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A Real-Time Radar Wind Analysis System For Nowcast Application

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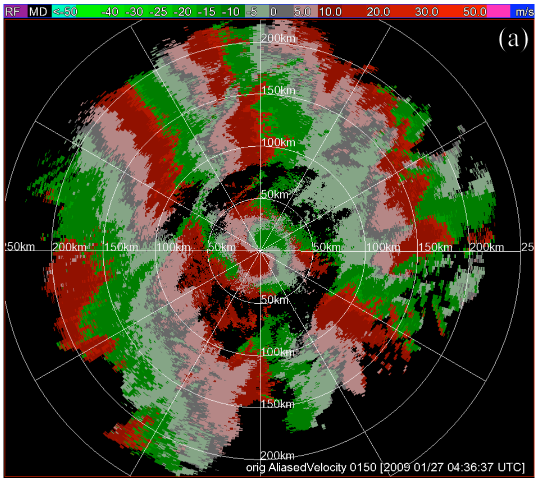
I. INTRODUCTION

A real-time radar wind analysis system (RWAS) has been developed (Xu et al. 2009a) to integrate observations from operational radars, Oklahoma Mesonet and NOAA Profiler Network to produce vector wind field (on a 2 km grid every 5-10 min) displayed on NSSL/WDSS-II ORPG and made available to NWS Norman Forecast Office. The early version of RWAS was delivered to Pacific Northwest National Laboratory for driving high-resolution emergency response dispersion models for homeland security applications (Fast et al. 2008). The upgraded techniques and improved performances of RWAS are reported below.

II. RADAR DATA QUALITY CONTROL

Radar wind analysis and data assimilation require rigorous data quality controls. To achieve this, the RWAS has been used to monitor data quality problems and test new QC and assimilation techniques. Facilitated by RWAS, the dealiasing method developed based on the alias-robust VAD analysis (Xu et al. 2010, 2011) was tested in real time and found occasionally fail to correct or flag severely aliased radial velocities around and above strongly sheared inversion layers in severe winter ice storms scanned by the operational WSR-88D radars using volume coverage pattern 31 (VCP31) with a reduced Nyquist velocity: $v_N < 12$ m/s. To solve this problem, the alias-robust variational analysis (Xu et al. 2009b) is refined and used in place of the alias-robust VAD analysis for the reference check, whereas the latter is modified by relaxing the VAD uniform-wind assumption and used to provide a first-guess background for the alias-robust variational analysis. This upgrades the method adaptively for VCP31 (Xu and Nai 2011). The satisfactory performance of the upgraded dealiasing method is shown as an example in Fig. 1.



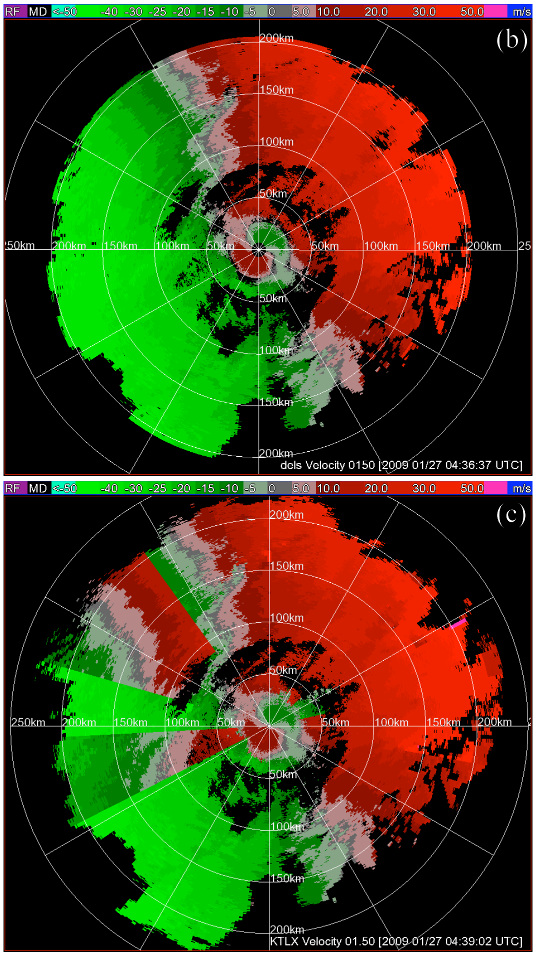


Fig. 1. (a) Raw velocity image scanned by the KTLX radar with VCP31 ($v_N = 11.51$ m/s) at 1.5° tilt for the Oklahoma ice storm at 043637 UTC on 27 January 2009. (b) Dealiased velocity image by the upgraded method. (c) Dealiased velocity image by the operational algorithm.

III. WIND ANALYSIS

The wind analysis in the upgraded RWAS performs the following three steps:

I. Produce VAD wind (u, v) from dealiased radar velocity data, and then use it as a background to assimilate profiler data at each vertical level (every 250 m above the radar site) with $\sigma_b^2 = \sigma_o^2$ and $L = 150$ km, where σ_b^2 (or σ_o^2) denotes the background (or observation) error variance and L the background error de-correlation length.

II. Use the wind field produced in step-I as a new background to assimilate the Oklahoma Mesonet wind data (at z = 10 m) with $\sigma_b^2 = \sigma_o^2$ and L = 60 km.

III. Use the wind field produced in step-II as a new background to assimilate super-observations generated by compressing dealiased radar velocities in three batches with the resolution coarsened to 13, 21 and 30 km (in both the radial and azimuthal directions), respectively, over the near ($r \le 40$ km), middle (40 km $< r \le 80$ km) and far ($r > 80$ km) radial ranges. The observation error is estimated (within 1 m/s $\le \sigma_o <$ 2 m/s) for each super-observation based on the number of dealiased radial velocities within the area represented by that super-observation.

The 2D optimal interpolation technique (Xu et al. 2006) is extended to 3D to assimilate each batch (serially from the far range to the near range) and update the background. After each update, σ_b^2 is re-estimated for the next update by subtracting the spatially averaged super-observation variance σ_o^2 from the spatially averaged variance of super-innovation (super-observation minus background). The 3D background error covariance is modeled by

$$C(\Delta\mathbf{x}, \Delta z) = \sigma_b^2\exp[-(|\Delta\mathbf{x}|^2/L^2 + \Delta z^2/D^2 + |\Delta\mathbf{v}|^2/V^2)/2], \quad (1)$$

where $\Delta\mathbf{x} = \mathbf{x}_2 - \mathbf{x}_1$ is the horizontal separation, $\Delta z = z_2 - z_1$ is the vertical separation, D is the de-correlation depth, $\Delta\mathbf{v} = \mathbf{v}(z_2) - \mathbf{v}(z_1)$ is the increment of the VAD wind $\mathbf{v} = (u, v)$ over Δz, and V scales the de-correlation enhanced by $\Delta\mathbf{v}$. The de-correlation length L (or depth D) is set to 25 (or 2), 18 (or 1) and 11 (or 0.3) km for the three serial updates, respectively. As a new shear-dependent term in (1), $|\Delta\mathbf{v}|^2/V^2$ is introduced (with V tuned to 1 m/s) to reduce the vertical correlation adaptively across a strong vertical-shear layer.

Fig. 2 shows the vertical profiles of the VAD winds (u, v) (blue curves) produced by the step-I analysis in comparison with those (shallow red curves) produced by the original alias-robust VAD analysis for the ice storm case in Fig. 1. As shown, the step-I analysis can produce VAD winds correctly over the depth covered by radar data and capture the strong vertical shear between 0.6 km $\le z \le$ 1 km. However, the original alias-robust VAD analysis starts to produce incorrect VAD winds as the vertical level z increases above 0.6 km and fails completely as z further increases beyond 1 km. Similar problems have been seen for the original alias-robust VAD analysis in other cases of winter ice storms scanned by using VCP31 with $v_N \le 12$ m/s, and they are well solved by the upgraded method.

The shear-dependent term $|\Delta\mathbf{v}|^2/V^2$ in (1) provides a simple and yet effective way to suppress the excessive vertical correlation adaptively across the shear layer as the latter tends to overly smooth the analysis vertically in the shear layer and cause spurious horizontal variations across the shear layer in the vicinity of the radar in the step-III analysis (not shown). Adding this shear-dependent term in (1) has improved the step-III analysis in RWAS for the ice storm in Fig. 1-2 as well as other severe winter ice storms scanned by the KTLX radar using VCP31 (with $v_N \le 12$ m/s).

IV. ACKNOWLEDGMENTS

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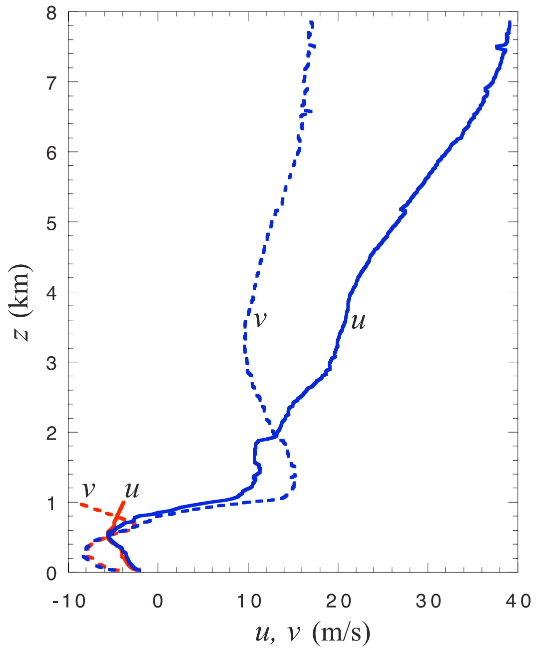

Fig. 2. Vertical profiles of VAD winds (u, v) produced by the step-I analysis in the upgraded RWAS (plotted in blue) and by the original alias-robust VAD analysis (plotted in red) for the case in Fig. 1.

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