The Transition of Research into the NCEP Operational HWRF System: Guidance for the Joint Hurricane Testbed Announcement of Opportunity

1. EMC Mission

The National Centers for Environmental Prediction, Environmental Modeling Center (NCEP/EMC) is responsible for developing significant improvements into NCEP's operational forecast systems to increase both the scope and quality of NCEP's products. Ranging from seasonal to interannual prediction and climate reanalysis to hourly rapid updates, NCEP/EMC has advanced the quality of its products and is ready to make further improvements through model enhancements and new computing resources. The NCEP production suite contains global and regional atmospheric prediction systems, real-time ocean and waves, hurricanes, air quality and hydrological systems. Modernization of the NCEP production suite is underway with construction of the NOAA Environmental Modeling System (NEMS) that is a software framework compatible with the community-based Earth System Modeling Framework (ESMF). The NEMS will be implemented in a phased approach beginning with the North American Model (NAM) in FY11.

2. The Hurricane Weather Research and Forecast (HWRF) System

The NCEP Hurricane WRF is based on the NMM dynamic core and has a movable, two-way nested grid capability for the 9km inner nest. The coarse domain has 27km horizontal resolution and covers a 75˚ x 75° region. The HWRF is configured with 42 vertical layers. Advanced physics include the GFDL surface physics to account for atmosphere/ocean fluxes, coupling with Princeton Ocean Model (POM), GFDL land surface model and radiation, Ferrier Microphysics and the NCEP GFS boundary layer and SAS deep convection. More information on the HWRF system can be found in the HWRF Scientific Documentation edited by the Developmental Testbed Center (DTC) and at the EMC HWRF web page.

3. The Operational HWRF Upgrade Process

3.1 The NCEP Production Suite

The NCEP production suite (NPS) is composed of numerical model systems spanning spatial and time scales of the Rapid Update Cycle (RUC) to Climate Forecast System (CFS). This includes all major components of the system including data acquisition and processing, data assimilation, the model cores and all associated post processing, GRIB grid generation and visualization. Overall, the NPS produces an estimated 14.8 million products per day.

3.2 Supercomputing to Support the Production Suite

The two high performance computing (HPC) systems within the Operational Central Computing System (OCCS) are identical in configuration but reside in two geographically diverse locations to ensure continuity of operations. Functionally, the OCCS consists of the NPS and the Transition-to-Operations (T2O) HPC systems. The NPS (or production HPC system) executes the operational production of the model runs from which the weather, climate and oceans forecasts are made. Currently the NPS produces and disseminates over 14.8 million operational model products each day to government agencies, commercial interests, and to the public. The T2O (or development machine) hosts work that supports model enhancements and next generation forecast models destined for NPS operations. The T2O serves as a critical link in the chain from research and development to operations.

The OCCS supports NPS and T2O functions with Primary and Backup HPC systems. Currently, the Primary system resides in the greater Washington, D.C., area, and the Backup system resides at the NASA IV&V facility, Fairmont, WV. During normal modes of operations, the NPS runs on the Primary system and the T2O runs on the Backup system. If the Primary system or site fails, T2O is suspended and NPS runs on the Backup system.

The operational and backup HPC systems are IBM Power6 p575's with the following attributes per system:

- 69.7 Teraflops Linpack
- 156 Power6 32-way Nodes
- 4,992 processors @ 4.7GHz
- 19,712 GB memory
- 320 TB of disk space per system

There is also a research and development HPC platform consisting of an IBM Power6 p575 that has roughly 1/3 of the capacity of the operational and backup systems described above. That machine supports development projects conducted by the NASA-NOAA-DoD Joint Center for satellite Data Assimilation, the Climate Testbed, and other collaborative projects hosted by NOAA.

3.3 Linkage between HWRF Upgrades with the Production Suite

The transition of research into the NCEP production suite is a complex process involving scientific enhancements, efficient coding requirements and rigorous testing standards. The operational environment requires NCEP management to make decisions between incremental improvements in skill and the level of additional cost and risk associated with the system improvements. New ideas and concepts must be rigorously tested in the operational system to ensure that the changes do not have unanticipated negative consequences in another part of the numerical model production suite. For example, when a change (i.e., model physics, resolution, additional data to be assimilated, etc.) is made to the Global Forecast System (GFS), the skill of the GFS is assessed over many hindcast months in addition to a real time parallel test. An additional complexity is associated with the interdependence of modeling systems in the NPS. For example, the GFS is used to provide initial and lower boundary conditions to the HWRF and GFDL hurricane regional models. Therefore, these systems must be tested with the new GFS system over a statistically significant sample. Even if the upgraded GFS testing shows a positive impact to global statistics, it is possible that the GFDL and HWRF systems could result in a degradation in tropical cyclone track and/or intensity forecast skill. Under such circumstances it is possible that the GFS implementation will not be made despite positive impacts found within that system. Outside organizations are naturally frustrated with what appears to be a slow, inefficient and risk adverse implementation process. However, operational implementation will always require rigorous testing of systems to mitigate the risk of degradation in service or system failures. Implementation rates are also dependent on computational and human resources. It is noted that NCEP is continuously examining ways to make the process more efficient and must do a better job of explaining the process to the research community to ensure realistic expectations are established.

3.3 The HWRF Development Cycle

Upgrades to the HWRF system are performed on an annual cycle that is dependent on the hurricane season and upgrades to the Global Data Assimilation System (GDAS) and GFS. There are basically 2 phases of development. The first is developmental testing that occurs prior to and during the hurricane season (roughly 1 April to 30 October) where potential upgrades to the system are tested individually but in a systematic and coordinated manor. The pre-implementation testing starts in November and is designed to test the most promising developments assessed in the development phase to define the HWRF configuration for the upcoming hurricane season. The results of the pre-implementation testing must be completed and the final HWRF configuration locked down by 15 March. Once frozen, the system is handed off to NCEP Central Operations for implementation by 1 June. The cycle is then repeated for the next set of proposed upgrades to the HWRF system. During the hurricane season (1 June to 30 November) changes are not made to the operational HWRF in order to provide forecasters with consistent and documented numerical guidance performance characteristics

3.4 HWRF Development Priorities

EMC, in partnership with TPC, is responsible for developing a plan for potential model upgrades. Priorities are obtained from the operational HWRF performance documented during the previous hurricane seasons and results obtained during the pre-implementation testing for the current hurricane season. The development priorities are then communicated to the community through the EMC HWRF Web page, the Joint Hurricane Testbed (JHT) and the DTC for inclusion into their Announcements of Opportunities. The HWRF development priorities are also provided to the community through the Hurricane Forecast Improvement Project (HFIP)

3.5 HWRF Pre-Implementation Testing for FY10

The HWRF system has been running operationally at NCEP since the 2007 hurricane season. Performance of HWRF in 2008 and 2009 resulted in an over intensification of tropical systems in both the Eastern Pacific and the Atlantic basins. Based on the 2008 and 2009 performance, one of the 2010 HWRF development priorities was to reduce the intensity bias through modification of the initialization procedure and specification of the surface heat and momentum fluxes.

Starting in August 2009, NCEP started pre-implementation testing of the HWRF system to determine the final configuration for the 2010 hurricane season. The following HWRF upgrades have been systematically tested and evaluated by EMC and TPC starting in the fall of 2009 to support the December 2009 GDAS upgrade and the proposed GFS upgrade scheduled for implementation 27 July 2010:

- ***Upgrade to surface exchange coefficients (closer to observations from CBLAST field experiment and dropsonde data)***
- ***Modifications to the vortex initialization procedure through use of conventional and satellite based observations in the inner nest (9 km domain)***
- ***Inclusion of Gravity Wave Drag parameterization and***
- ***Coupling with HyCOM ocean model in the Atlantic basin***

The HWRF FY10 pre-implementation test plan consisted of a series of systematic experiments for each of the individual configurations, requiring more than 600 runs of 2008-2009 Atlantic and East Pacific storms. The first step in defining the FY10 operational configuration was to define a new benchmark for the HWRF. The FY10 benchmark is identical to the operational HWRF used in 2008 and 2009 in every way except that there were several corrections made to rectify code errors in the treatment of downward shortwave radiation. Each of the proposed FY2010 upgrades listed above were tested in (and compared to) the FY10 benchmark and evaluated independently to ensure the upgrades had the expected impact on track and intensity forecasts. Then the individual upgrades were tested in combination using the operational 2008 GFS configuration, the December 2009 GDAS upgrade, and the planned July 2010 GDAS/GFS resolution increase and physics upgrade.

Results from the pre-implementation testing are presented in Figures 1 and 2 for the Atlantic and East Pacific Basins, respectively. In the Atlantic Basin the combination of all the upgrades listed above results in a reduction in track error compared to the baseline throughout the 5-day forecast period. Analysis of the track error shows that Hurricane Bill (2009) was not simulated well by the GFS May 2010 upgrade due to a persistent along track error. Removal of Bill from the sample results in additional reduction of track error compared to the FY10 baseline (not shown). Analysis of the track error shows that the proposed upgrades to both the HWRF and GFS had the highest percentage of superior track forecasts, the lowest average intensity error, and a significant reduction in the intensity bias for 72 hours and beyond. It is noted that the intensity bias is now negative from 12 to 48 hours. However, NCEP/EMC considers this to be a reasonable result for the 9 km horizontal resolution. It was found that the new enthalpy exchange coefficient obtained from the observational study of CBLAST, and the new drag coefficient obtained from the observational study of Powell et al (2003) had the largest positive impact on the reduction of intensity errors. However, results from the coupled HWRF-HYCOM system for the Atlantic basin indicated degradation of intensity forecast skill, with much higher negative bias at all forecast hours. The negative impact of HYCOM coupling on intensity forecasts compared to HWRF-POM coupled system resulted in withdrawing HYCOM from the proposed FY2010 upgrades. HWRF and HYCOM groups at EMC are currently working on addressing this problem, and EMC will run a real-time parallel HWRF-HYCOM system for the 2010 Atlantic hurricane season.

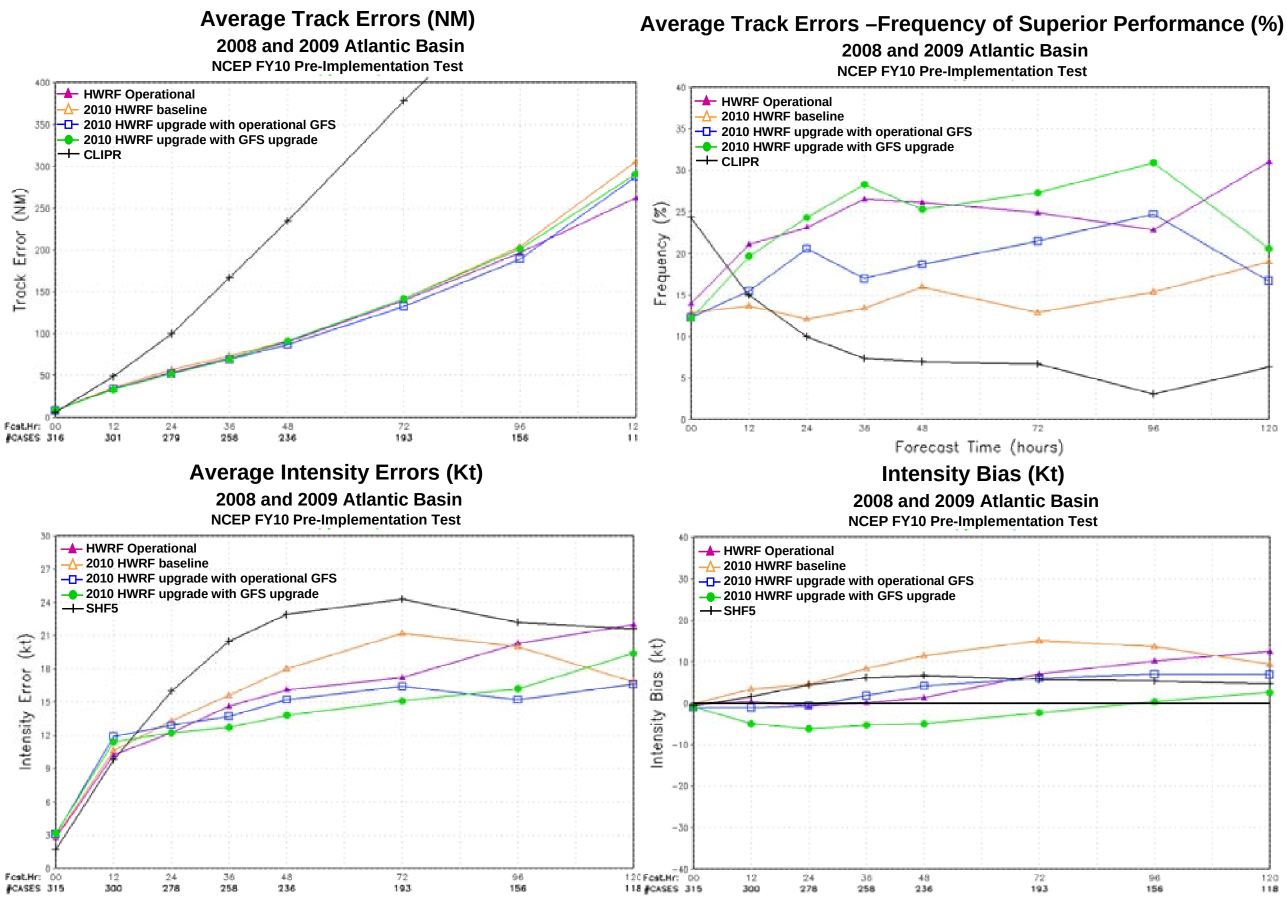

Figure 1: HWRF FY2010 pre-implementation test results for 2008-2009 Atlantic Basin. The 2010 baseline HWRF is identical to the operational HWRF and includes code corrections to radiation calculations. The 2010 HWRF upgrade configuration builds off the 2010 HWRF baseline and includes assimilation of satellite data on the 9km nest, gravity wave drag parameterization and updated surface flux exchange coefficients.

In the East Pacific Basin the planned HWRF and GFS upgraded systems resulted in a significant (10% to 20%) reduction of track errors at all forecast times. The proposed upgrades to both the HWRF and GFS had the highest percentage of superior track forecasts, the lowest average intensity error, and a near-zero intensity bias for 72 hours and beyond. Evaluation of pre-implementation test results led to the implementation of the upgraded HWRF for the 2010 hurricane season, and it is currently being run in operations.

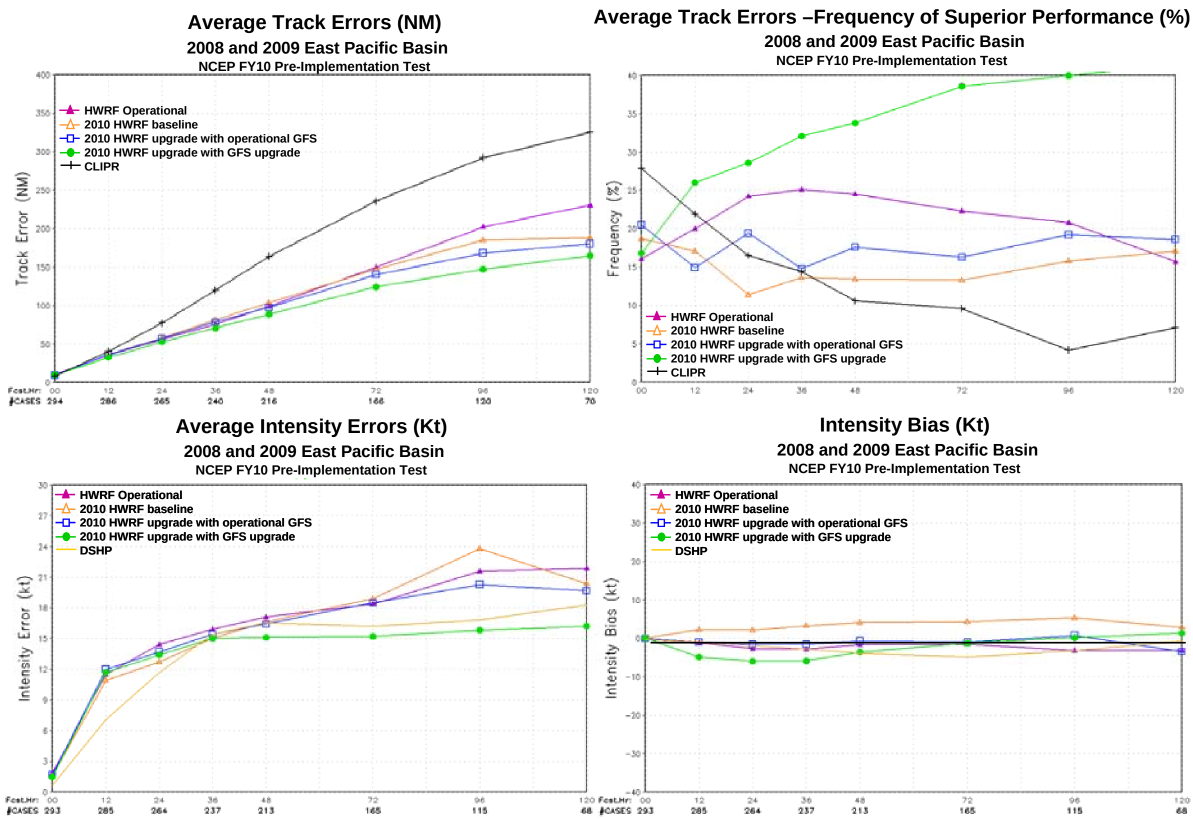

Figure 2: HWRF FY2010 pre-implementation test results for 2008-2009 East Pacific Basin. The 2010 baseline HWRF is identical to the operational HWRF and includes corrections to radiation calculations. The 2010 HWRF upgrade configuration builds off the 2010 HWRF baseline and includes assimilation of satellite data on the 9km nest, gravity wave drag parameterization and updated surface flux exchange coefficients.

3.6 Role of DTC in HWRF development and community support

EMC, in collaboration with the DTC, created the Community HWRF by merging the operational NCEP code based on WRF v2.0 onto the general WRF community code repository (currently v3.2) in order to create a single modeling system for research and operations. The DTC began supporting the community HWRF in April 2010, after a tutorial on WRF for hurricanes. The Community HWRF model is closely related to the operational HWRF, and DTC is providing code management, code downloads, datasets, documentation, tutorials, and a helpdesk. DTC also has setup repositories for the vortex initialization, ocean model, coupler, and vortex tracker. While the operational HWRF was designed to run on IBM mainframes, the Community HWRF has the added capability of running on Linux Systems with both the Portland Group and Intel compilers.

NCEP/EMC is planning to draw code from the community HWRF model to use in operations starting in 2011. Any new HWRF developments will become part of the community code, keeping the operational code synchronized with the community code in subsequent years. With this code management process, research and operations will be using the same code base, making it much more effective for new research and developments to be adopted in operations. DTC is also assembling a functionally equivalent operational environment to test and evaluate new HWRF developments over extended retrospective periods. JHT AO responders are encouraged to take advantage of this setup and support from DTC to have an accelerated and efficient R2O/O2R procedure.