Developing an Inner-Core SST Cooling Predictor for Use in Ships

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Principal Investigator: **Joseph Cione**
Hurricane Research Division
NOAA/AOML
Miami, FL 33149

Co- Investigator: **John Kaplan**
Hurricane Research Division
NOAA/AOML
Miami, FL 33149

Co-Investigator: **Chelle Gentemann**
Remote Sensing Systems
Santa Rosa, CA 95401

Co-Investigator: **Mark DeMaria**
NOAA/NESDIS/ORA
Fort Collins, CO 80523

1. Introduction

Recent results from Cione and Uhlhorn (2003) illustrate a clear link between inner-core sea surface temperature (SST) cooling (relative to ambient SST conditions ahead of the storm) and subsequent TC intensity change (Figure 1).

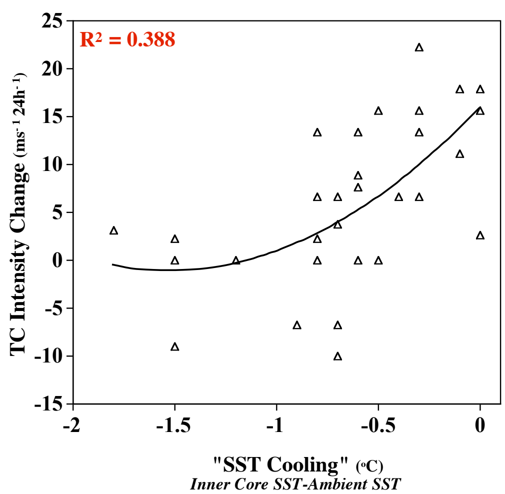

Figure 1. Scatter plot of 24h TC intensity change as a function of SST cooling (inner core - ambient SST) for 23 hurricanes between 1975-2002. The resulting polynomial (2nd order) best-fit is illustrated. Here, 38.8% of the variance with intensity change is explained (i.e. r^2=0.388). The units for intensity change are given as m s^{-1} 24 h^{-1} while SST is measured in ^{o}C. [Figure adapted from Cione and Uhlhorn (2003)].

Simply stated, hurricanes that cooled the least intensified the most. Relatively modest changes in inner-core SST (order 1.0°C) were shown to alter maximum total enthalpy flux (latent plus sensible) by 45% or more. Changes in surface energy flux of this magnitude can be the difference between a system that rapidly intensifies and one that quickly decays. Complicating matters further, inner core SST cooling patterns often go undetected since it is the most difficult region of the hurricane to accurately and routinely observe. Since operational coupled models have had difficulty simulating and validating inner-core SST cooling patterns (Bender et al 2000), the recent findings from Cione and Uhlhorn (2003) highlight the critical (and immediate) need to accurately account for inner-core SST conditions.

For several years, the Statistical Hurricane Intensity Prediction Scheme (SHIPS) (DeMaria and Kaplan 1999) has shown skill in predicting TC intensity change (DeMaria et al. 2002). The primary goal of this JHT project is to build on SHIPS existing skill by providing improved ambient SSTs as well as new and critically important SST estimates within the difficult to observe high wind inner-core TC environment. It is believed that incorporating a more accurate depiction of the ocean surface boundary condition (SST) into SHIPS will directly result in improved forecasts of TC intensity change, and as such, address the Tropical Prediction Center's (TPC) highest forecast priority (TPC A-1).

2. Accomplishments to date

2a. Algorithm Development

Since mid-July 2003, significant progress has been made towards developing Version 1.0 of the Predictive Inner-core SST Cooling Algorithm (PISCA) (Figure 2). Building on in-situ inner core hurricane observations documented in Cione and Uhlhorn (2003), a statistically stable cooling algorithm that utilized along track SST, TC latitude and storm speed as predictors was developed.

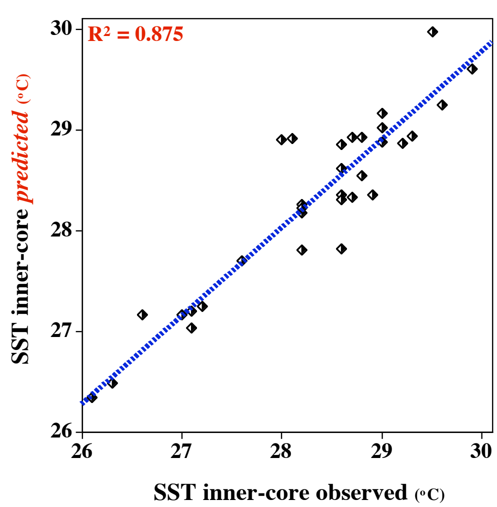

Figure 2. Scatter plot of in-situ SST vs. *predicted* inner-core SST [using the hurricane inner-core SST cooling algorithm developed from the 23-hurricane (1975-2002) sample from Cione and Uhlhorn (2003)]. The linear best-fit shown explains 87.5% of the variance (i.e. r^2=0.875). SST is given in °C.

2b. Dependant Sample Results (1989-2002)

Working closely with J. Kaplan and M. Demaria, Version 1.0 of PISCA for the Atlantic basin was tested in a dependant mode using 1000s of individual forecasts taken from the SHIPS 1989-2002 storm database. Analyses incorporating observations from tropical depression strength or greater systems resulted in improved SHIPS intensity forecasts over all time periods between 12-120h. These results are encouraging since no mean degradation was found at any forecast interval even though many weak systems were included in the analysis. When results were stratified by initial storm intensity and observed intensity change, the positive impact of utilizing inner core SSTs on SHIPS forecasts was found to be even more significant (see Figures 3-4).

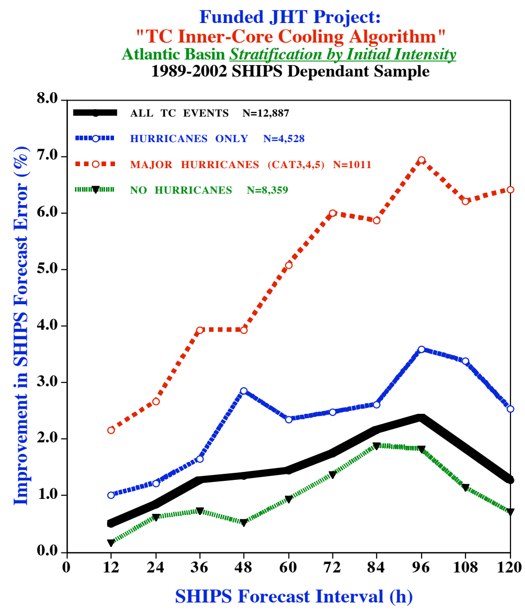

Figure 3. Improvement in SHIPS forecast error (in %) as a function of forecast interval (from 12h-120h) when inner core SST was used in lieu Reynolds SST. The four lines shown are: all forecasts of tropical depression strength or greater (BLACK); all forecasts of tropical depressions and tropical storms (GREEN); all forecasts of hurricanes (BLUE); and forecasts of major (Category 3, 4 and 5) hurricanes (RED). "N" refers to the total number of 12-120h forecasts within the sample.

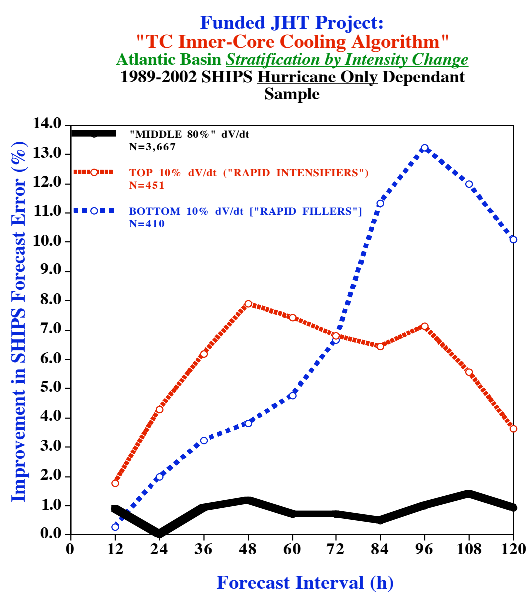

Figure 4. Improvement in SHIPS forecast error (in %) as a function of forecast interval (from 12h-120h) when inner core SST was used in lieu Reynolds SST. The three lines shown are: all forecasts of hurricanes EXCLUDING rapid intensifiers (top 10% of the sample) and rapid fillers (bottom 10% of the sample) (BLACK); ONLY forecasts of rapid intensifiers (top 10% of the sample) (RED); ONLY forecasts of rapid fillers

Figures 3 and 4 illustrate that intensity forecasts involving major (Category 3 4 and 5) hurricanes and forecasts associated with rapid intensity change (top and bottom 10% of the hurricane sample) netted the largest forecast improvements (7-13.5%) when PISCA was used in lieu of Reynolds SSTs (currently used operationally in SHIPS). These very encouraging results were recently presented in detail at the 2004 IHC meeting held in Charleston (1-5 March, 2004).

2c. Independent Sample Results (2003 Atlantic season SHIPS forecasts)

Given the inherent difficulties associated with accurately predicting TC intensity change and the obvious public concern associated with a major hurricane landfall event, it is very encouraging that PISCA appears to work best when forecasters potentially need it the most.

While these dependent sample results are very significant, the next step was to test the impact of using PISCA on an independent storm sample. Working closely with M. DeMaria and C. Gentemann in the spring of 2004, SHIPS forecast using PISCA estimates as well additional microwave-derived ambient SST values were tested in the SHIPS model using data from the 2003 Atlantic Hurricane season. Baseline SHIPS 2003 forecasts (that use Reynolds weekly SSTS) were compared with re-run SHIPS forecasts using PISCA and microwave SSTs. In addition, 50km resolution NCEP "real-time global" (RTG) daily SSTs were tested. The summary results from these SHIPS model re-runs for the 2003 season are shown in Table 1.

Table 1. SHIPS Forecast Sensitivity to SST (2003 North Atlantic Hurricane Season)

SHIPS Average Intensity Forecast Skill (relative to SHIFOR) Using Alternate SSTs (%)							
	Forecast Interval (hr)						
Model	12	24	36	48	72	96	120
SHIPS w/Reynolds ***(SST: weekly-100km-IR-operational)***	16.3	30.2	31.1	35.3	31.7	13.9	-10.0
SHIPS w/PISCA ***(SST: predicted-inner core)***	17.0	30.3	32.2	36.0	37.0	24.8	1.4
SHIPS w/ AMSR-E ***(SST: daily-25km-microwave)***	17.2	31.4	33.7	36.7	29.7	12.8	-10.6
SHIPS w/NCEP RTG ***(SST: daily-50km-IR)***	15.9	29.1	30.8	34.1	27.2	10.2	-12.3
SHIPS w/PISCA *minus* SHIPS w/Reynolds	**0.7**	**0.1**	**1.1**	**0.7**	**5.3**	**10.9**	**11.4**
No. Cases	*318*	*289*	*260*	*232*	*183*	*146*	*121*

Table 1. SHIPS average forecast sensitivity using various SST estimates for the 2003 North Atlantic hurricane season. SSTs tested include Reynolds (operationally used in SHIPS), PISCA-derived SSTs, daily microwave AMSR-E derived SSTs and IR daily SSTs (NCEP RTG). The skill shown is calculated as the fractional increase/decrease in forecast error from the baseline SHIFOR intensity forecast. Positive (negative) values denote forecast improvement (degradation) over SHIFOR. Shown in red, SHIPS w/PISCA minus SHIPS w/Reynolds depicts the forecast skill improvement found when SHIPS forecasts using PISCA SSTs are compared with SHIPS forecasts using Reynolds SSTs.

From Table 1, we see that SHIPS w/Reynolds SSTs, AMSR-E microwave SSTs and SHIPS w/ NCEP daily IR SSTs improve upon SHIFOR for forecast intervals less than 120 hours, while only the SHIPS w/PISCA forecasts improve on SHIFOR over <u>all</u> intervals through 120 hours. Table 1 also shows both PISCA and AMSR E SST improvements relative to SHIFOR over the 12-48h period are greater than SHIPS w/Reynolds improvements over that same timeframe. Additionally, significant average skill improvements were found (over SHIPS w/Reynolds) between 72-120h when PISCA SST estimates were used. Over the 72-120h forecast interval, average forecast average skill improvement (relative to SHIPS w/Reynolds) was found to be 8.8% for 450 cases and 11.1% between 96-120h.

In addition to the mean 2003 seasonal improvements shown above, Table 2a and 2b illustrate results for the (only) two storms (Fabian and Isabel) that were observed to rapidly intensify (dV/dt $\geq$30kts/24h) during the 2003 Atlantic hurricane season. Similar to findings shown in Table 1, SHIPS forecasts using PISCA outperformed the corresponding 'baseline' SHIPS forecasts using 100km weekly Reynolds SST. These results are also consistent with key findings illustrated in the dependant sample analysis shown in Section 1, where the magnitude of the forecast improvement (relative to SHIPS w/Reynolds) when PISCA SSTs were used was maximized during cases of significant intensity change. While the results in Table 2a and 2b are not as dramatic as found with PISCA estimates, when average forecasts are combined for both Fabian and Isabel an overall 1.5% skill improvement was found when daily AMSR-E microwave SST were used in SHIPS (relative to weekly Reynolds values).

Table 2a. SHIPS Forecast Sensitivity to SST (HURRICANE FABIAN 2003)

SHIPS Average Intensity Forecast Skill (relative to SHIFOR) Using Alternate SSTs (%)							
	Forecast Interval (hr)						
Model	12	24	36	48	72	96	120
SHIPS w/Reynolds *(SST: weekly-100km-IR-operational)*	4.3	7.1	7.9	13.5	19.3	0.0	-24.6
SHIPS w/PISCA *(SST: predicted-inner core)*	1.7	12.0	16.1	20.2	41.3	34.2	1.3
SHIPS w/ AMSR-E *(SST: daily-25km-microwave)*	9.0	12.3	11.5	15.3	21.2	4.5	-20.2
SHIPS w/NCEP RTG *(SST: daily-50km-IR)*	4.7	7.4	8.1	14.7	21.5	4.3	-21.2
SHIPS w/PISCA *minus* SHIPS w/Reynolds	**-2.9**	**4.9**	**8.2**	**6.7**	**22.0**	**34.2**	**25.9**
No. Cases	*45*	*43*	*41*	*39*	*35*	*31*	*27*

Table 2a. SHIPS average forecast sensitivity using various SST estimates for Hurricane Fabian (2003). SSTs tested include Reynolds (operationally used in SHIPS), PISCA-derived SSTs, daily microwave AMSR-E derived SSTs and IR daily SSTs (NCEP RTG). The skill shown is calculated as the fractional increase/decrease in forecast error from the baseline SHIFOR intensity forecast. Positive (negative) values denote forecast improvement (degradation) over SHIFOR. Shown in red, SHIPS w/PISCA minus SHIPS w/Reynolds depicts the forecast skill improvement (degradation in blue) found when SHIPS forecasts using PISCA SSTs are compared with SHIPS forecasts using Reynolds SSTs.

Table 2b. SHIPS Forecast Sensitivity to SST (HURRICANE ISABEL 2003)

SHIPS Average Intensity Forecast Skill (relative to SHIFOR) Using Alternate SSTs (%)							
	Forecast Interval (hr)						
Model	12	24	36	48	72	96	120
SHIPS w/Reynolds ***(SST: weekly-100km-IR-operational)***	25.4	26.2	26.2	31.3	21.3	6.5	-17.1
SHIPS w/PISCA ***(SST: predicted-inner core)***	28.7	28.4	28.2	36.4	32.2	22.4	0.1
SHIPS w/ AMSR-E ***(SST: daily-25km-microwave)***	23.6	25.7	28.8	31.9	17.7	2.7	-19.8
SHIPS w/NCEP RTG ***(SST: daily-50km-IR)***	24.1	23.3	23.6	26.2	14.3	0.2	-21.5
SHIPS w/PISCA *minus* SHIPS w/Reynolds	**2.7**	**2.2**	**2.0**	**5.1**	**10.9**	**15.9**	**17.2**
No. Cases	*49*	*47*	*45*	*43*	*39*	*35*	*31*

Table 2b. SHIPS average forecast sensitivity using various SST estimates for the Isabel (2003). SSTs tested include Reynolds (operationally used in SHIPS), PISCA-derived SSTs, daily microwave AMSR-E derived SSTs and IR daily SSTs (NCEP RTG). The skill shown is calculated as the fractional increase/decrease in forecast error from the baseline SHIFOR intensity forecast. Positive (negative) values denote forecast improvement (degradation) over SHIFOR. Shown in red, SHIPS w/PISCA minus SHIPS w/Reynolds depicts the forecast skill improvement found when SHIPS forecasts using PISCA SSTs are compared with SHIPS forecasts using Reynolds SSTs.

3. Proposed JHT year 2 work

As shown earlier in this report, Version 1.0 of the North Atlantic Inner-Core SST cooling algorithm was recently successfully tested using independent data from the 2003 Atlantic hurricane season. This effort will continue in 2004. The algorithm will be incorporated into a parallel version of SHIPS to test the impact of the algorithm on SHIPS intensity forecasts in real-time during the 2004 North Atlantic hurricane season.

Working in collaboration with M. Mainelli (TPC), preliminary efforts have begun to test the feasibility of incorporating a useful 'sub-surface' predictor into the cooling algorithm. At this time however, it is unknown if a viable new predictor will emerge or if it will materially improve the performance of the Version 1.0 algorithm. Nevertheless, attempts will be made to enhance the existing cooling algorithm by testing several potentially promising sub-surface predictors.

Another proposed enhancement includes incorporating high resolution (in time and space) SST data directly into the SHIPS model. Preliminary testing in this area has begun (C. Gentemann and M. DeMaria). Since the cooling algorithm utilizes an 'ambient' SST along the proposed storm track, it is believed that improvements to the ambient SST currently used in SHIPS (Reynolds weekly SSTs) will improve inner-core SST estimates, and as a result, future SHIPS forecasts of intensity change.

4. Changes to existing JHT Year 2 timeline and Year 2 budget

Nine months into this JHT project, we are on or ahead of schedule with respect to the timeline of major deliverables originally presented. However like most projects, minor modifications become necessary as the project evolves.

One such minor adjustment is to not pursue algorithm enhancements for non-hurricane strength events in Year 2. The basis for making this decision is two-fold. Recent testing of Version 1.0 of the North Atlantic Inner-Core SST cooling algorithm has shown that the biggest positive impact on SHIPS forecasts has been for stronger systems (of hurricane intensity or greater). After analyzing these results, investigators believe that there is a well-founded scientific basis as to why this is the case. Stronger storms are typically much more organized and more readily exhibit 'inner-core' characteristics and features. Also, the increased winds associated with stronger tropical systems should result in greater variability with respect to surface forcing (i.e. fluxes) for any given inner-core SST change.

The second reason for not pursuing this effort is linked to available resources. Investigating 100's of historical tropical storm and weaker events will take many man-hours to complete with no guarantee that the resulting cooling algorithm will be materially improved. Given the limited resources in our existing budget and perceived marginal scientific benefit, the investigators strongly believe that our efforts would be much better served investigating other avenues, particularly increased efforts to improve ambient SSTs and potentially incorporating a viable 'sub-surface' predictor in the existing algorithm.

The final suggested minor change is one of a budgetary nature. Co-Investigator M. Demaria is requesting travel funds in the amount of $2000 for the FY 2005 cycle in order to attend and present results at the spring 2005 IHC conference. Given the fact DeMaria has made significant contributions towards the success of this JHT project without requesting any funding in FY 2004, we hope the JHT will honor this modest request. All other budgetary requests remain unchanged for FY 2005.

References

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