P161

A PARAMETRIC WIND-PRESSURE RELATIONSHIP FOR CONCENTRIC CYCLOSTROPHIC VORTICES

Vincent T. Wood[1], Robin L. Tanamachi[1], and Luther W. White[2]
[1]NOAA/National Severe Storms Laboratory, Norman, Oklahoma
[2]Department of Mathematics, University of Oklahoma, Norman, Oklahoma

INTRODUCTION

- In situ probes make near-ground pressure and wind measurements within close range of an intercepted tornado.
- Do researchers using the probe measurements recognize whether the measurements result from the tornado being embedded in a background vortex (such as a tornado cyclone or mesocyclone or the combination of the two)?
- High-resolution mobile Doppler radar data revealed complex vortex structures including quasi-concentric multiple wind field maxima, as shown in FIG. 1, for example.

OBJECTIVE

- The objective of this study is to examine how simulated dynamic pressure drops change as a function of multiple-maxima tangential velocity profiles coupled with cyclostrophic balance assumption.

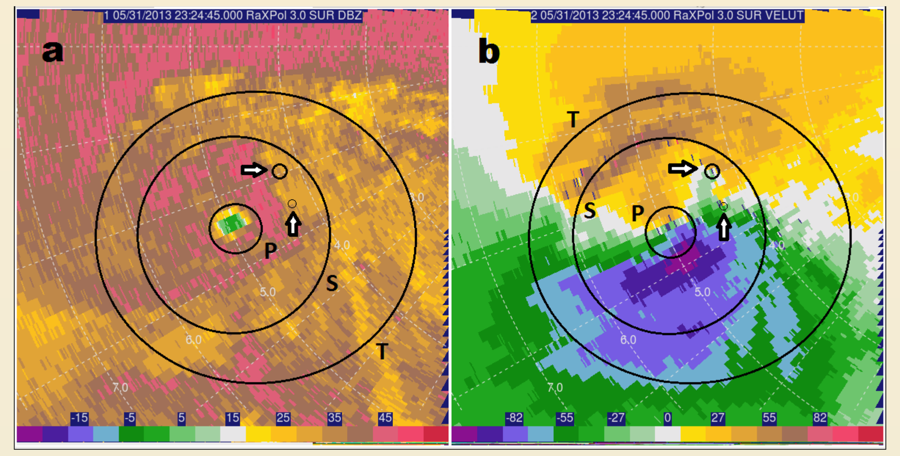


FIG. 1. Fields of (a) RaXPol radar reflectivity (dBZ) and (b) ground-relative Doppler velocity (m s^{-1}) of the El Reno, OK vortices of 31 May 2013 at 2324:45 UTC. At elevation angle of 3.0°, beam altitude at a 5-km range from the radar site is 0.26 km AGL. Dashed range rings are marked every 1 km, with dashed spokes provided every 10° in azimuth. Black circles represent approximate core sizes of the primary (P), secondary (S) and tertiary (T) vortices. Very small circles indicated by arrows show the possible presence of satellite vortices. Storm motion is 15 m s^{-1} from 204°. (Data courtesy of J. Snyder and H. Bluestein of University of Oklahoma.)

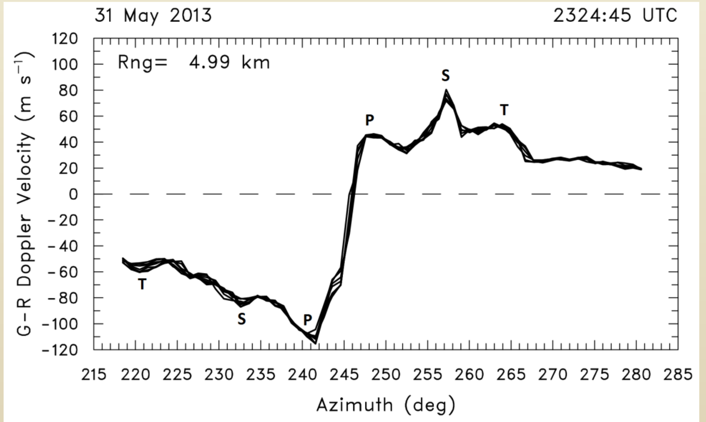


FIG. 2. A few adjacent azimuthal profiles of ground-relative Doppler velocities across the primary vortex signature (Fig. 1) centered at 5 km at 2324:45 UTC, 31 May 2013. Labels P, S, and T represent the primary, secondary and tertiary vortices, respectively. (Data courtesy of J. Snyder and H. Bluestein of University of Oklahoma.)

METHODOLOGY

- In an axisymmetric vortex, the assumption of balance between dynamic pressure drop and tangential wind speed is termed cyclostrophic balance with ρ being the air density assumed to be horizontally constant.
- The triple concentric vortex structure can be considered as a triple vortex composed of the primary, secondary, and tertiary vortex configurations.
- By isolating the primary tangential wind profile (V_p) from the secondary (V_s) and tertiary (V_t) tangential velocity profiles, the total cyclostrophic wind (V_c) profile in the cyclostrophic balance equation may be partitioned into the V_p, V_s and V_t velocity component: $V_c(r) = V_p(r) + V_s(r) + V_t(r)$, where the V_p, V_s and V_t velocity components are computed from the Wood-White parametric tangential wind model.
- Substitution of V_c into the total partitioned pressure deficit yields: $\Delta P_{tot}(r) = \Delta P_p(r) + \Delta P_s(r) + \Delta P_t(r)$.
- The partitioned pressure deficit components are expressed by

$$\Delta P_p(r) = \rho \int_\infty^r \left[\frac{V_p^2(\tau)}{\tau} + \frac{V_p(\tau)V_s(\tau)}{\tau} + \frac{V_p(\tau)V_t(\tau)}{\tau}\right] d\tau,$$

$$\Delta P_s(r) = \rho \int_\infty^r \left[\frac{V_s^2(\tau)}{\tau} + \frac{V_s(\tau)V_p(\tau)}{\tau} + \frac{V_s(\tau)V_t(\tau)}{\tau}\right] d\tau, \quad \text{and}$$

$$\Delta P_t(r) = \rho \int_\infty^r \left[\frac{V_t^2(\tau)}{\tau} + \frac{V_t(\tau)V_p(\tau)}{\tau} + \frac{V_t(\tau)V_s(\tau)}{\tau}\right] d\tau.$$

- The relative contributions of parametrically constructed V_p, V_s and V_t to the total pressure deficit ΔP_{tot} are explored and compared to elucidate the role of the partitioned tangential velocity profiles in the physical behavior of the corresponding pressure deficits at the vortex center, as will be shown below.

FIG. 3 (right). The "reference" vortex refers to a primary Rankine vortex (red curve) in the absence of external (blue) vortices A and B. The reference central pressure deficit (gray) is -117 hPa. When a secondary vortex A is added, new radial profiles (blue) of tangential velocity and pressure deficit result in total central pressure deficits (black). Parametrically vary-ing the tangential velocity profiles (brown arrows) produces different central pressure deficits.

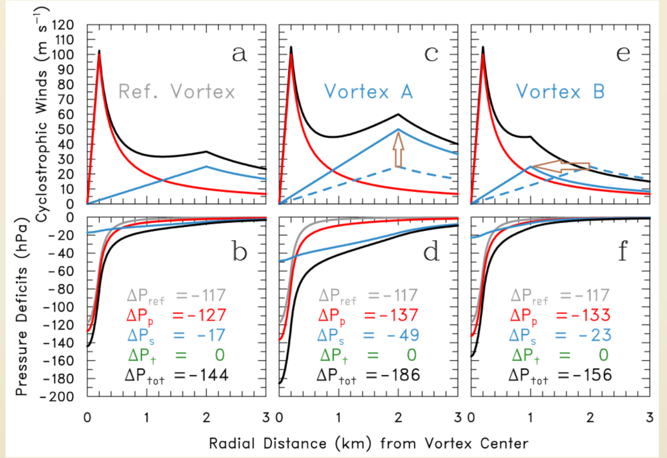


FIG. 4 (right). Same as FIG. 3, except that the central pressure deficits correspond to a change in the inner and outer profiles of tangential velocity of vortices C and D.

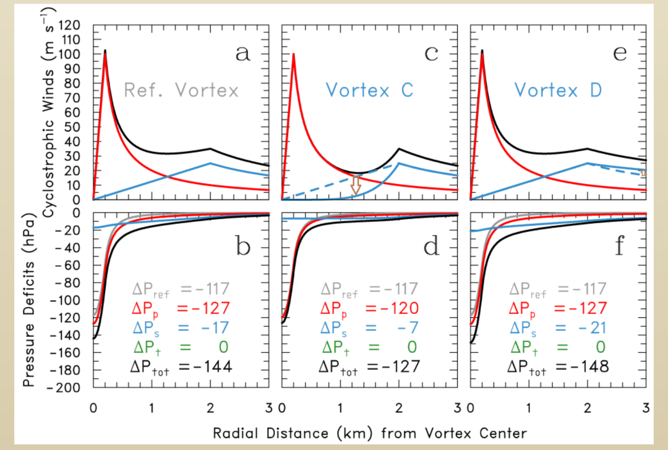


FIG. 5 (right). Same as FIG. 4, except that the central pressure deficits correspond to a change from a sharply-peaked to broadly-peaked profile of tangential velocity of vortex E.

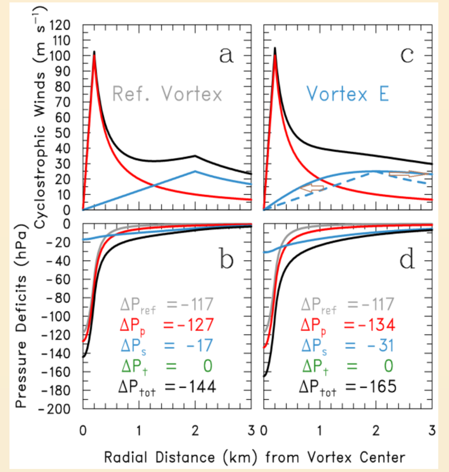
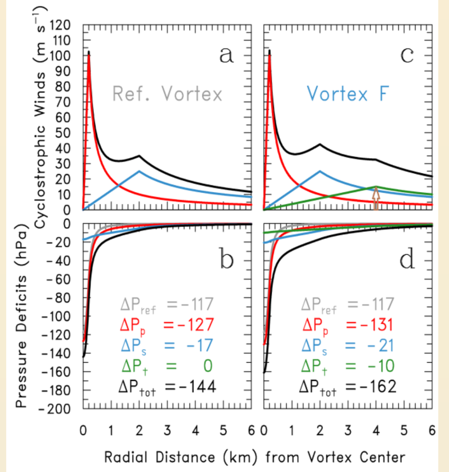


FIG. 6 (right). Same as FIG. 5, except that adding a tertiary vortex F (green) to the primary and secondary vortices produces a change in the central pressure deficits.



CASE STUDIES

We present a few examples in which the parametrically constructed model is fitted to a tangential velocity profile derived from high-resolution Doppler radar data collected in a real **S**ub-tornado-strength **C**onvective storm **V**ortex (SCV) of 26 May 2010 during VORTEX2 (Tanamachi et al. 2013, MWR, **141**, 3661-3690).

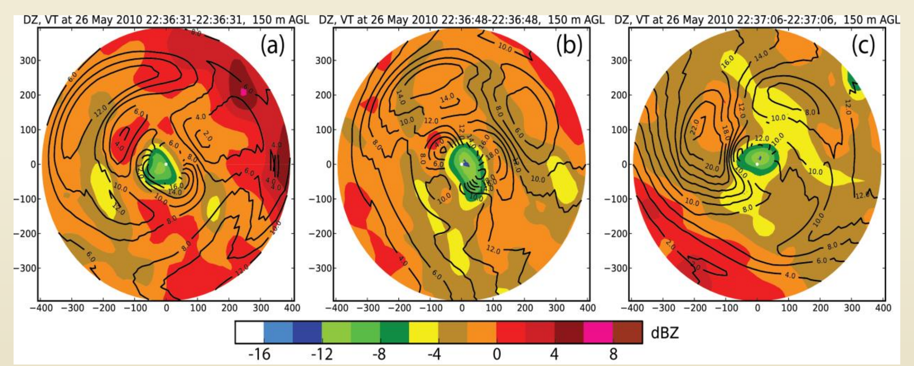
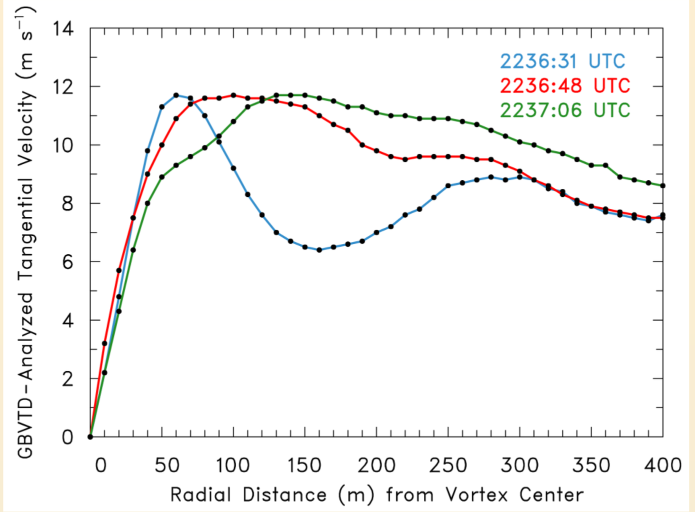


FIG. 7 (above). UMass W-band reflectivity (filled color contours, dBZ$_e$) and GBVTD-analyzed, vortex-relative, asymmetric azimuthal Doppler velocities (sum of wavenumbers 0-3, in black contour interval of 2 m s^{-1}) of SCV at (a) 2236:31, (b) 2236:48, and (c) 2237:06 UTC at height of 150 m AGL. The abscissa and ordinate scales for radial distance (m) from vortex center are indicated. Asymmetries and locations of varying wind maxima and minima in the wind fields are noticeably changed .

FIG. 8 (right). Radial distributions of the GBVTD-analyzed mean tangential wind (black dots) are presented. At 2236:31 UTC, two tangential velocity maxima (blue curve) occur, indicative of the dual concentric vortex configuration consisting of the primary and secondary vortices. The dual-maxima tangential wind profile changes to the single-maximum tangential wind profiles at 2236:48 and 2237:06 UTC.



Time	V_{px}	R_{px}	μ_{pi}	μ_{po}	λ_p	RMS	CC	V_{sx}	R_{sx}	μ_{si}	μ_{so}	λ_s	RMS	CC
2236:31	11.8	61.6	1.17	-1.35	0.69	0.04	1.00	6.4	306.8	6.56	-0.99	1.24	0.12	1.00
2236:48	11.8	100.9	1.00	-1.55	2.21	0.09	1.00	1.3	383.4	17.06	-0.01	0.95	0.11	0.98
2237:06	11.5	151.9	1.28	-3.38	7.56	0.21	1.00	NA	NA	NA	NA	NA	NA	NA

Table 1. Fitted model parameters generated by the Levenberg-Marquardt optimization method for primary (subscript p) and secondary (subscript s) vortices at 2236:31, 2236:48, and 2237:06 UTC. V_x is the maximum tangential velocity (m s^{-1}) that occurs at the core radius R_x (m). The tangential velocity profile is defined by (i) the growth parameter μ_i that predominantly dictates the inner (subscript i) profile near the vortex center, (ii) the decay parameter μ_o that primarily governs the outer (subscript o) profile beyond R_x and (iii) the size parameter λ that controls the radial width of the velocity profile straddling V_x. CC represents correlation coefficient value; RMS root-mean square error. NA represents not applicable.

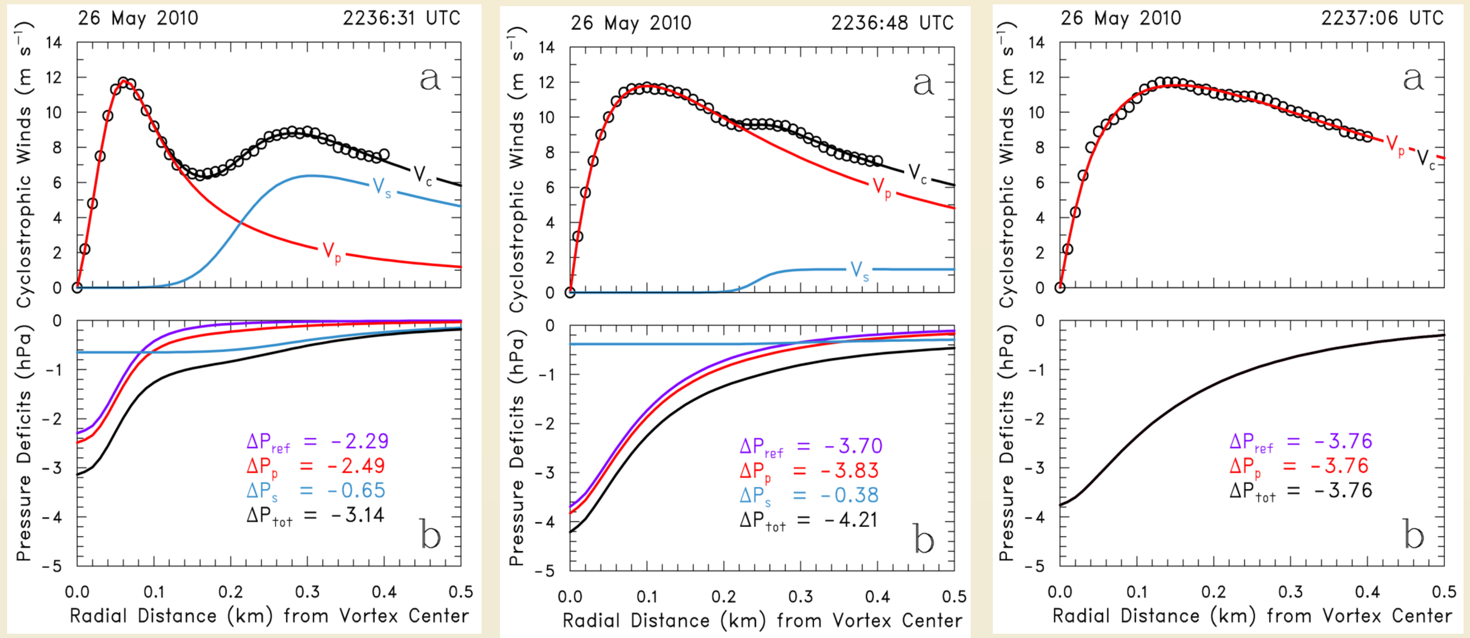


FIG. 9 (above). Radial profiles of (a) fitted tangential velocity for the total (black), primary (red) and secondary (blue) cyclostrophic vortices and (b) pressure deficit deduced from the fitted tangential wind profiles in (a) at 2236:31 UTC (left), 2236:48 UTC (middle), and 2237:06 UTC (right). The black circles refer to the observed data points. Having the fitted parameters available in Table 1, we use the formula $[V_c(r) = V_p(r) + V_s(r)]$ to parametrically construct the radial distributions of the primary and secondary tangential velocities and also the other formula $[\Delta P_{tot}(r) = \Delta P_p(r) + \Delta P_s(r)]$ to integrate the pressure deficit inward radially to reproduce radial profiles of primary and secondary pressure deficits. As a consequence, the overall radial distributions of cyclostrophic and deduced pressure deficit in the dual-vortex configuration are produced (black curves). Wind asymmetries and locations of varying wind maxima and minima in the wind fields (FIG. 7) produce significant changes in the radial distributions of fitted tangential velocity and deduced pressure deficit between 2236:31 UTC and 2237:06 UTC. For instance, an increase in λ_p (i.e., 0.69 to 2.21 in Table 1) causes the radial profile of the primary tangential velocity encompassing V_{px} to widen suddenly, thereby producing a central pressure drop from -2.49 to -3.83 hPa between 2236:31 UTC and 2236:48 UTC.

CONCLUSIONS

The Wood-White model coupled with the cyclostrophic balance assumption offered a diagnostic tool for parametrically constructing and estimating representative pressure deficit profiles deduced from a theoretical superposition of multiple-maxima tangential velocity profiles as well as from the fitted, GBVTD-analyzed tangential velocity profiles of the Prospect Valley, Colorado SCVs of 26 May 2010. The main conclusions of this study are as follows:

- The pressure deficit in a single vortex core has been shown to be sensitive to the varying shapes of the radial profile of tangential velocity.
- The cyclostrophic balance is partitioned into separate pressure components that correspond to multiple-maxima tangential wind profiles in order to quantitatively evaluate the significant fluctuations in central pressure drops.
- Varying any of the Wood-White parameters independently plays the same role in controlling various portions of the pressure deficit profile for a single vortex as for concentric vortices.
- The fitted parameters appear to be useful and diagnostic tools that permit one to interpret evolution of central pressure deficits corresponding to vortex morphology.

27th Conference on Severe Local Storms
American Meteorological Society
6 November 2014, Madison, WI

Contact: Vincent.Wood@noaa.gov