Assessing The Potential Of Over-the-loop Short-to-medium Range Ensemble Forecasts Using 'SHERPA'

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Sponsors:
Reclamation, USACE, NOAA

HEPEX Workshop: Ensembles for better hydrological forecasts
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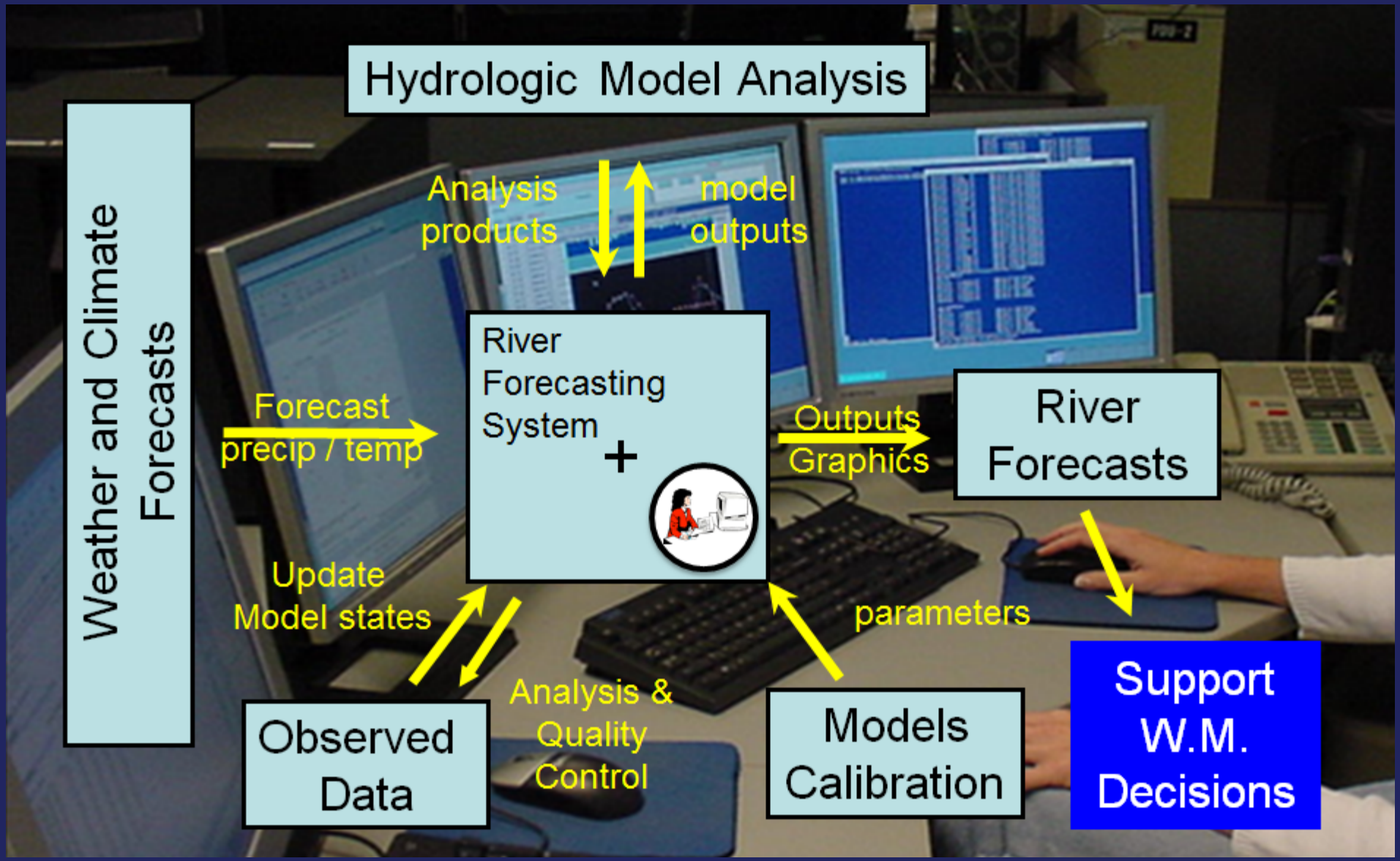
Motivation

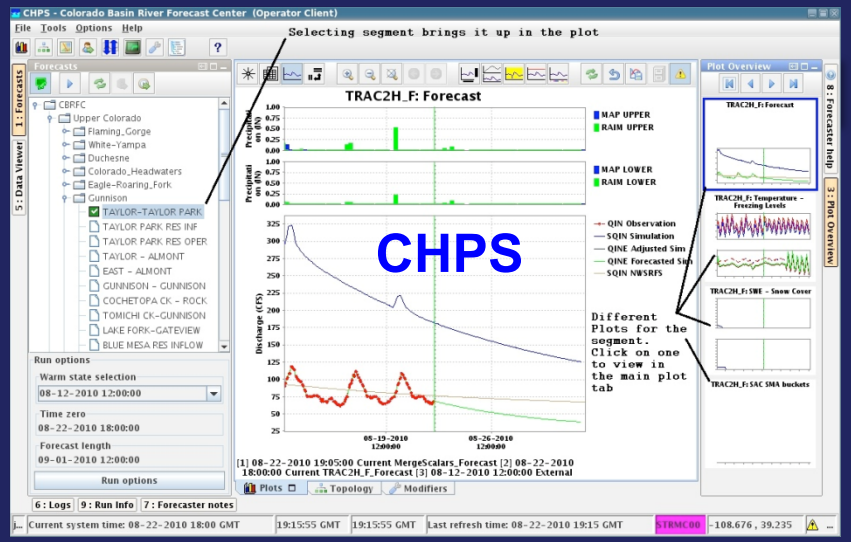
The manual river forecast process can be a bottleneck

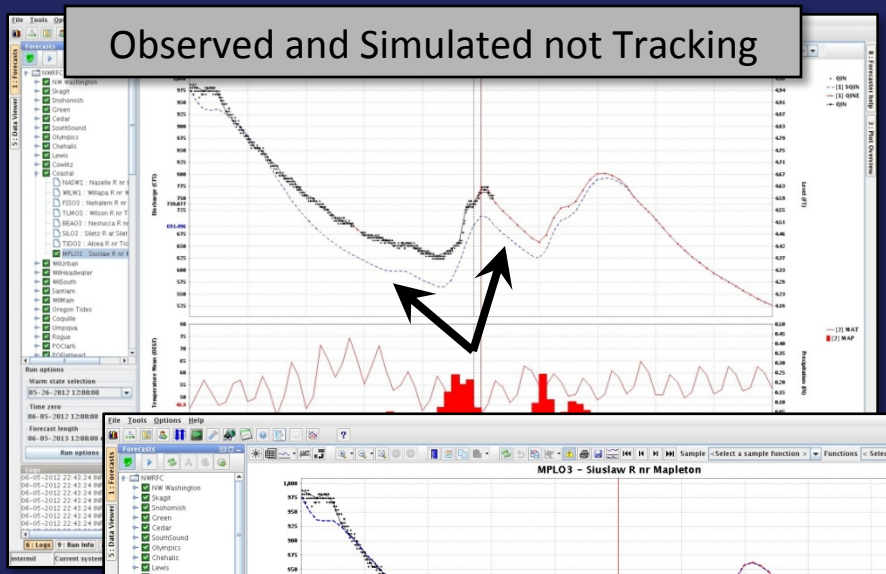


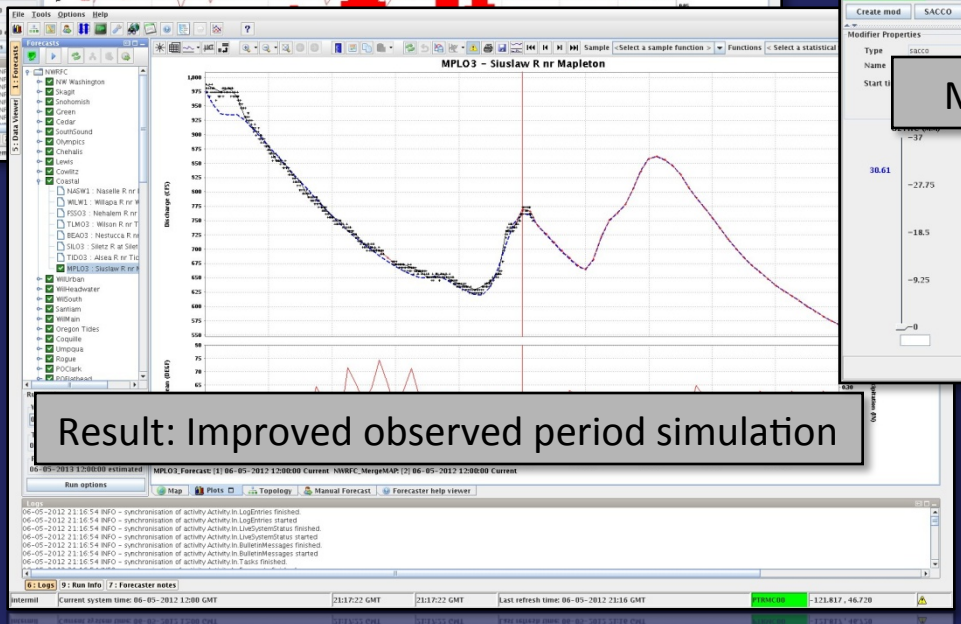
Slide by H. Opitz, NWRFC

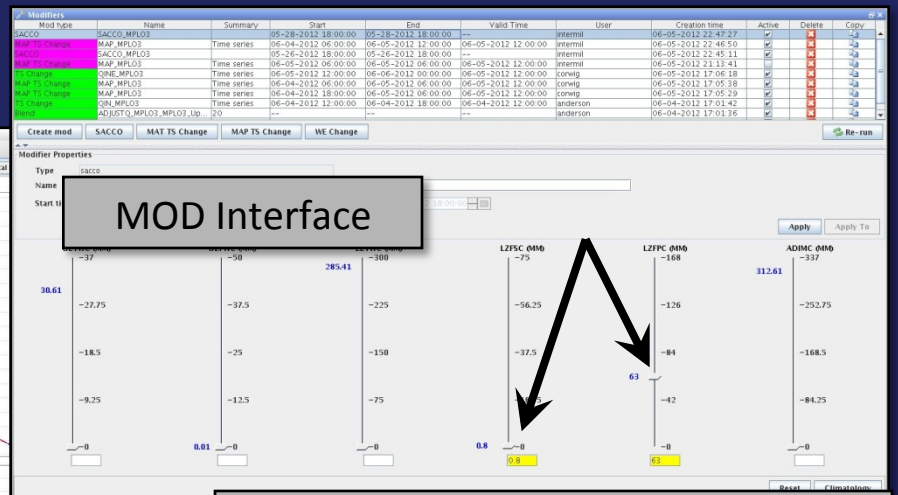
Runtime Modifications River Forecast Centers

- MOD capability has been available in the NWS >30 years
- Generic MOD capability implemented within FEWS
- Extend capability to other users outside of OHD-core models









Hydrologist render a *Run-Time modification* to the SACSMA Model and *increases* the lower zone primary and supplemental states

Configurations of human involvement in making streamflow forecasts

In the loop
Human involvement essential and central

Out of the loop
Completely automated, 'warn-on-forecast'

Over the loop
Automated but with forecaster intervention if needed, and forecasters interpret outputs for warnings

Assertions about Traditional Forecaster-in-the-Loop Streamflow Forecast Operations

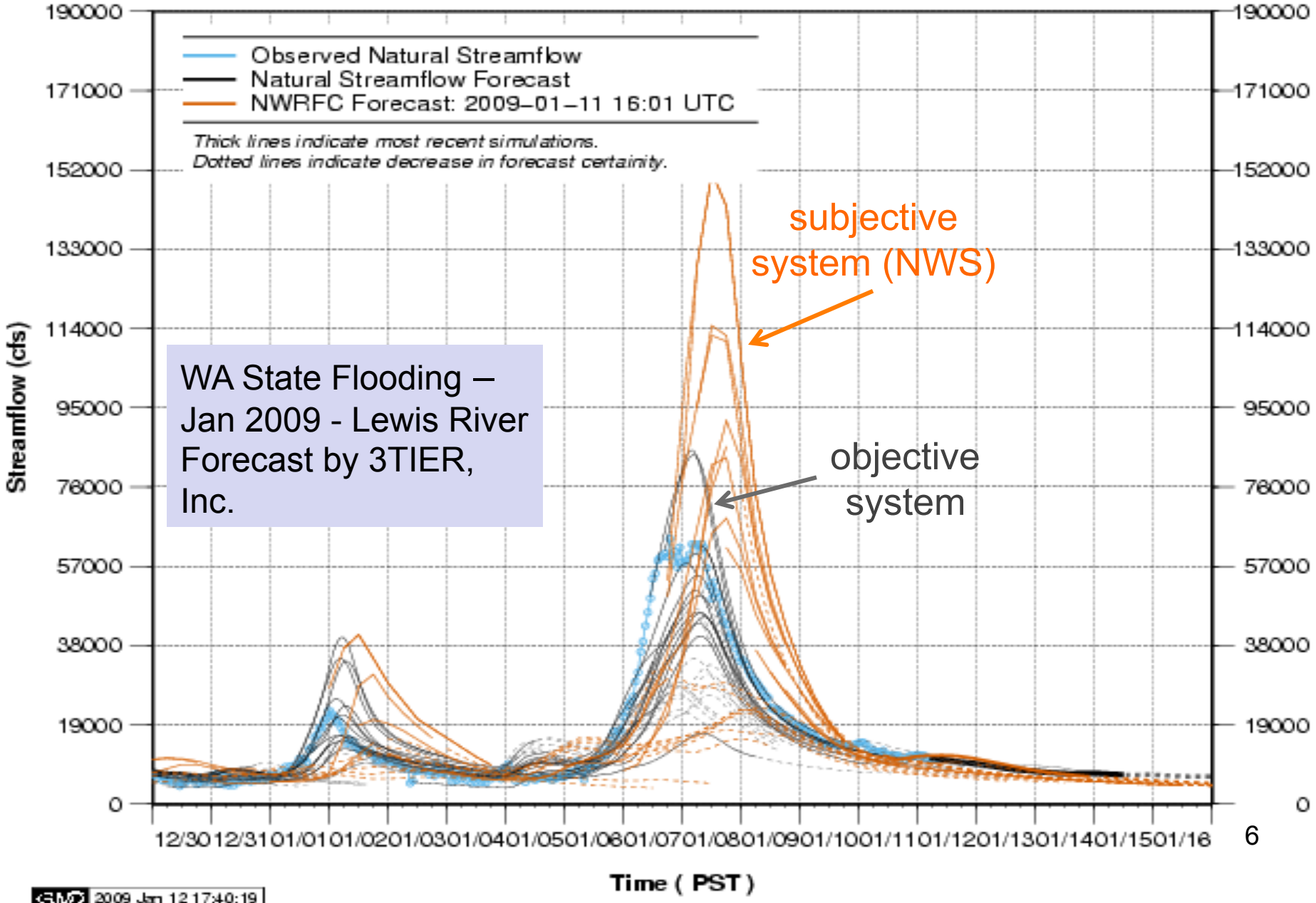
- The paradigm evolved because decades ago, systems/ data/models/methods were inadequate
  - forecaster interventions were the best way to correct obvious errors and leverage expert knowledge

- Today, some aspects are still a challenge (eg real-time met. analyses), but many others have greatly advanced

- The 'in-the-loop' paradigm is a roadblock to adopting a number of the new advances

- There is not a common belief that 'over-the-loop' forecasting is a viable paradigm

Over-the-Loop Systems Already Exist



Contrasts in Paradigm

Forecast Element	In-the-loop practice	Over-the-loop practice
Modeling	Low-dimensional lumped/ conceptual models	higher complexity distributed, process-oriented models (1+?)
Meteorological Analysis (spinup forcings)	Single-value, often inconsistent between retrospective and real-time, may have manual QC	Can be ensembles to assist in DA, parameter estimation, uncertainty representation
Parameter Estimation	Semi-manual (leverages forecaster judgment)	Automated, run on HPC, leverages new algorithms
Data Assimilation	Manual (leverages forecaster judgment)	Enables stat. techniques that rely on consistent simulations for training
Forecast Meteorology	Single-value (allows manual editing), no consistent records because of forecaster on-the-fly adjustments	Wide range of new resources (ensembles, reforecasts), allows statistical calibration and downscaling

Contrasts in Paradigm

Forecast Element	In-the-loop practice	Over-the-loop practice
Post-processing	Manual adjustment, or limited to a-priori rather than data driven methods (eg blends) due to lack of consistent records.	Enables data-driven, complex methods trained on past forecast performance.
Benchmarking / verification	Very difficult due to non-existence of a consistent 'system' and labor involved in forecasting	Enables systematic version comparisons/verifications: also forecast team effort improves 'the system' rather individual forecasts.
Hindcasting (supports follow-on models)	Difficult to impossible given the labor involved in forecasting and not meaningful due to lack of consistent adjustments.	Given sufficient computing, hindcasts can be run and re-run to the extent that past inputs are available.

Project Objectives

- Build an over-the-loop system (all processes automated) to produce short-range to seasonal ensemble flow predictions using currently available methods
  - draw from ensemble forecast advances and experience highlighted by HEPEX
  - use intermediate-complexity approach (resolutions, physics) to allow for components such as ensembles, calibration, hindcasting and uncertainty quantification

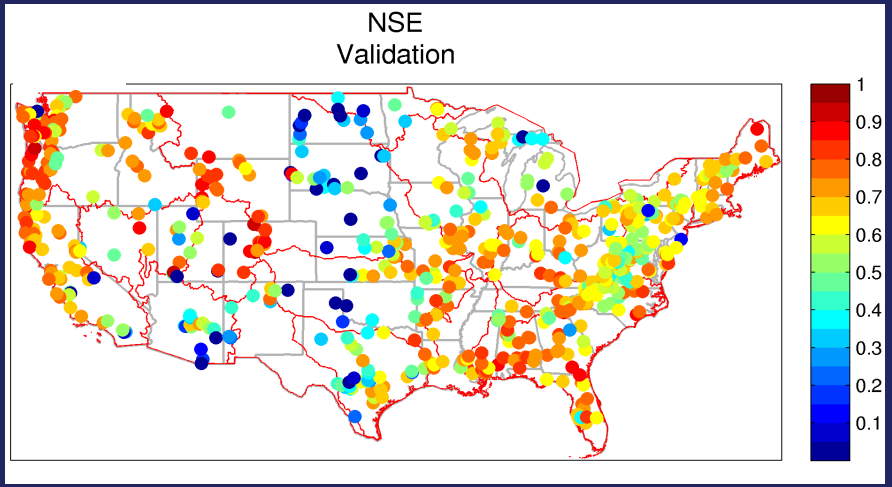
- Provide a public demonstration of the performance of over-the-loop forecasts for locations that are relevant to the forecasting and water management communities

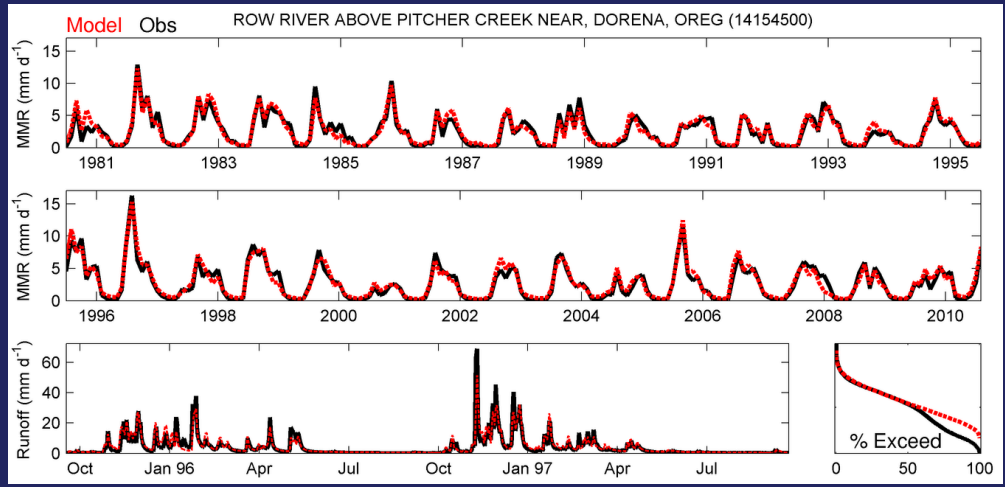
- Promote discussion about the role of the forecaster in a modern hydrologic prediction system

Building Blocks for Short-Medium Range Forecasts

CONUS-wide watershed simulation framework

- **Goal**: Create "many basins" platform for forecasting application and evaluation
- **Benefit**: Permits efficient study of forecasting elements (model, forcing, data assim, etc.) under a variety of basin and climate conditions
- **Specs**: Newman et al. 2015
  - Base model: National Weather Service operational Snow-17 and Sacramento-soil moisture accounting model (Snow-17/SAC) … more models to be added
  - Locations: 670 basins from GAGES-II, Hydro-climatic data network (HCDN)-2009
  - Forcings: DAYMET (http://daymet.ornl.gov/), NLDAS, and Maurer et al. (2002) for (a) lumped (Snow-17/SAC apps), (b) hydrologic response unit (from PRISM), and (c) elevation band
  - Calibration: automated Shuffled Complex Evolution (SCE) global optimization routine: 15 years, validation on remaining data for all lump forcing types; areas with seasonal snow, frequent precipitation perform best; high plains, desert SW perform worse





Newman, A. J., et al. 2015: "Development of a large-sample watershed-scale hydrometeorological dataset for the contiguous USA: Dataset characteristics and assessment of regional variability in hydrologic model performance," Hydrology and Earth System Sciences 01/2015; 19(1):209-223. DOI:10.5194/hess-19-209-2015

Case Study Basin Subset

- 50 watersheds (and growing), chosen for varying hydro-climates & regions, being relatively unimpaired, and supplying reservoir inflows

Predictability Project Case Study Watersheds

Home Info Links Contacts Disclaimer

The watersheds in the table below were selected from the CONUS-wide dataset of Newman et al. (2015) for use in assessing hydroclimate forecasting data and methods. These basins are considered relatively unimpaired (part of the HCDN network) but also have water management significance -- eg, provide inflow for reservoirs. A minimum of two watersheds with such characteristics per region were sought, but in some cases (eg, for SRR), they were not found, and the locations were chosen based on the quality of the NCAR simulations. A few additional basins were included for their relevance to other studies.

Regions

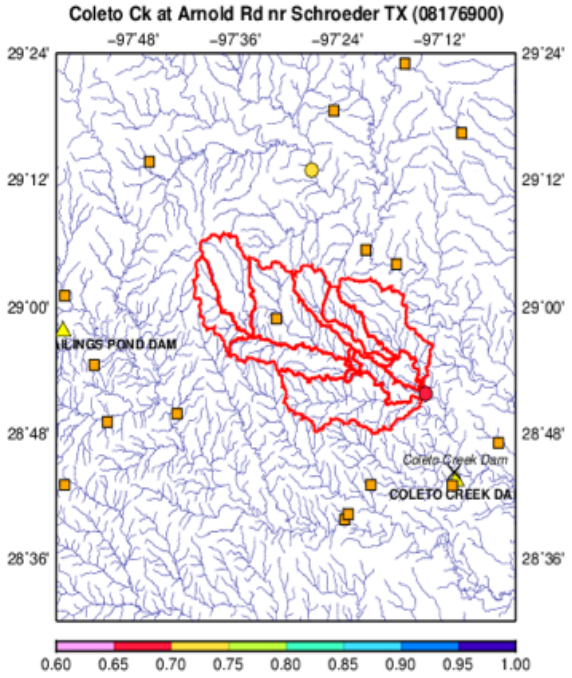
01 NE	02 MA	03 SAG	04 GL	05 OH	06 TN	07 UMS	08 LMS	09 SRR
187300 013500	413500 414500 415000 591400 606500	371500 178400 177000	057800 124000	340600 164000 285000	455500 504000	593900 507600	362587 376000	057000 129115

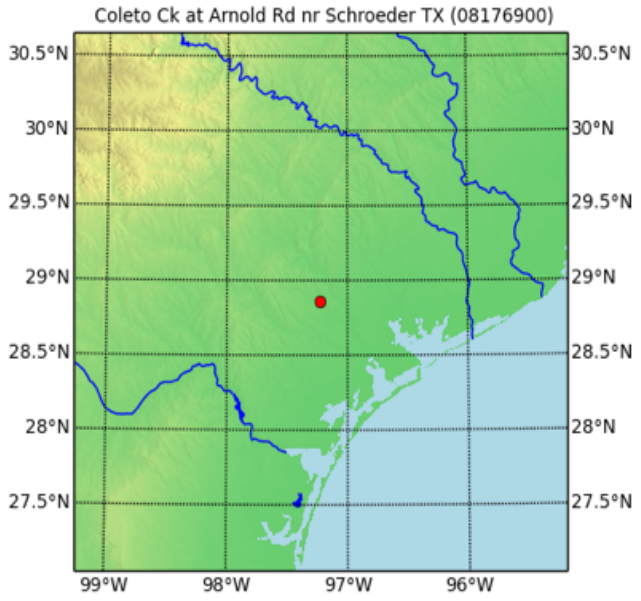
10 MO	11 ARW	12 TXG	13 RG	14 UCO	15 LCO	16 GB	17 PN	18 CA
468250 224000	340300 226500	176900 070200	324000 360500	107000 223000 352900 081600	508300 430500	234500 343500	154500 308990 025700 056500 158790	176400 480390

A second, smaller set of watersheds is being considered that are not from the HCDN/Newman dataset but from basins forecasted by the NWS River Forecast Centers and managed by the federal water agencies. These will serve as a focus for interaction with reservoir managers from the US Army Corps of Engineers and the US Bureau of Reclamation. These basins are also relatively unimpaired and generate inflows for several important reservoirs in the western US.

Description

Watershed Maps include:
outlets (circle, color = calibration NSE), reservoirs (triangle,X), SNOTELs (star), met stations (square).





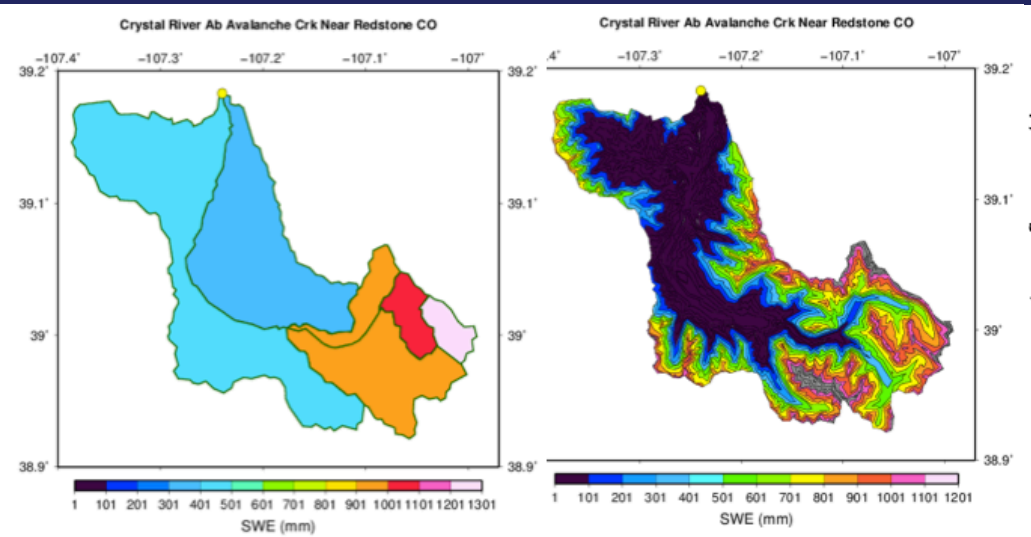
http://www.ral.ucar.edu/staff/wood/case_studies/

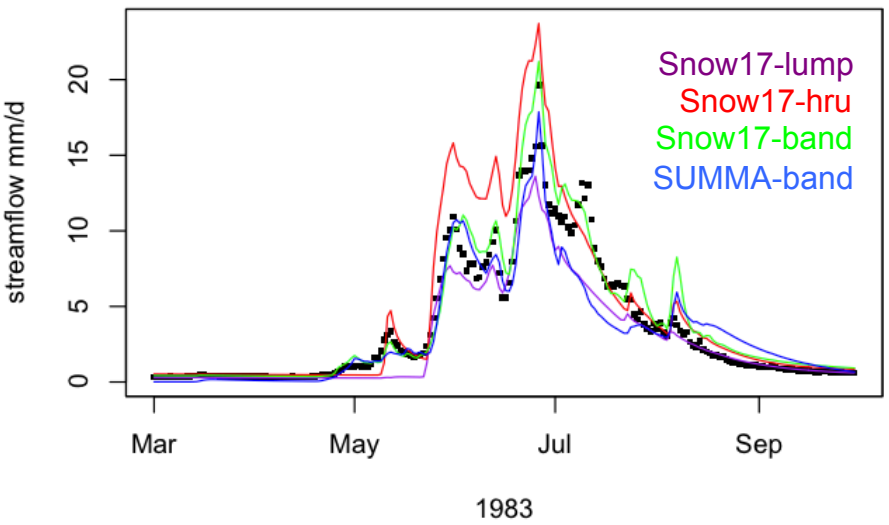
Building Blocks:
Watershed Modeling

- **Goals:** contrast ability of different modeling approaches to capture hydrologic variability and response
- **Benefits**: provides broader array of modeling options for forecasting
- **Specs**: baseline models are NWS models (Snow17/Sac/UH/etc, lumped); alternatives include gridded VIC, SUMMA in various configurations

Figures: Exploring various model configurations and physics
(Apr 1 SWE on left; streamflow on right; Crystal R. watershed, CO)

HRU Snow17/SAC band SUMMA streamflow comparison

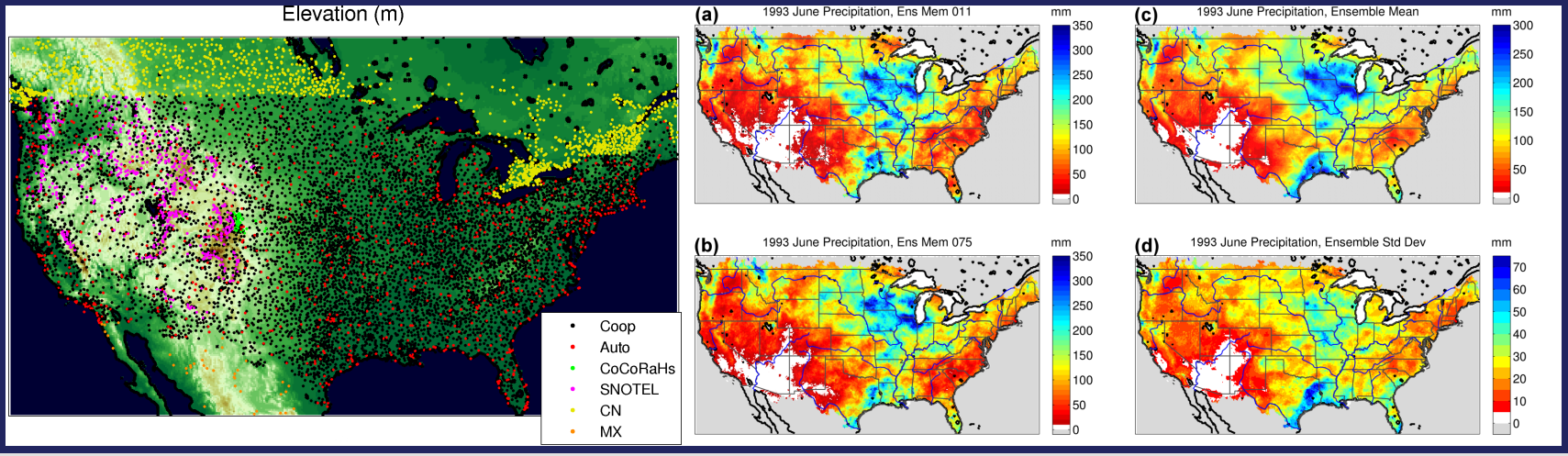




Building Blocks

Consistent Retro+Real-time Spinup Forcings

- **Need:** Calibrate Models, Estimate Initial Forecast States
- **Benefits**: supports (1) more robust historical calibration, (2) ensemble-based data assimilation to initialize forecasts
- **Specs**: 1/16º grid, 100 ensemble members
  - Example from Newman et al (2015): June 1993 precipitation
    - two example members (a-b)
    - ensemble mean (c)
    - ensemble standard deviation (d)

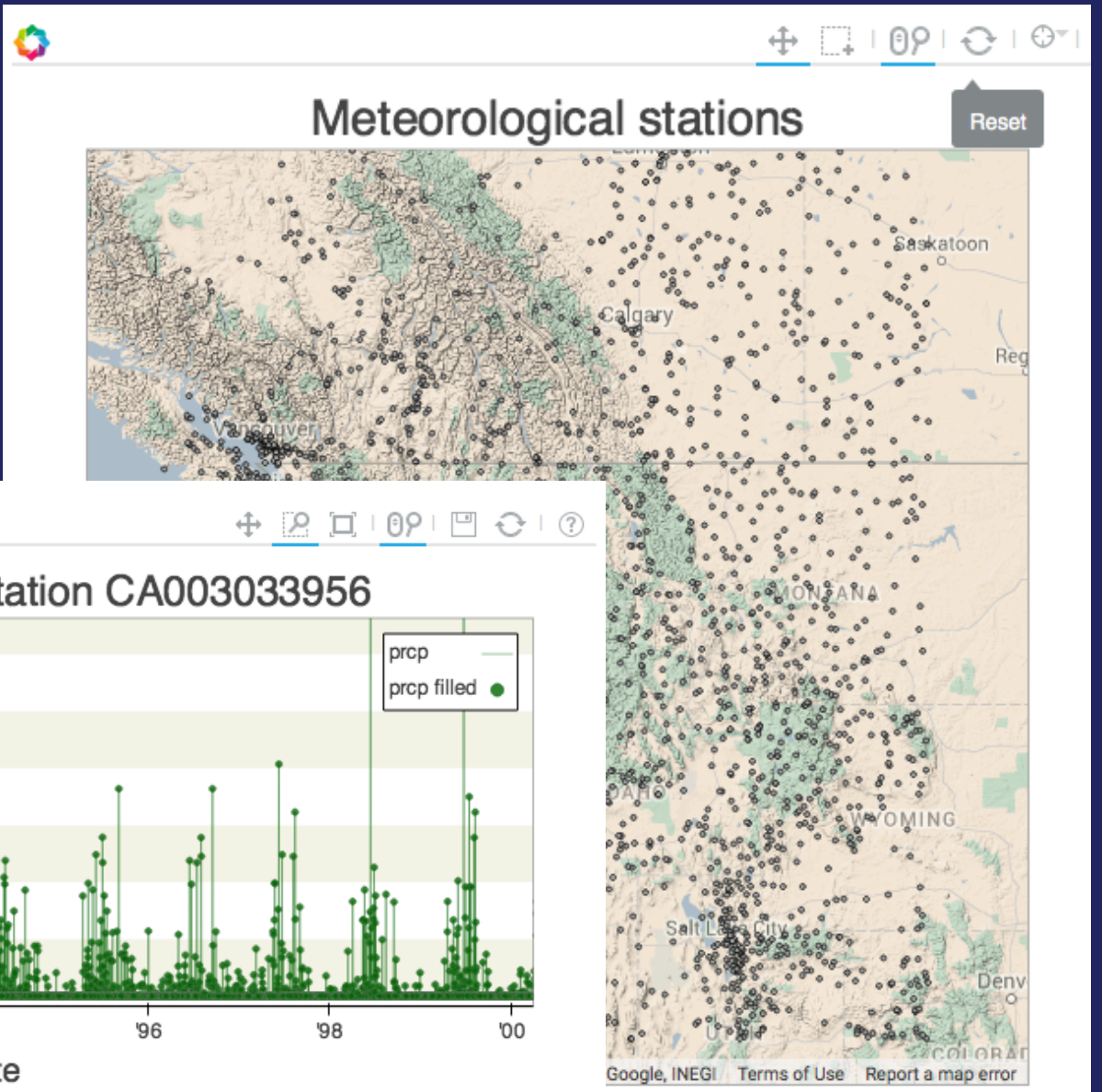


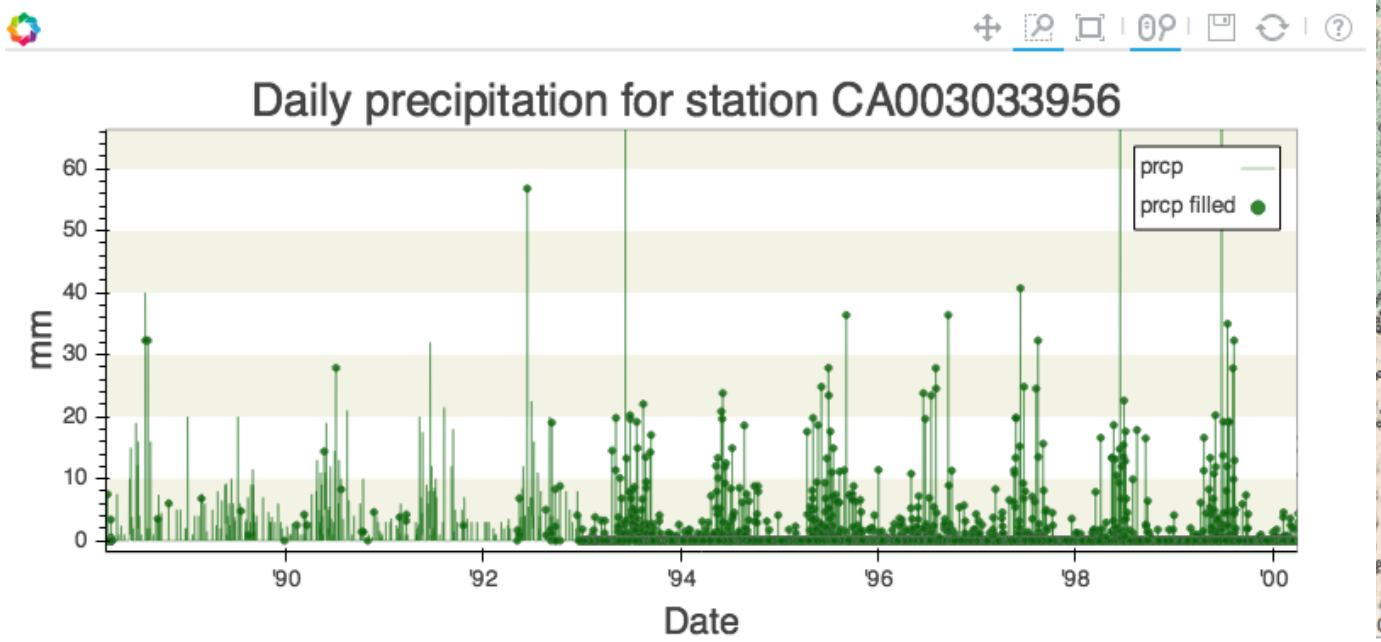
Newman, A. J., M. P. Clark, J. Craig, B. Nijssen, A. Wood, E. Gutmann, N. Mizukami, L. Brekke, and J.R. Arnold, 2015: "Gridded Ensemble Precipitation and Temperature Estimates for the Contiguous United States," Journal of Hydrometeorology 12/2015; 16:2481–2500. DOI:10.1175/JHM-D-15-0026.1.

Building Blocks

Consistent Retro+Real-time Met Analysis

- Real-time station data retrieval
- Automated QC (with documentation) and gap-filling
- A first -- real-time gridded ensemble forcings



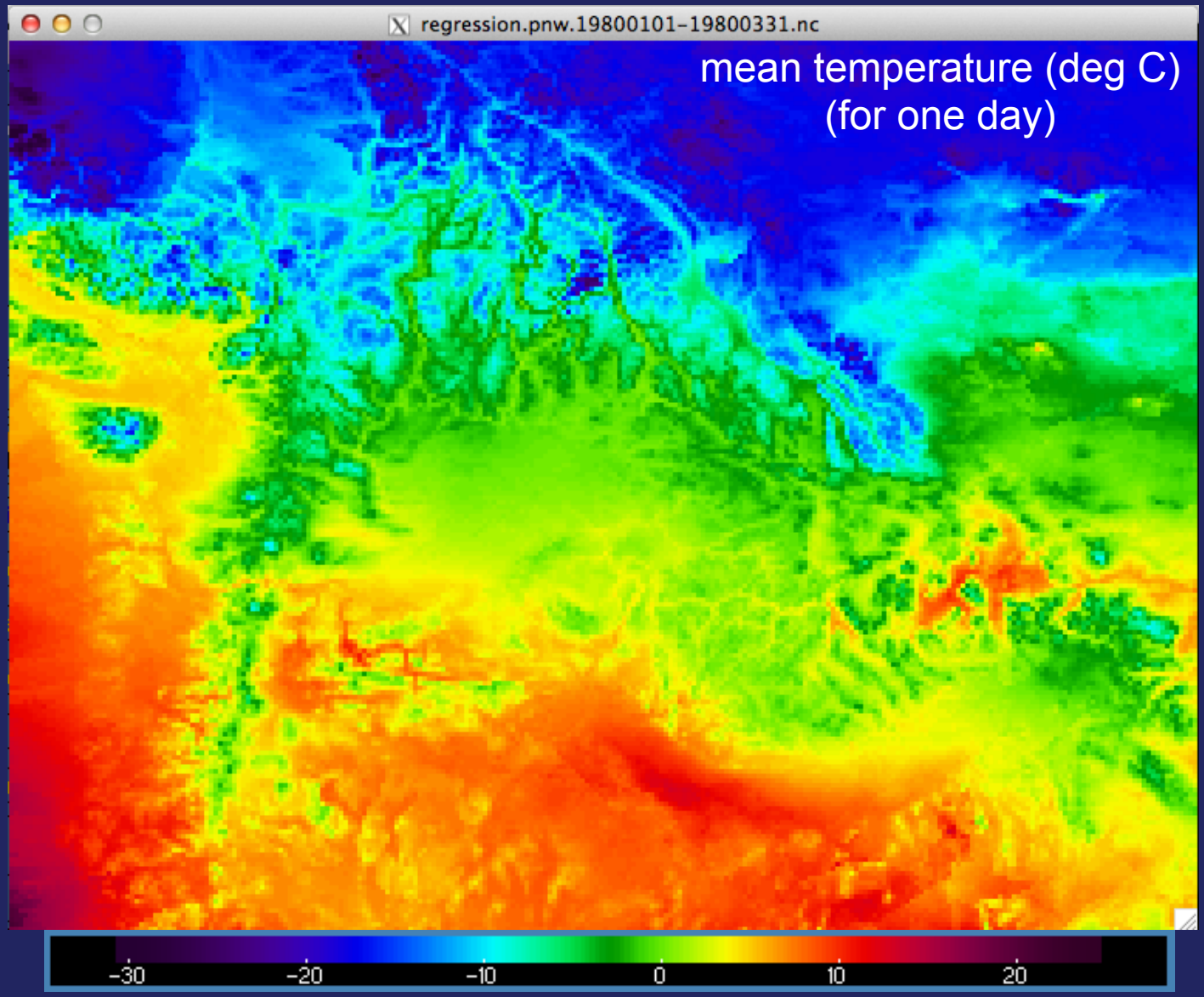


Building Blocks

Consistent Retro+Real-time Spinup Forcings

Automated generation of 1/16th gridded ensemble precipitation, temperature

- Gridded forcings used directly; or
- averaged to watershed-based model configurations



Building Blocks

Automated DA to improve initial conditions

- **Benefits**: improves initialization of watershed states, replaces manual modifications in forecasting process
- **Specs**: apply DA (PF and EnKF) with uncertainty from ensemble forcings to assimilate streamflow or SWE

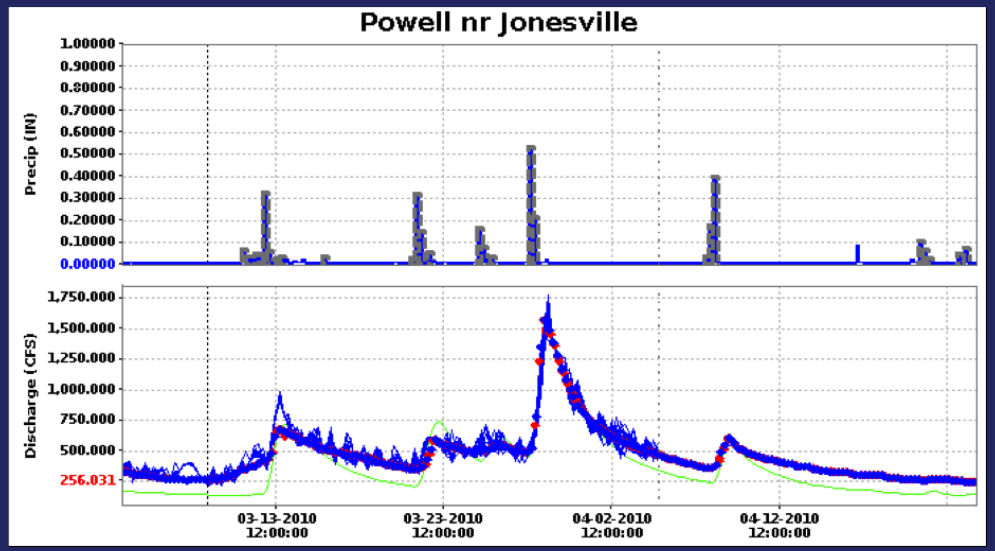


Figure: Particle Filter based ensemble DA with 6-hour update cycle automatically adjusts SAC model to correct for model and forcing errors

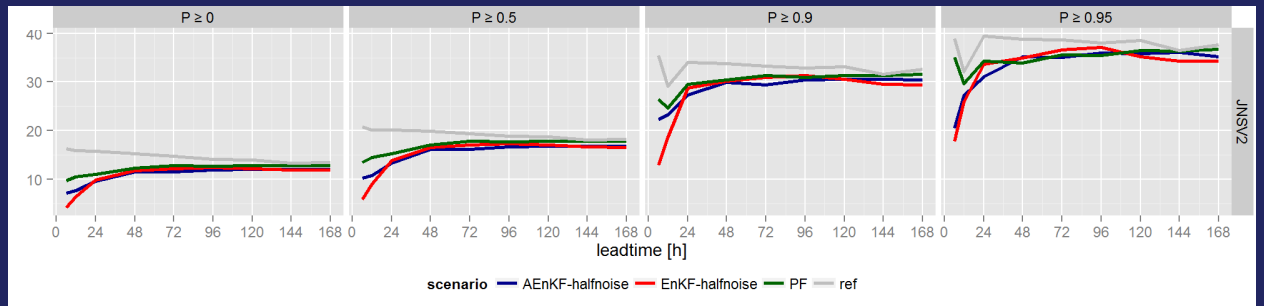


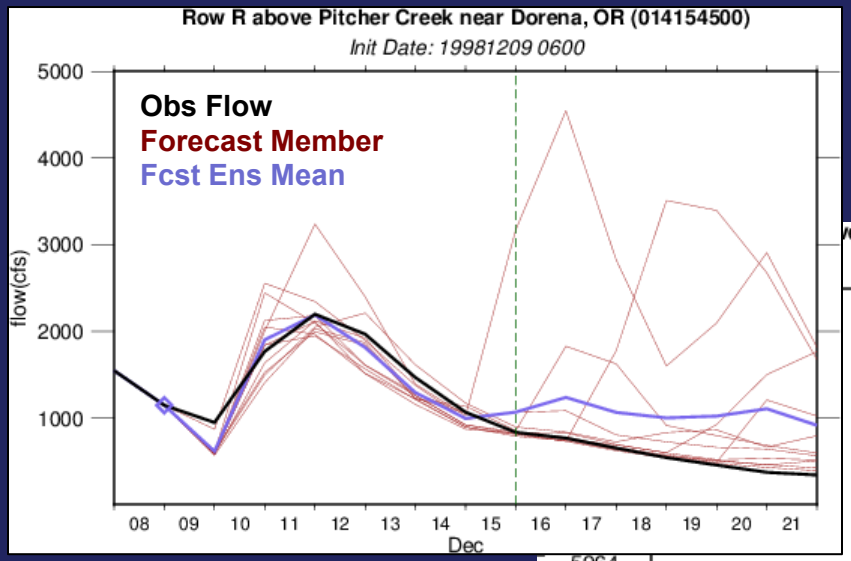
Figure: RMSE of forecasts with DA using PF, EnKF and AEnKF, versus the raw forecast

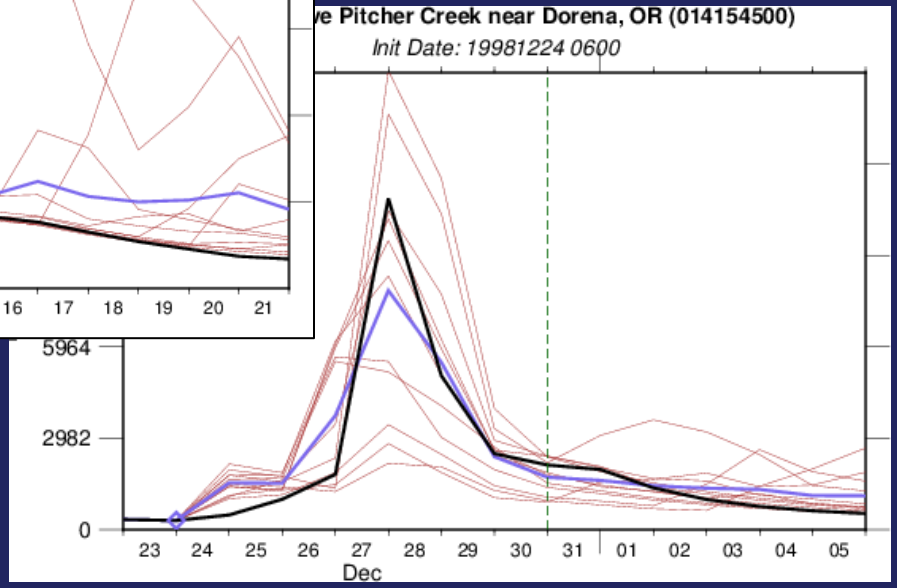
Building Blocks

Meteorological Ensemble Forecast Forcings

- **Goals:** downscaled ensemble met forecasts enable estimation of prediction uncertainty
- **Benefits**: supports risk-based approaches for forecast use
- **Specs**: use locally-weighted multi-variate regression to downscale GEFS (reforecast) atmospheric predictors to watershed precipitation and temperature

Figures: Case study hindcast of 15-day ensemble forecast including 7 days of downscaled GEFS as met forecast (Snow17/SAC model)





System for Hydromet Ensemble Research and Prediction Applications

an agile effort supporting ensembles, hindcasting, benchmarking, and development

SHERPA*

Observed Forcings
Maurer, Daymet, NLDAS

NWP / Climate Information
GEFS / CFSv2 / CFSR / Indices

Observed Forcings
Gridded Ensemble Meteorology Tool (**GMET**)

Downscaling / Calibration
ICAR, **GMET**, Statistical Methods

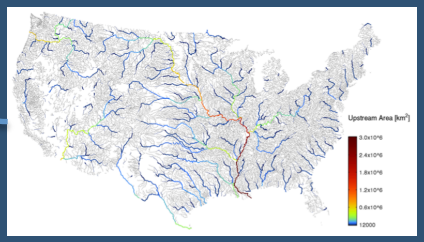
Regridding
Poly2Poly

Parameter Estimation
SCE, MOCOM, **MPR**

Hydrologic Models
NWSRFS, VIC, **SUMMA**, HEC-HMS, PRMS

Data Assimilation
enKF (SWE), PF (streamflow)

Channel Routing
mizuRoute, UH, Lohmann



running on open source
eg, python, R

publically available on
GitHub

Hydrologic Post-Processing
blend, quantile regression, quantile mapping

Product Generation
data & graphics (timeseries, maps, verification, process diagnostic)

ecFlow component coupler

Website

Collaborators
USACE, Reclamation, USGS, HEPEX, CUASHI, Private

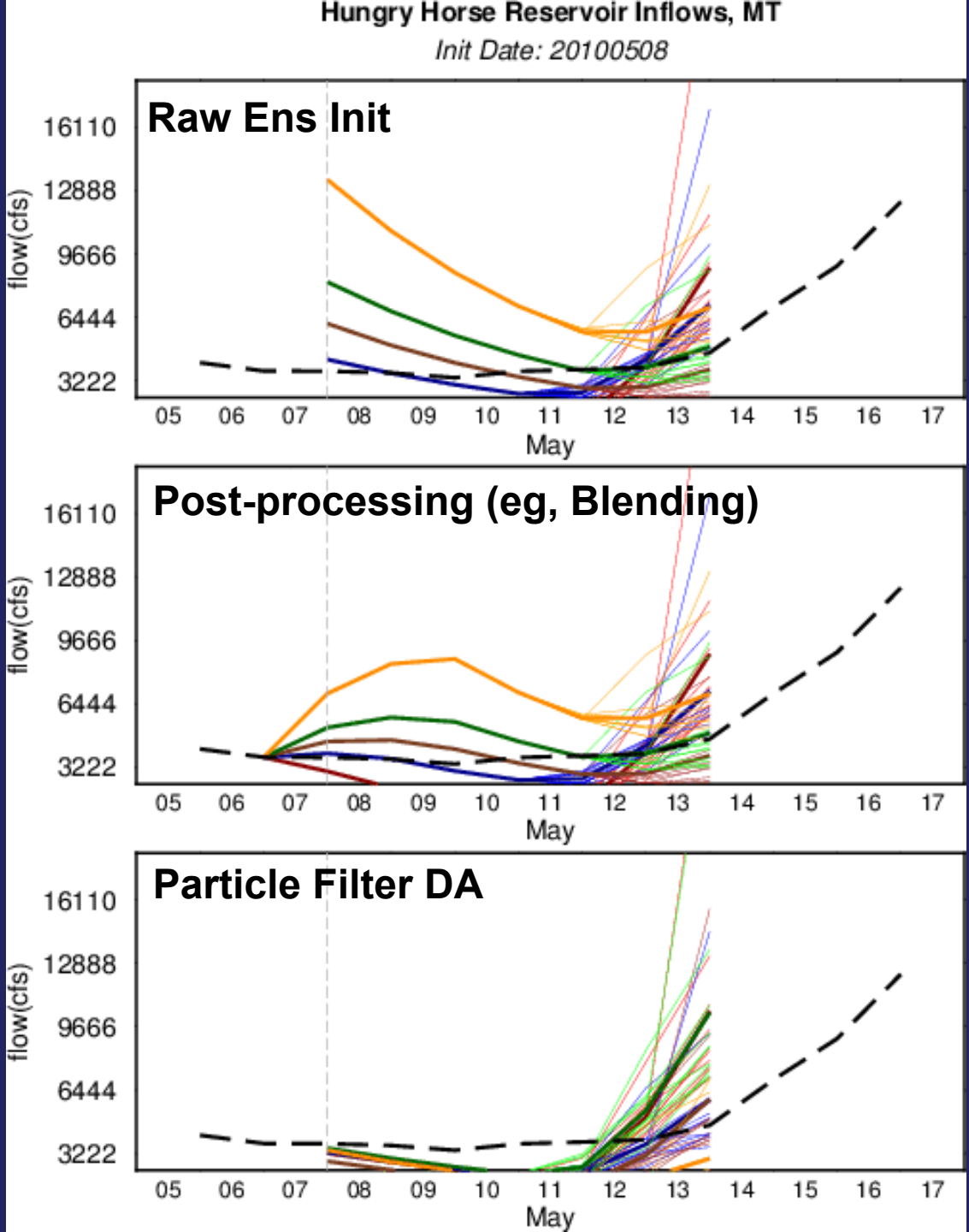
** to be renamed 'SHARP'*

Experiments

System allows for intercomparisons

- **Examples:**
  - DA via Particle Filter
  - Post-processing via linear blends (RFC method)

Figures: Ensemble-initialized GEFS-based flow forecast ensembles
(top) 5 ICs spanning range
(middle) same 5 ICs blended
(bottom) 5 highest weighted ICs (particles)



Key Points

- The goal is NOT to build a new forecasting system that the sponsoring water agencies will run
- The goal is to explore the idea that a more automated forecast workflow is viable, opening the door to many potential advances and expanded service
- The goal is also to provide experience and raise awareness about such alternative approaches, which are currently unfamiliar to many the operational prediction community
- *A change in forecast paradigm may require a change in user paradigms.*

A fear … but not a reality

The forecast center of the future will have only two employees – a person and a dog.

The person will be there to feed the dog.

The dog will be there to keep the person from touching the equipment.

-- paraphrasing Warren Bennis
(quote shared by T. Pagano)

Contacts

- NCAR: Andy Wood, Pablo Mendoza, Martyn Clark
- Univ. WA: Bart Nijssen, Elizabeth Clark