Automated Tornadic Vortex Wind Retrievals From Radar Observations

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1. Introduction

A varational method is develop and automated with data quality-control procedures to retrieve tornadic vortex winds from radar radial-velocity observations on each tilt of radar scan. This method has the following features: (i) The retrieval domain is centered at and moving with the detected vortex center on each tilt of radar scan. (ii) Vortex-flow-dependent background error covariance functions are formulated for the streamfunction and velocity potential in the moving frame. (iii) The square root of the background covariance matrix is derived, using the convolution theorem, from each covariance function and is used to construct the solution in a concise form in the cost-function.

2. Estimation of vortex center

The tornadic vortex area is identified as a by-product of the velocity dealiasing (see Appendix of Xu et al. 2013, *Advances in Meteorology*, Article ID 562386). The vortex center is estimated on each tilt of radar scan by applying the following two-step algorithm to the dealiased radial-velocity observation v_r^o in the vortex area:

I. Find $v_{r\max}$ and $v_{r\min}$ with $\varphi_{\max} > \varphi_{\min}$ along each range circle over the sector data area of 20 km arc length and 20 km radial range that covers the vortex, where $v_{r\max}$ (or $v_{r\min}$) is the maximum (or minimum) v_r^o and $\varphi_{\max}$ (or $\varphi_{\min}$) is the azimuthal angle of $v_{r\max}$ (or $v_{r\min}$) data point. Denote by r_m the radial range at which $(v_{r\max} - v_{r\min})/(\varphi_{\max} - \varphi_{\min})$ is largest and by φ_m the value of $(\varphi_{\max}+\varphi_{\min})/2$ on the rang circle of $r = r_m$. The vortex center location is then first estimated by (r_m, φ_m) in the radar coordinates, and the interpolated value of v_r^o at (r_m, φ_m), denoted by $v_r^o{}_m$, estimates the radial component of the moving velocity of the estimated vortex center.

II. Find and denote by $(r_j, \varphi_j) = (j\Delta r, \varphi_j)$ the location where $v_r^o - v_r^o{}_m$ changes sign (from negative to positive as φ increases) between two adjacent beams along the j-th range circle in the data window of 11 beams and 11 range gates centered at (r_m, φ_m), where Δr (= 250 m) is the range gate spacing. Denote by Δv_{rj} (> 0) the increment of v_r^o associated with the sign change of $v_r^o - v_r^o{}_m$ at (r_j, φ_j). The final estimate of the vortex center location is given by

$$(r_c, \varphi_c) = \textstyle\sum_j (r_j, \varphi_j)(\Delta v_{rj}/\Delta l_j)^2 / \sum(\Delta v_{rj}/\Delta l_j)^2,$$

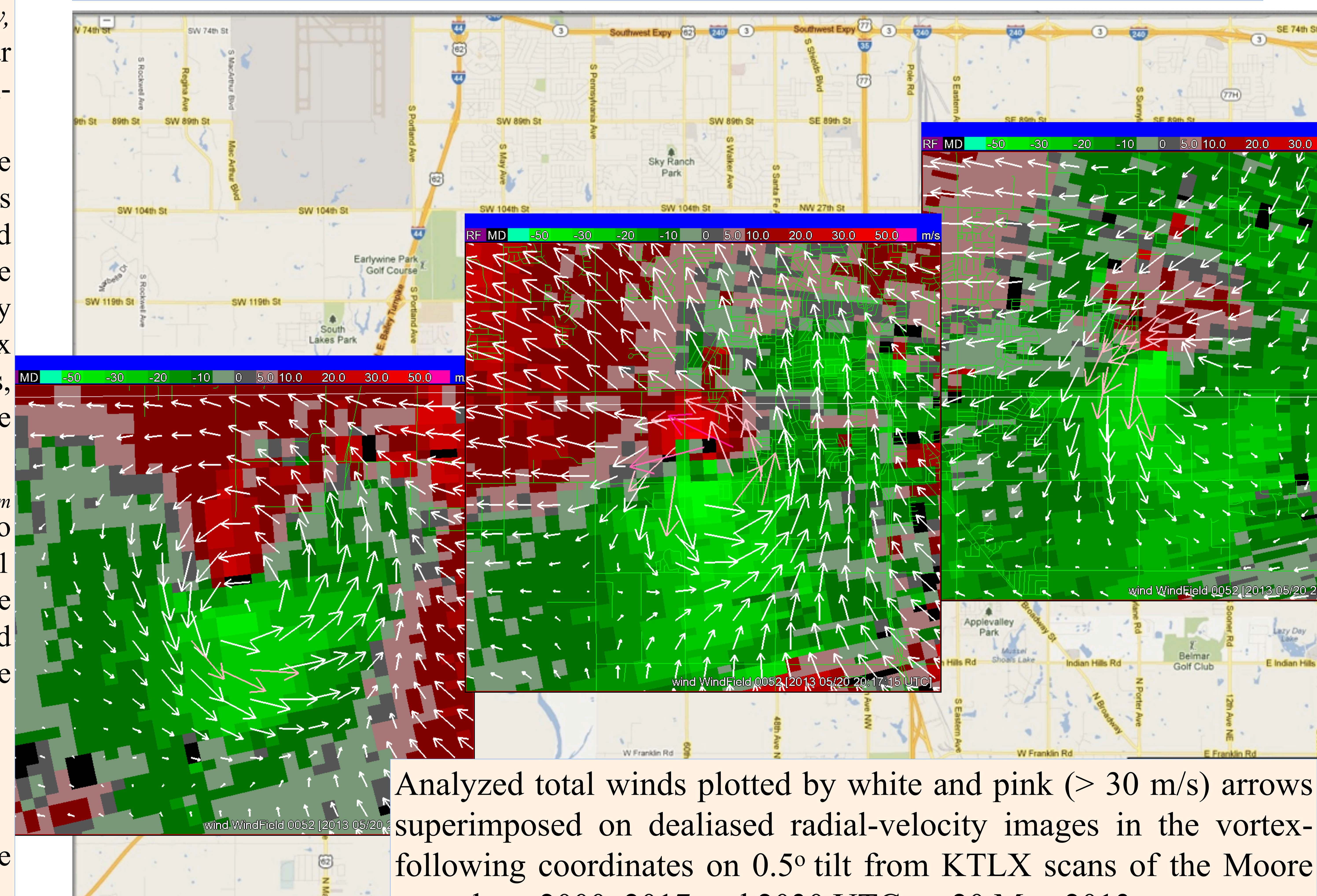
where $\sum_j$ denotes the summation over j for the five range circles that have the first five largest values of Δv_{rj}, and $\Delta l_j^2 = (r_j - r_m)^2 + r_j^2(\varphi_j - \varphi_m)^2$.

3. Varational method for vortex wind retrieval

In the varational method developed for the vortex wind retrievals, the control variables are the streamfunction ψ and velocity potential χ. Their background error covariance is formulated by $(\sigma_\psi^2, \sigma_\chi^2)C(\mathbf{x}_i, \mathbf{x}_j)$, where $C(\mathbf{x}_i, \mathbf{x}_j) = \exp[-(\rho_{ij}^2/R^2 + \phi_{ij}^2/\Phi^2)/2]$, $\mathbf{x} = (x, y)$, $(\ )_i$ [or $(\ )_j$] denotes the value of ( ) at the point i (or j), σ_ψ^2 (or σ_χ^2) is the background error variance for ψ (or χ), $\rho_{ij} = \rho_i - \rho_j$, $\phi_{ij} = \phi_i - \phi_j$, and R (or Φ) is the de-correlation length in ρ (or ϕ). Here, (ρ, ϕ) are related to (x, y)-coordinates by $\rho = \ln(|\mathbf{x}|/\rho_M)$ for $|\mathbf{x}| \le \rho_M$, $\rho = |\mathbf{x}|/\rho_M - 1$ for $|\mathbf{x}| > \rho_M$, and $\phi = \tan^{-1}(y/x)$, where $\mathbf{x} = (x, y)$, the origin of the coordinates is at the estimated vortex center, and ρ_M is the estimated radius of maximum tangential velocity of the vortex.

4. Results

The method has been successfully applied to tornadic mesocyclone observed by the operational KTLX and KFDR radars on 24 May 2011 and to the EF5 tornadic vortex observed by the KTLX radar that struck Moore in Oklahoma on 20 May 2013. Examples are shown below.



Analyzed total winds plotted by white and pink (> 30 m/s) arrows superimposed on dealiased radial-velocity images in the vortex-following coordinates on 0.5° tilt from KTLX scans of the Moore tornado at 2000, 2017 and 2030 UTC on 20 May 2013.