1.3 THE IMPACT OF MODIS SST COMPOSITES ON SHORT-TERM REGIONAL FORECASTS

Katherine M. LaCasse*[1], William M. Lapenta[2], Steven M. Lazarus[3], Michael E. Splitt[3],
Gary J. Jedlovec[2], and Stephanie L. Haines[1]

[1]University of Alabama in Huntsville, Huntsville, AL
[2]NASA Marshall Space Flight Center, Huntsville, AL
[3]Florida Institute of Technology, Melbourne, FL

1. INTRODUCTION

Mesoscale features, such as the sea breeze circulation, are common forecast challenges along the Florida peninsula (e.g., Bauman and Businger 1996). In addition to the sea breeze and associated deep convection, precipitation, a secondary solenoid (the secondary solenoid is more theoretical than observed, and a good science issue is the effect of this solenoid vs. wind stress), and cloud fields (e.g., stratocumulus) are also frequently observed along a relatively strong sea surface temperature (SST) gradient off the Florida east coast adjacent to the Gulf Stream. The SST gradients, associated with the Florida Current and cooler shelf water, are typically well defined in high-resolution SST datasets, such as the Earth Observing System (EOS) Moderate Resolution Imaging Spectroradiometer (MODIS) SST product. However current operational forecast models (e.g., the Rapid Update Cycle, RUC; Eta) are initialized with a relatively coarse (approximately 50 km) SST analysis produced daily at the National Centers for Environmental Prediction (NCEP; Thiebaux et al. 2003).

Here, the impact of the lower-boundary forcing (i.e., the specification of relatively localized SST gradients and anomalies) on short-term simulations (24h forecasts) generated by the Weather Research and Forecasting (WRF; Skamarock et al. 2005) prediction system is examined. As the next-generation mesoscale model designed for use by both the research and operational communities, the WRF model contains physics suited for mesoscale modeling, such as the Noah land-surface scheme and the Yonsei University (YSU) planetary boundary layer scheme. A particular focus of this research is on the evolution of marine, coastal, and land surface boundary layer-related parameters including winds, temperature, and moisture. WRF simulations, over a region that includes Florida and the northern Gulf of Mexico, are conducted initializing with both a relatively coarse-resolution SST product and a high-resolution SST composite. A case study period during May 2004 is chosen as it is a relatively clear/dry period, thereby limiting potential model complications associated with convective feedback during the Florida thunderstorm season. The primary objective of this research is to identify the degree to which the WRF responds to the high-resolution SSTs and to subsequently provide feedback to the relevant WRF development groups. This project is part of a collaborative effort between the NASA Short-term Prediction Research and Transition (SPoRT) Center and the Florida Institute of Technology (FIT). FIT is constructing a high-resolution real-time SST analysis system designed to initialize regional short-term (24 h) weather forecasts over the Florida peninsula (Lazarus et al. 2006). Additionally, related SPoRT work (discussed in part herein) involves the production of high-resolution SST composite products from the MODIS instrument (Haines et al. 2006).

2. SST PRODUCTS

2.1 Real-time, global, sea surface temperature (RTG-SST) analysis

The NCEP operational models use the Real-Time Global Sea Surface Temperature (RTG-SST) analysis, developed at the Marine Modeling and Analysis Branch (MMAB; http://polar.ncep.noaa.gov/sst/). Two-dimensional variational assimilation of ship, buoy, and satellite-derived SST data from the NOAA-17 Advanced Very High Resolution Radiometer (AVHRR) are used to create a daily operational SST analysis, at half-degree (latitude, longitude) resolution (Fig. 1a). A new, twelfth-degree resolution SST product is now produced operationally by the MMAB. In addition to the increased spatial resolution, this product also includes SST data from the NOAA-16 AVHRR.

---

* *Corresponding author address:* Katherine M. LaCasse, Univ. of Alabama in Huntsville, Huntsville, AL 35805; email: kate.lacasse@nasa.gov

2.2 MODIS sea surface temperature composite

The EOS MODIS SST product from the Aqua satellite is composited to produce full spatial coverage at 1 km resolution (Fig. 1b). This increased resolution adds much more structure to the SST fields compared to the RTG-SST product (Fig. 1c). The MODIS compositing algorithm identifies the five most recent clear-sky pixels and averages the warmest three of those five. Although dropping the coldest pixels reduces the likelihood of cloud contamination, it may also introduce bias in the composites. However, because the period of focus (May 2004) is a month over which the climatological SSTs increase, the "warmest pixel" selection method appears to correspond quite well with the observed SSTs over the region (Haines et al. 2006). SST data is available twice daily, at approximately 7 and 19 UTC. The data from the 'daytime' and 'nighttime' passes are kept separate because of the diurnal change in SSTs. For this study the SSTs are static within the WRF model, with the composite used being the one valid closest to the initialization time.

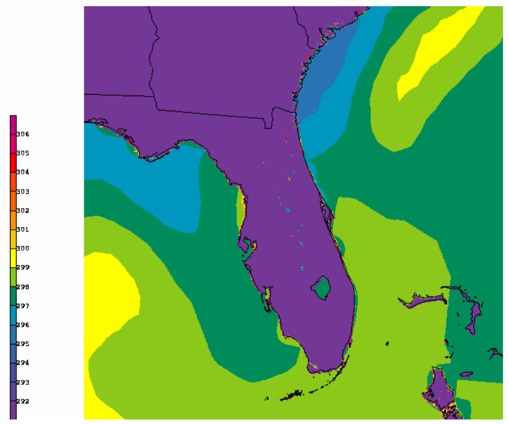

Fig. 1a: 13 May 2004 RTG-SST analysis (color filled, interval 1 K) for the domain of interest.

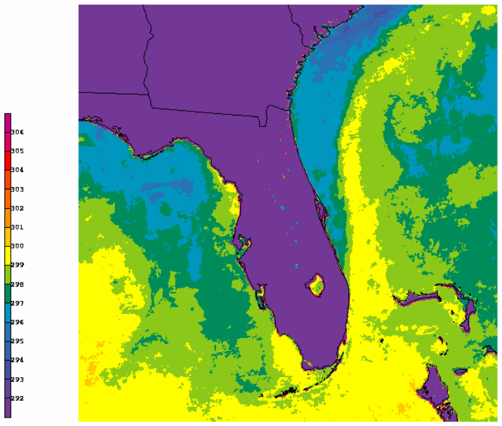

Fig. 1b: MODIS daytime SST composite (color filled, interval 1 K) mapped to the WRF domain (2 km resolution) and valid 13 May 2004.

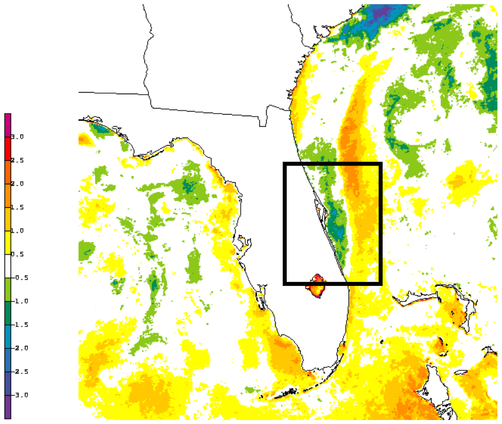

Fig. 1c: SST differences (MODIS – RTG; color filled, interval .5 K) valid 13 May 2004. The black box represents the domain in Fig. 4.

3. MODEL AND ASSIMILATION SYSTEMS

3.1 Advanced Regional Prediction System (ARPS) Data Analysis System

The Advanced Regional Prediction System (ARPS; Xue et al. 2001) consists of a number of components, including a data assimilation front end (ARPS Data Analysis System; ADAS) and a mesoscale/convective scale model. For this study, we use various components of the latest version of the ARPS package (version 5.2.3) including: ADAS, arpssoil, arps2wrf, and wrf2arps.

The ADAS assimilates observations through a successive correction/statistical technique that converges to optimal interpolation (Bratseth 1986). It is a very modular system that is capable of ingesting data from numerous sources and can account for the individual error characteristics of the various data streams. Similar to other analysis methods (e.g., optimum interpolation, variational), the ADAS adjusts a background field (e.g., a model forecast) by using a combination of observational data and information relating the relative observation-to-background field errors.

The program arpssoil uses antecedent precipitation data to update the soil moisture of the ADAS analysis. During the 3-h data assimilation window, analysis and forecast information is transferred between WRF and ARPS using arps2wrf and wrf2arps. While both models were configured to use the same horizontal grid spacing, some vertical interpolation is required (the ARPS vertical levels were chosen to minimize the amount of interpolation).

3.2 Weather Research and Forecasting (WRF) prediction system

The WRF model (version 2.1 is used herein) is designed to advance both the science and application of mesoscale weather forecasting at grid resolutions ranging from 1-10 km. For this study, particular emphasis is placed on the interaction of the surface with the atmosphere. The WRF physics options used for the for this research include the Noah land surface model, the YSU planetary boundary layer scheme, and the WRF Single-Moment (WSM) 6-class microphysics scheme. The domain is centered over the Florida peninsula and consists of 500 x 500 horizontal grid points at 2 km resolution with 51 vertical levels (Fig. 1b).

3.3 Forecast/assimilation cycle

To ascertain the impact of the MODIS SSTs, parallel runs are performed. The control run (CNTL) uses the standard RTG-SST product, while the experimental run (EXPR) replaces the SSTs with the aforementioned high-resolution MODIS SST composite. The simulations (24h forecasts) are run once per day for May 2004.

Both CNTL and EXPR are “pre-initialized” at 21 UTC using the 20 km RUC analysis as the background field for ADAS (see Fig. 2). For the EXPR run, the MODIS SST composite replaces the SSTs, while the CNTL run uses the RTG-SST product. The ADAS initialization of the WRF 3h forecast cycle includes the following data: METARs, ACARS, buoys, wind profilers, rawinsondes, and WSR-88D radial winds. In addition to the ADAS, the RUC provides the WRF lateral boundary conditions. The 3h window is designed to allow the WRF to adjust to the SST fields.

The 3h forecast from WRF provides the ‘new' background field for a second ADAS analysis valid at 00 UTC. Observations (near 00 UTC) are once again assimilated to create an analysis that, along with the 40 km 3h Eta forecasts, is then used to start the 24h forecast.

Fig. 2: ADAS/WRF cycle. The vertical red lines indicate ADAS analysis times, the horizontal blue line the 3h WRF forecast, and the horizontal black line the 24h WRF forecast (see text for more details).

4. PRELIMINARY RESULTS

Herein we attempt to address a number of different but relevant questions related to the use of high-resolution SSTs in short-term forecasts. Are biases in the WRF model evident? Does the model respond in an expected manner to the changed SST fields? Are the SST differences (between CNTL and EXPR) significant enough to impact the sea breeze and/or sensible weather elements over the Florida peninsula? What impact do the high-resolution SSTs have on the ability of the WRF model to reproduce observed cloud and precipitation patterns over and adjacent to the high-resolution SST gradients? What impact, if any, is there with respect to the marine boundary layer evolution? We attempt to address a few of these questions here.

4.1 Impact over Land

Time-series plots of 2 m temperature and dew point temperature over a fifteen day period in May 2004 indicate that the WRF has a daytime cool bias and a nighttime dry bias (Fig. 3). METAR observations were used to compute bias and root mean square (RMS) error values for both the CNTL and EXPR simulations, and these simulations had an averaged bias around -1.1 K and a RMS error of about 2.5 K. Similarly, CNTL and EXPR both had similar 2 m dew point temperature biases (-0.67 K) and RMS errors (1.9 K) when compared with METARs.

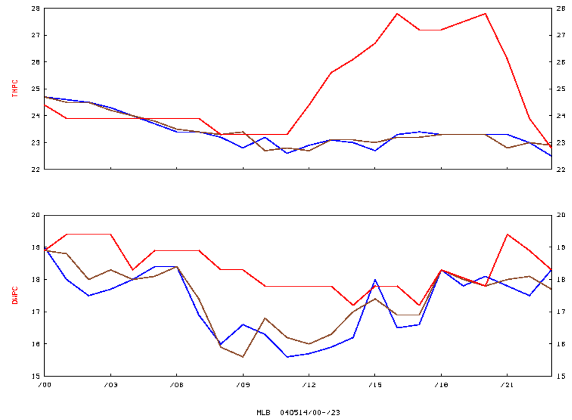

Fig. 3: Time-series of 2 m temperature (top, interval 1° C) and dew point temperature (bottom, interval 1° C) of METAR observations (red), CNTL (blue), and EXPR (brown) valid 00 – 23 UTC 14 May 2004 at Melbourne, FL.

Although a feature of significant interest, the sea breeze front (mean position, timing, etc.) appears to have been minimally impacted by the high-resolution SSTs. To quantitatively compare the impact of the SSTs on the location of the sea breeze front, the difference in frontal position between CNTL and EXPR along the coast of Florida will be recorded daily at 18 UTC at two distinct latitudes; 26° N and 29° N. The location of maximum convergence in the near-surface wind field, along with 10 m wind direction, is used to determine the location of the fronts. The comparison of an initial case from 27 May 2004 showed a difference between the CNTL and EXPR simulations of less than 2 km. This difference is small given the regional differences on the order of 1-2 K between the MODIS and RTG SSTs. However, these SST differences are not large when compared with the land/sea mesoscale forcing (i.e., temperature contrast), which drives the sea breeze circulation. It is anticipated that CNTL and EXPR simulation differences relating to smaller scale marine features (e.g., rope clouds, Gulf Stream convection, surface wind stress, etc.) are more likely to be dependent on variations in the SST structure.

4.2 Impact over Water

As stated earlier, the difference between MODIS and RTG SSTs is as large as 2 K in regions east of central Florida (Fig. 1c). These temperature differences have a direct effect on the sensible and latent heat fluxes in these regions. The WRF model responds in the expected manner with a larger sensible heat flux in regions of higher SSTs along the Gulf Stream (Fig. 4). This increased sensible heat flux then results in an increased 2 m temperature over this region (Fig. 5). Likewise, a higher latent heat flux is associated with an increase in evaporation caused by warmer SSTs (not shown).

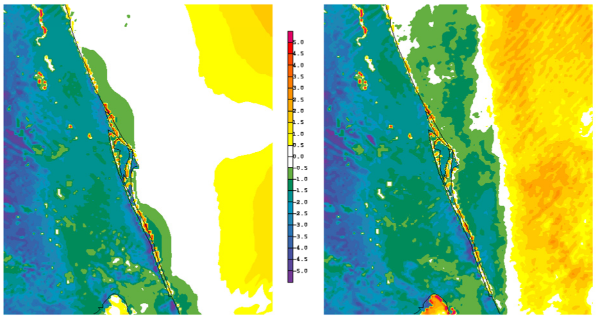

Fig. 4: Sensible heat flux (color filled, $0.5*10^{-1}$ Wm^{-2}) for CNTL (left) and EXPR (right) valid 01 UTC 14 May 2004.

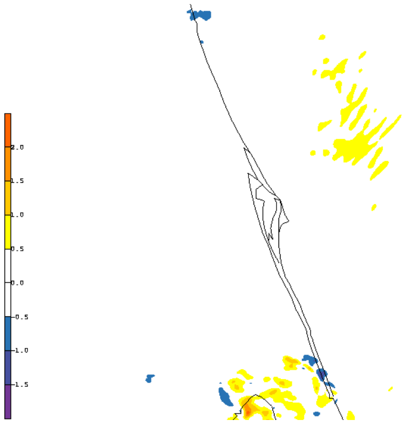

Fig. 5: 2 m temperature difference field (EXPR – CNTL; color filled, interval .5 K) valid at 01 UTC 14 May 2004.

To determine an overall impact of the high-resolution SSTs on 2 m temperature over the ocean, bias and RMS errors were calculated (buoy observations versus WRF) for thirteen days in May 2004. The average bias and RMS error were around -0.98 K and 1.5 K, respectively, for both CNTL and EXPR. As with the 2 m temperatures over land, buoy data indicate a WRF cool bias, and the differences between the CNTL and EXPR simulations were once again very small.

Observational studies have shown high correlation between surface wind stress measured by scatterometers and regions with strong SST gradients (e.g., Chelton et al. 2001; O'Neill et al. 2003). Furthermore, recent modeling studies (e.g., Chelton and Wentz 2005; Chelton 2005) have shown impacts on the wind stress by using higher resolution SST products. It is expected that these differences will manifest in the marine boundary layer (e.g., in the magnitude of 10 m wind speeds) in the vicinity of the Gulf Stream, which is well defined in the high-resolution MODIS SST composite (Fig. 1b). 14 May 2004 shows an example of the impact on the low level wind fields off the central east coast of Florida in a case of predominately easterly flow. Differences between the MODIS and RTG SST values are up to 2 K (Fig. 6a), but note that the differences in the SST gradients between the two products is significant (not shown). There are wind differences on the order of 0.6 ms^{-1} between the CNTL and EXPR runs. Where the winds encounter colder waters in the EXPR simulation, there is deceleration. Likewise there is an acceleration of EXPR winds associated with the warmer waters. These changes in wind speed are observed on both sides of the Gulf Stream (Fig. 6b). Differences in the wind divergence fields correspond to the regions of differences in wind magnitude, indicating a potential change in forcing for cloud formation (not shown).

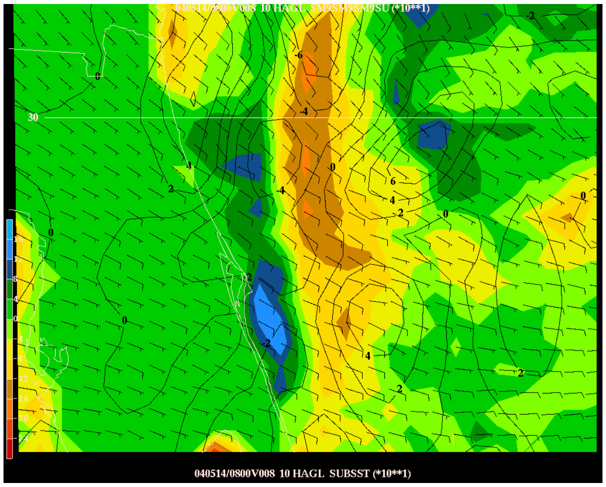

Fig. 6a: Difference (CNTL - EXPR) of SSTs (color filled, interval .4 K), 10 m wind magnitude (solid, interval .2 ms^{-1}), and 10 m wind (EXPR; wind barbs, ms^{-1}) valid at 08 UTC 14 May 2004.

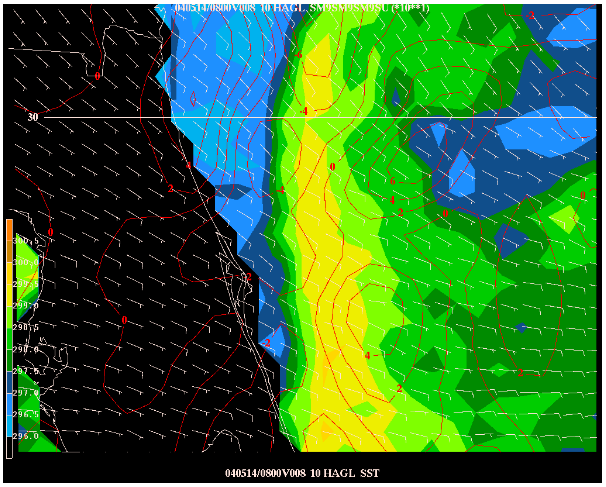

Fig. 6b: SSTs (EXPR; color filled, interval .5 K), 10 m wind magnitude difference (CNTL - EXPR; solid, interval .2 ms^{-1}), and 10 m wind (EXPR; wind barbs, ms^{-1}) valid at 08 UTC 14 May 2004.

5. FUTURE WORK

Research is currently underway to determine the impact of high-resolution SSTs on short-term WRF simulations. Statistics of bias and RMS error will be completed for the month of May 2004 using METAR and buoy observations as a way to highlight model biases. Also, the quantitative calculation of sea breeze location will show the amount of impact the high-resolution SSTs have over the Florida peninsula. The response of the marine boundary layer will be explored in more detail. Finally, a focus will be placed on determining if sensible weather, such as clouds and precipitation, observed over the Gulf Stream are accurately represented in the WRF simulations.

Acknowledgements:

This research was funded by the NASA Science Mission Directorate's Earth-Sun System Division in support of the Short-term Prediction Research and Transition (SPoRT) program at Marshall Space Flight Center

REFERENCES

Bauman, W. H. and S. Businger, 1996: Nowcasting for Space Shuttle Landings at Kennedy Space Center, Florida. *Bull. Amer. Meteor. Soc.*, **77**, 2295-2305.

Bratseth, A. M., 1986: Statistical interpolation by means of successive corrections. *Tellus*, **38A**, 439-447.

Brewster, K., 1996: Implementation of a Bratseth analysis scheme including Doppler radar. *Preprints, 15th Conf. on Weather Analysis and Forecasting*, Norfolk, VA, Amer. Meteor. Soc., 92-95.

Chelton, D. B., 2005: The impact of SST specification on ECMWF surface wind stress fields in the eastern tropical Pacific. *J. Climate*, **18**, 530-550.

Chelton, D. B., S. K. Esbensen, M. G. Schlax, N. Thum, M. H. Freilich, F. J. Wentz, C. L. Gentemann, M. J. McPhaden, and P. S. Schopf, 2001: Observations of coupling between surface wind stress and sea surface temperature in the eastern tropical Pacific. *J. Climate*, **14**, 17877-17904.

Chelton, D. B. and F. J. Wentz, 2005: Global Microwave Satellite Observations of Sea Surface Temperature for Numerical Weather Prediction and Climate Research. *Bull. Amer. Meteor. Soc.*, **86**, 1097–1115.

Haines, S. L., G. J. Jedlovec, S. M. Lazarus, and C. G. Calvert, 2006: A MODIS sea surface temperature composite product. *Preprints, 14th Conf. on Satellite Meteorology and Oceanography*, Atlanta, GA, Amer. Meteor. Soc.

O'Neill, L. W., D. B. Chelton and S. K. Esbensen, 2003: Observations of SST-induced perturbations of the wind stress field over the Southern Ocean on seasonal time scales. *J. Climate*, **16**, 2340-2354.

Skamarock, W. C., J. B. Klemp, J. Dudhia, D. O. Gill, D. M. Barker, W. Wang, and J. G. Powers, 2005: A Description of the Advanced Research WRF Version 2. *NCAR Technical Note,* NCAR/TN-468+STR, 88 pp.

Thiebaux, J., E. Rogers, W. Wang, and B. Katz, 2003: A New High-Resolution Blended Real-Time Global Sea Surface Temperature Analysis. *Bull. Amer. Meteor. Soc.*, **84**, 645-656.