The Developmental Testbed Center
WRF-RR Vertical Level (WRFRR-VL) Sensitivity Test – Design Plan

Point of Contact: Jamie Wolff
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1. Introduction

The Developmental Testbed Center (DTC; Bernardet et al. 2008) will be performing an evaluation of the sensitivity of the forecast verification statistics to the vertical placement of near-surface sigma levels in the Weather Research and Forecasting (WRF) model configured with the Advanced Research WRF (ARW; Skamarock et. al, 2008) core. The motivation for this test is to examine the impact of vertical resolution near the bottom of the atmosphere on forecasts of atmospheric variables near the land surface (2-m temp and dew point, 10-m wind, as well as precipitation) and on land-surface variables, particularly snow water equivalent and snowmelt. This task is in support of the implementation of the WRF Rapid Refresh (WRF-RR) at the National Centers for Environmental Prediction (NCEP). The results from this test, along with additional testing, may also be used to designate a WRF Reference Configuration.

The WRF-RR Vertical Level (WRFRR-VL) Sensitivity Test will have some of the same parameters in the end-to-end forecast system, including forecast domain and grid spacing, as the 2006 Core Test (CT06; Nance 2006). However, version 3.0 of the WRF Preprocessing System (WPS) will be used rather than the WRF Standard Initialization (SI), in addition to WRF and WRF Postprocessor (WPP) codes updated to version 3.0. The need to update the model and pre- and post-processor source codes stems from the importance of using the latest developments available, along with the need to use code that has been publicly released in order to make the results of the extensive testing most relevant to the user community.

2. Goals

The main goal of WRFRR-VL Test is to quantify the differences between forecasts produced by two configurations with different sigma level specifications. The two model configurations will be identical with the exception of the modification to the distribution of the nine lowest sigma levels in the WRF-ARW namelist. Forecast verification statistics will be computed for the two configurations and the analysis will be based on the objective statistics of the model output.

3. Experiment Design

This section describes the end-to-end forecast system components to be used in the WRFRR-VL Test. It is composed of the WPS, WRF-ARW model, WPP, NCEP Verification System, graphics generation, data archival, confidence interval generation and dissemination of data and results. Before this document was finalized, input from the WRF-RR and ARW developers was sought in order to establish the model configurations.

3.1 Codes to be Employed

In order to utilize the latest developments available, and in order to make the results of the extensive testing most relevant to the user community, the baseline codes for WRF, WPS and WPP will be the tarfiles publicly released as version 3.0. Relevant bug fixes may be incorporated if they are in the repository by the final software acquisition deadline.

The NCEP Verification System will be used to verify the post-processed forecasts for this test. Any relevant bug fixes for the NCEP Verification System may be incorporated by the final software acquisition deadline.

Forecast images will be generated using NCAR Command Language (NCL). The scripts to generate the images will be based on the ones used in the 2007 Core Test (CT07; see http://www.dtcenter.org/plots/coretest2007/), with revisions to add or improve images and to make the scripts consistent with the latest WPP code.

The Workflow manager developed by the National Oceanic and Atmospheric Administration (NOAA) Earth Systems Research Laboratory will be utilized to manage the execution of the end-to-end system. This workflow controls the system execution, starting tasks as soon as their dependencies have been met, monitoring task execution, and re-starting tasks when needed.

3.2 Domain Configurations

The 13-km grid used for the WRF-ARW in the 2006 Core Test (CT06; Nance 2006) will be employed in this test. This domain (Figure 1) was selected such that it fits within the RUC13 domain. The domain is 400 x 304 gridpoints, for a total of 121,600 gridpoints. The Lambert-Conformal map projection will be used and the configurations will use 50 vertical levels (51 sigma entries).

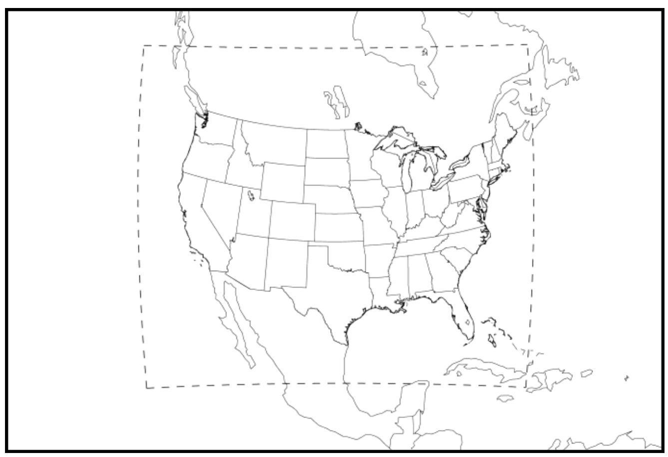

Figure 1. Map showing the boundary of the WRF-ARW computational domain (dashed line).

Several additional domains will be used as sub-regions for verification. Area-average results will be computed using the NCEP Verification System over the entire CONUS (G164), CONUS-West (G165), and CONUS-East (G166) (Figure 2). The surface and upper air components of the NCEP Verification System will also be configured to use the 14 regional domains shown in Figure 3 to compute regional averages of the statistics.

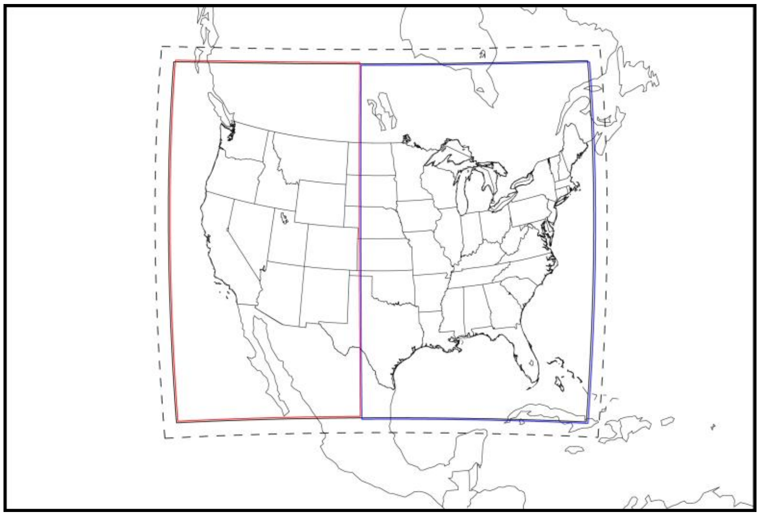

Figure 2. Map showing the boundaries of the verification domains: CONUS (solid black), CONUS-West (solid red), and CONUS-East (solid blue). The WRF-ARW computational domain (dashed line) is shown for reference.

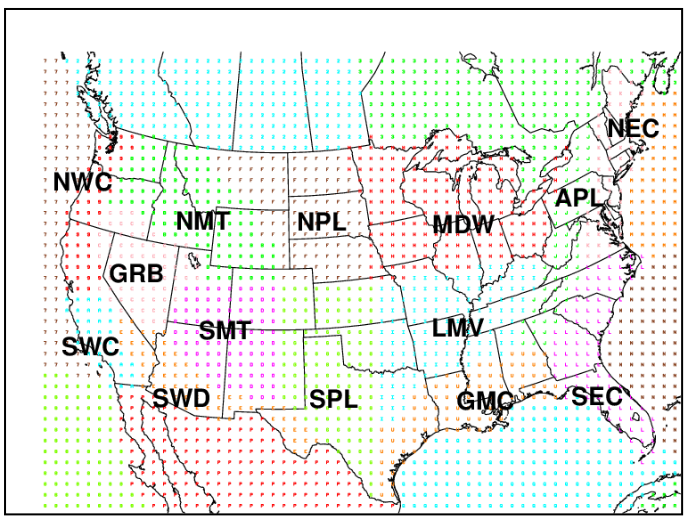

Figure 3. Map showing the locations of the 14 regional verification domains.

3.3 Initial and Boundary Conditions

The WRFRR-VL Test will utilize initial conditions (ICs) from the Rapid Update Cycle (RUC13) model and lateral boundary conditions (LBCs) from the North American Mesoscale Model (NAM212). For the retrospective period to be used, the NAM corresponded to the Eta model. This mixture of input data is chosen because RUC13 grids are not available out to 24 hours for the retrospective time period chosen. The NAM grids from the prior 06 UTC and 18 UTC cycle will be used to produce LBCs for the 12 UTC and 00 UTC forecast cycles, respectively. In order to use these two sources of input data, the ***real*** (WRF Initialization) program is run twice; first with the NAM input to generate the desired ***wrfbdy*** file and, second with the RUC input to generate the desired ***wrfinput*** file.

In addition, NCEP's daily, real-time, sea surface temperature (SST) product, which is produced on a one-twelfth degree latitude-longitude grid using a two-dimensional variational interpolation analysis of the most recent 24-hours ship and buoy data, satellite-retrieved SST data, and SSTs derived from satellite-observed sea-ice coverage will be use to initialize the SST field for the forecasts. Although the end-to-end system for this testing will not include a data assimilation component, the RUC13 cloud fields will be included in the initial conditions, so the runs considered in this study will not be truly cold start forecasts.

The time-invariant component of the lower boundary conditions (topography, soil and vegetation type etc.) will be generated through the ***geogrid*** program of WPS.

3.4 Forecast Periods

Forecasts will be computed for 25 March – 25 April 2006. Forecasts will be initialized at 00 and 12 UTC every day and run out to 24 hours. Missing input data during this time period will prohibit the generation of forecasts for the following cycles:

- 20060325 00 UTC
- 20060402 00 UTC
- 20060413 00 UTC
- 20060417 12 UTC
- 20060418 00 UTC

In addition, the following cycles will have incomplete verification statistics due to missing observation files:

- 20060329 23 UTC
- 20060423 00 UTC
- 20060423 12 UTC

3.5 Physics Suites

The physics suite configuration is described in the Table below.

Microphysics	Thompson
Surface Layer	Janjic
Planetary Boundary Layer	Mellor-Yamada-Janjic
Convection	Grell-Devenyi ensemble
Land-Surface Model	RUC
Radiation SW and LW	Dudhia/RRTM

3.6 Other Aspects of Model Configuration

Similar to CT06, the timesteps used are a long timestep of 72 s and an acoustic timestep of 18 s. Calls to the boundary layer, microphysics and cumulus parameterization will be done every time step, whereas calls to radiation will be done every 30 minutes and history files will be written every three hours.

The ARW solver offers a number of run-time options for the numerics, as well as various filter and damping options (Skamarock et al 2005). The ARW will be configured to use the following numeric options: 3^{rd}-order Runge-Kutta time integration, 5^{th}-order horizontal momentum and scalar advection, and 3^{rd}-order vertical momentum and scalar advection. In addition, the following filter/damping options will be utilized: three-dimensional divergence damping (coefficient 0.1), external mode filter (coefficient 0.01), off-center integration of vertical momentum and geopotential equations (coefficient 0.1), vertical-velocity damping, and a 5-km-deep diffusive damping layer at the top of the domain (coefficient 0.02).

3.7 Post-processing

The WPP will be used to destagger the forecasts, to generate derived meteorological variables, including mean sea level pressure, and to vertically interpolate fields to isobaric levels. The post-processed files will include two- and three-dimensional fields on constant pressure levels, both of which are required by the plotting and verification programs. Three-dimensional post-processed fields on model native vertical coordinates will also be made available.

3.8 Model Verification

Objective model verification statistics will be generated using the NCEP Verification System, which is comprised of the Surface and Upper Air Verification System and the Quantitative Precipitation Forecast (QPF) Verification System.

Forecasts for surface and upper air will be interpolated to the location of the observations (METARs, RAOBS, and ACARS) using the NCEP Surface and Upper Air Verification System, and the observational dataset will be the RUC Prepbufr files. The surface and upper-air verification statistics produced for temperature, relative humidity and winds will include the bias, root mean square error (RMSE), and decomposed (debiased) RMSE, computed separately for each observational type.

For the precipitation verification, a grid-to-grid comparison will be made in which the forecasts and the precipitation analyses will first be interpolated to the 12-km grid spacing of Grid 218 and then compared. Accumulation periods will be 3 h and 24 h. The observational datasets for the 3-h accumulations will be the NCEP Stage II and the River Forecast Center Analysis for the 24-h accumulation (valid at 12 UTC). The statistics computed will include the frequency bias and the equitable threat score.

Verification statistics will be stratified by lead time, vertical level, and regional area for 00 UTC and 12 UTC initialization hours combined. For the surface only, forecasts will be stratified by initialization hour (00 and 12 UTC) and 24 h QPF statistics will be generated for the 12 UTC cycles only. The areas for aggregation of statistics include: CONUS, CONUS-West, and CONUS-East (Figure 2). Additionally, the surface and upper air component of the NCEP Verification System will be configured to use the 14 regional domains shown in Figure 3 to compute regional averages of statistics.

Since every cycle will be run for both configurations of the model, the presentation of the results will take advantage of the pair wise nature of the test. With this methodology, differences between the verification statistics of the two configurations will be computed.

All verification statistics will be accompanied by confidence intervals (CIs). The CIs will be computed on the median values of the stratified results for the surface and upper-air statistics using parametric tests. For the precipitation statistics, a bootstrapping method will be used. The CIs on the differences between statistics for two configurations will assist in determining whether the members of the pair are significantly different. Since uncertainty measures are not computed by the NCEP Verification System, they will be generated separately. The confidence intervals will be incorporated by the DTC into the final written report.

A website for viewing the verification results will be made available to the staff conducting the test and to researchers.

3.9 Graphics Generation and Display

Graphics will be generated using NCAR Command Language (NCL). The scripts to generate the images will be based on the ones used in the CT07, with possible revisions to add or improve images and to make the scripts consistent with the latest WPP code.

The suite of images will be comprised of:

- 2-m temperature with 10-m wind vectors
- 2-m dewpoint with 10-m wind vectors
- 10-m wind speed and vectors
- runtotal accumulated precipitation with mean-sea-level pressure (MSLP)
- 3-h accumulated convective precipitation with MSLP and 1000-500 hPa thickness

- 3-h accumulated resolved precipitation with MSLP and 1000-500 hPa thickness
- 3-h accumulated total precipitation with MSLP and 1000-500 hPa thickness
- precipitation type
- simulated RADAR composite reflectivity
- snow depth
- snow water equivalent
- convective available potential energy
- convective inhibition
- precipitable water
- soil temperature (at 0, 5, 20, 40, 160, 300 cm below ground)
- soil moisture (at 0, 5, 20, 40, 160, 300 cm below ground)
- 850 hPa temperature with geopotential height and wind vectors
- 850 hPa wind speed with geopotential height and vectors
- 850 hPa Relative Humidity (RH)
- 850-500 hPa mean RH with 700 hPa wind vectors
- 700 hPa vertical velocity with geopotential height
- 500 hPa absolute vorticity with geopotential height
- 250 hPa wind vectors with geopotential height.

Difference plots between the two configurations for each of the above listed images will be created. In addition, difference plots will be produced for:

- 850 hPa zonal winds
- 850 hPa meridional winds
- 250 hPa zonal winds
- 250 hPa meridional winds

Finally, Skew-T soundings showing both configurations side-by-side from 14 stations will be created for:

- Albany, NY
- Caribou, ME
- Denver, CO
- Gaylord, MI
- Green Bay, WI
- Grey, ME
- International Falls, MN
- Lake Charles, LA
- Maniwaki QC
- Midland, TX
- Miramar NAS, CA
- Moosonee, ON
- Pickle Lake, ON
- The Pas, MB

All graphics will be displayed on a website so they can be accessible to the staff conducting the test and to researchers.

4 Computer Resources

- Processing resources:
  All forecast cycles and calculations will be computed on the NOAA Boulder supercomputer.
- Storage resources:

All archival will be done on the NCAR Mass Storage System. Forecasts generated at NOAA ESRL will be transferred to NCAR for storage.

- Web resources:
  Model forecast and verification graphics will be accessed through a web interface hosted at NCAR.

5 Deliverables

The NCAR Mass Store will be used to archive the input files used and the output files produced by the forecast system. The following files will be stored:

- RUC, NAM and SST files used for initial and boundary conditions.
- Datasets used for forecast verification (RUC Prepbufr and Stage II and RFC precipitation analyses).
- Static files produced by the ***geogrid*** component of WPS.
- Final output of WPS.
- Input and boundary condition files produced by ***real***.
- History files produced by WRF.
- Output of the ***wrfpost*** component of the WPP.
- Prepfits and vsdb files output by the NCEP verification system.
- Images produced by NCL.

Additionally, all source codes and executables used will be stored.

These files will be made available to the DTC and to the user community for further studies.

The DTC will produce a report outlining the results and conclusions from this test.

6 References

Bernardet, L., L. Nance, M. Demirtas, S. Koch, E. Szoke, T. Folwer, A. Loughe, J. L. Mahoney, H.-Y. Chuang, M. Pyle, and R. Gall, 2008: The Developmental Testbed Center and its Winter Forecasting Experiment. *Bull. Amer. Meteor. Soc*., **89**, 611-627.

Chuang, H.-Y., G. DiMego, M. Baldwin, and WRF DTC Team, 2004: NCEP's WRF post-processor and verification systems. 5th WRF/14th MM5 Users' Workshop, 22-25 June 2004, Boulder, CO.

Nance L., 2006. Weather Research and Forecasting Core Test – DTC Report (available from http://ruc.fsl.noaa.gov/coretest2/DTC_report.pdf).

Skamarock, W. C., J. B. Klemp, J. Dudhia, D. O. Gill, D. M. Barker, W. Wang and J. G. Powers, 2008: A Description of the Advanced Research WRF Version 3, NCAR Tech Note, NCAR/TN–475+STR, 113 pp.