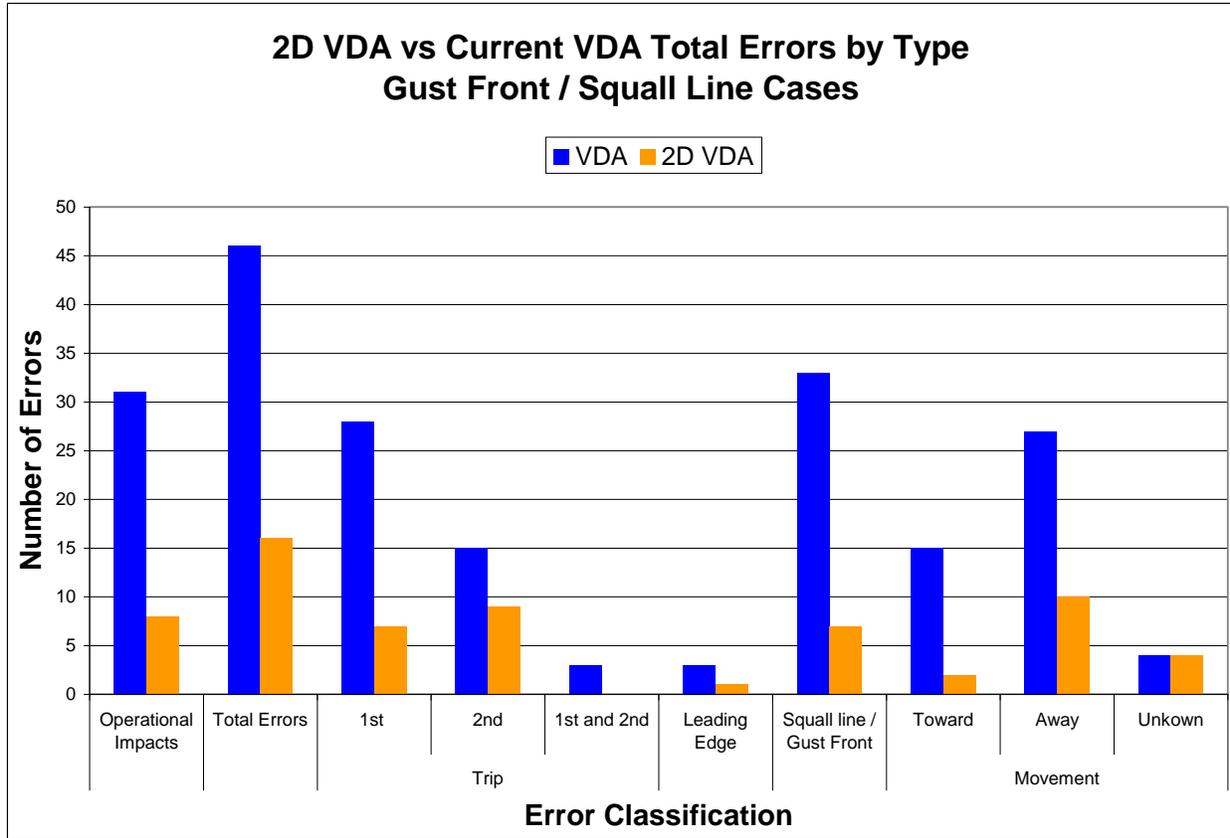


Figure A6: Total errors for all gust front cases combined based on classification.

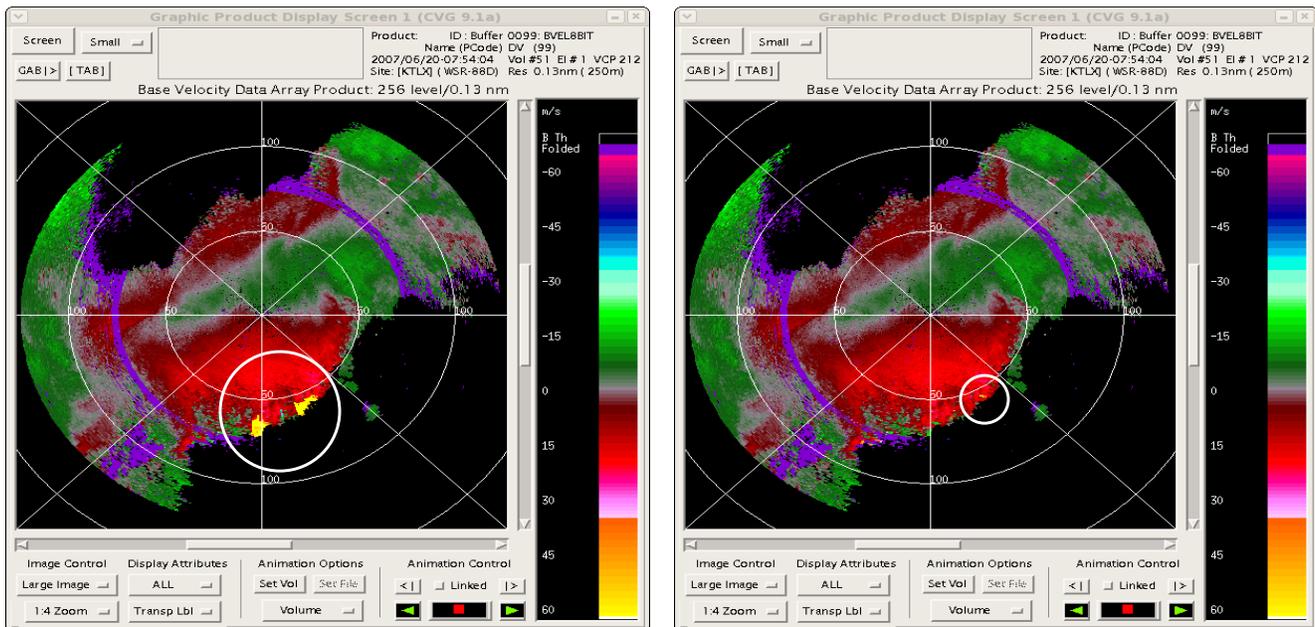


Figure A7: Velocity data from KTLX 20Jun07 at 07:54Z. The current VDA (left) has large dealiasing errors along the leading edge of the gust front, the 2-D VDA (right) has only a very small error.