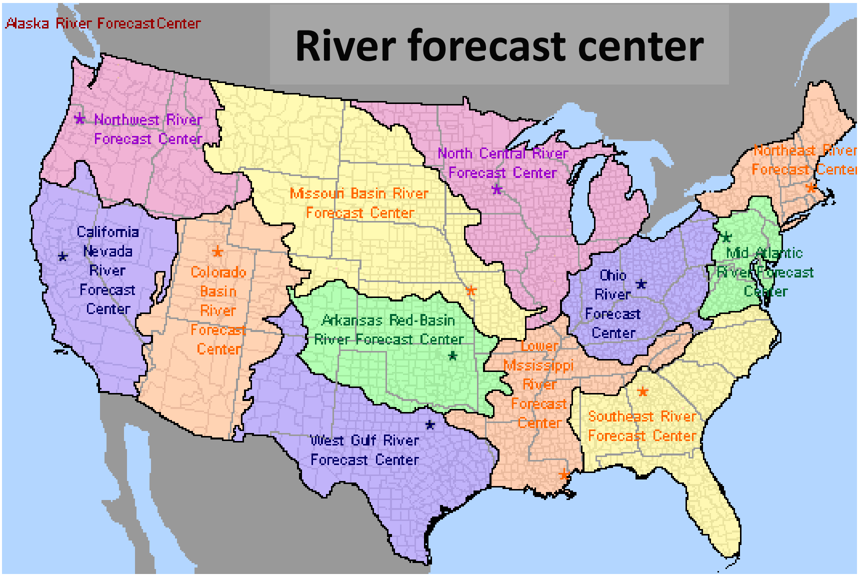
Enhancing Ensemble Streamflow Forecasting through an Integrated Multimodel System

Sanjib Sharma & Alfonso Mejia
Penn State

Aug. 29, 2019

Need of multimodel streamflow forecasting!



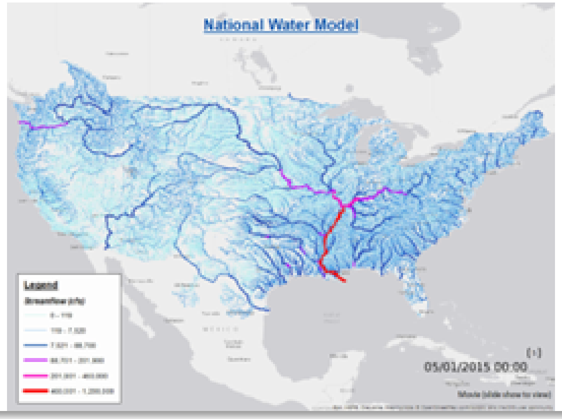
- ❑ **River forecast center**
  - ❑ Regional
  - ❑ Probabilistic forecasts (Experimental)
  - ❑ Spatially lumped modeling

- ❑ **National Water Model**
  - ❑ Continental
  - ❑ Spatially distributed modeling
  - ❑ Deterministic forecasts

Current River Forecast Points (~3,600)

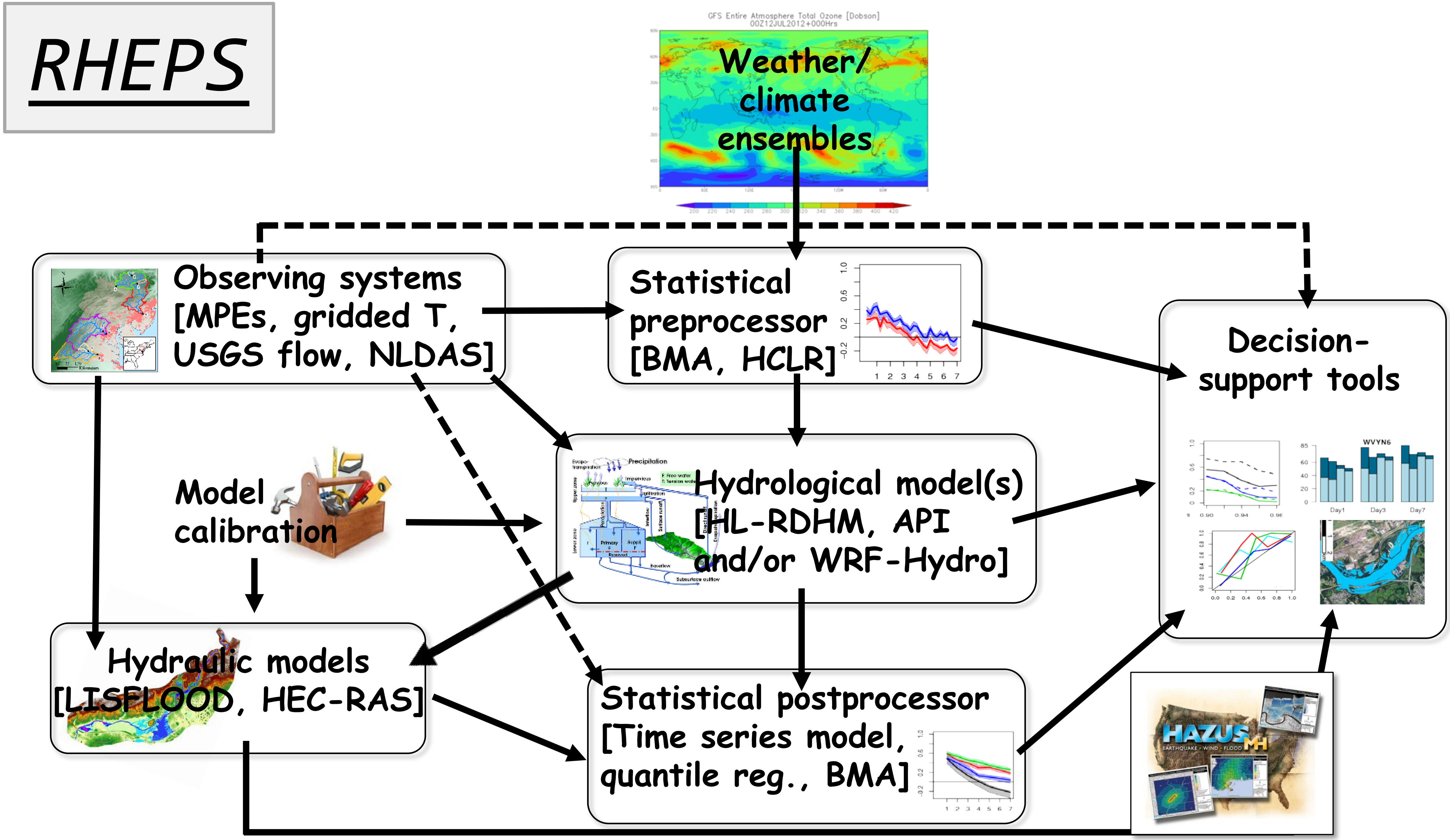
+

NWM Streamflow Output Points (~2.7 mil)



OWP OFFICE OF WATER PREDICTION

We assemble, implement and verify a regional hydrological ensemble prediction system [RHEPS]



RHEPS
GFS Entire Atmosphere Total Ozone [Dobson]
00Z12JUL2012+000Hrs
Weather/ climate ensembles
Observing systems [MPEs, gridded T, USGS flow, NLDAS]
Statistical preprocessor [BMA, HCLR]
Decision-support tools
Model calibration
Hydrological model(s) [HL-RDHM, API and/or WRF-Hydro]
Precipitation
Hydraulic models [LISFLOOD, HEC-RAS]
Statistical postprocessor [Time series model, quantile reg., BMA]
WVYN6
Day1
Day3
Day7
HAZUS MH
EARTHQUAKE · WIND · FLOOD

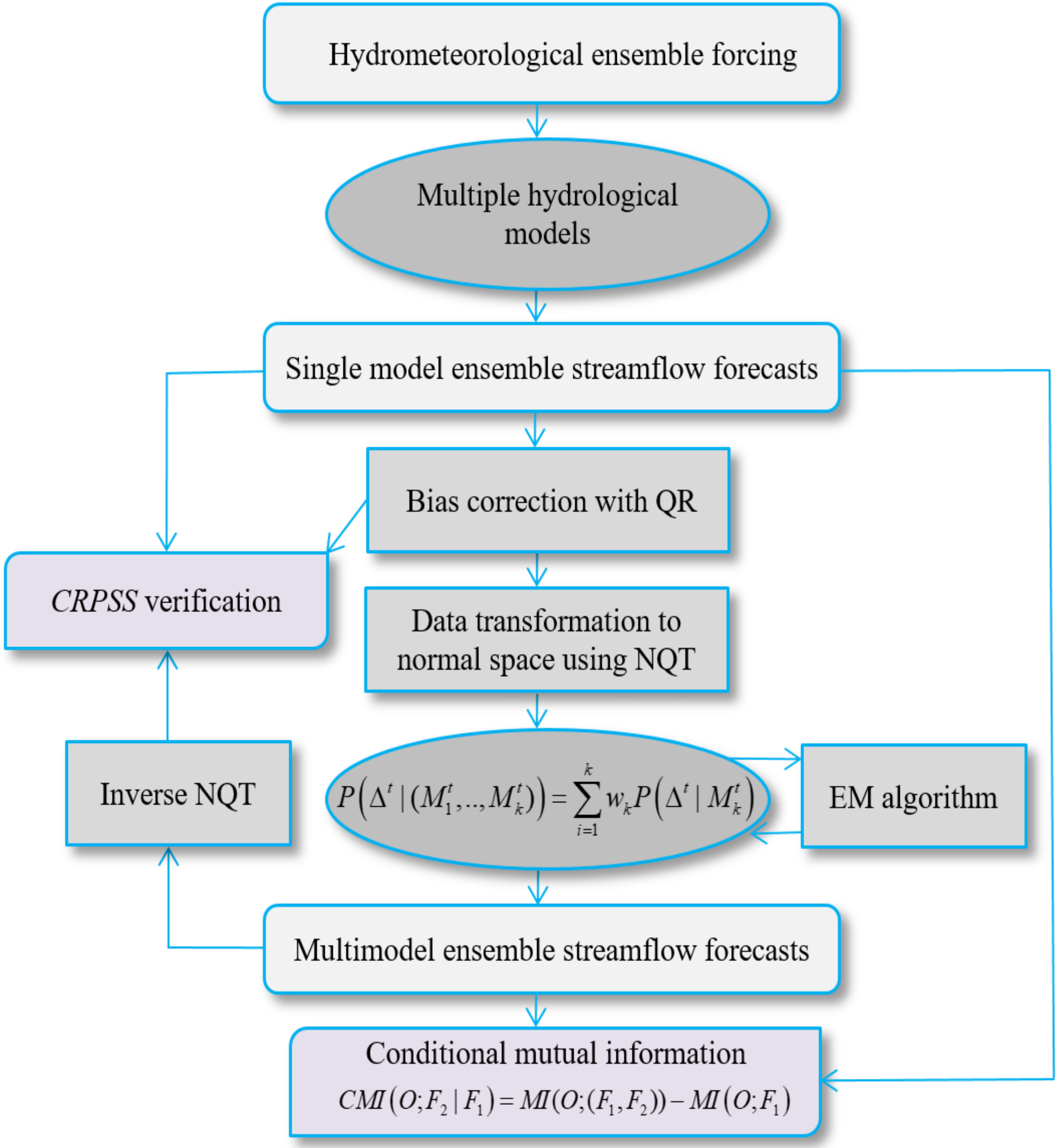
	Analysis/Simulation	Short-to-medium range	Subseasonal to seasonal	Long-term projection
Model Initialization	Hourly observations	Daily at 00Z	Every 10 days at 00Z	Daily Ens (13 mem)
Forecast Duration	Hourly [2002-2017]	1-7 days [2003-2013]	1-90 days [2002-2017]	1981-2099
Meteorological/Climatological Forcing	MPEs/Gridded T, NLDAS	GEFSRv2	CFSv2	CMIP5
Number of ensembles	Deterministic	11 ensembles	8 ensembles (time-lagged)	13 ensembles
Applications	Real-time streamflow information	Flood (inundation) forecast	Drought prediction, Water quality prediction & Agricultural planning	Flood hazard and risk assessment

RHEPS uses HPC system from Penn State and also tested to run in the cloud

Are multimodel ensemble streamflow forecasts more skillful than single-model forecasts?

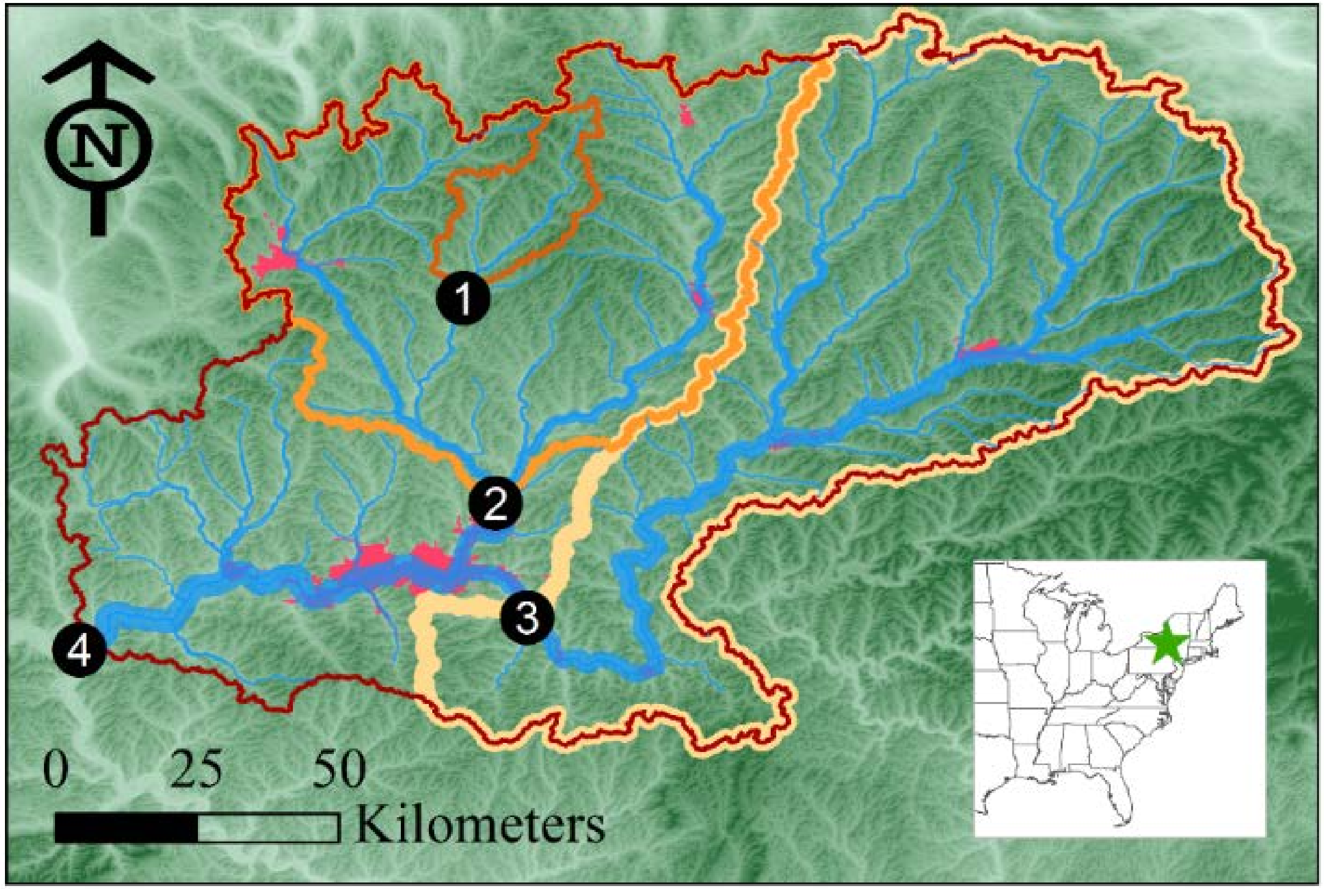
Hydrological models considered

- HL-RDHM (**distributed, conceptual**)
- Continuous API (**lumped, conceptual**)
  - Operational forecasts from NOAA’s MARFC
- WRF-Hydro (**distributed, land surface**)
  - Employs land surface model NoahMP
  - Gridded wave diffusion routing
  - 1x1 km^2 resolution
  - Dynamically Dimensioned Search (DDS) used for calibration



PENNSTATE
1855

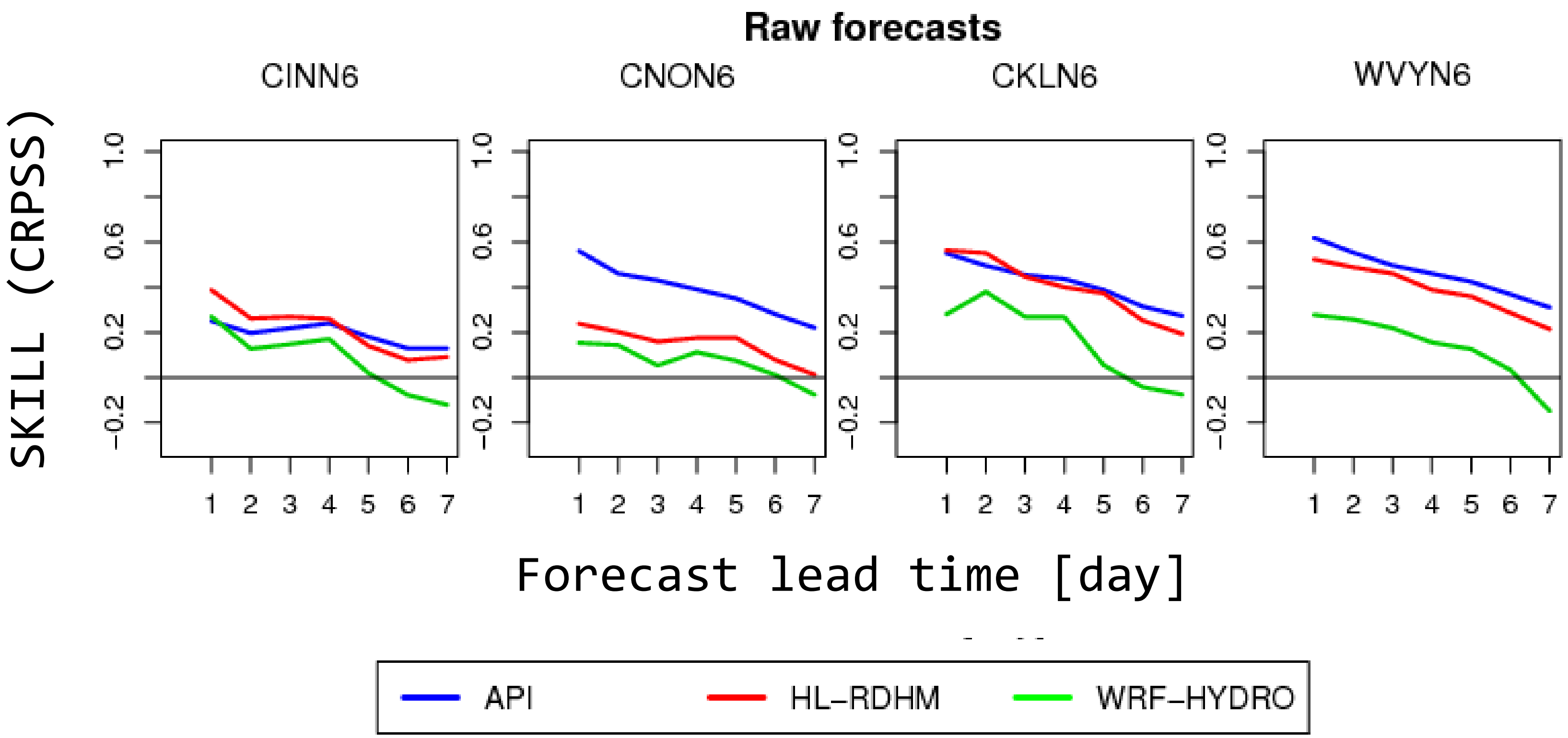
Four nested subbasins are chosen in the Middle Atlantic region



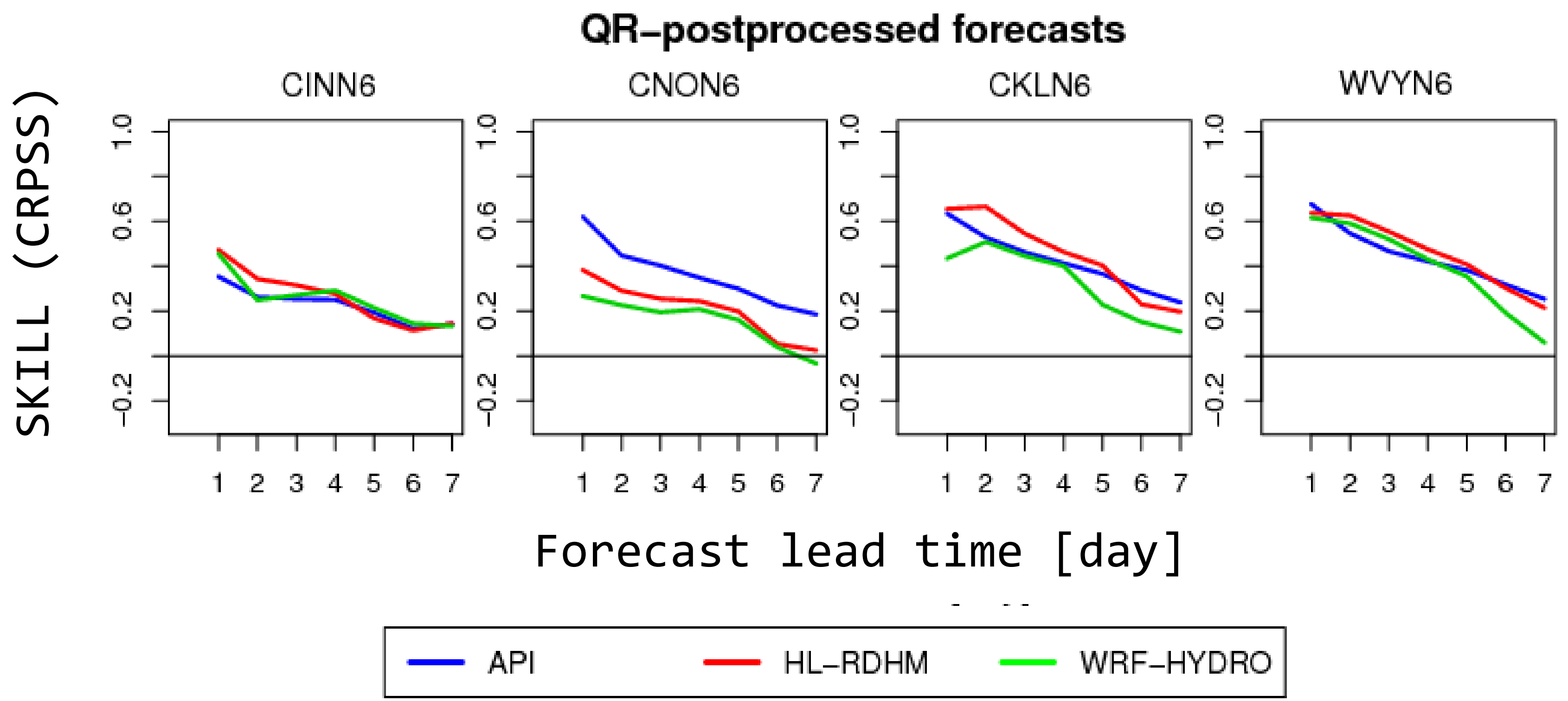
❶ Cincinnatus
❷ Chenango Forks
❸ Conklin
❹ Waverly

- Six years of multimodel forecast data are used for verification (2004-2009, warm season only).
- Verification is performed conditioned on forecast lead times (1-7 days) and basin scale.

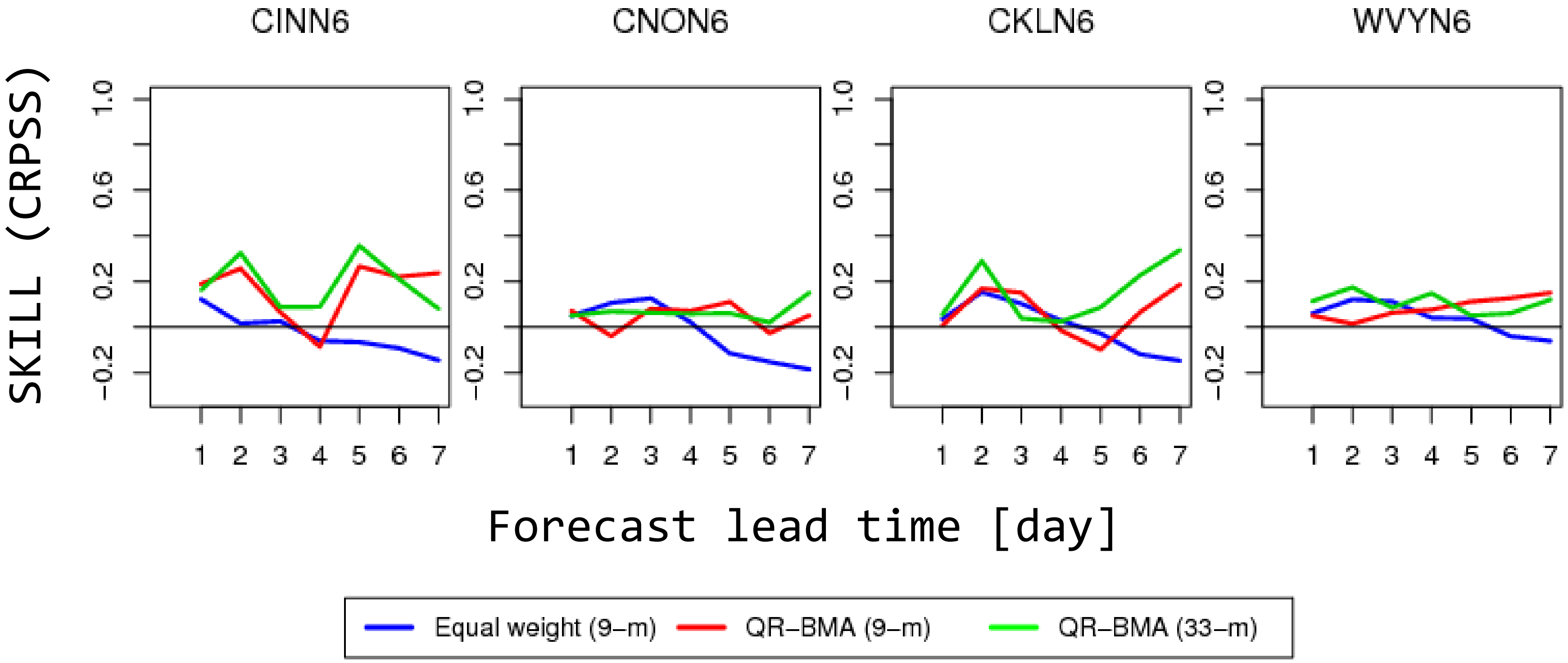
API and HL-RDHM tend to outperform WRF-Hydro for raw forecasts



All the models have comparable skill after QR-postprocessing



Multimodel forecasts have higher skill than the best single model forecast



Reference system
Postprocessed API

Are any skill improvements in multimodel forecasting dominated by model diversity or the addition of new ensemble members?

Conditional mutual information (CMI) is used as a skill measure

F_1 represents the single model forecast

F_2 represents the multimodel forecasts of the remaining models

$$\mathrm{CMI}(\mathrm{O};\mathrm{F}_2|\mathrm{F}_1) = \mathrm{MI}(\mathrm{O};(\mathrm{F}_1,\mathrm{F}_2)) - \mathrm{MI}(\mathrm{O};\mathrm{F}_1)$$

Decrease in uncertainty due to adding a second forecast

PENNSTATE
1855

CMI can be expressed as a function of partial correlation

$$\mathrm{CMI} \leq -\frac{1}{2}\log\left(1-\rho_{O2|1}^{2}\right)$$

Upper bound on skill improvement due to adding new ensemble member from same model:

$$\rho_{O2|1} \leq \sqrt{\frac{E_2}{(E_1+E_2)(E_1+1)}}$$

For E_1=3 and E_2=6

$$\mathrm{CMI} \leq 0.09$$

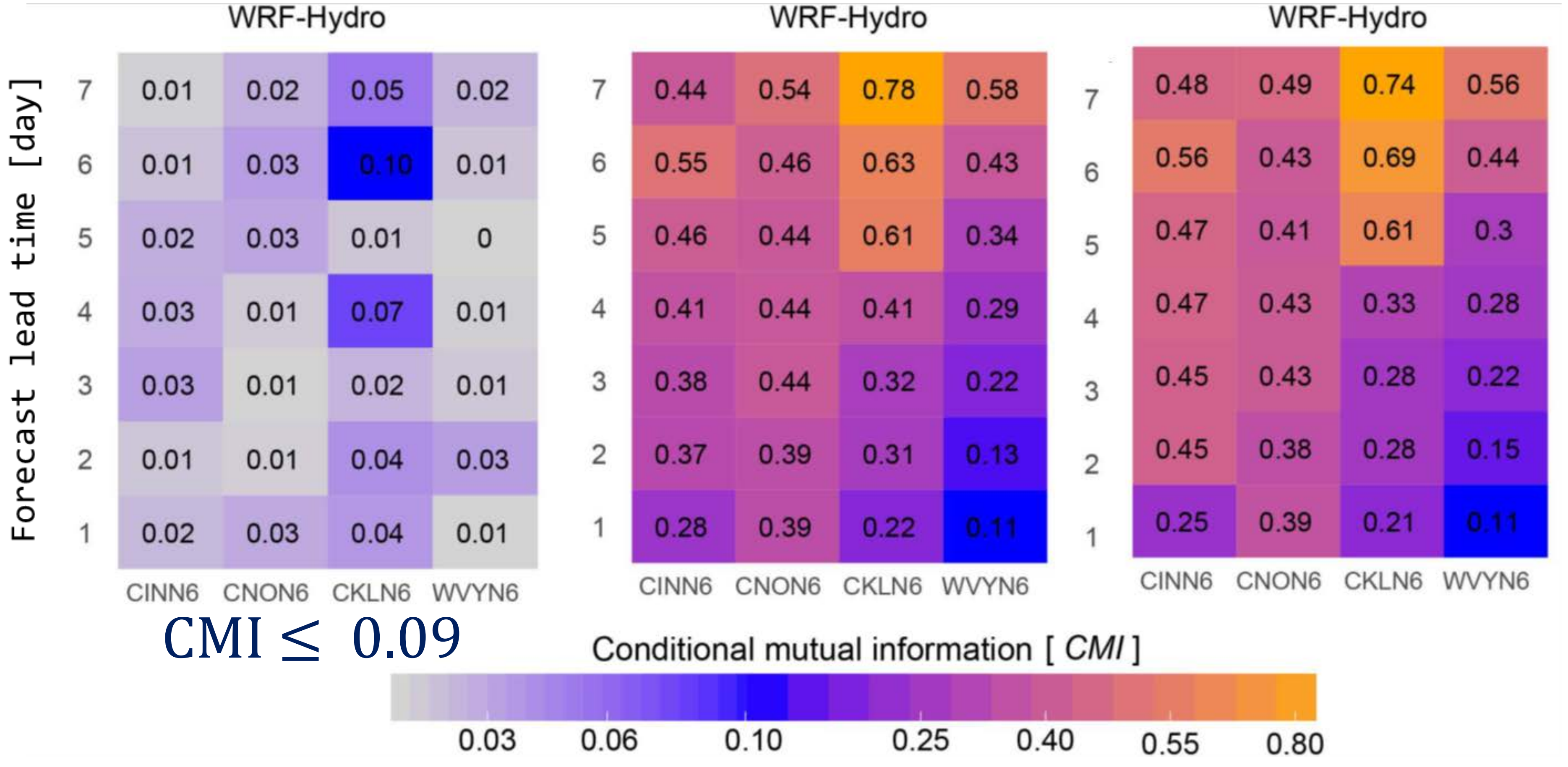
PENNSTATE 1855

Hydrological model diversity enhances forecast skill more than the ensemble size

9-m single model

9-m Multimodel
3 members each

33-m Multimodel
11 members each



PENNSTATE

It is concluded that…

- ❑ Multimodel ensembles are more skillful compared to the best single model forecasts.

- ❑ Each single model contributes additional information to enhance forecast skill.

- ❑ **Skill enhancements obtained by multimodel forecasts are found to be dominated by model diversity, rather than by increased ensemble size alone.**

PENNSTATE 1855

Thank you for your attention!

Contact:
Sanjib Sharma sanjibsharma66@gmail.com
Alfonso Mejia amejia@engr.psu.edu

Papers

Sharma*, S., G. Heather, G. Jorge, and A. Mejia (2019): Seasonal hydroclimate predictions anticipate nutrient and sediment loads using a dynamical-statistical approach, *Environmental Research Letter*.

Sharma*, S., R. Siddique, S. Reed, P. Ahnert, and A. Mejia (2019): Hydrological model diversity enhances streamflow forecast skill more than the ensemble size, *Water Resources Research*.

Sharma*, S., Siddique, R., Reed, S., Ahnert, P., Mendoza, P., and A. Mejia (2018): Relative effects of statistical preprocessing and postprocessing on a regional hydrological ensemble prediction system, *Hydrology and Earth System Sciences*.

Sharma*, S., R. Siddique*, N. Balderas*, J. D. Fuentes, S. Reed, P. Ahnert, R. Shedd, B. Astifan, R. Cabrera, A. Laing, M. Klein, and A. Mejia (2017), Eastern U.S. verification of ensemble precipitation forecasts, *Weather and Forecasting*.