UCAR/COMET: Final Outreach Project Report: October 1, 2006
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Assimilation of Multi-Satellite High Resolution Sea Surface Temperatures for a Real-Time Local Analysis and Forecasting System.

Accomplishments pertaining to the project tasks, as delineated in the proposal for *Year I*, and the 6 month report of Year II have been previously summarized. Year II project goals as stated in the original proposal are given as follows:

-Use MODIS variance statistics to aid in development of SST analysis weights
-Use GOES-12 variance statistics to develop SST analysis weights
-Continue/complete development of SST analysis

-Compare ADAS/ARPS select short-term simulations with/without high resolution SST analysis
-Transfer software to NWS
-Submit FIT/NWS publication(s) to Weather Analysis and Forecasting

Work on the first three items was underway at the time of the Year II 6 month report and have been completed. Of the latter 3 tasks, as proposed in the original COMET grant, two have been completed and are addressed individually within this summary.

1. Project Information, Objectives and Accomplishments: Year II

1.1 Academic and Forecast Partners

a. Corey Calvert, an M.S. graduate student, has worked in support of this project since its inception in June 2004. Mr. Calvert was supported under this grant and recently finished his MS work in March 2006. He was supported by the project after his graduation through May 2006 after which time he accepted a position at the Space Science and Engineering Center (SSEC) in Madison Wisconsin. Prior to his departure, the following major tasks had been completed 1.) prepare/submit a publication, 2.) complete work on an operational SST analysis system. The first of two manuscripts is currently undergoing revisions and we anticipate its publication in Monthly Weather Review (MWR) sometime in early 2007. We are in the process of submitting a second publication (to MWR) in relation with the modeling component of this work (see Section 2 "Related Accomplishments"). The PI is a co-author on this second paper as well as a third paper- both of which involve related collaborative projects with the Short-Term Prediction Research and Transition Center (SPoRT).

SUBMITTED PAPERS:

Lazarus, S. M., C. G. Calvert, M. E. Splitt, P. Santos, D. W. Sharp, P. F. Blottman, and S. M. Spratt: Multi-platform real-time sea surface temperature analysis for the initialization of short-term operational forecasts. *In revision* with Monthly Weather Review.

Haines S. L., G. J. Jedlovec, and S. M. Lazarus: A MODIS Sea Surface Temperature Composite for Regional Applications. *Submitted* to IEEE Transactions in Geosciences and Remote Sensing.

LaCasse, K., M., M. E. Splitt, S. M. Lazarus, and W. M. Lapenta: The Impact of MODIS SST Composites On Short-Term Regional Forecasts. *To be submitted* to Monthly Weather Review.

b. The “end-to-end” SST analysis system is now running operationally here at FIT and is discussed more fully in our manuscript (and was also previously described in our Year II 6 month report). The paper “*Multi-platform real-time sea surface temperature analysis for the initialization of short-term operational forecasts*” has been accepted, pending revisions and can be accessed in its current form at: http://my.fit.edu/~slazarus/misc/sst_anal_paper_v23.pdf.

c. As previously reported in our Year II 6 month report (and our MWR manuscript), the analysis system has undergone testing/tuning for a trial period for May 2004). The operational system has 4 distinct components including 1.) the creation of the first-guess composite (GOES-12), 2.) processing of the MODIS (Terra/Aqua) SSTs, 3.) analysis, and 4.) evaluation. A summary of the essential aspects of each component follows.

FIRST GUESS

The background composites are created via the following sequential elements: 1.) application of a secondary glint mask, 2.) removal of bottom reflectance, 3.) bias correction, 4.) and diurnal adjustment.

Glint Mask

For some reason, the NESDIS GOES-12 data stream fails to fully mask glint contaminated SSTs. We apply a second glint mask developed by Stephanie Haines at SPoRT with a zenith angle subroutine provided by Ron Suggs (NASA).

Bottom Reflectance

In addition to the residual glint issue, we have also identified spuriously warm SSTs, in the native NESDIS data, that occur during the daytime, but outside of the temporal glint window. These warm SSTs appear to be an artifact of bottom

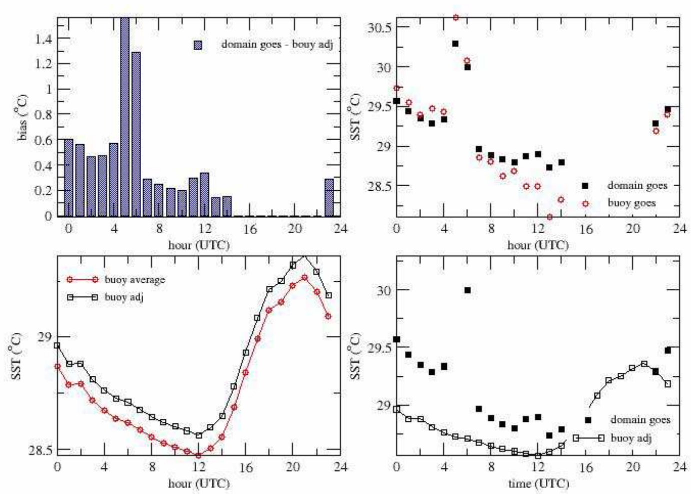

Fig. 1: *Operational SST bias statistics (^{o}C) for the 12 September 2006 analysis cycle. See text for description.*

reflectance. As a result, we are using the bottom topography to remove all daytime SSTs in depths ranging from 15 m to 25 m. At this point, it is not clear how much of this data is actually contaminated versus good quality. The removal of data within this depth range represents a conservative estimate so as to ensure that the bias correction is applied appropriately. For May 2004, this includes the "bimodal" range where there are two distinct bias estimates (see Figs. 4b and 4c in the Year 2 six month report). At the center of this range (around 20 m depth), the good and bad data appear to be evenly split. Despite the sun glint contamination, we do retain data at depths less than 15 m because this bias is correctable. Because the study was limited to May, we do not know whether this is a seasonal problem or exists throughout the year.

Bias Correction

In an effort to remove biases from both the background field (GOES composites) and observations (MODIS), average diurnal SST timeseries (for both the GOES and BUOY data) are now being generated operationally over the Florida NWS ADAS domain. Real-time bias statistics, which are being generated twice weekly, consist of monthly averaged buoy SSTs and zero latency GOES SSTs. The real-time statistics are comprised of data from nine buoys in the analysis domain (41009, 41010, 41012, 42013, 42014, 42021, 42022, 42036, and SGOF1). The bias statistics can be accessed on line at: http://my.fit.edu/wx_fit/sst/images/0609_images/. An example from a recent analysis cycle (12 September 2006) is shown in Fig. 1. The panels show various SSTs (^{o}C, clockwise from upper left) 1.) the magnitude of the bias correction of the zero latency GOES, 2.) monthly averaged timeseries for both the domain-wide (black-filled squares) and buoy co-located (i.e., nearest neighbor) GOES-12 zero latency SSTs (red circles), 3.) monthly averaged timeseries for the buoy SSTs (red circles) and adjusted buoy SSTs (open squares) and 4.) domain GOES-12 and adjusted buoy SSTs. The difference between the two timeseries in the lower right panel represent the bias correction shown in the upper left panel. Because the domain averaged GOES SSTs are warmer than the adjusted buoy SSTs, the zero latency GOES SSTs are cooled during the bias correction of the analysis process. The "spike" in the upper left panel at 05 UTC is a well-known artifact of the midnight blackbody calibration correction that was implemented in response to the diurnal solar heating of the instrument (Johnson and Weinreb 1996). Outside of this spike, bias corrections are generally on the order of 0.5^{o}C or less. The data gap between 15-19 UTC is associated with the removal of both glint and bottom reflectance contaminated GOES-12 SSTs (see manuscript or the "Problems Encountered" section of our previous COMET report). The secondary glint mask that is applied to the GOES data is a geometry-oriented approach that tracks the sun's position and then removes whatever spurious glint contaminated SSTs that remain in the NESDIS feed. SST data should reappear within the daytime window as the sun angle decreases.

Diurnal Correction

Following the bias correction, a diurnal correction is applied (see manuscript for a more complete description of this approach). This secondary correction is designed to account for the time lag associated with latent data that populates, in part, the GOES composites. An empirical algorithm based on surface energy balance principles is applied (Gentemann et al. 2003). *The current operational inputs to the parameterization are the latest RUC2*[1] *analysis 10 m winds and GOES surface*

1. 3h NAM forecast 10 m winds were used for the May 2004 study.

solar insolation. We are currently using the algorithm as tuned to the May 2004 case study period. However, we anticipate that the algorithm will be adjusted so as to allow for seasonal variations in the diurnal SST signal. The PI is currently discussing (with NWS personnel) the possibility of an extension of this portion of the work so as determine/evaluate the impact of the diurnal correction (as we applied it) throughout the year. If seasonal (or monthly) corrections are needed, a look-up table of corrections can be provided to the NWS.

Trend Correction

Despite the aforementioned adjustments, the composite timeseries will, in general, retain some bias with respect to the zero latency timeseries -- the degree to which will depend on the latency of the composite and the SST trends. Although the May 2004 data were trend corrected, we are not currently performing this correction in the operational data stream.

OBSERVATIONS (MODIS SSTs)

For the study period, MODIS data (both Terra and Aqua) were also bias corrected in a similar fashion to that of the GOES-12 SSTs, i.e., we used differences between the adjusted buoy and the average MODIS SSTs at the buoy locations in a separate step that preceded the analysis. Based on the analysis results for the May 2004 period (see submitted paper), we felt that the adjustments were not necessary and thus the *MODIS SSTs are not adjusted in the operational system*. The Goddard DAAC training data (May 2004) that were used to develop, test and tune the analysis system indicated a relatively significant daytime (16 UTC) cool bias in the Terra SSTs with the MODIS7 (MODIS at the seven available buoy locations) on the order of 1^{o}C cooler than the buoy SSTs (not shown). It is not clear what the source(s) of these spurious SSTs is (are) - whether they are related to limb effects caused by the Terra sensor, cirrus contamination (e.g., Dessler and Yang 2003), etc. It is also not clear whether or not this is an issue in the current SSEC MODIS (Terra) product that we are using operationally. The operational product from SSEC does differ from the science team product at the DAAC. Regardless, in order to avoid potential problems, these data have been removed (until we can verify otherwise), from the operational analysis. This reduces the maximum number of possible analyses from four to three per day.

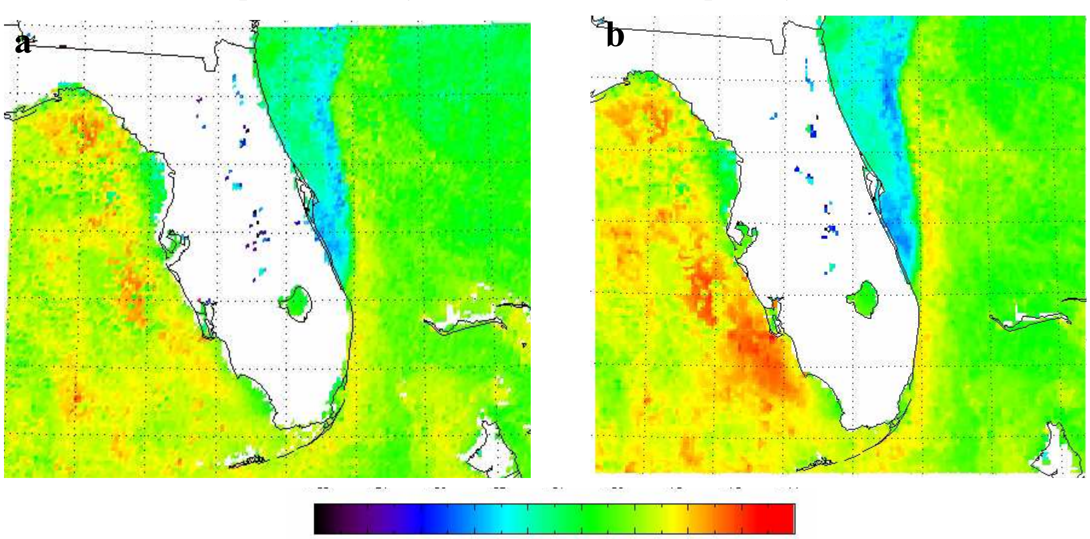

Fig. 2: *a.) Operational GOES SST composite (^{o}C, from step 5 above) valid 17 UTC 10 September 2006 and corresponding b.) 19 UTC SST (^{o}C) analysis.*

Current Operational QC/Bias Correction Summary:

Step 1: removal of additional (residual) GOES SST glint.
Step 2: removal of daytime GOES SSTs in shallow water
Step 3: daily update of 30 day running averages for zero latency GOES and buoy SSTs
Step 4: adjust buoy timeseries to domain representative values
Step 5: create composites
GOES bias removal
GOES diurnal correction (GOES solar & latest RUC2 analysis 10 m winds)
Step 6: Analysis

d. An example of the operational GOES composite product and attendant analysis is shown in Fig. 2. Note that the GOES composite lags the analysis time by 2 h due the latency of the GOES SSTs data obtained from NESDIS.

e. The PI presented "*Multi-platform real-time sea surface temperature analysis for the initialization of short-term operational forecasts"* at the 2006 Annual AMS conference in Atlanta last February and gave an invited talk at the University of Miami under a similar title in April 2006.

f. For brevity herein, the reader is referred to our manuscript for details regarding the major findings and conclusions of this work.

2. Related Accomplishments

a. *Significant* collaboration with the SPoRT facility in Huntsville AL continues. The status of these collaborations are discussed briefly below.

SST Composite Comparison (MODIS vs. GOES)
This work is an offshoot of the SST analysis work discussed herein. A version of these composites was used to initialize WRF simulations (see next section) over the same test period (May 2004) as the SST analysis system developed as part of this proposal. This work compared the SPoRT MODIS composite product against that of the FIT GOES composites, NCEP's RTG analysis, and the Operational Sea Surface Temperature and Sea Ice Analysis (OSTIA). The evaluation also included comparisons with in-situ buoy data. This work was presented at the AMS conference (Haines et al., 2006), and was just submitted (September 2006) for publication (with the PI as a co-author) to IEEE Transactions on Geoscience and Remote Sensing. Highlights of this work are:

1.) MODIS composites were found shown to contain significantly more spatial information than the RTG, and less noise and inconsistencies than the GOES SST composite.

2.) Comparison with in-situ buoy data showed the MODIS composite SSTs to be highly correlated to the buoy SSTs with generally small negative biases.

3.) Significant/sudden temporal changes in SST are generally not well captured in the composites until several days later. This was evident during the hurricane season of 2005, when it took several days for the composite to capture the cooling following the path of the hurricanes in the Gulf of Mexico region.

WRF/ADAS model simulations over Florida

This work was performed in lieu of the original work proposed, i.e., "*Compare ADAS/ARPS select short-term simulations with/without high resolution SST analysis*". SPoRT has contributed significant resources to this work including all numerical simulations and additional funds to support a research associate here at FIT. The 24 h WRF/ADAS simulations, for the same period (May 2004) as that used to evaluate the SST analyses for this project, included two runs per day (one with high resolution MODIS composite SSTs and the other using NCEP's RTG SST analysis). As previously mentioned, this work is nearing completion and will soon also be submitted to Monthly Weather Review. Highlights/impacts of the model simulations include:

1.) Results were stratified, by low-level flow, into "easterly" and "westerly" cases. This was done to separate the impact(s) of the high resolution SSTs for the cold-to-warm transition and warm-to-cold transition.

2.) The high resolution SST simulations produced increased (decreased) surface sensible and latent heat fluxes in regions where the MODIS SSTs were warmer (colder) than the RTG. More importantly, sensible heat fluxes increased in the MODIS SST WRF runs by as much as 100% in the Florida Current, while latent heat flux increases approached 30%.

3.) Different responses in sea level pressure between the two regimes. Although the maximum magnitude change in pressure is small (~ 8 Pa), it is on the order of that observed with mesoscale phenomenon such as sea or lake breezes.

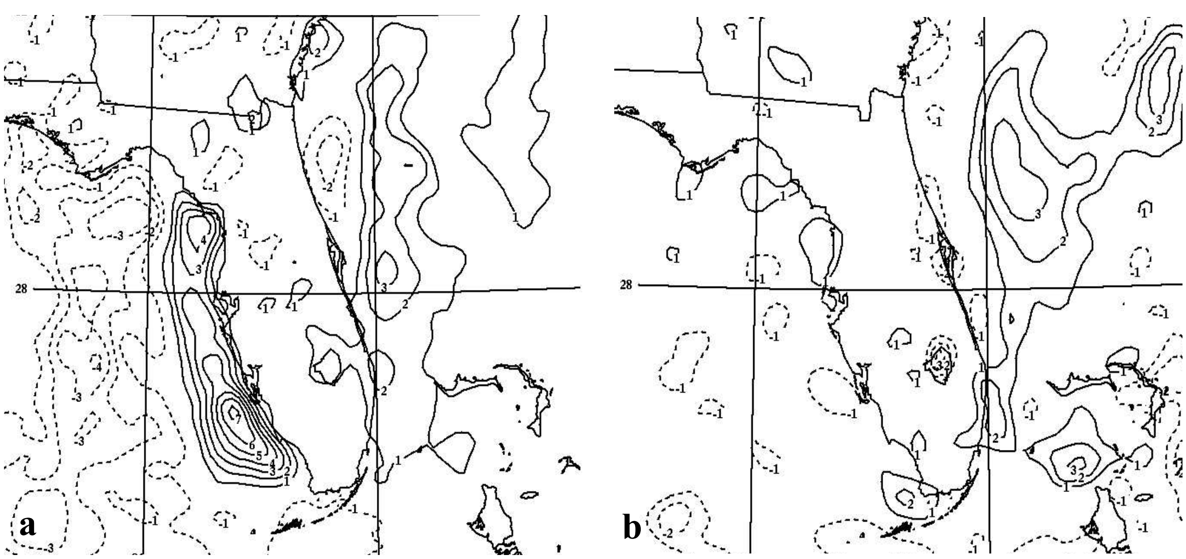

Fig. 3: *Average difference in 10 m wind (m s^{-1}) between WRF initialized with high resolution MODIS SSTs and RTG SST for nocturnal a.) easterly flow, and b.) westerly flow cases.*

4.) Maximum wind speed changes between test and control runs are on the order of 6% (9%) in the westerly (easterly) flow regime. During day-time conditions in easterly flow (Fig. 3a), the response in the wind field is much greater in amplitude over the western shelf of Florida. For westerly flow (Fig. 3b), the amplitude of the response is greatly decreased over the Florida Current and may be attributed to diurnal variations in low-level stability.

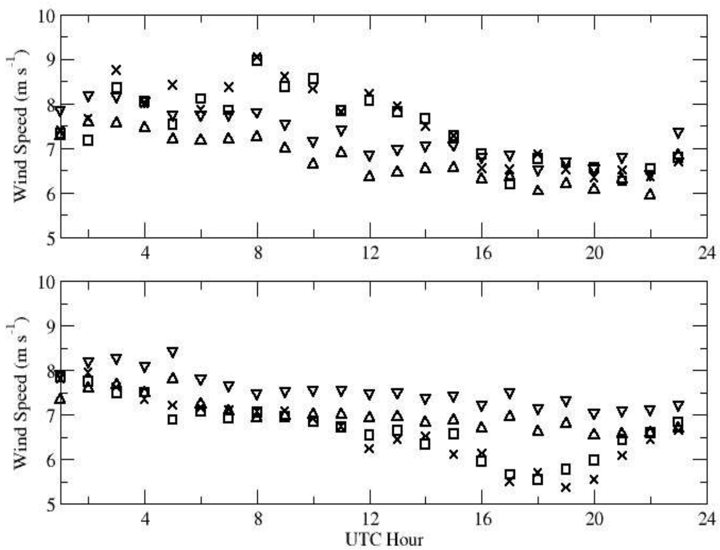

Fig. 4: *Hourly averaged wind speeds (m s^{-1}) for the easterly flow regime at NDBC buoy 41009 (top) and 41010 (bottom). Buoy (upward pointed triangle), Buoy-10m (downward pointed triangle), MODIS (square), and RTG (x).*

5.) Comparison of National Data Buoy Center (NDBC) buoy data with collocated WRF model output (buoy wind speed estimates were adjusted to the 10 m level) indicate that the WRF runs tend to over predict 10 m wind speeds with the poorest performance at buoy 41008 (see Fig. 4). The use of the high resolution MODIS SST, in general, nudged the model closer to the observations. Hourly averaged comparisons of 10 m wind speed for the easterly flow cases indicate that the model differences from the buoys are somewhat systematic (Fig. 4). For example at buoy 41009, on the western edge of the Gulf Stream, the WRF wind speeds are preferentially higher at night, which suggests potential problems associated with the WRF treatment of the nocturnal boundary layer over warm water. Conversely, WRF wind speeds are higher than the 10 m estimates at buoy 41010 during the hours of peak solar heating, indicating that the WRF may also be having problems handling the daytime surface layer (e.g., surface fluxes).

b. The PI had just begun work on a joint NASA proposal with SPoRT and the University of Alabama Huntsville, UAH. The proposal title: "An Improved Data Reduction Tool in Support of the Real-Time Assimilation of NASA Data Streams" was funded and will, in part, evaluate the impact of identifying and removing redundant SST data on the SST analyses. The PI is working with Information Technology personnel at the UAH to implement a two-dimensional version of the NCEP grid point statistical interpolation (GSI, Wu 2002) which is under development/testing as part of NCEP's Unified analysis system (i.e., one analysis for both their regional and global forecast systems -- see http://www.emc.ncep.noaa.gov/research/NCEP-EMCModelReview2004/EMC-Preliminaries.pdf for more).

c. The PI has just received a second SPoRT/NASA grant (97K for 2 years) "A climatological evaluation of the Florida sea breeze circulation". This work is motivated by the results/findings from the WRF RTG/MODIS SST simulations.

3. Summary of Benefits

3.1 Academic Partner
a. This project has led to the following significant accomplishments/outcomes:

*formal collaboration with SPoRT
***3** submitted journal articles
***4** conference papers
***2** additional funded proposals
*employment for 2 FIT graduate students (at SPoRT and SSEC)

b. In addition to the aforementioned outcomes, the following items were also a result of this project

*A greater understanding of the operational context through the forged "Forecast Partner" relationship.

*The financial support provided by COMET through this grant served as the primary support for Mr. Calvert's Masters.

*The financial support provided by COMET through this grant served as part-time support for Research Associate Mr. Splitt

*The financial support provided by COMET thought this grant served as the sole source of summer income for the PI during the summer of 2006.

***The work has led to collaborations with both NESDIS and SSEC personnel and has identified several problems with both (MODIS and GOES) operational SST data streams.

3.2 Forecast Partner

a. We (WFO Miami/Melbourne, FIT, and SPoRT) have just begun to establish an experimental design that will involve an <u>operational</u> model *intercomparison* of the high resolution MODIS SST composites (and FIT analyses), embedded within a parallel SPoRT WRF/LAPS configuation, versus the operational WRF/LAPS (WFO Miami) initialized with the RTG analysis. This additional work, in part, is an effort to "piggy-back" on the PIs completed project and reflects continued cooperation/collaboration with SPoRT and their mission.

b. This project reflects an effort to align both MFL and MLB with LAPS/WRF; this creates a more consistent vision of near-future growth for WFO local modeling, especially within the NWS Southern Region. The local commitment, in Melbourne, is still directed toward an ADAS/WRF arrangement. Importantly, local modeling is becoming an essential part of future plans for TacMet operations within ConOps (Tactical Meteorologist; Concept of Operations). In a clustered-peer configuration, clusters (small groups) of WFOs will likely support one another with data assimilation and local (distributed) modeling. What remains of this project, a transitioning of the FIT SST analysis scheme to the NWS, can be accomplished via a follow-up COMET Partners grant (at the time of this report the scheme is running at FIT with the output soon to be delivered to the NWS). As previously discussed, the WFO MLB ADAS was expanded to a domain which encompasses all of the Florida coastal waters to include the lower keys and the western panhandle. This larger domain represents a significant marine area that can directly benefit from multi-satellite SST data. Since last reporting, the WFO MLB has transitioned from ARPS to WRF (with LAPS as the front end). A transition from LAPS/WRF to ADAS/WRF is in the works.

c. The FIT SST analyses will be made available (in GRIB format) to the WFO Miami for their continued work with the WRF/LAPS system and to the other Florida WFOs for nowcasting, and to assist in populating the IFPS. As the results of the LaCasse et al. May 2004 study indicates, the various WRF sensitivities to the high resolution SSTs suggest that improved resolved thermal SST gradients, and SST/LST contrasts will eventually translate into better analyses and forecasts.

4. Presentations and Publications

The following are a list of talks and papers given since the last COMET report (Year 2, 6 month).

a. The PI presented at the 2006 AMS annual conference (Atlanta, GA): *Multi-platform Real-time Sea Surface Temperature Analysis for the Initialization of Short-term Operational Forecasts.*

b. The PI gave an invited talk, with the same title, at the University of Miami in April 2006

c. Related Conference Preprints:

Haines S. L., G. J. Jedlovec, S. M. Lazarus, and C. G. Calvert, 2006: An Aqua MODIS sea surface temperature composite product. Preprints, 14th Conference on Satellite Meteorology and Oceanography, Atlanta GA, Amer. Met. Soc., January 30-February 2, 2006.
LaCasse, K., M., W. M. Lapenta, S. M. Lazarus, and M. E. Splitt, 2006: The Impact of MODIS SST Composites On Short-Term Regional Forecasts. Pre-prints, 10th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface, Atlanta GA, Amer. Met. Soc., January 30-February 2, 2006.

Lazarus S. M., C. G. Calvert, M. E. Splitt, P. Santos, D. W. Sharp, P. Blottman, and S. Spratt, 2006: Multi-platform Real-time Sea Surface Temperature Analysis For The Initialization Of Short-term Operational Forecasts. Preprints, 10th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface, Atlanta GA, Amer. Met. Soc., January 30-February 2, 2006.

d. Related Refereed Journal Articles
See Section 1.1

5. Problems Encountered/General and Remaining Issues

5.1 Academic Partner

a. As has been previously reported, a significant number of project hours had been spent examining the data quality and bias removal (e.g., see Section 1.1). Because these have been reported previously, only a brief summary is given in Table 1 below. The 5th item (geolocation) is a recent finding and we have corresponded with Bob Potash at NESDIS regarding this potential problem with their operational product.

b. The diurnal adjustment was tuned to May -- the impact of this adjustment for other times of the year remains to be evaluated.

c. Two aspects of this work remain unfinished, namely:

i. transitioning of the FIT analysis system to NWS operations (MLB/MFL)
ii. identify an experiment period to test the impact of the FIT SST analysis system on the MIA WRF/LAPS system (and WRF/ADAS in MLB).

Item i: In a recent discussion with the NWS partners, the PI has agreed to supply the analyses in a GRIB formatted output for ingestion into the WRF/LAPS cycle in MIA and WRF/ADAS cycle in Melbourne. The PI anticipates completing the work (i.e., moving the software over to the NWS) in a supplemental COMET Partners grant.

Item ii: Has been at least partially addressed via the SPoRT collaboration with the MODIS SST composites and the WRF/ADAS simulations for May 2004. This work is rather significant and has lead to a separate paper (see Sections 1 and 2).

5.2 Forecast Partner

a. The forecast partners had replaced the RTG_SST within the ADAS/ARPS with GOES-only composites. Given the identified issues with sun glint and bottom reflectance during the day, both WFOs MLB and MIA had switched back to the RTG (Miami is using the new 1/12th degree RTG product). The RTG analysis, at both offices, will soon be replaced by the FIT analyses. WFO MLB is anxiously awaiting the arrival of the multi-satellite SST composites for supporting operational local modeling. In all likelihood MLB will have an ADAS/WRF configuration which employs the multi-satellite SST composites.

Table 1: Summary of data stream issues and solutions.

PROBLEM	SOLUTION
GOES sun glint	apply second glint mask to NESDIS data
Bottom reflectance	remove SSTs in daytime/shallow regions
MODIS Terra limb effects	remove daytime Terra SSTs
MODIS cloud contaminated pixels	apply background check
GOES composite geolocation	*shift grid*

6. References

Dessler, A. E., and P. Yang, 2003: The distribution of tropical thin cirrus clouds inferred from Terra MODIS data. *J. Climate*, **16**, 1241-1247.

Gentemann, Chelle, C.J. Donlon, A. Stuart-Menteth, F.J. Wentz, 2003: Diurnal Signals in Satellite Sea Surface Temperature Measurements. *Geophys. Res. Let.*, **30(3)**, 1140-1143.

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Johnson, R. X. and M. P. Weinreb, 1996: GOES-8 Imager Midnight Effects and Slope Correction, in GOES-8 and Beyond. *Proc. Society of Photo-Optical Instrumentation Engineers* (SPIE), **2812**, 596-607.