Report of the

UCACN Model Advisory Committee

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UMAC is a sub-committee of the

UCAR Community Advisory Committee for NCEP

Administered by the

University Corporation for Atmospheric Research

UMAC Members

Frederick Carr, co-chair
Richard Rood, co-chair
Alan Blumberg
Chris Bretherton
Andy Brown
Eric Chassignet
Brian Colle
James Doyle
Tom Hamill
Anke Kamrath
Jim Kinter
Ben Kirtman
Cliff Mass
Peter Neilley
Christa Peters-Lidard

UCACN Members

Gary Lackmann, co-chair
Warren Qualley, co-chair
Alan Blumberg
Lance Bosart
***Gilbert Brunet**
Frederick Carr
Shuyi Chen
John Dutton
James Kinter
***Bill Kuo**
***Tsengdar Lee**
Peter Neilley
Karen Shelton-Mur

*** Ex officio members of UMAC**

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Executive Summary

U.S. numerical environmental prediction is at a crossroads. Based on a number of measures, such as skill in global modeling or the use of high-resolution probabilistic prediction, American operational environmental prediction is no longer a world leader. In contrast, the U.S. has huge assets in environmental prediction, including the largest associated research community in the world, an open data policy, and a robust private sector community. Thus, a key finding of the UMAC committee is an optimistic one: U.S. environmental prediction, although lagging, has the potential to progress rapidly to world leadership. But this will only occur if fundamental changes are made in NOAA/NWS/NCEP operations, how research and development in NOAA operational environmental prediction is organized, and how NOAA works with the outside research community.

This report makes recommendations on a number of major issues that require rapid and effective attention:

Reduce the complexity of the NCEP Production Suite. The large number of modeling systems maintained by NCEP is overwhelming NCEP personnel, computer resources and stakeholders. It greatly reduces the ability of individual NCEP modeling systems to achieve excellence. A strategy for the phasing out of redundant or obsolescent models needs to be put in place.

The NOAA environmental modeling community requires a rational, evidence-driven approach towards decision-making and modeling system development. The NGGPS effort is a good start in this direction. Similar efforts are needed for regional modeling and water-related modeling systems.

A unified, collaborative strategy for model development across NOAA is needed. This will require a new management structure, in which priorities and resource trade-offs are made clear, communication is enhanced, and proper attention is paid to established governance and project management practices.

Essential to effective planning and execution is the creation of a Chief Scientist position for Numerical Environmental and Weather Prediction (NEWP). This individual is needed at the NOAA HQ level, in order to have coordinating authority for environmental modeling across NOAA. This person will lead the strategic planning effort, be responsible for the prioritization of requirements, and develop complementary and strategic partnerships (e.g., with stakeholders, NCAR, ECMWF, CMC, Met Office, NRL, academic and climate communities, etc.).

NOAA needs to better leverage the capabilities of the external community. This includes not only its Cooperative Institutes but also the academic and private sectors, through visiting scientist programs, extramural funding, national workshops, and other approaches.

NOAA must continue to enhance High Performance Computing (HPC) capabilities. Recent enhancements are welcome, but computer resources available to EMC are still profoundly below what is needed to realize U.S. potential for world leadership across the full suite of its environmental prediction responsibilities. Attention must also be given to more efficient use of existing HPC, storage and bandwidth, and research computing resources, as well as the application of new hardware and software technologies.

NOAA must develop a comprehensive and detailed vision document and strategic plan that maps out future development of national environmental prediction capabilities.

Execute strategic and implementation plans based on stakeholder requirements. In the past, major model and system development decisions have not been based on a comprehensive set of user and national requirements. NCEP should collect and document stakeholder requirements and prioritize them to balance stakeholder requirements, scientific excellence, and cost.

1. Introduction

1.1 Background and Charge

This document is the inaugural report of the UCACN Modeling Advisory Committee (UMAC), a sub-committee of the UCAR Community Advisory Committee for NCEP (UCACN), which is administered by the University Corporation for Atmospheric Research (UCAR).

In November 2008 UCAR was requested by the National Centers for Environmental Prediction (NCEP) to conduct a thorough review of the nine Centers that comprise NCEP, as well as the NCEP Office of the Director (OD). An Executive Committee plus five panels conducted the reviews, which are collectively referred to as the 2009 Review. The reports were completed in early 2010 and are available at http://www.vsp.ucar.edu/UCACN/index.html. One of the major recommendations of the 2009 Review was that NCEP should establish a permanent external advisory committee to provide guidance on improvement of products and services based on the latest advances in science and technology. As a result, UCACN was established by UCAR in March 2011; its primary responsibilities are:

1. *To conduct a comprehensive review of NCEP (the nine Centers and the Office of the Director) every five years, starting in the year 2015.*

2. *In the years between the comprehensive reviews, to:*
   a. *Monitor progress of the Centers in the context of the NCEP strategic plan and previous UCACN recommendations, and provide informal updates and advice to NCEP leadership through the UCAR President (or designate).*
   b. *Provide input to the strategic planning and long-range goals of the Centers and NCEP as a whole.*

As a result of UCACN discussions with NCEP Director, William Lapenta, during fall 2014, a consensus emerged that it would be of more value to NCEP to have a holistic strategic review of the entire NCEP Production Suite (NPS) in 2015 rather than a comprehensive review of all the individual centers. Thus the comprehensive review would be postponed to 2016. A sub-committee of the UCACN was formed to conduct the NPS review, the UCACN Modeling Advisory Committee (UMAC), that is comprised of 7 current members of UCACN (3 *ex officio*) and 11 new members from the U.S. and international modeling community. In essence, the UMAC was charged with developing the first unified NOAA modeling strategy to advance the U.S. to world leadership in numerical modeling capabilities. The full "Request for Review" is provided in Appendix I. The "Terms of Reference" for UMAC and its specific charge are:

1) Charge to UCACN in 2015: Review of the NCEP Production Suite
NOAA is a science based agency with an operational mission to provide environmental predictions. Therefore, NOAA leadership is striving to align its research portfolio with delivery of operational products and services. As described above, there is a

significant amount of NOAA research being devoted to numerical modeling that should advance the skill of the NPS components. In addition, a unified message from NCEP stakeholders obtained during the development of the strategic plan was the need to systematically obtain user requirements and incorporate them into the decision-making process that drives the NPS evolution.

The NCEP Director requests the formation of a UCACN Modeling Advisory Committee (UMAC) to provide a comprehensive, technical review of the NPS strategy for development. The proposed terms of reference of the UMAC are provided below:

Structure:

a. *The UMAC will be established no later than March 2015 and will exist for a minimum of three years.*

b. *The first review of the NPS will occur between June and August 2015 in College Park MD.*

c. *The UMAC will consist of approximately 12-14 members who are established subject matter experts in numerical modeling, drawn from academia, non-governmental organizations, the private sector and Federal and state agencies.*

d. *The Chair(s) of the UCACN and the Director of NCEP will select the members of the UMAC.*

e. *Members of the UCACN may be asked to also serve on the UMAC.*

f. *The UMAC will meet at least annually and provide a written report of its findings and recommendations to the UCAR Authority, who will then transmit the report to the Director of NCEP.*

2) UMAC Scope:

The NPS is operated by NCEP Central Operations and currently contains more than 20 end-to-end operational modeling systems ranging from on-demand dispersion, regional hurricane, continental ensembles, global ensembles and seasonal. It has systems for near shore coastal, global ocean, surge, space weather, and waves. Soon we will be adding on-demand tsunami and coupled terrestrial-ionosphere space weather capabilities. The future production suite will become even more complicated as we move towards complex earth system modeling systems across a wide time and space paradigm.

This will be the first ever holistic technical review of the NPS. All major model developers will provide input to the review to ensure communication takes place across all scales and components. Participants will also include representatives of the stakeholder community from NOAA (i.e., SPC, WPC, the NWS regions, NWC, OAR, NOS), public, private and academia.

1.2 Procedures, Stakeholder Survey and Agenda

UCACN Co-chairs Carr and Kinter worked with Lapenta on the early planning for the NPS Review and recruiting members for UMAC. The UMAC committee was constituted in March 2015. Several conference calls occurred between UMAC members and NCEP leaders to discuss the background, motivation and scope of the review, the stakeholder survey, current information on all modeling systems and other resource material for UMAC, and the agenda. A COG website was created for UMAC by Co-chair Rood which stored all the resource and other useful material: https://www.earthsystemcog.org/projects/umac_model_advisory/ . Much attention was paid to the development of a useful Stakeholder Survey, including convening two focus group telecons and involving NOAA social scientists as well as UMAC members to create well- posed questions. Unfortunately, we did not learn until June that the survey had to undergo an Office of Management and Budget (OMB) review, which eventually approved the survey after the meeting. It was then decided not to distribute the survey. Thus UMAC did not get the benefit of a stakeholder survey for this report, but plans to do one in the future. However, 27 stakeholders from the academic, public and private sectors were invited to the meeting and 18 attended. In addition, 23 "Observers" from NWS and NOAA leadership were invited to participate, with 19 attending. The stakeholders and observers joined UMAC members and the NCEP and NOAA modelers who made the presentations; the complete list of attendees is given in Appendix II.

An agenda was created that minimized the number of Powerpoint presentation slides (they were provided in advance) and maximized discussion time. All modeling systems run on the NCEP Weather and Climate Operational Supercomputing System (WCOSS) were discussed. The agenda is provided in Appendix III. Note that the links following a topic are associated with background materials for that topic and remain active (in the Word document version.)

1.3 UMAC Meeting

The inaugural UMAC meeting was held in NCEP's National Center for Weather and Climate Prediction (NCWCP) building on Aug. 4-7. The UMAC committee met on the evening of Aug. 3 to go over final preparations. The meeting proceeded as shown on the Agenda (Appendix IV), with some members participating online via Go-To-Meeting. The executive sessions at the end of each day were useful in beginning the process of developing our Findings and Recommendations (F&R), and determining what questions remained to be asked. On Friday, we provided an outbrief on our preliminary F&Rs to VADM Manson Brown (Assistant Secretary for Environmental Observation and Prediction), Louis Uccellini (NWS Director), Stephen Fine (Deputy Assistant Administrator of OAR for Laboratories and Cooperative Institutes) and a representative from Rick Spinrad's office (NOAA Chief Scientist). UMAC plans to produce the final report in November. A follow-up meeting in which NCEP will provide their initial response to the report is planned for the AMS Annual Meeting in January.

A complete list of acronym definitions appears in Appendix IV.

2. Overarching Findings and Recommendations

2.1 Introduction

UMAC's charge was to produce a holistic technical review of NCEP's Production Suite (NPS), and provide a report to the Director of NCEP. However, the committee recognizes that while NCEP is NOAA's operational facility for numerical environmental and weather prediction (NEWP) guidance, it can not accomplish its mission without leveraging developments from NOAA research labs and from the broader enterprise. In fact, a majority of NOAA's model R&D is performed in OAR labs, notably ESRL and GFDL, but also in AOML, ARL and NSSL, and the associated cooperative institutes. Thus, while UMAC's charge did not include a review of these organizations, it is difficult for NCEP to significantly enhance its NEWP capabilities without the full cooperation of all of NOAA.

UMAC notes that NOAA's organization of NEWP is unusual in many respects. No other peer environmental prediction service has chosen to separate its basic research and development from its applied, operational model implementation. No other national prediction service has produced such a diversity of prediction systems, most without the critical mass of resources to make each of them world-best. No other prediction service lacks top-level oversight spanning the research to the applied development. Not coincidentally, peer organizations with similar resources commonly produce more accurate guidance (for example, ECMWF), and some peer organizations with less total resources (UK Met Office, Canadian Meteorological Centre) are competitive or superior to NCEP.[1]

Accordingly, following this worldwide best practice, while UMAC has many recommendations focused on changes needed within NCEP, UMAC will also suggest additional findings and recommendations intended to ensure that NCEP and other NOAA line offices, research labs, cooperative institutes, and the external U.S. weather and climate research community work seamlessly together to achieve a unified model development strategy. We will recommend that NOAA management/administrative structures must also align to those goals to ensure success.

Therefore, in the two sections below, we will first provide the overarching recommendations that will require NCEP, NWS and NOAA leadership to work together in order to achieve its "Weather-Ready Nation" and "Second-to-None" goals. Then we will provide the most important recommendations from each of the five thematic areas (Global, Regional, Water, Ensembles/Post-Processing and NCEP as an End-to-End System). We also note here that UMAC regrets that it lacked expertise on air quality and space weather modeling, and thus has little to say about these areas.

[1] Resources are difficult to compare. The majority of NCEP's resources go to its seven forecast service centers (AWC, CPC, NHC, OPC, SPC, SWPC, WPC), with EMC and NCO accomplishing the numerical prediction function. It is safe to say that ECMWF (and perhaps other national prediction centers) have superior resources to EMC and NCO alone, but no national center has the combined resources of EMC, NCO and all the NOAA labs and institutes. This gives us confidence that a unified effort can move the U.S. to world-best status.

2.2 Findings and Recommendations for NCEP, NWS and NOAA Leadership

The **key finding** is an optimistic one: **U.S. Environmental Prediction has the potential to progress rapidly to world leadership.** This requires a new level of organization and bold, evidence-driven decision-making. The **recommended actions** to achieve this potential are:

- **Reduce the complexity of the NCEP Production Suite.** The large number of modeling systems maintained by NCEP is overwhelming NCEP personnel, computer resources and stakeholders. It greatly reduces the ability of individual NCEP modeling systems to achieve excellence. A strategy for identifying and phasing out redundant or obsolescent models needs to be put in place.

- **The NOAA environmental modeling community requires a rational, evidence-driven approach towards decision-making and end-to-end modeling system development.** The NGGPS effort is a good start in this direction. Similar efforts are needed for regional modeling and water-related modeling systems.

- **A unified, collaborative strategy for model development across NOAA is needed.** This will require a new management structure, in which priorities and resource trade-offs are made clear, communication is paramount, and proper attention is paid to established governance and project management practices.

- **Essential to this planning (and execution) effort is the creation of a Chief Scientist position for Numerical Environmental and Weather Prediction (NEWP).** This individual is needed at the NOAA HQ level, in order to have coordinating authority for environmental modeling across NOAA. This person will lead a strategic planning effort for future U.S. NEWP capabilities, be responsible for the prioritization of requirements and develop complementary and strategic partnerships (e.g., with stakeholders, NCAR, ECMWF, CMC, Met Office, NRL, academic and climate communities, etc.).

- **NOAA needs to better leverage the capabilities of the external community**. This includes not only its Cooperative Institutes but also the academic and private sectors, via visiting scientist programs, extramural funding, etc.

- **Continue to enhance HPC capabilities**. Note that concomitant attention must be given to more efficient use of existing HPC, storage and bandwidth requirements, and research computing needs, as well as the application of new hardware and software technologies.

- **Execute strategic and implementation plans based on vetted, stakeholder requirements**. Major model and system development decisions are not based on a comprehensive and vetted set of requirements. NCEP should collect and document stakeholder requirements and then manage, vet, and prioritize requirements to balance stakeholder requirements, scientific excellence, and cost.

2.3 Major Recommendations for Specific Modeling Themes

A. Global Modeling Systems

1. A core goal of NOAA and NWS should be attaining world leadership in global environmental prediction within five years. This will require large sustained investments in the development and testing of global prediction systems as has begun with the NGGPS initiative. NCEP should revise its mission statement to reflect this core goal.

2. NCEP should devise and execute a strategy for transition to a unified modeling system, including a strong emphasis on improving model physics and data assimilation, and improved verification and diagnostic methods, at all scales, within a decade.

3. NCEP should increase its use of an evidence-based approach towards model development and implementation, including rigorous, systematic testing, process-based diagnosis, and improved model verification and evaluation approaches to reduce systematic model errors.

4. NCEP should direct resources towards the development of NGGPS, transition resources away from the development of modeling components not likely to be included in the NGGPS, and develop a clear, detailed plan to implement and operationalize NGGPS.

B. Regional Modeling Systems

1. NCEP's regional modeling efforts should be increasingly guided by an evidence-based approach in which verification and testing precedes decisions regarding deployment of new modeling systems, major modeling changes, or strategic planning for regional modeling. Best practices of successful modeling efforts of other major operational centers can also provide useful guidance.
2. To reduce complexity and to facilitate more effective model development, NCEP should strive towards using one model dynamical core for all regional modeling applications, and in the long term adopt one core for both global and regional applications. Because of its effectiveness in promoting rapid progress, a unified approach has become standard operating procedure at other major operational centers.
3. NCEP should develop a convection-allowing ensemble over the United States. Such an ensemble is a clear national need and recommended in numerous NRC reports and national workshops.
4. NCEP should strive to bring high-resolution deterministic prediction, high-resolution ensemble prediction, rapid refresh modeling, and mesoscale data assimilation together into a single software framework.

C. Water Modeling Systems

1. Close coordination among EMC, NOS and the National Water Center (NWC) is critical, including shared plans for how requirements will be met through hiring personnel, prediction system developments, data assimilation and verification capabilities.

2. External factors to NCEP are driving requirements for NCO to execute prediction system

such as from NOS and NWC. There needs to be an objective, standardized process for reviewing, prioritizing, and allocating NCO resources.

3. The external review process at NOS seems to be a positive model first step that should be enhanced and integrated with and implemented at EMC.

4. The newly established National Water Center requires a well thought out stepwise plan to find the best path for water modeling and forecasting. Many conflicting choices are presenting themselves now.

5. It is important for the modelers in the NOAA water arena to be more visible in the community, e.g., appearing at conferences and submitting manuscripts for publishing in the peer reviewed literature.

6. Hydrologic prediction is inherently uncertain, in part because of precipitation uncertainty, in part because of significant uncertainty of the land-surface state and hydrologic prediction systems. For hydrologic forecasting beyond lead times of 48-72 hours, the computational approach should be inherently probabilistic.

D. Ensembles and Post-Processing

1. NCEP should consolidate its ensemble prediction under a unified dynamical core using physically-based stochastic parameterizations to treat model uncertainty in the ensembles. Ideally, one core would be used for both global and regional, but in the intermediate timeframe, separate regional and global cores may be inevitable.

2. The allocation of production-suite resources for ensemble prediction systems must be balanced with other uses based on a careful analysis of requirements.

3. Ensemble product generation from the SREF should be moved over to the GEFS, and the SREF should be discontinued after careful evaluation of GEFS for providing useful shorter range regional ensemble information.

4. If data from other mature ensemble prediction systems are available at little or no cost to NOAA from national or international partners, then their use should be evaluated by NOAA. However, the primary goal for NOAA's ensemble prediction development should be to produce numerical guidance of such quality that little is gained from leveraging other centers' outputs.

5. NOAA climate prediction resources should be used to fund the improvement of NOAA models, not external models.

6. NOAA's ensemble prediction community should work with the UMAC-recommended Chief Scientist for NEWP to produce plans that clarify objectives, resources, and infrastructures needed, and implement these plans with modern project management concepts and systems-engineering oversight.

7. Decisions on what computational and storage resources are allocated to reanalyses and reforecasts (R/R) should be done in a systematic manner, based on how they help NOAA meet its requirements, as recommended elsewhere by UMAC.

8. Nonetheless, given the demonstrated value of carefully constructed reforecast data sets, post processing and the production of supporting data sets (R/R) should be considered an integral part of NCEP's future production suite and resourced accordingly.

9. NCEP should ensure that future requirements for high-performance computing systems and associated disk space include the regular production of R/R.

10. NCEP and its partners should proceed to generate global R/R's on a regular basis rather than as one-off projects.

11. NWS should migrate its post-processing development resources from MOS, NAEFS, and other legacy systems toward the National Blend.

E. Air Quality, Dispersion Modeling, and Space Weather

1. The UMAC were presented materials and requests in Air Quality, Dispersion Modeling, and Space Weather. The UMAC does not, presently, have the expertise to comment substantially on discipline-specific issues for these forecast products. A number of the questions raised, however, are more in line with how these forecast products fit into the suite of forecast products and the end-to-end system.

2. The UMAC notes that the Air Quality, Dispersion Modeling, and Space Weather applications have relationships to both global and regional atmospheric modeling systems. There are relationships to both the dynamical and physical formulations of global and regional models, as well as to the data assimilation capabilities. The UMAC recommends that the requirements for these applications be documented and enter into the requirements reconciliation for global and regional systems, including the post-processing requirements. This would help to address noted challenges in "keeping up" with meteorological model outputs and variables needed for their operations.

3. The UMAC noted that the Air Quality effort maintained a development plan which was vetted with a panel of external experts, a practice consistent with UMAC recommendations and a procedure that might inform, more broadly, development of design and change review.

4. The UMAC notes that there are a number of mature space-weather groups in the U.S. and development of NOAA's capabilities should engage this community expertise and, perhaps, their algorithms. The UMAC commends the incorporation of space-weather model development in the NGGPS development and the use of NEMS coupling to support space-weather as an application within a unified global system.

F. NCEP as an End-to-End System

1. Focus on forecast products: The true deliverable is a forecast product, which need not be slaved to a particular model. This brings attention to management of systems that include all of the functions needed to deliver the forecast products.

2. Collect, document, manage and prioritize stakeholder requirements. The requirements need to be managed across the portfolio of forecast products represented in the NCEP Production Suite.

3. Develop formal processes for NCEP-wide, evidence-based decision making that balances stakeholder requirements, scientific excellence, and cost.

4. Commit to development and persistence of improved Governance and Project Management. This is required to support specific UMAC recommendations, for example,
    - Improve communications
    - Manage requirements
    - Terminate out-of-date systems
    - Make evidence-based decisions
    - Organize across NOAA, federal agencies, communities

5. Use the following recommendations to gain control over the existing complexity
    - Document and maintain complete range of products and systems
    - Identify and publicize leads for all products and systems
    - Hire or identify software leads, with proven expertise in scientific software
    - Develop Change Review Boards for all products and systems
    - Develop a software release schedule for major systems on the order of 12-24 months
    - Replace all the code that EMC uses with code developed with formalized software management
    - Evolve successful governance and management practices from examples, for example, NGGPS and NEMS

3. Findings and Recommendations for Specific Modeling Themes

A. Global Modeling Systems

3.A.1 Introduction

Global numerical weather prediction (NWP) systems, along with their regional prediction system counterparts, are the most important foundations of NOAA's weather and climate forecasting mission. Global models are required for any prediction capability beyond a few days and provide the necessary boundary conditions for many downstream models and applications including high-resolution short-range regional prediction. Global NWP systems also provide forecast products necessary to support the nation's international political and economic interests. Scientifically, global modeling systems are traditionally the vehicle in which many complex earth system processes are captured, such as two-way atmospheric-ocean and atmosphere-land coupling. Global modeling systems also provide a basis for benchmarking the quality of the nation's numerical weather prediction through comparative skill analyses with similar products from other organizations. As such, a fundamental recommendation of this committee is that NOAA should continue to invest heavily in its global modeling initiatives and operations sufficient to achieve and sustain worldwide leadership in this science and technology.

There are three modeling systems being used operationally for global prediction at NCEP:

- The Global Forecast System (GFS; currently a Global Spectral Model or GSM)
- The Global Ensemble Forecast System (GEFS; more discussion of GEFS is in Section 3.D on Ensembles and Post-Processing)
- The Climate Forecast System (CFS; currently version 2 or CFSv2).

The National Weather Service recently embarked on a major new initiative called the Next-Generation Global Prediction System (NGGPS). The NGGPS is expected to serve as the foundational framework for the future global modeling capabilities. Under NGGPS, a single community dynamical core (dycore) and parameterization suite will be developed for use in the GFS and GEFS systems (with possible use in future climate modeling systems as well). The new dycore will be capable of producing non-hydrostatic simulations; the software will be modular and managed via the NEMS architecture; it will permit coupled modeling, and more modular and scale-aware physical parameterizations. This has direct implications for near and long-term global model development and transition to operations at NCEP.

Closely related to these global prediction systems is the data assimilation system, which adjust model background forecasts to the newly available observations to produce initial conditions for making subsequent forecasts. This process applies not only in the global atmosphere, but also is required to initialize other components of the coupled Earth-system model.

Finally, there is vision of a "unified" modeling strategy in which all prediction systems, including global and regional models and their parameterizations, are united under a single modeling framework. As a first step towards unification, a recommendation of this committee, consistent with recommendations made by the UCAR Community Advisory Committee for

NCEP (UCACN), is that NCEP should limit its near-term development efforts to one global and one regional modeling system.

The current NCEP global operational prediction system is competitive with other national systems, but far from the world leader. The NCEP system 500-hPa anomaly correlation verification statistics are ahead of the U.S. Navy Global Environmental Modeling (NAVGEM) system. According to the British Met Office's business performance ranking of main national NWP centers relative to CBS Weighted NWP Index[1] NCEP's GFS model is about the same as the Canadian Meteorological Centre (CMC) and Météo-France, slightly behind the Australian Bureau of Meteorology (BoM), the Korean Meteorological Agency (KMA) and clearly behind the UK Met Office (UKMO) and the Japan Meteorological Agency (JMA). The NCEP global system, like all other national systems, ranks substantially behind the European Centre for Medium-range Weather Forecasts (ECMWF). GFS performance particularly lags in the southern hemisphere[2].

3.A.2 Overarching Recommendations

1. In order to become second to none in environmental prediction, it is essential that NOAA and NWS continue to make substantial investments in the development and testing of global prediction systems as has begun with the NGGPS initiative. Attaining world leadership in global prediction within 5 years should be a core goal of NOAA and its success in achieving such leadership should be a key metric of the agency and its personnel. NCEP should consider a new or amended mission statement such as "*NCEP modeling creates world-class global analysis and prediction products that are second to none in quality and utility*" and adopt benchmarks against that mission as the cornerstone metric of success of the institution and its personnel.

2. In order to streamline, simplify and open the development process to broader participation from the scientific community, devise a strategy for transition to a unified modeling system at all scales (mesoscale to climate) within a decade. In the interim, there should be a single model for all global prediction requirements, including ensemble prediction and another single model for regional prediction. Greater emphasis should be placed on improving model physics and data assimilation. Additionally, verification and diagnostic software and methods should be unified across modeling systems.

3. NCEP should increase its use of an evidence-based approach towards model development and implementation decisions. Future directions in model and data assimilation system development should be informed by rigorous and systematic testing. This will require improved model verification statistics and evaluation approaches. Greater emphasis on the process-based error diagnosis and reduction of systematic model errors and biases is needed.

[1] http://www.metoffice.gov.uk/media/pdf/t/m/MOSAC_2014_19.3_Brunet.pdf
[2] http://www.emc.ncep.noaa.gov/gmb/STATS_vsdb/

4 NCEP should direct resources towards development and successful implementation of the NGGPS, which can be accomplished by reducing resources currently earmarked for development of modeling components that are not likely to be included in the NGGPS and unified model strategy. UMAC strongly recommends that NCEP develop a clear detailed plan to operationalize the NGGPS, including timelines, resources required, and explicit plans for transitioning resources away from the development of the global spectral model as the NGGPS effort matures.

3.A.3 Specific-System Recommendations

1. **GFS**. The NCEP short-term plan for GFS is to continue GSM dynamical core development until such time as the new NEMS system is in place. The GSM physics package will continue to be actively developed with regular implementations, including a new physics package, until a new global system is ready from the NGGPS project.

   Findings and Recommendations:

   (a) NCEP should be committed to a single unified global modeling system for many reasons.
      (i) NCEP has limited personnel and computing resources; focusing its resources on achieving superiority in a narrower set of core models will increase the likelihood of success and offer a greater net return on investment to the nation.
      (ii) With a unified modeling approach, improvements made for one application (e.g., global NWP) can provide important benefits for other applications (e.g., climate).
      (iii) A unified modeling approach enables broader and deeper collaborations with the external scientific community since a simpler modeling environment will have less complex barriers to collaborations.
      (iv) While a multi-model ensemble has value in predicting the true variance in outcomes, there is sufficient diversity in global prediction systems operated by other domestic and international modeling institutions upon which multi-model products can be built. The nation would be better served by having NOAA invest in developing multi-model products based in part on ensemble predictions from external operational institutions, rather than developing its own multi- model capability.

   (b) As is the current EMC plan, further development of the current GFS dynamical core should be phased out. The resources released by this action can be used for improving global data assimilation and model physics, which would be useful for both GFS and the NGGPS. Specifically, all development of the GFS semi-Lagrangian dynamical core and any related non- hydrostatic GFS core development should cease and resources that are freed up applied toward the NGGPS. Further near-term improvements of the GFS physics suite should be undertaken, including the ongoing work as part of NGGPS. Implementation should only come after extensive testing and demonstration of comparable forecast skill, balanced over the full range of forecast timescales. Systematic model biases and errors need to be documented, tracked with time, and diagnosed. The physics development occurring as part of the Climate Process Teams needs to be leveraged. An increase of the GFS horizontal and vertical resolution should follow after advancement of physics and data assimilation.

(c) Currently, NCEP Central Operations (NCO) decreases the spatial resolution of the global model during the forecast period. There are indications that degrading spatial resolution in the middle of the forecast produces spurious effects since the long-term climatological behaviors of the model at the initial and degraded resolutions are different. The impacts of reducing resolution during forecasts should be carefully evaluated, with the intent of ending this practice if the degradation in forecast quality is substantial. In addition, NCEP should endeavor to create output products that have uniform resolution in space and time across the model's forecast period.

2. **GEFS**. The GEFS is NCEP's system that provides ensemble global prediction products. The current GEFS system consists of a single unperturbed control run and 20 parallel forecasts generated from a set of perturbed initial conditions, all with a reduced-resolution version of the GFS. The perturbed runs include tropical cyclone relocation and Stochastic Total Tendency Perturbation for model uncertainty. Ensemble forecast products provide valuable insights regarding the range of potential outcomes in the forecast, provide measures of predictability, and generally outperform their deterministic counterparts in bulk atmospheric measures. Maintaining a world-class ensemble global prediction capability should remain part of the long-term core mission of NCEP. Findings and recommendations regarding ensemble prediction are provided below in Section 4D. Specifically for GEFS, the development of the GEFS dynamical core should be frozen, and any enhancements in physics and data assimilation used in GFS should carry over to GEFS. The personnel resources released by this action can be used toward the development of NGGPS with ensemble capability.

3. **CFS**. The CFSv2 is a coupled Earth-system model having four component models for the atmosphere, ocean, land surface and sea ice. Several of the component models were adopted in collaboration with institutions outside NCEP: the global ocean component (Modular Ocean Model, version 4 – MOM4) and the sea ice model (Sea Ice System – SIS) are both from the NOAA Geophysical Fluid Dynamics Laboratory (GFDL). The near-term CFS development is intended to produce version CFSv3 that encapsulates all the developments since the current version went operational in 2011. The longer-term plan involves developing a multi-component model built on the coupled National Environmental Modeling System (NEMS) and the National Unified Operational Prediction Capability (NUOPC), both built upon the Earth System Modeling Framework (ESMF) software suite. This ties into the NGGPS plan (see below).

   Findings and Recommendations:

   (a) The CFSv2 is generally regarded as a leading seasonal prediction model. The CFSv2 is regularly consulted by the NCEP Climate Prediction Center as guidance for its monthly and seasonal outlooks, and, in the context of the North American Multi-

Model Ensemble, it is among the more reliable contributors to that guidance. The ECMWF System 4, also used to produce seasonal forecasts, is considered to produce forecasts superior to those of CFSv2 for some quantities and lead times.

(b) The development and improvement of CFS has lagged other modeling systems both at NCEP and elsewhere. The current operational system went into production in 2011 and has not been changed since. This is partly due to the high cost in human effort and high- end computing resources to produce a reanalysis and comprehensive set of re-forecasts. Plans for relatively rapid deployment of the next generation CFSv3 and for longer term strategic development of CFSv4 appear to be under consideration. This development cycle should be accelerated to produce an updated system on a regular, pre-announced schedule at most every 4 years.

(c) Unlike several other Earth-system modeling efforts, the CFSv2 was developed largely in isolation at NCEP and did not directly benefit from the large research community, such as those scientists who are engaged in the Community Earth System Model project.

(d) There is insufficient scientific in-house expertise at NCEP to analyze and develop the non-atmospheric components of the CFS, especially the ocean and sea ice components. A national seasonal prediction strategy and platform that encourages and integrates the entire community is needed.

(e) UMAC endorses the NCEP plan to rapidly deploy CFSv3 within two years.

(f) A more effective and productive engagement of the research community should be made the centerpiece of CFS development going forward. The Climate Forecast System beyond the two-year time horizon should be a development effort that strongly involves the community, including GFDL, ESRL, CESM and the university community. Because NGGPS (see below) is intended to involve the community and has ambitions to build a 7- or 8-component Earth system model for prediction, the CFS development path should be closely aligned with NGGPS planning, with a particular emphasis on rigorous testing of the coupled NGGPS system in sub-seasonal and seasonal prediction mode, as well as long climate simulation runs that can address long-term biases and non-physical behavior. Involving research groups both inside and outside NOAA will require strategic planning, including considerations of targeted funding.

(g) Skillful coupled model prediction depends on significant reanalysis and reforecast efforts that should be undertaken on a regular schedule with a base budget, not planned and funded as one-off activities. This is further elaborated in Section 4E below.

4. **NGGPS**. The Next Generation Global Prediction Systems (NGGPS) is a five-year (2015 – 2019) project to develop a new global prediction system with a high-resolution non-hydrostatic atmospheric dynamical core, advanced physics and data assimilation, coupled to at least six other component models (ocean, land surface, sea ice, ocean waves,

atmospheric chemistry, and aerosols). There is also development work for a "whole atmosphere" capability that has a higher atmospheric "top" and resolves circulations and processes in the upper atmosphere, up to and including the ionosphere.

Findings and Recommendations

(a) Atmospheric dynamical core - The NGGPS effort has established an evidence-based process for selecting a single non-hydrostatic dynamical core for all global atmospheric model applications over the next 6-9 months, which is consistent with one of UMAC's overarching recommendations.

(b) The committee strongly recommends that NCEP use only one dynamical core for all global model application.

(c) Atmospheric physics - There should be a process for the advancement of the global atmospheric model, that includes rigorous testing of the sub-grid scale physical parameterizations ("physics"). The UMAC endorses increased sophistication and realism of the parameterization of key physical processes, in addition to scale-aware capabilities for convection and boundary layer formulations and a physically based framework for stochastic parameterizations. The committee also endorses the maintenance of a user- friendly single column semi-prognostic model that can be used to test physical parameterizations and can serve to better leverage the developmental efforts of the research community. The plan for an open code repository will make it possible for a single physics package to be implemented in operations, while research on experimental versions of the physics package can be undertaken by the external community.

(d) Other components - The NGGPS will include 8 components (global atmosphere, ocean circulation, land surface, sea ice, ocean surface waves, aerosols, atmospheric chemistry and whole atmosphere, including ionosphere). The plan for non-atmospheric components are vague and need to be strengthened.

(e) NGGPS development will be accomplished within the NEMS/NUOPC/ESMF framework described above, which enables better version control and documentation of source that will encourage engagement of the research community. Coding for global systems at NCEP should be rigorously reviewed in the context of current state-of-the-art software engineering practice. The review should be undertaken by an independent board of experts in computer science and software engineering.

(f) The committee applauds the general vision of NGGPS as a community model. In order for that to happen, strong incentives must be provided for researchers, including large labs like GFDL and ESRL and individual university investigators such as those who participate in the CESM project, to actively use the NGGPS codes. Drawing on the experience of the CESM project is highly recommended. Strategic planning to extend this model of community development beyond the five-year timeline of NGGPS is therefore essential.

(g) UMAC strongly recommends that NCEP develop a clear science and implementation plan to get to NGGPS (including timelines, resources required) that includes strong collaboration with NOAA labs. This may require managing the development project as a system engineering effort with a project office that can ensure the project is on schedule and within budget.

5. **Global and coupled data assimilation**. Data assimilation is the methodology by which observations of the state of the atmosphere and related earth systems are synthesized with background forecasts to create initial conditions for a forecast model. Data assimilation science has received considerable attention in the past several decades as it is widely recognized that proper initialization of models is as important to improving the skill of the forecasts as is improving the observations collected and model used. Skillful data assimilation can be computationally expensive with major modelling centers often spending comparable computing resources on both the assimilation and forecast model. NCEP's current global atmospheric data assimilation system is referred to as the Gridpoint Statistical Interpolation (GSI) system and uses a hybrid ensemble Kalman Filter (Hybrid EnKF) as its core methodology.

Findings and Recommendations:

(a) The GFS skill has increased considerably with the hybrid-EnKF assimilation upgrade and we strongly endorse additional advancements to the GFS data assimilation system including the 4D-En-Var system. Implementation of the hybrid 4D-En-Var in operations should be considered a high priority.

(b) The current GSI code has many disadvantages, and a restructuring as proposed by JCSDA is strongly encouraged. These deficiencies include a lack of modularity; for example, the forward operator assumes a Cartesian grid structure. Forward operators are computationally expensive with ensemble data assimilation as currently configured; adjoints of the forward operator are not used to improve computational performance. The GSI cannot readily be applied to unstructured grids such as the icosahedral grid used in MPAS. Quality control is substandard; ensemble spread information is not used in the background check. Assimilation of radiances in cloudy areas could be improved.

(c) The committee endorses enhancing the further advancement of the data assimilation system in preparation for the NGGPS and building tools to routinely diagnose and monitor the observation impact of every observing system used in the assimilation system.

(d) As the primary developer and user of the data assimilation system, NCEP should take the leadership organizing and coordinating the data assimilation system development efforts through the multi-agency Joint Center for Satellite Data Assimilation (JCSDA). NCEP should support the effort at JCSDA to modernize the data assimilation systems using modern software engineering approaches and leveraging the lessons learned from Object Oriented Prediction System framework developed at ECMWF.

(e) Recognizing the limited number of individuals with suitable data assimilation experience in the U.S., NCEP and JCSDA should carefully develop a data assimilation system development and transition strategy similar to the one developed for global models (i.e. NGGPS). The manpower and computational resource should be prioritized toward the development of the new system instead of maintaining the old. NCEP should carefully manage the transition.

(f) NCEP should adopt a transparent, evidence-based approach in allocation of computing resources to data assimilation, consistent with the overarching recommendations of this committee.

B. Regional Modeling Systems

3.B.1 Introduction

The current portfolio of regional modeling systems run by NCEP is highly complex, using multiple models, multiple versions of the same models, and a complex collection of domains. Specifically, NCEP is now running operationally:

1. A full North American Model (NAM) run at 12-km grid spacing to 84-h using the NMMB model (Non-hydrostatic Multiscale Model on the B-grid), four times per day.

2. Four fixed one-way nested domains of the NMMB model run to 60-h four times per day
   a. 4-km CONUS nest
   b. 6-km Alaska nest
   c. 3-km Hawaii nest
   d. 3-km Puerto Rico nest

3. A very high-resolution (~1.3 km) nest of NMMB run to 36-h over a very limited area. This nest is placed at varying locations depending on need.

4. Daily high-resolution (3-4 km) runs over the four domains noted in (2) using the NMMB and WRF ARW cores but initialized by the Rapid Refresh (ARW core, 13-km) system over CONUS, and the GFS model over the three other nests.

5. A Rapid Refresh system (RAP) run using the WRF ARW core with a one-hour cycle over North America at 13-km grid spacing with forecasts out to 18-h.

6. A High Resolution Rapid Refresh (HRRR) system run using the WRF ARW core with a one-hour cycle over North America at 3-km grid spacing with forecasts out to 15-h.

7. A Hurricane WRF (HWRF) system with a triply nested structure (18-7-2 km) run with

the NMME atmospheric core coupled to the Princeton Ocean Model (POM). Initial and boundary conditions are provided by the NCEP GFS model. HWRF is run separately for up to 7 storms around the world. In the most recent season (2015), a 20 member HWRF ensemble was run using 27-9-3 km resolution. There are plans to go to a 40-member HWRF ensemble. The physical parameterizations in HWRF differ from the NMM and WRF-ARW.

8. The GFDL hurricane model, which runs nested within the GFS. The GFDL hurricane model is hydrostatic and run with a horizontal resolution of approximately 6 km. The intensity prediction accuracy of the GFDL model in the W. Atlantic has lagged other operational models in 2015 (such as HWRF and COAMPS-TC).

9. A Short-Range Ensemble Modeling System (SREF) with 26 members run at 16 km grid spacing over North America four times per day. Two model dynamical cores are used (NMMB, WRF-ARW) with varying physics options.

10. NCEP is now building a NAM-RR system, with the NMMB core being used as the center of a Rapid Refresh system parallel to the current RR system based on WRF-ARW.

11. Three different regional data assimilation systems are being run (RAP, NAMDA, HWRF), plus use of the GFS initializations for some regional modeling.

In summary, NCEP is running an extraordinarily complex collection of regional models, using four different dynamical cores, many domains, a large range of resolutions, and varied data assimilation systems and physics. This complex modeling environment has been developed without a strategic vision of long-term goals or evidence-based demonstration of the efficacy of the current approaches. Within EMC there is active consideration of reducing the number of modeling systems, a direction that should be encouraged. Several of the modeling systems used by NCEP (e.g., NMM/NMMB) are generally not used by the academic community, making it more difficult for NCEP to take advantage of the latest research.

3.B.2 Overarching Findings and Recommendations

Reviewing NCEP's regional modeling portfolio, UMAC finds that NCEP's regional modeling effort is excessively diverse and complex, making development and operations difficult and costly. It also reduces the effectiveness of R2O, reducing NCEP's ability to benefit from modeling research in the community. Accordingly, UMAC has the following recommendations:

1. NCEP's regional modeling efforts should be increasingly guided by an evidence-based approach in which verification and testing precedes decisions regarding deployment of new modeling systems, major modeling changes, or strategic planning for regional modeling. Best practices of successful modeling efforts of other major operational centers can also provide useful guidance.

2. To reduce complexity and to facilitate more effective model development, NCEP should strive towards using one model dynamical core for all regional modeling applications, and in the long term adopt one core for both global and regional applications. Because of its effectiveness in promoting rapid progress, a unified approach has become standard operating procedure at other major operational centers.

3. NCEP should develop a convection-allowing ensemble over the United States. Such an ensemble is a clear national need and recommended in numerous NRC reports and national workshops (e.g,, NRC: "Completing the Forecast" (2006)).

4. NCEP should strive to bring high-resolution deterministic prediction, high-resolution ensemble prediction, rapid refresh modeling, and mesoscale data assimilation together into a single model framework.

3.B.3 Specific-System Findings and Recommendations

1. The current complex array of modeling systems, model cores, and overlapping/duplicative modeling runs is highly inefficient, in terms of both human and computing resources. Careful strategic planning, substantial simplification of NCEP's regional modeling suite, and more extensive use of community modeling are required for NCEP regional modeling to achieve world-class performance.

    a. Considering these points, the committee strongly recommends that NCEP reduce its mesoscale modeling effort to a <u>single regional dynamical core during the next 2-3 years</u>. Furthermore, <u>NCEP should put high priority in building a unified modeling system</u>, whereby regional and global models use the same dynamical core and a common community-based physics suite. The latter transition should be completed during the next 5-10 years.

2. Strategic planning is required for both coherent model/system development and as a guide for outside users and the research community. Currently, NCEP does not appear to have a strategic vision or plan for its regional modeling, and thus the committee recommends that the development of such a plan be given substantial priority.

3. There is considerable evidence (e.g., Palmer et. al. 2009; ECMWF Tech Memo 598) that the use of stochastic physics and related approaches is a viable approach to represent model error in ensemble applications, in contrast to the multiple core/multiple physics option approach used in the NCEP SREF. Multi-model regional ensemble systems have a high cost in human resources and maintenance, and possess conceptual deficiencies.

4. NCEP should carefully test and evaluate approaches for achieving physics diversity during the next two years, and rapidly move (within 5 years) to the stochastic physics approach if it proves to be comparable to or superior to the current multi-model/ physics

parameterization approach, as suggested by current research and the experiences at other major centers.

5. The committee notes the NCEP SREF (16-km) has comparable resolution to the expected upgrade of NCEP's Global Ensemble Forecast system (GEFS, 25 km). The committee sees little reason for NCEP to maintain two hydrostatic ensemble systems of similar resolution, particularly since a global ensemble system is innately superior. The addition of physics diversity to GEFS would further support the ending of NCEP's SREF. NCEP should proceed with a comparison of the proposed GEFS system with SREF and drop SREF if the GEFS probabilistic forecasts are comparable or superior. The committee also encourages NCEP to increase GEFS resolution to approximately 15 km to better simulate key mesoscale features around the world – or consider performing a native GFS resolution (13 km) ensemble for shorter time periods.

6. There is an acute need for a convection-allowing (2-3 km) ensemble system in the U.S. to provide probabilistic guidance for severe storms and other mesoscale phenomena (e.g., orographic precipitation, downslope windstorms, coastal winds). Such an ensemble system has been recommended in numerous National Academy reports and community workshops/meetings. The absence of EMC guidance in this area has resulted in community responses outside of NCO operations to provide partial solutions to address these needs, such as the Storm Scale Ensemble of Opportunity (SSEO) and NCAR's current WRF-ARW high-resolution ensemble effort.

    a. To deal with this important requirement, NCEP, working with the academic community and national labs, should plan and construct a convection resolving (roughly 3 km) ensemble system over the CONUS during the next two years with as many members as computationally feasible and justified through testing, with an ultimate goal of 50-100 or more members. This ensemble should include both initial condition and physics diversity (achieved through stochastic physics approaches), making use of recently expanded computer resources and the reclamation of resources from terminated modeling systems (e.g., possibly SREF). There is considerable value in running even a small (5-10 member) ensemble and then acquiring additional computational resources for this system as funding and technology permits. A detailed short and long-term development and implementation plan is needed for this convection-allowing ensemble system, as it is a critical capability needed in operations to support the weather enterprise.

7. Since the GFS is now being run at the equivalent of 13-km grid spacing four times a day, the NAM (NMMB) 12-km run may no longer be necessary. There is substantial operational model verification to show the past and current superiority of GFS over NAM, providing objective evidence for ending the NAM 12-km run. NCEP should complete a careful comparison of the GFS and NMMB 12-km forecasts, phasing out the latter if the former shows equal or superior verification. This evaluation and decision should be made during 2016.

8. NCEP EMC staff is now developing a Rapid Refresh version of NAM called NAM-RR, making use of the NMMB core. This proposed modeling system appears to be duplicative of the current Rapid Refresh system, which runs the ARW core operationally. NAM-RR will require large amounts of computer resources resources and has been shown to have poor performance at convection-allowing resolutions. To proceed with this development, NCEP should provide evidence, based on extended verification, that such a NAM-RR system would add substantial value to the current RR system or the current RR system extended with stochastic physics. If this bar cannot be reached, the NAM-RR effort should be terminated.

9. There is considerable evidence that high-resolution mesoscale data assimilation should be ensemble based. It is also evident that rapid-refresh systems should also be ensemble based to secure uncertainty information over short time scales. It thus makes sense to have a common ensemble modeling framework serving multiple needs regarding ensemble forecasts and verification. Thus, over the longer term (3-6 years), NCEP should move towards an integrated high-resolution ensemble, rapid-refresh, and data assimilation system that will serve all regional ensemble needs. In such a system, a large (50-100 member) ensemble of high-resolution short-term (e.g., one-hour) forecasts will assimilate all available mesoscale observations. Extended (0-3 day) mesoscale ensemble runs should be made at regular intervals.

10. One of the problems plaguing NCEP's high-resolution modeling portfolio has been the isolation of much of its modeling effort from the benefits and positive impacts flowing from insights and developments of the research community. To allow NCEP to more effectively partner with the research community, UMAC recommends that NCEP should transition from its current in-house NMMB dynamic core to a community core, such as ARW or the new NGGPS core. It is important to note that a community core is not a core *offered* to the community, but a core *used actively* by a substantial fraction of the community.

11. The HWRF system represents an additional high-resolution modeling infrastructure dedicated to one application (tropical storms), in contrast to successful efforts at other institutions (such as UK Met Office, ECMWF), which use one modeling framework for all scales and phenomena. HWRF is computationally intensive, often running several high-resolution domains, relies on a large development and support staff, uses an old dynamical core (NMME), and recently has experienced substantial resource reductions.

    a. The committee believes the HWRF system would benefit greatly if it were to adopt the NCEP unified system approach that takes advantage of a community or NGGPS core. The current HWRF is not sufficiently generalized and is heavily dependent on the NMME. UMAC recommends that NCEP's future high-resolution hurricane infrastructure be model (and dynamical core) independent, so that the data assimilation, physics, and vortex initialization can be easily ported to a unified modeling system.

    b. A major question is whether HWRF should be run for storms across the globe, rather than being limited to hurricanes threatening the U.S. coastal zone. Furthermore, with appropriate domains encompassing U.S. coastal zones, a nesting capability may not be required, offering substantial simplification. Given the considerable computational and human resources required for the current HWRF, we recommend NCEP evaluate the cost-benefits of running HWRF using static coastal nests, thus eliminating the requirement for movable nests.

12. Current NCEP verification systems and public verification data are inadequate and do not provide NCEP or its user community with detailed regionally relevant statistics on model performance or illuminate model deficiencies. This issue requires attention and remediation. We recommend that NCEP unify its verification systems, and migrate toward a community verification system, based on infrastructure such as MET and METviewer, with comprehensive and regionally specific statistics. Other research entities, such as NOAA ESRL, also have built verification infrastructures that may be useful. If research and operations used the same verification system, R2O would be greatly enhanced. Additionally, the model development and evaluation process would benefit from a verification scorecard that is derived from stakeholder input.

13. More sophisticated statistical post-processing is required for U.S. regional modeling. Currently, private sector forecasting concerns (e.g., the Weather Company, Global Weather Corporation) are providing superior forecasts due to more modern post-processing of the same observation/model datastreams. UMAC recognizes, though, that the short time series of forecasts typically available with regional models, the relatively poor data sets trained against, the lack of data saved from the models, the high state of flux in regional model choices and the lack of a strategy for reforecasting for regional scales all provide significant challenges for addressing this issue quickly. Also, the separation of the statistical forecasting group at MDL from NCEP is not optimal for integration of post-processing research for NCEP modeling systems. Thus, UMAC further recommends that the relevant components of MDL be moved into NCEP to facilitate the development of a world-class statistical forecasting capability.

14. Extensive model documentation is a necessity for evaluating the value and strengths/weaknesses of NCEP modeling systems. It is also an important means of communication to the research and user community. The current NCEP model documentation is often inadequate, with dead links or out-of-date information. The NCEP SREF model description page provides a good illustration of the problem (http://wwwemc.ncep.noaa.gov/mmb/SREF-Docs/). Users should be able to view the latest model descriptions for all NCEP modeling systems on the NCEP website.

15. Unified data assimilation is needed for NCEP's regional modeling needs. Currently, NCEP has at least three separate mesoscale data assimilation systems for its regional runs (NAMDA, RAP/HRRR, and HWRF), with GFS initial conditions used for some runs without additional manipulation. These separate data assimilation systems are at the model level, with GSI serving as the underlying data assimilation approach. The use of separated data assimilation systems is a redundant, costly approach that is a poor use of human and infrastructure resources. The committee recommends simplification to

one regional assimilation system, with the long-term goal of unification of data assimilation across scales. The committee also recommends that NCEP routinely execute data assimilation observation impact studies to continually assess the performance of the data assimilation system and to document the most beneficial observing systems for the regional and hurricane prediction systems. The quantification of the observation impact is crucial to inform the current and future national observing systems, including satellite-based observations.

C. Water-Related Modeling Systems

3.C.1 Introduction

Reviewing NCEP's water-related modeling portfolio, UMAC finds that NCEP's effort is quite diverse and could benefit from closer coordination among EMC, NOS, and NWC.

3.C.2 Overarching Recommendations

1. Close coordination among EMC, NOS and the National Water Center (NWC) is critical, including shared plans for how requirements will be met through hiring personnel, prediction system developments, data assimilation and verification capabilities.

2. External factors to NCEP are driving requirements for NCO to execute prediction system such as from NOS and NWC. There needs to be an objective, standardized process for reviewing, prioritizing, and allocating NCO resources.

3. The external review process at NOS seems to be a positive model first step that should be enhanced and integrated with and implemented at EMC.

4. The newly established National Water Center requires a well thought out stepwise plan to find the best path for water modeling and forecasting. Many conflicting choices are presenting themselves now.

5. It is important for the modelers in the NOAA water arena to be more visible in the community, e.g., appearing at conferences and submitting manuscripts for publishing in the peer reviewed literature.

6. Hydrologic prediction is inherently uncertain, in part because of precipitation uncertainty, in part because of significant uncertainty of the land-surface state and hydrologic prediction systems. For hydrologic forecasting beyond lead times of 48-72 hours, the computational approach should be inherently probabilistic.

3.C.3 Specific-System Recommendations

1. Ocean

NCEP currently uses three ocean models, HYCOM for short-term forecasts (RTOFS), MOM within the CFS for long term forecasts, and POM in HWRF for hurricane forecasting.

a) HYCOM is the ocean component of the NAVY Global Ocean Forecasting System (GOFS) and has been optimized for high-resolution ocean prediction. The current MOU between Navy and NOAA allows for the provision of restart files as well as implementation of NCODA, the data assimilation code of GOFS. NCEP uses the restart files to provide global 5-day forecasts at 1/12 degree resolution. Future NCEP plans include higher resolution Atlantic, Pacific, and

Arctic configurations to be coupled to HWRF for hurricane prediction.

b) MOM4 is the current ocean component of the CFS at 1/2 degree resolution and has been used extensively for longer integrations and forecasts. Hybrid coupled DA is used for the forecast. Future plans include upgrading MOM4 to MOM6.

c) POM is the current ocean component of HWRF, but is in the process of being phased out and replaced by HYCOM (see above).

Findings and Recommendations:

1. While it would be beneficial for NCEP to use a single ocean model (less dilution of local expertise), NCEP has quite effectively used the expertise of the Navy in short-term forecasts and of GFDL in long-term forecasts. Switching to a single model at this point in time would be counterproductive, but that option should be investigated in the years to come using an objective, science-based process. There will be opportunities to a) test HYCOM's performance within the CFS since HYCOM is in NEMS, b) develop common data assimilation techniques to HYCOM and MOM since the ALE vertical coordinate of MOM6 is very similar to the one used in HYCOM, and c) examine model diversity by performing ensemble prediction with two ocean component models.

2. NCEP should continue to leverage Navy's expertise on high-resolution short-term ocean prediction and should strengthen its ties with GFDL. Regarding the latter, it is essential that NCEP develop strong local capability with MOM6 in order to take advantage of GFDL's expertise (postdoctoral program with option to hire for example or visiting scientist program). Finally, in order to fulfill the ocean data assimilation needs (global, coastal, and coupled), the data assimilation team needs to be strengthened given the recent departures and retirements.

2. Waves

Findings and Recommendations:

The WAVEWATCH III community seems strong (within and outside of NCEP), including training/workshops, and could be a model for developing community modeling activities.

3. Coastal

NOAA's National Ocean Service has the mission and mandate to provide guidance and information to support the nation's navigation and coastal needs. To support this mission, NOS has been developing and implementing a national network of hydrodynamic operational oceanographic nowcast and forecast modeling systems to support navigational and environmental applications in U.S. coastal, estuarine waters, and the Great Lakes.

Findings and Recommendations:

1. NOS currently operates and maintains 15 operational forecast systems for the eastern and western U.S. coasts (including Alaska and Hawaii, the Gulf of Mexico, and Great Lakes, covering approximately 35% of the CONUS coast. Over the next 5 to 8 years, NOS will work toward full CONUS coverage. Presently, there are 6 different hydrodynamic circulation models running on NOS platforms. The plan is to transition to two, but the process by which these two models are chosen needs to be documented in order to get endorsement by the users and science community. Given the plan for 100 % CONUS coverage and an expansion of mission (e.g., from supporting navigation to ecological forecasting), NOAA/NOS would greatly benefit from developing a strategy document (e.g., similar to other NOAA modeling "roadmaps") for the Operational Forecast System program and its validation.

2. NOAA/NOS does not have all that is required in-house to achieve its mission, so it is essential that partnerships be strengthened or developed. NOS would benefit from 1) a closer and more effective working relationship with NCEP to operationalize the systems, by having a senior NOAA scientist responsible for the interactions and 2) strong interactions and even formal partnerships with academics that have developed independent robust and accurate forecast systems. In particular, NOS is encouraged to leverage the metrics that are being developed within the GODAE OceanView Task teams.

3. We recommend caution when expanding into ecosystems applications since there is not of lot of in-house expertise and there are few observations to validate the forecasts.

4. Storm Surge

NOAA has a responsibility to accurately assess and predict the total water level during a coastal inundation event (as caused by surge, tides, waves, rivers, and other oceanographic and terrestrial water source effects). This also includes accounting for uncertainty in models and observations, and predicting it via ensembles and probabilistic forecasts.

Findings and Recommendations:

1. The approach taken by NOAA is to use two types of models: a simple model (SLOSH) that can be used for quick guidance and probabilistic products and a slightly more complex model (ADCIRC) that captures surge response better, but is computationally more demanding. NOAA should be applauded for developing an agency-wide Storm Surge Roadmap. The Roadmap, however, does not describe the stakeholder requirements in an integrated way, especially with regard to the effectiveness of the two types of model products. Nor does it state the requirements that might motivate more robust representation of physical processes. Therefore the roadmap appears to perpetuate the two modeling paths, based on the interests of the developers. Requirements need to be documented and reconciled, and the development of the storm surge products need to follow from these requirements. The Roadmap document outlines the activities of the personnel involved but fails to provide an apparent strategy or evidence of a commitment:

(i) to utilize the capabilities of SLOSH and ADCIRC together to provide an integrated set of storm surge products for the public; or

(ii) to coordinate model development activities. The former means that NOAA may not be maximizing the value of these combined modeling capabilities and the latter means that NOAA may not be investing wisely in further model development.

Improving the Roadmap to better capture the current NOAA's Roadmap Team's strategy and commitments should be planned.

2. Given that ADCIRC includes tides in a rigorous fashion, is coupled to a wave model and covers large domains while providing high resolution, it is hard to understand the reason for expanding SLOSH to include these capabilities. The justification for SLOSH in the NOAA Roadmap is speed and the recognized compromise is accuracy. The investments that are described in SLOSH clearly reflect a desire to expand its role beyond being fast (and in fact will cause it to run more slowly) and it is not clear how they mesh with ADCIRC's role in a coordinated strategy. It should be noted that SLOSH has a number of shortcomings that will limit its ultimate applicability, e.g., it is not written for use on modern multi-processor, high performance computers; it requires the use of fictitious water depths in deep water; and it has an inflexible representation of bottom stress for capturing varying land surface types that needs modification. It also has minimal (if any) buy-in as a development platform from the academic coastal ocean modeling community and thus does not benefit from the investments of this group. Thus, it is fundamentally limited in its future performance and accuracy compared to ADCIRC.

3. Since both SLOSH and ADCIRC are inherently incomplete with respect to bottom stress and use the average velocity of the water column in their parameterization of bottom stress, the rationale that the physically limited SLOSH and ADCIRC models must be used because they are less demanding of computational resources must be addressed and justified. NOS uses full 3-D models with complete physics for their operational forecasting and their use will likely lead to more accurate forecasts of storm surges. The current allocation for storm surges on WCOSS resources seems surprisingly small given the significance of this issue. The allocation should be expanded given the new computer power so that appropriate physics-based models can be run.

4. Development of academic partnerships jointly with NOS and NWS or directly with NCEP should be established.

5. Hydrology:

With support from the highest levels of NOAA and DOC, the newly established National Water Center (NWC) has embarked on an ambitious and long-overdue program to revolutionize U.S. national water modeling and forecasting. As part of this effort, the NWC has adopted the NCAR WRF-Hydro modeling system and is currently supporting an accelerated transition of the WRF- Hydro model to the NWS Weather and Climate Operational Supercomputing System (WCOSS) supercomputer.

Findings and Recommendations:

1. While the planned WRF-Hydro capabilities represent a substantial leap forward from the lumped, highly parameterized, forecaster-in-the-loop prediction currently done at the 13 River Forecast Centers, the computational costs are on par with other large atmospheric modeling systems, and therefore NWS must balance this investment against other competing demands for limited computational resources. Further, NWC must carefully consider how to evaluate the value of a more physical model, including potential biases and additional parameter uncertainties, versus a conceptual model that is more easily tuned for a single objective. NWC desires a capability of resolving water prediction at scales of individual hill slopes and catchments, and UMAC recommends dedication of resources commensurate with the importance of these requirements. However, the trade- off space for accuracy vs. computational cost must be more fully and objectively explored.

2. Aside from the scientific and computational considerations, the WRF-Hydro modeling system name is misleading. Perhaps the NWS should consider re-branding the project to be more descriptive.

3. Finally, the Water Resources Evaluation Service (WRES), which includes verification and benchmarking activities, is critical to the success of this effort. RFC and community buy-in will only be possible after extensive, publicly accessible verification and benchmarking efforts against observations and existing capabilities (hindcasts).

6. Land Surface

Land surface modeling within EMC consists of efforts aimed primarily at providing precipitation, soil moisture, snow, streamflow, and evaporation products to the drought community, in addition to initialization of and coupling with in-house models such as NAM, GFS, and CFS. Recent efforts have focused on unifying the land surface components of the modeling systems, by first moving towards a unified land surface model (the Noah LSM), developing common parameter datasets (e.g., MODIS or VIIRS-based vegetation data) as well as efforts to develop common land data assimilation systems (LDAS) that can be used to initialize forecast models such as NAM, GFS and CFS. Currently, only CFS has an operational LDAS, known as the Global LDAS (GLDAS). While NAM, GFS and CFS all run variants of the Noah LSM, the HRRR uses a different land surface model known as the RUC model, and the HWRF is in the process of upgrading to Noah.

Findings and Recommendations:

1. The committee applauds efforts to consolidate and streamline the land surface modeling and data assimilation efforts. By focusing its efforts on a single land surface model (Noah), common parameters (e.g., VIIRS GVF), and common community-based software infrastructure (NASA's Land Information System), the EMC land surface

group can more effectively incorporate advances in land surface physics and data assimilation that could benefit all EMC systems. The Noah-MP model is somewhat problematic, as the numerous physics options cannot be fully vetted. Hence, EMC needs a benchmarking effort to help objectively evaluate a land physics suite for use in operational systems.

2. Further, these efforts, particularly the North American LDAS (NLDAS), have a long history of strong community involvement and widespread use of the data, even though the NLDAS is not currently used to initialize any EMC models. The NLDAS project runs an ensemble of four land surface models (Noah, VIC, Mosaic, SAC) several days behind real-time, and became operational in August 2014. The NLDAS' only clear stakeholder is CPC and the drought community (e.g., NIDIS). However, the NLDAS capabilities are directly relevant to developing LDAS' for NAM, GFS, HRRR and HWRF. Further, the NLDAS objectives overlap somewhat with NWC national water modeling objectives, so it is critical to strategically consider the future of NLDAS vs. CPC (drought), EMC (NAM, HRRR, GFS, CFS) and NWC modeling efforts.

3. Given the overlaps between EMC and NWC requirements for land surface/hydrological modeling, a more comprehensive look at data (e.g., retrospective forcing data from reanalysis and/or analysis of record, modeling architectures (e.g., NGGPS and SREF) and the models themselves (Noah, Noah-MP, RUC, etc.) is needed.

4. Finally, unlike atmospheric model verification, land surface verification is not standardized or operational, and requires extensive data-gathering efforts from non-NOAA sources in addition to standardized techniques. Further, recent work on land model benchmarking suggests that complexity does not immediately yield improvement. Hence, land surface verification and benchmarking data and techniques should be developed and disseminated so that they are easily repeatable by the community.

D. Ensembles and Predictability

3.D.1 Introduction

EMC generates predictions from several ensemble systems tailored to the needs of customers at various time scales. These included (implicitly) a lagged ensemble from the HRRR, the SREF, the GEFS, and the CFS. Hydrologic ensembles are also produced by the NWC. Here we highlight several overarching issues related to the ensemble and predictability recommendations.

3.D.1.a. *Multi-model ensembles*. A major issue regarding EMC's ensemble design plans is the use of multi-model ensembles (MMEs). There is ample evidence that MMEs provide a greater diversity of solutions, and because there is commonly too little spread in ensemble prediction systems, the greater diversity leads to statistics that demonstrate more consistent spread and ensemble-mean error. This is seen as a prominent advantage of MMEs.

There are several challenges with this line of ensemble augmentation, however. First, is the spread "good", in the sense that it provides the user with information on state-dependent uncertainty, as opposed to reflecting a differential growth of systematic errors among members? This requires evaluation of the ensemble using more than simple spread and error vs. time plots. For example, binned spread-error relationships could be calculated, especially ones where spread and error have been normalized by climatological error variance so that these relationships do not reflect regional climatological differences in uncertainty.

A more fundamental problem exists with MMEs, including NOAA MMEs. As discussed elsewhere in the UMAC document, if available resources are spread across multiple dynamical cores and multiple suites of parameterizations, then the potential rate of improvement of any one system is slowed. Further, there is the potential for conflict between model improvement and maintaining spread in an ensemble prediction system. Suppose a dramatically improved parameterization for a particular type of physics (e.g., PBL) is developed that has minimal systematic error, while other existing parameterizations have systematic errors to varying degrees. In a MME, the old parameterizations may be retained in many members for sake of ensemble diversity, and only the few members that use the improved parameterization will have less systematic error. In this way, the rate of improvement of the overall ensemble prediction system is slowed.

Such concerns have led to decisions at other prediction centers, including CMC, ECMWF, and the UK Met Office, to consolidate their prediction systems and to treat the relative lack of spread through "stochastic parameterizations," whose development can be adequately resourced. This is practically an international consensus best practice now, and it underlies the UMAC recommended consolidation of ensemble prediction under a unified dynamical core as discussed below.

A final rationale for the use of single-dycore ensembles is that reforecasting is computationally less expensive. If every member has a unique systematic error, as may occur with MMEs, then the reforecast will require as many members as the real-time ensemble, in order to provide estimates of the systematic error for each member. If all members have exchangeable error statistics, a smaller reforecast ensemble may be practical for most applications.

3.D.1.b *Computational considerations*. Ensembles are computationally expensive. All things being equal, higher-resolution, larger-member ensembles will provide more usable probabilistic information than lower-resolution, smaller-member ensembles. Of course, there are many other ways to use the available computational cycles, including improving the data assimilation system, providing more retrospective analyses and forecasts, improving the parameterization suite, coupling state components of the model, and extending the forecasts to longer leads. UMAC's recommendations on ensembles should be considered in this larger context.

Considerations of predictability should also be considered when allocating computer resources. Suppose an examination of hurricane predictability demonstrated that small-scale fluctuations of the eye wall (e.g., asymmetries, replacement cycles) and attendant intensity changes were unpredictable beyond a time scale of 48 h. Unless the increased resolution demonstrably improved other aspects of the prediction, then the use of high-resolution ensembles would not be warranted.

3.d.1.c *Regional ensembles*. The resolution of the GEFS is likely to be enhanced significantly, making it similar in resolution to the current hydrostatic regional ensemble system, the SREF. Further resolution increases to the GEFS are possible if the cycles used with the SREF are reallocated to the GEFS. Given this and the numerical issues related to the use of lateral boundary conditions in the SREF, this system is an obvious candidate for pruning.

3.D.2 Overarching Recommendations

1. NCEP should consolidate its ensemble prediction under unified dynamical cores using physically based stochastic parameterizations to treat model uncertainty in the ensembles. Ideally, one core would be used for both global and regional, but in the intermediate timeframe, separate regional and global cores may be inevitable.

2. The allocation of production-suite resources for ensemble prediction systems must be balanced with other uses based on a careful analysis of requirements.

3. Ensemble product generation from the SREF should be moved over to the GEFS, and the SREF should be discontinued.

4. If data from other mature ensemble prediction systems are available at little or no cost to NOAA from national or international partners, then their use should be evaluated by NOAA. However, the primary goal for NOAA's ensemble prediction

development should be to produce numerical guidance of such quality that little is gained from leveraging other centers' data.

5. NOAA climate prediction resources should be used to fund the improvement of NOAA models, not external models.

6. NOAA's ensemble prediction community should work with the UMAC-recommended chief NEWP scientist to produce plans that clarify objectives, resources, and infrastructures needed, and implement these plans with modern project management concepts and systems-engineering oversight.

3.D.3 Specific-System Findings and Recommendations

1. *Regional convection-permitting ensembles*. UMAC notionally supports the development of a convection-permitting regional ensemble system for applications that support Warn- On-Forecast, heavy precipitation, severe local storms, hurricanes, and others. The resources allocated to a convection-permitting ensemble should be evidence-based, following other UMAC recommendations.

2. *SREF*: This system should be discontinued. Products requirements and developmental resources for the SREF should be shifted to a higher-resolution GEFS.

3. *GEFS*:
   a. Model initialization should be done with initial conditions generated by the operational ensemble-based data assimilation system.
   b. Given the challenges maintaining multiple dynamical cores and parameterization suites, ensemble diversity should be dealt with through the development of physically based stochastic parameterizations
   c. When the new global dynamical core from NGGPS is ready for operational development, the global ensemble developmental resources should be moved as quick as possibly to using this new core and its parameterization suite.
   d. Continued leveraging of analysis and forecast data from other independent centers such as the Canadian Meteorological Centre is recommended. Leveraging other international centers' existing ensemble prediction data to form blended products has been shown to improve skill. It is noted that this increases the complexity of data management for post-processing, however. Despite the recommendation for leveraging other centers' data, the primary goal for NOAA should be to produce numerical guidance of such quality that little is gained from leveraging other centers' data.

4. *CFS*:
   a. When ready, NOAA should concentrate its developmental resources for climate ensembles around the new dynamical core and parameterization suite provided by NGGPS.
   b. UMAC recognizes that other organizations around the US are also independently developing seasonal ensemble prediction systems. NOAA

should collaborate with these partners to incorporate the best elements from their systems into the evolving CFS rather than distributing its developmental resources into producing multi-model ensembles.

5. *Hydrologic ensemble prediction*. For hydrologic forecasting at small scales and for lead times more than a few hours, the computational approach should be inherently probabilistic, and hydrologic prediction systems should be designed accordingly. Hydrologic prediction is inherently uncertain, in part because of precipitation analysis and forecast uncertainty, in part because of significant uncertainty of the land-surface state and the imperfect descriptions of physical processes in hydrologic prediction systems. The design of NOAA's hydrologic prediction system should reflect this.

E. Reanalysis / Reforecast / Post-processing

3.E.1. Introduction.

Statistical post-processing refers to the objective modification of new forecast guidance using discrepancies noted between past forecasts and observations/analyses. Statistical post-processing can dramatically reduce systematic errors, ameliorate spread deficiencies common in ensembles, and when using suitable methods with high-quality data sets can produce skillful, very reliable probabilistic guidance. Given this, some of NOAA's requirements will be able to be met more rapidly and at less cost through the combination of numerical weather prediction and post- processing.

3.E.1.a. Post-processing discussion.

One of the management challenges with the current suite of NWS post-processed guidance is its growing diversity. Post-processing is performed in the NAEFS system, MOS, the National Blend, as well as in other products generated at other centers (the recent National Blend project will provide foundational guidance to the National Digital Forecast Database, which is used and modified to produce the worded NWS forecasts used across the US). There are overlapping functionalities; NAEFS, MOS, and the National Blend each provide post-processed guidance of many sensible-weather elements. Given limits on resources, some consolidation of the suite of post-processed guidance is in order.

3.E.1.b Reanalysis, reforecast, and supporting data set discussion.

Experience has shown that for longer-lead forecasts and for more rare events, large training sample sizes are needed in order to produce skillful, reliable guidance. It is increasingly common worldwide to generate reforecasts, i.e., retrospective forecasts using consistent assimilation and forecast models. Retrospective initial conditions are also needed, which motivates the production of reanalyses (of course, such reanalyses have many other potential uses as well). Were the reforecasts computed in real time on the same computer system used to generate real-time forecasts, then in some sense the reforecasts would be in competition for resources with the real-time system. This would require a somewhat reduced system resolution, or fewer reforecasts. However, unlike the real-time system, reforecasts do not have the same on- time reliability concerns. Reforecasts for the month of March might be computed in January, and if there were a computer outage, there would be ample time to catch up. Hence, it may make sense to perform the reforecast computations on a different system with less reliability but also presumably less computational expense per compute cycle.

The hydrologic forecasting community has indicated that even more extensive reforecast data sets would be useful to them, not just for statistical post-processing, but also for validating the forecasts of past high-flow events. Suppose the hydrologists requested a reforecast that included 15 years for training of statistical models and 15 additional years for validation. It is worth examining whether every day of reforecasts need to be computed for the 15 prior years, or perhaps whether several dozens to hundreds of additional case days will cover the range of highest-impact events that are of greatest validation importance.

Assuming high-quality reforecast and observation / analysis training data sets are in place, the conduct of statistical post-processing algorithms is not particularly computationally expensive. The greater resource challenge is the production of these high-quality supporting data sets. The generation of high-quality R/R's that are statistically consistent with the real-time system is logistically and scientifically challenging and cannot be treated as an afterthought. To be consistent with the operational data assimilation system, a modern generation reanalysis will need to be ensemble-based, cycling high-resolution forecasts and using the same state-of-the-art assimilation method used operationally (which is likely to be 4D-En-Var in the near future). That is a computationally expensive proposition.

Reanalyses and reforecasts (R/R) are probably too computationally expensive to be generated with every new change to the assimilation/forecast system. If the change introduces only minor changes to the systematic error characteristics, new R/R's will not provide an increase in value commensurate with their computational expense. However, if systematic errors change markedly with the upgrade, then post-processed guidance will not be nearly as skillful nor as reliable when if the training data consists of older reforecasts with different systematic errors. It's quite likely that a prediction systems' systematic errors will change significantly on a time scale of several years, not decades. Hence, this will require that NOAA build a durable infrastructure for periodic reanalysis generation, including building a flexible database for archival of the observations and associated information used in reanalyses. It will also require maintaining staff with expertise in reanalysis generation and evaluation. With the regularized production of R/R's, obsolescent forecast models such as the 2012-era GEFS will be able to be removed from production, rather than being retained because of the extensive associated R/R's.

Low-error, unbiased, high-resolution reanalyses of record (such as an enhanced real-time mesoscale analysis) are also very important for post-processing and model verification. Ideally these would span the length of reforecasts to permit full leverage of the reforecast training data.

3.E.2 Overarching Recommendations

1. Decisions on what computational and storage resources are allocated to R/R should be done in a systematic manner, based on how they help NOAA meet its requirements, as recommended elsewhere by UMAC.

2. Nonetheless, given the demonstrated value of carefully constructed reforecast data sets, post processing and the production of supporting data sets (reanalysis/reforecast, R/R) should be considered an integral part of NCEP's future production suite and resourced accordingly.

3. NCEP should ensure that future requirements for high-performance computing systems and associated disk space include the regular production of R/R's.

4. NCEP and its partners should proceed to generate global R/R's on a regular basis rather than as one-off projects.

5. NWS should migrate its post-processing development resources from MOS, NAEFS, and other legacy systems toward the National Blend.

3.E.2 Detailed Recommendations.

1. NCEP and its partners should evaluate whether multiple global reanalyses will be required to meet diverse community needs. Some may need to be generated periodically with evolving operational data (suitable for post-processing applications), and some less frequently, with fixed observation networks (for climate monitoring and related purposes).

2. NCEP should develop diagnostics that help it when system changes have altered forecast characteristics enough to warrant production of another R/R. Some forecast model or assimilation system changes may not affect the statistical characteristics enough to warrant the logistical expense of generating a new R/R.

   (a) Consideration of R/R's for regional models should wait until convection-permitting ensembles are a stable system. Elsewhere in UMAC recommendations, we note that major changes to regional modeling systems are recommended, changes that are likely to take years to implement.

3. Non-operational, less expensive computer resources should be used reforecasting/reanalysis, which does not have the same reliability and on-time delivery requirements as real-time forecasting.

4. Because post-processing is also dependent on the quality of the observational / analysis data used for training, adequate resources should be dedicated to their improvement.

5. NWS should continue to engage international partners (Met Office, ECMWF, JMA) to contribute to MME. In return, the NWS should be willing to make its post-processing software a community resource.

6. MDL and its partners should emphasize the development of post-processing techniques that provide the greatest improvement with the least training data. For example, many model biases may not be dependent on location, and training data from other sites may be able to be used, reducing the need for lengthy reforecasts. As new, more data-efficient methodologies are developed, this should be reflected in the configuration of future reanalyses and reforecasts.

7. Ph.D-level statisticians are needed in MDL to develop algorithms to leverage the high-quality training data. The dedication of MDL staff is noted, but their existing staff would benefit from new additions with deep expertise in statistical methods that could advance NWS beyond MOS.

8. Consider co-locating the statistical forecasting components of MDL with NCEP so post-processing is better integrated into the NWS NWP effort.

9. MDL and its partners should hire software-engineering professionals and develop a more durable, modular software infrastructure for the archival of training data and its post- processing. Data should be archived in formats that are more standard and have quicker I/O. MDL is encouraged in particular to explore netCDF as an alternative to GRIB or their internal formats.

4. NCEP as an End-to-End System

NCEP, now, has the potential to rapidly progress to world leadership. However, this requires a new level of organization and bold, evidence-driven decision-making. The UMAC recommends that NCEP take a more formalized systems approach to development and management of its model-guidance or forecast products. This section will describe what the UMAC means by a systems approach, suggest policies and practices that have proved successful, and provide concrete examples for clarity. A systems approach, using principles drawn from systems engineering, represents a profound change of NCEP's historical practices and requires a multi- year transformation. Such a transformation relies on commitment and continuity from leadership, with the goal to develop an organizational culture that always focuses on pulling together disparate and diverging efforts. Presently, often well-intentioned individuals and small groups spearhead many efforts; this results in a fundamental finding of the UMAC - excessive complexity of the modeling, computing, and services portfolio. The UMAC was provided examples of activities within NCEP that are seeds of a more integrated, formalized approach. These emergent centers of focus are encouraging and will be discussed below.

Overarching Recommendations

1. Focus on ***forecast products:*** The true deliverable is a forecast product, which need not be slaved to a particular model. This brings attention to management of ***systems*** that include all of functions needed to delivery the forecast products.

2. Collect, document, manage and prioritize ***stakeholder requirements***. The requirements need to be managed across the portfolio of forecast products represented in the NCEP Production Suite.

3. Develop formal processes for NCEP-wide, ***evidence-based decision making*** that balances ***stakeholder requirements, scientific excellence, and cost***.

4. Commit to development and persistence of improved ***Governance and Project Management.*** This is required to support specific UMAC recommendations, for example,
    - Improve communications
    - Manage requirements
    - Terminate out-of-date systems
    - Make evidence-based decisions
    - Organize across NOAA, federal agencies, communities

5. Initiate the following recommendations to gain control over the existing complexity
    - Document and maintain complete range of products and systems
    - Identify and publicize leads for all products and systems
    - Hire or identify software leads, with proved expertise in scientific software
    - Develop Change Review Boards for all products and systems

- Develop a software release schedule for major systems on the order of 12-24 months
- Initiate replacement of all the code that EMC uses with code developed with formalized software management
- Evolve successful governance and management practices from examples, for example, NGGPS and NEMS

The UMAC's analysis calls for a focus on the model-guidance products that are developed to optimize customer requirements, scientific excellence, and cost. There is a need for more integration and appropriate unification of systems to manage complexity. To be a world-class scientific organization, NCEP's future requires more unified systems, effective participation with the research community, and development of coupled forecast-analysis systems of increasing complexity. New, management practices are required to transform NCEP for an organization of scientists to a science-based organization.

The following narrative strives to provide meaning to these findings and recommendations and provide a framework on which to initiate ***a transformation to a science-based, service organization directed toward building a weather-ready nation***.

A New Level of Organization

Prior to the August meeting and in the formation of the agenda, the UMAC started the process of moving attention away from models or modeling systems, for example, GFS, to the forecast products or applications that the modeling systems were being built to support. The model is a tool that is a means to a forecast product, for example, a global medium-range forecast or a space-weather forecast. The forecast product is the intersection of stakeholder requirements with systems development. The forecast product should be model agnostic, with the scientific foundation and cost determining the model. The forecast product defines how to prioritize development decisions – how the tool must be built. With the attention on the forecast product, then end-user requirements (requests, expectations) can be balanced with scientific excellence and cost to delivery. In many instances, the focus on products as an organizing entity to support prioritization appears to be a reversal of current practice. That is, the science-based, forecast model is the focus, with the model being constructed to meet an un-prioritized, ephemeral set of customer expectations. The reconciliation of conflicting expectations is worked out after the tool is constructed.

A system is a set of interacting or interdependent parts forming an integrated whole. Is has structure, behavior, interconnection, and in this case, it has purpose. That is, the outcome of executing or running the system is expected to provide products that are deemed of value by stakeholders or end-users.

The model is but one part of a system needed to provide a forecast product. In modern forecast products, the model is integrated with an assimilation-based data analysis to provide model initial conditions. The term forecast-analysis model is used to connote this integration of data assimilation and forecast model. The forecast-analysis model is only part of the system required to provide a forecast product. The system to provide a forecast product includes: workflow, forecast-analysis model, software infrastructure, computational environment (present and future), services and derived products, end-user interfaces, and end-user and stakeholder experience. If the primary focus of NCEP activities is on the forecast-analysis model, then the other aspects of the forecast-product system, e.g., pre-processing, post processing, computational, end-user interface, etc. are left to accommodate the fragmented model development. This leads to cost inefficiency, difficult to sustain systems, and uneven satisfaction of stakeholder expectations.

Looking inward, the forecast-analysis model is, also, a system and includes: data acquisition, data pre-processing, data assimilation (analysis), the model (forecast), evaluation, forecast and analysis (two products), and post-processing. The model, the data assimilation, indeed, all of the listed parts of the forecast-analysis modeling system are also systems. The model, for example, has a dynamical core, physical parameterizations, and boundary conditions, which are coupled into a whole. Increasingly, systems require the coupling of forecast-analysis models. For example, a seasonal forecast requires an atmospheric component, a land component, an oceanic component, and an ice component. If decisions are made at the model-level, rather than at the forecast product level, then it is a natural outcome that the complexity becomes excessive, unmanageable, and in fact, the sustainability of the system as a whole is increasingly in doubt. Simply, perhaps, the decision to replace a physical parameterization with an algorithm that has more (or less) variables, has the potential to impact the use of data by the assimilation procedure, as well as impacts on computational parallelism, post processing, and customer interfaces.

Looking outward, a particular forecast product is only part of a portfolio of products; hence, one system in a set of product systems. There are cases where there are scientific relationships between products; that is, a change in one product has impacts on the quality of the other products. As an example, regional forecast products depend on global forecasts and analyses. Even in the absence of a scientific relationship, there are relationships realized in the workflows, the computational environment, end-user interfaces, etc.

Another class of interdependencies comes from models that are embedded in several products; for example, the GFS is used in short-term, medium-range, and seasonal forecasts as well as in the space-weather forecast. A focus on forecast products and, more generally, the entire portfolio of products allows for integrated management practices that support a reduction of complexity, optimization of competing requirements, management of resources and cost, and simplification of end-user interfaces.

The discussion above describes UMAC's findings and analysis of the existing NCEP forecast-product portfolio. In the future, forecast-product systems are expected to become more complex. The past decade has seen greater complexity in observational data systems, a trend that will continue into the future. Forecast-analysis models will require credible and comprehensive representation of, not only, the atmosphere, but the land, oceans, chemistry, and sea ice. The coupling brings new classes of scientific problems, as well as fundamental changes to model and product evaluation, workflow complexity, computational viability, end-user services and interfaces. NCEP already has difficulty managing complexity. With complexity growing from increasing science-based completeness, changing observing systems, changing computational technologies, and increasing numbers of applications of environmental guidance, NCEP must develop better ways to manage complexity; it is an existential priority.

Simply changing the focus from models or modeling systems to forecast products will not manage excess complexity. More formalized project management practices are required for NCEP product systems as well as for the subprojects that are required in each product system. Given that NCEP maintains a portfolio of interrelated products, with multiple sponsors, and uncountable stakeholders, formalized approaches to institutional management or governance are required.

Strategically, management of the complexity in NCEP's model-guidance portfolio suggests the need for integration or unification of efforts, tools, products, etc. The unification should strive to reduce complexity in a way that optimizes for end-user requirements, scientific excellence, and cost of product generation and delivery. The need for a more unified approach is amplified because system complexity is increasing for sound scientific reasons; this is a tension that will have to be actively managed.

There is another strategic fact that arises from the increasing complexity. NCEP will need to work with the community to engage needed expertise as well as to obtain algorithmic software. Over the past 15 years, several reports have pointed out the rich resources of the U.S. research community and the need for operational products to better utilize this community. Such community engagement requires NCEP to assume the role of an integrator of expertise and algorithms into an operational capacity. The UMAC noted that communication in NCEP was deficient, and the future will require far more effective and continuous communication practices. The need for communication and management demands effective methods of community governance. This is not a matter of polling the community for requirements, simply accepting community algorithms, or building a model that is openly available to the community. Rather, it requires the concept of participatory communities engaged in co-development and co-ownership of essential products. The governance needs to assure effective communication, as well as a process for prioritization and decision-making to meet the requirements for operational products.

Governance and Project Management

The UMAC recommends a new level of organization for NCEP, and the Overview Section introduces the need for more formalized approaches to governance and management. This section discusses governance and management in order to provide meaning to the UMAC's recommendation. The UMAC believes that UMAC's defining governance and management policies and practices beyond this guidance is not possible. It requires commitment and continuity from NCEP's leadership, with the internal evolution of governance and management methods that work for the organization.

The UMAC notes that more attention to governance and management will require substantial commitment of personnel's time. It will be difficult. Initially, more commitment to governance and management may be perceived as in conflict with the urgency to develop systems and improve products. Structured management may be viewed as in conflict with and antithetical to "science." The UMAC states that if a new level of organization for NCEP is not realized, then NCEP will not progress towards world leadership, and will face a series of increasingly more serious crises.

In support of its recommendation, the UMAC notes that documented software management principles, for example as represented in the traditional Capability Maturity Model (https://en.wikipedia.org/wiki/Capability_Maturity_Model) and the more recent Agile development methods (https://en.wikipedia.org/wiki/Agile_software_development), substantiate that early and ongoing design, planning, testing, and integration are key indicators on meeting stakeholder requirements on schedule and on budget. This has been proved repeatedly in organizations whose products and services depend on software.

Governance

For its recommendation, the UMAC uses the term "governance" to describe the policy and practices of how an organization functions; it aligns the organization with its goals. Project management is distinguished from governance, by project management being focused on the execution of tasks to provide products and services. There is an urgent need within NCEP to address both governance and project management. The UMAC recommends taking on project management improvement within specific projects to support the development of governance.

In NCEP's case, governance is needed, especially, when there is the need to manage relationships (e.g. across NOAA, across federal agencies, across communities), balance competing interests, and to make decisions at the organizational level that influence meeting stakeholder requirements, scientific excellence, and cost. We note that many NCEP products and their user groups will also require project-level governance. The UMAC, particularly, notes the need for governance to improve communications, to vet requirements, to terminate out-of-date systems, and to make evidence-based decisions across the entire portfolio of the model-guidance suite. Governance is essential to more effective interactions with the community, and with the participation of the community at the research-operations interface. Governance is needed within NCEP to manage its relationships with other elements of NOAA, as well as to manage external relationships with other government agencies and non-governmental stakeholders.

There are some essential attributes of governance. There is participation by interested people, who generally organize into bodies. Careful attention needs to be paid to forming the member's governing bodies, for example, sponsors, end-users, developers, executives, etc., to assure participants are included in effective ways. There are known rules of behavior. The members accept these rules. The rules allow for the balance of the interests by the participants and support accountability – the ability to defend decisions. Effective governance supports organizational function and contributes to organizational viability.

The advantages of good governance extend far beyond the function of the organization. Improved governance at NCEP should provide transparency into how decisions are made. This helps to build trust with end users and sponsors. Good governance, assuming rational, defensible decisions are made, helps to support resource requests and reduce external criticism that might arise because decision rationale is unknown. This allows end-users and sponsors to invest in the organization with a reasonable expectation of knowing when and how their requirements and expectations will be met.

Project Management

Project management is distinguished from governance by a much stronger focus on the delivery of a product on time and on budget. Requirements are turned into tasks, and the tasks are executed in a coordinated way. In the short term, it is essential that NCEP develop a culture of managed forecast products, where the product managers communicate and contribute to functioning of the organization as a whole; that is, to NCEP's governance.

The UMAC notes some basic shortcomings in project management that need to be addressed, urgently, in order to provide a core structure around which to organize. It was difficult for the UMAC to identify the complete range of products and systems in the model-guidance portfolio. It was more difficult to identify key personnel responsible for those systems. During the meeting, the UMAC repeatedly identified organizational gaps in communication, information, and knowledge. The NCEP Director and leadership needs to define NCEP's core, priority products, identify responsible leaders, and set up the structures and tools for regular and recorded communications. These leaders need to identify the basic elements of their product systems and interfaces to other systems. Early on, this group needs to take on the elimination of out-of-date (or duplicative) systems, which will improve NCEP's ability to take on necessary governance and management practices. This basic, organizational-scale understanding of mission, products, and services is a necessary early step towards a new level of organization. The practice of well- intentioned individuals and small groups making decisions on models and products, sometimes on the rationale that cost for a particular capability in an existing system is small, is fragmenting the organization and is a source of excess complexity.

Ultimately, project management for a forecast product, for example, the global medium-range forecast, divides into two natural classes. In the first class, there is the need to manage the relationships with the requirements, goals, and expectations of end users and sponsors. These external-to-NCEP derived requirements are then incorporated into the development of systems and services. A subset of the requirements describes the forecast and analysis outcomes that define the scientific development and computational execution of the forecast-analysis product system, e.g., the Global Forecast System. These project-level considerations are, de facto, project governance, and execute the evidence-based decisions that balance the requirements, scientific quality and cost for a particular product and its relationships with other products in the suite.

The second class of project management is that focused on turning requirements into tasks, which are in many cases executed in terms of development of scientific and systems software. Software and data are the tangible, long-lived foundation on which NCEP's success relies, and rigor in software and data management is essential for organizational excellence. The process of turning requirements into tasks is a balance of scientific, computational, and software feasibility. Management rigor in software development and implementation, e.g. software engineering, is critical for a science-based, service organization directed toward building a weather-ready nation.

The UMAC recommends that NCEP move as soon as possible to a software design and build process that is anchored on regularly scheduled releases. A release schedule for a major global system of 18-24 months, would allow definition of a coordinated set of end-user requirements, scientific capability, software development, computational requirements, test and evaluation plans, and cost that could be performed in that time span. Then a release package could be defined, which would allow both developers and end-users to anticipate upcoming capabilities.

There are attributes of project management and software engineering that are reliably present (standard practice) when validated products and services are delivered on schedule and budget. These attributes are essential practice for any product system whose complexity exceeds the ability of an individual to assume complete responsibility for development, evaluation, and execution; that is, any NCEP product. These project attributes include ongoing gathering of requirements and feedback, vetting, management; design; regular end-user and sponsor review; computational review; test and evaluation plans; documented tests at both unit and systems level; structured and recorded communication; documentation of software and services; publishing of products and services; training and education; known product and metrics that determine that goals are met; end-user and sponsor survey of product quality; a path for end-users and sponsors to fed into future development.

Of essential character to project management is a defined and documented process that assures communication of developers, scientists, end-users, sponsors, testers, evaluators, community, and the executive functions responsible for decision-making and product performance. The importance of regular communication that iterates requirements, capability, and cost cannot be over emphasized. Scientific software, which relies on high-performance computing and runs in complex workflows, requires special attention to scientific and computational requirements with the optimization of possibility and capability. Projects have multiple bodies of constituencies: e.g., Executive Board, Sponsor Board, Community User Groups, Core Development Team, External Advisory Board, etc. The frequency of communication depends on the function of the body and the timeline of the project.

The most essential functions, however, for NCEP to expand in the short term are those associated with Change Control or Review Boards[3], where decisions are made on system releases, balancing requirements, scientific capability, and cost. Effective Change Control Boards require that there be a software manager, who has experience with development of software that is driven by end-user requirements and scientific quality. The Change Control Board is populated with application developers representing agency and institutional stakeholders, and informed by the managers of resources, capabilities, and schedule. The Change Review Board: reviews and authorizes proposed changes to reference implementations maintained by development teams; updates the development and release schedules; reviews and approves the content of releases to assure that development tasks are completed; and needs to report to an executive function that sets metrics and evaluates performance.

[3] https://en.wikipedia.org/wiki/Change_control_board

An Example of Governance and Project Management:

The UMAC noted that the Next Generation Global Prediction System (NGGPS) was an important step forward in evidence- based decision-making. The NGGPS project has, for example, a dynamical core working group, which has engaged the broader research community in an open, documented process to select the dynamical core for NGGPS. There are working groups for physical parameterizations and computational performance as well. These working groups are being managed as a project, with testing, independent evaluation, deliverables and timelines.

NGGPS will use the NOAA Environmental Modeling System (NEMS) infrastructure for building modeling applications. NEMS is based on the Earth System Modeling Framework (ESMF), which provides high-performance grid remapping and other tools. Interoperability is supported by utilizing the multi-agency National Unified Operational Prediction Capability (NUOPC) Layer. The NUOPC Layer adds a standard syntax for initialization and run phases of a model and a standard way to build dependencies between ESMF-based system components. The commitment to NEMS is an important step towards unification of modeling systems, a major recommendation of the UMAC. The use of standards and services facilitates community participation. NGGPS envisions using tested and scientifically evaluated component models that are configured to meet the requirements for a portfolio of forecast products. This infrastructure provides a mechanism to support controlled scientific investigation of coupled systems, evaluated across a suite of products.

NEMS coupling system development has been ongoing for several years, with support from both the NOAA Climate Program Office and the National Weather Service/NGGPS. It has brought together models and scientists from multiple federal agencies and the broader community. The effort has exposed NCEP applications to the Community Earth System Model (CESM) community. This brings algorithms and expertise in, for example, sea ice modeling, a capability that is required in forecast systems at many time scales. Not only does this controlled environment bring community scientific expertise, but it brings community practices in software management (repositories, open source, licensing, etc.) and community governance. These are practices that emerge within the broader community as standards, facilitating interactions between the research and operations community.

The NGGPS and NEMS coupled system development efforts represent governed and managed projects. Many of the attributes of governance and project management, described above, are present in the NGGPS and NEMS efforts, and the UMAC recognizes the substantial progress represented by these efforts. NEMS has initiated a set of software engineering practices that follow established principles and are producing results. The maturation of these processes depends on greater engagement by teams at EMC responsible for code management and workflows, the identification of a software manager, and the establishment of unifying prioritization processes such as the Change Control Board. The UMAC recommends that NCEP systematically replace all the code that EMC uses with code that has been developed under rigorous requirements management, testing, version control, documentation, and performance review. The UMAC recommends that NCEP becomes part of the community governance that assures shared ownership of community code repositories to reduce the barriers and the natural separation and isolation that comes when access to operational code is fenced off.

The NGGPS and NEMS coupled system development activities are not the only examples of successful governance and project management. The UMAC notes that within the U.S., a number of successful community governance and management models have emerged. In order to address a future of increased scientific complexity, model unification, and greater partnership with the community, NCEP will need to be adaptive in governed, partnerships with the community. NCEP will integrate community capacity and supplement that capacity with the development required to meet their operational product generation. Such partnerships with community, a new model for open, community engagement, will support NCEP's efforts to realize the potential to rapidly progress to world leadership.

Transition to Increasingly Evidence-Driven Decision-Making

Measurement, testing, evaluation, and validation are integral to the scientific method. Though intuitive in the validation of a weather forecast, the collection of evidence is also an integral part of computer allocation, community engagement, and requirements analysis – in fact, all aspects of effective organizational function. The recommendation of the UMAC is for NCEP to develop an evidence-driven approach towards decision-making. This approach needs to extend across the portfolio of products, and they are an essential part of the project-management practices needed to transform NCEP for an organization of scientists to a science-based organization.

Here is an example posed to the UMAC, what should be the balance between deterministic and ensemble forecasting? Perhaps, what is the value of a single forecast with high-resolution and more comprehensive physics versus the value provided by an ensemble of lower resolution forecasts. This is an archetypical example of where decisions should be made with evidence derived from stakeholder requirements and stakeholder's metrics of usability, science-based evaluation, and cost. The downstream implications of the decisions include impacts on workflow, software infrastructure, computational systems, and services.

The UMAC was presented with or identified several problems where evidence-driven decision-making is required. For example, what is the justification and cost for multiple ensemble systems, with multiple models? What are the right amounts of resources to commit to reforecasts, which comes into tension with resolution and ensemble members? How are product requirements and delivery for hydrological forecasting balanced with other forecast products for which NCEP, NWS, and NOAA have responsibility? What is the evidence that 1-degree resolution is required to simulate category 5 hurricanes? How does NCEP balance the requirements and costs of the end users who want the best possible 8-hour forecast versus those who want the best possible 3-day forecast? How is best possible defined?

At the organizational level, evidence-based decision-making is a deliberative process requiring communication across the leads and teams of all of the products in the model-guidance portfolio. There will always be tensions and compromise, and the need for decisions that optimize cost, scientific excellence, and stakeholder interests. The evidence supporting the decisions needs to be documented to stand as the transparent justification for the decisions, as well as to provide the foundation for the next round of product development and improvement.

At the project level, evidence-driven decision-making requires more detailed discussion of types of evidence. Evaluation of forecast outcomes is a familiar and essential part of scientific development. For this document, this will be defined as scientific validation; i.e. comparison with observations. In the development of complex software systems there are multiple levels of testing and evaluation, some focused on assuring that individual parts of the system are performing as expected, and others focused on whether the system as a whole is performing as expected. For this document, these will be classified as tests, for example, unit tests and system tests. Verification follows from evaluation of test results verified by comparisons to analytic test cases and computational baselines. Therefore, verification is primarily computational, and validation is in the domain of earth science. It is reasonable to frame that a verified system is ready for the validation process.

The scientific validation plans for all of the product systems need to be documented and determined at the onset of a development cycle. What are the goals of this development cycle? How do we know that the goals have been accomplished? It is recognized that for complex systems there are multiple validation metrics and that they might not all be achieved. It is also recognized that the broad customer base leads to situations where the requirements of one customer might come at the expense of the requirements of other customers.

Scientific validation, therefore, requires recognition of several facts. The scientific method requires a measure of independence between those who develop systems and those who do the validation. Good management also requires such independence, because otherwise systems are always being manipulated to improve the developers' most valued metrics. Scientific validation is a deliberative process where multiple, documented metrics are optimized. Scientific validation requires stakeholder participation. The validation plan provides an essential element of the organizational evidence needed to optimize cost, scientific excellence, and stakeholder interests.

Verification and the tests that support verification are an essential part of systems development and software management. NCEP focuses on systems testing, comparison with archived forecasts or comparison to forecasts from a validated system (parallel runs). However, finer grain tests are essential for efficient and accurate development of complex systems. A test strategy that relies on running the entire modeling system is inherently inefficient due both to computational requirements and interactions of code changes in the complex system. Furthermore, more granular, documented tests are essential to support development by multiple developers, both internal to NCEP and from the broader community. Defined tests and documented test results are an essential part of the transitions across the research and operations interfaces.

The transition to organization-wide, evidence-driven decision-making stands at the foundation of the transformational changes required to realize the potential to progress towards world leadership. A chain of data and documentation to support the evidence needs to be developed from unit testing for software development, to scientific validation, to allocation of resources, to assessment of product quality and effectiveness. The use of objective, knowledge-based information sits at the base, extending from community engagement, intra-organizational trust, to managing complexity, to developing products on schedule and budget, to transparency to establish confidence of scientific evidence, and stakeholder success.

Comprehensive and Vetted Requirements

At the core of the UMAC's strategic recommendations is that NCEP needs to become an organization relying on evidence-based decisions that balance stakeholder requirements, scientific excellence, and cost. Requirements, therefore, come from three basic sources: stakeholders, science, and cost.

Each of these sources of requirements can be subdivided. Stakeholders, at some level, are the primary source of the requirements. The stakeholder group is enormously complex, including the general public and all variety of organizations: commercial, governmental, non-governmental, private and public. Stakeholders include sponsors and end-users, and they, also, hold much of determination that requirements are being met. Scientific requirements need to balance what is possible with what is practical and the expected impacts on the products. Scientific requirements also bring focus to scientific completeness and credibility in comparison to products of other centers; that is, what is the state of the science? Cost, which often focuses on computers, in fact, connects all elements of the system, including the ability to satisfy stakeholder requirements.

The UMAC recognizes that NCEP makes decisions based on evidence that meets requirements, for example, an improved weather forecast making use of a particular observation type. However, the UMAC noted several examples of disjointed decisions based on requirements that are not vetted as part of a whole. Some requirements have the character of the request of a particular end-user that prefers a particular modeling system. The basis of this preference might be because of performance in the end-user's particular application, the interface to the product, or other attributes. Other requirements have the character of advice by an advisory panel or from a scientific working group, which represents a particular development path. There are requirements that come from sponsors to fund particular system capabilities of use to their programs. Ultimately, the disjointed requirements become a powerful rationalization, for example, to continue to operate and build a particular system, sometimes, beyond a cost-effective system lifetime.

The UMAC, also, recognizes that it is a difficult challenge to collect, to determine, and to manage requirements, requiring strong management and leadership. Requirements suitable for inclusion of a new data type into a forecast-analysis, to prepare model output for a unified post-processing system, or to prepare software for the memory configuration of a new computer are not suitably managed across the entirety of NCEP. However, the systems to which these requirements contribute, need to be managed in a concerted fashion, feeding up, ultimately, into product requirements as well as NCEP requirements that balance stakeholder requirements, scientific excellence, and cost. Therefore, requirements are part of managed, organized, and vetted system.

With regard to scientific requirements, the UMAC recommends the development of holistic requirements (or values), which emphasize science-based correctness. Are processes being represented in a way that is consistent with physical (chemical, biological) principles? The UMAC understands that a best forecast, a fundamental expectation of NCEP, may be related to tuned parameters and filters. However, such engineered forecasts are likely to fail in unexpected ways that perpetuate more engineering to desired solutions. Furthermore, models that represent physical processes robustly are better positioned for development and the managing the increased physical (chemical and biological) complexity of future requirements.

Requirements for software infrastructure that manage model coupling; interfaces to data assimilation; computational efficiency; readiness for next-generation high-performance computing systems; evaluation, ensembles, and post-processing environments; end-user interfaces; etc. are important for the scientific integrity of systems and products, scientific evolution, operations and maintenance, and computational cost. Likewise, requirements for workflow and all system elements have important implications for the balanced, optimized approach to stakeholder requirements, scientific excellence, and cost. Ultimately requirements need to be managed under the umbrella of the portfolio of model-guidance products. Questions such as: Have the global products evolved to the point that they address requirements previously met by regional products? What is the cost-value calculation to maintain historical workflow cadence at the expense of new, scientifically justified products and systems? What is the organizational impact to maintain existing systems and work practices on the ability of NCEP to meet future requirements.

Finally, the paramount importance and complexity of requirements place their management, prioritization and execution as a crucial element of management and governance. Requirements, which are documented and managed in a transparent way that exposes the decision-making process, are a way to build trust with end users and sponsors. End users and sponsors can have confidence that their requirements are being addressed, and therefore, the ability to plan for when their requirements will be addressed. The management of a comprehensive and vetted set of requirements substantiates requests for resources as well as provides visible, tangible interfaces for community engagement.

Possible Strategy for Phasing Out of Redundant or Obsolescent Models

The UMAC recommends that NCEP develop, as part of its governance, a mechanism to evaluate product systems to determine stakeholder satisfaction, scientific merit, and cost. The review should be comparative, looking across the portfolio of products and vetted requirements, with determination of the ability to meet requirements within the portfolio. If a system's cost is determined to be high or if the scientific merit is determined to be deficient, then meeting the requirements by other products in the portfolio should be evaluated. Such systems are an out-of- date system, and they should be phased out.

The UMAC notes that the NOAA Partnership Policy[4] facilitates the ability of a single end user to sustain out-of-date systems. The Partnership Policy needs to be reviewed, and its impact on NCEP's capacity to provide state-of-the-science products needs to be evaluated. The NOAA Partnership Policy needs to be integrated into NCEP's governance to allow participation in the evaluation of product systems to determine stakeholder satisfaction, scientific merit, and cost. The UMAC also notes that there are likely other policies, unknown to the UMAC, that need to be exposed and included in NCEP's governance.

[4] http://www.nws.noaa.gov/fairweather/policy.php

The phase out of out-of-date systems should assure education of end-users and development of services to allow continuity of end-users products. During the phase out, expenditures on a system should be limited to maintenance and operations. The UMAC notes that the phase out of out-of-date systems would benefit, directly, from the systems approach advocated in this report. Of special importance would be standardization of end-user interfaces. The NCEP Director needs to set a future date when data are provided on a limited number of grids. The grids would be decided in an open, requirements-driven process. The grid properties would be published and a transition period defined for end users. Services, for example re-gridding, should be provided.

The reviews to assess the cost and benefits of maintaining product-generating systems should be at regular intervals. Special attention should be given to multiple products that are meeting similar requirements. Terms of reference for Product-Review Panels should be developed. Product-review Panels need to include end-users, sponsors, internal and external science experts, internal and external software developers, and budgetary analysis, including comparative analysis of costs of multiple systems that might meet a specific requirement. To provide opportunity for complete engagement of the end-user community, there should be a public comment period. If NCEP decides to continue the operation of systems that are deemed of low science merit, then the impact of that decision on other development and implementation priorities needs to be documented and justified.

Appendix I: Request for Review

University Corporation for Atmospheric Research Community Advisory Committee for NCEP (UCACN):

2015 Request for Review of the NCEP Production Suite

Dr. William Lapenta, NCEP Director 02 March 2015

Background:

In November 2008, UCAR was requested by NCEP to conduct a thorough and thoughtful review of the nine Centers that comprise NCEP, as well as the NCEP Office of the Director (OD). An Executive Committee plus five panels conducted the reviews, which are collectively referred to as the 2009 Review. The reports were completed in early 2010 and are available at http://www.vsp.ucar.edu/UCACN/index.html. One of the major recommendations of the 2009 Review was that NCEP should establish a permanent external advisory committee to provide guidance on improvement of products and services based on the latest advances in science and technology. As a result, UCACN was established by UCAR in March 2011; its primary responsibilities are:

1. To conduct a comprehensive review of NCEP (the nine Centers and the Office of the Director) every five years, starting in the year 2015;
2. In the years between the comprehensive reviews, to:
   a. Monitor progress of the Centers in the context of the NCEP strategic plan and previous UCACN recommendations, and provide informal updates and advice to NCEP leadership through the UCAR President (or designate);
   b. Provide input to the strategic planning and long--range goals of the Centers and NCEP as a whole.

Given that NCEP is currently developing its strategic plan for 2015-2020, the NCEP Director and the UCACN co-chairs have targeted the next comprehensive center reviews to take place in 2016. That provides NCEP the opportunity to operate under the new budget, portfolio and NWSHQ structures for a year before being reviewed. However, the NCEP centers are encouraged to interact with the UCACN to address strategic priorities identified in the FY15 annual operating plan (AOP) and those under development in the FY16 AOP.

In the fall of 2014, the UCACN terms of reference was modified such that the NCEP Director may request that UCACN work on a particularly important strategic issue on which NCEP requires guidance. ***The purpose of this document is to charge the UCACN to perform a comprehensive review of the NCEP Production Suite (NPS) and associated strategic plans in 2015***.

Requirement for NOAA Operational Environmental Modeling:

Numerical earth system prediction capabilities are critical to address evolving societal needs for natural disaster preparedness, ensuring food security for growing planetary population, national security and defense as well as future economic prosperity. The National Oceanic and Atmospheric Administration (NOAA) operational modeling suite at NCEP provides timely information on the future state of weather, land surface, ocean, sea ice, short-term climate, and ecosystems. The modeling suite provides input for the decision-making process for individuals and policy makers, and for sectors ranging from water resources to financial markets. The modeling systems directly support the National Weather Service (NWS) mission to provide weather, water, and climate data, forecasts and warnings for the protection of life and property and enhancement of the national economy.

There are numerous strategic and technical factors that must be taken into account when planning the evolution of the modeling suite. The NWS imperative of a Weather-Ready Nation (WRN) is about building community resiliency in the face of increasing vulnerability to extreme weather. Therefore, the foundational operational numerical guidance system must support the WRN initiative. Global modeling systems are now being run operationally at resolutions approaching 10km. Regional systems are running operationally at 3km and lower and are applied to convective predictability and severe weather. Advanced data assimilation techniques are being applied on global and regional scales. Demands are building for skillful outlooks in the week 3 and 4 time frame that will require coupled atmosphere and ocean global systems executed in ensemble mode.

Recent Infusion of Funding:

During the past several years the NOAA modeling enterprise has received national attention. The Disaster Relief Appropriations Act of 2012 provided $50M+ to advance the skill of NOAA operational numerical guidance systems for medium range weather prediction. Specific targeted areas include operational and research high performance computing, scientific development of data assimilation capabilities, model physics, dynamics and ensemble techniques. In FY14, the NWS introduced a new $14.3M initiative called “R2O” to improve the transition of research into NWS operations with an emphasis on operational global modeling and data assimilation. There are other programs within NOAA that have modeling components including the Warn on Forecast (WoF), National Multi-Model Ensemble (NMME), the National Earth System Prediction Capability (ESPC) and the NOAA Climate and Earth System Modeling Strategy.

Integrated NOAA Modeling Strategy:

NOAA has an unprecedented opportunity to advance its end-to-end modeling capability to meet both operational and research requirements. In January 2015, the NOAA administrator has tasked the NOAA Chief Scientist to revise the integrated modeling strategy connecting individual projects and programs across all the NOAA Line Offices with a common thread. The strategy is expected to be revised by the end of 2105. The results of the UMAC review will be used as input to the modeling strategy.

Charge to UCACN in 2015: Review of the NCEP Production Suite

NOAA is a science based agency with an operational mission to provide environmental predictions. Therefore, NOAA leadership is striving to align its research portfolio with delivery of operational products and services. As described above, there is a significant amount of NOAA research being devoted to numerical modeling that should advance the skill of the NPS components. In addition, a unified message from NCEP stakeholders obtained during the development of the strategic plan was the need to systematically obtain user requirements and incorporate them into the decision-making process that drives the NPS evolution.

The NCEP Director requests the formation of a UCACN Modeling Advisory Committee (UMAC) to provide a comprehensive, technical review of the NPS strategy for development. The proposed terms of reference of the UMAC are provided below:

Structure:

1. The UMAC will be established no later than March 2015 and will exist for a minimum of three years.
2. The first review of the NPS will occur between June and August 2015 in College Park MD.
3. The UMAC will consist of approximately 12-14 members who are established subject matter experts in numerical modeling, drawn from academia, non-governmental organizations, the private sector and Federal and state agencies.
4. The Chair(s) of the UCACN and the Director of NCEP will select the members of the UMAC.
5. Members of the UCACN may be asked to also serve on the UMAC.
6. The UMAC will meet at least annually and provide a written report of its findings and recommendations to the UCAR Authority, who will then transmit the report to the Director of NCEP.

UMAC Scope:

The NPS is operated by NCEP Central Operations and currently contains more than 20 end-to-end operational modeling systems ranging from on-demand dispersion, regional hurricane, continental ensembles, global ensembles and seasonal. It has systems for near shore coastal, global ocean, surge, space weather, and waves. Soon we will be adding on-demand tsunami and coupled terrestrial-ionosphere space weather capabilities. The future production suite will become even more complicated as we move towards complex earth system modeling systems across a wide time and space paradigm.

This will be the first ever holistic technical review of the NPS. All major model developers will provide input to the review to ensure communication takes place across all scales and components. Participants will also include representatives of the stakeholder community from NOAA (i.e., SPC, WPC, the NWS regions, NWC, OAR, NOS), public, private and academia.

Nowcasting and Short Range Systems (0-3 day):

- High Resolution Rapid Refresh (HRRR)
- Rapid Refresh (RAP)
- North American Mesoscale (NAM) and associated nests
- High Resolution Windows (HiRESW)
- Short Range Ensemble Forecast System (SREF)
- Air Quality (CMAQ; HYSPLIT)
- Great Lakes waves
- Coastal Ocean/Bays (ESTOFS)
- Near Shore Wave Prediction System (NWPS)
- Hydrology (HEFS, AHIPS)
- Tropical and Extratropical Storm Surge (ETSS; PSURGE; SLOSH)
- Solar flare (ENLIL)
- Geomagnetic
- Coupled space weather model (WAM)

Regional Hurricane (0-5 day):

Hurricane Weather Research and Forecast (HWRF) GFDL

Medium Range Systems (0-16 day; global):

- Global data assimilation and forecast system (GDAS/GFS)
- Real Time Ocean Forecast System (RTOFS)
- Global Ensemble Forecast System (GEFS)
- North American Multi-Model Ensemble (NMME)
- North American Ensemble Forecast System (NAEFS)
- NEMS GFS Aerosol Component (NGAC)

Extended Range (0-45 days):

- Global Ensemble Forecast System (GEFS)
- Climate Forecast System (CFS

Seasonal (0-9 months):

- Climate Forecast System (CFS)
- North American Multi-Model Ensemble (NMME)
- North American Ensemble Forecast System (NAEFS)

Appendix II: Meeting Attendees

UMAC Member	Blumberg	Alan	UCACN; Stevens Tech
UMAC Member	Brown	Andy	Met Office
UMAC Member	Brunet	Gilbert	UCACN; Environment Canada
UMAC Member	Carr	Fred	UCACN; University of Oklahoma
UMAC Member	Chassignet	Eric	FSU, Director, COAPS
UMAC Member	Doyle	Jim	NRL, Monterey
UMAC Member	Hamill	Tom	NOAA/ESRL
UMAC Member	Kinter	Jim	UCACN; COLA/GMU
UMAC Member	Kuo	Bill	UCACN; DTC; NCAR
UMAC Member	Tsengdar	Lee	UCACN; NASA HQ
UMAC Member	Mass	Cliff	University of Washington
UMAC Member	Neilley	Peter	UCACN; Weather Company
UMAC Member	Peters-Lidard	Christa	NASA/GSFC
UMAC Member	Rood	Ricky	University of Michigan
Role	**Last Name**	**First Name**	**Organizaton/Title (if available)**
Stakeholder	Berchoff	Don	Americas and Transport, MetraWeather
Stakeholder	Bradford	Steve	FAA
Stakeholder	Craven	Jeff	NWS Central Region SSD
Stakeholder	DePodwin	Dan	AccuWeather
Stakeholder	DeWitt	Dave	NOAA/NWS/NCEP/CPC
Stakeholder	Dutton	John	Prescient Weather
Stakeholder	Edman	Andy	NWS Western Region SSD
Stakeholder	Eicher	Rob	AMS Broadcaster Chair
Stakeholder	Eleuterio	Daniel	ONR/ESPC 322MM/AG
Stakeholder	Grimit	Eric	Vaisala
Stakeholder	Greybush	Steven	Penn State University
Stakeholder	Grumm	Rich	NOAA/NWS
Stakeholder	Hartman	Rob	HIC @ CNFRC
Stakeholder	Jacobs	Neil	Panasonic Avionics Corporation
Stakeholder	Koval	Joe	The Weather Channel
Stakeholder	Muzio	Miles	Media/NWA
Stakeholder	Novak	David	NCEP Weather Prediction Center
Stakeholder	Ross	Jeremy	Prescient Weather
Stakeholder	Ryan	William	Penn State University
Stakeholder	Schneider	Russ	NCEP Storm Prediction Center
Role	**Last Name**	**First Name**	**Organizaton/Title (if available)**
Observer	Auligne	Tom	JCSDA/ESSIC
Observer	Carman	Jessie	NOAA/OAR/OAWS
Observer	Cortinas	John	NOAA/OAR/OAQWS

Observer	Farrar	Micheal	NWS
Observer	Fine	Steven	NOAA/OAR
Observer	Gross	Brian	NOAA/NWS
Observer	Higgins	Wayne	NOAA/OAR/CPO
Observer	Ji	Ming	NOAA/NWS/STI
Observer	Kain	Jack	NOAA/OAR/NSSL
Observer	Kelleher	Kevin	NOAA/OAR/ESRL/GSD
Observer	Kyger	Ben	NOAA/NCEP/NCO
Observer	Lapenta	William	NCEP
Observer	Michaud	Dave	NWS/CP
Observer	Murphy	Murphy	NOAA/NWS/COO
Observer	Shambaugh	Jamie	OAR
Observer	Stajner	Ivanka	NOAA/NWS/STI
Observer	Stone	Peter	NOAA/NOS
Observer	Toepfer	Fred	NOAA/NWS/STI
Observer	Warren	Steve	NOAA/NWS
Role	**Last Name**	**First Name**	**Organizaton/Title (if available)**
Developer	Alexander	Curtus	OAR/ESRL/GSD
Developer	Benjamin	Stan	OAR/ESRL/GSD
Developer	Burke	Pat	NOS
Developer	Chawla	Arun	NWS/NCEP/EMC
Developer	Cosgrove	Brian	NWS/NWC
Developer	Derber	John	NWS/NCEP/EMC; OAR/ESRL/PSD
Developer	DiMego	Geoff	NWS/NCEP/EMC
Developer	Du	Jun	NWS/NCEP/EMC
Developer	Ek	Mike	NWS/NCEP/EMC
Developer	Feyen	Jessie	NOS
Developer	Gilbert	Kathryn	NOAA/NWS/WPC/OPC
Developer	Gochis	David	NCAR
Developer	Iredell	Mark	NCEP/EMC
Developer	Lee	Pius	OAR/ARL
Developer	Mehra	Avichal	NWS/NCEP/EMC
Developer	Michalakes	John	NOAA/NCEP/EMC (IMSG)
Developer	Millward	George	NWS/NCEP/SWPC
Developer	Moorthi	Shrinivas	NOAA
Developer	Peroutka	Matthew	NWS/OSTI Meteorological Development Lab
Developer	Pyle	Matt	NWS/NCEP/EMC
Developer	Saha	Suru	NWS/NCEP/EMC
Developer	Tallapragada	Vijay	NWS/NCEP/EMC
Developer	Taylor	Arthur	NWS

Developer	Van der Westhuysen	Andre	NWS/NCEP/EMC
Developer	Viereck	Rodney	NWS/NCEP/SWPC-EMC
Developer	Weygandt	Steve	OAR/ESRL/GSD
Developer	Wicker	Lou	OAR/NSSL
Developer	Whitaker	Jeff	OAR/ESRL/PSD
Developer	Zhu	Yuejian	NWS/NCEP/EMC

Appendix III: UMAC Meeting Agenda

Tuesday, August 4, 2015 Note: the links following a topic are associated with background materials for that topic		
Time	**Topic**	**Presenter(s)**
0800-0830	**Registration**	
0830-0845	**Welcome and NCWCP Logistics**	**Bill Lapenta** (NCEP) **and Kendra Greb** (UCAR)
0845-0900	**Opening Statements from the UMAC Co- Chairs**	**Fred Carr and Ricky Rood**
0900-0930	**Introductions; Meeting Purpose, Expectations and Outcomes**	**Bill Lapenta** (NCEP)
0930-0945	**FY16 Production Suite plans**	**Rebecca Cosgrove** (NWS/NCEP/CO)
0945-1000	**NOAA Operational and R&D Computing Plans**	**Brian Gross** (NOAA/OCIO)
1000-1030	**BREAK**	
1030-1130	**Each invited stakeholder will be given 3 minutes to provide Production Suite high- level requirements**	**All Invited Stakeholders**
1130-1200	**Discussion, Question and Answer session with Stakeholders--UMAC & Modelers**	**UMAC; Stakeholders and Modelers**
1200-1300	**LUNCH**	
1300-1315	**Earth System Prediction Capability**	**Jessie Carman** (OAR/OARO/OWAQ)
1315-1330	**Next Generation Global Prediction System (NGGPS) Overview**	**Fred Toepfer** (NWS/STI)
	NGGPS: Next-Generation Global Prediction System, Components and Models	
1330-1345	**Impact of NGGPS on GFS Evolution**	**Hendrik Tolman** (NWS/EMC)
	Transition to Operations	
1345-1430	**Discussion, Q&A**	**UMAC Lead**

1430-1500	**BREAK**	
1500-1515	**Global Model Development Priorities**	**Vijay Tallapragada** (NWS/EMC)

	GFS: Global Forecast System, Description and Plan	
	NGAC: Aerosols, Overview	
	NGAC: Aerosols, References	
	NGAC: NEMS GFS Aerosol Component	
1515-1530	**Global Data Assimilation Priorities**	**John Derber** (NWS/EMC) **and Jeff Whitaker** (OAR/ESRL/PSD)
	GFS: Global Forecast System, Description and Plan	
1530-1545	**Whole Atmosphere for Space Weather**	**Rodney Viereck** (NWS/SWPC/SWSB)
	Space_Weather: Model and Plans Space_Weather: Geospace Model Selection	
1545-1600	**Discussion; Q&A**	**UMAC Lead**
1600-1615	**Global Ensemble Strategy**	**Yuejian Zhu** (NWS/EMC)
	GEFS: Global Ensemble Forecast System, Description	
	NAEFS: North America Ensemble Forecast, Description	
1615-1630	**Coupled Modeling for Weeks 3 & 4**	**Yuejian Zhu** (NWS/EMC) **and Suru Saha** (NWS/EMC)
	GEFS: Global Ensemble Forecast System, Description	
	CFSV2: Climate Forecast System, Model and Plans	
1630-1645	**Coupled Modeling for Seasonal to Interannual**	**Suru Saha** (NWS/EMC)
	CFSV2: Climate Forecast System, Model and Plans	
	CFSV2: Climate Forecast System Forecast Performance	
	CFSV2: Climate Forecast System Retrospective Forecast Evaluation	
1645-1700	**Seasonal to Interannual multi-model approach**	**Jin Huang** (NWS/CPC) **and Yuejian Zhu** (NWS/EMC)
	NMME: National Multi-Model Ensemble, Description and Plans	
1700-1715	**Discussion; Q&A**	**UMAC Lead**
1715-1800	**UMAC Executive Session**	

Wednesday, August 5, 2015 Note: the links following a topic are associated with background materials for that topic		
Time	**Topic**	**Presenter(s)**
0800-0830	**COFFEE**	
0830-0845	**Global Ocean Modeling Strategy**	**Avichal Mehra** (NWS/EMC)
	RTOFS: Real-Time Ocean Forecast System, Status and Plans	

0845-0900	**Sea ice modeling**	**Bob Grumbine** (NWS/EMC)
	KISS: Sea Ice (CICE), Plan	
0900-0915	**Discussion; Q&A**	**UMAC Lead**
0915-0930	**Global and Regional Wave Guidance**	**Arun Chawla** (NWS/EMC)**, Henrique Alves** (NWS/EMC) **and Andre Van der Westhuysen** (NWS/EMC)
	NWPS: Wave Prediction, Model and Plans	
	Waves_Suite: Model and Plans	
0930-0945	**Coastal and Bay requirements and plans**	**Pat Burke** (NOS)
	NOS - OFS: Ocean Operational Forecast System, Description of Products	
	NOS - OFS: Ocean Operational Forecast System, Description and Plans	
0945-1000	**Discussion; Q&A**	**UMAC Lead**
1000-1030	**BREAK**	
1030-1045	**NOAA Environmental Modeling System Infrastructure**	**Mark Iredell** (NWS/EMC)
	NEMS: Overarching System from NGGPS Meeting	
1045-1100	**NEMS and NGGPS Integration**	**Hendrik Tolman** (NWS/EMC)
1100-1115	**Discussion; Q&A**	**UMAC Lead**
1115-1130	**Requirements for hurricane track and intensity guidance**	**Vijay Tallapragada** (NWS/EMC)
	HWRF: Model and Plans	
1130-1145	**Examination of Nesting Requirements for CONUS and OCONUS in 2020+**	**Vijay Tallapragada** (NWS/EMC)**, Geoff DiMego** (NWS/EMC) **and Stan Benjamin** (OAR/ESRL/GSD)

	NGGPS: Nested Grids from NGGPS Meeting	
1145-1200	**Discussion; Q&A**	**UMAC Lead**
1200-1300	**LUNCH**	
1300-1315	**Evolution and Priorities for OCONUS and CONUS Guidance Systems**	**Geoff DiMego** (NWS/EMC) **and Stan Benjamin** (OAR/ESRL/GSD)
	Regional: NAM, HiResW, SREF, Description	
	RTMA_and_URMA: Mesoscale Assimilation	

1315-1330	**Development of a convective permitting OCONUS and CONUS ensemble system**	**Lou Wicker** (OAR/NSSL)**, Stan Benjamin** (OAR/ESRL/GSD) **and Geoff DiMego** (NWS/EMC)
	WoF: Warning on Forecast, Configuration	
	WoF: Warning on Forecast, Vision	
1330-1345	**Discussion; Q&A**	**UMAC Lead**
1345-1400	**Dispersion Modeling**	**Ariel Stein** (OAR/ARL)
	NAQFC: National Air Quality Forecast Capability, Operations	
1400-1415	**Air Quality**	**Pius Lee**(OAR/ARL)
	NAQFC: National Air Quality Forecast Capability, Operations	
1415-1430	**Discussion; Q&A**	**UMAC Lead**
1430-1500	**BREAK**	
1500-1515	**Extratropical Storm Surge Modeling**	**Jessie Feyen** (NOS/OCS/CSDL/CMMB)
	ESTOFS: Extratropical Storm Surge, Atlantic and Gulf, Description	
	ESTOFS: Extratropical Storm Surge, Pacific, Description	
	ESTOFS: Extratropical Storm Surge, Pacific, Evaluation	
1515-1530	**Probabilistic Storm Surge Modeling**	**Author Taylor** (NWS/STI/DSB)
	SSR: Storm Surge Roadmap, Model Descriptions (ADCIRC, ESTOFS, ETSS, HSSOFS, SLOSH, NWPS)	
	SSR: Storm Surge Roadmap, Plan	
	HSSOFS: Hurricane Storm Surge, Development and Testing Description	
	HSSOFS: Hurricane Storm Surge, Development and Evaluation	

1530-1545	**Discussion; Q&A**	**UMAC Lead**
1545-1600	**National Water Center Hydrologic Modeling Strategy**	**Brian Cosgrove** (NWS/NWC)
	WRF_Hydro: Description Plans	
	WRF_Hydro: Technical Description	
1600-1615	**Off Line Land Modeling**	**Mike Ek** (NWS/EMC)
	NLDAS: Land Data Assimilation, Description	
	NGGPS: Land from NGGPS Meeting	
1615-1630	**Discussion; Q&A**	**UMAC Lead**
1630-1645		

1645-
1800
UMAC Executive Session

Thursday, August 6, 2015 Note: the links following a topic are associated with background materials for that topic		
Time	**Topic**	**Presenter(s)**
0800-0830	**COFFEE**	
0830-0845	**Statistical Post Processing**	**Matthew Peroutka** (NWS/STI/WIAB)
	NGGPS: Postprocessing From NGGPS Meeting	
0845-0900	**National Blend**	**Kathy Gilbert** (NWS/HPC)
0900-0915	**Discussion; Q&A**	**UMAC Lead**
0915-0930	**Ensemble Reforecasts**	**Yuejian Zhu** (NWS/EMC), **Hendrik Tolman** (NWS/EMC)
	GFS: Global Forecast System, Description and Plan	
	GEFS: Global Ensemble Forecast System, Description	
	CFSV2: Climate Forecast System, Model and Plans	

0930-0945	**Reanalyses**	**Suru Saha** (NWS/EMC)
GFS: Global Forecast System, Description and Plan		
GEFS: Global Ensemble Forecast System, Description		
CFSV2: Climate Forecast System, Model and Plans		
0945-1000	**Discussion; Q&A**	**UMAC Lead**
1000-1030	**BREAK**	
1030-1045	**Verification Strategy (Atmosphere)**	**Geoff DiMego** (NWS/EMC)**, Fanglin Yang** (NWS/EMC)**, Stan Benjamin** (OAR/ESRL/GSD)
GFS: Global Forecast System, Description and Plan		
Regional: NAM, HiResW, SREF, Description		
NGAC: Aerosols, Verification		
CFSV2: Climate Forecast System Forecast Performance		
CFSV2: Climate Forecast System Retrospective Forecast Evaluation		
HWRF: Model and Plans		
1045-1100	**Verification Strategy (Air Quality)**	**Pius lee** (OAR/ARL)**, Ariel Stein** (OAR/ARL) **and Jeff McQueen** (NWS/EMC)
NAQFC: National Air Quality Forecast Capability, Operations		

NAQFC: National Air Quality Forecast Capability, Verification		
1100-1115	**Discussion; Q&A**	**UMAC Lead**
1115-1130	**Verification Strategy (Global Ocean, Waves and sea ice)**	**Avichal Mehra** (NWS/EMC)**, Arun Chwala** (NWS/EMC)**, Bob Grumbine** (NWS/EMC)
RTOFS: Real-Time Ocean Forecast System, Status and Plans		
KISS: Sea Ice (CICE), Plan		
NWPS: Wave Prediction, Model and Plans		
Waves_Suite: Model and Plans		
1130-1145	**Verification Strategy (land and hydrology)**	**Mike Ek** (NWS/EMC) **and Brian Cosgrove** (NWS/NWC)
NLDAS: Land Data Assimilation, Description		
WRF_Hydro: Description Plans		
1145-1200	**Discussion; Q&A**	**UMAC Lead**
1200-1300	**LUNCH**	
1300-1430	**UMAC Q&A Open Floor**	

1430-1500	**BREAK**
1500-1700	**UMAC Executive Session**
1700	**ADJOURN**

Friday, August 7, 2015		
Time	**Topic**	**Presenter(s)**
0800-0830	**COFFEE**	
0830-1000	**UMAC Executive Session**	
1000-1030	**BREAK**	
1030-1200	**UMAC out-brief to NOAA Modelers, Observers and Leadership**	
1200	**ADJOURN**	

Appendix IV: Acronyms

ADCIRC	ADvanced CIRCulation model
ALE	Arbitrary Lagrangian Eulerian (vertical coordinate)
AMB	Assimilation and Modeling Branch (GSD/ESRL)
AMS	American Meteorological Society
AOML	Atlantic Oceanographic and Meteorological Laboratory
AOP	Annual Operating Plan
ARL	Air Resources Laboratory
ARW	Advanced Research WRF
AWC	Aviation Weather Center
AWIPS	Advanced Weather Information Processing System
AWIPS-2 (or II)	Advanced Weather Information Processing System (generation 2)
BoM	Bureau of Meteorology (Australia)
CAPS	Center for Analysis and Prediction of Storms (OU)
CBS	Commission for Basic Systems (WMO)
CESM	Community Earth System Model (NCAR)
CFS	Climate Forecast System
CFSv2 (v3, v4)	Climate Forecast System version 2 (or 3 or 4)
CIO	Chief Information Officer
COAMPS-TC	Coupled Ocean/Atmosphere Mesoscale Prediction System - Tropical Cyclone
CMC	Canadian Meteorological Centre
CoG	Commodity Governance
COLA	Center for Ocean-Land-Atmosphere Studies
CONUS	Continental United States
COSMIC-2	Constellation Observing System for Meteorology Ionosphere and Climate
CPC	Climate Prediction Center
CPO	Climate Program Office
CSDL	Coastal Survey Development Lab
CTB	Climate Test Bed
DA	Data Assimilation
DoC	Department of Commerce
DoD	Department of Defense
DoE	Department of Energy
DoI	Department of the Interior
DTC	Developmental Testbed Center
Dycore	Dynamical core (of a model)
ECWMF	European Center for Medium-range Weather Forecasting
EMC	Environmental Modeling Center
EnKF	Ensemble Kalman Filter
ESMF	Earth System Modeling Framework
ESPC	Earth System Prediction Capability
ESRL	Earth System Research Laboratory
F&R	Findings and Recommendations
FAA	Federal Aviation Administration
FIM	Flow-following (Finite-volume) Icosahedral-grid Model
4DVar	Four-Dimensional Variational (Data Assimilation)
4D-En-Var	Four-Dimensional Ensemble Kalman Filter Variational (Data Assimilation)
FVCOM	(Unstructured Grid) Finite Volume Coastal Ocean Model
GEFS	Global Ensemble Forecast System

GFDL	Geophysical Fluid Dynamics Laboratory
GFS	Global Forecast System
GIS	Geographic Information Systems
GLDAS	Global Land Data Assimilation System
GOES	Geostationary Operational Environmental Satellites
GOFS	Global Ocean Forecasting System (Navy)
GPRA	Government Performance and Results Act
GPS	Global Positioning System
GPU	Graphical Processing Unit
GRIB	Gridded Information in Binary
GSD	Global Systems Division
GSI	Gridpoint Statistical Interpolation
GSM	Global Spectral Model
GVF	Green Vegetation Fraction
HFIP	Hurricane Forecast Improvement Project
HIWPP	High Impact Weather Prediction Project (in OAR)
HMT	Hydrometeorological Testbed
HPC	High Performance Computing (or, formerly, Hydrometeorological Prediction Center, now called Weather Prediction Center)
HQ	Headquarters
HRRR	High-Resolution Rapid Refresh
HRRRE	High-Resolution Rapid Refresh Ensemble
HWRF	Hurricane Weather Research and Forecasting (model)
HWT	Hazardous Weather Testbed
HYCOM	Hybrid Coordinate Ocean Model
IDSS	Impact-based Decision Support Services (or System)
I/O	Input/Output
IOOS	International Ocean Observing System
ISI	Intraseasonal, Seasonal and Interannual
IT	Information Technology
IWT	Integrated Warning Team
JCSDA	Joint Center for Satellite Data Assimilation
JMA	Japan Meteorological Agency
KMA	Korean Meteorological Agency
LDAS	Land Data Assimilation System
LSM	Land Surface Model
MDL	Mesoscale Development Laboratory
MME	Multi-Model Ensemble
MOA	Memorandum of Agreement
MODIS	Moderate Resolution Imaging Spectroradiometer)
MOM	Modular Ocean Model
MOS	Model Output Statistics
MOU	Memorandum of Understanding
MPAS	Model for Prediction Across Scales
NAEFS	North American Ensemble Forecast System
NAM	North American Model
NAMDA	North American Model Data Assimilation
NAPA	National Academy of Public Administration
NASA	National Aeronautics and Space Administration
NAVGEM	(U.S.) Navy Global Environmental Modeling

NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NCO	NCEP Central Operations
NCODA	Navy Coupled Ocean Data Assimilation
NCPP	National Climate Prediction Project
NCWCP	NOAA Center for Weather and Climate Prediction
NEMS	NOAA Environmental Modeling System
NESDIS	National Environmental Satellite Data and Information Service
NetCDF	Network Common Data Format
NEWP	Numerical Environmental and Weather Prediction
NGGPS	Next Generation Global Prediction System
NIDIS	National Integrated Drought Information System
NIM	Non-hydrostatic Icosahedral Model
NLDAS	North American Land Data Assimilation System
NMMB	Non-hydrostatic Multiscale Model on the B-grid
NMME	National (North American) Multi-Model Ensemble
NOAA	National Oceanic and Atmospheric Administration
Noah	NOAA land surface model
Noah-MP	NOAA land surface model, multi-physics option
NOS	National Ocean Service (NOAA)
NPS	NCEP Production Suite
NPSS	NOAA Polar Satellite System
NRC	National Research Council
NRL	Naval Research Laboratory
NSSL	National Severe Storms Laboratory
NUOPC	National Unified Operational Prediction Capability
NWC	National Water Center (also National Weather Center) NWP Numerical Weather Prediction
NWS	National Weather Service
O2R	Operations to Research
OAR	Oceanic and Atmospheric Research (NOAA)
OFCM	Office of Federal Coordinator of Meteorology
OMB	Office of Management and Budget
OPC	Ocean Prediction Center
OSTP	Office of Science and Technology Policy
PBL	Planetary Boundary Layer
POM	Princeton Ocean Model
QPE	Quantitative Precipitation Estimates
QPF	Quantitative Precipitation Forecasts
R2O	Research to Operations
R&D	Research and Development
RAP	Rapid Refresh (model)
RFC	River Forecast Center
ROMS	Regional Ocean Modeling System
RR	Rapid Refresh
R/R	Reanalyses and reforecasts
RTOFS	Real-Time Ocean Forecast System
RUC	Rapid Update Cycle (model)
SAC	Sacramento land surface model
S2S	Subseasonal to Seasonal

SIS	Sea Ice System
SLOSH	Sea, Lake and Overland Surges from Hurricanes
SPC	Storm Prediction Center
SREF	Short-Range Ensemble Forecasts
SS&I	Storm Surge and Inundation
SSEO	Storm Scale Ensemble of Opportunity
SWPC	Space Weather Prediction Center
UCACN	UCAR Community Advisory Committee for NCEP
UCAR	University Corporation for Atmospheric Research
UK	United Kingdom
UKMO	United Kingdom Meteorological Office
UMAC	UCACN Modeling Advisory Committee
UM(S)	Unified Modeling (System)
U.S.	United States
USAF	United States Air Force
USWRP	United States Weather Research Program
VAdm	Vice-Admiral
VIC	Variable Infiltration Capacity (land surface model)
VIIRS	Visible Infrared Imaging Radiometer Suite
VSP	Visiting Scientist Program
WAM	Whole Atmospheric Model
WAVEWATCH III	Third-generation wave model
WCOSS	Weather and Climate Operational Supercomputing System
WFO	Weather Forecast Office
WMO	World Meteorological Organization
WoF	Warn on Forecast
WPC	Weather Prediction Center
WRES	Water Resources Evaluation Service
WRF	Weather Research and Forecasting (model)