Developing Positive Team Collaborations

BY STEVEN A. ACKERMAN

In his May 2006 *Bulletin* article, Toby Carlson offers some provocative thoughts on the current funding situation for meteorological research in the United States. While his main focus is on funding reform, his comments on artificial teamwork and forced collaborations for the sake of proposals suggest another area in need of reform. I would like to offer some thoughts on the advantages of team research and how we might form better research partnerships. Research communities are an effective means by which individuals come together to achieve goals, from those related to individual projects to those that guide an entire institute.

Collaboration has already found a stronghold in education and business. Collaborative work serves as an effective teaching method. Studies suggest that students working in groups tend to learn more and retain information longer than when the same content is delivered in another format. Peer teaching and learning have long been part of the education process. Similarly, collaboration in the workplace is not a new business model. People have always worked together to improve the success of their endeavors. As with education, these collaborations bring people, ideas, and information together to accomplish a specific objective and to do so effectively.

But what about the place of effective collaborative work in research? The value of collaborative learning in education and business environments directly translates to a collaborative research community. My positive experience with research groups has proven this statement to be true, and below I share my thoughts on what makes a research community thrive. I will use examples from research on learning communities and make analogies to my own experience with the Cooperative Institute of Meteorological Satellite Studies (CIMSS; University of Wisconsin—Madison), one of many NOAA cooperative institutes, to support these opinions.

Research communities thrive when they bring people together for shared learning, discovery, and the generation of knowledge. Research communities thrive when all participants take responsibility for achieving the goals. Drawing from education research on learning communities, I posit that there are four core ideas that define a successful research community.

Shared discovery and learning. Bringing together people of varied backgrounds and skill sets to inspire alternative ways of thinking provides new approaches to solving complex problems. To truly succeed, the interaction throughout the team must be functional and is necessary to accomplish the research objectives. Participants must share their discoveries and take responsibility for achieving goals. Collaborative research activities where participants share responsibility for the learning and research that takes place are important to the development of a research community.

Connections to other related research, applications, and life experiences. Research communities flourish when implicit and explicit connections are made to experiences and activities beyond the program in which one participates at any given moment. People must be able to situate their research in a larger context, solidifying their place in the broader community and thereby decreasing their sense of isolation.

In a *Space Policy* article in 1986, William Bishop reviewed the advances in the remote sensing of Earth that had taken place in the previous 25 years. He noted, "Remote sensing from space can only thrive as a series of partnerships." He used CIMSS as a positive working example of the

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government–academia partnership, noting, "The Institute pioneered the computation of wind speeds at cloud heights by tracking cloud features from image to image. These are now a stable product provided from the satellites to the global models at the National Meteorological Center." This partnership still thrives because of the need, as defined by NOAA, and the expertise at the institutes. NOAA and university scientists share responsibility in the research rather than relying on the expert-centered approach of many faculty-led research groups.

CIMSS continues to be a leader in the measurement of winds from satellite observations, and has expanded its expertise to a variety of satellite applications. Through this partnership, over two dozen algorithms from winds to clouds to biomass burning have been successfully transitioned from CIMSS research projects to NOAA operations. This collaboration has flourished because of the explicit connections between the researchers and the larger community needs. Through the cooperative institute, the university team is conscious of the needs and opportunities beyond an individual project; they appreciate the potential impact of their research on a larger community. Researchers recognize that their work may find its way into the hands of other users. The recent successful launch of the Cloud–Aerosol Lidar and Infrared Pathfinder Satellite (CALIPSO) and Cloudsat are positive examples of NASA collaborations.

Functional connections among researchers. The opportunity for collaboration should be strongly supported in research. Research communities thrive when the interactions among researchers are meaningful and functional, and are necessary to accomplish the work. We should turn to each other to explore ideas and get feedback on answers to questions. Meaningful connections must extend throughout the entire research community—among students, postdoctorate fellows, faculty, and staff. Participation in well-functioning cooperative groups supports individual confidence and fosters positive feelings about the research, as well as the individual's role.

For teams to be successful, all members must contribute. Bringing people together merely to fulfill proposal requirements is akin to bribing people to work in groups. The motivation must be an interest in the opportunity to collaborate and learn from each other, and to break out of the traditional individualistic competitive research framework. This requires that all members value the unique contribution of other team members and recognize that intellectual growth stems from relationships between all group members.

Inclusive environment. Research communities succeed when the diverse backgrounds and experiences of participants are welcomed in such a way that they help to inform the group's collective research. Group members need to reach out and connect with others from backgrounds different from their own. There is empirical evidence that a variety of perspectives can stimulate idea production, and that group heterogeneity contributes to this enhancement of group creativity. While there are potential downsides to very diverse groups (such as communication issues or lower performance in the early stages of group work), teams that learn how to capitalize on their variety of perspectives will likely generate higher-quality ideas.

Developing a diverse group can be difficult, and it sometimes needs to be done intentionally, not only through hires, but also through postdoctorate positions, international collaborations, or partnerships with other institutes.

A few final thoughts on building a quality research community remain. Is there an optimum team size? We need teams that are large enough to effectively divide tasks between team members, but small enough to avoid spending excessive time on group management. However, small groups, such as a faculty member and a graduate student, need not be isolated. They can be part of a research community through participation in conferences, workshops, and larger research teams. The faculty–graduate student model of research has and will continue to advance our understanding of the Earth sciences.

Undoubtedly, teams will evolve and change size to address new problems. They may evolve to become part of a larger network or develop into a research institute that includes partnerships outside of the organization. These partnerships succeed when there is a real need. CIMSS has grown steadily over its more than 25-year history. This growth was not for the sake of growth, but rather filled a need for maintaining current research strengths while growing into a more collaborative research group to support NOAA goals and foster

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new research interests of the principal investigators. Throughout this growth, the expertise of scientific programmers, students, and staff were valued as much as that of the principal investigators and administrators, which is another key to building a strong team.

Finally, easy access to fellow members in a research community is important, and face-to-face discussions help in the sharing process. Good communication is critical to the community's success.

As the field continues to grow and the funding pool continues to shrink, the need for purposeful and productive collaboration rises. We need to reexamine our research communities, find ways to make them more collaborative and more effective, and help them to thrive.

FOR FURTHER READING

Bishop, W. P., 1986: Partnerships in remote sensing: A theme with some examples. *Space Policy*, **2,** 322–341.

Brower, A. M., and K. Dettinger, 1998: What is a learning community? Towards a comprehensive model. *About Campus*, **3,** 15–21.

Carlson, T. N., 2006: Deficiencies in the present funding process in meteorology. *Bull. Amer. Meteor. Soc.*, **87,** 567–570.

Hesse, M., and M. Mason, 2005: The case for learning communities. *Community College Journal*, **76,** 30–35.

McLeod, P. L., S. A. Lobel, and T. H. Cox, 1996: Ethnic diversity and creativity in small groups. *Small Group Res.*, **27,** 248–265.

Editor's Note: *This essay and its companion (on page 634) grew out of a recent meeting grappling with the growth in medium-range forecasts. Such forecasts push the envelope of scientific capabilities as well as require a deeper understanding of the demand for new kinds of meteorological information . . . hence the two-part approach to conveying the discussions on this emerging issue.*

The Future of Medium–Extended-Range Weather Prediction

Challenges and a Vision

BY MICHAEL C. MORGAN, DAVID D. HOUGHTON, AND LINDA M. KELLER

The current challenges confronting medium-to-extended–range numerical weather prediction (NWP) are

1) uncertainties in the model initial state and a characterization of model errors,
2) lack of an understanding of the dynamics of particular phenomena and the limits of predictability, and
3) increased sophistication and specialization of forecast consumers and forecast consumer requirements.

Recognition of the first two challenges is nearly as old as the enterprise of forecasting itself, while the last challenge has emerged more recently. In order to meet these challenges, the enterprise of medium-to-extended–range NWP must necessarily undergo fundamental changes. In this essay, we briefly discuss the challenges currently faced and the advances necessary to meet these challenges. Based, in part, upon a synthesis of discussions,[1] we offer our view of a possible future for midlatitude medium-to-extended–range forecasts.

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Because it is recognized that the NWP problem involves a complex, nonlinear dynamical system of equations whose solution is highly dependent on an imperfectly known initial state and imperfectly known and modeled physics, attempts to quantify both the initial condition uncertainty and model error have remained at the forefront of ongoing research. The need to reduce initial condition uncertainty is clear, as studies have demonstrated that in about a week's time, an entire hemisphere may be affected by a change in the initial model state at a given location. While the structure and distribution of analysis uncertainties remain largely unknown, the use of differences between operational analyses as surrogates for analysis uncertainties reveals, not surprisingly, large differences over data-sparse regions. These differences are due to a combination of factors, including differences in the data assimilation techniques employed, the types and number of observations assimilated, and background fields used in the assimilation.

Characterization of model errors, in particular those associated with parameterized physical processes, also remains an outstanding problem. Parameterized convective processes don't redistribute heat, moisture, and momentum properly and, as a consequence, an upscale growth of forecast errors arises from these smaller-scale, parameterized processes. Even though future higher-resolution models may be able to explicitly resolve convective processes,

[1] The discussions were held during the March 2004 Predictability Workshop at the University of Wisconsin—Madison (http://aurora.meteor.wisc.edu/workshop).

the necessary parameterization of the microphysics within these convective elements will still be prone to errors. Additionally, the dependence of model error on the forecast state must be better understood in order to more fully characterize model error.

Acknowledging the uncertainties in the specification of the initial model state and the errors inherent in NWP leads to the inexorable conclusion that NWP is more than a deterministic problem. A more general view of the forecast problem necessarily treats it as a probabilistic problem whose solution is a specification of a likely forecast state coupled with associated statistics (including the variance, skewness, and kurtosis) of that state. By exploiting the underlying uncertainties and deficiencies in models and analyses, ensemble forecasts are an important tool for the quantification of these various measures of forecast uncertainty. Operational prediction centers, having utilized ensemble forecasts for several years, are now developing objective methods to use these forecasts to improve forecast skill. Advances and challenges in the definition and utilization of ensembles for quantitative use involve many considerations. Foremost is the requirement that ensembles realistically include all model-related aspects of resolution effects and parameterization uncertainty limitations so that ensemble bias is reduced and ensemble spread is increased. To the extent that the quality of ensemble forecasts is improved, a much clearer assessment of the limits of medium-to-extended–range predictability on a range of spatial scales for a number of phenomena will be possible.

With regard to the medium-to-extended–range predictability of phenomena, many issues remain unresolved. These issues include: the predictability of weather regime onsets, downstream development and "second-generation" cyclogenesis, and the role of forcing that is "external" to the midlatitude troposphere (including arctic circulations, organized tropical convection, and stratospheric phenomena) in midlatitude predictability. Aside from the previously mentioned improvements in NWP models, advances necessary for enhancing 1–2-week forecasts of these phenomena include improved observational and monitoring strategies. Ongoing research has revealed the positive impacts of adaptive modification of the observing network to improve forecasts of a particular length in a given region. Indeed, there is evidence that the positive phase of the Pacific–North America (PNA) teleconnection pattern—characterized by anomalously low geopotential heights over the central Pacific and along the southeast U.S. coast with anomalously high geopotential heights over the northwestern United States—is associated with a well-defined, upper-tropospheric precursor. Identification of the origins of that precursor may provide insight into where additional observations might help improve forecasts of the PNA onset, thereby extending medium-range predictability.

Several issues must be addressed for adaptive targeting of observations to be realized operationally. Of fundamental importance are the identification of forecast objectives, measures of improvement of these objectives, and the selection criteria for the types of additional observations to clarify these forecast objectives. It has been shown (e.g., by Rolf Langland) that due to deficiencies in operational data assimilation schemes, assimilation of "good" observations may result in unintended degradation of a forecast, and hence observations beneficial for one user may be detrimental for others. Thus, sophisticated data selection and data impact studies will be required for adaptive observing strategies to become feasible in an operational environment.

Because of the lead time involved in medium-to-extended–range forecasts, development of observing strategies must involve multinational or even global cooperation between government agencies responsible for the provision of data and forecasts. As an example, during periods for which the Asian jet extends across the central Pacific, 3–5-day forecasts over the continental United States may require additional observations spanning central Asia across the North Pacific. This may become even more problematic when considerations of the private sector, which may wish to deploy observations for clients, are accounted for. As John Dutton noted in a *Bulletin* article in 2002, "The reality is that success in seeking individual [competitive] advantage in the provision of weather and climate services would probably ensure the loss of overall community capability and resources." Clearly this effort must be viewed as a community endeavor.

In the future, subseasonal prediction problems will be more commonly characterized as being "probabilistic" or "statistical" rather than "synoptic." Synoptic forecast problems may be identified as those that involve the prediction of individual weather systems and their attendant weather (e.g., providing specific information on the timing of weather systems and, in particular, extreme weather events); while statistical forecast problems are those resolved by prediction of the evolutions of various statistical characterizations of the forecast variables (e.g., mean and variance of temperature at a station or the probability that a forecast precipitation amount will exceed a particular threshold value). This distinction between "synoptic" and "statistical" forecasts has an important impact on how such forecasts of the future will be prepared and disseminated.

In some situations today, a forecaster's assessment of the forecast uncertainty associated with a given weather event is not passed on to the forecast consumer, even though this is potentially valuable information. For example, during winter situations, the precipitation type, amount, and duration are intimately tied to the track and speed of a surface cyclone. A forecaster's experiences and knowledge applied to NWP model output may lead to the conclusion that a particular outcome is highly likely. Until recently, the most likely scenario and associated weather would have formed the basis for the forecast of such an event, while the other possibilities would either have been discussed or clarified. Such a situation is now more commonly resolved by the forecaster describing a subset of the most likely evolutions of the forecast state, and then providing the forecast consumer with the likely weather impacts of each evolution.

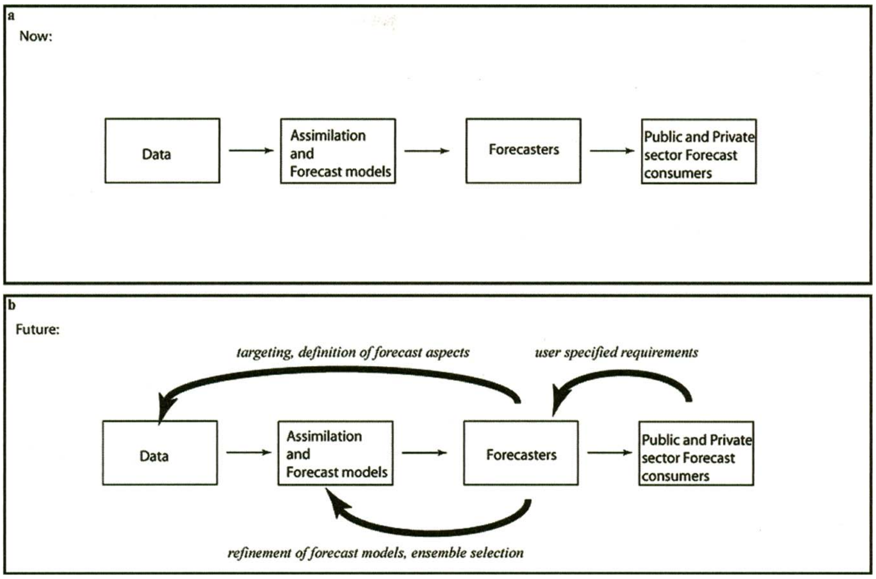

Fig. 1. Schematic showing (a) current and (b) future flow of data and information in the forecast process.

At present, the ensemble of NWP model outputs available to forecasters is rather limited, and the tools to process this output to develop useful descriptions of the scenarios are rudimentary. Both of these limitations again suggest the need for improved ensembles to more clearly discriminate between forecast scenarios. Additionally, though, it is necessary to develop techniques to use ensemble output to define a set of probability-ranked forecast scenarios with probabilities also attached to the concomitant (sensible) weather associated with each scenario.

As pointed out by Dutton, modifications to the forecast system infrastructure will likely be required. At present (Fig. 1a), the one-way flow of data (largely from fixed, ground-based observational networks) and information in the forecast process is insufficient to meet the needs of increasingly sophisticated forecast users and is inadequate for providing data-enhanced targeted observing/forecasting strategies. The flow of both data and information in future NWP systems will be multidirectional (Fig. 1b), with the deployment and distribution of targeted observations determined by user-specified forecast objectives. In this future system, the forecast consumer's needs drive modifications to the forecast infrastructure, with the expertise of the forecaster serving these needs. The forecaster acts as an engineer, routinely and directly altering the observing network and modeling infrastructure by dynamical and synoptic user-motivated interventions.

To meet the emerging challenges of medium-to-extended–range forecasts, undergraduate and graduate students as well as members of the operational community will need further training. This training would include such traditional areas as probability and statistics theory and also more nontraditional areas such as data assimilation, adjoint techniques, ensemble generation, and perhaps visualization and interpretation of large datasets (in anticipation of the vast amount of model output likely to be produced in the coming years). Finally, forecast users will need additional training to better understand how forecasts can be used.

In conclusion, major changes in the techniques, applications, and management for medium-to-extended-range weather forecasting are anticipated. Collaboration among the research, operational, private, and user sectors will be essential for moving forward in the most effective way. This will require effective two-way communication and understanding among these four sectors.

FOR FURTHER READING

Dutton, J. A., 2002: Opportunities and priorities in a new era for weather and climate services. *Bull. Amer. Meteor. Soc.*, **83,** 1303–1311.

The Future of Medium–Extended-Range Weather Prediction

User Perspectives

BY LINDA M. KELLER, DAVID D. HOUGHTON, AND MICHAEL C. MORGAN

Along with the increased skill of the short-term (1–3 day) weather forecasts, the prospects for accurate 3–14 day forecasts have improved, thereby opening up new possibilities for forecast users. In the United States, the National Weather Service (NWS)'s Hydrometeorological Prediction Center (HPC) currently provides forecast products and guidance for the 3–7-day range, including maximum and minimum temperature, surface circulation and fronts, and precipitation probabilities, while the NWS Climate Prediction Center is responsible for longer-range forecasts such as the 6–10- and 8–14-day probability outlooks for temperature and precipitation. The potential and current uses of these products for agriculture, aviation, utilities, and commodities are numerous, but can only be fully and productively realized if the economic, educational, and decision-making needs of specific users are taken into account. Discussions of user needs with our colleagues have yielded an outline of some of these opportunities and challenges of medium- and extended-range forecasts.[1]

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EXAMPLES OF USER PERSPECTIVES. *Agriculture.* Both crop and livestock producers are heavily dependent on short-term forecasts (< 1 day). However, longer-term forecasts of temperature, precipitation, solar radiation, and humidity are also useful for a variety of reasons. For example, pest, fungus, and mold outbreaks in crops are modulated by temperature and humidity, and having sufficient moisture for crops may require irrigation. Conditions favorable for such disease outbreaks or water shortages develop over a period of days to weeks and can devastate a crop if mitigation is delayed. Crop and soil moisture models are becoming more common and require accurate forecasts of specific meteorological variables. Most of the forecast variables are available as gridded fields from the NWS National Digital Forecast Database, but some information, such as solar radiation, while calculated by forecast models, is not output for use in other models. An understanding of input variables for specialized agricultural models, for example, would indicate which variables should be saved as model output and provided to users.

For planting and harvesting concerns, forecasts during spring and fall are more important than summer forecasts due to the increased variability of temperature and moisture during these seasons. For example, as the growing season draws to a close, the

[1] These points stem from a March 2004 Predictability Workshop at the University of Wisconsin—Madison (http://aurora.meteor.wisc.edu/workshop).

concern is whether crops need to be harvested early due to cold temperatures or can stay in the fields several more days. Exact timing of the first frost is crucial, and accurate forecasts several days in advance can make a huge difference in saving a crop.

Livestock producers have other concerns. Their operations are heavily regulated to control dust and odor. Daily-to-weekly wind and humidity forecasts are needed to determine when manure can be spread without causing odor or dust problems for neighbors. In addition, state laws may limit manure application when there is a chance of rain or when the ground is frozen. Laws are written without a good understanding of forecasting products and their reliability. For example, if manure may not be applied when there is a 40% chance of rain in the next 2–3 days, who provides the official prediction—the National Weather Service, a private forecasting company, etc.? Not only are accurate forecasts needed, but forecasts that are downscaled to specific sites or areas are also needed. If it rains on the verification location, but not on a producer's field, can the producer be charged with violating the law? Producers may need to keep a log of their own weather observations, although questions of accuracy would still need to be settled.

Aviation. The main concern is with flight safety. Aviation operations need hourly forecasts to keep up with changing conditions. Another critical aspect is the scheduling of passenger flights. Three-to-seven day forecasts for major events such as a winter storm are needed to determine how many seats to make available for sale, taking into account the possible load levels for extra fuel. To deny boarding to ticketed passengers costs airlines goodwill and money, so efforts are made to minimize changes of the load level. Pilots and crews are paid according to the published schedule, so it is important to an airline to limit the number of cancelled flights. Pilot and crew schedules can be adjusted several days in advance, so that planes and crew are not kept waiting at closed airports for hours.

Energy production/utilities. The utilities that produce power as well as utility suppliers (such as natural gas and oil producers) are mainly interested in temperature and wind forecasts. Temperature is the more important factor since either hot or cold extremes result in the need for extra energy. Utilities focus on any condition that could change their load levels. Summer is an especially critical time, when temperatures a few degrees higher than forecast could send the utility into brownout conditions. Utilities can procure extra supplies, while producers can shift supplies to areas of need given enough lead time. It is much better for utilities and their customers to be prepared for the possibility of a brownout than to experience one unexpectedly. Also, if utilities have to buy power on the spot market, it can significantly raise the cost of energy for the customers.

Commodities. Markets for commodities are extremely sensitive to weather forecasts. The markets are more interested in trends in forecasts than the actual forecast details. In particular, the 6-to-10–day period is where most of the energy management decisions can benefit from accurate forecasts. Forecasts of anomalies are important, but the above- or below-normal designation alone does not convey enough information. Commercial interests need to know how much above or below normal the anomalies are expected to be. Changes in both temperature and precipitation relative to earlier expectations have a dramatic influence on agricultural market prices.

As agribusiness firms expand their interests, the need for specialized forecasts increases. Local forecasts for different areas are needed to anticipate spatial price differentials because one area may not be as affected by weather extremes as another. In addition, there is an increasing need to acquire weather data and forecasts for China and parts of the Southern Hemisphere, for example, as agricultural commodities are now a year-round business with imports from all over the globe. With such widely distributed and specialized interests, many forecast services are being provided by the private sector, but the reference point for products and verification continues to be NOAA.

OTHER CONSIDERATIONS.

Decision-making. Weather forecasts are critical for managing the price risk faced by firms in both energy and agricultural markets. Forecasts can be used as explicit variables in empirical price forecast models or as intuitive input for price analysis. Precise probability assessments are critical in using forecasts for price risk management. Agricultural firms (including food processors) can hedge the price risk associated with uncertain supply by using the futures market for basic agricultural commodities. Likewise, energy markets can hedge the price risk associated with uncertain demand using futures markets for energy.

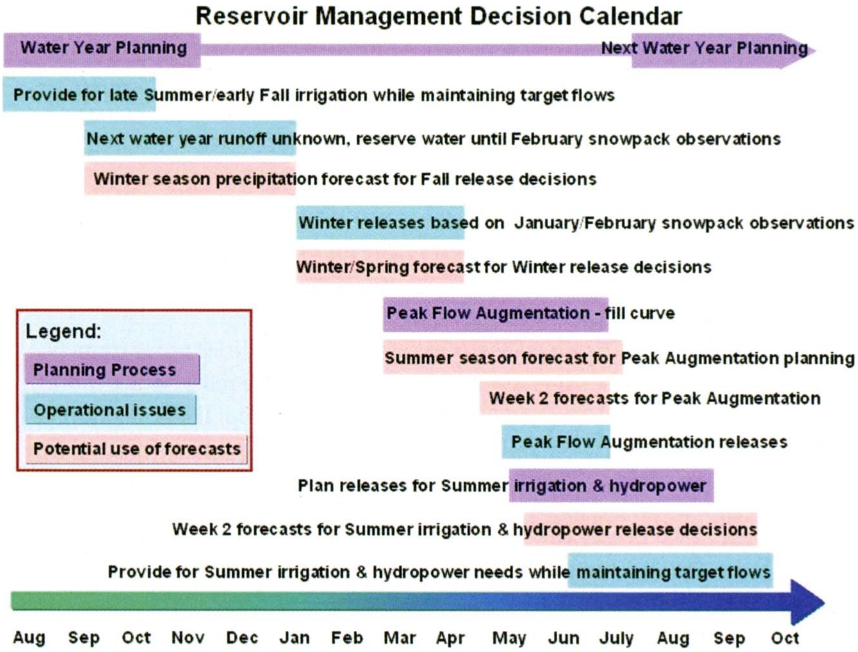

Fig. 1. Example of a risk-management model used in decision making for reservoir management (after Ray 2004).

Risk-management models are useful for decision making. In regions with precipitation confined to one season, for example, water-resources management involves adjusting reservoir levels to maximize water available for irrigation and hydropower while minimizing the potential for flooding (Fig. 1). Two-week forecasts would help manage the reservoir levels based on forecast inflow from the watershed and forecast water usage.

Another kind of risk-management model is a cost/loss or value model. This kind of model assigns a value to success, failure, and false alarm based on the cost of following the forecast or doing nothing. Assessing the value of a forecast in this way allows the user to make decisions that will minimize the cost or loss. The usefulness of this kind of model depends on the experience of the user. If false alarms occur too often, an inexperienced user may not trust the forecast and the decisions indicated by the value model. An experienced user may realize the limitations of the forecast and/or forecast model in certain situations and make that part of the decision-making process.

Another aspect of decision making is determining the uncertainty associated with each forecast. In order to convey uncertainty, forecasters first have to define what is uncertain about the forecast for the user. Some users want details of probabilities for specific areas and time frames. Others are content with general statements or best-guess information. The forecaster also has to decide whether the uncertainty lies in time/space or intensity/magnitude or both, and how important either of these is to the user.

The biggest challenge when dealing with forecast uncertainty is communicating the details to the users. Alternatives to textual or statistical descriptions to convey the information have been explored by broadcast meteorologists who need to present a lot of information in a short time. An example is the "box-whiskers"-type plot for daily temperatures to give a range of uncertainty (Fig. 2).

Verification. The verification of a probabilistic forecast must be performed in a systematic and consistent manner. The methods and definitions used for verification must be the same across all verifying agencies. In addition, the location and/or spacing of the observations used for verification need to be adequate to represent the scale of the phenomena being forecast. For example, the verification of precipitation requires a denser network of observations than is needed for pressure verification.

One value of verifying a forecast is to enable forecasters to learn from their mistakes. However, depending on the needs of the users, what may be a mistake for one may not be a mistake for another. In another sense, it may be hard to say there is ever a mistake with a probabilistic forecast. Forecasters and users need to clearly understand what is meant by verification and what is used to determine if a forecast verified. Users also need to understand what message the forecasters are attempting to convey in their forecasts and how much confidence they have in the forecast.

Education. Improvements in satisfying user needs are heavily dependent on the education of both the forecaster and the user. One starting point is to talk to the users and find out what kinds of information are needed. Sometimes users are not sure what products they really need until they know what is available. Private forecast services will provide information in a format that their clients can easily use and understand. NWS forecast products may need to be presented in a different way or updated more frequently for users of their information. Products can be developed with user assistance and testing that can eventually become part of the operational suite of information. Communicating with forecasters (i.e., using instant messaging to NWS offices) and providing feedback on specific products and/or forecasts is useful for both forecasters and users.

The NWS Climate Services Division has begun planning to provide more and better information for users of its products. Each NWS regional and field office will provide customer outreach, downscaling for climate forecasts, product and information dissemination, and integration and quality control of surface observations. One goal is to issue routine real-time diagnostic discussions of forecasts. Forecast personnel would be able to direct users to climate information and applications as well as receive feedback on products from users.

The education of a forecast user generally comes from the user's forecast provider. Users of private forecasting services are likely to have training and experience in the use of forecast products, and their forecast provider will assist them in learning how to use the products developed for their specific needs. NWS forecasts are geared to the general public and those operations that do not use private forecasting services (e.g., small farms). The training and education of the users of public forecasts generally falls to the media. A local meteorologist may explain the reasons for certain weather conditions, have a weather-fact segment as part of the forecast, or have a column in the local paper. The Weather Channel performs similar functions for a national audience. In addition, special segments are prepared to explain more general concepts such as long-range forecasting and climate change.

A CHALLENGE FOR THE FUTURE. It will take a great deal of cooperation to optimize the joint role of the public and private weather services in providing medium- and extended-range forecast

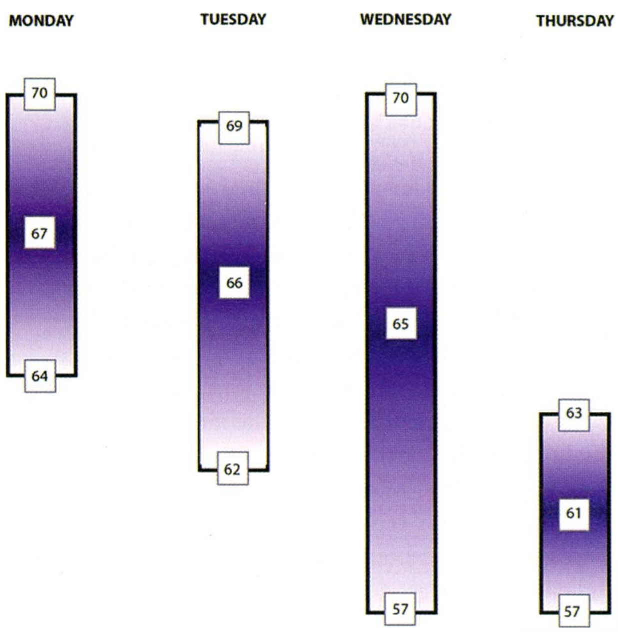

Fig. 2. A "box-whiskers" format for presenting the range of uncertainty in a temperature forecast. The lengths of the forecast bars reflect the possible range of temperatures, while the shading reflects the probability density for the forecast temperature.

information to users. NWS products will remain essential to the private sector. On the other hand, since the NWS is not able to greatly increase the number of observing sites, the localized special observing networks developed in the private sector for specific users could potentially add value to the standard forecast products if the observations are added to the data stream. Sharing of private observational data with the NWS, however, brings a whole new set of questions and concerns. Privately generated data are usually considered proprietary information. If the NWS were allowed to use these data, how would it be kept separate and secure? If the data actually improves the forecasts, does that improvement give a competitive advantage to other private forecasters who did not have to make an investment of time and money to build an observational network? If users switched to other forecasters whose charges were less expensive because they didn't have to make that investment, what happens to the profitability of the forecast services who build the networks? An additional concern is to have a standardized means to certify that the observation techniques meet the same standards required for official NWS sites. While these may be theoretical issues, there is no denying that additional observations, especially in data-sparse regions, are desirable. Public and private forecast services should examine the issues and devise ways to cooperate and to jointly maximize the services to users.

FOR FURTHER READING

Dutton, J. A., 2002: Opportunities and priorities in a new era for weather and climate services. *Bull. Amer. Meteor. Soc.*, **83,** 1303–1311.

Ray, A. J., 2004: Linking climate to multi-purpose reservoir management: Adaptive capacity and needs for climate information in the Gunnison Basin, Colorado. Dissertation, Geography Department, University of Colorado, 328 pp. [Available from A. Ray, NOAA/CDC, 325 Broadway, Mailcode R/CD, Boulder, CO 80305.]

Zhu, Y., Z. Toth, R. Wobus, D. Richardson, and K. Mylne, 2002: The economic value of ensemble-based weather forecasts. *Bull. Amer. Meteor. Soc.*, **83,** 73–83.