THE FUTURE OF HUMANS IN AN INCREASINGLY AUTOMATED FORECAST PROCESS

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The meteorological community is considering new roles for forecasters as increased accuracy in computer-generated weather forecasts continues to reduce the need for human intervention.

Our role as humans in the forecast process has been a very sensitive and highly debated issue within the meteorological profession since the advent of numerical weather prediction (NWP) models in the 1960s. NWP model guidance continues to improve to such a degree that forecasters are discovering their ability to add value to NWP model forecasts is outpaced (Brooks et al. 1996). This has resulted in an increasing reliance on NWP model guidance, an issue first described by Snellman (1977). Since that time, new roles for forecasters have been contemplated in an effort to determine the optimum role for humans in the forecast process in order to produce the best forecast products possible for all users of weather forecast information. This article represents results from a collaborative effort of the forecast community to identify the ways in which these roles might continue to change in the future.

Reliance on NWP model guidance to initialize a gridded forecast database has become particularly evident in the National Weather Service (NWS) since the late 1990s. Since then, forecasting has shifted from the manual production of text-based forecasts to the

Editor's note: The fast-changing nature of forecasting work has spurred some of the most vital discussions at recent American Meteorological Society (AMS) gatherings. This article synthesizes salient issues that emerged at a forum on the title topic that took place on 12–13 January 2004 at the AMS annual meeting in Seattle, Washington. A similar forum conducted by the Meteorological Services of Canada in 2003 is summarized online at www.weatheroffice.com/forecastersforum/. These fora brought together forecasters and managers so that all interested parties could discuss issues pertinent to the future role of humans in the forecast process. At the two-day AMS forum, attendees were divided into eight randomly assembled groups, with each group discussing a separate issue. Individuals rotated through all of the issues, resulting in considerable diversity within each group for each issue. Later, results of the discussion for each issue were addressed in an open forum. As many as 200 people attended, and they represented the broad diversity of the international professional community. The authors have continued moderating fora and workshops to address the future duties and goals of forecasters, including looking at those outlined here in more depth. Readers are encouraged to look for further specifics about this ongoing and active dialog among forecasters in upcoming issues of *Weather and Forecasting*.

production of gridded forecast databases through the utilization of graphical software tools, with text and other forecast products derived from these databases (Glahn and Ruth 2003). Software can be developed to derive products tailored to specific customers each time the gridded database is updated. As forecasting evolves, the time devoted to the forecast process continues to expand.

Today, there are more data and guidance available to forecasters than at any other time in the past (Doswell 2004). Consequently, with the increase in production of derived forecast products, forecasters in the NWS and elsewhere have stated that the forecast process can be dominated by graphic and text forecast production, more than meteorological diagnosis and analysis.

We will attempt here to convey some of the striking themes that have emerged in discussions about this evolving NWP context for forecasters.

TODAY'S SUCCESSFUL FORECASTER. There was remarkable consensus among participants at our forum in Seattle, Washington, in 2004 on nearly 20 desirable traits of a good forecaster. The characteristics can be grouped into two broad areas—meteorological/technical skills and personality components—and are applicable to forecasters in all sectors of the profession.

Increasing technological proficiency is a desired quality of forecasters. The forecaster must adapt well to new technologies and techniques. Knowledge must be synthesized into useable weather information, and forecasters must be cognizant of the needs, knowledge level, and expectations of the customer.

It is important to learn from peers who have more forecasting experience. It is also important to distinguish between experience in the mechanics of producing a forecast and experience in meteorological diagnosis and prognosis (Doswell 1986). A forecaster who routinely learns from past events will ultimately improve forecasting skill, multitasking ability, and situational awareness. Conversely, a forecaster who does not take the initiative to learn from past events, choosing instead to forecast primarily using computer model guidance and focus on maintaining proficiency on the ever-changing mechanical procedures of producing forecasts (Roebber and Bosart 1996), will not realize such growth. When high-impact weather is imminent, the forecasters with experience in diagnosis and prognosis add the most value to computer-generated model guidance (Hahn et al. 2003). A strong interest and passion for meteorology is a significant source of motivation for such forecasters.

Management and people skills, including task delegation, prioritization of duties, and being a role model and mentor to other forecasters, are also prominent themes among our colleagues' comments. Forecasters should acknowledge others' perspectives to limit overconfidence, and they should retain a sense of objectivity to refrain from "wishcasting." Honesty is also essential to improve communication with other forecasters. The forecaster should be able to withstand criticism and disagreement and accept accountability when mistakes are made. Perhaps most importantly, a forecaster must possess the stamina required for shift work and lengthy hours.

One commonly articulated characteristic is "professional dedication." Today's forecasters apparently feel that successful forecasters generally should be able to assimilate and integrate a wide variety of data using advanced and evolving technology, and to adapt to changing technology, even when changes are perceived as premature or misguided. Additionally, they should provide useful feedback to researchers and the NWP community; frequent scrutiny of model output should be one component of the forecast process. More generally, communication between agencies and among the research/modeling community and forecast team members is essential for successful forecasters.

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NWP IN THE FORECAST PROCESS. In keeping with the forecaster pedagogy of the last few decades, an overwhelming theme that has emerged from discussions is the idea that NWP solutions should provide guidance. This notion cuts across age groups and affiliations (NWS, military, private sectors, etc.), and is an indication that a détente with NWP products persists among human forecasters. Some people are emphatic that NWP solutions do not supply users with truth, but are an approximation to it, and thus are valuable for directing the prediction process for the human forecaster. Many seem uncomfortable with the vision of an entirely automated forecast process devoid of human intervention. It should be noted, however, that discussion produced little agreement as to the time period (0–6, 12–48, >48 h) for which NWP guidance is most valuable. There is more agreement that due to coarse model spatial and temporal resolutions, much value could be added to NWP model output for all forecast time periods in a graphical gridded environment.

There are many roles for NWP in the forecast process. In particular, NWP should set the synoptic-scale stage (what the models do best, presently), provide a baseline for human forecasters to improve upon, facilitate feedback from human forecasters for model improvement, allow forecasters to test hypotheses, and help assess or quantify uncertainty.

One of the most intriguing suggestions we have heard was that in the future meteorologists would be forecast managers on a day-to-day basis. This is a different paradigm from the one we currently employ, where the human forecaster is the beneficiary of the "forecast funnel" (Snellman 1982), and from whom the forecast flows. In the proposed paradigm, forecast managers would be like airline pilots, that is, typically large aircraft fly themselves, and pilots only intervene at critical times (e.g., takeoff, landing, computer failure). During catastrophic data–computer failure humans would most likely cease to be forecast managers and return to their more traditional roles. This would be true, especially during periods of inclement and severe weather. Clearly, the presence of meteorologists (as with commercial pilots) is crucial in an increasingly automated working environment and must continue to be for the foreseeable future.

FORECAST SYSTEM EVALUATION AND VERIFICATION. In the future, forecasters are going to need to develop greater "customer awareness." As a result, it is of primary importance that forecasts be evaluated from the perspective of forecast users. In this way, the importance of humans in the forecast process can be measured in ways that matter to the people who ultimately pay for the forecast process. To do this, forecasting services will have to identify and interact with users of their forecast products, learn about their weather-sensitive decisions, and see how weather forecast information helps those users make their decisions. At this time, there is little information available on how the general public uses and understands weather forecast products. One way that this could be addressed is via a "Nielsen ratings" survey to find out what fraction of the public actually gets forecast information, what information they use, and how they interpret it.

Any useful evaluation system must provide forecaster feedback (in near–real time) to help them improve their forecasting. Ideally, the system should make it easy to do postmortems on events and for forecasters to compare their forecasts to those of numerical models.

Our colleagues generally seem to agree that emphasis on verification will need to change in the future. The current focus on calculation of the mean-squared error of maximum and minimum temperature or probability of precipitation likely masks the role of human forecasters. "High impact" events should receive the most emphasis. This necessarily implies that forecast verification will need to be stratified to look at important and/or difficult forecasts, such as when observed conditions deviate significantly from climatology. Further methods to evaluate forecasts of phenomena or conceptual models, rather than point-to-point weather forecasts, are needed.

Evaluation of hazardous weather warnings is clearly important, but current measures (probability of detection, false-alarm ratios) may not tell us all we want to know. Thus, a forecast of "supercell thunderstorms in a county warning area" with several hours lead time could be evaluated, rather than simply looking at occurrence or nonoccurrence of precipitation.

PROBABILISTIC FORECASTS. The value of probabilistic forecasts (PF) for quantifying uncertainty is widely recognized (AMS 2002). An understanding of forecaster confidence allows users more responsibility in decision making.

One major consideration in the transition to PF is that there appears to be a divide between what forecasters know and what the user community (e.g., the general public, emergency managers, Departments of Transportation, and all types of weather-sensitive interests) knows. This divide is as large as it has ever been; evidently many users, in particular the general public, continue to expect more deterministic forecast information than meteorologists can offer. One proposal from the 2004 Forecaster Forum was to stop using number probabilities, and instead to either refer to low, medium, and high probabilities, or use ranges when appropriate. Additionally, confidence factors could be quantified for problems of the day, and stated within narrative forecast discussions.

There is also a strong need for more sophisticated PF tools and guidance. Creating ensemble tools and increasing the number of ensemble members should improve the value of probabilistic guidance that must be integrated into the PF tools. It is also clear that forecasters need software that is designed to allow for the expression of the probabilities of other forecast elements in addition to the probability of precipitation. Users also need tools and education to properly interpret forecast guidance probabilities, especially if there is a transition to more quantitative expressions of probability for additional weather forecast elements.

With the proper education, more users will understand, employ, and accept PF. However, the general public's lack of appreciation and understanding of PF remains a major obstacle to the widespread use thereof, even as forecast ranges and graphical "cones" for hurricane-track forecasts have given PF increasing exposure. In fact, PF may be best understood as a graphical forecast, tailored to the needs of each user group. The characteristics of the graphics would also be an important factor in the use and understanding of PF. Conversely, the more sophisticated weather-sensitive users value a quantifiable expression of risk. Surveys are necessary to understand their need for and understanding of PF so that the information can be tailored to the needs of each user group. Successes and failures in the implementation of PF should be shared within all the sectors of our profession, so we can all learn from each other in an effort to accelerate the transition to PF.

OPERATIONAL FORECASTING TOOLS.

What tools would best serve operational forecasters in the future, and how should those tools be designed and tested? One common theme was the multidimensional visualization of data. Meteorologists have primarily been viewing the atmosphere in two dimensions, which imposes a limitation on the identification of conceptual models. The research community has provided software capable of three-dimensional (3D) data viewing for at least 20 years.

One factor affecting the ability to view 3D data is the current state of computer hardware. In this age, computer hardware is improving to the point that it can support some 3D software in an operational environment. Computing capacity and processing speed is advancing at such a rate that soon there will no longer be a need for limiting data displays to two dimensions.

Also commonly recognized is the necessity for better data assimilation and analysis tools. However, before data can be assimilated, it must be available, with preferably denser observation networks. Furthermore, these data need to be assimilated into operational models in a more accurate and efficient manner, and analyzed using tools that improve our understanding of the current state of the atmosphere.

Another challenge in operational forecasting is implementing tools that are not fully developed and tested. Technological advances often produce better science and service; however, care must be taken to introduce new tools into the forecast process with minimal negative impact on the process itself and consequently the final forecast product.

The advent of the NWS National Digital Forecast Database (NDFD) and Gridded Forecast Editor (GFE) poses additional challenges (Mass 2003). For instance, the system requires an increasing number of forecast elements, in some cases out to 7–15 days in the public and private sectors, respectively, with forecasters having a limited ability to recognize the optimum situations to add value to NWP model guidance.

NDFD also incorporates the capability to locally modify model parameters to adjust local model output (e.g., Etherton and Santos 2004). For example, ensemble runs of a local model, using different parameterizations, could produce an ensemble mean and range of possible solutions for forecast guidance. In the future, forecasters could modify model solutions and analyze output to investigate cause-and-effect relationships in the atmosphere, and eventually the output will represent the most likely solution.

Artificial intelligence also could potentially improve the value of model guidance. Much research has been done in recent years, which has increased the maturity of fuzzy logic (e.g., Hicks 2004) and neural network applications (Kuligowski and Barros 1998). Self-learning datalogging and data-mining techniques would bring a new dimension to model choices and model usage.

Finally, we need more sophisticated climatological applications. Conditional climatologies from the enormous volume of data should continue to be developed, with sophisticated software designed to aid in the decision-making and forecasting processes.

TRAINING. The changing role of the human in the forecast process makes routine training and education imperative. In general, all operational forecasters lack understanding of at least some aspect of NWP models, more because they lack time for education and training than because of an unwillingness to learn. Both NWP and more critical thinking are needed in the undergraduate curriculum.

Entry-level meteorologists need to be somewhat familiar with the forecast process and mechanical forecast product composition techniques within the respective sector of the meteorological profession they intend to enter. Once a meteorologist has entered the workforce, dual training tracks are necessary—science (diagnosis and prognosis) and operations (mechanical production). Both tracks need to continue through the entire career of the forecaster.

Another emerging requirement for forecasters is training in leadership, decision making and related skills of team building, collaboration, and communication. Managing the complex data and forecast guidance and dividing workloads effectively in rapidly changing weather situations have become integral to the overall forecast process.

FUTURE DUTIES OF A FORECASTER.

A considerable shift in future duties seems quite possible, especially as the meteorological community works to define roles and duties for all sectors in the profession. One primary theme through our discussions with colleagues has been a probable transition from forecaster to communicator or interpreter. This may take some meteorologists away from the basic forecast construction into a more focused, applied use of weather information specifically adapted for better decision making.

The communication transition in this future role includes effective internal communication and collaboration within organizations, which is a prerequisite for effectively communicating weather information to users. The transition is especially true of forecasters with adjacent or overlapping areas of responsibility. Internal communication and collaboration will become progressively more important to maintain credibility in a society with such open access to data. This increase in collaboration between forecasters is a moderate paradigm shift within some organizations. Increased forecast collaboration is necessary to help achieve spatial and temporal consistency: forecasters across a given region must agree to a meteorologically consistent evolution of atmospheric features, focusing on high-impact weather, to obtain this subregion-to-subregion consistency. As such, improving communication continues to be a priority within the meteorological profession. For example, weather forecasts will increasingly be in graphical form and should be updated frequently so the flow of information is seamless for a broad spectrum of users.

CONCLUSIONS AND RECOMMENDATIONS.

Regardless of perceptions of user preferences, a widespread campaign is needed to educate all users on the optimum use of PF. There is a significant segment of the user community that takes specific actions based on specific thresholds, and forecasters currently provide the specific forecast values. Does the issuance of probabilistic, as opposed to deterministic, forecasts diminish the user's perception of the leadership and decision making of the forecaster?

The methods of disseminating information to users must be addressed as the meteorological community strives to improve internal communication and communication to users. Based on the accuracy of current computer-generated forecast (Brooks et al. 1996), relatively modest improvements in forecast accuracy can be expected in the future. Consequently, our biggest gains in improving the value of forecasts may be through effective communication, resulting in more effective decision making by users and improved perception of our forecasts. Forecasters will have the most impact by helping design and produce a variety of graphical and text products.

One possible step toward improving the necessary collaboration includes knowing the strengths and weaknesses of each forecaster, so the "team" of meteorologists, composed of the forecasters responsible for any given subregion, know how to modify their forecasts based on each forecaster's strengths.

Steps for attaining these goals must be outlined and collectively agreed upon by both the forecasters and management. Without the forecasters and management working together in pursuit of the optimum role of the human in the forecast process, the future role of humans will remain very uncertain.

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