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ASSESSING DETECTION AND ESTIMATES OF LOW-LEVEL SUPERCELL HORIZONTAL VORTICITY DIAGNOSED FROM DOPPLER RADAR DATA: SIMULATION STUDY

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INTRODUCTION

- Consensus researches in the severe storms community demonstrated that the upward tilting of low-level horizontal baroclinically-generated vorticity causes the development of low-level rotation in mesocyclones.

OBJECTIVE OF THIS STUDY

- To determine if the detection of large horizontal vorticity in certain locations of a supercell and in certain directions (given a favorable radar viewing angle) might give the radar meteorologist or forecaster an early warning of imminent tornadogenesis.

METHODOLOGY

- A "truth" supercell simulation was generated using a high-resolution cloud model.
- This simulation was conducted to investigate estimates of simulated low-level supercell azimuthal component of baroclinically-generated vorticity from virtual Doppler radar data.

3D VORTICITY COMPONENTS IN RADAR SPHERICAL COORDINATES

- Defined in the right-handed radar spherical coordinates (R, α'_o, β) centered on a Doppler radar, three vorticity components (Fig. 1) are given as

Radial Vorticity: $\omega_R = \frac{1}{R\cos\alpha'_o}\frac{\partial}{\partial\alpha'_o}\left(\cos\alpha'_o\, V_\beta\right) - \frac{1}{R\cos\alpha'_o}\frac{\partial V_{\alpha'_o}}{\partial\beta}$,

Normal Vorticity: $\omega_{\alpha'_o} = \frac{1}{R\cos\alpha'_o}\frac{\partial V_R}{\partial\beta} - \frac{1}{R}\frac{\partial}{\partial R}\left(RV_\beta\right)$, and

Azimuthal Vorticity: $\omega_\beta = \frac{1}{R}\frac{\partial}{\partial R}\left(RV_{\alpha'_o}\right) - \frac{1}{R}\frac{\partial V_R}{\partial\alpha'_o}$,

where

R = slant range,
α'_o= correct elevation angle,
β = azimuth angle measured clockwise from due north,
V_R = Doppler radial velocity component in the R direction,
$V_{\alpha'_o}$ = non-Doppler normal velocity component lying in the α'_o-surface, and
V_β = non-Doppler azimuthal velocity component in the β direction.

- Note that $V_{\alpha'_o}$ and V_β are unobserved because they are normal to the radar viewing direction. Hence, they are ignored.
- Simulated V_R data were used to calculate and assess the observed parts of the normal ($\omega_{\alpha'_o}$) and azimuthal (ω_β) vorticity values.

FIG. 1

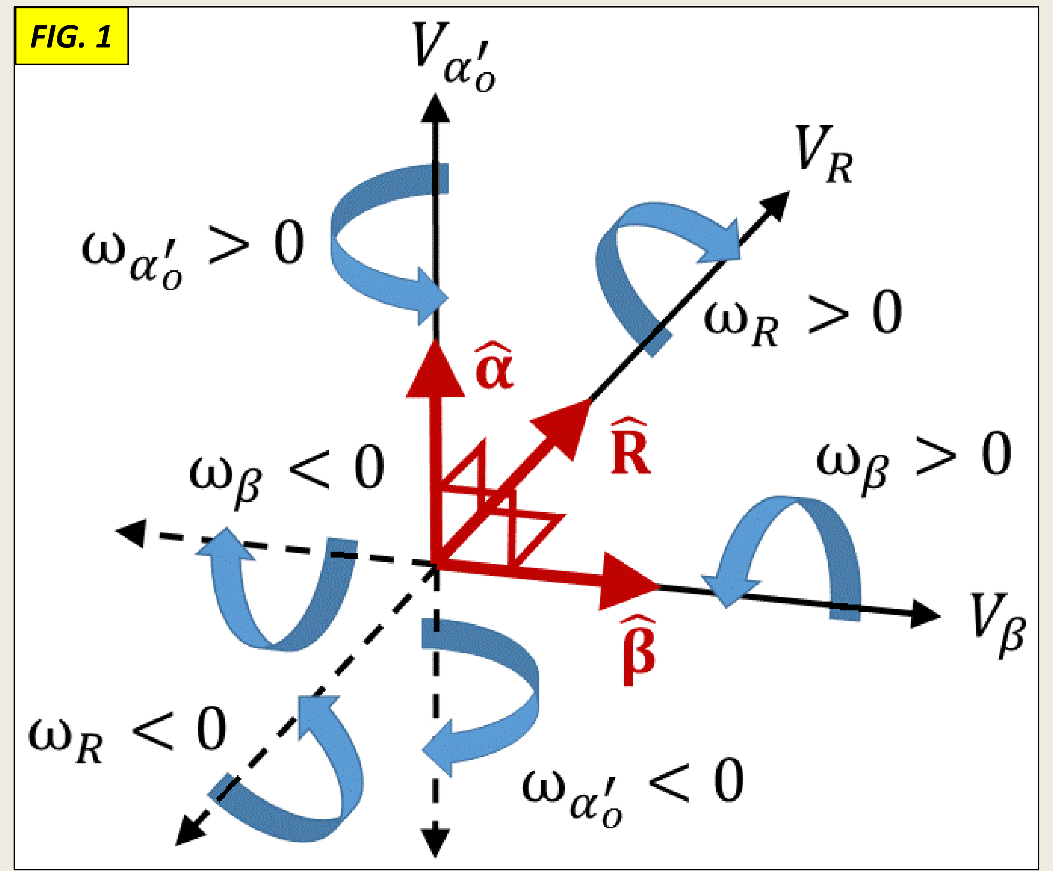


FIG. 1. Illustration of unit basis vectors (red) ($\hat{\mathbf{R}}$, $\hat{\boldsymbol{\alpha}}$, $\hat{\boldsymbol{\beta}}$) of the radar spherical coordinate system and 3D velocity (V_R, $V_{\alpha'_o}$, V_β) and vorticity (ω_R, $\omega_{\alpha'_o}$, ω_β) components. Positive (negative) rotation is counterclockwise about the axis of rotation in each positive (negative) direction of $\hat{\mathbf{R}}$, $\hat{\boldsymbol{\alpha}}$, and $\hat{\boldsymbol{\beta}}$. Blue curved arrow represents the sense of rotation about the axis of rotation in a 3-D perspective viewpoint.

HIGH-RESOLUTION NUMERICAL MODEL

- The supercell simulation was generated using the Advanced Research Weather Research and Forecasting (WRF-ARW) model (Skamarock et al. 2008) with 111-m uniform horizontal and vertically stretched grid spacings (~100 m near the surface to ~600 m between 10 and 22 km AGL), typical cloud model settings, and parameterized turbulence. The 111-m grid was run concurrently within a 333-m simulation in a one-way nested configuration. A free-slip lower boundary condition was used, effectively disregarding the effects of surface drag.
- A hook echo grew (Figs. 3-5) as a tornado (T1) developed ~80 min into the simulation (Figs. 2-5) and became very intense with surface winds briefly exceeding 110 m s-1.

FIG. 2

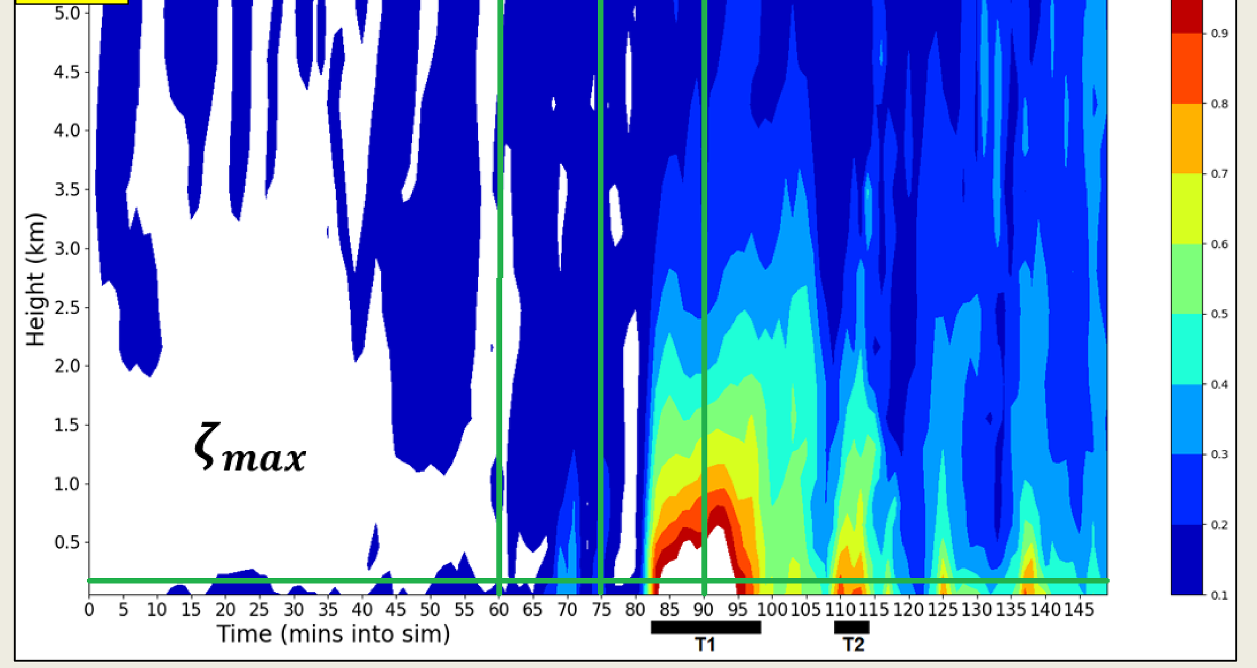


FIG. 2. Height-time plot of the numerical vertical vorticity (ζ_{max}, s^{-1}) peaks. White shading surrounded by dark red shading refers to $\zeta_{max} > 1$ s^{-1}. The maximum value of ζ_{max} is 1.3 s^{-1}. The other white shading surrounded by a dark blue shading refers to $0 < \zeta_{max} < 0.1$ s^{-1}. Black rectangles represent durations of two tornadoes, as indicated by T1 and T2. Intersections of green lines indicate locations of ζ_{max} and $\omega_{\alpha'_o}$ at t = 60, 75 and 90 min and at z = 0.17 km, as shown in Figs. 3-5.

SALIENT FEATURES IN FIGS. 3-5 ARE GIVEN AS:

- At low levels, the Doppler azimuthal vorticity measurements (ω_β) are detected *prior to* the detection of Doppler normal vorticity ($\omega_{\alpha'_o}$) measurements.
- Regions of ω_β are intensifying as they are advected spirally toward a location where an upward tilting of low-level horizontal vorticity causes the development of low-level rotation in a tornado.
- The ω_β vectors, when pointing to the right (left) of and perpendicular to the radar viewing direction, are positive (negative). These locations and directions may give the radar meteorologist or forecaster an idea of where imminent tornadogenesis would form.
- Some significant features of the ω_β values are in very low-reflectivity regions and may therefore not be detected with real radar.

FIG. 3

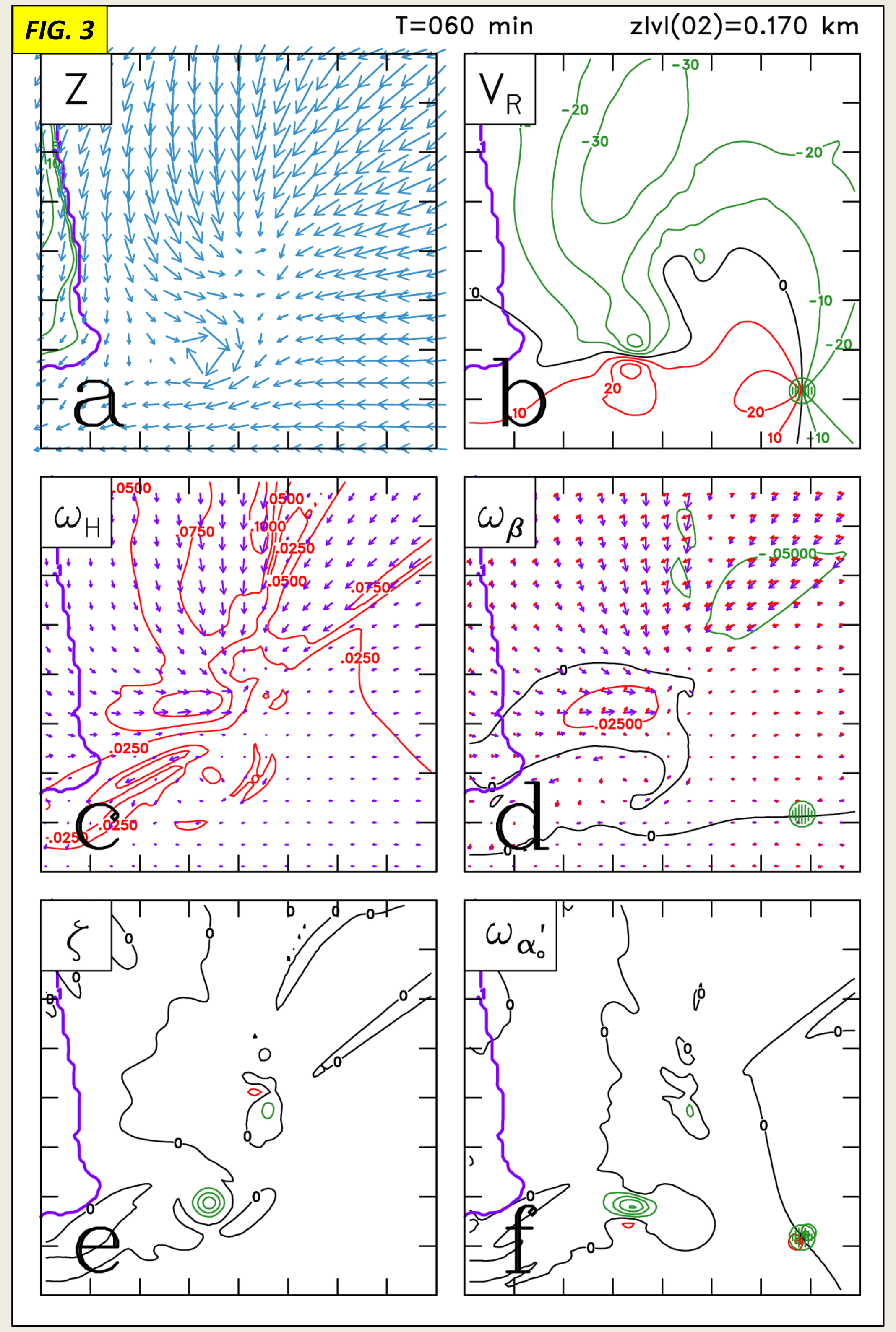


FIG. 4

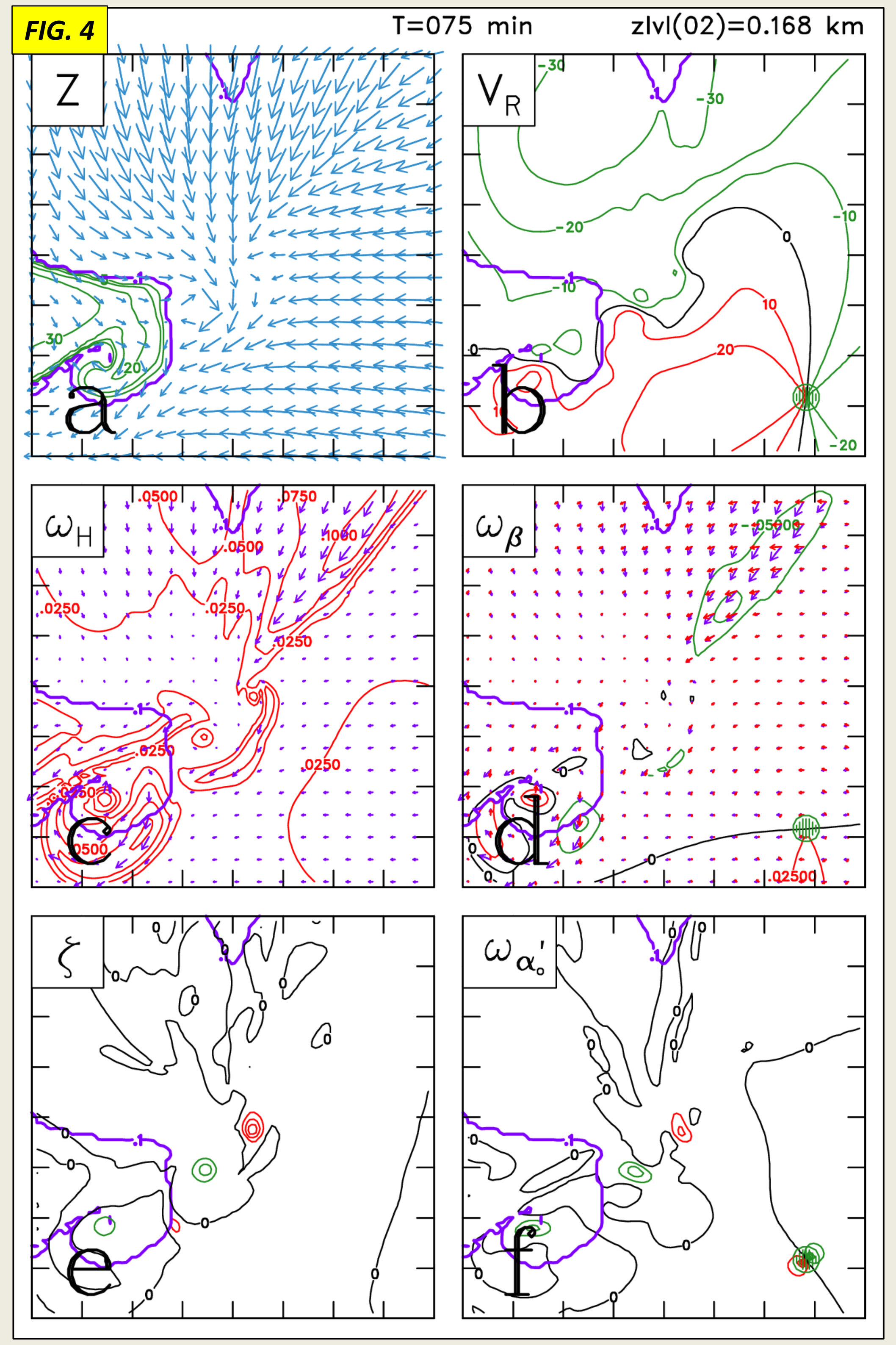
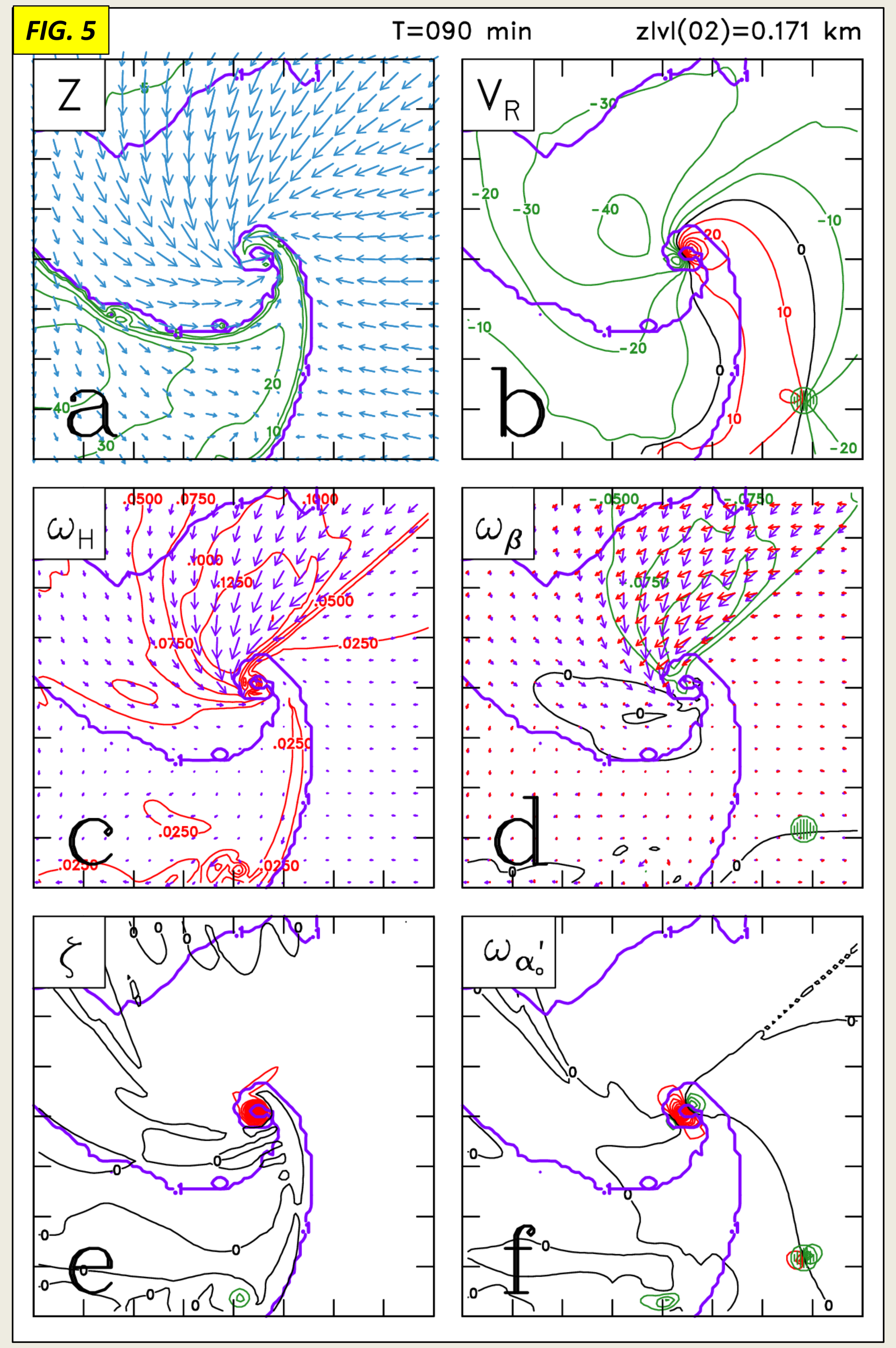


FIG. 5



FIGS. 3-5. Shown at a given time (T=60, 75 and 90 min) are plots of (a) storm-relative wind vectors (blue, m s^{-1}) with superimposed reflectivity contours (green, 5, 10, 20, 30, & 40 dBZ and purple, 0.1 dBZ), (b) Doppler velocity contours (V_R, m s^{-1}, green, red) corresponding to the wind field shown in (a), (c) horizontal streamwise vorticity contours (ω_H, s^{-1}, red) with purple vectors, (d) Doppler azimuthal vorticity contours (ω_β, s^{-1}, red, green) with red vectors being normal to radar viewing direction and connected to horizontal streamwise vorticity vectors (purple), same as in panel (c), (e) vertical vorticity contours (ζ, s^{-1}, red green), and (f) Doppler normal vorticity contours ($\omega_{\alpha'_o}$, s^{-1}, green, red). In each panel, grid size is 8 km x 8 km with one tickmark equaling to 1 km. In (b), (d), and (f), the radar is assumed to be located at a green, heavy dot in the lower, right corner. Height is at 0.17 km.

CONCLUSIONS AND ON-GOING WORK

- Preliminary estimates of ω_β and $\omega_{\alpha'_o}$ were diagnosed from virtual Doppler radar data.
- The detection of ω_β in certain locations and directions relative to radar viewing direction may give the radar meteorologist or forecaster an early warning of imminent tornadogenesis.
- We will continue this work by highlighting the roles of ω_β and $\omega_{\alpha'_o}$ and also the effects of varying range, azimuth and elevation on ω_β and $\omega_{\alpha'_o}$ calculations.
- It is suggested that automated Doppler horizontal and normal vorticity algorithms will be developed to provide additional diagnostic information pertinent to convective storm nowcasting.

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