# The Developmental Testbed Center

# WRFv3.2.1 QNSE Test Plan

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## 1.  Introduction

The Developmental Testbed Center (DTC) will be performing re-testing and evaluation of two Weather Research and Forecasting (WRF) model configurations with the Advanced Research WRF (ARW) core (Skamarock et. al, 2008) for the Air Force Weather Agency (AFWA).  Both configurations were designated as DTC Reference Configurations (RCs) when testing was initially conducted in 2009 with WRF v3.1.1.  One configuration is based on AFWA's Operational Configuration, while the second configuration substitutes AFWA's current operational PBL and surface layer schemes with the Quasi-Normal Scale Elimination (QNSE) schemes developed by Sukoriansky, Galperin and Perov, (Sukoriansky et. al, 2005).  Both of these configurations will be re-designated as DTC RCs with the output archived and, along with the results, made available to the WRF community.

The end-to-end forecast system will employ the WRF Preprocessing System (WPS), WRF, and WRF Postprocessor (WPP).  Post-processed forecasts will be verified using the Model Evaluation Tools (MET).  Except for the WRF code, which will be a tag from the WRF repository, the versions of the packages used correspond to the current public releases.  Any known, relevant bug fixes to these versions at the time the testing is performed will also be incorporated.

## 2.  Goals

The overarching goal of the WRFv3.2.1 QNSE Test is to document any changes in forecast skill resulting from moving to WRF v3.2.1.  In addition, the differences between forecasts produced by two configurations that are exactly the same, except for the PBL and surface layer schemes will again be quantified. Forecast verification statistics will be computed for the two configurations and the analysis will be based on the objective statistics of the model output.  A secondary goal of this test and evaluation will be to re-designate both configurations as DTC RCs and widely publish the output and results for the benefit of the entire WRF community.

## 3. Experiment Design

The end-to-end forecast system is composed of the WPS, WRF-ARW model, WPP, MET, graphics generation, data archival, and dissemination of data and results.

### 1. Codes to be Employed

The baseline codes utilized will be the official released versions of WPS (v3.2.1), WRF (v3.2.1), WPP (v3.2), and MET (v3.0). The requirement to use code that is checked-in and tagged within the WRF repository ensures that the code changes have been vetted through the WRF Developers Committee and run through regression testing.  For the results to be most relevant to the user community, testing will be conducted utilizing officially released code.  Relevant bug fixes to all software packages will be incorporated if any are known by the final software acquisition deadline.

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 manager controls the system execution, starting tasks as soon as their dependencies have been met, monitoring task execution, and re-starting tasks when needed.

### 2. Domain Configurations

A 15-km contiguous U.S. (CONUS) grid will be employed in this test. The domain (Figure 1) was selected such that it covers complex terrain, plains and coastal regions spanning from the Gulf of Mexico, north, to Central Canada in order to capture diverse regional effects for worldwide comparability. The domain is 403 x 302 gridpoints, for a total of 121,706 gridpoints.  The Lambert-Conformal map projection will be used and the configurations will use 56 vertical levels (57 sigma entries), with a pressure top of 10 hPa.
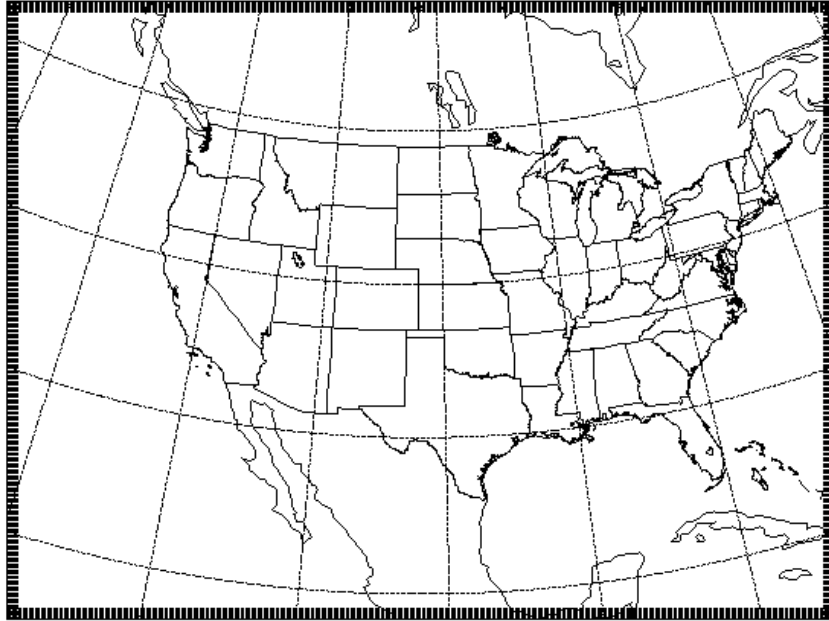
**Figure 1. Map showing the boundary of the WRF-ARW computational domain.**

Verification results will be computed for selected spatial aggregations, including the entire CONUS domain and the 14 regional domains shown in Fig 2.
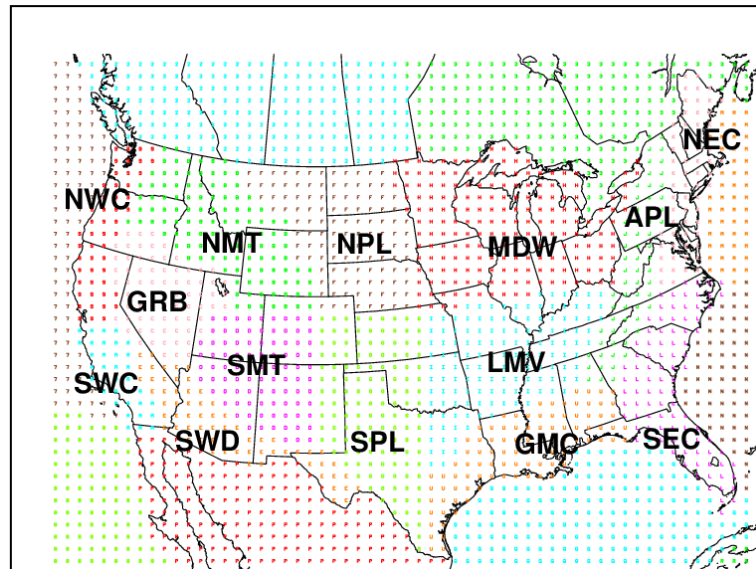


**Figure 2. Map showing the locations of the 14 regional verification domains.**

### 3. Initial and Boundary Conditions

Initial conditions (ICs) and lateral boundary conditions (LBCs) will be derived from the 0.5° x 0.5° Global Forecast System (GFS). AFWA's Agricultural Meteorological Modeling System

(AGRMET), also on a 0.5° x 0.5° global domain, will be utilized for the lower boundary conditions (LoBCs). In addition, a daily, real-time sea surface temperature product from Fleet Numerical Meteorology and Oceanography Center (FNMOC) will be used to initialize the sea surface temperature (SST) field for the forecasts. This product is produced on a near global Mercator projection with ~12 km resolution near the equator and ~9 km resolution at mid-latitudes. It is created from Advanced Very High Resolution Radiometer (AVHRR) Global Area Coverage (GAC) satellite-retrieved SST data and in situ SST data from ships and buoys (fixed and drifting).

The time-invariant component of the lower boundary conditions (topography, soil and vegetation type etc.), using United States Geological Survey (USGS) input data, will be generated through the *geogrid* program of WPS.

### 4. Forecast Periods

Forecasts will be initialized every 36 hours from 2 June 2008 through 31 May 2009. The forecasts will be run out to 48 hours with output files generated every 3 hours. The initialization times will include 00 and 12 UTC for a total of 243 cases.

### 5. Physics Suites

The physics suite configurations are described in the Table below.

|  | Current AFWA Config | QNSE replacement |
|---|---|---|
| **Microphysics** | WRF Single-Moment 5 scheme | WRF Single-Moment 5 scheme |
| **Radiation SW and LW** | Dudhia/RRTM schemes | Dudhia/RRTM schemes |
| **Surface Layer** | Monin-Obukhov similarity theory | QNSE |
| **Land-Surface Model** | Noah | Noah |
| **Planetary Boundary Layer** | Yonsei University scheme | QNSE |
| **Convection** | Kain-Fritsch scheme | Kain-Fritsch scheme |

### 6. Other Aspects of Model Configuration

A long timestep of 90 s and an acoustic step of 4 will be used. 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.

The ARW solver offers a number of run-time options for the numerics, as well as various filter and damping options (Skamarock et al 2008). The ARW will be configured to use the following numeric options: 3rd-order Runge-Kutta time integration, 5th-order horizontal momentum and scalar advection, and 3rd-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). Positive-definite moisture advection will also be turned on.

### 7. Post-processing

The *wrfpost* program within 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.

### 8. Model Verification

Objective model verification statistics will be generated using the MET package. MET is comprised of grid-to-point comparisons which are utilized to compare gridded surface and upper-air model data to point observations, as well as grid-to-grid comparisons which are utilized to verify quantitative precipitation forecasts (QPF).

Forecasts for mean-sea level pressure and surface and upper-air temperature, height, dewpoint, and wind will be interpolated to the location of the observations (METARs, RAOBS, and buoy data) using MET. The NCEP Global Data Assimilation System (GDAS) prepbufr files will be used as the observational dataset. Bias and bias-corrected RMSE (BC-RMSE) will be computed for temperature, dewpoint, and winds, computed separately for each observational type.

For the precipitation verification, a grid-to-grid comparison will be made in which the precipitation analyses will first be interpolated to the 15-km model integration domain and then compared to the forecast. Accumulation periods will be 3 h and 24 h. The observational datasets will be the NCEP Stage II analysis for the 3-h accumulation and the NCEP/CPC daily gauge analysis for the 24-h accumulation (valid at 12 UTC). Traditional verification metrics 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 fields, forecasts will also be stratified by initialization hour (00 and 12 UTC). The regional areas for aggregation of statistics for the surface and upper-air fields will include the full domain (shown in Fig 1) and the 14 regional sub-domains (shown in Fig 2).

Since every forecast 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 for each individual initialization and lead time of the two configurations will be computed.

For surface and upper-air, both the individual and pair-wise verification statistics will be accompanied by confidence intervals (CIs) computed from standard error estimates using a correction for autocorrelation. 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 pair-wise differences between statistics for two configurations will assist in determining whether the differences are statistically significant.

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

### 9. Graphics Generation and Display

Graphics will be generated using NCAR Command Language (NCL).

The suite of images will be comprised of:
- 2-m temperature with 10-m wind vectors
- 2-m dewpoint temperature with 10-m wind vectors
- 10-m wind speed and vectors
- run total 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
- 850 hPa temperature with geopotential height and wind vectors
- 850 hPa wind speed with geopotential height and vectors
- 850 hPa dewpoint temperature

- 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 (one from each sub-domain) will be created for the following sites:
- Quillayute, WA
- Vandenberg AFB, CA
- Desert Rock, NV
- Spokane, WA
- Denver, CO
- Tucson, AZ
- Rapid City, SD
- Amarillo, TX
- Davenport, IA
- Springfield, MO
- Jackson, MS
- Blacksburg, VA
- Albany, NY
- Charleston, SC

All graphics will be displayed on a website in order to be accessible to the staff conducting the test and to researchers.

### 10. Data Archival and Dissemination of Results

Input and output data files from several stages of the end-to-end system will be archived to the NCAR Mass Storage System (MSS) and the results will be summarized in a report.

### 4. *Computer Resources*
- Processing resources:

All forecasts and calculations will be computed on the NCAR supercomputer.

- Storage resources:
  All archival will be done on the NCAR Mass Storage System.

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

## 5. *Deliverables*

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

- GFS, AGRMET, and SST files used for initial and boundary conditions.
- Datasets used for forecast verification (GDAS Prepbufr and Stage II and NCEP/CPC 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.
- Output of MET.
- 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*

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.

Sukoriansky, S., B. Galperin, and V. Perov, 2005: Application of a new spectral theory of stably stratified turbulence to the atmospheric boundary layer over sea ice. *Boundary-Layer Meteorol.,* **117,** 231-257.

Appendix A:  Subset of WRF *namelist.input*

```
&time_control
run_hours                   = 48,
interval_seconds            = 10800,
history_interval            = 180,
frames_per_outfile          = 1,
restart                     = .false.,
io_form_history             = 2,
/

&domains
time_step                   = 90,
time_step_fract_num         = 0,
time_step_fract_den         = 1,
max_dom                     = 1,
e_we                        = 403,
e_sn                        = 302,
e_vert                      = 57,
num_metgrid_levels          = 27,
dx                          = 15000,
dy                          = 15000,
p_top_requested             = 1000,
interp_type                 = 1,
lowest_lvl_from_sfc         = .false.,
lagrange_order              = 1,
force_sfc_in_vinterp        = 6,
zap_close_levels            = 500,
adjust_heights              = .true.,
eta_levels                  = 1.000, 0.997, 0.992, 0.985, 0.978, 0.969, 0.960, 0.950,
                              0.938, 0.925, 0.910, 0.894, 0.876, 0.857, 0.835, 0.812,
                              0.787, 0.760, 0.731, 0.700, 0.668, 0.635, 0.600, 0.565,
                              0.530, 0.494, 0.458, 0.423, 0.388, 0.355, 0.323, 0.293,
                              0.264, 0.237, 0.212, 0.188, 0.167, 0.147, 0.130, 0.114,
                              0.099, 0.086, 0.074, 0.064, 0.054, 0.046, 0.039, 0.032,
                              0.027, 0.022, 0.017, 0.013, 0.010, 0.007, 0.004, 0.002,
                              0.000,
/

&physics
mp_physcis                  = 4,
ra_lw_physics               = 1,
ra_sw_physics               = 1,
radt                        = 30,
sf_sfclay_physics           = 1,
sf_surface_physics          = 2,
bl_pbl_physics              = 1,
bldt                        = 0,
cu_physics                  = 1,
cudt                        = 5,
surface_input_source        = 1,
num_soil_layers             = 4,
mp_zero_out                 = 2,
/
```

```
&dynamics
rk_ord                    = 3,
diff_6th_opt              = 2,
diff_6th_factor           = 0.10
w_damping                 = 1,
diff_opt                  = 1,
km_opt                    = 4,
damp_opt                  = 0,
zdamp                     = 5000.,
dampcoef                  = 0.01
khdif                     = 0,
kvdif                     = 0,
smdiv                     = 0.1,
emdiv                     = 0.01,
epssm                     = 0.1,
time_step_sound           = 0,
h_mom_adv_order           = 5,
v_mom_adv_order           = 3,
h_sca_adv_order           = 5,
v_sca_adv_order           = 3,
pd_moist                  = .true.,
pd_scalar                 = .false.,
pd_chem                   = .false.,
pd_tke                    = .false.,
/

&bdy_control
spec_bdy_width            = 5,
spec_zone                 = 1,
relax_zone                = 4,
specified                 = .true.,
/
```

Appendix B: Case list

| 00 UTC Initialization | 12 UTC Initialization |
|---|---|
| June 2008: 4, 7, 10, 13, 16, 19, 22, 25, 28 | June 2008: 2, 5, 8, 11, 14, 17, 20, 23, 26, 29 |
| July 2008: 1, 4, 7, 10, 13, 16, 19, 22, 25, 28, 31 | July 2008: 2, 5, 8, 11, 14, 17, 20, 23, 26, 29 |
| August 2008: 3, 6, 9, 12, 15, 18, 21, 24, 27, 30 | August 2008: 1, 4, 7, 10, 13, 16, 19, 22, 25, 28, 31 |
| September 2008: 2, 5, 8, 11, 14, 17, 20, 23, 26, 29 | September 2008: 3, 6, 9, 12, 15, 18, 21, 24, 27, 30 |
| October 2008: 2, 5, 8, 11, 14, 17, 20, 23, 26, 29 | October 2008: 3, 6, 9, 12, 15, 18, 21, 24, 27, 30 |
| November 2008: 1, 4, 7, 10, 13, 16, 19, 22, 25, 28 | November 2008: 2, 5, 8, 11, 14, 17, 20, 23, 26, 29 |
| December 2008: 1, 4, 7, 10, 13, 16, 19, 22, 25, 28, 31 | December 2008: 2, 5, 8, 11, 14, 17, 20, 23, 26, 29 |
| January 2009: 3, 6, 9, 12, 15, 18, 21, 24, 27, 30 | January 2009: 1, 4, 7, 10, 13, 16, 19, 22, 25, 28, 31 |
| February 2009: 2, 5, 8, 11, 14, 17, 20, 23, 26 | February 2009: 3, 6, 9, 12, 15, 18, 21, 24, 27 |
| March 2009: 1, 4, 7, 10, 13, 16, 19, 22, 25, 28, 31 | March 2009: 2, 5, 8, 11, 14, 17, 20, 23, 26, 29 |
| April 2009: 3, 6, 9, 12, 15, 18, 21, 24, 27, 30 | April 2009: 1, 4, 7, 10, 13, 16, 19, 22, 25, 28 |
| May 2009: 3, 6, 9, 12, 15, 18, 21, 24, 27, 30 | May 2009: 1, 4, 7, 10, 13, 16, 19, 22, 25, 28, 31 |