Hydrological Ensemble Predictions of The Feilaixia Basin

Aizhong Ye, Feng Ma, Zheng Zhou, and Qingyun Duan

GCESS/Beijing Normal University

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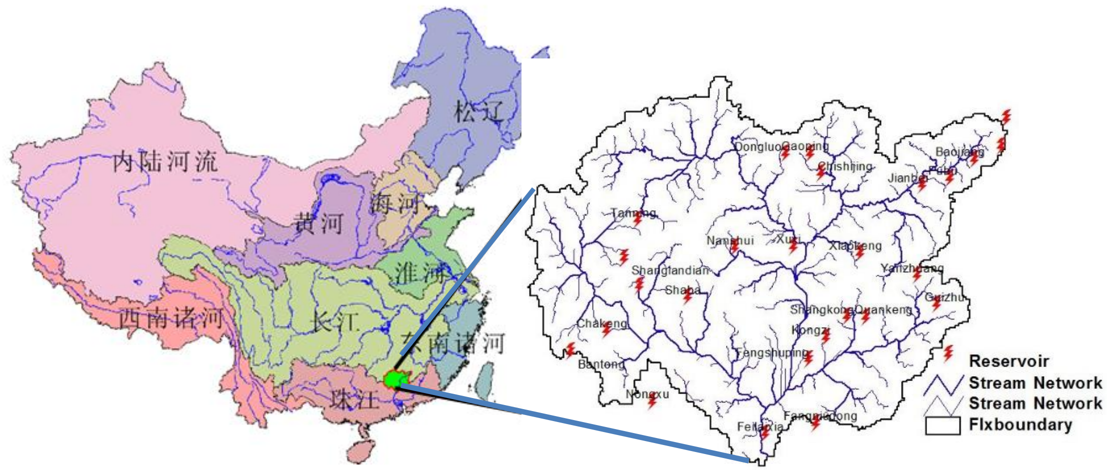
Outline

1. Background
2. Beijing Normal University Hydrological Ensemble Predict System (BNU-HEPS)
3. Hydrologic Ensemble Predictions of the Feilaixia Basin

Background

- Feilaixia Basin, located north of Guangzhou City, suffers from frequent flood hazards
- The basin contains many reservoirs, which play a critical role in flood protection of Guangzhou City
- Accurate and reliable reservoir inflow forecasts critical to the optimal reservoir operations for flood protection purpose

Feilaixia basin



Goal

- To develop a multi-model hydrologic ensemble prediction system which follows the HEPEX framework:

  - Incorporating precipitation and temperature forecasts from numerical weather and climate prediction models

  - Integrating ensemble pre-processing, land data assimilation, parameter optimization and ensemble post-processing

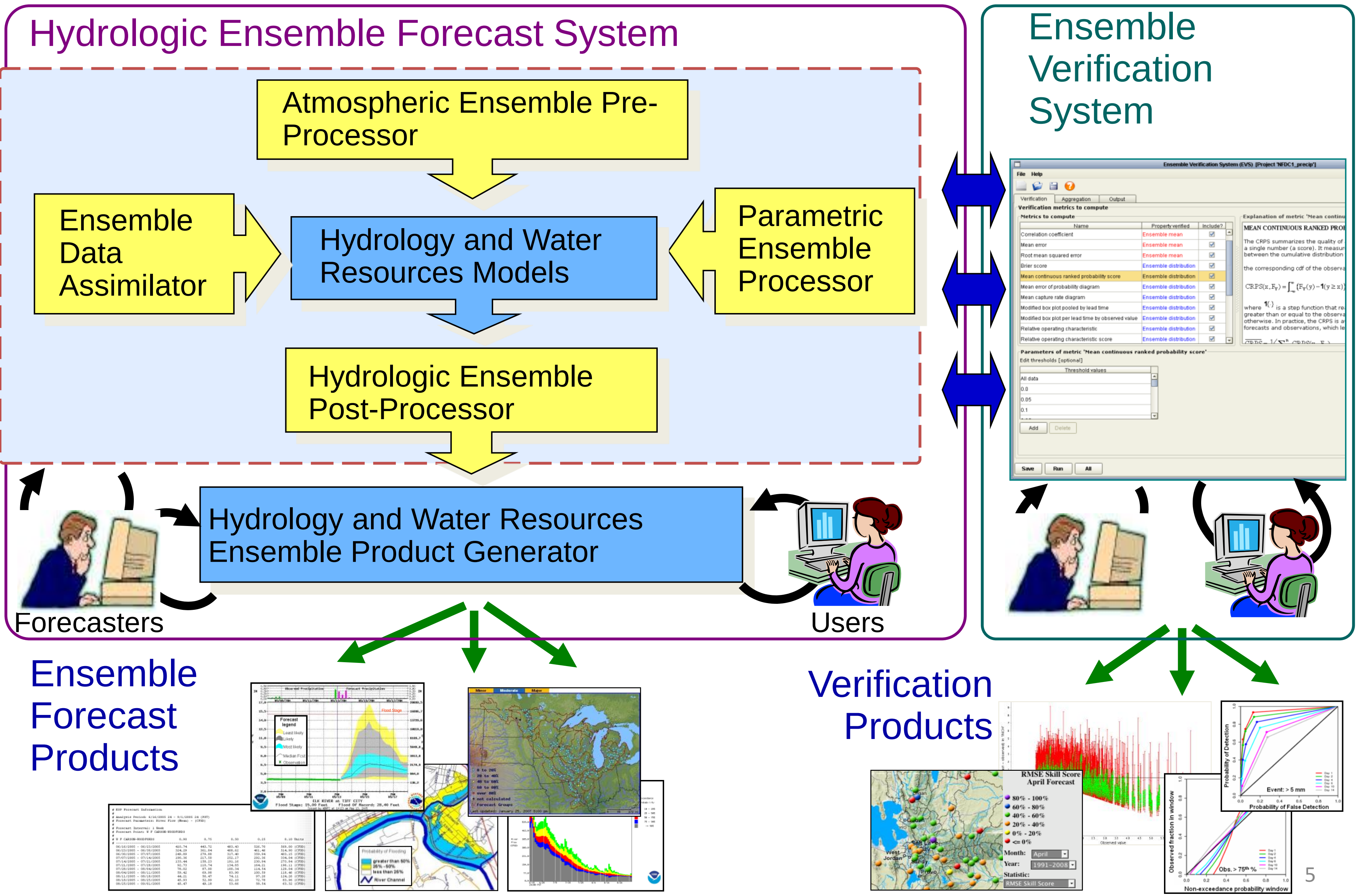
  - Including multiple hydrologic models

  - Ensemble verification

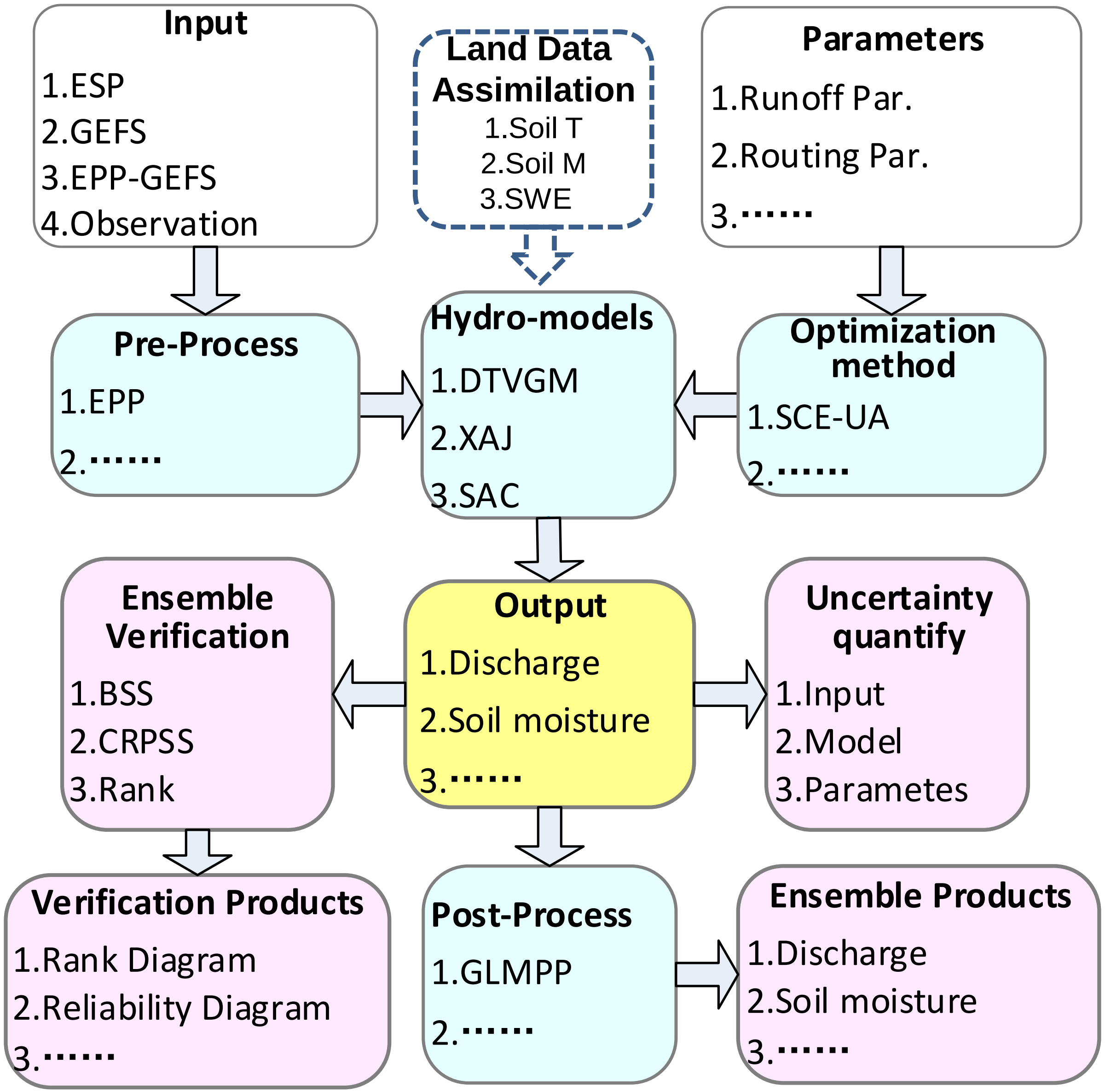
Questions to Be Answered

- How much can we gain from NWP precipitation forecasts over the precipitation climatology?
- How important is pre-processing of NWP precipitation forecasts?
- How much can we gain from multiple hydrological models and multi-model averaging?

The HEPEX Framework



The BNU-HEPS Framework



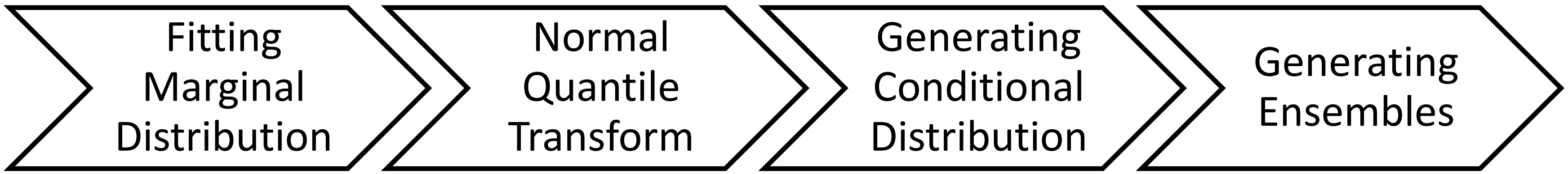
The Ensemble Pre-Processor (EPP)

- **Objective**:
  - To produce reliable and skillful ensemble precipitation and temperature forecasts that can be used to drive hydrological models

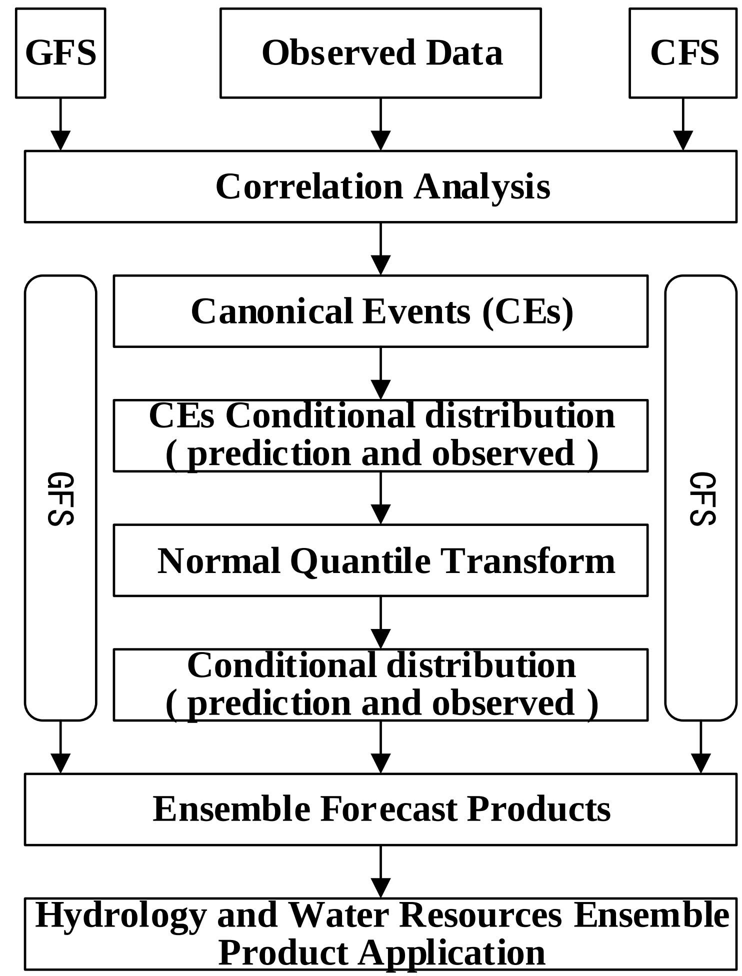
- **Functions:**
  - **Produce ensemble forcing from weather and climate forecasts** (including single-valued QPF, QTF, and ensemble GFS, CFS)
  - **Remove bias** in weather and climate forecasts
  - **Correct spread** problems in meteorological ensembles
  - **Preserve space-time variability** and uncertainty structure
  - **Downscale** meteorological forecasts to hydrological basins

Liu, Y., Q. Duan, L. Zhao, **A. Ye,** Y. Tao, C. Miao, X. Mu, and J. C. Schaake (2013), Evaluating the predictive skill of post-processed NCEP GFS ensemble precipitation forecasts in China's Huai river basin, Hydrological Processes, 27(1), 57-74.

The EPP Methodology



- Step1:
  Fit marginal distribution of forecasts and observations respectively.
- Step2:
  Apply Normal Quantile Transform (NQT) to construct bivariate standard normal distribution.
- Step3:
  Generate conditional distribution of observations corresponding to given forecasts.
- Step4:
  Generate individual ensemble members.



The Distributed Time-Variant Gain Hydrologic Model

Runoff

Water balance:

$$P_i + W_i = W_{i+1} + Rs_i + E_i + Rss_i + Rg_i$$

Runoff:

$$Rs_i = g_1 \left(\frac{AW}{Wum \cdot Cov_j} \right)^{g2} \cdot P_i$$

0<g1<1 0<g2

Soil moisture:

$$AW = \frac{Wu_i + Wu_{i+1}}{2}$$

$$W_i = Wu_i + Wg_i$$

Evaporation:

$$E_i = \frac{AW \cdot Ep_i}{Wum \cdot Cov_j}$$

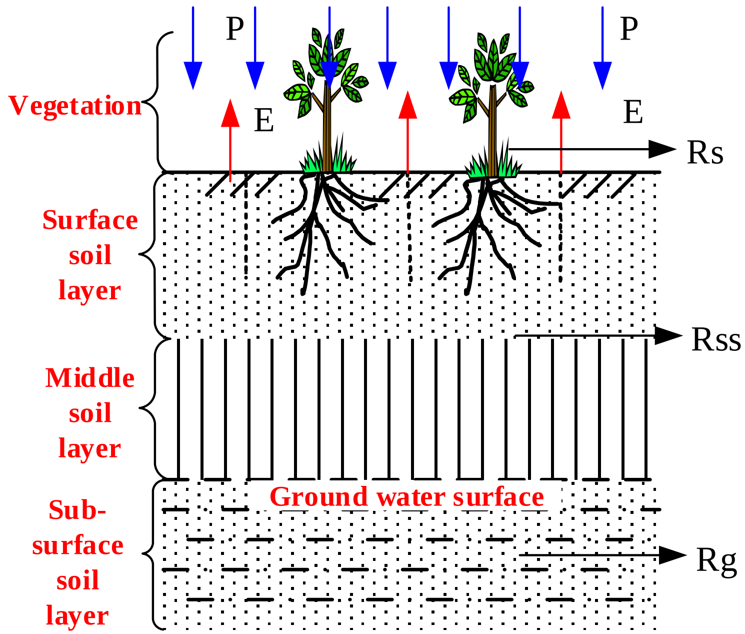
Subsurface runoff:

$$Rss_i = AW \cdot Kr$$

Ground water:

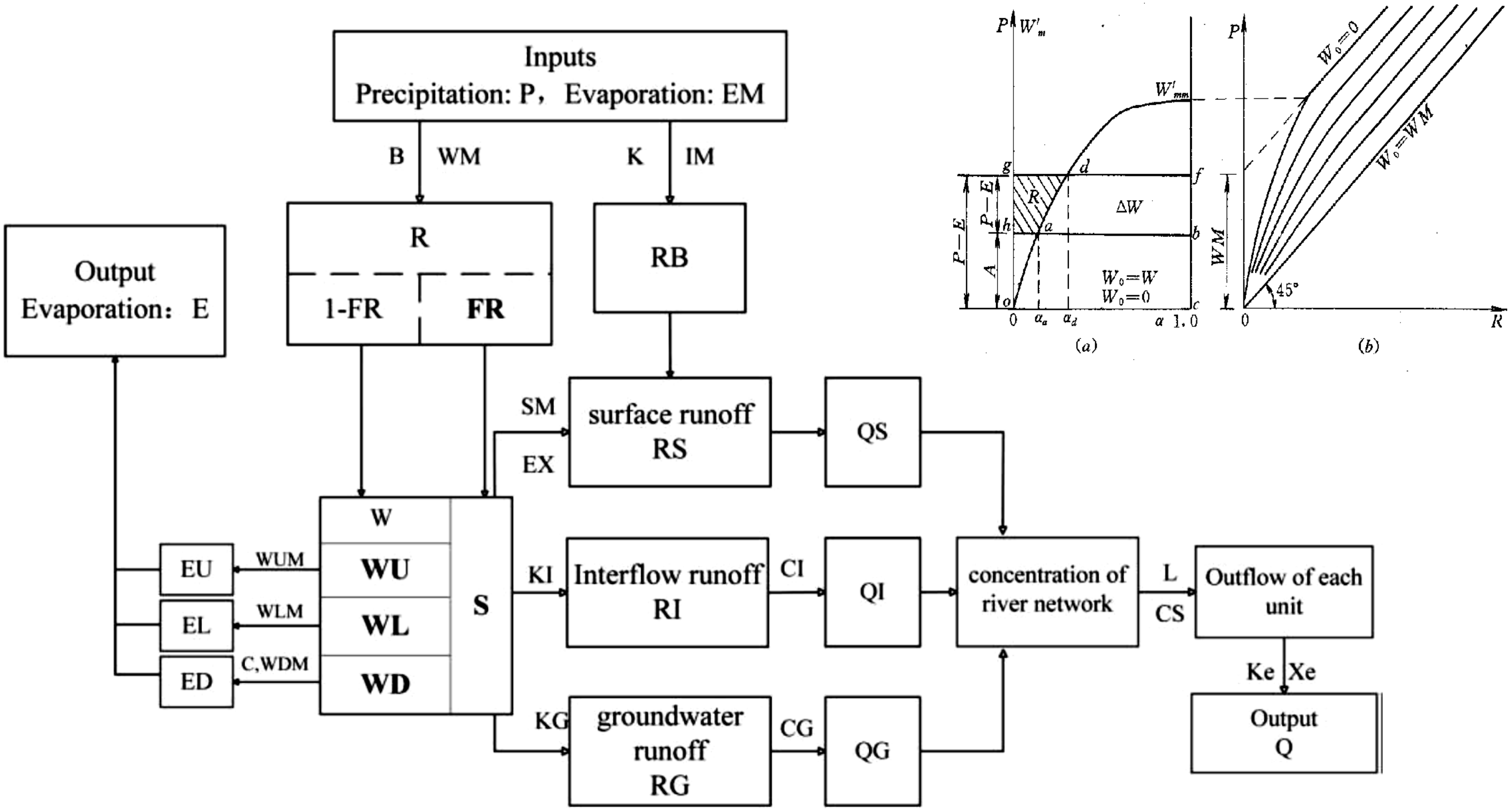
$$Rg_i = Wg_i \cdot Kg$$

$$\begin{aligned} &if\ (W_i > Wgm)\ then \\ &\quad \Delta Wg = Wgm - Wg_i \\ &\quad Wg_i = Wgm \\ &\quad Wu_i = Wu_i - \Delta Wg \\ &else \\ &\quad Wg_i = W_i \end{aligned}$$



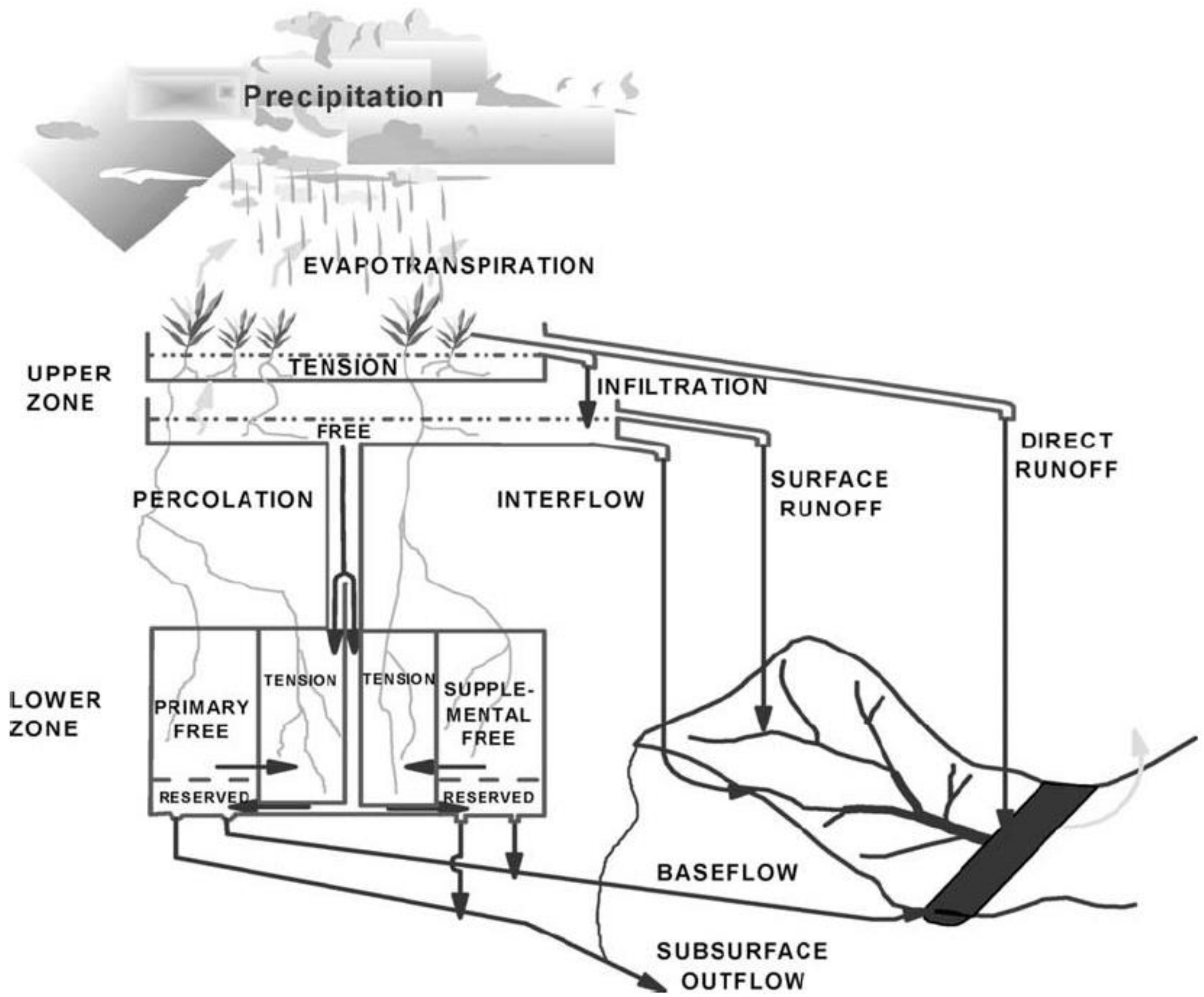
Ye A, Duan Q, Zeng H, Li L, Wang C, 2010. A Distributed Time—Variant Gain Hydrological Model Based on Remote Sensing. *Journal of Resources and Ecology* **1**, 222-30.

The Distributed Xinanjiang Hydrologic Model



Zhao, R. J. The Xinanjiang model applied in China. Journal of Hydrology. 135, 371–381.

The Distributed Sacramento Hydrologic Model



K. Ajami N, Gupta H, Wagener T, & Sorooshian S (2004) Calibration of a semi-distributed hydrologic model for streamflow estimation along a river system. Journal of Hydrology 298(1–4):112-135.

The Routing Model

The routing model is kinematic wave model。

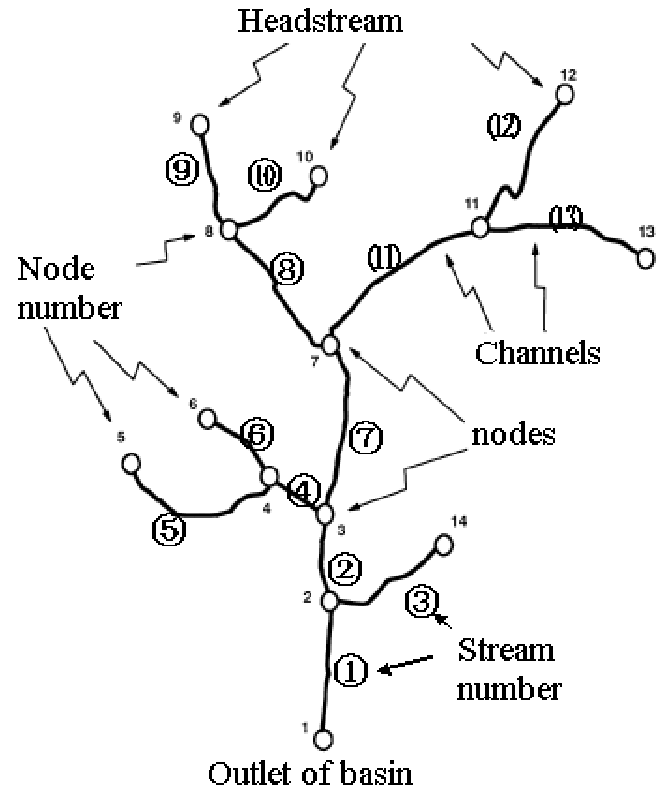
Saint － Venant equations: mass conservation equation and momentum equation

1. Number of node

2. Calculate from headwater to outlet of basin

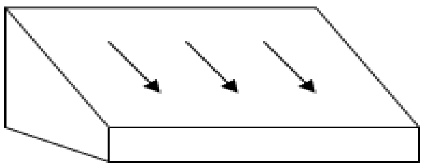
3、the out discharge is next node’s input discharge

4、the discharge of the outlet is the basin discharge

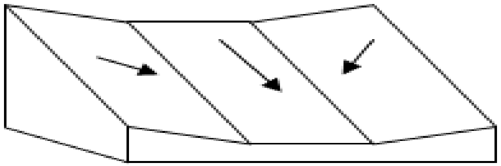


$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q$$

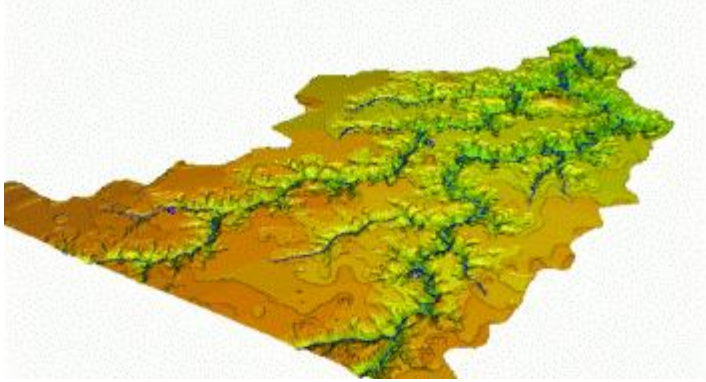
$$S_f - S_0 = 0$$



Hillside



River channel



Ye A, Duan Q, Zhan C, Liu Z, Mao Y, 2013. Improving kinematic wave routing scheme in Community Land Model. Hydrology Research 44, 886-903.

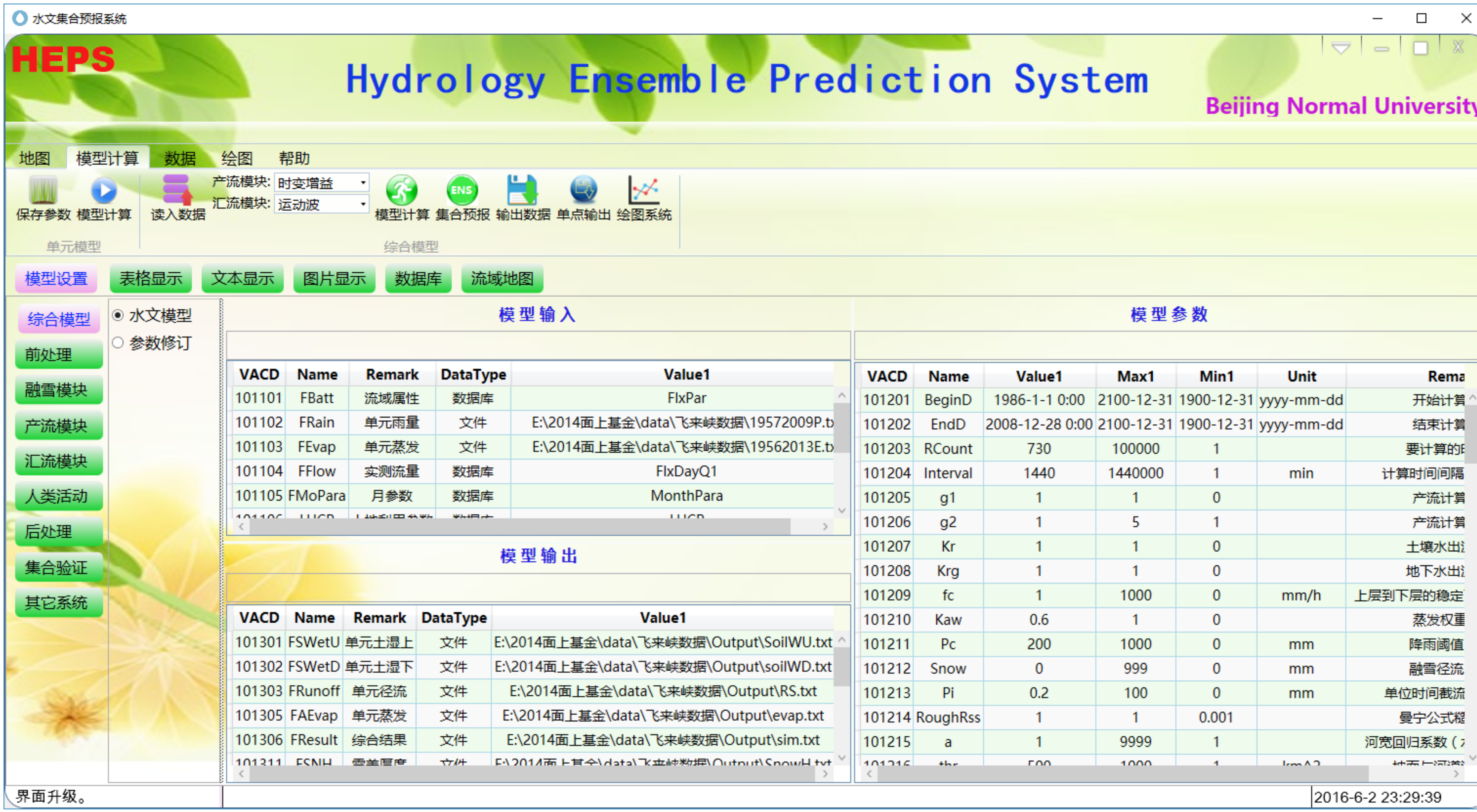
Verification Measures .1

Verification Measures	Formulas	Descriptions	Perfect/ No skill
Nash-Sutcliffe efficiency value (NSE)	$NSE = 1 - \frac{\sum_{i=1}^{N}(x_i - y_i)^2}{\sum_{i=1}^{N}(y_i - \bar{y})^2}$	Assessing the predictive power of hydrological models; quantitatively describe the accuracy between forecasts and observations	1 / ≤0
NSE calculated on inverse transformed flows	$NSE_I = 1 - \frac{\sum_{i=1}^{N}\left(\frac{1}{x_i} - \frac{1}{y_i}\right)^2}{\sum_{i=1}^{N}\left(\frac{1}{y_i} - \overline{\frac{1}{y_i}}\right)^2}$	Assessing the predictive power of hydrological models; quantitatively describe the accuracy between forecasts and observations	1 / ≤0
NSE calculated on benchmark model	$NSE_B = 1 - \frac{\sum_{i=1}^{N}(x_i - y_i)^2}{\sum_{i=1}^{N}(y_i - z_i)^2}$	Assessing the predictive power of hydrological models; quantitatively describe the accuracy between forecasts and observations	1 / ≤0
Root Mean Square Error (RMSE)	$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - y_i)^2}$	Association of forecasts and observations over a long time period	0/ ∞
Pearson Correlation Coefficient	$R = \frac{\sum_{i=1}^{N}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{N}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{N}(y_i - \bar{y})^2}}$	Linear dependency between forecasts and observations	1 / ≤0
rBias	$rBias = \left(\sum_{i=1}^{N} x_i \Big/ \sum_{i=1}^{N} y_i - 1\right) \cdot 100\%$	Relative difference between forecasts and observations	0/ ∞

Verification Measures .2

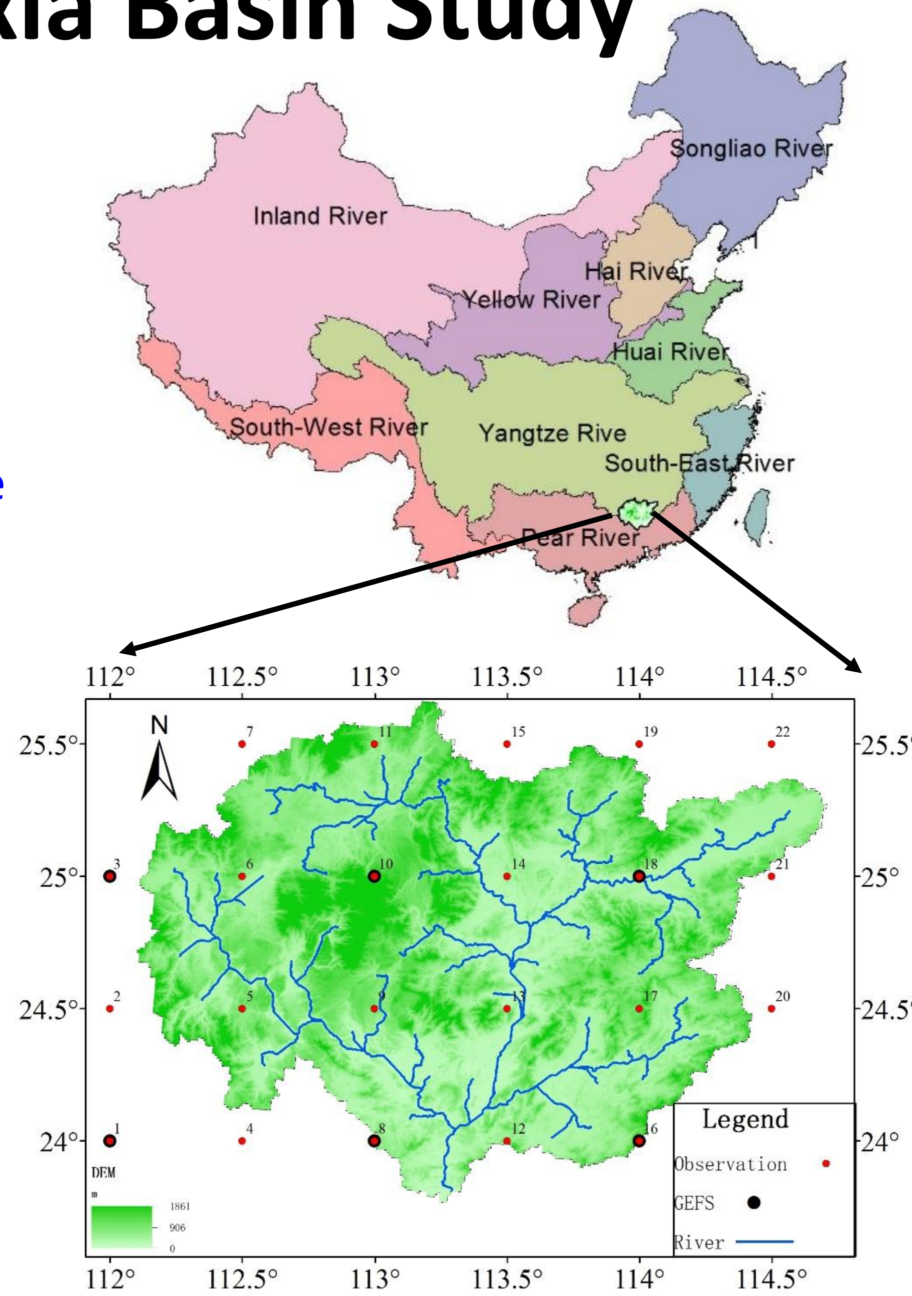
Verification Measures	Formulas	Descriptions	Perfect/ No skill
BSS	$BS = \left[flag(y,t) - \frac{1}{n}\sum_{i=1}^{n} flag(x_i,t) \right]^2$ $flag(x,t) = \begin{cases} 1, x \geq t \\ 0, x < t \end{cases}$ $BSS = \left(1 - \frac{BS}{BS_{ref}}\right), x_j < y < x_{j+1}$	Brier Skill Score. t is the threshold. Ref. is a reference forecast (e.g., climatology)	1/0
CRPSS	$CRPS = \sum_{i=1}^{j-1} P_i^2 \cdot (x_{i+1} - x_i) + P_j^2 \cdot (y - x_j)$ $+(P_j - 1)^2 \cdot (x_{j+1} - y) + \sum_{i=j+1}^{n} (P_i - 1)^2 \cdot (x_{i+1} - x_i)$ $CRPSS = \left(1 - \frac{CRPS}{CRPS_{ref}}\right), x_j < y < x_{j+1}$	Continuous Rank Probability Skill Score. P is the probability that was forecast.	1/0

The BNU-HEPS Software Platform

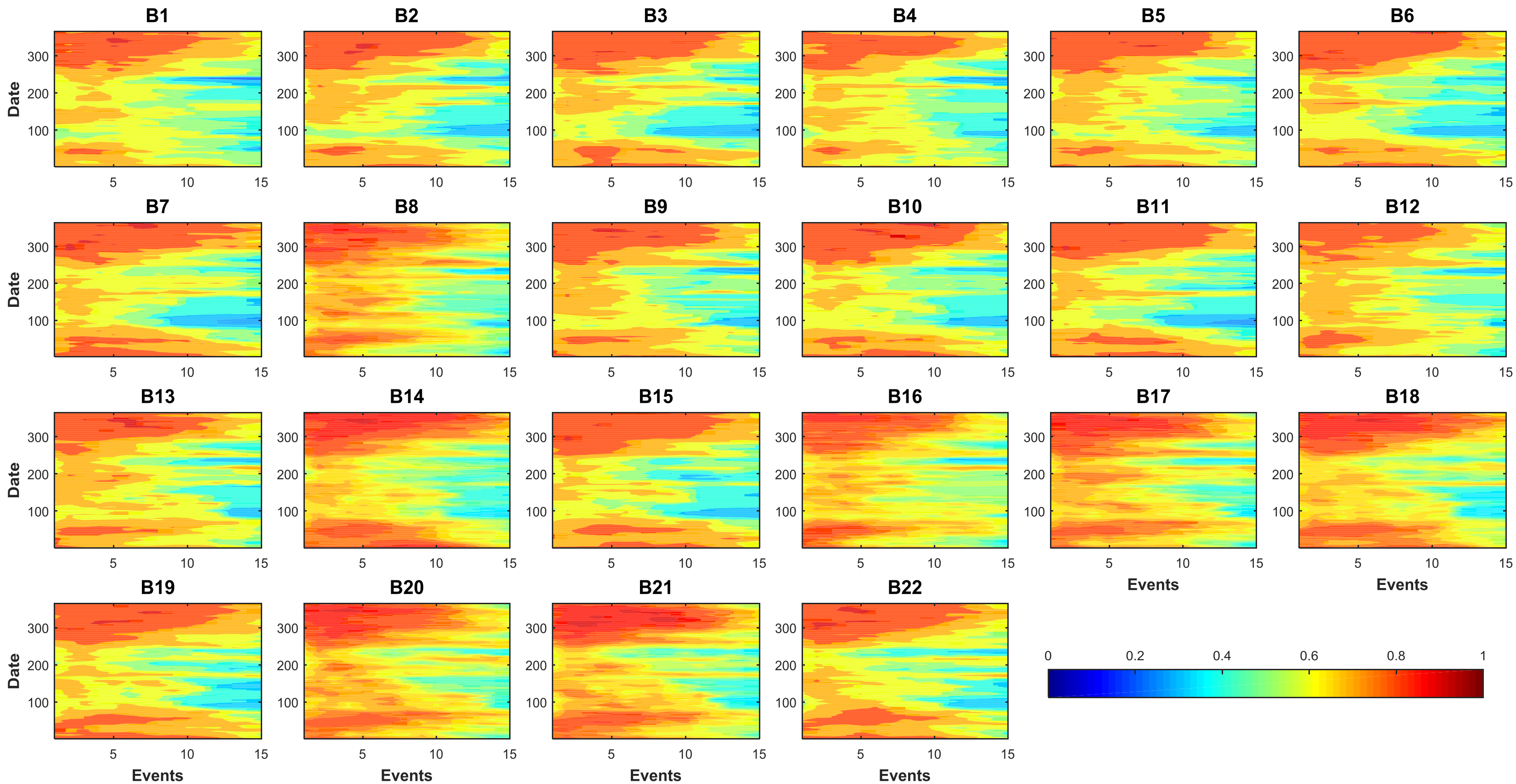


Data for Feilaixia Basin Study

- **NCEP Global Ensemble Forecast System (GEFS) forecasts:**
  - Data period: 1984-2016
  - Precipitation/Temperature forecasts with16-day lead-time for every day 1.0ºx1.0º global coverage (360x181)
  - Data format: Grib2
- **Observed Daily Precipitation:**
  - Data period: 1957-2016
  - 0.5ºx0.5º Grid
- **Observed Daily Discharge:**
  - Data period: 1980-2010
  - Feilaixia station (Outlet)



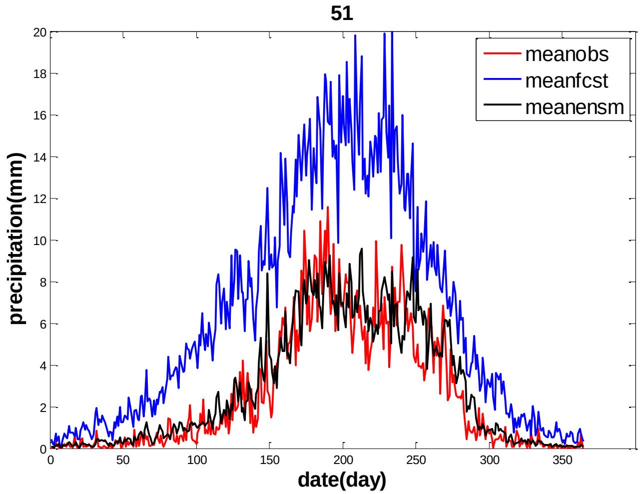
The Correlation between GEFS Forecasted and Observed Precipitation

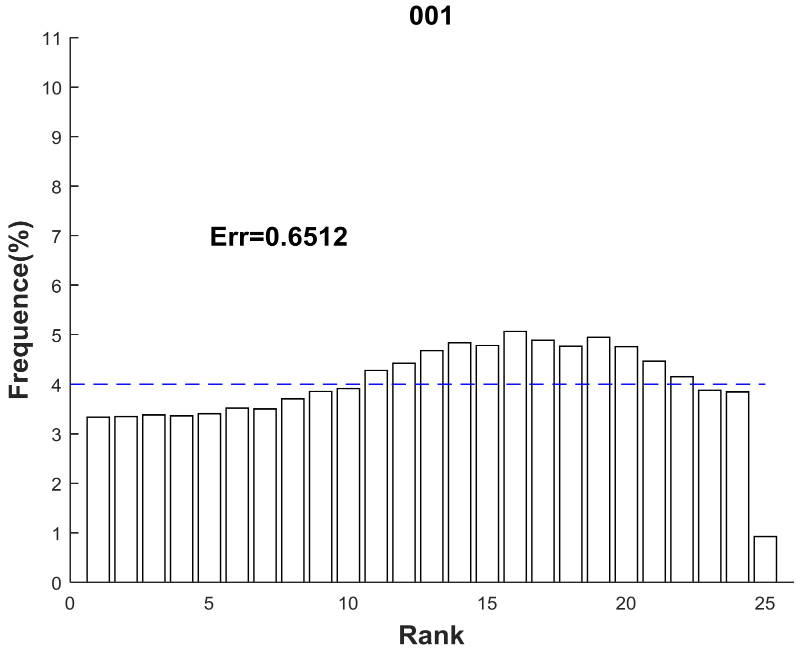


1986-2009	Events	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Event	Start	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	End	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

How much can we gain from pre-processing of GEFS precipitation forecasts?

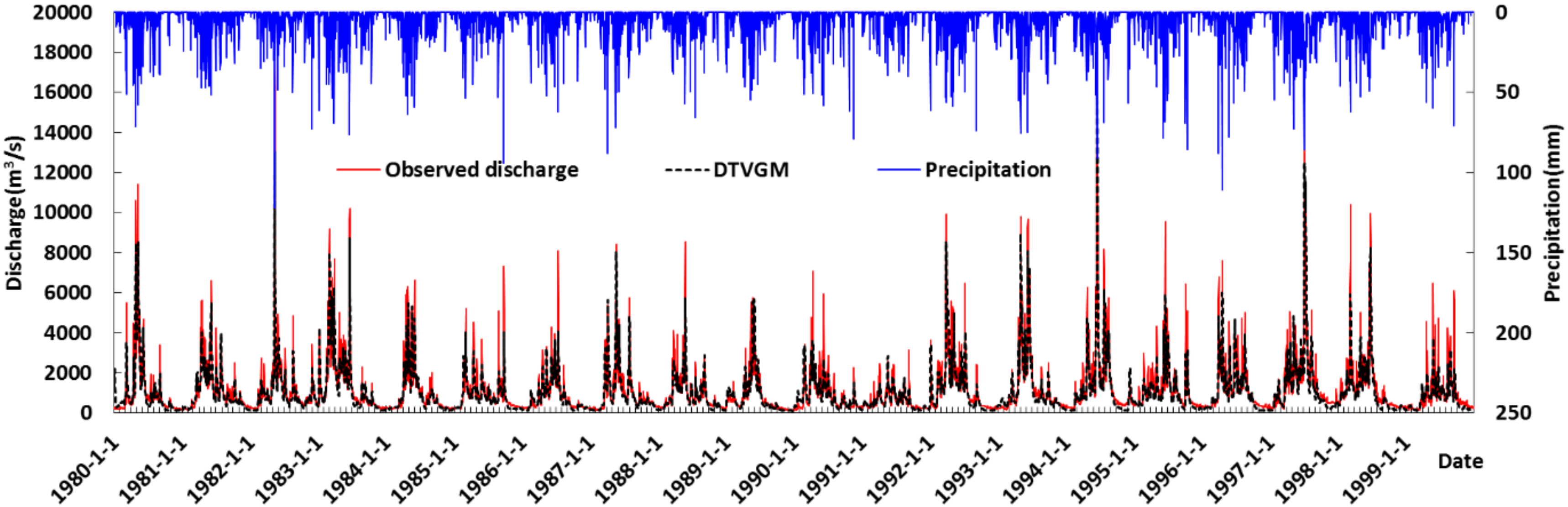
- **Bias removal**



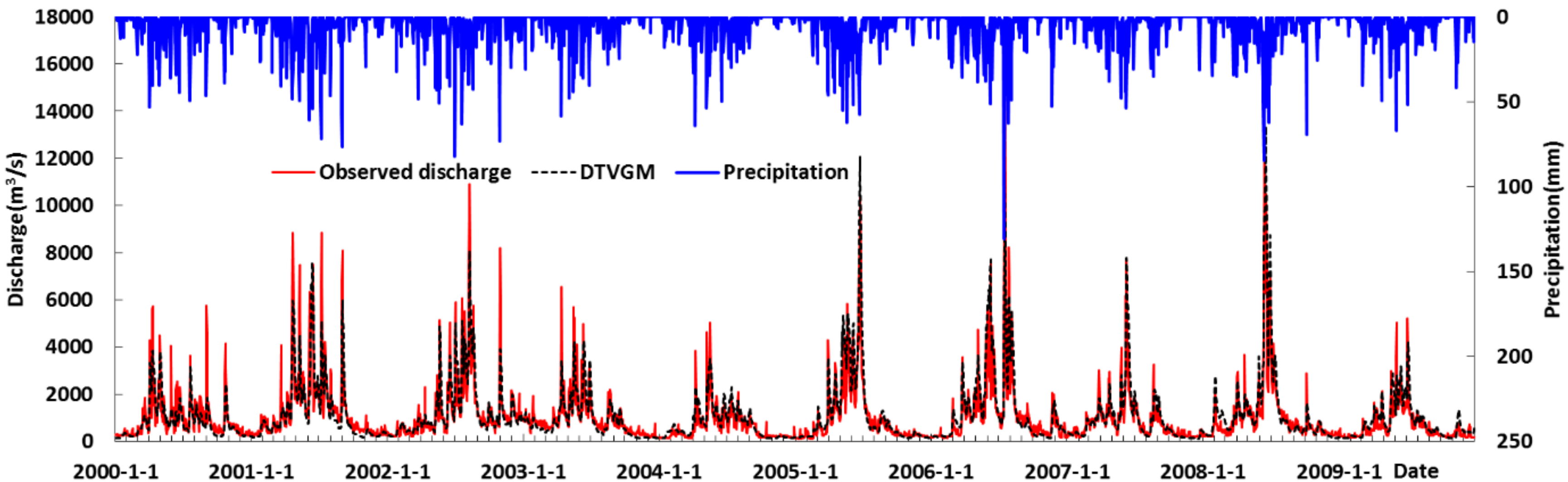


The DTVGM Streamflow Discharge Simulation

- **Calibration**

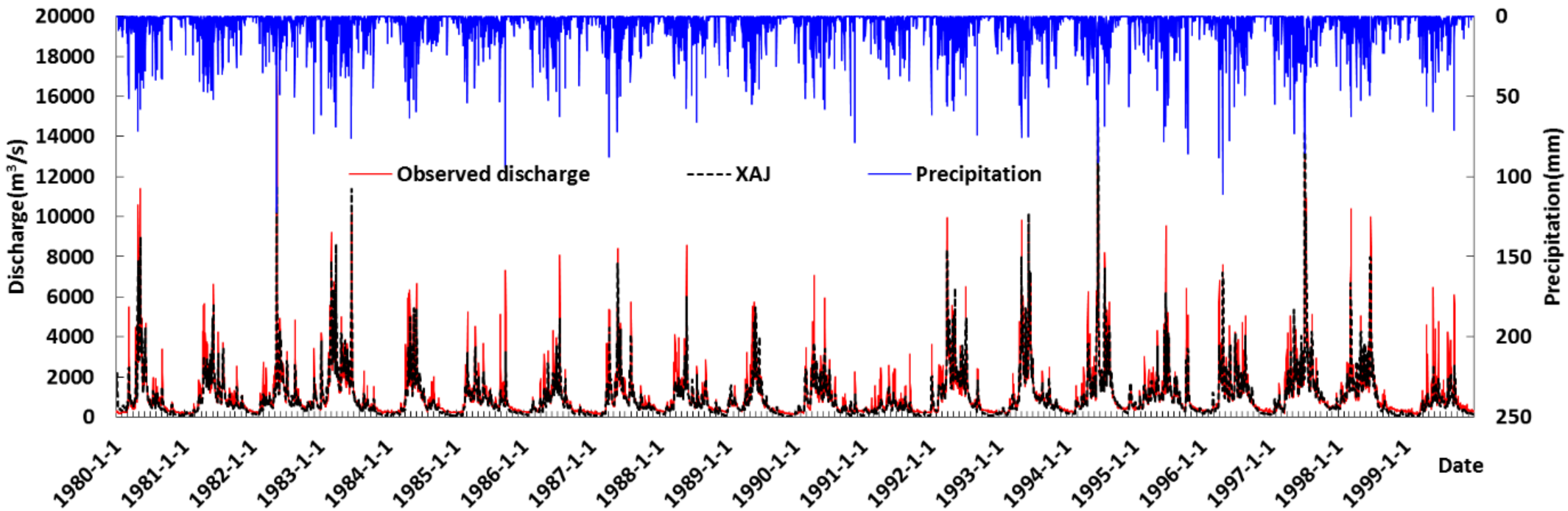


- **Verification**

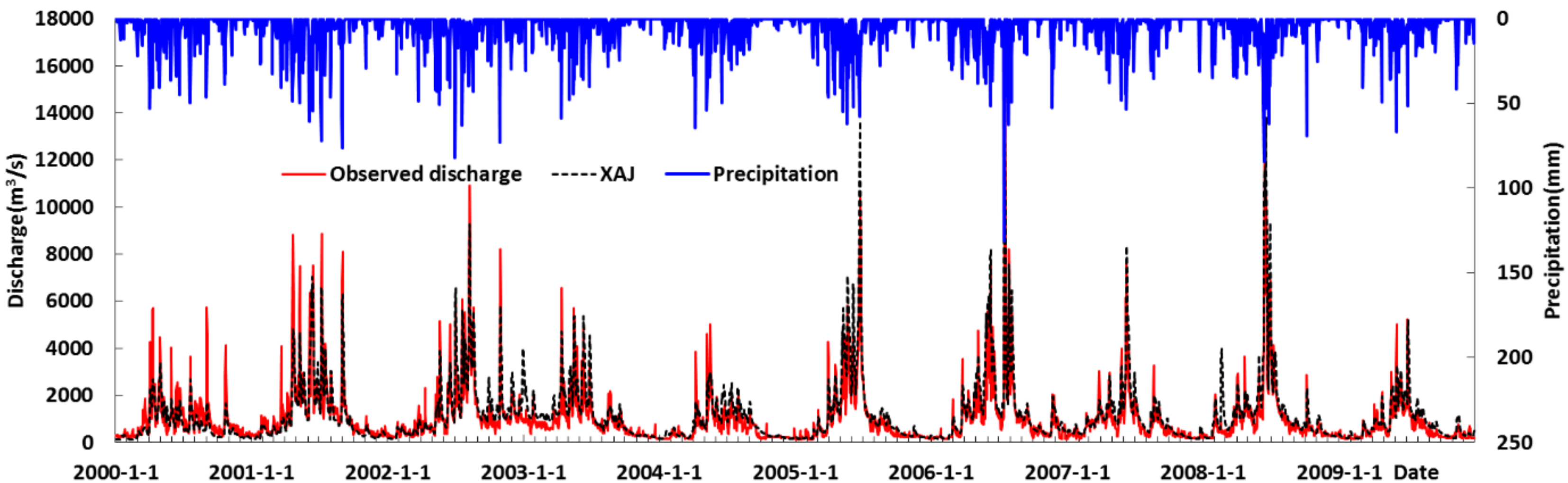


The XAJ Streamflow Discharge Simulation

- **Calibration**

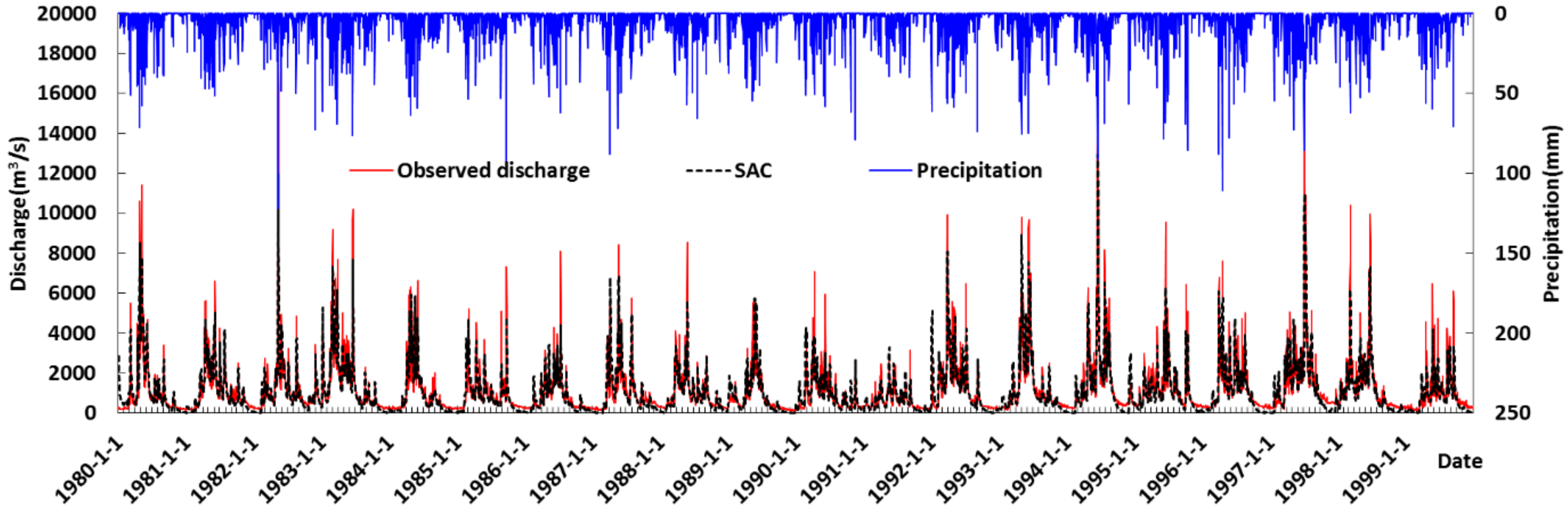


- **Verification**

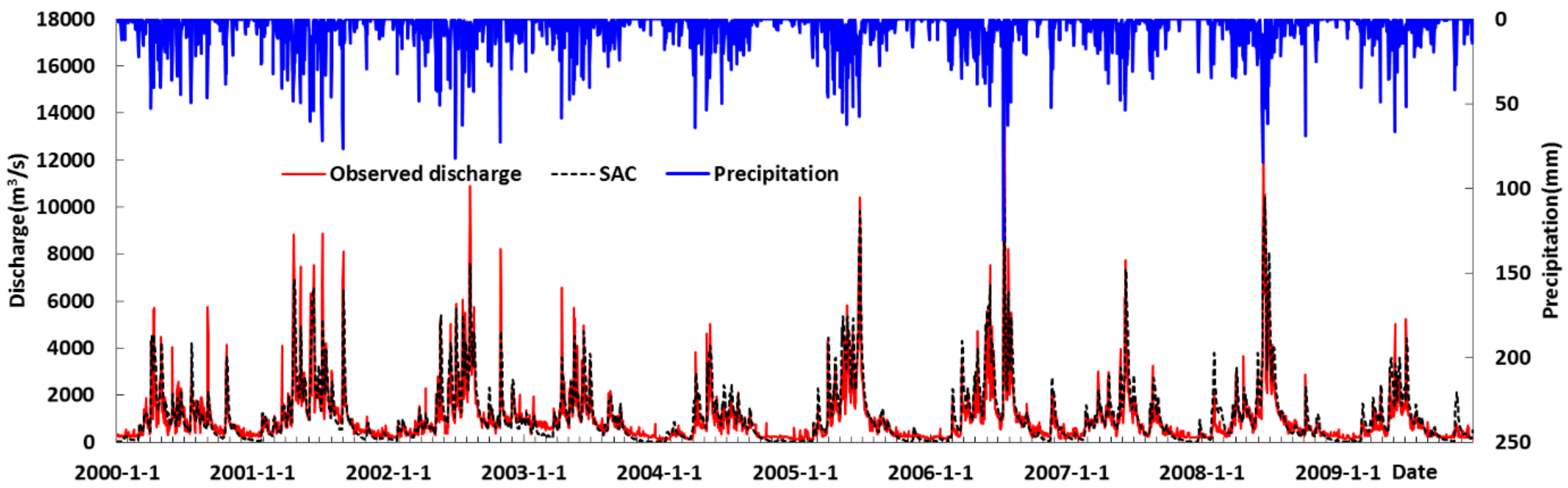


The SAC Streamflow Discharge Simulation

- **Calibration**



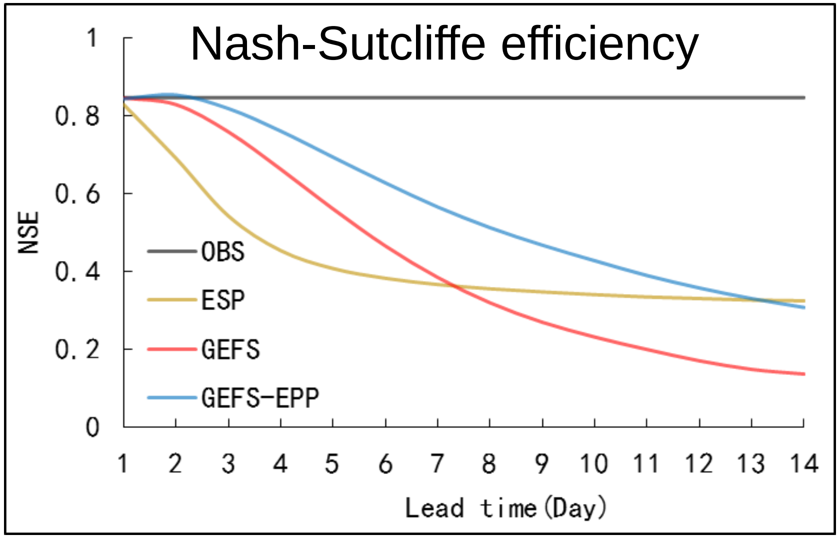
- **Verification**

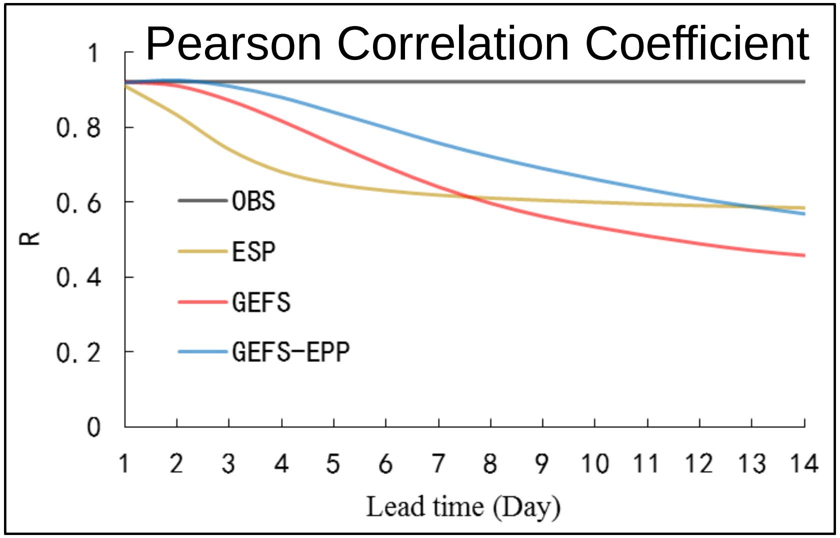


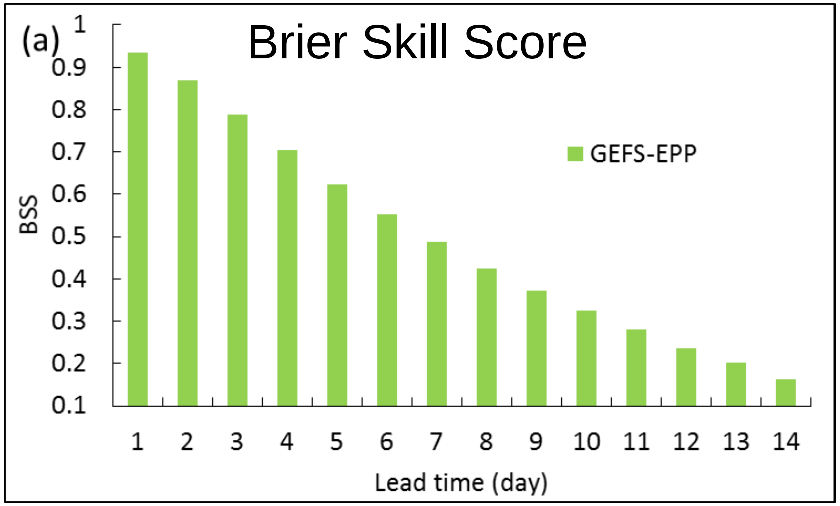
Summary of Performance Measures For Different Models

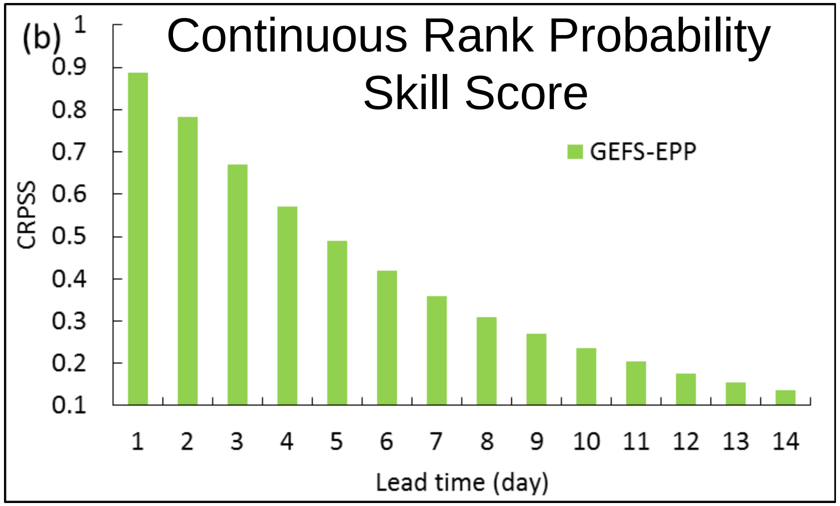
Model		R	NSE	NSE_I	NSE_B	rBias	RMSE
DTVGM	Calibration (1980-1999)	0.941	0.883	0.166	0.841	-5.5%	459.363
	Validation (2000-2009)	0.901	0.786	0.419	0.711	6.3%	574.552
XAJ	Calibration (1980-1999)	0.93	0.857	-4.709	0.806	-10.1	506.434
	Validation (2000-2009)	0.91	0.771	0.564	0.691	16.1%	593.465
SAC	Calibration (1980-1999)	0.937	0.878	-78.9	0.835	-0.5%	467.907
	Validation (2000-2009)	0.888	0.741	-69.248	0.651	11.3%	631.507

The DTVGM Model Performance Measures

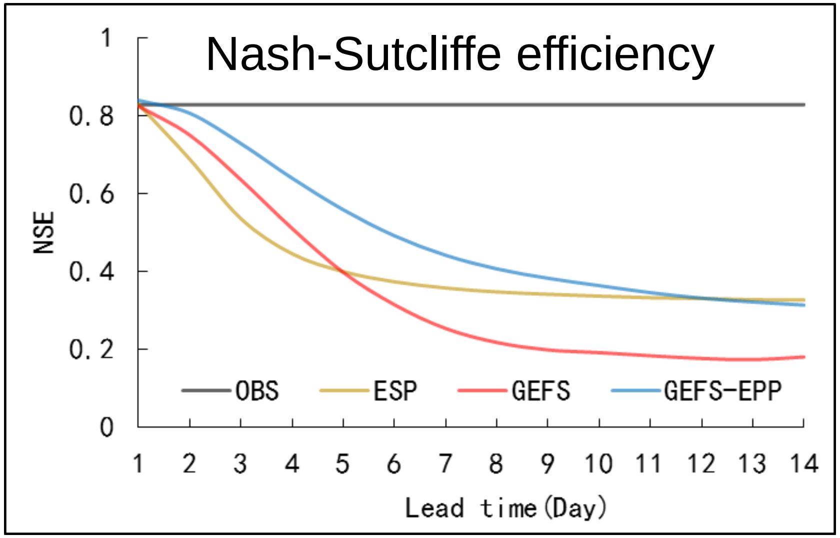


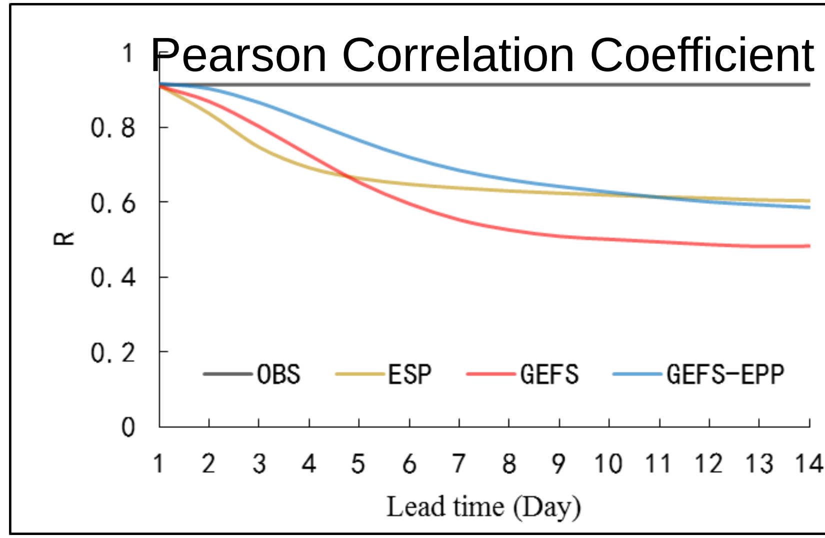


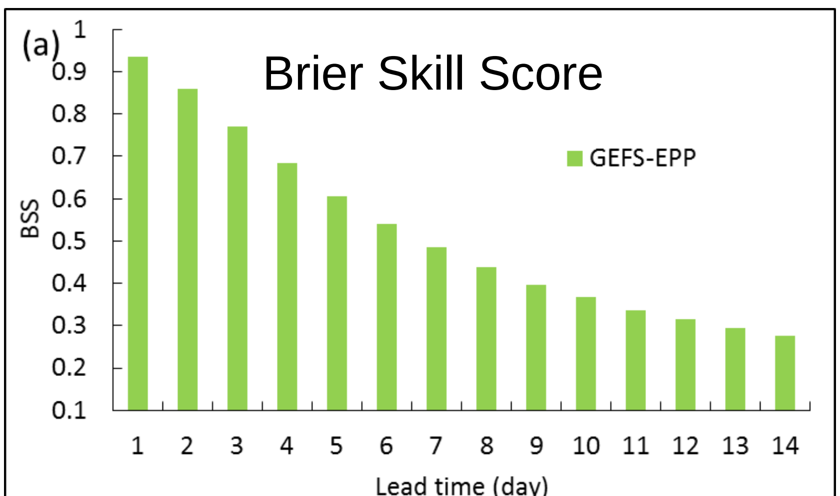




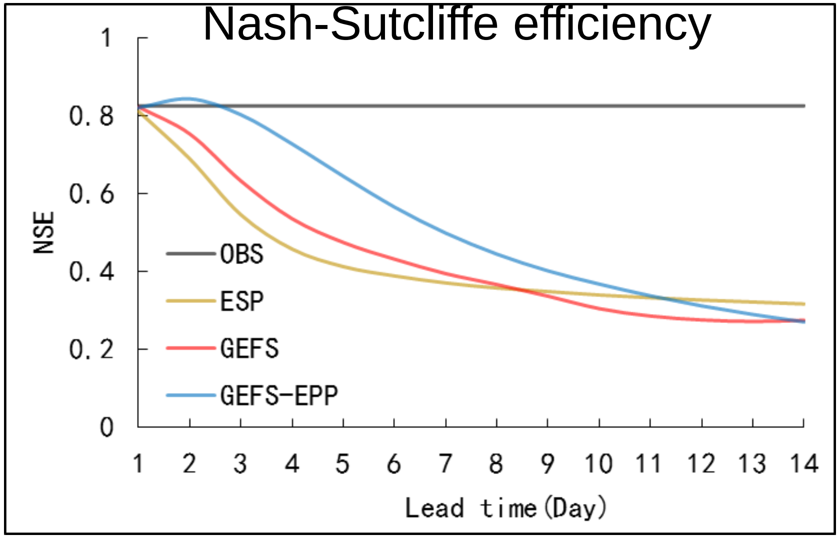
The XAJ Model Performance Measures

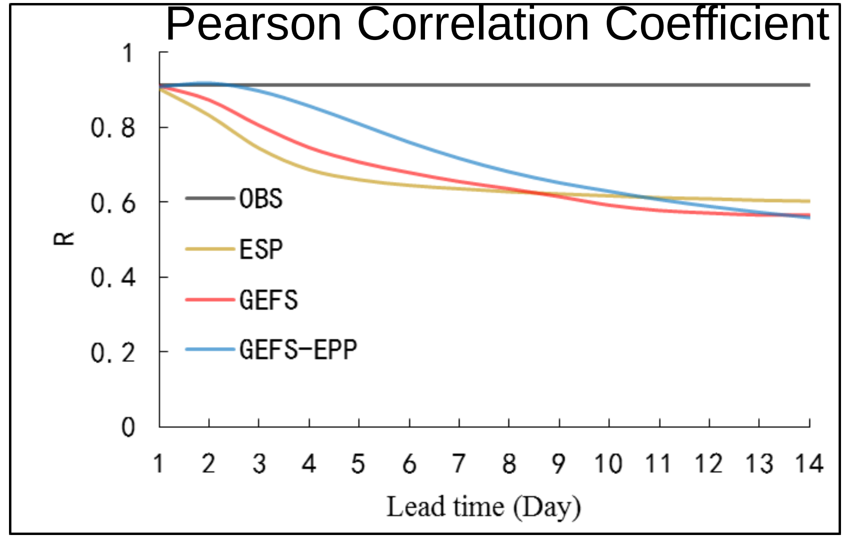


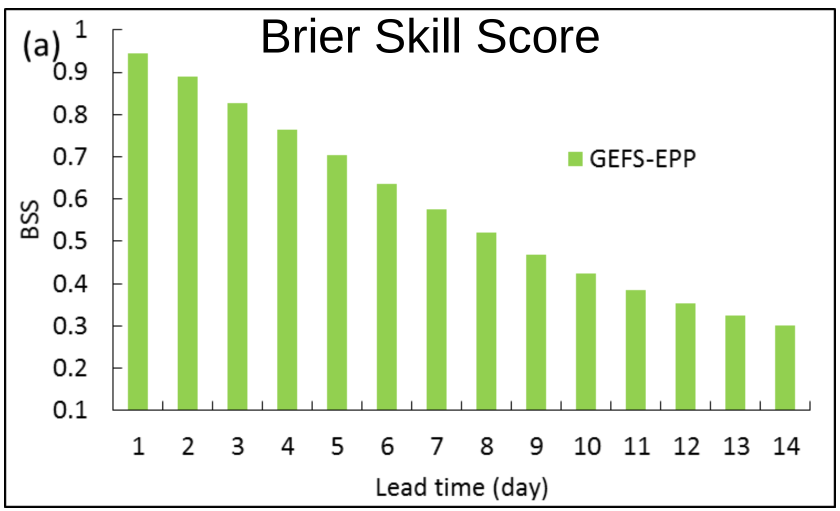


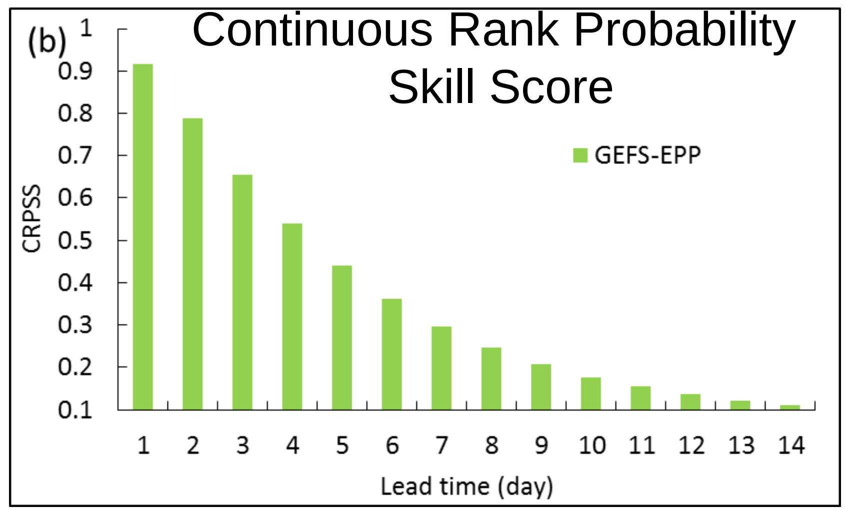


The SAC Model Performance Measures









Summary

- A hydrological ensemble prediction system (BNU-HEPS) has been developed which follows the HEPEX framework. Currently BNU-HEPS has the following functions
  - Ensemble pre-processing
  - Parametric uncertainty quantification
  - Multi-hydrological models
  - Verification
  - Ensemble post-processing

- Applications in Feilaixia basin:
  - Raw GEFS is not as good as ESP, but the pre-processed GEFS is much better than ESP

- Future plan:
  - To incorporate data assimilation and multi-model averaging functions into BNU-HEPS

A few words on “Handbook of Hydrometeorological Ensemble Forecasting”

- <u>Editors-in-Chiefs:</u>
  - Q. Duan, F. Pappenberger, J. Thielen, A. Wood, H. Cloke and J. Schaake

- <u>Book Structure:</u>
  - 11 Sections
  - Total number of chapters assigned: 59
    - Pending chapters (not yet overdue): 16
    - Overdue chapters: 6
    - Chapters in review: 21
    - In production: 16

- <u>Updated timelines:</u>
  - All chapters due: June 30, 2016, with exceptions approved by EICs
  - All reviews completed by July 31, 2016
  - Online version completion: December 31, 2016
  - Print version: sometime in 2017

Thanks！

Contact: qyduan@bnu.edu.cn
azye@bnu.edu.cn