P13A.14 PERFORMANCE OF TWO VELOCITY DEALIASING ALGORITHMS ON TERMINAL DOPPLER WEATHER RADAR DATA

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1. INTRODUCTION

The Supplemental Product Generator (SPG) has been developed to ingest Terminal Doppler Weather Radar (TDWR) base data and provide this data, along with algorithm products, to National Weather Service (NWS) forecast offices. Since the TDWR is a 5 cm wavelength radar, it typically operates at lower Nyquist velocities than the WSR-88D. The TDWR base data also contains far more non-precipitation echo compared to the WSR-88D, with very low reflectivities (<–5 dBZ) being common throughout the volume scan (i.e., not just at low elevation angles). This abundance of non-precipitation echo, which often contains regions of noisy or biased velocity data, coupled with low Nyquist velocities, often leads to a very challenging situation for dealiasing the velocity data. In weather situations involving high wind speeds and/or wind shear regions (e.g., gust fronts associated with squall-lines), together with a TDWR scanning at a low Nyquist velocity, dealiasing errors are common. Sometimes, the errors are so extensive that it is very difficult to properly utilize the velocity data (e.g., Fig. 1). Hence, improving the dealiasing capability of the SPG would greatly enhance the value of the TDWR velocity data. In pursuit of this goal, this project set out to compare the performance of the current SPG velocity dealiasing algorithm to a newly developed 2D multi-pass dealiasing algorithm (Zhang and Wang 2006).

2. METHODS

The SPG uses the same velocity dealiasing algorithm as in the WSR-88D Radar Product Generator, including checks involving a vertical wind profile updated via the Velocity Azimuth Display (VAD) algorithm. For this project, the default adaptable parameter settings were used. Test cases were started without a manually entered initial vertical wind profile. Hence, the vertical wind profile was generated solely from the VAD algorithm.

The new 2D multi-pass dealiasing algorithm (2DMPDA) is based on the horizontal continuity of velocity fields. The algorithm first determines a set of reference radials and gates by finding the weakest wind region on an elevation scan. Then, from these reference radials and gates, the scheme checks continuities among adjacent gates and corrects for the velocity values with large differences that are close to double the Nyquist velocity. Multiple passes of dealiasing are performed, and velocities identified as aliased with low confidence in an earlier pass are not dealiased until a discontinuity is detected with high confidence on a subsequent pass. Unlike the SPG velocity dealiasing algorithm, the 2DMPDA does not use a vertical wind profile. For more details on the algorithm, see Zhang and Wang (2006).

The performance of the two dealiasing algorithms was compared using data collected from the Baltimore/Washington (BWI) TDWR site for 8 severe weather events (Table 1). The storm types for these 8 events range from squall-lines to hailstorms with strong three-body-scatter-spikes (Lemon 1998) to supercells associated with the remains of Hurricane Ivan. The process started by running the SPG on the entire set of data available for each storm event. Base data output files were generated for each elevation scan in netCDF format, viewable by NSSL's WDSS-II display (Lakshmanan et al. 2007). Then, a subset of the event, during which the most intense storm activity was occurring, was selected for evaluation. Output files (also in netCDF format) from the 2DMPDA were generated using the raw TDWR velocity data for the subset time period. For some test cases, primarily during 2004, the SPG would occasionally abort a volume scan due to the azimuth tolerance threshold being exceeded. Hence, not all of the elevation scans which are normally part of a full volume scan were available for evaluation. Also, for the 6 June 2005 case, only elevation scans up to 13.4° were evaluated (due to there being minimal echo at higher elevation angles at the start of the case, and this

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case having the longest subset time period).

The scoring procedure was quantitative in nature and similar to that used in another recent project evaluating the accuracy of WSR-88D velocity dealiasing (Brown and Wood 2005). Each elevation scan analyzed was given an initial score of 100, and "points" were subtracted for each dealiasing error observed (Table 2). In difficult situations where it was not obvious whether or not an error had occurred, or what the correct solution was, then no points were subtracted (for that particular area of the elevation scan). Although the maximum penalty for a single error was –50 points, there was no limit on the number of separate errors that could be tabulated for the entire elevation scan. Hence, numerous small errors could ultimately add up to a sizable penalty.

3. TEST RESULTS

Based on the scoring methodology presented above, the 2DMPDA did a slightly better job overall at dealiasing the TDWR velocity data compared to the current SPG dealiasing algorithm (Table 3). The 2DMPDA performed better than the SPG on 6 of the 8 test cases, with the greatest difference for the 6 June 2005 case, which had the lowest average Nyquist velocity. Looking at performance as a function of elevation angle, it is interesting that all of the superior performance for the 2DMPDA occurs at the two lowest angles (Table 4), with the SPG performing slightly better than the 2DMPDA at higher angles. One reason for this latter finding is that the 2DMPDA often made what appeared to be simple mistakes on scans at higher elevation angles (e.g., Fig. 2). Looking at performance as a function of Nyquist velocity, it is not surprising to see poorer performance for lower Nyquist velocities; this is particularly true for the SPG (Table 5). And it is at the lower Nyquist velocities that the 2DMPDA substantially outperforms the SPG. However, for Nyquist velocities >19 m s^{-1}, the SPG generally outperforms the 2DMPDA.

One major difference between the SPG dealiasing algorithm and the 2DMPDA is that the latter does not use external wind data (i.e., a vertical wind profile). Lacking this information caused the 2DMPDA to suffer scoring penalties on 55 occasions, with the average performance score being 68. This is substantially worse than any of the performance scores for the 2DMPDA in Tables 3-5, and suggests that, at least for TDWR data, the 2DMPDA would benefit from having a check involving a vertical wind profile.

Another area where the 2DMPDA underperformed versus the SPG dealiasing algorithm involved mesocyclone and other significant storm-scale shear signatures. Although the data set analyzed here did not contain a large number of these signatures, the 2DMPDA had greater difficulty properly dealiasing these signatures than did the SPG dealiasing algorithm (e.g., Fig. 3). This is likely due to the design of the 2DMPDA, which puts equal, if not greater, emphasis on azimuthal continuity of the velocity field versus radial continuity.

4. CONCLUSIONS

The test results for this project indicate that the new 2D multi-pass dealiasing algorithm offers the potential for improved TDWR velocity data, particularly at lower Nyquists. However, even though the 2DMPDA did perform better overall versus the SPG dealiasing algorithm, it did not do as well as the SPG with important severe weather signatures, such as mesocyclones. Hence, further testing is needed, along with perhaps adaptable parameter adjustments or other algorithm enhancements, before the 2DMPDA could be recommended as a replacement for the current SPG dealiasing algorithm. Modifications to the 2DMPDA, such as utilizing a vertical wind profile, would likely be beneficial.

Another area that could help improve the velocity dealiasing process, possibly in a major way, would involve better preprocessing of the raw velocity data before it is sent to the dealiasing algorithm. The TDWR base data often contain substantial amounts of non-precipitation echo with reflectivities <–5 dBZ. Velocity values in these low-reflectivity regions can be noisy or strongly biased (i.e., differ greatly from nearby velocities in a precipitation area; e.g., Fig. 4), and lead to the initiation of a large-scale dealiasing error, which may propagate into a higher-reflectivity precipitation area. At lower elevation angles, there frequently appear to be areas of range-folded data that are not being properly identified as such (probably because these data are just above the threshold used to identify range-folding), leading to regions of noisy data. This sometimes led to instances where there were fewer dealiasing errors on the low-PRF (and lower Nyquist) 0.5° elevation scan versus the "regular" (higher Nyquist) 0.5° scans. The TDWR data also suffer from substantial numbers of artifacts at lower elevation angles. These appear as "blocks" of nearly identical velocity values, usually having the dimension of 1-3 gates in range by 1-3 degrees in azimuth (e.g., Fig. 5). There can be several of these artifacts on an elevation scan, in random locations.

With most dealiasing errors confined to, or initiating in, low-reflectivity regions, it is likely that removing this data prior to dealiasing an elevation scan would eliminate many of the currently observed dealiasing errors. Although the Federal Aviation Administration may wish to retain this low-reflectivity data in order to help identify weak microbursts and/or gust fronts, the utility of this data for NWS severe weather applications appears to be limited. It is possible that a major improvement in the quality of TDWR velocity data could be obtained by additional filtering of the base data, at a threshold appropriate for severe weather applications, before dealiasing is attempted.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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Table 1. List of the test cases. All times are in UTC, and the date corresponds to the start time (no cases had more than 12 hours of available data). The time interval (in min) corresponds to the subset period.

Date	Available Data		Subset Selected		Time	Total scans
	Start Time	End Time	Start Time	End Time	Interval	evaluated
7 Jul 2004	18:36:14	01:26:41	20:00:07	20:57:26	57	174
14 Jul 2004	18:04:40	01:53:10	19:04:59	20:06:58	62	169
4 Aug 2004	20:55:15	01:25:12	22:56:46	00:01:49	65	224
11 Aug 2004	18:07:22	02:17:53	19:19:19	20:30:21	71	252
17 Sep 2004	22:47:01	02:45:50	22:47:01	23:52:04	65	168
6 Jun 2005	21:07:13	07:52:12	21:57:01	23:26:00	89	225
23 Jul 2005	03:11:54	08:01:47	04:37:28	05:42:31	65	231
27 Jul 2005	19:08:48	01:40:07	21:46:27	22:51:29	65	230
All					539	1673

Table 2. Penalties for different types of dealiasing errors.

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

Table 3. Overall performance scores for each test case.

Date	Number	Average	Average score	
	of scans	Nyquist (m s^{-1})	SPG	2DMPDA
4 Aug 2004	224	22.4	98.4	97.9
11 Aug 2004	252	22.9	94.6	96.2
7 Jul 2004	174	19.8	94.1	98.1
14 Jul 2004	169	19.8	90.7	93.6
23 Jul 2005	231	23.1	96.5	97.0
27 Jul 2005	230	21.9	93.8	96.8
6 Jul 2005	225	16.7	77.4	88.9
17 Sep 2004	168	21.7	92.1	89.5
All	1673	21.1	92.2	94.9

Table 4. Overall performance scores for each elevation angle. Note that the Nyquist velocity is only variable for elevation angles up to 10°.

Elevation Angle	Number of scans	Average Nyquist (m s^{-1})	Average score SPG	2DMPDA
0.5°	505	18.9	82.2	91.3
1.0°	89	19.6	91.1	94.4
3.3°	171	19.5	94.9	94.1
6.6°	171	19.5	94.9	94.4
10.0°	169	19.5	93.9	93.8
13.4°	166	22.4	97.7	97.6
19.4°	136	25.8	99.6	99.3
28.1°	133	25.8	99.9	99.6
42.0°	133	25.8	100	99.6

Table 5. Overall performance scores for each Nyquist velocity. Note that although data were generated on 6 June 2005 using the 25.8 m s^{-1} Nyquist velocity (at elevation angles >13.4°), that data were not used in the performance evaluation.

Nyquist (m s^{-1})	Number of days used	Number of scans	Average score SPG	2DMPDA
14.3	5	71	74.2	84.2
14.6	3	23	83.0	95.2
14.9	1	11	76.0	84.4
15.2	5	47	86.3	89.7
15.6	3	84	76.5	88.7
16.0	6	82	77.9	87.3
16.4	1	38	80.2	94.1
16.8	2	36	74.8	86.0
17.2	2	25	83.4	91.6
17.7	2	13	86.9	92.5
18.1	3	6	86.3	87.0
18.6	3	15	88.3	89.7
19.2	3	32	94.6	89.1
19.7	5	66	96.8	95.8
20.3	3	74	97.1	95.1
21.0	3	29	96.2	96.2
21.7	3	42	94.3	94.0
22.4	8	578	95.6	96.8
25.8	7	402	99.8	99.5

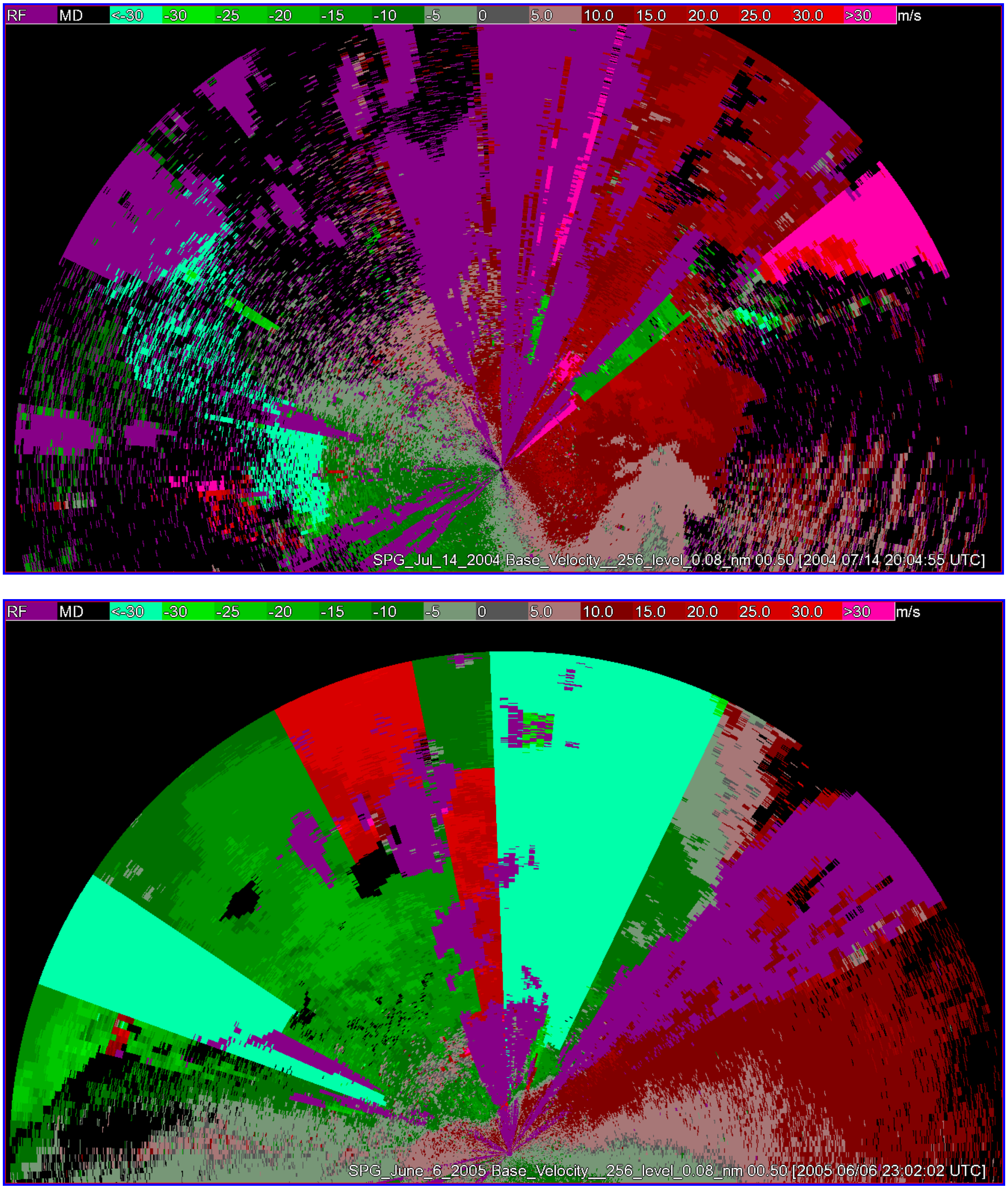

Fig. 1. Examples of velocity dealiasing errors from the SPG.

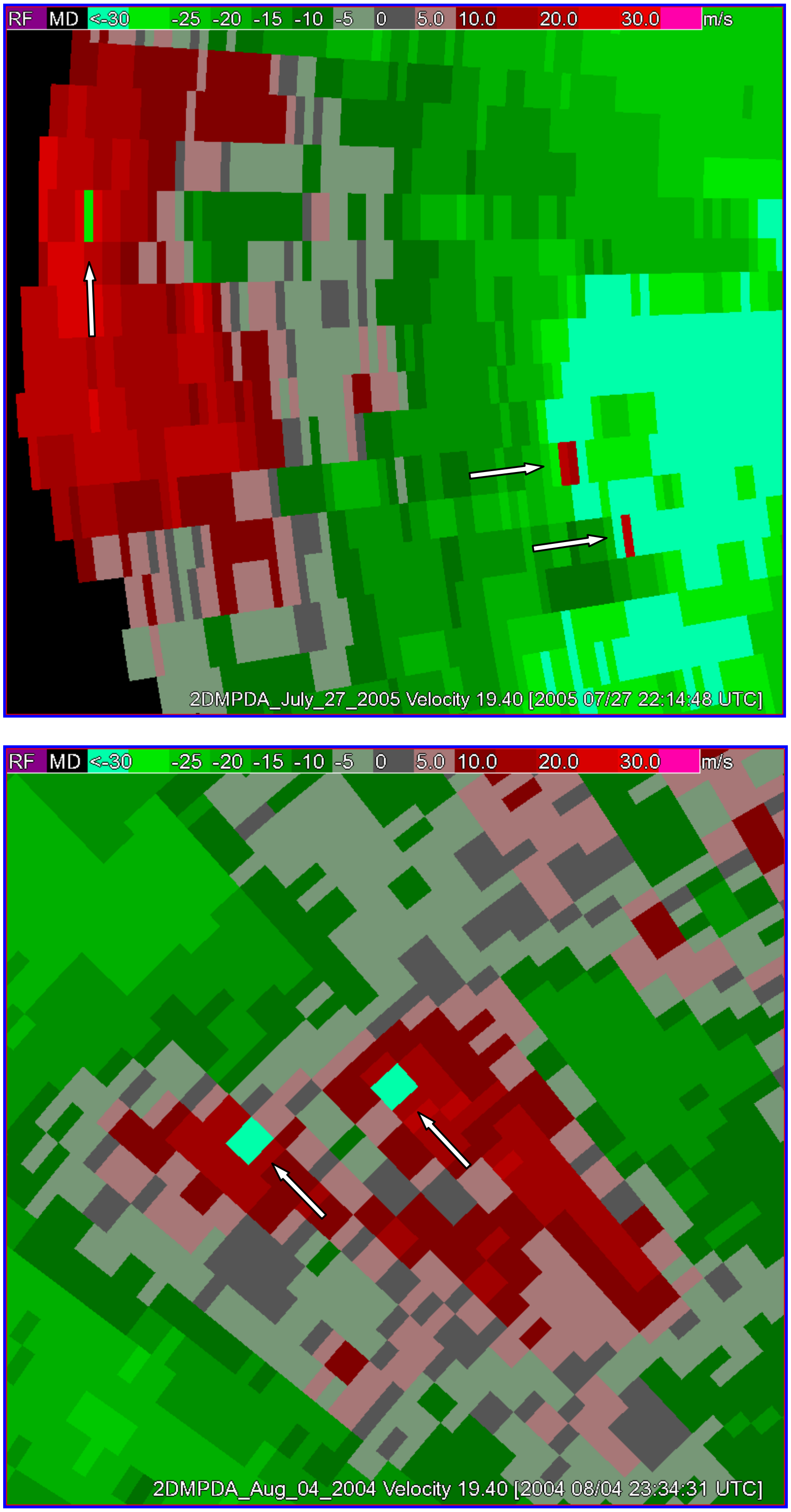

Fig. 2. Examples of simple mistakes made by the 2DMPDA.

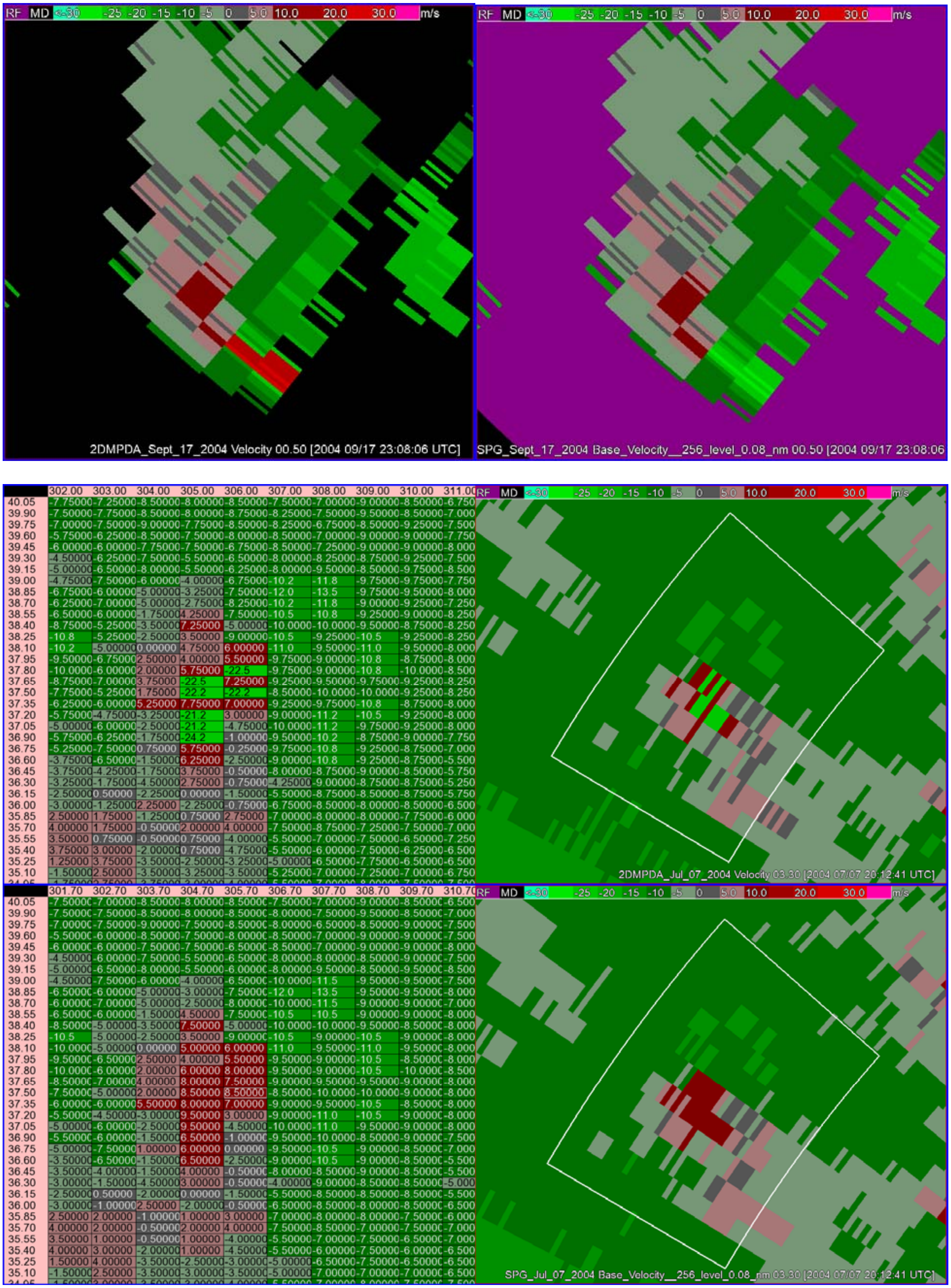

Fig. 3. Examples of velocity dealiasing errors made by the 2DMPDA (top-left and middle) involving storm-scale shear signatures, and the correct velocity data produced by the SPG (top-right and bottom).

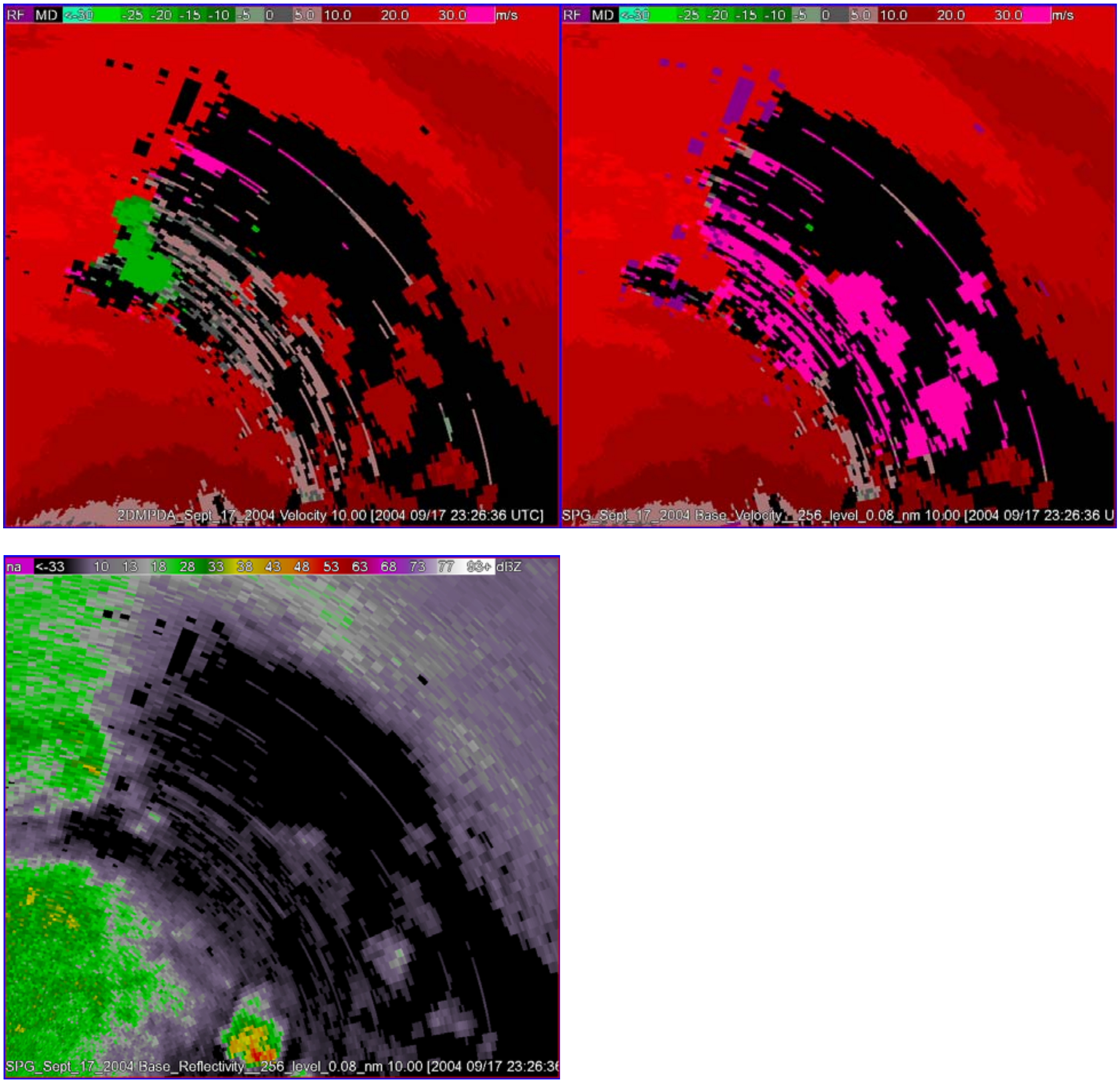

Fig. 4. Example of strongly biased velocity values associated with low reflectivities leading to a large-scale dealiasing error. Top-left shows 2DMPDA results and top-right shows SPG results.

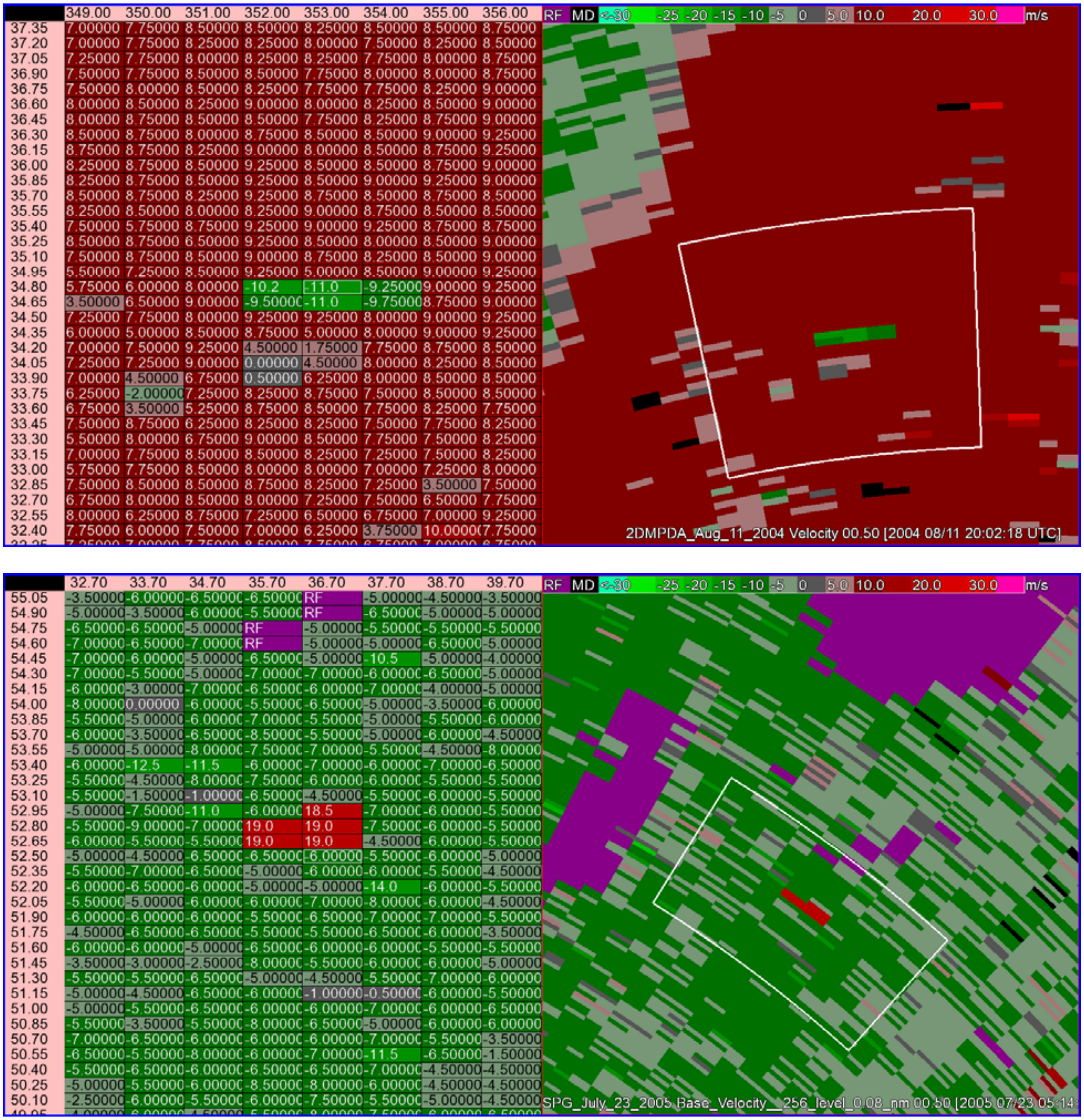

Fig. 5. Examples of artifacts in the TDWR velocity data. Top shows 2DMPDA data and bottom shows SPG data.