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Community Support and Testing of the Hurricane WRF model at the Developmental Testbed Center

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1. Introduction

The Hurricane Weather Research and Forecasting model (Hurricane WRF or HWRF) is a coupled atmosphere-ocean hurricane forecast model run operationally by the National Oceanographic and Atmospheric Administration (NOAA) National Centers for Environmental Prediction (NCEP) to provide guidance to the National Hurricane Center (NHC). While HWRF track forecasts have demonstrated skill when compared with a climatology and persistency baseline, HWRF intensity forecasts provide limited additional value to NHC, as seen in preliminary verification results for the 2011 season shown at the NOAA Hurricane Forecast Improvement Project (HFIP) annual workshop (J. Franklin 2011, http://www.hfip.org/events/review_meeting_gsi_nov_11/tues_am/Franklin%20HFIP%202011%20Annual%20Review.pdf).

With the goal of improving HWRF forecasts, the HWRF team at the Environmental Modeling Center (EMC) of NCEP has partnered with the Developmental Testbed Center (DTC – Bernardet et al. 2008) to accelerate the rate of transfer of new research and technologies to HWRF. The DTC is an institution with nodes at the National Center for Atmospheric Research (NCAR) and the Global Systems Division (GSD) at the NOAA Earth System Research Laboratory. The main mission of the DTC is to support the infusion of promising new numerical weather prediction and data assimilation capabilities developed by the research community into operational applications.

The DTC's strategy to make new research results available for operational consideration hinges on three activities: establishing solid code management practices so that all HWRF developers use a single code base, supporting the community in using HWRF and adding innovations to the code, and conducting HWRF testing and evaluation. This paper gives a brief description of the HWRF model and provides more details of the DTC's activities to stimulate transition of new research to operations.

2. HWRF Overview

The atmospheric component of HWRF is a configuration of the WRF model that has been designed to simulate and predict tropical cyclones (Gopalakrishnan et al. 2011). It includes the Non-hydrostatic Mesoscale Model (NMM) dynamic core with a vortex-following moving nest. The physics suite includes the Simplified Arakawa-Schubert (SAS) cumulus scheme, the Geophysical Fluid Dynamics Laboratory (GFDL) model surface layer and radiation parameterizations, the Global Forecasting System (GFS) boundary layer parameterization, and the tropical Ferrier microphysics scheme. HWRF's oceanic component is a version of the Princeton Ocean Model adapted for tropical cyclones (POM-TC), which was developed at the University of Rhode Island (URI). The atmospheric and oceanic components communicate through a coupler developed at NCEP/EMC. HWRF post-processing makes use of the NCEP Unified Post-Processor (UPP) and of the GFDL external vortex tracker, which can extract the tropical cyclone's location, intensity and structure from the model output.

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In its 2011 operational configuration, HWRF was run with two atmospheric domains. The parent domain covered a 75°x75° area with a grid spacing of approximately 27 km, while the moving nest domain covered 6°x6° with a 9 km grid spacing. In 2011, HWRF was run coupled in the Atlantic basin, and uncoupled (atmosphere only) in the Eastern North Pacific basin.

At the time of this writing, retrospective runs for the final 2012 operational configuration have been completed. Based on NHC's evaluation and recommendations, a new triple-nested HWRF will be implemented into operations for the 2012 hurricane season (Tallapragada et al., 2012). Operational HWRF in 2012 will use three domains, of horizontal grid spacing of 27, 9, and 3 km respectively. The parent domain will cover a 75°x75° area, while the two telescopic moving nests will cover areas of about 10°x11° and 5°x5.5°, respectively. HWRF will run in coupled atmosphere-ocean mode in both the Atlantic and Pacific basins.

HWRF is initialized every six hours and run out to 126 hours. The atmosphere is initialized from GFS analyses, and a vortex initialization technique is used to remove the GFS vortex and include the vortex from the previous 6-h HWRF forecast, after its location and intensity are corrected according to observations. The initialization is enhanced further with the use of the Gridpoint Statistical Interpolation (GSI) three-dimensional variational data assimilation system, which is used to add observations in the storm's environment. A features-based ocean initialization process generates initial conditions for the oceanic component POM-TC. HWRF atmospheric and oceanic components then run in parallel and exchange information through the coupler: the atmospheric model calculates and sends the momentum and heat fluxes to the ocean, while the ocean model sends the sea surface temperature to the atmosphere.

Figure 1 is a schematic flowchart of the HWRF components. The various colors differentiate the eight components of HWRF described above.

3. HWRF code management

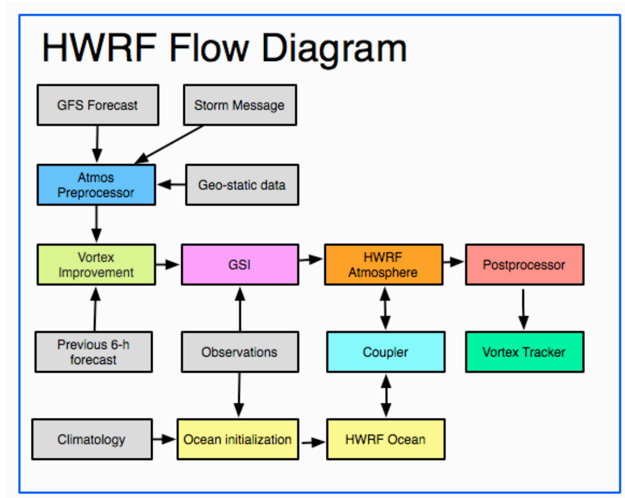

Figure 1. HWRF flow diagram.

One of the paradigms used by the DTC to facilitate the transfer of innovations to operations is that a single code base should be used for research, development and operations. While some HWRF components originated from community code (defined here as code freely available, documented and supported to general users, such as WRF), during the HWRF initial development at EMC leading to the 2007 initial operational implementation, the code diverged from that used by the general community. In collaboration with NCEP/EMC, in 2009 and 2010 DTC ported all operational capabilities to the existing community codes. This was done for four of the eight HWRF components: WRF, WRF Pre-Processor (WPS), GSI, and the post-processor. The other four HWRF components (vortex initialization, POM-TC, coupler, and GFDL vortex tracker) did not have community codes. For those four components, the DTC established community codes containing the operational capability. Therefore, by 2010, every HWRF component had its code in a repository under version control, from which code releases could be made.

In 2010, DTC did a beta release of the community HWRF code. A second release was done in 2011 (v3.3a), corresponding to the 2011 operational capability (Bao et al 2011). Before each release, the code is ported and tested in multiple computational platforms. The support provided by DTC to HWRF users and developers is described in Section 4, and some of the pre-release testing is discussed in Section 5.

4. Support to users and developers of HWRF

The DTC maintains a WRF for Hurricanes website (dtcenter.org/HurrWRF/users) where users can obtain code releases, a users' guide, scientific documentation, and test datasets. Releases of well-tested stable code are planned in a yearly schedule, corresponding to the configuration used in operations in that year's hurricane season. There are currently 330 HWRF users, who have full access to extensive benchmarks of the community code. Additionally, a helpdesk can be reached at wrfhelp@ucar.edu. Resident tutorials were taught in Boulder, CO, in 2010 and 2011, and an online tutorial has been made available in 2012.

While access to the HWRF code in this fashion meets the needs of the majority of users, it does not address all the requirements of HWRF developers, especially those who are working in the operational environment. Those working in rapid development mode, geared towards operational implementation in a 1-5 year time frame, need to work in close collaboration with each other and EMC. They need access to state-of-the-art experimental versions of the code, and not to the fixed last seasons model. To support that activity, the DTC is now providing direct access to the code repository to expert, friendly developers. They can obtain the latest versions of the code, and use "branches" in the code repository to add their contributions, which can be seen by and shared with other developers. The DTC is currently supporting 40 developers in this mode, and the 2012 operational configuration was chosen after a suite of tests was conducted using the code emerging from this multi-developer collaboration (Tallapragada et al. 2012).

5. HWRF testing

HWRF testing is conducted at the DTC with two primary motivations. The first is to ascertain the code integrity and its proper functioning in multiple computational platforms. This type of testing makes the code more robust by documenting and possibly resolving problems identified in the test.

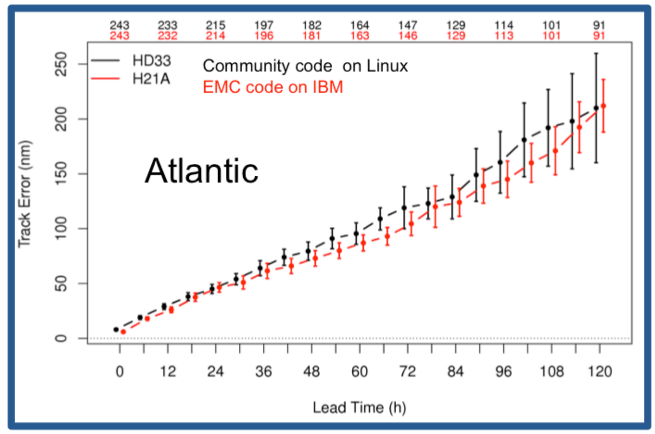

Figure 2. Average track error (nm) for Atlantic cases of the 2010 season as a function of forecast lead time (h) for HWRF runs conducted at the DTC on a Linux cluster using the Intel compiler (black) and runs with similar code conducted at NCEP in an IBM machine with the AIX compiler (red).

Figure 2 shows a test conducted at the DTC to ascertain that the capabilities of the 2011 operational baseline capability had been correctly incorporated in the community code. This assessment was done by running 31 complete storms in retrospective mode for the 2010 season. The runs conducted by the DTC in a Linux platform were compared against their counterpart conducted by NCEP on the operational AIX (IBM) platform. The hypothesis for this test was that the forecasts for specific cases would differ between the two runs, but that bulk statistics would be similar. Contrary to expectation, results showed significant differences between the average track errors of the two runs. Follow up investigation of the source of difference revealed that a non-initialized variable was being used in the SAS cumulus parameterization. This bug behaved differently in the two platforms, leading to the differences. This bug was communicated to

NCEP, who implemented the fix operationally mid-season in June 2011. More details about this test can be found at http://www.dtcenter.org/eval/hwrf_hd33_h21a.

The second type of assessment focuses on new capabilities that can be considered for operational implementation. The first step towards this assessment is the creation of a benchmark, termed a Reference Configuration (RC). website. As an example, in 2011 the DTC designated a RC corresponding to the 2011 operational configuration. Comprehensive forecast verification statistics from over a thousand retrospective cases from the 2010 and 2011 seasons were generated and are available at dtcenter.org/config. These statistics are used to inform needs for diagnostic activities, to guide future development, and to create a control against which innovations can be tested.

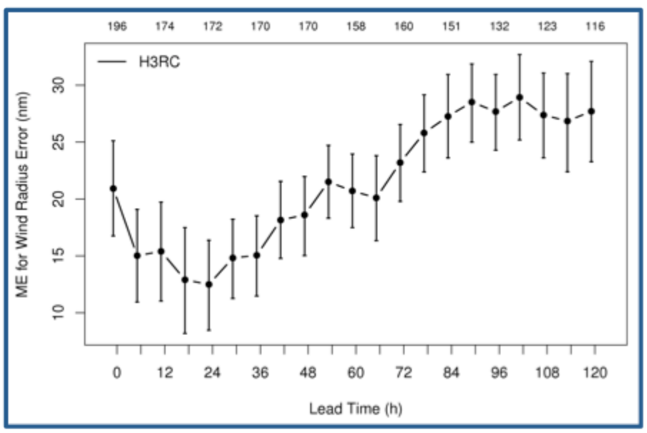

Figure 3. Wind radii error (kt) as a function of forecast lead time for the 64-kt threshold in the northeast quadrant of the storm. Average and 95% confidence intervals for over five hundred cases of the 2010 and 2011 Atlantic seasons.

As an example, Fig. 3 shows the average error for the wind radii for the 64 kt radii in the northeast quadrant of the storm. The positive error values indicate that the forecast storm core is too large when compared to the Best Track. The errors decrease in the first day of the forecasting, indicating that the storm is initialized too large and that the model tents to contract it. Later in the forecast, the errors grow, indicating that the storm expands.

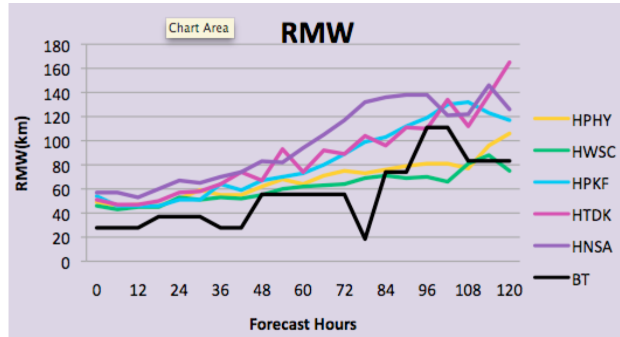

Figure 4. Radius of Maximum Wind (km) as a function of forecast lead time for the Best Track (black) and five configurations of HWRF: operational SAS (HPHY), operational SAS with shallow convection (HWSC), new SAS implemented by YSU (HNSA), Kain-Fritsh (HPKF), and Tiedke (HTDK).

There are several factors that control storm size and structure in a model. Initialization, lateral diffusion, and physical processes all play a role. Following priorities determined at the HFIP workshop on Physical Parameterizations, DTC used the community HWRF code configured as the 2011 operational HWRF to conduct case studies to determine HWRF's sensitivity to cumulus parameterizations, and to document the influence of the cumulus parameterizations on storm size.

Figure 4 shows the evolution of the Radius of Maximum Wind (RWM) as a function of forecast lead time for Hurricane Irene initialized on August 23, 2011 at 00 UTC. The forecasts using five different cumulus parameterizations are compared against the analyses. It is seen that the RMW is initialized too large in HWRF and that, while the observed storm expands, the forecast storm expands at a much faster rate. There are substantial differences between the RMW forecast by the various cumulus schemes, with the operational configuration producing the smaller storm, and the variant using the new SAS scheme implemented by the Yonsei University (YSU) producing the largest one.

6. Concluding remarks

As a part of DTC's effort to bridge the NWP research and operation communities, HWRF is now a community supported code at EMC. Yearly releases of well-tested stable code are provided through the DTC website, along with a helpdesk, extensive documentation, test cases, and datasets. In addition, the DTC has established a new code management protocol for HWRF, which allows expert developers to access, share and contribute experimental code.

The DTC conducts testing and evaluation activities for HWRF. Those include pre-release testing, testing to ascertain that new capabilities have been correctly transitioned to HWRF, testing to evaluate new development for potential operational implementation, and analyses of datasets contributed by external groups.

The goal of these efforts is to promote collaboration between the research and operational communities, in order to accelerate the improvement of HWRF and operational hurricane prediction.

7. Acknowledgment

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