Assessing streamflow predictability across the contiguous U.S. and opportunities to reduce uncertainties

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The predictability of streamflow across the contiguous USA

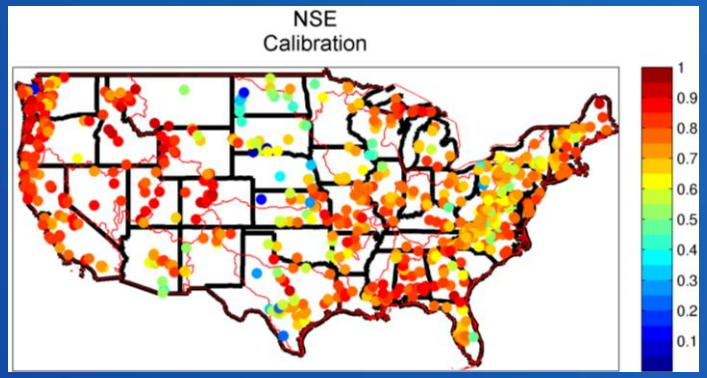
Gap(s) Addressed

Enhanced suite of hydrologic predictions spanning lead times of days to seasons and consistent with the continuum of weather to climate forecast products

More detailed meta-information describing product skill, reliability and development

Sample Results

CONUS basin scale calibration



Research Question(s)

1. What streamflow forecast skill can be realized through current methodological approaches and operational datasets?

2. For different types of forecasts and user needs, what method or data improvements are most critical?

Collaborators/Schedule/Source of Support

- Reclamation, US Army Corps of Engineers
- Schedule:
  - Fall 2013 -- Watershed simulation datasets, Idealized Predictability
  - Summer 2014 – Improved days to seasons forecasting, data assimilation, Case studies
- Funding: Reclamation, US Army Corps of Engineers; complemented by NOAA MAPP

RECLAMATION

Outline

- Motivation, Questions & Goals
- System Development & Performance
  - System development choices
  - CONUS calibration results
- Predictability Results
  - Regional variations in predictability
- Probabilistic Forcing
  - CONUS gridded forcing dataset
  - Example ensemble output
- Summary & Discussion

CAVEAT: The work described in this presentation is part of an exploratory research effort at the National Center for Atmospheric Research, and does not represent the official product of any state, local or federal agency. USE AT YOUR OWN RISK

Key reports

Addressing Climate Change in Long-Term Water Resources Planning and Management

User Needs for Improving Tools and Information

Executive Summary

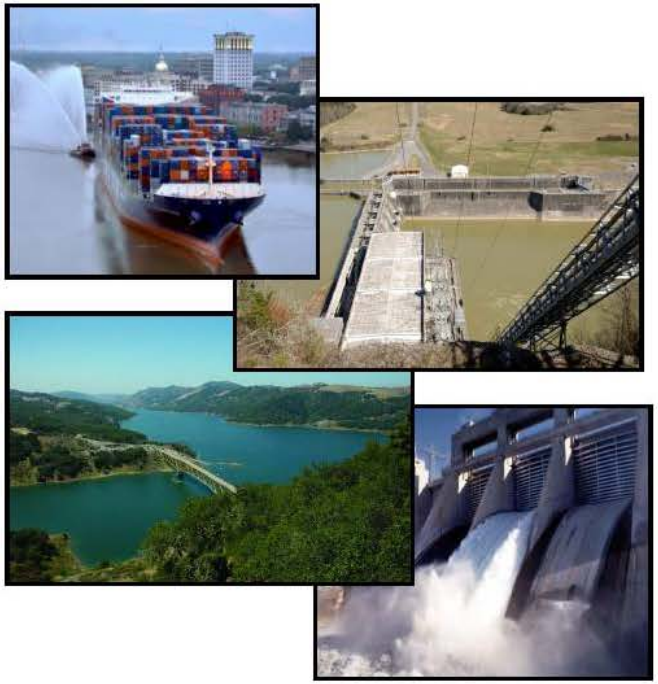
US Army Corps of Engineers®

January 2011

Approved for public release; distribution is unlimited

Short-Term Water Management Decisions

User Needs for Improved Climate, Weather, and Hydrologic Information



NOAA

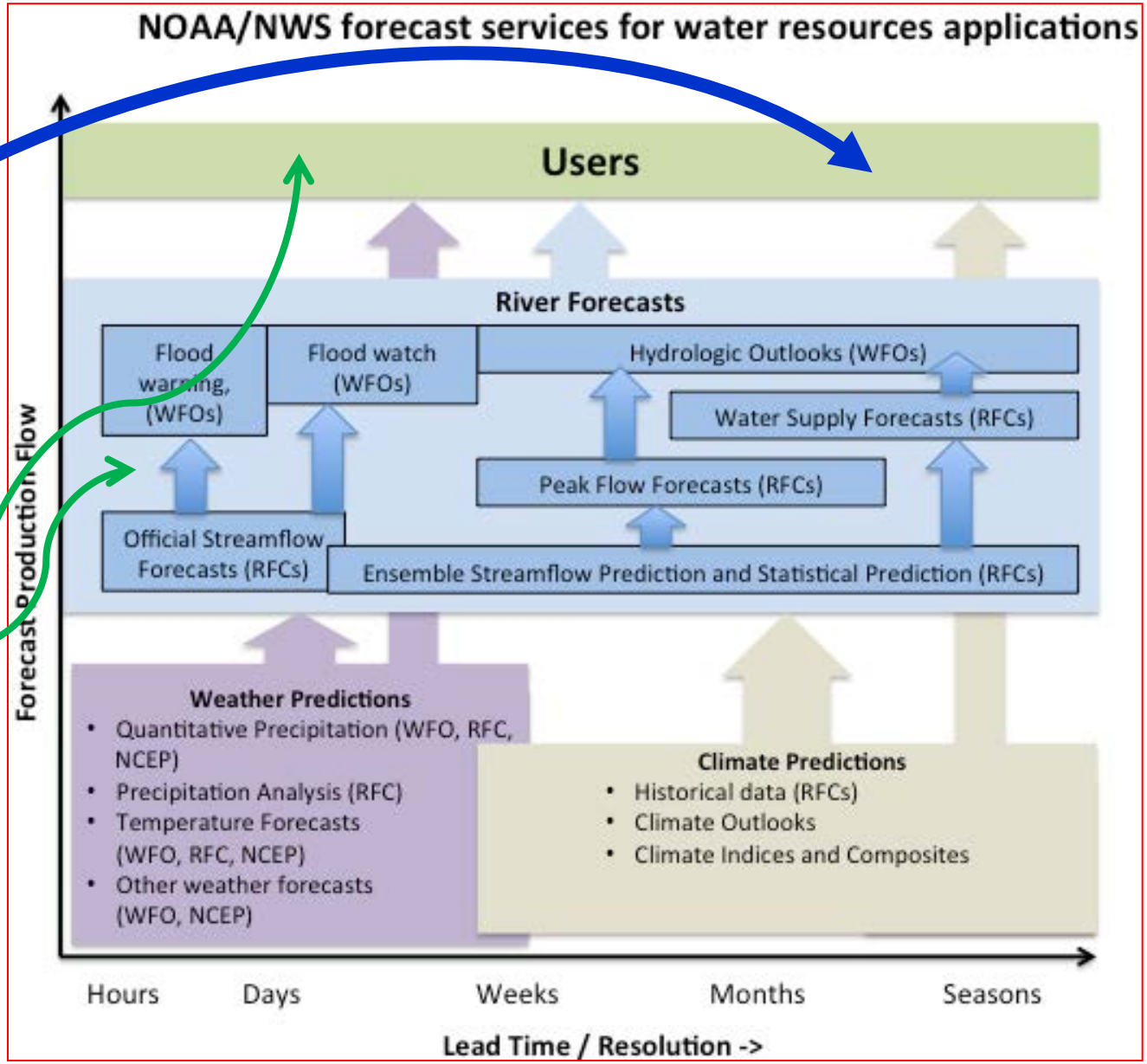
U.S. DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

US Army Corps of Engineers®

Monitoring and forecast products reviewed in the ST-doc

Also:
NRCS NWCC water supply forecasts

Monitoring products:
USGS stream gauging
NRCS SNOTEL
NRCS snowcourse
NWS COOP observer
RFC Precipitation analysis



ST doc needs

Category: Forecasting

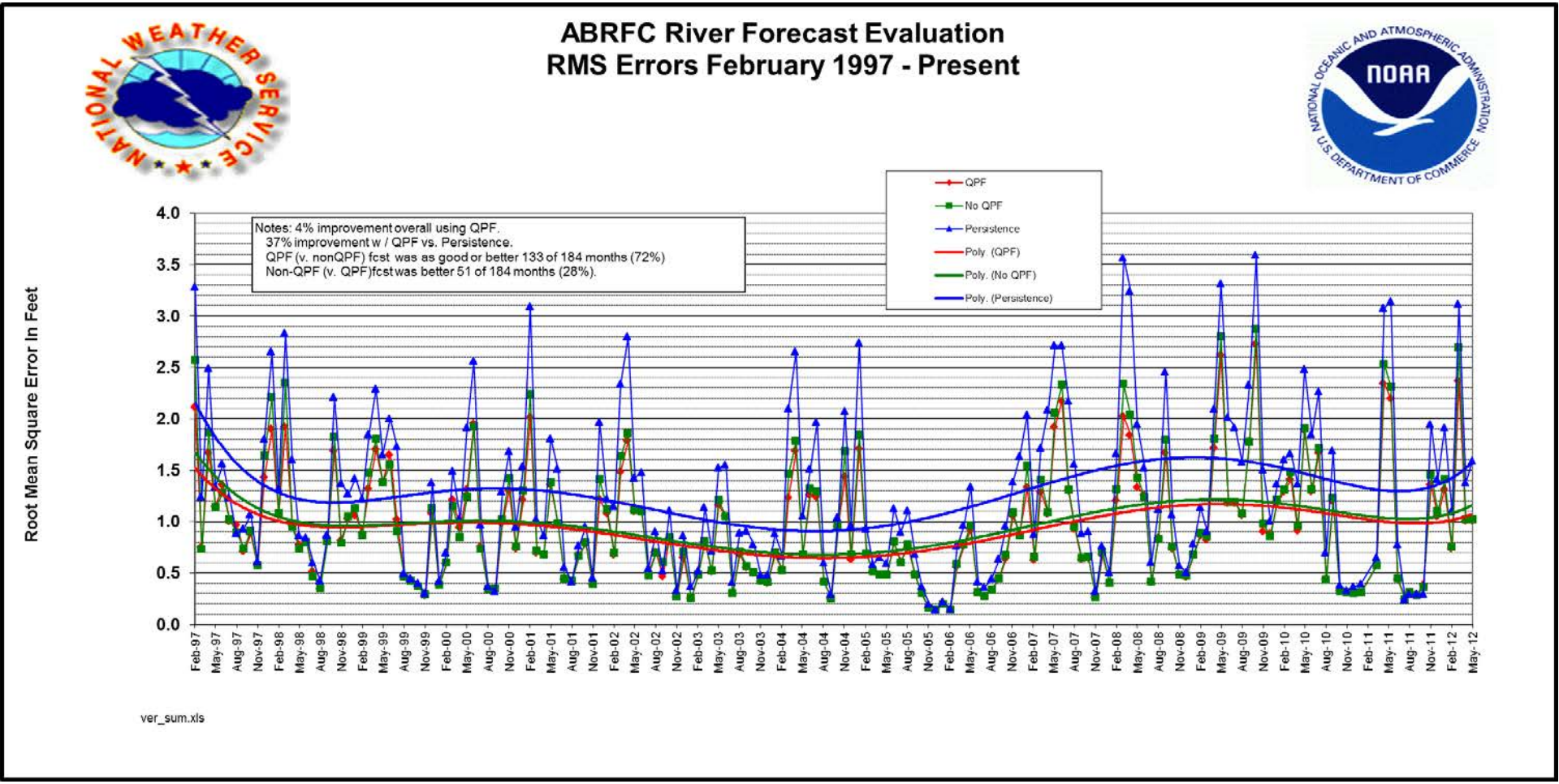
General	F1	Enhanced suite of hydrologic predictions spanning lead times of days to seasons and consistent with the continuum of weather to climate forecast products
Precipitation, supporting fine-resolution outlooks	F2	More reliable quantitative precipitation forecasts (QPF) with lead times of hours to days
	F3	Improved precipitation forecasts for landfalling storms in coastal areas
Streamflow, supporting fine-resolution outlooks	F4	Enhanced streamflow predictions with lead times of hours to days, particularly during storm events
Streamflow, supporting medium-resolution outlooks	F5	Enhanced streamflow predictions with lead times of days to weeks, particularly during the snowmelt season
Runoff volume, supporting coarse-resolution outlooks	F6	Improved anticipation of runoff volumes with lead times of months to seasons
Water level	F7	Enhanced prediction products characterizing potential water levels during storm events
Other hydroclimate	F8	Multivariate suite of climate to hydrologic predictions that comprehensively characterizes the state and evolution of basin hydrologic conditions with lead times of days to seasons

Category: Understanding and Using Information Products in Water Management

Information on product development and qualitative attributes	U1	More detailed meta-information describing product skill, reliability, and development
Information synthesis	U2	Guidance on how to synthesize available hydroclimate information relative to its collective applicability to water management situations

Are operational forecasts improving?

In the last 2 decades, there have been notable advances in capabilities supporting hydrologic prediction. *Are we harnessing those advances*?



http://www.srh.noaa.gov/abrfc/fcstver/fcstver_view.php?img=versum1.gif&alt=1997-to-Current

Science Questions & Approach

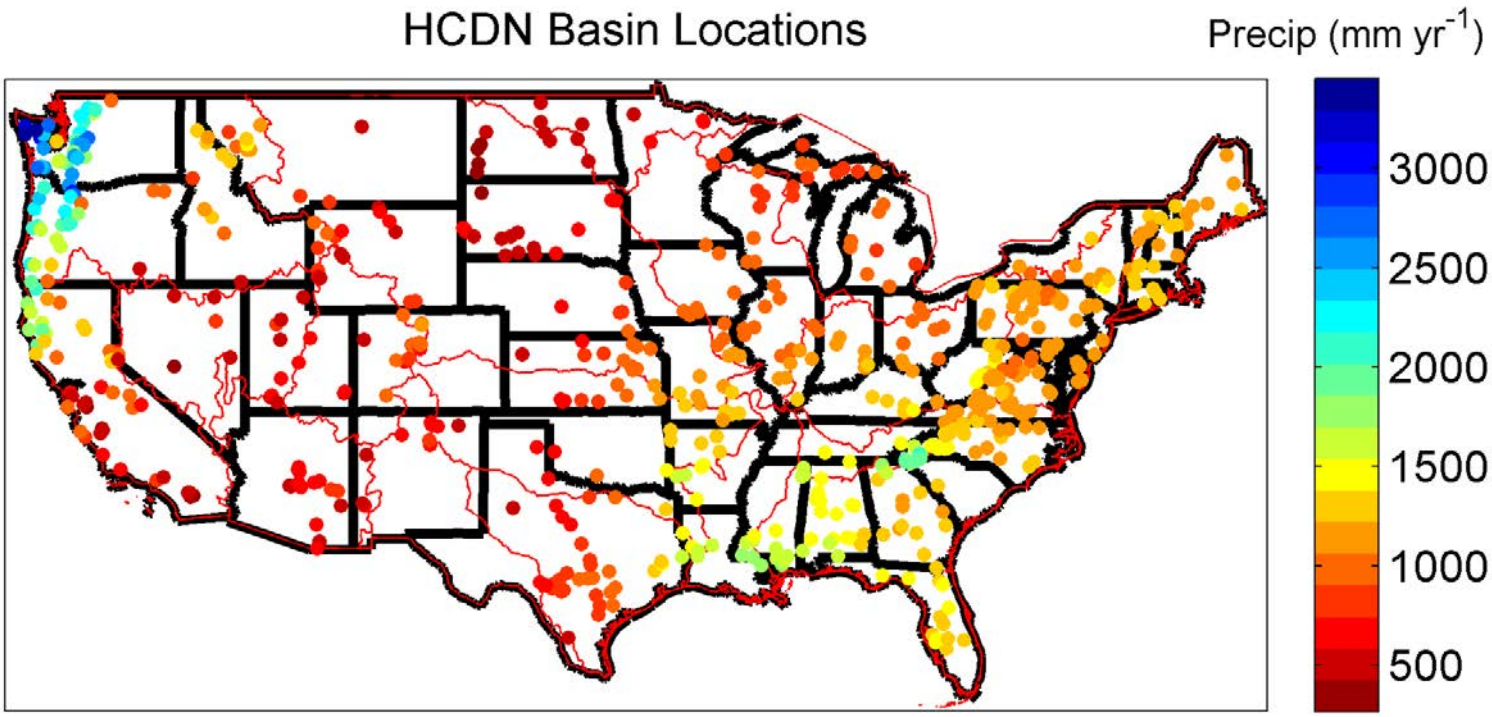
- Overarching questions:
  - For different types of forecasts and user needs, what method or data improvements are most critical?
  - What streamflow forecast skill can be realized through current methodological approaches and operational datasets?

- *To develop answers to above question:*
  - Implement a CONUS wide watershed simulation framework
  - Identify opportunities through CONUS wide predictability experiments (eg quantifying initial condition vs. meteorological forcing importance)
  - Develop CONUS wide probabilistic precipitation and temperature datasets for a variety of purposes
  - Quantify benefits of state-of-the-art forecasting methodologies to reduce uncertainties
    - data assimilation, weather and climate forecasting, ensemble methods, post-processing, verification

SYSTEM DEVELOPMENT & PERFORMANCE

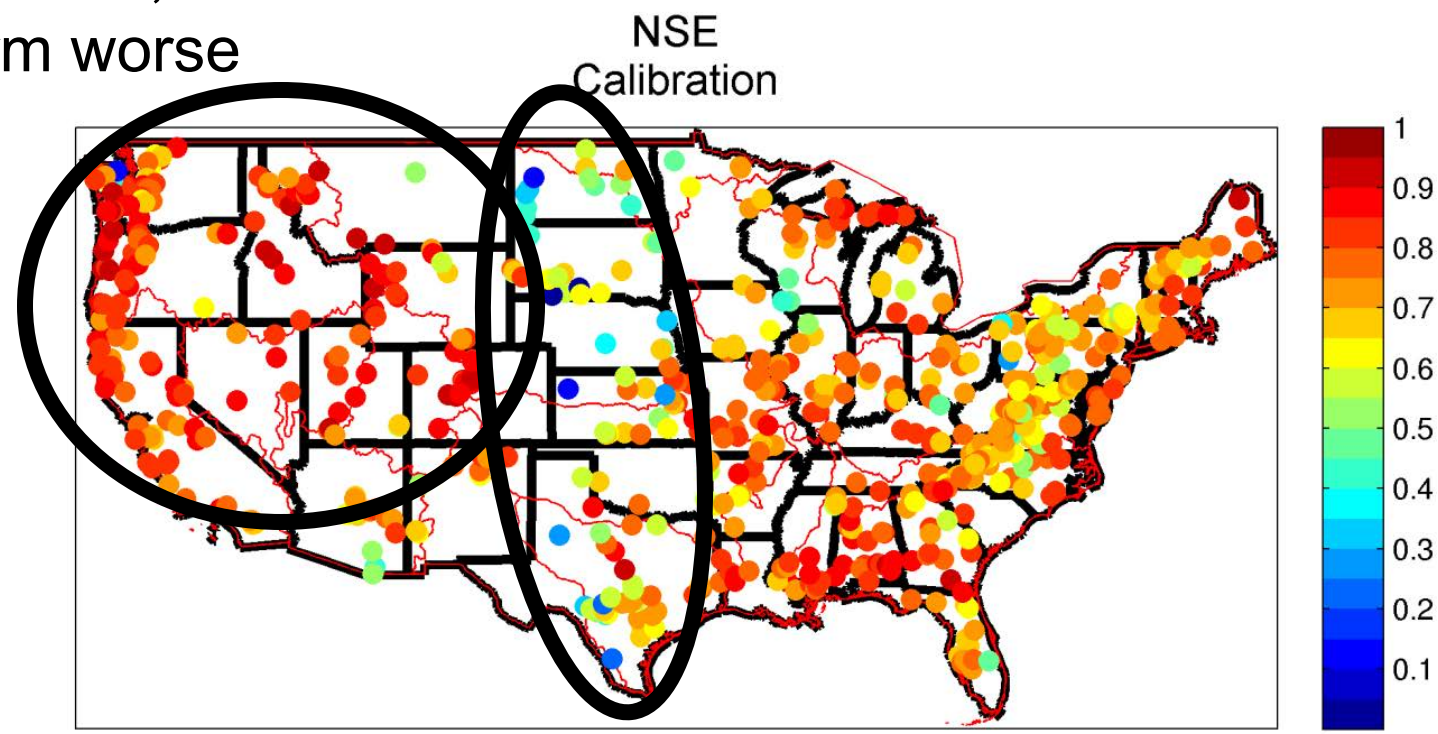
Data & Modeling System

- Basin Selection
  - Used GAGES-II, Hydro-climatic data network (HCDN)-2009
  - Forcing via Daymet (http://daymet.ornl.gov/)
  - National Weather Service operational Snow-17 and Sacramento-soil moisture accounting model (Snow-17/SAC)
  - Shuffled complex evolution (SCE) global optimization routine



Calibration Results ~670 basins

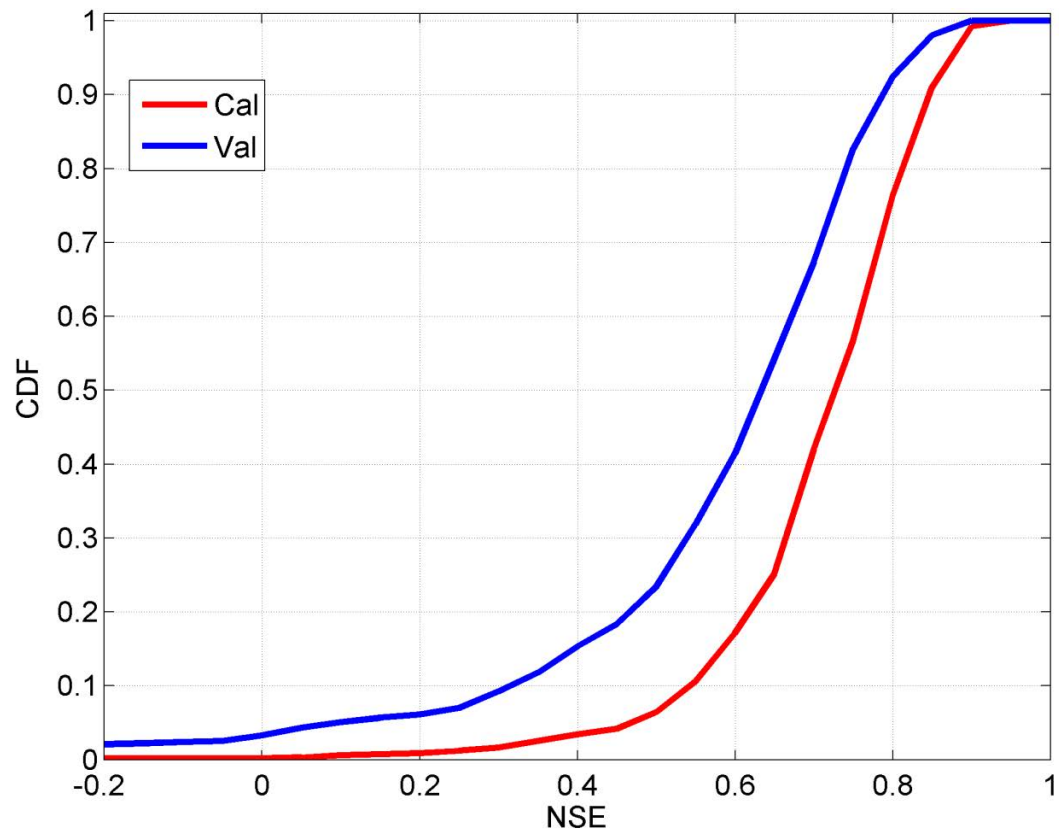
- Calibrated NSE varies across CONUS
  - Areas with seasonal snow, frequent precipitation perform best in terms of NSE
  - High plains, desert SW perform worse



Results are preliminary and subject to change

Calibration Results ~670 basins

- NSE CDF for calibration & validation periods
  - 90% of basins >0.55 NSE for calibration period
    - 15 yr calibration
    - Remaining years for validation
  - No QC at this point (besides data availability requirements)
  - Benchmark for all basins



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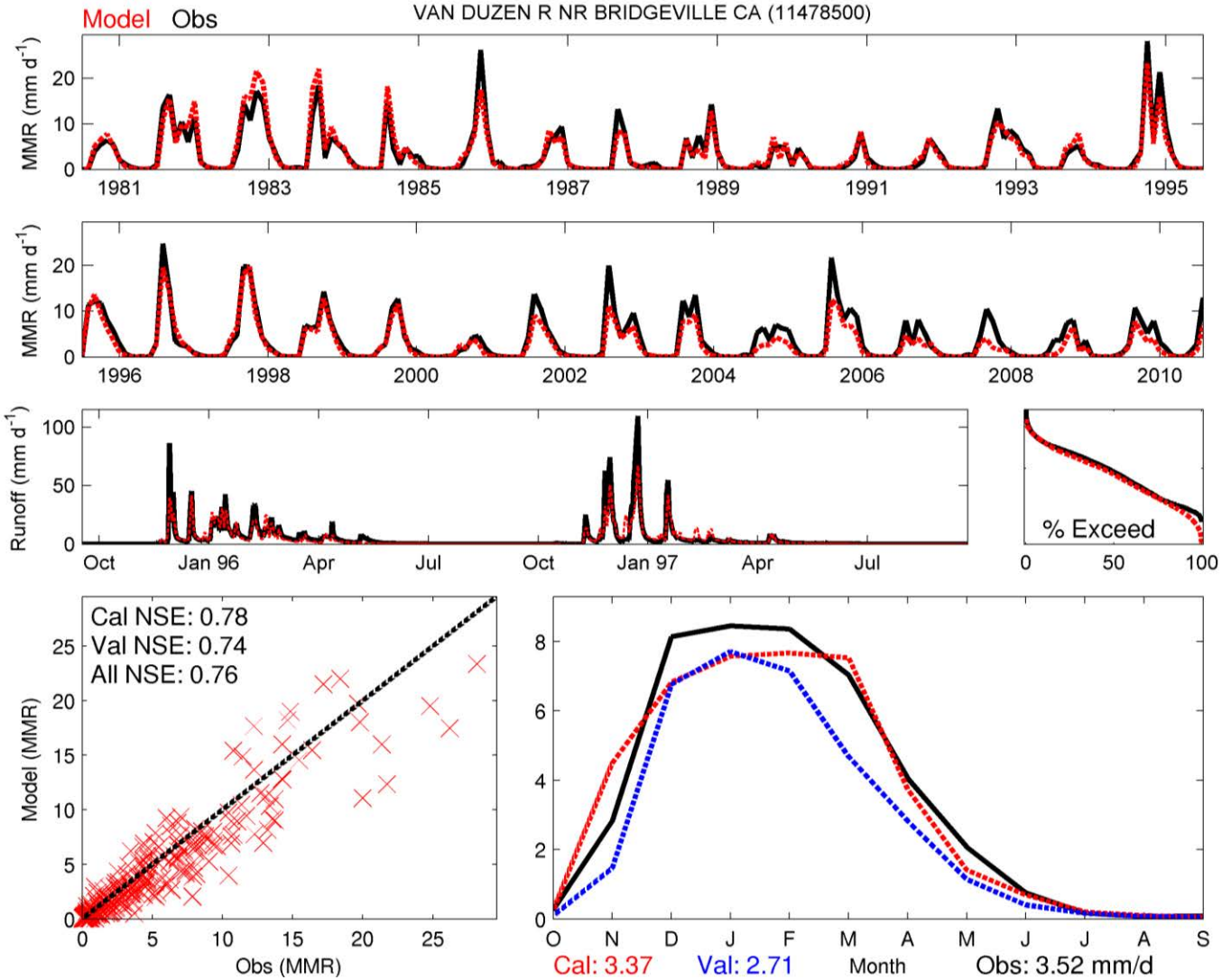
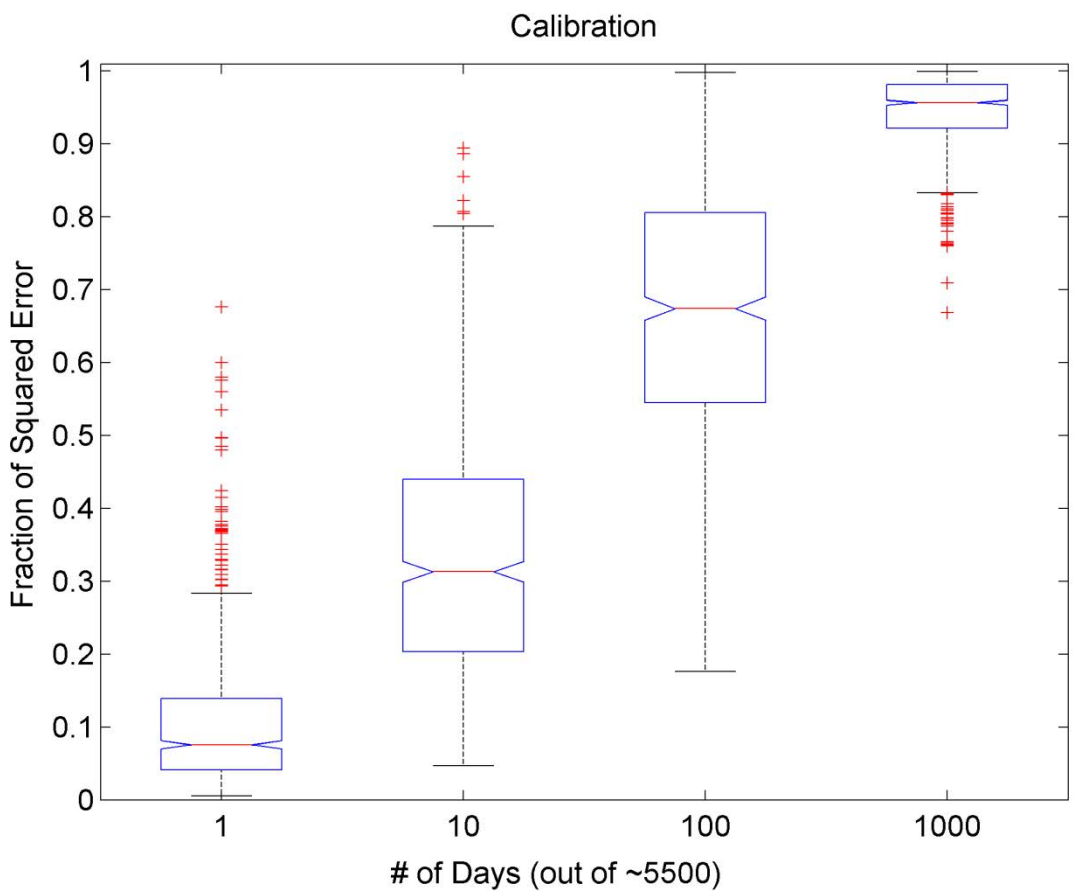
Calibration Results

- Example summary:



Hydro-Climatic Performance Variations

- Fraction of objective function due to *n* data points
- 50% of gages have ≤ 10 points contributing >33% of objective function value



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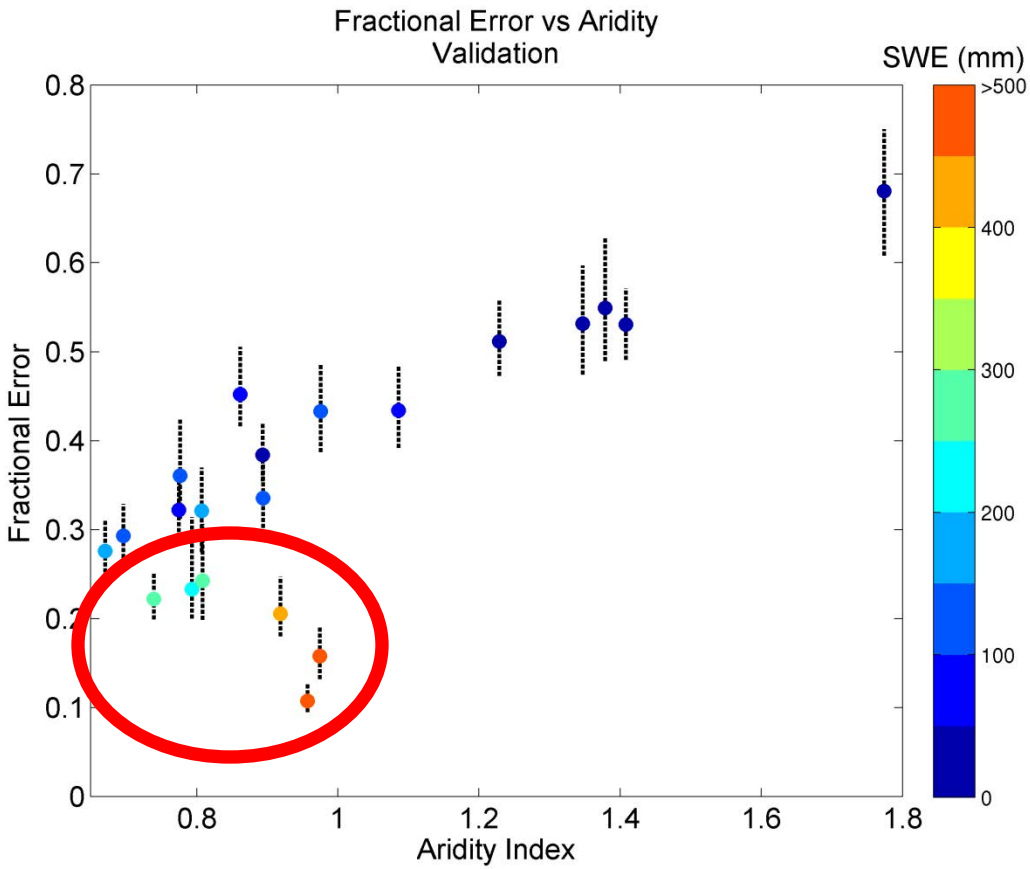
Hydro-Climatic Performance Variations

- Ranked Fractional Error (100 largest error days)
  - Fractional error increases with aridity
    - Infrequent extreme error events (skewed error distribution)
  - Basins with snowpack have more uniform errors
    - Fewer high error days



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Dataset Development Summary

- Developed forcing data time series for ~670 CONUS watersheds for basin (lump), hydrologic response unit (HRUs from PRMS) and elevation bands
- Acquired all available daily streamflow data from USGS

- Forcing data and streamflow records now available
  - Dataset is generating significant interest from various research groups

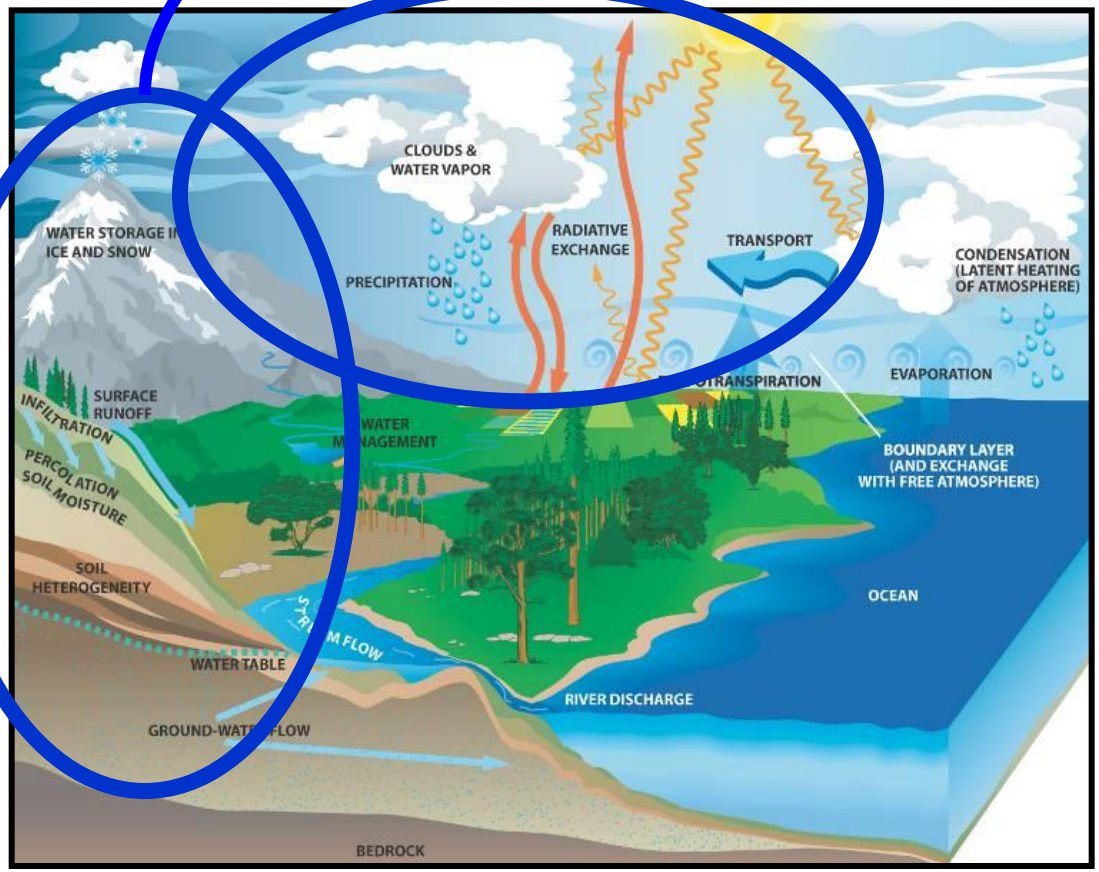
- Dataset and system description paper in preparation

PREDICTABILITY EXPERIMENTS

Opportunities for prediction

hydrological predictability

meteorological predictability



Water Cycle (from NASA)

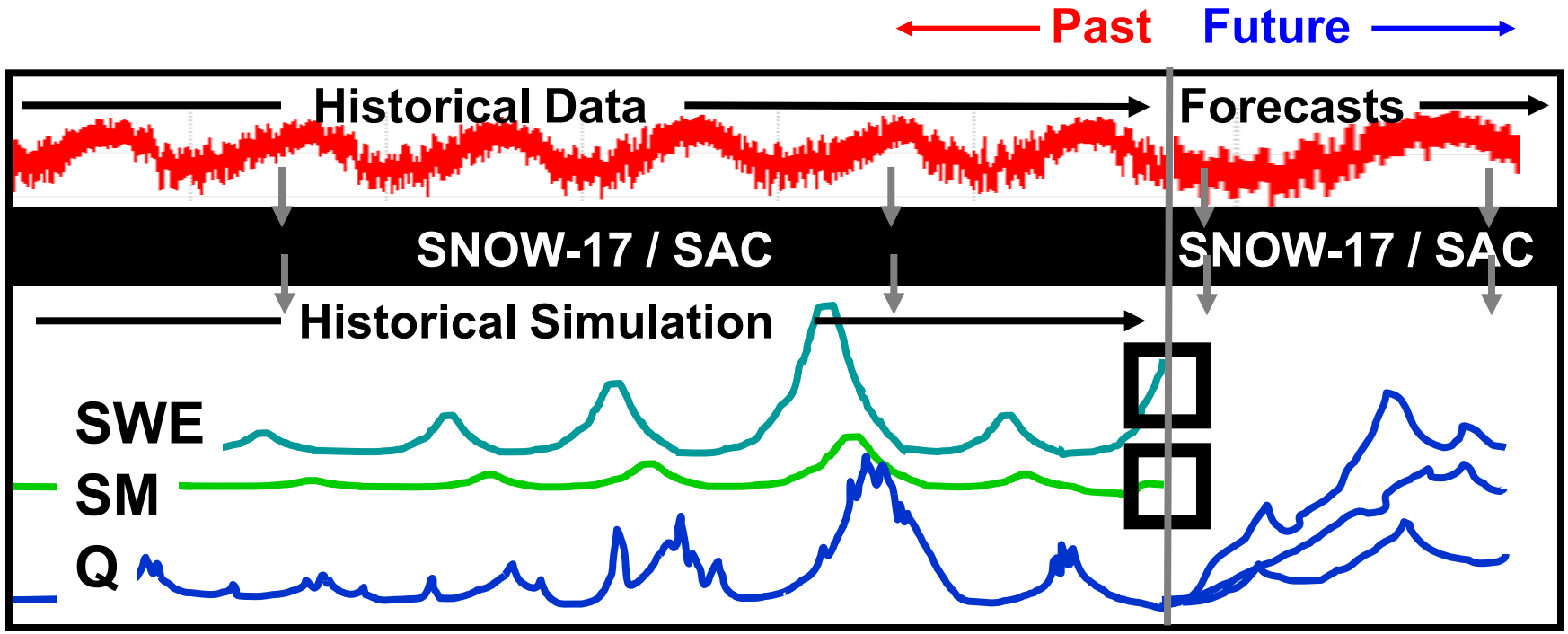
<u>Hydrological Prediction</u>: How well can we estimate the amount of water stored?

- Accuracy in precipitation estimates
- Fidelity of hydro model simulations
- Effectiveness of hydrologic data assimilation methods

<u>Meteorological predictability</u>: How well can we forecast the weather and climate?

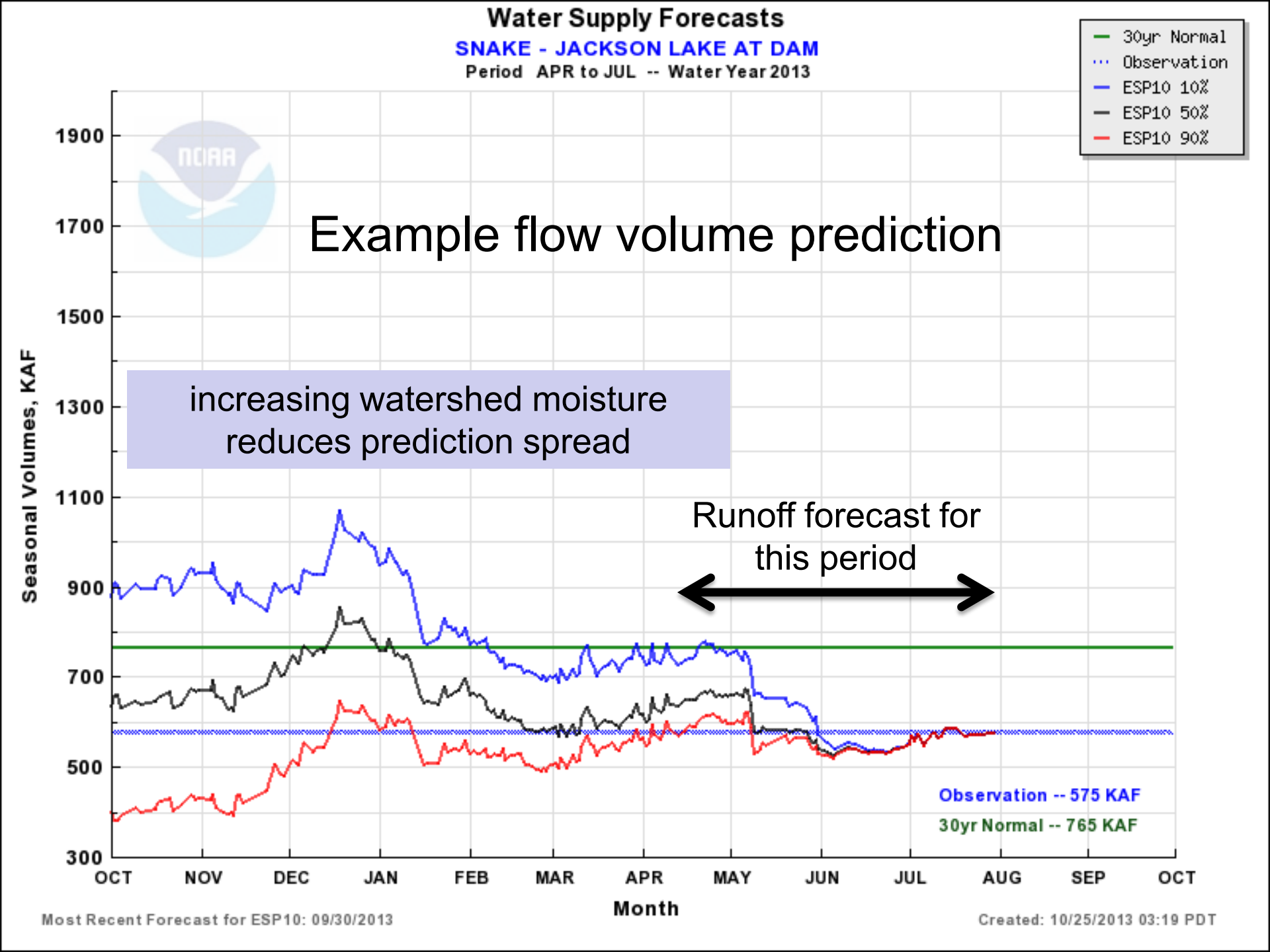
<u>Opportunities</u>: Which area has most potential for different applications?

Streamflow Prediction Challenges:
forecast future weather (hours to seasons)



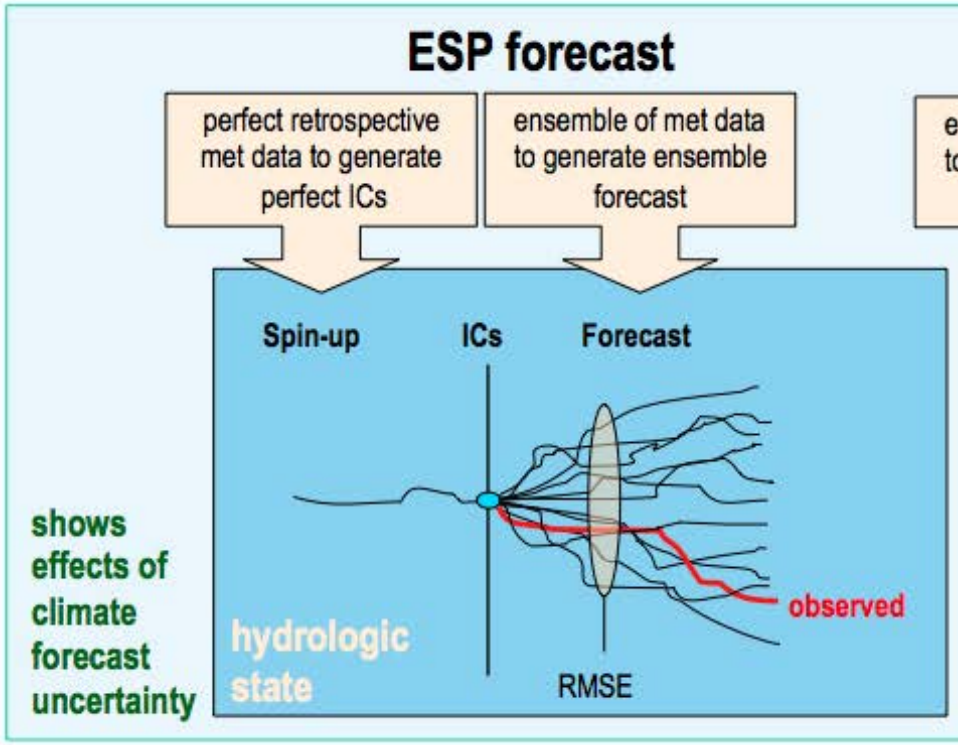
General State of Practice

- (near-period) use of numerical weather predictions; usage period varies by streamflow forecasting office and weather prediction skill in their region
- (far-period) climatology via Ensemble Streamflow Prediction (ESP), sometimes conditioned by seasonal climate forecasts (for seasons and locations having skill)
- aggregate to client needs (e.g., daily to seasonal information)


Water Supply Forecasts
SNAKE - JACKSON LAKE AT DAM
Period APR to JUL -- Water Year 2013
30yr Normal
Observation
ESP10 10%
ESP10 50%
ESP10 90%
Example flow volume prediction
increasing watershed moisture reduces prediction spread
Runoff forecast for this period
Observation -- 575 KAF
30yr Normal -- 765 KAF
Seasonal Volumes, KAF
1900
1700
1500
1300
1100
900
700
500
300
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
Month
Most Recent Forecast for ESP10: 09/30/2013
Created: 10/25/2013 03:19 PDT

Assessing Predictability

- ESP: Ensemble Streamflow Prediction
- NWS technique for model-based forecasting

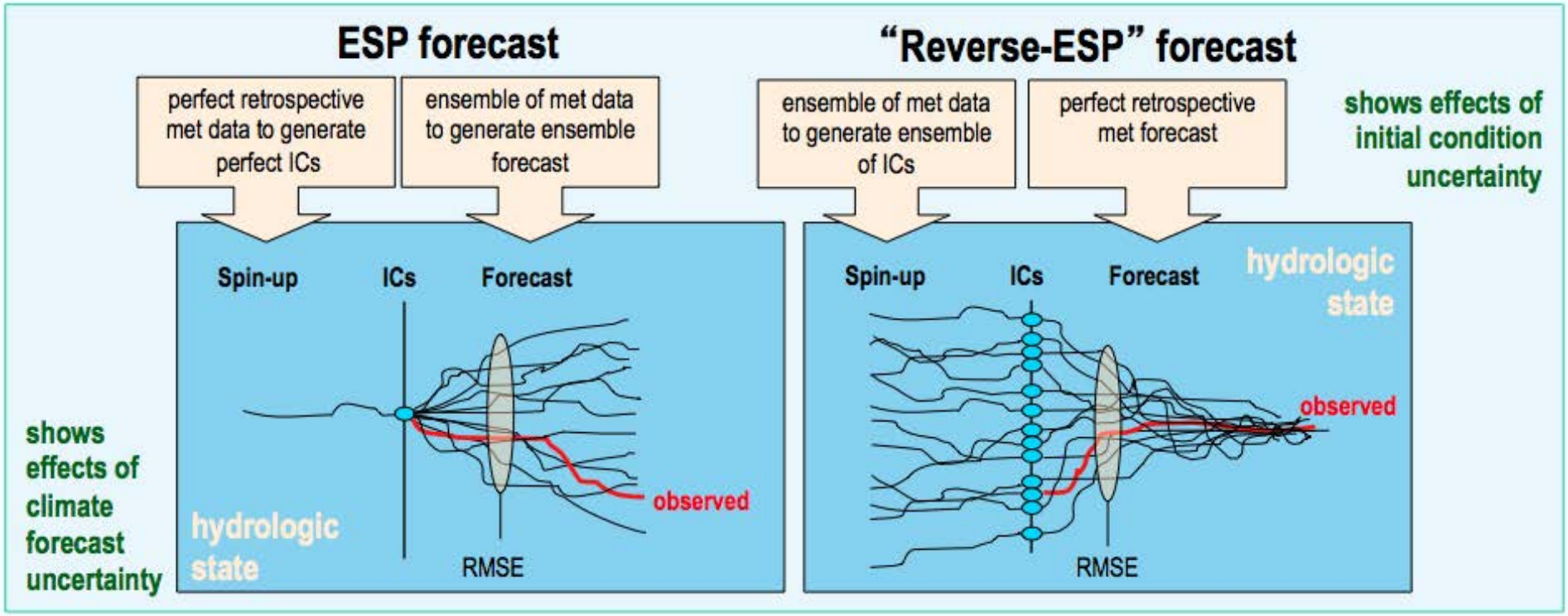


- The model is run up to the forecast date with observed weather
- The model's simulation of initial watershed conditions assumed to be perfect
- Future weather/climate is unknown, "climatological" – use an ensemble of historical weather sequences

Assessing predictability

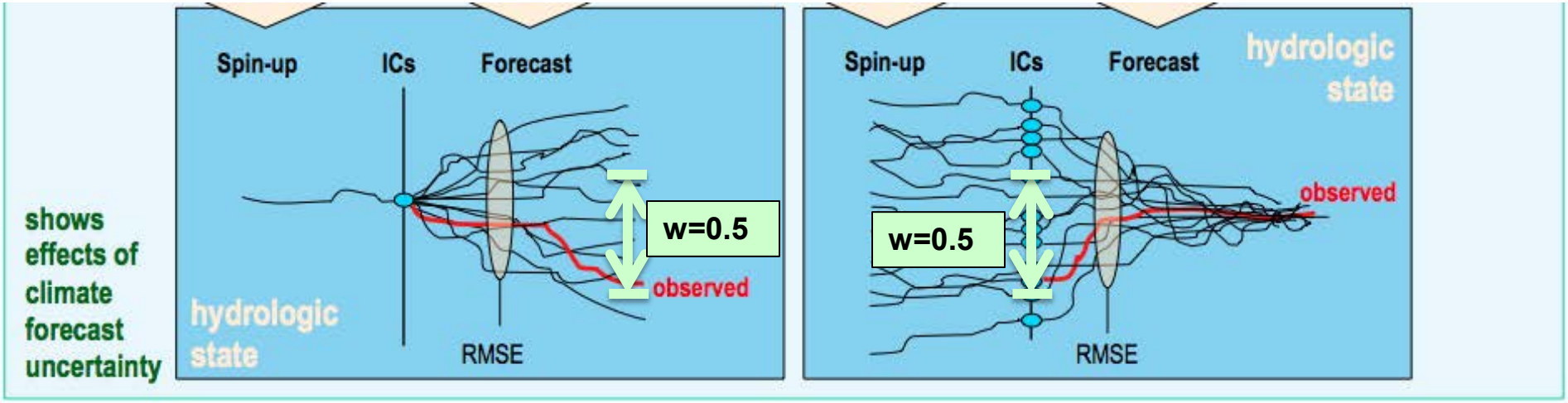
An Earlier Approach

- run hindcasts (many years of forecasts in the past)
- use ESP to measure benefit of known initial conditions (ICs), unknown met forecast
- use "reverse-ESP" to measure the effect of known met forecast, unknown future climate (Wood and Lettenmaier 2008, GRL)



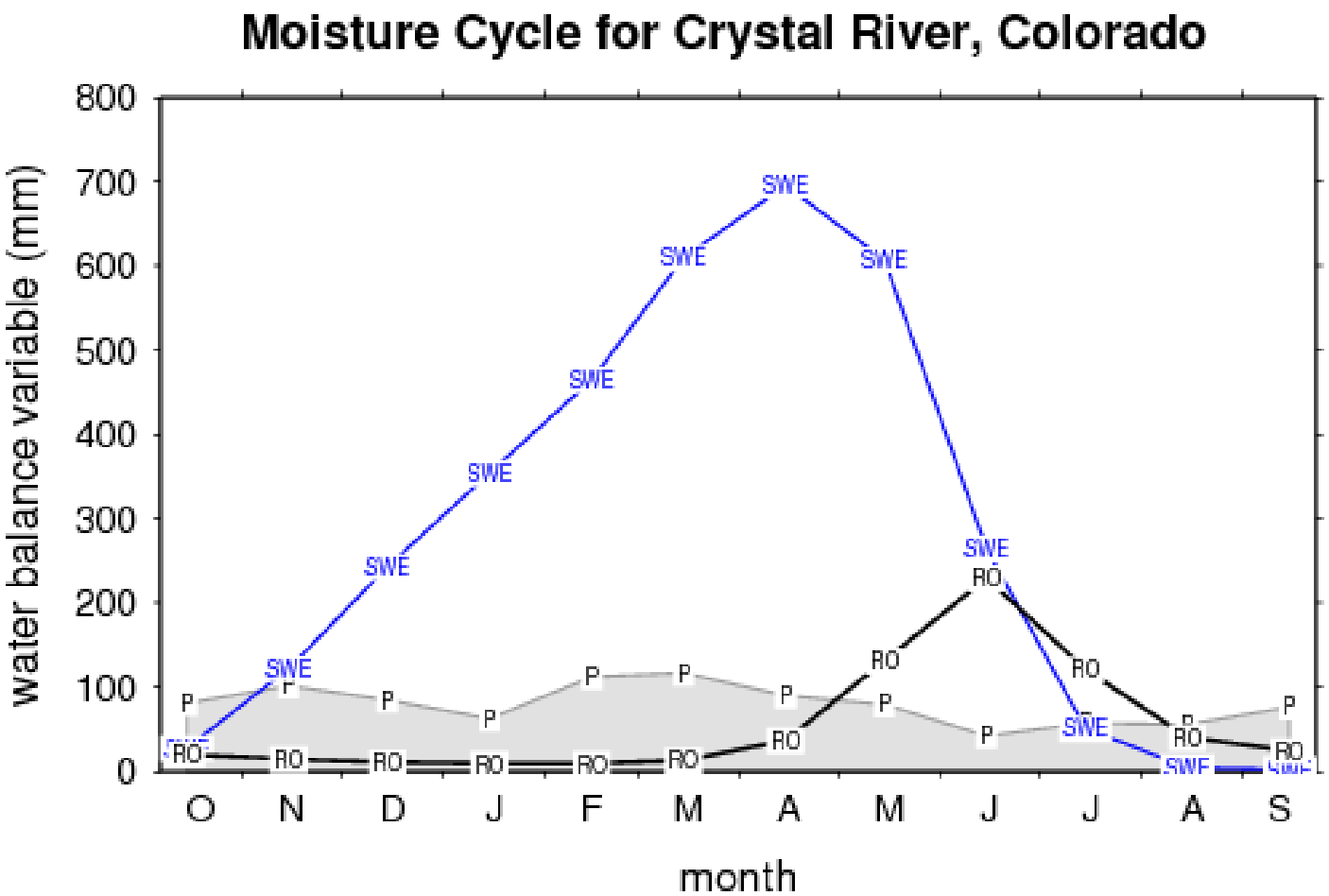
Moving beyond the end points

- ESP, 'reverse ESP' set the end-points
- What do more realistic uncertainties show?
- Expanded approach
  - Scale IC and Met Forecast variance (uncertainty) between
    - 0 = perfect knowledge
    - 1 = climatological uncertainty
  - Assess flow forecast skill for all combinations (81) of scalings:
    - 0, 0.05, 0.10, 0.25, 0.50, 0.75, 0.90, 0.95, 1.00



Seasonal Variation in Predictor Importance

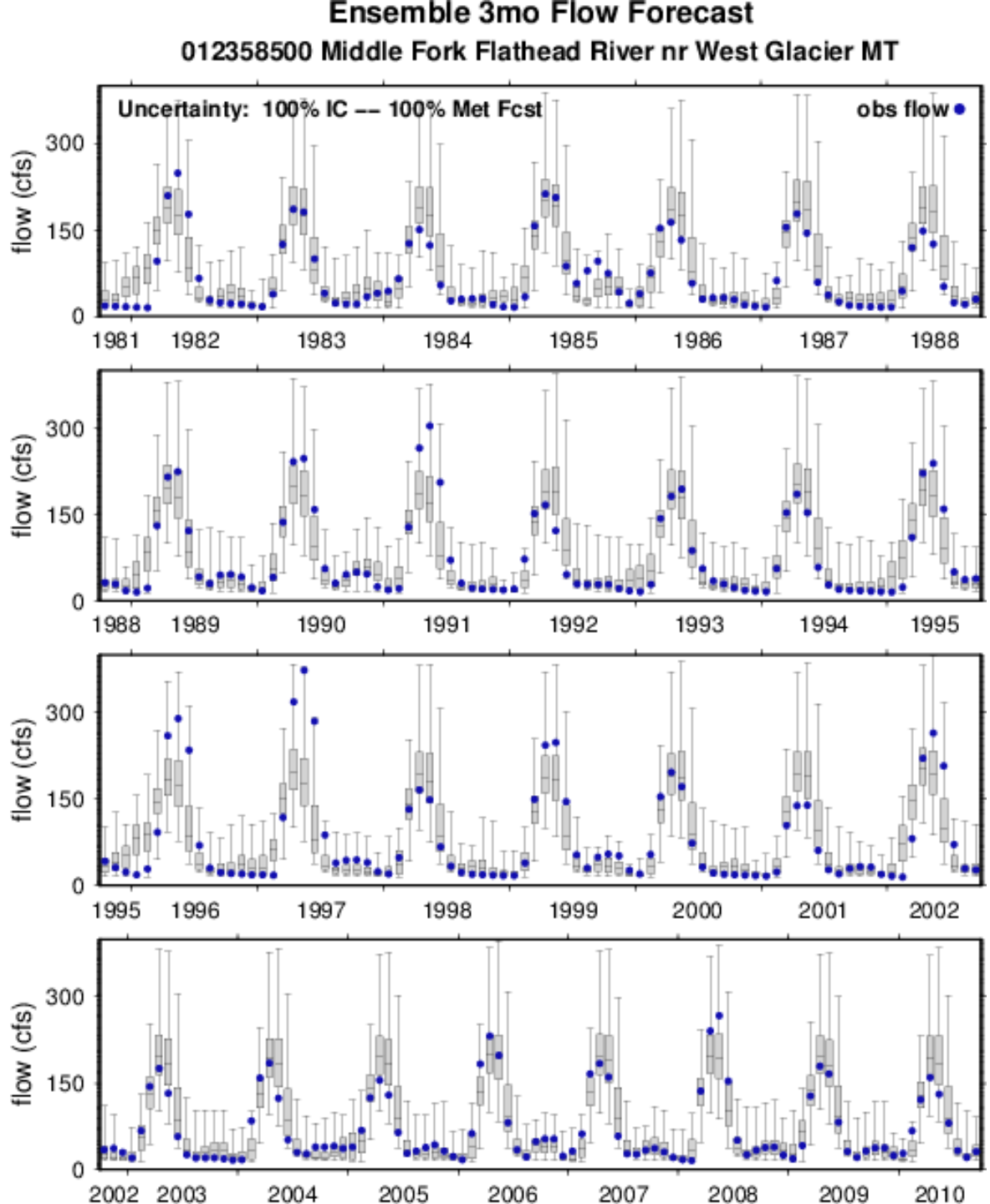
- Example: A snowmelt basin



no knowledge

variance weights

- IC = 1.0
- Met Fcst = 1.0



Results are preliminary and subject to change

ESP knowledge

variance weights

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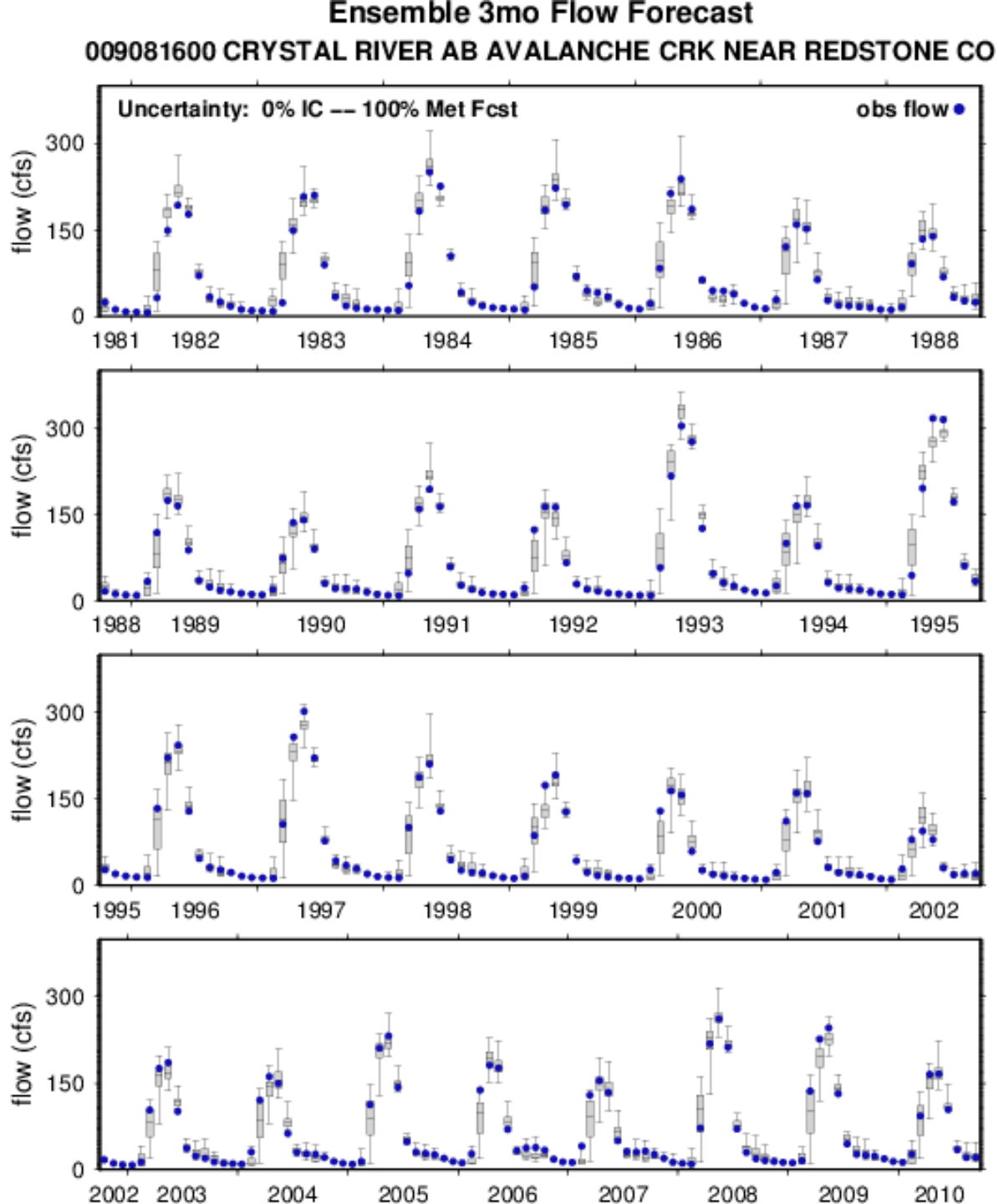

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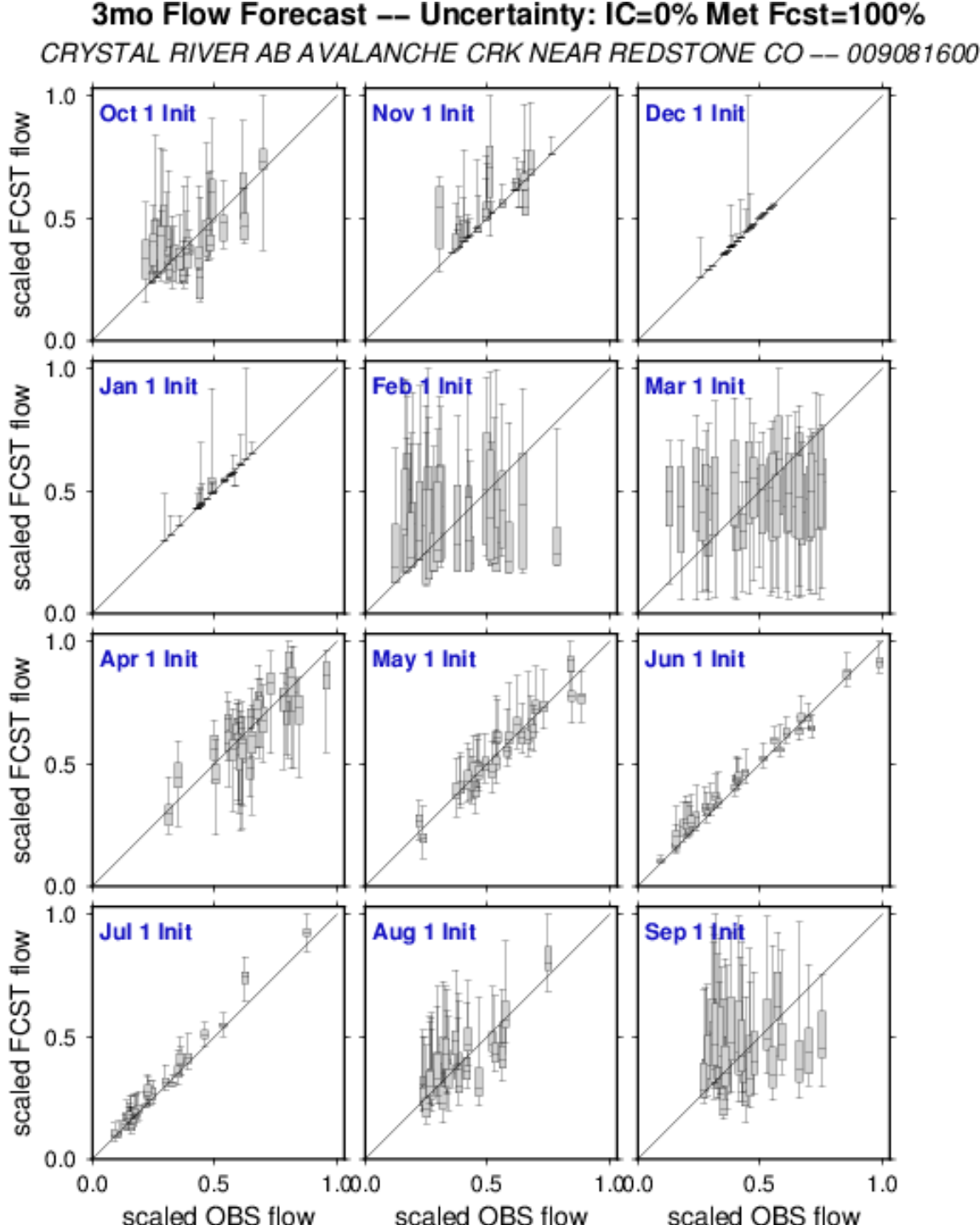

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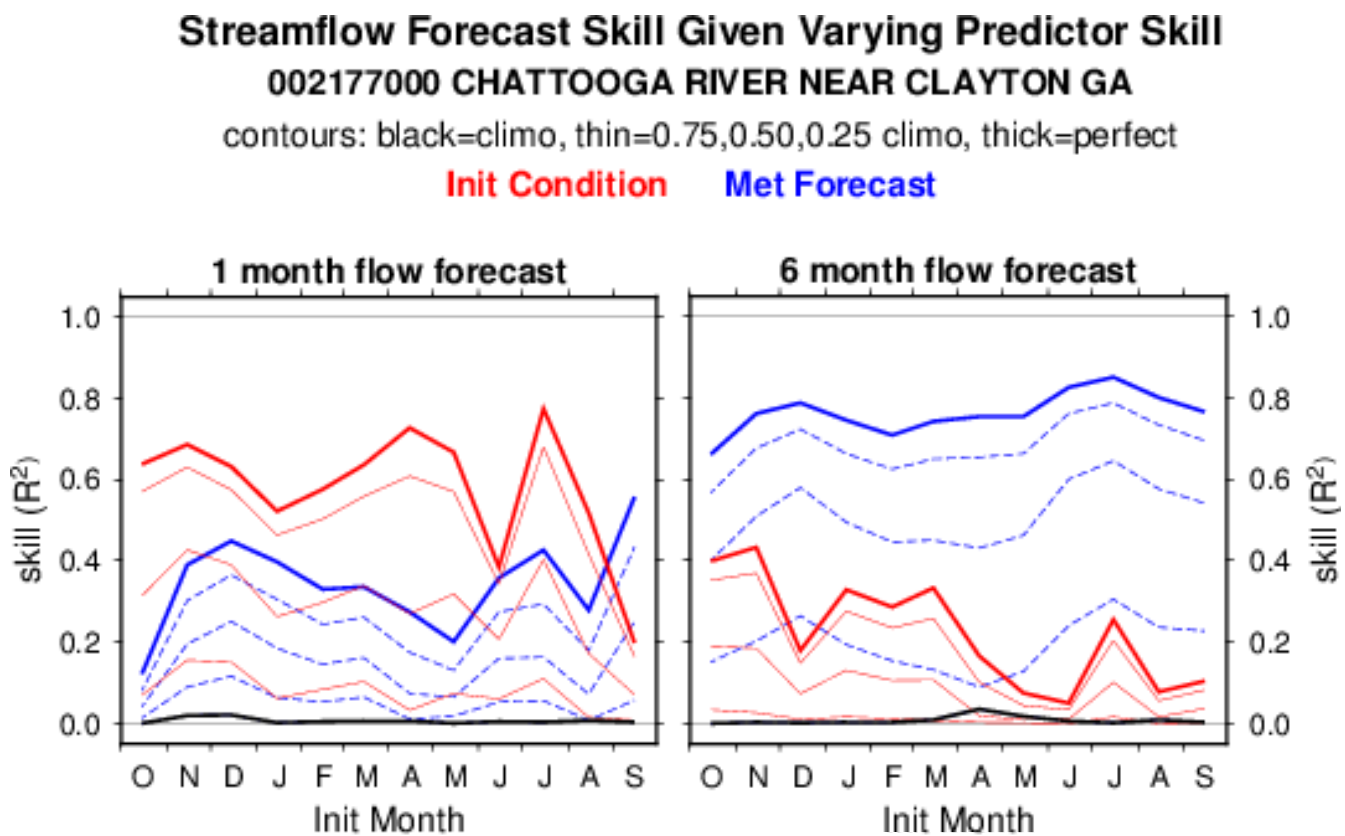
Flow Forecast Skill Sensitivities

A Rain-Driven Basin

Assuming no skill in one source (model accuracy for watershed states, or forecasts)…what are the benefits of adding skill in the other source?

- IC skill matters most for 1 month forecasts
- For longer forecasts, met forecast skill dominates



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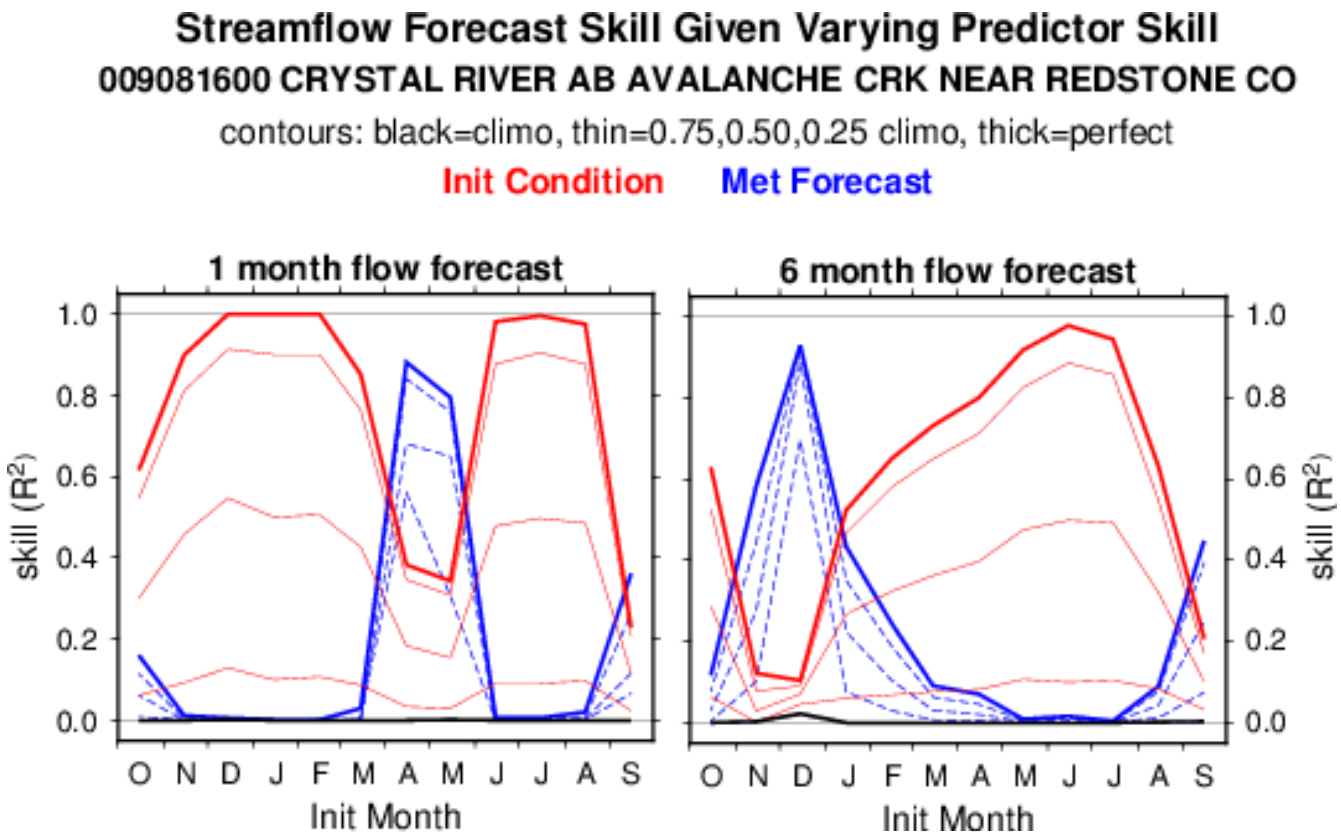
Flow Forecast Skill Sensitivities

A Snowmelt Basin

- Wide seasonal variations in influence of different skill sources
- Cold/Warm and Dry/Wet patterns are clear
- Skill increases in meteorology produce non-linear skill changes in flow

Assuming no skill in one source (model accuracy for watershed states, or forecasts)…what are the benefits of adding skill in the other source?



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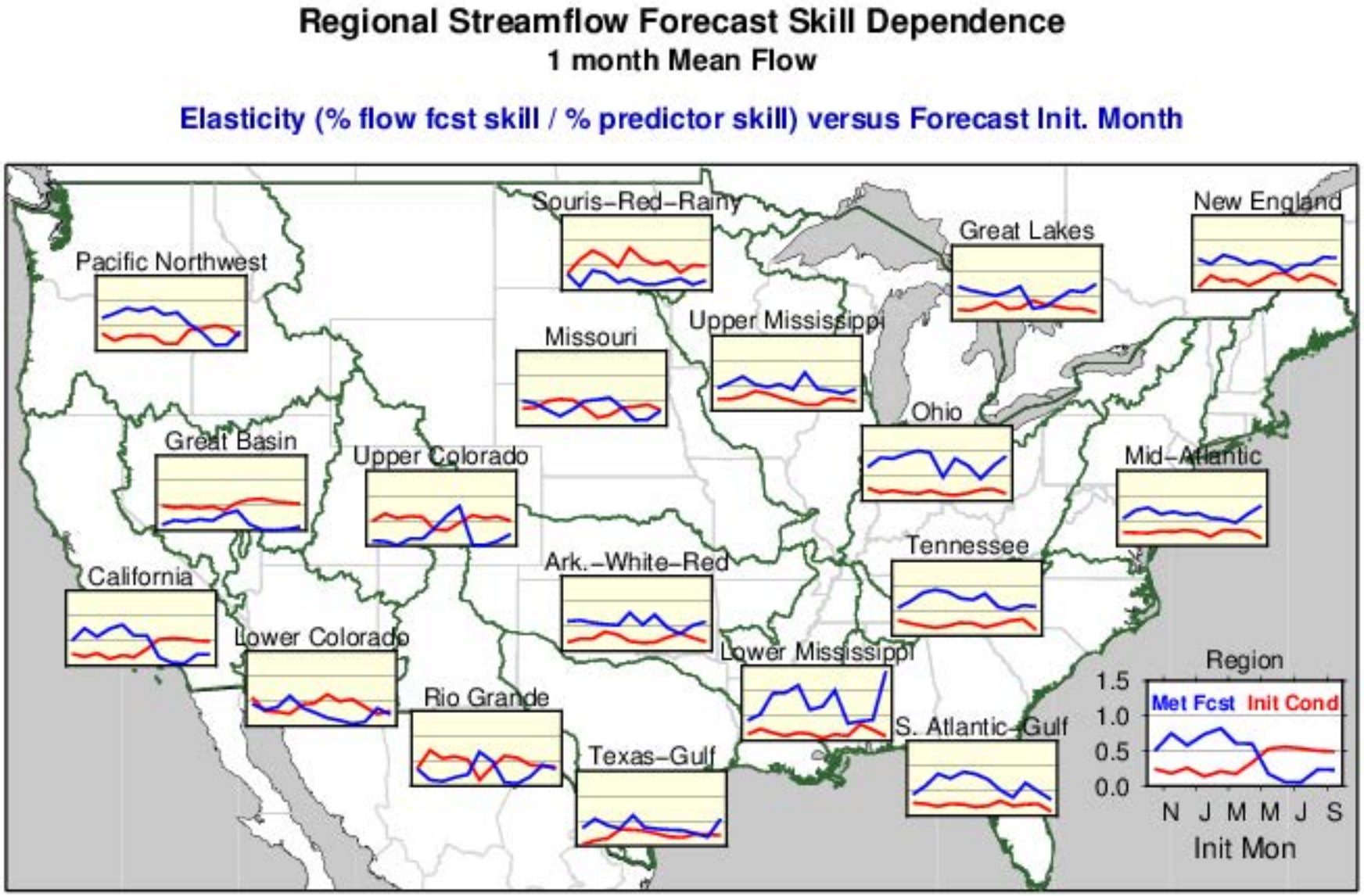
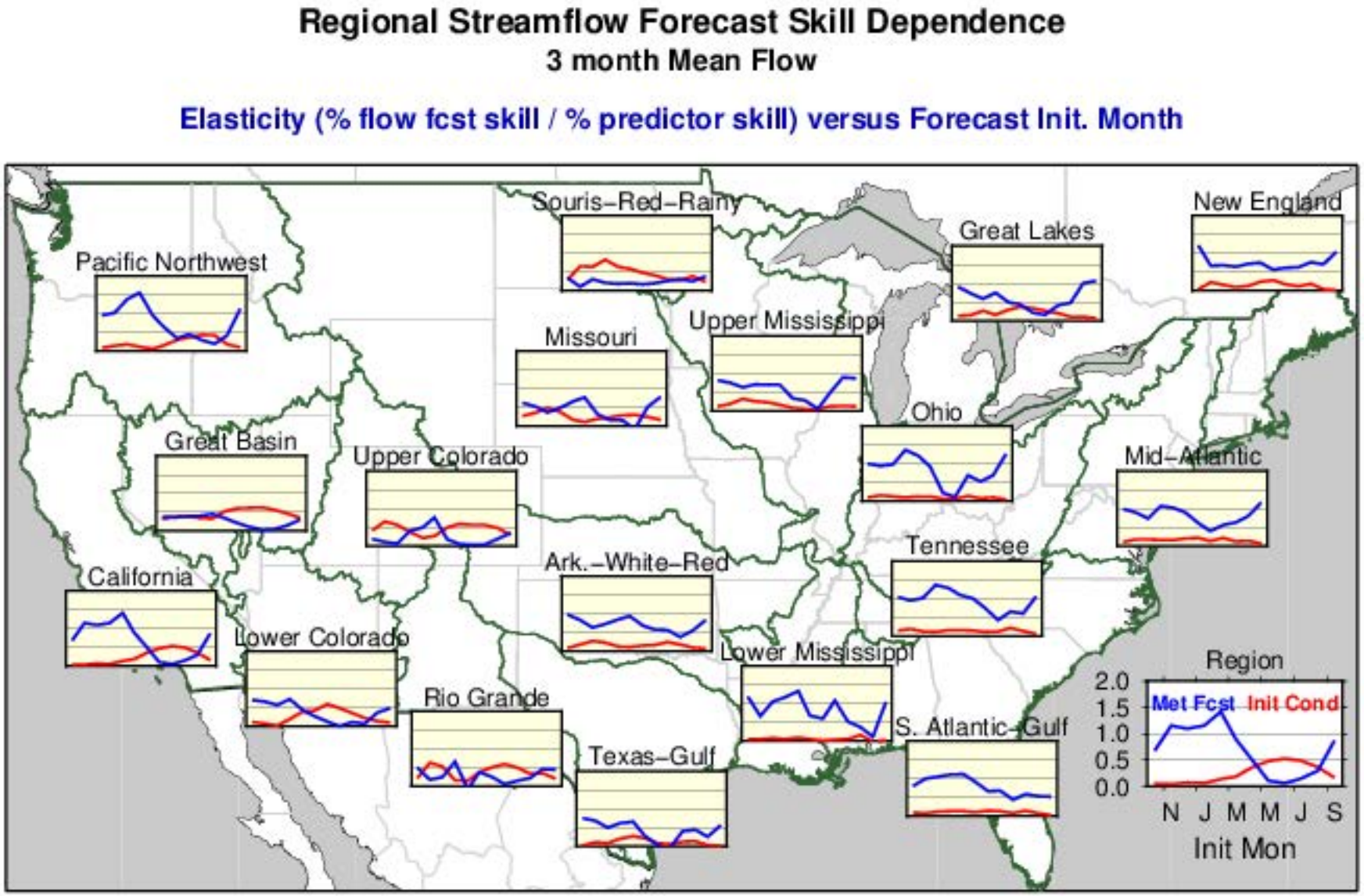
Assessing regional variations



- Based on ~420 watersheds, 30 year hindcasts

Results are preliminary and subject to change

Assessing regional variations



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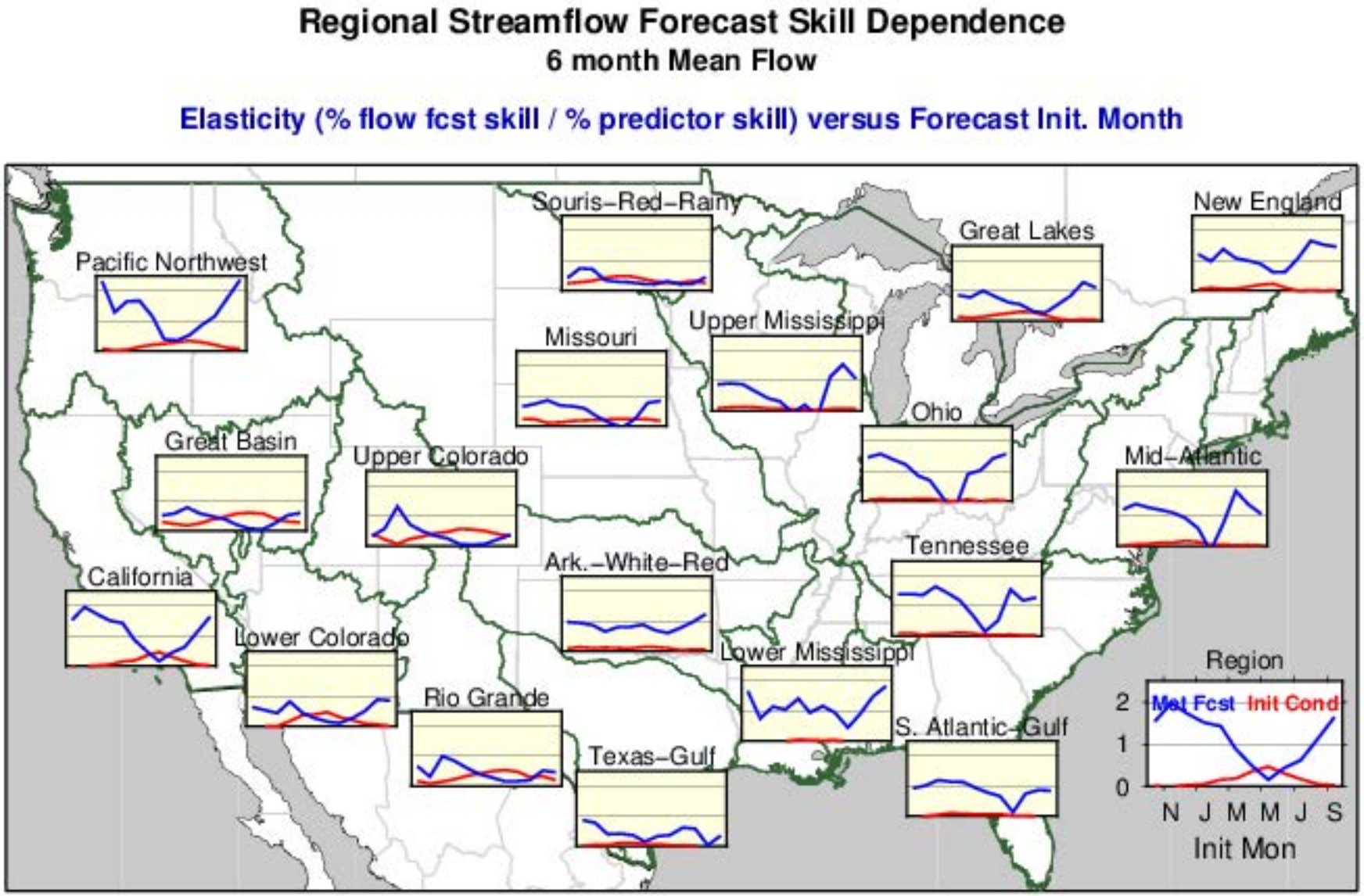
Assessing regional variations



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Results are preliminary and subject to change

Predictability Summary

- Predictability
  - Laying groundwork for understanding influence of initial condition and met. forecast uncertainties
  - Future work will assess:
    - short-range predictability variations
    - how current state-of-the science strategies and datasets perform – actual weather and climate forecasts, better forcings, physical models
  - see example: http://www.ral.ucar.edu/staff/wood/weights/

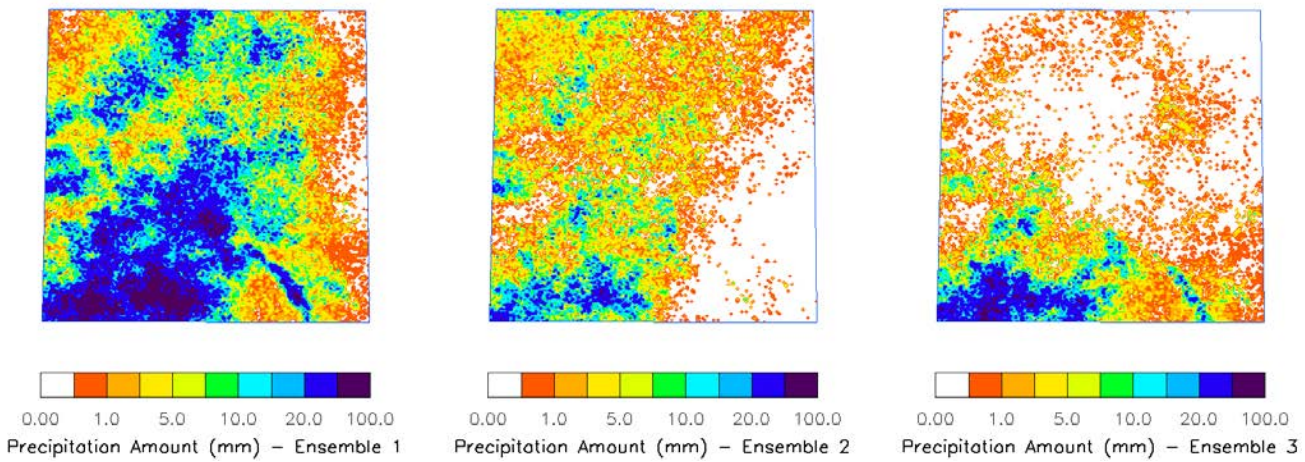
PROBABILISTIC FORCING

Uncertainties in Model Inputs

Example over the Colorado Headwaters

Step 1:
Estimate probability of precipitation (POP), amount and error at each grid cell

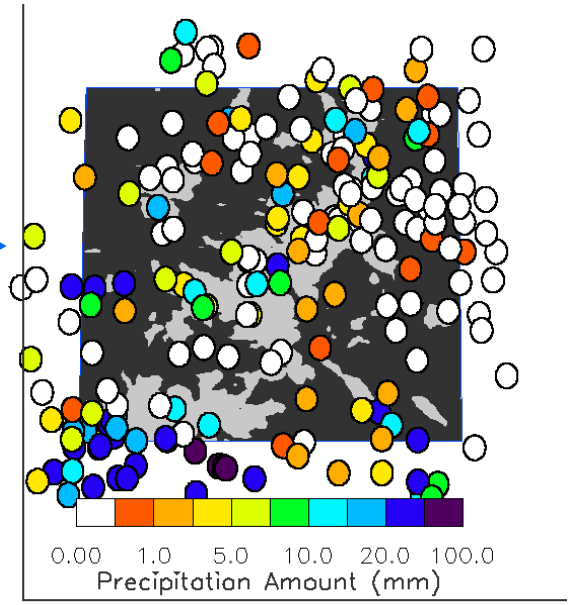
Step 2:
Synthesize ensembles from POP, amount & error



Gap: CONUS-domain ensemble hyper-resolution forcing data
(Precip, Temp, RH, wind, SW, LW)

- Use all available data networks, remote sensing products and NWP reanalyses
- Ensure consistency among variables and realistic space-time variability

corresponding observations



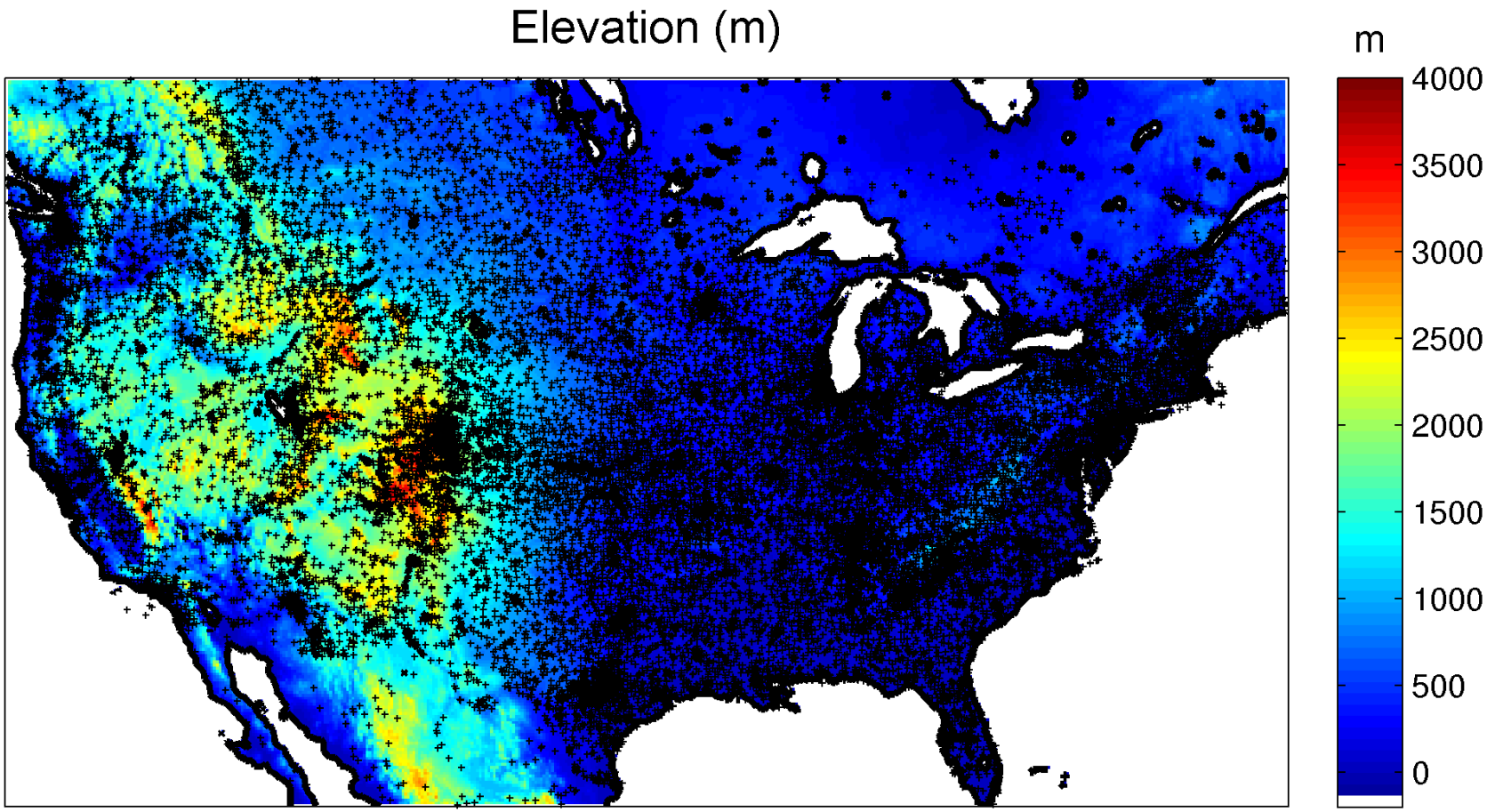
Clark & Slater, 2006 – *JHM*

Development of Serially Complete Station Dataset

- Collected daily Global Historical Climate Network (GHCN) and SNOTEL observations for 1980-2012
  - All available stations in Canada, USA, Mexico
- Following Eischeid et al. (2000), processed stations with >10 years of data and nearby stations that have 10 years of overlap with target station
  - Developed version 0 of serially complete time series of precipitation and temperature
  - ~11,000 stations with serially complete data
  - 1980-2012

Example CONUS Precipitation

- 1/8° grid (~12 km)
- Valid data over all land pixels



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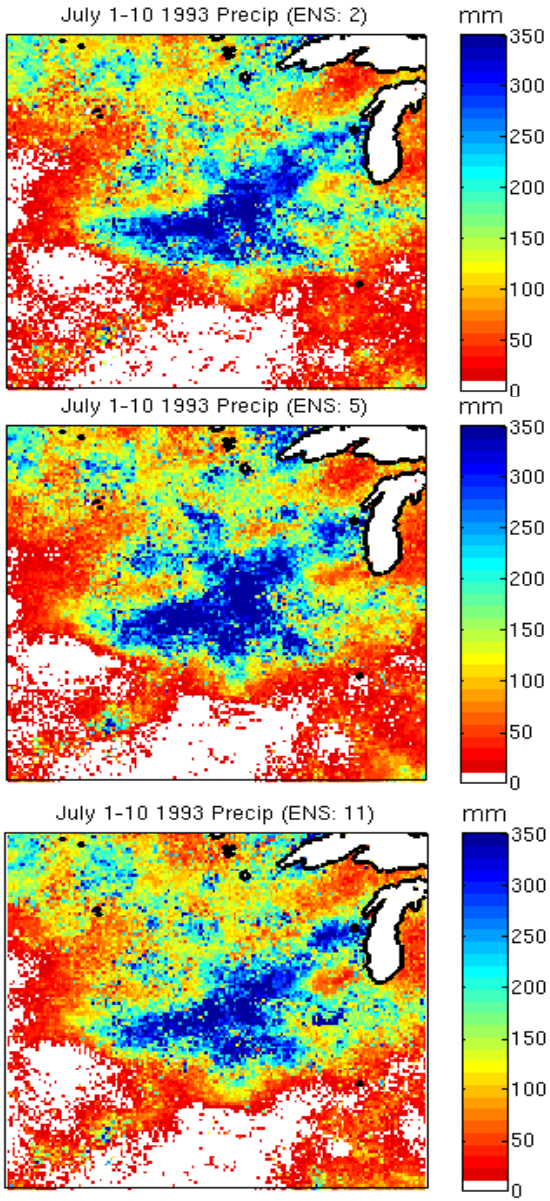
Example CONUS Precipitation

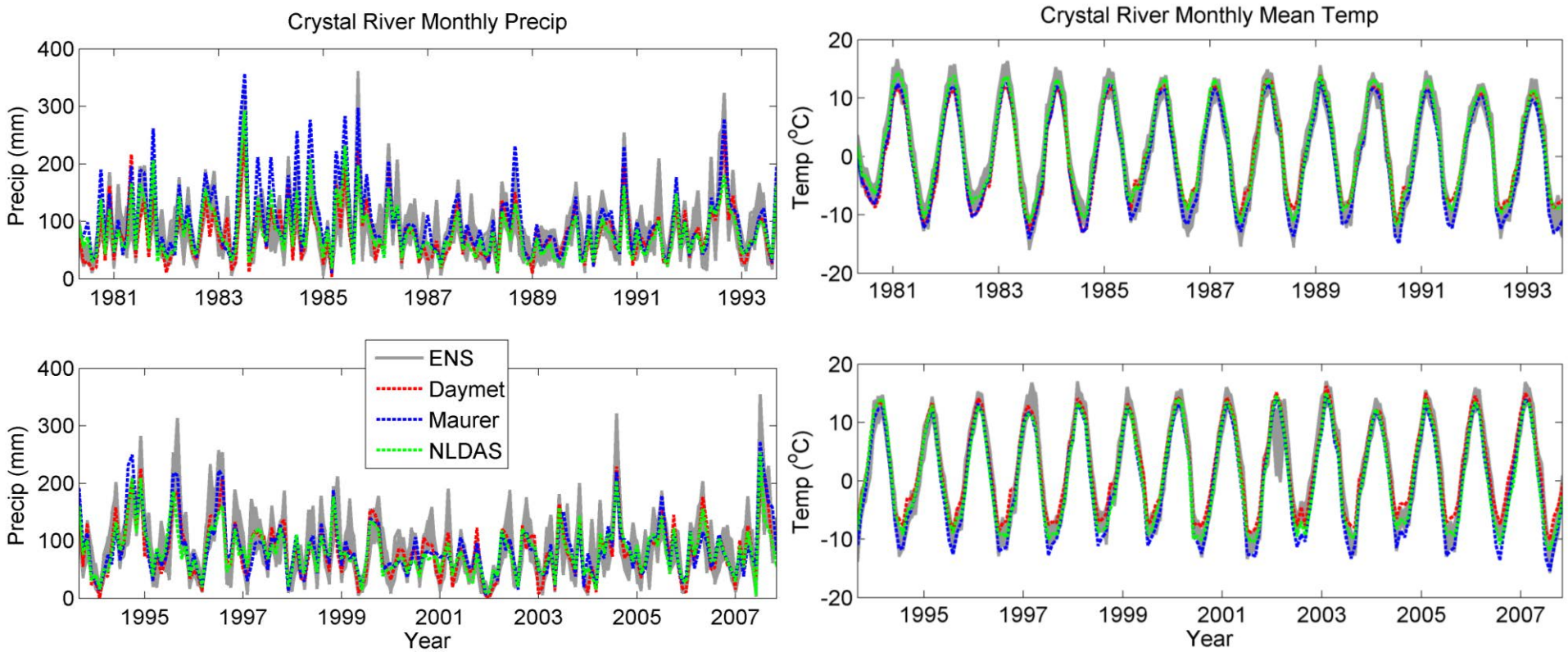
- July 1-10, 1993 example precipitation from three ensemble members



Results are preliminary and subject to change

Example Basin Precip & Temperature

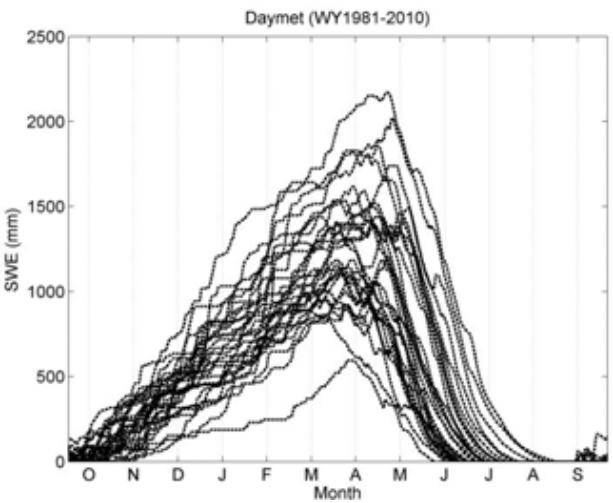
- Monthly time series for Crystal River, CO
  - Basin mean values
  - Maurer precipitation more extreme prior to ~1990
  - Maurer generally coldest

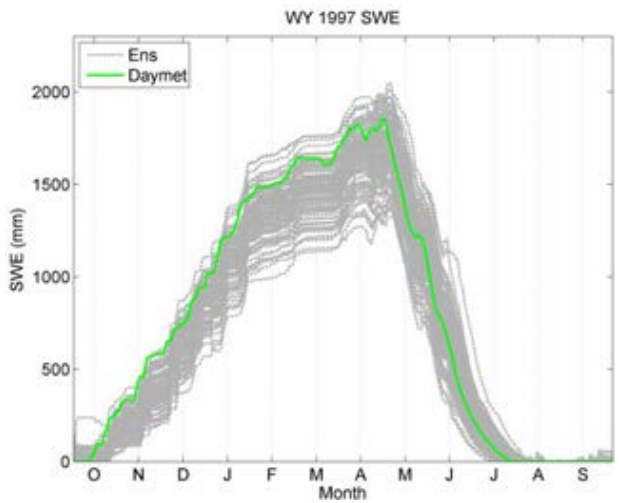


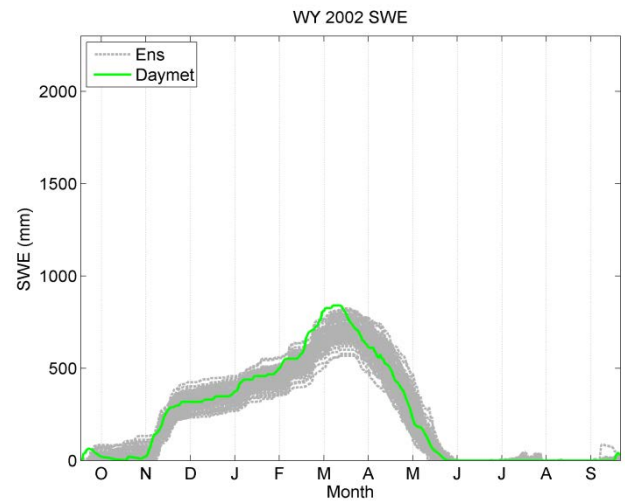
Results are preliminary and subject to change

Example Application

- Crystal River, CO
- "Climatological" variation in SWE
  - Each line is one WY (1980-2010)
- Ensemble variation in SWE
  - WY 1997 & 2002
- Propagate uncertainty through model states







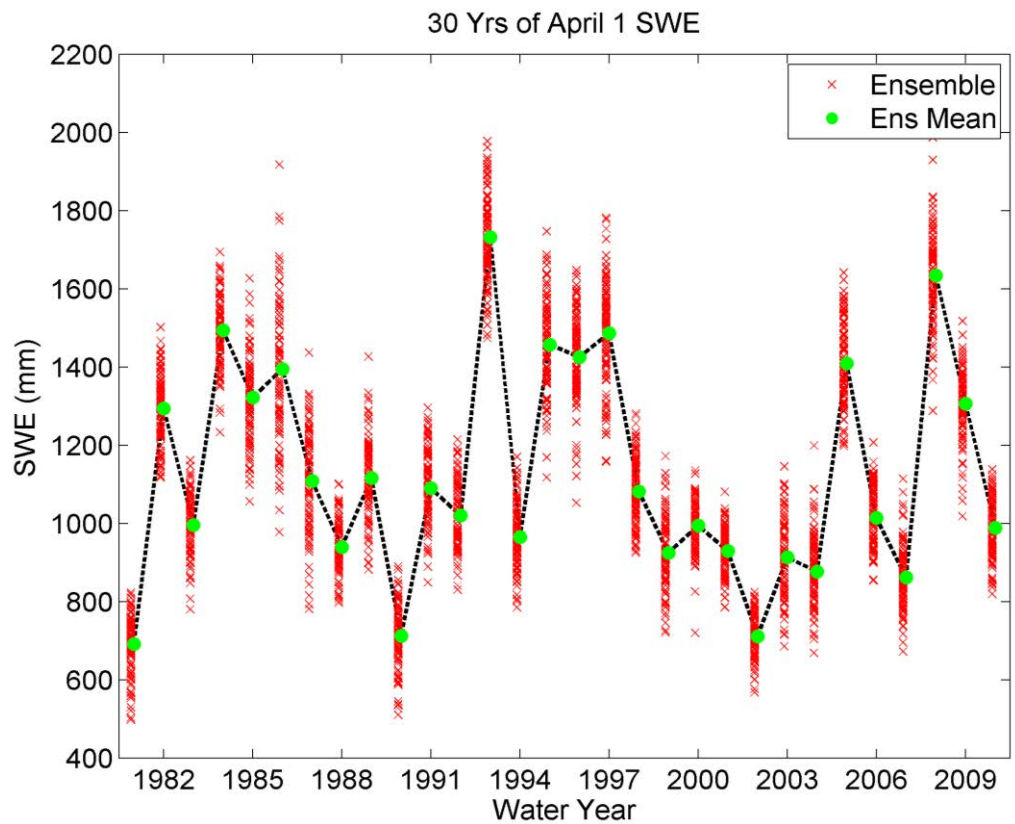
Results are preliminary and subject to change

Example Application

- Crystal River, CO
- Estimate of ensemble spread relative to climatology
  - Estimate of the weighting factor used in VESPA

$$Var[Ens]/Var[C]$$

  - For any given April 1st: ensemble variance ~12% of ensemble mean climatology



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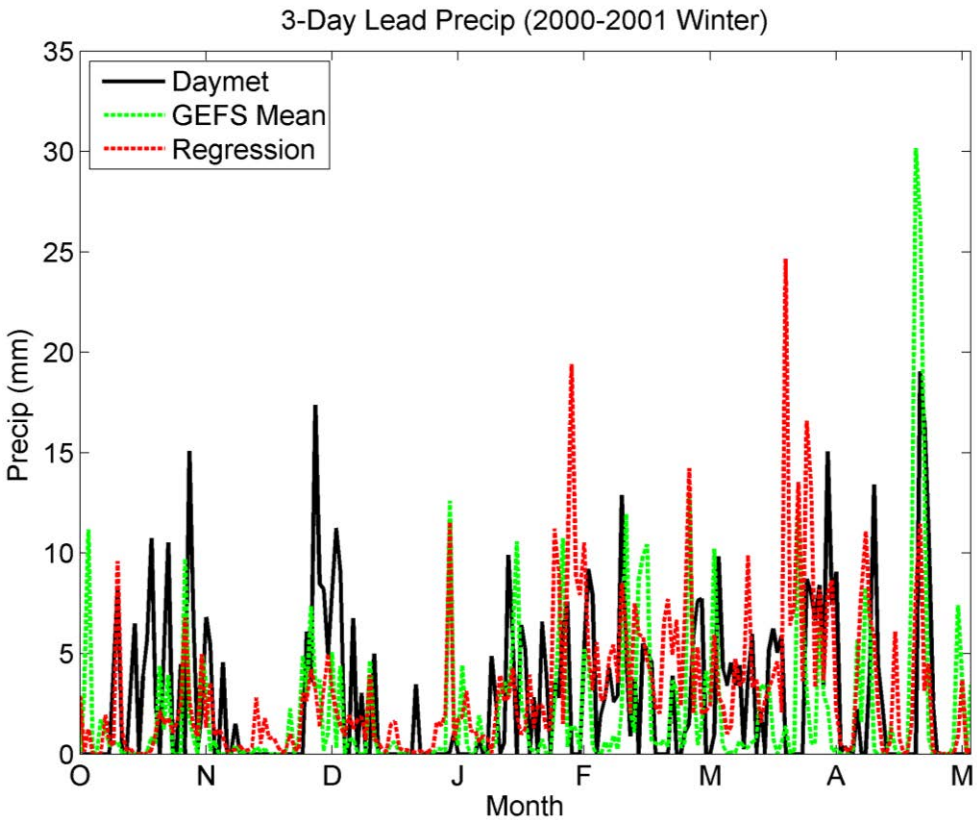
Forecast Ensemble Generation

- Beginning regression/analog generation of 0-14 day NWP forcing data from GEFS
- Example for Crystal River, CO
- RMSE, bias slightly improved over GEFS mean
  - RMSE: 4.7 vs 5.0 mm/day
  - Bias: 1.13 vs 0.78
- Ongoing work:
  - Determine error characteristics
  - Generate ensembles



Results are preliminary and subject to change

Ensemble Summary

- Version 0 of serially complete station data completed
- Version 0 of CONUS 1/8° precipitation and temperature ensemble completed
- Ensemble forcing data can be applied to basins (or any polygon) via grid-to-basin correspondence
- Allows for propagation of forcing uncertainty through model states
  - Estimates of state uncertainty relative to climatology
- 0-14 day NWP ensemble generation underway

SUMMARY

The predictability of streamflow across the contiguous USA

Summary

- Developed automated prediction framework for use in modeling and forecasting research
- Idealized Predictability Assessment laid groundwork for understanding relative importance of initial conditions and meteorological forecasts
- Developed probabilistic meteorological forcings for use in data assimilation and uncertainty quantification

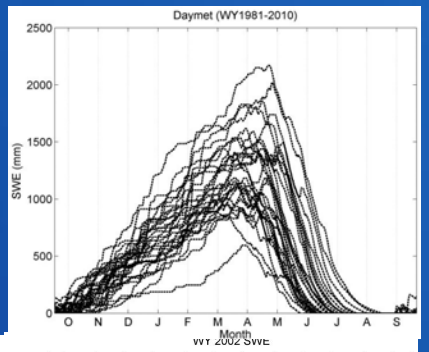
Key Lessons Learned

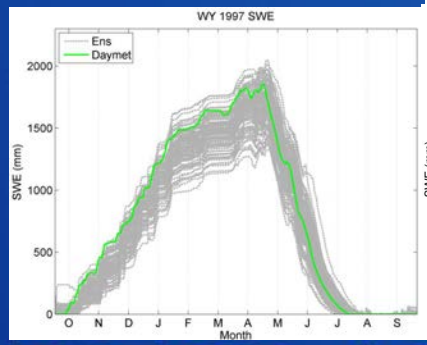
- Automated objective calibration can be effective and is a rich area for investigation
- Controlling influences on forecast skill vary widely by lead time, predictand and season
- Ensemble forcings are feasible and can add valuable perspective on hydrologic uncertainties

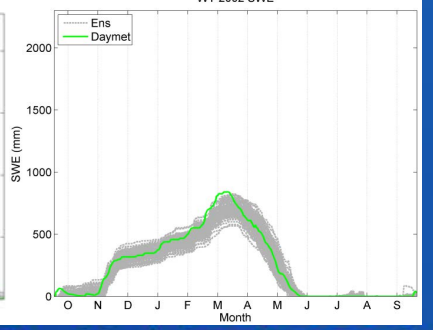
Next Steps/Future Work

- Assess short term (fine resolution) idealized predictability (briefly)
- Implement and assess state of the art approaches in weather and climate forecasts, data assimilation and post-processing
- Develop demonstration case studies oriented toward water management

SWE climatology (top) versus high and low year SWE ensembles (bottom)







RECLAMATION