3C.6 IMPROVING OCEAN STATE INITIALIZATION IN COUPLED TROPICAL CYCLONE FORECAST MODELS

George R. Halliwell, Lynn. K. Shay
MPO/RSMAS, University of Miami, Miami, FL
Eric W. Uhlhorn
CIMAS, University of Miami, Miami, FL
S. Daniel Jacob
GEST, UMBC/NASA GSFC, Greenbelt, MD
Ole Martin Smedstad
Planning Systems Inc., Stennis Space Center, MS

1. INTRODUCTION

Coupled ocean-atmosphere models do not accurately forecast tropical cyclone (TC) intensity at present, partly due to inadequate representation of the ocean. The oceanic contribution to TC intensification depends on the relative importance of a positive and a negative feedback mechanism: Positive feedback results when the increasing wind speed of an intensifying TC increases evaporation rate and supplies the storm with additional thermal energy for intensification. Negative feedback occurs when increasing wind speed cools SST more rapidly, thus decreasing evaporation rate and thermal energy available to the TC. SST alone cannot predict whether the ocean will promote or inhibit intensification. Ocean heat content (OHC) relative to 26°C is a more reliable indicator of the ocean contribution to intensification (Leipper and Volgenau, 1972; Shay *et al*., 2000). OHC is given by

$$\mathrm{OHC} = c_p \int_0^{D_{26}} \rho \left[T(z) - 26 \right] \, dz, \qquad (1)$$

where c_p is the specific heat of seawater at constant pressure, ρ is water density and D_{26} is the depth of the 26°C isotherm. In the Gulf of Mexico (GOM), oceanographic features such as the Loop Current (LC) and associated warm core rings (WCRs) have much higher OHC (comparable to the high OHC of the northern Caribbean Sea) than the Gulf Common Water present over most of the interior GOM.

To improve TC intensity forecasts by coupled hurricane prediction models, the state of the ocean must be accurately initialized with respect to (1) correctly locating oceanographic features associated with large OHC differences and (2) correctly initializing temperature (and salinity) profiles at all locations. We investigate ocean model initialization in the northwest Caribbean and southeast GOM for September 2002 just prior to hurricane Isidore. Climatologies cannot provide initial fields because they smear out large OHC gradients associated with variable oceanographic features. September mean OHC from the WOA01 climatology (Boyer *et al*., 2004) shows the highly-smoothed representation of the LC-WCR complex and also illustrates the OHC maximum present in the northwest Caribbean Sea (Figure 1). These features must be properly initialized to produce accurate simulations of the ocean response to TCs (Jacob and Shay, 2002). Climatology also cannot represent anomalous oceanographic conditions that may be present. We will demonstrate the necessity of using both models and observations to produce optimal initial fields for ocean models and the necessity of thoroughly evaluating these fields before they are used.

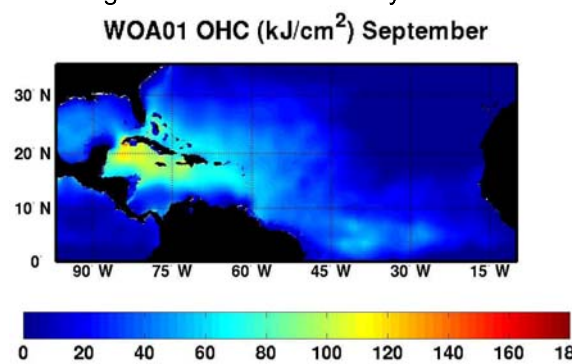

Figure 1. Mean September OHC in the North Atlantic Ocean from the 0.25° World Ocean Atlas 2001 climatology.

2. PRE-ISIDORE INITIAL CONDITIONS

Prior to hurricane Isidore, the upper ocean was substantially warmer than normal throughout the northwestern Caribbean Sea and within the LC in the southeastern GOM. Two maps of OHC just prior to Isidore (19 September 2002) were produced by objective analysis of Airborne Expendable Conductivity Temperature and Depth (AXCTD) temperatures profiles, one in the northwest Caribbean and the other in the southeast GOM (Figure 2). Observed OHC values in the northwest Caribbean were typically 150-180 kJ cm^{-2} (Figure 2), about 50% larger than the September climatological values of 100-120 kJ cm^{-2} (Figure 1) and much larger than the minimum 16.7 kJ cm^{-2} required to support TCs (Leipper and Volgenau, 1972). The discrepancy is even greater in the southeast GOM because of excessive horizontal smoothing in the climatology.

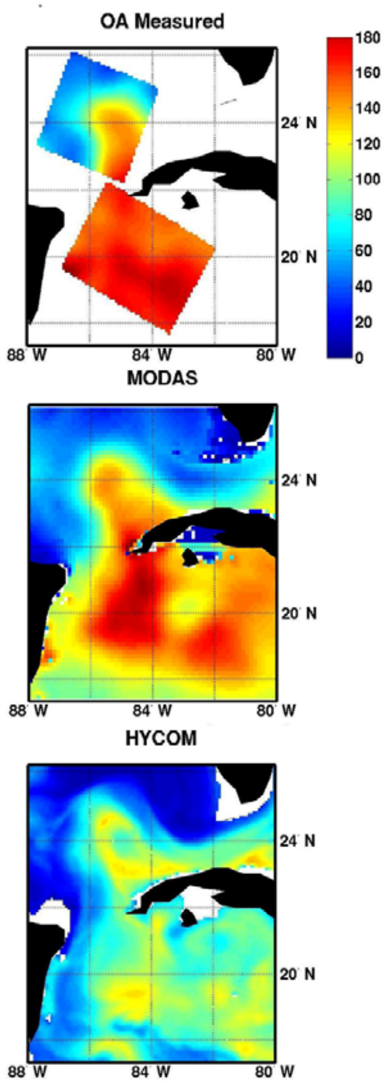

Figure 2. OHC maps from observations (top), the MODAS temperature analysis (middle), and the HYCOM assimilative hindcast (bottom) on 19 September 2002 prior to hurricane Isidore.

The anomalously warm conditions extend throughout the upper 500 m of the water column in the northwest Caribbean (Figure 3), with the observed temperature exceeding climatology by 2-4°C. The observed salinity profile is relatively close to climatology above 80 m, but water between 80 and 200 m was fresher than normal while water below 200 m was saltier than normal. As a result, the observed salinity maximum was about 70 m deeper than climatology.

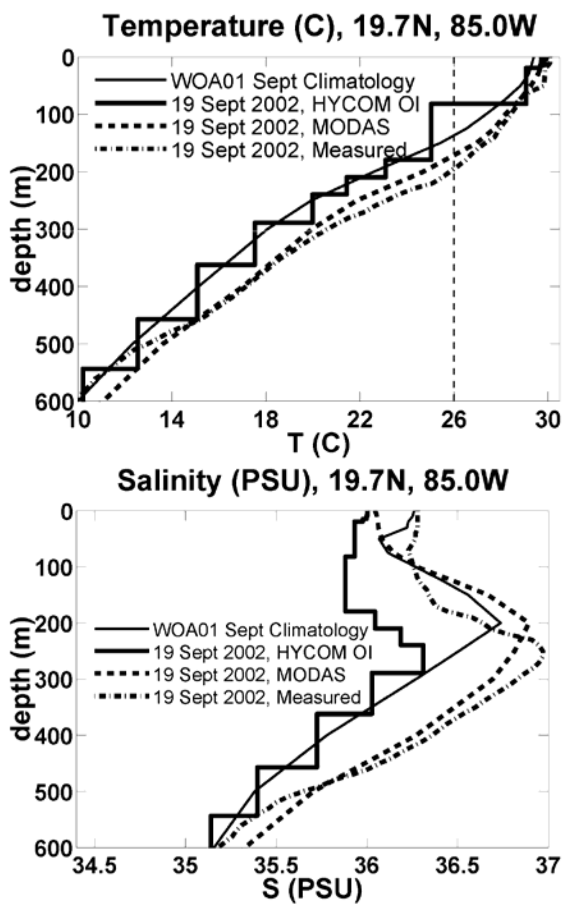

Figure 3. Temperature (top) and salinity (bottom) profiles at a location of an AXCDT profile in the northwest Caribbean Sea on 19 September 2002 prior to hurricane Isidore.

3. EVALUATION OF INITIAL CONDITIONS PROVIDED BY A GODAE ASSIMILATIVE OCEAN HINDCAST

We evaluate one Global Ocean Data Assimilation Experiment (GODAE) nowcast product for providing the initial ocean state, specifically the Atlantic Ocean 0.08° assimilative hindcast produced by Planning Systems, Inc. and the Naval Research Laboratory. This product assimilates satellite altimetry (with vertical information projection) and SST into the HYbrid Coordinate Ocean Model (HYCOM) (e.g. Bleck, 2002); Chassignet *et al*., 2003; Halliwell, 2004). Comparison of OHC maps hindcast by HYCOM to OHC maps derived from aircraft observations (Figure 2) demonstrate that the HYCOM hindcast reproduces the correct LC path. Unfortunately, the second requirement for the initial conditions is not satisfied as large errors exist in temperature and salinity profiles. In the northwest Caribbean (Figure 3), the HYCOM hindcast temperature profile tends to follow climatology, which results in similar OHC values between HYCOM (Figure 2) and September climatology (Figure 1). In the HYCOM hindcast, the upper ocean is much fresher than both climatology and observations above 250 m and much fresher than observations between 250 and 500 m. The HYCOM hindcast also tends to be too cold and too fresh in the Gulf Common Water north of the LC (not shown).

4. IMPROVING THE INITIAL CONDITIONS

The temperature and salinity biases in the HYCOM hindcasts resulted from biased initial conditions. The Atlantic assimilation was initialized from an old, highly-biased climatological Miami Isopycnic Coordinate Ocean Model run. (HYCOM evolved from MICOM). Furthermore, the assimilation of satellite altimetry with vertical projection of information was incapable of correcting the initial biases.

Ongoing development of the HYCOM-GODAE nowcast system will substantially correct these biases by employing a more realistic initialization procedure and then assimilating three-dimensional fields of all dynamical and thermodynamical variables. Assimilation will be performed by coupling HYCOM to the existing Naval Coupled Ocean Data Assimilation (NCODA) system. The present NCODA system, running at NAVOCEANO and FNMOC, is a fully three-dimensional multivariate optimum interpolation system (Cummings 2003). Temperature, salinity, geopotential, and velocity components are analyzed simultaneously, with incremental velocity adjustments in geostrophic balance with the geopotential increments and geopotential increments in hydrostatic agreement with the temperature and salinity (density) increments.

Since the NCODA assimilation system will be under development for at least the next several months, we have developed an interim HYCOM assimilation product where the ocean model is relaxed to three dimensional temperature and salinity fields from the 0.125° Modular Ocean Data Assimilation System (Fox *et al*., 2002). MODAS is a set of tools that grids and analyzes global ocean observations in two or three dimensions. Optimum interpolation is used to initially grid all fields. In regions where insufficient observations are available, fields are relaxed slowly toward their climatological values. Evaluation of this HYCOM-MODAS hindcast is just commencing. We expect biases to be much reduced in this product because OHC values prior to Isidore derived from the three-dimensional MODAS temperature analysis are much closer to observed values than to the old HYCOM hindcast (Figure 2). MODAS temperature and salinity profiles are also much closer to the observed profiles in the northwest Caribbean (Figure 3). The MODAS interim product will serve as a benchmark for evaluating the HYCOM NCODA hindcasts for providing initial conditions when it becomes available

5. SUMMARY

We are addressing the difficulties involved in accurately initializing an ocean model for studies of the ocean response to TCs and for coupled TC simulations and predictions, emphasizing the paramount importance of ocean observations in this endeavor. Adequate observational coverage for both temperature and salinity is necessary for assimilation into an ocean model to reproduce the state of the ocean with sufficient accuracy to provide initial and boundary conditions for performing TC simulations and predictions. Observations are also critically important for evaluating the accuracy of the initial conditions and the subsequent performance of the ocean model.

Acknowledgements: The observational and modeling efforts were supported through NSF grant ATM-04-44525, and the observational program benefited from NOAA support through the efforts of the pilots, technicians, engineers and scientists at NOAA's Aircraft Operation Center (Dr. Jim McFadden) and Hurricane Research Division (Dr. Frank Marks). The modeling effort was also supported by NOAA and ONR through the National Oceanographic Partnership Program through ONR grant N000140510095.

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