Spatially variable advection correction of Doppler radial velocity data

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Radar-data-based analysis products such as accumulated rainfall maps, dual-Doppler wind syntheses, and thermodynamic retrievals are prone to substantial error if the temporal sampling interval is too coarse. Techniques to mitigate these errors typically make use of advection correction procedures (space-to-time conversions) based on Taylor's frozen turbulence hypothesis in which the analyzed field is idealized as a pattern of unchanging form that translates horizontally at constant speed. Mathematically, the frozen turbulence constraint (as applied to the reflectivity field R) can be written as $DR/Dt = 0$, where $D/Dt = \partial/\partial t + U\,\partial/\partial x + V\partial/\partial y$, and U and V are constant pattern-translation components. These components can, in general, differ substantially from the actual air velocity components u and v. Advection correction procedures using this or related constraints are either supplied with independent estimates of U and V, or compute U and V as part of a comprehensive analysis procedure.

Shapiro et al. (2010a,b) derived a variational frozen-turbulence-based advection correction procedure for the reflectivity field in which the computed U and V pattern-translation components varied spatially. In leave-one-out verification tests of that procedure with Terminal Doppler Weather Radar (TDWR) and Weather Service Radar, 1988, Doppler (WSR-88D) data of a supercell thunderstorm, the reflectivity-based procedure yielded analyzed reflectivity fields with lower root-mean-square errors and higher correlation coefficients than reflectivity fields that were advection-corrected with any constant advection speed.

The present study is concerned with a spatially variable advection correction procedure for the Doppler radial velocity field v_r. The analysis problem for the radial velocity field is much more difficult than that for the reflectivity field because even if the vector velocity field satisfies the frozen-turbulence hypothesis, the radial component of the velocity vectors does not (see footnote 2 in Shapiro et al. 2010a for an illustrative example of this problem). However, Gal-Chen (1982) showed that if the velocity vectors satisfy the frozen turbulence hypothesis then the radial velocity field satisfies a second derivative constraint of the form $D^2(rv_r)/Dt^2 = 0$. Our radial velocity analysis problem is phrased as a variational problem in which errors in this second derivative constraint are minimized subject to smoothness constraints on the U and V fields. The Euler-Lagrange equations for this problem are derived and a solution is proposed in which the trajectories of the pattern-motion, the U and V pattern-translation fields, and the radial velocity field are analyzed simultaneously using a combined analytical and numerical procedure. Results of the procedure are first presented from analytical data tests using radial velocities sampled from an array of intense counter-rotating vortices embedded in (and rotating with) a solid-body vortex. We then present results from real data tests using rapid-scan radar data of convective storms over central Oklahoma on 4 September 2018. The data were obtained using the Atmospheric Imaging Radar (AIR), a rapid-scan X-band mobile Doppler radar (Isom *et al.* 2013, Kurdzo *et al.* 2017). The AIR is maintained and operated by the Advanced Radar Research Center (ARRC) of the University of Oklahoma.

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