THE WRF PROCESS: STREAMLINING THE TRANSITION OF NEW SCIENCE FROM RESEARCH INTO OPERATIONS

Nelson Seaman[1],
NOAA/NWS/Office of Science and Technology, Silver Spring, MD

Robert Gall and Louisa Nance
Development Testbed Center
National Center for Atmospheric Research, Boulder, CO

Steven Koch and Ligia Bernardet,
NOAA/OAR/Forecast Systems Laboratory, Boulder, CO

Geoffery DiMego,
NOAA/NWS/NCEP/Environmental Modeling Center, Camp Springs, MD

Jordan Powers,
National Center for Atmospheric Research, Boulder, CO

and Frank Olsen,
Northrup-Grummann, Inc., at Air Force Weather Agency, Offutt AFB, NB

1. INTRODUCTION

Beginning in 1998, a partnership was forged that now encompasses seven organizations (NCAR, NCEP, AFWA, FAA, NOAA/OAR, NRL and the Office of the Oceanographer of the Navy), its purpose being to build and sustain a "next-generation" mesoscale NWP modeling system for research and operations. Unlike traditional approaches to numerical weather prediction (NWP), the Weather Research and Forecast (WRF) system is not only a community *model*, but is also an *infrastructure* that facilitates scientific collaboration and interoperability, and a *process* that promotes continuous infusion of new science and technology for use in NWP research and operations. Over the past six years, most basic components of the WRF modeling system have been built and tested. Large portions of WRF software have been made available for distribution to the researcher community and the first operational implementation of WRF is scheduled for 1 October 2004 at NCEP.

Without exception the application of new models intended for operations requires extensive, rigorous testing and evaluation over many cases in all seasons to ensure accurate predictions and code integrity. However, the heavy computational demand of such massive testing often strains the resources of operational centers, which must maintain their daily production schedules while continuing development and maintenance of their existing codes. Similar limitations often restrict the thoroughness with which developers can test and evaluate new models before their distribution to the research community.

2. THE WRF TEST PLAN

The Development Testbed Center (DTC) was created in 2003 as a key part of the WRF infrastructure to accelerate testing and evaluation of new models and developmental codes. The first task of the DTC was to design and execute the WRF Test Plan. The Test Plan is a collaborative effort by scientists from NCAR, FSL, NCEP, AFWA, and Northrup-Grumman to examine a range of model configurations for possible implementation by NCEP in a high-resolution WRF ensemble prediction system. While the immediate application is the development of an NCEP WRF ensemble, many elements of the Test Plan provide a basis for rigorous evaluation of future WRF versions as well.

2.1 Model Configurations

The current battery of tests was conducted on domains corresponding to NCEP's High-Resolution Windows (HRWs), (Figure 1). The tests were limited to three regional domains covering the CONUS, plus an Alaska domain. Eight model configurations were prepared for the tests (Table 1). These were designed around the two WRF dynamical cores: the Eulerian mass (EM) core developed by NCAR (to be renamed the Advanced Research WRF core, or ARW) and the Non-

[1]Corresponding author address: Dr. Nelson L. Seaman, NOAA/NWS/NCEP, W/NP2 WWBG, 5200 Auth Road, Camp Springs, MD 20746

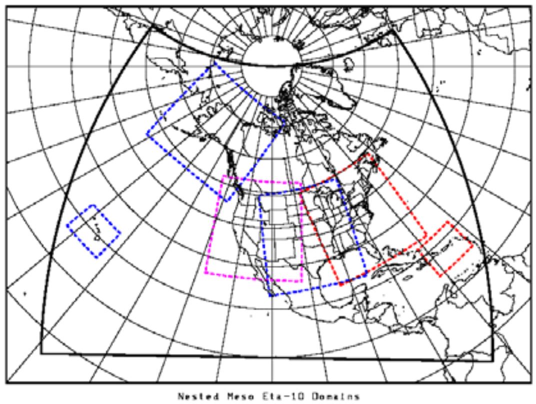

Figure 1. NCEP's six High-Resolution Windows domains (dashed) embedded in the North American domain of the Eta model (solid).

Table 1. Model Configurations for the WRF Test Plan.

Config. No.	Dynam. Core	Analysis Source	Pert. IC/BCs	Physics Suite
B1	EM	RUC	NO	NCAR
B2	NMM	EDAS	NO	NCEP
S3	EM	RUC	NO	NCEP
S4	NMM	EDAS	NO	NCAR
P5	EM	RUC	YES	NCAR
P6	NMM	EDAS	YES	NCEP
N7	EM	RUC	YES	NCAR
N8	NMM	EDAS	YES	NCEP

hydrostatic Mesoscale Model (NMM) developed by NCEP. The first two are the base configurations (B1 and B2 in the table) that used the original physical parameterization suites associated with each core (includes convection, explicit microphysics, land-surface, turbulence and radiation parameterizations). All configurations built on the NMM core used initial conditions (ICs) interpolated from the NCEP Eta model by FSL's Standard Initialization (SI) software. Configurations built on the EM used ICs interpolated by the SI from the RUC model on the CONUS domains, but ICs from Eta were used on the Alaska domain because the RUC does not extend far enough northward. All eight versions used boundary conditions (BCs) interpolated by SI from Eta. All NMM configurations had 60 vertical levels and a horizontal resolution of 8 km. The EM configurations had 50 levels and 10-km horizontal resolution to approximately balance the computational requirements of EM and NMM. Configurations B1 and B2 can contribute to the variability of an ensemble by representing uncertainties due to the model dynamics.

Next, Configurations S3 and S4 are similar to B1 and B2, except that the original physics suites are swapped between the cores. Thus, in S3 EM was configured with NCEP's physics suite and in S4 the NMM was configured with NCAR's physics. These experiments were designed to add variability to a potential ensemble resulting from different well-tested sets of parameterizations for the dominant physical processes. They also allowed evaluation of the relative importance of physics versus dynamics in the solutions.

Finally, four configurations were designed in which positive (P5 and P6) and negative (N7 and N8) bred anomalies ("perturbations") are added to the ICs/BCs. The bred anomalies were extracted from runs of the NCEP Global Forecast System on a case-by-case basis and interpolated to the ICs/BCs of the HRWs, so that perturbations were cycled from one case to the next. Thus, each model core received a positive and negative pair of bred perturbations designed to represent in an ensemble (at least to a degree) uncertainties originating from imperfect observations and analysis methods.

2.2 Running the Test Plan Cases

The eight model configurations described above were applied to a full month of fully cycled cases from each of four seasons: August 2002, October 2002, February 2003 and May 2003. To allow for regional differences, all cases for each month were run on two selected domains. For August 2002, the model configurations were run on the West and Central HRW CONUS domains. For October 2002, all configurations were run on the East CONUS and Alaska domains. February cases were run on the East and West CONUS domains, while May cases were run over the East and Central CONUS domains. Altogether, this generated 16 model runs (eight configurations on two domains) for each of 121 cases, yielding 1936 model runs.

Computational resources were supplied by NOAA/OAR's Forecast Systems Lab and the Navy's NAVO facility at Bay St. Louis, MS. Since FSL ran on a large Linux cluster and NAVO used an IBM SP-4 system, all WRF software was ported across the different platforms and carefully benchmarked before the Test Plan runs began. Software originating from NCEP and NCAR also was retro-checked from FSL and NAVO to ensure accuracy of the results across computer platforms. Once the codes and platforms were qualified as reliable, all the experiments were run in about six months. NCEP and FSL model validation software is being used to calculate and plot statistics by domain, month, level and variable. New software developed by NCEP will allow different combinations of experiments to be ensembled together and evaluated during the summer of 2004. Here we will show only a few examples from the statistical evaluations, with more thorough presentations given in other papers published in the preprints volume of the 2004 WRF Users' Workshop.

2.3 Results from the WRF Test Plan

Figure 2 gives an example of results now emerging from evaluations of the Test Plan experiments. It shows the August 24-h daily precipitation bias scores and equitable threat scores for the first four WRF Exps., plus Eta. The runs B1 (red) and S4 (black), both using the NCAR physics, tend to over-predict the heavy precipitation bins (high bias), while runs S3 (blue) and B2 (gray), using the NCEP physics, cluster with the Eta (dotted), which under-forecasts the heavy precipitation bins (low bias). A similar result occurs for May (not shown). Thus, for warm season rainfall, solutions are dominated by the physics rather than the dynamical cores. Additional evaluations (not shown) demonstrate that, especially in winter, wind field statistics tend to cluster according to the dynamical core, with the NMM core performing somewhat better. For the height field, EM and NMM overall tend to have comparable errors. However, the general result is that both WRF cores have statistics that are not very different than those of the operational Eta. This is a favorable result, given that the HRW domains are much smaller than that of the Eta.

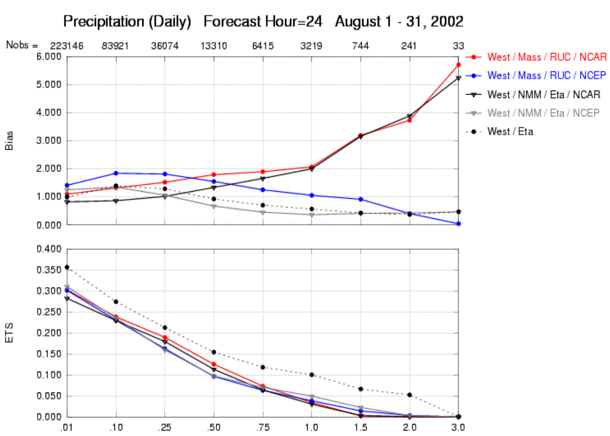

Figure 2. WRF Bias scores (top) and equitable threat scores (bottom) as a function of precipitation intensity for the western CONUS HRW domain during August 2002. Eta (dashed) is shown for comparison.

3. WRF PRECIPITATION STRUCTURE

During the same period that the modeling software was being developed for the WRF Test Plan, parallel investigations were conducted by NCAR and NCEP to better understand the fine-scale structure of pecipita-

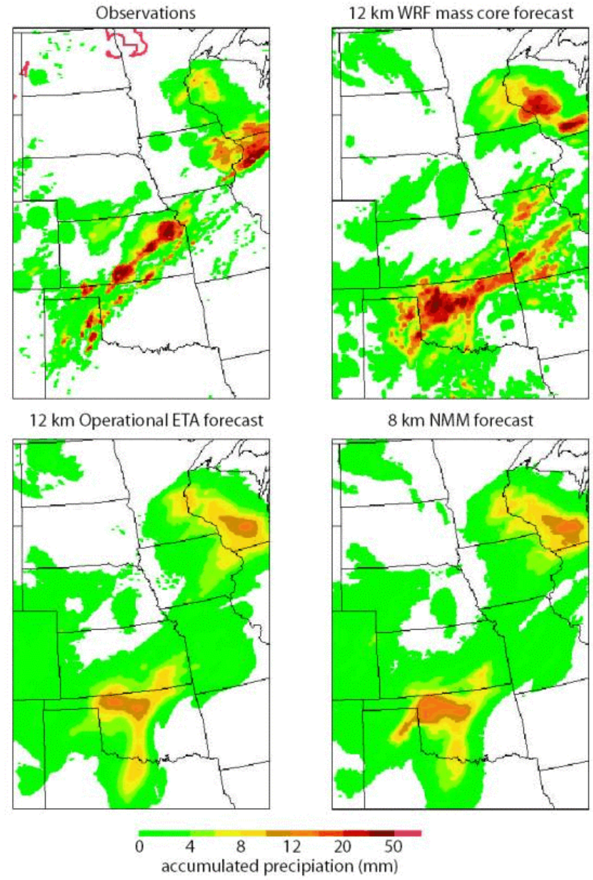

Figure 3. Observed 3-h precipitation totals (upper left) versus three model predictions for 1500-1800 Z, 4 June 2002: 12-km WRF-EM shown in upper right; 12-km Eta shown in lower left; 8-km NMM (outside WRF) shown in lower right. (After Skamarock and Baldwin, 2003).

tion fields forecasted by EM and NMM (using their native physics suites). These tests were stimulated in part by Skamarock and Baldwin (2003) who showed higher peak values and finer-scale horizontal structure in rainfall predicted by the WRF-EM with NCAR physics, compared to the Eta and NMM models with operational NCEP physics (Figure 3). When NMM was migrated into the WRF framework, it became straightforward to test the two models with swapped physics, as in the WRF Test Plan. This facilitated scientific investigation at both NCAR and NCEP (Skamarock 2004; Janjic 2004) and stimulated further experimentation with the WRF-NMM's precipitation physics. Recently, these investigations have led to the development of an experimental version of NCEP's precipitation physics capable of generating fields with higher maxima and finer-scale structure than those using standard NCEP physics. The example in Figure 4 shows more realistic rainfall in the WRF-NMM, compared to the original NMM.

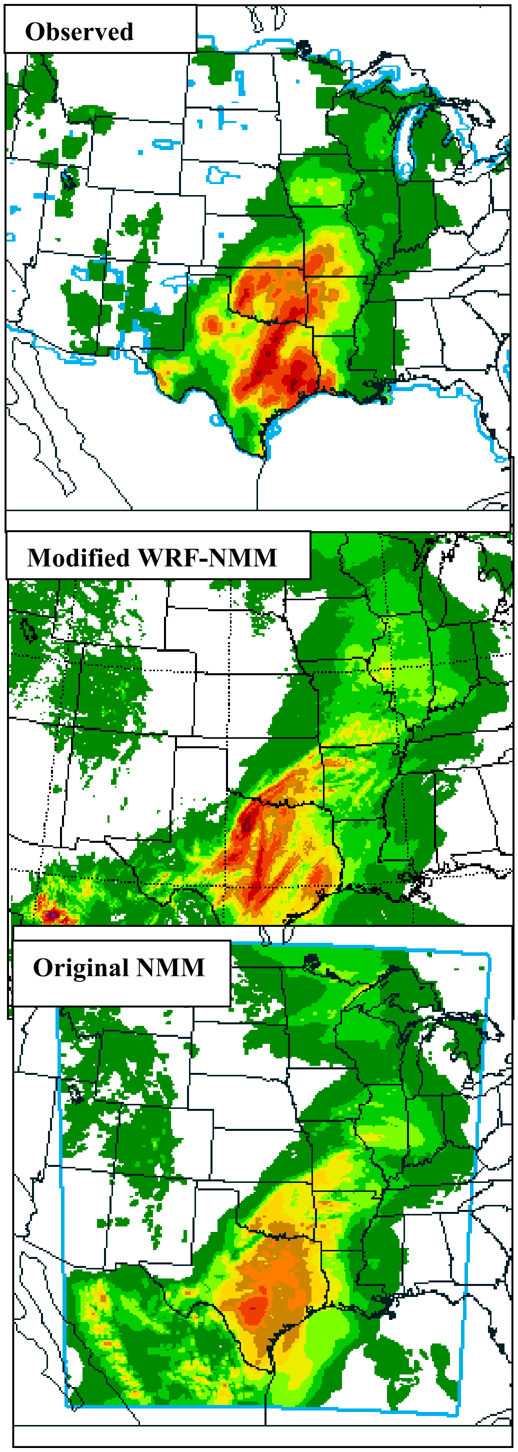

Figure 4. Observed and forecasted 24-h precipitation totals ending 12 Z, 17 January 2004.

4. SUMMARY

This paper demonstrates how the WRF process already has been successful in using the WRF model and its infrastructure to answer important scientific questions that are having an immediate effect on the first operational implementation of the WRF system. The interoperability of the dynamical cores and physical parameterization suites made possible by WRF has facilitated numerical investigations, so that nearly 2000 runs could be conducted under the auspices of the DTC in a few months. Evaluation of these runs is underway and soon will enable NCEP to construct a WRF-based mesoscale ensemble that will be implemented into operations by 1 October 2004. At the same time, the DTC will re-run many of the warm season experiments with NCEP's experimental modified precipitation physics installed in the WRF-EM and WRF-NMM. As a result, it is expected that the WRF system will produce greater structure in the precipitation fields than has been typical of NCEP operational numerical predictions in the past. Thus, the WRF process is already proving its value by accelerating the rate at which new science can be implemented into operations and made available for the wider research community.

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REFERENCES

Janjic, Z.I., 2004: The NCEP WRF core. AMS 20th Conf. on Wea. Anal. & Fcstng/16th Conf. on Num. Wea. Pred., Seattle, WA, 11-15 Jan., Paper 12.7, 21 pp.

Skamarock, W, 2004: Evaluating Mesoscale NWP models using kinetic energy spectra. Submitted to Mon. Wea. Rev., **132**, 44 pp.

Skamarock, W. and M. Baldwin, 2003: An Evaluation of filtering and effective resolution n the WRF Mass and NMM dynamical cores. Available from NCAR/MMM, 16 pp.