Development and Evaluation of the Second Hurricane Nature Run Using the Joint OSSE Nature Run and the WRF Model

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I. Background and Objectives

- The goal of this project is to make a number of very high quality simulations of Atlantic hurricanes that can be used as a "nature runs" for Observing System Simulation Experiments (OSSEs) and other research purposes.

- The nature run is used to generate "simulated observations" that will be fed into forecast models such as HWRF to determine the extent to which these observations can improve forecasts.

- To take advantage of pre-existing, pre-validated synthetic observations, this nature run is embedded in the Joint OSSE Nature Run (JONR) which is a global nature run developed for similar purposes.

- Nolan et al. (2013) documented the development and an extensive validation of a first hurricane nature run.

  Here, we describe the development and a limited evaluation of a second hurricane nature run.

II. The Joint OSSE Nature Run and Case Selection

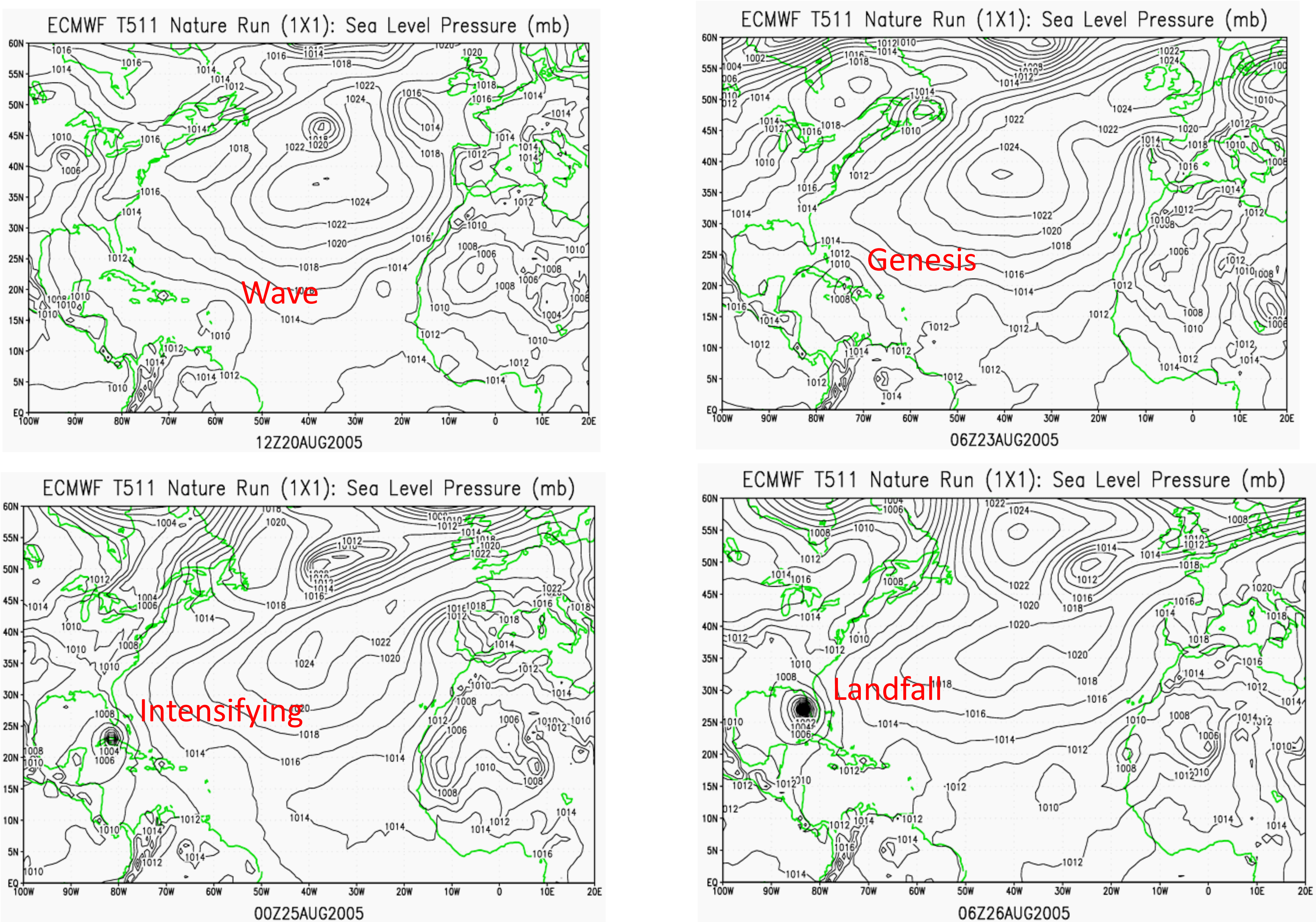
- The JONR is a free-running simulation with seasonal forcing and prescribed surface boundary conditions for 13 months over 2005-2006.

  The nature run used T511 spectral resolution, equivalent to roughly 35 km horizontal grid spacing over the tropical Atlantic.

- Many tropical storms and hurricanes developed during the simulated Atlantic hurricane season which used prescribed SSTs from 2005.

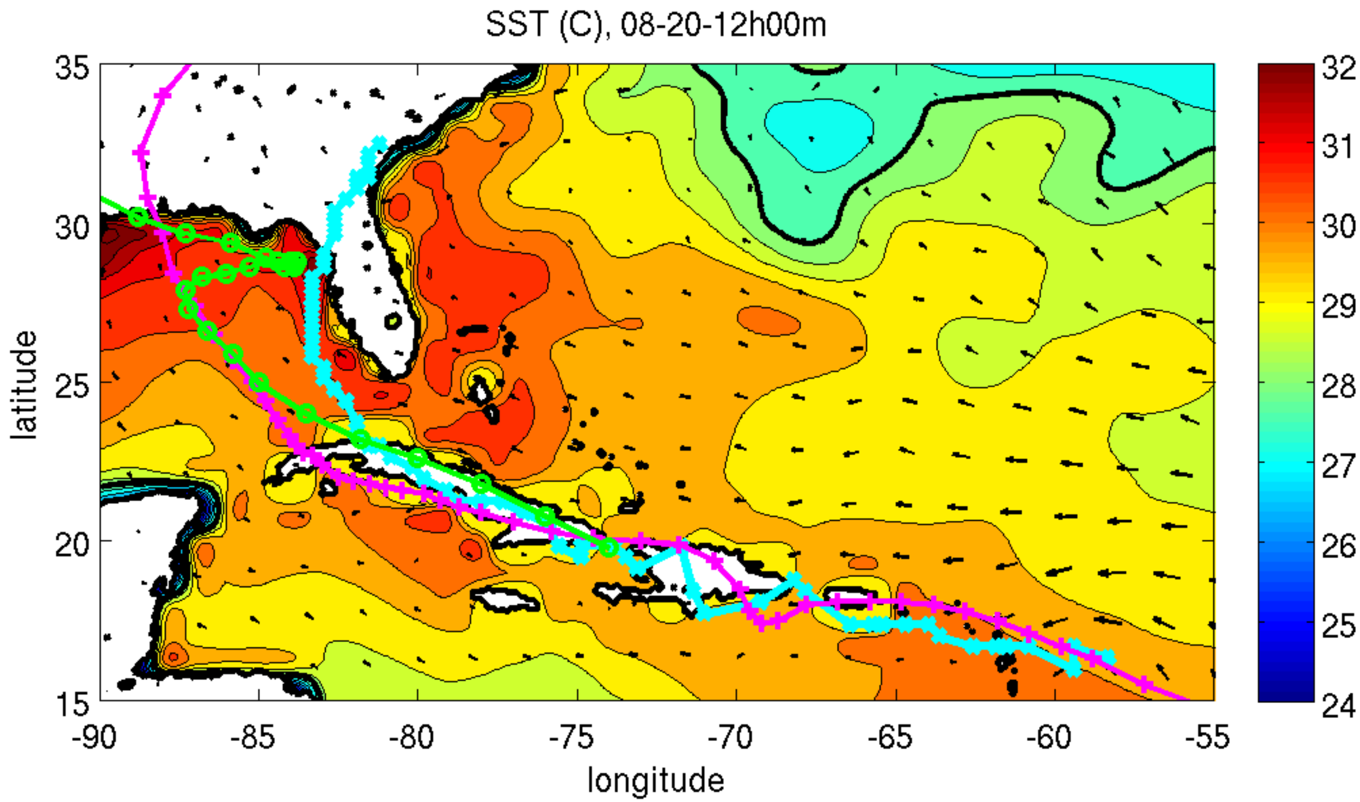
  Nolan et al. (2013) selected one that exhibited all phases of the classic Atlantic hurricane life cycle: genesis from an African Easterly Wave, a period of rapid intensification, several days of mature structure, and then recurvature into the North Atlantic.

- For the second hurricane nature run, we choose a storm that experiences significant land interaction during its development as well as landfall over Florida and the Southeast United States.



GRIB files from the ECMWF nature run from 12Z Aug. 20 to 12Z Aug. 28 are used for initial and boundary conditions for the second hurricane nature run.

Analog Storms



The cyclone selected from the JONR for this case appears to form and intensify during passage over the Greater Antilles (cyan markers show position every 3 hours). While unusual, the behavior has been exhibited previously by a number of Atlantic Hurricanes. The paths of two such storms, Frederic (1979) and Elena (1985) are shown below in comparison to the track of the JONR cyclone. While Frederic (magenta) had previously achieved hurricane status, it had only tropical depression status between Haiti and Cuba, and regained tropical storm strength while over the west end of Cuba. Elena (green) was identified as a tropical depression and became a named tropical storm while its center was still over the north coast of Cuba.

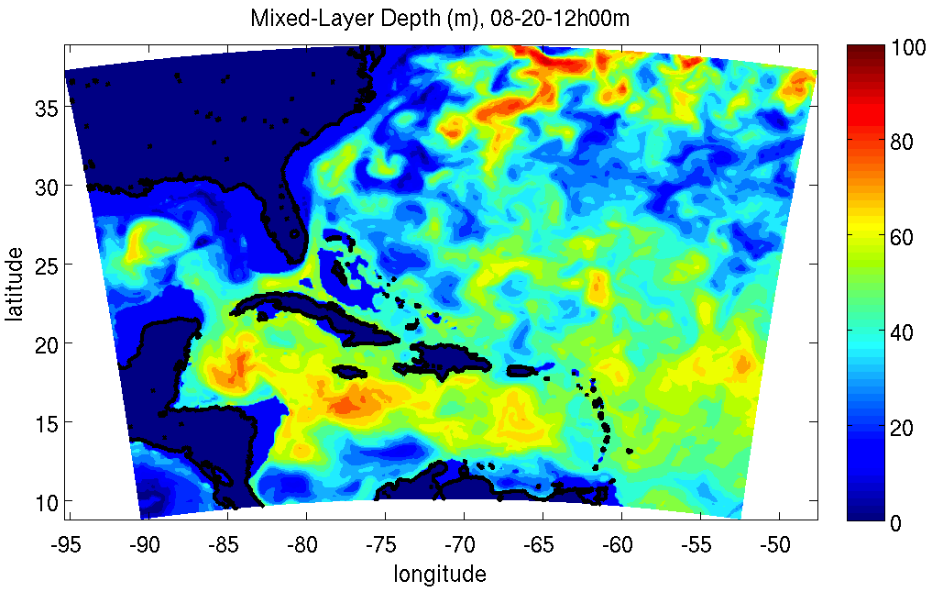
Contours show initial SST field with 0.5°C intervals, and 28°C thickened.

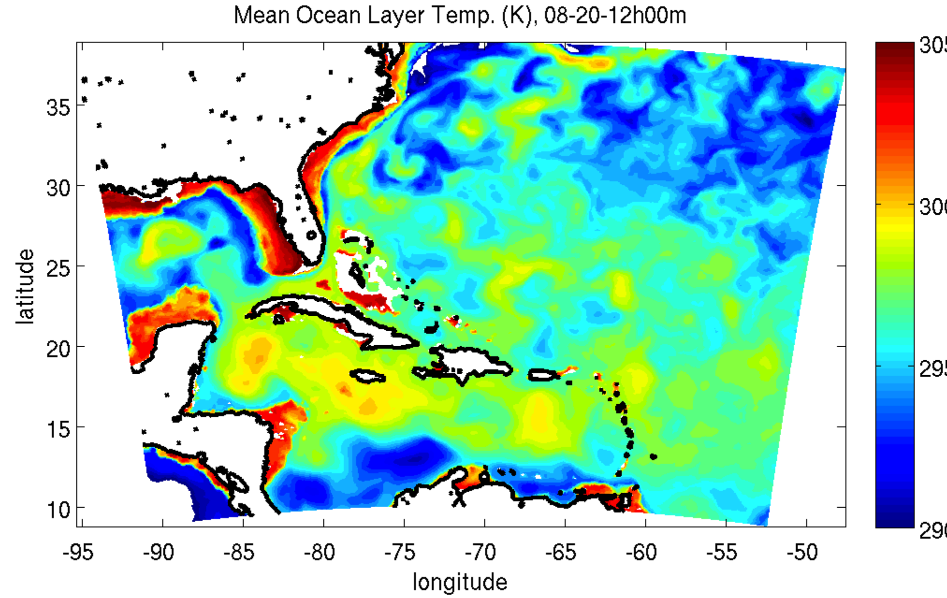
III. HNR2 Modeling Strategy

WRF 3.4.1 was used with nearly identical resolutions and physics as in the first nature run, including:

- 1 km innermost nest grid spacing
- 60 vertical levels up to 50 hPa
- WRF 6-class double-moment microphysics
- RRTM-G shortwave and longwave radiation
- YSU planetary boundary layer scheme
- Surface layer drag coefficient formula changed back to WRF 3.1.1 (better pressure-wind relationship)
- "Nudging" of large-scale fields to global model fields with 24-hour relaxation time scale, on domain 1 only.

Feature	HNR1	HNR2	Remarks
Model	WRF 3.2.1	WRF 3.4.1	Model Upgrade
Resolution	27km/9km/ 3km/1km	9km/ 3km/1km	Better coastlines and topography
Domain Sizes	240x160/120x120/ 240x240/480x480	480x360/ 360x360/480x480	New 3km grid same size as old 9km grid
Output Frequency	30 min/30 min/ 30 min/6 min for 13 days	30 min/ 30 min/5 min for 8 days	More frequent, but less data
Radiation Calls	6 min all domains	5 min all domains	Updates to radiation fields match output times
Ocean Mixed Layer Depth	Initialized at 25 m over whole ocean	Realistically varying mixed layer depth from HYCOM Analysis	Especially needed for crossing Florida Current and Gulf

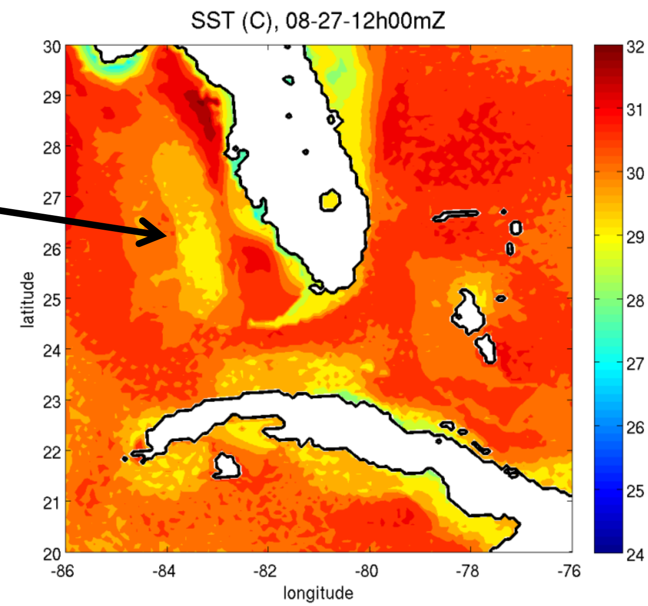




The mixed layer depth for the 1-D ocean cooling model is estimated from this HYCOM analysis from 2005

The "mean ocean layer temp." is a temperature below which the 1-D model cannot cool the SST.

Due to limited mixing, only a narrow cold wake of ~1.5 C is produced.



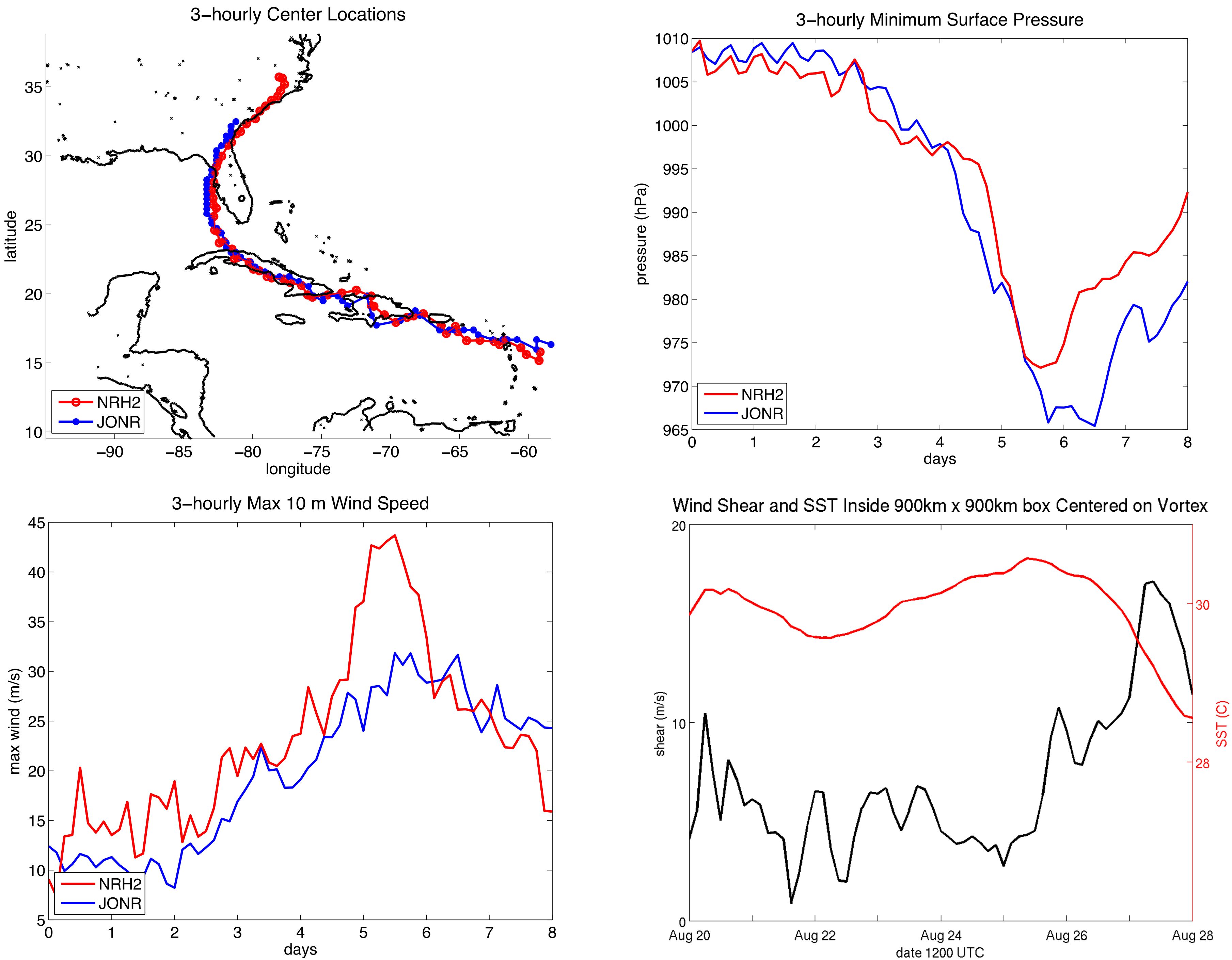
IV. Results

- As can be seen on the following pages, the track of the hurricane in the WRF 1km nature run follows the JONR cyclone very closely, but during the last 24 hours it falls behind.

- Although a surface pressure minimum can be followed beforehand, a distinct surface circulation does not form until the mid-level circulation passes between Haiti and Cuba.

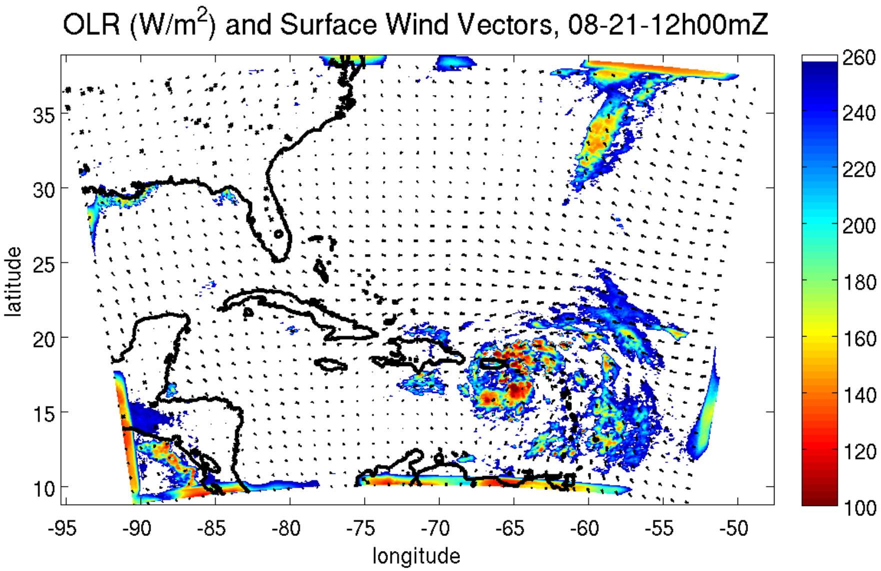
- The storm is able to maintain tropical storm strength, and even intensify slightly, while traveling over Cuba. This is at least in part because the environmental wind shear is very low, less than 5 m/s, for much of this period.

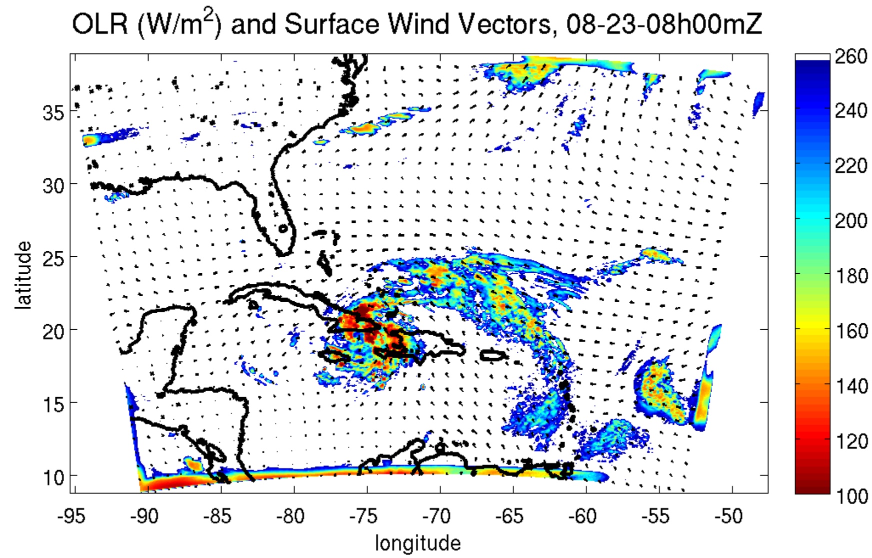
- Once over the Eastern Gulf of Mexico, the storm rapidly intensifies before making landfall directly over the Tampa/St. Petersburg area.

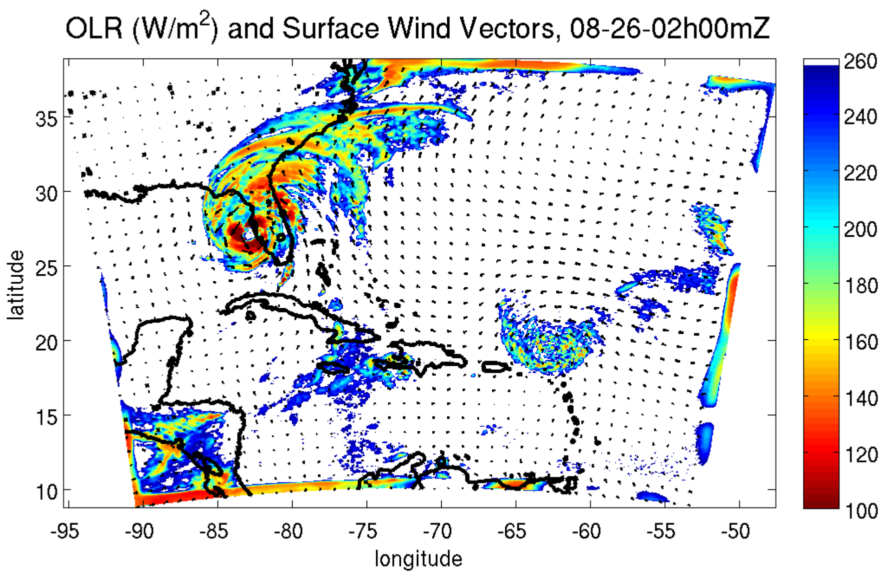


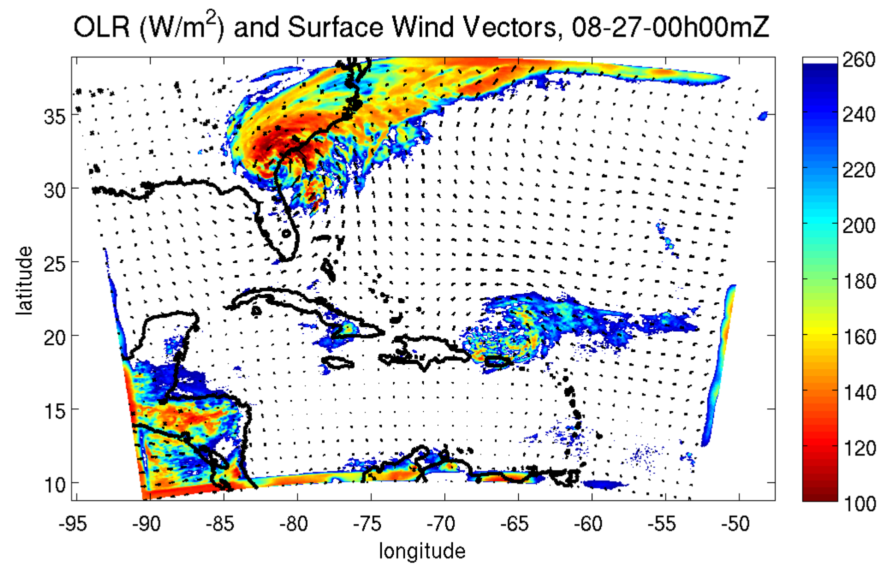
3−hourly Center Locations
latitude
longitude
NRH2
JONR
3−hourly Minimum Surface Pressure
pressure (hPa)
days
NRH2
JONR
3−hourly Max 10 m Wind Speed
max wind (m/s)
days
NRH2
JONR
Wind Shear and SST Inside 900km x 900km box Centered on Vortex
shear (m/s)
SST (C)
Aug 20
Aug 22
Aug 24
Aug 26
Aug 28
date 1200 UTC

The figures below show the model-simulated outgoing longwave radiation (OLR) and surface wind vectors (scaled to 40 m/s) on the 9 km grid at various stages of the storm evolution.

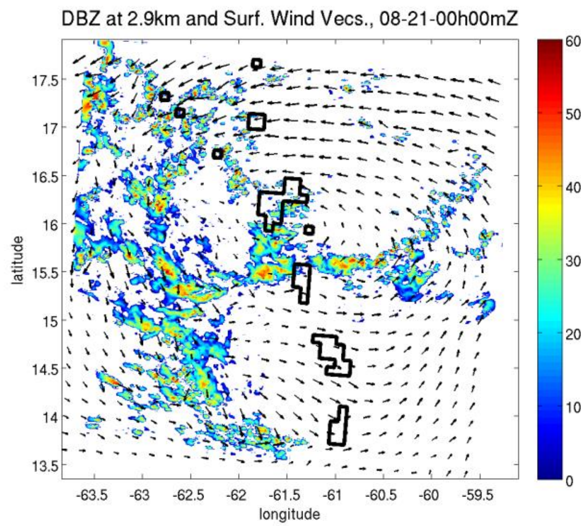


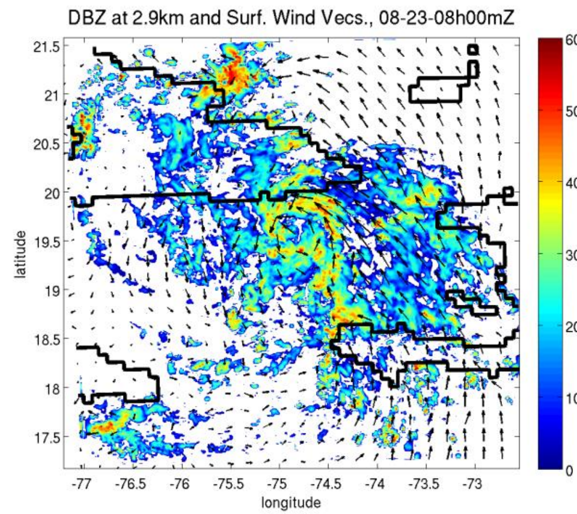


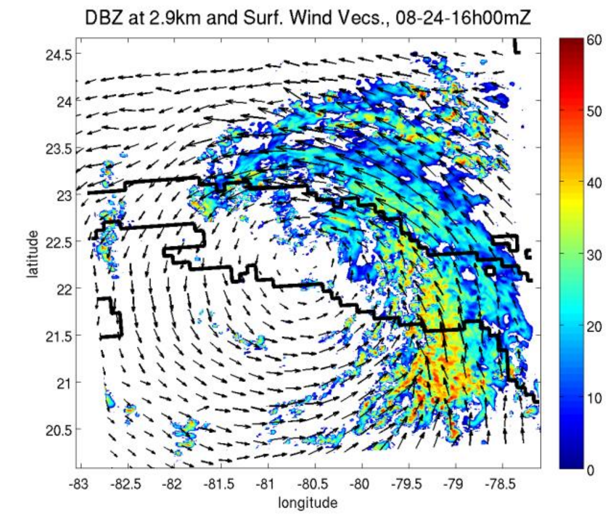


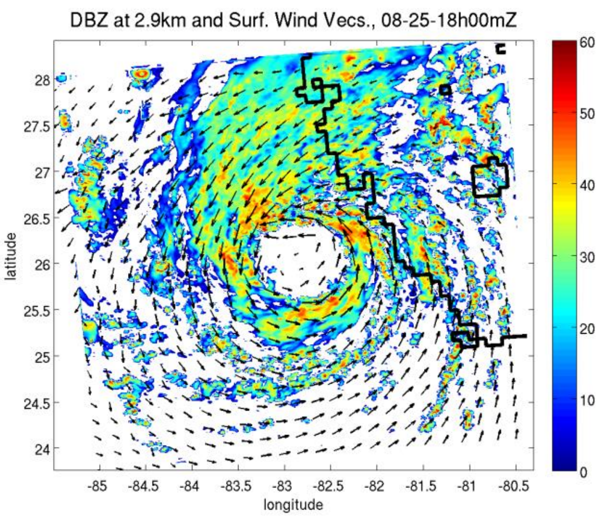


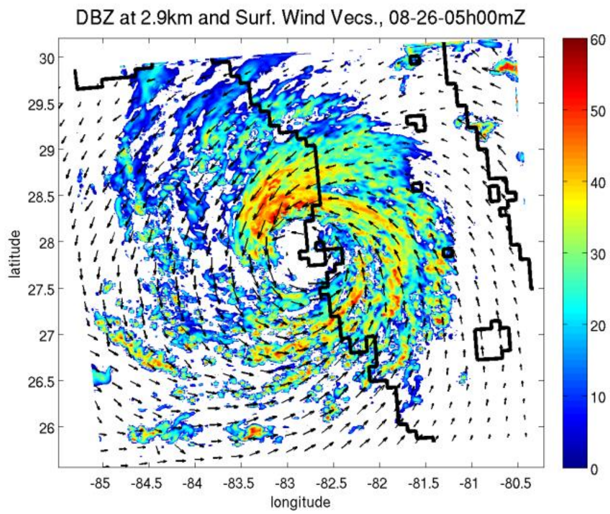
These images show simulated flight-level reflectivity and surface wind vectors every 20 km.
Vectors are scaled by 20 m/s in the upper plots and 40 m/s in the lower plots.

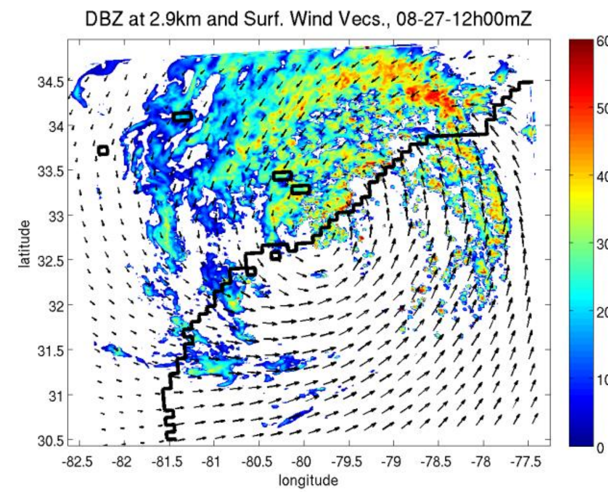




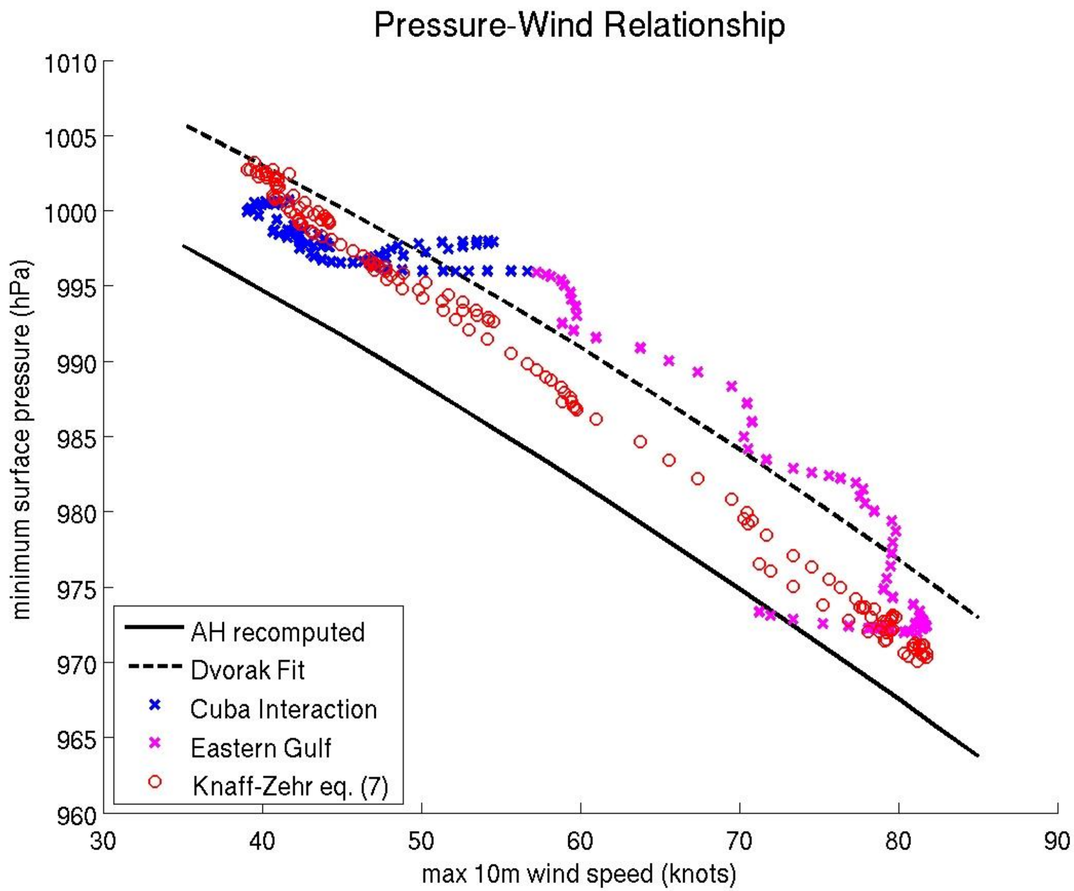








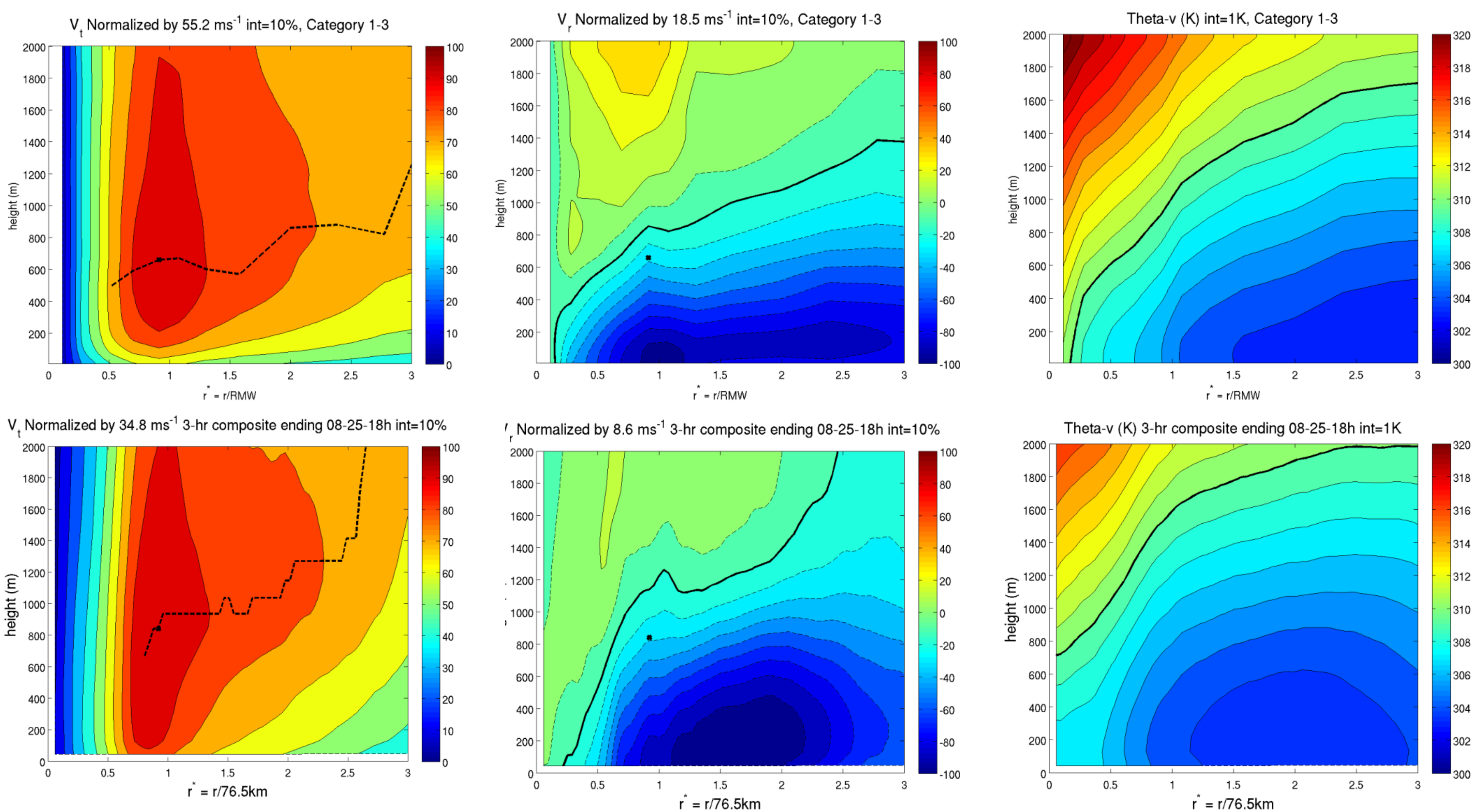
V. Evaluation

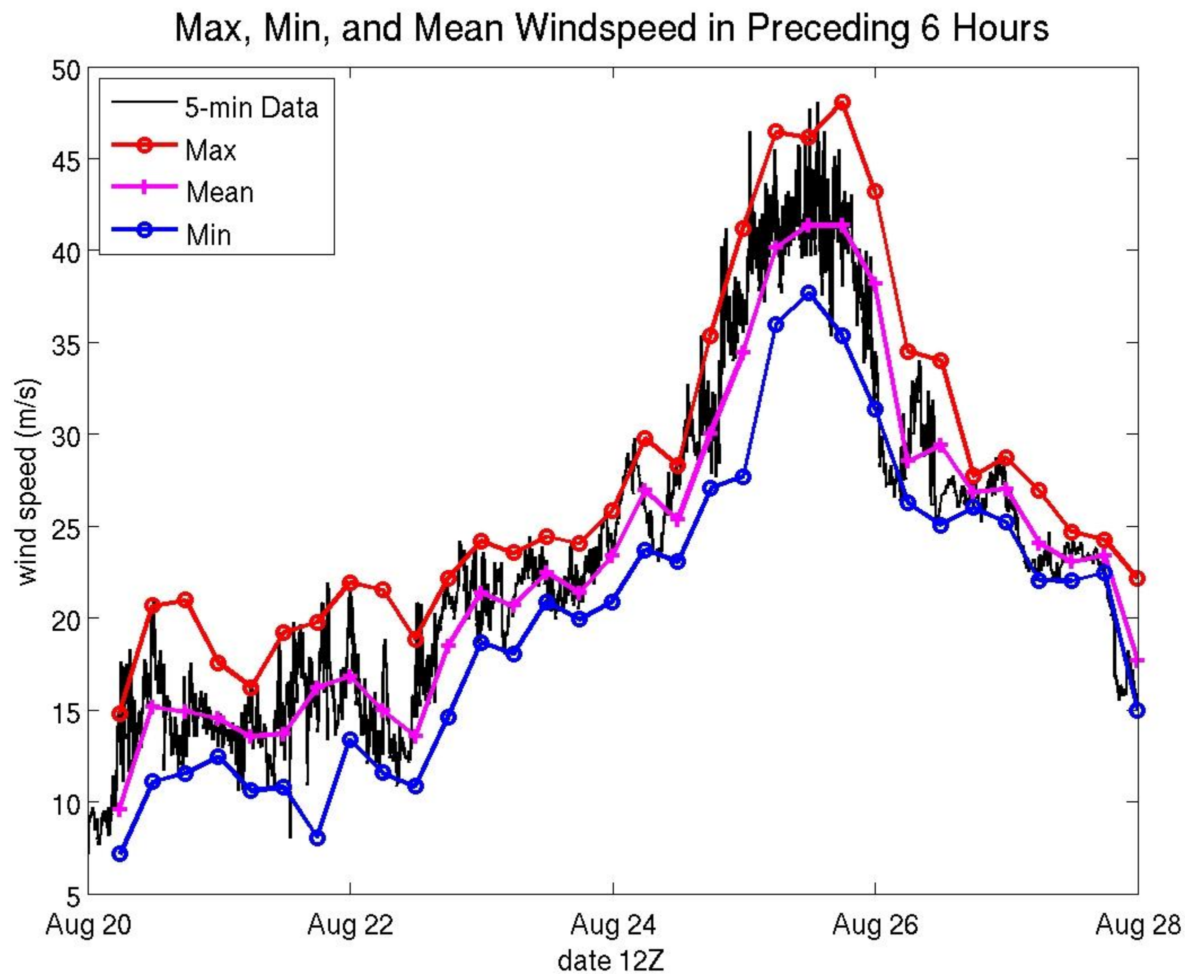


The above figure shows several pressure wind relationships presented by Knaff and Zehr (2007): A curve fit to the Dvorak table; a revised curve for the Atkinson-Holliday data; and the red circles show pressures computed from their new formula that uses peak wind speed, storm motion, latitude, and a measure of storm size. Each data point uses the peak wind speed from the 1km grid, adjusted to 1-min means by a gust factor formula, and then averaged 30 minutes in time for representativeness. The data points are from 12Z Aug. 23 (tropical storm) to 12Z Aug. 26 (landfall north of Tampa).

Inner-Core Boundary Layer Structure

Jun Zhang et al. (2011) produced composites of boundary layer wind and temperature fields from thousands of dropsondes. The top row of figures show this data. The radial size of the storm is normalized by its radius of maximum winds, and the wind speeds are normalized by the peak inward radial speed and the peak tangential speed, respectively. The thick solid lines show the 10% contour for the radial inflow, the dashed line shows the height of the maximum tangential wind, and the x's mark the location of the peak tangential wind. The lower figures show similarly processed azimuthal-mean fields from NRH2 at the time of maximum intensity. A good comparison is likely compromised by the weakness of the hurricane and its land interactions with Florida and Cuba at this time.





This figure shows an example of what can be learned from high-frequency model output. The black curve shows the peak wind speed from the 1km grid saved every 5 minutes and adjusted to 1-min mean winds using a gust factor formula. The blue, magenta, and red curves show the minimum, maximum, and mean wind in the previous six hours. The use of infrequent model output to indicate simulated intensity can randomly underestimate or overestimate the representative intensity by 3-5 m/s in either direction.

VI. Data Sets

The output from both nature run simulations have been archived.

- All WRF state variables, diagnosed surface fields, and all physics tendencies (boundary layer/friction, cumulus, radiation).
- 3D fields saved every 30 minutes on the 9km and 3km grids.
- 3D fields saved *every 5 minutes* on the 1 km grid.
  1 hour = 20 GB.
- 2D surface fields from the 1km grid saved *every 10 seconds* for a 24 hour period during intensification and landfall.

The NetCDF output files are now freely available for transfer. They can be used for any purpose, such as visualization, simulating observations, or studying physical processes such as genesis, intensification, and landfall.

If you are interested in this data set, contact Dave Nolan directly.