Forecasting Seasonal Hydrologic Response in Major River Basins Under Climate Variations

Tanvir H Bhuiyan[1], Mark N French[2]

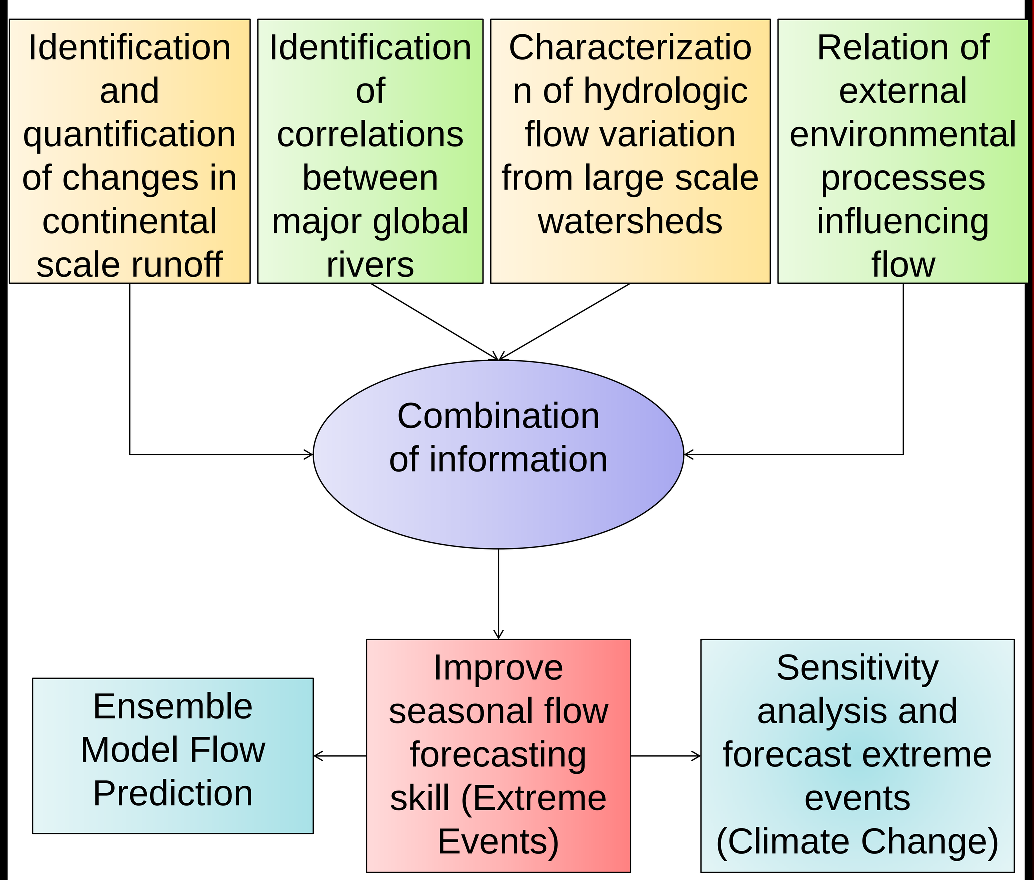
Department of Civil and Environmental Engineering, University of Louisville, Louisville, Kentucky, USA

Correspondence to: Tanvir H Bhuiyan, Email: ahbhui01@exchange.louisville.edu

Abstract

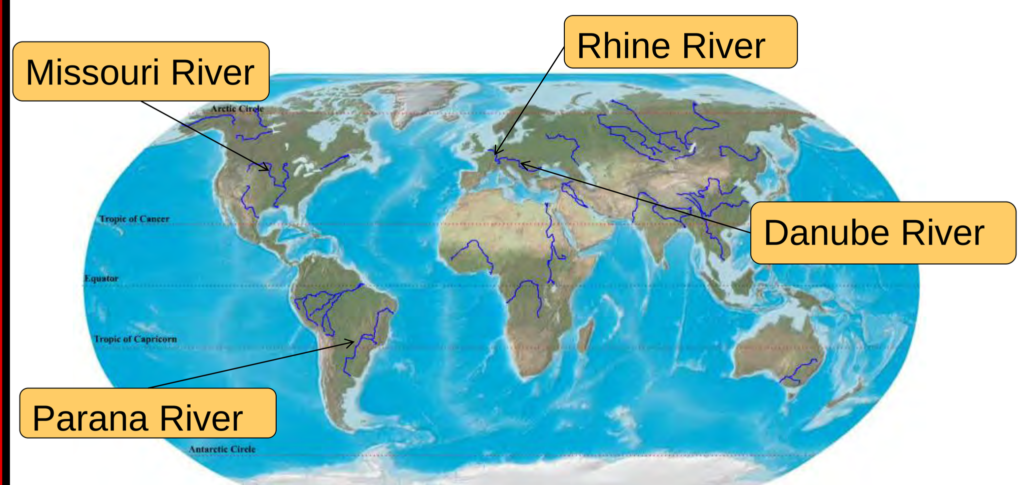
Global climate change has already had observable effects on the environment. Changes include sea level rise, decrease of sea ice, intense heat waves, more frequent temperature extremes, enhanced seasonal precipitation and runoff, reduced dry season precipitation etc. However, under these changing climate circumstances, science projects that these phenomenon will likely increase in frequency and extreme magnitude including events like floods, droughts, cyclone and diurnal temperature variations. Research studies are needed to assess and quantify the historical occurrence context of these extreme events and develop innovative forecasting techniques to reduce adverse impacts on society. Previous studies have focused on developing basin scale hydrologic forecasts models based on climate anomalies such as El Nino, La Nina episodes which significantly influence global climate and as well as annual and seasonal rainfall and stream flow. Specifically, the impact of climate change on streamflow could be significantly modified by anomalies in temperature and rainfall quantity and geographic distribution. This work intends to identify and quantify changes in continental scale runoff and connect with correlations between flows of major rivers globally. The goal is for this information to be used in developing a technique combining flow conditions of major rivers with environmental forcing variables like El Nino, La Nina, sunspot cycle, and others with a view to improve flow forecasting skill. The scale of interest is extreme events such as droughts and floods on a seasonal to annual basis. Additionally, this research will characterize hydrologic flow variation from large scale watersheds and quantify the relation of external environmental processes influencing flow on a seasonal to annual time scales. Preliminary work illustrates the relation among annual, monthly and seasonal flow records of 4 major rivers: Parana, Danube, Rhine and Missouri. The river flows are studied in a seasonal context with the external environmental forcings such as sun spot numbers (SSN) and Southern Oscillation Index (SOI). Initially, the characteristics of each river flow records were identified and analyzed to illustrate the ability of stochastic models to reproduce simulated and forecast historical flow rates. Then relations between continental flows and external climate variables responsible for the changes in flows incorporated. The current work focuses on extreme events and evaluation of response under probabilistic variations in each component of environmental forcing to understand and quantify expected responses to stream flow under climate change scenarios.

Objectives



Data & Methodology

The seasonal data (Winter, Spring, Summer and Fall) of the 4 rivers namely Parana (South America), Danube (Europe), Rhine (Europe) and Missouri (North America) from year 1936 to1979 were used for this analysis.

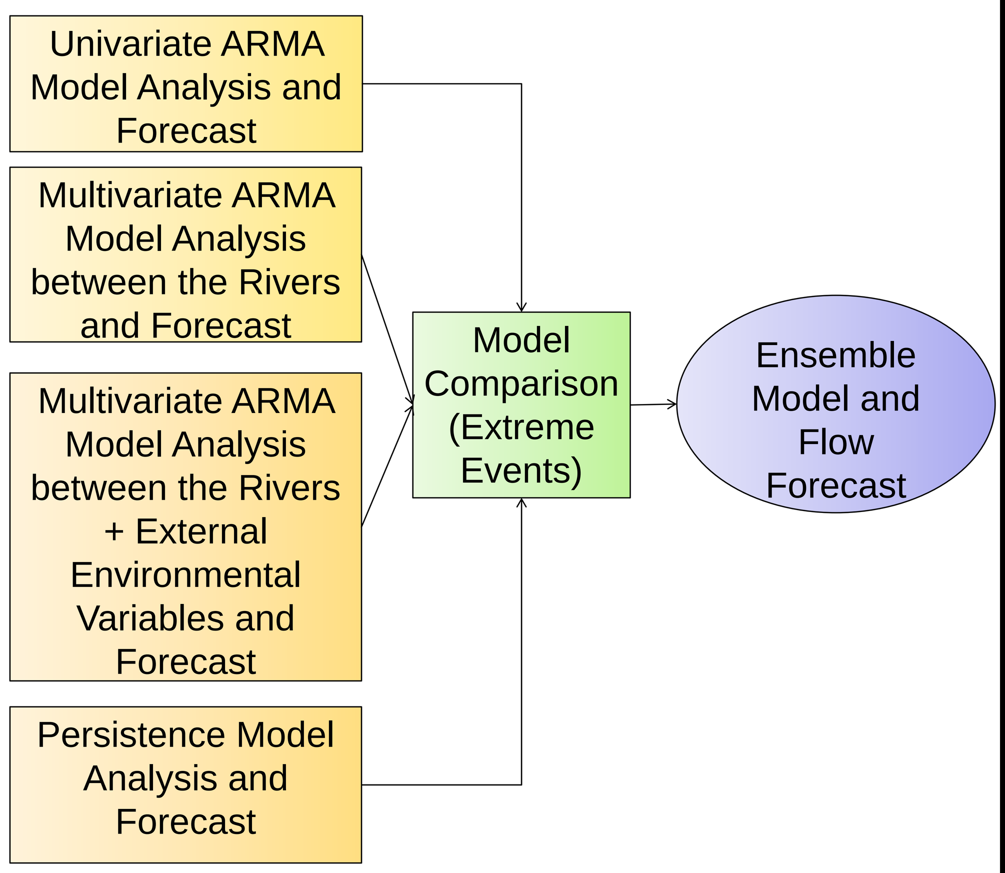


Besides that seasonal Southern Oscillation Index (SOI) and Sunspot Cycle (SSN) were also incorporated as external environmental variables. Autoregressive Moving Average (ARMA) Models of the following variable combinations were used here for forecasting seasonal flows of the rivers:

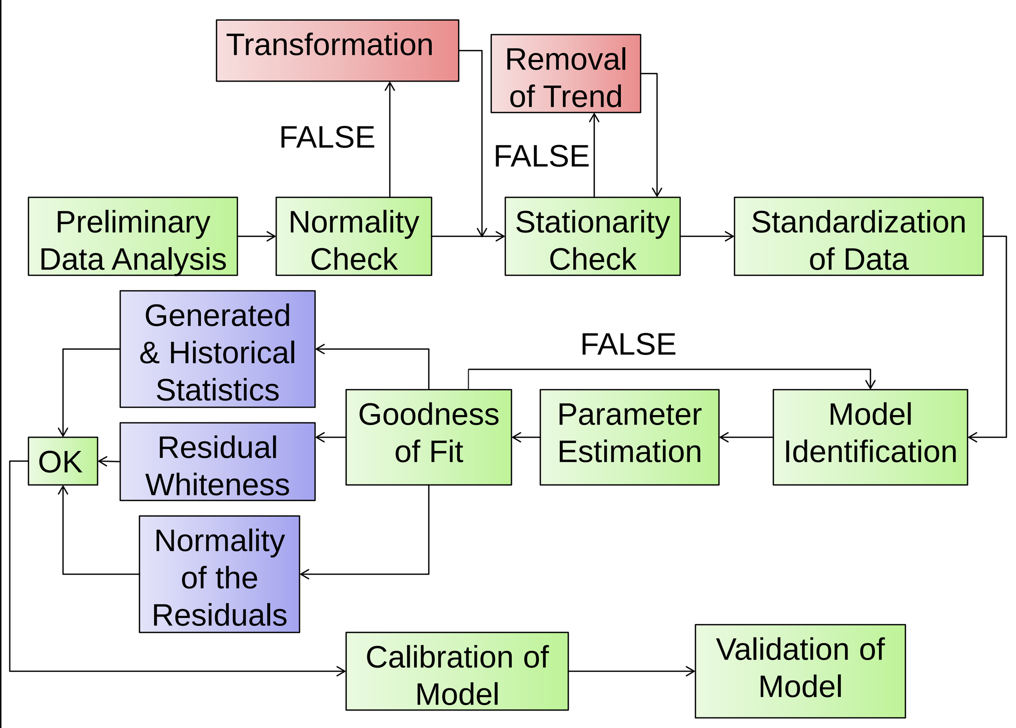
- Univariate ARMA(1,1) Models of 4 rivers
- Multivariate ARMA(3,0) Model with 4 Rivers
- Multivariate ARMA(3,0) Model with 4 Rivers and SOI
- Multivariate ARMA(3,0) Model with 4 Rivers and SOI and SSN
- Multivariate ARMA(3,0) Model with 3 Rivers and SSN
- Persistence Model
- Ensemble Model

The modeling procedures were divided into 2 steps
a. Calibration: 33 years of data (1936-1968)
b. Validation : 11 years of data (1969-1979)

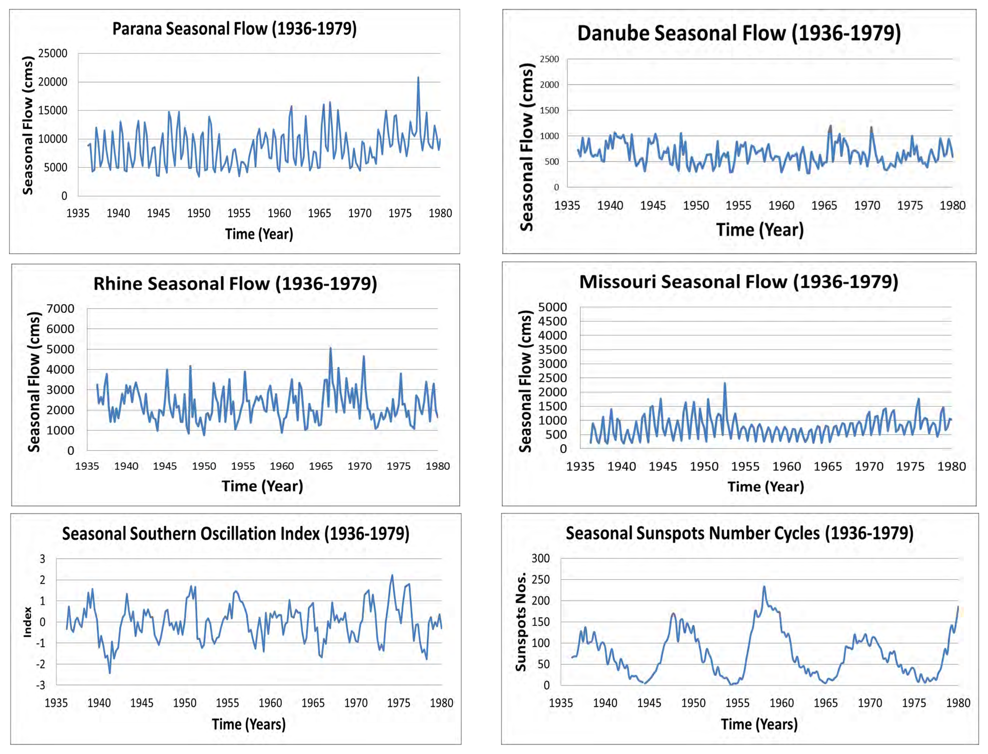
Methodology



Different Steps of ARMA Models



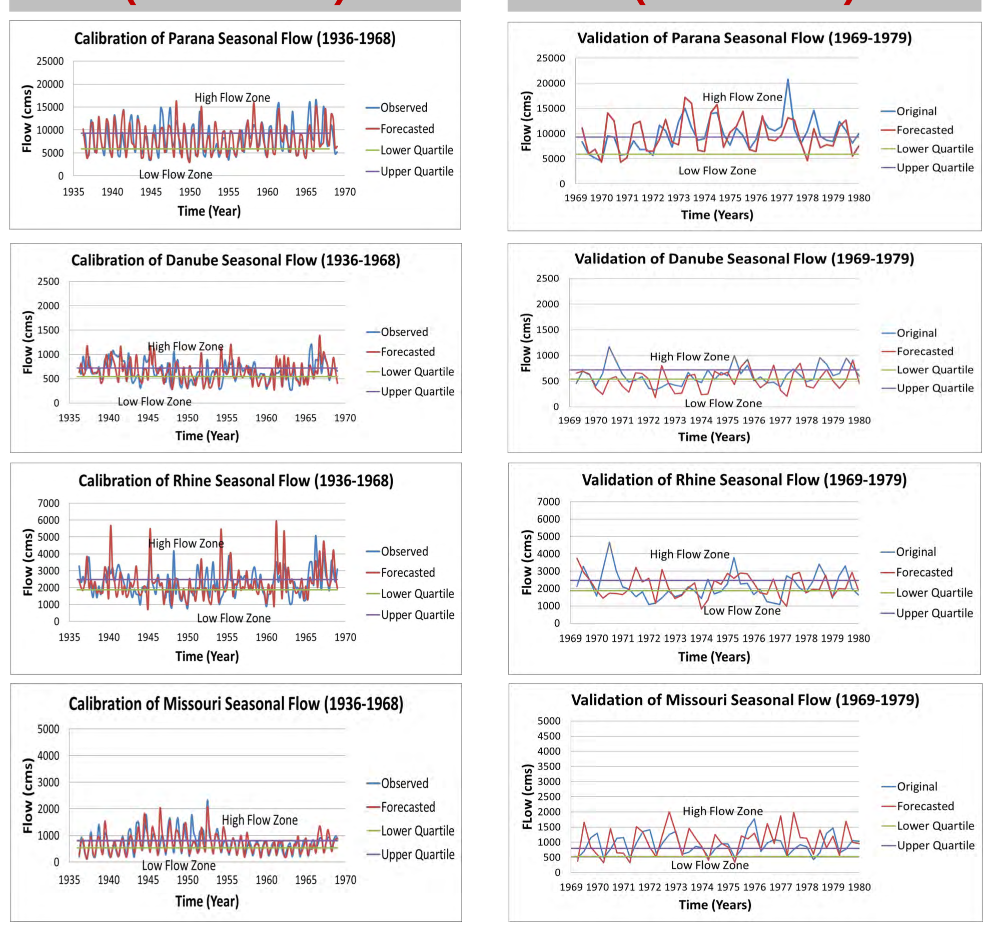
Model Analysis



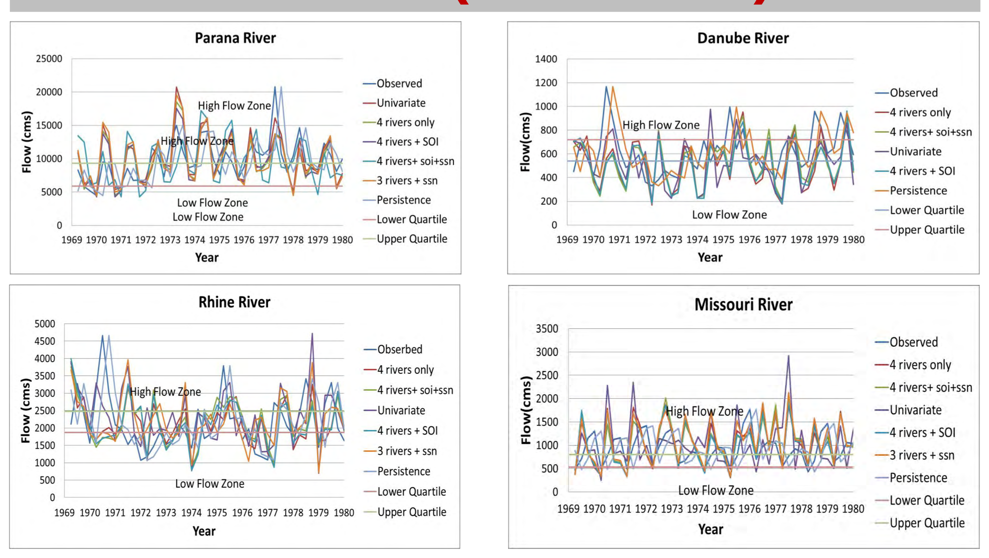
Seasonal Flow Forecasting

The following figures show forecasting with Multivariate ARMA(3,0) model with 4 Rivers, SOI and SSN. All the other model results were also calculated in the same way

Model Calibration (1936-1968) | **Model Validation (1969-1979)**



Comparison of Different Model Results (1969-1979)



Results

Ratios of Standard Deviation

River	Univariate	M. Variate 4 Rivers	M. Variate 4 Rivers + SOI	M. Variate 4 Rivers + SOI + SSN	M. Variate 3 Rivers + SSN	Persistence
Model Calibration						
Parana	0.916	0.972	0.943	0.945	0.951	0.997
Danube	1.151	1.128	1.039	1.066	-	1.004
Rhine	1.232	1.147	1.203	1.212	1.057	1.006
Missouri	1.113	0.982	0.971	0.975	0.988	1.006
Model Validation						
Parana	1.204	1.158	1.124	1.118	1.211	1.024
Danube	1.081	1.146	1.041	1.077	-	1.001
Rhine	1.079	0.851	0.853	0.847	0.908	1.011
Missouri	1.699	1.459	1.439	1.421	1.530	0.999

Results

Pearson Correlation Coefficient

River	Univariate	M. Variate 4 Rivers	M. Variate 4 Rivers + SOI	M. Variate 4 Rivers + SOI + SSN	M. Variate 3 Rivers + SSN	Persistence
Model Calibration						
Parana	0.568	0.514	0.550	0.550	0.536	0.036
Danube	0.178	0.165	0.186	0.201	-	0.125
Rhine	0.166	0.186	0.174	0.182	0.205	0.081
Missouri	0.495	0.533	0.566	0.555	0.534	0.028
Model Validation						
Parana	0.508	0.393	0.419	0.389	0.373	0.133
Danube	0.139	0.075	0.065	0.071	-	0.139
Rhine	0.179	0.007	0.002	0.002	0.013	0.147
Missouri	0.005	0.113	0.092	0.116	0.091	0.022

Flow Categorization and Forecast

River flows below 33 percentile have been used here as an indication of low flow and above 66 percentile have been taken as high flow. Flows in between two limits are categorized as average flow.

Parana River

River	Univariate	M. Variate 4 Rivers	M. Variate 4 Rivers + SOI	M. Variate 4 Rivers + SOI + SSN	M. Variate 3 Rivers + SSN	Persistence
Low Flow Validation (Total: 5 Nos.)						
Correct	2	2	2	1	2	3
Not well picked	3	3	3	4	3	2
High Flow Validation (Total: 23 Nos.)						
Correct	16	16	16	15	14	14
Not well Picked	7	7	7	8	9	9

Danube River

River	Univariate	M. Variate 4 Rivers	M. Variate 4 Rivers + SOI	M. Variate 4 Rivers + SOI + SSN	M. Variate 3 Rivers + SSN	Persistence
Low Flow Validation (Total: 19 Nos.)						
Correct	12	13	12	12	-	10
Not well picked	7	6	7	7	-	9
High Flow Validation (Total: 9 Nos.)						
Correct	4	3	2	4	-	3
Not well Picked	5	6	7	5	-	6

Rhine River

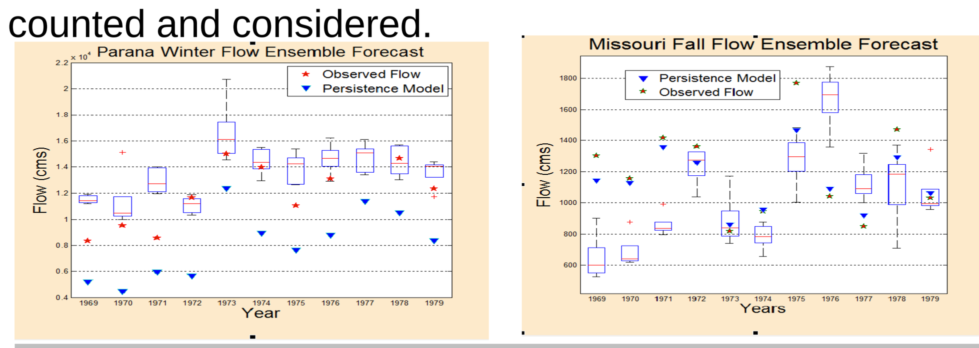
River	Univariate	M. Variate 4 Rivers	M. Variate 4 Rivers + SOI	M. Variate 4 Rivers + SOI + SSN	M. Variate 3 Rivers + SSN	Persistence
Low Flow Validation (Total: 20 Nos.)						
Correct	11	8	8	9	8	11
Not well picked	9	12	12	11	12	9
High Flow Validation (Total: 12 Nos.)						
Correct	7	3	3	4	4	5
Not well Picked	5	9	9	8	8	7

Missouri River

River	Univariate	M. Variate 4 Rivers	M. Variate 4 Rivers + SOI	M. Variate 4 Rivers + SOI + SSN	M. Variate 3 Rivers + SSN	Persistence
Low Flow Validation (Total: 6 Nos.)						
Correct	3	5	5	5	5	0
Not well picked	3	1	1	1	1	6
High Flow Validation (Total: 25 Nos.)						
Correct	15	20	19	22	22	14
Not well Picked	10	5	6	3	3	11

Ensemble Forecast

In ensemble forecasts, the results from different models were combined and quantified in terms of likelihood which allows the variability of different models to be counted and considered.



Future Work

More rivers from different continents and other variables such as precipitation, sea surface temperature etc. will be included in the analysis. Sensitivity analysis due to climate induced changes will be performed to see the accuracy of the models in predicting extreme climatic conditions in river flows such as droughts, floods etc.