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 is being implemented in a phased approach beginning with the North American Model (NAM) that became operational in October 2011.

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

The atmosphere-ocean coupled Hurricane Weather Research and Forecast (HWRF) modeling system is developed and supported by the Environmental Modeling Center (EMC) and runs in the National Centers for Environmental Prediction (NCEP) production suite on the NOAA Central Computer System. The HWRF model is based on WRF NMM dynamic core and consists of multiple movable two-way interactive nested grids that follow the projected path of the storm. To significantly improve hurricane forecast skill, the hurricane modeling team at NCEP/EMC implemented major changes to the 2012 version of HWRF. The biggest improvement is the triple-nest capability that includes a ***cloud-resolving innermost grid operating at 3 km horizontal resolution.*** HWRF employs a suite of advanced physics developed for tropical cyclone applications. These include the GFDL surface physics to account for air-sea interaction, coupling with Princeton Ocean Model (POM), GFDL land surface model and radiation, Ferrier Microphysics, NCEP GFS boundary layer, GFS SAS deep convection and GFS shallow 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. Operational HWRF modeling system and its development branches are available to the researchers in the community modeling framework maintained and supported by DTC, and can be accessed from the DTC HWRF repository as well as from the DTC website.

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 1.5 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 (CCS) are identical in configuration but reside in two geographically diverse locations to ensure continuity of operations. Functionally, the CCS 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, ocean and wave forecasts are made. Currently the NPS produces and disseminates over 1.5 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 CCS 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 current operational and backup HPC systems are IBM Power6 p575's with the following attributes per system:

- Identical Systems (per site)
  - IBM Power 6/P575/AIX
  - 73.9 trillion calculations/sec
  - 5,314 processing cores
  - 800 trillion bytes of storage

Starting in 2013, NCEP is upgrading the HPC to new Weather and Climate Operational Supercomputer System (WCOSS) with the primary facility set up in Reston, VA and the backup facility in Orlando, FL. Initial configuration for this machine will have approximately 3x operational capability with the following attributes:

- Identical Systems (per site)
  - IBM iDataPlex/Intel Sandy Bridge/Linux
  - 208 trillion calculations/sec
  - 10,048 processing cores

- 2,590 trillion bytes of storage

Recent enhancements to the computing in NOAA also provides unprecedented opportunity to conduct research and development on high-performance linux clusters shared by different agencies within NOAA, namely Jet (Boulder, CO), Zeus (Fairmont, WV) and GAEA (Oak Ridge, TN). Among these, Jet cluster is owned and specially designed by NOAA's Hurricane Forecast improvement project and allows researchers to test and experiment the next generation global and regional modeling efforts geared towards improving the hurricane forecast skill. Details of these machines are provided in the hyperlinks for each of these machines and also from EMC model transition team webpage.

3.3 Linkage between HWRF Upgrades and NCEP 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.

3.4 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 manner.

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

3.5 HWRF Development Priorities

EMC, in partnership with NHC, 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)

3.6 HWRF Pre-Implementation Testing for FY12

The HWRF system has been running operationally at NCEP since the 2007 hurricane season. Although the performance of the HWRF model in the 2011 hurricane season improved significantly compare to 2008 and 2009 seasons in terms of track and intensity forecast, there is still much room to improve both intensity and track prediction skills. Especially, it is known that the HWRF simulated hurricane vortex has tendency of producing larger size storm with forecast time. This tendency amplifies with time because of the cycling nature of the HWRF vortex initialization procedure, and it greatly contributed towards degradation of HWRF forecasts. Therefore, one of the main focus areas of FY12 HWRF development was to improve storm structure in the HWRF on top of improving track and intensity forecast skills, which was accomplished by implementing cloud-resolving higher resolution third nest (3km) and modifying physical parameterizations based on observational evidence and suitable for higher resolution.

In an unprecedented effort, HWRF team, with support from HFIP and several partners within NOAA as well as academia, started pre-implementation testing of the HWRF system as early as January 2011 and continued testing various upgrades to determine the final configuration for the 2012 hurricane season. The following HWRF upgrades have been systematically tested and evaluated by EMC and NHC:

- ***Implement the triply nested HWRF system with the resolution of 3km inner-most domain***
- ***Modification of air-sea enthalpy exchange coefficient fitting to the CBLAST observation data and modification to vertical diffusion coefficient in GFS PBL to reduce boundary layer depth***

- ***Tuning of several key parameters of the deep convection (SAS) and microphysics (Ferrier) schemes***
- ***Add the GFS shallow convection scheme which helped reducing the unrealistic light precipitation over the open ocean***
- ***Coupling 1D POM in the Eastern Pacific basin***
- ***Optimize the observation data (prepbufr) impact in GSI of the HWRF system and***
- ***Upgrade nest motion algorithm to accommodate the cloud-resolving high resolution inner-most domain***

The HWRF FY12 pre-implementation test plan consisted of a series of systematic experiments for each of the individual configurations, requiring more than 10000 runs of 2010-2011 Atlantic and East Pacific storms. Thanks to the support of HFIP management, the high performance computer facility (jet) was heavily used in FY12 pre-implementation test plan. The FY12 baseline is configured to have triply nested domain and slight modification of momentum diffusivity in PBL and each of the proposed upgrades listed above were tested and evaluated independently to ensure the upgrades had the expected impact on track, intensity and structure forecasts. The combined upgrades (FY12 proposed HWRF system) were tested using the planned July 2012 GFS Hybrid DA upgrades.

Results from the proposed FY12 HWRF system are presented in Figures 1 and 2 for both Atlantic and Eastern Pacific basins. In addition to track and intensity errors, a new verification metric is added in order to address the aforementioned storm size issue. In terms of intensity and track errors, the FY12 proposed HWRF system showed significantly improved forecast skills. The forecasted tracks of the FY12 proposed HWRF system are about 20% more accurate than those of the 2011 operational HWRF in both Atlantic and Eastern Pacific basin storms (Fig.1 left panels). In addition to the improvement of track forecast skills, the intensity predictions from the FY12 also showed considerable improvement. While the intensity errors of the FY12 HWRF showed improvement of about 10% in the Atlantic basin, the Eastern Pacific intensity forecasts demonstrated even bigger improvement (about 35%) at later time of the forecast period.

Figure 2 shows the intensity bias (upper panels) and size verification for 50kt radius (lower panels). The intensity bias verifications seem neutral compare to the 2011 operational HWRF system. One of the highlights of the FY12 HWRF system improvements is from the size of tropical storms. As can be seen in the lower panels of figure 2, the 2011 operational HWRF had large size at the initial time and it sometimes get bigger with forecast time. On the contrary, the FY12 proposed HWRF system produced almost zero bias of storm size and this accurate storm size remains throughout five day forecast time. With its increased resolution and model upgrades, this version of the HWRF provides a solid foundation for improved tropical cyclone intensity prediction.

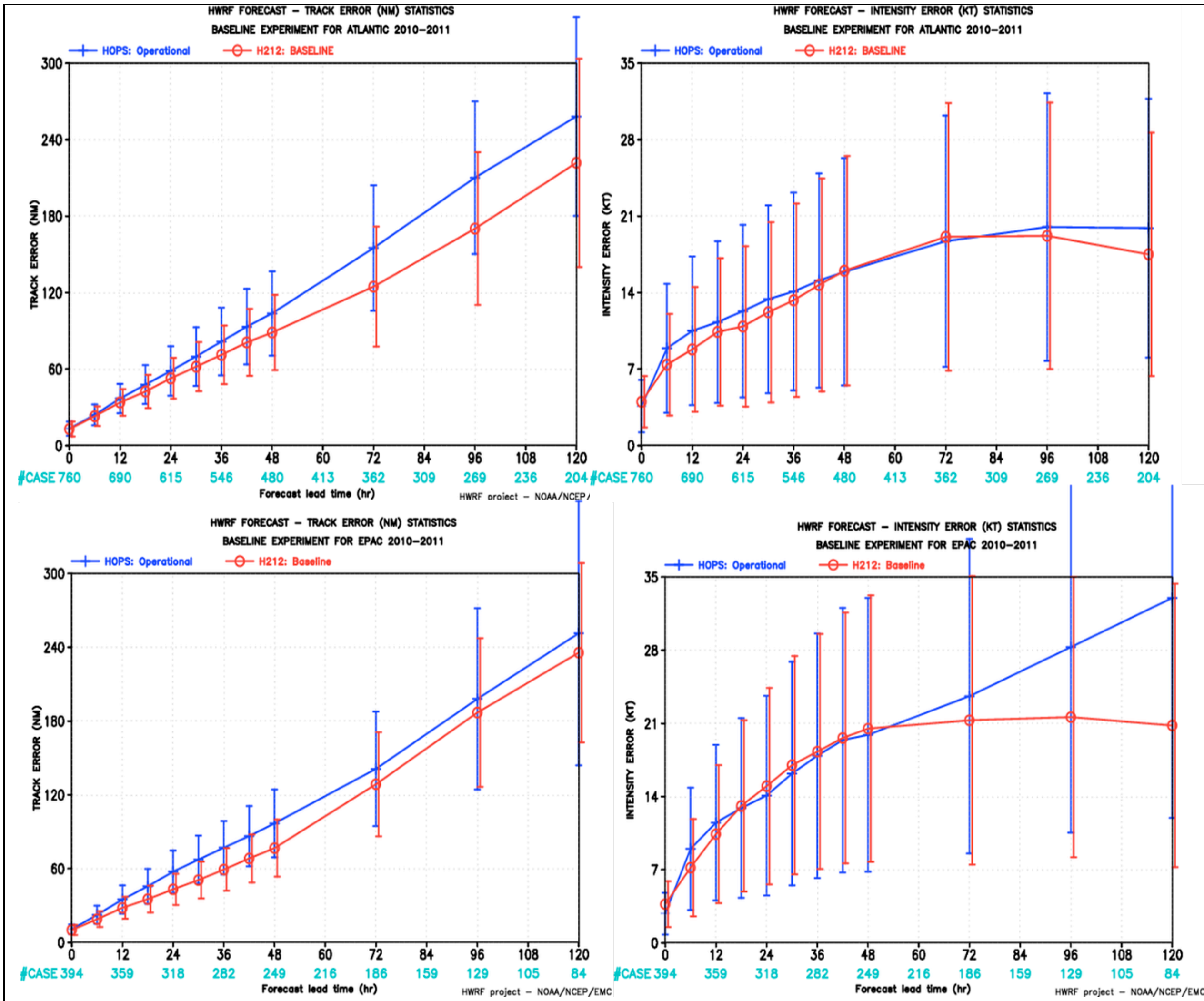

Fig.1: Track and intensity errors of the FY12 pre-implementation test (red lines) compare to the 2011 operational HWRF system (blue lines). Upper panels are for Atlantic basin, the lower panels are for Eastern Pacific basin. The left panels are track errors, and the right panels are intensity errors. The track errors of the proposed FY12 HWRF system reduces about 20% in both Atlantic and Eastern Pacific basins compare to the 2011 operational HWRF. While the intensity errors of the FY12 proposed HWRF in Atlantic basin improved about 10%, those in Eastern Pacific basin improved about 35% especially at 4 and five day forecast.

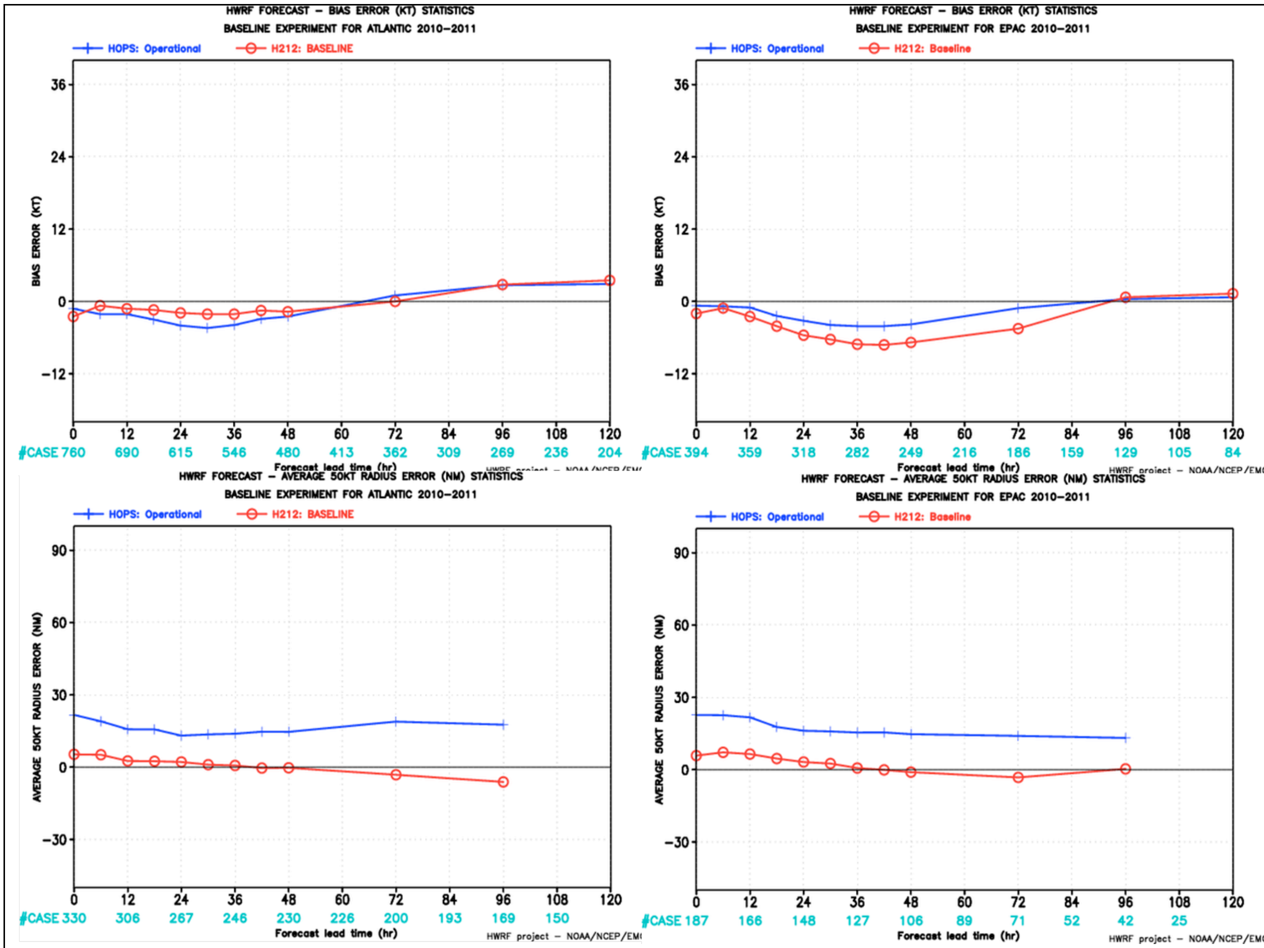

Fig.2: Intensity bias (upper panels) for Atlantic basin (left) and Eastern Pacific basin (right). The lower panels show the errors of 50kt radius for the proposed FY12 HWRF system (red line) vs. the2011 operational HWRF system.

3.7 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 started drawing code from the community HWRF repository 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 has also assembled 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.