4D.4 SEPARATION OF HURRICANE AND ENVIRONMENTAL WINDS VIA SINGLE-DOPPLER RADAR VOLUMETRIC DATA ANAYLSIS: RESULTS FROM HURRICANE BRET (1999)

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1. INTRODUCTION

A vertical profile of the horizontal wind directly above a single-Doppler radar can be estimated from the Doppler velocity data by making assumptions about the wind field. The Velocity Azimuth Display (VAD - Browning and Wexler 1968) and the Volume Velocity Processing (VVP - Waldteufel and Corbin 1979) methods were developed around the assumption of *linearity*; that is, the wind field is estimated from a first-order Taylor series expansion of its components. The VAD method analyzes the Doppler velocity taken around 360° azimuth at a fixed range, r, and altitude, z, from the radar. The VVP method is an extension of the VAD method that involves an analysis of full-volume Doppler velocity data. It provides estimates of many of the kinematic properties of the wind field that are not extractible in the VAD scheme, such as the vertical variations in the wind field. Donaldson and Harris (1989) developed a Doppler velocity model for *nonlinear* wind fields that included combinations of axisymmetric curvature, diffluence and shear that are likely found in hurricanes. They showed that the ratios of the divergence and deformations to the wind speed in cyclonic flow can be estimated from the VAD method with better than 95% accuracy for r/R < 0.6, where R is distance from the radar to the hurricane's circulations center. Building upon these results and the findings of Donaldson (1991), Harasti and List (1995) derived explicate expressions for the wavenumber zero wind components and their parameters in terms of the VAD coefficients. This work led to the development of the Hurricane-customized Extension of the VAD (HEVAD) method (Harasti and List 2001). The HEVAD method provides vertical profiles of the wavenumber zero components of the swirling hurricane wind and the environmental wind at the radar-origin of coordinates.

Just as VVP is the next logical extension of VAD, the Hurricane VVP (HVVP – Harasti 2003) is the full-volume extension of the HEVAD method. The complete separation of the zeroth-, first-, and second-order Taylor Series coefficients in HVVP, including the allowance for vertical variations, provides for a more robust alternative to HEVAD. The focus of this paper is on the component of HVVP that retrieves the environmental winds.

2. AN OVERVIEW OF HVVP

The HVVP method begins from the modified VVP method presented in Koscielny et al. (1982). Additional Taylor series terms are added to the equations that account for the quadratic variations of the Cartesian wind components u and v. Harasti and List (2001) showed that these parameters account for a large proportion of the nonlinearity present in the wind field of a hurricane. The observed Doppler velocity, V_D, is assumed equal to the sum of the estimated Doppler velocity and the measurement error ε. The estimated Doppler velocity, V_D, is expressed as the product of two vectors, **P**, the predictors, and **K**, the parameters, as follows:

$$
\left.\begin{array}{ll}
V_D = \mathbf{P_m^T K_m} + \varepsilon, & \\
\text{where} & \\
P_1 = \cos\theta_e \sin\phi, & K_1 = u_0, \\
P_2 = r\cos^2\theta_e \sin^2\phi, & K_2 = u_x, \\
P_3 = \cos\theta_e \sin\phi\left(z - z_0\right), & K_3 = u_z, \\
P_4 = \cos\theta_e \cos\phi, & K_4 = v_0, \\
P_5 = r\cos^2\theta_e \cos^2\phi, & K_5 = v_y, \\
P_6 = \cos\theta_e \cos\phi\left(z - z_0\right), & K_6 = v_z, \\
P_7 = r\cos^2\theta_e \sin\phi\cos\phi, & K_7 = u_y + v_x, \\
P_8 = r^2\cos^3\theta_e \sin^3\phi, & K_8 = u_{xx}/2, \\
P_9 = r^2\cos^3\theta_e \sin\phi\cos^2\phi, & K_9 = v_{xy} + u_{yy}/2, \\
P_{10} = r^2\cos^3\theta_e \cos^3\phi, & K_{10} = v_{yy}/2, \\
P_{11} = r^2\cos^3\theta_e \cos\phi\sin^2\phi, & K_{11} = u_{xy} + v_{xx}/2, \\
P_{12} = r\cos^2\theta_e \sin^2\phi\left(z - z_0\right), & K_{12} = u_{xz}, \\
P_{13} = r\cos^2\theta_e \cos^2\phi\left(z - z_0\right), & K_{13} = v_{yz}, \\
P_{14} = r\cos^2\theta_e \sin\phi\cos\phi\left(z - z_0\right), & K_{14} = u_{yz} + v_{xz}, \\
P_{15} = \cos\theta_e \sin\phi\left(z - z_0\right)^2, & K_{15} = u_{zz}/2, \\
P_{16} = \cos\theta_e \cos\phi\left(z - z_0\right)^2 \text{ and} & K_{16} = v_{zz}/2.
\end{array}\right\} \quad (1)
$$

The radar volume scan is divided up into overlapping layers of 500 m thickness, spaced 100 m apart. The origin of the spherical coordinates (r, ϕ, θ_e) of the V_D data is centered on the radar, where the elevation angle of the radar beam, and the altitude of the analysis layer are θ_e and z_0, respectively. The coordinate system is rotated such that the zero azimuth points to the azimuthal direction of the hurricane's circulation center, ϕ_C. Harasti et al. (2004) describe techniques to estimate the radar-polar coordinates of the circulation center, (R, ϕ_C). The x and y axes of the rotated coordinate system are parallel to the tangential and radial wind

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components of the hurricane at (x,y,z) =(0, 0, z_0), V_t and V_r, respectively. Equation (1) is solved by least squares, yielding vertical profiles of the coefficients of the parameter vector **K** directly above the radar.

The parameters K_1 and K_4 are the total wind components u_0 and v_0. The environmental wind vector is obtained from the decompositions $u_0 = u_e + V_t$ and $v_0 = v_e - V_r$, where u_e and v_e are the environmental wind components. HVVP utilizes a modified Rankine vortex model with superimposed asymmetries in the azimuthal direction concentric to the circulation center. V_t and V_r are retrieved from the evaluation of K_2, K_5 and K_7, which are related to the vortex parameters. One must include the unevaluated **K** parameters and their corresponding predictors in (1) to obtain unbiased least squares estimates of the evaluated parameters.

3. RESULTS AND CONCLUDING REMARKS

Hurricane Bret (1999) was a category four hurricane before it weakened to a category three hurricane a few hours before landfall along the coast of Texas (Fig. 1). The HVVP method was applied to the WSR-88D volume scan data from Corpus Christi (KCRP) and Brownsville (KBRO) near 23:43 UTC August 22 1999 using the first three elevation tilts at 0.5°, 1.5° and 2.5°. This data provided HVVP solutions for the 500 m layers between 0.3 and 1.8 km altitude. Figure 2 shows vertical profiles of the HVVP u_e and v_e components derived from the KBRO and KCRP data. Also shown for comparison are the mean u and v components over the square region shown in Fig. 1, which were derived from a NOAA/AOML/HRD triple-Doppler radar wind analysis (Dodge et al. 2002). Note the anti-cyclonic shear in u_e across the ~200 km distance between KCRP and KBRO, and a ~50° backing in the wind direction with height above KBRO.

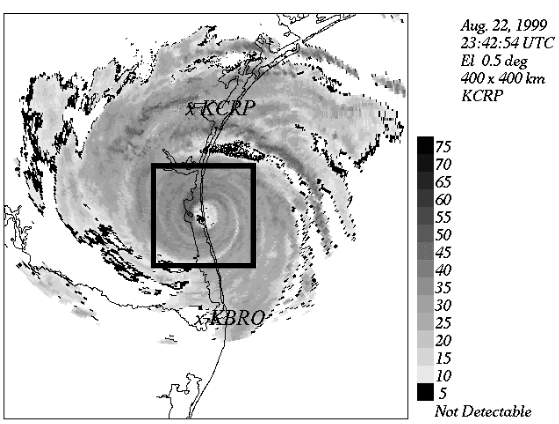

Fig. 1. Reflectivity (dBZ) map of Hurricane Bret derived from the KCRP surveillance scan taken at an elevation angle of 0.5° on 23:42:54 UTC August 22 1999. KCRP and KBRO are located at the "*x*" points. The square boundary near Bret's center denotes the horizontal extent of a NOAA/AOML/HRD triple-Doppler radar wind analysis used for comparison.

These results from Hurricane Bret are very encouraging, and it is hoped that further testing of HVVP will vindicate it as a valuable tool for both research and operational applications. Studies of HVVP-estimated environmental wind shear could shed light on the effect of the environment on hurricane structure and motion. Murillo et al. (2004) discuss one of several potential operational uses for HVVP.

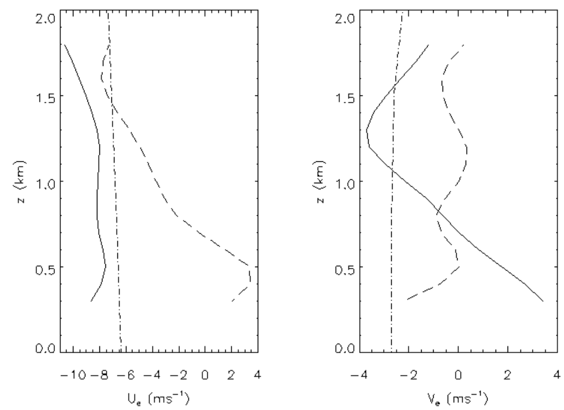

Fig. 2. Vertical profiles of the HVVP environmental wind components above KBRO (solid) and KCRP (dashed) near 23:43 UTC August 22 1999. The dash-dot line shows the NOAA/AOML/HRD triple-Doppler mean wind at this time.

4. ACKNOWLEDEMENTS

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