# S#.1 TROPICAL CYCLONE-RELATIVE ENVIRONMENTAL HELICITY AND THE PATHWAYS TO INTENSIFICATION IN SHEAR

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## 1. INTRODUCTION

Tropical cyclone-relative environmental helicity (TCREH) is a measure of how the wind vector changes direction with height, and it has been shown to modulate the rate at which tropical cyclones (TCs) develop both in idealized simulations and in reanalysis data. The channels through which this modulation occurs remain less clear. This study aims to identify the mechanisms that lead to the observed variations in intensification rate. The location of convection associated with TCs relative to the TC center is modulated by the ambient vertical wind shear. Numerous studies (e.g., Frank and Ritchie 2001; Wang et al. 2004; Riemer et al. 2010; Reasor and Eastin 2012) have demonstrated the importance of deep layer (850 – 200 hPa) wind shear with regard to altering the development, intensity, and structure of TCs. Onderlinde and Nolan (2014) found that the shape of the vertical wind profile can have significant impact on TC development rates even when the 850 – 200 hPa wind shear vector is held constant. TCREH is defined as the vector product of the TC motion-relative environmental wind and horizontal vorticity vectors:

$$TCREH = \int_0^h \left[(\mathbf{v}-\mathbf{c})\cdot\left(\mathbf{k}\times\frac{\partial \mathbf{v}}{\partial z}\right)\right] dz \qquad (1)$$

where *h* is the depth over which TCREH is computed, **v** is the horizontal component of the wind field, and **c** is the motion vector of the TC.

Previous studies have discussed how the precession of the middle or upper-level circulation around the low-level TC center affects the timing to genesis or rate of intensification (Reasor and Montgomery 2001; Rappin and Nolan 2012; Zhang and Tao 2013). Zhang and Tao (2013), Stevenson et al. (2014), and Chen and Gopalakrishnan (2015) noted that intensification ensued soon after the upper-level center of the vortex precessed beyond 90 degrees to the left of the vertical wind shear vector. We find that the sign of TCREH is related to rate of this precession with positive TCREH favoring a faster precession.

## 2. AZIMUTHAL DISTRIBUTION OF FLUXES AND CONVECTION

Numerous idealized TCs were simulated using a customized version of the Weather Research and Forecast Model (WRF) which used point-downscaling (Nolan 2011) and analysis nudging (Stauffer and Seaman 1990, 1991) to control the TC environment. Figure 1 shows a comparison of environmental wind hodographs for simulations with positive (red) and negative (blue) TCREH.

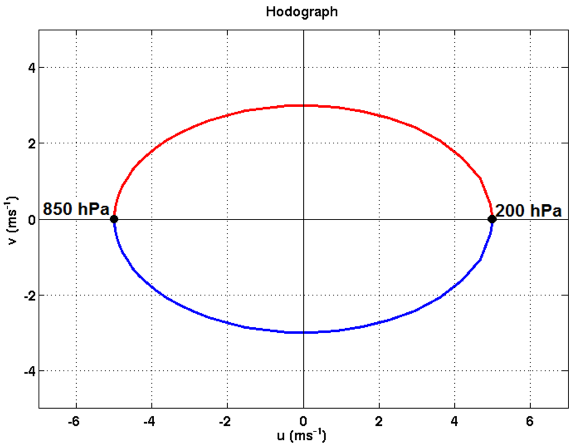

**Fig. 1.** Hodographs for two simulations: one with positive (red) and one with negative (blue) TCREH.

Notice in Fig. 1 that the 850 – 200 hPa wind shear vectors are identical for both simulations (10 ms$^{-1}$ westerly shear). Figure 2 shows a time

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series of the minimum central pressure (hPa) for the simulations with positive and negative TCREH corresponding to the environmental hodographs shown in Fig. 1.

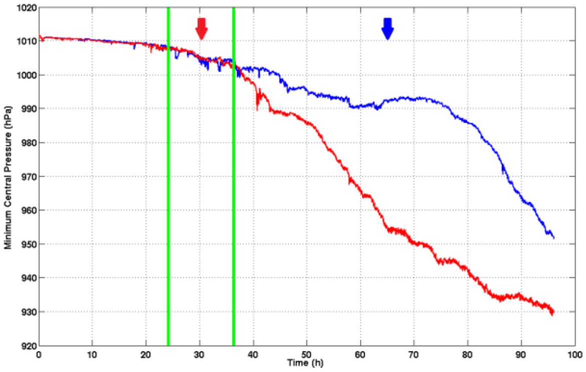

**Fig. 2.** Evolution of minimum central pressure for the 667 m simulations with positive (red) and negative (blue) TCREH. The green lines encompass the time period during which much of the composite analysis of section 3.1 occurred. The red (blue) arrow denotes when the mid-level circulation center first advances into the upshear-left quadrant when TCREH is positive (negative).

These simulations reveal that the location of larger surface latent heat flux advances into upshear quadrants near the radius of maximum winds (RMW) more quickly when TCREH is positive. Figure 3 shows surface latent heat fluxes which are averaged over 4 h subsets of the 12 h period prior to the divergence of minimum central pressure between two simulations: one with positive and one with negative TCREH. The top row (panels a – c) of Fig. 3 shows how fluxes of larger magnitude proceed into the upshear quadrants sooner than they do in the case with negative TCREH (bottom row: panels d – f).

Locations of maximum convection follow a similar pattern as the fluxes with propagation into upshear quadrants occurring more rapidly when TCREH is positive. It is this advancement of convection and surface fluxes that leads to the discrepancy in intensification rate.

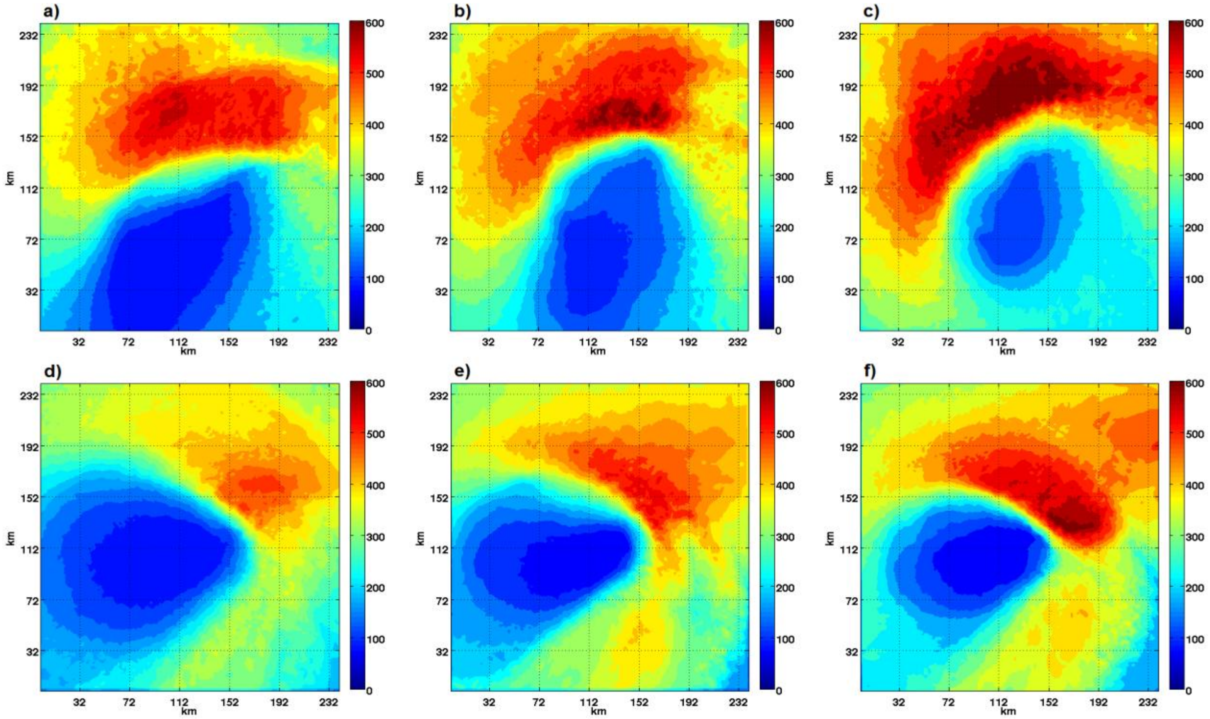

**Fig. 3.** Time-averaged surface latent heat flux ($Wm^{-2}$) for a simulation with positive TCREH equal to 43 $m^2s^{-2}$ (top row: panels a – c) and negative TCREH equal to -43 $m^2s^{-2}$ (bottom row: panels d – f). Column 1 (panels a and d) shows surface latent heat flux averaged from 24 – 28 h, column 2 (panels b and e) shows 28 – 32 h, and column 3 (panels c and f) shows 32 – 36 h. These three 4 h time periods correspond to the 12 h period just prior to the divergence of minimum central pressure between the two simulations.

## 3. TRAJECTORY ANALYSIS

Results from forward trajectories show that near-surface parcels experiencing large latent heat flux are advected around the TC center and lofted into new convection more frequently when TCREH is positive. Figure 4 shows 6 h forward trajectories for the 667 m positive-TCREH simulation from time t = 30 – 36 h. Trajectories do not follow cyclonically curving paths en route to the TC core in this time period (t = 30 – 36 h) when TCREH is negative.

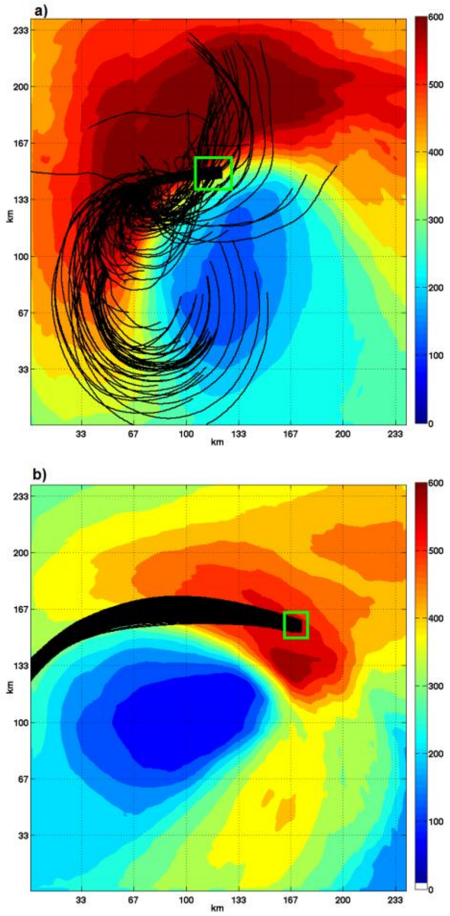

**Fig. 4.** 6 h forward trajectories for parcels originating on the lowest model level in a region of large latent heat flux overlaid on 6 h time-averaged surface latent heat flux ($Wm^{-2}$) from t = 30 – 36 h for simulations with positive (a) and negative (b) TCREH. These trajectories are from the 667 m grid spacing idealized simulation. The green boxes denote the beginning of the forward trajectories.

## 4. SUMMARY

TC intensification rate is modulated by the shape of the environmental wind profile, i.e., TCREH. Time composites of surface latent heat flux and simulated reflectivity show how the maxima of these features rotate cyclonically into upshear quadrants more rapidly when TCREH is positive. Trajectories show that the process of advecting buoyant, $\theta_e$-enhanced air into the TC is more efficient and a much higher percentage of parcels are lofted into convection in the upshear quadrants near the RMW when TCREH is positive.

## 5. REFERENCES

Chen, H., S. G. Gopalakrishnan, 2015: A Study on the Asymmetric Rapid Intensification of Hurricane Earl (2010) Using the HWRF System. *Journal of the Atmospheric Sciences* **72**:2, 531-550.

Frank, W. M., and E. A. Ritchie, 2001: Effects of vertical wind shear on the intensity and structure of numerically simulated hurricanes. *Mon. Wea. Rev.*, **129**, 2249–2269.

Nolan, D. S., 2011: Evaluating environmental favorableness for tropical cyclone development with the method of point downscaling. *J. Adv. Model. Earth Syst.* , 3, Art. M08001, 28 pp.

Onderlinde, M. J., and D. S. Nolan, 2014: Environmental Helicity and Its Effects on Development and Intensification of Tropical Cyclones. *J. Atmos. Sci.*, **71**, 4308–4320.

Rappin, E. D., and D. S. Nolan, 2012: The effects of vertical shear orientation on tropical cyclogenesis. *Q. J. R. Meteorol. Soc.* , ***138*** , 1035-1054.

Reasor, P. D., and M. D. Eastin, 2012: Rapidly Intensifying Hurricane Guillermo (1997). Part II: Resilience in Shear. *Mon. Wea. Rev.*, **140**, 425–444.

Reasor, P. D., M. T. Montgomery, 2001: Three-Dimensional Alignment and Corotation of Weak, TC-like Vortices via Linear Vortex Rossby Waves. *J. Atmos. Sci.*, **58**, 2306–2330.

Riemer, M., M. T. Montgomery, and M. E. Nicholls, 2010: A new paradigm for intensity modification of tropical cyclones: Thermodynamic impact of vertical wind shear on the inflow layer. *Atmos. Chem. Phys.*, **10**, 3163–3188.

Stauffer, D. R., and N. L. Seaman, 1990: Use of Four-Dimensional Data Assimilation in a Limited-Area Mesoscale Model. Part I: Experiments with Synoptic-Scale Data. Mon. Wea. Rev., **118**, 1250–1277.

Stauffer, D. R., N. L. Seaman, and F. S. Binkowski, 1991: Use of Four-Dimensional Data Assimilation in a Limited-Area Mesoscale Model Part II: Effects of Data Assimilation within the Planetary Boundary Layer. *Mon. Wea. Rev.*, **119**, 734–754.

Stevenson, S. N., K. L. Corbosiero, and J. Molinari, 2014: The Convective Evolution and Rapid Intensification of Hurricane Earl (2010). *Mon. Wea. Rev.*, **142**, 4364–4380.

Wang, Y., M. Montgomery, and B. Wang, 2004: How much vertical shear can a well-developed tropical cyclone resist? Preprints, *26th Conf. on Hurricanes and Tropical Meteorology,* Miami, FL, Amer. Meteor. Soc., 100–101.

Zhang, F., and D. Tao, 2013: Effects of Vertical Wind Shear on the Predictability of Tropical Cyclones. *J. Atmos. Sci.*, **70**, 975–983.