Enclosed is the Year One Final JHT Report for:

A PROPOSAL FOR TRANSITION OF RESEARCH TO OPERATIONS: Upgrades to the GFDL Hurricane Prediction System for 2006

WITH A REVISED PLAN FOR YEAR 2

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Major upgrades to the GFDL Hurricane Prediction System were developed and tested during the past year through JHT funding. These changes were the primary component of the first year of the JHT project which focused on improvements to the physics in the current operational GFDL model. The physics upgrades were made in close collaboration with scientists at NCEP (National Centers for Environmental Prediction) and URI (University of Rhode Island) and will be fully transitioned into the Hurricane WRF (HWRF) model that is scheduled to replace the GFDL system in 2007. Consistent with our original time line, during the first 3 months of 2006 the new model with these physics upgrades has been rigorously tested for a sample of 11 storms (148 forecasts) during the 2004 and 2005 Atlantic hurricane season. A summary of these changes is presented in the next section. Since it is anticipated that the new upgrades will improve the model's ability to more accurately predict the behavior of tropical cyclones in sheared environments, the test cases selected ranged across the entire spectrum of storm intensity from highly sheared storms such as Lisa (2004) and Philippe (2005) to more intense storms such as Ivan (2004), Dennis, Katrina, Rita, and Wilma (2005). So far these tests have been very positive with a significant reduction of error both in the track and intensity. It is anticipated that this upgraded model will become operational in time for the start of the 2006 hurricane season.

Although there has not been a computer upgrade at NCEP this year it was possible to implement these changes operationally due to an additional effort made over the past several months to significantly improve the efficiency of the model's wall clock time. This enabled the upgraded forecast system to fit into the 70 minute time slot, which was a requirement if it is to be approved for operational implementation.

SUMMARY OF THE NEW MODEL UPGRADES

As outlined in the original JHT proposal, the major physics package that was evaluated this past year in the GFDL system was a version of the Ferrier micro-physics package that will become operational in HWRF. This was accomplished along with evaluation of an improved parameterization of the momentum fluxes that was developed in collaboration with scientists at URI. In particular the surface roughness (zo) was modified at higher wind conditions based on output of the Wave Watch III wave prediction model at NCEP. Several changes to the heat and

enthalpy fluxes were also made to give a more realistic intensification for developing storms when the model was run with the Ferrier micro-physics scheme. Another physics upgrade added in this new package, was the addition of the dissipative heating term in the vertical diffusion tendency equation. Improvements to the ocean initialization were made by scientists at NCEP and URI. One of these changes to the ocean initialization will enable a more realistic specification of the loop current based on the observed position and structure. Tests indicated that in storms like Katrina and Rita this change could make at least a one category difference in the storm intensity for storms passing over the loop current in the Gulf of Mexico.

One final change that is being evaluated separately for possible implementation in 2006 is to fully couple the GFDL hurricane model to the Wave Watch III model rather then specify the surface roughness only as a function of the wind speed. By computation of the surface wave spectra the wave model is able to give a more realistic distribution of the surface roughness which in reality is highly asymmetric with respect to the storm center. However it is unclear whether this change will be made operational this season as it has been shown to significantly impact the tracks in many cases, with some track degradation in Hurricanes Dennis and Lisa compared to the results without full wave coupling.

Nevertheless, both versions of the model (with and without the coupling to the Wave Wave III) have shown significant improvements both in track (*Figure 1*) and storm intensity (*Figure 2*) with about a 10% increase in track forecast skill at 2, 3 and 4 days. Most of the storms exhibited reduction in track error at 48 and 72h, with the exception of Hurricane Wilma (*Figure 3*).

Also, significantly improved intensity prediction of sheared storms such as Lisa and Philippe were found (*Figure 4*) with the new model physics. Overall, most of the intensity forecasts were improved with the exception of Hurricanes Dennis and Emily, in which the new GFDL model greatly underestimated the storm intensity. It is unclear why this happened for these early season storms, although the SST analysis used is being evaluated as a possible contributing cause.

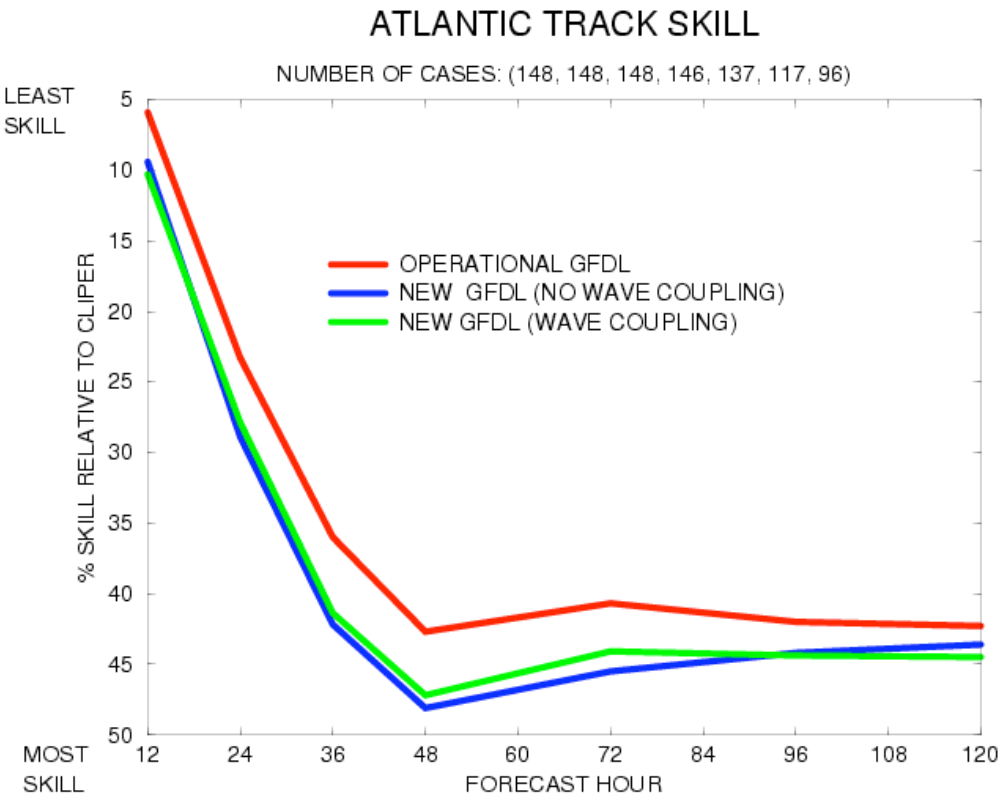

Fig. 1 Average forecast track error normalized relative to CLIPER (Climatology-Persistence) for selected track forecasts from the 2004 and 2005 Atlantic hurricane seasons, for the 2005 operational GFDL model (red line) and the new model with upgraded physics both with (green) and without (blue) coupling to Wave Watch III.

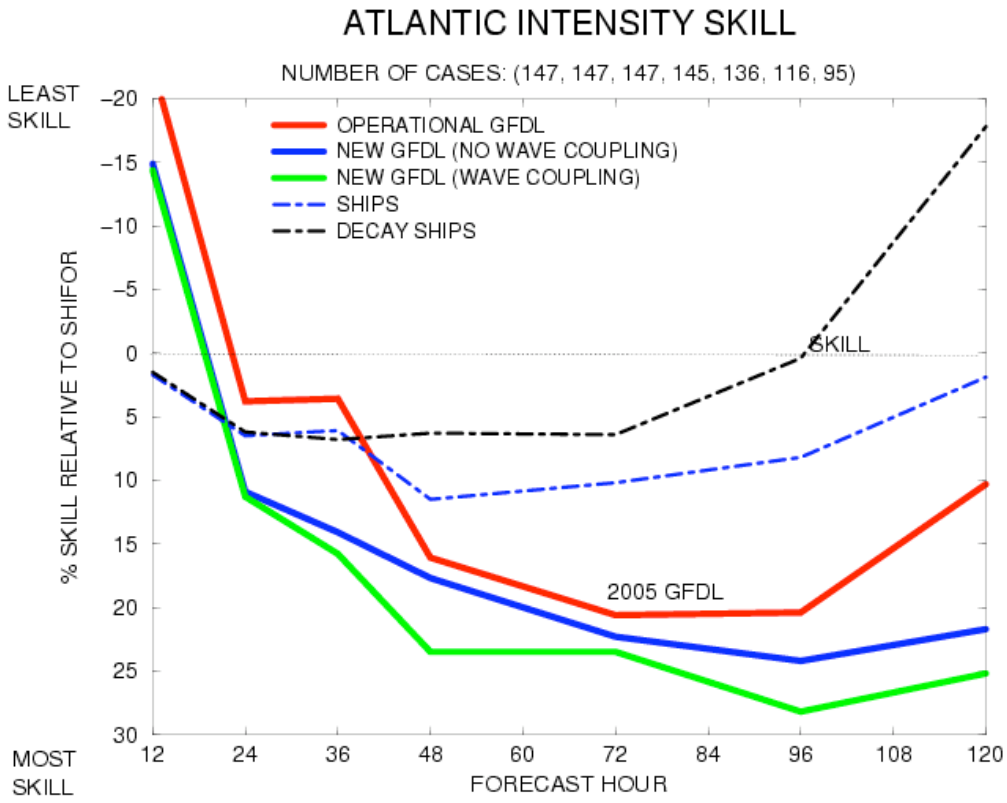

Fig. 2 Average forecast intensity error normalized relative to SHIFOR for selected intensity forecasts from the 2004 and 2005 Atlantic hurricane season, for the 2005 operational GFDL model (red line) and the new model with upgraded physics both with (green) and without (blue) coupling to Wave Watch III. Also plotted is the statistical intensity model (SHIPS) as well as the SHIPS version run with the effect of land (Decay Ships).

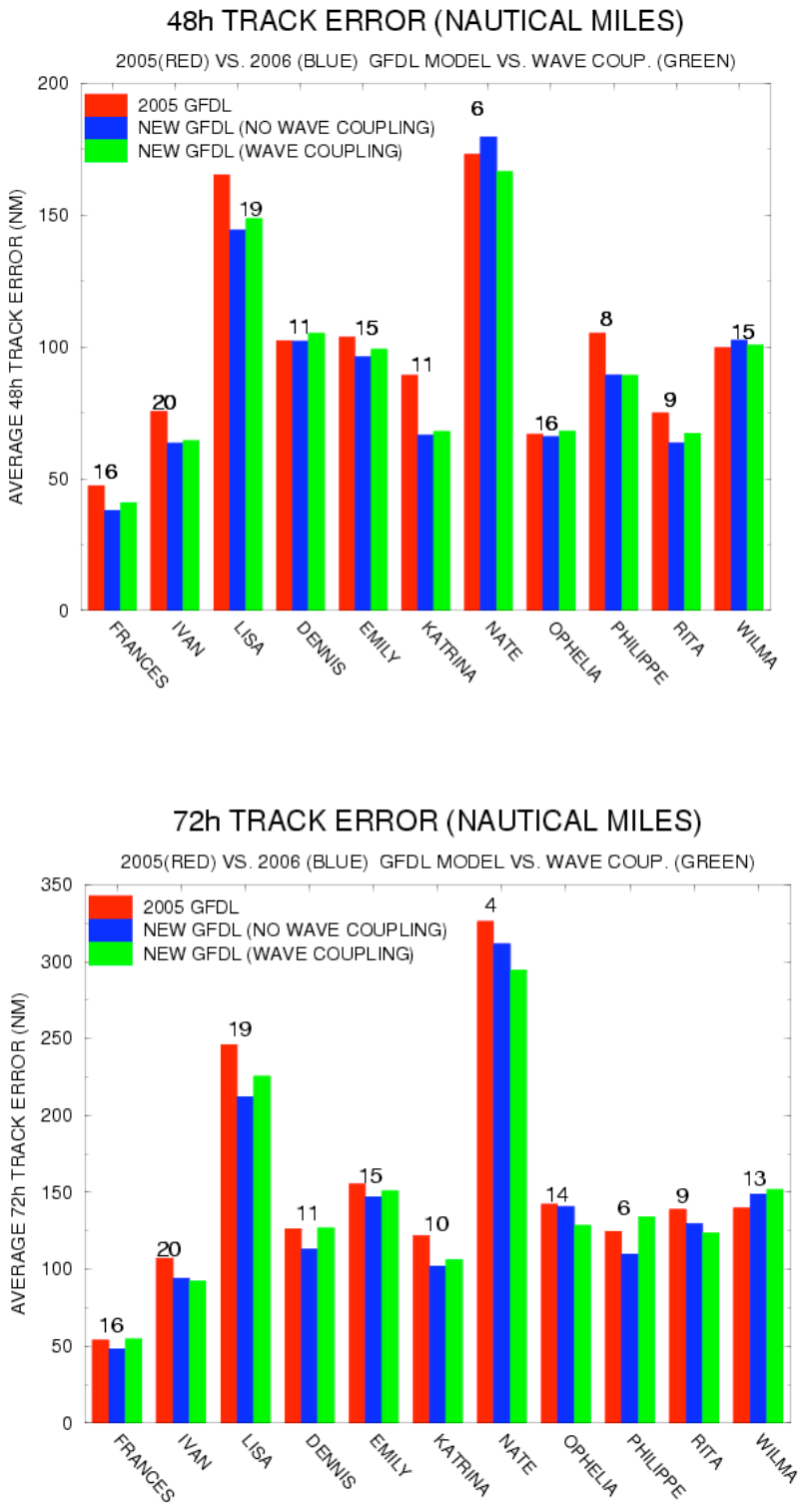

Fig. 3 Distribution of 48h (top) and 72h (bottom) forecast track error for the 11 storms tested using the operational GFDL model (red), the new GFDL model both without (blue) and with (green) coupling to Wave Watch III.

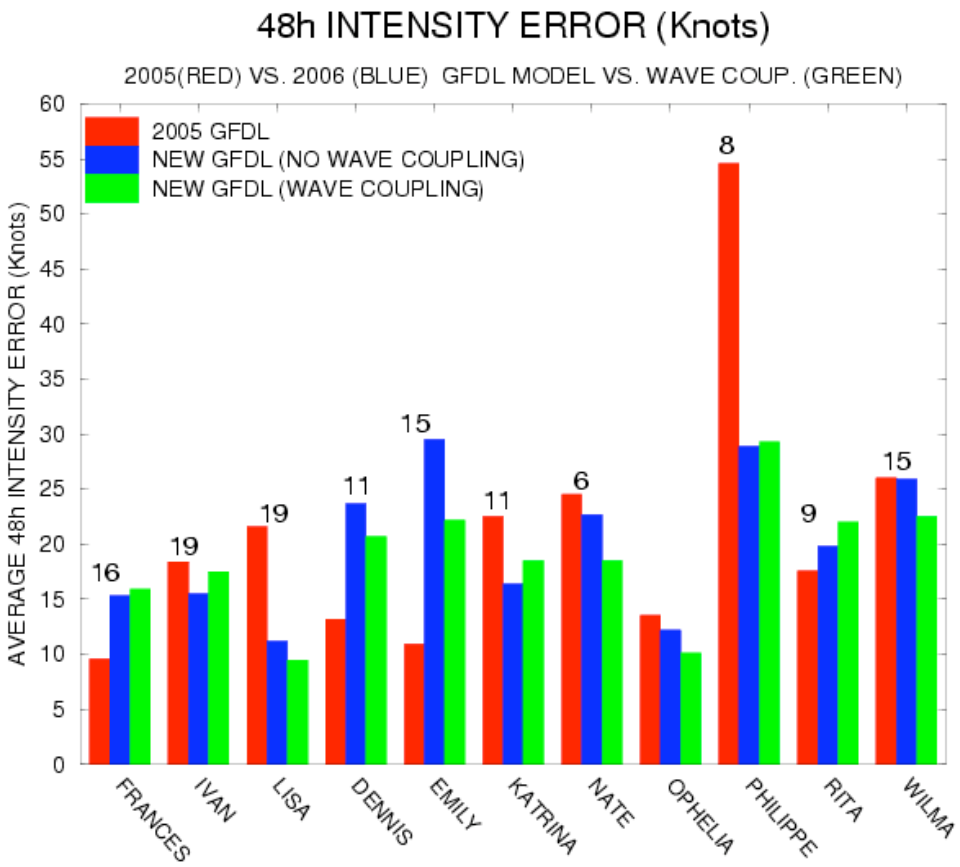

Fig. 4 Distribution of 48h forecast intensity error (knots) for the 11 storms tested using the operational GFDL model (red), the new GFDL model both without (blue) and with (green) coupling to Wave Watch III.

REVISED WORK PLAN FOR YEAR 2

During the first part of the second year of JHT funding, GFDL scientists will work closely with personnel at NCEP to transfer the new model and forecast system to operations. Transfer of the final version of the upgraded modeling system should be made by the third week of April, to enable the entire system to be operational by June 1 or sooner. Once the system is operational it will continue to be evaluated closely as the new hurricane season begins. Currently plans call for the GFDL model to become frozen after this last implementation is made and the transition toward hurricane WRF is accelerated.

In the original proposal, the work plan of this JHT project called for GFDL scientists to begin extensive testing of the final version of the 2006 GFDL model on storms from previous hurricane seasons during the summer of 2006. However, preliminary comparisons of the present

version of the HWRF model that is still under development and the GFDL model have shown large differences in the tracks of many storms during the 2005 hurricane season. This was also true when comparisons were made with the upgraded GFDL model, which should have the same treatment of the moist physics processes (e.g., Ferrier micro-physics and Simplified Arakawa-Schubert convective parameterization), and nearly identical planetary boundary layer physics. In consultation with EMC personnel, this has necessitated a revision of the current work plan, to help determine some of the reason for these differences.

In the revised work plan, GFDL scientists will import the three above-mentioned physics modules in Hurricane WRF into the GFDL model. Careful comparisons will be made of the differences in track and intensity using each of the three packages in the GFDL system, analyzing terms such as the diabatic heating and model tendencies. If significant differences are found using the HWRF packages, reasons for these differences will be isolated to enable the physics packages in the two models to become consistent. It is anticipated that this process will take 2-4 months to complete, although a shorter or longer amount of time is possible. Once it is determined that the moist physics and boundary layer packages in the two models are essentially the same, extensive testing of the final version of the GFDL model will commence on additional storms during pervious hurricane seasons. These runs are essential to determine that the new HWRF model can perform comparably to the GFDL model in both the Atlantic and East Pacific for track and intensity.

Finally, consultation with Navy personnel at FLEET will continue to enable the high-resolution version of the GFDL code to be implemented operationally in the Navy's version of the GFDL model (GFDN). This code was transferred to the Navy at the end of 2005 and testing in now beginning on selected cases. Before the final version is made operational, additional testing of some of the new physics upgrades that are being made operational in NCEP's version of the GFDL model will possibly also be evaluated in GFDN. It is anticipated that the upgraded version of the GFDN model will also become operational by June, 2006.

WORK PLAN FOR YEAR 2

Summary of Revised Time line as outlined in the Statement of Work

January 1st, 2006 through March 31st, 2006

1.) Complete extensive testing of upgraded GFDL system on selected cases from the 2005 and 2006 hurricane seasons.

2.) Report results at IHC meeting.

April 1st , 2006 through June 1st, 2006

1.) Finalize upgraded GFDL model and transfer system to NCEP/NCO for operational testing.

2.) Implement new GFDL model at NCEP before start of the 2006 hurricane season.

3.) Help FLEET personnel in the operational implementation of the high-resolution GFDL in the Navy's version of the GFDL model (GFDN). This includes possible transfer of some of the new physics upgrades being made operational in GFDL to the GFDN model.

June 1st through September 30th, 2006

1.) Import HWRF physics packages into the GFDL model and compare with forecasts made with the GFDL physics modules.
2.) Isolate differences between the various physics modules and help rectify these differences in new Hurricane WRF modules.
3.) Begin extensive reruns of the final GFDL benchmark model on other storms from the 2004 and 2005 hurricane seasons in both the East Pacific and Atlantic.

October 1st, through January 31st, 2007

1.) Continue reruns of final GFDL benchmark model on storms from previous hurricane seasons.
2.) Help in the evaluation of the track and intensity forecasts of the GFDL and HWRF models as well as evaluation of differences in the storm structure and precipitation.
3.) Aid FLEET personnel in further upgrades to the GFDN model.

March, 2007

1.) Report results at IHC meeting.

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