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COMPARISON OF HURRICANE INTENSITY AS REALIZED IN AN AXISYMMETRIC MODEL WITH MPI THEORY

John Persing*, and Michael T. Montgomery
Colorado State University, Fort Collins, CO

1. INTRODUCTION

The maximum potential intensity (MPI) theory of Emanuel (1995b) (E-MPI) is compared to the modeled storm intensity in a cloud-resolving, axisymmetric model (Rotunno and Emanuel 1987; RE87). E-MPI has been compared with the observed distribution of intensities of hurricanes (Emanuel 2000) and found to be a fairly well observed maximum, yet questions remain on whether it should be regarded as a rigorous maximum. Simulations at high resolution using the RE87 model find storm intensities that greatly exceed E-MPI. Whatever reservations on applying E-MPI to reality, it should be uniquely suited to model the maximum intensity of a numerical model that shares its assumptions of axisymmetric geometry and bulk aerodynamic formulation of exchange with an ocean with constant temperature.

2. E-MPI THEORY

E-MPI states that the maximum attainable intensity of a hurricane is a function of sea surface temperature (SST, or T_s), outflow temperature (T_o), and surface relative humidity (RH). The role of RH in E-MPI is to limit the radial structure of the storm and to model the rate of exchange of entropy with the ocean, but RH does not exist as a variable in the RE87 model. An alternative is tested using Eq. 13 of E95b, here in dimensional form

$$V^2 = \frac{C_k}{C_D}\left(T_s - T_o\right)\left(s_s^\star - s_b\right) \qquad (1)$$

where V is the wind speed, C_k and C_D are the exchange coefficients of enthalpy and drag, and $s_s^\star$ is the saturated entropy at the sea surface and s_b is the entropy at the top of the sub-cloud layer. This equation is local to the base of the eyewall and cannot be determined from environmental conditions (thus it cannot serve as an MPI) but it is well suited to test the basic assumptions of E-MPI.

3. RE87 MODEL

The RE87 model is cloud-resolving, nonhydrostatic, axisymmetric grid mesh model with a staggered C-grid of fixed spacing. Our default run is very similar to runs of RE87, having an SST of 26.3 C. Our experiments are to successively double resolution, which are referred to as the 2x run, 4x run, etc. Doubling of resolution occurs both radially and vertically and the time step is halved with each increase. The default resolution is $\Delta r = 15$ km and $\Delta z = 1250$ m with a 20 s time step.

4. SUPERINTENSITY

We introduce the term *s*uperintensity to describe the state where modeled storm intensity greatly exceeds that estimated from (1). Figure 1 shows superintensity in the later stages of the default run and in the 4x run. This confirms the result of Hausman (2001) for the RE87 model of increasing intensities with increasing resolution. Use of (1) would provide a 62 m s^{-1} estimate for the 4x case. Convergence appears to occur by the 4x run in terms of storm intensity and central pressure, but peak updraft speed is stronger in the 8x run than in the 4x run. Superintensity cannot be simply explained by changes in the radius of maximum winds (RMW) since the RMW has converged to about 22 km in the 2x run.

The two different periods of apparent quasi-steady state behavior from the default case, first at near MPI, then at a more intense state, presents an opportunity to study cause of superintensity. What is noticed is the development of a low-level enhancement of θ_e at the transition from one state to the other (day 15). In the 4x run, the θ_e maximum occurs during initial spin-up associated with a narrow channel of descent interior to the eyewall. Since the eyewall is resolved with only one or two radial grid points, descent must occur throughout the eye in the default run. If this

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*Corresponding author address: John Persing, Department of Atmospheric Science, Colorado State University, Fort Collins, CO 80523-1371; email: john@eady.atmos.colostate.edu

high θ_e air were introduced into the eyewall, it would potentially represent a local buoyancy source, thus we refer to this enhancement as a buoyancy reservoir.

Figure 2 shows a family of back-trajectories "seeded" at $z = 5$ km across the eyewall updraft at the 24th day of the 4x run. Three different source regions for updraft air are evident: 1) the boundary layer inflow, 2) middle-level inflow, and 3) the eye. The presence of mid-level inflow is consistent with observation of peak updraft heights well above the boundary layer. Parcels in the eyewall rise against slight stability, which is evidence that a force is necessary to promote lifting beyond simply surface friction. The warmest parcels in the updraft derive from the eye. Parcels while they remain in the eye experience rapid fluctuations in entropy, which is evidence of mixing. Several inflow parcels slip into the eye, reside there for 2 to 8 hours (only 12 hours of trajectories were computed), then are ejected into the eyewall.

5. DISCUSSION

Our results suggests that the buoyancy force is driving the system away from its E-MPI. The ability to support a stronger updraft than can be explained with the neutral ascent of E-MPI theory provides for enhanced vorticity stretching and a mid-level inflow that can promote spinup. It is not clear if E-MPI can be rectified to account for this force, but it is worthwhile to reexamine the Carnot engine analogy. The formulation of Emanuel 1995b limits the family of available dynamical pathways for a hurricane to exist in. The RE87 model at high resolution evolves via a different dynamical pathway. We have not yet proved that this is a more effective pathway for production of entropy, but the lower central pressures with constant SST and the existence of an active eye point in that direction.

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6. REFERENCES

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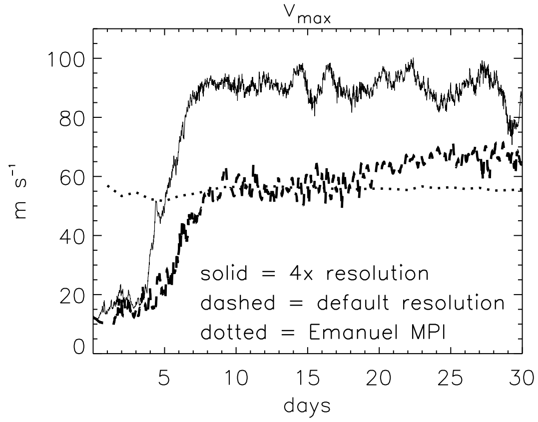

Figure 1: Simulated storm intensity in the default and 4x runs. Overlaid is E-MPI, $RH = 80\%$, with T_o from the default case. For the 4x run, T_o is not significantly different (≈ 1 m s^{-1}).

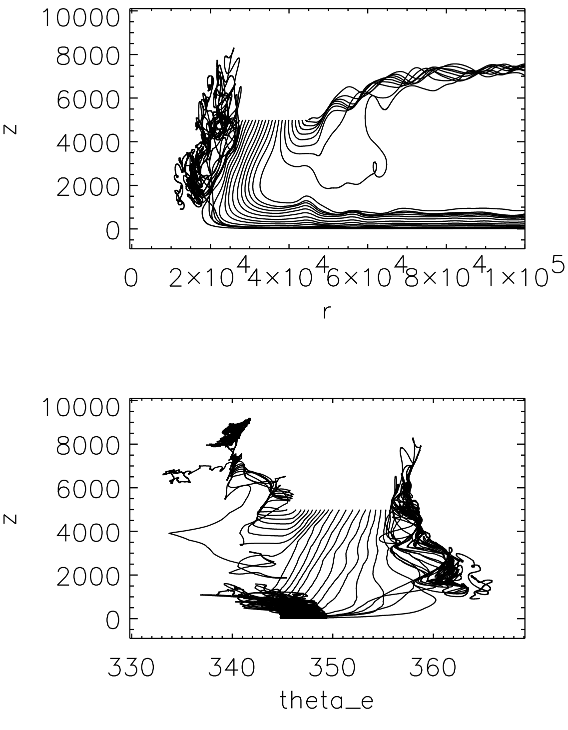

Figure 2: Trajectories from the 4x run (a), and θ_e versus time on the same trajectories (b).