# Accounting for Uncertainty Propagation: Streamflow Forecasting using Multiple Climate and Hydrological Models

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## Abstracts

Water resources management depends on dealing inherent uncertainties stemming from climatic and hydrological inputs and models. Dealing with these uncertainties remains a challenge. Streamflow forecasts basically contain uncertainties arising from model structure and initial conditions. Recent enhancements in climate forecasting skill and hydrological modeling provide an breakthrough for delivering improved streamflow forecasts. However, little consideration has been given to methodologies that include coupling both multiple climate and multiple hydrological models, increasing the pool of streamflow forecast ensemble members and accounting for cumulative sources of uncertainty. The approach here proposes integration and coupling of global climate models (GCM), multiple regional climate models, and numerous hydrological models to improve streamflow forecasting and characterize system uncertainty through generation of ensemble forecasts.

**Keywords : Ensemble Streamflow Forecast, GCM, Uncertainty, Rainfall-Runoff Model**

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## 1. Introduction

Water resources planning and management efficacy is subject to capturing uncertainties stemming from climatic and hydrological inputs and models. Accounting for and properly dealing with these propagating uncertainties remains a formidable challenge. Streamflow forecasts fundamentally contain uncertainties arising from assumed initial climatic conditions, model structure, and modeled processes. While streamflow forecasts continue to play a pivotal role in resource and economic planning by refining process models (e.g. crop, water resources, economic), quantifying the associated uncertainties is critical for climate risk management, and may posses equally significant implications for basin management.

Approaches to streamflow forecasting predominantly fall into two categories: statistical or dynamical (climatic-hydrological model integration.) The former frequently utilizes predictors of sea-surface temperature or a related index to directly estimate streamflow through regression techniques (*Souza Filho &Lall 2003*). The second approach seeks to couple climate and hydrological processes by passing downscaled information in an iterative (online) or static (offline) fashion. Although the mechanics differ, forecast uncertainty estimates are achievable in either approach by applying Monte Carlo stochastic

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**** 정회원·서울시립대학교 토목공학과 박사과정 수료·Email: waterboy@uos.ac.kr methodologies to generate forecast ensembles. Recent enhancements in climate forecasting skill and hydrological modeling serve as an impetus for further pursuing models capable of delivering improved streamflow forecasts.

In this paper, a general streamflow forecasting framework incorporating multiple climate and hydrologic models from dynamical and statistical approaches is proposed. The problem setting, including descriptions of existing climate, hydrologic and coupled model systems and processes is initially outlined. Following is a description of the application site chosen and associated data sets employed for demonstration. The proposed forecasting framework is subsequently outlined in detail, followed by results of imposing this framework through a hindcast on the application site. The paper concludes with a summary and discussion.

## 2. Description of Application Siteand Data

### 2.1 Iguatu basin in the Jaguaribe River basin, Brazil

The streamflow forecasting framework proposed, and outlined in the subsequent section, is applied to the Iguatu basin (19,100 km2), which lies within the larger Jaguaribe basin, a 72,000 km2 semi-arid area in northeast Brazil. The city of Iguatu lies at the outlet of this basin on the Jaguaribe River. The basin experiences one rainy season annually, from January to May. During this time, the Atlantic Intertropical Convergence Zone (ITCZ) reaches its southernmost position, lying very near to or over the region, enhancing atmospheric instability and producing precipitous systems. Abnormal latitudinal migrations of the ITCZ are associated with excess (southward) or deficit (northward) rainfall. Previous investigations have firmly established that SST anomaly forcing is the primary factor responsible for the interannual variability of rainfall in northeast Brazil Positive (negative) rainfall anomalies are frequentlyobserved when the Atlantic SSTs are colder (warmer) than normal north of the Equator and warmer (colder) than normal south of the Equator. Droughts also tend to coincide with the El Niño-Southern Oscillation (ENSO) episodes. Slowly evolving SST anomalies, particularly in the tropical oceans, can be predicted with some degree of skill at lead times of several months. Seasonal rainfall forecasts with lead times up to four months are skillful over northeast Brazil (*Sun et al. 2006*).

### 2.2. Application site data

Observed precipitation and streamflow time series exist for the 1912-1996period, although the monthly streamflow record at Iguatu is incomplete. Figure 1 illustrates January-June streamflow at Iguatu (essentially annual) for years with no missing months. Average daily precipitation over the basin is calculated using the Thiessen polygon method. Monthly evaporation is based on climatological values (Basin data acquired from the Planning Study of the Jaguaribe River Basin [COGERH, 1998]).

ECHAM4.5 GCM precipitation data is obtained from the International Research Institute for Climate and Society's Data Library (Roeckner et al. 1996).

## 3. Forecasting Approach and Model Descriptions

This approach proposes the integration of multiple GCMs, RCMs, hydrologic models, and multi-model combination techniques in successive fashion for ensemble streamflow forecasting. The overall framework proposed is presented pictorially in Figure 1. Generally, persisted or forecasted sea-surface temperatures drive GCMs, producing low resolution precipitation that may be downscaled with statistical or dynamical RCMs. Dynamical approaches often require bias correction based on hindcasts and historical observations. If desired, downscaled precipitation (and other climatic variables) may be run through a weather generator to produce an ensemble of plausible scenarios, further increasing the forecast pool. Downscaled precipitation is fed into hydrological models to generate streamflow forecasts, which are subsequently combined to create a super-ensemble for probabilistic evaluation. To impose the framework on the Iguatu basin, a streamflow hindcast is performed over the 1974-1996 period.

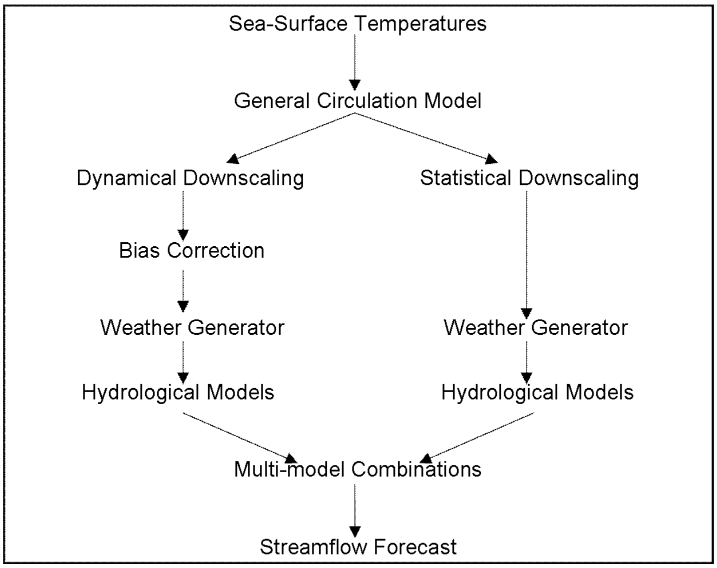
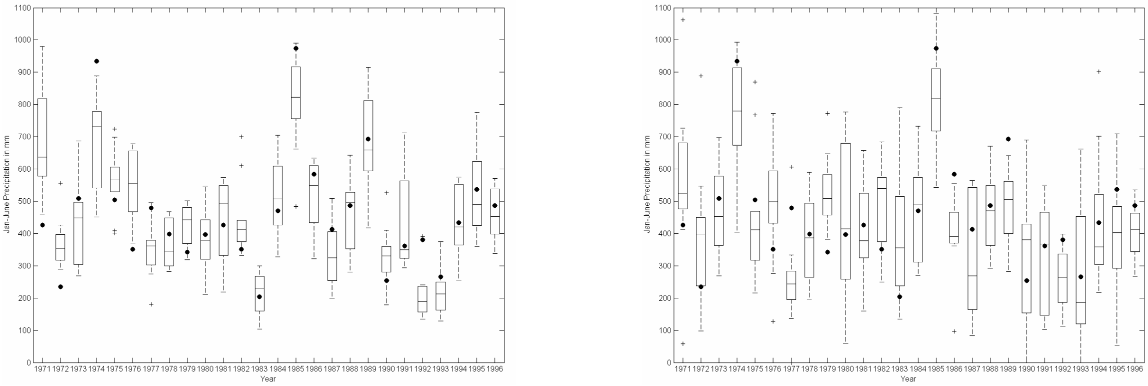


Figure 1: Proposed framework for streamflow forecasting.

## 4. Results and Analysis

This bias correction methodology is fairly effective for the Jaguaribe basin, but some years still indicate insufficient or excess precipitation in comparison to the observed record. Figure 2 depicts box plots of the January-June total precipitation for each corrected ensemble member and the observed record for 1971-1996. While for most years the ensemble members envelop the observed value, as desired, a few years indicate under or over predictions by all ensemble members (e.g. 1974 and 1976) even after bias correction. However, the general wet or dry bias of the RSM model appears to be effectively removed. The correlation coefficient between the ensemble mean and observed precipitation is 0.79; the median RPSS for the ensemble mean equals 0.1, indicating a small improvement over climatology.


a) dynamic downscaling

b)statistical downscaling

Figure 2. Box plots of downscaled January-June total precipitation for 1971-1996. Boxes constructed from all ten bias corrected RSM ensemble members; observed values shown as filled circles.

The SMAP and Sacramento SMA hydrological models are calibrated against 1913-1969 monthly streamflow at Iguatu by optimizing model parameters. The objective function for optimization in both cases centers on minimizing the sum of the squared errors. Initial parameters values for the Sacramento SMA model were taken from *Thiemann et al. (2001)*. Correlation coefficients for the models are nearly identical at 0.90. Monthly time-series (not shown here) also indicate strong correlation, with coefficients at 0.87 and 0.90, for SMAP and Sacramento SMA, respectively.

Coupling the climate and hydrological models, a streamflow hindcast is performed on the 1974-1996 period. Four ensembles of hindcasts (ten members each) are produced by combining the two downscaling techniques with the two hydrological models. Figure 3 portrays results of driving the calibrated SMAP and Sacramento SMA models with the statistically downscaled and bias corrected precipitation ensemble. Streamflow ensembles are displayed as box plots, with the box covering the 25th to 75th percentile; observed values are indicated by filled circles. Coupled model skill scores are reasonably strong, and suggest that the models and precipitation downscaling techniques generally capture the features of the basin. The SMAP coupled models appear slightly superior to the Sacramento SMA models, especially considering the likelihood function ratio and BIC.

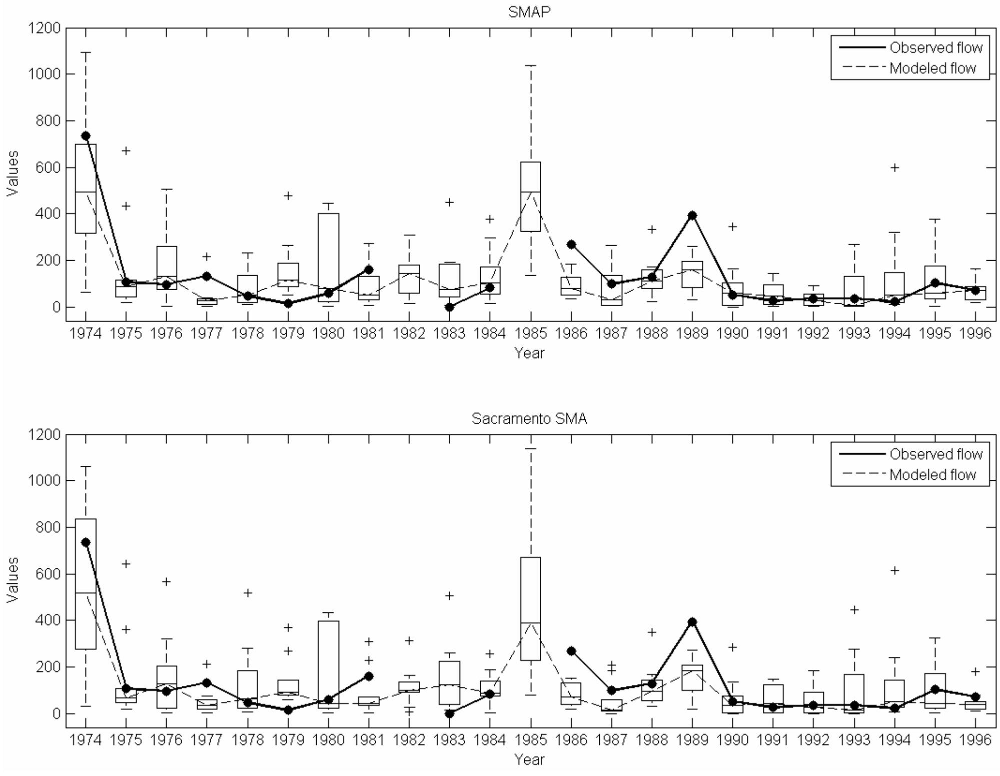


Figure 3. Box plots of statistically downscaled January-June total precipitation for 1971-1996. Boxes constructed from ten downscaled ECHAM4.5 ensemble members; observed values shown as filled circles.

The overall performance of the framework on the Jaguaribe basin appears robust in comparison to similar basin studies. Souza Filho & Lall (2003) construct a semi-parametric streamflow forecast model conditioned on sea surface temperatures, and produce similar skill. Although the framework proposed here is considerably more complex and multifaceted than the semi-parametric model, it does boast sufficient flexibility for improvements at many stages, model substitutions, orother potential lines of analysis.

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## Reference

Roeckner, E., and co-authors, 1996: The atmospheric general circulation model ECHAM4: Model description and simulation of present-day climate. Max-Planck-Institut fur Meteorologie Rep. 218, Hamburg, Germany, 90 pp.

Souza Filho, F. A., and U. Lall, 2003: Seasonal to interannual ensemble streamflow forecasts for Ceara, Brazil: Applications of a multivariate, semiparametric algorithm. Water Resources Research, 39(11), 1307, doi:10.1029/2002WR001373.

Sun, L., D.F. Moncunill, H. Li, A.D. Moura, F.A. Souza Filho and S.E. Zebiak, 2006: An Operational Dynamical Downscaling Prediction System for Nordeste Brazil and the 2002-04 Real-Time Forecast Evaluation. Journal of Climate, 19, 1990-2007.

Thiemann, M., M. Trosset, H. Gupta, and S. Sorooshian, 2001: Bayesian recursive parameter estimation for hydrologic models. Water Resources Research, 37(10), 2521, doi: 10.1029/2000WR900405.