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# The Tropical Cyclone - Jet Interaction

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## 1. Introduction

A common feature of tropical cyclones is the existence of asymmetric outflow jet(s) in a thin layer typically found between 100 and 300 hPa. The organization of tropical cyclone outflow into asymmetric jets suggest certain regions of the environment may be more conducive to outflow than others. As an example, consider the role of inertial stability in providing resistance to outflow. The amount of work that must be done by the outflow to expand against the environment is proportional to the absolute vorticity so that anticyclonic regions provide less resistance to outflow than cyclonic regions.

The role of upper tropospheric inertial stabilty in outflow asymmetries is evident when viewing the outflow layer satellite derived winds. Three common outflow patterns are:

(1) to the north toward the anticyclonic shear side of the westerlies.

(2) to the south where there is a smaller Coriolis parameter.

(3) any direction in which there is outflow associated with mesoscale convective organization (e.g. ITCZ).

In the continous atmosphere, tropical cyclones can utilize preferential outflow regions several thousand kilometers distant. In a discrete model, such large seperation distances allow the vortex and environment to evolve independent of the other unless brought together by a steering flow.

Emanuel (1986) formulated a maximum potential intensity (MPI) theory for tropical cyclones based on the Carnot heat engine cycle where the net work done in a cycle is balanced by the net heat put into the system. Heat is added to the system through the wind induced surface heat exchange (WISHE) while heat is removed through radiative cooling in the outflow. Work is performed both in the inflow in overcoming surface friction and in the outflow in expanding the outflow anticyclone against the environment. In Emanuel's steady-state theory, it is assumed that angular momentum surfaces flare out to infinity (anticyclone expands out to infinity) as it is assumed the storm is mature and the outflow anticyclone is fully developed. It is pruposed here that the greater the work required to spin up the outflow anticyclone, the slower the intensification rate or the weaker the resultant intensity.

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## 2. Theory

Considerable uncertainty remains as to whether an environmental (trough) interaction is beneficial or detrimental to intensity. Bosart et al. (2000) suggested that any interaction that occurs when a tropical cyclone is near it's MPI is detrimental as there is little room for further intensification. It is also possible that any interaction, during a time when a tropical cyclone is exceedingly far from it's MPI, is detrimental to intensity. If the vortex has not intensified to the extent that the inertial response dominates the gravitational response, any environmental secondary circulation will promote upright convection in a small sector of the vortex, as there is no mesoscale organization under the control of the balanced primary circulation. In other words, there is no adjustment of the wind field to the convectively generated mass anomaly and the vortex fails to spin up. Figure 1b) shows the time evolution of the peak updraft speed for a tropical cyclone simulation. Initially there are strong updrafts in excess of 30 m/s associated with the upright convection generated by the frictionally induced inflow. As the storm evolves and the inertial response grows in strength these strong updrafts weaken and reach a steady-state or slowly strengthening phase which corresponds with the slowly intensifying stage of the tropical cyclone. Most of the intensification, as measured by minimum sea level pressure, occurs as the storm is growing the inertial response so there is a a rather narrow window in which the environmental interaction can benefit storm intensity. This was verified by running similar experiments as described below except with a weaker vortex (not shown).

In terms of MPI, there are several ways to increase the intensity of the tropical cyclone. The most common way is to increase the heat input into the eyewall via the air-sea interaction. A second way to increase intensity is to decrease the amount of work expended in building the outflow anticyclone. If the environment is anticyclonic, minimizing the energy needed to overcome the Coriolis torque, more energy should be available to overcome frictional dissipation. In Emanuel's axisymmetric theory and modeling (1987) he found there to be minimal to no impact in changing the environment's inertial stability. It should be noted that Emanuel used a 10 m/s initial vortex with a no CAPE sounding. The evolution of the tropical cyclone was so slow (10 days in a two-dimensional model to reach near peak intensity) that the outflow anticyclone was able to fully develop on it's own with no impact on intensification rates or MPI. The goal of

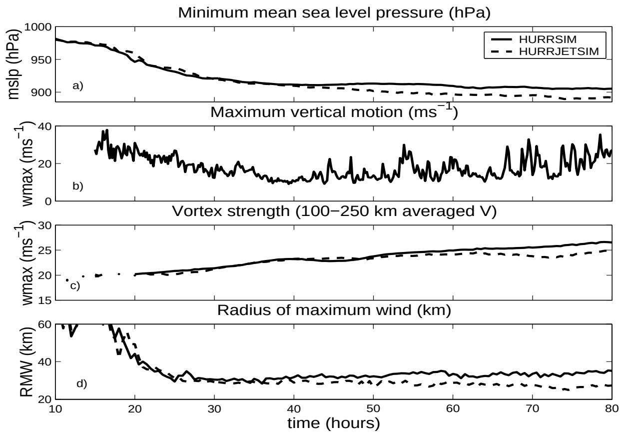


FIG. 1. a) Mean sea level pressure evolution (hPa) of HURRSIM and HURRJETSIM (dashed), b)Maximum updraft strength for HURRSIM m/s, c)100-250 km mean tangential wind m/s, d)radius of maximum wind (km)

this study is to determine the impact of an asymmetric outflow environment, with low inertial stability and small vertical shear near the vortex, on intensity. To accomplish this goal, a uniform jet is placed north of the vortex as described below.

## 3. Modeling Study

### *a. Model setup*

The University of Wisconsin-Nonhydrostatic Modeling System (UW-NMS; Tripoli 1992) is used with 3 nested grids of resolution 48 (Grid 1), 12 (Grid 2), and 3 (Grid 3) km. The initial vortex used was formulated by Emanuel (1987) for axisymmetric simulations with a maximum wind of 25 m/s at a radius of 100 km. The jet was formulated with exponential functions with a maximum wind of 45 m/s and an efolding distance of 325 km. There are no along jet variations in speed so that initially there are no entrance or exit regions. Two simulations were run, the first is the control run (HURRSIM) in which there is no jet. The second simulation (HURRJETSIM) contains both the vortex and the jet. To determine the impact of low inertial stability in the outflow environment without the detrimental impact of vertical

### *b. Simulations*

Results of the simulations show that the tropical cyclone embedded within the low inertial stability of the anticyclonic shear side of the jet (HURRJETSIM) was 20 hPa deeper 80 hours into the simulation (Fig 1a). This result is consistent with the theory presented above. Not suprisingly, HURRJETSIM has a more compact eyewall with an azimuthally averaged radius of maximum wind 7 km closer to the storm center then HURRSIM (Fig 1d).

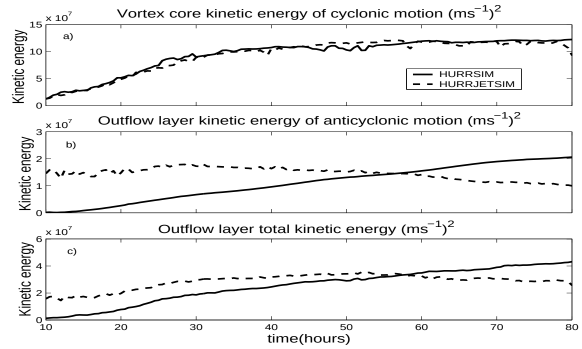


FIG. 2. Kinetic energies (per unit mass). a) total cyclonic kinetic energy of the vortex core, b) total anticyclonic kinetic energy of the outflow layer, c) total kinetic energy of the outflow layer

Figure 2a shows the sum of the kinetic energies of all points with cyclonic motion within 150 km of the storm center between 100 m and 10 km in height. Both simulations show a nearly identical monotonic increase in kinetic energy. This is to be expected as HURRJETSIM is a much more compact tropical cyclone as seen in the azimuthally averaged 100-250 km mean 500 m tangential winds (Fig 1c). Figure 2b shows the sum of the kinetic energies of all points within the 12-15 km layer (outflow layer). While both simulations exhibit a slow increase during the first 30 hours of the simulations, HURRJETSIM plateau's while HURRSIM monotonically increases throughout the entire simulation. After the rapid deepening stage, HURRSIM is unable to continue the slow intensification exhibited in HURRJETSIM because energy is always being expended by the tropical cyclone to expand the outflow anticyclone.

There is a strong asymmetry in the outflow (not shown) with the bias being toward the region of lower inertial stability. HURRJETSIM has the appearance of convective-symmetric instability with midtroposheric inflow to assist in the acceleration of the primary circulation. There is also a weak outflow asymmetry in HURRSIM most likely associated with the tropical cyclone being closer to the southern boundary.

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