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ON THE OPTIMIZATION OF THE AIR FORCE WEATHER WEAPON SYSTEM'S NEXT GENERATION MESOSCALE NUMERCIAL WEATHER PREDICTION MODEL: THE WEATHER RESEARCH AND FORECAST MODEL (WRF)

Mark T. Surmeier * and Jerry W. Wegiel
HQ Air Force Weather Agency (AFWA)

1. INTRODUCTION

Air Force Weather Agency (AFWA), Air Force Weather's strategic center, delivers the highest quality tailored information, products and services to the nation's combat forces. The Air Force Weather Weapon System's (AFWWS) mesoscale numerical weather prediction (NWP) model is the key component of this support. Because all aspects of military operations are affected to some degree by the weather, it is essential this component be state-of-the-science and optimized for maximum accuracy. The Air Force Weather Weapon System's current mesoscale Numerical Weather Prediction model, the Pennsylvania State University (PSU) / National Center for Atmospheric Research (NCAR) Mesoscale Model 5 (MM5), possesses many deficiencies and does not meet many war-fighter requirements. That is why AFWA has made it a priority to address the many shortfalls of this system by partnering with the numerical weather prediction community to build the nation's next generation mesoscale numerical weather prediction model, the Weather Research and Forecast (WRF) model. Addressing these deficiencies will allow the AFWA to better anticipate and exploit the weather for battle anytime, anywhere from the mud to the sun.

The WRF modeling project has the objective of developing, maintaining, and sustaining the nation's next generation mesoscale model and data assimilation systems for the numerical weather prediction community. AFWA has contributed significant resources to the success of this project since 1998.

* *Corresponding author address*: Mark T. Surmeier, HQ AFWA, Air & Space Science Directorate, 106 Peacekeeper Drive, STE 2N3, Offutt AFB, NE 68113-4039.

2. CONTRIBUTIONS

AFWA's Department of Defense (DoD) can-do-attitude and status have brought many unique opportunities to this national effort. Specifically, as a DoD agent, AFWA has leveraged DoD resources available through the High Performance Computing Modernization Program (HPCMP). The HPCMP was initiated in 1992 in response to congressional direction to modernize the Department of Defense (DoD) laboratories' high performance computing (HPC) capabilities.

AFWA is linked to DoD's Defense Research and Engineering Network or DREN. The DREN represents one of the three components of the HPCMP. It is a robust, high-capacity, low-latency nation-wide network that provides connectivity between and among the HPCMP's geographically dispersed HPC user sites, centers, and other networks (Figure 1).

Figure 1. Defense Research and Engineering Network (DREN) map courtesy of HPCMP.

DREN connectivity has allowed AFWA to leverage the immense computational and storage resources that wouldn't be available otherwise. For instance, the Naval Oceanographic Office Major Shared Resource Center (NAVOCEANO MSRC), Stennis Space Center, MS, is one such HPC facility hosting a variety of super computing platforms. In particular, NAVO MSRC manages one of the largest IBM Processor 4 platforms in the world. The P4 is the latest and most advanced processor developed for supercomputing by IBM. It also happens to be AFWA's architecture upon which its common modeling infrastructure is based.

A second component of the HPCMP is the Software Applications Support programs. One of these two software applications support programs called the Common High-performance Software Support Initiative, or CHSSI, was instrumental in accelerating and enhancing the development of the WRF model. In 1999 HPCMP awarded AFWA with a 3-year, $1.5M project titled, Weather Research and Forecast Model Development. These resources enabled WRF developers to deliver a robust, highly scalable, portable, and modular mesoscale NWP model suitable for both research and operations to the WRF community.

These resources also allowed for the development of an advanced 3-Dimensional VARiational data assimilation system, or 3DVAR. Data assimilation experts at the National Center for Atmospheric Research were so impressed with this system that they adapted it for use with their MM5 mesoscale modeling system. As a result, the Air Force Weather Agency was the first DoD numerical weather prediction modeling center to implement a 3DVAR data assimilation system into operations on 26 September 2002. The goal of developing this advanced data assimilation system was two-fold. Allow for full-spectrum utilization of this nation's multi-billion dollar remote sensing assets and prepare AFWA for the National Polar-orbiting Operational Environmental Satellite System (NPOESS) era.

Programming Environment and Training, or PET, is the second of two HPCMP software applications support programs. Fiscal year 2003 funding a project titled, Infrastructure Development for Regional Coupled Modeling Environments, was significant because it allowed AFWA, NCAR and the other principal partners in the WRF development effort to break down some of the technical and requirements-based barriers impeding other centers from joining the national development effort.

This project developed and demonstrated a flexible, reusable software infrastructure for high-resolution regional coupled modeling systems that abstracts the details and mechanics of inter-model coupling behind an application program interface (API) that also serves as the API to I/O and data format functionality. Removing such barriers is a reflection of AFWA's commitment to leveraging any and all available resources toward the national effort.

The third and final component of the HPCMP is the HPC centers themselves. AFWA advocacy has resulted in HPCMP sponsorship of a Challenge-like WRF testing and evaluation project. Specifically, the IBM P4 platform at the NAVO MSRC has been adopted as a Development Test bed Center. These resources have allowed for the execution of the community's WRF System Test Plan. Execution of said plan is a critical path requirement for operational implementation by the WRF principal partners and is the primary focus at AFWA at this time.

3. CURRENT FOCUS

The WRF system currently under development will replace AFWA's existing mesoscale modeling system in 2005. Prior to operational implementation, it is incumbent upon AFWA to determine the optimal combinations of physics packages to assure the most accurate prediction is attained in a cost effective fashion for any place on the globe. To that end, AFWA has devoted a considerable amount of effort towards thoroughly testing the end-to-end system. Real-time testing of the WRF codes began on 1 May 2001 with the beta release of WRF (Version 1.0). Migration from the height to mass coordinate version of WRF followed a year later with Version 1.2). This preliminary phase of testing was conducted on an on-site development platform at AFWA. WRF Version 1.2 was adopted for a series of retrospective tests. Significant amounts of personnel and computational resources were applied in generating several thousand WRF forecasts (Δx =15-km; forecast length = 0-48hrs) at the NAVO MSRC using eight permutations of physics options in seven regions around the world for the months of Aug 2002. A second set of simulations were conducted for the

Southwest Asia region for the period 17 Feb – 17 Apr 2003 using 16 permutations of physics options.

Performance evaluations of the retrospective runs for these time periods are presently underway. A WRF-index, loosely founded on the United Kingdom Met Office's UK NWP Index, will be used to objectively gauge the performance of these configurations of the WRF modeling system. The goal is to derive a customer-focused metric resulting in a single quantitative value. Each follow-on enhancement to the system could then be evaluated on a pre-determined set of benchmark cases. Future WRF-index values would then be normalized corresponding to the initial WRF-index value. Ideally, AFWA's WRF-index could be used to track and report changes on the performance of the modeling systems for specific customers at the desired frequency.

AFWA is in the process of porting the end-to-end system from the NAVO MSRC onto its Operational Test bed on-site at AFWA. These codes will be base lined in early November and merged with WRF Version 1.4 when it is officially released at the end of CY 2003. Version 1.4 will then be used for follow-on testing in preparation for operational implementation.

4. WAY AHEAD

The US Air Force recently took steps to increase its participation in the Joint Center for Satellite Data Assimilation (JCSDA) with the appointment of Dr. Michael McAtee of The Aerospace Corporation. Dr. McAtee will serve as AFWA's technical liaison to the JCSDA and provide onsite technical support. AFWA recently moved into the world of variational data assimilation with last year's successful implementation of the DoD's first operational 3DVAR system.

The 3DVAR system, which supports worldwide operational execution of AFWA's mesoscale forecast model, relies heavily on the use of satellite data to provide critical information over conventionally data-sparse contingency areas such as Iraq and Afghanistan. AFWA's active participation in community data assimilation efforts such as JCSDA and the Weather Research and Forecast (WRF) model are seen as key to their ability to meet the needs, present and future, of the US military. In addition to sponsoring Dr. McAtee's participation, AFWA is establishing and funding an UCAR visiting scientist position at the JCSDA. Applicants are begin sought to address one or more of the following:

- Weather Research and Forecast (WRF) system development;
- Three dimensional variational (3DVAR) and advanced four dimensional data assimilation techniques for satellite data (primary), as well as radar, wind profiler, aircraft, and other non-conventional data;
- Improved mesoscale cloud forecasting and cloud microphysics, including assimilation of real-time satellite-based cloud and precipitation information;
- Mesoscale modeling techniques, to include cumulus, boundary layer and radiation parameterizations, and radiative transfer applications for the assimilation of satellite radiance observations;

Details on the position requirements and the application process can be found at the UCAR Visiting Scientist Web Site: http://www.vsp.ucar.edu.

The JCSDA appointee, Dr. McAtee and the other members of WRF Working Group 10: Advanced Data Assimilation Systems, will be embarking on a project to develop a 4-Dimensional VARiational (4DVAR) data assimilation system for WRF. The goal of the three-year project will be to deliver a robust, scalable, portable, state-of-the-science advanced data assimilation system to the DoD for its next generation mesoscale numerical weather prediction model, WRF.

5. SUMMARY

AFWA's commitment to the national WRF project is plainly evident in the resource commitment described here. The common goal and vision shared by more than 120 devoted scientists and engineers throughout this nation have assured the WRF project remained on time and on track. At this time, the foundation has been laid for smooth transition of the WRF research project into operations. Successful transition of WRF into operations will assure there won't be any *skeletons in the closet* (ref. the National Research Council's Report, *From Research to Operations in Weather Satellites and Numerical Weather Prediction—Crossing the Valley of Death)*.

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