White Paper

on

Proposed Way Forward for the Ad Hoc Committee on Uncertainty in Forecasts

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Purpose and Introduction

The purpose of this White Paper is to stimulate thought and discussion on the way forward for the American Meteorological Society (AMS) Ad Hoc Committee on Uncertainty in Forecasts (ACUF). The ACUF was formed recently by the AMS Commission on the Weather and Climate Enterprise (CWCE) Board on Enterprise Communication (BEC) to engage the weather and climate enterprise (Enterprise) in identifying a vision for forecast uncertainty characterization and communication. In forming this committee, the AMS is responding to Enterprise recognition of the need to communicate more complete forecast information to an increasingly educated user community as reflected in the 2006 National Research Council report: "Completing the Forecast. Characterizing and Communicating Uncertainty for Better Decisions Using Weather and Climate Forecasts." (CFR)[1]. In particular, this White Paper serves as a basis for the ACUF's Charter by proposing a mission, vision, deliverable, organization, and work plan for the Committee.

Uncertainty is a fundamental characteristic of fluid system prediction, including the weather, water, and climate (hydrometeorological) predictions germane to the missions and needs of the public, private, and academic components of the Enterprise. According to the CFR, "…effective communication of uncertainty information in hydrometeorological forecasts benefits users' decisions". Although there are notable exceptions, most current forecast products and services are based on single, deterministic predictions with no accompanying forecast uncertainty information. Consequently, decisions by users and customers at all levels are generated largely without the benefit of knowing and accounting for the inherent uncertainties of the forecast upon which they rely. Furthermore, while there are increasing numbers of individual development and prototyping efforts within the Enterprise to generate and communicate more forecast uncertainty information, there is no comprehensive approach to identify and validate user needs and science opportunities, and to develop and implement responsive products and services that leverage partner capabilities and ensure optimum comprehension by users and customers.

The recommendations (see the Appendix) from the CFR should serve as a guide for the ACUF's work. Although the CFR was commissioned by the National Oceanic and Atmospheric Administration (NOAA) and its advice specifically geared toward that agency, the report recommends that "the entire Enterprise should take responsibility for providing products that effectively communicate forecast uncertainty information"; and that product (and service) development should be collaborative with Enterprise partners and users from the outset. It is therefore fitting that the AMS CWCE has formed this ACUF to engage the Enterprise in this challenge. As Co-Chairs, we believe that the ACUF has a great opportunity to propose an Enterprise-wide foundation for developing, producing, and providing new forecast uncertainty products and services that will benefit the Nation by harvesting previous and ongoing assessments of user needs for forecast uncertainty and by coordinating partner efforts to build responsive forecast uncertainty capabilities. We also see the work of the ACUF as an opportunity to enhance the public/private/academic partnership in general by establishing a

[1] Completing the Forecast. Characterizing and Communicating Uncertainty for Better Decisions Using Weather and Climate Forecasts. Washington, D.C., National Academies Press.

paradigm of mutually-beneficial roles and responsibilities for Enterprise partners to plan and execute other initiatives and endeavors as recommended in the National Research Council Report, *Fair Weather: Effective Partnerships in Weather and Climate Forecasts*[2].

Proposed Committee Mission, Vision, and Deliverable

The mission of the ACUF should be to develop an Enterprise-wide vision and implementation plan for the provision of hydrometeorological forecast uncertainty information to the Nation building off the recommendations of the CFR. The Committee's vision should be an Enterprise partnership that generates and communicates hydrometeorological forecast uncertainty information that meets the Nation's needs for informed decisions protecting life and property, supporting National Defense and Homeland Security, enhancing the economy, and the meeting specific needs of partners, users, and customers. The Committee deliverable should be an Enterprise Implementation Plan for Forecast Uncertainty that has been reviewed and coordinated appropriately with Enterprise partner organizations and includes the following major elements:

- Needs, Opportunities, and Benefits of Providing Hydrometeorological Forecast Uncertainty Products and Services to the Nation
- Enterprise Vision and Goals for Forecast Uncertainty Products and Services
- Description of What is Needed to Meet the Goals and Reach the Vision
- Roles and Responsibilities of Enterprise Partners
- Enterprise-wide Implementation Roadmap

Organization, Approach, and Workplan

The Co-Chairs of the ACUF should be responsible for staffing and managing the Committee. Over 50 people from government, the private sector, and academia (both physical and social scientists) have volunteered to work on the ACUF. To make the most effective and efficient use of the expertise, energy, and time of this group, workgroups of topic experts should be formed along the major elements of the Implementation Plan described above. We envision the task of these workgroups will be to draft material for their respective sections of the plan, which will be reviewed, coordinated, and integrated by an integration workgroup consisting of the Committee Co-Chairs, the Workgroup Leads, and other Committee members appointed by the ACUF co-Chairs and Working Group Leads. Each workgroup should consider appropriate recommendations from the CFR, other sources of information, and its own deliberations to prepare their plan sections. Some of the challenges that the workgroups will encounter when planning and developing their sections include:

[2] NRC 2003. Fair Weather: Effective Partnerships in Weather and Climate Services. Washington, D.C., National Academies Press.

- Needs, Opportunities, and Benefits of Providing Forecast Uncertainty Products and Services

  – Challenge: Time-effectively harvesting existing studies and requirements, and gathering and documenting new needs for forecast uncertainty at appropriate levels of specificity. There are significant sociological and behavioral science issues here and potentially, a large spectrum of needs from diverse user groups, including the Enterprise partners themselves.

- Enterprise Vision and Goals for Forecast Uncertainty

  – Challenge: Identifying a long-term vision and intermediate goals for forecast uncertainty products and services based on what is needed, possible, cost-effective, and makes business sense.

- Description of What is Needed to Meet the Goals and Reach the Vision

  – Challenge: Defining the "end-to-end" Enterprise system that will enable the development, generation, and provision of forecast uncertainty information. These end-to-end components may include: socio-economic, behavioral, and earth-science research; observations, data assimilation, ensemble-modeling, and model postprocessing; automated and human value-added information and interpretation; communications and other IT, and databases; and decision aides, training and education.

- Roles and Responsibilities of Enterprise Partners

  – Challenge: Using existing and proposing new guiding Enterprise policies and organizational principles for developing, generating, and providing forecast uncertainty products and services.

- Enterprise-wide Implementation Roadmap
  – Challenge: Recommending linkages and coordination mechanisms -- Putting all the pieces together in an integrated, coherent plan that partners and stakeholders can sign up to and advocate.

Proposed Committee Workplan

The Committee should complete its work and deliver an Enterprise Implementation Plan for Hydrometeorological Forecast Uncertainty within 24 months. The high-level workplan is as follows:

Finalize Committee Charter and Identify Workgroup Leads and Memberships…….Oct. 07

Define Workgroup Deliverables, Tasks, Methodologies, Timelines, and Resource Needs..Dec. 07

Full Committee Discussion and Review of Work Plan at AMS Annual Meeting…….....Jan. 08

Workgroups Meet as Necessary Accomplish Tasks…….....……Jan.–Aug 08

Full Committee Review of Preliminary Subgroup Deliverables……..…….....…Sept. 08

First Draft of Subgroup Sections ……..…….…..……..…...Oct. 08

First draft of Complete Enterprise Implementation Plan……..……Dec. 09

Full Committee Review of First Draft Implementation Plan (at AMS Annual Meeting)…. Jan. 09

Stakeholder Review and Comment of Draft Implementation Plan……..….Feb.-May 09

Final Draft of Enterprise Implementation Plan…….……Sept. 09

Appendix A

Recommendations from the 2006 National Research Council Report: *Completing the Forecast, Characterizing and Communicating Uncertainty for Better Decisions Using Weather and Climate Forecasts*

Overarching Recommendations:

Recommendation 1.0: The entire Enterprise should take responsibility for providing products that effectively communicate forecast uncertainty information. NWS should take a leadership role in this effort.

Recommendation 2.0: NWS should improve its product development process by collaborating with users and partners in the Enterprise from the outset and engaging and using social and behavioral science expertise.

Recommendation 3.0: All sectors and professional organizations of the Enterprise should cooperate in educational initiatives that will improve communication and use of uncertainty information. In particular, 1) hydrometeorological curricula should include understanding and communication of risk and uncertainty, 2) ongoing training of forecasters should expose them to the latest tools in these areas, and 3) forecast providers should help users, especially members of the public, understand the value of uncertainty information and work with users to help them effectively incorporate this information into their decisions.

Recommendation 4.0: NWS should develop and maintain the ability to produce objective uncertainty information from the global to the regional scale.

Recommendation 5.0: To ensure widespread use of uncertainty information, NWS should make all raw and post-processed probabilistic products easily accessible to the Enterprise at full spatial and temporal resolution. Sufficient computer and communications resources should be acquired to ensure effective access by external users and NWS personnel.

Recommendation 6.0: NWS should expand verification of its uncertainty products and make this information easily available to all users in near real time. A variety of verification measures and approaches (measuring multiple aspects of forecast quality that are relevant for users) should be used to appropriately represent the complexity and dimensionality of the verification problem. Verification statistics should be computed for meaningful subsets of the forecasts (e.g., by season, region) and should be presented in formats that are understandable by forecast users. Archival verification information on probabilistic forecasts, including model-generated and objectively generated forecasts and verifying observations, should be accessible so users can produce their own evaluation of the forecasts.

Recommendation 7.0: To enhance development of new methods in estimation, communication, and use of forecast uncertainty information throughout the Enterprise, and to foster and maintain

collaboration, confidence, and goodwill with Enterprise partners, NWS should more effectively use testbeds by involving all sectors of the Enterprise.

Recommendation 8.0: The committee endorses the recommendation by the NRC "Fair Weather" report to establish an independent advisory committee and encourages NOAA to bring its evaluation of the recommendation to a speedy and positive conclusion.

Recommendation 9.0: NWS should dedicate executive attention to coordinating the estimation and communication of uncertainty information within NWS and with Enterprise partners.

Uncertainty in Decision Making Recommendations:

Recommendation 2.1: For users who have difficulty with numeric probabilities and prefer a less analytic approach, forecast uncertainty should be expressed using relative frequencies rather than probabilities.

Recommendation 2.2: The Enterprise should signal to users the different sources of uncertainty in their probabilistic forecasts and risk communication products.

Recommendation 2.3: The utility of any forecast uncertainty product should be evaluated within the individual, social, and institutional contexts of the recipient. What to include and not include should in part be a function of the intended user and their ability to handle different sorts of information.

Recommendation 2.4*:* NWS should acquire social and behavioral science expertise including psychologists trained in human cognition and human factors, with training in behavioral decision theory, statistical decision theory, survey design and sampling, and communication theory, with special focus on graphics and product development.

Estimating and Validating Uncertainty Recommendations:

Recommendation 3.1: As the Global Climate and Weather Modeling Branch and the Mesoscale Modeling Branch of the Environmental Modeling Center continue to develop their ensemble forecasting systems, they should evaluate the full range of approaches to the generation of initial ensembles and apply the most beneficial approach. The Environmental Modeling Center should focus on exploring the utility of ensemble-based data assimilation approaches (and extensions) to couple ensemble generation and data assimilation at both the global and the mesoscale levels.

Recommendation 3.2: The National Centers for Environmental Prediction should complete a comprehensive evaluation to determine the value of multiple dynamical cores and models, in comparison to other methods, as sources of useful diversity in the ensemble simulations.

Recommendation 3.3: The National Centers for Environmental Prediction should (a) reprioritize or acquire additional computing resources so that the Short-Range Ensemble Forecasting system can be run at greater resolution, or (b) rethink current resource use by

applying smaller domains for the ensemble system or by releasing time on the deterministic runs by using smaller nested domains.

Recommendation 3.4: The NOAA National Operational Model Archive and Distribution System (NOMADS) should be maintained and extended to include (a) long-term archives of the global and regional ensemble forecasting systems at their native resolution, and (b) re-forecast datasets to facilitate post-processing.

Recommendation 3.5: The National Center for Environmental Prediction, in collaboration with appropriate NOAA offices, should identify the length of re-forecast product necessary for time-scales and forecasts of interest, and produce a re-forecast product each time significant changes are made to a modeling/forecasting system.

Recommendation 3.6: Efforts on the proposed National Digital Guidance Database should be accelerated and coordinated with those on the NOAA National Operational Model Archive and Distribution System (Recommendation 3.4).

Recommendation 3.7: NWS should work toward a culture and systems that encourage interactions among all components of the Enterprise and should use testbeds as a means of bringing together diverse groups from different disciplines and operational sectors. With the help of external users and researchers, NWS centers and research groups should construct and disseminate a prioritized list of operational goals and associated research questions. These lists should be dynamic, providing mechanisms by which NWS can elicit feedback from the research and user communities and the research and user communities can support and drive the direction of NWS. Potential solutions to these research questions could then be explored in testbeds.

Recommendation 3.8: The Climate Prediction Center should investigate methods to use the full distribution of the Climate Forecast System ensemble members (e.g., through a post-processing step) rather than relying solely on the ensemble mean or median. In addition, the center should make use of reforecast datasets and historical forecast performance information for developing the monthly and seasonal probabilities.

Recommendation 3.9: The Climate Prediction Center should develop more effective objective methods for combining forecast components to improve forecast performance.

Recommendation 3.10: The Climate Prediction Center should examine whether it is appropriate to distribute forecasts with little skill and whether projections should be limited to shorter time lengths. Information about prediction skill should be more readily available to users.

Recommendation 3.11: The National Weather Service and the National Centers for Environmental Prediction should fully support the Climate Testbed to engage the Enterprise, particularly the research community, in operational problems and develop meaningful approaches that enhance and improve operational predictions.

Recommendation 3.12: The Office of Hydrologic Development should implement operational hydrology databases that span a large range of scales in space and time. The contribution of

remotely-sensed and on-site data and the associated error measures to the production of such databases should be delineated.

Recommendation 3.13: The Office of Hydrologic Development should organize workshops with participation from all sectors of the Enterprise to design alternatives to the Advanced Hydrologic Prediction System ensemble prediction system components and develop plans for intercomparisons through retrospective studies, demonstration with operational data, and validation, and for participation in testbed demonstration experiments.

Recommendation 3.14: The Office of Hydrologic Development should develop methods for seamlessly blending short-term (weather) with longer-term (climate) ensemble predictions of meteorological forcing within the operational ensemble streamflow prediction system. This will require NCEP model output downscaling and bias adjustment, and real-time data availability.

Recommendation 3.15: NWS should expand its verification systems for ensemble and other forecasts and make more explicit its choice of verification measures and rationale for those choices. Diagnostic and new verification approaches should be employed, and the verification should incorporate statistical standards such as stratification into homogeneous subgroups and estimation of uncertainty in verification measures. Verification information should be kept up to date and be easily accessible through the Web.

Communicating Forecast Uncertainty Recommendations:

Recommendation 4.1: The National Weather Service should expedite development of the Interactive Forecast Preparation System toward a system that can access, produce, and communicate uncertainty guidance for most forecast parameters. Such a revised system should be able to access deterministic and ensemble prediction systems, historical error statistics, and statistically post-processed forecast information (e.g., Model Output Statistics) to allow production of uncertainty information with varying levels of subjective and objective contributions. The system should be capable of preparing probabilistic products to communicate probability density functions and other types of uncertainty information (e.g., probability of temperature less than freezing or wind speed greater than 26 knots).

Recommendation 4.2: The National Weather Service should release the Area Forecast Discussion only in layperson English to facilitate its broad use and understanding. For more sophisticated users, NWS could provide more detailed technical information linked to the Area Forecast Discussion.

Recommendation 4.3: The Climate Prediction Center should provide full exceedence probability distributions of the projected monthly and seasonal temperature and precipitation values in both graphical and tabular forms. A straightforward graphical presentation of this information should be developed that is understandable to relevant user groups.

Recommendation 4.4: To ensure consistency in the communication of uncertainty information and user comprehension, NWS should more fully study and standardize uncertainty terms, icons, and other communications methods through all pathways of forecast dissemination.

Recommendation 4.5: NWS should amend NWS Directive 10-102 to require collaboration with users on product development throughout the development process. Moreover, users' comprehension and interpretation of products should be formally evaluated at several stages during the product development process.