J2.3 VERIFICATION OF ENSO-WEIGHTED LONG-RANGE ENSEMBLE STREAMFLOW FORECASTS IN THE BLUE NILE RIVER

Mohamed Habib * and Allen Bradley

IIHR-Hydroscience & Engineering, The University of Iowa, Iowa City, Iowa, USA

Mohamed Elshamy and Doaa Amin

Nile Forecast Center, Ministry of Water Resources and Irrigation, Giza, Egypt

1. Introduction

Verification has been of increasing interest to the hydrology research community over the last two decades. Many hydrologists have shown the need of adding verification components to the hydrologic forecasting operational systems (Welles et al. 2007). This paper utilizes verification measures to judge the proposed forecast system enhancements introduced to the Nile Forecast System (NFS). These enhancement include (1) weighting of different members of the long-range ensemble streamflow forecasts using ENSO variations, and (2) data assimilation for the system simulation from which the initial states for the forecasts are taken.

2. Study Area

The Blue Nile River flows from the Ethiopian highlands until it reaches the Sudanese-Ethiopian boarder where Diem, the streamflow gauge used in this study, is located. Blue Nile continues flowing through Sudan until it reaches Khartoum where it is joined by the White Nile to form the Nile River that flows until Egypt. Blue Nile is the main tributary of The Nile River contributing 65-85% to river flow at Aswan, Egypt. A map illustrating the Diem location within the Nile Catchment is shown in Figure 1.

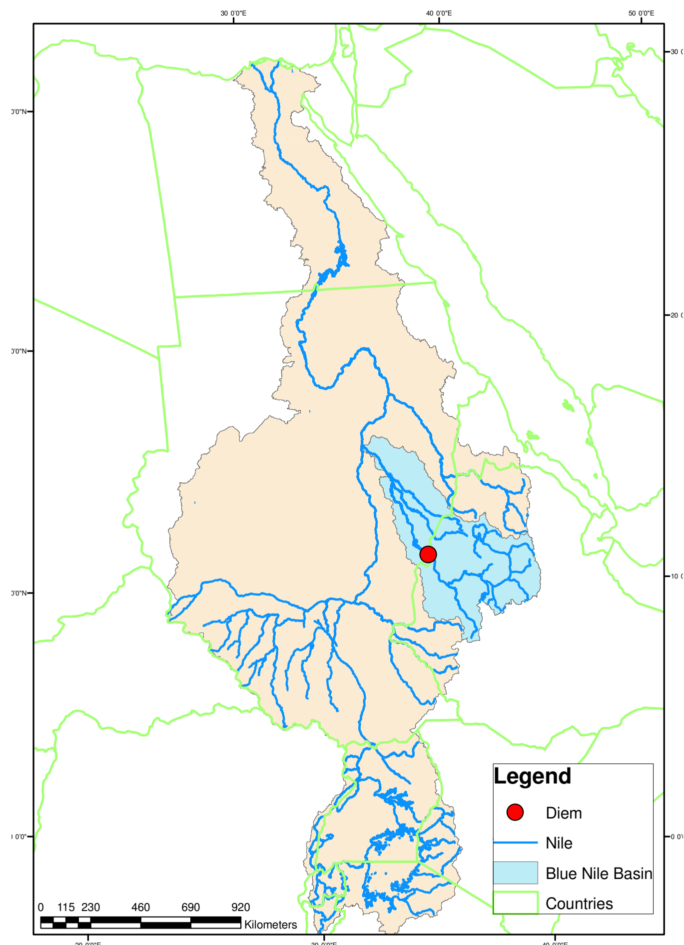

Fig. 1. A map of the whole Nile Basin with the Blue Nile basin in Blue and the Diem station is pointed by a red circle.

3. Nile Forecast System

The Nile Forecast System is implemented at the Ministry of Irrigation and Public Works in Egypt by the National Weather Service. Initial model simulation is used to produce the initial conditions for the forecast system. Data assimilation is then used to enhance the input flow data. Multiple historical weather sequences are used in the system to produce different ensemble members for the forecast. Finally, a long-range ensemble river forecast is produced. Different historical weather sequences are assigned weights depending on the climate information for the historical year relative to those of the forecasted year. A schematic sketch explaining the forecasting process is

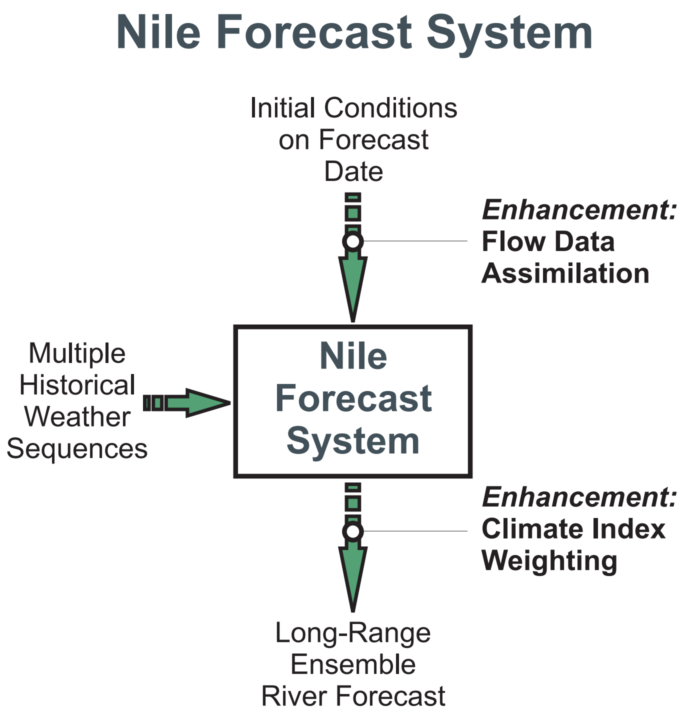

FIG. 2. A schematic sketch for the Nile Forecast System. Proposed enhancements are shown within the whole system.

shown in Figure 2.

4. Experimental Design

a. Retrospective Forecast Generation

The existing operational archive is simply too short for a meaningful verification analysis, so retrospective ensemble forecasting (also known as hindcasting or reforecasting) is needed to generate a suitable verification data set. We generated retrospective forecasts on a weekly basis from 1992 to 2009; the forecasts were then saved for The Blue Nile at Diem where historical stream-gage observations exist. A continuous simulation run beginning in 1988 established initial model states (known as carryover storage) for all forecast dates through 2009. Data assimilation adjustment of model initial states was done for the retrospective forecasts.

Although retrospective ensemble forecasts can accurately simulate the operational components of a forecast system, it cannot faithfully capture the real-time interventions (such as manual adjustment to model states or the interpretation of model output) through which human forecasters add value to the forecast process in real-time. For this reason, the verification data sets generated from retrospective ensemble forecasts mimic closely, but can never fully reproduce the actual operational forecasts that would have been issued.

b. Forecast Processing

The raw ensemble forecasts consist of a set of flow hydrographs, each one generated using the initial conditions valid on the forecast date, and the weather data for the years in the historical record. We then process the ensemble into forecast products for verification. For verification, we gathered all the forecasts made on the same calendar date, resulting in up to 18 unique forecast-observation pairs. The forecast is generated using the weather inputs for 60 years from 1950 to 2009.

5. Baseline Forecast

A well calibrated and validated model is used to produce a continuous record of simulated flows for the starting dates of the forecasts. For each forecast date the meteorological data are saved. These data represent the initial conditions (also called initial states) for the forecasting process. The previously observed weather data (for the same period as forecast period) from each year of the historical record is used as a different scenario to produce different members of the ensemble forecast. Finally, an ensemble forecast is produced with one value as initial flow and multiple flow hydrograph, each representing the different effect on the river flow depending on the weather data of each historical year.

6. Enhanced Forecast Methods

The forecast is produced using the simulated flow produced from the model to account for initial conditions without any modification. One of the enhancement methods of the forecasting system at the initial conditions stage (pre-forecasting) is data assimilation. Another enhancement to the forecasting system, but at the post-forecasting stage, is climate index weighting.

a. Data Assimilation

According to Nile Forecast Center (2007), there are many factors affect the quality of the simulated flows (e.g. poor rainfall estimation, errors in observed data, inadequate model structures, and poor model parameters). The error causing factor changes from one area to another, which makes it impossible to identify which factor needs to be fixed. Therefore changes to one or more variables are performed so the simulated flow matches the observed one. Both magnitude and spatial distribution of rainfall estimates are felt to be the largest sources of simulation errors (Nile Forecast Center 2007). The assimilator is an updating algorithm based on a nonlinear programming technique. It iteratively runs the forecast program and temporarily adjusts the rainfall input and initial state vari-

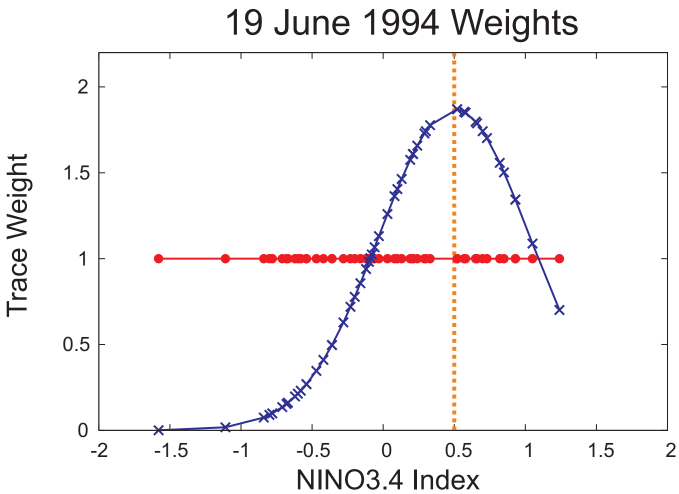

FIG. 3. Baseline forecast has equal weights for each trace. Climate weighting uses the ENSO index at the time of the forecast to assign weights to each trace. Blue curve shows the weights assigned to the different traces, while the red curve shows an equal value. For example: traces corresponding to NINO3.4 of 0.5 will have almost double weight in the climate weighted forecasts versus a single weight for traces in the baseline forecast.

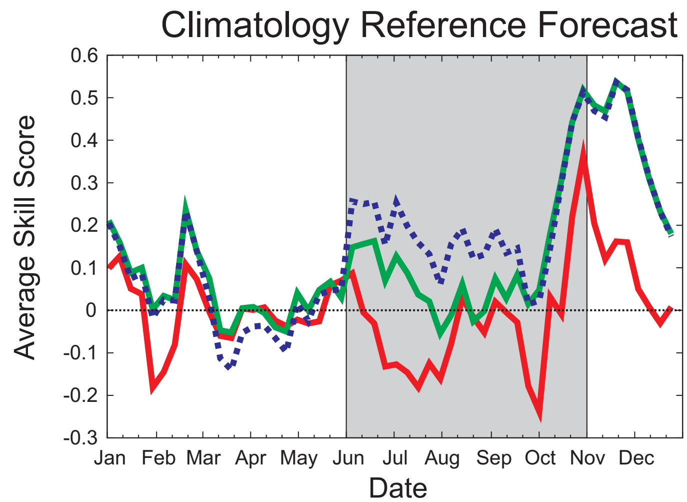

FIG. 4. Average skill score for the 90-day volume forecast issued every week from 1992-2009. Red line represents the baseline forecast, Green and Blue colored lines are for the forecasts that has data assimilation and data assimilation with climate weighting respectively. Shaded area represents the flood season.

ables until weighted differences meet a 25% error criteria. It runs for a simulation period of 28 days and then shifts for a week and adjust the flow for the next 28 days and so on for the whole simulated period. Data assimilation changes mean annual precipitation in order get the simulate flows to better match the observations. The end result is that the moisture state variables to change to better reflect current conditions for forecast simulation. These new moisture states are then used to initialize the forecast.

b. *Climate Index Weighting*

Strong correlation has been proven between ENSO indices and averages of monthly flows in the Nile River at Aswan (Eltahir 1996). In this study, strong correlation is shown between the ENSO indices and the flow in The Blue Nile at Diem. The baseline forecast weights each trace equally. Climate weighting uses the ENSO index at the time of the forecast to assign weights to each trace. Figure 3 shows different weighting schemes for the forecast traces. Flow volumes (90-days) are correlated with the ENSO index (NINO3.4). High flows tend to occur with low index values, which are associated with La Niña conditions. Also, low flows tend to occur with high index values, which are associated with El Niño conditions. After the peak of the Blue Nile flood, flows during the recession are most strongly correlated to flood season ENSO index values.

7. Results of Verification

An average skill score (SS) for the ensemble forecasts, analogous to a continuous ranked probability skill score (Bradley and Schwartz 2009), is calculated for each forecast date using a set of 18 retrospective forecasts for the date from the whole forecasting period (1992-2009). The average skill score shown in Figure 4 as a function of forecast date for the baseline forecasts, forecasts with data assimilation, and forecasts with data assimilation and climate weighting.

The results shows that data assimilation alone significantly improves forecast quality for the Blue Nile issued throughout the whole year (as compared to the baseline forecast), and especially during the flood season and the flow recession after the flood. Climate index weighting with data assimilation significantly enhanced the quality of the forecast more than just data assimilation during the flood season. It is recommended that the climate index weighting component and data assimilation be added to the operational forecasting process, since the quality of the forecast are significantly enhanced during the flood season and the subsequent flood recession, which are the most important periods for forecast use.

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