Verification of Experimental Short-Term Streamflow Ensemble Forecasts Produced by the U.S. National Weather Service

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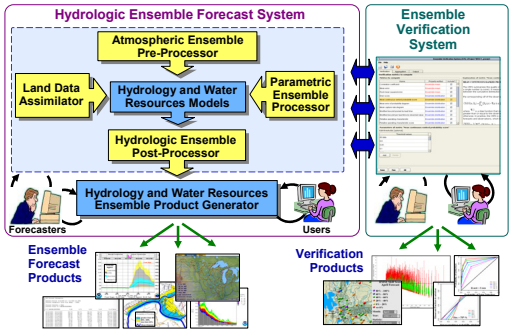
INTRODUCTION

In the National Oceanic and Atmospheric Administration (NOAA)'s National Weather Service (NWS), the River Forecast Centers (RFCs) produce hydrologic forecasts to address a variety of water forecasting needs, such as flood risk management, water supply management, streamflow regulation, recreation safety, and ecosystem management. Such a wide range of applications requires forecasts at multiple space-time scales and for multiple forecast horizons: from minutes for flash flood predictions on small, fast responding, basins to years for water supply forecasts on larger areas.

As challenges in water resources management and risk mitigation continue to increase, the NWS Office of Hydrologic Development, in collaboration with the NWS River Forecast Centers, has been actively developing an experimental capability for **Hydrologic Ensemble Forecast Service (HEFS)** to better quantify and reduce the uncertainties associated with the major sources of error in hydrologic forecasting. The HEFS aims to provide for all forecast horizons uncertainty-quantified forecast and verification products that could be tailored to users' needs. The HEFS uses the NWS's Community Hydrologic Prediction System (CHPS), an open service-oriented architecture that facilitates the incorporation of new models and tools, establishes interoperability with partners, and accelerates research-to-operations transition of new or improved scientific components.



Hydrologic Ensemble Forecast Service in development at the NWS

EXPERIMENTAL ENSEMBLE FORECAST SERVICE (XEFS)

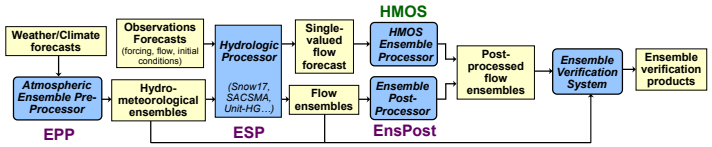
As the basis for the future operational HEFS, **the eXperimental Ensemble Forecast Service (XEFS)** (www.weather.gov/ohd/XEFS) has been developed at OHD to account for all major sources of uncertainty through the following components:

- the **atmospheric Ensemble Pre-Processor** to produce bias-corrected forcing input ensembles for the hydrologic models at the RFC basin scale using available weather and climate forecasts;
- the **land Data Assimilator** component to quantify the uncertainty in the initial conditions of the hydrologic models by ingesting available measurements of land surface states (e.g. soil moisture, snow depth) and initial streamflow among others;
- the **hydrologic Ensemble Post-Processor** that accounts for the residual hydrologic uncertainty and corrects for remaining systematic bias;
- the **Ensemble Verification System** (publicly available at www.nws.noaa.gov/oh/evs.html) (Brown et al, 2010) to evaluate the quality of the forecast ensembles in order to demonstrate improvements and identify the main sources of skill and error in the forecasts (as function of lead time, regime, space and time scale, and other forecast attributes).

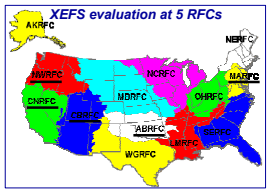
VERIFICATION OF XEFS STREAMFLOW ENSEMBLE FORECASTS

The current XEFS capability uses two different approaches to generate streamflow ensemble forecasts:

- Approach 1 (called **EPP-ESP-EnsPost**) models separately the different sources of uncertainty with 1) the atmospheric ensemble pre-processor (EPP) component (Schaake et al, 2006; Wu et al, 2010) that produces forcing input ensembles, 2) the Ensemble Streamflow Prediction (ESP) component that propagates the input uncertainty through a suite of hydrologic models to generate streamflow ensembles using the current hydrologic conditions, 3) the hydrologic ensemble post-processor (EnsPost) (Seo et al, 2006) that accounts for the hydrologic uncertainty and corrects for remaining systematic bias in the streamflow ensembles.
- Approach 2 (called **Hydrologic Model Output Statistics - HMOS**) (Regonda et al, 2010) quantifies the total uncertainty associated with the single-valued hydrologic forecast while correcting the bias and preserving the skill that is present in the short range operational forecast. Unlike approach 1, approach 2 is simple and parsimonious.



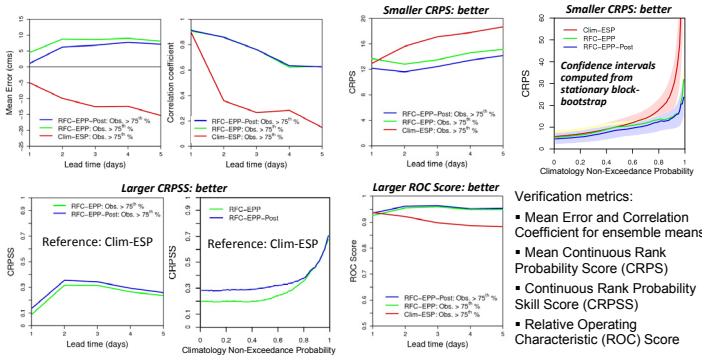
XEFS streamflow ensembles from EPP-ESP-EnsPost and HMOS approaches



The XEFS is currently being evaluated on multiple test basins within 5 RFCs. To evaluate the performance of the two streamflow ensemble approaches, multi-year hindcasting is performed to retroactively produce large samples of EPP-ESP-EnsPost and HMOS streamflow ensembles and verify them with EVS. We present dependent verification results for the North Fork of the American River (NFDC1, 875 km²) near Sacramento, California.

VERIFICATION OF EPP-ESP-EnsPost ENSEMBLES

The EPP was used to produce 6-hr precipitation and temperature ensembles out to 5 days into the future using only the RFC operational single-valued forcing input forecasts. These EPP ensembles were ingested into ESP and EnsPost to generate 6-hr post-processed streamflow ensembles. The resulting flow ensembles ("RFC-EPP-Post") were compared with 1) flow ensembles without EnsPost ("RFC-EPP") to show the value added by EnsPost, 2) flow ensembles generated by ESP from climatology ("Clim-ESP") to show the value added by EPP with the RFC single-valued forcing input forecast. Dependent verification results are presented for the period of 01/01/2001-12/24/2006 for a total of 1920 forecast-observed pairs.



Verification metrics:

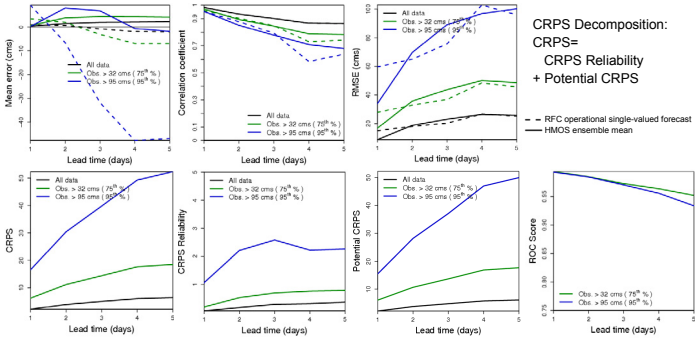
- Mean Error and Correlation Coefficient for ensemble means
- Mean Continuous Rank Probability Score (CRPS)
- Continuous Rank Probability Skill Score (CRPSS)
- Relative Operating Characteristic (ROC) Score

VERIFICATION OF HMOS ENSEMBLES

- The HMOS application models the probability distribution of observed flow at future time steps given the observed flow at the current time step, the RFC operational single-valued forecast, and the Quantitative Precipitation Forecasts (QPF) at different future time steps.
- The distribution is modeled by developing a regression from an archive of single-valued forecast flows and corresponding observed flows, which were pooled together for different flow categories defined from the bias-adjusted flow forecasts and accumulated QPF amounts.
- The regression model is developed for each flow category and for each forecast lead time in the Gaussian space. The regression constant is estimated by minimizing the Mean Continuous Ranked Probability Score (CRPS) in the original flow space:

  $$\text{Observed flow}_t = (1-b_t) * \text{observed flow}_{(t-1)} + b_t * \text{forecast flow}_t + \text{error}_t$$

  where t is time step, b is the regression constant
- For this study, HMOS uses ~1400 observed-forecast pairs at 6-hour interval for five days into future and corresponding QPF values from the period of 01/01/2003-05/15/2009. Flow categories are defined with thresholds of 50th flow percentile and QPF amounts of 0 and 12.7 mm.



CRPS Decomposition:
CRPS=
CRPS Reliability
+ Potential CRPS

CONCLUSIONS & FUTURE WORK

- The EPP-ESP-EnsPost ensembles show significant skill compared to climatology-based ESP (e.g., positive CRPS Skill Score for all lead days), especially for larger events. The gain in skill comes primarily from using EPP with the RFC forecasts.
- In the single-valued sense, the HMOS ensembles show reduced biases, particularly over the first few lead days, and preserve the skill of the operational forecasts. Small CRPS reliability values suggest good calibration of the ensembles. Large ROC Score values indicate good event discrimination.
- Additional ensemble verification is underway on a variety of basins in collaboration with the RFCs and NCEP to evaluate and enhance the XEFS components. The different ensemble forecasting methodologies need to be rigorously inter-compared at multiple space and time domains as new or enhanced observing and forecast technologies and products become available.

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