2009 Community Review of the

NCEP EnvironmentalModeling Center

Carried out by the

University Corporation for Atmospheric Research

<u>EMC Review Panel:</u>
Kelvin Droegemeier, chair
Antonio Busalacchi
John Dutton
Brian Gross
Ying-Hwa (Bill) Kuo
Michael Morgan
StevenSmith
John Towns

<u>NCEP Review Executive Committee:</u>
Frederick Carr, co-chair
James Kinter, co-chair
Gilbert Brunet
Kelvin Droegemeier
Genene Fisher
Ronald McPherson
Leonard Pietrafesa
Eric Wood

December 2009

Table of Contents

Executive Summary

The University Corporation for Atmospheric Research (UCAR) was requested in November 2008 by the National Centers for Environmental Prediction (NCEP) to facilitate a thorough and thoughtful community review of the nine centers that comprise NCEP, as well as the NCEP Office of the Director.This report summarizes the review of the Environmental Modeling Center (EMC)that was conducted by the panel that also reviewed NCEP Central Operations (NCO).

For the NOAA numerical weather and climate prediction endeavor to serve the nation adequately and be comparable tothose that are the best in the world, NOAA must ensure that EMC and NCO work to:

- Create a culture and work environment that attracts an extraordinary cadre of talented scientists skilled in various aspects of numerical weather and climate prediction. This will require innovative personnel policies, a much greater fraction of civil service positions, opportunities for advancement based on scientific and technological contributions, and systematic mechanisms and commitments for ensuring cooperation and collaboration with the national and international modeling communities.

- Deploy computer capabilities that are comparable to or better than those of other major international centers. This will require a substantial increase in computer power and data management and storage facilities;

- Provide adequate human resources to meet the stated operational mission;

- Employ data assimilation capabilities that are significantly advanced beyond those now used. This will require a careful examination and comparison of next-generation possibilities, including four-dimensional variational analysis (4D-Var) methods and ensemble Kalman filter approaches as well as a hybrid variational-ensemble approach; and

- Embrace an entirely new approach to model development and implementation. This will require a substantial effort to focus on creating a single, powerful, flexible,multi-scale atmosphere-ocean-land surface modeling approach that can be specialized to specific resolutions and time scales. It should be an effort that involves the entire national weather modeling community and engages partners from other agencies, academia, and the private sector. It will require a substantial commitment from NOAA and it is both urgent and absolutely essential to begin today in order to advance U.S. capability to an acceptable level in the decade to come.

1. Introduction

1.1 Purpose: Context and Summary of Charge

The University Corporation for Atmospheric Research (UCAR) was requested in November 2008 by the National Centers for Environmental Prediction (NCEP) to facilitatea thorough and thoughtful community review of the nine centers that comprise NCEP, as well as the NCEP Office of the Director. NCEP is organized under the National Weather Service (NWS) of the National Oceanic and Atmospheric Administration (NOAA). The nine centers include:

- Aviation Weather Center (AWC; Kansas City, MO)
- Climate Prediction Center (CPC; Camp Springs, MD)
- Environmental Modeling Center (EMC; Camp Springs, MD)
- Hydrometeorological Prediction Center (HPC; Camp Springs, MD)
- NCEP Central Operations (NCO; Camp Springs, MD)
- Ocean Prediction Center (OPC; Camp Springs, MD)
- Space Weather Prediction Center (SWPC; Boulder, CO)
- Storm Prediction Center (SPC; Norman, OK)
- Tropical Prediction Center (TPC; Miami, FL)

This report summarizes the review of EMCand was conducted by the panel that also reviewed NCO. The last major review facilitated by UCAR was conducted in 1997, with a follow-up review held in 2001.

The 2009 review of NCEP was undertaken because the centers of NCEP are viewed collectively as a critical national resource that delivers national and global weather, water, climate and space weather guidance, forecasts, warnings and analyses to its partners and external user communities. These products and services respond to user needs to protect life and property, enhance the Nation's economy and support the Nation's growing need for environmental information. As the centerpiece of the National Weather Service's science-based forecast enterprise, NCEP serves as the focal point for weather, climate and space weather modeling, analysis and dissemination of forecast products and services. As such, it is essential that NCEP be held to a set of high standards that define the quality, quantity, timeliness, impact and improvement over time of its products and services. An independent, external evaluation of the effectiveness with which NCEP is accomplishing its mission and realizing its vision was deemed necessary.

It has been over a decade since most centers have been assessed, as external reviews of each center occurred independently most recently during the period 1996 – 2001. In particular, the complementary roles and interactions among the centers were not comprehensively reviewed. The goal of the current review is to evaluate the entire range of NCEP activities, with particular emphasis on the way in which the various centers interact with each other, and in some cases rely upon each other, and with other NOAA, federal, academic and non-governmental entities.

This is a particularly appropriate time to conduct such reviews insofar as many national and international challenges have arisen that require NCEP to operate at the highest possible level of scientific and technological excellence. Examples of challenges facing the Nation for which NCEP's products and services are essential include the following:

- The growing threat of hazardous weather reached a new and staggeringly high level of severity in the 2005 hurricane season during which 28 named storms threatened the U.S. Atlantic and Gulf of Mexico coastlines, including Hurricane Katrina that caused massive damage and loss of life in New Orleans and along the Gulf coast.

- The 2007 International Panel on Climate Change released its fourth assessment report, stating unequivocally that the Earth's climate is changing at an unprecedented rate as a result, in part, of human activities. This recognition, along with the growing predictive understanding of the influence of El Niño and the Southern Oscillation, and a host of other climate factors and conditions, on climate-sensitive sectors of the U.S. population and economy, has led NOAA to begin planning for a suite of National Climate Services.

- Adverse weather continues to strongly affect the aviation industry, and the NWS' pledge of support to satisfy the weather requirements of the Federal Aviation Administration's (FAA's) new Next Generation Air Transportation System (NextGen) will place increased demands on NCEP services.

- Solar activity, in the form of flares and coronal mass ejections, has a profound influence on the Earth's atmosphere (causing beautiful auroral displays) and can project fluxes of high energy particles that can disrupt communications, navigation, satellites, electric power grids, and human space flight. Solar activity has an approximately 11-year cycle and has been at a minimum for the past few years, and is expected to rise to its next maximum in 2013. Given the increasing dependence of the U.S. and world economies on aviation, telecommunications, and the Global Positioning System (GPS), the coming Solar Maximum has the potential to be highly disruptive.

Because the threat to life and property from weather, climate and space weather anomalies has never been higher and continues to rise, the products and services of NCEP must be of the highest quality, timeliness and impact.

In order to provide a review that could be most useful to NCEP, the UCAR review was organized into five panels, each of which was asked to review two NCEP Centers both individually and as a complementary pair. The five panels were asked to review:

- AWC and SPC
- CPC and HPC
- EMC and NCO
- OPC and TPC
- SWPC

In each case, the pair of Centers was chosen specifically because the two Centers in each pair are expected to work more closely together, having affinities of mission and/or stakeholder communities.

Each panel was asked to review the Centers' vision and mission to determine its relevance, appropriateness and alignment with NCEP's strategic plan. The review also assessed the productivity and quality of the scientific activities, and the quality, relevance and impact of operational products and services. Special emphasis was placed on the ability to gauge and meet customer demand and emerging requirements, the effectiveness of activities intended to support technology transfer based on research conducted either within or outside NOAA, and the effectiveness of collaboration with the academic research community or the private sector. The review evaluated the balance between operations and research and development and assessed the plans for evolving the suite of products and services. Finally, as indicated above, the interactions of each center with its "sister" Center (except SWPC) and the outside communities were evaluated. The full charge to the review panels is provided in Appendix A.

1.2 Procedure

The review panel conducted its site visit to EMC on 7-8 July 2009. To prepare for the visit, a set of questions was provided to center leadership. In return, a comprehensive binder of material was provided to the review panel. This included responses to the panel's questions, EMC overview documents, and information on customers, products, and services; transition of research to operations; performance measures; budgets; strategic plan; etc. A web-based surveyalso was distributed to a variety of stakeholders.

During the on-site visit, EMC Director Steve Lord presented highlights of the center, including successes and challenges. Other presentations were given by branch chiefs as well as crosscutting teams. Considerable time was spent conducting interviews with branch staff and teams on topics including administration, information technology and facilities, community engagement, and science/research. Additionally, a closed lunch was held during the first day of the visit with contract employees, visiting researchers, civil servants and early career staff. The visit concluded with a briefing of initial findings and recommendations to EMCleadership and NCEP Director, Dr. Louis Uccellini.

2. Overview of the Environmental ModelingCenter

2.1 Mission and Vision

The EMC is part of NWS and one of two major supportcenters in NCEP. According to the EMC Five-Year Implementation and Operations Plan (2009-2013) document dated 21 August 2008, the mission of EMC is to:

> *Maintain, enhance and transition-to-operations numerical forecast systems for weather, ocean, climate, land surface and hydrology, hurricanes, and air quality for the Nation and the global community and for the protection of life and property and the enhancement of the economy.*

Likewise from the same document, the vision of EMC is:

> *With our partners, to be the world's best and most trusted provider of numerical forecast systems for weather, ocean, climate, land-surface and hydrology, hurricanes and air quality.*

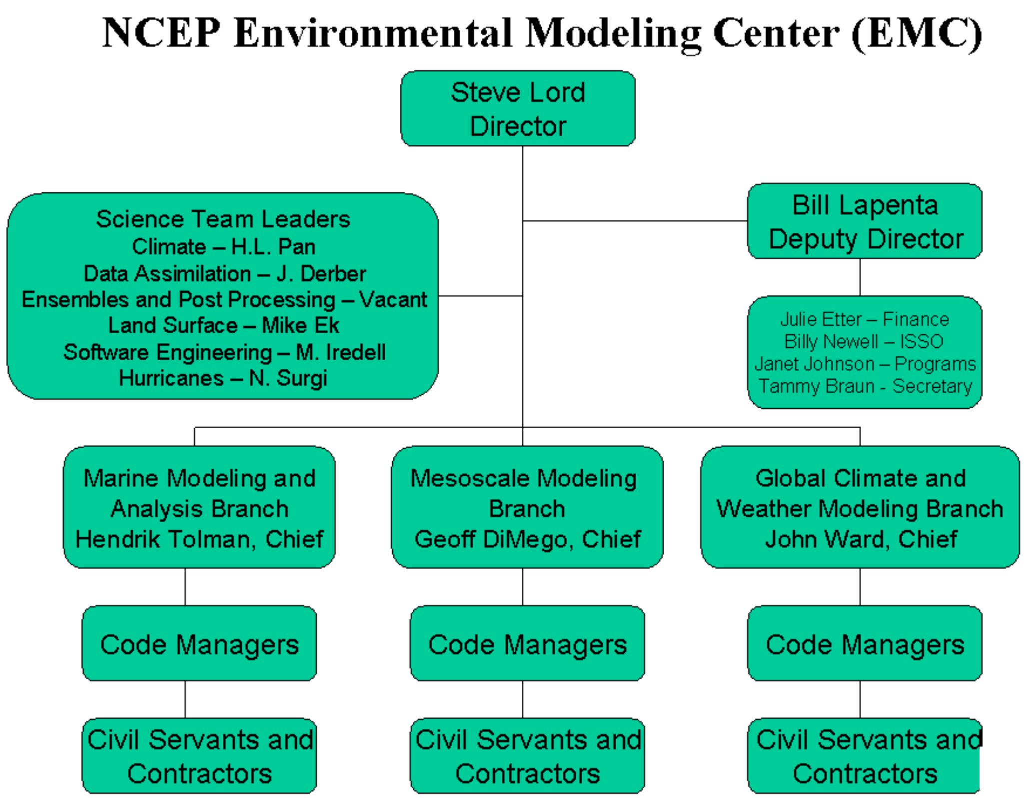
According to its web site, EMC improves numerical weather, marine and climate predictions at NCEP through a broad program of applied, mission-focused research in data assimilation and modeling. In support of the NCEP operational forecasting mission, EMC develops, improves and maintains data assimilation systems and models of the atmosphere, ocean, waves, air quality, land surface and coupled systems, using advanced methods developed internally as well as cooperatively with scientists from universities, NOAA laboratories and other government agencies, and the international scientific community.

2.2 Brief History

Formerly the Development Division of the National Meteorological Center, EMC was created as part of a comprehensive modernization of the National Weather Service, the planning for which began in the 1980s. According to McPherson(1994)[1], the guiding philosophy behind establishing EMC was to assemble a critical mass of outstanding modelers in a single location. This was in stark contrast to the decentralized and fragmented structure that preceded it.

2.3 Organizational Structure

As shown in the figure below, EMC is organized into a Marine Modeling and Analysis Branch, Mesoscale Modeling Branch, and Global Climate and Weather Modeling Branch. In response to



previous reviews (1997 and 2001), a number of crosscutting Science Teams have been assembled in climate, data assimilation, ensemble modeling and post processing, land surface

[1] McPherson, R.D., 1994: The National Centers for Environmental Prediction: Operational climate, ocean, and weather prediction for the 21st Century. *Bull. Amer. Meteor. Soc.*, 75, 363-373.

modeling, software engineering, and hurricanes. At the time of the present review, EMC staff comprised 163full-time equivalent (FTE)employees consisting of 50 civil servants, 88 contract employees, 10 visiting scientists, and 15 vacant positions for which recruitments are underway.

The Marine Modeling and Analysis Branch is responsible for the development of improved numerical marine prediction modeling systems within NCEP/NWS. It provides analysis and real-time forecast guidance (1-16 days) for waves, oceanographic, and cryospheric parameters over the global oceans and coastal areas of the US. It also monitors performance of operational guidance products and evaluates the quality of retrievals of ocean surface data from satellite borne sensors, improves their quality as needed, and examines the impacts of the data on forecast models.

The Mesoscale Modeling Branch conducts a program of applied, mission-focused research and development in support of the NCEP operational forecasting mission for mesoscale prediction. This includes mesoscale four-dimensional data assimilation of domestic satellite and conventional observations, advanced numerical techniques applied to mesoscale modeling problems, parameterization of mesoscale atmospheric processes and interactions between the atmosphere, ocean and land surfaces, diagnostic and verification studies of model performance, domestic aviation product development, domestic air quality prediction, real-time mesoscale analyses, severe weather prediction, mesoscale data quality control and data impact studies to evaluate potential improvements in forecast skill with new observing systems. The Branch, like all others, publishes research results in various media for dissemination to the world meteorological community.

Likewise, the Global Climate and Weather Modeling Branch conducts a program of applied and mission-focused research and development in support of the NCEP operational forecasting mission for global prediction. This includes topics such as four dimensional data assimilation of satellite and conventional observations on a global scale, advanced numerical techniques for modeling the atmosphere and interactions between the atmosphere, ocean and land surfaces, parameterization of sub-grid scale processes in the atmosphere, ocean and land surfaces, development of a climate data assimilation system and reanalysis studies for archival and use by the scientific community, international aviation product development, diagnostic and verification studies of global model performance, data quality control and evaluation of new observing systems, and support for tropical prediction. The branch publishes research results in various media for dissemination to the world oceanographic and meteorological community.

The six EMC science teams, composed of staff from multiple branches, contractors and visiting scientists, are designed to address crosscutting topics across the EMC suite of research and operational modeling.

3. Progress Since the Previous Review

In support of EMC's striving for international pre-eminence achieved through vision, careful planning, focused and collaborative science, and communication with and commitment to the operational and user communities, the 1997reviewteam articulated six principal recommendations for EMC. Below these recommendations are described and the progress to date on each presented.

*<u>1997 Recommendation #1:</u>*TheEMC must craft a realistic shared vision and strategic plan to encourage better teamwork, improve cross-branch collaboration, reduce unnecessary duplication of effort and improve management follow-through on important issues. The plan should delineate a path to preeminence and realistically address resources required.

*<u>Background:</u>*The 1997review team identified a set of persistent problems that dated back to the 1992 review with respect to a lack of a center-wide, long-range strategic plan and a lack of short-range goals. The 1997review team believed "that planning is a weakness within EMC, and that EMC personnel, management and external constituencies, including the annual budget process, are hampered as a consequence." Further, the 1997 review team identified the need for improved cross-branch coordination to provide team interactions and overall coordination of the scientific and operational efforts on-going in each individual branch. The review team believed that such coordination would maximize the productivity of each group in each branch and insure the most efficient use of available manpower.

Progress: The EMC conducted a Global Branch reorganization, established a data assimilation team, and adopted practices consistent with Earth System Model Framework (ESMF)-based model development for the next generation global and regional models. The EMC has also shown a planning process that is forward-thinking and encompassing of all current mandates in an attempt to leverage current and future high-end computing (HEC) resources.

*<u>1997 Recommendation #2:</u>*The EMC should restructure toward a matrix form of organization to improve cross-branch interactions in data assimilation, parameterization and numerics.

*<u>Progress:</u>*The EMC has responded to this recommendation by implementing a matrix management model,including the establishment of science teams in data assimilation, land surface processes, hurricanes, climate, software engineering, and ensemble development. The data assimilation team has aided in streamlining the development and coordination of a unified assimilation system, the Gridpoint Statistical Interpolation (GSI) scheme used by both the Global Forecast System (GFS) and the North American Mesoscale (NAM) Model. Although the use of matrix management has improved cross-branch interactions (e.g., with respect to data assimilation), it also has resulted in team leaders being drawn away from core responsibilities to staff projects funded with external resources.

*<u>1997 Recommendation #3:</u>*The EMC should be a high priority for new and redirected base funding within NWS/NCEP.

Background: During the 1997 review, the chief budget issue within EMC was the dramatic change in partitioning between base support and support via grants and contracts. The latter "soft" support had grown from a small percentage in 1986 to 49% of the $7.5 million total in FY 1995. In the opinion of the review panel, although competition for soft funds could serve as an incentive to produce better science in a more efficient manner, the partitioning of EMC's budget into base (51%) and soft (49%) support had negative consequences on staff time and on the organization's attractiveness to present and future employees. The review panel recommended that if preeminence were the goal, EMC should be a high priority for new and redirected base funding within NWS/NCEP.

*Progress:*In FY 2002, EMC received an additional $1.7 M in base funds to relieve some of its dependency on soft money. The funds were used to support civil servants previously funded via soft money as well ascontractor personnel involved in operational code support. Additional funds were used to support 20% of EMC operating costs (including office supplies and travel funds). Also in FY2002, EMC received $1.118M in base funds for augmentation of its data assimilation program conducted collaboratively with the Joint Center for Satellite Data Assimilation (JCSDA).

The dependency on external, non-base support has continued to grow.

*1997 Recommendation #4:*The EMC, with the assistance of NCEP and NWS, must find a way to distribute full resolution Eta model output to local forecast offices and other users of EMC products, including the commercial sector.

Background: In 1996 (and now as well), a large and growing demand existed for easy access to NCEP data necessary to run models in real-time at NWS local Forecast Offices and universities. Further, local Forecast Offices were not at that time able to access Eta model output at full resolution in a timely fashion.

*Progress:*The EMC has made progress in providing higher-resolution model output to NWS offices and other users of EMC products. Most notably, since the last review, EMC model output has been made available via the National Operational Model Archive and Distribution System (NOMADS) data server. The goal of distributing operational resolution model output to users outside of NCEP remains elusive due to ever-increasing model resolution outpacing data transfer and storage capabilities.

*1997 Recommendation #5:*The EMC must be able to procure high-end computing systems on the world market best suited to its needs, as requirements for upgrades are justified.

*Progress:*The EMC continues to lag behind peer global model centers, such as ECMWF, in computational capability and forecast model objective skill. While this has been a recognized need in order to compete on the global stage, it continues to be unmet within current budget and procurement processes.

*1997 Recommendation #6:*The EMC must develop mechanisms for assessing user satisfaction, including quality factors, with its products and services. The annual NWS Users' Meeting is a good first step. However, other Federal agencies, state and local governments, and a wide range of commercial enterprises make extensive use of EMC products and services, and their derivatives. They should be assessed on a regular, formal basis.

Progress: EMC now sponsors an annual NCEP Production Suite Review (NPSR) that allows all major users (representatives of NWS regions and NCEP service centers) and collaborators to identify requirements for future forecast suite elements as well as bring to the attention of EMC staff problems and issues with the current suite. Although these additional forums have provided valuable feedback, linking new requirements with increases in budgeted resources has not always occurred.

4. Summary of Stakeholder Survey

To gain a better understandingof stakeholder perspectives regarding EMC, a survey was distributed to numerous stakeholders in the military, NOAA, academic organizations, members of the American Meteorological Society (AMS), and Certified Consulting and Broadcast Meteorologists. A total of 342 responses were received.

Nearly 80% of the respondents use EMC-developed model output, and these individuals reported as their primary organization of employment another part of NCEP, another part of NOAA, military, other Federal agency, state/local government, non-profit/non-governmental organization (NGO), for-profit/private enterprise, media/broadcasting, private consulting firm, educational/academic institution, and other. Approximately 50% of those responding were from another part of NOAA or an educational/academic institution.

The strongest positive responses obtained related to the relevance of EMC products. Approximately 80% of the EMC stakeholders strongly agree or agree somewhat that EMC products and services are relevant to the stakeholder organization, and that the stakeholder organization would lose significant capability without EMC products and services. The strongest negative responses pertained to outreach, responsiveness, technology refresh, product improvement, research transition, quality of EMC products and services, and peer comparisons.

Over 33% of those responding strongly disagree or disagree somewhat that EMC has effective mechanisms for requesting input from external stakeholders; that EMC has effective mechanisms for responding to stakeholder questions and problems; that EMC is well positioned to handle a changing technology landscape in the next 5-10 years; that EMC products and services are improved at an appropriate pace; that research outcomes, including those produced within EMC as well as those brought in from external organizations and programs, are translated into useful products and services in a timely fashion; that EMC products and services represent state-of-the-art capability; and that EMC compares well against comparable organizations both domestically and internationally with which the stakeholder interacts. Many of these questions also had substantial responses that either somewhat or strongly agree with these assertions. In particular, the responses arebimodal regardingEMC's state-of-the-art capability and its comparison against comparable organizations.

5. General Observations and Overarching Issues

Weather is relevant toalmost every American almost every day. Severe weather takes a heavy toll in lives, injuries, and economic loss; prolonged climate anomalies disrupt important industries and public services. Thus, reliable prediction of important weather and climate events becomes a critical government function in support of public safety, economic vitality, and homeland security.

Today, the core of the weather prediction process is a set of complex numerical models of the atmosphere and ocean running on supercomputers that transform current atmospheric, oceanic, and land surface conditions into forecasts of weather and ocean patterns days in advance. The computer systems take observations gathered from satellites, radiosonde ascents, transport aircraft, and surface observing systems and convert them into a global mosaic of atmospheric events to come. The modelsdepict the paths of storms yet to form, the waves and meanders in the jet stream aloft, the movement and collision of air masses – cold and warm – and they give the first hint of severe weather brewing over land or over sea.

Computer-generated forecasts are the foundation for almost all NCEP and NWS weather prediction activities. The computer programs—the numerical models of the atmosphere that generate the forecasts—are developed or acquired from outside EMCand tested atEMC. Given the importance of weather to activities ranging from individual recreation to national defense, onemight expect that we as a nation and NOAA as the responsible organization would provide the resources for the U.S. computer weather forecasts to be as good as they possibly could be—to be the best in the world. But, alas, we do not.

The main theme of this review is that the level of EMC accomplishment is remarkable and laudable considering the parsimony of the resources made available. The staff is significantly over-stressed and computer capabilities and data storage facilities are woefully inadequate. NOAA personnel policies discourage and confuse rather than motivate. External funds are essential to EMC, but a plethora of individual budget lines reshape priorities and lead to distraction. As a consequence of the heroic attempt to maintain adequate capability despite inadequate resources, EMC is forced into focusing on today's problems rather than looking forward boldly and creatively to the challenges of tomorrow.

Making Computers Sing

Many atmospheric science graduate students in American universities work on research related to numerical analysis of atmospheric data or to numerical prediction of weather and climate. Many of them have been fascinated by—or obsessed with—weather from early childhood.

As they work on their thesis research, they learn to manage contemporary computer systems running the Unix or Linux operating systems used on all scientific supercomputer systems. Their monitors show screens very different from what most of us see, for these students are working with command line systems, in which the commands to the computer are typed as a few words at a time and then the lines reporting progress scroll by on the screen. Not only is this a most effective way to generate and manage complex computer programs, it becomes a badge of honor to be a command line programmer. As they learn advanced computer techniques from each other, these young men and women become members of the special community that can make computers sing.

They graduate as talented atmospheric scientists, still obsessed with weather, but now equipped with computer skills to contribute to the advance of numerical weather prediction, to create computer models that will predict the weather better than ever before.

It would seem that a national numerical weather prediction center like EMC would be a magnet for these young scientists—an opportunity to work at the top of the profession, to enjoy the accomplishments made possible by extraordinary computer resources, to be at the very center of the weather biz, to be where the nation's weather forecasts begin.

But very few jobs exist for such individuals at EMC, usually only with contractors rather than with NOAA, and other opportunities are more attractive for many reasons. And so they go off to make other computers sing.

The constant tension between unmet demands and inadequate resources has a number of adverse effects. Most significantly, EMC is widely viewed as insular and protective rather than as a leader in the national and international numerical weather prediction community. This must change, for the world of numerical weather prediction is becoming increasingly complex and demanding, requiring national collaboration to create and nurture national conceptual and software frameworks that will then enable capability at the agency or forecast center level. The national numerical weather prediction center should be a leader in this process, not a bystander.

Numerical weather prediction is changing in another dimension as well because observation and forecast systems are becoming more closely linked and interdependent. Advanced methods of preparing observational data for forecast models, along with a new generation of satellites, will soon be requiring as much computational power as forecasts themselves. NOAA spends far more on satellites to collect data than it does on the computers to turn data into forecasts.

Today, EMC and NCO are successfully meeting the needs of most clients both within the government and the private sector. The numerical products are produced and delivered on time, according to a schedule that is mutually satisfactory. But the demands on NCEP for delivery of higher and higher resolution products having increasingly greater skill will grow as increases in computer and communication capabilities in the private and academic sectors accelerate demand. Indeed, NCEP is today delivering reduced resolution versions of some of its computer products.

Heroic attempts to maintain capability despite inadequate resources are not succeeding. NOAA must provide EMC with sufficient resources so that it can develop formal processes for program management, for attracting and supporting collaboration with academia and other major forecast centers, for a research effort focused on the next generation of numerical weather prediction capabilities, and for a more formal and effective process of defining needs for computer capabilities over the next decade or two. And in providing these resources, NOAA must recognize that an EMC focused on the future, an EMC leading in development of numerical forecast capability, an EMC meeting user needs not now even imagined, will require even more resources to enhance its service to the nation. The investment will be rewarded with handsome dividends in improved management of weather and climate risk and opportunity in both the public and private sectors.

6. Findings and Recommendations

6.1Missionand Vision

The present mission statement for EMC,

“Maintain, enhance and transition-to-operations numerical forecast systems for weather, ocean, climate, land surface and hydrology, hurricanes, and air quality for the Nation and the global community and for the protection of life and property and the enhancement of the economy.”

although adequate, is uninspiring because it begins with the word “maintain.” A more effective approach would be something along the lines of “Provide the most effective numerical forecast systems…”. This suggested wording implicitly includes development, enhancement, translation, and maintenance but avoids the term “advanced” because something that is advanced isn’t necessarily most effective. Additionally, because hurricanes representa weatherphenomenon, including them in the list is redundant. Rather than listing specific phenomena or processes, which will never be complete, EMC might consider saying its forecast systems are used for atmospheric, oceanic, and environmental prediction from local to global scales and from minutes to years/decades. Finally, it is unclear whether EMC's mission is to protect life and property and enhance the economy on a global scale. The current mission statement is ambiguous in this regard because it places Nation and global community together.

The vision statement,

"With our partners, to be the world's best and most trusted provider of numerical forecast systems for weather, ocean, climate, land-surface and hydrology, hurricanes and air quality."

is much more compelling but is problematic in again providing an incomplete listing of weather phenomena and processes. Ultimately, EMC must determine whether it can indeed achieve the vision put forth. In contrast to ECMWF, which operates a single model and is structured far differently, EMC operates numerous models having different frameworks and purposes. Although EMC is moving toward a common model framework (the NOAA Environmental Modeling System, or NEMS), the sheer number of models supported, in comparison to the number of staff, may never allow it to be the "best in everything."

6.2Customers and Partners

The computer models, data processing software, and concomitant model output provided byEMC serve a diverse set of customers and engage a number of partners within other NCEP service centers, NWS forecast offices, the commercial sector, and research and education institutions. The provision of this software and expertise is consistent with EMC's vision. That the number and variety of products and services EMC delivers to its diverse spectrum of users is deemed valuable by users, as confirmed by the web-based survey, is a tribute to EMC.

The EMC's ability to sustain and advance its relationship with its partners and customers will be determined by its ability to assess and apprehend the needs of this diverse community, and by its ability to streamline the products and services it provides consistent with its stated vision and available resources. In addition, EMC's future success in numerical weather prediction is intimately linked with its ability to meaningfully interact with the research community in advancing the "state-of-the-science" used in its modeling suite.

6.2.1 Findings

*Finding CP1:*The EMC has insufficient and ineffective interaction with the research community and with other NCEP centers. Although many successful research collaborations exist involving EMC and the external community (e.g., satellite data assimilation work with the JCSDA and university collaborators, the development of storm-scale numerical weather prediction systems with the University of Oklahoma, National Severe Storms Laboratory (NSSL)and SPC), EMC acknowledges that a long-standing perception persists of its lack of receptivity to innovations from outside its walls. *The review panel believes this perception is reality*. Evidence for this is manifest in the research community's lack of understanding of EMC's necessarily highly-regimented production suite schedule, which favors fast, efficient code over what may be considered operationally incompatible, state-of-the-science capabilities. In addition, inadequate facilities for hosting meetings and workshops, an inadequately funded visiting scientist program, and an overworked staff that is unable to visit peer institutions and universities because of production deadlines contributes to a dulling of the intellectual environment so vital to EMC's success. Discussions with other NCEP service centers reveal a similar lack of connectivity with EMC.

*Finding CP2:*The EMC has too many customers, products, and services for its budget.Unlike its peer operational centers around the world, EMC has extensive mission requirements with a large number of differing model elements composing its production suite. EMC management views each component of the "jigsaw puzzle" (production suite) as sacrosanct. Even with expected (modest) increases in computing capability, the projected development and deployment of a suite of forecast models being run at increasingly finer resolution will further strain limited resources.

6.2.2 Recommendations

*Recommendation CP1:*TheEMC must be proactive in reaching out to the community, including its sister NCEP centers, to assess needs and priorities and foster more effective understanding of activities and stimulate working relationships. In order for EMC's achievements to match its vision, it must ensure that its work is addressing community needs and priorities and working effectively with its sister NCEP centers. Further, it must be more effective in engaging the research community so as to take full advantage of research developments that can enhance its operational capabilities. Although EMC conducts the annual NPSR, wherein customers and partners are invited to provide input into EMC's requirements setting process, greater engagement with the community – particularly the research community – is needed. The World Meteorological Organization (WMO) programs, including the World Weather Research Programme (WWRP), the World Climate Research Programme (WCRP; inclusive of the Global Energy and Water Cycle Experiment (GEWEX), Climate Variability and Predictability (CLIVAR), Stratospheric Processes and their Role in Climate (SPARC), and Climate and Cryosphere (CliC) programs), and the Working Group on Numerical Experimentation (WGNE) provide invaluable access to the international research community. The EMC has been historically underrepresented in these programs in comparison to its European, UK, Canadian, Australian, and Japanese counterparts.

In order to be the world's leading environmental modeling center, EMC needs to foster a vibrant, intellectually stimulating research environment by increasing interactions with the national and international research communities. Although the move to a new building undoubtedly will provide the infrastructure and environment necessary to support meetings and workshops, especially with collaborators at the University of Maryland, a robust visiting scientist program and improved use of community test beds also is needed. Further, support for EMC staff members to visit peer operational centers, including all sister NCEP centers, for extended exchanges no doubt would enhance the intellectual vitality of all participating organizations.

However, mechanistic changes such as visiting programs and new space are not sufficient; EMC needs to change its personality in working with the broader community and foster a culture of "EMC without walls" rather than the present framework in whichactivities are consideredby all as either internal or external to EMC.

*Recommendation CP2***:**The EMC must streamline its portfolio of products and services. Through greater engagement of the community, EMC must re-prioritize its products and services to ensure that planned increases in resolution, sophistication of data assimilation and physics parameterizations, and increasing number of model executions via ensembles can be achieved with the highest value possible. One consideration toward achieving this goal is the adoption of a single (unified) multi-scale modeling approach capable of global, regional, and local prediction. Although this concept has long been debated, the clear message from other prediction centers around the world is that such a framework appears to be essential for meeting tomorrow's challenges in light of unavoidable limitations in funding and staffing.

6.3 Products and Services

In most respects, EMC can be viewed as the heart of NCEP. The cadre of products and services produced operationally by EMC ultimately become the foundation of services created by other NCEP centers, NWS and domestic and international user communities. Duringthe past decade, EMC has increased significantly its production suite to include various numerical models and ensembles that produce forecast output ranging from hours to months in the future. In many respects, this increase has been viewed as synonymous with progress, and in many cases such an assessment is valid. However, the obverse is that therapid increase in new numerical models operated by EMC has created overlap within products and personnel and strained already limited resources, fundamentally limiting advancement because the addition of new models does not scale linearly with the resources needed to support them. These increased support costs could be reduced or eliminated with a new streamlined approach.

The success of EMC ultimately is based on the timeliness, availability and accuracy of the products and services created for its wide user base. In the face of advancing technology and increased competition from private organizations and international agencies, it is imperative EMC havea strategic plan that realistically melds all its available resources and utilizes them with maximum effectiveness. In that regard, EMC must look to streamline and consolidate its increasingly growing product suite.

In addition, the increasing gap in product accuracy now occurring between EMC and other modeling centers likely will continue without a new, refined approach to model and product development. This approach must be all-inclusive, incorporating all available resources within the research, academic and user communities, along with a thoughtful plan for budgeting computing resources and a rigorous review of current EMC development and production practices.

6.3.1 Findings

*Finding PS1:*The EMC is producing an enormous number of products and services that are viewed as valuable by the community. However, the growing model suite and diverging platforms of these implementations seem overbearing and potentially detrimental to future capabilities. The EMC has shown an ability to adapt and grow to fit user needs, and during the past decade, the EMC production suite has grown to include long-range and short-term ensemble products, increased resolution and forecast periods for short-range and long-range models, as well as inclusion of high-resolution mesoscale, air quality and global ocean modeling. It is commendable that EMC provides the global community with reliable, daily products; however, it is equally apparent that the current approach to development and ongoing support of these products probably isunsustainable, thus threateningachievement of EMC's vision. The EMC leadership has recognized the lack of resources needed to sustain its approach to numerical model development, including adoption of NEMS. However, the review panel did not see evidence of a strategic plan to organize available resources, both internally and across the user community, to streamline its production suite in a broader sense.

*Finding PS2:*The EMC has created several valuable and noteworthy products that clearly demonstrate its ability to successfully cooperate and synthesize the community's needs into an operational product. Specifically, it has implemented a number of major new capabilities over the past five years that showcase its ability to serve a diverse user base. Some of these advances and implementations include:

- Data Assimilation Team: Unification of the Global, Regional, Real-time Mesoscale Analyses (RTMA) with the GSI system.
- Ensemble Team: Implementation of North American Ensemble Forecast System (NAEFS) with Canada.
- Climate Team: Implementation of the Climate Forecast System (2004) and its reforecast data base.
- Hurricane Team: Implementation of the Hurricane Weather Research and Forecast (WRF) system.
- Land Surface Team: Unification of the NOAA Land Surface Model (LSM) across Global Forecast System (GFS), WRF-NMM (Non-hydrostatic Mesoscale Model) and WRF-ARW (Advanced Research WRF model) applications.
- Global Branch: Implementations in 2005 that include use of the GSI analysis, addition of a hybrid sigma-pressure coordinate to improve representation of the stratosphere, and a rewritten and modernized radiation package.
- Mesoscale Branch: Implementation of explicit-convection High-Resolution Window Runs to support the SPC/NSSL Spring Program.
- Marine Branch: Adoption of the WAVEWATCH III wave model as the defacto community operational and research standard.

The EMC leadership also recognizestheymust increase the speed with which research outcomes are transitioned to operational implementation,using an improved approach that leverages resources within theexternal research and academic communities. EMC must take a leadership role in promoting its operational needs to foster a more effective, mutually beneficial relationships with the research community.

*Finding PS3:*TheEMC understands the importance of meeting user requirements and providing high quality service.

6.3.2 Recommendations

*Recommendation PS1:*TheEMC must develop an approach to consolidate the vast number of numerical models currently being developed and supported.The EMC is to be commended for a 'can do' culture that seeks to meet expanding needs of internal and external user communities. However, EMC must find a balance between implementing new mandates, some of which are unfunded, and sustaining current mission needs. In order for EMC to push forward in what undoubtedly will be a resource-constrained environment for the foreseeable future, it must seek to eliminate the growing number of divergent numerical models currently under development or in production.

It also is apparent that the diversity of models today has placed a strain on the ability of EMC to support and quickly implement upgrades and enhancements to its production suite. In addition, inefficiencies inherently occur because some models produce similar, overlapping products, and this duplication consumes valuable staff time as well as computing resources. The EMC should develop a plan to migrate the current suite toward a more unified modeling approach that can leverage all resources currently available – from research and operations staff to computing capacity. This approach also will provide for a more suitable environment to effectively and efficiently transition visiting and on-site staff in and out of EMC.

*Recommendation PS2:*The EMC must adopt a formal approach for consistently delivering full-resolution products to the entire user community.The EMC's vast array of products has created an equally large user community that relies upon them. Unfortunately, many of the products disseminated from EMC models are substantially degraded in both temporal and spatial resolution relative to their native frameworks and are limited in other ways (e.g., representing only certain fields). As a result, EMC should take a leadership position within NCEP – working with NCO and others, given the considerable information technology (IT) issues involved – to formalize and implement an approach for disseminating full-resolution, comprehensive information from its models. Doing so will leverage the creative, developmental and computational capacity of the global community, thus providing valuable feedback for future model improvement.

*Recommendation PS3:*The EMC must work closely with NCO to ensure continuation of the current high standard of product reliability without becoming too risk averse, which could slow the progress of enhancements and upgrades to the production suite. The process of transition from research to operations (R2O) is inappropriately informal and needs a terms of reference document to improve its effectiveness. This should be jointly developed between EMC and NCO and could be one mechanism to help alleviate the organizational tensions noted elsewhere in this report.

6.4 Information Systems

The information systems (IS) infrastructure at EMC has two roles. At the high end, it encompasses supercomputing and related resources essential for developing and executing models. In addition, it includes the general IT infrastructure (desktop systems, networking, printers, etc.) of the center. We have considered both types of resources here in light of how they impact the ability of EMC to achieveits mission.

6.4.1 Findings

*Finding IS1:*High performance computing resources available at NCEP are far below those needed to achieve its goal of being the world's foremost weather and climate prediction enterprise.It has long been recognized that the lack of adequate high performance computing capability is a major factor in NCEP's less than desirable competitive position amongworld forecasting centers. Although computing power alone will not elevate NCEP to world leadership, failure to address this issue will continue to place NCEP at a notable disadvantage.

The table below, provided by the EMC Director, demonstrates the notable advances that could be wrought with thoughtful investments in a much more capable HEC system.

*Finding IS2:*TheEMC is severely lacking in non-HEC computing resources, particularly disk space, necessary to support its mission.A key limitation in the ability of EMC staff members to effectively accomplish their work is a severe lack of disk space on development systems managed by NCO. The imposed disk quotas limit not only the scale and scope of models that might be run, but they also limit the ability for developers to implement new models. Several EMC teams are experiencing this problem and it suggests a lack of effective communicationregarding EMC needs and resource provisioning decisions by NCO.

*Finding IS3:*TheEMC lacks a structured management process, of the type used in many organizations – especially those having complex structures – to ensure effective planning and resource allocation. The complete lack of formal project management is exacerbating many of the issues raised in this report.

	ECMWF Current	NCEP Current	NCEP with ECMWF Computing Resources
	NWP 2 X per day	4 X per day	4 X per day
Data Assimilation	4D-var, 25 km/91L model, 210-80 km analysis	3D-var, 38 km/64L model	4D-var, 27 km/64L model
Global Deterministic	25 km/91 L, 10 days	38 km/64L, 7.5 days; 75 km 16 days	22 km/64 L
Global Ensemble	50 km/62L, 10 days, 80 km to 15 days	75 km/28L, 15 days	50 km/64L, 15 days
Ocean Waves	40 km to 10 days, ensemble at 100 km to 15 days	56 km global to 15 days, multiple concurrent high-res nests	28 km global to 15 days and multiple concurrent nests
Monthly	50 km/62L to 1 month	100 km/64 L, 360 runs per month after reforecast project is completed	100 km/64 L, 360 runs per month
Seasonal	41 members/month, 125 km/62L to 7 months	120 members/month, 200 km/64L to 9 months	120 members/month, 200 km/64L to 9 months
Regional Deterministic	None	12 km to 84 h	4 km CONUS, 6 km Alaska, 3 km severe weather, fire weather, and aviation nests
Regional Ensemble	None	35 km, 21 members to 84 h	25 km, 21 members to 84 h
Real Time Ocean	None	10 km, North Atlantic, 5 days	global eddy resolving model
Air Quality	None	12 km CONUS to 3 days	4 km CONUS, Alaska, Hawaii to 3 days
Hurricane	None	9 km, 7500 km domain, 5 days, 8 runs	4 km, 7500 km domain, 5 days, 8 runs

6.4.2Recommendations

*<u>Recommendation IS1:</u>*TheEMC must be provided with adequate computational resources for both operations and research.TheEMC must request sufficient resources for substantially enhanced HEC capability, at the very least through the NOAA Planning, Programming, Budgeting and Execution System (PPBES) process, and leverage opportunities for using external computing resources whenever practical (e.g., from nationally available supercomputing facilities supportedby the National Science Foundation (NSF) or other agencies). The computing resources needed to support a broad range of activities, from research and development to test beds to operations, must be balanced so that today's research can be implemented in tomorrow's production suite. An objective set of guidelines must be instituted to align research computing allocation decisions with the appropriate experts at EMC and NCO, but with shared goals in mind. Procurement of new systems must accommodate requirements across the NCEP family of centers.

*<u>Recommendation IS2:</u>*TheEMC should work with NCO to implement IT solutions (e.g., desktop resources and connectivity, software) to increase flexibility and capability.This should include development of a written agreement between EMC and NCO to clearly define lines demarcating the roles and responsibilities of both organizations. As it is apparent that NCO provides many IT support services to EMC and the NCEP service centers, EMC also must have a written service agreement with NCO to clearly define the responsibilities and service levels NCO is to provide. Clear metrics should be established (e.g. time to establish an account, problem escalation) andclear definitions made of rules and procedures governing hardware and software utilization. These clarifications will help ensure effective understanding and the setting of appropriate expectations.

*<u>Recommendation IS3:</u>*Many groups within EMC need to consider using external computing and other resources, e.g., at NSF or other centers. It is clear that considerable development and test work could be performed via access to external IS resources. Although the availability of resources identical to those used for the production suite is necessary for optimization and final implementation testing, much of the functional testing and impact analysis of model changes can be accomplished using external resources. Considerable resources are available to NOAA from the NSF TeraGrid, and access to them should be vigorously pursued. A side benefit of such utilization includes increased interaction with and visibility in the research community, particularly in the area of HEC, networking, and data stewardship.

*<u>Recommendation IS4:</u>*TheEMC should institute formal project management practices, which will provide greater discipline and focus in planning, resource allocation, risk management and execution.Such practices will assist in balancing demands with available resources and in responding to unfunded mandates with well understood impacts and resource reallocation implications. Additionally, the planning phase of this structured process will produce clear requirements that also can feed into the planning processes of other NCEP centers.

*<u>Recommendation IS5:</u>*EMC and NCO should collaborate to implement a formal systems engineering approach to EMC-NCO processes to allow for coordination and, especially, planned evolution.Systems engineering focuses on how complex engineering projects should be designed and managed. It provides a structured approach not only to requirements-gathering, prioritization, assessment of technological capabilities, design, task planning, optimization,

testing and implementation, but also for the orderly evolution of a design and its implementation. Though it is apparent many of the elements of systems engineering are present in current EMC processes, a more formal and complete systems engineering implementation would provide structure and coordination of the processes and a better means for resource allocation.

6.5 Science and Technology

TheEMC operates a large number of modeling suites in support of its mission, including numerical forecast systems for weather, ocean, climate, land-surface and hydrology, hurricanes and air quality. In the near future, EMC may be asked to provide spaceweather and tsunami prediction guidance. With its vision to be the best and most trusted provider of numerical forecast systems, EMC is continuously challenged to stay at the cutting edge of science and technology in environmental prediction, including software frameworks, data assimilation, numerical techniques, model physical parameterizations,ensemble forecasting, coupling of Earth system modeling components, post-processing, and verification. In order to achieve this bold vision, it is essential that EMC have a vigorous in-house modeling research program and maintain strong interactions with national and international research communities.

6.5.1 Findings

*Finding ST1:*The EMC global model suite ranks 4^{th} or 5^{th} in the world, based upon objective skill scores, a rank that has deteriorated since the last review.It is patently unacceptable for the United States – given its extraordinary need for accurate weather and climate information across all sectors of society – to operate a global forecast system that lags well behind those of other nations and has continued to lose ground over the past several years. The reasons for this ranking are many and complex, ranging from inadequate computing resources to insufficient staffing levels, the latter driven by the support of too many modeling systems. This report offers specific findings and recommendations along those lines, but the review panel wishes to note here, with a clear and unequivocal statement, that *EMC global model skill cannot be allowed to remain in such an embarrassing position in the world*.

*Finding ST2:*TheEMC is effective in supporting a limited number of students (funding, hosting) and this effort should be expanded with the move to the new building.The review panelis pleased to note that EMC hosts students and has been effective guiding their work on important scientific and technical problems related to prediction science. These students will become next-generation scientists, and their involvement in operational research will help promote the continued growth and development of EMC. Through these students, EMC also develops strong interactions with university faculty and researchers, allowing new ideas to be tested for operational implementation. We strongly encourage expansion of this program with the move to the new building, which will offer greater flexibility in office space.

*Finding ST3:*TheEMC has an inadequate research visitor program. Although EMC has a significant number of visiting scientist appointments (e.g., via the SAIC contract), these positions are not truly visitor positions. Many visiting scientists have worked at EMC for a long period of time (i.e., longer than 10 years).Effectively, these long-term positions become surrogates of EMC staff, though without formal NOAA appointments. A common definition of a visitor is an individual who stays at the visiting institution not more than two years, with an intention to go back to his/her home institution. Using this standard, it is clear EMC does not have an adequate visitor program. With the need for EMC to be positioned at the cutting edge of science and technology, it is very important that a continuous flow of new ideas be maintained via a broadly inclusivevisiting researcher program.

*Finding ST4:*TheGFS performance "dropouts" represent a significant problem that must be addressed.It has been found that the NCEP GFS model experiencessignificant reductions in performance from time to time. A dropout is defined to occur when the five-day forecast 500 HPa anomaly correlation falls below 0.7. These occurrences are an important factor in explaining why NCEP global model forecast skill is not as high as that of ECMWF and UKMO, and thus eliminating dropouts is an important issue to help close the gap.

6.5.2 Recommendations

*Recommendation ST1:*NOAA, NWS, NCEP and EMC leadership must vigorously address recommendations in this report, and take other necessary actions, to propel US operational global model skill to a leadership position in the world. It is vitally important that the organizations noted above understand the importance of, and take strong action to implement, the recommendations made in this report. The many challenges described herein are substantial, yet the opportunities are equally great. Failure to act with vigorous determination and leadership – at a time when the need for effective weather and climate prediction guidance are at unprecedented levels and science and technology are advancing at record paces – would be a grave disservice to the nation.

*Recommendation ST2:*NOAA, NWS, and NCEP leadership should assist EMC in developing a vibrant, intellectually stimulating research capability and strengthen interactions with the national and international research communities.With the constant demand of operating and maintaining a large number of prediction suites that consumes most of its resources, EMC has limited ability to develop and maintain a vibrant and intellectually stimulating research program. The lack of resources also prevents EMC from having strong interactions with the national and international research communities. The lack of such interaction directly limits the ability of EMC to translate the most effective science outcomes into practice, and also limits the ability of researchers outside EMC to engage challenging research problems directly beneficial to EMC.

For example, an effective R2O transition requires investments in "operations to research" (O2R) by making the operational systems available to the research community.Doing so requires considerable resources beyond what the Developmental Test Bed Center (DTC) can provide. The review panel recommendsthat NOAA, NWS and NCEP leadership find ways of providing the resources and guidance necessary to transform EMC into an organization – recognized by the world – as the nexus of intellectually stimulating research and open interaction.

*Recommendation ST3:*NOAA, NWS, and NCEP leadership should assist EMC in developing a meaningful visiting scientist program, perhaps in conjunction with NSF, UCAR, and others. A robust visitor program would allow leading researchers from national and international research and operational institutions to visit and interact with EMC staff, resulting in promising new ideas to be tested for possible operational implementation. Such a visitor program wouldbe an important component of achieving Recommendation ST1 above. We also recommend that

NOAA and NWS leadership work with NSF and UCAR to secure additional resources for such a program.

Recommendation ST4:Accelerate the design of a flexible and adaptable modeling system that will lead to reductions in the number of individual models operated by EMC. As noted earlier in Recommendation PS1, EMC is operating and maintaining a large number of individual models, thusconsuming a significant fraction of EMC resources and placing a strain on its ability to interact with the research community, pursue new initiatives, and meet unanticipated requirements. EMC must make a serious effort to reduce the number of individual models within its operational suite. A unified modeling approach, as that now being pursued with NEMS,is needed to leverage available resources, both in terms of personnel as well ascomputational capacity.

An excellent example of thisrecommendation in action is the GSI system, which is being used for global, regional and mesoscale data assimilation. No reason exists to continue the development of the Regional Spectral Model (RSM) and Eta models, knowing that the primary model framework to be used for regional and mesoscale prediction is WRF (NMM and ARW). We strongly encourage EMC to look seriously at all modeling systems and accelerate the design of NEMS that will lead to reductions in the number of individual models. In this context, EMC also should consider maintaining common physics suites for regional and global models. The recommended reduction in the number of individual models (and model components) would free existing EMC resources for other purposes, as noted above. This recommendation bears on issues such as the present capability and future plans of the Short Range Ensemble Forecast (SREF), which though valuable represents yet another arguably unnecessary challenge in managing a large portfolio of models.

Finally, EMC should vigorously pursue a broad spectrum of approaches to data assimilation in the context of NEMS, especially hybrid ensemble-variational techniques as are now being developed jointly by EMC, the NOAA Earth System Research Laboratory (ESRL) and the National Aeronautics and Space Administration (NASA). The reasoning behind this recommendation is that, by the time a variational-only system would be implemented by EMC some 3 to 4 years from now – given that ECMWF has been using this approach for many years – the gap between NCEP and ECMWF, and possibly other prediction centers, no doubt will have grown even wider.

Recommendation ST5:The collaborative effort between NCO and EMC on GFS performance "dropouts" should be continued and strengthened.Solving the dropout problem requires close collaboration between NCO and EMC staff, and the review panel notes with satisfaction that a joint NCO-EMC team has been established to address dropouts and is making good progress. We strongly support continued emphasis on the dropout problem and encourage NCEP leadership to direct adequate resources to it, perhaps by engaging external researchers on a temporary basis. Specifically, because the monitoring and quality control processing of observations rests with NCO and could be contributing to dropouts, NCO should redouble its efforts to identify potential problems that might be associated with dropouts.

6.6 Peopleand Organizational Culture

The EMC is an organization that starts withbasic scientific principles to create computer models that predict the evolution of atmospheric and oceanic events days to months in the future. It has been remarkably successful in the sense that a complex suite of models runs day and night on a very tight schedule, delivering state-of-the-art forecasts that are critical to a broad spectrum of users throughout the nation and the world.

Thus EMC today is successful, although not the "best in the world" as desiredin the vision statement. Whether it will achieve that goal in the years to come will depend on EMC leadership, staff, and organizational culture. It also will depend on whether NCEP and NOAA leadership provides the resources, flexibility, encouragement, and inspiration necessary for EMC to become the world leader in numerical prediction of weather and seasonal climate variations.

Senior leadership of NOAA, NWS, and NCEP must collaborate to strongly support and maintain a focus on the vision that EMC will be the "best and most trusted source of numerical forecast systems …". These senior leaders must ensure that the following recommendations are considered and implemented if the EMC vision is to be realized. They are responsible, and are to blame, if EMC fails to meet this clarion call for exceptional service to the nation and the world.

6.6.1 Findings

*Finding POC1:*TheEMC leadership and staff have created an organization that meets the day-to-day challenges of model development and numerical prediction and functions reasonably well.It was evident during the on-site review that the talented EMC staff members share a strong commitment to the EMC mission and enjoy a rewarding satisfaction in their accomplishments and contributions. The EMC Director has an impressive, detailed understanding of the tasks at hand and the challenges that must be met. The Director, Deputy Director, Branch Chiefs, and Team Leaders appear to work well together.

The EMC staff members view the leadership team as strong advocates for employees and for the organization as a whole, although communication and guidance from the top of the organization to lower levels could be improved so that all employees understand both priorities and impediments to progress.

*Finding POC2:*TheEMC accomplishments mask a number of serious stresses and strains that are likely to prevent it from attaining its vision as "best in the world".Some of the problems are internal to EMC, some a consequence of NOAA and federal personnel policies. The most significant internal challenge concerns the apparent lack of willingness on the part of EMC leadership to recognize the reality of insularity, work collaboratively with NCO to resolve important differences that are impeding progress, and be disciplined in scaling back and consolidating the number of models and related systems so as to achieve the EMC vision. The EMC staff members are overwhelmed with many projects and cannot focus on achievements that will lead to preeminence. Senior staff is working at an overload pace that cannot be sustained, and NCEP leadership does not seem to appreciate the severity of, or be willing to address, these challenges.

*Finding POC3:*TheEMC organizational structures and workforce planning need attention. The EMC has responded to previous review recommendations by implementing a matrix management model. However, the main use of the model has been to staff projects funded with external resources and as a consequence, team leaders are drawn away from core responsibilities. The lack of a clear delineation of mission and responsibilities for EMC and NCO creates a difficult situation for both organizations and forces staff members into ad hoc arrangements in order to circumvent tension at higher levels.

The longevity of the staff is an important advantage, though EMC is now facing considerable turnover and the loss of significant experience and knowledge. Although the federal Civil Service (CS) allows scientists to be promoted into senior ranks as scientists, NWS personnel policies seem to link promotion to acceptance of management responsibilities. Throughout EMC, ineffective and cumbersome government personnel practices work against the superior achievement evident in competing organizations that today are best in the world.

*Finding POC4:*The dependence on, and commitment to, outside funds stresses the EMC staff and deflects attention from the core tasks of the organization.NOAA provides EMC (in 2009) with direct funding of about $12M for the core mission and for 65 civil service employees. Some 30 other funding sources, including other NOAA organizations and other federal agencies, provide another $11M for a wide variety of tasks, many of them performed largely by employees of EMC contractor companies. This portfolio requires considerable attention of EMC executives and senior scientists and distracts them from core mission.

*Finding POC5:*TheEMC seems to focus on day-to-day demands rather than on the bold and innovative advances required to achieve its vision.The EMC planning seems to be incremental and fails in setting clear and definitive priorities. The culture appears to be one of risk aversion and EMC seems to be a follower—at best—rather than a leader in the now global movement toward collaborative community numerical models and frameworks. The plethora of models EMC maintains consumes the strength of staff and requires duplication of scientific and programming effort.

*Finding POC6:*Although NextGen represents a potentially transformative activity for NCEP, little evidence exists that EMC recognizes the importance of NextGen and is planning effectively for it.The meteorological services required to support higher density, trajectory-based operations and integrative decision support frameworks in NextGen could radically transform how NCEP in general and EMC in particular do business. The review team saw little evidence of a thoughtful strategic plan, developed in close coordination with FAA and other relevant organizations, regarding NextGen.

6.6.2 Recommendations

*Recommendation POC1:*TheNCEP and EMC leadership need to create a new personality for the organization both internally and externally.Although a variety of technical or mechanistic solutions will be effective for addressing some of the recommendations made herein (e.g., implementation of a formal visiting scientist program, and more structured procedures for code changes), NCEP and EMC leadership must recognize that such changes alone will not solve some of the most important problems faced by EMC – problems relating to community perception regarding EMC values, EMC's willingness to consider alternative views and new ideas, and EMC's openness to collaboration. These factors are not mechanistic but rather reflect the personality of the organization, and the manner in which they are conveyed to the community rests with the EMC director. The director sets the tone for the organization, and as noted in Finding POC1, the present director does an exceptional job dealing with technical issues. However, an organization rises and falls based upon other dimensions of leadership as well, as noted above, and considerable attention needs to be given to them if EMC hopes to achieve both its technical vision and its role as international leader.

*Recommendation POC2:*TheEMC must develop and implement a more formal process for defining core mission goals and setting priorities for thoseefforts required to achieve preeminence.The strategic planning necessary to streamline EMC activities and ensure success will be demanding,difficult work. It also must be collaborative and will require considerable dedication by the best minds in the organization. Some of EMC's goals and priorities will be dependent upon resources such as computer capability and staff talent and availability. EMC cannot continue to accept new tasks without new resources, expecting overloaded staff members to adapt to even more overload. The priorities developed must provide the resolve and motivation to say 'No!' to tasks that do not represent core mission goals, are not included in priorities, and are not supported with resources. Other core goals must be more cultural and long-lasting, including a dramatic revision in the posture of the organization toward change, toward community modeling initiatives, and toward acceptance of good ideas regardless of their source.

*Recommendation POC3:*TheEMC must be bold, must take a long view, must focus on goals instead of tasks, and must put tomorrow ahead of today.Scientific understanding, computing and communications technology, observational capabilities, and demands for reliable environmental information are increasing at an accelerating pace. If EMC, NCEP, NWS and NOAA are to be relevant tomorrow, they all must start thinking very seriously *today* about tomorrow. They must start thinking about demands and opportunity brought by acceleration of change. EMC needs to encourage bold, blue-sky thinking, it needs to stimulate ideas never before considered, and it must foster those outrageous ideas that reveal the key features of the future yet to come.

*Recommendation POC4:*TheEMC must seek enlightened and challenging external advice from leaders in the field and from an EMC component of an NCEP external advisory board created under the aegis of the NOAA Scientific Advisory Board. The essential task of the external advisers and the external advisory board will be to drive EMC to embrace and implement Recommendation POC2. Then EMC can look forward to the years ahead with verve and vigor; then it can march toward its vision with both courage and confidence.

*Recommendation POC5:*All levels of NOAA must focus on ensuring that EMC has a sufficient number of sufficiently capable staff members to accomplish its core mission goals. Establishing adequate and flexible mechanisms for motivating, rewarding, and promoting talented scientists is essential to making EMC an attractive career choice. Success in developing and operating numerical models that give NCEP global preeminence requires financial, physical, computational, and human resources. Of these, human resources must be considered first and must be given highest priority. Computers cannot (yet) convert scientific principles into algorithms and convert algorithms into computer code. Working at the very heart of the U.S. weather prediction enterprise should be attractive and rewarding for many atmospheric scientists. It could be made more attractive than it is now with more flexible and more enlightened approaches to career opportunity and advancement that strike an appropriate balance among scientific management, creativity, knowledge production, and service. As an important step to improving the work environment, NCEP and EMC should create a formal orientation and mentoring program for new employees and visitors that stresses the goals, procedures, and rewards of the enterprise.

*Recommendation POC6:*NOAA must act to reduce the EMC dependence on, and commitment, to outside funds and projects.The first step is to increase the funding for civil service scientists who will contribute to the main mission. The second step should be to examine carefully whether the work supported by outside funds should be done by contract employees within EMC or whether it might be done by contract employees or private firms engaged by the agencies now transferring funds to EMC. The ratio of external to internal funds in EMC should be much smaller than it is now to ensure an adequate focus on being 'the world's best and most trusted provider' of numerical weather forecasts in the service of the nation.

*Recommendation POC6:*NOAA, NWS and NCEP leaders must significantly increase their role in planning for NextGen, especially with regard to EMC.This includes but is not limited to issues related to product and service planning, provision of necessary resources, development of effective communication strategies, and adequate frameworks for testing and evaluation.

*Recommendation POC7:*The NCEP Director should work with the Directors of EMC and NCO to address some of the cultural and other challenges responsible for creating stress between the two organizations.

6.7 Business Processes

The mission of EMC is to respond to operational forecasting requirements by maintaining the current operational production suite, identifying enhancements to it, and developing and implementing those enhancements in the next generation operational production suite. EMC business processes are crucial for the organization to complete its mission efficiently and effectively. These processes must include planning the next generation production suite, deciding how this suite will be developed and maintained, and how it will be transitioned into operations. These tasks must align with NOAA, NWS, and NCEP strategic goals, adhere to NOAA business processes, particularly those for planning, budgeting, and executing its programs, and make effective use of EMC's human resources.

6.7.1 Findings

*Finding BP1:*Linking science teams with branches in a matrix configurationresponds to previous review recommendations.At the same time, most crosscutting projects appear to be externally (i.e., soft) funded, which may reduce their likelihood of completion. Some employees interviewed during the site visit recognized the pros (exposure to multiple projects) and cons (too little, too much, or conflicting direction) to matrix management. Some of the most productive staff members are diverted from core priorities by these efforts.

*Finding BP2:*TheEMC planning lacks focus and prioritization.It is unclear how the next generation production suite will be developed. Although NPSR is the primary requirements process and is viewed favorably by NWS, EMC's role in its specification is vague, as is how NPSR integrates into NOAA's planning processes. Some concern was expressed during the site visit regarding EMC's isolation from prioritization of research in NOAA, and staff expressed a lack of clarity regarding the "right" level of research for EMC, vice development.

In part because of the lack of focus and effective planning processes, EMC has accepted too many projects, diluting the talent required to complete core achievements that will lead to preeminence. Moreover, senior staff workload cannot be sustained. Some staff members have consistently long workweeks exceeding 55 hours, in addition to substantial travel commitments.

*Finding BP3:*TheEMC has serious stresses with NCO. It appears that lines demarcating the roles and responsibilities of EMC and NCO have blurred, with the perception that these two organizations compete for "turf", particularly in processes associated with approving and implementing production suite changes. Friction arises frequently because EMC and NCO do not share the same concerns or culture. Transition to the P6-based computing system, for example, has not been a smooth one, and the unavailability of systems has prevented progress in EMC's development activities. The "moratorium" on production suite upgrades due to the HEC transition lasted far too long, and the HEC system managed by NCO lacks balance due to a shortage of disk space, further reducing the pace of EMC's research.

Further, management of IT infrastructure is rather confused, and lines demarcating the roles and responsibilities of EMC and NCO have blurred also. NCO handles many or even most approvals for items such as system accounts, email addresses, etc., and NCO appears very slow in responding, often taking 6+ months to provide approvals. This seriously impacts the value offered by visitors. NCO also has control over the approval of software and hardware usage on the network,which often places detrimental restrictions on staff. Although EMC has an Information Technology Help Desk, its staff members admittedly are not at all qualified to perform their IT security duties. All of these circumstancesare complicated by the fluid nature of NOAA security policy.

*Finding BP4:*TheEMC R2O is hampered by inadequate support for test beds and less than effective utilization.Test beds are one of the key avenues through which innovation enters the production suite. However, EMC does not always manage the test beds. For example, CPC runs the Climate Test Bed and uses it to improve CPC products, not EMC climate models.

*Finding BP5:*Federal laws, rules, and regulations impose numerous obstacles to recruiting, retaining, and promoting EMC employees, contractors, and visitors.The number of CS employees at EMC essentially is fixed and at capacity, despite a strong desire expressed by contractors and visitors to achieve a CS position, as well as funding now available to convert at least some of them. This leads to considerable difficulty in succession planning. Although some progress has been made in the CS/non-CS (or soft funded) staff ratio, the problem still remains and the current practice is unsustainable.

During on-site interviews, some contractors expressed a sense of distance from decision-making – that they are treated the same as CS employees, but with little value attached to their input. Most NOAA staff awards can go to CS employees only. Although CS pay is relatively low compared to industry and academia, flexibility promotes an acceptable work-life balance. Because physical access to and account authorization on NCEP's National Critical Systems is strictly limited due to export restrictions, contractors, especially those without US citizenship, face a lengthy and difficult process, beyond EMC's control, to gain access to the computing resources they need. Travel requests must be made abnormally early, thus limiting the ability of staff members to participate in useful activities that have relatively short announcement lead times.

*Finding BP6:*Unattractive and unsafe facilities impede recruitment and retention.The current EMC facilities are embarrassingly inadequate, both in terms of working office space and space for conferences and meetings. This is a long-standing problem that is exacerbated by the delay in moving to the new National Center for Weather and Climate Prediction at the University of Maryland.

6.7.2Recommendations

*Recommendation BP1:*TheEMC should focus on core mission goals, including products and services, to prevent overextension, dilution and unnecessary activity.TheEMC should assess its core competencies vis-à-vis its mission, and focus its human and computing resources on maximizing the use of those competencies toward meeting mission goals. TheEMC also should integrate NOAA, NWS, and NCEP business processes, particularly PPBES planning activities, to streamline planning efforts and more effectively leverage the experience of EMC personnel. NCEP and/or EMC should have the ability to say "No!" to unfunded mandates and to the continuance of existing activities if they are not justified and core to the EMC mission. The complete lack of formal project management exacerbates many of the issues mentioned here. Implementing standard project management practices will help in many areas: planning execution, coordination and reporting. It also will help address the requirement of balancing demands with available resources and responding to unfunded requests with well understood impacts and resource re-allocation.

*Recommendation BP2:*TheEMC must be provided with adequate computational resources for both operations and research, along with a set of governance rules for these resources. EMC must request sufficient resources for substantially enhanced HEC capability, at the very least through the NOAA PPBES process, and leverage opportunities for using external computing resources whenever practical. The computing needed to support the broad range of EMC activities – from research and development to test beds to operations – must be balanced so that today's research can be implemented in tomorrow's production suite. An objective set of guidelines must be instituted to align research computing decisions with the appropriate experts at EMC and NCO, but with shared goals in mind. Procurement of new systems must accommodate requirements across the NCEP family of centers.Often, considerable functional testing and impact analysis of model changes can be accomplished with the use of external resources. Such a strategy should be pursued to allow more focused use of limited NCEP resources.

*Recommendation BP3:*TheEMC must be provided with adequate base funding consistent with its mission and vision, and adequate personnel and mechanisms for promoting, rewarding and motivating them. The ratio of CSto non-CS employees, which has long been an issue, needs to be addressed.Adequate base funding, with allowances for labor cost-of-living adjustments, will permit EMC to attack the key prediction problems that are keeping it from preeminence (e.g., drop-outs). Additional CS positions must be obtained so that qualified visitors and contractors can move into them and thereby provide EMC with capable future leadership. It is not practicable for EMC to continue with such a small ratio of CS to non-CS or soft money employees. When feasible, EMC should remove distinctions among CS, contract, and visiting staff to promote a single team approach to meeting EMC's mission. Streamlining processes for travel authorization and computer accounts also is essential.

*Recommendation BP4:*Expeditious completion of the new building and NCEP's move to it are vital to the future of EMC.TheNOAA, NWS and NCEP leadership should work collaboratively to ensure this move is completed in the most expeditious manner possible.

*Recommendation BP5:*The NCEP Director should work with the Directors of EMC and NCO to address some of the cultural and other challenges responsible for creating stress between the two organizations.

Appendix A

National Centers for Environmental Prediction Review
Charge to the Review Panels

Charge

The University Corporation for Atmospheric Research (UCAR) will carry out a review of the National Centers for Environmental Prediction (NCEP) in 2009 through a series of panels that will assess the individual Centers, their interaction with each other and with other NOAA, federal, academic and non-governmental entities to determine how effectively NCEP is accomplishing its mission and realizing its vision. In particular, for each Center and NCEP as a whole, the Review will assess:

- Statements of mission, vision and five-year plans.
- Productivity and quality of scientific activities and/or operational products and services with an emphasis on the progress since the most recent review.
- Relevance and impact of the researchand/or products. Ability to meet customer demand and emerging requirements.
- Effectiveness of activities or specific plans for transition of research to operations (R2O), including research conducted outside NCEP within NOAA, within the federal research enterprise, and in academia or the private sector.
- Effectiveness of activities or specific plans for support of research by and/or joint efforts with program elements within NOAA that provide support for or conduct research as their primary mission and also with outside entities (academia; research laboratories) via the provision of operational products, services and in-house support (operations to research - O2R).
- Balance between operational responsibilities and research and development initiatives.
- Programmatic plans for new scientific activities and operational products and services, including plans for continuations and terminations.

In addition, the Review will address any specific other issues or questions raised in the course of the review.

Procedure

1. The Review will be organized under the leadership of an Executive Committee composed of two co-chairpersons, representatives of the operational environmental prediction and NCEP user communities, and each of the chairpersons of the individual Center Review Panels. Each Center Review Panel will have 5-6 members with diverse representation from academia, federal labs and users. The Executive Committee will develop a slate of panel members in consultation with the Director of NCEP. The Executive Committee will recommend a panel review slate to the President of UCAR, who will appoint the Review Panels.

2. The following documentation will be requested from each Center and NCEP:
   - Vision and mission statement (strategic plan, if extant)
   - Organization chart and list of present staff and visitors (staff turnover since last review)
   - Summary narrative of recent highlights and accomplishments
   - Summary narrative of R2O and O2R activities
   - Summary narrative of collaborative work
   - List of publications and/or reports since last review (with sample of reprints)
   - List of products and services, along with selected samples
   - Summary of budget, sources of support and expenditures
   - The NCEP and/or individual Center responses to the reviews conducted between 1996 and 2001.

3. Each Center will be asked to submit documentation, at least one month before the on-site visit, to UCAR for distribution to Review Panel members before the on-site visit.

4. An on-site review (typically 1.5-2 days) will be conducted at each Center. The date for each review will be fixed in consultation with the Center Director and the Director of NCEP.

5. Each Review Panel will provide a preliminary briefing to the Director of NCEP at the conclusion of each on-site review.

6. Each Review Panel will write a report of its findings. A draft of the review report for each Center will be shared with the Center Director to correct any factual errors.

7. The Executive Committee will write a final report, directed to the President of UCAR, that summarizes the findings of the reviews of the individual Center as well as NCEP as a whole, and will make recommendations for improvements.

UCAR will provide administrative help for the preparation of the individual Center Review Panel reports and the final report of the NCEP Review.

Appendix B

EMC Review Panel Membership

Kelvin Droegemeier (Chair)
University of Oklahoma

Antonio Busalacchi
University of Maryland

JohnDutton
Prescient Weather Ltd
The Pennsylvania State University (Emeritus)

Brian Gross
NOAA Geophysical Fluid Dynamics Laboratory

Ying-Hwa (Bill) Kuo
National Center for Atmospheric Research

Michael Morgan
University of Wisconsin – Madison

Steven Smith
AccuWeather, Inc.

John Towns
National Center for Supercomputing Applications
University of Illinois at Urbana-Champaign

NCEP Review Executive Committee Members

Frederick Carr (Co-chair)
University of Oklahoma

James Kinter (Co-chair)
Center for Ocean-Land-Atmosphere Studies

Gilbert Brunet
Environment Canada

Kelvin Droegemeier
University of Oklahoma

Genene Fisher, Panel Chair
American Meteorological Society

Ronald McPherson
American Meteorological Society (Emeritus)

Leonard Pietrafesa
North Carolina State University

Eric Wood
Princeton University

Appendix C

Acronyms and Terms

4D-Var	Four-dimensional Variational Analysis
AMS	American Meteorological Society
ARW	Advanced Research WRF Model
AWC	Aviation Weather Center
BP	Business Practices
CliC	Climate and Cryosphere Project
CLIVAR	Climate Variability and Predictability Program
CP	Customers and Partners
CPC	Climate Prediction Center
CS	Federal Civil Service
DTC	Developmental Test Bed Center
ECMWF	European Center for Medium Range Weather Forecasts
EMC	Environmental Modeling Center
ESMF	Earth System Modeling Framework
ESRL	Earth Systems Research Laboratory
Eta	Model (Step mountain coordinate)
FAA	Federal Aviation Administration
FTE	Full-Time Equivalent
GEWEX	Global Energy and Water Cycle Experiment
GFS	Global Forecast System
GPS	Global Positioning System
GSI	Gridpoint Statistical Interpolation
HEC	High-End Computing
HPC	Hydrometeorological Prediction Center
IS	Information Systems
IT	Information Technology
IS	Information Systems
JCSDA	Joint Center for Satellite Data Assimilation
LSM	Land Surface Model
MV	Mission and Vision
NAEFS	North American Ensemble Forecast System
NAM	North American Mesoscale (NAM) Model
NASA	National Aeronautics and Space Administration (NASA)
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NCO	NCEP Central Operations
NEMS	NOAA Environmental Modeling System
NextGen	Next Generation Air Transportation System
NGO	Non-Governmental Organization

NMM	Non-Hydrostatic (WRF) Mesoscale Model
NOAA	National Oceanic and Atmospheric Administration
NOMADS	National Operational Model Archive and Distribution System
NPSR	NCEP Production Suite Review
NSF	National Science Foundation
NSSFC	National Severe Storms Forecast Center
NSSL	National Severe Storms Laboratory
NTOP	NCEP Technical Operating Plan
NWS	National Weather Service
O2R	Operations-to-Research
OAR	Office of Atmospheric Research
OPC	Ocean Prediction Center
POC	People and Organizational Culture
PPBES	Planning, Programming, Budgeting and Execution System
PS	Products and Services
R2O	Research-to-Operations
RSM	Regional Spectral Model
RTMA	Real-time Mesoscale Analysis
SPARC	Stratospheric Processes and their Role in Climate Program
SPC	Storm Prediction Center
SREF	Short Range Ensemble Forecast
ST	Science and Technology
SWPC	Space Weather Prediction Center
TeraGrid	Teraflop Grid-Based Infrastructure funded by NSF
TPC	Tropical Prediction Center
UCAR	University Corporation for Atmospheric Research
UKMO	United Kingdom Meteorological Office
WCRP	World Climate Research Programme
WGNE	Working Group on Numerical Experimentation
WMO	World Meteorological Organization
WRF	Weather Research and Forecast Model
WWRP	World Weather Research Programme