The Transition of High-Resolution NASA MODIS Sea Surface Temperatures into the WRF Environmental Modeling System

Jonathan L. Case, ENSCO, Inc / Short-term Prediction Research and Transition (SPoRT) Center

Gary J. Jedlovec, NASA Marshall Space Flight Center / SPoRT Center

Pablo Santos, NOAA/NWS Miami, FL

Jeffrey M. Medlin, NOAA/NWS Mobile, AL

Robert A. Rozumalski, NOAA/NWS National SOO Science and Training Resource Coordinator, Boulder, CO

The NASA Short-term Prediction Research and Transition (SPoRT) Center has developed a Moderate Resolution Imaging Spectroradiometer (MODIS) sea surface temperature (SST) composite at 2-km resolution (Haines et al. 2007, *IEEE Trans. Geosci. Remote Sens.*) that has been implemented in version 3 of the National Weather Service (NWS) Weather Research and Forecasting (WRF) Environmental Modeling System (EMS). The WRF EMS is a complete, full physics numerical weather prediction package that incorporates dynamical cores from both the Advanced Research WRF (ARW) and the Non-hydrostatic Mesoscale Model (NMM). The installation, configuration, and execution of either the ARW or NMM models is greatly simplified by the WRF EMS to encourage its use by NWS Weather Forecast Offices (WFOs) and the university community. The WRF EMS is easy to run on most Linux workstations and clusters without the need for compilers. Version 3 of the WRF EMS contains the most recent public release of the WRF-NMM and ARW modeling system (version 3 of the ARW is described in Skamarock et al. 2008), the WRF Pre-processing System (WPS) utilities, and the WRF Post-Processing program. The system is developed and maintained by the NWS National Science Operations Officer Science and Training Resource Coordinator, Dr. Robert Rozumalski.

To initialize the WRF EMS with high-resolution MODIS SSTs, SPoRT developed the composite product consisting of MODIS SSTs over oceans and large lakes with the NCEP Real-Time Global (RTG) filling data over land points. Filling the land points is required due to minor inconsistencies between the WRF land-sea mask and that used to generate the MODIS SST composites. This methodology ensures a continuous field that adequately initializes all appropriate arrays in WRF. MODIS composites covering the Gulf of Mexico, western Atlantic Ocean and the Caribbean are generated daily at 0400, 0700, 1600, and 1900 UTC corresponding to overpass times of the NASA Aqua and Terra polar orbiting satellites. The MODIS SST product is output in gridded binary-1 (GRIB-1) data format for a seamless incorporation into WRF via the WPS utilities. The full-resolution, 1-km MODIS product is sub-sampled to 2-km grid spacing due to limitations in handling very large dimensions in the GRIB-1 data format. The GRIB-1 files are posted online at ftp://ftp.nsstc.org/sstcomp/WRF/, which is directly accessed by the WRF EMS scripts. The MODIS SST composites are also downloaded to the EMS data server, which is accessible by the WRF EMS users and NWS WFOs.

The SPoRT MODIS SST composite provides the model with superior detail of the ocean gradients around Florida and surrounding waters, whereas the operational RTG SST typically depicts a relatively smooth field and is not able to capture sharp horizontal gradients in SST. Differences of 2–3°C are common over small horizontal distances, leading to enhanced SST gradients on either side of the Gulf Stream and along the edges of the cooler shelf waters. These sharper gradients can in turn produce atmospheric responses in simulated temperature and wind fields as depicted in LaCasse et al. (2008, AMS *Monthly Weather Review*). Differences in atmospheric verification statistics over a several month study were generally small in the vicinity of south Florida; however, the validation of SSTs at specific buoy locations revealed important improvements in the biases and RMS errors, especially in the vicinity of the cooler shelf waters off the east-central Florida coast.

A current weakness in the MODIS SST product is the occurrence of occasional discontinuities caused by high latency in SST coverage due to persistent cloud cover. An enhanced method developed by Jedlovec et al. (2009, *GHRSST User Symposium*) reduces the occurrence of these problems by adding Advanced Microwave Scanning Radiometer – EOS (AMSR-E) SST data to the compositing process. Enhanced SST composites are produced over the ocean regions surrounding the Continental U.S. at four times each day corresponding to Terra and Aqua equator crossing times. For a given day and overpass time, both MODIS and AMSR-E data from the previous seven days form a collection used in the compositing. At each MODIS pixel, cloud-free SST values from the collection are used to form a weighted average based on their latency (number of days from the current day). In this way, recent

SST data are given more weight than older data. One of the primary issues involved in incorporating the AMSR-E microwave data in the composites is the tradeoff between the decreased spatial resolution of the AMSR-E data (25 km) and the increased coverage due to its near all-weather capability. Currently, the AMSR-E is given a weight of 20% compared to MODIS data, thereby preserving the spatial structure observed in the MODIS data. Day-time (night-time) AMSR-E SST data from Aqua are used with both Terra and Aqua MODIS day-time (night-time) SST data sets.

The Transition of High-Resolution NASA MODIS Sea Surface Temperatures into the WRF Environmental Modeling System

Jonathan L. Case

ENSCO, Inc/NASA Short-term Prediction Research and Transition (SPoRT) Center
Huntsville, AL

Coauthors: ***Gary J. Jedlovec, Pablo Santos, Jeff M. Medlin, and Robert A. Rozumalski***

Presentation Outline

- What is the WRF Environmental Modeling System (EMS)?
- NASA/SPoRT's MODIS Sea Surface Temperature (SST) composite
- Examples of model sensitivity to MODIS SSTs
- Upcoming improvements to MODIS SST composite product
- How can I use the MODIS SSTs in the EMS?

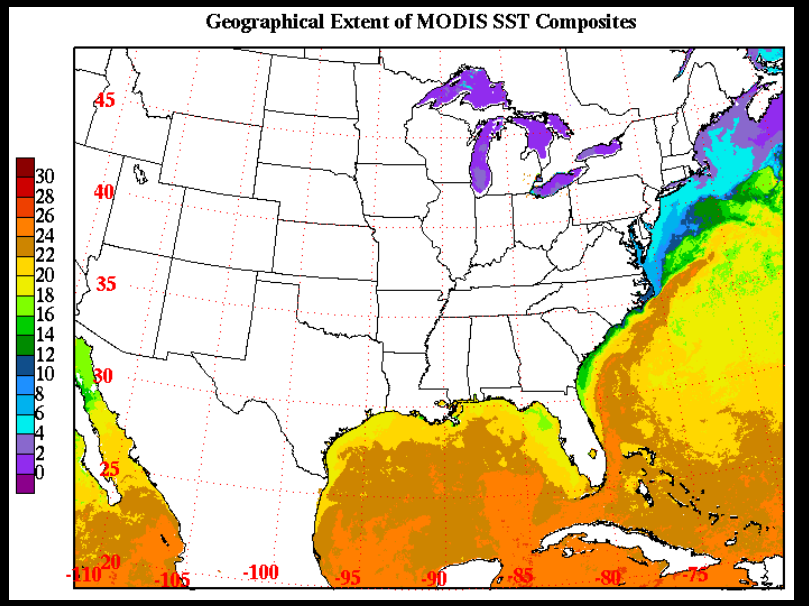
WRF Environmental Modeling System

- Weather Research and Forecasting (WRF)
  - Community numerical weather prediction (NWP) system
  - Contains two distinct NWP models
    - Advanced Research WRF (ARW, NCAR)
    - Non-Hydrostatic Mesoscale model (NMM, NCEP)

- Environmental Modeling System (EMS)
  - Product of the NWS Science Operations Officer (SOO)/ Science and Training Resource Center (STRC)
  - Complete, end-to-end system that runs the ARW or NMM models in real time, with optional nesting
  - Handles all downloads and interpolations of initial/boundary conditions
  - Automated post-processing can produce graphical output and display forecasts in AWIPS

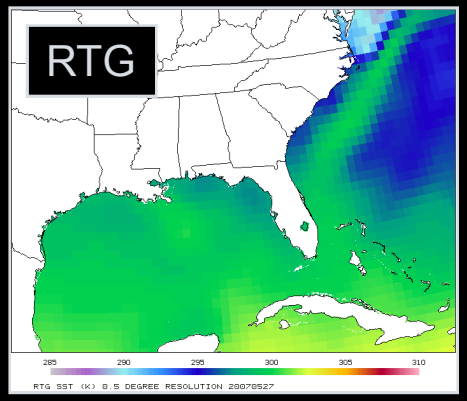
SPoRT MODIS SST Composites

- Real-time, 1-km SST product
  - Produced 4x daily at 04, 07, 16, and 19z
  - Geographical coverage shown at right
  - GRIB-1 files posted to public ftp site
    - ftp://ftp.nsstc.org/sstcomp/WRF/
    - Sub-sampled to 2-km for model uses

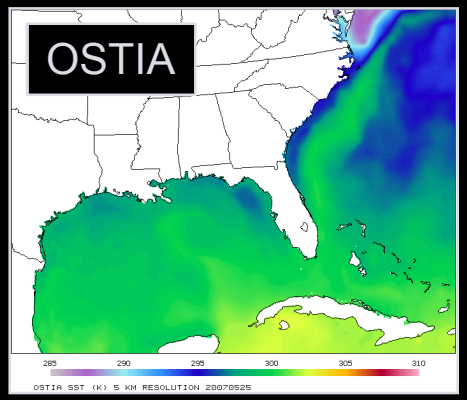


- Compositing technique
  - Haines *et al.* (2007), *IEEE Trans. Geosci. Remote Sens.*, **45,** 2919-2927.
  - Query multiple passes of polar-orbiting Earth Observing System (EOS) satellites (Aqua and Terra)
  - At each pixel, examine 5 most recent readings
    - Take average of 3 warmest readings
    - Helps eliminate cloud contamination

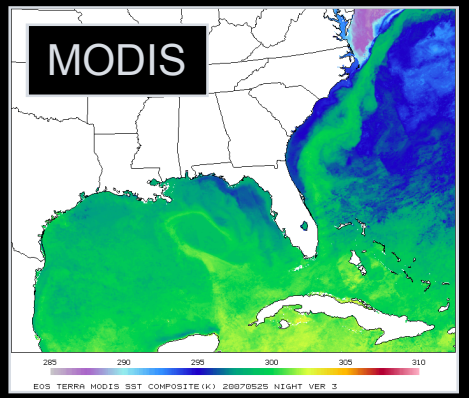
SST Product Comparison



NCEP once daily
1/12 deg resolution

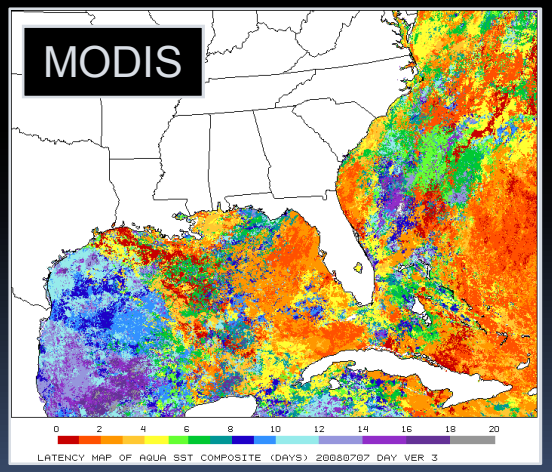


Once daily
5-km resolution



Four times daily
2-km resolution

- MODIS provides superior resolution
- Quality check with the latency product
- Current weakness is high latency in areas with persistent cloud cover
- Collaboration with NASA Jet Propulsion Laboratory to improve product with microwave data (AMSR-E)

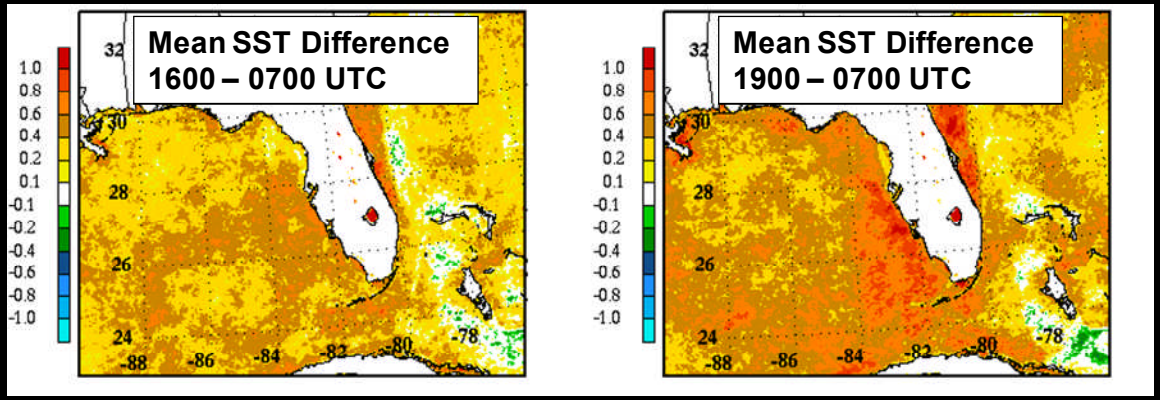


Latency Product

Capturing Diurnal Changes in SST

Diurnal Trends: June-July 2007

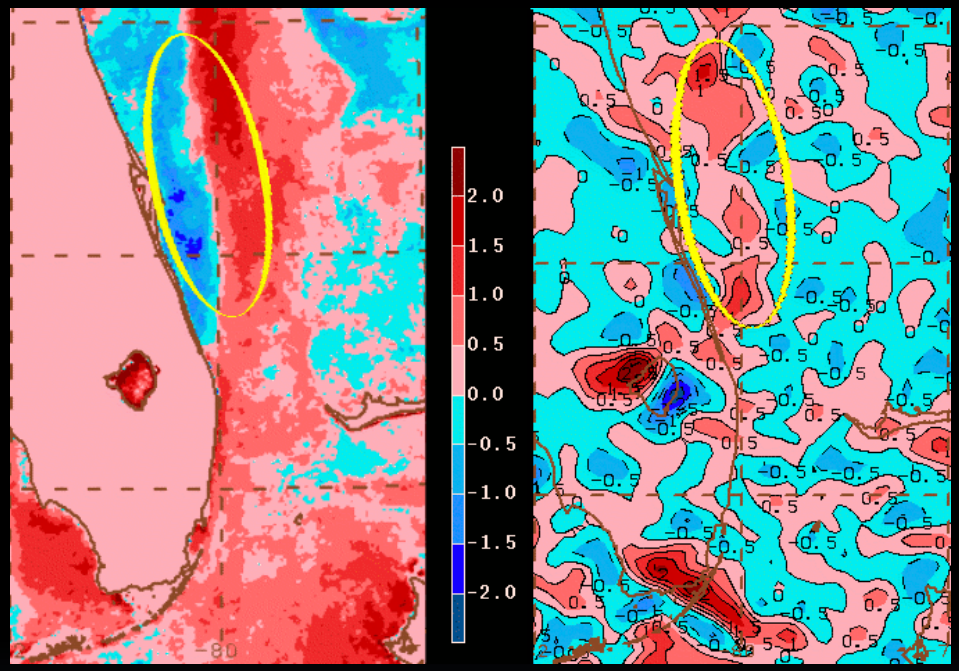
- Warming shown throughout the day
  - Largest diurnal change near coastal Florida waters.
  - Corresponds with shallow continental shelf waters.
- Slight warming from morning to morning consistent with seasonal trend in June and July.



WRF Model Sensitivity Examples

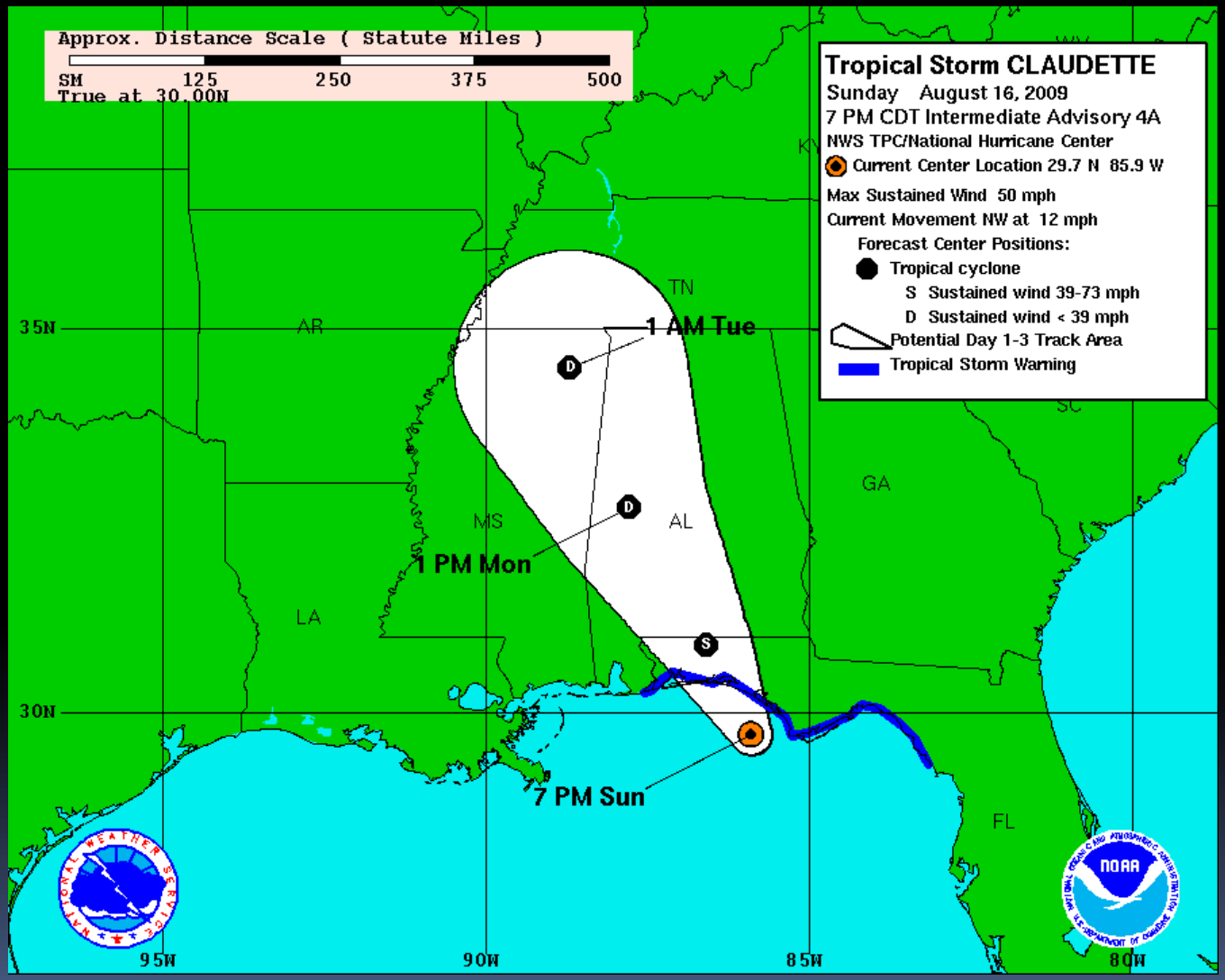
Enhanced Convergence Near Gulf Stream Under Easterly Flow

- Mean SST Differences (left)
  - MODIS – RTG
  - Averaged from 9-19 May 2004
  - Prevailing easterly flow
- Convergence/Divergence difference field (right)
  - WRF simulation comparisons
    - One using NCEP RTG SSTs
    - The other using MODIS SSTs
    - Averaged over 9-19 May 2004
  - Enhanced 10-m convergence along gradient in SSTs
  - Promotes cloud/possible precipitation development along Florida East Coast under easterly flow (a common feature there)



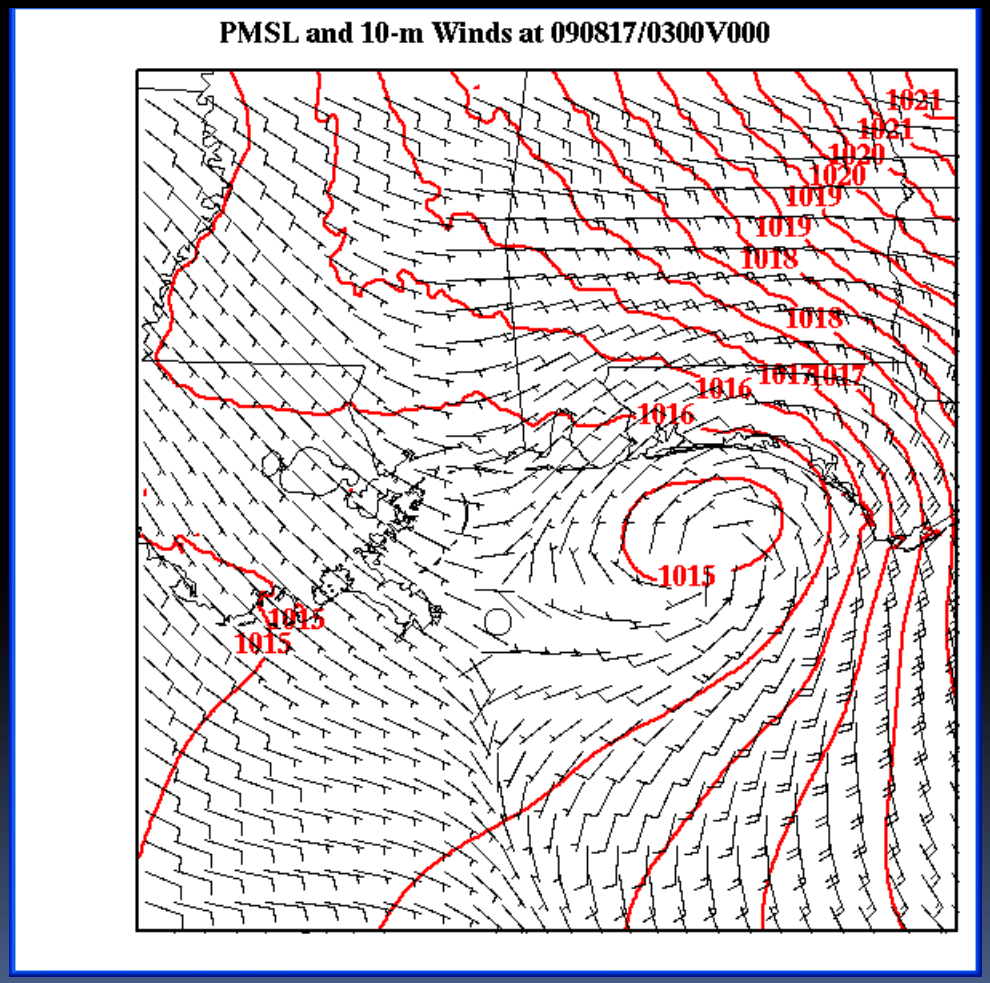
- LaCasse *et al.* (2008), *Mon. Wea. Rev.*, **136,** 1349-1372.

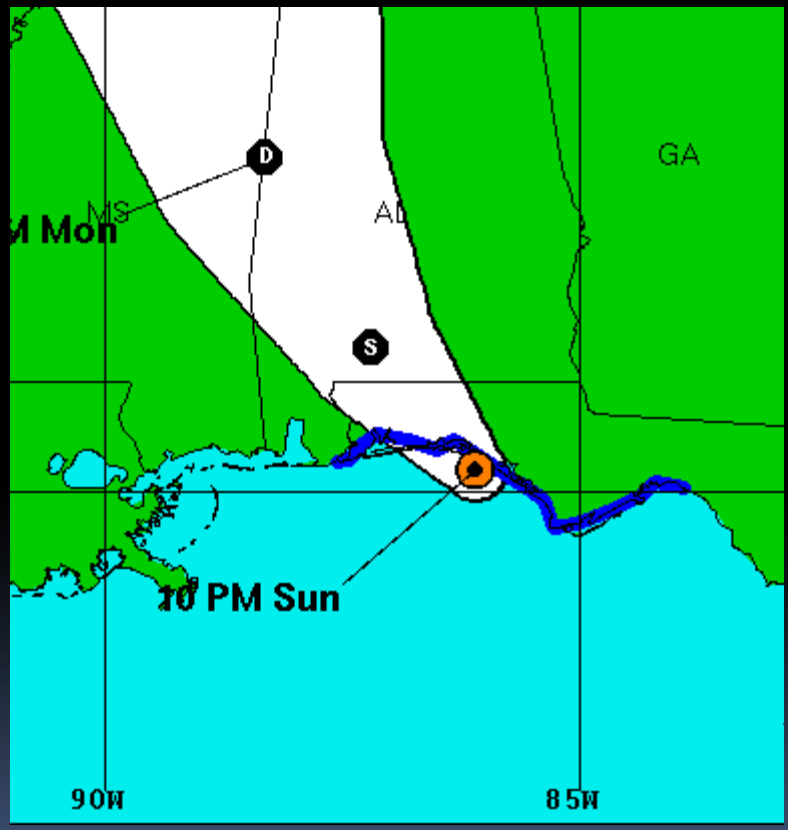
Tropical Storm Claudette: 17 AUG 2009



Model Initial Conditions: GFS 3-h Forecast

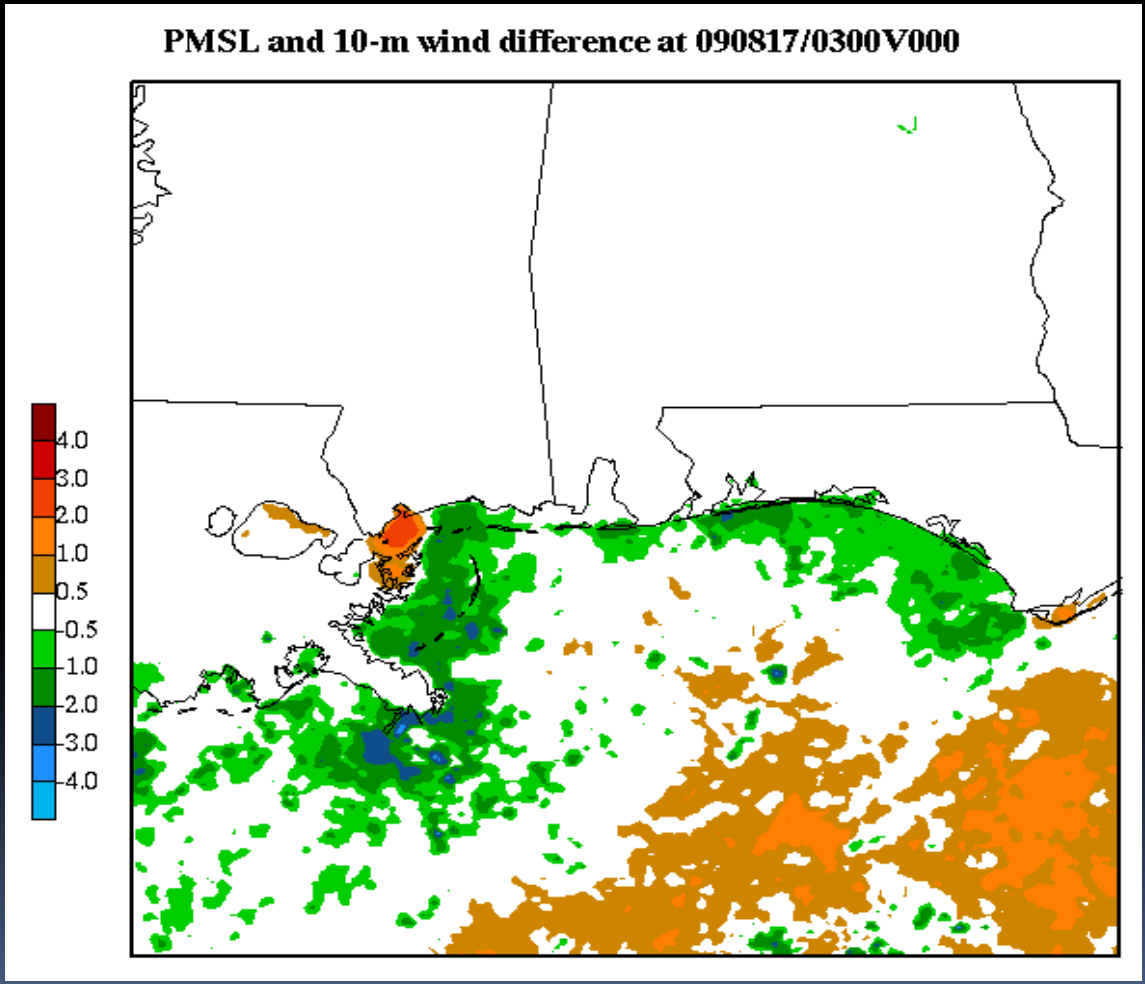
- Low slightly too far south-west compared to analyzed location





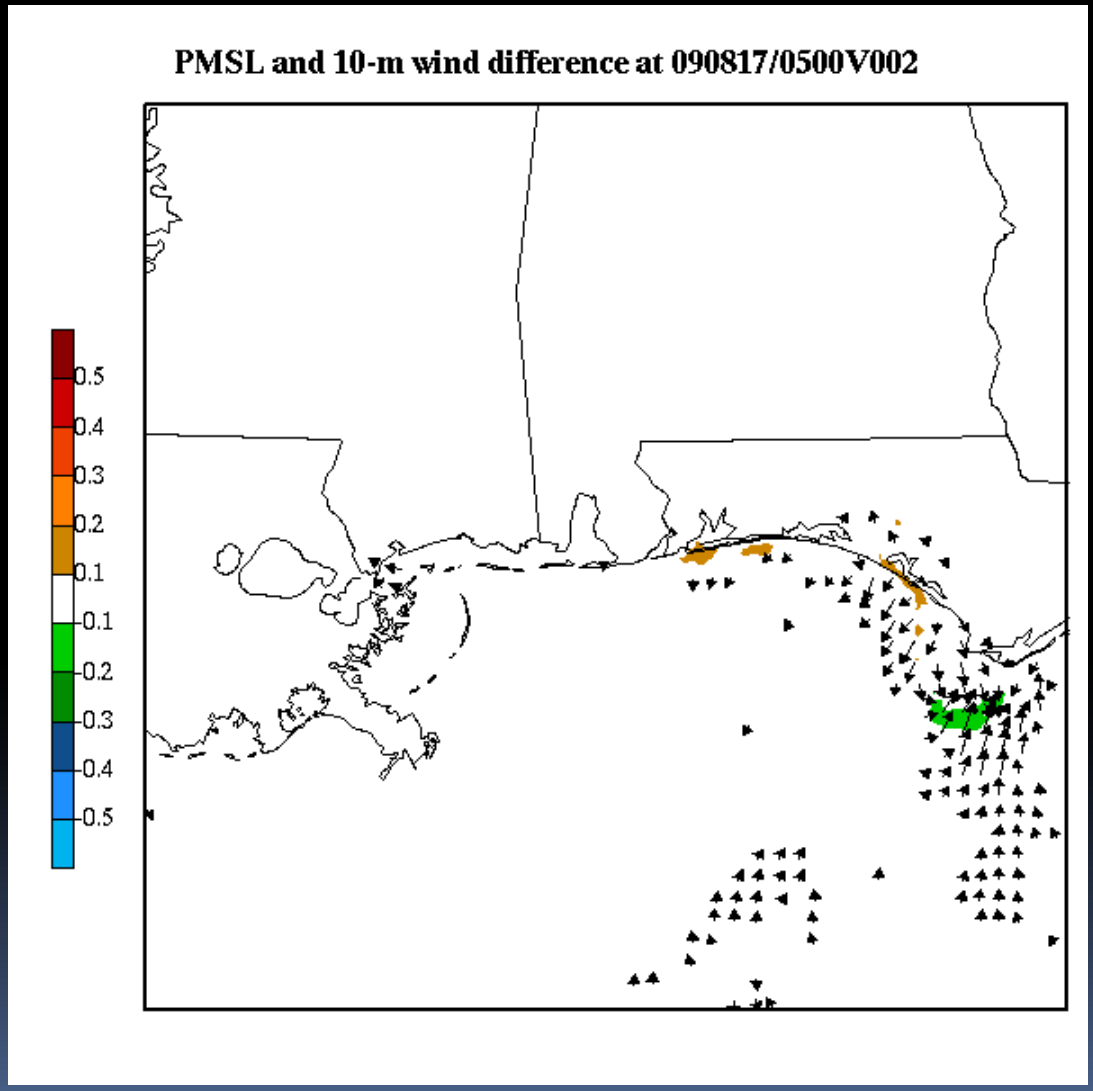
SST Differences: MODIS – RTG

- Warmer SSTs offshore of western Florida; cooler near-shore



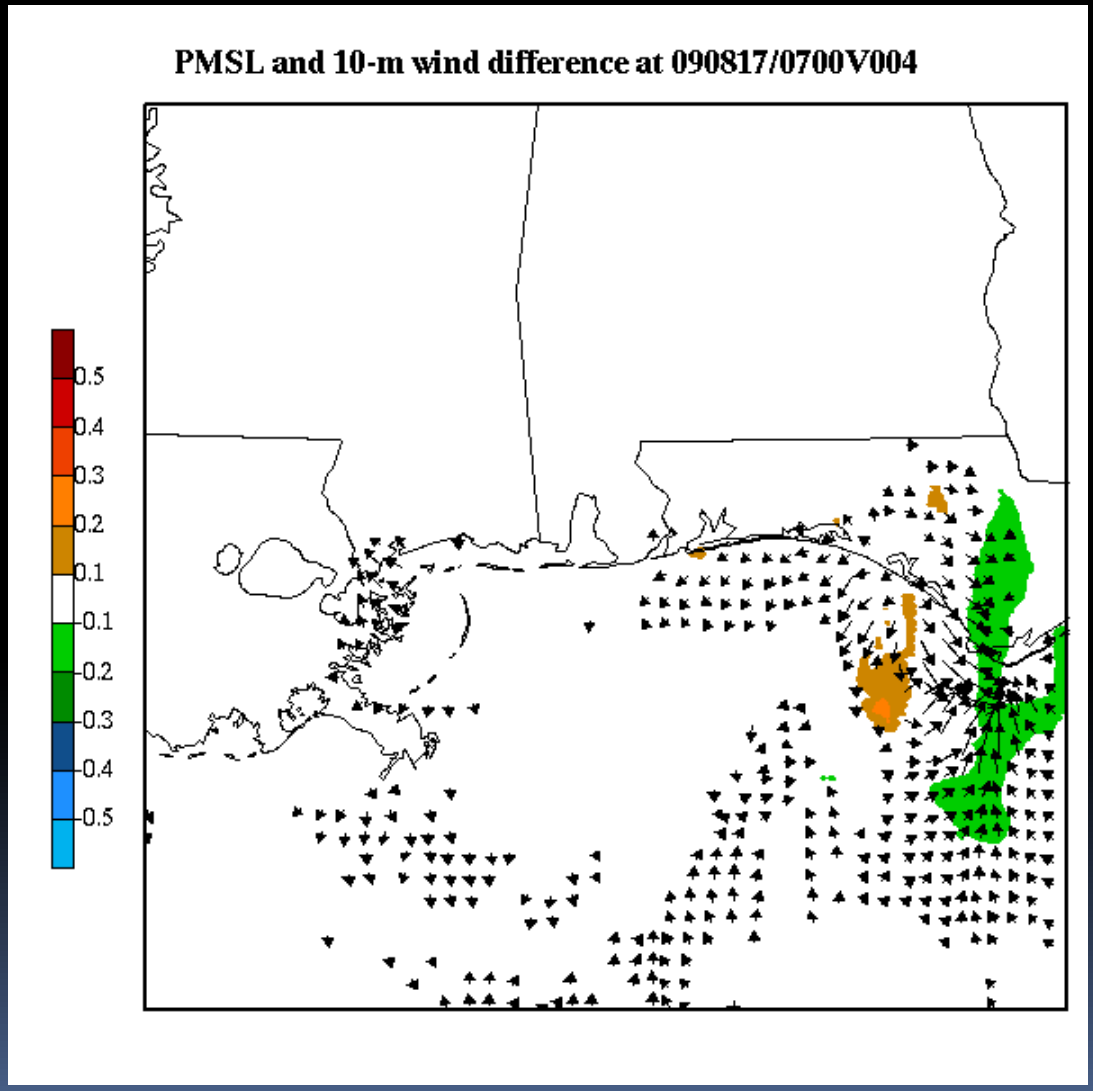
Forecast Diffs in PMSL and 10-m Winds: 2-hour forecast (MODIS – RTG)

- MODIS SSTs in local model run at NWS Mobile, AL
- Favorable response in short-term WRF forecasts
- Enhanced cyclonic flow and slightly lower pressures on east side of storm
- Small meso-low in Mobile's simulation (not shown)
- Nudged simulations of storm further east, closer to reality



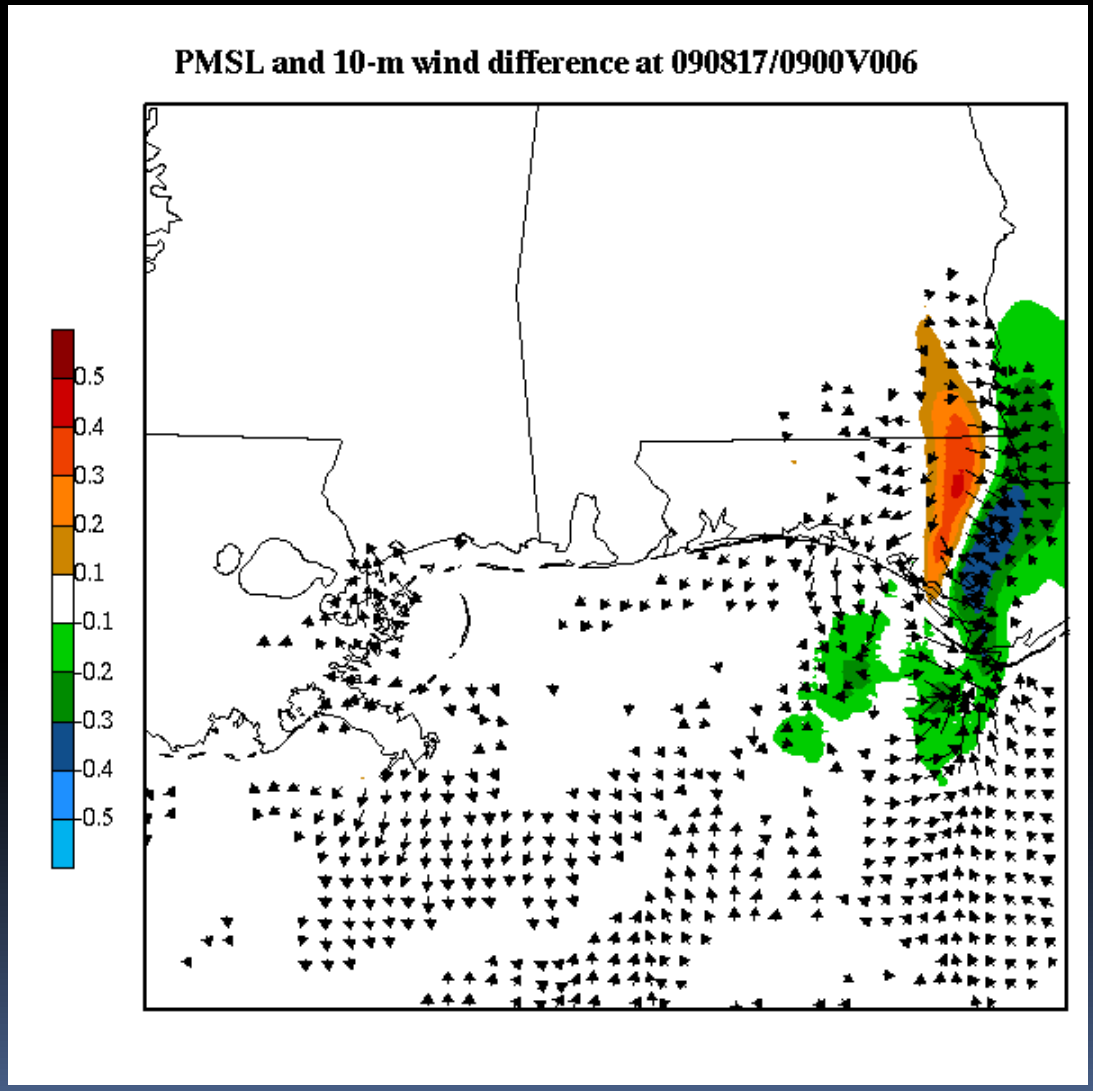
Forecast Diffs in PMSL and 10-m Winds: 4-hour forecast (MODIS – RTG)

- MODIS SSTs in local model run at NWS Mobile, AL
- Favorable response in short-term WRF forecasts
- Enhanced cyclonic flow and slightly lower pressures on east side of storm
- Small meso-low in Mobile's simulation (not shown)
- Nudged simulations of storm further east, closer to reality



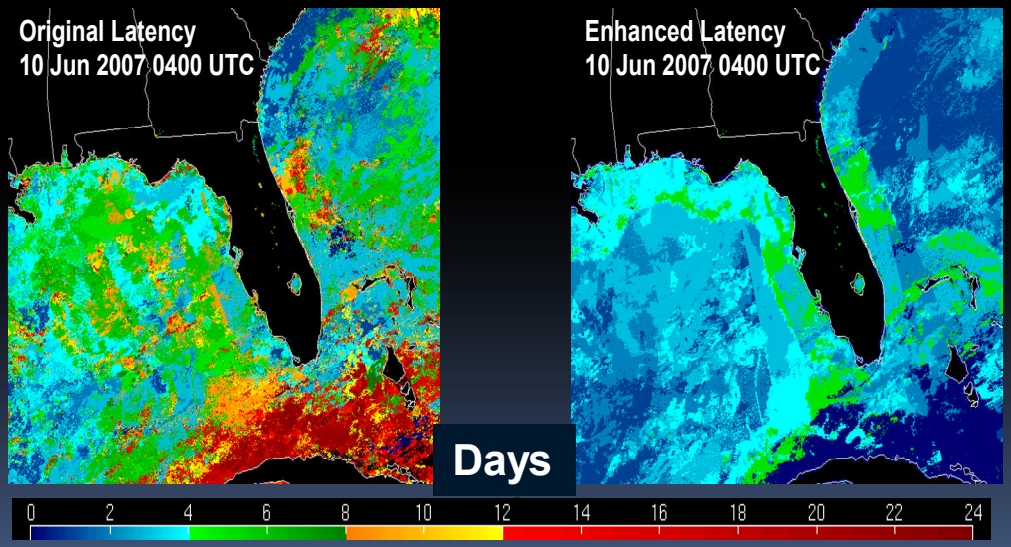
Forecast Diffs in PMSL and 10-m Winds: 6-hour forecast (MODIS – RTG)

- MODIS SSTs in local model run at NWS Mobile, AL
- Favorable response in short-term WRF forecasts
- Enhanced cyclonic flow and slightly lower pressures on east side of storm
- Small meso-low in Mobile's simulation (not shown)
- Nudged simulations of storm further east, closer to reality



SPoRT's Enhanced SST Composite

- Experimental/enhanced SST compositing technique
  - Latency-weighted combination of MODIS, AMSR-E (microwave), and OSTIA
  - Retains structure of MODIS while dramatically improving data latency
  - Reduced SST errors in Florida Keys during summer 2007 experiment
  - Improved 2-m Temp forecasts in the WRF EMS over original MODIS
- NASA JPL to take-over production on an expanded domain



Long Key, FL stats

0400 UTC	Mean Bias	Correlation	Variance
Original - Buoy	-1.933	0.587	4.296
Enhanced - Buoy	**-0.693**	**0.915**	**0.595**

1600 UTC	Mean Bias	Correlation	Variance
Original - Buoy	**-0.395**	0.881	0.998
Enhanced - Buoy	-0.678	**0.909**	**0.546**

How Can I Use MODIS SSTs in the WRF EMS?

- Upgrade to version 3 of the WRF EMS
- Let it rip!
- Some SPoRT commentary:
  - Use of MODIS SST is the default option in EMS v3
  - Package handles automatic acquisition / interpolation to model grids
  - For those already acquainted with the EMS:
    - SPoRT recommends setting BESTHR = modis in ems_autorun.conf
    - Captures diurnal SST variations in model initial conditions
    - Again, this is the default option

Summary

- NASA SPoRT's high-resolution MODIS SSTs have been incorporated into the WRF EMS version 3
  - SPoRT has demonstrated model sensitivity and improvement through the use of MODIS SSTs
  - Significant enhancements forthcoming to the MODIS SST product with reduced data latency

- Please visit the following:
  - NASA SPoRT Center website: http://weather.msfc.nasa.gov/sport/
  - Wide World of SPoRT blog: http://weather.msfc.nasa.gov/sportblog
  - Become a "SPoRT Fan" at Facebook: http://www.facebook.com/NASA.SPoRT