5A.2 EXAMINING THE IMPACTS OF HIGH-RESOLUTION LAND AND OCEAN SURFACE INITIALIZATION ON LOCAL MODEL PREDICTIONS OF CONVECTION IN THE SOUTHEASTERN U.S.

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1. INTRODUCTION

One of the most challenging weather forecast problems in the southeastern U.S. is daily summertime pulse convection. During the summer, atmospheric flow and forcing are generally weak in this region; thus, convection typically initiates in response to local forcing along sea/lake breezes, and other discontinuities often related to horizontal gradients in surface heating rates. Numerical simulations of pulse convection usually have low skill, even in local predictions at high resolution, due to the inherent chaotic nature of these precipitation systems. Forecast errors can arise from assumptions within physics parameterizations, model resolution limitations, as well as uncertainties in both the initial state of the atmosphere and land surface variables such as soil moisture and temperature. For this study, it is hypothesized that high-resolution, consistent representations of surface properties such as soil moisture, and soil temperature and sea surface temperature (SST), ground fluxes, and vegetation are necessary to better simulate the interactions between the surface and atmosphere, and ultimately improve predictions of local circulations and summertime pulse convection.

The Short-term Prediction Research and Transition (SPoRT) Center has developed high-resolution SST composites derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) instruments aboard the NASA Aqua and Terra polar-orbiting satellites (Haines et al. 2007). The SPoRT Center has demonstrated the exquisite detail that can be depicted by these four-times-per-day composites compared to the once daily operational Real-Time Global (RTG) product used by the National Centers for Environmental Prediction (NCEP) models, which has a substantial impact on horizontal gradients in modeled sensible and latent heat fluxes over water bodies (LaCasse et al. 2008; Case et al. 2008a). They have also examined the sensitivity of Weather Research and Forecasting (WRF) model simulations over oceanic regions to the high-resolution information, depicting the modifications to the nocturnal marine boundary layer under certain flow regimes over Florida. For example, LaCasse et al. (2008) depicted decreased static stability near the Florida East Coast under easterly flow regimes, and favored zones of low-level convergence near the coast under easterly flow and over the Gulf Stream under westerly flow. These model sensitivities to SSTs can have important implications to operations by providing modeled Planetary Boundary Layer (PBL) interactions with the detailed SSTs not currently available with any national or global product.

The SPoRT Center has also been conducting studies to examine the impacts of high-resolution land surface initialization data generated by offline simulations of the NASA Land Information System (LIS; Kumar et al. 2006, 2007) on subsequent numerical forecasts using the WRF model (Case et al. 2008b). The NASA LIS is a high performance land surface modeling and data assimilation system that integrates satellite-derived datasets, ground-based observations and model reanalyses to force a variety of land surface models (LSMs). By using scalable, high-performance computing and data management technologies, LIS can run LSMs offline globally with a grid spacing as fine as 1 km to characterize land surface states and fluxes. Case et al. (2008b) presented improvements to simulated sea breezes and surface verification statistics over Florida by initializing WRF with land surface variables from an offline LIS spin-up run, conducted on the same WRF domain and resolution. In addition, Case et al. (2008c) demonstrated the ability to use both LIS land surface fields and MODIS SSTs to initialize the surface and sub-surface variables over a coastal domain, thereby providing a high-resolution lower boundary initial condition over the entire modeling domain.

This current project extends the previous work done over Florida, now focusing on cases of typical pulse convection over the southeastern U.S., with an emphasis on improving the local short-term WRF simulations over the Mobile, AL and Miami, FL NOAA/National Weather Service (NWS) county warning areas. This modeling study makes use of both the SPoRT MODIS SSTs and LIS land surface initialization datasets to quantify the sensitivity and possible improvements realized from these NASA capabilities. Furthermore, this study serves as a proof of concept to show that LIS and MODIS SST data can be easily incorporated into WRF for the benefit of NWS offices interested in running a local WRF application. The remainder of this paper is organized as follows. Section 2 provides some background information on the SPoRT Center and its programmatic and technical objectives. Section 3 describes the methodology for the current

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sensitivity experiment. Preliminary results are presented in Section 4, and a summary and vision for future work is given in Section 5.

2. THE NASA SPORT CENTER

The NASA SPoRT Center at the Marshall Space Flight Center (MSFC) seeks to accelerate the infusion of NASA Earth Science observations, data assimilation, and modeling research into weather forecast operations and decision-making at the regional and local level. It directly supports the NASA strategic plan of using results of scientific discovery to directly benefit society. The program is executed in concert with other government, university, and private sector partners. The primary focus is on the regional scale and emphasizes forecast improvements on a time scale of 0–24 hours. The SPoRT Center has facilitated the use of real-time NASA data and products to 13 National Weather Service (NWS) Weather Forecast Offices (WFOs) and several private weather entities primarily in the southeast United States. Numerous new techniques have been developed to transform satellite observations into useful parameters that better describe changing weather conditions.

The unique weather products have helped local WFOs improve forecasts of reduced visibility due to fog, low clouds, and smoke and haze from sources such as forest fires and agricultural burning, the onset of precipitation, the occurrence and location of severe weather events, and other local weather changes. Additionally, high resolution satellite data provided by SPoRT has been used by the private sector to inform the marine weather community of changing ocean conditions and with tropical storm and hurricane monitoring.

3. EXPERIMENT DESIGN

A modeling sensitivity experiment is conducted with version 3.0.1.1 of the Advanced Research WRF (ARW; Skamarock et al. 2008) in which the land and ocean/lake surface data from the NCEP North American Mesoscale (NAM) model is replaced with high-resolution data from a LIS offline simulation and MODIS SST composites, respectively. Details on the specific model configurations, initialization datasets, and verification methodologies are described below.

3.1 Model Configuration and Period of Study

This investigation consists of a set of Control and experimental ARW simulations initialized once per day at 0300 UTC from June to August 2008. The model is integrated 27 hours to 0600 UTC the following day, similar to some operational WRF runs done at NOAA/NWS Miami, FL and Mobile, AL. The simulation domain (depicted in Figure 1) consists of a single grid of 309 x 311 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 of 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 LIS+MODIS-initialized simulations (hereafter LISMOD), 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; thus, 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). All WRF runs use 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 sensible and latent 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 runs, all initial conditions for the atmosphere, land, and RTG SSTs come from the native-resolution (12-km, grib 218) NCEP NAM model 3-h forecast initialized at 0000 UTC. Three-hourly boundary conditions for both the Control and LISMOD runs are provided by the NAM model 3-h to 30-h forecasts. The SSTs remain fixed throughout the 27-h ARW simulations. Interpolation of initial and boundary condition data are done with the WRF Pre-Processing System (WPS) utilities.

3.2 Initialization Data in Experimental Simulations

The LISMOD experimental runs are identical to the Control configuration except for the land surface initial fields and the fixed SSTs. The land surface initial conditions of the Control are replaced by output from an offline LIS spin-up run. Meanwhile, the fixed RTG SSTs of the NAM model are replaced by the high-resolution SPoRT MODIS SST composites. Details on the LIS land surface and MODIS SST data, and how the data are incorporated into WRF are described in the sub-sections below.

3.2.1 **LIS Initialization Data**

For the offline LIS run, version 2.7.1 of the Noah LSM is run in LIS version 5 at the same horizontal resolution and center point as the WRF grid, but on a slightly larger domain to demonstrate that the WPS utilities can adequately interpolate the LIS data. Ideally, the LIS grid setup would be identical to the WRF simulation domain to avoid inconsistencies between the LIS and WRF soil fields introduced by horizontal interpolation. However, we aim to demonstrate a possible operational configuration in which SPoRT provides a generalized LIS initialization dataset to a variety of users (e.g. various NWS WFOs) running their own local WRF applications on domains that do not necessarily match the LIS grid. Such a scenario is probably the most practical method for providing LIS initialization data to multiple users.

For consistency, the Noah LSM in the offline LIS run uses the same soil and vegetation database as used in the WRF model. The soil type and properties are represented by the State Soil Geographic (STATSGO; Miller and White 1998) database. For the land-water mask and land cover, the U.S. Geological Survey (USGS) 1-km global database derived from the Advanced Very High Resolution Radiometer (AVHRR) satellite data from 1992–1993 is up-scaled to the 4-km grid.

Additional required parameters used in the offline LIS runs include quarterly climatologies of albedo (Briegleb *et al.* 1986) and maximum snow-free albedo (Robinson and Kukla 1985), monthly climatologies of greenness fraction data derived from the AVHRR satellite (Gutman and Ignatov 1998), and a deep soil temperature climatology (serving as a lower boundary condition for the soil layers) at 3 meters below ground, derived from 6 years of Global Data Analysis System (GDAS) 3-hourly averaged 2-m air temperatures using the method described in Chen and Dudhia (2001).

The offline LIS run is cold-started on 1 January 2004 with a uniform first-guess soil temperature and moisture value. The Noah LSM is allowed to reach an equilibrium state during a spin-up integration of 4 years, 5 months from 1 January 2004 to 1 June 2008, using an integration time step of 30 minutes. Atmospheric forcings for the LIS run are provided by GDAS analyses (Derber et al. 1991). The GDAS has global coverage with three-hourly data at a horizontal resolution of 0.469° (~52 km). In addition, supplemental precipitation forcing from the Stage IV high-resolution analyses replaces the GDAS precipitation, providing much more detailed precipitation fields than GDAS. The Stage IV product consists of hourly ~4-km precipitation analyses produced operationally by the U.S. River Forecast Centers, based on rain gauges and radar precipitation estimates from the Weather Surveillance Radar-1988 Doppler network (Lin and Mitchell 2005; Lin et al. 2005). The forcing fields are downscaled to the running resolution in LIS using bilinear or conservative (for precipitation) interpolation approaches. In the case of downward shortwave radiation, an additional zenith-angle based temporal disaggregation is applied. The forcing fields of downward-directed longwave radiation, pressure, 2-m air temperature and 2-m relative humidity are further topographically corrected via lapse-rate and hypsometric adjustments using the elevation data differences between the LIS grid and the native GDAS forcing grid.

The LIS is output in Gridded Binary-I format (GRIB1) daily at 0300 UTC for the period of record (June – August 2008) to initialize the WRF land surface fields in the LISMOD simulations. The GRIB1 formatted LIS data is used by the WPS with only a few minor modifications required. First, the output units in LIS soil moisture are changed to volumetric water content to be consistent with the units used in WPS/WRF. Second, the WPS file "METGRID.TBL" is modified to handle the LIS land-sea mask for interpolation of data to the WRF grid. The new LIS land-sea mask defined in METGRID.TBL is then applied to each of the land surface variables to be interpolated to the WRF grid. Finally, the interpolation method used in WPS for the LIS fields is a nearest-neighbor approach, as this method preserves the most detail and minimizes differences caused by interpolation. A summary of all the LIS fields incorporated into the WRF initial conditions is given in Table 1.

3.2.2 **MODIS Sea Surface Temperatures**

A 1-km MODIS SST composite, produced at the NASA SPoRT Center, is created by combining multiple passes of the Earth Observing System MODIS SST data (Haines *et al.* 2007). The compositing assumes that the day-to-day variation of SST is relatively small — the degree to which this assumption is valid will likely vary spatially and seasonally. Data from both the Terra and Aqua platforms are combined to create separate day/night composites. The composites examine the five most recent clear-sky SST values at each pixel. It then averages the warmest three of these five pixels in order to minimize the impact of cloud contamination.

Daytime (nighttime) passes through the composite region occur at approximately 1600 and 1900 UTC (0400 and 0700 UTC), respectively. The composites are output in GRIB1 format to ensure a seamless interpolation to the WRF grid with the WPS programs. Prior to being interpolated to the WRF grid, however, each 1-km MODIS SST composite is sub-sampled to a coarser grid with 2-km horizontal grid spacing due to limitations in array dimensions of the GRIB1 format.

Finally, the MODIS composite from 0400 UTC the previous day is incorporated into the daily WRF initial conditions at 0300 UTC to minimize diurnal variations in SST relative to the model initialization time. The only exception occurs for model initializations from 3–14 June 2008, when data are missing for the 0400 UTC MODIS composites. For these LISMOD model initializations, the 0700 UTC MODIS composites from the previous day are used to initialize the SSTs.

3.3 Verification Methodology and Tools

For verifying precipitation and other fields in both the Control and LISMOD runs, we plan to make extensive use of the Meteorological Evaluation Tools (MET) package. Created by the WRF Developmental Testbed Center at the National Center for Atmospheric Research, the MET package is a highly-configurable, state-of-the-art suite of model verification tools. It was developed using output from WRF but may be applied to the output of other modeling systems as well. MET provides a variety of verification techniques, including:

- Standard verification scores comparing gridded model data to point-based observations,
- Standard verification scores comparing gridded model data to gridded observations, and
- Object-based verification method comparing gridded model data to gridded observations.

More information on MET can be found at the web site http://www.dtcenter.org/met/users/index.php. An online User's Guide for MET version 1.1 is available at http://www.dtcenter.org/met/users/docs/users_guide/MET_Users_Guide_v1.1.pdf.

Our objectives for using MET at NASA/SPoRT is to incorporate a more standardized verification platform from which to conduct model evaluations. For this specific project, we are especially interested in capitalizing on the object-oriented verification methodologies that have been implemented in MET. Known as the Method for Object-based Diagnostic Evaluation (MODE; Brown et al. 2007), this utility classifies "objects" in gridded fields, calculates a wide variety of object attributes, and merges/pairs forecast objects with observed objects to determine the similarities and differences between the various objects. We plan to apply this utility to obtain more meaningful precipitation verification statistics for high-resolution forecasts of the pulse-type convection over the southeastern U.S.

4. PRELIMINARY RESULTS

This section provides preliminary results that illustrate some of the differences between the LIS land and MODIS SST initialization versus the interpolated NAM data in the Control runs. Sample forecast impacts are presented, as well as output from the MODE analysis tool available in the MET verification package.

4.1 Differences in Surface Initialization Datasets

The combination of LIS spin-up data and MODIS SSTs provides a considerably more detailed representation of the land and water surface compared to the Control run using interpolated NAM model data. The depiction of 0–10 cm soil moisture at 0300 UTC 1 June 2008 in Figure 2 helps to illustrate this point. While the regional patterns of soil moisture are fairly similar, the LISMOD initialization data provides information more consistent with the resolution of the WRF model in Figure 2b.

The difference field also indicates systematically drier initial conditions in this soil layer from southern Mississippi to northwestern South Carolina (Figure 2c). Over Florida, drier soil moisture is interspersed with local pockets of wetter soil moisture. These soil moisture variations are likely attributed to differences between the 12-km NAM Data Assimilation System (NDAS), which front-ends the NAM model, and the GDAS, which forces the LIS off-line run in combination with the Stage-IV precipitation analyses. Also, the ability of the 4-km LIS to better capture local areas of convective-type precipitation compared to the 12-km NDAS explains the local variations in soil moisture over Florida. It should be noted that the NDAS also uses the Stage-IV precipitation product to initialize its soil fields, similar to our offline LIS run.

A high-impact event that affected the domain during the period of record is Tropical Storm Fay in late August. This storm produced prodigious amounts of rainfall across eastern and northern Florida, and southwestern Georgia, with some locations receiving over 700 mm. Refer to the accompanying presentation file on the AMS website for an animation of the Stage-IV rainfall during the 8-day period from 18–26 August.

Needless to say, the volumetric soil moisture increases dramatically during this 8-day period over the affected areas. The root zone layer in the Noah LSM (40–100 cm) should have the greatest impact on the subsequent evapo-transpiration into the atmosphere. Figure 3 depicts the moistening of the 40–100 cm soil layer from 18–26 August, comparing changes in the Control initialization (Figure 3a) to the LISMOD initialization (Figure 3b). Both model initialization differences show a similar broad pattern of moistening from Florida and southern Georgia into east-central Mississippi. The LISMOD differences have much more detail as expected; however, the LISMOD has substantially highly amounts of moistening across much of the eastern Florida peninsula. Additional investigation is needed to determine the cause of these differences over Florida by comparing the method of soil moisture initialization in NDAS to that of our LIS spin-up run.

Meanwhile, the SPoRT MODIS SST product provides much more detail over the oceanic regions of the Gulf of Mexico and Atlantic waters (Figure 4). For this particular model run initialized at 0300 UTC 1 June, SSTs are obtained from the 0400 UTC 31 May MODIS composite in order to simulate a real-time model configuration. Substantial differences are found in the vicinity of the shallow near-coastal waters near the Florida coast, and over the Gulf Stream east of Florida, where differences up to 2°C or more occur.

The most noteworthy aspect of the MODIS composite is its ability to capture the fine-scale horizontal gradients in SSTs compared to the once-daily NCEP RTG product. The smoothness of the RTG data in Figure 4a precludes the model from capturing the relatively cool shelf waters off the Florida East Coast. However, the LISMOD SSTs in Figure 4b are able to depict the cool shelf waters and the magnitude of the Gulf Stream east of Florida. The SST differences illustrate the sharper horizontal gradients captured by the SPoRT MODIS product in Figure 4c.

4.2 Sample Forecast Sensitivities of Precipitation

At first glance, the precipitation forecast sensitivities appear somewhat subtle, despite relatively significant changes in the details of the land and water initial conditions. A qualitative examination of several different days during the period of record (not shown) indicates that the broad patterns of forecast precipitation in the Control and LISMOD runs are generally similar. Most of the differences in forecast precipitation arise from small-scale fluctuations in individual convective elements that evolve differently due to the variations in the land and water surface. If the Control forecast is significantly in error with the large-scale precipitation features, then the LISMOD is also generally in error. Therefore, it appears that the forecast precipitation in our model configuration is still largely driven by the atmospheric initial and boundary conditions, in addition to model dynamics and physics.

A sample 6-h forecast precipitation comparison ending 0000 UTC 2 June 2008 is presented in Figure 5.

This plot shows how the 15–21 h forecast 6-h precipitation patterns are quite similar overall in the Control and LISMOD runs (Figure 5a and b). However, the difference field depicts numerous small-scale fluctuations between the forecasts (Figure 5c), even over the Gulf of Mexico associated with the inclusions of the MODIS data. By comparing to the Stage-IV product in Figure 5d, we see that both simulations over-predict precipitation across much of Georgia and South Carolina, while under-predicting the convection over northern Florida and northern Mississippi. In this particular case, there is west-northwest flow and model errors could be dominated by initial and boundary conditions, especially from Mississippi to South Carolina.

Output from the MET "MODE" object classification program in Figure 6 shows an example of the type of non-standard precipitation verification we would like to accomplish with this project. In this image, MODE classifies a number of LISMOD forecast objects (left column) and Stage-IV observed objects (right column), from the 6-h time window ending 0000 UTC 2 June, and then merges the objects together based on correlations (i.e. "interest" thresholds) and a variety of tunable input parameters. The MODE program is highly configurable, and therefore requires non-trivial amount of effort to obtain the proper set of parameters based on the level of detail desired. Also, there are numerous output statistics that quantify the characteristics of each individual object, the merged/grouped objects, and the observed/forecast objects identified with each other. Additional significant effort is required to understand the physical meaning of these statistics and how best to apply the statistics to the verification problem at hand.

5. SUMMARY AND FUTURE WORK

This paper describes a sensitivity simulation experiment in which the interpolated land and ocean surface fields from the NCEP NAM model in a Control WRF model simulation are replaced with high-resolution datasets provided by unique NASA assets in an experimental simulation: the LIS and SPoRT/MODIS SSTs. The LIS is run in an offline mode for several years at the same grid resolution as the WRF model in order to provide WRF with compatible land surface initial conditions in an equilibrium state. The MODIS SSTs provide more detailed analyses of the SSTs over the oceans and large lakes compared to the RTG product used in the Control model runs.

Preliminary results indicate the LISMOD initial conditions contain much more detail, consistent with the WRF model resolution (as expected), when compared to the Control initial conditions. The large-scale patterns of soil moisture are fairly similar, but the LISMOD initial conditions do have some systematic regional differences, probably due to the LIS better resolving the fine-scale precipitation features of the Stage IV data compared to the 12-km NDAS. The MODIS SSTs are able to better capture the spatial variability in SSTs, especially in the waters surrounding the Florida peninsula. The forecast precipitation fields are fairly similar, especially in the overall larger-scale patterns. However, numerous small-scale differences occur over both land and ocean.

Future efforts will involve applying many of the MET capabilities to conduct a rigorous model verification for the entire period of record, emphasizing precipitation statistics. The MODE capability will be a particular focus, with the goal of obtaining a meaningful, quantitative verification of convective systems beyond the usual threat scores and biases that are traditionally used to determine the skill of numerical weather forecasts. Such verification statistics will help determine whether the small-scale differences in predicted precipitation are improved by initializing with the high-resolution LIS and MODIS information.

Future efforts may also involve examining the impacts of assimilating remotely-sensed soil moisture data, and/or introducing bi-weekly greenness vegetation fraction composites (as opposed to monthly climatologies) into offline NASA LIS runs and WRF simulations. Finally, based on positive impacts, the offline LIS runs could be transitioned into an operational mode similar to the MODIS SST composites, providing land surface initialization data to NWS WFOs in near real time.

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Figure 1. Domain of the WRF model configuration over the southeastern United States.

Table 1. A list of the LIS land surface fields and corresponding names in the WPS "METGRID.TBL" file, as used to initialize the LISMOD experimental WRF model runs.

Land Surface Field	**Name in WPS "METGRID.TBL"**
Canopy Water*	CANWAT
0-10 cm Soil Moisture	SM000010
10-40 cm Soil Moisture	SM010040
40-100 cm Soil Moisture	SM040100
100-200 cm Soil Moisture	SM100200
0-10 cm Soil Temperature	SM000010
10-40 cm Soil Temperature	SM010040
40-100 cm Soil Temperature	SM040100
100-200 cm Soil Temperature	SM100200
Skin Temperature	SKINTEMP
Snow Water Equivalent	SNOW

*Canopy water is initialized to "0" in the default WRF source code.

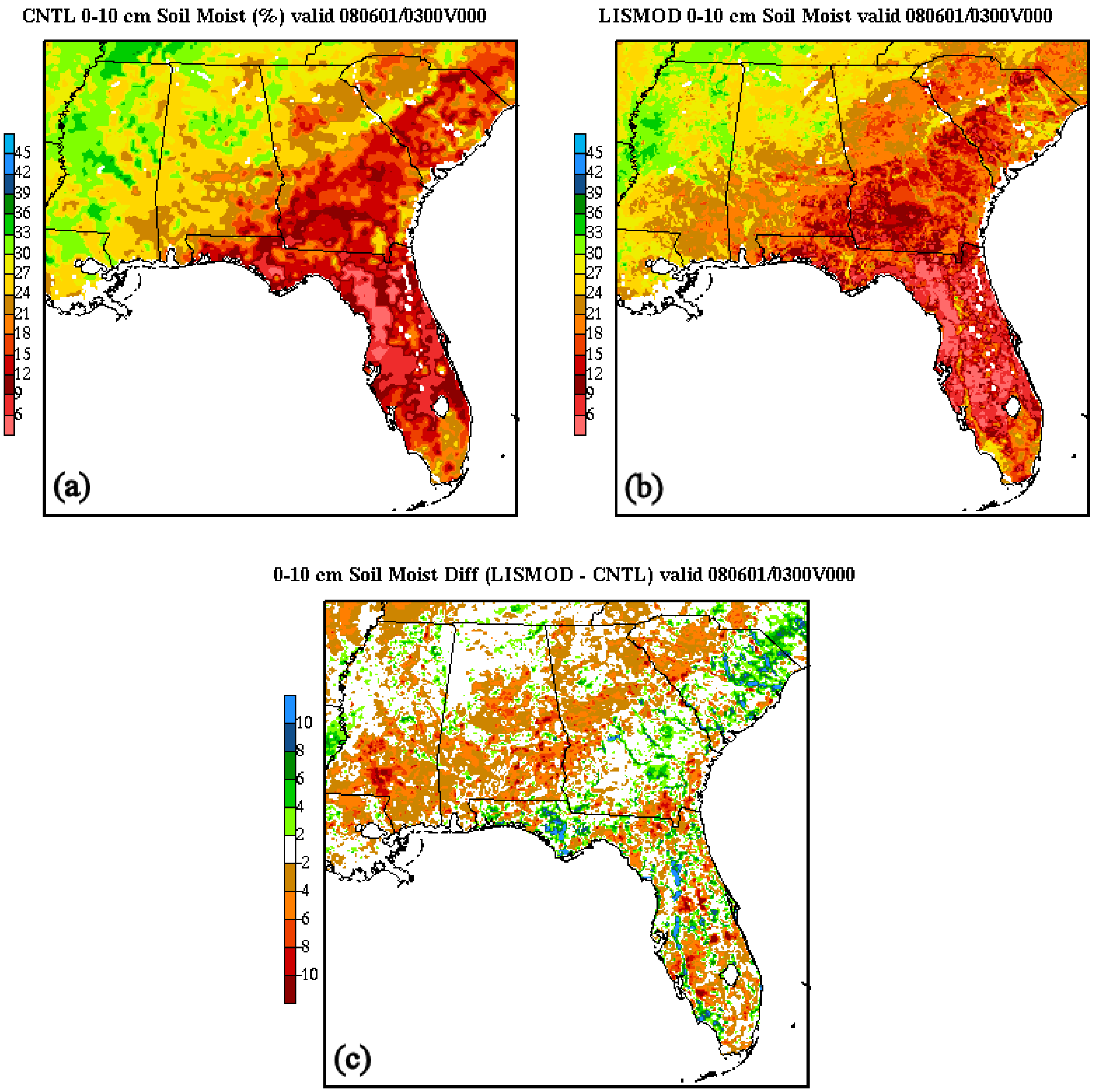

Figure 2. Comparison between WRF-initialized 0–10 cm volumetric soil moisture for the (a) Control (NAM model), (b) LISMOD (LIS spin-up), and (c) difference field (LISMOD – Control) valid at 0300 UTC 1 June 2008.

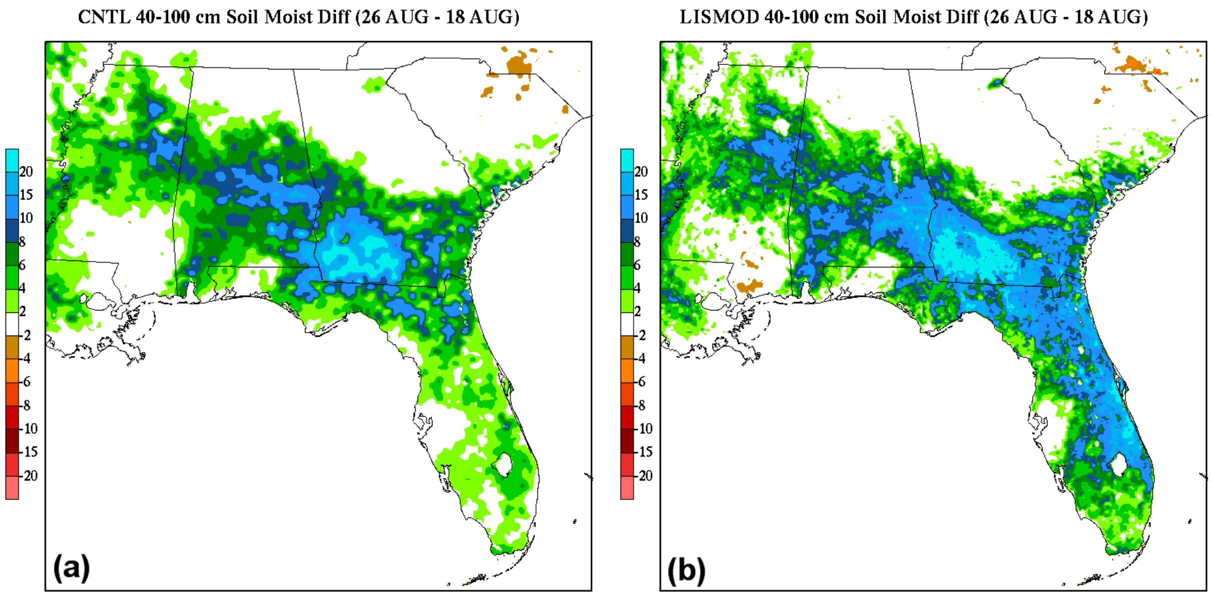

Figure 3. Change in volumetric soil moisture in the Noah root zone layer (40–100 cm) for the 0300 UTC WRF initializations from 18–26 August 2008, associated with Tropical Storm Fay, valid for the (a) Control run, and (b) LISMOD run.

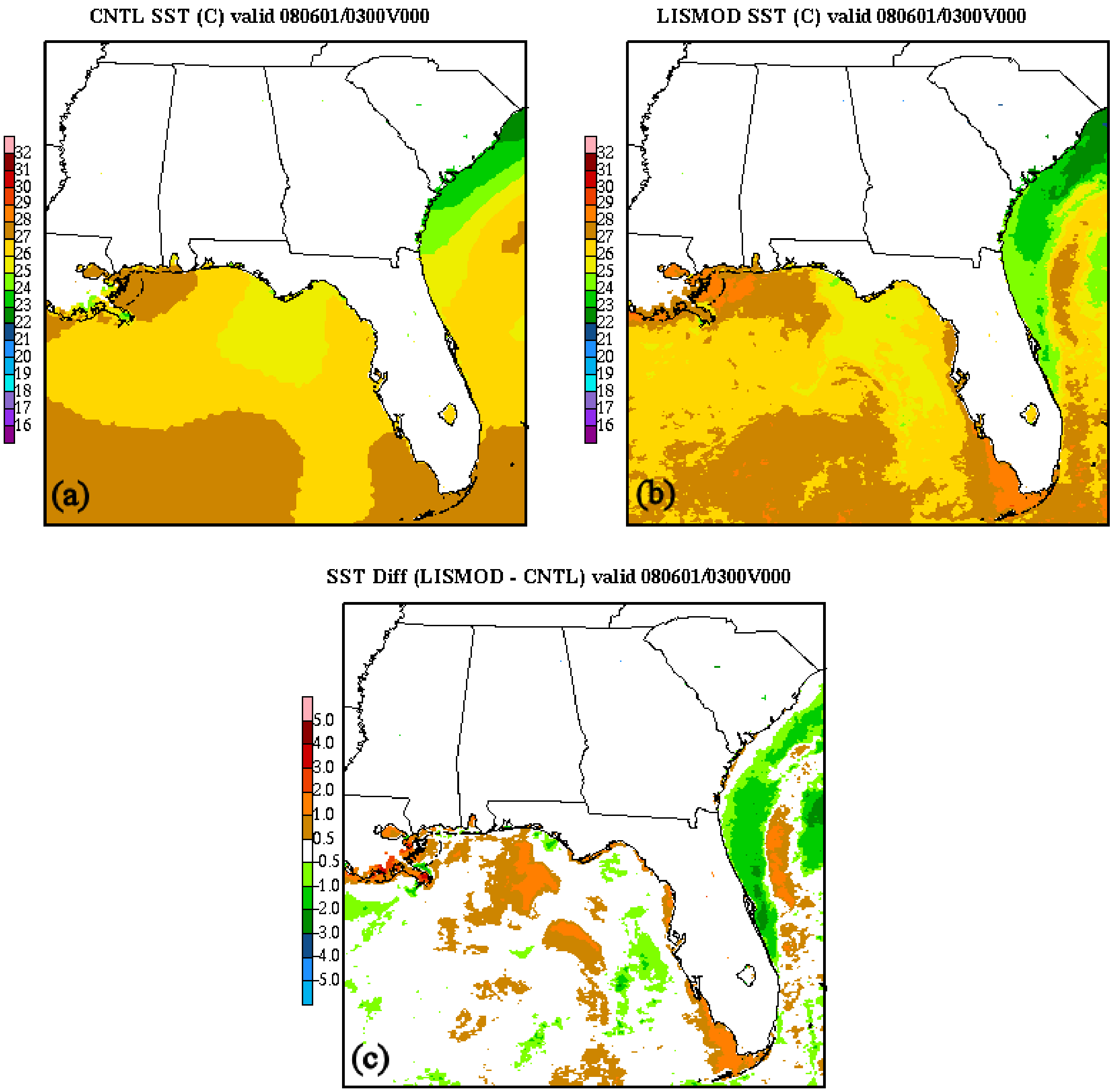

Figure 4. Comparison between WRF static SSTs for the (a) Control (NAM model / RTG product), (b) LISMOD (SPoRT MODIS data), and (c) difference field (LISMOD – Control), valid for the model run initialized at 0300 UTC 1 June 2008.

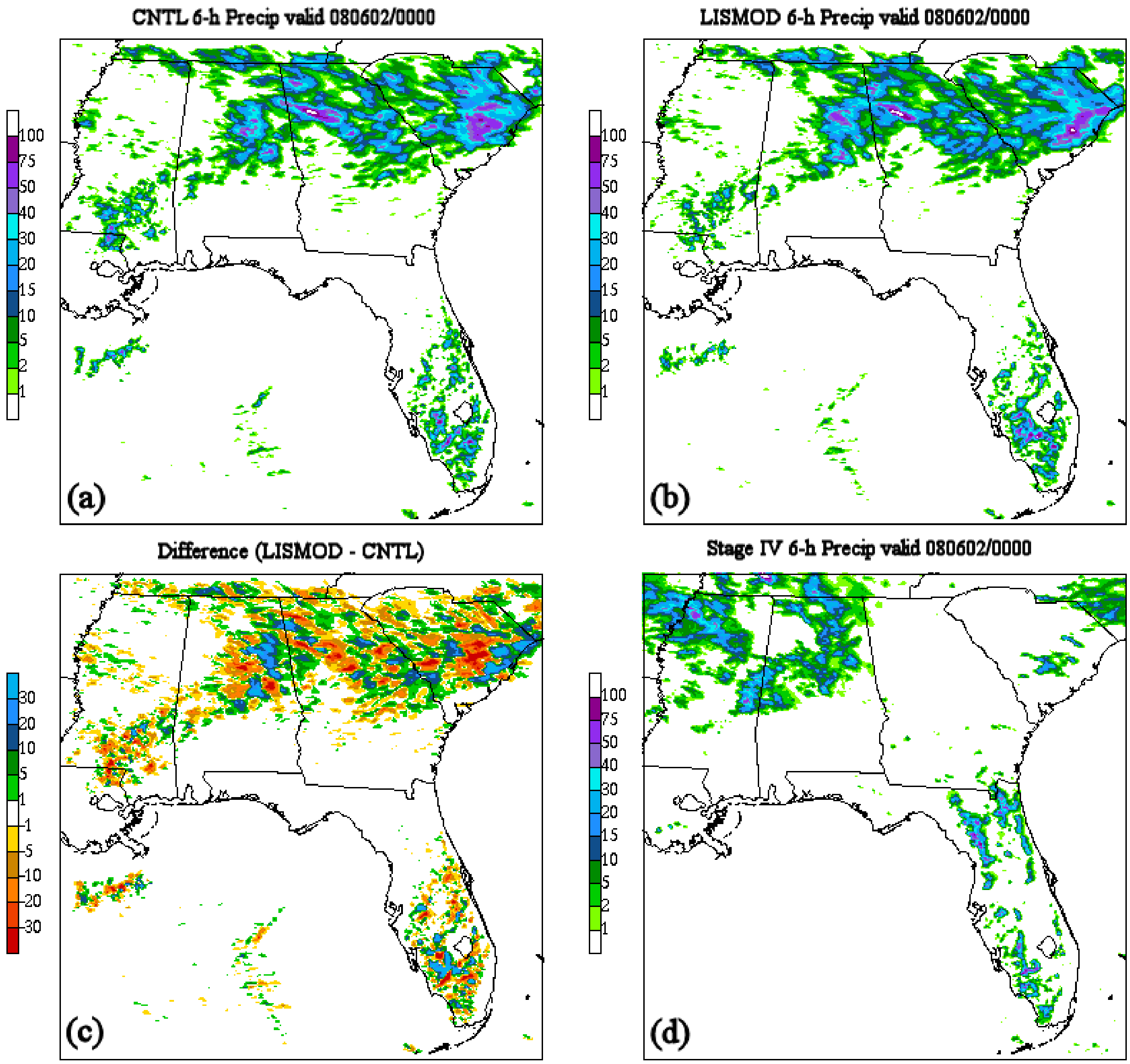

Figure 5. Comparison of accumulated precipitation (mm) for the 6-h period ending 0000 UTC 2 June for (a) the Control run, (b) the LISMOD run, (c) the difference between LISMOD and Control, and (d) the Stage IV precipitation.

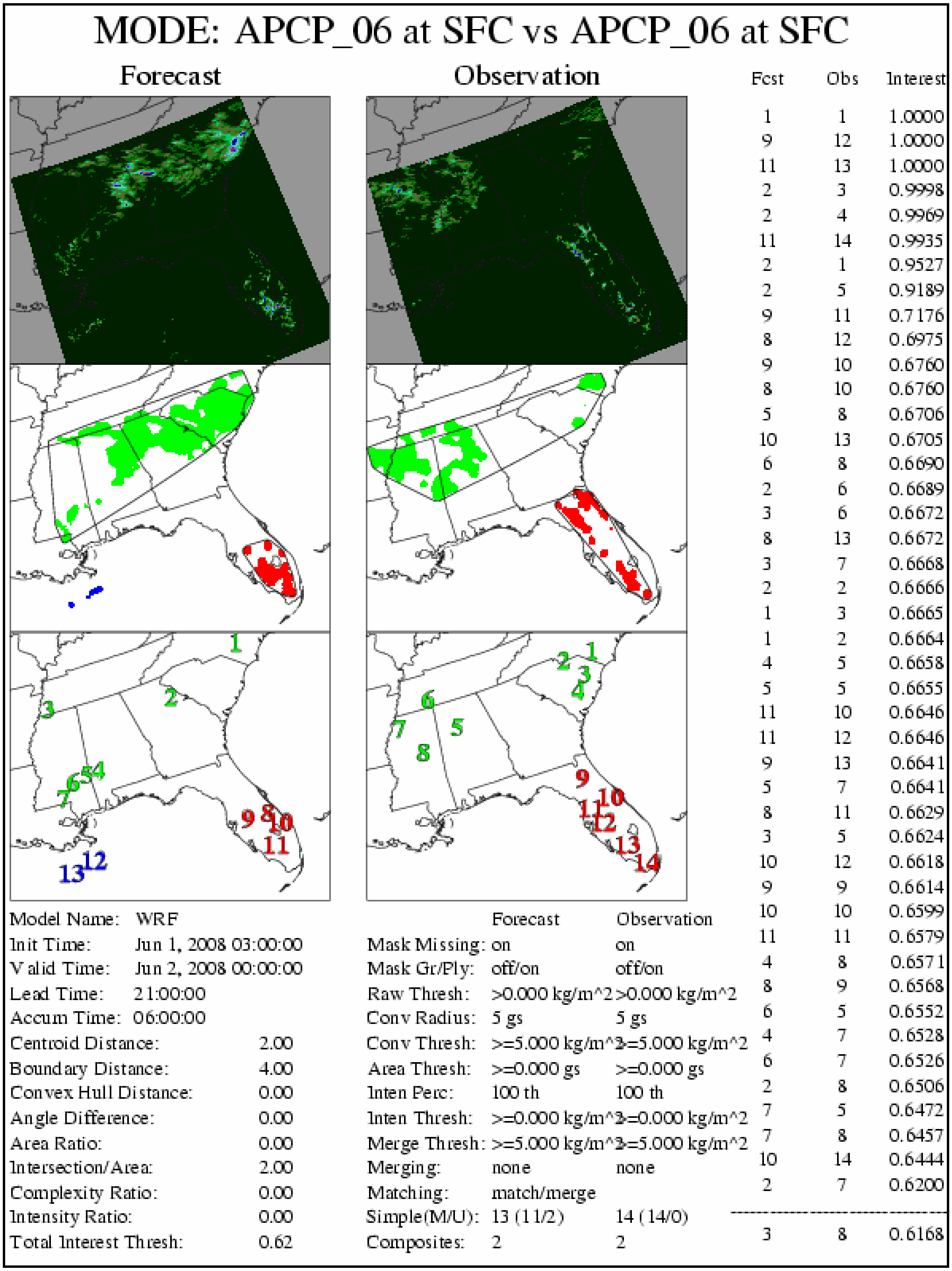

Figure 6. Sample object classification and output from the MET "MODE" program operating on the 6-h accumulated precipitation fields (valid at 0000 UTC 2 June 2008) from the LISMOD forecast and Stage IV precipitation field.