Decadal Prediction and Stochastic Simulation of Hydroclimate Over Monsoonal Asia

Andrew W. Robertson[1], Edward R. Cook[2], Rosanne D'Arrigo[2], Michael Ghil[4], Upmanu Lall[3], Padhraic J. Smyth[5], Arthur M. Greene[1], Mickael D. Chekroun[4], Dmitri Kondrashov[4], Scott Triglia[5]

1 International Research Institute for Climate and Society (IRI), Columbia University
2 Tree Ring Laboratory, Lamont Doherty Earth Observatory, Columbia University
3 Dept. Earth and Environmental Engineering & Columbia Water Center, Columbia University
4 Dept. of Atmospheric and Ocean Sciences, University of California, Los Angeles
5 Dept. of Computer Science, University of California, Irvine

Motivation

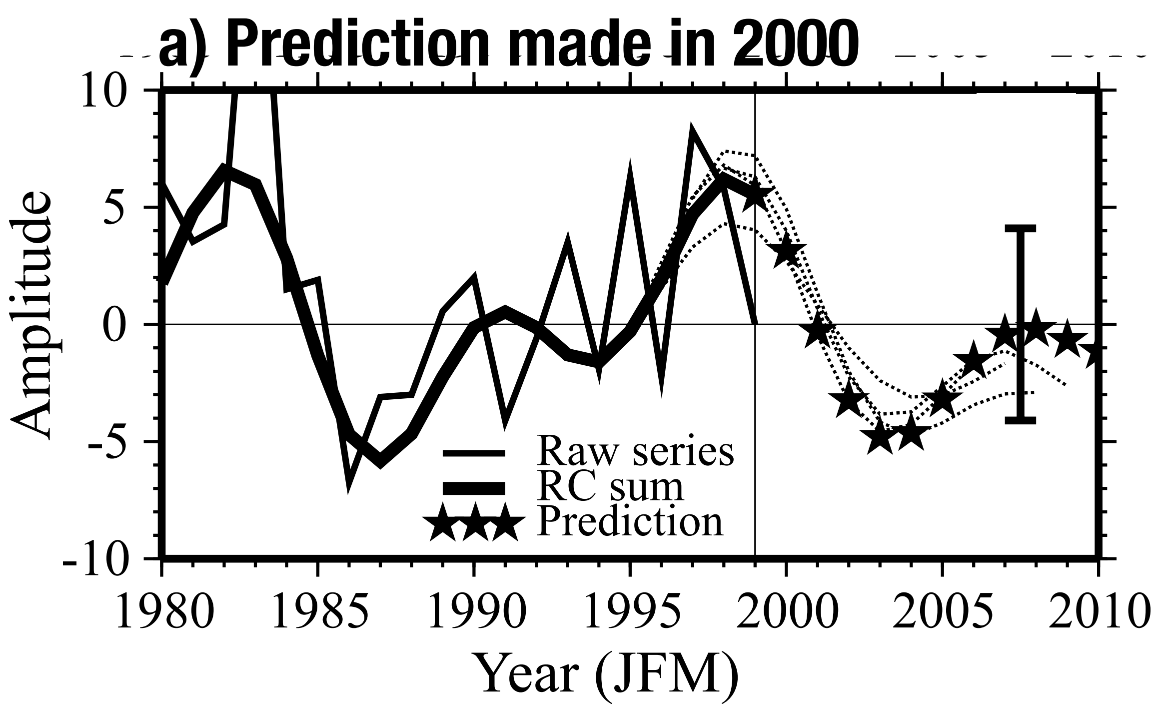
- Fine spatio-temporal scale estimates of climate over the next 10 to 50 years are needed for long-term planning in water resource and flood management.
- At these scales current GCM climate projections have very large uncertainties.
- What to do?

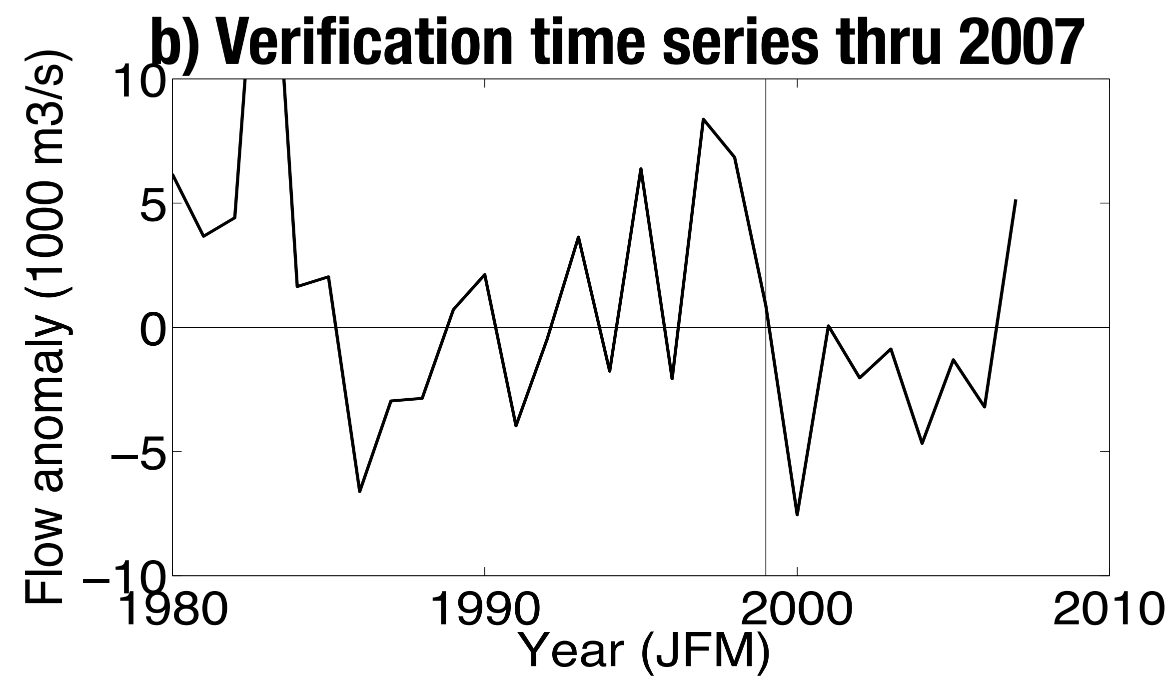
Project Goals

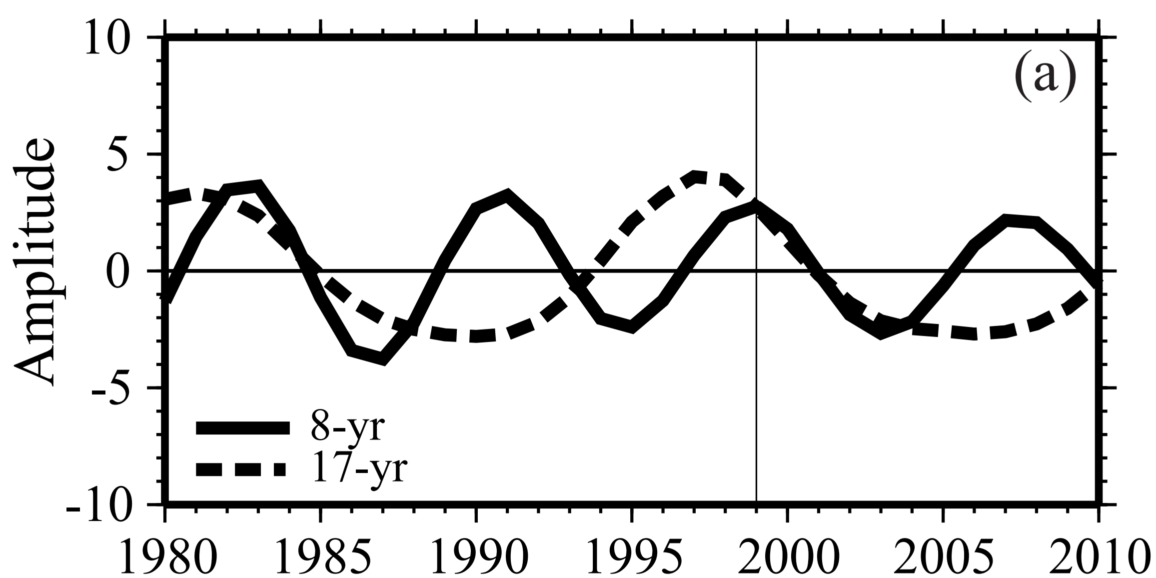
1. Develop and test statistical methods of interannual-to-interdecadal simulation & prediction of river flows over monsoonal Asia
2. Use multi-centennial tree-ring based reconstructions of stream flow to better identify natural modes of climate variability across monsoonal Asia, and test the candidate prediction schemes retrospectively.
3. Merge empirical estimates of climate variability with GCM climate change projections using Monte Carlo simulation to quantify the PDF of the uncertainties
4. Test simulations using hydrologic models for two major reservoir systems over Asia:
    4.1. Bhakra Beas reservoir in northern India,
    4.2. Yangtze River Three Gorges Dam reservoir in China

1. Empirical prediction models

Statistical decadal streamflow forecasts using Singular Spectrum Analysis





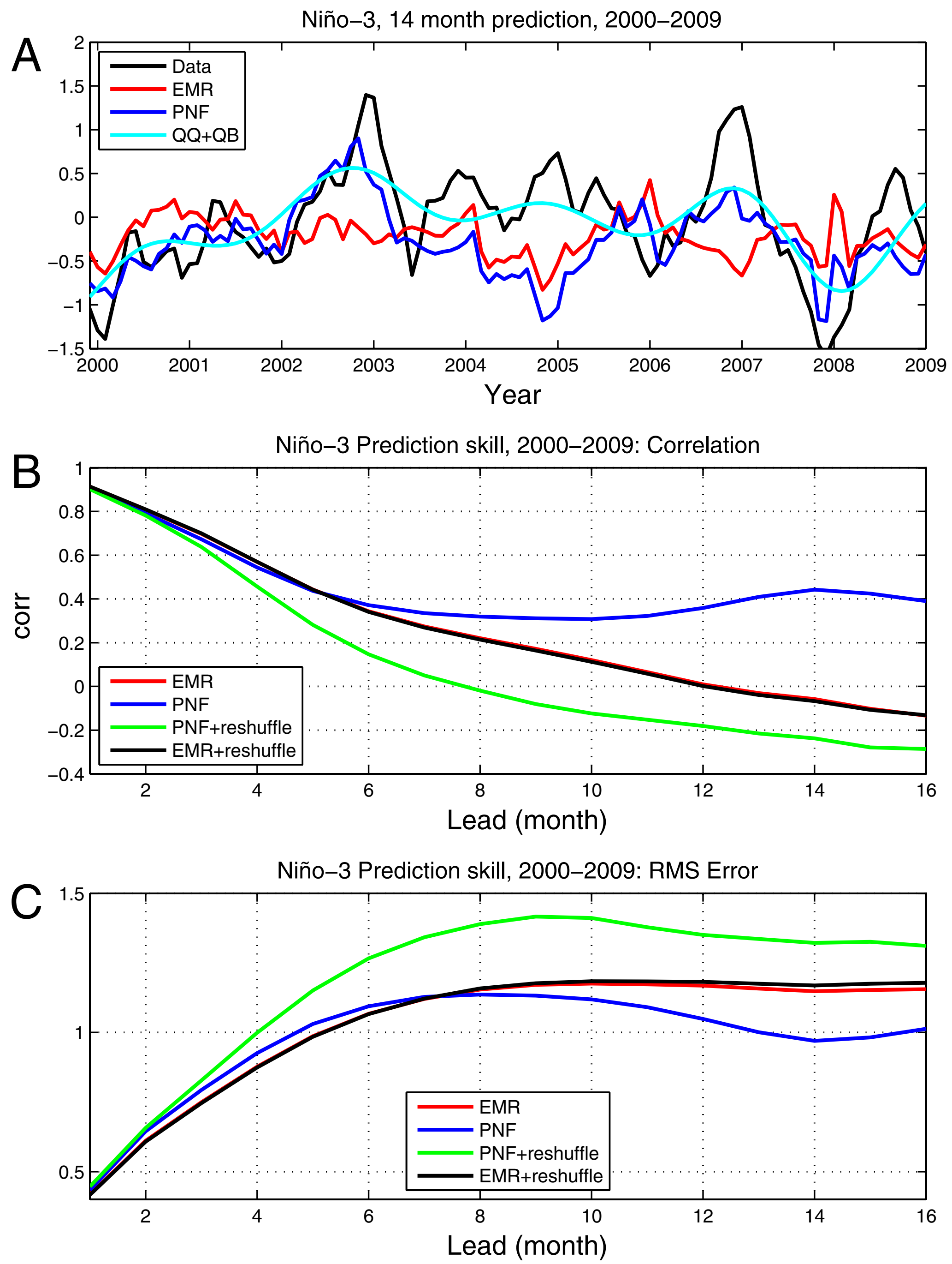


Parana River flow real-time forecast based on Singular Spectrum Analysis & Linear Prediction

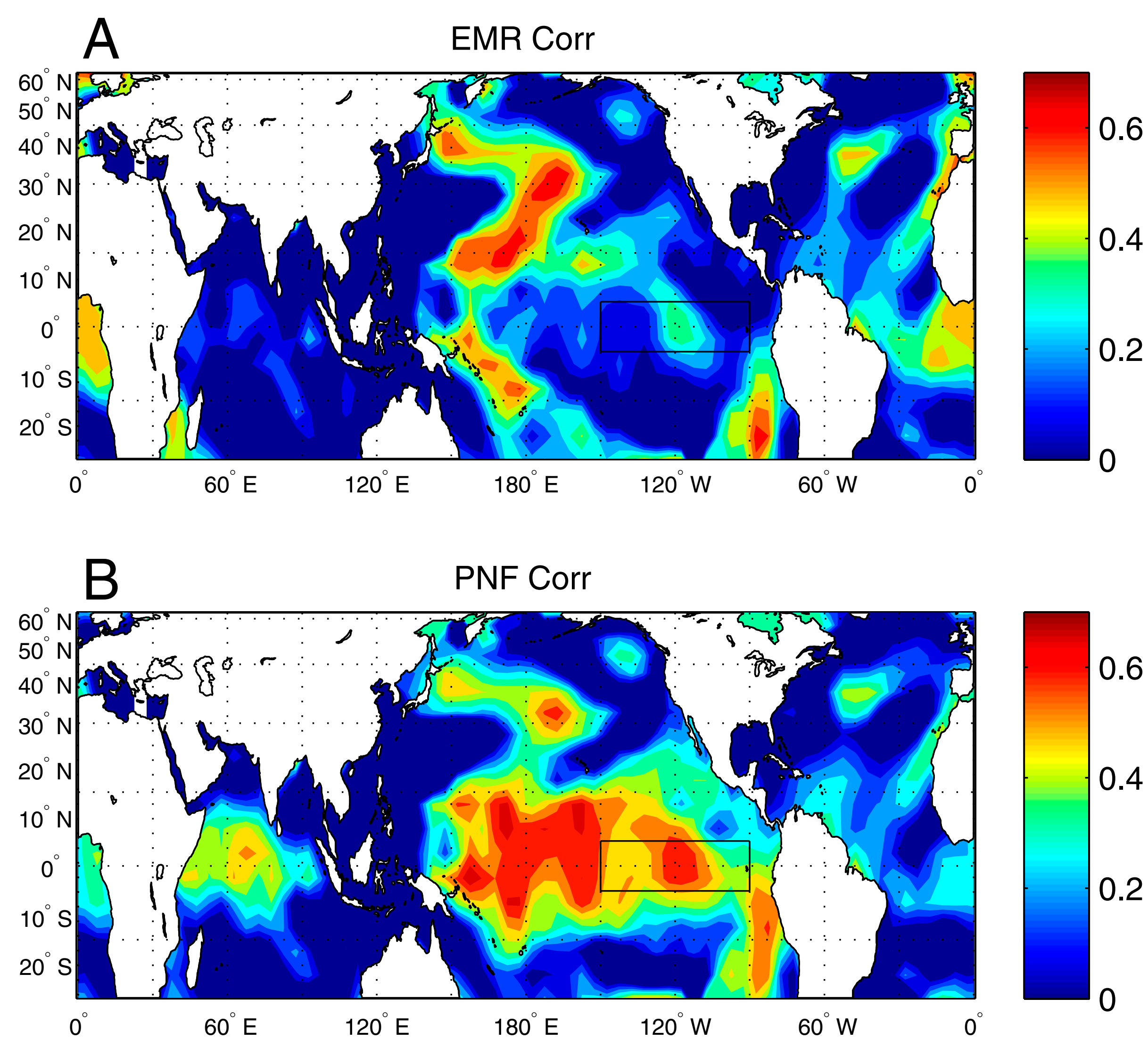
Robertson et al. (2001, GRL)

Stochastic inverse models (EMR) with past noise forecasting (PNF)

$$\dot{\mathbf{x}} = \mathbf{A}\mathbf{x} + \mathbf{B}(\mathbf{x},\mathbf{x}) + \mathbf{L}(\mathbf{x},\mathbf{r}_t^l,\xi_t,t), \qquad 0 \leq l \leq L-1.$$



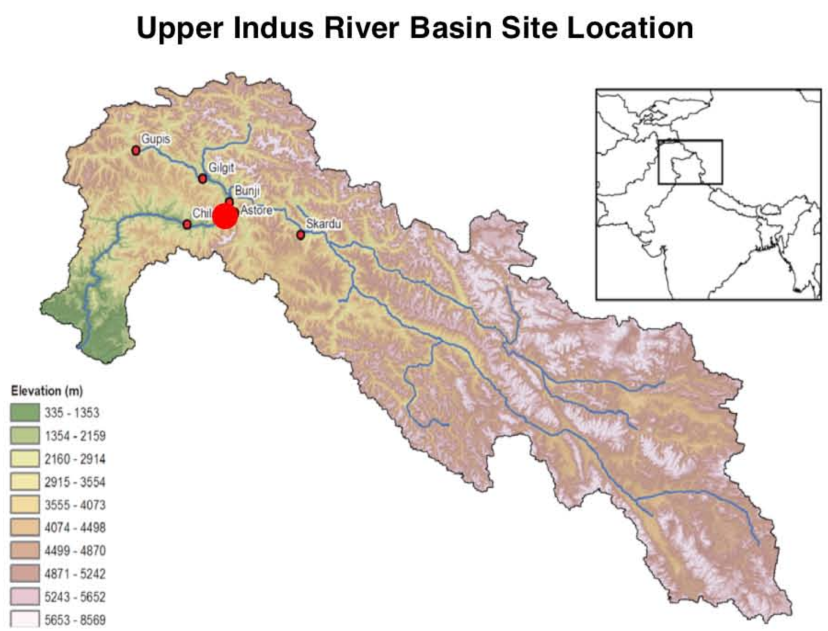
ACC SST Skill at 14-mo lead

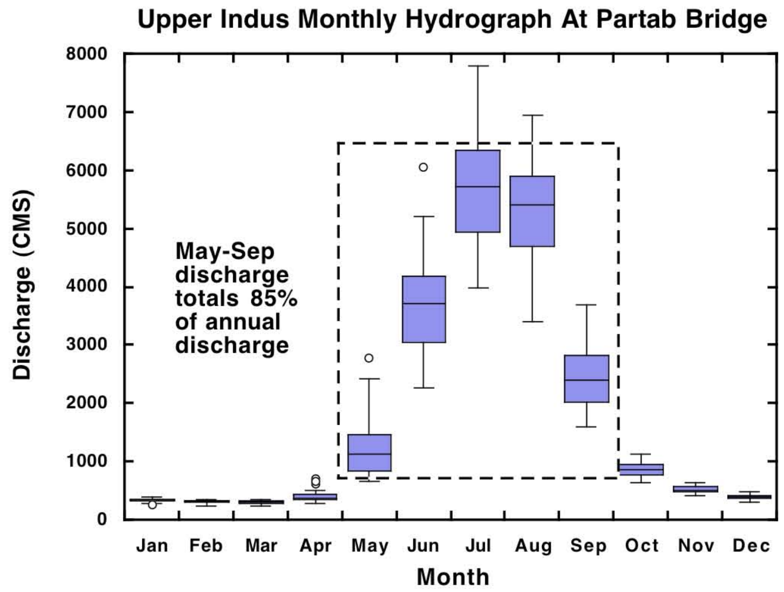


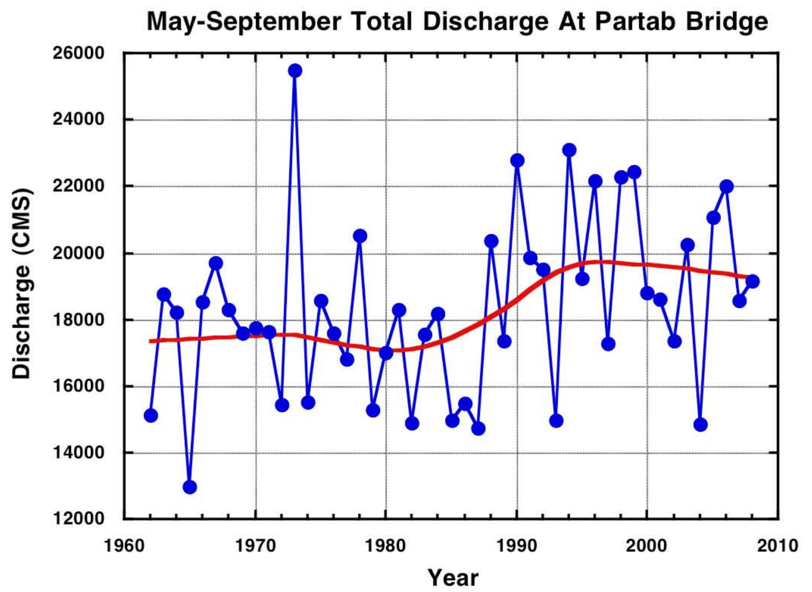
Chekroun et al. (2011, PNAS)

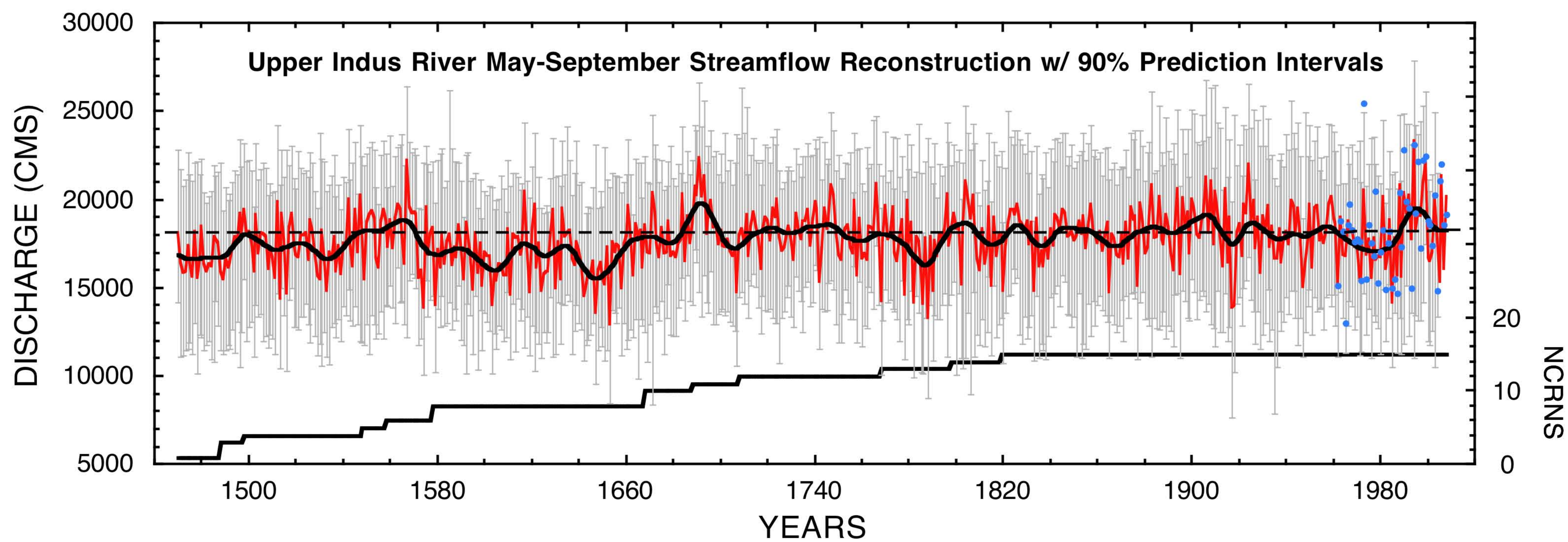
2. Tree-ring based reconstructions of stream flow

Tree-ring reconstructions of Upper Indus River Discharge



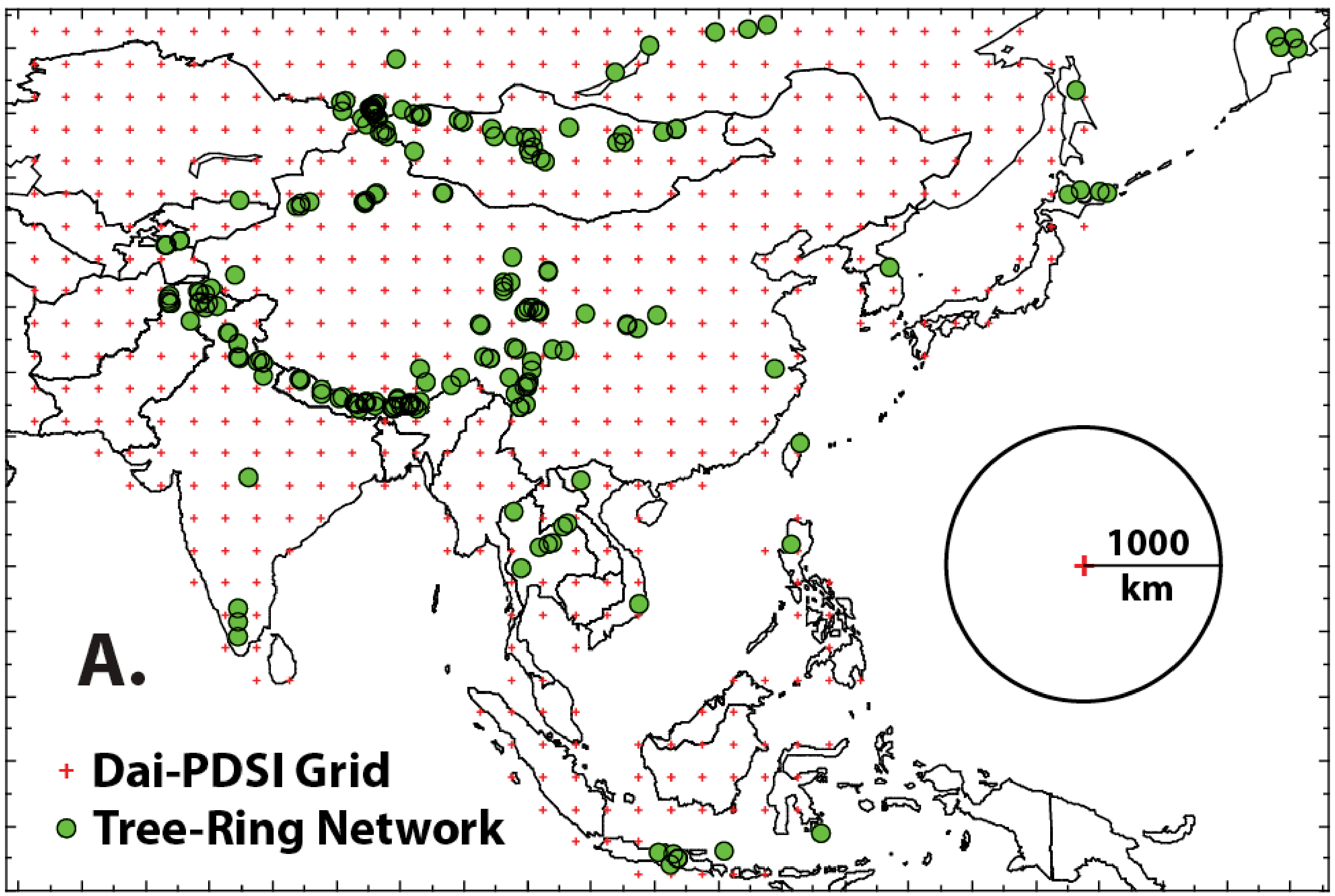






E. Cook

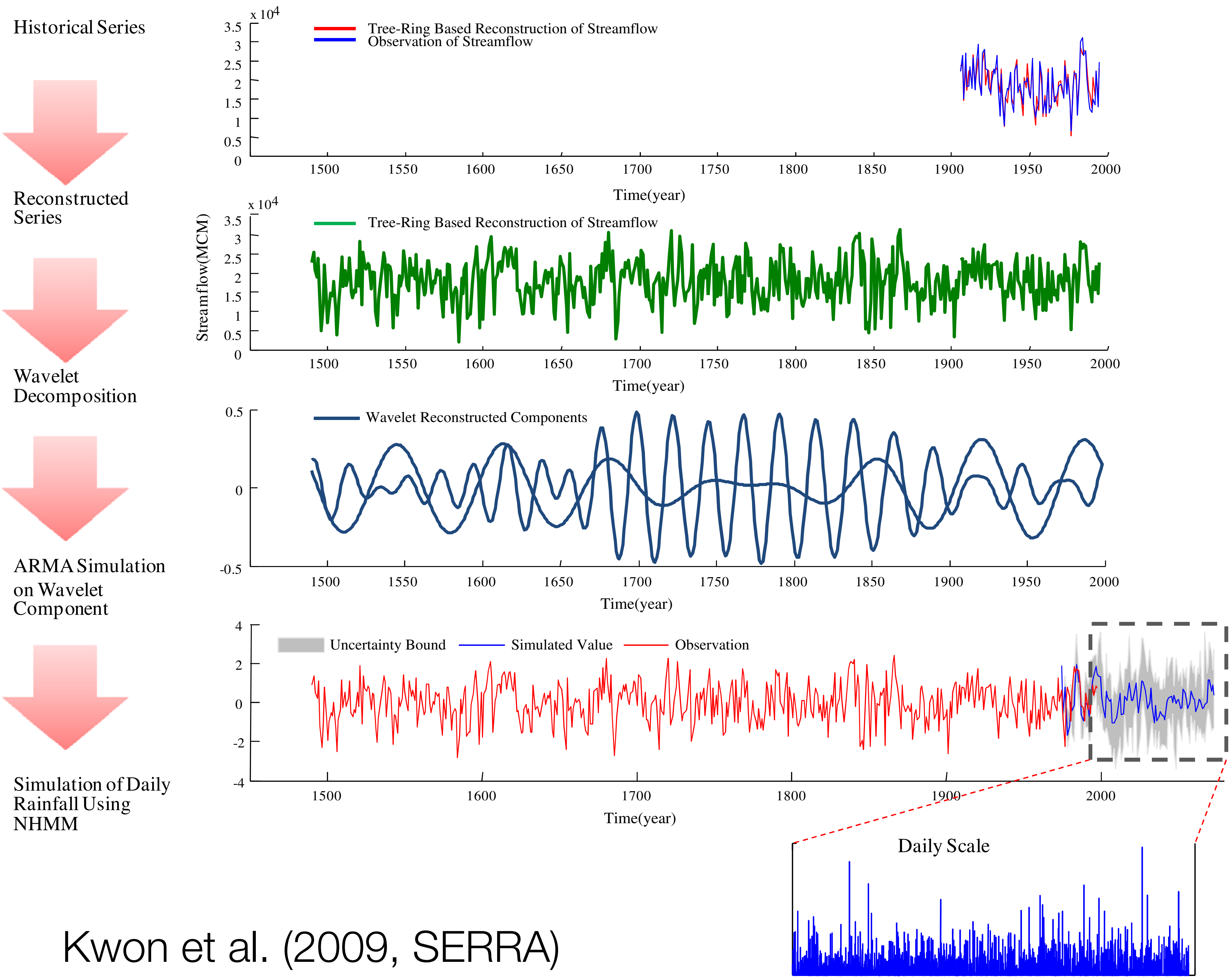
Monsoon Asia Drought Atlas (MADA) 1300–2005



Cook et al. (2010, Science)

3. Monte-Carlo simulation based on low-frequency modes

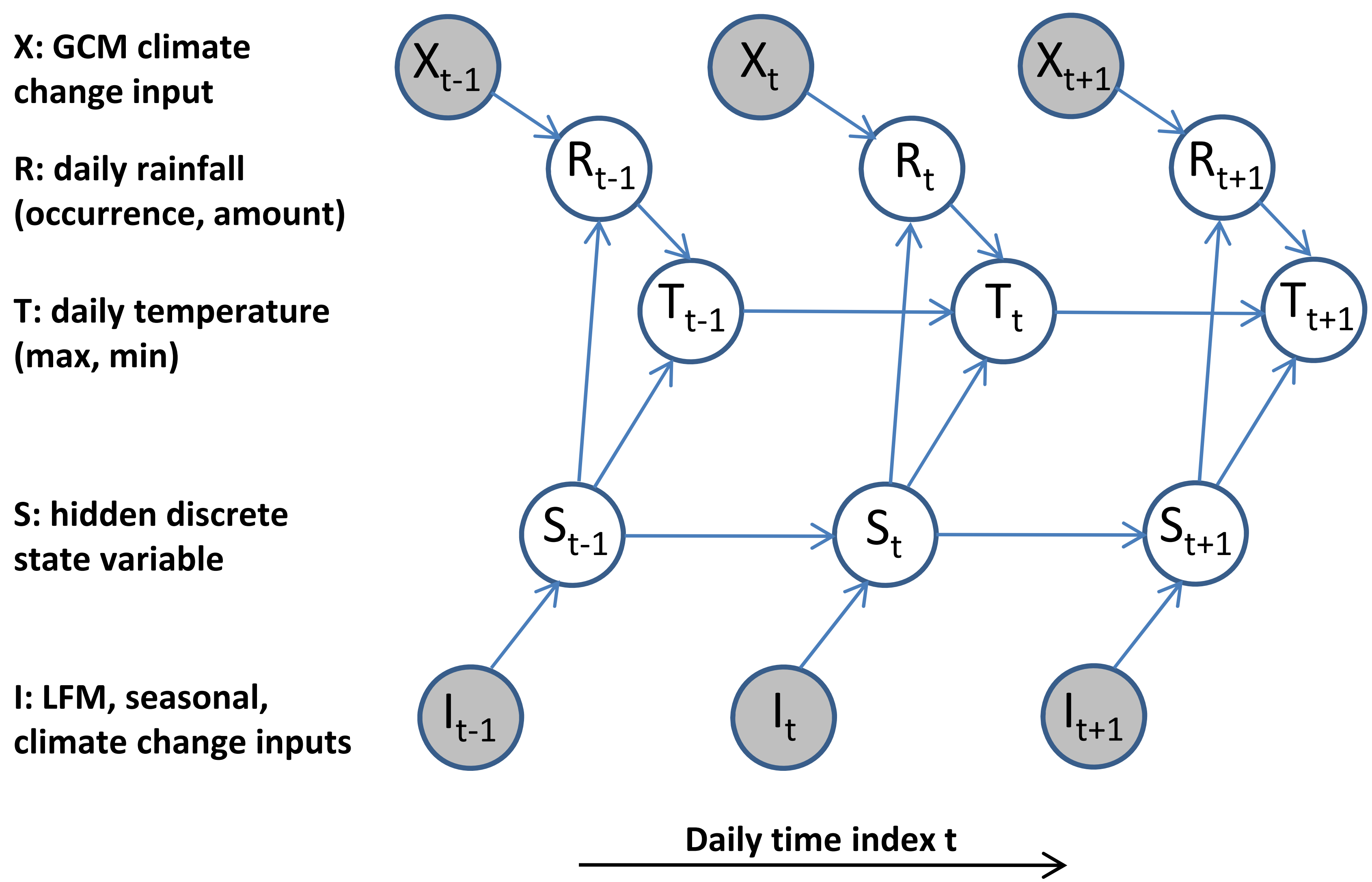
Concept of data-driven stochastic simulation



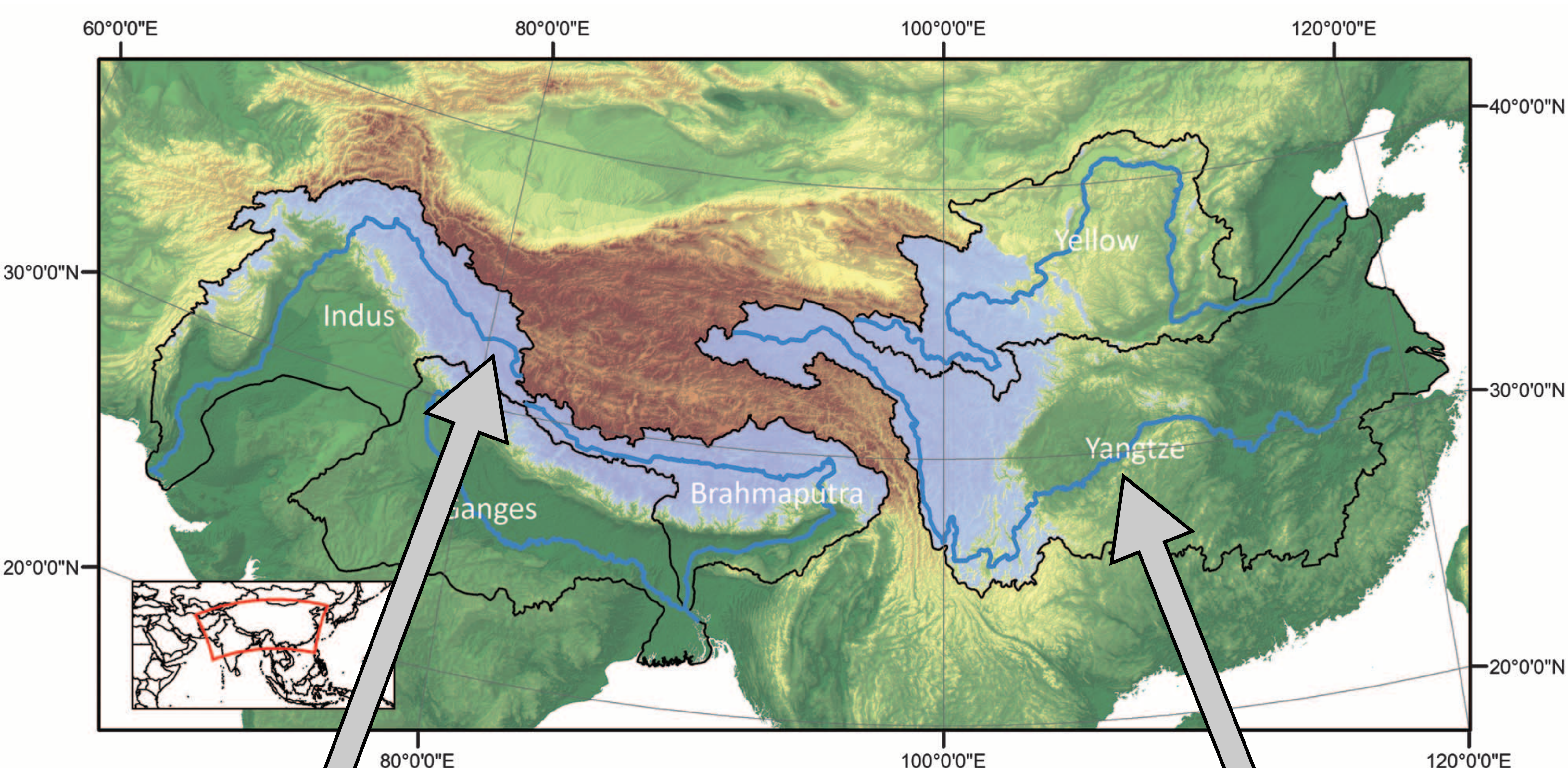
Schematic representation of generation of daily rainfall scenarios conditional on a scenario of seasonal/ annual climate indices

Kwon et al. (2009, SERRA)

Graphical model structure for stochastic downscaling of rainfall and temperature



4. Hydrologic modeling case studies



Bhakra Dam, India

Three-Gorges Dam, China

Dynamic Risk Management : Multipurpose Reservoir System Operation guided by Multiscale Climate Information: Beas-Sutlej Rivers, India

Decisions: 1. Storage (as a f(time) to allocate for monsoon flood volume
2. Irrigation &Hydropower release schedule & canal flows

Challenges: Prediction of a) spring fill cycle flows and timing, b) monsoon flood flow volume and duration, and c) winter precipitation and melt period dynamics. Marked interannual and decadal variability with superposed glacier melt trend.

Approach:

Stochastic, Multisite, month to decade climate Simulator conditioned on historical, paleo and GCM data

Irrigation Demand

Reservoir Inflows

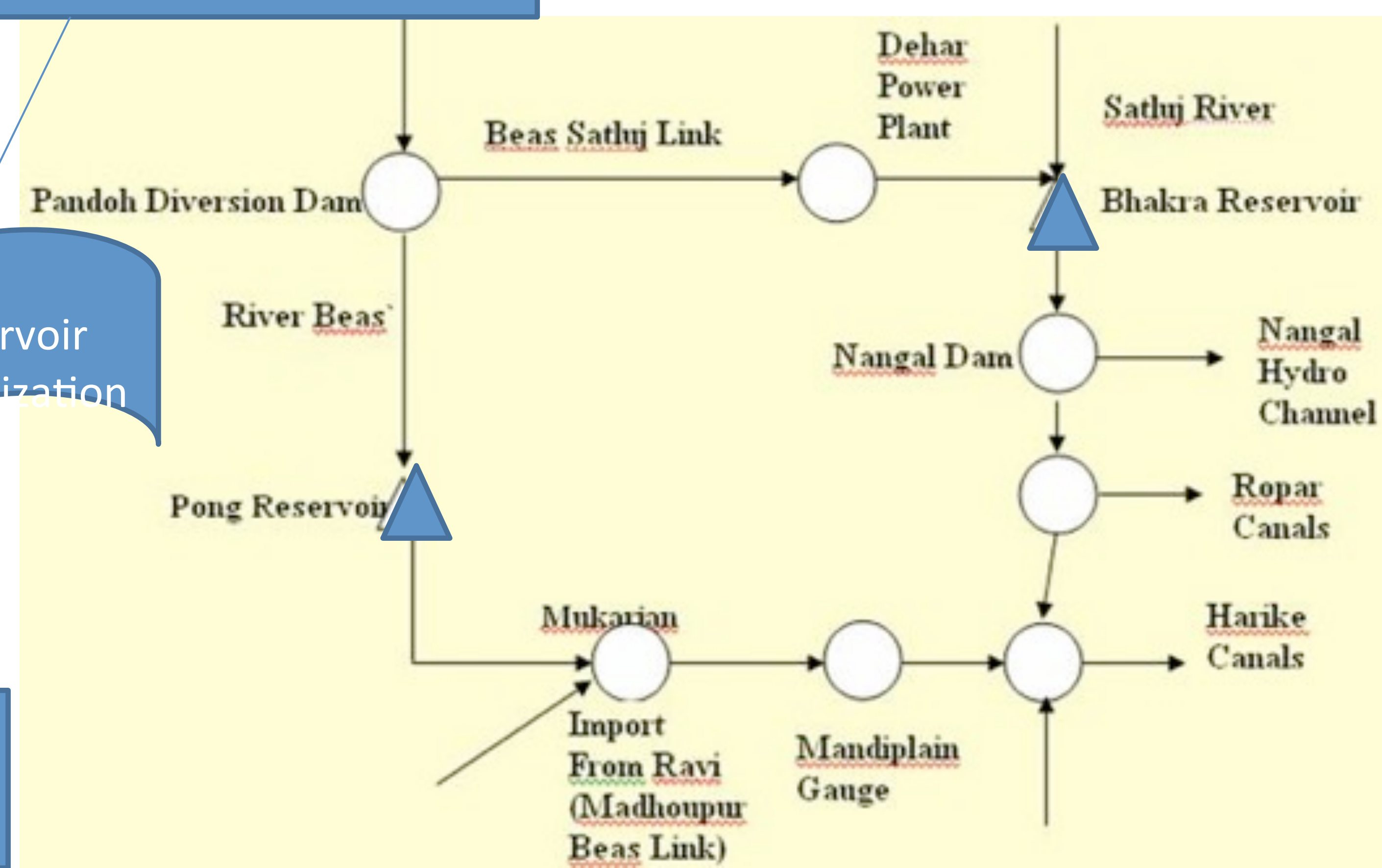
Multiobjective reservoir simulation-optimization model

Updated Reservoir operating policy

Current reservoir level & recent flow history

0-14 day weather forecasts & Short term inflow forecasts

Real time Reservoir Operation Optimization



Training and Collaboration with Beas Bhakra Management Board /Interface to DHI DSS

Summary

- Fine spatio-temporal scale estimates of climate over the next 10 to 50 years are needed for long-term planning in water resource and flood management.
- Stochastic simulation in conjunction with reservoir management models provides a pathway to adapt to climate change by building resiliency through testing sensitivity to hydroclimate drivers.
- Empirical stochastic models in conjunction with proxy reconstructions of hydroclimate provide a means to resolve decadal-scale variations and test potential predictabilty