Mesoscale Model Development and the Meteorological Community

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Abstract: Although the U.S. remains a leader in mesoscale model development and application, the community is not fulfilling its potential. The resources of the U.S. mesoscale forecasting community are considerable; unfortunately, these assets have not been efficiently applied, with insufficient coordination among model developers and with the user community. Furthermore, important components of the mesoscale community have not been represented at the tables where critical decisions are made, most notably regarding the Weather Research and Forecast (WRF) model. This note suggests that the Developmental Testbed Center (DTC) could play a central role in enabling the U.S. modeling and forecasting community to move ahead more effectively and rapidly. A specific plan, beginning with a community workshop on mesoscale prediction, is proposed.

I. Introduction

The U.S. mesoscale prediction community is the largest in the world and possesses considerable resources. Three government numerical weather prediction centers (NCEP, FNMOC, AFWA) run operational mesoscale models, a large university community is involved in research and development of new mesoscale modeling technologies (while training the next generation of meteorologists), the private sector runs mesoscale models and uses model output to serve a wide variety of users, and real-time mesoscale prediction is occurring at dozens of locations around the nation. Over a half dozen mesoscale modeling systems have been developed during the last two decades, and the National Science Foundation and other agencies have supported basic research that provides a strong foundation for future development. A major recent achievement has been the development of WRF, a new community modeling system designed to function efficiently in modern computing environments. The fact that NCEP (Environmental Modeling Center, EMC) and NCAR (MMM) have worked together on such a national modeling system has been a major advance, as is the open architecture of the new system.

But even with all these strengths, there has been a growing realization in the meteorological community that current progress has been limited by a lack of coordination, sharing of resources, and community decision making. A major concern has been that the community is divided, with the universities generally using one set of modeling systems (MM5, RAMS, ARPS), while operational centers apply others (Eta, COAMPS); such division of effort hampers the flow of research and trained modelers to operational centers, while lessening support of academic research by national agencies.

The development of WRF marks an attempt to develop a true community mesoscale model, shared by the research and operational communities. Unfortunately, while WRF has met with some success, it has suffered from inadequate coordination, alternative visions, and a lack of broad community direction. A general model infrastructure and a dynamical core (known as the Advanced Research WRF: WRF-ARW) have been developed at NCAR. The National Weather Service developed its own next-generation model (the Nonhydrostatic Mesoscale Model, NMM), which runs within the WRF infrastructure. Thus, instead of having one community model there are now two dynamical cores that run under a single infrastructure "wrapper." The hope of having "plug compatible" physics that could move between the two cores has proven difficult to achieve. Development of a common data-assimilation system for WRF has branched into two independent paths: one taken by NCAR and the other taken by the Joint Center for Satellite Data Assimilation (supported by NCEP, NASA, AFWA and Navy). Recently, the U.S. Navy has joined the WRF fold, with the intent of adding an interface layer that allows the use of its COAMPS physics and I/O modules within the WRF infrastructure.

A further complication has been the ongoing tensions, primarily between the NCAR (MMM) and NCEP WRF developers, with each suggesting that their core is superior (better spectral characteristics, superior performance characteristics, etc.), and the concerns of NCEP (and others) about the complexities and ease of use of the WRF infrastructure.

With limited personnel and resources that have been divided between two cores, WRF development has proceeded more slowly than expected; for example, nudging, a data assimilation technique important to the short-term forecasting, regional climate, air quality and research communities, is under development but currently remains unavailable. Neither NCAR, NCEP, NRL/Monterey nor the university community appears to have the resources to make rapid progress in evaluating and improving physical parameterizations. Many physics parameterizations are not available for both cores, with plug compatibility still unattained. Model preprocessing for WRF has remained relatively primitive, although work is now proceeding to address this deficiency. A number of development teams were established to oversee WRF model improvements; unfortunately, many of these groups have been inactive. Until recently, attempts to evaluate the two WRF cores have been superficial, leaving users with insufficient information on their relative value, either as deterministic models or as components of mesoscale ensemble systems. Recently, the Developmental Test Center has begun running extensive forecast comparisons between the NMM and ARW cores that should be available soon.

The success of a community modeling system requires broad community participation and oversight, and the latter has been insufficient for WRF. The WRF effort has been directed by a limited collection of government agencies (NOAA, Navy, Air Force, FAA) and NCAR, with no direct representation of the academic and private sectors on the decision-making executive oversight board. The WRF Science Board, which was tasked to supply scientific oversight, met infrequently and proved ineffective. Recently, a WRF Research Applications Board (which meets once a year for a few hours) has been established to provide more input from the research community on model development, but WRF *decision making* is still in the hands of a limited collection of Federal agencies and NCAR. NCAR personnel sometimes claim they can speak for the universities, but in reality they do not. The burgeoning private sector, with a growing presence in research and development, as well as application of model forecasts, has no impact on decision making or prioritization. Limited input is collected at annual MM5/WRF user workshops, but in the end, NCAR and Federal agency personnel make the decisions. Without broad representation of other groups that develop and use the model, non-optimal decisions are inevitable, leaving much of the community feeling disconnected, and the lack of ownership and involvement lessens the probability of garnering additional resources.

Despite these technical and managerial obstacles, WRF can be a vehicle for rapid advancement in mesoscale modeling and for fulfilling the vision of more cooperative community development, but this will require new approaches to joint research, development, and community management of the modeling effort. Equally as important, mechanisms for facilitating more effective cooperation with and among the research and operational communities working on other modeling systems must be developed. Many of the major problems (e.g., physics parameterizations) are common to all mesoscale models and thus coordination, information sharing, and active cooperation is crucial.

II. Moving Towards a Solution: Enhancing the Role of the DTC

A Natural Centerpiece for the Mesoscale Modeling Community

A promising approach for addressing common issues and problems of the mesoscale modeling community is to expand the recently initiated Developmental Testbed Center (DTC). The Developmental Testbed Center was conceived as a facility where the numerical weather prediction research and operational communities could interact to accelerate testing and evaluation of new models and techniques both to improve the technology and to facilitate operational implementation. The DTC is a distributed facility with components at the National Center for Atmospheric Research (NCAR DTC), NOAA's ESRL/GSD (Earth System Research Laboratory, Global Systems Division), and at the Naval Research Laboratory (NRL) in Monterey. This center, with limited funds, is currently involved in testing/supporting both the ARW (NCAR) and NMM (NWS) dynamical cores of WRF. It also supports a small visitor's program, maintains parts of the WRF reference code, and runs WRF-NMM tutorials in Boulder. The DTC is funded by a wide range of agencies and entities (NOAA, NSF through NCAR, AFWA, and the FAA) and is not a model developer. With wide-ranging support and the fact that it is not an advocate of single modeling system, *the DTC appears to be uniquely placed to bring the mesoscale community together and serve as a neutral arbiter and resource for the entire community*.

National Mesoscale Coordination and the DTC

This section will outline a plan to promote increased cooperation and coordination for the U.S. mesoscale modeling community. For the reasons noted above, this proposal give the DTC an expanded role in mesoscale model coordination and testing. The following are some suggested steps to build a new community-based approach to model development and application.

(1) The community should organize a workshop on the future of mesoscale prediction.

The organizers of this gathering should encourage attendance from the entire modeling/forecasting community, as well as users of mesoscale model output, to critically, but creatively, discuss the future of U.S. mesoscale modeling research, development, and operations. The need for community coordination and resource sharing as well as the potential role of the DTC should be the major topics of this gathering. A well-attended community forum on the U.S. Weather Prediction Enterprise (July 2005) showed that there is considerable interest in community-wide solutions, and the proposed meeting would be a natural follow-on that could propose specific steps towards new cooperative approaches. The sponsors/organizers of last year's community forum (American Meteorological Society, the Weather Coalition, and others) would be particularly appropriate to lead the proposed gathering. Such a meeting is now planned for the end of June 2006.

(2) A community modeling coordinating committee (CMCC) should be established, replacing the current DTC Advisory Board.

A committee that represents the full range of the mesoscale prediction community is needed: one that would help coordinate the community's activities and provide national leadership regarding prioritization of research and development activities. This committee should include individuals from the operational community and mission agencies, the academic and private sectors, as well as the user community. With the guidance from its working groups (see below), this committee will highlight areas in which additional efforts or cooperation are needed and will work to gather/coordinate resources to insure rapid progress and reduce unnecessary duplication. In addition to coordinating community research and development, it would hold regular fora and workshops to secure community input and guidance on important modeling issues. A possible approach to establishing such a board would be an expansion of the current DTC Advisory board. The purview of the proposed board would be far larger than the current DTC board, with its considerations including, but not limited to, WRF.

(3) *Standing, active* working groups should be established for guiding the development of key aspects of weather prediction model development.

Greater progress in model development and more effective use of national resources requires a higher level of cooperation and coordination than currently exists. To do so requires frequent comprehensive reviews of the state of the science, with recommendations on prioritization. The first attempts at such review were completed by the various Prospectus Developments Teams (PDTs) of the U.S. Weather Research Program (USWRP). Although many of the PDT reports were very well done, they are now out of date. A more recent attempt at such a review has been completed by the WRF Research Application Board (RAB). WRF has also included working groups in major modeling areas (physics, data assimilation, chemistry modeling, and others), but many of these groups have either been inactive or have met infrequently. Furthermore, these groups have been limited to the WRF modeling system.

It is proposed that the current WRF working group structure be subsumed into community working groups under the DTC umbrella. Possible working groups include:

- Model Physical Parameterizations
- Observations, Objective Analysis, and Data Assimilation

- Model Development, including the evaluation of new vertical coordinates and numerical approaches.
- Ensembles, Statistical Post-processing, and Probabilistic Prediction
- Forecast and Model Verification
- Meteorological Model Data Applications (Air Quality, Transportation, etc.)
- Modeling System Infrastructure and Optimization

Each of the working groups could have sub-groups in major areas that require coordination (e.g., a microphysics subcommittee). The working groups would take over the responsibilities for the yearly state-of-the-science review currently provided by the WRF RAB. The working groups would meet together at least twice a year with more frequent conference calls and would report to the CMCC. Through the DTC, the working groups either singly or together would sponsor topic workshops (e.g. on improving PBL parameterizations) on critical mesoscale modeling issues.

(4) The annual WRF users workshop should be followed by a workshop on community mesoscale modeling (WCM).

An important annual meeting for those interested in mesoscale modeling has been the MM5/WRF annual user workshops. These workshops have generally been structured more like scientific conferences, with large numbers of talks and insufficient time and organization for community discussion and prioritization. It is proposed that NCAR MMM continues the annual workshop as a forum for presenting and discussing WRF users results. As it does so, special care should be used to insure representation of all members of the WRF community, particularly those who use WRF-NMM. Immediately following the WRF users workshop, a new workshop on community mesoscale modeling should follow. This meeting, run by the DTC, will provide a venue for community prioritization and discussion for issues dealing with mesoscale modeling. Although WRF models and users will probably be the largest block in the community meeting, the gathering will not be limited to WRF, but rather the needs of the entire mesoscale community. As part of the community meeting there will be reports from the community working groups on the current state of development efforts and proposed future priorities.

(5) Other DTC Responsibilities

Holding meetings, determining community priorities, and serving as a coordinating body requires only modest resources. With additional resources the DTC can be effective in other important areas:

a. **Developing a state-of-the-art evaluation facility for testing model dynamical cores, data assimilation and physics parameterizations**.

One of the major current deficiencies of U.S. mesoscale modeling efforts is a lack of robust verification and evaluation of model and parameterization performance. Substantial personnel and computing resources are required for such work. A suite of test simulations and access to real-time modeling is a prerequisite for such evaluation and verification, with the necessary highly trained personnel. In addition, access to the full operational and archived data streams is required, as is the availability of a wide range of forecast evaluation tools. DTC could serve as the central U.S. facility for providing comprehensive, state-of-the-art verification for current operational and research versions of U.S. mesoscale modeling systems.

b. Insuring that a wide variety of physical parameterizations are available for WRF dynamical cores.

As noted above, physics interoperability has not been generally achieved due to a number of reasons, such as lack of resources to insure WRF interface standards are followed. DTC could have a dedicated group of scientists that will work with model and physics developers to insure that more physics packages can work effectively in the WRF framework and for all dynamical cores.

Although the DTC can play a critical role in organizing and coordinating the U.S. mesoscale community, as well as serving crucial roles such as being the repository of WRF reference codes, it will not serve in the role of a model developer. Such development work will be remain at NCAR, NCEP EMC, NRL Monterey, and at the many university modeling efforts around the nation (e.g., UOK ARPS, Colorado State RAMS).

An Example of the Proposed System

Consider the following example. Surface temperature verification statistics from the DTC, NCEP, and regional real-time prediction efforts indicate a substantial warm bias when shallow cold layers occur near the surface. An initial examination of this problem by the model physics working group suggests that the problem is widespread and closely connected with PBL parameterization failure at night under stable conditions. The problem is presented to the Community Mesoscale Coordinating Committee (CMCC), which decides that priority needs to be given to this problem. The committee calls for a special workshop on this issue. After the workshop, the committee prepares an action plan: NSF, NOAA, DOD, Forest Service and EPA will fund a joint research program with a field component, with NCAR and university scientists playing a major role (joined by colleagues at Federal laboratories). The problem is identified and a collection of new parameterizations are developed. The new schemes are tested by DTC and several regional real-time efforts for a wide variety of historical and real-time events, with several private sector firms (wind energy industry) offering an evaluation using their data resources. After comprehensive testing the best schemes are released as part of the WRF reference code and made available for other modeling systems.

Closing Comments

Coordination, Not Co-option

The structure described above is directed towards creating a mechanism for national coordination and resource sharing. Parties involved in this new structure are free to follow their own needs, prerogatives, and priorities. It is both hoped and expected that the value of working together will provide substantial benefits that will motivate continued cooperation, coordination and resource sharing. Such has been the experience in the Northwest Regional Modeling consortium (Mass et al 2002), which has tested many of the approaches described above on a more limited scale.

Moving Together or Moving Apart

Given the obvious difficulties that accompany community modeling, there are some who feel that their organization would do better on its own, controlling their own modeling system and tailoring it to meet the needs of their specific users. But such an approach can promote duplication in a fiscal environment where resources are limited, and can result in the lack of critical mass for solving key problems. The separation of operational and research communities has been a profound drag on U.S. prediction efforts and must be overcome. Only by combining community resources and knowledge can the U.S. insure leadership in mesoscale modeling and numerical weather prediction.

Mesoscale model development requires the resources and input from the entire community, with all sectors of the community sharing in key decisions. WRF and mesoscale modeling development must move in this direction if it to realize its potential. A promising example is the Earth System Modeling Framework (ESMF) development, which has taken on the community governance paradigm. The DTC, and the coordinating committees it establishes, can help move the mesoscale modeling community in this direction. Although the DTC effort can assist all U.S. mesoscale-modeling efforts, the WRF model will be its priority. Under the above plan, WRF can be transformed from a predominantly developer-driven modeling system to one that is customer driven.

Resources for WRF Development and the DTC

A number of agencies and groups have made significant contributions to WRF development and the DTC. NOAA funding has supported the development of the WRF-NMM core and its implementation (along with the WRF-ARW core) in NWS applications and operations. NOAA has also contributed substantial funding for the DTC. FAA has provided resources to adapt WRF codes for more accurate prediction of aviation-sensitive variables. AFWA, which is now moving to WRF as its predominant modeling system, has been a major supporter of WRF development and the DTC. NSF, through its support of NCAR, has provided funds for WRF development as well as the DTC. The NSF has also played a critical role in supporting the underlying science and technologies supporting modern weather prediction, from parameterizations (e.g., the

IMPROVE project and microphysics improvements) and observing systems (e.g., new water-vapor sensing technologies for use on commercial aircraft developed at NCAR), to entire mesoscale modeling systems (e.g., ARPS). As WRF develops into the predominant national mesoscale development effort, NSF should become a major participant on the planning councils and as a contributor to shared community resource requirements, particularly pertaining to facilitating the underlying science that provides the foundation for numerical weather prediction. As WRF takes on an increasing national role and as greater community involvement is effected through the reforms described, other major agencies interested in mesoscale model application (e.g., EPA, USDA Forest Service, U.S. DOT) can be expected to become increasing resource contributors to the effort. The aggregate support of the academic community is a huge resource, ranging from model and physics development and the creation of new data assimilation approaches, to testing the model for a wide range of research and real-time cases and training future users of the modeling system. The potential of private sector support is considerable, including the provision of proprietary observing system information for verification/model development and the joint development of modeling technologies.