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INTEGRATION OF METEOROLOGICAL FORECASTS/CLIMATE OUTLOOKS INTO EXTENDED STREAMFLOW PREDICTION (ESP) SYSTEM

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1. INTRODUCTION

The usefulness of utilizing long-range weather predictions for making extended hydrologic forecasts has been the subject of debate among hydrologists for a long time. These predictions are of marginal skill for significant portions of the continental United States, especially at hydrologic-relevant spatial and temporal scales. However, the interest in using monthly and seasonal temperature and precipitation outlooks for making extended hydrologic predictions has increased considerably in the past few years for two main reasons: (1) the prospect exists for improved weather forecast accuracy through enhanced ocean-atmosphere and land-surface coupled models; and (2) for a number of hydrologic applications, even a small gain in forecast skill can potentially lead to a much larger increase in their social and economic value.

The portion of the National Weather Service (NWS) River Forecast System that produces extended probabilistic forecasts of streamflow and streamflow-related variables for periods up to 12 months is called the Ensemble Streamflow Prediction (ESP) system. The ESP creates an ensemble of streamflow traces using multiple years of historical time series of precipitation and temperature as possible future meteorological realizations. These traces are then analyzed statistically to make a probabilistic forecast of any streamflow-related variable. The ESP was not originally configured to handle weather forecasts as input (with the exception of a deterministic short-term precipitation forecast), and a forecaster might assign weights to simulated streamflow traces based on his/her judgment about the similarity between the weather conditions of each historical year and the forecast for the current year. Since such weighting was subjective, it was generally not performed at all. In order to enhance long-range hydrologic predictions through climate forecasts, a methodology was developed in the National Weather Service to facilitate incorporation of climate outlooks into the ESP. The schematic of the new ESP system with integrated weather forecasts is given in Figure 1.

Figure 1. The schematic of the current Extended Streamflow Prediction system

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2. METEOROLOGICAL FORECASTS/ CLIMATE OUTLOOKS USED

The primary weather products of interest for the ESP are long-range probabilistic climate predictions available from the Climate Prediction Center (CPC) of the NWS/National Center for Environmental Prediction (NCEP). These products, released approximately the middle of each month, are monthly surface precipitation totals and temperature outlooks for the next month, and for 13 3-month outlooks (starting with a 2-week lead time, successively lagged by one month each and covering a period up to 13 months in the future). Each forecast includes maps of probability anomalies of monthly/seasonal average surface temperature and total precipitation indicating probability estimates of temperature and precipitation falling within the lower, middle, and upper third of their climatological distributions (below-normal, near-normal, or above-normal category). For more information on these products visit the CPC web page at *htpp://nic.fb4.noaa.gov:80/products/predictions/multi_season/13_seasonal_outlooks/*, or see, for example, O'Lenic (1994).

Since these outlooks are issued with a lead time of approximately 15 days, depending on the ESP run date, they may not be applicable for up to the first 2 weeks of the forecast period. In the absence of probabilistic operational forecasts, and in an effort to provide some type of weather information for that period as well, two additional NCEP products were added. The first one is a 1- to 5-day forecast, made daily at the Hydrometeorological Prediction Center (HPC). Since March 1997, the form of a 1- to 5-day precipitation forecast is quantitative (i.e., amount of precipitation expected in inches previously forecast was issued in categories). A temperature forecast is expressed as maximum and minimum anomalies from a 5-day climatological mean value in degrees Fahrenheit. The products may be found on the following web page: *htpp://www.nws.noaa.gov/fax/nwsfax.shtml.* The second product is a 6- to 10-day outlook of average temperature and total precipitation, issued every Monday, Wednesday, and Friday at the CPC. The current 6- to 10-day average surface temperature forecast is given in one of the following five categories: much-below-normal, below-normal, near-normal, above-normal, and much-above-normal. The precipitation forecast is given in one of the following four categories: no precipitation, below-normal, near-normal, and above-normal (e.g., Van den Dool and Rukovets, 1994, CPC web page at *htpp://nic.fb4.noaa.gov:80/products/predictions/6-10_day/*). Because of their nonprobabilistic format, both products are only a transient addition to the ESP until new techniques for integrating NCEP global ensemble forecasts in the ESP are fully developed in the Office of Hydrology of the NWS (see Perica et al, 1997).

3. METHODOLOGY

3.1 General

Since the basis for this ESP enhancement was the integration of current CPC probabilistic monthly and seasonal climate outlooks, the developed methodology relies upon inputs describing shifts in climatological distributions. It is based on adjusting historical mean areal precipitation (MAP) and temperature (MAT) time series relative to current meteorological forecasts/ climate outlooks before being used as input into the ESP such that their modified marginal exceedence probabilities are consistent with the issued CPC forecasts. The comparison is done at spatial and temporal scales at which weather forecast are issued. What that implies is that, most of the time, only two sets of coefficients (one for precipitation and one for temperature) are needed for an entire ESP forecast area. However, if the forecast area is significantly larger than a few tens of thousands of square kilometers, it may be necessary to perform separate adjustments for two or more subareas.

The assumption was made that the observed and forecast values come from similar distributions. Temperature was modeled as a Gaussian process, and a conditional part of precipitation distribution (i.e., nonzero part) was assumed to be well represented by Gamma distribution. That assumption was tested on 1948-1993 data set from the Des Moines forecast group of the North Central River Forecast Center area. It was showed that, in general, Gamma (two or three parameter Gamma) provided a better fit for 5-day, monthly, and seasonal totals than Weibull or log-normal distributions could.

Because the current CPC temperature (and precipitation) outlooks are conservative, the effect of the forecast in reducing the uncertainty (i.e., distribution variance) is negligible. Therefore, it was assumed that forecasted temperature probability anomalies are reflected only in distribution averages. Differences between forecast-based expected values and climatological averages were used to define adjustment coefficients δ_i:

$$\delta_i = T_{fcst} - T_{hist}$$

where T_{fcst} is a distribution average temperature defined for a forecast relevant for time interval i; and T_{hist} is an average temperature defined from the climatology for the same period. Units of δ_i have to match units in which MAT values are given. These coefficients are to be applied to each climatological MAT value observed during the time period i (where that period may be a 5-day period, a month, or a 3-month period, depending on the weather forecast used.)

Precipitation adjustment was performed in a slightly different manner. Since existing CPC probabilistic forecasts integrate zero and nonzero rainfall, unconditional probabilities were first transformed into conditional using climatological probability of precipitation. Although this transformation is rarely needed for monthly and seasonal data, it is important when dealing with 5-day precipitation totals. Once Gamma distributions were fitted to forecast-based and climatological information, ratios of distribution averages were used as nondimensional adjustment coefficients, λ_i , that were applied to each historical MAP value observed during the time i:

$$\lambda_i = P_{fcst} / P_{hist}$$

where P_{fcst} is a distribution average precipitation accumulation that is calculated based on a forecast applicable for time interval i ; P_{hist} is an average precipitation accumulation defined from the climatology for the area of interest and the same period of time. The difference in the type of adjustment used for MAP and MAT time series is derived from a different nature of the processes. Precipitation adjustment has to preserve a non-negativity requirement for precipitation amounts, while temperature adjustment has to allow for both negative as well as positive temperatures.

In order to incorporate nonprobabilistic 1- to 5- and 6- to 10-day forecasts into the ESP using the methodology developed for probabilistic monthly/ seasonal forecasts, these forecasts had to be transformed into probabilistic statements. This was accomplished by assigning, in advance, a distribution-anomaly number for each forecast category. The assigned numbers equaled the smallest difference between all nonexceedence probabilities in a specific category and a 50 percent nonexceedence probability. For example, for the 6- to 10-day temperature forecast, an "above normal" category defines the range of temperatures with a climatological probability of nonexceedence between 70-88 percent; therefore, the selected distribution shift was 20 percent (difference between the lower limit of the category and median, i.e., 70-50). To account for a "no precipitation" forecast, an assumption was made that it was a "sure event" if a climatological probability of precipitation for a given 5-day period was less than 10 percent, otherwise, a negative 30 percent distribution shift was used. For a 1- to 5-day deterministic precipitation forecast, a given number was treated as expected value of conditional Gamma distribution.

For periods in which different forecasts overlap only the "most accurate" forecast was used to define adjustment coefficients. For hydrologic purposes, the meteorological forecast accuracy was assumed to be a function of lead time and duration of the forecast period such that forecasts of shorter duration and with a shorter lead time were considered to be more accurate than forecasts with longer lead-times and valid periods. In this framework a 1- to 5-day forecast is the most accurate forecast, a 6- to 10-day forecast is more accurate than monthly/seasonal forecasts, a monthly forecast is more accurate than a seasonal forecast covering the same period, and seasonal forecasts are only relevant for a period of time starting at the end of a first-month forecast (seasonal forecast accuracy does not depend on lead time). Finally, if there is a period that is not covered with current weather information, the relevant weather forecast from the previous ESP run is used, provided that it exists and that it is not older than 30 days; otherwise, climatology was maintained. Depending on forecast availability, periods with no forecast may arise at any time, but such periods will occur regularly for ESP runs between the 15th of a month (when new CPC climate outlooks are issued) and the end of a month.

3.2 Algorithm

The first step is to query a file created by a previous ESP run in which forecasts have been updated since the last run. Information available from the file includes meteorological forecasts used to calculate adjustment coefficients, forecast start dates and valid periods, and time series of daily coefficients used to modify MAP and MAT historical time series at the previous ESP run. If such a file does not exist, or if there has been more than one month since the last run, the adjustment coefficients are set to their initial values; otherwise, coefficients that were relevant to a period of time between two runs are moved to the end of the time series and replaced with their initial values. For periods with updated forecasts, new adjustment coefficients are calculated. First, coefficients are defined from 1- to 5-day and from 6- to 10-day forecasts. For a 1- to 5-day temperature forecast, an average of a maximum and minimum 5-day mean temperature anomaly is directly applied to adjust all coinciding MAT data. For a 6- to 10-day period, the temperature forecast is converted into a distribution-anomaly number assigned in advance for each category (as described in section 3.1). Differences between forecast-based expected values and climatological averages are used to define adjustment coefficients applied to modify MAT values. Categorical precipitation forecasts are first turned into probability-anomaly shifts based on anomaly numbers assigned in advance for each category, then averages of conditional forecast-based and climatological Gamma distributions are calculated, and finally their ratios are used as adjustment coefficients that are applied to matching MAP values.

The adjustment coefficients are then defined based on monthly/seasonal climate outlooks. The anomaly forecasts of precipitation are first converted to conditional-distribution probability shifts. Ratios between forecast-based and climatological averages (or differences for temperature) are used to define one monthly and 13 seasonal average anomalies. Starting at the end of the first month, calculated seasonal anomalies are used to define monthly adjustment coefficients. As each month is forecast in three overlapping seasonal forecasts (e.g., February is forecast in December-January-February, January-February-March, and February-March-April), and because it is assumed that seasonal forecast accuracy does not depend on a lead time, the final monthly coefficient is taken as a simple average of three numbers (or two for a 45-day lead-time month). The simple average is selected after testing several alternative algorithms that used all 13 forecasts in parallel, which produced extremely unstable monthly numbers due to inconsistencies in overlapped seasonal forecasts. These monthly adjustment coefficients are applied to coinciding MAP and MAT values. Finally, climatological MAP and MAT time series are modified and written in a file to be used by the ESP.

4. CONCLUSIONS

The methodology was developed for integrating primarily probabilistic monthly and seasonal climatological outlooks into the current NWS ESP system. A reason why nonprobabilistic 1- to 5-day forecasts and 6- to 10-day outlooks were added as well is that, on some occasions, monthly and seasonal outlooks are not applicable for the first two forecast weeks. In addition, 5-day forecasts are believed to be more accurate at spatial and temporal scales relevant to hydrologic applications. To account for their nonprobabilistic format, the developed methodology had to be adjusted. This "modified methodology", as well as the forecasts themselves, should be considered only as temporary for a 1- to 14-day forecast period for two main reasons: (1) the form of available meteorological forecasts already changed or will significantly change in the near future, and (2) there is research underway in the Office of Hydrology/ Hydrologic Research Laboratory with aim toward developing more skillful techniques that will use NCEP ensemble-based products to prepare hydrology-relevant probabilistic quantitative precipitation forecasts. A verification program that will permit the NWS to evaluate the value of using CPC long-term forecasts for hydrologic purposes has been in a test mode since March 1997. The Des Moines forecast group of the North Central River Forecast Center has been the test site for the program, but no evaluation results are available at this time.

5. REFERENCES

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