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Award Period: 09/01/2013 - 08/31/2015
Project Title: Improving the GFDL/GFDN Operational Tropical Cyclone Models at NOAA/NCEP and Navy/FNMOC
Recipient Name: University of Rhode Island
PIs/PDs: Isaac Ginis and Morris Bender
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Reporting Period: 03/01/2014 - 08/31/2014
Final Report: No
Report Due Date: 09/30/2014

Work Accomplishments:

1. Tasks originally scheduled for Year 1

a) Transition the 1/18° benchmark GFDL/N, perhaps with physics changes, to operations.
b) Transition open MP software in 1/18° GFDL/N, for improved efficiency, to operations.
c) Begin testing the radiation package with an increased number of vertical levels.
d) Continue to test the upgraded Ferrier microphysics in preparation for operations.
e) Transition the meso-SAS convective scheme to operations, pending positive results.
f) Transition GFDL/MPIPOM-TC to operations in the Atlantic, pending positive results.
g) Set up the worldwide MPIPOM-TC domains in GFDN and conduct initial testing.
h) Select the optimal set of air-sea interface physics packages and transition the hurricane-wave-ocean coupled system to operations in the Atlantic, pending positive results.

2. Tasks accomplished this period, adjusted based on evolving priorities and results

a) Evaluation of the 2014 GFDL model upgrade in the Western Pacific

As reported in our March 2014 JHT progress report, the operational National Weather Service version of the GFDL model was upgraded in 2014 with increased inner nest resolution (Task a), improved physics (Tasks a, c, d, and e, and h), and a new ocean coupled system (called MPIPOM-TC; Task f). Extensive testing from previous Atlantic and Eastern Pacific hurricane seasons demonstrated that the new GFDL model lead to significantly reduced (10-15%) intensity errors and some modest improved track skill. The new ocean coupling has recently been extended to all other ocean basins in a version of the GFDL model that was ported to the HFIP Jet super-computer system (Task g), where it has run in near real time for the Western Pacific basin since the beginning of July, 2014. The GFDL forecasts, run from NCEP's GFS (Global Forecast System) forecast fields, have been sent to the Joint Typhoon Warning Center (JTWC), providing forecast guidance to supplement their suite of operational models. The new model (black) has demonstrated improved intensity skill at almost all lead times compared to other dynamical model guidance (*Fig. 1*), including the current Navy version of the operational GFDL model (GFDN, red, which is initialized from the Navy's global forecast model, NavGem), the 2014 version of HWRF (green), and COAMPS-TC (blue).

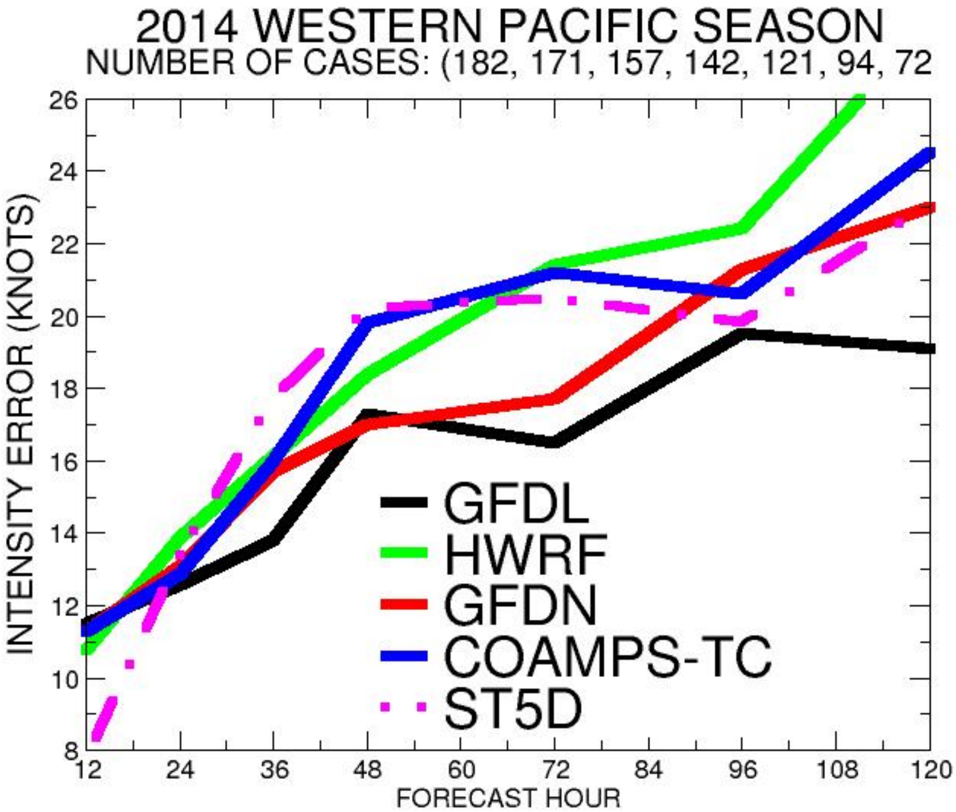

Figure 1. *Average Intensity errors for the upgraded GFDL model (GFDL), currently run in the Western Pacific in real time on the Jet supercomputer system, compared to some of the other operational forecast guidance (HWRF, GFDN, COAMPS-TC, and the five day statistical intensity model - ST5D).*

The new upgraded GFDL also is demonstrating improved track skill (*Fig. 2*) in the 1-4 day forecast lead times, compared to the current operational GFDN, with some degradation at day 5. However, much of the lost skill at day 5 was due to forecasts of one long lived storm, Typhoon Halong (*wp11*), particularly during an exceptionally poor two-day model performance when the new GFDL forecast system erroneously turned the storm sharply north (*e.g., Fig. 3, left*), although the model still provided reasonable guidance at other forecast times (*Fig. 3, right*).

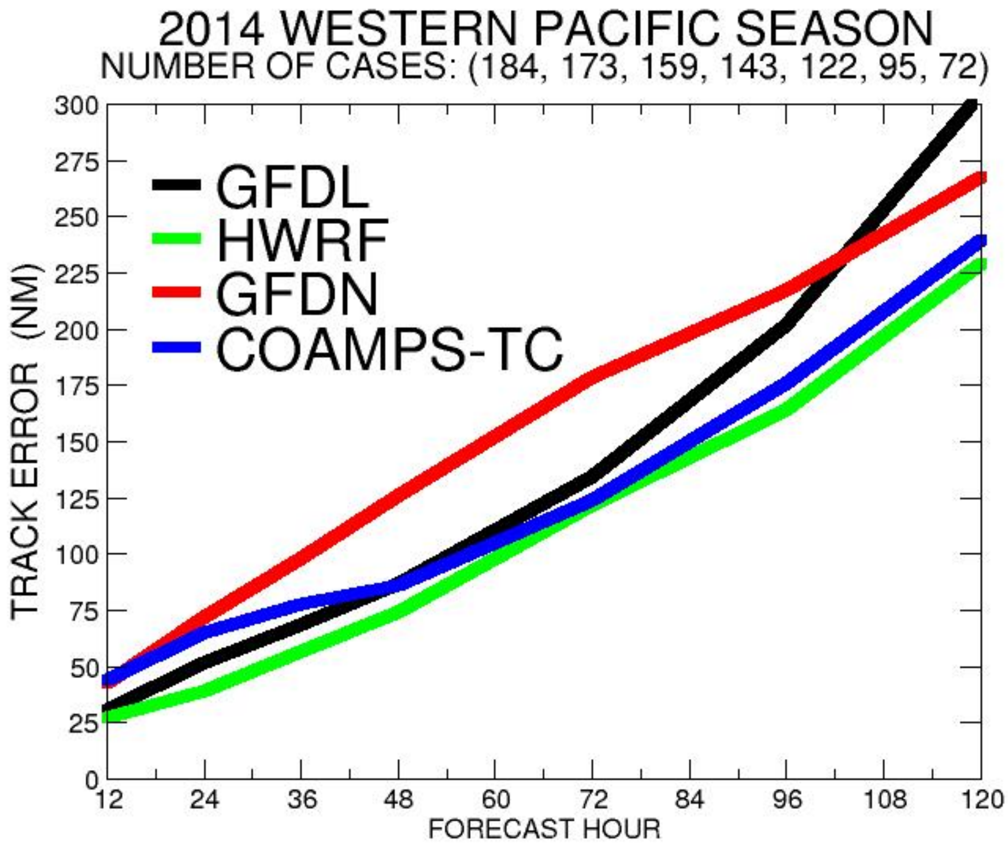

Figure 2. *Average Track errors for the upgraded GFDL model (GFDL) currently run for the Western Pacific in real time on the Jet supercomputer system, compared to some of the other operational forecast guidance (HWRF, GFDN, and COAMPS-TC).*

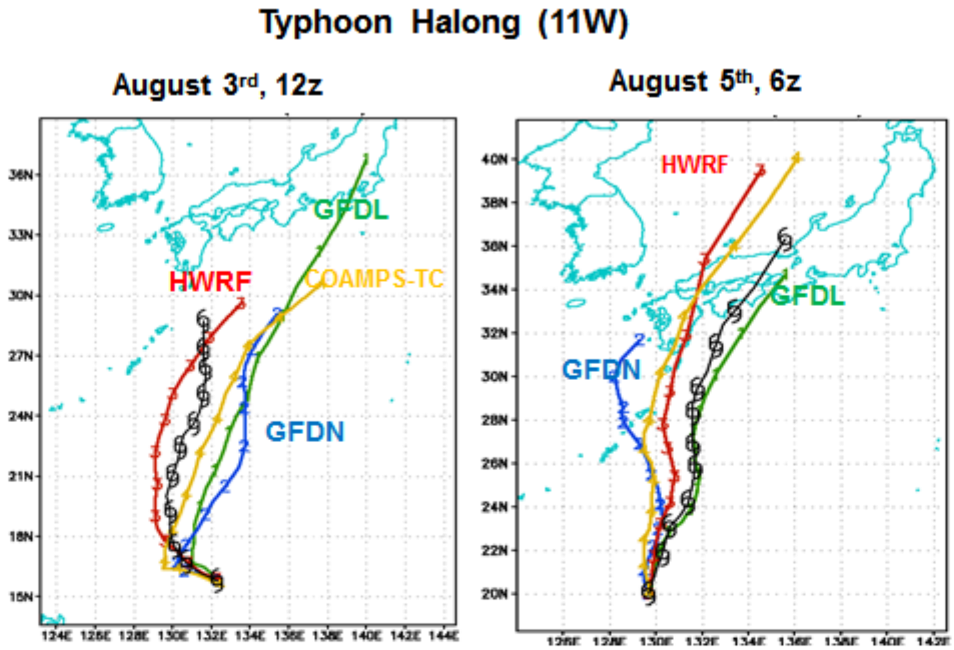

Figure 3. *Two sample track forecasts for GFDL (green) compared to other forecast guidance when the new model provided both exceptionally poor guidance (left) and good guidance (right).*

The new GFDL modeling system being run for the Western Pacific is identical to the version run by the NWS, with one important exception. In reruns of the new GFDL model for the previous 2013 Western Pacific season, it was found that the forecasted storm track and intensity was negatively impacted by the gale force wind radii used in the vortex initialization and estimated from the JTWC TCVitals file, which appeared too small compared to some observed data. In addition, the radial extent of the storm (rb) estimated from the reported radius of the last closed isobar in the JTWC TCVitals file also appeared to be inaccurate. Hence, an improved estimate of rb was formulated based on an assumption that the angular momentum of a parcel is roughly conserved from rb to the radius of gale force winds. The 2013 Western Pacific cases were rerun with the new rb and with the radius of gale force winds based on the GFS gale force wind radii, reported on the atcf decks, instead of the JTWC TCVitals gale force wind radii. This new rb estimate, based on the GFS gale force wind radii, significantly reduced intensity errors relative to the JTWC-based rb formulation (*Fig. 4*), particularly at days 3-5 (~15%). Based on these results, and pending further testing, the improved specification of rb will likely be made operational in both GFDL and GFDN in the next model upgrade. In addition, this result clearly indicates that the reported storm size and structure can have an important impact on both forecasted track and intensity, reinforcing the point that these quantities need to be estimated as accurately as possible by the forecast agencies (e.g., NHC, JTWC).

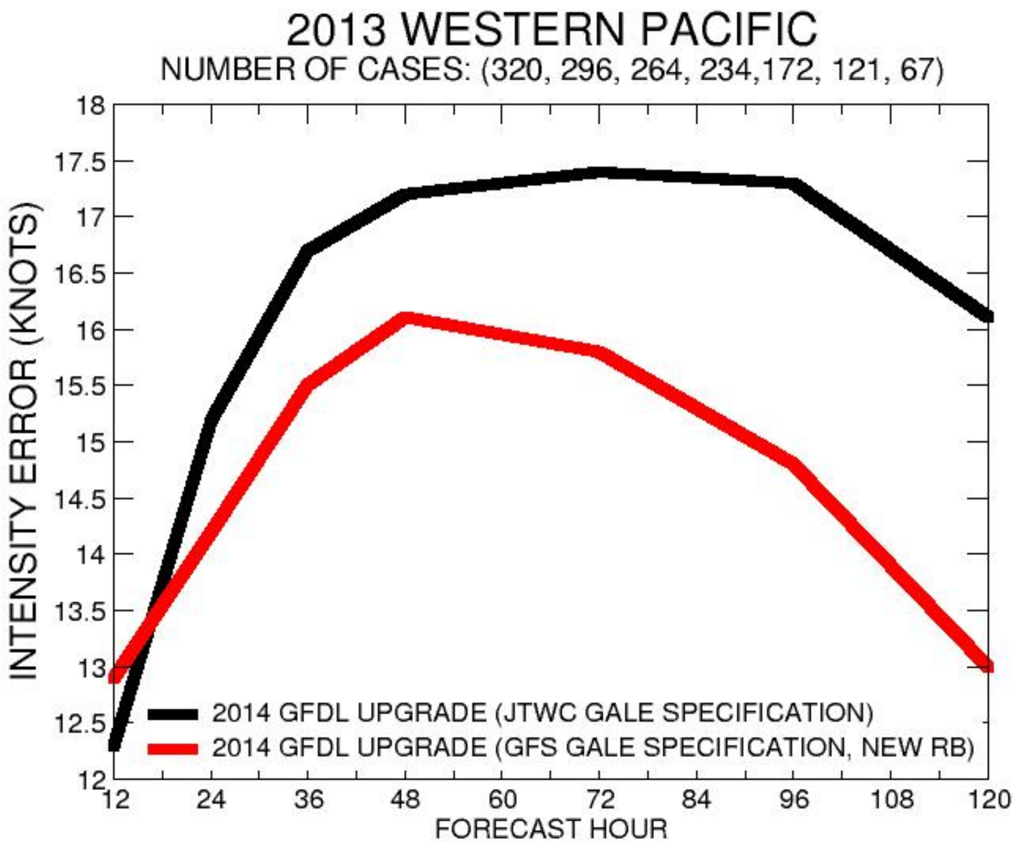

Figure 4. *Average intensity errors for the new GFDL model run for storms in the 2013 Western Pacific Typhoon season, using the JTWC TCVitals information and current storm size (rb) specification (black), compared to a version using both the GFS Gale winds reported in the operational ATCF decks and a new formulation of rb (red).*

b) Improving and evaluating the wave coupling in the GFDL model

We continued to improving and evaluating the new GFDL/WAVEWATCH III/MPIPOM-TC system. In the three-way air-wave-sea coupled framework, which is based on a comprehensive, physics-based treatment of the wind-wave-current interaction, the bottom boundary condition of the atmospheric model incorporates sea-state dependent air-sea fluxes of momentum, heat, and humidity, and it includes the effect of sea-spray. The wave model is forced by the sea-state dependent wind stress and includes the ocean surface current effect. The ocean model is forced by the sea-state dependent wind stress and includes the ocean surface wave effects (i.e. Coriolis-Stokes effect, wave growth/decay effect).

During this time period, we have incorporated two different wind stress parameterization schemes, one based on Donelan et al. (2012) and the other based on Reichl et al. (2014). In addition, we adjusted the behavior of the drag as a function of wind speed to be consistent, on average, with the C_d formulation implemented in the 2014 operational GFDL model. Examples of the spatial distribution of the drag coefficient under a typical (idealized) TC are shown in Fig.

5 (top panels). Although the wind speed is nearly axisymmetric, the drag coefficient significantly varies depending on the location relative to the hurricane center. In particular, the drag coefficient is significantly reduced in the front right quadrant in both parameterizations. The sea state dependence of the drag coefficient at different wind speeds is shown in Fig. 5 (bottom panels). The sea state dependence is enhanced most significantly at higher wind speeds.

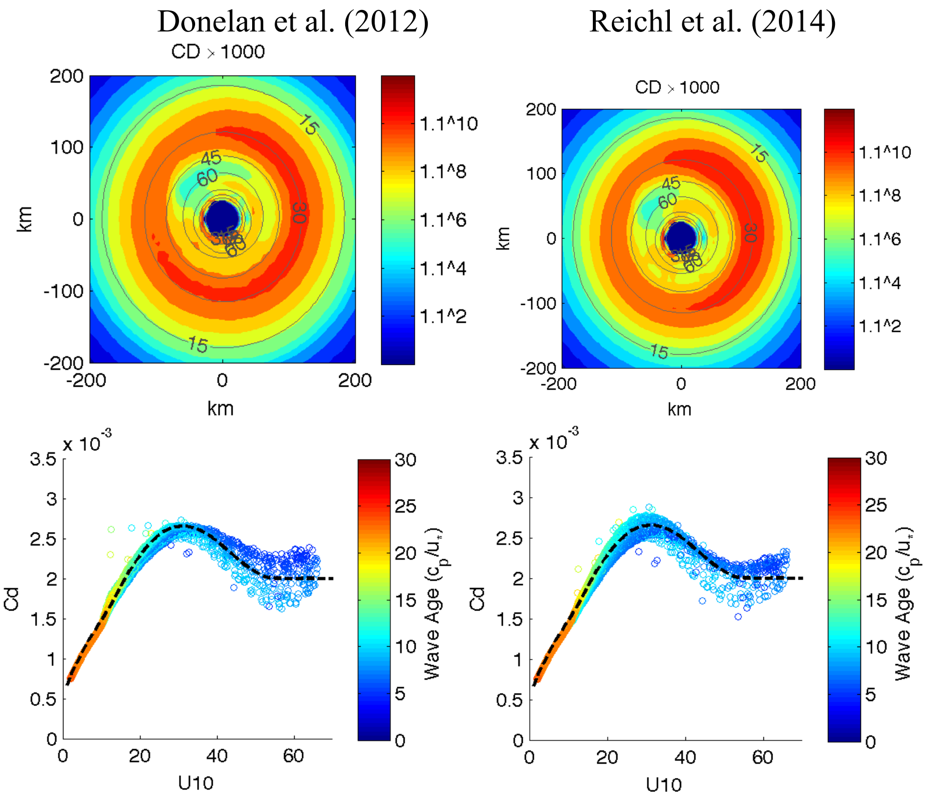

Figure 5*. 10-meter neutral drag coefficient for an idealized tropical cyclone with a radius of maximum wind of 50 km and a maximum wind speed of 65 m/s. The top panel shows spatial distributions. The tropical cyclone is moving from right to left at 5 m/s. The bottom panels show sea state dependence of the drag coefficient at different wind speeds. Left panels: Donelan et al. (2012) drag coefficient; Right panels: Reichl et al. (2014) drag coefficient.*

We have begun careful evaluation of the new GFDL system for real hurricane simulations. Figure 6 shows the track and intensity prediction of Hurricane Irene (Initial time: Aug. 22, 2011 12Z). With the wave coupling, both the track and intensity forecasts are noticeably improved. Figure 7 shows the simulated significant wave height at 72 hr. It is interesting to note the differences in the spatial distribution and magnitude of the cold wake in the simulations with (left) and without (right) wave coupling (Fig. 8). We are in the process of running a large set of retrospective cases with the new GFDL coupled system, and we plan to provide the results in the next progress report.

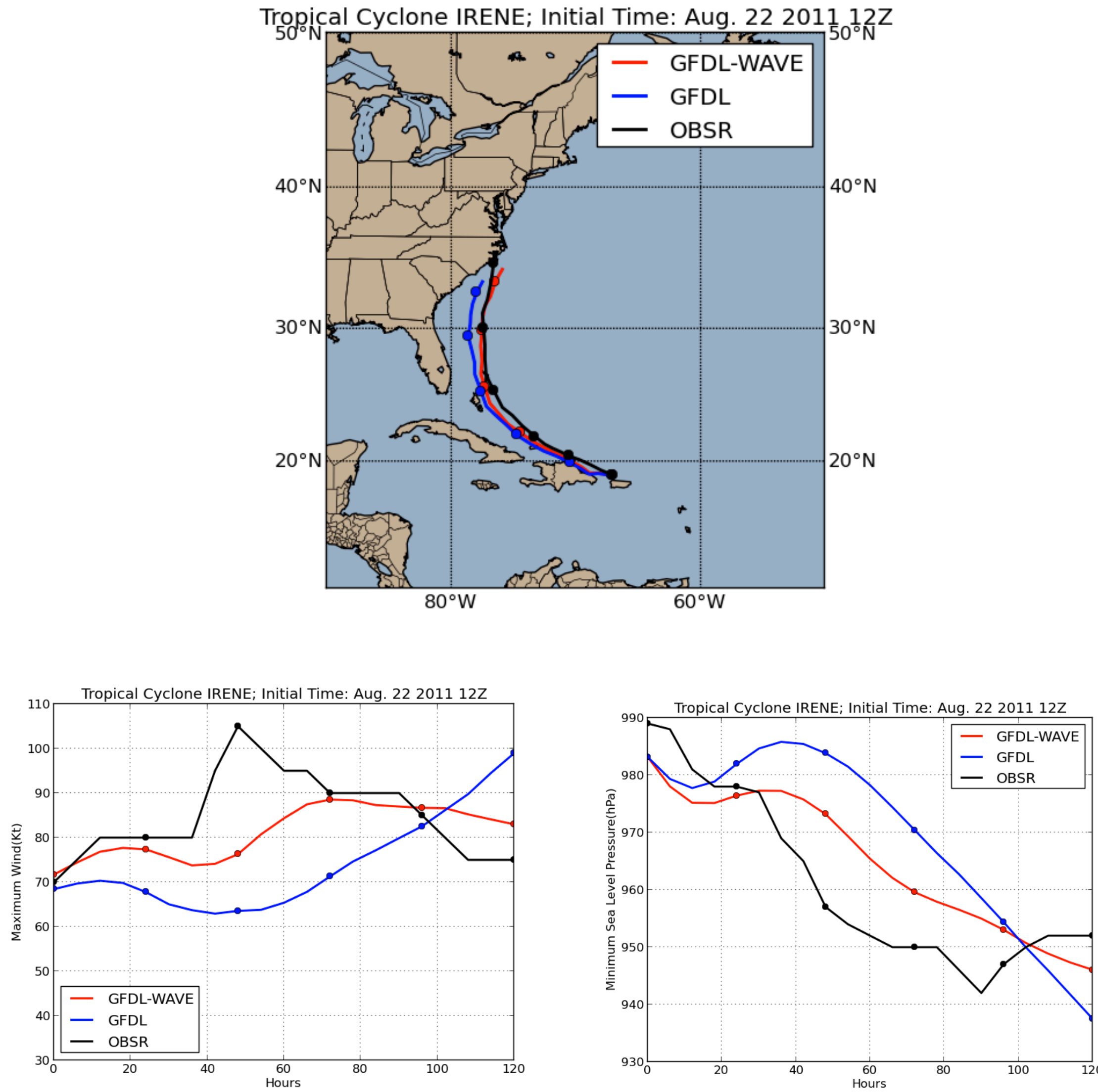

Figure 6*. Track and intensity prediction of Hurricane Irene (Initial time: Aug 22, 2011 12Z) with the new GFDL hurricane-wave-ocean system in comparison to the operational GFDL hurricane-ocean system and observations.*

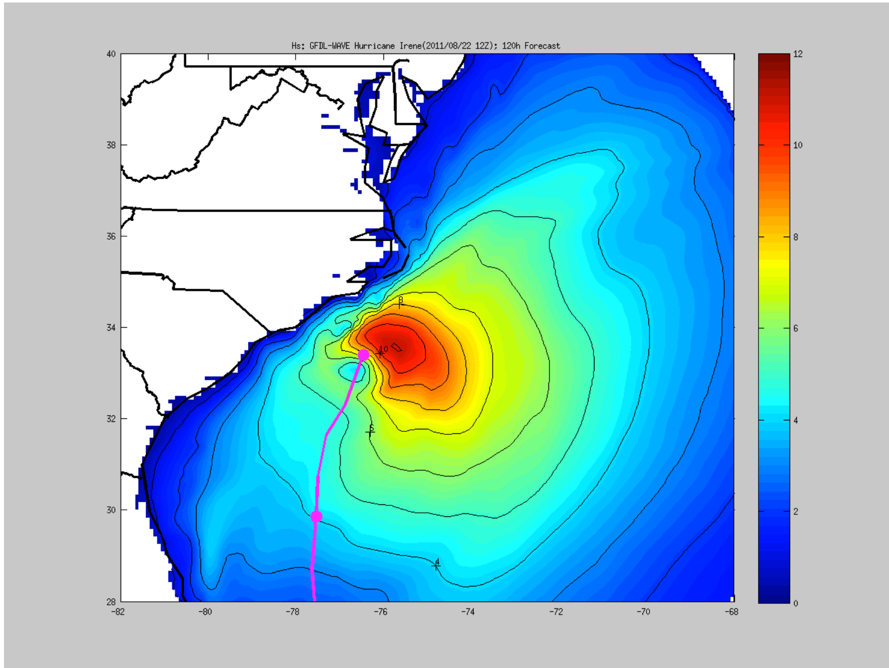

Figure 7. *Significant wave height at 72 hr of the Hurricane Irene (Initial time: Aug. 22, 2011 12Z) simulation with the new GFDL hurricane-wave-ocean system.*

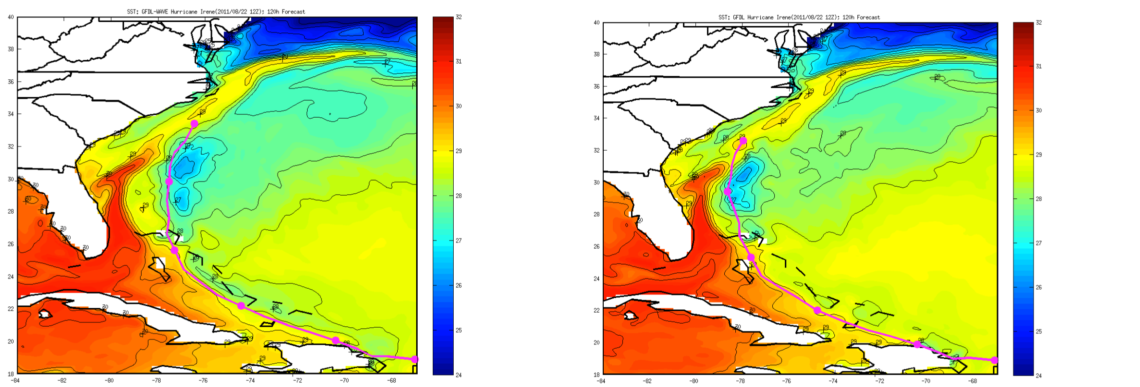

Figure 8. *Comparison of SST (°C) at 72 hr of the Hurricane Irene (Initial time: Aug. 22, 2011 12Z) simulation with the new GFDL hurricane-wave-ocean system (left) and the GFDL hurricane-ocean system without wave coupling (right).*

<u>References:</u>

Donelan, M. A., M. Curcic, S. S. Chen, and A. K. Magnusson, 2012: Modeling waves and wind stress. *J. Geophys. Res.,* **117,** C00J23.

Reichl, B. G., T. Hara, and I. Ginis, 2014: Sea state dependence of the wind stress over the ocean under hurricane winds. *J. Geophys. Res. Oceans,* **119,** 30-51.