14D.2 PROCESSES AFFECTING THE OCEAN'S FEEDBACK ON THE INTENSITY OF A HURRICANE

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1 Introduction

Turbulent entrainment of cold thermocline water into the ocean's mixed-layer constitutes an important negative feedback on the intensity of tropical cyclones by cooling the sea surface temperature (SST) in the storm's immediate wake (e.g., Price, 1981; Schade, 1994). In previous coupled hurricane-ocean model studies, entrainment was found to be the dominant term in the heat budget of the mixed-layer (Bender et al., 1993). But as entrainment is a nonlinear process, there are several physical processes and parameters that may affect its magnitude. The intensity of entrainment is governed by the strength of the shear across the base of the mixed-layer, which is generally strongest when the mixed-layer is shallow and the mixed-layer currents are strong. Since ocean dynamics can affect both of these parameters, it may be possible for such processes to affect the rate of entrainment and the magnitude of the ocean's feedback on tropical cyclone intensity. Price (1981) investigated the influence of nonlocal dynamics such as pressure gradients, upwelling, and horizontal advection on the upper ocean's response to a moving storm; in this research, our goal is to determine if such ocean dynamics influence the intensity of a tropical cyclone.

2 Models and Experiments

In order to test what influence mixed-layer dynamics have on the intensity of a tropical cyclone, we employ a coupled hurricane-ocean model. The hurricane model is axisymmetric and has high radial resolution in the storm's core (Emanuel, 1989). This model is coupled to Cooper and Thompson's (1989) four-layer, three dimensional ocean model; the manner by which the two models are coupled is described by Schade (1994). No surface heat fluxes are included in the prognostic temperature equation; the only way by which an initially homogeneous SST field may change, in this model, is if thermocline water is mixed into the upper layer. Entrainment, therefore, is the only process *directly* responsible for the ocean's feedback on storm intensity. The goal of this research is to test the importance of nonlocal dynamics on a tropical cyclone's intensity; we are investigating processes that may enhance or impede entrainment, thus effecting changes in the SST indirectly. Ekman pumping, which is proportional to the curl of the surface wind stress, will induce mixed-layer deepening through downwelling in regions beneath atmospheric anticyclonic vorticity, as mass converges in the upper layer of the ocean owing to Ekman transport; beneath cyclonic vorticity in the atmosphere, a divergence of mass will produce upwelling and a shrinking of the mixed-layer depth. A hurricane is composed of a core of cyclonic vorticity within the radius of maximum winds, but the sign of the vorticity is anticyclonic at larger radii. In order to test whether Ekman pumping and other nonlocal dynamics contribute to the ocean's negative feedback, we compare full physics runs of the coupled model with runs in which the ocean model is reduced to a collection of column models, each operating independently of its neighbors. In this, pressure gradients, divergence, and advection are neglected in the momentum, thermodynamic, and continuity equations. Experiments from this reduced physics model are called "independent column runs."

3 Results

In order to quantify the strength of the ocean's feedback, we calculate a feedback factor, F, defined by Schade (1994), after the model has reached a steady-state:

$$F = \frac{\Delta p_c}{\Delta p_u} - 1. \qquad (1)$$

Here Δp_c is the difference in pressure between the core of the hurricane and an ambient pressure far from the storm in an interactive, coupled run; Δp_u is the pressure difference in an uncoupled run with a static SST field. As the SST field can never warm in the wake of our model storm, the ocean's feedback and the sign of F are always negative.

Table 1 shows the values of F for full physics and independent column runs of the coupled model for several model storms. The speed of translation

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and accelerations affect the magnitude of the feedback, but little quantitative difference is seen between full and reduced physics runs of the ocean model. If Ekman pumping in the periphery of the hurricane had deepened the mixed-layer appreciably before the core of the storm approached, the entrainment in the independent column run would have been weaker, resulting in a smaller negative feedback. Also, storms which accelerate or decelerate disproportionately subject a patch of ocean to anticyclonic or cyclonic vorticity for an extended period of time; if nonlocal dynamics affected the feedback, these two cases should have differences between the full physics and independent column runs. Figure 1 shows the mixed-layer depth and currents in the wake of a storm moving uniformly west at $7\,ms^{-1}$ from a full physics run. The greatest errors generated by the omission of nonlocal dynamics occur in the wake of the hurricane, as the inertial oscillations described by Price (1981) disappear in the independent columns run. But as the hurricane's intensity is only sensitive to the oceanic response at short radii, there appears to be little impact on the atmospheric response for all storms moving at a modest pace. Only for slowly moving storms (translations speeds less than $\sim 3\,ms^{-1}$) is there any notable difference between the two runs, but even in this case the quantitative difference is only about 5%. This is consistent with an analytical study by Geisler (1970) which shows that the character of the ocean's response beneath the core of a storm depends on whether or not the storm is translating faster or slower than the fastest baroclinic waves.

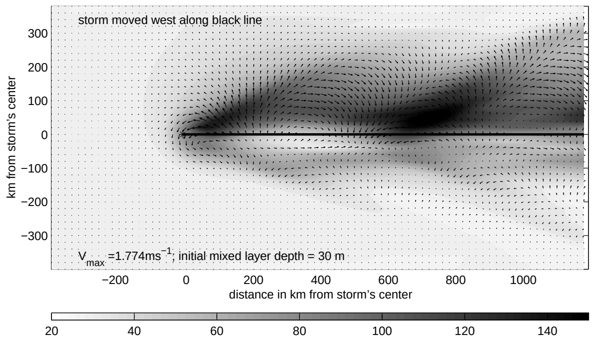
4 Conclusions

Entrainment clearly dominates the ocean's feedback to storm intensity, and nonlocal dynamics do not strongly influence the magnitude of entrainment beneath the core of a storm. They do, however, profoundly affect the wake of a storm, and will prove important for any storm path that crosses back over its own wake. While little quantitative difference is seen between full and reduced physics runs, the ocean's feedback is clearly important; storm intensity is much weaker than in an uncoupled run. The results of this work show that a simple parameterization of entrainment may prove to be a reliable substitute for a full three dimensional ocean model to model the ocean's feedback on hurricane intensity. Only for very slowly moving hurricanes, or for ones with a path interacting with the wake of a storm, will the omission of nonlocal dynamics affect the magnitude of the ocean's feedback.

Table 1: Values of F for coupled runs with an initial mixed-layer depth of $30\,m$.

case	full phys.	ind. col.
uniform translation ($7\frac{m}{s}$)	-.43	-.43
accelerating ($5 \rightarrow 16\frac{m}{s}$)	-.27	-.27
decelerating ($16 \rightarrow 5\frac{m}{s}$)	-.34	-.33
slow translation ($2\frac{m}{s}$)	-.60	-.57

Figure 1: Full physics coupled run mixed-layer depth (m) and currents.



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