# The Tropical Cyclone - Jet Interaction

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## 1. Introduction

It is generally accepted that the maximum potential intensity (MPI) a hurricane can attain is controlled by sea surface temperatures (SST's) and the thermodynamics of both the storm core and that of the environment (Emanuel 1986; Holland 1997). In nature, few storms actually attain their MPI and therefore fail to utilize all the thermodynamic energy available to them. Two major mechanisms that are responsible for this deficiency are the modification of the air-sea interaction by sea surface stresses and the interaction of the tropical cyclone with environmental flow fields.

Upwelling beneath and mixing across the thermocline in response to strong wind stresses promoted by the primary hurricane circulation result in declining SST's and therefore weaker cyclone intensity. Emanuel (1999) showed that a large percentage of storms can be accurately modeled with the use of an idealized coupled ocean-atmosphere model.

Tropical cyclones can also undergo dynamical interactions with it's environment. Such interactions are likely to occur in the thin outflow layer (typically between 11 and 14 km) where the inertial stability associated with the primary circulation is weak. Bosart et al. (2000) and Kimball et al. (2002) looked at the hurricane-trough interaction using real and idealized data, respectively. Each found that deformation (forced by the hurricane outflow) reduced the upper trough's horizontal scale and resulted in a decrease of the magnitude of the vertical shear over the hurricane. The reduction in vertical shear allowed the hurricane to approach it's MPI.

While it is not possible for a tropical cyclone to exceed it's MPI, the rate at which it intensifies to (or weakens from) it's MPI is highly variable and is dependent upon the environment in which the tropical cyclone is embedded. An idealized simulation of the hurricane-jet interaction provides an environment wherein intensification rates can be examined without the negative impact of vertical shear. With the vortex placed on the anticyclonic shear side of the jet, in a region of weak inertial stability, it is possible to see what role convective forcing plays on tropical cyclone intensification.

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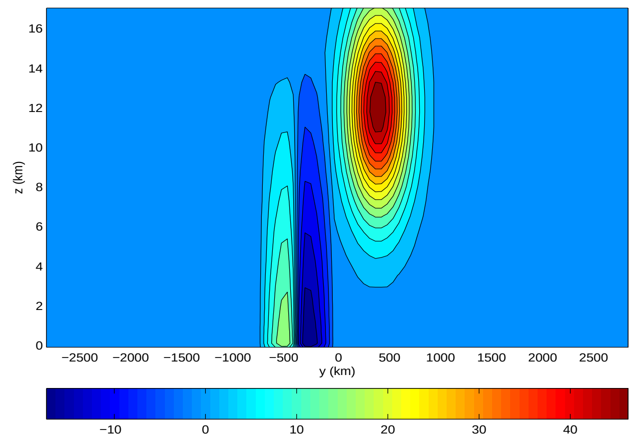


FIG. 1. Initial zonal wind (m/s) as viewed from the east.

## 2. Modeling Study

### *a. Model setup*

The University of Wisconsin-Nonhydrostatic Modeling System (UW-NMS; Tripoli 1992) is used with 3 nested grids of resolution 64 (Grid 1), 16 (Grid 2), and 4 (Grid 3) km. The initial vortex used was formulated by Emanuel (1987) for axisymmetric simulations with a maximum wind of 20 $ms^{-1}$ at a radius of 100 $km$. The jet was formulated with exponential functions with a maximum wind of 45 $ms^{-1}$ and an efolding distance of 325 $km$ (Figure 1). There are no along jet variations in speed so that initially there are no entrance or exit regions The model was initialized with a sounding that possesses zero CAPE to eliminate the occurence of any strong convection on the north side of the jet (from thermal wind considerations). The initial moisture profile was adjusted to produce 500 $Jkg^{-1}$ of CAPE, gaussian in shape, centered on the tropical storm to facilitate the growth of the vortex. 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.

### *b. Simulations*

The intensity evolution as measured by minimum mean sea level pressure (Fig. 2) indicates that while HURRSIM eventually spins up to tropical cyclone strength, HURRJETSIM slowly strengthens but fails to spin up. To assist in the

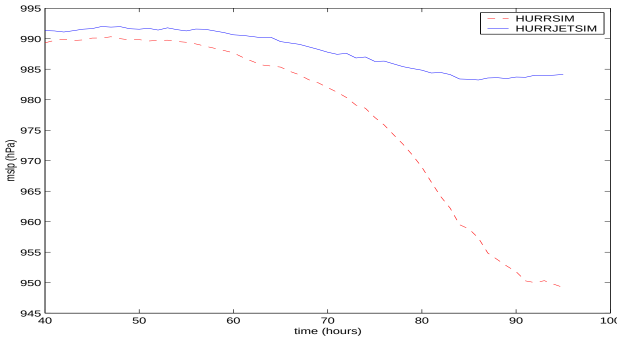


FIG. 2. Time evolution of minimum sea level pressure.

understanding of this failure, comparison of the eyewall vertical motion is shown in Hovmoeller diagrams, where the eyewall radius is defined as the azimuthally averaged radius of maximum vertical motion. In HURRSIM, convective asymmetries form and are advected (as they are embedded in a strong tangential flow) cyclonically around the eyewall (Fig 3a). The eyewall contracts (not shown) and the primiary circulation intensifies. In HURRJETSIM, convection is forced in the northeast quadrant of the storm (Fig. 3b) at a radius of 100 km from the storm center. The convection is forced continually at this radius preventing any eyewall contraction and spinup of the primary circulation which in turn prevents any significant advection of the convective anomalies and inhibits the development a well defined eyewall.

As the convection devolps in HURRJETSIM, the outflow is vented to the north- northeast where there is deformation of the initially uniform jet (Fig 4a). The outflow acts to split the jet so that a jet entrance region develops to the north of the evolving vortex. The tropical cylone then becomes the upward branch of this secondary circulation (Fig 4b) leading to the continued convective forcing in the northeast quadrant of the tropical cyclone.

## 3. Discussion and Future Work

To make the simulations more realistic it would be necessary to include a mean flow, such as a weak non-divergent deformation flow such that the cyclone is carried northward while leaving the jet relatively unchanged. This way, the interaction can be made to occur at various times in the evolution of the tropical cyclone. The present setup is not ideal as the convective forcing begins at the initial time before the divergent boundary layer flow has developed. In addition to the mean flow, there are several additional factors that need to be considered as directly influencing the tropical cyclone-jet interaction.

- Domain Size - The use of periodic boundary conditions in the zonal direction has a large impact on both the domain size and how much time is needed for the

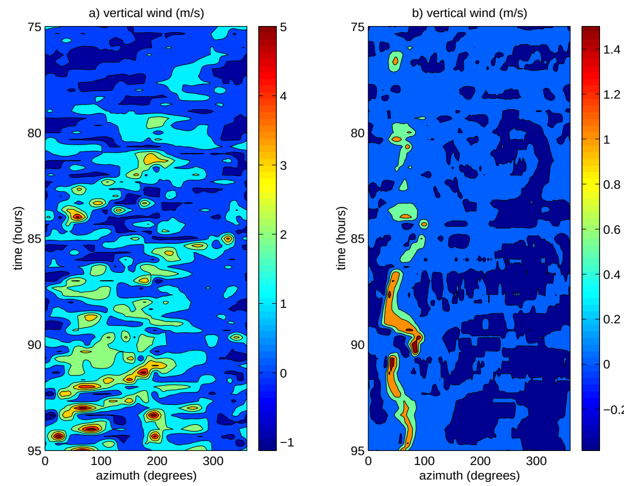


FIG. 3. Hovmoller diagrams of vertical motion (m/s) at an altitude of 1.5 km; 0 degrees corresponds to north and you traverse clockwise around the eyewall as you move from left to right in the diagram a) HURRSIM b) HURRJETSIM

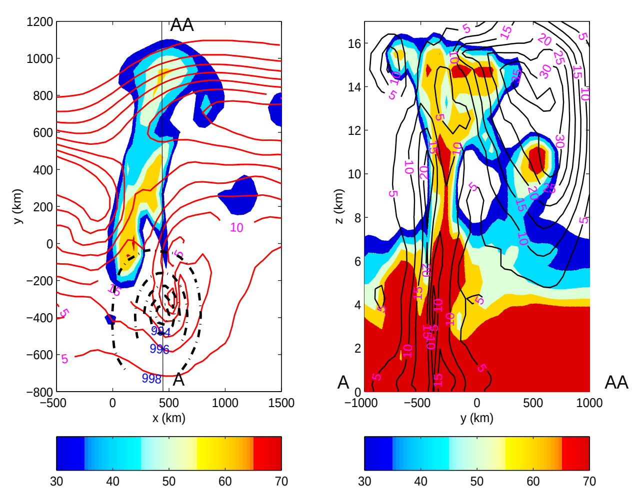


FIG. 4. Cross sections of HURRJETSIM on grid 1 at 78 hours. Isotachs are contoured while relative humidity is colorfilled. a) x-y section at 12 km altitude; MSLP is contoured in black b) y-z cross section pictured in a)

cyclone to spin up. It is unrealistic to have features that are genereated by the tropical cyclone-jet interaction propogate across the boundary and impact the future evolution of the interaction.

- CAPE - Large vertical velocities associated with a large resevoir of CAPE will result in enhanced diabatic heating and hydrostatically lower pressures. These lower pressures will drive stronger inflow and lead to a more rapid intensification of the storm. The focus of this work is on how the interaction with a jet modifies the intensification rate so it would be counter-productive to have the intensification too closely tied to the amount of conditional instability. At the same time, some CAPE is necessary so that the storm can spin up in a reasonable period of time.

- Convective Parameterization - Presently, there is no cumulus parameterization on grid2. At 16 km resolution the simulated motions are becoming hydrostatic $(k_z >> k_x)$ so that explicitly resolved convection will be more intense and slower to evolve then if these same motions were modeled on a higher resolution grid (Weisman 1997). These artificial changes in intensity and temporal evolution have to be weighed against artificially specifying the convective mass fluxes by means of a parameterization.

- Initial Vortex Strength - The initial strength of the vortex also plays a role in how quickly the tropical cyclone begins it's rapid intensification. As the vortex is initially nondivergent it takes time to develop the convergent boundary layer flow that supports the mature tropical cyclone. The stronger the initial vortex, the stronger the frictional drag and hence a more rapidly evolved inflow.

## 4. Acknowledgments

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