P535 EVALUATION OF ENHANCED HIGH RESOLUTION MODIS/AMSR-E SSTS AND THE IMPACT ON REGIONAL WEATHER FORECASTS

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1. INTRODUCTION

The use of high resolution MODIS SST composite products to initialize the Weather Research and Forecast (WRF) model has been shown to improve the prediction of sensible weather parameters in coastal regions (LaCasse et al. 2007; Case et al. 2008a). In an extended study, Case et al (2008b) compared the MODIS SST composite product produced operationally by the Short-term Prediction Research and Transition (SPoRT) Center (Jedlovec et al. 2006) to the RTG SST analysis (Thiebaux et al. 2003) and evaluated forecast differences for a 7-month period from February through August 2007 over the Florida coastal regions. In a comparison to buoy data, they found that that the MODIS SST composites reduced the bias and standard deviation over that of the RTG data. These improvements led to significant changes in the initial and forecast heat fluxes and the resulting surface temperature fields, wind patterns, and cloud distributions. They also showed that the MODIS composite products produced at Terra and Aqua satellite overpass times capture a component of the diurnal cycle in SSTs. However, not properly incorporate these effects in the WRF initialization cycle can lead to temperature biases in the resulting short term forecasts.

To support the broader operational use of the MODIS SST composite product for short term weather forecast applications, the SPoRT project has linked the SST data set to the most recent version of the National Weather Service (NWS) WRF Environmental Modeling System (EMS, Rozumalski 2007). The WRF EMS is a complete, full physics numerical weather prediction package that incorporates dynamical cores from both the National Center for Atmospheric Research Advanced Research WRF and the NCEP Non-hydrostatic Mesoscale Model (NMM). The installation, configuration, and execution of either the ARW or NMM models is greatly simplified by the WRF EMS to encourage its use by the NWS WFOs and the university community. The WRF EMS is easy to run on most Linux workstations and clusters without the need for compilers. Version 3 of the WRF EMS (currently a Beta version) contains the most recent public release of the WRF-NMM and ARW modeling system, the WRF Pre-processing System (WPS) utilities, and the NCEP WRF Post-Processing (WPP) program. The system is developed and maintained by the NWS National Science Operations Officer (SOO) Science and Training Resource Coordinator, Dr. Robert Rozumalski. More information on the EMS software can be found in the online user's guide at http://strc.comet.ucar.edu/wrf/wrf_userguide.htm.

In order to initialize the WRF EMS with high-resolution MODIS SSTs, SPoRT developed a version of the composite product consisting of MODIS SSTs over oceans and large lakes with the NCEP Real-Time Global (RTG) product filling data over land points. Filling the land points is required due to minor inconsistencies between the WRF land-sea mask and that used to generate the MODIS SST composites. This methodology ensures a continuous field that adequately initializes all appropriate arrays in WRF. Composites covering the Gulf of Mexico, the western Atlantic Ocean and northern portions of the Caribbean are generated daily at 0400, 0700, 1600, and 1900 UTC. The MODIS SST composite product is output in gridded binary-1 (GRIB-1) data format for a seamless incorporation into WRF via the WPS utilities. The GRIB-1 files are posted online at ftp://ftp.nsstc.org/sstcomp/WRF/, which can be directly accessed by the WRF EMS. The MODIS SST composites are also downloaded to the SOO/STRC data server, which is directly accessible by the WRF EMS and NWS WFOs.

Case et al. (2008b) noted that cloud contamination and data latency may explain some of the SST discrepancies and the reduced performance of the WRF forecasts over some regions and at some forecast times. In an effort to reduce product latency and improve the accuracy and representativeness of the SST composite product, an enhanced compositing approach has been developed and implemented to reduce the shortcomings of the past approach. This paper highlights the enhanced approach, documents its improved representation of SST fields for the Florida coastal regions, and shows the resulting impact on WRF forecasts over Florida and the surrounding coastal waters as a result of using the enhanced product for model initialization.

2. ENHANCED COMPOSITING TECHNIQUE

The original polar orbiting SST data compositing technique, which provides spatially continuous, representative, high-resolution SST fields using data from the Moderate-resolution Imaging Spectrometer (MODIS) on NASA's Terra and Aqua satellites, was developed by Haines et al. (2007). This compositing technique generated four maps of SST data per day using data from the previous days' satellite overpasses to augment and fill in for clouds and missing data in the

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current day's MODIS coverage. The original approach calculated high-resolution (1-km) SST composites based on finding a minimum of three cloud free pixels at each location for a given collection period (up to 30 days). The two warmest pixels were then averaged and the value was used to represent the SST at that pixel. A latency map was generated for each composite that provided information on the number of days of data necessary to find the minimum three cloud free pixels.

The enhanced SST composite described here is a collaboration with scientists working with the Physical Oceanography (PO) DAAC at JPL (Vazquez et al. 2009). Instead of using real time data from direct broadcast ground stations (as used in the original technique), the enhanced approach uses near real time Global High Resolution Sea Surface Temperature (GHRSST) L2P data (Donlon et al. 2007) from the PODAAC. The availability of GHRSST L2P data provides several enhancements to the composite methodology:

- includes passive microwave SST data from the Advanced Microwave Scanning Radiometer-EOS (AMSR-E) into the compositing process,
- implements a straightforward strategy for using the error characteristics in GHRSST L2P data in the calculation of the composites,
- extends the compositing region to the entire West and East Coasts of the United States,
- uses the proximity flags in the GHRSST L2P data to remove cloud and erroneous pixels.

A key component in using these enhancements is the implementation of a more sophisticated temporal weighting scheme which includes observational errors for each data set. In the enhanced approach, SST composites are produced over a given region at four times each day corresponding to Terra and Aqua equator crossing times (i.e., Terra day, Aqua day, Terra night, and Aqua night). Day-time (night-time) AMSR-E SST data from Aqua are used with both Terra and Aqua MODIS day-time (night-time) SST data sets. For a given day and region, the data from the previous seven days form a collection used in the compositing process. At each 1-km pixel, cloud-free SST values (as determined by the L2P confidence flags) from the collection (both AMSR-E and MODIS) are used to form a weighted average based on their latency (number of days from the current day) and quality (also from the L2P data stream). In this way recent, more accurate SST data are given more weight than older data. One of the primary issues involved in incorporating the AMSR-E microwave data in the composites is the tradeoff between the decreased spatial resolution of the AMSR-E data (25-km) and the increased coverage due to it's near all weather capability. In addition, the AMSR-E data are masked within ~100 km of the coastline. To alleviate this limitation, data from Europe's Operational Sea Surface Temperature and Sea Ice Analysis (OSTIA) are incorporated to improve the latency near coastal zones. Currently, the AMSR-E and OSTIA are given a weight of around 20% relative to the MODIS data. In this way the spatial structure observed in the 1-km MODIS data is preserved in the compositing process. An example of the MODIS / AMSR-E SST composite product for June 1, 2007 using the above methodologies is presented in Figure 1. The use of MODIS data preserves much of the detailed structure in the 1-km data as can be seen in the various thermal features such as the loop current in the Gulf of Mexico and details of the Gulf Stream off the East Coast of the United States.

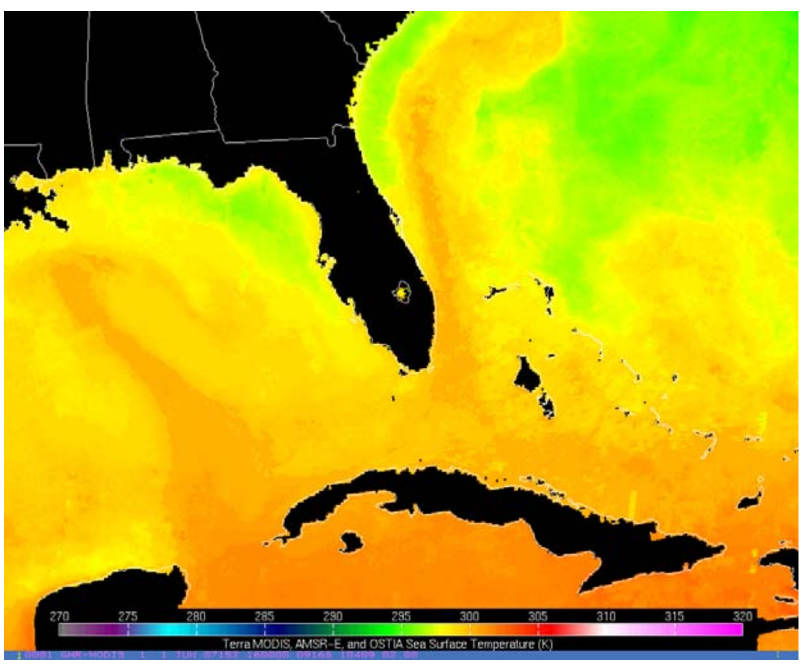
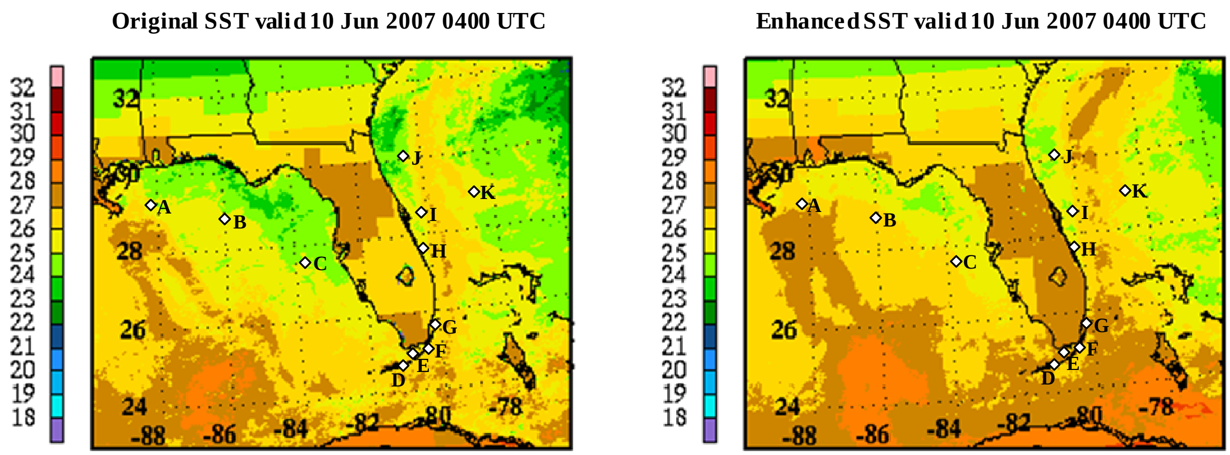


Figure 1. A sample high-resolution SST composite at 1600 UTC 1 June 2007 using the enhanced technique described in the text.

3. VALIDATION OF ENHANCED COMPOSITE

Both the original and enhanced SST compositing algorithms were used to produce SST analyses surrounding the Florida Peninsula during June and July 2007, a subset of the period evaluated by Case et al. (2008b). These composite products were generated four times daily at 0400, 0700, 1600 and 1900 UTC using the enhanced MODIS / AMSR-E compositing approach described above. The purpose of generating the products over these days and times was to examine the improvements in regional forecasts of sensible weather parameters with WRF by using the enhanced composite algorithm. The previous work indicated a cold bias in the SSTs over the use of the RTG SST data during convectively active time periods in south Florida, which led to a degradation in the forecast 2-m temperatures. Product latency was suspected to be a cause for the degraded forecast results of the higher resolution SSTs. June and July over Florida present a time and location of general increased convective activity (with corresponding clouds and MODIS latency) and thus provides an appropriate case to evaluate the performance of the enhanced product.

Initial differences between the two composite products can be assessed by comparing the SST fields for the entire Florida domain. An example of such comparison is shown in Figure 2. At this time, 0400 UTC on 10 June 2007, two major differences are apparent between the products. First, a slight smoothing of temperature features has occurred in the enhanced SST composite compared to the original. [Note that the composites are produced at 1-km spatial resolution but are interpolated to a 2-km forecast grid for use in the WRF model.] This may be due to the lower-resolution AMSR-E data that has been incorporated into the enhanced product algorithm. Second, at many locations the enhanced product displays SST values that are warmer than those from the original. The largest warming occurs throughout the coastal waters of the Gulf of Mexico, south of the Florida Keys and in the Atlantic Ocean north of the Bahamas. These warmer SSTs in the enhanced product are likely the result of the reduced latency in the enhanced product which then better portrays the warming of the ocean throughout the June and July time. In order to quantify improvements in the enhanced SST product, the original and enhanced SST composites were compared with in-situ observations at 11 buoy locations throughout the Florida domain. These buoy locations appear as white diamonds in Figure 2 and are labeled with an identification name for ease of discussion. The variety of buoy locations were chosen based on their differing proximity to land and ocean current features such as the Gulf Stream. The buoy observations were obtained from NOAA's National Data Buoy Center.



	Buoy ID	Name		Buoy ID	Name		Buoy ID	Name
A	42040	Mobile South	E	LONF1	Long Key	I	41009	Canaveral
B	42039	ESE Pensacola	F	MLRF1	Molasses Reef	J	41012	St Augustine
C	42022	West FL Central	G	FWYF1	Fowey Rocks	K	41010	Canaveral East
D	SMKF1	Sombrero Key	H	41114	Fort Pierce			

Figure 2. Comparison of original SST composite product (left) and the enhanced SST composite (right) on 10 June 2007 at 0400 UTC. Validation buoy locations appear as white diamonds with corresponding descriptions at the bottom.

A bulk comparison of the original and enhanced SST composite products, which includes all valid data days over the June and July 2007 period from the 11 observation buoys, reveals a decrease in the mean bias from -0.916°C in the original product to -0.273°C in the enhanced product for the 0400 UTC composite time (see Table 1). Similarly, the mean bias decreases from -1.342°C in the original to -0.459°C in the enhanced product at the 0700 UTC composite time. Thus, the enhanced SST product shows marked improvement in accurately determining the SSTs over the Florida domain at these nighttime composite times.

Table 1. Mean difference (bias) in SST (°C) at each product composite time incorporating all 11 observational buoy locations.

	0400	0700	1600	1900
Orig.- Buoy	-0.916	-1.342	-0.150	-0.298
Enh.- Buoy	-0.273	-0.459	-0.174	-0.428

The improvements in the mean biases do not, however, occur at the 1600 UTC and 1900 UTC composite times. In both of these cases, the mean biases of the enhanced product increase slightly from those of the original product. However, the mean biases of the original product at 1600 UTC and 1900 UTC are already small compared to those at 0400 UTC and 0700 UTC. The day to night bias difference for both the original and enhanced composite products is likely due to the reduced accuracy of cloud detection schemes at night resulting from the lack of visible imagery and surface to air temperature contrasts (Jedlovec et al. 2008). This increases the data latency at night in both algorithms.

A comparison of the SST products at individual buoy locations will show the trends in the SST data captured by the composites. Figure 3 shows the time series plot of one such buoy at Canaveral (location I in Figure 2) at both the 0400 UTC and 1600 UTC composite times, representating nighttime and daytime passes respectively. The buoy observations (green triangles) are highlighted by a 3-day average line (black) which shows the general trend of the SST at this location throughout June and July 2007 for ease of examination. The buoy observations show a general increasing trend from about 25°C in early June to just over 30°C in late July with slight fluctuations on the weekly scale.

At the 0400 UTC composite time, the original SST composite product (blue diamonds) shows large plateaus throughout the time period and little correlation with either the absolute values or the trend of the buoy observations. This is especially true during the month of July when the original SST product value remains pretty much constant, undoubtedly due to high latency caused by cloud cover. Conversely, the enhanced SST composite product (red squares) follows the values and trends of the buoy observations much more closely. A prime example of this is during the last third of July, when the enhanced SST composite product nearly matches the 2°C decrease and sudden rebound of the buoy data. The mean bias for this buoy decreases from -1.097°C in the original product to -0.354°C in the enhanced composite product. Also, the correlation with the buoy observations increases from 0.792 to 0.906 with the enhanced product (for these and similar statistical comparisons for other buoys at 0400 UTC, see Table 2 (1600 UTC, Table 3)).

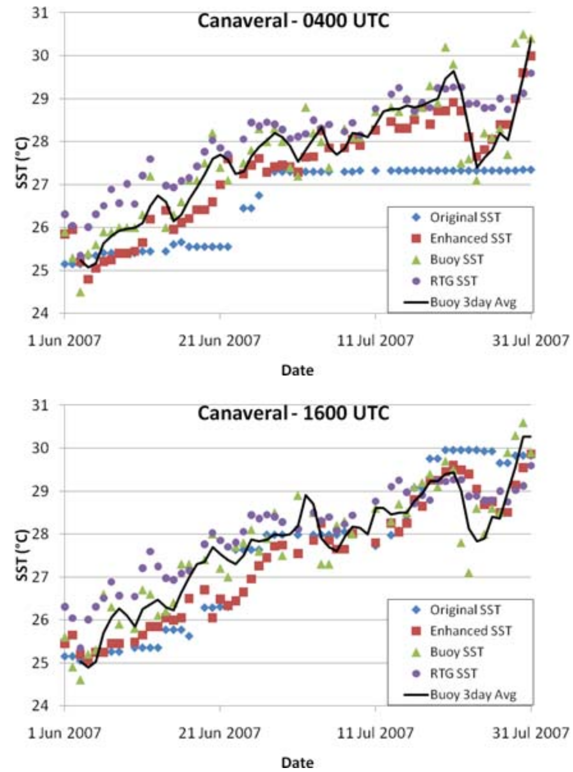


Figure 3. Comparison of original, enhanced and RTG SST products with buoy observations at Canaveral (location I in Figure 2) from 1 June 2007 to 31 July 2007. 0400 UTC composite time at top; 1600 UTC composite time at bottom.

Recall that the overall statistics showed no improvement in the bias at 1600 UTC. However, when looking at the SST trends at the Canaveral buoy location for 1600 UTC, the correlation with the buoy observation is slightly better using the enhanced composite product than the original. Also, the enhanced product follows the trend during the last third of June more closely than original, which remains constant for continuous days.

The previous analysis of the original SST composite product (Case et al. 2008a) included a comparison of the MODIS-based product with the RTG SST product, a twelfth-degree analysis issued daily by NCEP. This analysis showed that the original MODIS SST product did not perform as well as the RTG SST product during portions of June and July 2007. For further comparison to the enhanced SST product, the RTG SST product has been added to

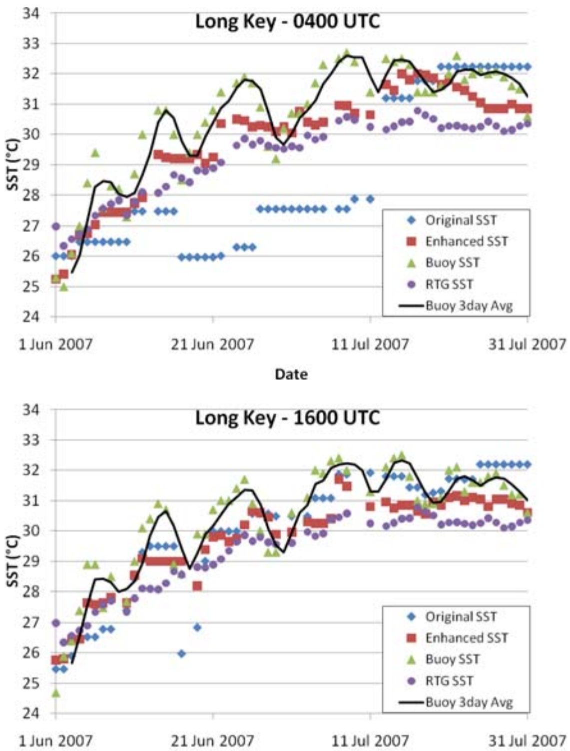


Figure 4. Same as Figure 3, but for buoy location Long Key.

the time-series charts for the Long Key buoy (purple circles) in Figure 4. The 0400 UTC composite time indicates that the enhanced SST product does in fact improve on the RTG SST analysis. The mean bias decreases from -1.254°C to -0.693°C using the enhanced product. While neither the RTG nor the enhanced SST products follow the nearly biweekly temperature cycles extremely well, the enhanced product does perform better than the RTG and both perform much better mimicking the buoy trend than the original SST composite product. Quantitatively, the correlation with the buoy improves from 0.587 with the original composite to 0.899 with the RTG analysis to 0.915 with the enhanced SST composite product.

While the time series plots for the Canaveral and Long Key buoys provide good evidence for validation of the improvements made by the enhanced SST composite product, further comparison of the products at each of the 11 buoy locations provides more convincing statistics supporting the improvement made by the enhanced composite product. Tables 2 and 3 display the mean bias, mean absolue error, correlation with buoy and variance for the 11 validation buoy locations at 0400 UTC and 1600 UTC, respectively. For ease of comparison, the best value in each category have been colored blue and the worst have colored red.

At the 0400 UTC composite time, the enhanced SST composite product appears to be better than the original composite product in nearly all instances. However, at times the mean bias of the RTG product is better than both the original or enhanced product. Both the correlation and variance of the enhanced product are better than those of the RTG, however. The improved quality of the enhanced SST composite product is not quite as evident at the 1600 UTC composite time, however, only 4 of the 44 comparisons exhibit poor performance with the enhanced composite, and the enhanced composite is overwhelmingly superior in the mean absolute error, correlation with buoy, and variance comparisons compared to the other two products.

Table 2. Summary of statistical comparisons by buoy location at 0400 UTC composite time.

	Mean Bias			Mean Absolute Error		
	Enhanced-Buoy	Original-Buoy	RTG-Buoy	Enhanced-Buoy	Original-Buoy	RTG-Buoy
Fort Pierce	-0.110	-0.599	1.534	0.389	0.739	1.534
Fowey Rocks	0.315	-0.976	0.672	0.390	1.340	0.679
Long Key	-0.693	-1.933	-1.254	0.865	2.229	1.398
Molasses Reef	-0.070	-0.456	0.486	0.308	0.581	0.549
Sombrero Key	-0.346	-1.114	-0.241	0.449	1.285	0.483
Mobile South	-0.386	-0.709	0.133	0.485	0.851	0.493
ESE Pensacola	-0.276	-0.345	0.036	0.369	0.477	0.293
West FL Central	-0.338	-0.975	-0.190	0.474	1.278	0.364
Canaveral	-0.354	-1.097	0.369	0.572	1.131	0.597
Canaveral East	-0.342	-0.902	-0.271	0.533	0.918	0.509
St Augustine	-0.462	-0.780	-0.333	0.536	0.827	0.442
	(closest to 0 in blue, farthest in red)			(closest to 0 in blue, farthest in red)		
	Correlation with Buoy			Variance		
	Enhanced	Original	RTG	Enhanced-Buoy	Original-Buoy	RTG-Buoy
Fort Pierce	0.931	0.867	0.879	0.204	0.382	0.387
Fowey Rocks	0.973	0.763	0.961	0.104	1.785	0.151
Long Key	0.915	0.587	0.899	0.595	4.296	0.912
Molasses Reef	0.965	0.937	0.954	0.148	0.358	0.196
Sombrero Key	0.953	0.785	0.933	0.221	1.502	0.305
Mobile South	0.928	0.859	0.916	0.342	0.680	0.381
ESE Pensacola	0.968	0.954	0.975	0.149	0.325	0.126
West FL Central	0.974	0.906	0.975	0.209	1.091	0.157
Canaveral	0.906	0.792	0.901	0.337	0.720	0.393
Canaveral East	0.927	0.886	0.881	0.301	0.403	0.403
St Augustine	0.954	0.944	0.953	0.349	0.424	0.367
	(closest to 1 in blue, farthest in red)			(closest to 0 in blue, farthest in red)		

Table 3. Summary of statistical comparisons by buoy location at 1600 UTC composite time

	Mean Bias			Mean Absolute Error		
	Enhanced-Buoy	Original-Buoy	RTG-Buoy	Enhanced-Buoy	Original-Buoy	RTG-Buoy
Fort Pierce	0.267	0.257	1.278	0.496	0.544	1.278
Fowey Rocks	0.486	0.557	0.542	0.548	0.814	0.598
Long Key	-0.678	-0.395	-1.134	0.832	0.855	1.266
Molasses Reef	0.041	0.095	0.422	0.324	0.500	0.520
Sombrero Key	-0.566	-0.261	-0.531	0.652	0.547	0.620
Mobile South	-0.134	-0.125	0.141	0.445	0.548	0.563
ESE Pensacola	-0.252	-0.444	-0.017	0.357	0.505	0.272
West FL Central	-0.237	-0.185	-0.272	0.391	0.715	0.467
Canaveral	-0.340	-0.145	0.312	0.659	0.706	0.599
Canaveral East	-0.164	-0.602	-0.148	0.449	0.830	0.476
St Augustine	-0.192	-0.435	-0.450	0.376	0.601	0.518
	(closest to 0 in blue, farthest in red)			(closest to 0 in blue, farthest in red)		
	Correlation with Buoy			Variance		
	Enhanced	Original	RTG	Enhanced-Buoy	Original-Buoy	RTG-Buoy
Fort Pierce	0.929	0.921	0.919	0.298	0.363	0.292
Fowey Rocks	0.953	0.933	0.942	0.177	0.604	0.220
Long Key	0.909	0.881	0.862	0.546	0.998	0.855
Molasses Reef	0.956	0.899	0.950	0.173	0.456	0.193
Sombrero Key	0.897	0.911	0.909	0.458	0.491	0.353
Mobile South	0.901	0.895	0.877	0.384	0.499	0.427
ESE Pensacola	0.975	0.961	0.978	0.146	0.234	0.112
West FL Central	0.981	0.925	0.969	0.162	0.769	0.208
Canaveral	0.856	0.855	0.897	0.589	0.855	0.436
Canaveral East	0.925	0.901	0.898	0.293	0.793	0.377
St Augustine	0.972	0.967	0.962	0.233	0.468	0.360
	(closest to 1 in blue, farthest in red)			(closest to 0 in blue, farthest in red)		

4. FORECAST IMPACTS

In order to further assess the improvements made by the enhanced SST composite over the original, both products were used to initialize a local version of the WRF EMS model over southern Florida. The same WRF configuration, coverage and resolution was used as in the previous SPoRT modeling evaluation conducted over the NWS Miami, FL operational domain (Case et al. 2008b). The NCEP's Nonhydrostatic Mesoscale Model (Janjić et al. 2001) dynamical core was run at 4-km grid spacing for 27 hours within the EMS software. The Control model run consisted of the operational WRF configuration as run at Miami, FL using the RTG SSTs. The two experimental runs used the original and enhanced MODIS composite products for the model SSTs. In all instances, the SSTs were held fixed throughout the entire WRF model simulation.

More accurate initialization of the SST field in local weather models should improve the performance of the models in predicting short-term weather conditions near coastal regions. To depict a sample forecast sensitivity, the WRF model was initialized at 0900 UTC 22 Jun 2007 for the control (RTG SST) and both SPoRT composite products. This date and time was chosen because of the large SST differences between the three products at 0400 UTC at Long Key, which fits centrally in the forecast domain. Figure 5b shows a 9-hour forecast 2-m temperature difference field (enhanced SST product – original SST product) over the WRF model domain. The enhanced SST composite product produces warmer 2-m air temperatures throughout much of the oceanic region compared to the original SST, due to the warmer model skin temperatures over water (Figure 5a) that caused warming in the corresponding atmospheric temperature in certain areas. A time-series plot in Figure 6 shows the 2-m temperature error for all three forecast runs compared to the air temperature observations at Long Key. Throughout the entire forecast period, the 2-m temperature forecast error using the enhanced SST composite is much closer to zero than the experimental run with the original SST composite product. This shows an improvement in the ability of the forecast model to produce more accurate results when given the improved enhanced SST composite values. Temperature forecast errors for both the enhanced and RTG SST cases hover around zero, a sign that similar temperature forecasts are made at this location.

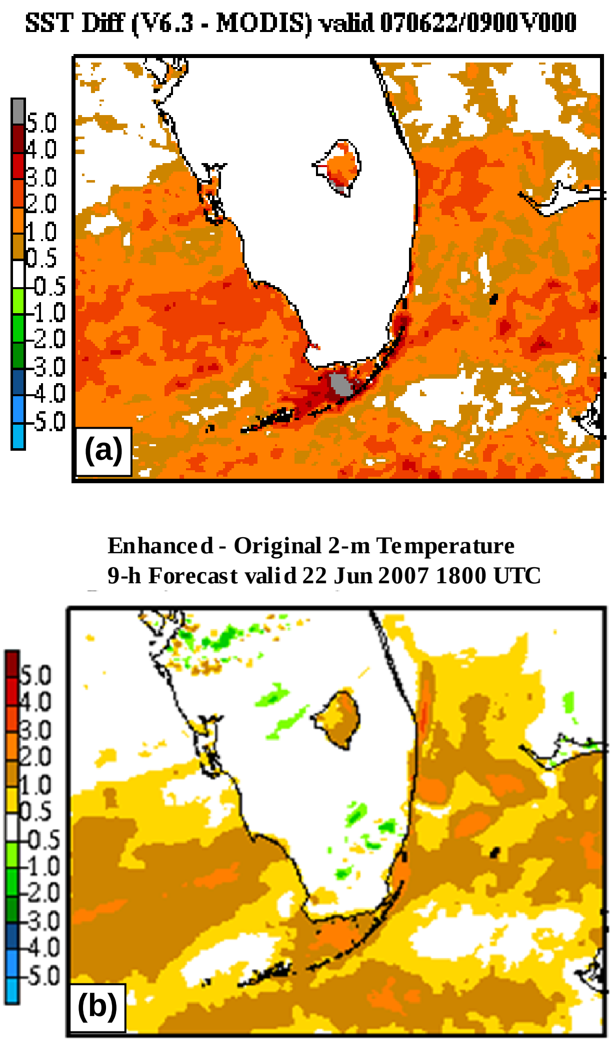


Figure 5. (a) Difference in 0400 UTC SST between enhanced product and original MODIS, and (b) Difference in WRF 2-m temperature for the 9-h forecast valid 1800 UTC 22 June 2007.

A similar result occurs when considering all of the over-water observations during a period where cloud cover resulted in significant latency in the original SST values. Figure 7 and Figure 8 show the combined, forecast 2-m temperature and 10-m wind speed verification statistics for all of the water sites during the two-week period from 17–30 June for the 0900 UTC initialization. In this period the original SST values at 0400 UTC used for initialization were noticeably cooler than the observations and were often constant from day-to-day due to cloud cover induced latency (see top portion of Figure 3 and Figure 4). The use of the enhanced SSTs shows the bias, root mean square error and mean absolute error to be nearly equivalent to that of the model runs using the RTG SST, and hence, has addressed the SST data latency issue as well as the SST cool bias. The latter is well demonstrated by the improved wind speed bias in Figure 8 as a result of a warmer boundary layer and likely greater mixing of higher wind speeds to the surface. The significance of these results is that the model initialized with the enhanced SST has performed as well as initializations using the RTG SSTs, but the enhanced SST field has retained the mesoscale detail and variations in the SST field as seen by MODIS. This aspect of the enhanced SST product should make it a superior product for use in numerical modeling. A more detailed look at individual events and regimes is needed to identify the specific benefits of the enhanced SST product to the model. In addition, work needs to be done to discover possible improvements or new configurations of the model to take advantage of the highly detailed SST structure and gradients.

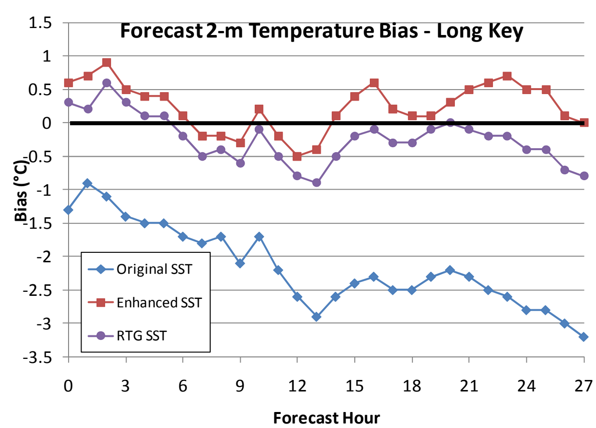


Figure 6. Forecast 2-m temperature bias at Long Key buoy (location E in Figure 1) initialized 22 Jun 2007 0900 UTC with original, enhanced and RTG products.

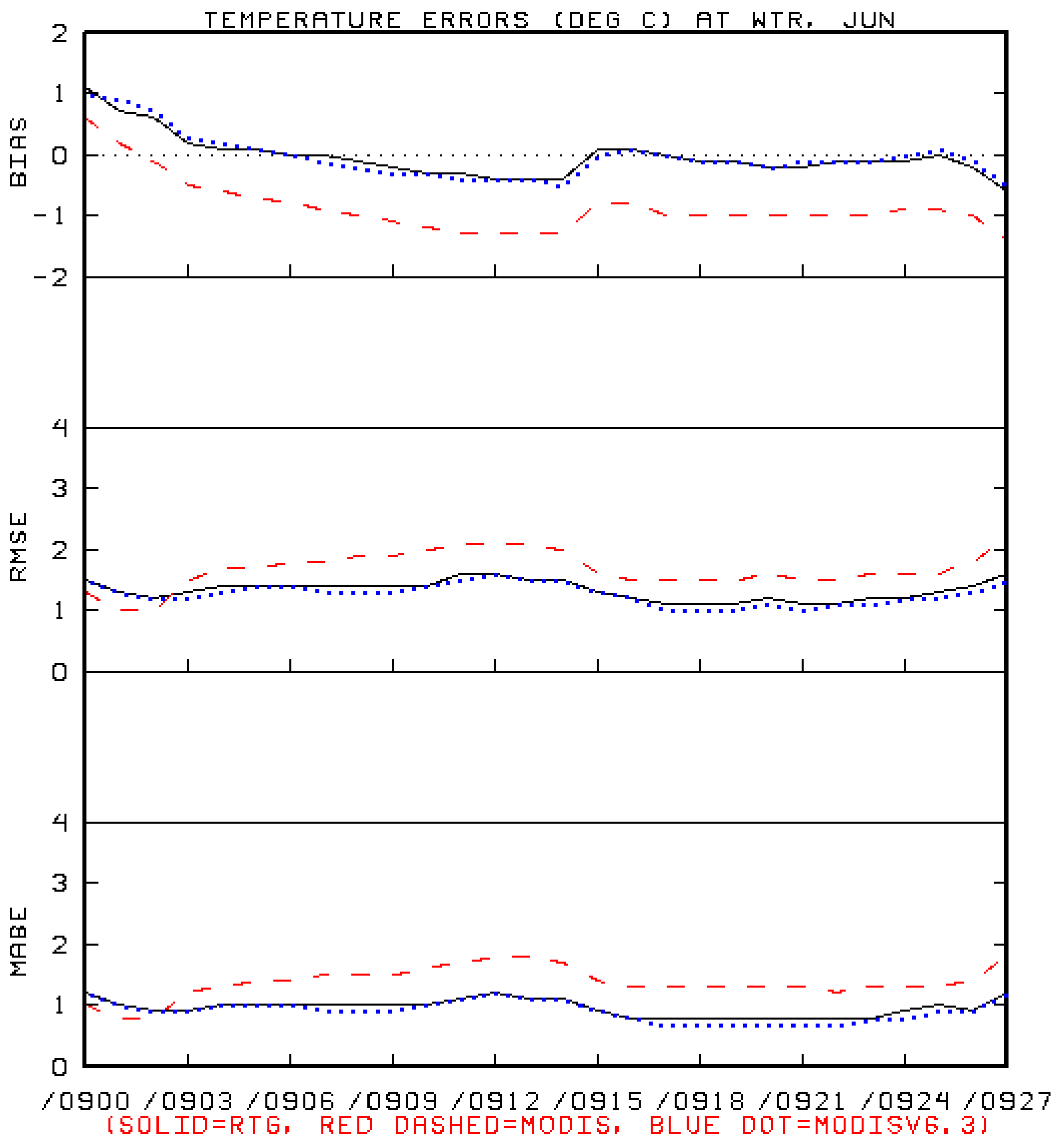


Figure 7. Verification of 2-m temperatures from daily 0900 UTC WRF runs over the Miami, FL local operational domain during 17-30 June 2007, validated at all available buoy/C-MAN locations in south Florida. Statistics shown include the bias (top panel), root mean square error (middle panel), and mean absolute error (bottom panel).

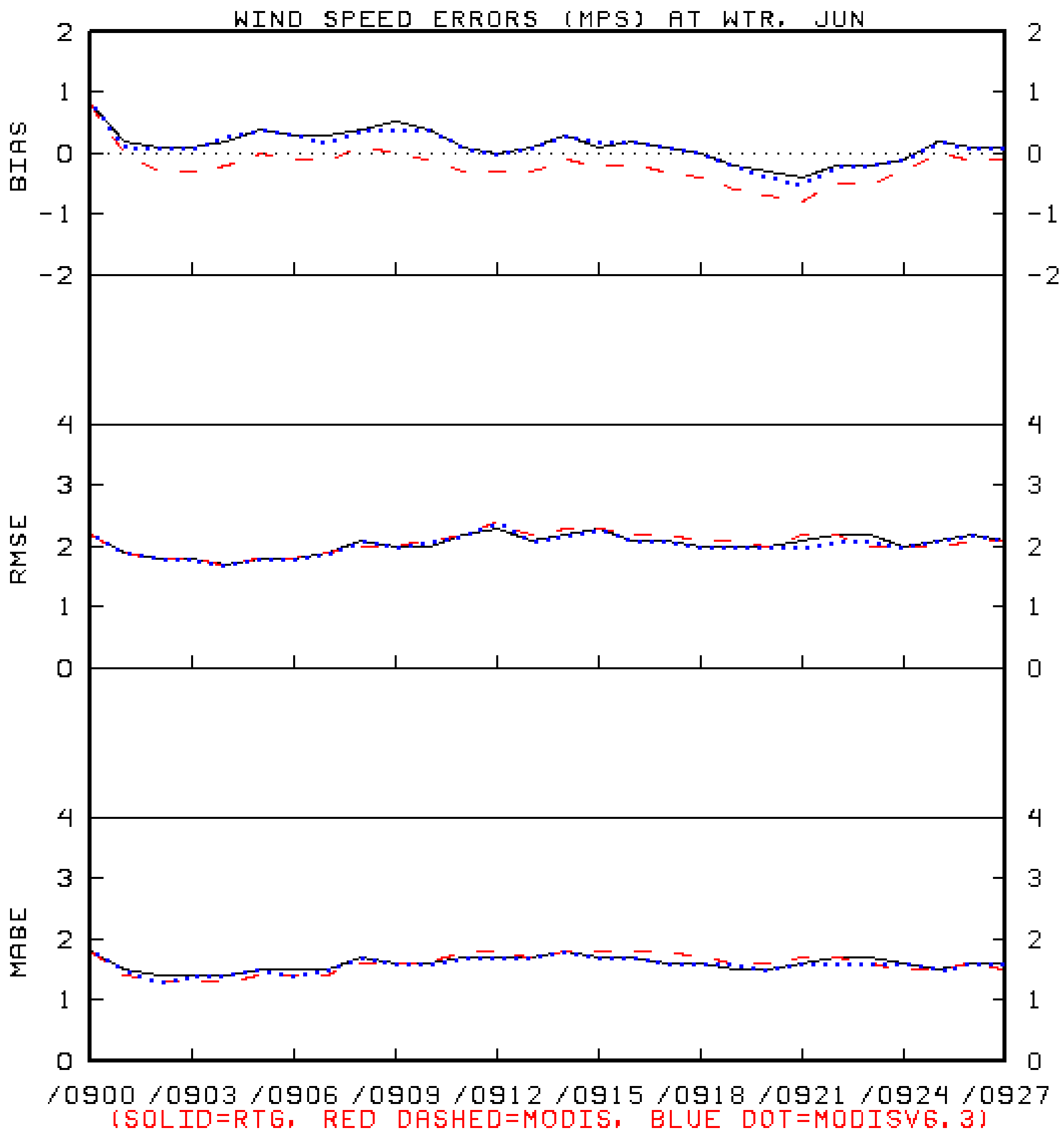


Figure 8. Same as in Figure 7 except for 10-m, wind speed.

5. SUMMARY

An analysis of the enhanced high-resolution SST composite product using data from June and July 2007 around Florida has revealed an improvement over the original MODIS SST composite product developed by the NASA SPoRT Center. The enhanced product improves on data latency by incorporating information from AMSR-E and OSTIA, while maintaining the fine-scale detail of oceanic SSTs from the original MODIS product. Furthermore, the enhanced SST composite product verifies better with in-situ buoy observations than both the original SST composite and the operational RTG SST product. The enhanced product thereby provides more accurate information for short-term numerical forecasts of sensible weather.

Future work should include additional verification of the enhanced product as well as continued testing with forecast model applications. Many of the buoy locations in this analysis fall within the shoreline area in which AMSR-E data are not available for integration into the enhanced product, and as such represents a limitation for evaluation. Many of these areas were filled with OSTIA information only. Offshore buoy and ship observations should be used in order to further evaluate the effectiveness of the AMSR-E incorporation. Also, a wider range of forecast times and parameters should be compared using all three products to promote greater confidence in the abilities of the enhanced SST composite product and to note forecast initialization conditions when the enhanced product performs particularly well or poorly. Finally, other cases may be examined to evaluate the improvements made by the enhanced SST product. Of particular interest is application to tropical meteorology regarding SST impacts on hurricane development within the forecast model, as well as marine convective initiation and precipitation during the tropical wet season.

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