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ANALYIS OF UPPER-OCEAN THERMODYNAMIC OBSERVATIONS FORCED BY HURRICANE LILI

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1. Introduction

As part of a joint NOAA/NSF hurricane field program, an experiment was designed to determine the contribution of pre-existing and storm-induced ocean features to changes in tropical cyclone (TC) intensity and surface wind field structure. The experimental strategy included obtaining observations to diagnose the three-dimensional thermodynamic and current structure of the upper-ocean prior to, during, and after passage of a TC. Additionally, atmospheric data would be collected to accurately estimate the sea surface forcings responsible changes in oceanic structure.

From 18 Sept. to 4 Oct. 2002, a series of research flight missions were executed in and around Hurricanes Isidore and Lili. The flights from 18-23 Sept. involved experiments associated with Isidore, and obtained ocean observations in the NW Caribbean Sea and SE Gulf of Mexico. Unfortunately, due to the erratic (and difficult to forecast) storm track, much of the sampled region in the Gulf of Mexico was never traversed by Isidore. Somewhat serendipitously, Hurricane Lili did cross the region on 2 Oct. as a Category 2 storm on the Saffir-Simpson scale, and was in the process of rapidly intensifying to Category 4. A final mission was executed on 4 Oct. to measure the ocean response.

As part of the overall analysis of these observations, the upper-ocean thermodynamic structure is quantified based on vertical profiles of temperature and salinity. This analysis represents one component of the primary research objective, which is to derive oceanic mixed layer (OML) mean budgets of mechanical energy and vorticity under direct forcing from a mature tropical cyclone. It is hoped that this research will contribute to improvements in the parameterizations of kinetic energy and momentum transfer at the air-sea interface for coupled numerical modeling efforts.

2. Observations

Vertical profiles of temperature and salinity are used to analyze the thermodynamic structure of the upper ocean (OML and pycnocline). Temperatures are measured by Airborne Expendable Bathythermograph (AXBT) probes, Airborne Expendable Current Probes (AXCP), and Airborne Expendable Conductivity-Temperature-Depth (AXCTD) probes. AXCTDs also measure salinity profiles.

The temperature and salinity profiles are separately objectively analyzed to a common grid using an optimal estimation technique. The grid location is chosen based on a number of factors, including common data coverage, storm track, and location of the surface wind forcing analysis. The grid is rotated to align with the mean storm direction (290°) during the in-storm research flight, such that gradients of dependent variables can be computed along- and cross-track. Contour plots of surface temperatures are shown in Figs. 1 and 2, which represent the pre- and post-storm fields, respectively.

The OML is the layer of the upper ocean near the surface in which the mean dependent variables are approximately constant with depth. For this study, the depth of the OML is determined from the objectively analyzed temperature profiles; here, the depth is defined as the point where the temperature has decreased 0.4 C from the SST. The horizontal distributions of the OML depth, along with individual observations, are shown in Figs. 3 and 4. In terms of the mixed-layer depth, it is apparent that Lili traverses three distinct oceanic regimes. The interior of the loop current is characterized by the deep OML in the SE of the analysis area. The storm then enters the strong baroclinic zone of the Loop Current system. Finally, Lili enters the waters of the Gulf of Mexico which contain warm, but much shallower OML depths.

3. Conclusions and Future Work

In the analysis of the overall energy budget, the density (mass) field is necessary for estimating the potential portion of mechanical energy. The density field is computed from the objectively analyzed temperature and salinity observations. The interior part of the Loop Current warm core shows fairly little change after the storm's passage, while significant density increase (due to OML cooling) is apparent in the Gulf of Mexico to the NW of the loop current.

The horizontal distribution of observed OML thermodynamic variables (temperature and density) under strong surface forcing is presented. Observations of upper ocean profiles of temperature and salinity were obtained prior to, during, and after passage of Hurricane Lili on 2 October 2002. Analyses show that Lili passed through an area of significant horizontal ocean variability. Three distinct regions are identified: 1) warm waters of the loop current warm-core eddy, characterized by mixed-layer depths of 100 m or more, and

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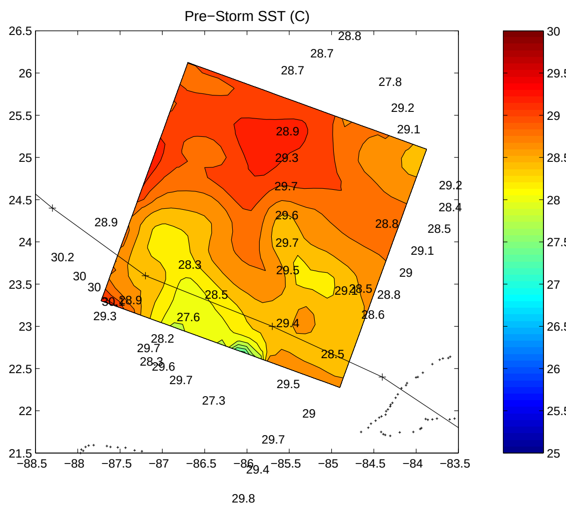

Figure 1: Observations and objectively analysis of sea surface temperature (C) representing the pre-storm upper ocean environment. The track of Lili is indicated along with 6 hr. positions.

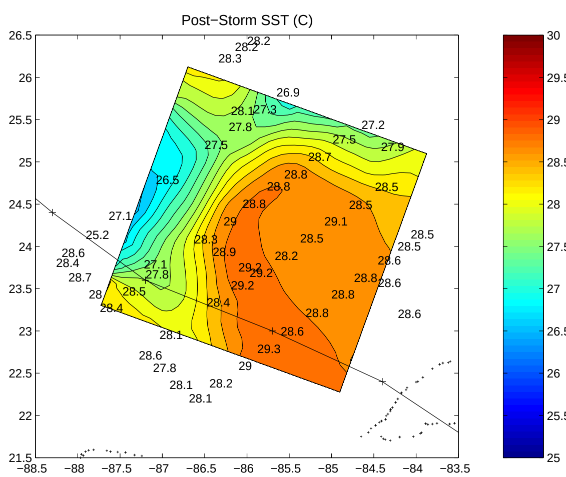

Figure 2: Same as Fig. 1 but for post-storm analysis.

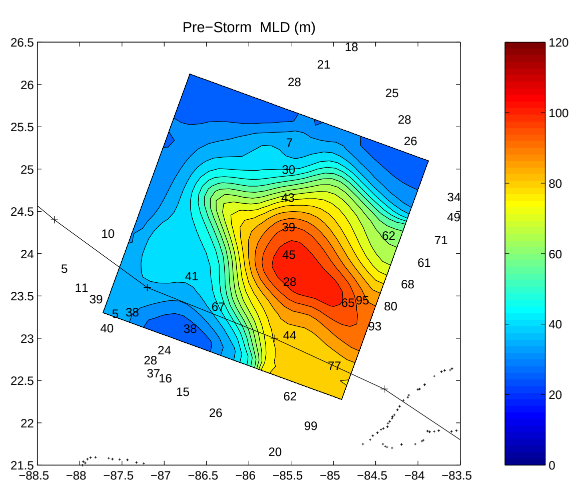

Figure 3: Observed and analyzed OML depth (m) for the pre-storm region.

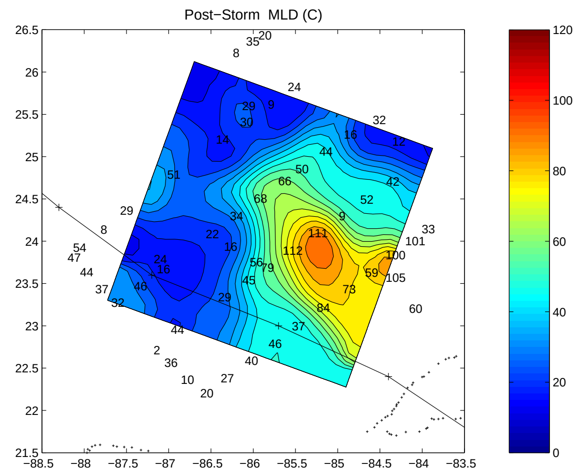

Figure 4: Same as Fig 3 but for the post-storm region.

relatively weak thermocline stratification (order $N = 4$ cph); 2) a strong baroclinic zone identified with the loop current system having geostrophic velocity magnitudes of order 1 $\mathrm{m\,s^{-1}}$; and 3) the waters of the Gulf of Mexico with warm surface temperatures but having shallower OML depth (30 m) and stronger stratification of order $N = 10$ cph.

Future work will include analyses of current profiles obtained by AXCP. These observations will be used to derive the distribution of OML kinetic energy and relative vorticity under forcing from Hurricane Lili. This data will assist in completing mechanical energy and vorticity budget analyses of the OML.

Acknowledgement

This work is funded under a grant from the National Science Foundation (ATM 01-08218). Special thanks are due to Tom Cook and Scott Guhin (UM/RSMAS) for data processing, and to the NOAA/Aircraft Operations Center.