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PIs/PDs: Isaac Ginis and Morris Bender
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Work Accomplishments:

1. Tasks scheduled for Year 2

a) Implementation of ASIM into GFDL/GFDN
b) Implementation of sea-spray parameterization into GFDL/GFDN
c) Testing the new GFS shallow convection, GFS Boundary Layer parameterization and ASIM in GFDL/GFDN and transition to operations in 2012.
d) Testing, evaluation and operational implementation of ASIM into HWRF

2. Tasks accomplished this period

The forecast operations of both NOAA's National Hurricane Center and Navy's Joint Typhoon Warning Center require more accurate HWRF and GFDL/GFDN models as integral parts of the multi-model ensemble forecast efforts. When the operational GFDL model was formally unfrozen by NCEP at the end of the 2010 hurricane season, it became an excellent opportunity to make major upgrades to the model, which has been frozen since 2006. We, therefore, made significant efforts during the first six months of Year 2 to accelerate the development, implementation, and testing of major upgrades to the GFDL/GFDN system for operational implementation in preparation for the 2011 hurricane season. We also made an upgrade to the ocean model component of the GFDL/GFDN and HWRF forecast systems for 2011 operational implementation. Accordingly, our work plan for Year 2 was modified, as we added additional tasks to achieve these goals. Particularly, the following additional tasks were accomplished:

a) Upgrading the Simplified Arakawa-Shubert (SAS) cumulus parameterization scheme in GFDL/GFDN
b) Modifying formulations of the air-sea exchange coefficients in GFDL/GFDN
c) Expanding the Eastern Atlantic ocean model domain in GFDL/GFDN and HWRF
d) Numerous bug fixes

Here we briefly summarize the main results.

a) Upgrading the Simplified Arakawa-Shubert (SAS) cumulus parameterization scheme in GFDL/GFDN

In 2003, the original cumulus parameterization in the GFDL/GFDN models was replaced with the simplified Arakawa-Shubert (SAS) cumulus parameterization scheme that was operational in the Global Forecast System (GFS) at that time (Bender et al, 2007). Since 2003, the SAS parameterization has been improved in the GFS, but none of these changes have been evaluated in the GFDL/GFDN models. In June 2010, a new physics package was made operational in the GFS. This package contained improved deep convection and planetary boundary layer (PBL) schemes. Also, a new shallow convection (SC) scheme that employs a mass flux parameterization replaced the turbulent diffusion based approach in the previous GFS scheme (currently, neither the GFDL/GFDN nor HWRF model use any shallow convection scheme). As part of this model upgrade, we have implemented and carefully evaluated the new GFS deep convection scheme into GFDL/GFDN. The new deep convection package was tested on a large number of historic storms in the Atlantic and East Pacific basins along with modified surface exchange coefficients, modified dissipative heating, and several model bug fixes. Large improvement was found in the track forecast skill, particularly at longer lead times. A summary of the track forecast skill of the 2010 and 2011 GFDL models in the Atlantic is shown in Fig. 1.

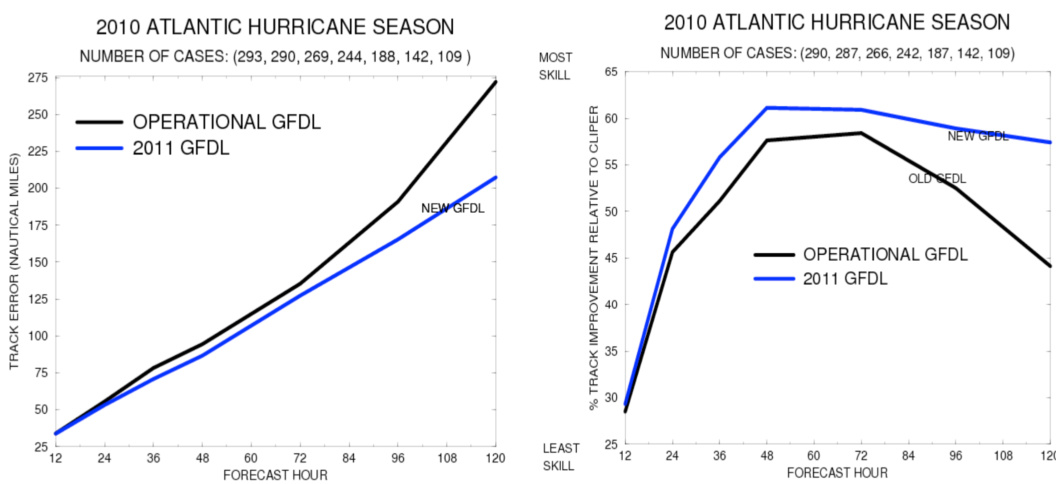

Figure 1. *Summary of the track GFDL forecast skill in Atlantic basin with in the new GFDL model in comparison to the 2010 operational system.*

Two examples of the improved track forecasts for Hurricane Julia (2010) are shown in Figure 2.

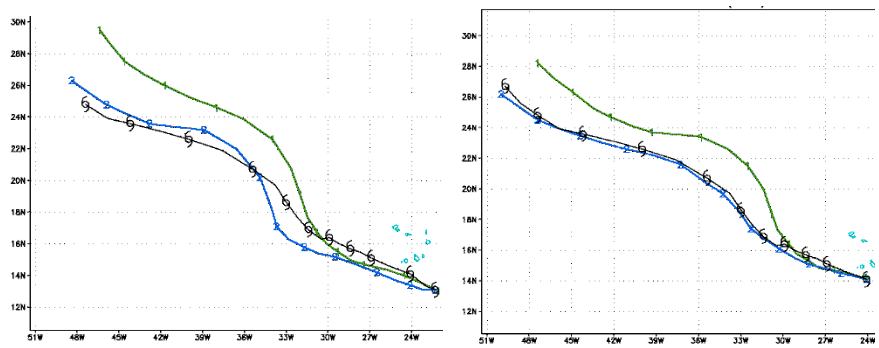

Figure 2. *Track forecasts for Hurricane Julia (initial times: 18Z, Sep. 12 (left) and 06 Sep. 13 (right) with the 2010 GFDL (blue) and the 2011 GFDL (green).*

The intensity forecast skill was slightly degraded at forecast days 4 and 5 primarily due to over prediction of Hurricane Thomas (2010). We are currently in the process of testing these upgrades in the GFDN system in other ocean basins for possible operational implementation in 2011.
The other two GFS physics packages, the shallow convection and PBL schemes, will be implemented into GFDL/GFDN in the near future.

b) Expanding the Eastern Atlantic ocean domain in GFDL/GFDN and HWRF

In the operational GFDL, GFDN, and HWRF coupled systems, the Atlantic basin is divided into two overlapping but separate integration domains for computational efficiency (Figure 3): the western Atlantic, known as the United domain (Domain 1), and the eastern Atlantic (Domain 2) (Bender et al., 2007). One domain is chosen automatically at the beginning of each forecast, depending on the initial position and predicted track from the previous forecast. The use of separate domains results in an occasional loss of ocean coupling when a hurricane moves outside of the eastern domain during a forecast. To help rectify this problem, we expanded the eastern domain by relocating its western boundary (Domain 2) from 60^{o}W to 75^{o}W, as shown in Figure 3.

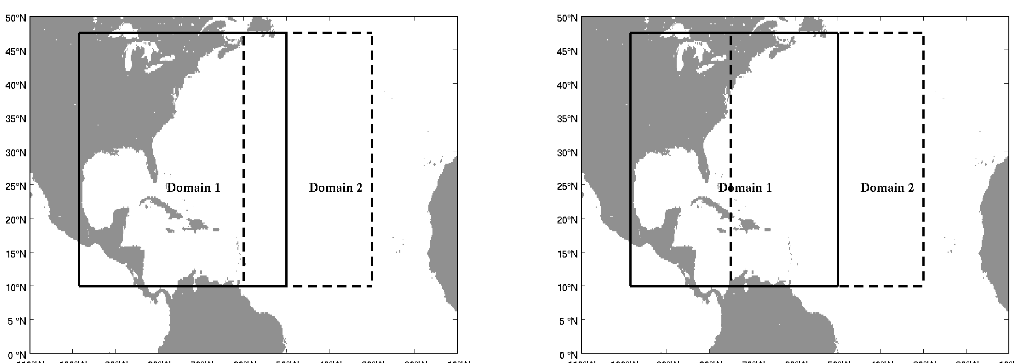

Figure 3. *The ocean model computational domains in the GFDL and HWRF coupled systems. Left: 2010 operational configuration. Right: new configuration.*

c) Implementation of ASIM into GFDL coupled hurricane-wave-ocean model

We have successfully coupled the GFDL hurricane model with the WWIII wave model and implemented URI's Air-Sea Interface Module (ASIM) (Fan et al. 2009, 2010) with ESRL sea spray parameterization (Fairall et al, 2009). The air-sea coupler has been redesigned to handle wind-wave-current interaction processes. We developed the following new coupled modeling strategies: 1) in the hurricane model, the parameterizations of the air-sea heat and momentum fluxes and the spray source functions explicitly include the sea state dependence and ocean currents; 2) the wave model is forced by the sea-state dependent momentum flux and includes ocean current effects; and 3) the ocean model is forced by a sea-state dependent momentum flux that accounts for the air-sea flux budget. A series of idealized and real-case studies have been performed to evaluate the effect of wind-wave-current interaction and sea spray effects on the GFDL model forecast skill.

We worked with Jian-Wen Bao and Chris Fairall at ESRL to fully incorporate sea spray effects and to modify the atmospheric fluxes to work with the new spray-induced fluxes. Our simulations with the GFDL hurricane-wave-ocean system with sea spray effects show significant impact of sea spray on the momentum and heat fluxes. An example of the drag coefficient with and without sea spray effect is shown in Figure 4.

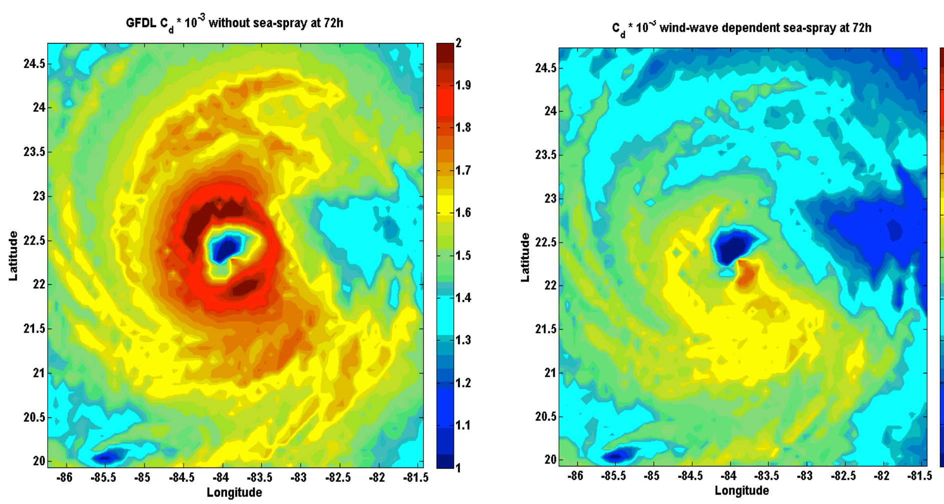

Figure 4. *Drag coefficient at 35-m height in the GFDL hurricane-wave-ocean coupled system without (left) and with (right) sea spray effects.*

One of the novel features implemented in ASIM is the method of coupling between breaking waves and the sea spray generation model. Without wave coupling, the source function is parameterized in terms of energy lost to the wave breaking process, which is simply related to the wind speed. The effective droplet source height is related to the significant wave height. Within the framework of ASIM, the total energy lost to breaking is accurately estimated by explicitly accounting for the sea state dependence and the air-sea flux budget (Fan et al. 2010). The source height is determined not from the significant wave height but from the input wave age (wave age of the wind-forced part of the spectrum) and the wind stress. This modification is important under hurricanes because the dominant scale of breaking waves is related to the scale of the actively wind-forced waves – not related to the scale of swell generated elsewhere. An example of the effect of wave coupling on the sea spray mass flux is shown in Figure 5.

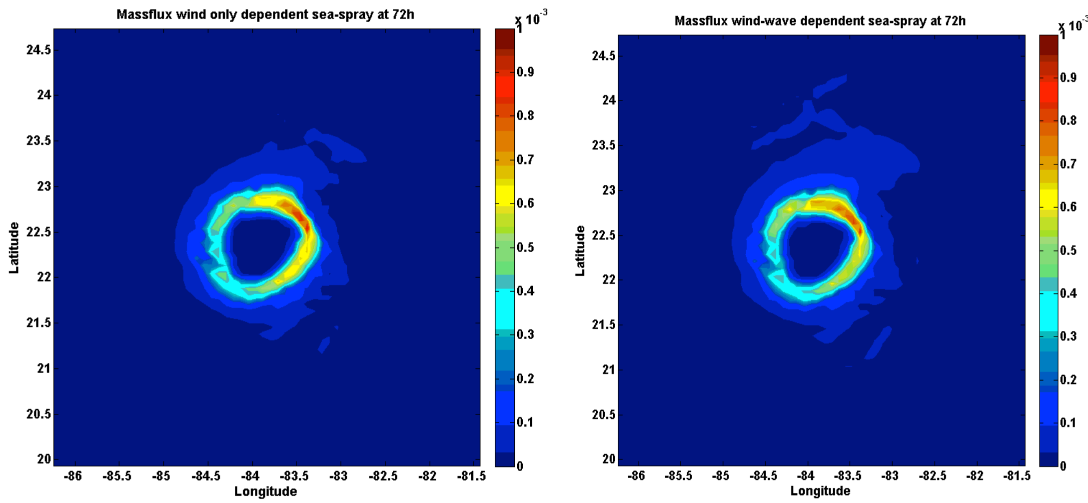

Figure 5. *Sea spray mass flux (kg m^{-2} s^{-1}) simulated in the GFDL coupled system in two sensitivity experiments: wind-only dependent sea spray source function (left) and sea-state dependent sea spray source function (right).*

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