P1.23 SINGLE-DOPPLER RADAR ESTIMATION OF HURRICANE AND ENVIRONMENTAL WINDS IN THE LOWER TROPOSPHERE

Paul R. Harasti*
National Center for Atmospheric Research, Boulder, Colorado

1. INTRODUCTION

The Hurricane-customized Extension of the VAD (HEVAD - Harasti and List, 2001) method is a single-Doppler radar technique that estimates the earth-relative, horizontal wind field (hereafter referred to as the total wind) of hurricanes in the lower troposphere (LT - up to 3 km altitude). The HEVAD method has recently been improved in two ways. First, the data processing methodology has been refined. Second, the procedure for synthesizing the estimated wind components has been modified. This paper presents a summary of the latter along with new results from a case study of Hurricane Bret (1999).

2. MODIFICATIONS TO THE HEVAD METHOD

The HEVAD method is an extension of the VAD method, customized for hurricanes that are predominantly axisymmetric. The primary circulation is approximated by a modified, Rankine vortex

$$V_t(\zeta, z) = V_t(R, z)\left[R/\zeta\right]^{X_t}, \qquad (1)$$

where V_t is the tangential wind measured at the radial distance ζ from the vorticity center and at the altitude z within the LT. The radar is located at $\zeta = R$. X_t is a constant exponent that is calculated explicitly in the region $\zeta \geq \zeta_m$, where ζ_m is the radius of maximum wind. The radial wind (V_r) is modeled and calculated in a similar way. The Cartesian components of the mean asymmetric wind (U_m, V_m) are also estimated within the vicinity of the radar (the *radar-local* environmental current (EC)) throughout the LT. Vertical profiles of V_t, V_r, U_m, and V_m are constructed for the LT directly above the radar. These profiles are extrapolated and/or combined to yield total wind estimates throughout the entire domain.

Three modifications to the HEVAD method are recommended: (1) $V_t(\zeta_m, z)$ calculated from equation (1) may be extrapolated into the region $\zeta < \zeta_m$ using the typically observed value of $X_t = -1$. (2) V_r should only be extrapolated out to horizontal distances of $\sim R - \zeta_m$ from the radar since V_r typically changes sign from one side of the hurricane to the other. For the same reason, an extrapolated estimate of V_r should not be included in the estimate of the total wind speed across the entire hurricane. Omitting V_r from the estimate of the total wind speed results in a negligible bias, typically of ~1 ms^{-1}. (3) *Background*: The total asymmetric wind is comprised of the EC and an asymmetric perturbation. If the asymmetric perturbation is small relative to the axisymmetric components (V_t and V_r), and if it varies *linearly* throughout the horizontal domain sampled by the radar, then it averages out in the mean (Caya and Zawadski, 1992), yielding unbiased estimates of U_m and V_m. If the deviations are small but vary in a *nonlinear* fashion, then the estimates of U_m and V_m are biased by an unknown, but likely small amount. Holland (1983) points out that the EC can vary greatly across the hurricane's domain. *Conclusion*: An estimate of the total wind speed over the *entire* domain should not include U_m and V_m. Rather, the storm motion should be used instead since it is likely to be a better proxy for the domain-averaged EC. However, U_m and V_m can still be used to provide valuable information about the horizontal and vertical variability of the EC. For example, it is possible to convert the vertical cross sections of U_m and V_m obtained during the entire radar observation period into radius-altitude cross sections through the hurricane by using the storm track.

3. RESULTS AND DISCUSSION

Hurricane Bret was observed simultaneously by two WSR-88D radars (KBRO and KCRP) along the Texas coast as it made landfall on August 22, 1999 near 23:42 UTC. Fig. 2c shows that KCRP was located in a region of convective precipitation whereas KBRO was located in a region of shallow stratiform precipitation (below KCRP's radar beam). The polar coordinates (ζ, β) of KBRO and KCRP relative to the vorticity center were (R, β_r) = (105 km, 184°) and (R, β_r) = (102 km, 351°), respectively.

Fig. 1 shows the vertical profiles of the retrieved HEVAD wind components derived from the KBRO (solid curves) and KCRP (dashed curves) VAD data. There is a very striking similarity in the trends along the profiles shown in Fig. 1a-c despite the ~200 km separation of the radars. The $V_t(R)$ profiles shown on the left side of Fig. 1a agree to within ~2 ms^{-1}, thus verifying the near axismymmetry of Bret, given the similar values of R. The $V_r(R)$ profiles shown in Fig. 1b depict outflow and inflow over KBRO and KCRP, respectively. This radial flow from north to south across the hurricane is in agreement with the radial wind results obtained from Peter Dodge, NOAA/AOML/HRD (see Dodge et al., 2002 for a description of their method - similarly obtained estimates are hereafter referred to as "Dodge").

The profiles in Fig. 1c-d show how greatly the EC can vary over the hurricane's domain. The averages of these curves are consistent with a net west-north-westward motion of the storm whose velocity was

*Corresponding author address: Dr. Paul R. Harasti, NCAR, ATD–Advanced Study Program, Box 3000, Boulder, Colorado, 80307-3000. E-mail: harasti@ucar.edu. NCAR is sponsored by the National Science Foundation.

$(u,v)=(-3.1,1.8)$ ms^{-1}. Such an asymmetric flow pattern of eastward moving air in the north-west quadrant and westward moving air in the south-west quadrant agrees qualitatively with previous observational studies of hurricanes with similar trajectories and wind shear patterns (deduced from Dodge); e.g., Fig. 13a of Marks et al. (1992), adjusted to an earth-relative frame of reference, and the wind vectors inferred from Fig. 13b *plus* Fig. 13c of Willoughby et al. (1984).

The calculated estimates of X_t were in near-perfect agreement for KBRO and KCRP: 0.29 ± 0.02 and 0.28 ± 0.02, respectively. The V_t profiles were extrapolated to all values of ζ using equation (1). The right side of Fig. 1a shows the vertical profiles for $V_t(\zeta_m)$ which agree to within ~2 ms^{-1} of Dodge. These curves reveal at least two altitudes where $V_t(\zeta_m)$ was a local maximum: z_m = 0.78 and 2.04 km over KBRO and z_m = 0.95 and 1.88 km over KCRP. Fig. 2a-b show the estimates of the total wind speed at the lowest z_m values for KBRO and KCRP, respectively. The total wind was computed as the vector sum of V_t, evaluated at all values of ζ, plus the storm translational velocity. Fig. 2a-b agree well with each other, and with the wind speeds near the same altitude shown in Fig. 4 of Dodge et al. (2002). The 100 x 100 km region shown in Fig. 2a-b was chosen to facilitate this comparison; the HEVAD estimates actually extend well beyond this area. Also, the HEVAD estimates of the total wind speed at higher altitudes (not shown) agree very well with the GBVTD and TREC wind speed results for the same altitudes; e.g., Fig. 1 of Harasti et al. (2002). Besides its ability to estimate U_m and V_m, the advantage that the HEVAD method has over these other methods is that the estimate of the total wind speed can be estimated at hurricane radii ζ > R where GBVTD is unable to obtain wind estimates, and where there may be insufficient radar echo for TREC to be applied (e.g., the lack of echo beyond KBRO in Fig. 2c).

REFERENCES

Caya, D., and I. Zawadzki, 1992: VAD analysis of nonlinear wind fields. *J. Atmos. Oceanic. Tech.*, **9**, 575-587.

Dodge et al., 2002: See paper 16A.3 of these preprints.

Harasti et al., 2002: See paper 12A.8 of these preprints.

Harasti, P.R., and R. List, 2001: The hurricane-customized extension of the VAD (HEVAD) method: wind field estimation in the planetary boundary layer of hurricanes. Preprints: 30th Conf on Radar Met., Munich, Germany, Amer. Met. Soc., 463-465.

Holland, G.J., 1983: Tropical cyclone motion: Environmental interaction plus a beta effect. *J. Atmos. Sci.*, **40**, 328-342.

Marks, F.D., Jr., R.A. Houze, Jr., and J.F. Gamache, 1992: Dual-aircraft investigation of the inner core of Hurricane Norbert. Part I: Kinematic structure. *J. Atmos. Sci.*, **49**, 919-942.

Willoughby, H.E., F.D. Marks, Jr., and R.J. Feinberg, 1984: Stationary and moving convective bands in hurricanes. *J. Atmos. Sci.*, **41**, 3189-3211.

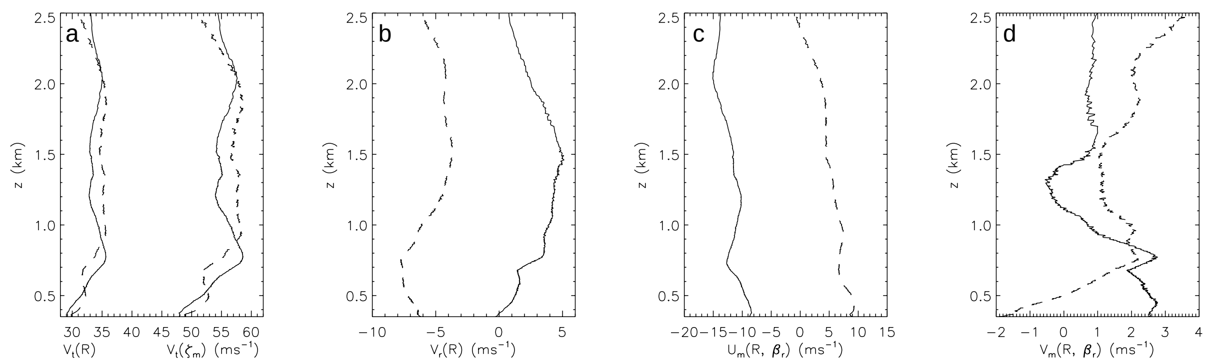

Figure 1. Vertical profiles of the retrieved HEVAD wind components derived from the KBRO (solid curves) and KCRP (dashed curves) VAD data. Shown are (a) left curves $V_t(\zeta=R)$ and right curves $V_t(\zeta=\zeta_m)$, (b) $V_r(\zeta=R)$, (c) $U_m(\zeta=R,\beta=\beta_r)$, and $V_m(\zeta=R,\beta=\beta_r)$.

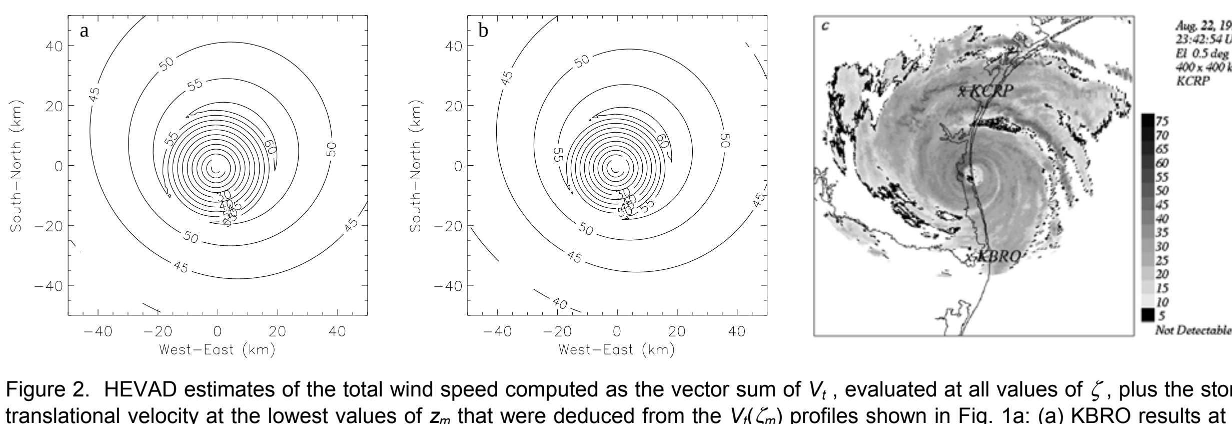

Figure 2. HEVAD estimates of the total wind speed computed as the vector sum of V_t, evaluated at all values of ζ, plus the storm translational velocity at the lowest values of z_m that were deduced from the $V_t(\zeta_m)$ profiles shown in Fig. 1a: (a) KBRO results at z_m =0.78 km and (b) KCRP results at z_m =0.95 km. Contour units are ms^{-1}. Distances indicated are relative to the vorticity center. (c) Reflectivity (dBZ) map of Hurricane Bret derived from the KCRP surveillance scan taken at an elevation angle of 0.5° on August 22, 23:42 UTC. The locations of KCRP and KBRO are shown ("*x*" labels), and note that the area depicted is 400 x 400 km.