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THE IMPACT OF OCEANIC HEAT CONTENT ON HURRICANE INTENSITY FORECASTS USING THE SHIPS MODEL

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1. INTRODUCTION

Both atmospheric and oceanic influences can aid in tropical cyclone (TC) intensification. Studies of the ocean’s role are now being focussed on sub-surface ocean structure in conjunction with sea surface temperature (SST) instead of previous research of SST alone. In regions where the oceanic mixed layer is deep, the SST cooling due to upwelling and mixing tends to be reduced, so there is considerably more thermal energy available to be transferred to the atmosphere than in areas where a very shallow layer of warm water exists. If the amount of thermal energy is known, a relationship between the ocean and TC intensity change can be explored. Not only is it critical to know the depth of the oceanic mixed layer, but also detecting where mesoscale features such as warm and cold core rings are located. Since these oceanic regimes and features can be relatively close to coastal regions, they can produce sudden intensity changes that can be detrimental to life and property (Marks *et al*. 1998). Shay *et al.* (2000) demonstrated how these mesoscale features, in particular a warm core ring, contributed to the intensification of Hurricane Opal in 1995. If ocean heat content (OHC) can statistically and dynamically be incorporated into guidance, then intensity forecasts could be improved. Through the retrieval and analysis of high resolution blended TOPEX/Poseidon (T/P) and European Research Satellite (ERS-2) radar altimetry data in combination with hydrographic data, the OHC relative to 26°C water is estimated by applying the approach used by Mainelli-Huber (2000). By evaluating the pre-storm oceanic conditions combined with the atmospheric factors, the contribution of the overall TC environment to intensity change is addressed.

In this study, the relationship between OHC and tropical cyclone intensity change is investigated for cases from 1997-2001. Atmospheric factors are accounted for by combining the OHC data with the set of predictors included in the Statistical Hurricane Intensity Prediction Scheme (SHIPS). The SHIPS model (DeMaria and Kaplan 1999) includes climatology and persistence, atmospheric effects such as environmental vertical wind shear, and SST. The OHC data will be evaluated to determine if it adds to the predictive information already included in SHIPS.

2. DATA SAMPLE

The pre-storm OHC was analyzed from 54 Atlantic tropical cyclones from 1997-2001 on a domain that extended from 0-40°N and 100-50°W. The OHC was then averaged along the observed storm track and added to the SHIPS database. For comparison, the climatological OHC was also obtained by interpolating monthly mean values to the storm locations. The SHIPS model predicts intensity change (maximum wind) at 0-12, 0-24, … 0-72 h, so the OHC was averaged along the storm track over these same time intervals. The data sample is restricted to cases that remain over water for the entire forecast interval. Only those cases where the storm was initially inside the OHC analysis domain were included in the sample. The OHC was held constant for the part of the track that moved out of the OHC analysis domain. With these restrictions, there are 436 cases at 12 h, which gradually diminishes to 207 cases at 72h.

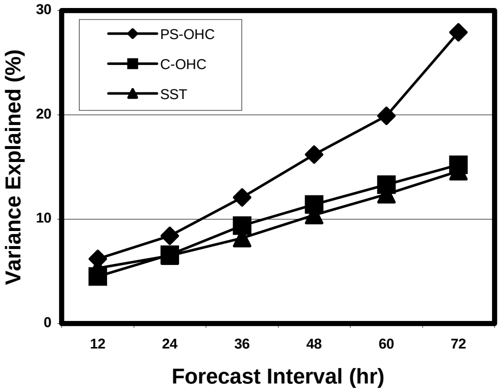

Figure 1. The variance explained by the correlation of the pre-storm OHC, the climatological OHC, and the SST with the intensity change at 12-72 h.

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3. RESULTS

As a first test of the predictive capabilities, the SST along with the climatological and pre-storm OHC were individually correlated with the intensity changes at 12-72 h. Figure 1 shows the square of the correlation coefficient (variance explained) for each parameter. This figure shows that the SST and the climatological OHC explain about the same amount variance of the intensity changes. However, the pre-storm OHC explains a considerably larger fraction of the variance, especially after 24 h.

Although the results in Fig. 1 are encouraging, the OHC would need to add to the information already contained in SHIPS in order to improve the prediction. To test this possibility, the 14 predictors of the 2001 operational version of SHIPS were fitted to the observed intensity changes, using the 1997-2001 sample of cases with the OHC data. SHIPS uses multiple-regression for the data fit. Once the regression coefficients are determined, the average intensity forecast error was calculated for this 14-predictor version of the model. Then, a 15th variable was added (pre-storm or climatological OHC) and the process was repeated. The statistical significance (at the 99% level) of the coefficient for the OHC variable was determined using a standard F-test, and the reduction in the average forecast error was calculated.

When the extra variable was the climatological OHC, the regression coefficient was not statistically significant at any forecast interval from 12-72 h, and the average forecast errors were reduced by 1% or less. This result suggests that the climatological OHC does not provide any additional predictive information for SHIPS.

When the pre-storm OHC was included as the 15th variable, the regression coefficient was statistically significant at all time periods except 12 h. The forecast errors were reduced by 1.0, 2.2, 3.5, 4.7, 5.2 and 3.8% at 12-72 h. This result indicates that the pre-storm OHC is providing independent predictive information for the SHIPS model, and should lead to improved forecasts.

In the above evaluation, the reduction in the forecast error was determined in the context of a dependent sample of 436 cases with 12 h forecasts. The total sample for the version of SHIPS that will be run during the 2002 Atlantic hurricane season includes about 1800 forecast cases from 1989-2001 over the entire Atlantic basin. To directly include the OHC as a predictor, it would be necessary to eliminate a large fraction of the cases in the SHIPS developmental sample. This reduction would probably have a negative impact on the forecast performance on independent (real-time) cases. To avoid this problem, the SHIPS model without the OHC data will be developed using the total data sample. Then, the differences between the predicted and observed intensity changes will be calculated. A second regression will then be performed with the OHC data as the independent variable, and the deviations from the SHIPS prediction as the dependent variable. Using this approach, the smaller data sample will be used only for the development of the relationship between the intensity changes and OHC. In real-time, the second equation can be applied as a correction to the SHIPS forecast if the OHC data is available.

The SHIPS database is also being used to develop a rapid intensification index, where the emphasis is on identifying storms that have the potential to rapidly strengthen, rather than on the prediction of intensity changes of the basin-wide sample. The impact of the OHC on the rapid intensification is also being investigated.

4. CONCLUDING REMARKS

The ocean heat content was estimated for a large sample of Atlantic tropical cyclones from 1997-2001 in the region from 0-40^{o}N and 100-50^{o}W (436 forecast cases from 54 storms), and the relationship with intensity change was investigated. Results showed that the pre-storm OHC had a much higher correlation with the observed intensity changes at 12-72 h than the climatological OHC or the SST. Results also showed that the pre-storm OHC significantly improved the predictions from the SHIPS model in a dependent evaluation. This result suggests that the pre-storm OHC can provide predictive information that is independent of the SST and atmospheric parameters already included in the model. The impact of the OHC on the real-time forecasts of the SHIPS model will be evaluated during the 2002 hurricane season, as part of the Joint Hurricane Test-bed of the U.S. Weather Research Program.

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