IMPORTANCE OF OCEAN OBSERVATIONS FOR INITIALIZING OCEAN MODELS FOR TROPICAL CYCLONE FORECASTS

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ABSTRACT

Combined model-observational studies are critically important for evaluating and improving ocean model performance in coupled tropical cyclone forecast models, particularly in regards to the magnitude and pattern of SST cooling and the resulting impact on intensity forecasts. In oceanic regions with energetic mesoscale eddies or boundary currents, the correct initialization of these oceanic features is the most important factor for producing accurate SST forecasts. Ocean fields for initialization obtained from data-assimilative ocean hindcasts produced as part of the Global Ocean Data Assimilative Experiment (GODAE) have been quantitatively evaluated. Due to satellite altimetry assimilation, these products realistically represent the location and horizontal structure of important ocean features. However, relatively large errors and biases are frequently observed prior to individual storms in vertical profiles of temperature, salinity, and density, which then lead to incorrect forecasts of SST cooling. The impact of this problem on ocean model performance and SST cooling is discussed for Hurricanes Isidore (2002) and Katrina (2005). Additional targeted and operational observations of upper-ocean profiles will be required to reduce these initial errors and biases, particularly in the Caribbean Sea and Gulf of Mexico where ARGO floats are usually not present. Future plans include the use of Observing System Simulation Experiments to evaluate the impact of new observational strategies.

1. BACKGROUND

For a coupled tropical cyclone (TC) prediction model to correctly forecast intensity evolution, it must accurately predict the magnitude and pattern of sea surface temperature (SST) cooling over the region directly forced by the storm, particularly beneath the storm's inner core. The ocean model component must therefore accurately predict the magnitude and pattern of temperature cooling within the ocean mixed layer (OML) under intense TC forcing. SST evolution is sensitive to the initial temperature-salinity and associated density profiles provided to the ocean model because between 70 and 90% of OML cooling typically results from the entrainment of colder water into the OML. Initial errors in the thickness of the surface warm layer can produce large errors in the predicted SST cooling rate [1]. Initial stratification errors will also degrade the rate of OML deepening and cold water entrainment produced by the vertical mixing parameterization of the ocean model.

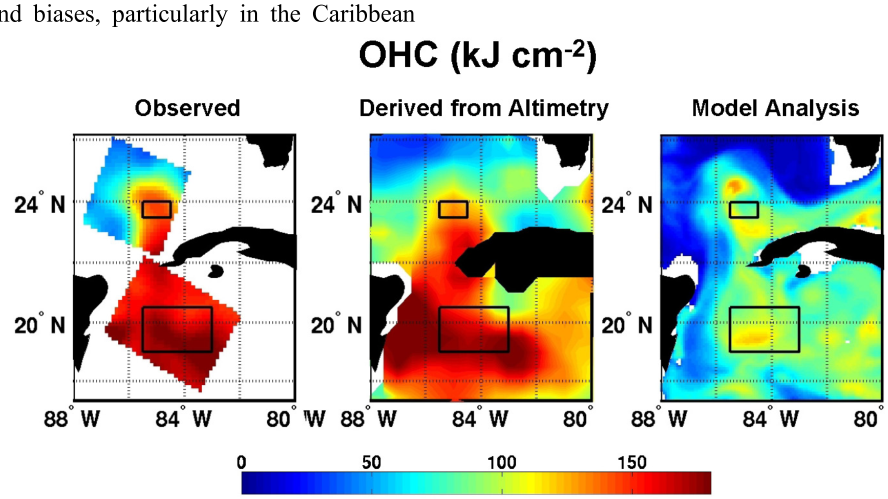

Figure 1. Prior to Hurricane Isidore (2002), OHC mapped from aircraft observations (left), derived from satellite altimetry (center) and obtained from a HYCOM-based data-assimilative ocean hindcast

These issues place a high premium on accurate initialization of ocean model fields. Basin-scale and global data-assimilative ocean hindcasts produced by the Global Ocean Data Assimilative Experiment (GODAE) are an attractive choice for ocean model initialization because they provide balanced ocean fields to the nested regional ocean model. However, [1] demonstrated that these products often have large errors and biases in the upper ocean that degrade SST forecasts. Examples are presented here for Hurricanes Isidore (2002) and Katrina (2005).

2. ERRORS AND BIASES IN OCEAN INITIAL FIELD PRIOR TO ISIDORE AND KATRINA

Maps of ocean heat content relative to 26°C (OHC) prior to Hurricane Isidore within a region covering the northwest Caribbean Sea and southeast Gulf of Mexico (Fig. 1). OHC takes into account both the temperature and thickness of the upper ocean warm layer, and equals zero if nearsurface water warmer that 26°C is not present [2]. Since SST in the western Atlantic is usually above 29°C during most of hurricane season, low OHC typically indicates a thin warm layer that is susceptible to rapid entrainment cooling. Regions with large OHC typically cool by about 1°C or less while regions with small OHC cool by up to several degrees due to shear-induced mixing.

One of the OHC maps prior to Isidore (Fig. 1) was produced by the optimum interpolation of targeted aircraft profile measurements [3] within two subregions, one in the Gulf of Mexico and the other in the Caribbean. The second map was produced by the analysis of satellite altimetry in conjunction with satellite SST and climatological ocean information [4]. The third map was extracted from an Atlantic Ocean data-assimilative hindcast produced using the HYbrid Coordinate Ocean Model (HYCOM) at the U. S. Naval Research Laboratory [5]. Correspondence between the aircraft observations and the satellite-derived OHC pattern is good, but the data-assimilative ocean model clearly underestimated OHC throughout the domain.

A similar cold bias in the HYCOM product existed in the Gulf of Mexico prior to hurricane Katrina (Fig. 2). The direct result of these cold biases in the initial fields is substantial overcooling in simulations of the ocean response to these two storms (not shown). In a coupled forecast model, this overcooling will significantly influence air-sea heat exchange and potentially the accuracy of the intensity forecast. One important contribution to model bias is the scarcity of upper-ocean profile observations. At any given time, there are usually no ARGO floats in the regions shown in Figs. 1 and 2 because Caribbean islands usually block entry while any that do enter or are released are swept through and out of the domain by the Loop Current and Florida Current.

As shown in Figs. 1 and 2, the location of major ocean features is generally realistic in the HYCOM ocean analysis. This realism has been demonstrated for other storms such as Hurricane Ivan [1], and is a direct result of the assimilation of satellite altimetry. However, due in part to insufficient *in-situ* observational coverage, a significant cold bias is usually encountered in the HYCOM analysis. The data assimilation procedure [6] used a water-mass conserving technique [7] that projects anomalous temperature and salinity profiles associated with anomalous SSH downward into the water column. However, this procedure is optimized to adjust the main pycnocline structure and does not optimally reproduce anomalies in the temperature and thickness of the nearsurface warm layer. New strategies are required to improve ocean model initialization, particularly in the Caribbean Sea and Gulf of Mexico where ARGO floats are rarely present.

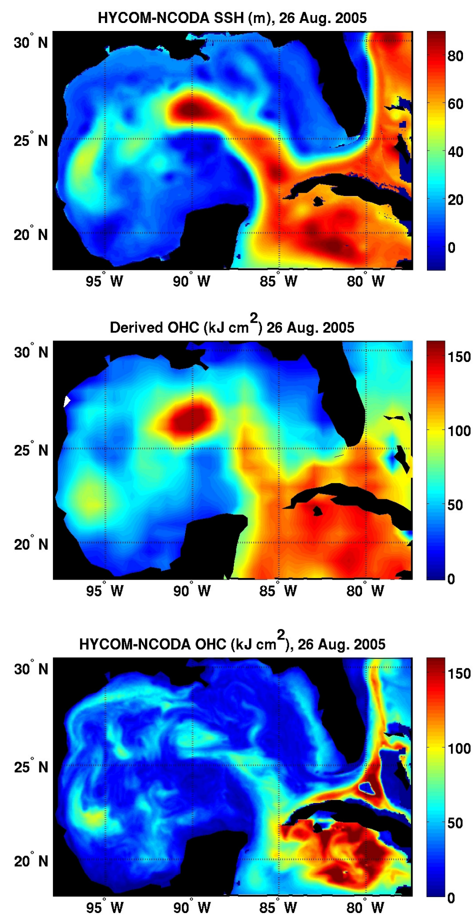

Figure 2. Prior to Hurricane Katrina, sea surface height (SSH) from a HYCOM-based data-assimilative ocean hindcast (top) along with OHC derived from satellite altimetry (center) and obtained from the ocean hindcast (bottom)

3. STRATEGY FOR IMPROVING OCEAN MODEL INITIALIZATION

Assimilation of satellite altimetry is necessary to accurately initialize important ocean features, but additional upper-ocean observations are required to reduce errors and biases in temperature and stratification profiles before ocean models can be expected to accurately forecast SST evolution. The required observing system improvements can be divided into two categories:

- enhancements to the operational observing system provided by satellites, floats and drifters, volunteer observing ships, and ocean moorings (e.g. PIRATA) that are made available in near-real time to the operational centers that produce GODAE data-assimilative ocean hindcasts; and
- targeted ocean observations acquired prior to individual storms by aircraft or unmanned autonomous vehicles.

A reasonable strategy should first consider cost-effective improvements to the operational observing system, and then consider the use of targeted observations in regions where operational observations do not constrain operational ocean hindcasts with sufficient accuracy. If targeted observations are required, mechanisms must be set up to provide these observations in near-real time to operational centers.

Due to the expense of these additional observations, both operational and targeted, Observing System Simulation Experiments (OSSEs) have a potentially important role in designing optimum ocean observing strategies. Regional considerations are important due to uneven distribution of observations such as ARGO floats, and also because properties of ocean features associated with the magnitude and horizontal gradients of OHC have large regional differences. Our planned work in the near future will include the evaluation of existing GODAE products for ocean model initialization prior to a large number of storms in different ocean regions to quantify the need for additional observations [3].. To the extent that additional measurements are needed to improve upper ocean stratification and OHC, we will use OSSEs to evaluate new observational strategies.

4. REFERENCES

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