5A.1 IMPACT OF LAKE OKEECHOBEE SEA SURFACE TEMPERATURES ON NUMERICAL PREDICTIONS OF SUMMERTIME CONVECTIVE SYSTEMS OVER SOUTH FLORIDA

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1. INTRODUCTION

The NASA Short-term Prediction Research and Transition (SPoRT) Center, the Florida Institute of Technology, and the NOAA/NWS Weather Forecast Office at Miami, FL (MFL) are collaborating on a project to investigate the impact of using high-resolution, 2 km Moderate Resolution Imaging Spectroradiometer (MODIS) sea surface temperature (SST) composites within the Weather Research and Forecasting (WRF) prediction system. The NWS MFL is currently running WRF in real-time to support daily forecast operations, using the National Centers for Environmental Prediction Nonhydrostatic Mesoscale Model (NMM; Janjić et al. 2001) dynamical core within the NWS Science and Training Resource Center's Environmental Modeling System (EMS) software. Twenty-seven hour forecasts are run daily initialized at 0300, 0900, 1500, and 2100 UTC on a domain with 4-km grid spacing covering the southern half of Florida and adjacent waters of the Gulf of Mexico and Atlantic Ocean. The SSTs are initialized with the NCEP Real-Time Global (RTG) analyses at 1/12° resolution.

The project objective is to determine how accurate specification of the lower-boundary forcing over water using the MODIS SST composites (Haines et al. 2007) within the 4-km WRF runs will improve sea fluxes and hence, produce more accurate evolution of coastal mesoscale circulations and the associated sensible weather elements. SPoRT conducted parallel WRF EMS runs from February to August 2007 identical to the operational runs at NWS MFL except for the use of MODIS SST composites in place of the RTG product as the static SSTs over water. During the course of this evaluation, an intriguing case was examined from 6 May 2007, in which lake breezes and convection around Lake Okeechobee evolved quite differently when using the high-resolution SPoRT MODIS SST composites versus the lower-resolution RTG SSTs. This paper analyzes the differences in the 6 May simulations, and also examines a separate simulation using a different WRF configuration in which the SSTs over Lake Okeechobee were allowed to vary during the simulation. The diurnal variation of SSTs over the relatively shallow Lake Okeechobee is also discussed.

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2. EXPERIMENT DESIGN

Experiments are being conducted to assess the impact and potential benefit of the use of high-resolution MODIS SST for real-time short-term weather prediction. Two sets of experiments are described here that examine the use of a) temporally static MODIS SST throughout the model domain, and b) temporally evolving MODIS SST only within Lake Okeechobee, which are tied to in-situ measurements.

2.1 NWS MFL Experiments with WRF-NMM

The NWS MFL is currently running the WRF-NMM system in real-time to support daily forecast operations, within the EMS software. The EMS is a stand-alone modeling system capable of downloading the necessary daily datasets, and initializing, running and displaying WRF forecasts in the NWS Advanced Weather Interactive Processing System (AWIPS) with little intervention required by forecasters. Twenty-seven hour forecasts are run daily with start times of 0300, 0900, 1500, and 2100 UTC on a domain with 4-km grid spacing covering the southern half of Florida and the far western portions of the Bahamas, the Florida Keys, the Straights of Florida, and adjacent waters of the Gulf of Mexico and Atlantic Ocean (Figure 1). Each model run is initialized using the NCEP North American Mesoscale (NAM) modeling system. The SSTs are initialized with the NCEP Real-Time Global (RTG) analyses at 1/12° resolution (~9 km); however, the RTG product does not exhibit fine-scale details consistent with its grid resolution.

SPoRT is conducting parallel WRF-NMM EMS runs identical to the operational runs at NWS MIA in every respect except for the use of MODIS SST composites in place of the RTG product as the initial and boundary conditions over water. The MODIS SST composites for initializing the SPoRT WRF runs are generated on a 2-km grid four times daily at 0400, 0700, 1600, and 1900 UTC, based on the times of the overhead passes of the Aqua and Terra satellites. The incorporation of the MODIS SST composites into the SPoRT WRF runs is staggered such that the 0400 UTC composite initializes the 0900 UTC WRF, the 0700 UTC composite initializes the 1500 UTC WRF, the 1600 UTC composite initializes the 2100 UTC WRF, and the 1900 UTC composite initializes the 0300 UTC WRF.

The May 2007 data sets provided a period in which the impact of SST specification in a convective environment can be evaluated between the Control

(RTG SST) and the MODIS (MODIS SST) runs. Model runs from a 6 May 6 2007 mesoscale convective system (MCS) will be examined here.

2.2 Lake Okeechobee SST Update Simulation

To test the temporally updated SSTs in WRF, we set up separate Control and experimental simulations using version 3.0.1.1 of the Advanced Research WRF (ARW; Skamarock et al. 2008) initialized at 0900 UTC 1 May 2007. The model is integrated 27 hours to 0600 UTC 2 May the following day, similar to the operational WRF runs done at NOAA/NWS Miami, FL. The simulation domain (Figure 1) consists of a single grid of 209 x 211 staggered points in the zonal and meridional directions, respectively, at 4-km horizontal grid spacing. The grid contains 39 sigma-pressure vertical levels extending from the surface to a domain top at 50 mb. The vertical spacing is stretched from a minimum of 0.004 sigma near the surface (corresponding to ~40 m) to a maximum of 0.034 sigma at upper levels.

For both the Control and SST-varying simulations (hereafter SSTVAR), the ARW physics options consist of the rapid radiative transfer model (Mlawer et al. 1997) and the Dudhia scheme (Dudhia 1989) for longwave and shortwave radiation, respectively. The WRF Single Moment 6-class microphysics scheme (WSM6, Hong and Lim 2006; Skamarock et al. 2008) is used without any convective parameterization physics. Therefore, all convection is determined explicitly by the WSM6 microphysics and model dynamics. The planetary boundary layer and turbulence processes are parameterized by the Mellor-Yamada-Janjić scheme (Janjić 1990, 1996, 2002). Horizontal diffusion is handled by the two-dimensional Smagorinsky first-order closure scheme (Smagorinsky et al. 1965). The land surface processes are simulated with the Noah LSM as configured in version 3.0.1.1 of the ARW, being nearly identical to the version run operationally at NCEP (Chen and Dudhia 2001; Skamarock et al. 2008; Ek et al. 2003). Surface-layer calculations of friction velocities and exchange coefficients needed for the determination of surface fluxes in the LSM are provided by the NCEP Eta similarity theory scheme (Janjić 1996, 2002). The positive-definite advection options for moisture and scalars are enabled to remove the possible unphysical effects and high precipitation bias that can result from the "clipping" of negative mixing ratios in the 3rd order Runge-Kutta transport scheme (Skamarock and Weisman 2008; Skamarock et al. 2008).

For the Control run, all initial conditions for the atmosphere and land come from the native-resolution (12-km, grib 218) NCEP NAM model 3-h forecast initialized at 0600 UTC. Three-hourly boundary conditions for both the Control and SSTVAR runs are provided by the NAM model 3-h to 30-h forecasts. The MODIS SST analysis at the model initialization time remain fixed throughout the 27-h ARW simulation in the Control run. Interpolation of initial and boundary condition data are done with the WRF Pre-Processing System (WPS) utilities.

In the SSTVAR simulation, updated SSTs are incorporated into the ARW at 3-hourly intervals, consistent with the atmospheric boundary condition update frequency. New SSTs are modified values from the MODIS SST product and vary only over Lake Okeechobee. The MODIS SSTs over Lake Okeechobee are modified using in-situ lake surface temperature data provided by the South Florida Water Management District (SFWMD). In the model pre-processing and initialization step, each modified MODIS SST composite at 3-hourly intervals is interpolated to the model domain, and then the "sstupdate" option is activated in the WRF "namelist.input" file to create an additional boundary file called "wrflowinp_d01". This file stores the time-varying SST data for the ARW to incorporate throughout the simulation, similar to the "wrfbdy_d01" file for atmospheric boundary conditions. During the SSTVAR model integration, the SSTs are kept fixed for each 3-hourly forecast interval until the next SST dataset is read.

3. PRELIMINARY RESULTS

3.1 6 May 2007 MCS Simulation

Southern Florida was situated in northwesterly upper-level flow with a surface cold front approaching from the northwest as cyclogenesis occurred off the coast of North Carolina (Figure 1). Thunderstorms developed during the day and evolved into an MCS (Figure 2) late in the afternoon. Storm reports from the Storm Prediction Center included an F0 tornado, hail up to 1 inch, and reports of wind damage (Figure 3).

Four model simulations for this weather event are compared: the 0300 and 0900 UTC Control and MODIS runs. The SST differences between the Control and MODIS simulations are depicted in Figure 4. The MODIS 0300 UTC SST are significantly warmer than the Control run over portions of the West Florida Shelf, Lake Okeechobee and near the Bahamas, while cooler in the southwestern part of domain, over the Florida Current, and especially along the Florida-Hatteras Shelf. The 0900 UTC SST differences are similar, with the exception of Lake Okeechobee in which the MODIS SST are cooler than the Control SST for the simulation.

All four model simulations develop a cluster of thunderstorms over the center of the Florida Peninsula that migrates to the southeast. Figure 5 shows model output for 0000 UTC 7 May 2007 for the two sets of simulations, 21 hours and 15 hours into the forecast for the 0300 and 0900 UTC simulations, respectively. Interestingly, the earlier model set produced convection as far south as the southern tip of the Florida Peninsula which verified by WSR-88D data (Figure 2f). Model composite reflectivity and surface streamlines are similar spatially between the Control and MODIS simulations, but with reflectivity differences of note in individual thunderstorm cells in both the 0300 and 0900 UTC runs. Maximum 10-m wind gusts within the simulation valid times of 6 May 2007 2200 UTC – 7 May 2007 0300 UTC ranged from 13.6 to 14.9 m s^{-1}, with the highest recorded in the 0900 UTC MODIS run. Maximum cloud top heights ranged from 12657 – 13813 m, with the highest recorded in the 0300 UTC MODIS run. Maximum composite reflectivity ranged between 43 and 45 dBZ, with the maximum value achieved in both MODIS runs. The significantly warmer SST in the 0300 MODIS run over Lake Okeechobee did not appear to produce the most intense convection, as might be expected with the significantly warmer lake water.

Comparison of the Control and MODIS SST runs 4 hours into each simulation reveal differences in the evolution of the surface wind field (Figure 6). Impacts are seen over the Florida-Hatteras Shelf similar to those reported by LaCasse et al. 2008. The most noticeable differences are the impacts in the vicinity of Lake Okeechobee. The impact to the surface wind magnitude and divergence fields are substantial in the 0300 UTC set, whereas the 0900 UTC simulations indicate little impact in this region. The differences in the 0300 UTC set are attributed to the significantly warmer MODIS SST in the 0300 UTC simulation.

3.2 1 May 2007 Lake Okeechobee SST Update Simulation

The motivation for using time-evolving SSTs over Lake Okeechobee stemmed from the observation of strongly diurnal-varying SST in the MODIS composite, as well as the model result differences seen in the NWS MFL experiments. Other studies (Wang et al. 2003) have noted the varying surface water temperature over the Lake, which is large in comparison to the typical diurnal variation over ocean. Conditions from 1 May 2007 provided for a clean experiment with minimal convection. Surface wind flow was predominantly out of the east.

The SST forcing in the Control and SSTVAR runs are shown in Figure 7 for a point near the center of the Lake (26.94°N Latitude, -80.81°E Longitude). The SSTVAR simulation SST is up to 4°C warmer than the control run within 6 hours. The difference in SST forcing is small by 24 hours into the forecast (one diurnal cycle). Impact to the surface sensible and latent heat fluxes over the Lake is noted with substantially higher values in the SSTVAR simulations (Figure 8).

Differences between the Control and SSTVAR simulated 2-m temperature and 10-m wind are shown in Figure 9 at 12 hours into the model forecasts. Air temperature is notably warmer due to the modified SST in the SSTVAR run. SSTVAR 10-m wind over the western portion of the Lake shows a larger easterly component, attributed to enhanced surface mixing in the SSTVAR simulation. An initial comparison of the model 10-m wind to observations from the SFWMD (Figure 10) over two locations over the Lake show mixed results. At the SFWMD station LZ40 location, the SSTVAR simulation wind speeds remain elevated overnight and through the morning which may be attributed to a lack of decoupling in the surface layer. The Control run, with presumably poorer surface specification, verifies better during this period. At the SFWMD L004 station, the observations fall between the Control and SSTVAR speeds, but the timing of the onset of stronger surface winds appears to be better captured by SSTVAR.

4. SUMMARY AND FUTURE WORK

This paper describes the experimental design for testing high-resolution SST specification on real-time mesoscale weather predictions. Static and time-evolving SST experiments were evaluated for an MCS event and for quiescent conditions, respectively. Impacts in using high spatial resolution MODIS SST products are noted in the model simulations of an MCS. Impact is also observed using time-evolving SST for an easterly flow regime over Florida.

Assessing the impact of the initial conditions differences on the evolution of the MCS needs to be evaluated more thoroughly, particularly in the vicinity of Lake Okeechobee where initial model differences are most noted in the path of the MCS. Evaluation of time-evolving SST on model forecasts will receive further evaluation.

5. ACKNOWLEDGEMENTS/DISCLAIMER

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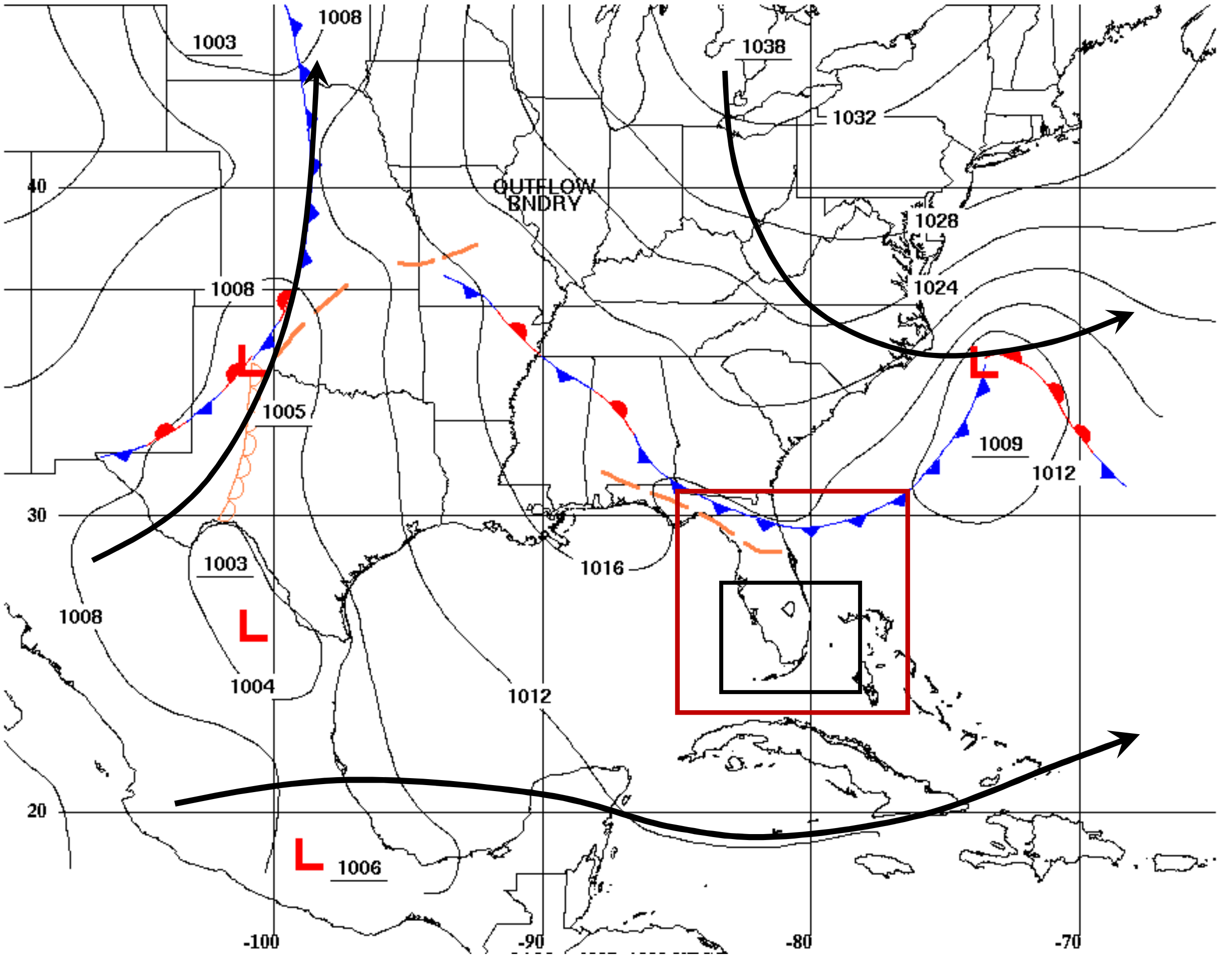

Figure 1. HPC surface analysis for 6 May 2007 1800 UTC and WRF model domains for the NWS MFL (black box) and Lake Okeechobee (red box) experiments. Upper level wind maxima added by authors.

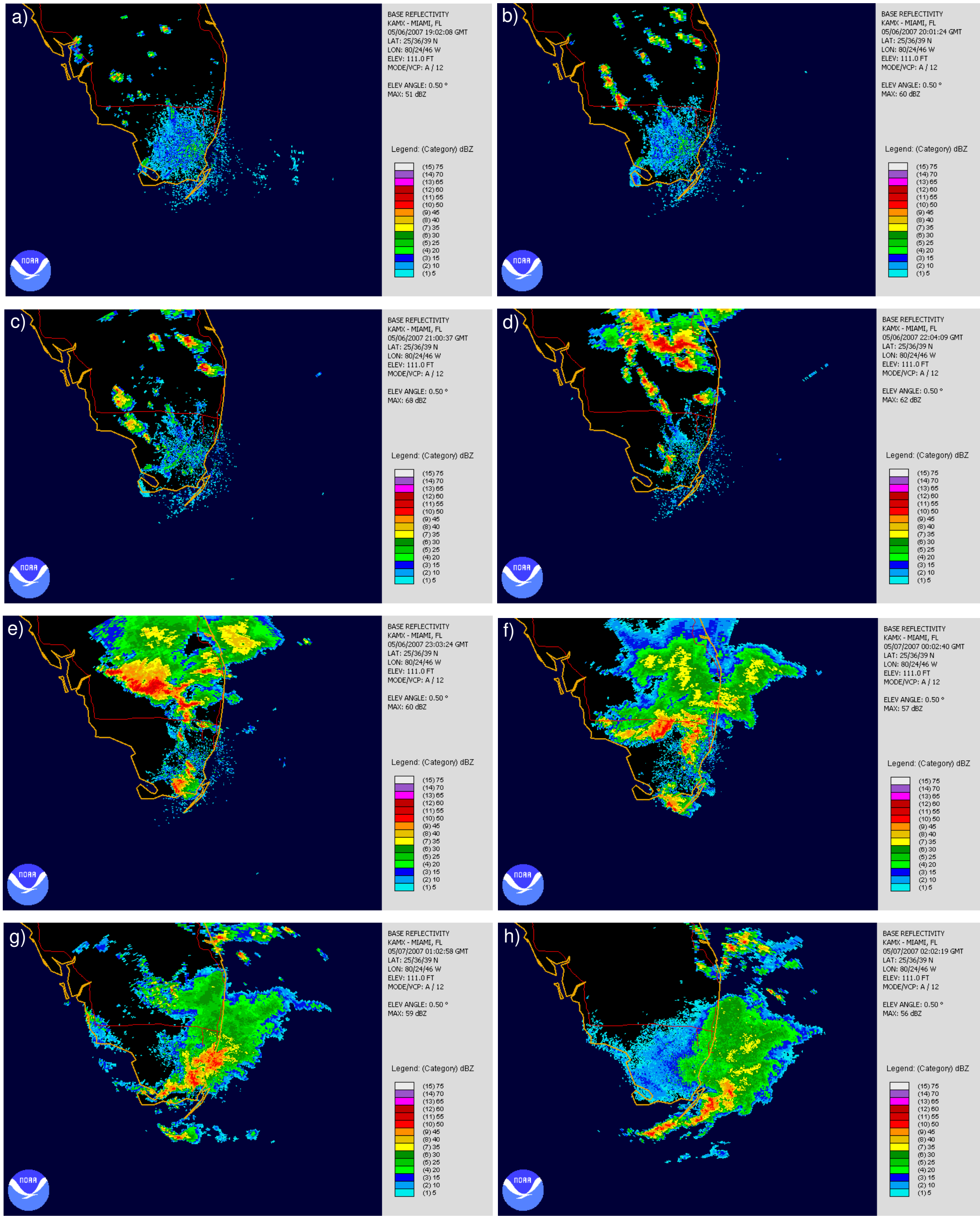

Figure 2. Sequence of hourly Level III base reflectivity images from the Miami, FL WSR-88D valid at (a) 1900 UTC 6 May, (b) 2000 UTC 6 May, (c) 2100 UTC 6 May, (d) 2200 UTC 6 May, (e) 2300 UTC 6 May, (f) 0000 UTC 7 May, (g) 0100 UTC 7 May, and (h) 0200 UTC 7 May, 2007.

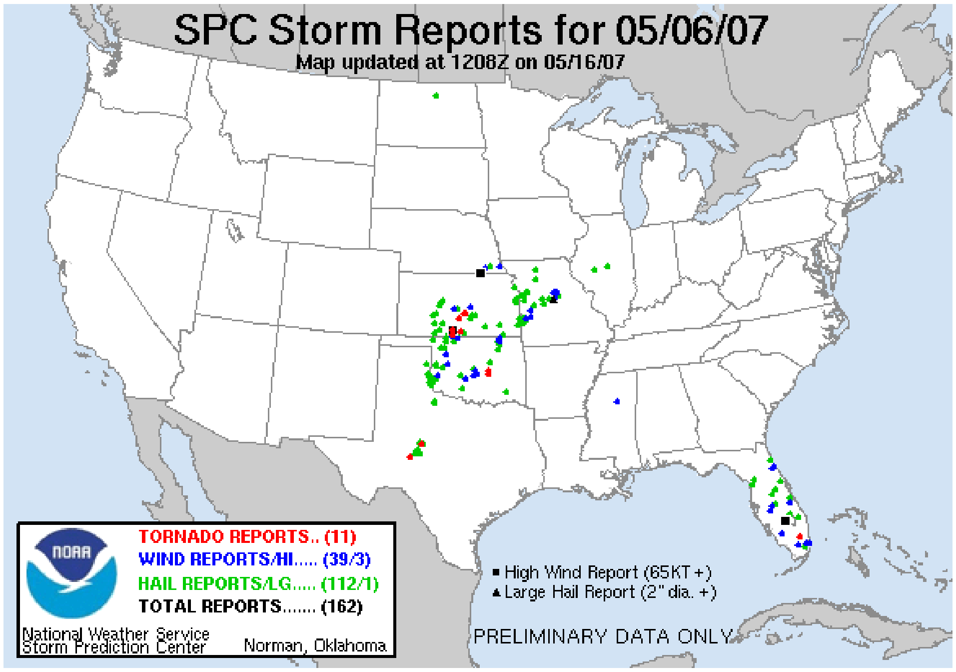

Figure 3. Storm Prediction Center (SPC) archived severe weather reports for 6 May 2007.

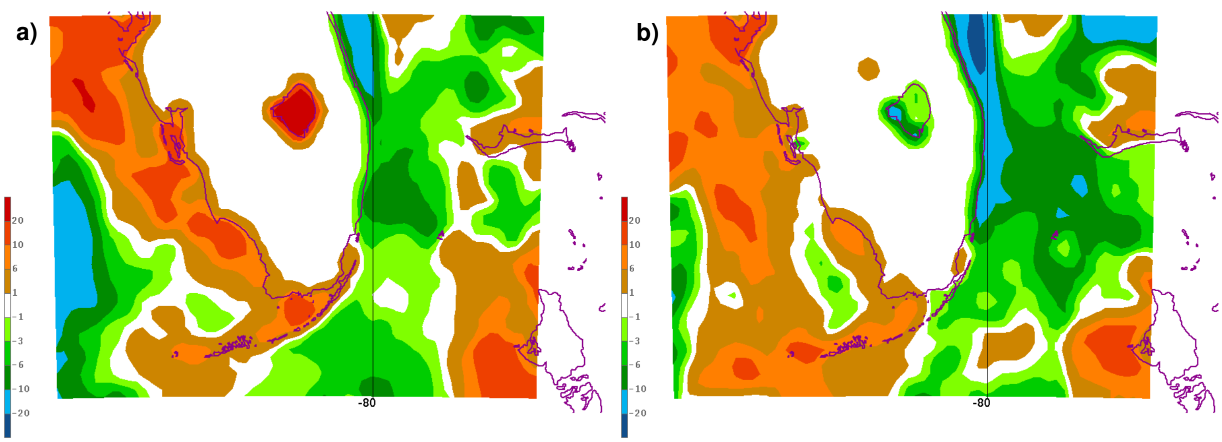

Figure 4. SST Differences (MODIS-Control) in 0.1°C increments for the 6 May 2007 a) 0300 UTC and b) 0900 UTC NWS MFL MCS simulations.

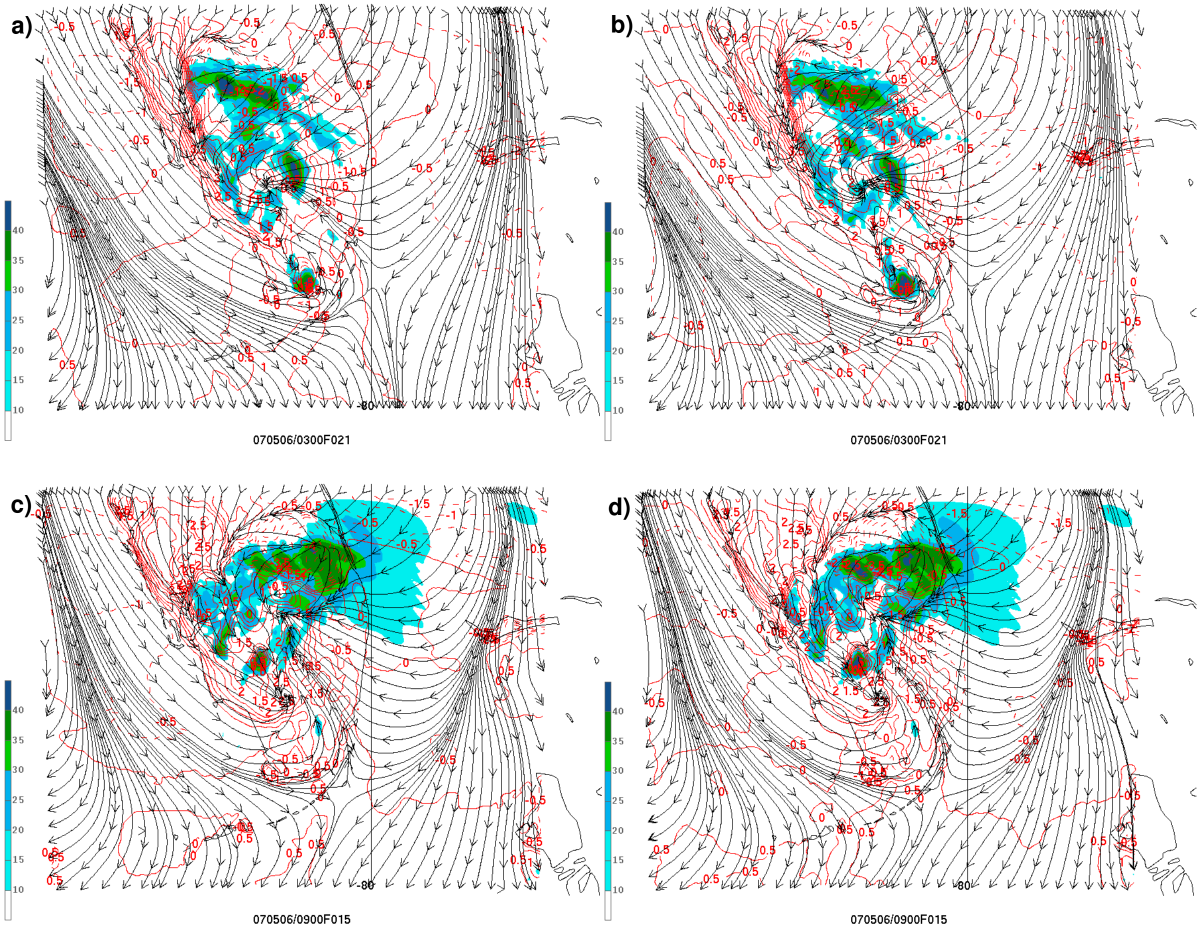

Figure 5. Model composite reflectivity and 10-m wind streamlines valid at 7 May 2007 0000 UTC for the a) 0300 UTC Control, b) 0300 UTC MODIS, c) 0900 UTC Control and d) 0900 UTC MODIS simulations.

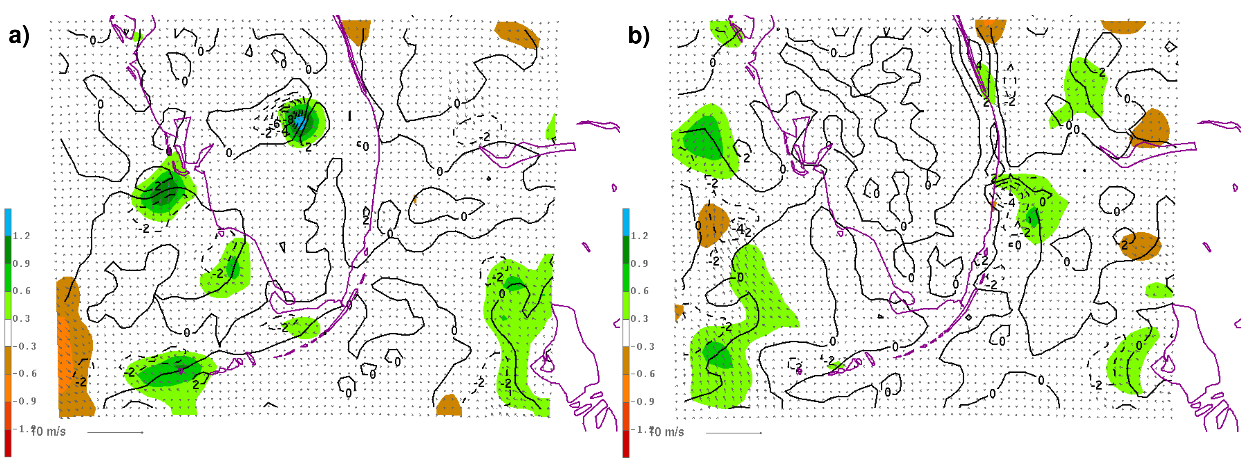

Figure 6. Model differences (MODIS-Control) in 10-m wind speed (m s^{-1},shaded), divergence (*10^{-5} s^{-1}, contoured), and wind speed vector differences (reference vector 10-m s^{-1}) 4 hours into the a) 0300 UTC and b) 0900 UTC NWS MFL MCS simulations.

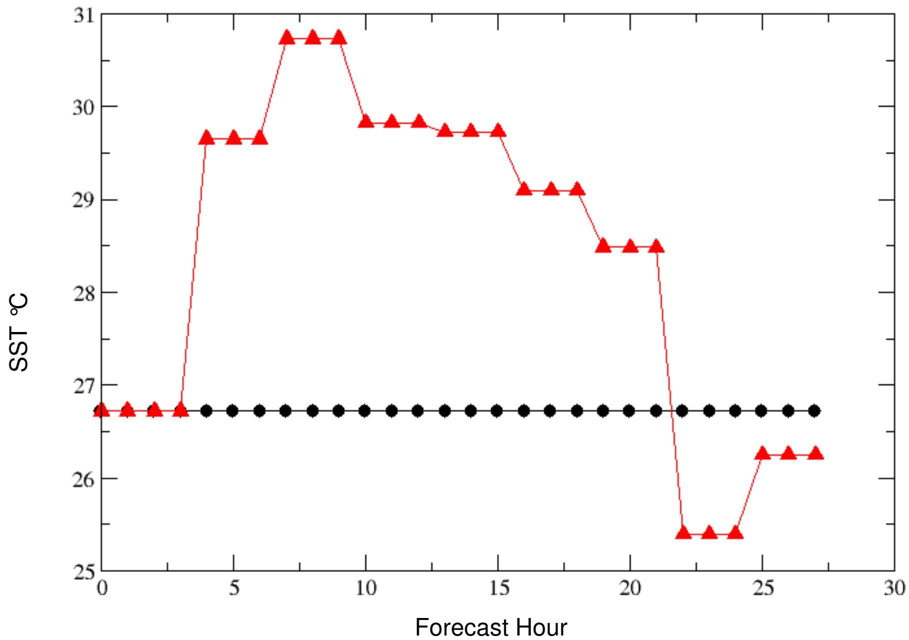

Figure 7. SST (°C) forcing values for a point centered over Lake Okeechobee for the Control (black circle) and SSTVAR (red diamond) simulations. SSTVAR were updated every 3 hours in tandem with the other model forcing.

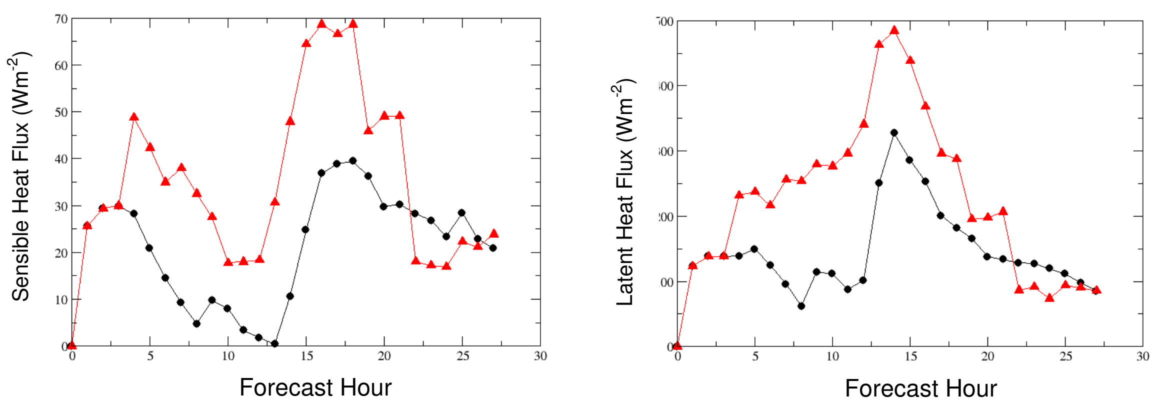

Figure 8. a) Sensible and b) latent heat fluxes (W m^{-2}) for a point centered over Lake Okeechobee for the Control (black circle) and SSTVAR (red diamond) simulations.

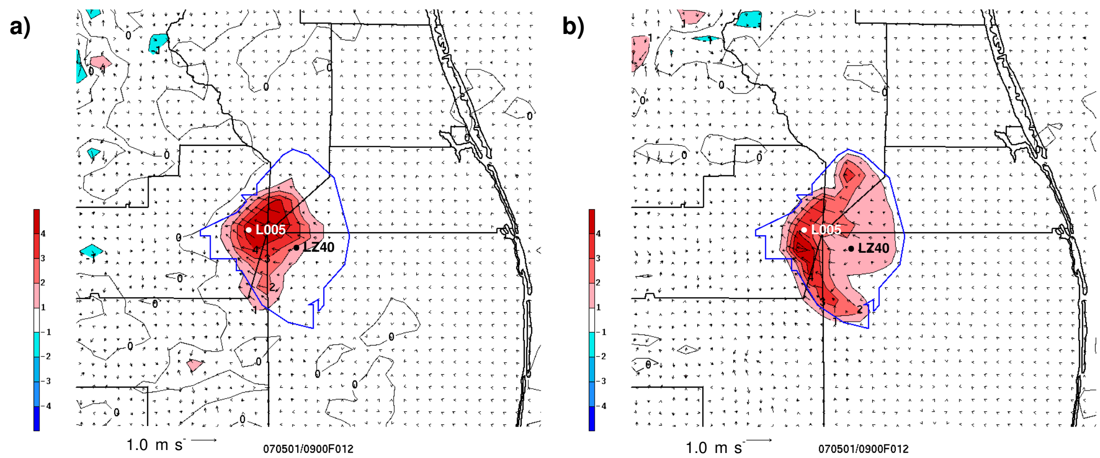

Figure 9. Model differences (SSTVAR – Control) 12 hours into the simulation for a) 2-m temperature and 10-m wind vector and b) 10-m wind speed and wind vector (repeated). The reference wind vector is 1 m s^{-1}. SWFMD Stations L005 and LZ40 are also labeled.

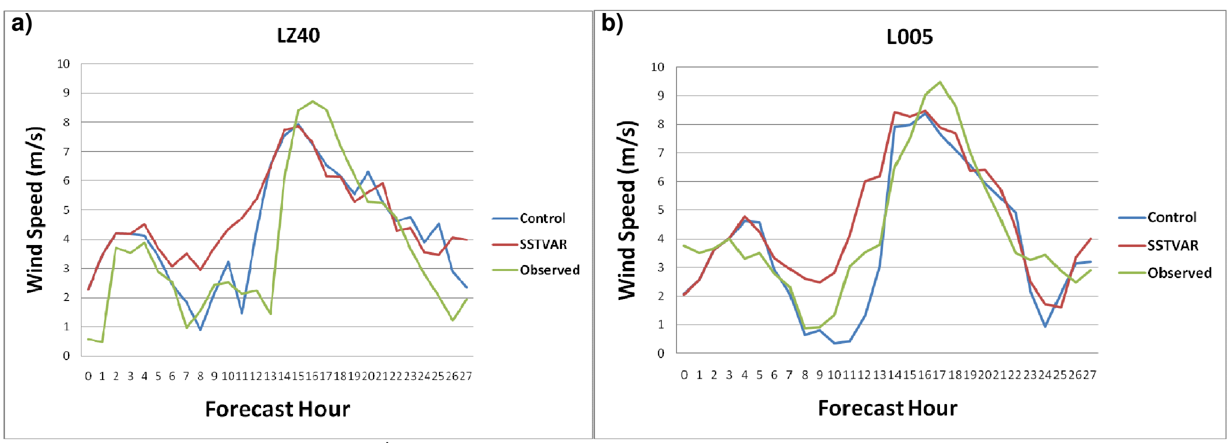

Figure 10. 10-m wind speed (m s^{-1}) from the Control, SSTVAR and in-situ observations at a) SFWMD Station LZ40 and b) SFWMD Station L005 for the 1 May 2007 Lake Okeechobee experiment.