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TROPICAL CYCLONE INTENSITY CHANGE UNDER THE INFLUENCE OF UPPER-TROPOSPHERIC TROUGHS IN IDEALIZED SIMULATIONS

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1. INTRODUCTION

Tropical cyclone (TC)–trough interaction remains a significant challenge in TC intensity forecasting. Climatologies of Atlantic TC–trough interactions have found that these events are generally unfavorable for TC intensification, yet some TCs still intensify following an interaction (DeMaria et al. 1993; Hanley et al. 2001; Peirano et al. 2016). Four physical processes are hypothesized to affect TC intensity during trough interactions, three favorable and one unfavorable. The three favorable processes are: (1) an increase in angular momentum eddy flux convergence (EFC) in the TC outflow layer, (2) an increase in upper-level divergence through the development of an upper-level jet, and (3) superposition between the trough and TC potential vorticity (PV) (Molinari and Vollaro 1989). The unfavorable process is enhanced vertical wind shear from the trough that tilts and ventilates the TC (Tang and Emanuel 2010).

Using 35 years of ERA-Interim reanalysis, Peirano et al. (2016) showed that EFC is a poor predictor of TC intensification during a trough interaction event, especially compared to vertical wind shear. Composites of weakening and strengthening trough interaction events indicate that weak, vertically shallow, and horizontally narrow troughs are most favorable for TC intensification (Fig. 1). In addition, satellite observations of infrared brightness temperature indicate that intensifying TC–trough interaction events have convection that deepens and wraps upshear of the TC center. This evolution is associated with reduced vertical wind shear and ventilation, which allows the convection to strengthen symmetrically about the center, which is favorable for intensification (Nolan and Gasso 2003). Additionally, the enhanced convection reduces the PV in the TC outflow layer, and the divergent outflow advects this low PV toward the trough, slowing the trough's progression and potentially causing it to break.

Motivated by these observational results, idealized TC–trough interaction events were simulated using the Weather Research and Forecasting – Advanced Research (WRF-ARW) model. Sensitivity tests of the strength and size of the trough's PV anomaly, as well as the strength of the initial TC vortex, were performed, and the aforementioned physical processes occurring during trough interaction events were investigated. In this extended abstract, I will focus only on the strength of the initial TC vortex, but further sensitivity tests will be included in the oral presentation.

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2. DATA AND METHODOLOGY

Using WRF-ARW, a trough within a westerly jet in thermal wind balance on an f-plane was initialized upwind of an idealized TC (Fig 2). The westerly jet was initialized by interpolating along an arctangent curve between a subtropical Atlantic mean October sounding at the northern boundary and the Dunion moist tropical sounding at the southern boundary (Dunion and Marron 2007).

The trough was initialized by adding an elliptical temperature perturbation to the interpolated temperature field. The vertical profile for the trough temperature perturbation was taken from a zonal mean temperature anomaly of a representative trough in the ERA-Interim reanalysis. A cross section of this temperature anomaly is given in Fig. 3.

The idealized TC was inserted via the WRF-ARW Rankine vortex bogussing scheme (Nguyen and Chen 2011). To test the sensitivity of the evolution of the TC–trough interaction to the initial TC intensity, the initial intensity of the vortex was varied between 10 and 30 m s^{-1}.

3. RESULTS

A control model run was performed with a 20 m s^{-1} initial vortex embedded in a westerly jet and downstream of a trough. In this simulation, the TC intensified throughout the 3-day simulation (Fig. 4a) despite the presence of moderate to high vertical wind shear, which was calculated between 850–200-hPa in the 200–800-km annulus (Fig. 4b). Additionally, matching observations, EFC does not seem strongly correlated to 24-h intensity change, evidenced by the fact that EFC switches from positive to negative values during the simulation (Fig. 4c), yet the TC intensifies throughout.

The evolution of the upper-tropospheric PV field suggests that the TC's strong anticyclonic (low PV) outflow prevents the approach of the trough over the TC core. Beginning very soon after model initialization, there is a large, rapid expansion of low PV air that surrounds the TC (Fig. 5, top panel). As the trough approaches, the high PV of the trough is impeded from approaching the core of the TC by the low PV outflow. Furthermore, the strong PV gradient between the low PV outflow and high PV trough is collocated with a strong jet, and the TC is located in the favorable right entrance region (Fig. 5, bottom panel). The causality and favorability of these effects requires further investigation, such as diagnosing the PV advection by the irrotational wind in the formation of the strong jet (Archambault et al. 2013), as well as the strength of the divergence over the TC due to the upper-level jet.

Sensitivity tests suggest that the likelihood the TC will intensify during a trough interaction is dependent upon the initial TC intensity (Fig. 6). The 10 m s^{-1} initial vortex failed to intensify beyond 1000 hPa, but all other initial vortex strengths deepened more than 50 hPa. The PV evolution of the initial vortices greater than 10 m s^{-1} is quite similar as described above. The 10 m s^{-1} initial vortex did not develop in a similar way, despite similar values of initial vertical wind shear to the control run (not shown). Instead, the TC was never able to expand a large area of low PV outflow, only a weak jet developed near the TC, and the trough was able to reach the TC's inner core (Fig. 7). As the trough reached the inner core of the TC (at ~48h), shear values began to exceed those of the control run by ~1–2 m s^{-1}. These results suggest that strong advection of low PV outflow is important for the survival of the vortex, and subsequent strengthening, as the trough approaches. More objective methods of measuring these effects will be performed for the oral presentation.

4. ACKNOWLEDGEMENTS

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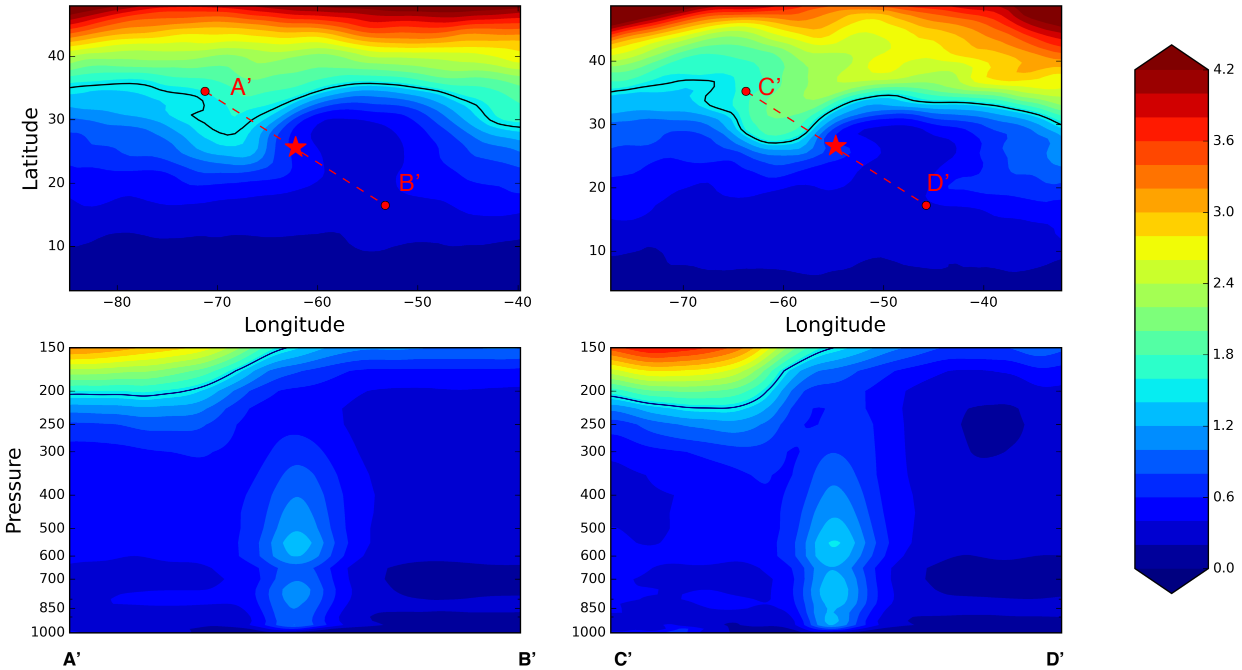

Figure 1. TC-centered trough interaction composites at the initial time of trough interaction. Top panels are 200-hPa PV (PVU). Bottom panels are vertical cross sections of PV along the red dashed line from A' to B' or C' to D' in the panel above. Strengthening (weakening) composites are shown in the left (right) panels. Star indicates composite TC location. 1.5-PVU surface given by the thin, black line.

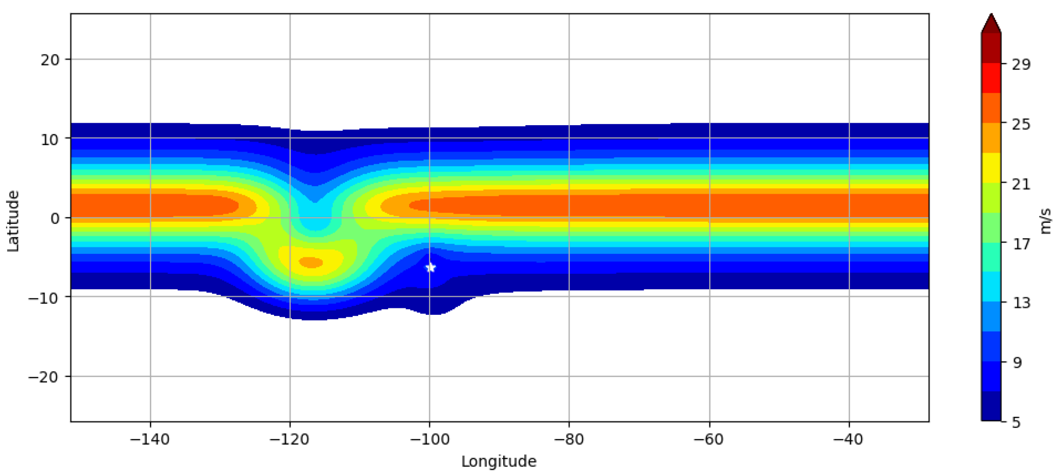

Figure 2. Initial 200-hPa wind speed (m s^{-1}). TC location indicated by white star. Note: because the domain is on an f-plane, latitude north and south of the "equator" represents only physical distance in the model simulations.

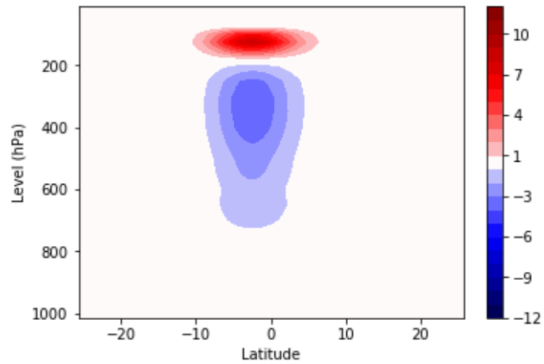

Figure 3. Latitudinal cross section of the temperature anomaly (K) through the center of the model trough.

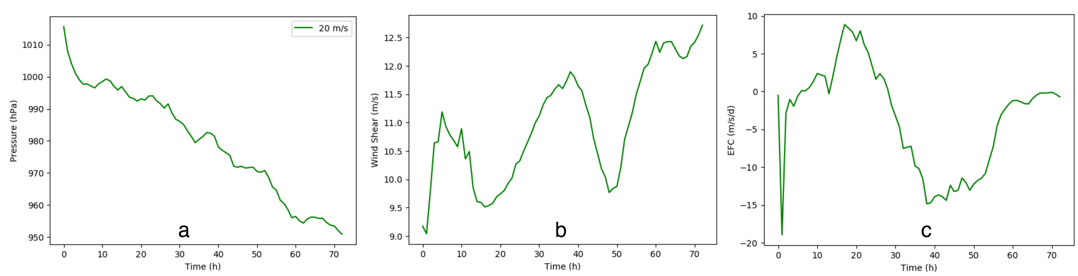

Figure 4. Minimum sea level pressure (a), vertical wind shear over the TC (b), and EFC in the 300–600-km annulus surrounding the TC throughout the 3-day control (20 m s^{-1} initial vortex) model simulation.

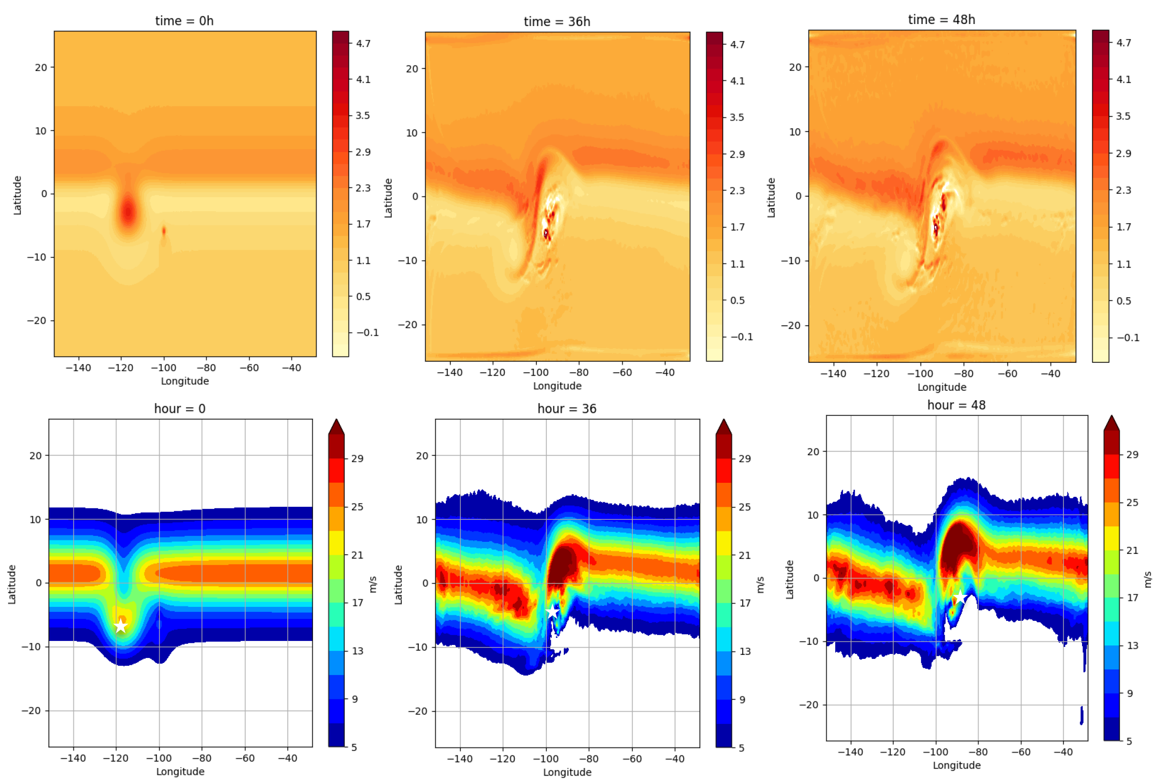

Figure 5. 200-hPa PV (top panel) and 200-hPa wind speed (bottom panel) at 0h, 36h, and 48h forecast times for the control run (20 m s^{-1}) initial vortex. Initial TC location indicated by white star on bottom panel.

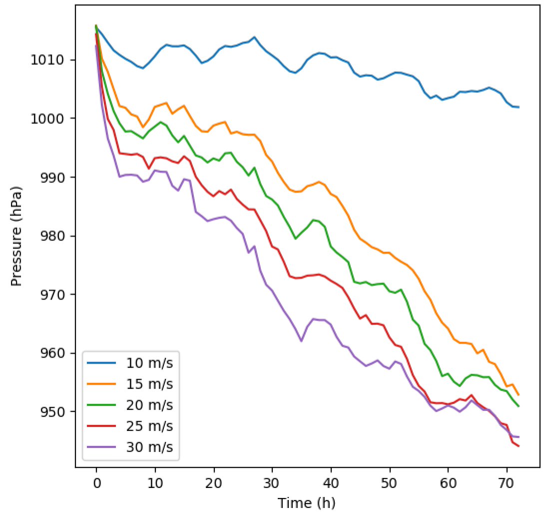

Figure 6. Minimum sea level pressure (hPa) at each forecast hour for each initial vortex strength.

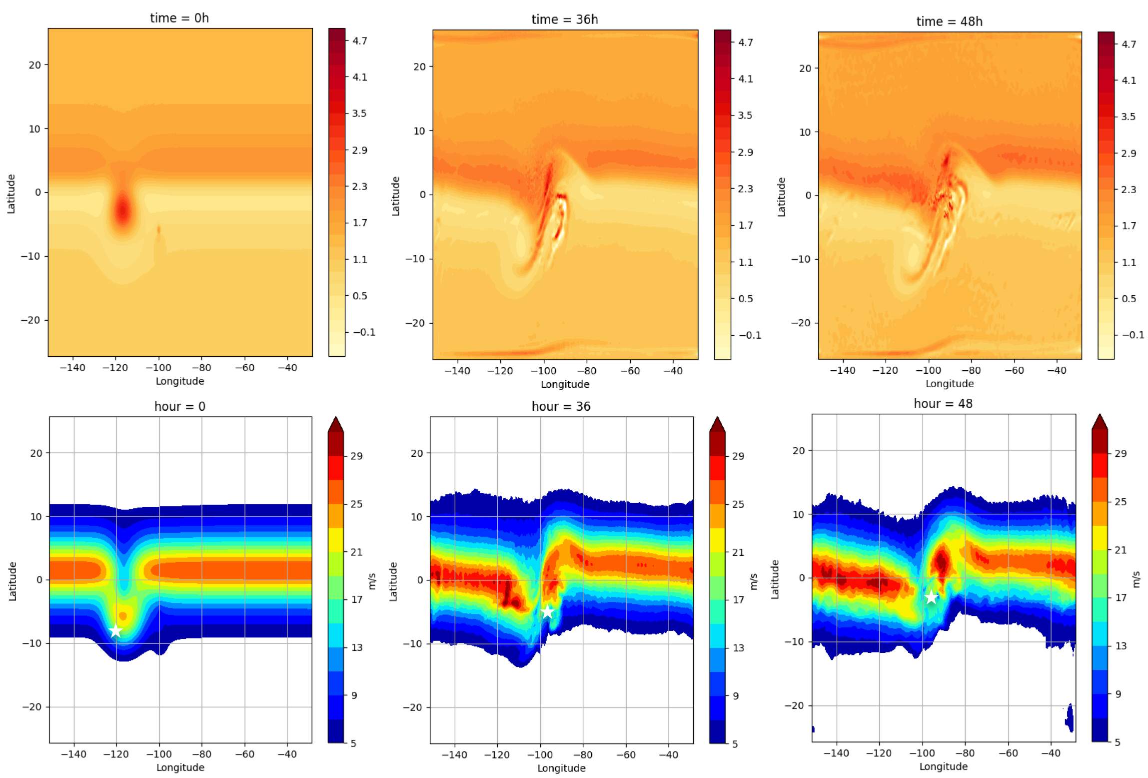

Figure 7. 200-hPa PV (top panel) and 200-hPa wind speed (bottom panel) at 0h, 36h, and 48h forecast times for the weak (10 m s^{-1}) initial vortex. Initial TC location indicated by white star on bottom panel.