Applications of a Velocity Dealiasing Scheme to Data from China New Generation Weather Rader System (CINRAD)

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Introduction

Radar observations play an increasingly important role in numerical weather prediction (NWP) where real time forecasts of actual storms, initialized by current data are within reach. A radar network with a total of 158 Doppler radars in China, called CINRAD (China Next Generation Weather Radar), is one such network that could provide much needed observations of precipitation, wind, and hail in near real time. These data will soon be assimilated into GRAPES (Global and Regional Assimilation and PrEdiction System), which is a 3D-Var system developed in China. It is anticipated that radar data assimilation at the convective scale has the potential to improve the prediction of hazardous weather in China.

The application of radar data in real-time NWP requires substantial automation, adequate accuracy, and robust quality control (QC) techniques for the data. One challenge with radar data is related to velocity aliasing. An example is shown in Fig. 1. The raw radial velocities measured by CINRAD at Wenzhou station at 10:45 UTC 29 July 2008 at both elevation angles 0.5^0 and 4.3^0 contain aliased velocities, and those at the elevation angle 19.5^0 does not due to smaller velocities.

The current WSR-88D 2-Dimensional (2D) Velocity Dealiasing Algorithm (NEXRAD, Eilts and Smith, 1990) is fundamentally based on minimizing velocity gradients along a radial, and has proven to be a robust and reliable algorithm, having been used for a number of years for dealiasing radial velocity measurements for producing operationally useful output in the United States. In this study, we apply the 2D VDA to CINRAD data for different weather regimes in China. Modifications to the NEXRAD scheme are proposed, and results are compared with the original scheme.

Velocity Aliasing

The scope of unambiguous velocities interval derived from the complex time sample for a given pulse repetition frequency (PRF) sent out by a radar is given by [$-V_{\max}$, $V_{\max}$] (Ray and Ziegler 1977) where $V_{\max} = (PRF)\lambda/4$ is the maximum velocity called Nyquist velocity. Any frequency shifts exceeding PRF/2 will cause velocity aliasing problem. The observed velocity (V_0) could be different from the true radial velocity (V_T) and they are related as follows: $V_0 = V_T \pm 2n * V_{\max}$, $n = 0, 1, 2, \cdots$.

The existence of velocity aliasing in Doppler radar radial velocity measurements is a challenge for radar data assimilation. An effective velocity dealisasing scheme must be applied to recover the true signals (V_T) from the raw measurements (V_0) before their being assimilated in the GRAPES systems.

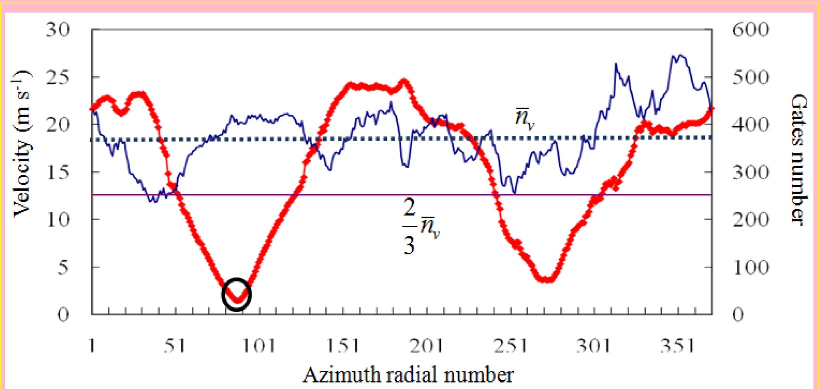

Fig. 2: The mean absolute values of the measured velocities at all valid gates along each radial (red curve) and the total number of the valid gates along each radial (blue curve). Purple line indicates 2/3 of the average number of the valid gates .

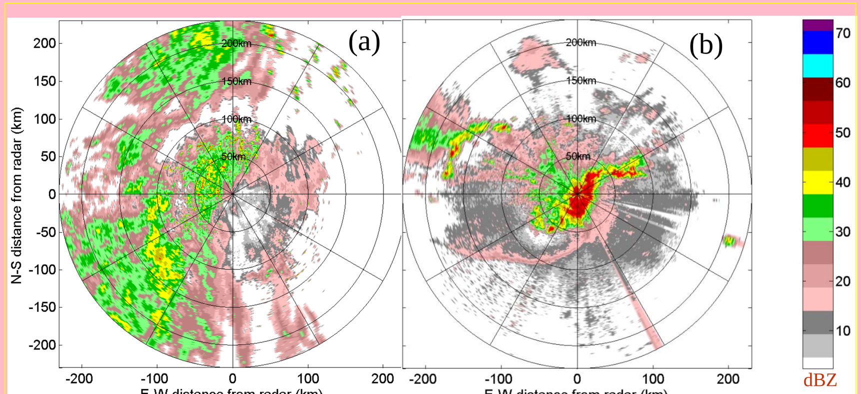

Fig. 4: Reflectivity on 0.5^0 elevation angle at (a) 10:45 UTC 29 July 2008 for the typhoon case (Wenzhou station) and (b) 1339UTC 3 June 2008 for a squall line case (Shangqiu station).

Algorithm Description

The following new modifications and additions to the NEXRAD algorithm were considered and proposed.

Module 1: Noise Removal (preconditioning of the data)

This module consists of the following two steps:

Step 1: Velocity data is removed if the corresponding spectrum width is higher than 8 m s^{-1} and the reflectivity is less than 20 dBZ.

Step 2: Noisy velocity data near aliased areas that are not completely removed in Step 1 are further removed in this step. First, the sum of the absolute velocities of all the valid gates in each radial, $\overline{V}$, is calculated. Velocities smaller than a threshold value, α, is removed, where α is larger if $\overline{V}$ is larger. For examples, if $\overline{V} = 20$ m s^{-1}, $\alpha = 2.5$ m s^{-1}; and if $\overline{V} = 15$ m s^{-1}, $\alpha = 1.5$ m s^{-1}.

Module 2: Selection of the First Radial

Velocity dealiasing along a radial is carried out based on dealiased velocity results on valid gates of the previous radial (see Module 3). It is therefore important to choose an initial radial along which there is no aliasing present. Smaller velocities are less probable to be aliased. Figure 2 illustrates how the first radial is chosen. Since NEXRAD and many other algorithms depend on previous "unfolded" radials in addtion to radial shear, it is important that the initial radial chosen is devoid or nearly devoid of aliases velocities. If there is only one azimuth for which this is satisfied based upon this model, then implementation of Module three is mandated.

Module 3: Dealiasing

Starting from the first radial chosen in Module 2, implement the NEXRAD algorithm by Eilts and Smith (1990), but in both counterclockwise and clockwise directions. Step 1 in Module 1 is also included in this implementation.

Module 4: Error Check

Before replacing the observed value with the dealiased velocity, the dealiased result is compared with the average velocity of all the valid gates in previous four radials and seven gates nearest to radar. If the difference between the dealiased result and the average value is less than Nyquist, then dealiased result is correct. Otherwise, either repeat Module 3 or just keep the observed value.

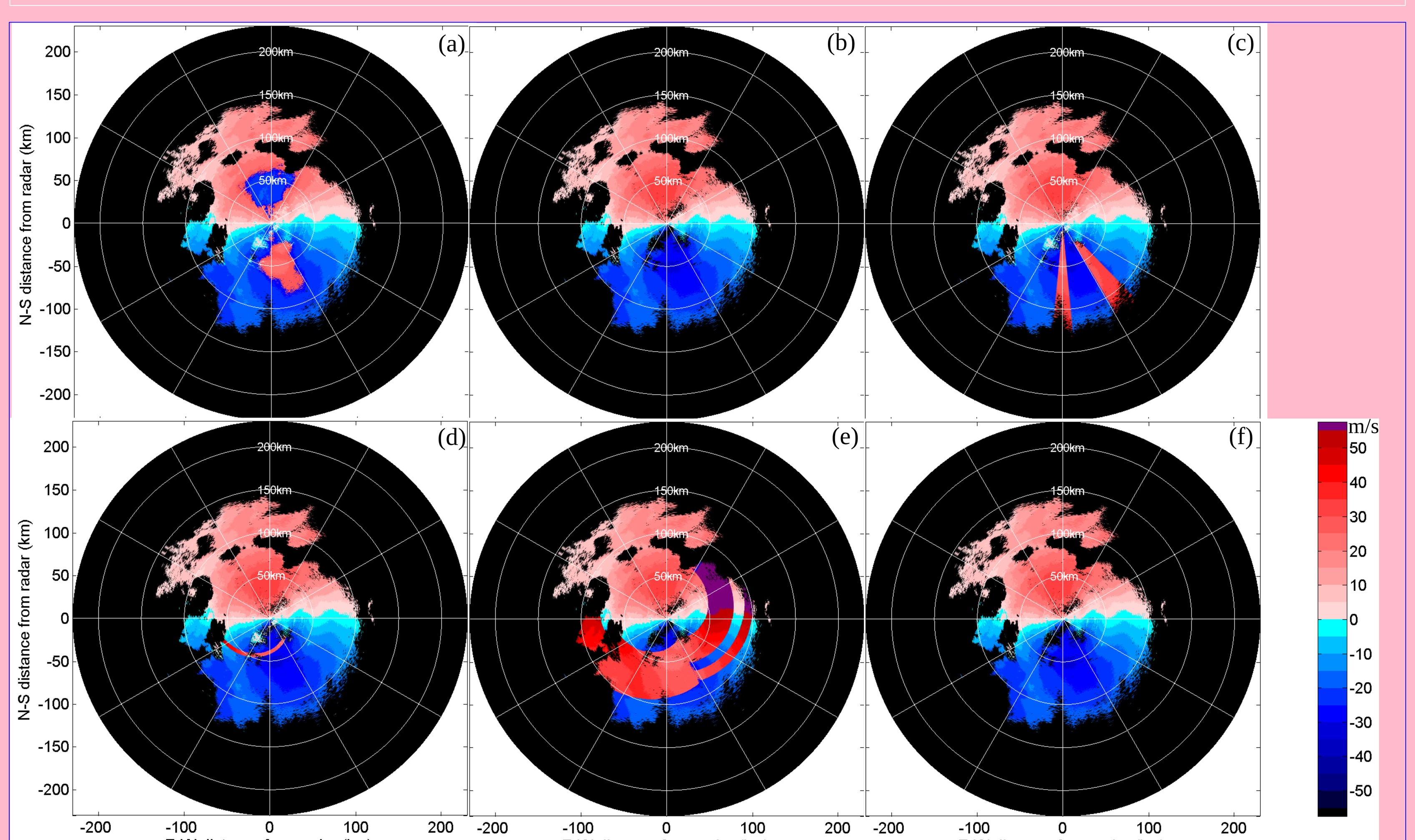

Figure 5: Radar radial velocity on 3.3^0 elevation angle from Wenzhou station at 10:45 UTC 29 July 2008 a) raw velocity, b) reference velocity, c) NEXRAD algorithm, d) improved NEXRAD without step 2 in module 1 dealiased, e) improved 2-D VDA without initial radial search, f) complete improved 2-D VDA.

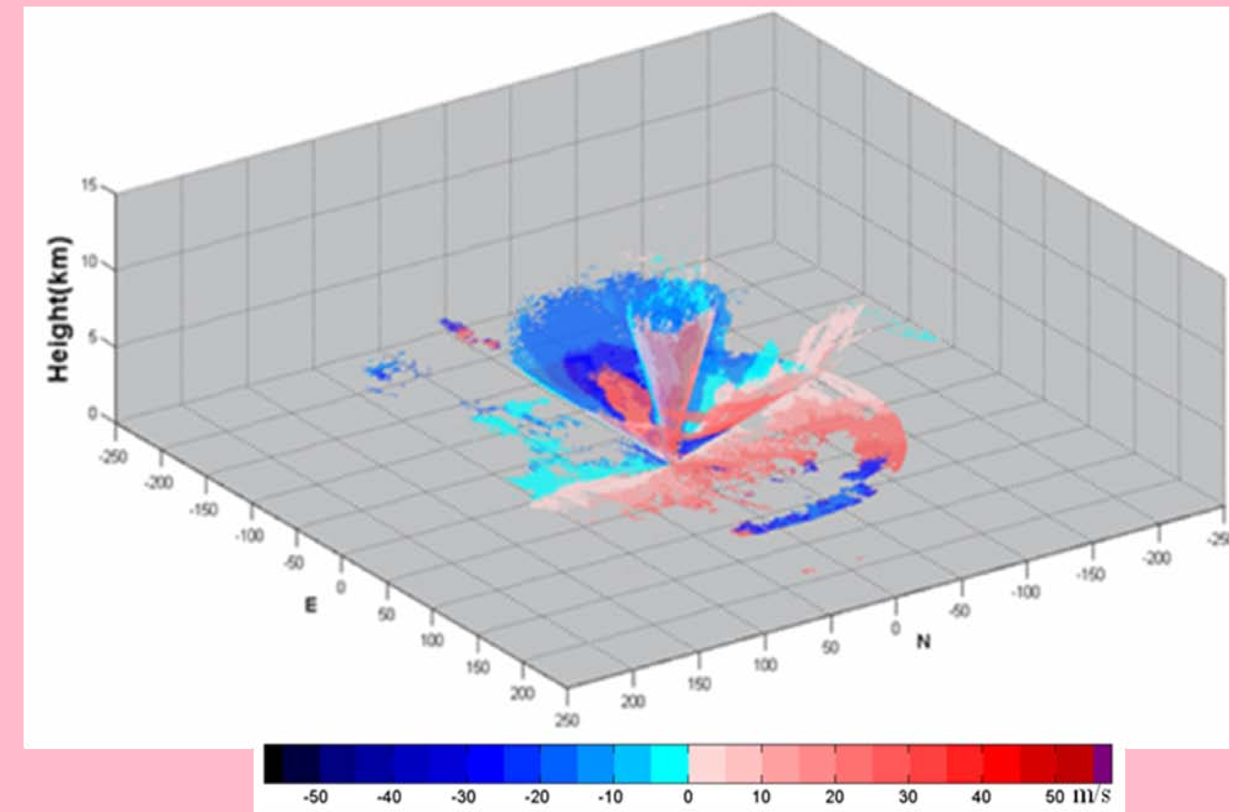

Figure 1: Raw radial velocities measured by CINRAD at Wenzhou station at 10:45 UTC 29 July 2008 at three elevation angles: 0.5^0 (lowest elevation angle), 4.3^0 and 19.5^0 (highest elevation angle).

Case Description

The above dealiasing algorithm is applied to a typhoon case and a squall line case. Figure 3 shows the track of Typhoon "Fungwong" from 0000 UTC 24 July 2008 to 1800 UTC 31 July 2008. The reflectivity distributions for both cases at the elevation angle of 0.5^0 are shown in Fig. 4.

The "Truth"

The NCAR (National Center for Atmospheric Research) SOLO II package is a widget-driven, interactive program that displays sweeps of the radar data and enables the user to manually edit (i.e., unfold) the velocity data. The SOLO II assisted, manually edited, and subjectively generated velocity fields will be used as the "true" velocity field for developing and testing an automatic dealiasing algorithm for CINRAD data.

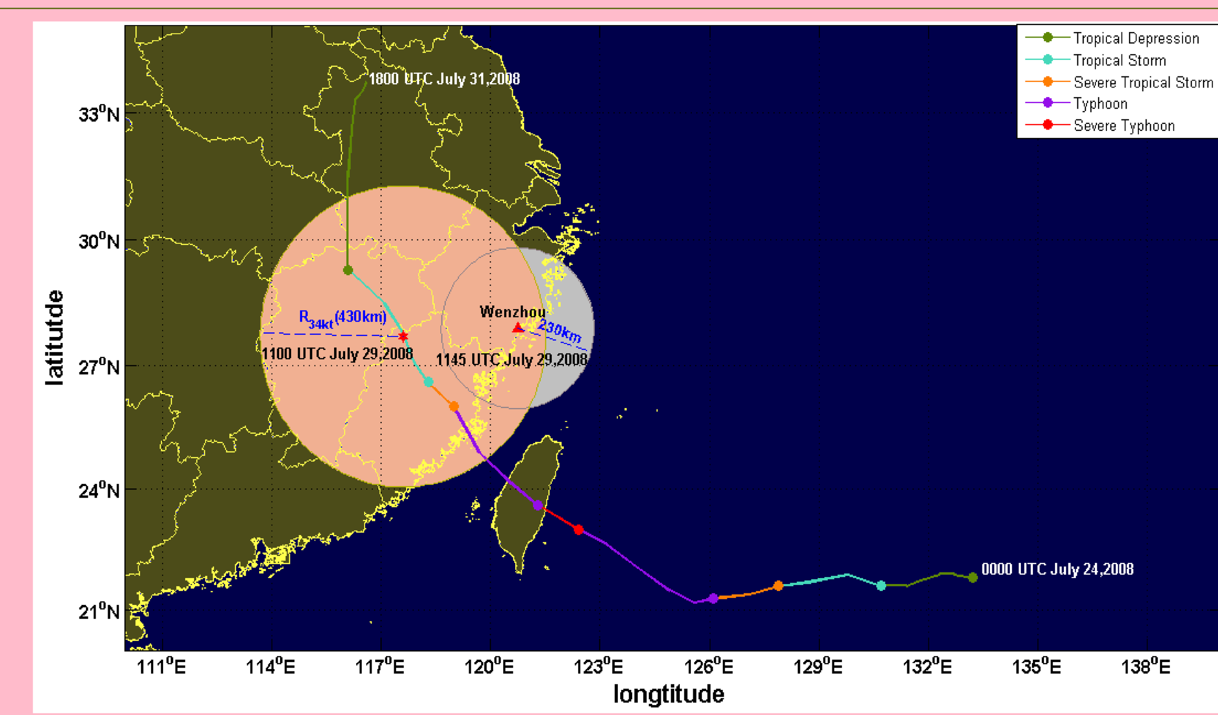

Figure 3: Typhoon track of "Fungwong" from 0000 UTC 24 July 2008 to 1800 UTC 31 July 2008. Pink circle indicates the radius of 34kt wind and the smaller circle indicates the maximum observation domain of the Wenzhou radar station.

Table 1. List of all the 14 test cases and the dealiasing result of improved 2-D VDA about these cases.

	Radar site	Time	System	Number aliased data (A)	Number correctly dealiased (B)	Number incorrectly dealiased (C)	Number missed dealiased (D)
1	Wenzhou	1045UTC 29 July 2008	T	90549	90029	272	520
2	Xiamen	1023UTC 8 Aug 2009	T	104545	103521	2489	1024
3	Shantou	1252UTC 11 Aug 2007	T	18996	18959	105	37
4	Wenzhou	1414UTC 18 July 2008	T	999	999	0	0
5	Jinhua	1603UTC 18 Sep 2007	T	14882	14874	5	8
6	Shangqiu	1339UTC 3 June 2009	S	24576	24322	327	254
7	Hefei	1245UTC 5 June 2009	S	24459	23946	280	513
8	Bengbu	0837UTC 14 June 2009	S	8555	8296	176	259
9	Zhengzhou	1120UTC 30 July 2007	H	2120	2099	36	21
10	Zhengzhou	1942UTC 5 Aug 2007	H	608	608	0	0
11	Zhumadian	1051UTC 14 July 2007	H	82	82	0	0
12	Fuyang	0141UTC 8 July 2007	H	322	322	0	0
13	Fuyang	2344UTC 24 July 2007	H	354	354	0	0
14	Hefei	0909UTC 8 June 2003	H	23796	23349	66	447
15	Total			314843	311760	3756	3083

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Dealiasing Result

Figure 5a shows raw radial velocity with the elevation angle of 3.3º at 10:45 UTC 29 July 2008 for Typhoon "Fungwong" observed at Wenzhou station. Two widespreading velocity aliasing areas are noticed. In addition, a significant range folding and many missing data exist in the radial velocity fields. The "truth", i.e., dealiased by SOLO II and then mannually edited, is presented in Fig. 5b. Dealased results using the NEXRAD algorithm without the proposed modifications are shown in Fig 5c. It is seen that while the aliased velocities (large positive velocities in negative velocity regions and vise versa) are removed, many noisy radials are generated. Abnormal velocity noises are also produced if the Step 2 in Module 1 is not included (Fig. 5d), or Module 3 is skipped (Fig. 5d). The best result is obtained only if all the modules outlined in Section 4 are implemented (Fig. 5e). In other words, the "truth" is reproduced by an objective velocity dealiasing scheme described in Section 4.

An example for the dealiasing results for the squall line case is shown in Fig. 6. The NEXRAD 2D VDA scheme works well except in a small region highlighted by the yellow circle in Fig. 6c. Aliased velocities are not completed corrected near the outer edge (i.e., larger radius) of aliased region. The best results, again, are obtained after implementing all the modifications proposed in Section 3.

Statistical Results

The modified 2-D VDA for velocity dealiasing algorithm has been applied to CINRAD data for 35 different weather systems, including five Typhoon cases, three squall line cases and 27 heavy rain cases. There were some very diffcult dealiasing problems due to noise (e.g., ground clutter), range folding, missing gates and strong azimuthal and radial shears. Out of the total 35 cases, there are 14 cases for which aliased radial velocities are found present. Statistical results on the quality of dealiasing for these 14 cases are shown in Table 1 and Fig. 7. It is seen that the dealiased results for typhoon and heavy rain cases are better than for the squall line cases. The modified NEXRAD performs very well, with 99.02% of the aliased velocity observations being successfully corrected compared with the SOLO II assisted and manually edited results (Section 4). Only 2.17% of the velocities where either not correctly dealiased or missed dealiasing due to range folding or noises. A quality flag is then added to these data for their future applications in data assimilation.

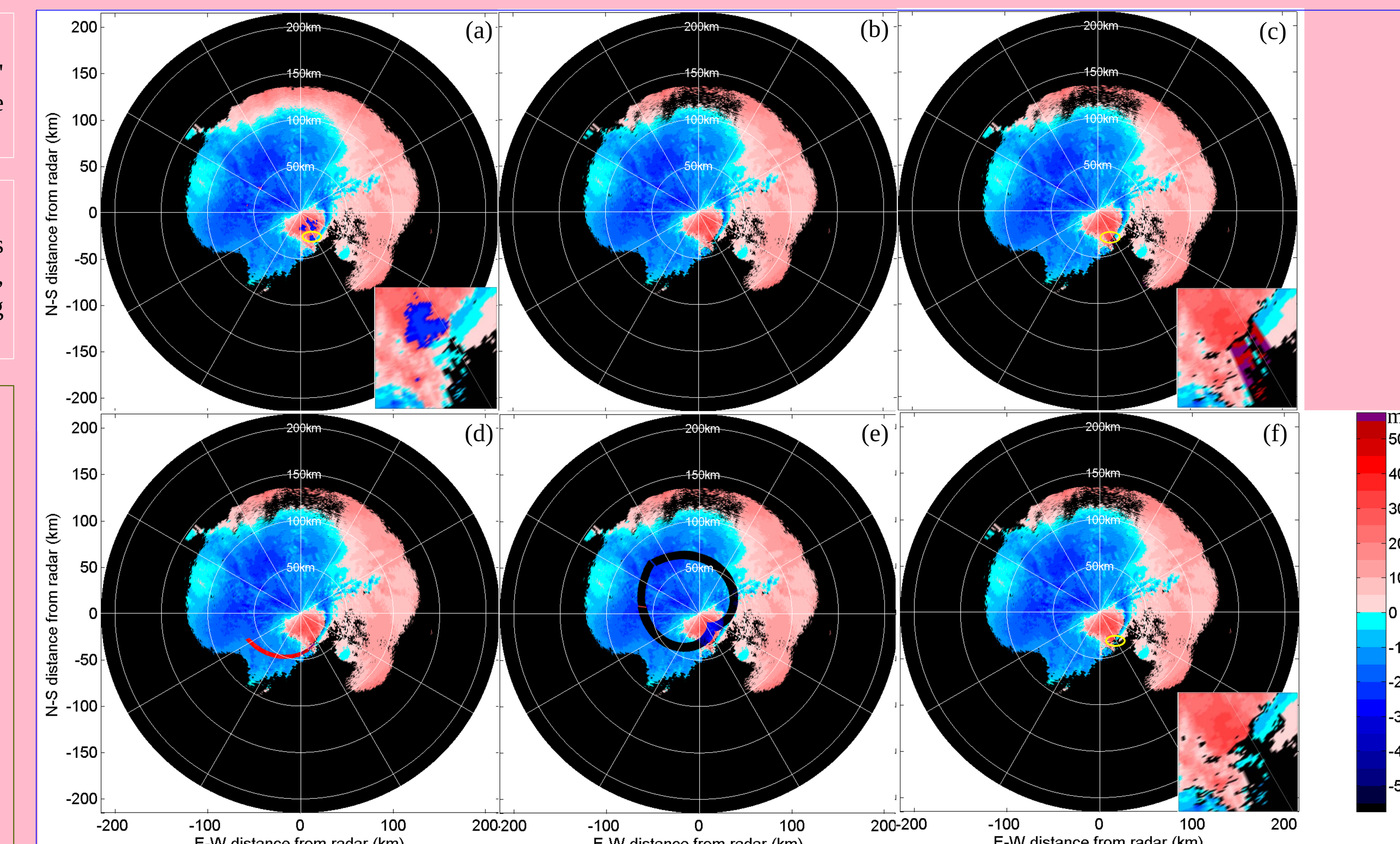
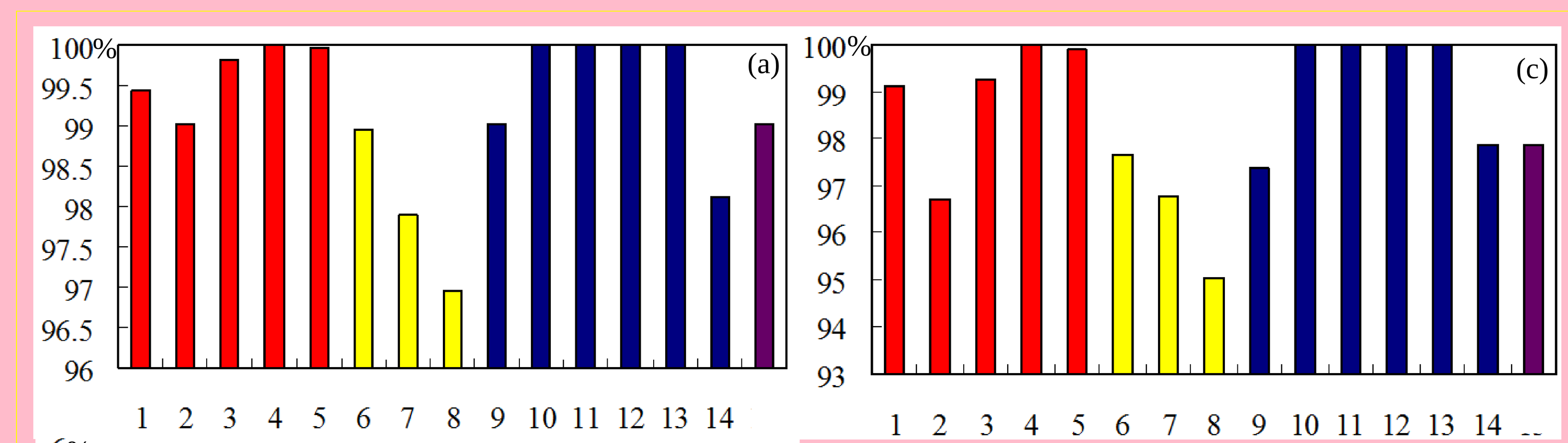
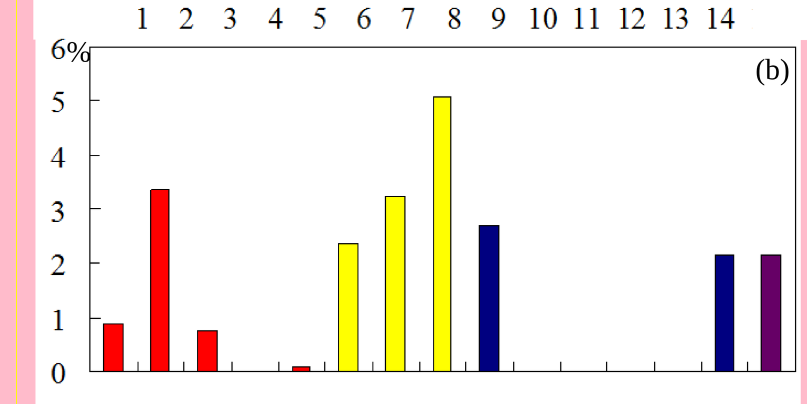


Figure 6: Same as Fig. 5 except for the squall line case measured at Shangqiu station at 13:39 UTC 3 June 2009.





POD (Probability of Detection) = B/A

FAR (False Alarm Rate) = C/A

CSR (Critical Success Rate) = B/(B+C+D)

Figure 7: Statistical results of a) POD, b) FAR, and c) CSR for all the 14 cases with aliased data (red: typhoon, yellow: squall line, blue: heavy rain, purple: mixed). The last column represents the average of the 14 cases.

Summary and Conclusions

An improved velocity dealiasing algorithm is developed based on the NEXRAD scheme. Performances of the proposed algorithm are examined for the CINRAD S-band observations. This algorithm includes four modules to remove weak signal, determine the starting radial, to identify aliased velocities, and to remove aliasing and correct the data. The proposed dealiasing algorithm was tested for 14 different weather processes of typhoons, squall lines and heavy rains. The results show that the algorithm is robust and stable for dealiasing S-band CINRAD radial velocity measurements. The performance for typhoon cases and heavy rain cases are slightly better than for squall line. The algorithm can correctly dealiased more than 99% of the aliased radial velocity data when compare with the SOLO II-assisted, manually edited results. 2.17% of the velocities dealiased failed, because those velocities were near data with range folding or near some noise still did not removed clearly. Future investigations are being conducted to improve the remaining 2.17% aliased velocities, which often appear near the edge of data missing or range folding areas.

Reference

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