J5.7 TOWARD A SCIENCE INFUSION STRATEGY FOR NWS PROBABILISTIC QUANTITATIVE PRECIPITATION FORECASTING (PQPF)

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1. INTRODUCTION

The NWS Strategic Plan (1999) calls for provision of weather, water, and climate forecasts in probabilistic terms by 2005. This constitutes a major change from the traditional, single value or categorical forecast format that characterized NWS operations in the past. Issues related to (1) the generation of numerical weather prediction guidance; (2) its statistical postprocessing; (3) the enhancement of such guidance by forecasters; and (4) the use of such probabilistic forecasts have to be addressed and resolved. The successful implementation of the changes require an NWS-wide concerted effort

Accordingly, the National Weather Service is developing a science infusion strategy to produce probabilistic quantitative precipitation forecast (PQPF) information (and other hydrologic forcing variables) for the Advanced Hydrologic Prediction Services (AHPS) program. The resulting PQPF process will be an integrated system to produce a seamless suite of consistent products for lead times ranging from nowcasts out to a year. The plan will define how different laboratories and centers can work together and with the scientific community to meet these requirements.

NWS short- and medium-range QPF products (e.g. from HPC) have traditionally been single value predictions of the expected amount of future precipitation. Extended- and long-range forecasts (e.g. from CPC) have been expressed probabilistically. Because it is important for AHPS to consider uncertainty in QPF at all forecast lead times from now-casts to one year, new PQPF techniques need to be developed.

To initiate work on the new strategy, on June 3-4, 2002 an NWS PQPF Science Strategy Workshop was held at NCEP. Key participants from EMC, MDL, HPC, CPC and OHD, representing 5 NWS organizations involved in PQPF development and implementation, formed an ad hoc working group and addressed issues related to the optimal development and use of Probabilistic Quantitative Precipitation Forecasts (PQPF).

This paper is a progress report on the development of an integrated PQPF strategy, prepared by the PQPF working group. The plan will describe science issues and strategies identified by the working group as critical for the implementation of an integrated PQPF system, including a verification system that can be used to monitor and manage the PQPF forecast process at all the different NWS Laboratories and Centers involved. This paper reflects current individual views of some of the working group members. It does not present NWS policy or even formal policy recommendations. Its primary purpose is to foster open discussion on topics that should be included in the science infusion strategy so that the scientific community can help NWS make the best possible use of state-of-the-art science. This is envisaged through linkages with the USWRP, the USGCRP and other agencies that can accelerate science infusion from the scientific community into NWS operations.

Though PQPF is the focus of the current document, the methods developed, and the experience accumulated in its implementation process are expected to be readily transferable to issues related to the probabilistic forecasting of other weather, water, and climate variables to fulfill the vision of the NWS Strategic Plan.

2. SERVICE REQUIREMENTS FOR PQPF

Assessment of the integrated PQPF forecast process must start with a preliminary evaluation of the needs of the end users. The PQPF science strategy will be designed to produce products and services for two kinds of users. The first user is AHPS, a user internal to NWS with a range of specific requirements for probabilistic weather and climate forecast information including PQPF. Some external users may also want forecast products produced for AHPS. A second type of user is external to the NWS and simply needs to make a yes-no decision.

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Other weather and climate variables are required for AHPS in addition to precipitation. These are air temperature, potential evaporation and freezing level. The main challenge for this science strategy is to guide a transition from forecasts of the single value / categorical to the probabilistic. The science issues for the transition to PQPF are similar for other weather and climate variables. Since PQPF poses the greatest challenge, it is the focus of this science strategy. Nevertheless, it is expected that appropriate parts of this strategy will also be applied to other weather and climate variables.

2.1 *Probabilistic Forecast Format*

A forecast is an estimate of a variable associated with the future occurrence of an event. In case there is uncertainty in the forecast the future value of the variable is expected to occur over a range of values. All information about the future weather in this case can be expressed only as a probability distribution, specifying the relative likelihood that the observed value will fall in different sub-ranges of the forecast interval. One end result of a complete forecast process is a probability distribution.

2.2 *AHPS PQPF Requirements*

AHPS applications require forecasts not only for a single variable at one point in space and time but for the joint occurrence of several variables over large areas for lead times ranging from less than an hour to as long as a year. Hydrologic forecast systems used in AHPS require forecasts to be in the form of ensembles of values for specific hydrologic sub-areas and for time steps ranging from a few minutes up to 6 hours. The final forecast product that is applied in AHPS is the output of a complex forecast process. How this process should be guided to evolve from its present state to fully meet the needs of AHPS and other users is the main subject of this strategy.

2.3 *An Example to Illustrate the Requirement for Probabilistic Forecasts*

A farmer may need to decide whether or not to protect his/her crop against frost on a particular day. How can such a decision be based on a probability distribution? It turns out that such decisions can optimally be made only on the basis of probability distributions.

A study of the potential economic value of weather forecasts reveals that if the farmer is to incur a certain loss given that adverse weather (temperature below a critical value) occurs should activate some protection against the adverse weather (at a certain cost) if the probability of frost is greater than the ratio between his cost and loss. It can be shown that following this procedure based on probabilistic forecasts will minimize the overall weather related costs over the long run (see, e. g., Toth et al 2002 and references therein). Given a forecast probability distribution, the optimal categorical forecast (yes or no) for the exceedance of the critical temperature will therefore be a function of the user's cost-loss ratio. Even if two farmers use the probability forecast and the same critical temperature value, depending on their different cost-loss ratios one may convert the probability forecast into a "yes", the other into a "no" categorical forecast for the exceedance of the same critical temperature value.

Clearly, a single value or categorical yes-no forecast will be optimal only for users with a particular cost-loss ratio - for all other users, it will be sub-optimal. In their application, probabilistic forecasts, however, can be converted into optimal yes-no decisions for all users, characterized by any cost-loss ratio.

2.4 *Potential Advantages of the Ensemble Approach*

Ensemble based probabilistic forecasts possess two potential advantages over their single value based counterparts. First the mean of an ensemble, in general, provides a better estimate of the future state of a nonlinear system than a single forecast (see, e. g., Toth and Kalnay 1997). This translates into forecasts with less uncertainty (more accuracy). Second, the ensemble based probabilistic forecasts, unlike those based on a single value, can potentially capture case dependent variations in forecast uncertainty.

Consider two probabilistic forecast systems predicting the same expected value. One predicts the same uncertainty (say the probability of exceeding a critical temperature is 20%) every day. The other predicts half the time 0, and the other half of the time 40% probability. Assuming the climatological probability is 50%, the information content of the forecasts from the first system is I=0.28, while that from the second is I=0.52. The
higher information content again indicates less uncertainty (and therefore more accuracy) for the ensemble system.

Recent studies (see Zhu et al. 2002

and references therein) indicate that ensembles generated by Numerical Weather Prediction (NWP) models can successfully capture case dependent variations in forecast uncertainty.

Ensemble forecasts provide a sample of possible future weather scenarios. Depending on the particular application, ensemble forecasts can be used either as "traces", i. e., individual realizations of possible scenarios, or as probability distributions. Some users, for example those generating hydrological ensembles, require the traces that also describe temporal and cross-variable correlations, while others require only the knowledge of the derived probability distribution. Note that ensemble forecasts naturally contain potentially critical information on the spatial, temporal, and cross-variable structure of events. When the ensemble forecasts are converted into point-wise probability distributions this information is lost unless joint probability distributions are also considered.

The conversion of a finite sample of forecasts into a continuous probability distribution raises some questions. In the conversion process, information given in a sample needs to be interpolated (smoothing) and extrapolated. How such procedures should be optimally carried out as a function of ensemble size needs to be explored.

The ensemble, and the derived single and joint probability distributions can be used to automatically answer practically any question related to the future state of the atmosphere. Estimates can be given not only for simple questions like that about the most likely state of the atmosphere but also for more complex questions like what is the likelihood of the temperature being in a certain range and having no precipitation over a period of time.

3. INTEGRATED NWS PQPF PROCESS

Many activities are linked as part of an integrated PQPF forecast system as is illustrated by the matrix shown in Table 1. The matrix shows that different activities are need to support different PQPF functions (across columns) depending on forecast lead times (rows).

Forecast lead time can be partitioned into 4 categories:

Very short range (0 - 6 hours)
Short range (6 hours - 3 days)
Medium range (4 days - 2 weeks)
Long range (1 month - 1 year)

These suggested time intervals do not define rigid boundaries, but serve only to provide a framework for discussion.

PQPF forecast functions can be organized into 4 categories:

Models -
    including regional and global NWP models, long range climate models and statistical prediction models
Statistical Postprocessor-
    statistical techniques to remove model bias, to improve model resolution and to combine results from different models
Forecaster -
    representing human added value roles
Statistical Preprocessor -
    to remove bias and to meet hydrologic down-scaling requirements

3.1 *Models.*

The PQPF forecast process begins with precipitation forecasts generated by different Numerical Weather Prediction (NWP) models developed by the Environmental Modeling Center (EMC), and operated by the National Centers for Environmental Prediction (NCEP). Traditionally, NCEP have produced a single high resolution “control” forecast depicting a possible scenario for the evolution of future weather. We note that if a series of such forecasts are available with corresponding observations, one can construct a statistical scheme for the bias correction and conversion of such forecasts into a probabilistic form.

Alternatively, an NWP model can generate ensemble forecasts that naturally lend themselves for probabilistic interpretation. Given an ensemble of N forecasts the probability of a weather event forecast by m members of the ensemble can be given as m/N. Probabilistic forecasts, of course, can also be generated through the use of a series of single forecasts and associated verifying observations. In the presence of forecast uncertainties, such a technique, however, will be limited since it disregards the nonlinearities present in the natural system.

3.2 *Statistical Post-processor.*

Probabilistic forecasts based on an ensemble of NWP model runs can potentially serve as an objective guidance for human forecasters. This guidance, however, may exhibit undesirable properties in terms of bias both in the first (expected value) and second moments (standard deviation, or

Table 1 - Elements of NWS PQPF Process

Forecast Period	Models	Postprocessor	Forecaster	Preprocessor
Very short range	MDL/HL	MDL/HL	HPC / WFO	WFO Flash Flood Preprocessor
Short range	EMC	MDL	HPC / RFC-HAS	RFC - ESP: Simplified Ensemble PP SREF Preprocessor
Medium range	EMC	MDL/CPC	CPC/HPC	RFC - ESP: MRF Preprocessor
Long range	EMC/CPC	CPC	CPC	RFC - ESP Probability Shift PP

ensemble spread) of the forecast probability density function (pdf).

These biases are present since neither the NWP model, nor the ensemble techniques are perfect. Statistical post-processing of NWS ensemble forecasts, based on past verification statistics, can reduce these biases. Such post-processing will assure that forecast probability values are statistically consistent with corresponding observed frequency values (called reliability) and that the forecasts attain as much skill in separating in advance events from non-events as possible (called resolution). At the Meteorological Development Laboratory (MDL) techniques have traditionally been developed for post-processing single NWP guidance products. by and new techniques are needed to improve model generated PQPF forecasts.

3.3 *Forecaster*.

Human forecasters add value to QPF forecasts. Man/machine interactive tools are needed to support the forecaster role. Forecasters are located at the Hydrometeorological Prediction Center (HPC), the Climatological Prediction Center (CPC), River Forecast Centers (RFC) and Weather Forecast Offices (WFO).

3.4 *Statistical Preprocessor*.

Local ensemble processing systems at RFC's and WFO's are needed to ingest the PQPF forecast information, do additional re-scaling and downscaling, and provide detailed ensemble forcing data required by local hydrologic forecast procedures. The Preprocessor category represents new activities that must be developed to meet AHPS hydrologic forecast model requirements. Preprocessor techniques may be similar to some of the statistical post-processing techniques used at NCEP.

4. REMAINING SECTIONS OF THE PLAN

The rest of the plan will be prepared during the next several months. The next section will discuss probabilistic forecasting. Then we expect to have separate sections for each of the forecast functions (columns in Table 1) that summarize the current status of the functions, science issues, and opportunities to infuse new science. The sections for each forecast function will cover all forecast ranges. There will be a section on verification will precede a section on priorities and performance measures. Finally there will be sections on training and links to the science community.

Comments are welcome. Please send them to the corresponding author.

5. REFERENCES

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