2009 Community Review of the NCEP Hydrometeorological Prediction Center

Carried out by the University Corporation for Atmospheric Research

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Executive Summary

A review of the National Oceanic and Atmospheric Administration (NOAA) Hydrometeorological Prediction Center (HPC) was conducted in June 2009 as part of a comprehensive review of the National Centers for Environmental Prediction (NCEP). The HPC review panel was asked to examine the Center's mission to determine its relevance, appropriateness and alignment with NCEP's strategic plan, in addition to assessing the quality, relevance and impact of its operational products and services, and the productivity and quality of its scientific activities.

The HPC provides a valuable service to the nation though the forecast guidance it offers related to quantitative precipitation forecasts (QPF), model diagnosis and interpretation, medium-range prediction and surface analysis. The stakeholder survey showed that many HPC products and services are widely used and are considered to be of very good quality. The review panel found the HPC staff to be hard working and dedicated. The panel noted that HPC has a very effective and widely praised international training activity. HPC has fostered a productive relationship with the Climate Prediction Center (CPC) and works well with NCEP Central Operations (NCO), resulting in an effective day-to-day delivery of their guidance products and services.

Below are the key findings and recommendations as arranged by the theme areas of NCEP's Strategic Plan. These findings and recommendations are related to each other and should not be considered in isolation. Additional findings and recommendations are in the body of the report.

Mission and Vision

The panel found that the roles and responsibilities of HPC are solid, and thoroughly consistent with its historic mission, but HPC lacks effective strategic and implementation plans, as evidenced by the material provided to the review panel. This material indicated that the current plans are insufficient and seriously lack the necessary information to guide HPC's development and evolution over the next five years. This concern impacts all aspects of the center's activities. The consequence of not having effective plans cuts across all aspects of the review, and should be seen as a significant overarching finding.

Recommendation*:* HPC needs to develop a Strategic Plan that has a long-term vision that recognizes potentially transformative elements to its mission and operations from science infusion, advances in weather forecasting and verification (including multi-model ensemble systems), changes in information systems that impact both how HPC receives observations, forecasts and related information, and how HPC will distribute its products to its users. This calls for anticipating mission evolution, and planning beyond incremental change. HPC must recognize this and engage and solicit advice from their stakeholders and other people (both within and outside of NOAA) in its plans. Guidance from the National Weather Service (NWS) administration concerning the role of central services would be beneficial. Any strategic planning must be accompanied by a detailed Implementation Plan that indicates the level of effort, interactions or reliance on other NCEP centers or NWS offices, and expected outcomes with a time schedule. Such implementation needs to consider budget implications.

Customers and Partners

The panel found many activities with significant improvement over the past decade. These include improved communication with stakeholders, particularly the NWS field offices. A daily joint map discussion with CPC offers evidence of improved collaborations within NCEP. However, interactions with the Environmental Modeling Center (EMC) are limited, and represent a missed opportunity to improve forecast models by offering verification experience and insights to EMC, and to bring cutting edge science to HPC.

Recommendation*:* Stronger partnerships with EMC (for example, development and adoption of contemporary verification metrics, interpretation and improved utilization of ensemble forecasting systems), CPC (week 2 forecast guidance), and NCO (product delivery) must be developed. Meaningful partnerships in the broader research community must also be established, including a greatly expanded visitor program, and increased outreach via the Hydrometeorological Testbed (HMT) program.

Products and Services

HPC provides well-respected products of considerable benefit to the NWS and to many other stakeholders. New product developments have been well received by stakeholders (e.g. winter weather guidance, Alaska desk, and model discussions). Unfortunately, other opportunities are not being adequately pursued such as those involving ensemble techniques and high-resolution modeling. These missed opportunities increase the risk of HPC becoming obsolete.

Recommendation*:* HPC must better recognize opportunities for creating products with significant impact, especially at smaller spatial and temporal scales, ensemble interpretation and display, and for week 2 guidance. HPC should implement specific plans for developing innovative products in these areas, and to communicate product changes in a clear and timely manner to its stakeholders. For budgetary reasons, HPC must also review and retire products and services that have limited use or impact, and develop plans to transition users for those products to alternative products that will serve their needs.

Information Systems

Internally, in several respects, HPC is ill equipped to reliably support current operations, exploit rapidly advancing technologies, or meet increasingly sophisticated user expectations.

Recommendation*:* HPC needs improved external support from the NCEP Office of the Director (OD) and NCO to develop a forward looking vision for improving its information systems.

Science and Technology

It is important that HPC recognizes that their products and services cannot be static, as the science behind their products is rapidly evolving. The future relevance of HPC products and services is dependent on HPC's successful infusion of science and technology, which would allow HPC to evolve as it must in today's environment. While a newly established visitor program and the formation of the HMT demonstrate a willingness to energize science infusion, these efforts need to be greatly expanded in order to achieve the potential benefits they afford. With currently limited science infusion activities, HPC is falling behind scientifically in several key areas. This requires a systematic engagement with the research and development community, especially those segments outside of NCEP. There are other opportunities with Office of Atmospheric Research (OAR) laboratories, visiting scientist programs and partnering with academia that can help HPC.

Recommendation*:* HPC should develop a plan with prioritized areas of science infusion (advanced verification methods, quantitative utilization of ensemble forecast systems, improved utilization of high spatial and temporal resolution models), and specific mechanisms for engaging with other NCEP units, OAR laboratories and the research community outside of NOAA, from which it is largely isolated with only sporadic interactions In addressing this, HPC should place high priority on developing an invigorated HMT that effectively partners with the above groups.

People and Organization

The panel found that HPC staff are dedicated professionals intensely focused on producing high-quality forecast products. Within HPC, there exist staff members that are knowledgeable in evolving techniques and new avenues for forecast products and services, but they are limited in their ability to develop and implement these techniques and ideas.

Recommendation*:* The HPC Director should make clear that staff initiative, creativity, and contributions are both valued and expected. Original contributions are essential to the HPC mission, and should be stimulated with the implementation of additional mechanisms for rewarding and nurturing efforts to advance the scientific envelope in the process of generating forecast products and services, and publishing in the peer-reviewed scientific literature.

Business Processes

HPC isn't sufficiently proactive in developing a forward-looking, aggressive business model, oriented on serving its stakeholders' needs with products that incorporate recent scientific advances.

Recommendation*:* HPC must develop a business model that is more demanding of its information providers (EMC forecasts and NWS data) and technology providers (NCO), and more responsive to the needs and requirements of its stakeholders. Meaningful, extensive, and sustained partnerships with the broader research community must be established immediately, through the HMT, visitor programs, and a well-articulated Strategic Plan.

1. Introduction

1.1 Purpose 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 conduct a thorough and thoughtful 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 is focused on the Hydrometeorological Prediction Center.

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 a review 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 that the nation must meet 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 Intergovernmental 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) 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 aurora displays and projecting fluxes of high energy particles that can disrupt communications and Global Positioning Satellites (GPS). Solar activity has been at a minimum for the past few years, and is expected to rise to its maximum in the next few years. Given the increasing dependence of the U.S. and world economies on telecommunications and 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 community were evaluated. The full charge to the review panels is provided in Appendix A.

1.2 Procedures

The Review Panel consisted of six members, whose names are listed in Appendix B, who were appointed by the President of UCAR. The review panel carried out a site visit to HPC on June 30 – July 1 starting at noon of the first day, and met in executive session July 2 to develop preliminary findings and recommendations, and to debrief the center director as well as the Director of NCEP on the site visit.

Prior to the site visit, documentation was requested from HPC regarding the center's mission and vision, and any strategic plan documents separate from the NCEP strategic plan. In addition they were asked to provide an organization chart and list of present staff and visitors; a summary of the center's budget and sources of support, including extramural support; list of publications and/or reports for last two or three years; material outlining recent highlights and accomplishments and collaborative work.

During the site visit the panel received presentations from the center director James Hoke and the branch chiefs (Robert Kelly for the Forecast Operations Branch and Ed Danaher for the Development and Training Branch). Additional presentations were provided on major center activities (Science Infusion, Science and Operations, Hydrometeorological Testbed, International Desk, and Information Technology and Operations). The presentations augmented the written materials provided to the panel and allowed for questions and discussion with the panel. The director's presentation addressed broadly the center's mission and vision, its staffing and budget, accomplishments and activities since the last review, its products and services, any manpower issues and future plans, including concerns and/or opportunities. The branch presentations provided information on areas of responsibilities for the branch, including workload and personnel issues, products, development and services, interactions within HPC, between NCEP centers, and outside of NCEP, and future challenges. The presentations on the major center activities provided information on their goals and those of the center; whether they are being met with current efforts; successes, weaknesses, plans and expectations; level of any interactions within HPC, between NCEP centers, and outside of NCEP, and future challenges. The panel also met separately with HPC leadership, managers, and project leaders for further discussions as well as with HPC staff in small groups. There was also a "walk-in" opportunity for any staff to meet individually with the panel. All of the above material, presentations and discussions form the basis for the findings and recommendations contained in this report.

2.0 HPC Overview

The Hydrometeorological Prediction Center (HPC) is NCEP's hydrometeorological service center, one of seven NCEP service centers across the country, helping NCEP to achieve its mission. HPC is collocated with two other service centers (the Climate Prediction Center and Ocean Prediction Center), the Environmental Modeling Center and NCEP Central Operations at the NOAA Science Center in Camp Springs, Maryland.

The HPC mission statement reads:

> *"(HPC) delivers weather forecast guidance products and services in support of the daily activities of the National Weather Service and its users"*

with the vision

> "*To be a leader in the NWS collaborative forecast process and recognized as a center of excellence by providing high-quality forecast guidance and real-time numerical model diagnostics."*

The guidance products and services include quantitative precipitation forecasts (QPFs), excessive rainfall forecasts, river flood outlooks based upon NWS River Forecast Center forecasts, heavy ice and snow guidance from the Winter Weather Desk; medium-range weather guidance; model diagnostic discussions and associated graphics tools; surface analyses and the Daily Weather Map (issued continuously since January 1, 1871); basic weather forecasts and South America, Central America, and Caribbean prognostic discussions and training.

In more detail, with regard to model diagnostics, HPC carries out real-time evaluation of Numerical Weather Prediction (NWP) models from EMC as well as evaluating models from other centers (United Kingdom Meteorological Office - UKMO, European Center for Medium Range Weather Forecasts - ECMWF, Canadian model). HPC analyzes the model output with an eye for initialization problems, run-to-run consistency, and general trends from which they develop their guidance products. Discussions are issued to Weather Forecast Offices (WFO) and posted to the Internet in multiple stages during a shift. QPFs for liquid water equivalent, issued in 6-hour time steps through Day 5 as graphics, grids, and text discussion are a primary HPC product, and one that many HPC stakeholders cite as the most important product for their organization. Since its last review in 1999, HPC has developed its Winter Weather Desk with products that include forecasts of snow and ice amounts, and forecast probability for snow and ice thresholds, visibility, event duration, and for snow accumulation on roads. The HPC Surface Analysis Desk covers the North American domain and produces the National Forecast Chart and Storm Summaries, and is responsible for advisories for inland remnants of tropical cyclones. Their short-term basic weather forecasts are 6-hourly out to 60 hours while the 3-7 day Medium Range Forecasts are over the Continental United States (CONUS), Hawaii and Alaska (the latter since 2008) and include forecasts of 500-mb height, Mean Sea Level Pressure (MSLP), and fronts covering North America, the Eastern North Pacific, and the Western North Atlantic, and maximum and minimum temperature and probability of precipitation for CONUS. These forecasts are the basis for the HPC suite of gridded products that also includes dew point, cloud

cover, wind speed and direction, and weather type. HPC is the backup to the National Hurricane Center. In addition it has responsibilities for all precipitation forecasts associated with tropical cyclones in the West Atlantic and Eastern Pacific

The HPC International Desk is a partnership with the World Meteorological Organization (WMO) and Meteorological Services in Regions III & IV that provides training that enhances the scientific capacity of the participating national meteorological services. The goal of the program is to train an international cadre of meteorologists who can face the challenges of a modern forecast office. The program utilizes a "train-the-trainer" approach with a focus on weather analysis and forecasting methodologies that are independent of specific platforms, within an operational environment at HPC followed up through distance learning and on-site training. For 20 years, HPC has sponsored a Residence Program for international visitors, which focuses on continued professional development. To date 218 visitors have participated in the program (which has a 14-18 month waiting list); these visitors include 121 from 8 countries working with the South American Desk, 93 at the Tropical Desk from 20 countries, 2 Visiting Instructors and 2 United States Air Force (USAF) visitors. The international training activities also include a trained Africa Desk Coordinator in CPC who provides a bridge between NCEP operations and CPC, and helped spin-up an African Desk effort supporting the Severe Weather Forecast Demonstration Project

HPC delivers its forecast products and guidance to a diverse set of users, of whom the 122 local NWS Weather Forecast Offices (WFO) are the primary constituents. Other users of HPC products include the aviation community, the emergency management community, the media, academia, and the general public. To meet its mission HPC is divided into the Forecast Operations Branch with 5 Senior Branch Forecasters, 21 Forecasters, 5 Surface Analysts and 2 Meteorological Technicians, and the Development and Training Branch, which includes a Science and Operations Officer, a Coordinator for the HPC International Desks, 5 Meteorologist Developers and a Hydrometeorological Testbed contractor. Since the last review the center has grown by seven meteorologists (six forecasters and one surface analyst). The activities within the Development and Training Branch appear to have changed somewhat, with the addition of the Hydrometeorological Testbed and the NWS Modernization Meteorologist position closed.

HPC provides its guidance products and participates in collaborative forecast and diagnostic activities with other NCEP centers and Federal agencies to ensure the accuracy, consistency and quality of its guidance products. HPC has also been involved with other nations' weather forecast guidance, particularly in Central, South, and Caribbean America, through its international desk, which also offers training to these countries' forecasters.

3. Progress Since Last Review

HPC has progressed significantly since the last review. This progress is attributed to management and staff responses to several recommendations in that report, and advances from NWS, NCEP and HPC's own initiative. There are also recommendations and concerns from the 1999 review where progress has been slow and where HPC and NCEP must focus effort and resources to resolve.

The panel asked for and the director reported on the response to the last HPC review, dated March 1999. Additionally, the panel asked that the center report on new developments since that review. The purpose of these requests was for the panel to hear, from the center's perspective, whether issues that arose during the last review have been addressed, and to hear about new developments, initiatives and responsibilities that have occurred since the last review.

That review found that the core competencies of the HPC included (i) Quantitative Precipitation Forecasts; (ii) model diagnosis and interpretation; (ii) medium-range prediction; and (iv) surface analysis.

The major issues and recommendations from that review included:

1. HPC resources being used for development were inadequate to sustain HPC's development needs going forward, given needed technique development and the introduction of new technologies, and that HPC needed a more disciplined approach for science and technology infusion into its processes and products.

2. There was concern that HPC's verification efforts were undergoing a gradual and serious degradation, which needed to be reversed.

3. There was the concern that HPC core competencies needed to be maintained and improved through strengthening HPC's interactions with EMC, SPC, and provider organizations such as the National Environmental Satellite, Data and Information Service (NESDIS), and through strengthening staff training and development.

4. A concern that HPC didn't fully understand its stakeholder needs (both current and evolving), with the recommendation that HPC improve identifying user needs and interactions with their users and stakeholders.

HPC management and staff have made progress in a number of important areas. These include developing a close and productive relationship with CPC and a stable working relationship with NCO, the effective use of NCEP Advanced Weather Interactive Processing System (NAWIPS), improved verification procedures and performance statistics, and the development of an evolving suite of products, notably in relation to the winter weather desk and the Alaska medium-range desk. The "synergy" meetings represent a significant positive development towards collaboration between the NCEP centers. The collection of verification data is on a stable organizational footing, with forecasters expected to take responsibility for diagnosis and correction of any factors that adversely affect their personal verification statistics. Opportunities

to assess forecaster verification statistics should be increased and used as a learning mechanism, as discussed in section 6.

Since the last review, HPC has made significant progress in fostering improved relations and communications with WFO field offices where advice and consultation now flows both ways. The use of Web-based delivery has contributed to more effective product and service delivery. Finally, we also noted an invigorated and even more effective international desk with high quality training under a most enthusiastic and capable leader.

While the panel was pleased that many concerns and recommendations from the 1999 review were addressed, in some cases HPC-identified improvements were inadequate or somewhat superficial. As an example, the recent formation of the Hydrometeorological Testbed is not adequate to address previous concerns about the need for improved science and technology infusion into HPC's processes and products, and is also inadequate to rectify the observed imbalance between development and operations. The current review team found the HMT to be essentially unfunded, undeveloped and without an adequate science plan. This is discussed further in section 6.5. There is a continuing concern that stated interactions between HPC and EMC aren't happening to the extent needed for improved model development, and that EMC participation in the daily map discussion is limited in scope and somewhat sporadic.

On balance, the Panel believes that HPC is able to satisfy its mission better today than it was 10 years ago, while continuing to exhibit some weaknesses in the performance of its mission.

4. Summary of Stakeholder Survey

A stakeholder survey was developed by the panel and sent to approximately 370 people. The stakeholder list was the same for both CPC and HPC and included a broad cross-cut of groups that utilize CPC and HPC products. The survey list included the Directors of Regional Climate Centers (non federal sites), Hydrologists in Charge or the Service Coordination Hydrologists at the NWS River Forecast Centers, the Meteorologists in Charge at the Weather Forecast Offices, additional stakeholders from other Federal agencies, state climatologists, participants from a 2008 NOAA Climate Working Group Climate Services Workshop as well as seventy randomly-selected American Meteorological Society (AMS) Certified Consulting Meteorologists(CCM), people at Regional Integrated Sciences and Assessments(RISA), both for-profit and non-profit non-governmental organizations (NGO) and educational institutions. A total of 84 individuals (23% of those surveyed) responded to the survey who identified themselves as federal employees (39%), private sector (14%), educators (11%), and media (9%), with smaller numbers of respondents in other categories.

Overall the respondents identified themselves as knowledgeable about climate and hydrometeorological information. The main results of the survey are as follows:

1. 80% of the respondents agreed that HPC products are appropriate and relevant to the mission of their organization. Further, they had high praise for HPC personnel for their professional manner with 62% agreeing (strongly or somewhat) that HPC understands their organization's hydrometeorological needs.

2. Many products were cited as providing benefits to their organizations, with the following most cited as being useful: QPF, including precipitation outlooks related to tropical cyclones, was the most identified product followed by model diagnostics and discussions. Over 80% felt that the products and services were of appropriate quality for both HPC's mission and relevant to their organization's needs. 70% agreed that without HPC's products and services their organization would lose significant capability, with replacement products mostly being model-based (reflecting QPF as being the dominant product.) Stakeholders are unclear regarding whether HPC was improving products at an appropriate pace, with the majority agreeing somewhat that the pace is appropriate and 30% being neutral; or developing new products and retiring old products at the appropriate pace – with 28% being neutral and 30% agreeing 'somewhat' that the pace is appropriate. Almost all respondents stated that the HPC products were obtained through the web along with AWIPS, over 90% agreeing that they were readily available in a timely manner.

3. The survey revealed that HPC isn't communicating effectively enough with its stakeholders. For questions related to whether HPC has effective mechanisms for requesting inputs from their stakeholders, responding to questions and problems, soliciting suggestions for improving products and services, communicating information about new products and services, or products and services planned to be discontinued, or receiving suggestions regarding products and services (possible improvements or new ones), the survey found the majority of responses were neutral or weakly positive. Specific examples of improved or additional HPC products ranged from higher resolution and regional QPF products, event-driven products, merging QPF within a climate perspective (storm return periods for, say 1, 2 and 5 day accumulations), to map zoom capabilities and better product archival.

The common themes across the survey responses are the recognition of the quality of HPC personnel; the recognition of the importance and quality of HPC's products; a need to continue to develop effective communication with their stakeholders, especially as it relates to soliciting their inputs and suggestions, and the continued development of their products to finer resolution. Most respondents interacted with HPC one-on-one in a rather informal manner. This is fine for those users that have access, but some respondents felt that they didn't have access, so HPC must clarify mechanisms for interacting with their broader user community.

5. General Observations and Overarching Issues

The review panel identified three overarching issues that cut across center activities and affect many of its functions and in some cases extend outside NCEP to the NWS and outside groups. These issues are further discussed in sections 6, but are summarized here.

5.1 Strategic and Implementation Planning

Strategic and Implementation Plans provided to the review panel are insufficient and lack the necessary information needed to guide HPC's development and evolution over the next five years. These plans should indicate that management views planning as being important and provide guidance on (i) the allocation of resources and prioritized activities, (ii) communication to HPC staff about the direction of the center, and (iii) communication of the evolution of HPC products and services to the NCEP OD, other NCEP centers, and stakeholders. The 2009-2013 Implementation Plan is revealing in that it is a relatively bureaucratic "check the box" document. This left the review panel the impression that the plan doesn't contain the required forward thinking, prioritization and articulation of the implementation activities, all of which are required to move HPC forward.

Thus, HPC appears to be a relatively static organization – performing its current operational products and services competently but under-resourcing development activities and failing to fully develop the Hydrometeorological Testbed, which should be a primary mechanism (but not the only one, as discussed in section 5.3) for science and technology infusion. The lack of effective strategic and implementation plans cuts across all aspects of the review, and should be seen as a significant overarching issue. To address this, NCEP management should require HPC to develop an effective, forward looking Strategic Plan, with a limited number of prioritized milestones and detailed implementation activities with milestones. Such a plan would provide HPC and its stakeholders focused strategic guidance in terms of science infusion, product development, and product delivery.

5.2 Potential Changes to HPC's Mission

HPC's mission is to deliver weather forecast guidance products. Yet advances in model forecasts and data systems, including multi-model ensemble systems, the creation of the Winter Weather Desk, an increased focus on extreme weather events, and medium range forecasting raises the issue of an unspoken transition from weather *guidance* products to weather *forecast* products.

For example, as the accuracy of model predictions increases, and with the advent of higher-resolution model output and sophisticated ensemble forecast systems, HPC is ideally situated to assume a leadership role in bringing the benefits of these developments to the community. Educating stakeholders on the utility and technical aspects of these products, and the important role of presenting and interpreting the underlying information to stakeholders in a manner that adds value should fit well within HPC's purview.

As the grid length of NWP models diminishes, the use of legacy QPF verification strategies becomes questionable. If these metrics are used to justify the existence of HPC, then the primary role of the organization can be questioned. The HPC should aggressively move to keep up with the emerging spatial verification strategies that are currently being developed by the research community.

Such a mission evolution may be in progress. If so, it should evolve with advice and consultation solicited from both within and external to NOAA. Mission evolution potentially affects all aspects of HPC's activities from the model forecasts it receives from EMC (and NCEP's international partners like Environment Canada, UKMO and ECMWF) to its staff and their activities, and the products and services its "desks" provide, to the generation and delivery of its the products and services for its stakeholders. The implementation plan is silent on how underlying changes to HPC's activities may affect its mission.

5.3 Improved and Expanded Engagement with the Research and Development Community

Despite HPC's stated intention to develop science and technology infusion activities under the HMT, these efforts are not yet sufficiently mature to accomplish their intended purpose. Continued incremental change will result in the HPC being increasingly isolated from the research community, and may eventually render it obsolete. Emerging techniques in QPF verification, high-resolution NWP, and ensemble prediction demand a more aggressive approach. Forecasters and developers must remain abreast of the latest developments, and difficult decisions may be needed in retiring older products. The HPC can and should provide leadership in bringing new techniques to stakeholders once their ability to add value has been established. A testbed facility is the ideal vehicle for this purpose.

For example, the development and practical application of ensemble prediction techniques loomed large in HPC's future 10 years ago, and still appears in section 4.5 of HPC's Implementation Plan. However, parts of this earlier vision remain unrealized, and more could be done to leverage research developments in this area, along with stronger coordination with other national and international ensemble prediction efforts. During the site visit, the panel heard about the use of multiple forecast models (Global Forecast System - GFS, Canadian, UK and ECMWF) in providing forecast guidance. The panel was heartened that HPC is using multi-models and ensembles in their guidance products. Nonetheless, it is the sense of the panel that the use of this information is too qualitative. There is the feeling by the panel that HPC must implement procedures to exploit more fully the information content from the forecast model suite, and in this regard is not benefiting from developments in other weather centers or by the research community to which they are inadequately connected. The concern was expressed in other areas, such as probabilistic QPF, where HPC's links into this research appear insufficient, but would help HPC meet its 2009-2013 HPC Implementation Plan (HPC-IP) goals under task 2.1.4.

Internally, HPC lacks the capacity to effect such science and technology transitions in a timely and optimal manner. Neither does it appear to have an effective program with strong and sustained interaction with those researchers outside of HPC who possess the necessary skills and

interests to collaborate with HPC. A plan to articulate such collaboration with the outside community is urgently needed.

6. Findings and Recommendations

Most of the recommendations are related to each other and should not be evaluated in isolation, but rather considered collectively. This section is divided into seven sections: Mission and Vision, Customers and Partners, Products and Services, Information Systems, Science and Technology, People and Organizational Culture, and Business Processes.

6.1 Mission and Vision (MV)

> HPC Mission: The Hydrometeorological Prediction Center delivers weather forecast guidance products and services in support of the daily activities of the National Weather Service and its users.
>
> HPC Vision: To be a leader in the NWS collaborative forecast process and recognized as a center of excellence by providing high-quality forecast guidance and real-time numerical model diagnostics.

The HPC fills a unique position within NCEP, and the NWS. The mission of the HPC is strongly tied to support services for the NWS field offices and River Forecast Centers. Since the time of the previous review, the relation between the HPC and NWS field offices has improved, and the stakeholder survey provides concrete evidence that the HPC is successfully fulfilling its mission (see section 4). For the majority of its user base, HPC understands their hydrometeorological needs, and useful new products and services such as the winter weather desk have been developed in response to these needs. Another example is found in the significant efforts that have been extended to provide guidance to the Alaska region; with forecasters there having found this guidance valuable. The review panel survey found that a large majority of respondents felt that HPC was in tune with the needs of the user community.

Finding MV1: The HPC management and staff have progressed substantially since the last review and have responded positively to the recommendations from that review. Greatly improved relations and communications with field offices are evident, for example.

Finding MV2: However, in light of its position primarily as a service organization, it remains a challenge for the HPC to retain focus on its core competencies, which are QPF, medium-range forecasting, surface analysis, and model diagnostic discussions. The written comments in the stakeholder survey raised important issues regarding future needs and products. It was stated that with WFOs becoming more event-driven and high-impact weather focused, HPC needs to follow suit, but some survey respondents described HPC's procedures as being somewhat rigid. The review panel recognizes that an operational service center requires structure in its operational format. However, the needs of its users are evolving; for example, (a) the desire for

event-based guidance (like that offered for winter weather), (b) the desire for probabilistic QPF and ensemble weather forecast guidance, (c) the need for guidance on use of improved resolution models and production of regional summaries, (d) improved model diagnostics and verification, and (e) increased use of Geographic Information Systems (GIS) technology. Thus HPC must be flexible and open in its development and delivery of products and services. As a result, inherent challenges exist at HPC involving the *prioritization* of user requests for new products and services, and developing the necessary *synergistic foci* from among the incoming requests and ongoing activities. HPC must evaluate carefully its current product development paradigm to assess whether it inhibits development of new products that would take full advantage of the latest tools and techniques available in atmospheric and hydrologic sciences.

Finding MV3: The absence of strategic guidance from the NWS concerning the future role of centrally generated products and services in NWS operations has resulted in uncertainty about the future activities in HPC, and could affect its mission. Planning for the evolution of the HPC product suite cannot proceed without such guidance. One result is that the HPC priorities with respect to products and services are somewhat diffuse and fragmented. The approach to development of products doesn't appear to reflect capabilities and technology of the 21st century with respect to improved model forecasts, ensemble content, probabilistic forecasts and web services, as examples.

This discussion is further elaborated in section 6.3 (Products and Services), but the link between current products and services, prioritizing stakeholder requests, and pushing the scientific development envelope all necessitate specific guidance. It is recognized that the HPC mission and vision are closely tied to broader NCEP priorities, but a more independent vision for the HPC is needed to allow a forward-looking focus on HPC product development and science infusion.

Some stakeholders stated that HPC is slow to infuse new scientific developments into its products. As an example, while HPC looks at ensemble forecasts from the North American Ensemble Forecast System (NAEFS), the in-house Short-Range Ensemble Forecasting (SREF) and from other centers, scientifically-based procedures must be better utilized to objectively exploit the information content from such forecast systems. As another example, HPC must utilize more effectively newly developed and evolving product and service delivery technologies that include user-focused web services for both the public and private sectors. The HPC vision requires vigorous and dynamic strategic and implementation plans. The review panel was provided and reviewed its 5-Year Implementation Plan (FY 2009 – 2013) dated September 2, 2008. Quite frankly, the plan comes across as a "bureaucratic checklist" with an implementation bullet followed by a checklist as to which years the activity will take place. The Implementation plan must avoid passive, reactive strategies for change, articulate specifically how and when the milestones will be met, with which partners, and what metrics will be used to determine its success.

Finding MV4: The Strategic and Implementation Plan provided to the review panel is insufficient and lacks the necessary information needed to guide HPC's development and evolution over the next 5 years. The current Implementation Plan, which consists of approximately 130 milestones, provides no prioritization of activities or information regarding

implementation activities. The development of an effective Strategic and Implementation Plan is critical to HPC's mission and for the effective development of new products and services for the evolving needs of their stakeholders.

Recommendation MV1: HPC needs to develop an effective, forward-looking Strategic Plan, with a limited number of prioritized milestones and detailed implementation activities. Such a plan would provide HPC and its stakeholders focused strategic guidance in terms of science infusion, product development, and product delivery. Such a plan should solicit input from its stakeholders, its partners within NCEP (e.g. EMC, CPC, NCO), and the broader research community.

6.2 Customers and Partners (CP)

Finding CP1: Customer service and partnership building are vital functions for HPC's inherently operational mandate. HPC successfully meets the majority of its customers' primary needs and provides valuable products and services. HPC's primary customer base, WFOs and River Forecast Centers (RFC), generally view the products and services of HPC favorably. However, it is also evident that the customer base is broader than its core constituency within the National Weather Service. Results from the UCAR panel stakeholder survey (section 4) suggested that there were perceived differences in how responsive HPC is to feedback or input, or sufficient information on product development. As discussed in section 6.1, HPC must be positioned to strategically anticipate emerging needs of its traditional customer while also learning about the needs or requirements of non-traditional customers.

Finding CP2: The response to the 2009 UCAR panel stakeholder survey was generally positive. The center has a clear measure of its value to its traditional customer base, especially in the realm of QPF. HPC products and services are widely used and highly respected for a wide-range of applications. However, engagement with customers does not utilize many recently developed capabilities for best practices in web services.

Finding CP3: HPC has well-established and enabling partnerships with CPC, EMC, NCO, and other NOAA institutions. However, during the panel's 4-day review of HPC and CPC, key opportunities were revealed for even stronger partnerships between HPC and CPC. Because of some overlapping interests, HPC and CPC must identify core initiatives that might benefit from joint strategic thinking and planning. One of these relates to week-2 guidance, which is discussed in detail in section 6.3.

Finding CP4: HPC relies on model forecasts from EMC as well as from other countries (specifically, from Environment Canada, UK Met Office and ECMWF). Despite considerable progress since the previous UCAR review panel report, the feedback from HPC operations to EMC could be further strengthened. The review panel feels that more structured activities with EMC around model diagnostics and verification would help EMC's model development.

Finding CP5: NCO appears to provide the technological expertise within NCEP for Internet-based product delivery, which is quickly becoming the medium for the dissemination of HPC

products for many users outside WFOs. Thus, an effective partnership with NCO is needed to meet evolving user needs. Additional findings related to information technology are in section 6.4.

Recommendation CP1: HPC must continue and strengthen its communication with its stakeholders, especially in the areas of retiring products or developing new products, and in developing effective internet-based user interactions. HPC must also continue to foster and markedly accelerate the collaborative partnership with NCEP Visiting Scientist Programs and NWS Collaborative Science, Technology and Applied Research (CSTAR) activities.

Recommendation CP2: Establish a Warning Coordination Meteorologist (WCM) at HPC to further promote HPC-customer interactions. With successful implementation of event-driven products and services, and the interpretation of evolving products, outreach to stakeholders will become increasingly important. A WCM who is conversant in both the science behind the products, and possesses an understanding how well these products work for decision makers is essential to HPC's mission. The creation of a WCM position at HPC would increase community awareness of HPC activities.

Recommendation CP3: HPC should consider more strategic engagement and interactions with emerging communities of non-traditional users (e.g., emergency managers, farmers, energy sector managers) through internet-based communications, attendance at stakeholder meetings/workshops, joint activities with RISAs, and other appropriate forums.

Recommendation CP4: EMC developers would benefit from increased participation in the HPC briefings and model diagnostic discussions. HPC does not appear to envision itself as a partner with EMC in forecast improvement. While there are currently several avenues through which HPC provides feedback to EMC (e.g. pre-implementation evaluations, the annual NCEP model review meeting, and the HPC Science and Operations Officer (SOO) contacting EMC with significant comments from HPC forecasters regarding model performance), the panel feels that the activities need to be more formalized and strengthened, and should include elements like verification assessments of routine and extreme weather, diagnostic studies, joint center "skill drop out" teams and so forth. The panel applauds the efforts of the HPC SOO, who is well equipped to foster communication between the centers.

Recommendation CP5: HPC needs to strengthen activities with NCO to provide improved web services and related technologies to its stakeholders.

6.3 Products and Services (PS)

Finding PS1: As evident from the review panel stakeholder survey, from the site visit, and from panel member interactions with the community, HPC is doing an excellent job of providing high-quality, relevant, and widely used products and services to their stakeholders. Survey respondents identified the winter weather products, model diagnostic discussion, and QPF guidance as particularly valuable.

Finding PS2: The response to the stakeholder survey (see section 4) was consistently positive. HPC products and services have important value to its stakeholders, are widely used and highly respected in a variety of applications. Survey respondents identified QPF as their most used HPC product. The review panel identified HPC core competencies as being QPF, medium-range forecasting, surface analysis, and model diagnostic discussions.

However, the spectrum of product-generation activities is quite broad, with eight different "desks" generating a disparate array of guidance products. This is often the consequence of a user-driven organization that doesn't have sufficient prioritization and focus. The 1999 UCAR review recommended that HPC tighten the focus on its "core competencies". As seen in the 2009-2013 HPC-IP, and discussed in section 6.1, new products and services are developed "based on customer and partner requests as they arise" (Milestone 1.1.3). While significant progress has been made in the implementing the recommendations from the 1999 review (see section 3), this aspect remains to be addressed, and is perhaps symptomatic of a lack of focused strategic guidance, as discussed in section 6.1.

Finding PS3: By providing its broad variety of products and services, HPC is stretched too thinly. To meet HPC's broad array of operational products and services, the center has not adequately funded science infusion (e.g. HMT) and not prioritized development activities. Development and science infusion would benefit from a more streamlined product suite, which would increase opportunities to incorporate cutting-edge science into their development activities (e.g. improved procedures for quantitatively utilizing ensemble information or improved verification procedures).

Finding PS4: For many years, HPC has out-performed raw numerical model QPF; this is a testament to the skill of its forecasters. However, as forecasts improve, ensemble techniques mature and model resolutions increase, new directions for HPC will need to be developed. This aspect was recognized in the site-review presentations by HPC staff, but this recognition also leads to questions about the direction of future product development. While some inertia in any organization is natural, it is notable that the review panel survey found only half of (11 out of 22) respondents agreed that HPC products represent state-of-the-art capability (survey question 64). Some specific findings relevant to the current and future product suite include: (i) HPC recognition that some of their products may eventually become obsolete due to continual model improvement and forecast technique evolution, and (ii) a sense of awareness by management and staff that opportunities exists to develop products at temporal and spatial scales that fall outside the current range of products. The HPC recognizes opportunities for expansion to smaller spatial scales and utilization of explicit prediction of organized convection by advanced numerical models, as well as stronger utilization of ensemble information. Currently, use of the information content available from ensemble forecast systems is greatly under-utilized.

Finding PS5: The HPC site review team is aware of the NCEP goal of "seamless" prediction from very short to seasonal time scales. By pairing the HPC and CPC reviews, the panel was in an advantageous position to consider bridging the gap between largely deterministic short-range weather forecasts and more probabilistic extended forecasts. The joint HPC-CPC map

discussion offers the opportunity for additional blurring of these realms in future product development. The review panel also notes that HPC and CPC products and services currently meet in the 1- to 2-week range. Week-2 prediction is a major challenge for techniques traditionally associated with deterministic weather prediction. Similarly, the probabilistic techniques traditionally employed by climate science contribute to forecast skill at week 2. Bridging this gap with CPC would be an important joint center achievement, and would contribute to NCEP strategic goal of seamless prediction.
Finding PS6: HPC carries some marine forecasting responsibilities for medium-range prediction over the Pacific.

Recommendation PS1: HPC management must develop a plan for streamlining the delivery of operational products and services to increase resources for development activities. Management should make sure that there is a correct balance in the Development and Training Branch such that providing operational products, say by the International Desk, doesn't negatively impact the time available for development activities. One opportunity for streamlining was identified to be the International Desk. The International Desk is a truly outstanding example of successful out-reaches and should be continued and supported in every way. However, as a desk delivering operational products outside of the U.S., it has exerted a negative impact on the time and flexibility of the HPC development team.

Recommendation PS2: HPC must recognize opportunities to develop procedures to transition their products towards smaller spatial scales and longer temporal scales, together with probabilistic content, as supported by the science. For example, improved prediction of organized warm season convection, in conjunction with the availability of explicit convection in high-resolution numerical model forecasts, represents an area in which useful predictability is not currently realized. Some members of the HPC staff recognize these opportunities but have limited capacity to act on these due to a variety of reasons that may include: limited technical knowledge, and competing duties and responsibilities. The HPC SOO should consider studies (perhaps in collaboration with the SPC/National Severe Storms Laboratory (NSSL) Spring Experiment or under the HMT) on evaluating storm-resolving model QPF output

Recommendation PS3: Development of improved skill at week 2 should be a high priority for NCEP. The week-2 development opportunity requires the skills and interests of HPC and CPC jointly applied and integrated. CPC and HPC should formally create a week-2 development team (W2DT). As recognized by co-sponsorship of The Observing System Research and Predictability Experiment (THORPEX) Program by the WMO and the World Climate Research Programme (WCRP), W2DT should apply the methodologies and metrics of the extended range weather community together with sub-seasonal predictions of the short-range climate community. A joint HPC-CPC effort stands a far better chance to generate products and services of importance and relevance to a wide range of stakeholders in need of information at this range.

Recommendation PS4: The open-ocean forecasting responsibilities should be transferred to the OPC.

6.4 Information Systems (IS)

Finding IS1: HPC faces significant challenges in trying to keep pace with emerging technologies that continue to diversify and evolve rapidly, and as other NWS units and users of NWS products become more technologically advanced. To the extent that HPC information systems and tools technologically fall behind other NWS units and other groups delivering hydrometeorological products, HPC risks becoming less relevant to the overall weather enterprise. Implementation of transformative, rather than marginal, improvements in product generation and delivery capabilities will require a more expansive paradigm in the design of products, the interface by which users access products, and the underlying technological systems for delivering products.

Operation and development of information systems within HPC are hampered by the lack of organizational interaction with and support by the NCEP Central Operations (NCO). There doesn't appear to be an effective NCEP strategy in place for HPC support that recognizes the increasing importance of information technology and systems for delivery of HPC products to increasingly diverse and sophisticated users and partners. Issues noted during the review ranged from insufficient storage of outputs to support forecast verification activities, lack of robust policies for dealing with software code patches by NCO, and the unavailability of multiple platforms for testing internet browser compatibility of new product layouts.

Finding IS2: HPC leadership is not providing a forward looking vision for improving information systems to modernize the delivery of HPC products and services. It's not clear that HPC leadership appreciates the potential of newer technologies for improved delivery of HPC products and services (e.g., user-controlled customization of products, user-controlled evaluation of forecast skill), the changing nature of software design (e.g., to provide systemic interoperability of code, databases, outputs) or implementation (e.g., through collaborative development processes).

Finding IS3: HPC Information Technology (IT) staff are to be commended for their efforts to incorporate and respond to new technologies. However, multiple responsibilities and limited training and expertise in software engineering compromise HPC's progress in incorporating technological advances into their operational processes and products.

Finding IS4: HPC clearly gives continuity of operations high priority, as it should. (For example, arrangements have been made for the SPC to do QPF products in the event HPC is down.) However, internally, HPC's structure for managing "non-operational" software code has created multiple possible points of failure for verification codes and information, as single forecasters have full responsibility for developing, maintaining, and extending "their" code. Verification information is critical for HPC's understanding of their forecasts and for EMC in assessing their models.

Finding IS5: As HPC moves forward with the HMT and works to entrain new methods and tools into their operations, the role of information systems in this process will be important, but may be underappreciated at present. The ability of HPC to entrain externally developed tools will be limited by the use of meteorologists, as part-time software engineers. While HPC staff are dedicated and work to learn new technologies, that is no substitute for software engineering

expertise in designing, implementing, or transitioning software code and information systems that are easy to maintain, to extend to new capabilities, or to upscale to support large numbers of new users, larger volumes of information, or a greater variety of applications.

Recommendation IS1: NCEP should establish policies, processes, and practices that will allow users to create customized interactions with HPC information systems, including dynamic process initiation so that users can perform customized analysis and generate customized products on demand, user accounts and registration that allow maintenance of choices and portfolios across sessions, and implementation of new methods for providing information and engaging with users (e.g., podcasts, webinars).

Recommendation IS2: NCEP should establish policies, processes, and practices that will foster interoperability among products and tools for non-NOAA stakeholders. This includes a process of active engagement with external groups that are developing new tools for users (public, academic, and private sector), and easy access to explicit technical information, e.g., meta-data. Engagement with the Earth Science Information Partners (ESIP) Federation, Earth Observing System Clearinghouse (ECHO), and similar groups is encouraged, with participation by HPC IT staff. (It is assumed that within HPC/NWS/NOAA, Second Generation Advanced Weather Interactive Processing System (AWIPS-II) will achieve this, but HPC must participate sufficiently in the development of AWIPS-II to make sure that their NWS stakeholders get the maximum benefit from HPC products and services.)

Recommendation IS3: HPC should, working with NCO, institute programming teams having shared responsibility for specific software development, maintenance, and extensions. Best practices for information systems management should be implemented, including institution of collaborative software development processes and practices. This includes version control systems, task tracking, code reviews, and development of design documents.

Recommendation IS4: HPC with NCEP OD should establish policies, processes, and practices that more effectively leverage external partner capabilities in designing and implementing new products and decision support tools. This includes policies and processes for prioritizing research-to-operations transitions, assessing whether a transition is best accomplished through adoption of externally developed code or internal redesign and implementation, moving software code to HPC and training staff on both system operations and code extensions, and for ensuring continued access of research groups to the operational code base which facilitates continued development of additional capabilities. The latter includes formal mechanisms for collaborative software development.

Recommendation IS5: HPC should provide external research groups with explicit guidance on HPC requirements that new products or tools must meet to be compatible with their operations (e.g., automation requirements) or information systems (e.g., coding standards, interoperability with operating systems or databases).

Recommendation IS6: NCEP should provide HPC with software engineering capabilities through changed policies that allow hiring outside the meteorologist classification or by assignment of NCEP NCO staff to HPC.

6.5 Science and Technology (ST)

The following recommendation and findings are with respect to the science and technology basis for HPC's guidance, analyses, forecasts, and warnings over all spatial and temporal scales: The infusion of technology into Internet-based product delivery, with the partnership of NCO, is discussed in section 6.4.

Finding ST1: At present, the HPC's approach to science infusion is embryonic, and is not adequately supported. HPC has not fully exploited or leveraged ties with the academic research community, nor with other NOAA laboratories and centers. Perhaps the largest missed opportunity is with respect to the formation and application of ensembles in the forecast process. Examples include the North American Ensemble Forecast System (NAEFS), Short-Range Ensemble Forecasting system (SREF), and THORPEX global multi-model ensembles. Additionally, high-resolution ensembles of the type employed in the SPC/NSSL Spring Experiment, and feature-based verification represent other significant opportunities that are not currently being exploited. The HPC's Implementation Plan identifies that planned activities related to tbe HMT are the primary mechanisms to accelerate the infusion of science and technology into operations. At present, the HMT is underfunded and without an effective science plan, hindering Research-to-Operations (R2O) planning.

Finding ST2: Through its operational forecast orientation and diagnostic analyses, HPC has significant experience with forecast failures and model biases. This experience is of great use to EMC. While EMC scientists may have a better theoretical grounding, which is also valuable, they often lack a similar degree of "hands-on" diagnostic experience that exists at HPC. It would appear that HPC/EMC "tiger teams" could provide a balanced approach to model diagnosis and improvement, and to the application of ensembles for improved forecasts and weather guidance.

Finding ST3: The HPC approach to verification improvement is ad-hoc and somewhat minimal in scope. A limited program exists to provide feedback to EMC; there needs to be a formal program to evaluate forecast skill, and there is a need to infuse this information into the HMT and training.

Recommendation ST1: HPC needs to develop a science and implementation plan for the HMT that provides an articulation of HPC's R2O priorities, unresolved scientific questions that the HMT would address, and a vision for engaging the research community that includes academic institutions and national labs, including NOAA OAR labs and cooperative institutes. Mechanisms for engagement that could address this recommendation might include (but are not limited to): (1) collaborative requests for proposals with the National Science Foundation, National Aeronautics and Space Administration (NASA), or the Department of Energy (DOE); (2) a web-link or document on the HPC website clearly articulating priority questions or research gaps; (3) town hall meetings at major science meetings or conferences; (4) more participation in CSTAR or similar programs; (5) activities of the Science and Operations Officer and Warning Coordination Meteorologist; and (6) more aggressive coordination through the HMT, when developed.

Recommendation ST2: HPC management and its SOO need to develop plans to accelerate the infusion of science and technology into its operations and development branches. Two particular areas of concern are verification and ensemble techniques. HPC needs a comprehensive evaluation of their verification program, with an eye on its expansion in scope and improvement, HPC has the skills and interests within its ranks and the mission to conduct verification development to a higher standard than is currently practiced. Object-oriented verification techniques are especially applicable to mesoscale events and warm season precipitation. HPC needs a diagnostic approach to the development of ensemble prediction techniques that could guide HPC forecasters in determining how and in what weather situations ensembles can be best used. This implies an evolution from a qualitative use of Multi-Model Ensembles (MME) information and "forecaster value-added" guidance to an objective forecast guidance process. It is recognized that such an effort requires a significant increase in development personnel and effort. As discussed above, a science infusion plan should include a strategy for engaging the broader scientific community and could be part of a science and implementation plan for the HMT, which was discussed above.

6.6 People and Organizational Culture (POC)

Finding POC1: The review panel observed that the HPC staff consists of many dedicated, professionals who are intensely focused on producing high-quality forecast products using mainly traditional techniques. There is also a significant group that envisions evolving techniques and new avenues for forecast products and services.

Finding POC2: Staff morale in general is on the whole positive, but could be improved by additional opportunities and encouragement for innovation and professional growth. In particular, line forecasters should be brought into problem-specific diagnostic efforts with HPC development staff and similar staff in CPC and EMC with far greater frequency than presently scheduled. For example, each research project could have a liaison from the Forecast Operations Branch to involve them in testing and evaluation. This demands additional streamlining of the forecast process to allow more time for diagnostic participation.

Finding POC3: In interviews with the staff, the panel had impression that the strength and specificity of priorities communicated by management to the staff had, in some instances, the unintended effect of inhibiting staff initiative and creativity, and precluded them from offering contributions and suggestions related to Center-wide plans and programs.

Finding POC4: The Science and Operations Officer is well equipped to foster professional development among the forecast staff. The SOO should more actively assume the role of translating line forecaster observations and concerns about the performance of models and *continually* convey such feedback to EMC, as appropriate (also see section 6.5.)

Finding POC5: The International Desk, under the leadership of Mike Davison, is an outstanding example of successful international outreach. However, despite its success, it is overly reliant

upon a single individual and needs broader support. Some International Desk activities negatively impact the time available for development activities.

Finding POC6: While several female forecasters have recently departed through no evident fault of the HPC, there is a lack of diversity on the current staff.

Recommendation POC1: The panel recommends the implementation of additional mechanisms for rewarding and nurturing efforts to advance the scientific envelope in the process of generating forecast products and services. Incentives could include additional travel opportunities to present research at scientific conferences and encouragement to publish in the refereed scientific literature.

Recommendation POC2: The Director should clearly convey to the staff that staff initiative, creativity and contributions to advances in science, technology and HPC practices are valued. HPC management should encourage staff suggestions to HPC plans and programs. As part of its strategic planning, HPC needs to consider the balance between the number of personnel in each branch, and activities where Forecast Operations Branch forecasters can collaborate with Development and Training Branch meteorologists that foster initiatives from all levels. As part of this balance among staff, HPC should consider the balance of staff with Bachelor, Masters and PhD degrees. As HPC considers candidates for open positions, consideration should be given to their interests in applied research and development and publishing along with their interests in operational forecasting. The panel believes that more staff with advanced degrees would help facilitate innovation and would foster 'grass root' contributions for improved products and services.

Recommendation POC3: Concerted efforts are needed to increase diversity and should be aggressively pursued by HPC management.

6.7 Business Processes (BP)

HPC is in the business of providing weather forecast guidance to a diverse set of stakeholders both within NWS (WFOs and RFCs) as well as outside (e.g. FAA, Federal Emergency Management Agency - FEMA, private sector). HPC wants to "implement business processes that encourage efficiency and proficiency, and that hold individuals accountable for results at all levels" (2009-2013 Implementation Plan). It is unclear that the current management of HPC achieves these goals. The suppliers of their 'raw products' are EMC and other national forecast centers (Canada, the UKMO and the ECMWF), NESDIS and the NWS observing network. They distribute their products through NWS channels (AWIPS) and web-services with the assistance of NCO. To properly manage and advance HPC is a challenge that requires understanding of many elements: the basic forecasts received by HPC, the development of the products that fill HPC's stakeholders' needs and the delivery of products to service stakeholders. The stakeholder survey indicated that some stakeholders were confused on how to provide feedback to HPC on product developments, or whether HPC was receptive to receive feedback. HPC must fulfill the needs of their stakeholders and work with them to understand new and evolving needs. HPC must recognize that EMC and NCO are their suppliers and HPC should work with them to achieve cutting-edge products, and HPC should help them in evaluating and

improving their services *to HPC*. Thus, HPC must develop a business model that is more demanding of its information providers (EMC forecasts and NWS data) and technology providers (NCO), and more responsive to the needs and requirements of its customers – its stakeholders. HPC staff must be engaged in this process.

Finding BP1: HPC isn't proactive enough in developing a forward-looking, aggressive business model, oriented on serving its stakeholders needs.

Finding BP2: The HPC staff members have insufficient opportunity to get involved in the relevant scientific communities that could provide an important source of innovation for product development.

Finding BP3: A lack of focused strategic guidance and a broad spectrum of product-generation activities have resulted in staff that are overworked and spread thin, and provides little time for innovation.

Recommendation BP1: HPC management needs to develop mechanisms to encourage improved products by its providers (i.e. EMC and NCO) and to articulate to its stakeholders how it will better serve them. NCEP management must assist HPC in developing and implementing a stronger business process plan, since the execution of such a plan impacts centers across NCEP.

Recommendation BP2: HPC should implement mechanisms for rewarding and nurturing efforts to advance the scientific scope of HPC as part of the process of generating forecast products and services. Staff incentives could include additional travel opportunities to present research at scientific conferences and strong encouragement to read and publish in the refereed scientific literature.

Appendix A

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 research and/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

HPC Review Panel Membership

Eric F. Wood, Chair
Princeton University

Richard Carbone
National Center for Atmospheric Research

Holly Hartmann
University of Arizona

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Appendix C

List of Acronyms and Terms

AMS	American Meteorological Society
AWC	Aviation Weather Center
AWIPS	Advanced Weather Interactive Processing System
AWIPS-II	Second Generation Advanced Weather Interactive Processing System
BP	Business Practices
CCM	Certified Consulting Meteorologist
CONUS	Continental United States
CP	Customers and Partners
CPC	Climate Prediction Center
CSTAR	Collaborative Science, Technology and Applied Research
DOE	Department of Energy
ECHO	Earth Observing System Clearinghouse
ECMWF	European Center for Medium Range Weather Forecasts
EMC	Environmental Modeling Center
ESIP	Earth Science Information Partners
FAA	Federal Aviation Administration
FEMA	Federal Emergency Management Agency
GFS	Global Forecast System
GIS	Geographic Information Systems
GPS	Global Positioning Satellites
HMT	Hydrometeorological Testbed
HPC	Hydrometeorological Prediction Center
HPC-IP	2009-2013 Hydrometeorological Prediction Center Implementation Plan
IS	Information Systems
IT	Information Technology
MME	Multi-Model Ensemble
MSLP	Mean Sea Level Pressure
MV	Mission and Vision
NAEFS	North American Ensemble Forecast System
NASA	National Aeronautics and Space Administration
NAWIPS	NCEP Advanced Weather Interactive Processing System
NCEP	National Centers for Environmental Prediction
NCO	NCEP Central Operations
NESDIS	National Environmental Satellite, Data and Information Service
NextGen	Next Generation Air Transportation System
NGO	Non-Governmental Organization
NOAA	National Oceanic and Atmospheric Administration
NSSL	National Severe Storms Laboratory
NWP	Numerical Weather Prediction
NWS	National Weather Service
O2R	Operations-to-Research
OAR	Office of Oceanic and Atmospheric Research

OD	Office of the Director
OPC	Ocean Prediction Center
POC	People and Organizational Culture
PS	Products and Services
QPF	Quantitative Precipitation Forecasts
R2O	Research-to-Operations
RFC	River Forecast Center
RISA	Regional Integrated Sciences and Assessments
SOO	Science and Operations Officer
SPC	Storm Prediction Center
SREF	Short-Range Ensemble Forecasting
ST	Science and Technology
SWPC	Space Weather Prediction Center
THORPEX	The Observing System Research and Predictability Experiment
TPC	Tropical Prediction Center
UCAR	University Corporation for Atmospheric Research
UKMO	United Kingdom Meteorological Office
USAF	United States Air Force
W2DT	Week-2 Development Team
WCM	Warning Coordination Meteorologist
WCRP	World Climate Research Programme
WFO	Weather Forecast Office
WMO	World Meteorological Organization