14D.5 THE UPPER OCEAN SALINITY RESPONSE TO TROPICAL CYCLONES

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1. INTRODUCTION

The study of ocean salinity is an interesting problem that is often overlooked due to a lack of observations. Unlike sea surface temperature (SST) observations widely available from remote sensing, sea surface salinity (SSS) data are very limited. Tropical Cyclones (TC), however, can potentially produce vast changes in the salinity signature of the upper ocean. Due to typically very heavy rains associated with TC, the upper ocean salinity response can be affected by the fresh water flux into the ocean. The salinity can also be affected by the wind stress of the TC on the ocean's surface. Previous studies have shown that the SST response resembles a cold wake, which consists of a trail of decreased temperature behind the storm. This arises due to the wind stress-generated vertical mixing in the upper ocean. The mixing acts to entrain the cooler waters from the thermocline into the mixed layer thus leaving a cold wake in the SSTs. The salinity response from this forcing would lead to increased values due to a mid-level maximum found in typical salinity profiles. On the other hand, the rainfall acts to reduce the SSS when mixed into the upper ocean. The observed SSS response is thus the combined result of these two competing effects.

Most current coupled air-sea tropical cyclone prediction models neglect the rainfall in their calculations since the significance of the salinity response has yet to be determined. The salinity, temperature, and density of the ocean are linked according to the equation of state for seawater. Changes in the salinity will impact the density stratification of the upper ocean, leading to changes in the magnitude of the turbulent mixing. This can, in turn, affect the SST response and modify the sea-surface heat fluxes. This paper presents the results of a numerical modeling study of the salinity response of the upper ocean as a result of idealized TC forcing.

2. EXPERIMENTAL DESIGN

The model experiments were conducted using the Princeton Ocean Model. This model is particularly useful in ocean-atmosphere interaction studies due to its inclusion of the Mellor-Yamada turbulence closure vertical mixing scheme. This ensures realistic vertical fluxes of momentum and salinity that are critical for this problem.

The model domain consisted of a horizontally uniform distribution of temperature and salinity profiles taken at 24.5°N, 88.5°W in the Gulf of Mexico in August. The initial velocities were set to zero. The atmospheric forcing included the wind stress and rainfall. The surface wind stress was composed of an axisymmetric structure moving zonally (westward) at a constant speed. The freshwater flux associated with the TC rainfall was specified as the surface boundary condition for the salinity equation (Barnier, 1998). It is expressed as the algebraic sum of the evaporation and precipitation. For simplicity, the structure of the rain forcing was assumed to be similar to the wind stress: axisymmetric in structure and with a maximum at the radius of maximum winds. The value of maximum rain was determined through an analysis of satellite derived rain measurements compiled at the Naval Research Laboratory, Monterey Tropical Cyclone web site (http://kauai.nrlmry.navy.mil/sat-bin/tc_home).

It has been documented that a number of factors are involved in determining the response of the ocean due to TC forcing. Storm factors that are relevant include the intensity, size, and storm speed (Price 1981). Also the initial state of the ocean should be considered. The storm parameters used in the control case are shown in Table 1. Various test cases considered the effects of storm size, translation speed, and intensity. Each case was simulated for three days with and without the rain forcing.

Table 1. TC parameters in the control experiment

Maximum winds (ms^{-1})	Maximum rainfall (10^{-6} ms^{-1})	Radius of max winds (km)	Storm speed (ms^{-1})
35	6.4	50	5

3. RESULTS

The results discussed here will focus on the control case for simulations of the ocean response to a TC with and without the rain flux. They are rather intriguing. The inclusion of the freshwater flux has led to vastly different pictures of the upper ocean salinity anomalies created by the TC forcing. Fig. 1 shows the SSS anomalies created in the case without any rain. The storm track is noted with tick marks at 12-hour

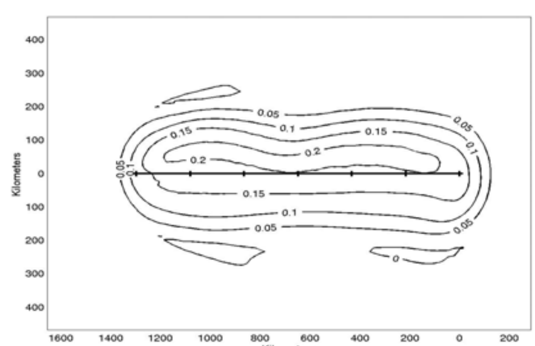

Figure 1. SSS anomalies (ppt) created from the control case without rain. The TC was moving from the right to the left with a speed of 5 m/s.

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intervals. Notice that the anomalies are all positive (increased values). This shows the direct result of the turbulent mixing and entrainment of the mid-level saltier waters. Also the area of anomalies is contained to approximately four times the radius of maximum wind on either side of the storm center. Coinciding to the rightward bias seen in the temperature response, the maximum anomalies of the salinity are just to the right of the storm track and are calculated to be around 0.2 ppt.

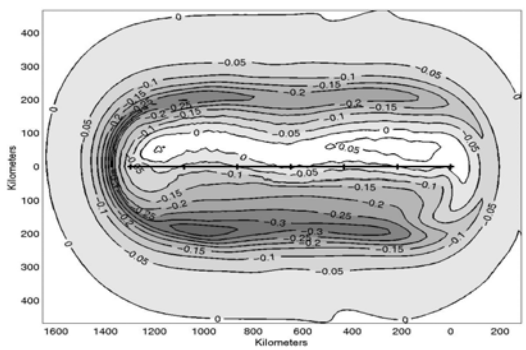

Figure 2. As in Fig. 1, but from the control case including rain.

Similar structure of the positive SSS anomalies is seen in the case with rain (Fig. 2), however, the magnitude and spatial size of the response are largely different. Salinity decrease (negative anomalies) are now observed in front of the storm center and on the periphery spanning more than six times the radius of maximum wind. Surface values can decrease up to 0.35 ppt in these areas. The positive anomalies seen in Fig. 1 are reduced by the inclusion of the freshwater flux. They are up to four times smaller in some areas. The negative anomalies display a pronounced leftward bias due to significantly weaker entrainment to the left of the storm, while the fresh water flux is nearly symmetric.

The differences between these cases translate beneath the surface as well. Vertical sections taken 200 km behind the storm center are shown in Fig. 3 (without rain) and Fig. 4 (with rain). The rainfall effects are confined to the upper ocean layer. In the case without rain, the positive salinity anomalies extend down to about 30 m, tilting to the right (rightward bias). In the rainfall case the upper ocean layer below the TC has become mostly fresher to a depth of about 60 m. This indicates that the freshwater flux at the surface dominates the entrainment at the bottom of the mixed layer lowering salinity values by up to 0.35 ppt on the left side of the storm. The leftward bias of the response to TC forcing is again seen with negative anomalies on the left side being of larger magnitude than those on the right. Near the TC track for both cases, the lower salinities below about 100 m indicate upwelling. Two symmetric regions of higher salinity are due to downwelling on the TC periphery.

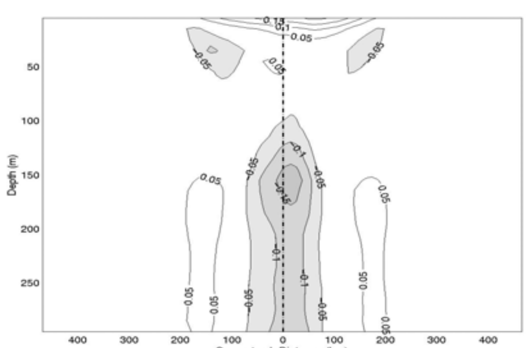

Figure 3. Vertical cross-section of the upper ocean salinity anomalies (ppt) 200 km behind the TC center for the control case without rain.

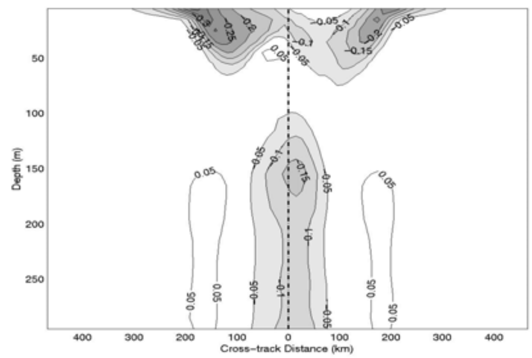

Figure 4. As in Fig. 3, but for the control case including rain.

4. SUMMARY

The inclusion of rain as a freshwater flux into an ocean circulation model simulating the ocean's salinity response to TC forcing has shown interesting results. Simulations with and without the flux showed vastly different distributions of salinity anomalies. The SSS in cases without rain showed only positive anomalies while cases including rain showed large negative anomalies in front of the storm center and at the periphery. In the latter case salinity anomalies can penetrate to a depth of 60 m. These anomalies may affect the temperature response, including SST, and thus modify the surface heat fluxes. This is a result that could potentially be quite useful for TC predictions and deserves further investigation with a fully coupled tropical cyclone-ocean model.

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