P81

VIRTUAL NEAR-RADAR DOPPLER VELOCITY SIGNATURES OF LOW-LEVEL SUPERCELL HORIZONTAL AND VERTICL ROTATIONS: SIMULATION STUDY

Vincent T. Wood[2], Robert P. Davies-Jones[1,2], and Corey K. Potvin[2,3,4]

[1]Emeritus, [2]NOAA/OAR/National Severe Storms Laboratory, [3]Cooperative Institute for Mesoscale Meteorological Studies, and [4]School of Meteorology, University of Oklahoma, Norman, Oklahoma, USA

INTRODUCTION

- A large number of studies within the severe storms community demonstrated that the upward tilting of low-level horizontal vorticity causes the development of low-level rotation in supercell mesocyclones.

OBJECTIVES OF THIS STUDY

- To assess the potential utility of Doppler radar to (a) investigating this vorticity process, and (b) anticipating imminent tornadogenesis.

METHODOLOGY

- Obtained a WRF-ARW cloud model to generate a "truth" supercell simulation and radar pseudo-observations.
- Developed *Doppler azimuthal* and *normal vorticity* components defined in a radar coordinate system.
- Assessed these components' suitability as proxies for the simulated low-level horizontal and vertical vorticity components, respectively.

3D VELOCITY AND VORTICITY COMPONENTS IN RADAR COORDINATES

- Defined in the right-handed radar coordinate system (r, α, β) centered on a Doppler radar (Fig. 1), the 3D vector velocity of the radar targets:

$$\mathbf{V} = V_r\hat{\mathbf{r}} + V_\alpha\hat{\boldsymbol{\alpha}} + V_\beta\hat{\boldsymbol{\beta}},$$

where V_r = Doppler radial velocity component in the r direction,
V_α = non-Doppler normal velocity component tangent to an α surface,
V_β = non-Doppler azimuthal velocity component in the β direction,
r = slant range,
α = launch angle (beam elevation angle at radar), and
β = azimuthal angle measured clockwise from due north.

- Note that V_α and V_β are unobserved because they are normal to the radar viewing direction. Hence, they are ignored.
- The 3D vorticity vector $\boldsymbol{\omega} = \nabla \times \mathbf{V}$ of the **V**-field (Fig. 1):

$$\omega_r\hat{\mathbf{r}} + \omega_\alpha\hat{\boldsymbol{\alpha}} + \omega_\beta\hat{\boldsymbol{\beta}}$$

where ω_r = Doppler radial vorticity,
ω_α = Doppler normal vorticity,
ω_β = Doppler azimuthal vorticity

- Since V_α and V_β are unobserved, the observable (*ob*) parts of $\boldsymbol{\omega}$ are given as

$$(\omega_\alpha)_{ob} = \frac{\kappa_f}{2}\operatorname{cosec}\left(\frac{\kappa_f r}{2}\right)\sec\left(\alpha - \frac{\kappa_f r}{2}\right)\frac{\partial \bar{V}_r}{\partial \beta},$$

and

$$(\omega_\beta)_{ob} \approx -\frac{\kappa_f}{\sin(\kappa_f r)}\frac{\partial \bar{V}_r}{\partial \alpha},$$

where $\kappa_f = \left(\frac{1}{5.76} - 1\right)\cos\alpha / a$ is the ray curvature for flat-earth geometry, a = earth radius of 6371 km, and $\bar{V}_r$ is the mean Doppler velocity.

FIG. 1

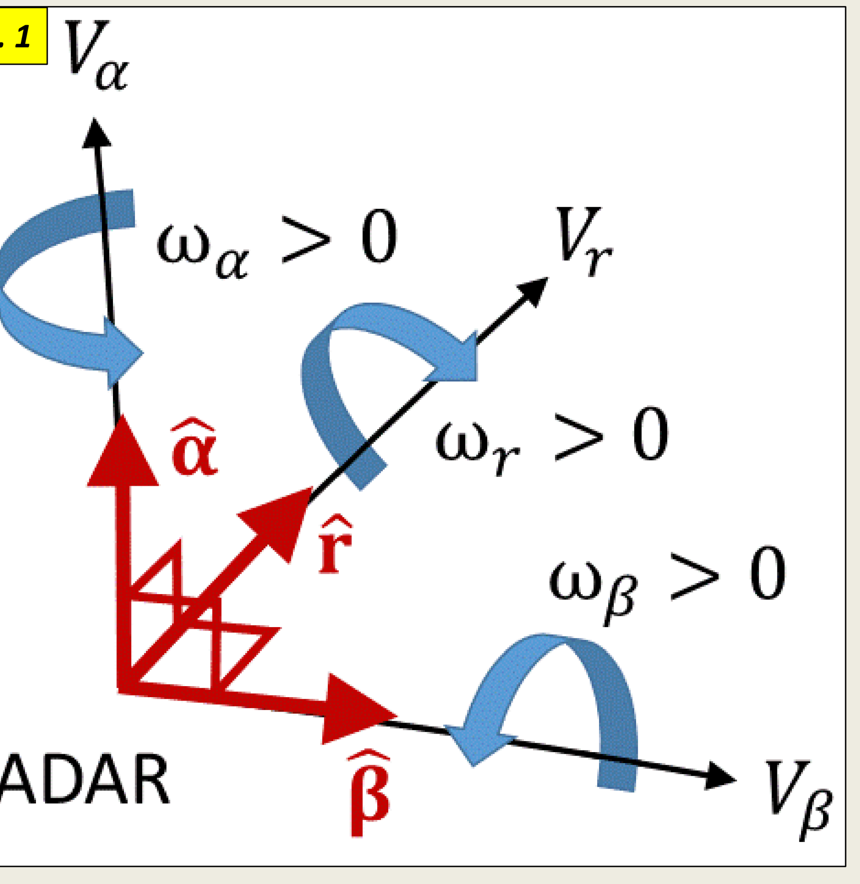


FIG. 1. Illustration of unit basis vectors (red) $(\hat{\mathbf{r}}, \hat{\boldsymbol{\alpha}}, \hat{\boldsymbol{\beta}})$ of the radar spherical coordinate system and 3D velocity (V_r, V_α, V_β) and vorticity $(\omega_r, \omega_\alpha, \omega_\beta)$ components. Positive rotation is counterclockwise about the axis of rotation in the positive 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 with the following conditions:

a) 111-m uniform horizontal and vertically stretched grid spacings (~100 m near the surface to ~600 m between 10 and 22 km AGL),
b) typical cloud model settings,
c) parameterized turbulence,
d) the 111-m grid run concurrently within a 333-m simulation in a one-way nested configuration,
e) a free-slip lower boundary condition, effectively disregarding the effects of surface drag.

FIG. 2

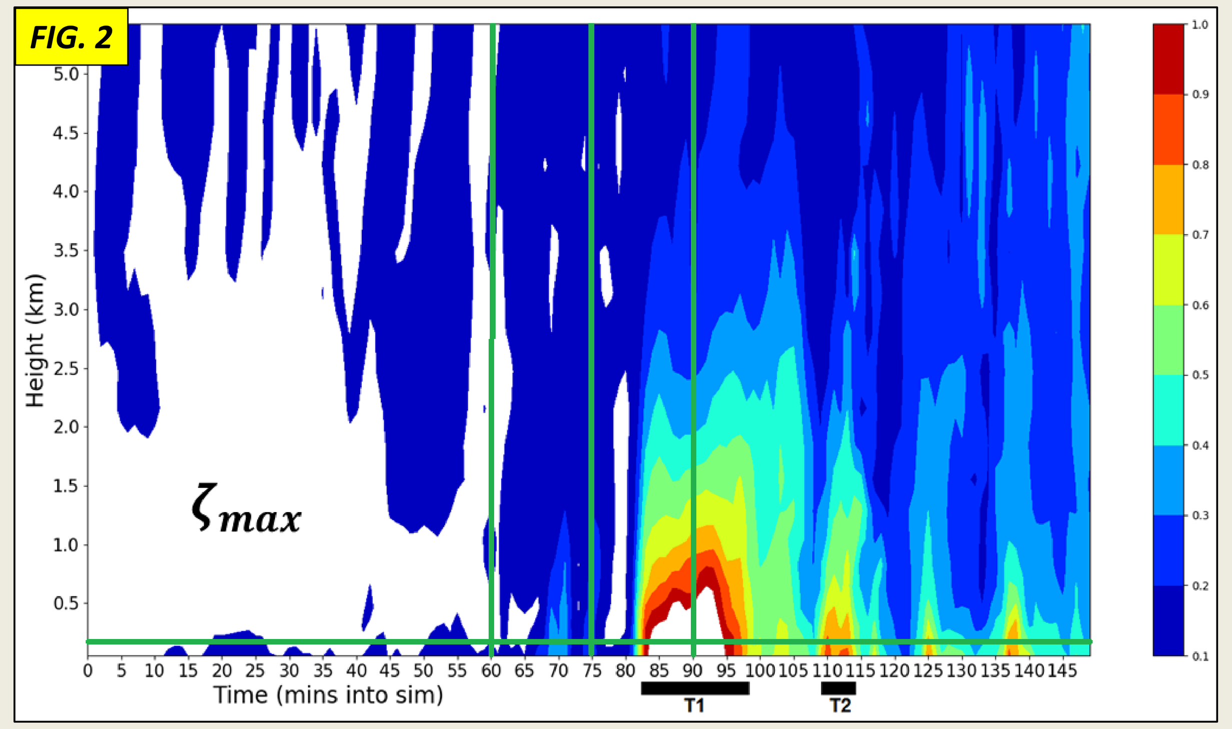
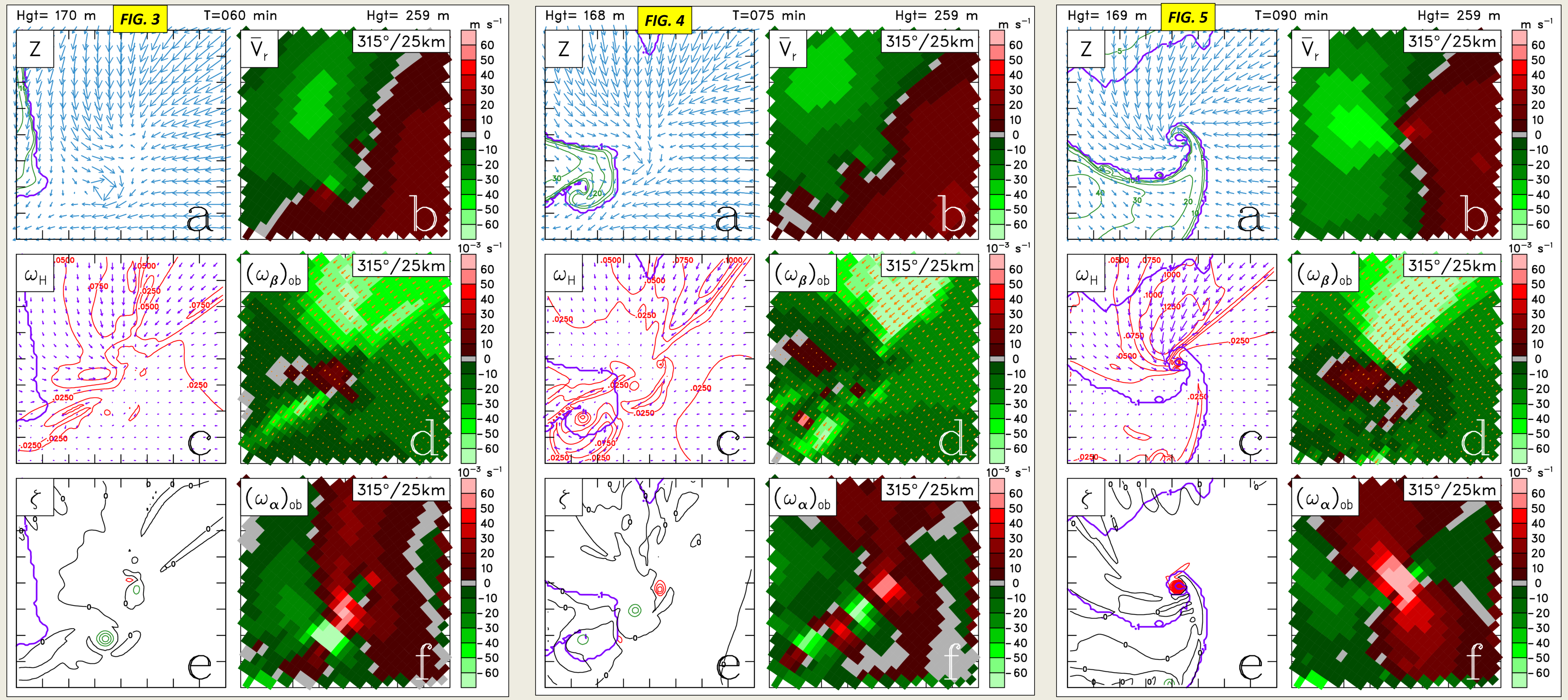


FIG. 2. Height-time plot of the numerical vertical vorticity (ζ_{max}, s^{-1}) peaks. White shading surrounded by dark red shading refers to $\zeta_{max} > 1$ s^{-1}. The maximum value of ζ_{max} is 1.3 s^{-1}. The other white shading surrounded by a dark blue shading refers to $0 < \zeta_{max} < 0.1$ s^{-1}. Black rectangles represent durations of two tornadoes, as indicated by T1 and T2. Intersections of green lines indicate locations of ζ_{max} 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, amplification of Doppler azimuthal vorticity measurements $(\omega_\beta)_{ob}$ *precede* the amplification of Doppler normal vorticity $(\omega_\alpha)_{ob}$ and numerical vertical vorticity (ζ) measurements.
- Regions of $(\omega_\beta)_{ob}$ 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 $(\omega_\beta)_{ob}$ 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. The impacts of these observational limitations will be explored in future work.

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 bands ($\bar{V}_r$, 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 bands [$(\omega_\beta)_{ob}$, s^{-1}, red, green] with orange vectors being normal to radar viewing direction, (e) vertical vorticity contours (ζ, s^{-1}, red green), and (f) Doppler normal vorticity bands [$(\omega_\alpha)_{ob}$, 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 center grid is located at 25 km and 315° from the radar. Center height of the grid is at 0.17 km.

CONCLUSIONS AND ON-GOING WORK

- Simulation was conducted to assess estimates of $(\omega_\beta)_{ob}$ and $(\omega_\alpha)_{ob}$ diagnosed from virtual near-radar Doppler velocity signatures at low levels.
- Trends in these estimates corresponded well to trends in the horizontal and vertical vorticity components.
- Amplification of the $(\omega_\beta)_{ob}$ fields *preceded* the amplification of ζ and $(\omega_\alpha)_{ob}$.
- We theorize that these Doppler vorticity signatures may help the radar meteorologists or forecasters anticipate imminent tornadogenesis.
- Continue this work by obtaining real radar data of tornadoes at close proximity to a WSR-88D.
- The emerging conclusions will determine whether or not the Doppler radar detection of amplifying horizontal vorticity at low levels in supercells could provide early warning of tornadogenesis.

29th Conference on Severe Local Storms
American Meteorological Society
22-26 October 2018, Stowe, VT

Contact: Vincent.Wood@noaa.gov

NOAA NSSL CIMMS
Cooperative Institute for Mesoscale Meteorological Studies