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USE OF A ONE-DIMENSIONAL OCEAN MIXED-LAYER MODEL FOR COUPLED TROPICAL CYCLONE SIMULATIONS

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1. INTRODUCTION

It is generally accepted that the modification of the sea surface temperature (SST) in response to tropical cyclone forcing can have a feedback effect on the evolution of the storm intensity. The recent application of coupled atmosphere-ocean forecast models attempts to account for changes in SST during the forecast period. The evolution of the SST in the wake of a tropical cyclone is largely a result of one-dimensional vertical mixing processes in combination with the three-dimensional thermocline upwelling behind the storm. The upwelling, however, takes about half an inertial period to evolve, so the changes in SST directly under the storm are due primarily to direct wind stirring [Ginis (1995); NCAR (1998)]. This study examines whether a simple, robust ocean mixed layer model can be used for coupled tropical cyclone forecast modeling. A coupled system using this method would avoid many of the complications of globally relocatable ocean modeling. and real-case, uncoupled and coupled simulations.

2. APPROACH

This study first uses a series of idealized ocean-only simulations to explore whether an array of simple one-dimensional models makes an adequate ocean component for a coupled tropical cyclone system. The ocean sea surface temperature response to storm forcing in a one-dimensional model is compared with that from a full three-dimensional model, with a particular emphasis on the average SST within 100 km to 200 km of the storm center.

The three-dimensional ocean model used for these simulations is the Princeton Ocean Model (POM; Blumberg and Mellor 1987). The POM was modified into a mixed-layer model by removing all horizontal terms from the momentum tendency equation, and horizontal mixing from the tracer equation (the tracer equation includes advection). An additional dissipation term is added to the momentum equation to account for horizontal dissipation and advection. The experiments also included a simpler model without tracer advection – and so with no horizontal terms – and calculated on an A-grid rather than the original POM C-grid. All versions of the model were configured with 1/6^o resolution on a 241x181x19 mesh over 2000 m depth, with 10m vertical resolution in the top 100 m.

The ocean initial conditions used for the results presented here are an idealized representation of mesoscale ocean features present in the Gulf of Mexico. An anticyclone is imbedded in an otherwise horizontally uniform stratification using September 15 climate T,S profiles for 90^{o}W,25^{o}N, representative of the late-summer Gulf. The circular eddy is constructed with the September 15 climate values for 85^{o}W,17^{o}N, representative of the late-summer Caribbean. The eddy is constructed by applying a Gaussian horizontal structure with a 200 km length scale, and spinning up the eddy with a 10-day integration. The tropical storm forcing is applied so that the center of the storm is over the center of the eddy at hour 96 of the integration.

The same initial ocean conditions are used for a series of coupled atmosphere-ocean simulations that explore the effect on the modeled storm track and intensity. For the coupled simulations, the anticyclone mass and velocity fields are cut and pasted into the background stratification at the 48 h position of the storm determined from an atmosphere-only integration.

The atmospheric model used for the coupled simulations is the GFDL/NOAA hurricane forecast model (Kurihara, et al., 1998). It uses movable mested meshes, and is configured with three meshes with horizontal resolutions of 1^o, 1/3^o, and 1/6^o, and with 18 levels in the vertical. The domain of the outermost mesh is 75^o in latitude and longitude, and the two nested meshes are 11^o and 5^o respectively, in latitude and longitude. The nested meshes are centered on the tropical cyclone and move so that the tropical cyclone is maintained in the area of fine horizontal resolution. The model is initialized with a symmetric storm bogus based on the structure of Fran (1996) in uniform background easterly flows of 5, 2.5, and 0 m/s.

The model coupling is performed by passing surface momentum and buoyancy fluxes from the atmospheric model to the ocean model, which returns a sea surface temperature (SST) prediction to the atmospheric model. The ocean model is integrated one timestep (1200 s) for every ten timesteps (of 120 s) of the atmospheric model. The fluxes are interpolated between the uniform horizontal mesh of the ocean model and the nested meshes of the atmospheric model.

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3. RESULTS

In ocean-only simulations (Figure 1), the 1D model shows good skill at predicting the average SST depression within 100 km of the storm center (SST - prestorm SST), and at tracking the evolution of the changes in SST during the storm progression across the mesoscale eddy. The results from the 1D model are degraded most for slow-moving storms, as we would expect (Ginis, 1995).

A similar conclusion can be drawn from the results of the coupled simulations (Figure 2), where the 1D model again shows good skill at predicting the evolution of the SST changes as the modeled storm crosses the mesoscale feature. Biases between the 3D and 1D results may result from an inappropriate choice for the dissipation timescale for the velocities in the 1D ocean model; a more extensive series of integrations may suggest a different choice for that parameter. We note that the 1D results are most degraded during the initial phase, when the ocean model is responding to the sudden onset of the winds, an effect that will be much reduced in an operational forecast system. From the storm central surface pressure for the 0 m/s background flow case, it appears that a small intensity bias develops over the first 36 h (Figure 3); a more continuous ocean initialization should improve that bias.

4. REMARKS

The results from these idealized ocean-only and coupled tropical cyclone-ocean models demonstrate the capability of a one-dimensional ocean mixed-layer model for tracking ocean surface temperature changes during tropical cyclones. The one-dimensional model skill appears to fall off for slow-moving storms. A series of real-case integrations with the ocean initial conditions based on accurate analyses of the ocean state will be performed to evaluate the intensity forecast skill of the coupled system with reduced ocean physics.

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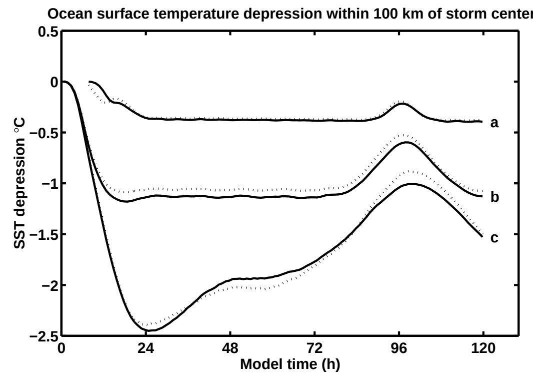

Figure 1: The mean ocean surface temperature depression within 100 km of the storm center in ocean-only experiments with storm speeds of 10, 5, and 2.5 m/s westward (a-c, respectively) using the full 3D (solid line) and 1D (dashed line) models.

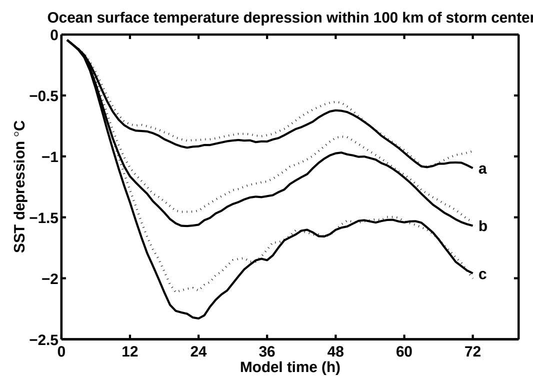

Figure 2: The mean ocean surface temperature depression within 100 km of the storm center in coupled model experiments with background easterly wind speeds of 5, 2.5, and 0 m/s (a-c, respectively) using the full 3D (solid line) and 1D (dashed line) ocean models.

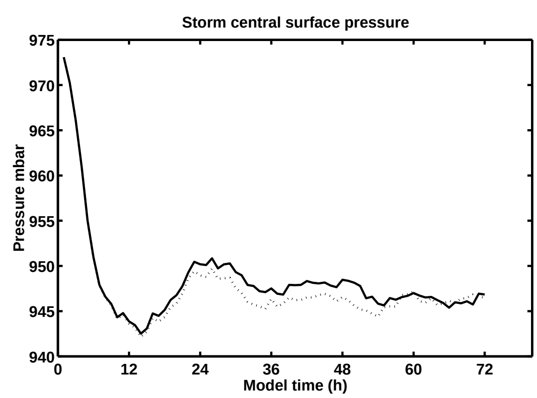

Figure 3: The central surface pressure in the coupled system for the case with 0 m/s background zonal flow using the full 3D (solid line) and 1D (dashed line) ocean models.