The Developmental Testbed Center

HWRF 2011 Operational Capability Test Plan

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1. Introduction

The DTC will be performing testing and evaluation for the Hurricane WRF system, known as HWRF (Gopalakrishnan et al. 2011). HWRF will be configured as close as possible to the operational HWRF model, employing the same domains, physics, coupling, and initialization procedures as the model used at the NOAA NCEP Central Operations and by the model developers at NCEP EMC. The configuration to be tested matches the 2011 Operational HWRF implemented at NCEP on May 15, 2011.

The HWRF System has the following components: WPS, prep_hybrid (WRF preprocessor for input of GFS spectral data in native coordinates and binary format), vortex relocation and initialization, GSI 3D-Var, WRF model using a modified NMM dynamic core, POM, features-based ocean initialization, UPP, GFDL vortex tracker, GrADS-based graphics, and NHCVx. All acronyms are listed in Appendix C. HWRF is currently designed for use in the North Atlantic and North East Pacific basins. Atlantic forecasts are in coupled ocean-atmosphere mode, while Pacific forecasts use only the atmospheric model.

2. Goals

The overarching goal of the HWRF 2011 Operational Capability Test Plan is to establish the skill of the community HWRF code for tropical storm forecasting to ascertain that all 2011 operational capabilities have been successfully ported to the community code. This will be done through a comparison of the results of the forecasts generated by DTC with the community code (dubbed HD33) against those generated at NOAA NCEP using the H21A configuration of HWRF.

In order to facilitate this comparison, HD33 will be run using the prep_hybrid tool to ingest the GFS reforecast pre13j dataset to create initial and boundary conditions for the atmospheric fields. It is recognized that prep_hybrid is not a tool currently supported to the community and that the GFS reforecasts are not easily accessible by the community. Therefore, these runs will not be used to designate a DTC Reference Configuration, which should use community components whenever possible.

It is not expected that HD33 and H21A forecasts will match exactly. There are differences in computing platform, as the HD33 runs will be conducted in a Linux cluster and H21A was run n the NCEP operational IBM platform. Additionally, different versions of the tracker were used in the two sets of forecasts. While differences between HD33 and H21A forecasts are expected to be small for cold start runs, the cycling nature of HWRF will cause an amplification of the differences for the later initializations of a given storm. It is expected that while HD33 and H21A results might differ for specific storms, the forecast skill will be similar over a sufficiently large sample of cases. Table 1 summarizes the differences between HD33 and H21A.

Table 1. Differences between HD33 and H21A

	HD33	**H21A**
Institution conducting test	DTC	EMC
Computer platform	Linux Cluster *tjet*	NCEP IBMs *CCS*
Source code repository	Community	EMC
Scripts	DTC	EMC
Automation	NOAA GSD Workflow Manager	EMC HWRF History Sequence Manager
I/O format	NetCDF	Binary
UPP	Community UPP Beta v0.5c	EMC UPP modified for HWRF
Tracker	Community repository	EMC operational tracker
Sharpening procedure in ocean initialization for Atlantic domain	Used in ocean spin up Phases 3 and 4 and in coupled model run	Used in ocean spin up Phase 3 only (known bug)
Snow Albedo	Older dataset	Newer dataset

3. Experiment Design

The end-to-end system is composed of WPS, prep_hybrid, vortex relocation and initialization, GSI, ocean initialization, POM, WRF, coupler, UPP, tracker, graphics generation, data archival, and dissemination of results.

a. Codes to be employed

The software packages utilized will be obtained from the community repositories for all codes, except fore prep_hybrid and NHCVx, which are not currently supported to the community. NHCVx will be obtained from a DTC in-house code repository. The revisions for all codes are listed below:

- WRF - https://svn-wrf-model.cgd.ucar.edu, revision 4947

- WPS – https://svn-wrf-wps.cgd.ucar.edu, revision 602
- UPP – Beta release v0.5c (revision 75)
- GSI – official release v2.5
- Vortex Relocation and Initialization, prep_hybrid, miscellaneous libraries and tools: https://svn-dtc-hwrf-tne.cgd.ucar.edu, revision 245
- POM and POM initialization – https://svn-dtc-pomtc.cgd.ucar.edu, revision 85
- Coupler - https://svn-dtc-ncep-coupler.cgd.ucar.edu, revision 37
- Tracker - https://svn-dtc-gfdl-vortextracker.cgd.ucar.edu, revision 53
- NHCVx - https://svn-dtc-nhcvx.cgd.ucar.edu, revision 28

The scripts will be obtained from the DTC in-house repository at https://svn-dtc-hwrf-tne.cgd.ucar.edu, revision 158.

b. Domain Configurations

The HWRF domain will be configured the same way as used in the NCEP/EMC operational system. The atmospheric model employs a parent and a movable nested grid. The parent grid covers a 75x75° area with 0.18° (approximately 27 km) horizontal grid spacing. There are a total of 216 x 432 grid points in the parent grid. The nest covers a 5.4 x 5.4° area with 0.06° (approximately 9 km) grid spacing. There are a total of 60 x 100 grid points in the nest. Both parent and nest use the WRF-NMM rotated latitude-longitude projection and the E-staggered grid. Indices in the E-staggered grid are such that a square domain has approximately twice as many points in the y-direction than the x-direction. The location of the parent and nest, as well as the pole of the projection, vary from run to run and are dictated by the location of the storm at the time of initialization. Forty-two vertical levels (43 sigma entries) will be employed, with a pressure top of 50 hPa.

HWRF is run coupled to the POM ocean model for Atlantic storms and in atmosphere-only mode for East Pacific storms. The POM domain for the Atlantic storms depends on the location of the storm at the initialization time and on the 72-h NHC forecast for the storm location. Those parameters define whether the East Atlantic or United domain of the POM will be used. Both POM domains cover an area from 10.0°N to 47.5°N in latitude, with 225 latitudinal grid points. The East Atlantic POM domain ranges from 60.0° W to 30.0° W longitude with 157 longitudinal grid points, while the United domain ranges from 98.5° W to 50.0° W with 254 longitudinal grid points. Both domains have horizontal grid spacing of approximately 18 km in both the latitudinal and longitudinal directions. The POM uses 23 vertical levels and employs the terrain-following sigma coordinate system.

Additional intermediate domains are used for the atmospheric model during the vortex relocation and initialization procedures (see Bao et al. 2011), and during postprocessing (see item 3.g below).

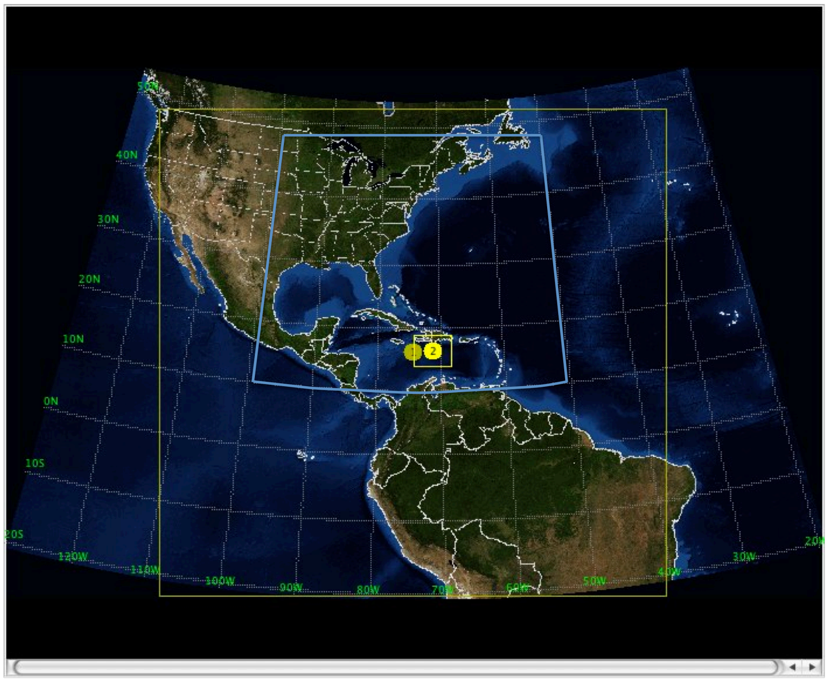

Figure 1. Sample domains for the atmospheric (yellow lines outline the stationary outer domain and the moving nest) and oceanic (blue line outlines the United OM domain) components of HWRF.

c. Initial and Boundary Conditions

Initial Conditions will be based on pre13j GFS analysis. Pre13j GFS refers to the retrospective runs of the GFS implemented operationally on May 9, 2011. The IC and BC for the atmosphere will be obtained from the binary spectral GFS files in native vertical coordinates using prep_hybrid. The IC for the surface fields will be obtained from the 1x1° GFS files in GRIB format using WPS. HWRF applies a vortex relocation procedure as described in Bao et al. 2011 and Gopalakrishnan et al. 2011. In the presence of a 6-h forecast from a HWRF run initialized 6-h before the initialization time for a given cycle, the vortex relocation procedure will remove the vortex from the GFS analysis and substitute it with the vortex from the previous HWRF forecast, after correcting it using the observed location and intensity. When a previous HWRF forecast is not present, the GFS vortex is removed and substituted by a synthetic vortex derived from a procedure that involves theoretical considerations and HWRF climatology. This procedure is referred to as *cold start*.

For storms classified as *deep* by the NHC at the time of model initialization, the HWRF initialization is updated using GSI. The data supplied to GSI consists of conventional restricted prepbufr observations, satellite observations from NOAA, metop-a, AQUA, GOES, and AMSU A and B satellites. For any given analysis, only a subset of the observations are employed because of quality and availability of the datasets. No data is assimilated in the inner core of the storm, that is, the GSI modifications to the HWRF initialization are only applied to the storm environment (outside 150 km radius from the storm center).

d. Forecast Periods

Forecasts will be initialized every 6 hours for the storms listed in Table 1 and will run out to 126 hours. A cold-start initialization will be employed for the first NHC Storm Message (INVEST) of each storm, and the HWRF vortex will be cycled for all subsequent initialization of each storm.

e. Physics Suite

The physics suite configuration (Gopalakrishnan et al. 2011) is described in Table 2. The convective parameterization is applied in both the parent and nest domains with momentum mixing (coefficient 1.0) activated in both.

Table 2. Physics Suite for HD33 test.

Microphysics	Ferrier for the tropics (85)
Radiation SW/LW	GFDL/GFDL (98/98)
Surface Layer	GFDL (88)
Land Surface Model	GFDL slab model (88)
Planetary Boundary Layer	GFS (3)
Convection	Simplified Arakawa-Schubert (4)

f. Other aspects of code configuration

The HWRF system will be compiled with the environmental variables WRF_NMM_CORE, WRF_NMM_NEST and HWRF set to 1 in order for the executables to contain the HWRF-specific instructions.

As in the operational configuration, a time step of 54 s will be used for the parent grid, while a time step of 18 s will be used in the nest. Calls to the turbulence, cumulus parameterization and microphysics will be every 4.5 minutes for the parent domain and 54 s on the nest. Calls to the radiation will be every 54 minutes on the parent grid and 9 minutes on the nest. Coupling to the ocean model and nest motion are restricted to a 9-minute interval.

The gravity wave drag parameterization will be applied in the parent-domain only, and the advection will be using the Lagrangian scheme.

g. Post-processing and Vortex Tracking

The unipost program within UPP will be used in the parent and nest domains to destagger the forecasts, to generate derived meteorological variables, including MSLP, and to vertically interpolate the fields to isobaric levels. The post-processed fields will include two- and three-dimensional fields on constant pressure levels and at shelter level, all of which are required by the plotting and verification programs.

Using the copygb program contained in UPP, the post-processed parent and nest domains will both be horizontally interpolated to a latitude-longitude grid with similar domain size to the parent domain and grid spacing similar to the native nested domain. Those two grids with same domain and grid spacings will then be combined in order to create a high-resolution grid covering an area similar to the parent domain. Additionally, the post-processed forecast from the nest domain will be horizontally interpolated to a high-resolution standard latitude-longitude grid with similar domain to the nest in order to generate graphics.

Tracking will be on the combined domain. For purposes of verification and graphics generation, the input will be six hourly postprocessed files. Tracking for the purposes of cycling the HWRF vortex will be with three-hourly postprocessed files.

h. Model Verification

The characteristics of the forecast storm (location, intensity, structure) as contained in the HD33 and H21A ATCF files produced by the tracker will be compared against the Best Track using the NHCVx. The HD33 ATCF files will be produced by the DTC as part of this test, while the H21A ATCF files will be supplied by EMC. The NHCVx will be run separately for each case, at 6-hourly forecast lead times, out to 126 h, in order to generate a distribution of errors.

A R-statistical language script will be run separately on an homogenous sample of the HD33 and H21A datasets to aggregate the errors and to create summary metrics including the mean and median of track error, along-and across track error, intensity error, absolute intensity error, and radii of 34, 50, and 64 kt wind in all four quadrants. All metrics will be accompanied of 95% confidence intervals to describe the uncertainty in the results due to sampling limitations. The largest outliers (worst forecasts) will be identified.

Additionally, pairwise differences (HD33-H21A) of track error, along-and across track error, intensity error and absolute intensity error will be computed and aggregated with a R-statistical language script. Ninety-five percent confidence intervals will be computed to determine if there is a statistically significant difference between the two configurations.

i. Graphics

Graphics will be generated using GrADS scripts originally developed at EMC. Graphics will include line plots of track, maximum winds and mean sea level pressure.

Additionally, the following 4 graphics will be produced for six-hourly lead times

- 850-hPa streamlines and isotachs on the combined domain
- 850-hPa streamlines and isotachs on the nest
- MSLP and 10-m winds on the nest
- Zonal cross sections of zonal and meridional wind on the nest

- Meridional cross section of zonal wind on the nest

All graphics will be displayed on the DTC Testing and evaluation website.

j. Data Archival and Dissemination of Results

Input and output data files from several stages of the end-to-end system will be archived in the NOAA ESRL/GSD MSS and the results will be summarized in a report.

4. Computer resources

- Processing resources

  All forecasts will be computed on the HFIP Linux cluster *tjet* located at NOAA GSD. For the coupled run, 91 processors will be used for the atmospheric model, 1 for the coupler, and 1 for POM. GSI will be run in 24 processors. All other programs will be run in a single processor.

- Storage resources

  All archival will be on the NOAA GSD MSS.

- Web resources

  Model forecast and verification graphics will be accessed through a web interface available on the DTC website.

5. Deliverables

The NOAA GSD MSS will be used to archive the files input and output by the forecast system. Appendix B lists the output files that will be archived. Additionally, all code compilation logs, input files and fixed files used in the runs will be archived. These files will be made available to the community for further studies.

The DTC website will be used to display the forecast and objective verification graphics.

Finally, a report will be written summarizing the results and conclusions from this test.

6. References

Bao, S., R. Yablonsky, D. Stark, and L. Bernardet, 2011. HWRF Users' Guide V3.3a. Developmental Testbed Center, 88pp.

Gopalakrishnan, S., Q. Liu, T. Marchok, D. Sheinin, N. Surgi, R. Tuleya, R. Yablonsky, and X. Zhang, 2011: Hurricane Weather and Research and Forecasting (HWRF) Model: 2011 scientific documentation. L. Bernardet, Ed., 75 pp.

Acknowledgements

This design document was written with input from the hurricane teams at DTC and EMC. The EMC HWRF group has provided the H21A tracks for verification and comparison against HD33.

Appendix A: Case List

Table 3. Cases for HD33 Test. Columns on the table refer to the storm name, storm number, beginning and ending case (month, day and time UTC in format mmddhh). Typically the first case of a storm is initialized as a cold start and subsequent cases are cycled. When the NHC storm message is missing during a storm, there is an interruption in the cycling, and a new cold start is done. This is indicated on the table by using multiple lines for a single storm.

2010 Atlantic				
Alex	01L	22	062600	070106
Bonnie	03L	10	072212	072418
Collin	04L	24	080218	080812
Danielle	06L	37	082118	083018
Earl	07L	41	082512	090412
Fiona	08L	16	083100	090318
Gaston	09L	7 17	090112 090312	090300 090712
Hermine	10L	9	090600	090800
Igor	11L	53	090812	092112
Julia	12L	33	091212	092012
Karl	13L	15	091418	091806
Lisa	14L	23	092100	092612
Matthew	15L	12	092318	092612
Nicole	16L	6 1	092812 093006	092918 093006
Otto	17L	17	100606	101006
Paula	18L	15	101118	101506
Richard	19L	23	102100	102612
Shary	20L	8	102900	103018
Thomas	21L	37	102918	110718
Total Atlantic		426		
2010 Pacific				
Blas	03E	18	061712	062118
Celia	04E	40	061906	062900
Darby	05E	25	062300	062900
Six	06E	6 1	071500 071618	071606 071618
Estelle	07E	19	080600	081012
Eight	08E	5	082012	082112
Frank	09E	28	082118	082812
Ten	10E	5	090306	090406
Eleven	11E	3	090400	090412
Georgette	12E	7	092112	092300

Total Pacific		156		
Total Test		582		

Appendix B: Files to be archived in the MSS

- Messages
    - domain_center
    - Tcvital
- geogrid output
    - geo_nmm*
    - namelist.wps
- real output
    - namelist.input
    - fort.65
    - wrfinput_d01
- WRF ghost output
    - ghost_d02_0000-00-00_00:00:00
- WRF analysis output
    - wrfanl_d02_yyyy-mm-dd_hh:00:00
- Vortex relocation output
    - wrfinput_d01
    - wrfghost_d02
- GSI output for parent and ghost domains
    - wrf_inout
    - ${SID}L.${yyyymmddhh}.gsi_cvs[1,2].biascr
    - logs
        - stdout
        - fort.201 through fort.215
- Ocean Initialization output
    - ocean_region_info.txt
    - getsst/mask.gfs.dat
    - getsst/sst.gfs.dat
    - getsst/lonlat.gfs
    - phase4/track
    - logs
        - getsst/getsst.out
        - phase3/phase3.out
        - phase4/phase4.out
- Coupled WRF-POM run input and output
    - RST.final
    - wrfinput_d01
    - wrfbdy_d01
    - wrfanl_d02
    - EL.*
    - GRADS.*
    - OHC.*
    - T.*
    - TXY.*
    - U.*
    - V.*
    - WTSW.*
    - rsl.*
- Postprocessing output
    - WRFPRS*

- Tracker output
    - Short track (12 h forecast) from forecasts at 3-h intervals
        - Combined domain
            - gvt_combined_12hr_3hrly_HD33_${SID}_${yyyymmddhh}.txt
        - Parent domain
            - gvt_parent_12hr_3hrly_HD33_${SID}_${yyyymmddhh}.txt
    - Long track (126h forecast) from forecasts at 6-h intervals
        - Combined domain
            - fort.64
    - Long track (126h forecast) from forecasts at 3-h intervals
        - Combined domain
            - gvt_parent_12hr_3hrly_HD33_${SID}_${yyyymmddhh}.txt

- Graphics Output
    - hwrf_plots/${SID}.${yyyymmddhh}/*gif
- Verification Output
    - nhc_HD33_${SID}_.${yyyymmddhh}.txt
- logs
    - All files

Appendix C: List of Acronyms

3D-Var – Three dimensional Variational Analysis

ATCF – Automated Tropical Cyclone Forecasting

BC – Boundary Conditions

DTC – developmental Testbed Center

EMC – Environmental Modeling Center

GFDL – Geophysical Fluid Dynamics Laboratory

GFS – Global Forecasting System

GSD – Global Systems Division (of NOAA Earth System Research Laboratory)

GSI – Global Statistical Interpolator

GRIB – Gridded binary data format

HD33 – HWRF configuration used in this test (stands for HWRF DTC v3.3)

H21A – HWRF configuration similar to HD33 used in a previous test

HWRF – Hurricane Weather Research and Forecasting

IC – Initial Conditions

MSLP – Mean Sea Level Pressure

MSS – Mass Storage System

NAM Post – North American Model Post-processor

NCEP – National Centers for Environmental Prediction

NHC – National Hurricane Center

NMM – Non-hydrostatic Mesoscale Model

NOAA – National Oceanic and Atmospheric Administration

POM – Princeton Ocean Model

Pre13j GFS – Retrospective runs made with GFS

SID – Storm Identification

UPP – Unified Post-Processor

WPS – WRF Preprocessing System

WRF – Weather Research and Forecasting

yyyymmddhh – Year, month, day and hour of forecast initialization