P1.24 EXAMINING THE EIGHT-DAY EVOLUTION OF UPPER LEVEL WINDS IN HURRICANE FLOYD

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1. INTRODUCTION

During Hurricane Floyd in 1999, experimental GOES-8 super-rapid-scan operations (SRSO) provided 1-minute frequency imagery for periods of 2.5 to 3.5 hours on eight consecutive days covering its development from tropical storm to near landfall (8 September - 15 September). Using accurately-determined cloud motions captured on these time scales, very detailed wind fields in the upper-level core region of Floyd were created using a modified version of the high-density satellite-derived winds code developed at the Cooperative Institute for Meteorological Satellite Studies (Velden et al. 1998).

Using these wind vector fields along with aircraft reconnaissance data and other remotely sensed datasets, it has been shown that the development of the upper level cyclone in the near core region of Floyd leads intensification (Knaff and Velden 2000). The next step is to determine what factors control the evolution of the upper level tangential winds. Specifically, we examine the tangential wind tendency equation (Eq. 1), where *r* is radius, *t* is time, *u* is the radial wind, *v* is the tangential wind, ω is the vertical wind, the over-bars represent azimuthal means, the primes represent deviations from the azimuthal means, and the subscript *L* means these calculations are done with respect to a moving storm.

(1) $$\frac{\partial v_L}{\partial t} = -\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 \bar{u}_L \bar{v}_L\right) - \frac{\partial}{\partial p}\left(\bar{v}_L \bar{\omega}\right) - f_0 \bar{u} - \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 \overline{u'_L v'_L}\right) - \frac{\partial}{\partial p}\left(\overline{v'_L \omega'}\right) - \overline{f' u'}$$

For convenience, the terms on the right hand side of Eq. (1) are referred to as RMFC (relative mean flux convergence), VMFC (vertical mean flux convergence), PMFC (planetary mean flux convergence), REFC (relative eddy flux convergence), VEFC (vertical eddy flux convergence), and PEFC (planetary mean flux convergence), respectively.

2. DATASETS AND METHODOLOGY

SRSO imagery was available during the 8-day period typically covering 1300 UTC to 1545 UTC, with blocks of 8 consecutive one-minute images occurring every half-hour. Very-high-density wind vectors were created from cloud displacements using a time interval of 3 minutes between images. Local high-resolution analyses (horizontal grid spacing of 0.1° latitude by longitude) were created for each mandatory level. The analyses strongly weight the high-density wind vectors, with the Navy's NOGAPS model analyses used as background fields.

Using the gridded analyses at 150mb, the tangential wind tendency budget is constructed. The vertical wind (ω) is estimated using the divergence (δ), assuming that δ occurs in a layer ΔP. The only missing component needed for a complete budget analysis is a measure of vertical wind shear in this layer. This missing component we hope to estimate using the residuals of this analysis. The VMFC and VEFC terms of the tangential wind budget in our calculation become,

(2) $$-\frac{\partial(\overline{v_L}\,\overline{\omega})}{\partial p} = \overline{v_L}\,\frac{1}{r}\frac{\partial(r\overline{u_L})}{\partial r}$$

(3) $$-\frac{\partial(\overline{v'_L \omega'_L})}{\partial p} = \overline{v'_L\left[\frac{1}{r}\frac{\partial(r u'_L)}{\partial r} + \frac{1}{r}\frac{\partial v'_L}{\partial \lambda}\right]}$$

neglecting the second half of the chain rule (i.e. vertical motion times the vertical tangential wind shear).

Using the above assumptions, the tangential wind tendency equation is estimated for each wind field and these results are then integrated over a 2.5-h period. This calculated tendency is then compared to the observed tendency in the tangential winds. The residuals of this calculation estimate the neglected terms in the vertical tangential wind fluxes involving the vertical wind shear (VWR). Using this method a complete budget is then presented over a six-day period of Floyd's lifecycle, starting on 10 September and ending on 14 September.

3. RESULTS

Figure 1 shows a complete tangential wind tendency analysis valid on 12 September 1999 between 1304 and 1535 UTC. Hurricane Floyd was intensifying steadily at this time. The top panel of this figure shows the azimuthal mean tangential and radial components of the wind, which illustrate the existence of a strong upper level cyclonic outflow at this time. The corresponding relative flux convergence terms (RMFC, REFC) are shown in the second panel. Here we can see that the azimuthal mean vortex is acting to spin down the vortex at a rate of 250 $ms^{-1}d^{-1}$, while the eddy terms have smaller magnitudes and are acting to increase (decrease) V_t inside (outside) 100 km. The next panel shows the vertical flux terms VMFC, VEFC, and VSR. Here again, the mean terms have a relatively large magnitude compared to the eddy terms, but the eddies are increasing V_t at radii greater than 100km. The VSR terms are of the same magnitude and sign as

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the mean fluxes, suggesting that the two are related. It is not surprising that the VSR have such a large magnitude. Realistic vertical motions of 5 hPa s^{-1} (2 ms^{-1}) and vertical shears of 1 ms^{-1} over 25 hPa (2 ms^{-1} over 2km) create fluxes on the order of 150 $ms^{-1}d^{-1}$. The next panel shows the planetary fluxes, which are negative and relatively small. The observed dV_t/dt, which is increasing inside 80 km, is shown in the bottom panel.

The observation of positive V_t tendency near the center should be associated with intensification as it would be related to increased upper-level warming in the center of the cyclone and pressure falls at the surface. Radial average flux calculations within 50 km of the center and 6-hourly (12-18 UTC) central pressure and maximum wind changes from the best track for all six analyzed days are given in Table 1. Horizontal fluxes refer to RMFC + REFC + PMFC + PEFC and vertical fluxes refer to VMFC + VEFC + VSR. The results show that positive tangential wind tendency on Sept. 10th - 12th occurs when the storm was generally intensifying. The budget analysis suggests what processes cause the observed wind accelerations.

Table 1: Hurricane Floyd's 6-hour central pressure (hPa) and max wind (kts) changes along with estimates of the upper-level tangential wind tendency and associated horizontal and vertical fluxes. Units for the fluxes are in units of $ms^{-1}d^{-1}$.

Date	6-h ΔP	6-h ΔI	dVt/dt	H. Fluxes	V. Fluxes
10 Sept	-14	0	6.9	-148.5	155.4
11 Sept	+4	+5	8.6	-94.5	103.1
12 Sept	-15	+10	42.6	-93.1	135.7
13 Sept	+2	-10	-0.4	-262.4	262.0
14 Sept	0	+5	10.6	-140.1	150.7
15 Sept	+4	-5	-21.5	-65.1	43.6

4. SUMMARY

The upper-level tangential wind tendency budget is calculated for a six-day period during Hurricane Floyd from wind fields calculated by the CIMSS high-density satellite wind algorithm using GOES rapid-scan images. Findings suggest that wind fields of this type are useful for creating these budgets. The tangential wind tendency budgets appear consistent with our knowledge of the upper-level flow associated with tropical cyclones. The imbalance between the positive vertical fluxes and negative horizontal fluxes close to the cyclone center are related to intensity change. Furthermore, the budgets examined here determine causal relationships between tropical cyclone structure and intensity change.

Future work will concentrate on two areas: 1) the relationship between observed convective activity and the magnitude of the vertical flux (better estimate the VSR terms), and 2) the comparison of these budgets to other storms sampled in this manner (Luis and Marilyn).

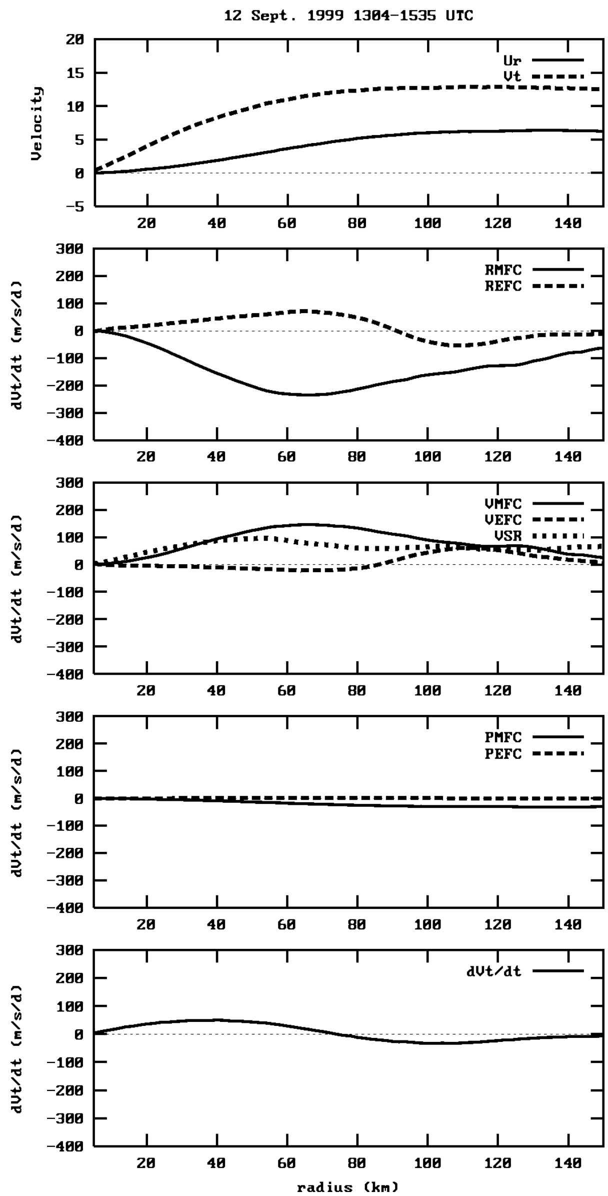

Figure 1: Integrated wind fields and fluxes during Hurricane Floyd (9999) described in the text.

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