Improving dual-Doppler retrieval of the vertical wind using a vertical vorticity constraint

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MOTIVATION

\begin{itemize}
  \item Vertical wind $w$ is poorly sampled by quasi-horizontally scanning radars
  \item Must therefore use mass conservation constraint and boundary condition(s) to retrieve $w$ from horizontal divergence field
  \item Unfortunately, divergence often unobserved near surface due to earth curvature, ground clutter, and rough terrain, and in low-SNR regions
  \item Leads to locally severe errors in retrieved $w$ (analysis underdetermined)
  \item Seek to improve $w$ retrieval by imposing vertical vorticity equation as an additional dynamical constraint
\end{itemize}

MESOSCALE VERTICAL VORTICITY EQUATION

\[
\frac{\partial \zeta}{\partial t} + \mathbf{u} \cdot \nabla \zeta + \nu \frac{\partial \zeta}{\partial x} + \nu \frac{\partial \zeta}{\partial y} + \frac{\partial \zeta}{\partial z} = \left( \frac{\partial w}{\partial x} - \frac{\partial v}{\partial y} \right) - \left( \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \right)
\]

TECHNIQUE OVERVIEW

\begin{itemize}
  \item 3D-VAR formulation (cost function minimization problem)
  \item Weakly satisfies radial winds from both radars, anelastic mass conservation equation, smoothness constraint, and (optionally) the vertical vorticity equation
  \item Impermeability condition exactly satisfied at surface
  \item Provision made for spatially-variable advection and evolution of wind field
\end{itemize}

REAL-DATA EXPERIMENTS

\begin{itemize}
  \item 8 May 2003 Oklahoma tornadic supercell
  \item Observed by KTLX (WSR-88D), KOKC (TDWR)
  \item $\Delta \Phi = 1$, $\Delta R = 250$ m/$150$ m, $\Delta T = 5$ min/4 min
  \item Retrievals performed over 20 km analysis domain (see figure) with 500 m grid spacing
  \item Improvement similar to ARPS $\Delta T=5$ min experiments
\end{itemize}

OSS EXPERIMENTS WITH SIMULATED SUPERCELL

\begin{itemize}
  \item Supercell simulated using Advanced Regional Prediction System (ARPS)
  \item Emulated radars positioned ~35 km from analysis domain center
  \item Pseudo-observations computed every 200 m in range, 1° in azimuth, elevation
  \item Dual-Doppler retrievals performed over 20 km analysis domain (box in figure)
  \item Volume scan time $\Delta T$ varied between 30 s and 5 min
\end{itemize}

THREE MAIN EXPERIMENTS

\begin{itemize}
  \item CONTROL: all pseudo-observations used in analysis, vorticity constraint OFF
  \item NOVORT: pseudo-observations only used above 1.5 km AGL, vorticity constraint OFF
  \item VORT: pseudo-observations only used above 1.5 km AGL, vorticity constraint ON
\end{itemize}

Vorticity constraint substantially improves retrieved $w$ in main updrafts/downdrafts:

\begin{itemize}
  \item Improvement from vorticity constraint increases as $\Delta T$ decreases or data rejection level increases:
\end{itemize}

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Accounting for flow advection, evolution in calculation of $\frac{\partial \zeta}{\partial t}$ substantially improved the retrievals; best method for doing so varied with $\Delta T$. 

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