Modeling the Oceanic Response to Air-Sea Fluxes Associated with a Tropical Storm

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1. Introduction

A new boundary layer model is used with a numerical ocean model to simulate and better understand the impacts of turbulent fluxes of heat and momentum between the ocean and atmosphere during energetic forcing events, such as tropical cyclones. In particular, the case of Tropical Storm Harvey in the Gulf of Mexico during September, 1999, is simulated and analyzed. Winds derived from the NASA SeaWinds scatterometer aboard the QuikSCAT satellite are used as input to the atmospheric flux model, along with air temperatures from an atmospheric model and sea surface temperatures from the ocean model. Experiments are run with both momentum and heat fluxes, and then with momentum and heat fluxes applied separately, to illustrate the roles that the surface forcing mechanisms play in governing the evolution of the upper ocean thermal structure.

Results show that the sea surface temperature (SST) response is dominantly driven by the surface heat flux. Surface cooling also promotes a deepening of the mixed layer through convective mixing. The surface wind stress, upwelling favorable under a tropical cyclone, can enhance the surface cooling by entraining cooler deeper water into the surface mixed layer.

2. The Model

The Navy Coastal Ocean Model (NCOM) (Martin 2000) has been configured to simulate the Gulf of Mexico (GoM) and northwestern Caribbean with a horizontal resolution of 1/20° in latitude and longitude as in Morey et al. (2003), but with an increase in the vertical resolution to 60 levels (20 sigma levels above 100 m and 40 z-levels below). The model assimilates MODAS (Modular Ocean Data Assimilation System, Fox et al. 2002) three-dimensional synthetic temperature and salinity profiles, and is horizontally nested within the Navy Research Laboratory 1/8° NCOM global hindcast model for lateral boundary conditions. Output from this GoM hindcast model is used for initialization of the experiments described in this paper. No data assimilation is used during the experiments.

An atmospheric flux model based on the Bourassa-Vincent-Wood (BVW) boundary layer model (Bourassa et al. 1999) is coupled to the NCOM. This flux model has the advantage of more accurately calculating air-sea fluxes dependent on the sea state, air-surface temperature and humidity difference, and 10 m wind velocity. For the experiments presented here, the flux model is used assuming local wind-wave equilibrium and a prescribed air-sea humidity difference. Calculation of the surface momentum flux, latent heat flux, and sensible heat flux then reduce to functions of the air-sea temperature difference and the 10 m wind velocity for these experiments.

Air temperatures for these experiments are extracted from the European Center for Medium Range Weather Forecasting (ECMWF) Global Advanced Operational Surface Analysis and winds are derived from the SeaWinds scatterometer aboard the polar orbiting QuikSCAT satellite. The scatterometer wind data are objectively gridded using the Eta-29 atmospheric model data as a background field (Morey et al. 2004). The resulting input fields to the flux model consist of 1° air temperature and ½° 10 m winds, both at 12-hour time intervals, and NCOM SST at each model time step. The coupled model is run for September 15, 1999 – September 23, 1999.

3. Results

T.S. Harvey passed over the eastern Gulf of Mexico during September 19 – 22, 1999, making landfall along the southwest coast of the Florida peninsula. Numerical model results show that surface heat fluxes (latent and sensible) were largest coincident with the strongest winds and reached magnitudes in excess of 600 W/m^2 (Figure 1). Substantial cooling associated with the tropical storm can be seen offshore of the West Florida Shelf, where the SST was reduced by more than 1.5° C (Figure 2, indicated by the arrow). A model run in which neglected wind stress (although wind speed was used in the heat flux calculations) produced similar

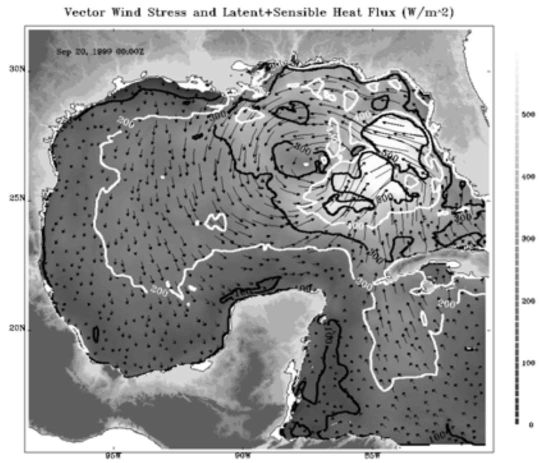

Fig. 1. Vector wind stress (arrows) and latent plus sensible heat fluxes (positive upward) modeled on September 20, 1999.

cooling, though somewhat less pronounced in the region of maximum response to the storm. In a third experiment, the sea surface was insulated. The cooling over the basin was not as pronounced, but the SST was reduced by more than 0.6° under the path of the storm, coincident with the region of maximum cooling in the control experiment with all fluxes calculated.

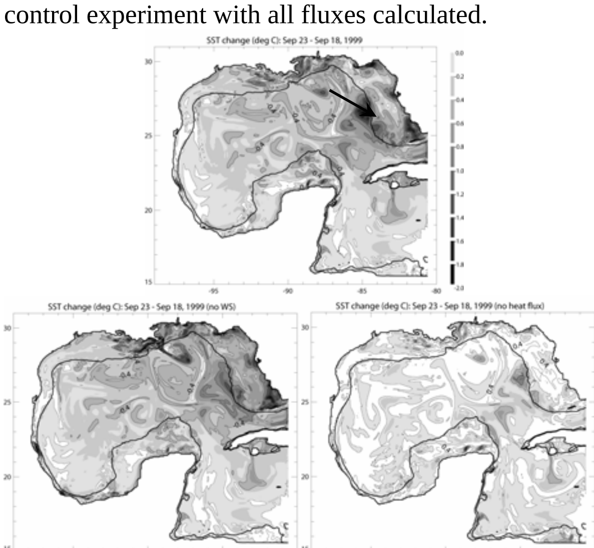

Fig. 2. Sea surface temperature change from September 18 to 23, 1999. Only cooling is shaded. Top: Model run with heat and momentum fluxes. Lower Left: Model with no wind stress (momentum flux). Lower Right: Model with insulated sea surface (no heat fluxes).

The time series of the temperature profiles at the center of the most extreme cooling (indicated by the arrow in Figure 2) for each experiment show the subsurface ocean response to the tropical cyclone (Figure 3). Upwelling of the isotherms and subsequent inertia gravity waves are evident, as is the cooling of the surface mixed layer. The experiment neglecting wind stress shows that convective mixing is responsible for maintaining the mixed layer depth, and heat loss results in cooling of the mixed layer. The experiment that neglects surface heat fluxes shows that the wind driven upwelling reduces the mixed layer depth, and entrainment of cooler water into the mixed layer also contributes to the cooling of the upper ocean.

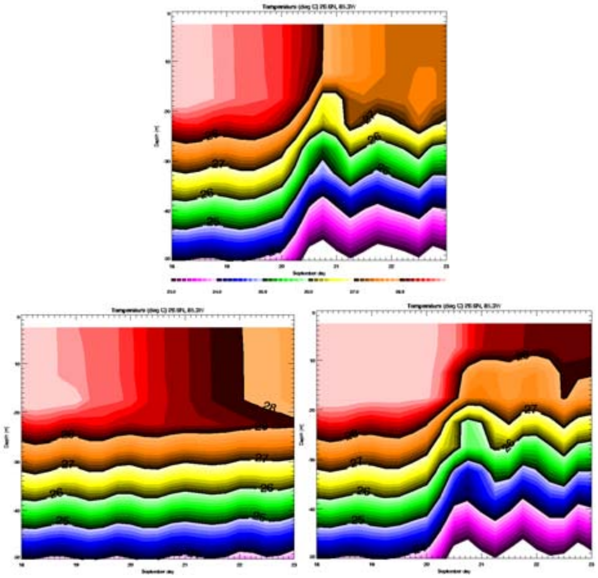

Fig. 3. Time series of the upper 50m temperature profile near the location specified by the arrow in Figure 2. Top: Model run with heat and momentum fluxes. Lower Left: Model with no wind stress (momentum flux). Lower Right: Model with insulated sea surface (no heat fluxes).

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