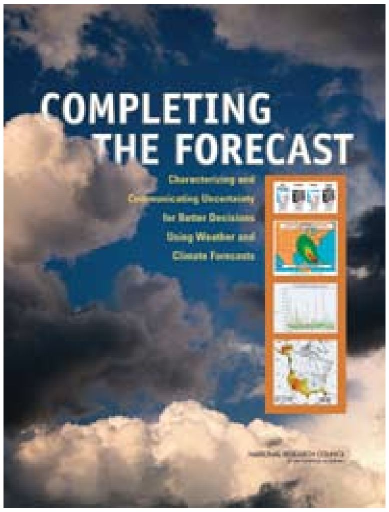
Completing the Forecast

Characterizing and Communicating Uncertainty for Better Decisions Using Weather and Climate Forecasts

Most weather forecasts today are "single valued"—for example "it will be 70 degrees on Friday"—and do not convey the uncertainty, or likelihood, that an event will occur. Generating forecasts that contain uncertainty and communicating how to use them improves people's ability to make decisions based on the forecast. The weather, seasonal climate, and hydrology communities now recognize that uncertainty should be a fundamental part of forecasts. NOAA's National Weather Service can take a leading role in this transition by partnering with others to understand user needs, generate relevant and rich informational products, and utilize effective communication vehicles.



The chaotic character of the atmosphere, coupled with inevitable inadequacies in observations and computer models, results in forecasts that always contain uncertainties. These uncertainties generally increase with forecast lead time and vary depending on weather conditions and location. Uncertainty is thus a fundamental characteristic of weather, seasonal climate, and hydrological prediction, and no forecast is complete without a description of that uncertainty, or likelihood, of a particular event.

Nonetheless, for decades, users of weather, seasonal climate, and hydrological (collectively called "hydrometeorological") forecasts have been conditioned to receive incomplete information. Users—who include the public, city managers, as well as experts with significant training in statistics and risk management—have become comfortable with single-valued forecasts, such as "the high will be 70 degrees Farenheit." Users apply their own experience to determine how much confidence to place in those forecasts.

Most forecast products, including those from the National Oceanic and Atmospheric Administration's (NOAA's) National Weather Service (NWS), continue this legacy. Decisions by users at all levels, perhaps most critically those associated directly with protection of life and property, are being made without the benefit of knowing the uncertainties of the forecasts upon which they rely. Do we send the snow plows out and, if so, when? Do we purchase additional fuel supplies for the coming months and, if so, how much? Do we order mandatory evacuations because of an approaching storm and, if so, when?

Fortunately, NWS and others who provide hydrometeorological forecasts recognize the need to include uncertainty as a fundamental part of forecasts and are seeking ways to improve the forecast process. This study, which was requested by NWS in response to ideas first raised in the report *Fair Weather: Effective Partnerships in Weather and Climate Services* (NRC, 2003), explores how to improve the generation, communication, and potential use of uncertainty information for hydrometeorological forecasts. In particular, NWS asked the committee to address how user needs for uncertainty information can be identified, the limitations of current methods of estimating and validating uncertainty and recommended improvements, and how to best communicate uncertainty information.

The Value of Communicating Uncertainty Information

The inclusion of uncertainty in forecasts has socioeconomic, scientific, and ethical value, and can help ensure user confidence. From a socioeconomic perspective, managers of transportation systems (e.g., airports, highways, railroads), reservoirs, and flood preparedness, for example, all value uncertainty information. In the case of the 1997 billion-dollar flood of the Red River in North Dakota, the uncertainty in the flood level was well within the typical range yet the public and government agencies were insufficiently prepared for the flood in part because they had limited uncertainty information.

With the increasing availability of uncertainty information (e.g., Figure 1), users—each with their own sensitivity to costs and losses and with varying thresholds for taking preventive action—can better decide for themselves whether to act and the appropriate level of response. Providing single-valued forecasts when considerable uncertainty exists inevitably undermines user confidence. The state of the science has progressed—it not only acknowledges the inherent uncertainty in predictions but has developed ways to express uncertainty so it is more useful.

OVERARCHING FINDINGS AND RECOMMENDATIONS

Moving toward effective estimation and communication of uncertainty information has many implications. Because of the immense breadth and depth of this challenge, detailed solutions are beyond the reach of a single committee. Consequently, this report provides general ideas for consideration by NWS and the entire community of providers and users of weather, seasonal climate, and hydrological forecasts (called "the Enterprise" in the recommendations that follow). The report's nine overarching recommendations, summarized here, all merit equal priority. Additional, detailed recommendations appear in the full report and these add further specificity and breadth. All recommendations should be considered in the context of NOAA's Policy on Partnerships in the Provision of Environmental Information.

Enterprise-wide Involvement

Hydrometeorological services in the United States are an Enterprise effort. Therefore, effective incorporation of uncertainty information will require a fundamental and coordinated shift by all sectors of the Enterprise, a shift that will take time and perseverance. As the nation's

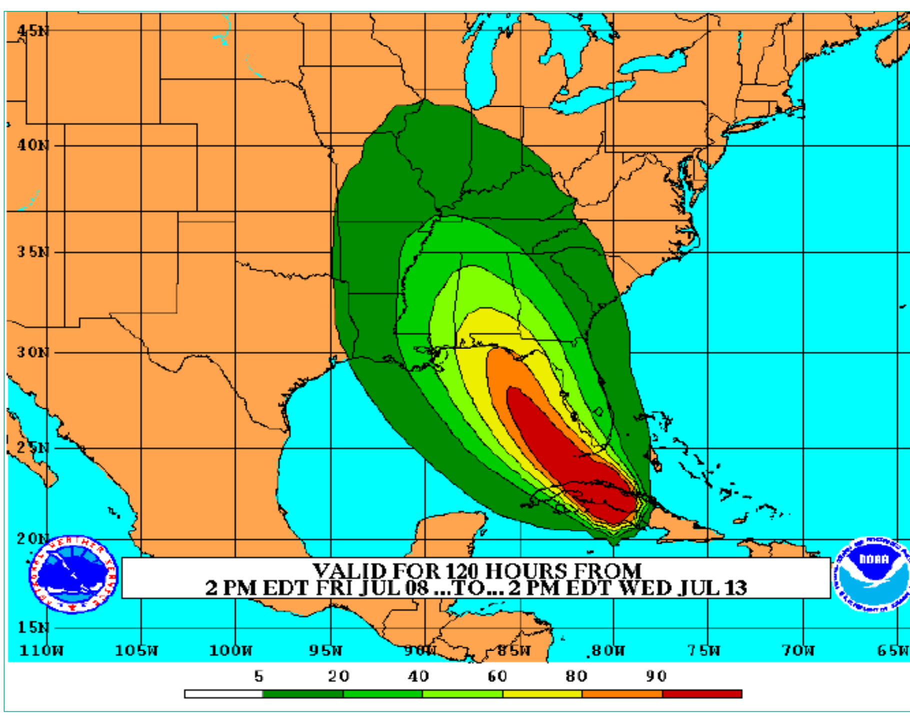


Figure 1. Experimental National Weather Service product showing uncertainty in wind speeds for Hurricane Dennis expressed as probability of wind speeds greater than tropical storm force (39 miles per hour). The colored bar at the bottom of the figure gives the probability scale in percent. Such a "probabilistic" forecast conveys uncertainty in the prediction in contrast to "deterministic" forecasts, which predict only one future state of the system, with no information regarding forecast uncertainty.

public weather service, NWS has the responsibility to take a leading role in this transition.

Recommendation 1: The entire Enterprise should take responsibility for providing products that effectively communicate forecast uncertainty information. NWS should take a leadership role in this effort.

Product Development Incorporating Broad Expertise and Knowledge from the Outset

Understanding user needs and effectively communicating the value of uncertainty information for addressing those needs are perhaps the largest and most important tasks for the Enterprise. Yet, the variety of resources that have knowledge of user needs is not being fully tapped by NOAA, and user perspectives are not incorporated from the outset of the product development process.

Recommendation 2: NOAA 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.

Education on Uncertainty and Risk Communication

Enhanced Enterprise-wide educational initiatives will underpin efforts to improve communication and use of uncertainty information. There are three critical areas of focus: 1) undergraduate and graduate education, 2) recurrent forecaster training, and 3) user outreach and education.

Recommendation 3: 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.

Uncertainty Information from the Global and Regional Scale Models

The ability of NOAA to distribute and communicate uncertainty information is predicated on the capacity to produce post-processed model output containing uncertainty information on a variety of spatial scales. Currently, NOAA maintains long-range (global) and short-range (regional) ensemble prediction systems that generate a collection of forecasts, each starting from a different initial state, that indicates the uncertainty in the prediction. However, the short-range system undergoes no post-processing and uses an ensemble generation method (breeding) that may not be appropriate for short-range prediction. In addition, the short-range model has insufficient resolution to generate useful uncertainty information at the regional level. For forecasts at all scales, comprehensive post-processing is needed to produce reliable (or calibrated) uncertainty information.

Recommendation 4: NOAA should develop and maintain the ability to produce objective uncertainty information from the global to the regional scale.

Ensuring Widespread Availability of Uncertainty Information

NWS, through the National Centers for Environmental Prediction (NCEP), produces a large amount of model output. The ensemble forecasts and output from statistical post-processing already produce a wide variety of uncertainty information. However, both the model output and statistical information regarding its skill are difficult to access from outside NCEP. Thus, NWS is missing an opportunity to provide the underlying datasets that can drive improved uncertainty estimation and communication across the Enterprise.

Recommendation 5: 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.

Broad Access to Comprehensive Verification Information

To make effective use of uncertainty products, users need complete forecast verification information that measures all relevant aspects of forecast performance. In addition, comprehensive verification information is needed to improve forecasting systems. Such information includes previous numerical forecasts, observations, post-processed uncertainty information, and detailed verification statistics (for raw and post-processed probabilistic forecasts).

Recommendation 6: 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.

Effective Use of Testbeds

Testbeds are emerging as a useful mechanism for developing and testing new approaches and methodologies in estimating, communicating, and using uncertainty information. The effectiveness of testbeds is limited when all appropriate sectors of the Enterprise are not included.

Recommendation 7: 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, NOAA should more effectively use testbeds by involving all sectors of the Enterprise.

Enterprise Advisory Committee

Only through comprehensive interaction with the Enterprise will NWS be able to move toward effective and widespread estimation and communication of uncertainty information. One mechanism for engaging the entire Enterprise is an independent NWS advisory committee with broad representation Such a committee is under consideration by NOAA in response to a recommendation in the Fair Weather report (NRC, 2003).

Recommendation 8: The committee endorses the recommendation by the National Research Council 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.

Uncertainty Champion

Incorporating uncertainty in forecasts will require not only the attention but also the advocacy of NWS management. Given the scope of this challenge, the level of effort involved will demand a "champion" within the NWS leadership—an individual who can effectively organize and motivate NWS resources and engage the resources and expertise of the entire Enterprise.

Recommendation 9: NWS should dedicate executive attention to coordinating the estimation and communication of uncertainty information within NWS and with Enterprise partners.

CONCLUSION

By partnering with other segments of the Enterprise to understand user needs, generate relevant and rich informational products, and utilize effective communication vehicles, the National Weather Service can take a leading role in the transition to widespread, effective incorporation of uncertainty information into hydrometeorological predictions.

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This report brief was prepared by the National Research Council based on the committee's report. For more information, contact the Board on Atmospheric Sciences and Climate at (202) 334-3426 or visit http://nationalacademies.org/basc. Copies of *Completing the Forecast* are available from the National Academies Press, 500 Fifth Street, NW, Washington, D.C. 20001; (800) 624-6242; www.nap.edu.

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