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A SIMPLE PARAMETERIZATION OF SEA SURFACE COOLING BENEATH A HURRICANE INNER CORE

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1. INTRODUCTION

Wind-induced upwelling often leads to cooling of the sea surface temperature (SST) along the wake of a hurricane. These cold wakes can exhibit SST reductions on the order of 4-5° C, and when tropical cyclones (TC) cross over these wakes a decrease in intensity is often observed. However, the impacts of localized SST cooling on TC intensity are not relegated to such a large magnitude of cooling. Cione and Ulhorn (2003) show that even the smaller magnitudes of cooling, on the order of 1-2° C, may play an important role in hurricane intensity change when located directly beneath the hurricane inner core due to their large impact on the maximum total enthalpy flux in this high-wind region. These results suggest that in order to accurately determine hurricane intensity change, this inner core SST change must be properly quantified.

The current version of the Statistical Hurricane Intensity Prediction Scheme (SHIPS) model uses a simple parameterization for inner core SST change that depends on latitude and storm translational speed. The use of this parameterization in the SHIPS model run over dependent years 1982-2006 provides improvement in forecast skill over using no parameterization at all. However, there are several other storm-based and oceanic parameters that may contribute to localized SST change that have not yet been considered.

The purpose of this preliminary study is to investigate the role of storm-related and upper ocean variables, namely storm intensity and ocean heat content, in inner core SST change, and to develop a simple parameterization for inner core SST change and its resultant impact on hurricane development. Since SST observations under the eyewall are scarce, output from the HWRF ocean-atmosphere coupled model is used as data for the statistical development. A multiple regression analysis is used to investigate the contribution of parameters and to quantify the relationship between inner core SST change and the parameters.

2. DATA

Reruns of the HWRF atmosphere-ocean coupled model for Atlantic named tropical systems from 2004-2006 were used for this analysis. Although not all storms were rerun for this dataset, 491 runs for 35 of the 55 named storms in that time period were available. For each storm, runs were available every 12 hrs (0 and 12 UTC). Parameters of interest were calculated for each run at the analysis time and the 24, 48, 72, 96 and 120 h forecast times. The model fields used in this study include analysis and forecasted TC positions, intensities, and ocean temperature profiles.

3. PARAMETERS

The parameter values needed for this study are storm translational speed, maximum intensity, ocean heat content (OHC), and inner core SST change. Translational speed was computed from the HWRF forecast center positions and the maximum intensity is directly given in the HWRF forecast at each forecast time. Ocean heat content (OHC) was derived from model ocean temperature profiles using equation 1 from Cione and Ulhorn (2003),

$$Q_H(x, y, t) = \rho c_p \int_{z(T=26)}^{0} \Delta T(x, y, z, t)\, dz, \tag{1}$$

where c_p is the specific heat of water at constant pressure (4178 J kg^{-1} K^{-1}), ρ is the average density of the upper ocean (1026 kg m^{-3}) and ΔT is the difference between T(z) and 26° C over the depth interval dz. The units of Q_H (i.e., OHC) are given in kJ cm^{-2}. The shallowest point available in the HWRF ocean temperature profile was used at the SST, which was at a depth z = 5 m. The change in inner core SST was

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calculated at each forecast time by subtraction of the inner core SST at that time from the SST at the analysis time for that run. Examples of HWRF-derived SST and OHC are shown in Figures 1 and 2, respectively. Fig. 1 illustrates the cold wake behind Hurricane Rita (2005) and the smaller (~ 1°C) SST reduction beneath Rita's inner core.

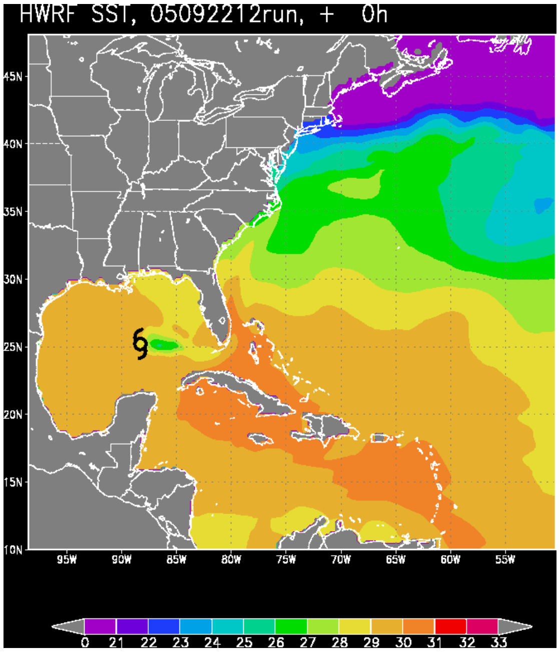

Figure 1. Plot of SSTs (in °C) on 9/22/05 at 12 UTC, when Hurricane Rita had intensity of 120 kts.

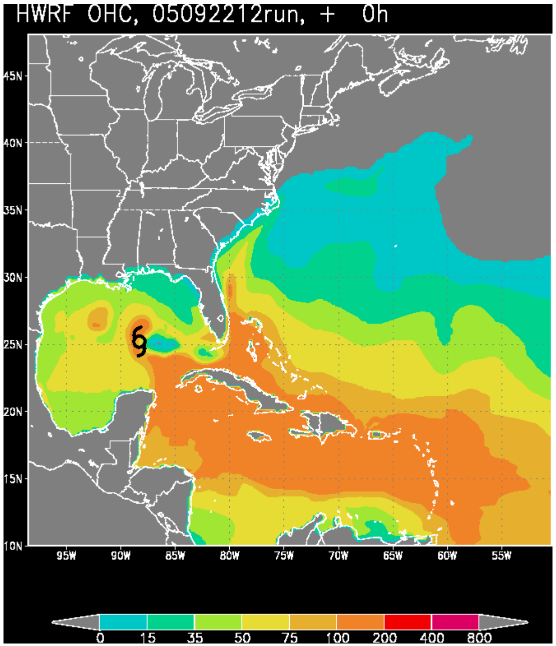

Figure 2. Plot of OHC (in kJ cm^{-2}) at the same time as Figure 1.

This analysis requires the SST and OHC values beneath the TC inner core. Following the methodology of Cione and Ulhorn (2003), the TC inner core was defined as the area within 60 km radius of the TC center position. Inner core values were defined as the average of all data points within this radius and each inner core needed to have valid data at 90% of its included model grid points to be included in the analysis. In other words, storms with inner cores more than 10% over land or with more than 10% of their ocean data missing or having errors were not included.

4. REGRESSION ANALYSIS

After data processing, there were 1399 HWRF cases for use in the multiple regression analysis. The dependent variable used for the regression is the inner core SST decrease, defined as $dSST_{IC}$ = SST(t=0) – SST(t=t'). The independent variables were maximum intensity (Vmax), translational speed (Spd), and OHC. In addition to the regression analysis performed with these three values, which we will refer to as the linear parameterization analysis or LP, a regression including the six additional quadratic terms was also performed to develop the quadratic parameterization (QP). Each parameter set was standardized prior to the regression analysis. The resulting coefficients are shown in Table 1.

The variance explained (R^2) by LP and QP are 47% and 57%, respectively. The signs of the coefficient values for LP make physical sense when one considers each dependent variable's expected impact on the amount of SST cooling under the TC inner core. More intense TC would be expected to produce greater upwelling due to stronger surface winds, and hence we would expect a positive coefficient. However, the faster a TC is moving the less time its winds have to induce upwelling in the ocean below, and hence we'd expect a negative coefficient. OHC is related to the depth of the 26°C isotherm, which in turn indicates the depth of the warm waters of the mixed layer. One would expect regions with larger OHC (i.e., deeper mixed layer) to be more resistant to large SST decreases resulting from the upwelling of colder water beneath the mixed layer. The relationship would lead to a negative coefficient, which is what we find for the LP analysis.

Since the dependent and independent variable values were normalized prior to regression analysis, the magnitude of the coefficients also tells us which of the independent variables are contributing most to the regression analysis. In comparing the 3 linear terms for both LP and QP, the storm intensity contributes the most to the relationship by far, with the translational speed being the next largest contributor and OHC contributing the least.

Table 1. Coefficients (normalized) derived from multiple regression analysis for the linear parameterization (LP) and the quadratic parameterization (QP).

	LP	QP
Maximum Intensity (Vmax)	0.625	0.751
Translational Speed (Spd)	-0.361	-0.400
Ocean Heat Content (OHC)	-0.121	0.264
$(\mathrm{Vmax})^2$		0.712
$(\mathrm{Spd})^2$		0.597
$(\mathrm{OHC})^2$		-0.008
Vmax*Spd		-0.770
Vmax*OHC		-0.701
Spd*OHC		0.058

5. EVALUATION, CONCLUSIONS AND FUTURE WORK

To test these new parameterizations, the current SST cooling parameterization inbedded in the SHIPS model was replaced by LP and QP and run over the developmental reanalysis dataset, which includes cases from 1982 to 2006. Only cases for which satellite altimetry OHC was available were used for all testing runs, which limited data availability to cases after 1995. Test runs included a run with no parameterization, with the current parameterization (CP), LP, and QP, and were run over the same set of data. The percent forecast skill improvement was then calculated for each parameterization in reference to using no parameterization at all, which is shown in Figure 3.

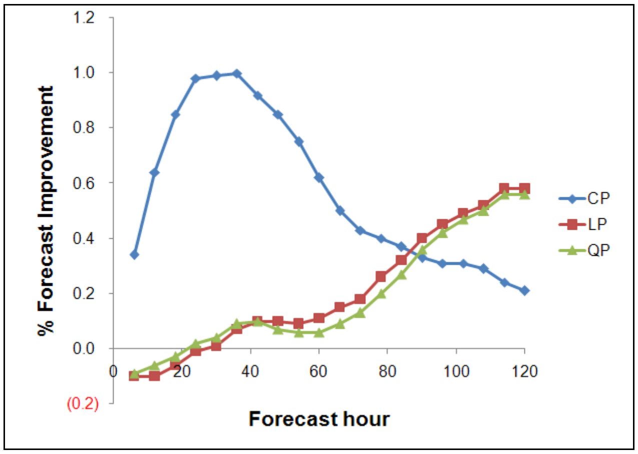

Figure 3. The percent SHIPS intensity forecast improvement at various forecast hours through 120 h for the current parameterization (CP) and the new linear (LP) and quadratic (QP) parameterizations.

Fig. 3 shows that the current parameterization outperforms both of the new parameterizations at earlier forecast times, but that after t = 90 h the new parameterizations provide a larger improvement in forecast skill. All parameterizations provide some amount of forecast improvement over using no parameterization after t=24 h, supporting the assertions that inner core SST changes have an influence on TC intensity and that this relationship should not be ignored when forecasting TC intensity and intensity change.

The preliminary results of this analysis imply that the current parameterization used in the SHIPS model is improving its forecast skill for all forecast times. However, the results from substituting LP and QP show that CP may not be encompassing the entirety of the physics associated with inner core SST change, particularly at larger forecast times. Further work needs to be done to examine the relationship between SST cooling and storm intensity and OHC. Other storm characteristics such as wind radii structure and other ocean characteristics such as thermocline depth may also be examined.

6. REFERENCES

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