Near real time data assimilation and uncertainties for hydrological forecasting

Nathalie Voisin[1], Vimal Mishra[2], Mark Wigmosta[1], Dennis P. Lettenmaier[2]

HEPEX International workshop on Post-processing and Verification of hydrological ensemble predictions

7-9 June 2011, UNESCO-IHE, Delft, the Netherlands

Wednesday June 8

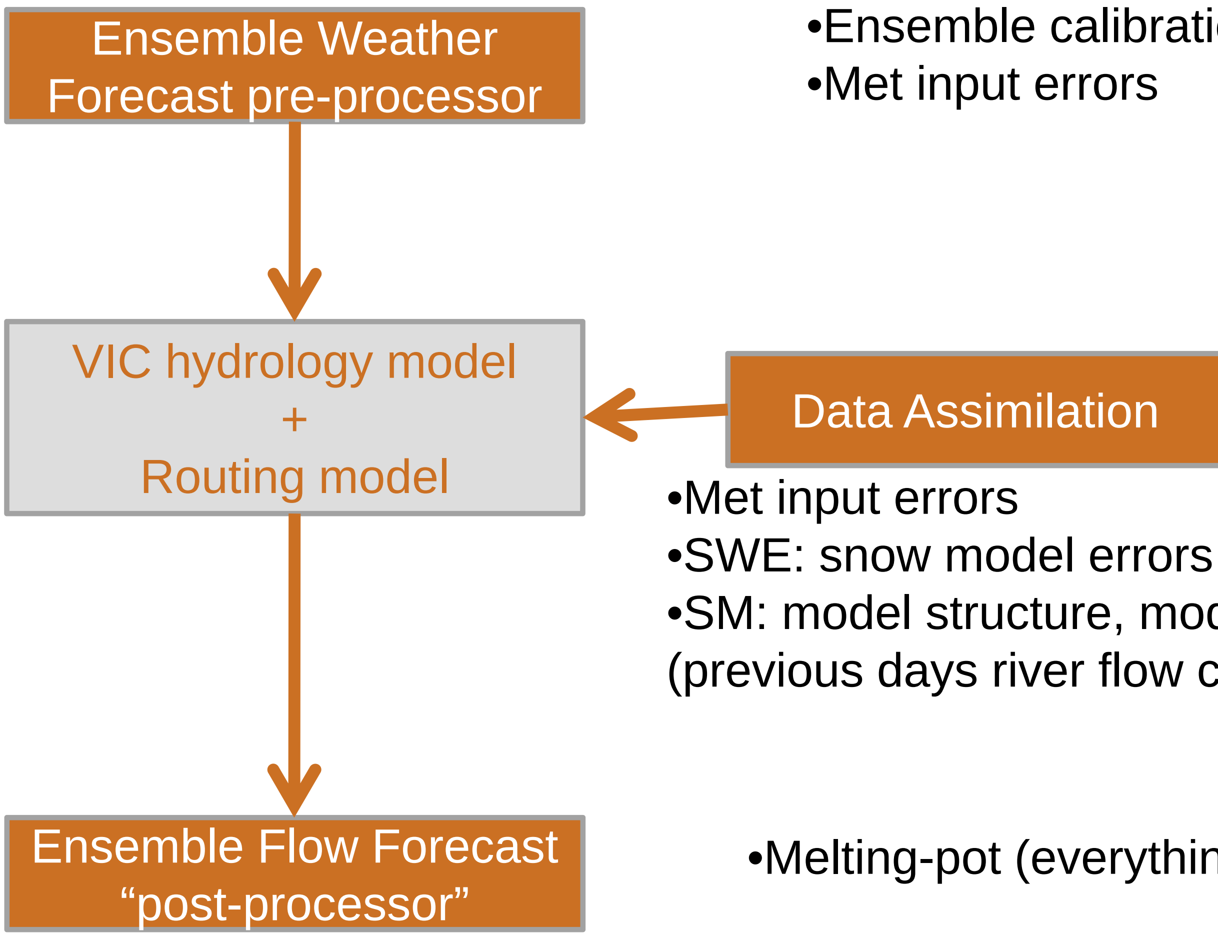
[1]Pacific Northwest National Laboratory, Richland, WA

[2]University of Washington, Civil and Environmental Engineering, Seattle, WA

UNIVERSITY OF WASHINGTON

Pacific Northwest NATIONAL LABORATORY

Data Assimilation and Uncertainties



- Ensemble calibration
- Met input errors

- Met input errors
- SWE: snow model errors (in situ SWE obs)
- SM: model structure, model parameterization (previous days river flow conditions)

- Melting-pot (everything)

Outline

- Snow Water Equivalent (SWE) assimilation
  - Approach
  - Results
  - Conclusions
- Soil Moisture (SM) assimilation
  - Approach
  - Results
  - Future directions

Pacific Northwest
NATIONAL LABORATORY

Approach – snow data assimilation

- SWE assimilation can correct for:
  - Errors in precipitation input leading to errors in model SWE
  - Errors in snow/rain differentiation and spatial distribution over the model grid cell which also lead to model SWE errors

- Point observations vs spatial average model predictions lead to complications

Pacific Northwest
NATIONAL LABORATORY

Approach

- Improve the Wood and Lettenmaier (2006) SWE assimilation for short term flow forecasting:
  - Weighted average between point-based observed and spatially (and vertically) distributed simulated anomalies:
  - Linearly decreasing weights based on distance and elevation:
    - $SWE_{station}$ >= 10 cm
    - Wdistance = MAX[0 ,1 - distance(station,grid cell) / 50 km]
    - Welevation = 1 – MAX[0 , $|Elev_{station}-Elev_{gridcell}|$ / 2000 m]
    - $Wtotal_i = Wdistance_i \, . \, W\,elevation_i$

$$\mathbf{SWE_{new} = (1\text{-}K)SWE_{VIC}+K*SWE\_SIGNAL_{stations}}$$

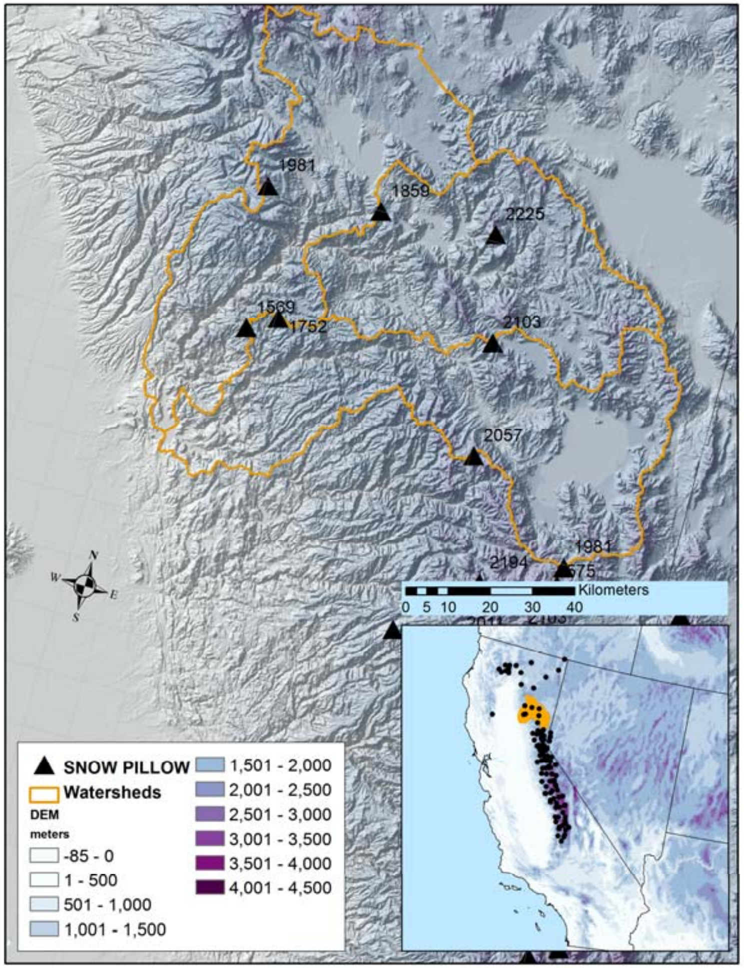
$$\mathbf{SWE_{new} = (1\text{-}K)SWE_{VIC}+\sum[Wtotal_i \,.\, CDF_{VIC}^{-1}(CDF_{station}(SWE_{station}))]}$$

where $\mathbf{\sum Wtotal_i = K}$

CDF_{VIC} and $CDF_{station}$ based on 1990-2005 daily SWE

Pacific Northwest NATIONAL LABORATORY

Feather River Basin, California



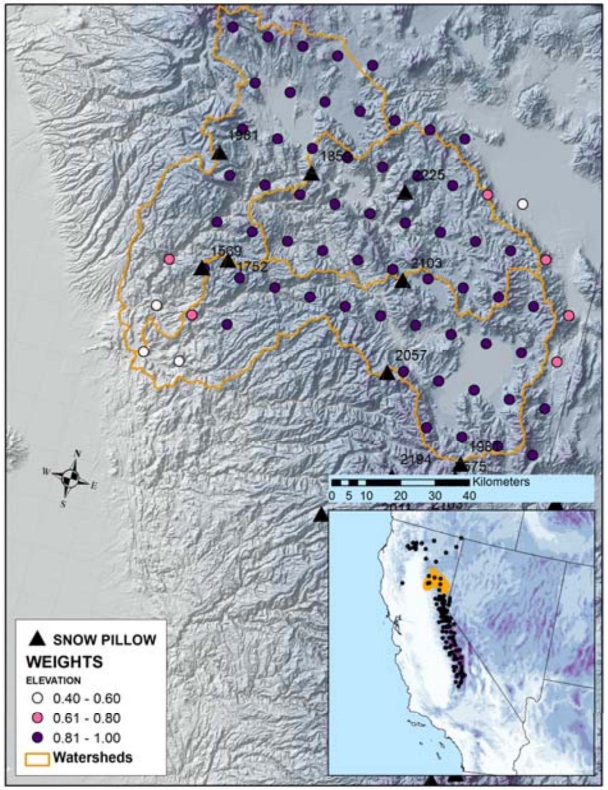
Snowmelt driven basin
13 000 km^2
~3 day concentration time
Up to 15 SNOTEL stations influencing each VIC grid cell (50 km radius)

Figure created by Erik Venteris

Pacific Northwest NATIONAL LABORATORY

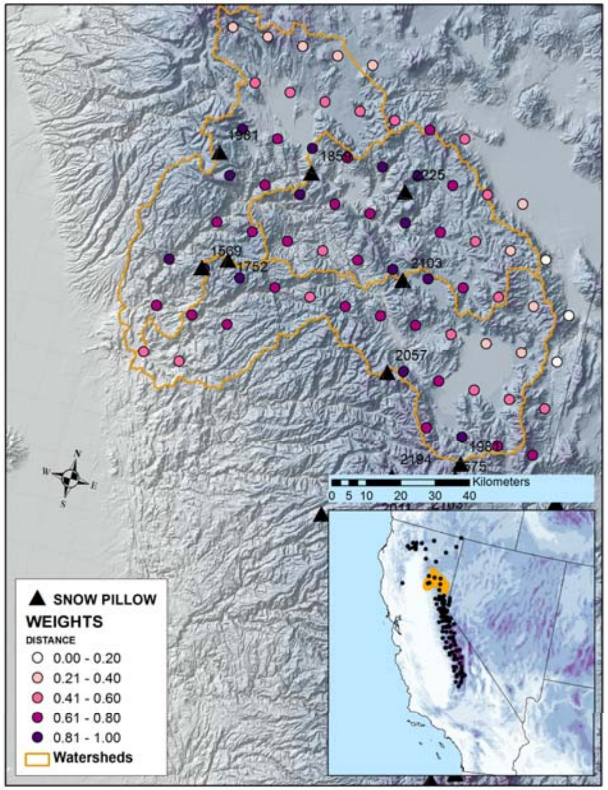
SNOTEL influence on simulated SWE

Elevation-based



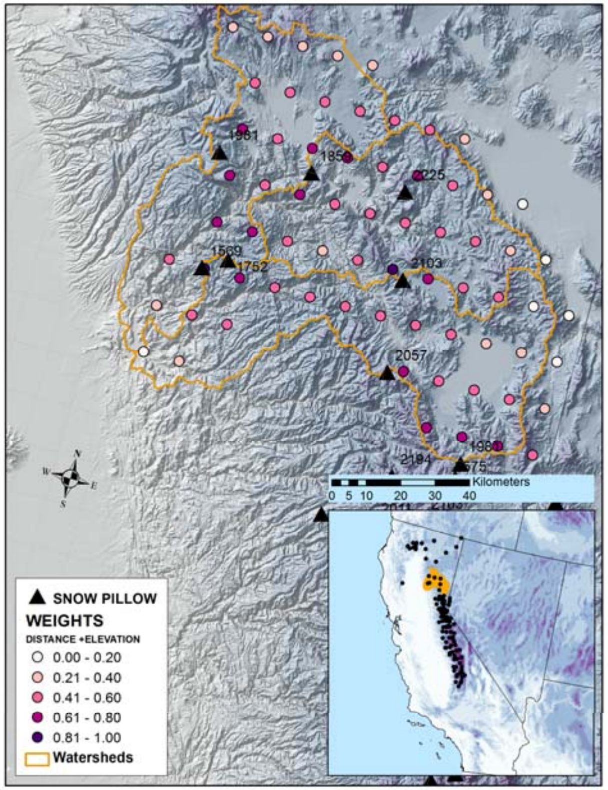
(0.8-0.9)

Distance-based



(0.2-0.8)

Distance and Elevation-based



(0.1-0.8)

Weights decrease

Pacific Northwest
NATIONAL LABORATORY

Figures created by Erik Venteris

Science Questions

- Can SNOTEL SWE assimilation improve short term flow forecasts?

- What is the uncertainty in the flow forecasts due to uncertainties in the SWE assimilation ?
  - Different weights
  - Uncertainty in spatial and vertical disaggregation of the point-based SWE information

- How significant is the uncertainty in the spatial disaggregation of observed SWE information with respect to model parameterization uncertainty?

Pacific Northwest NATIONAL LABORATORY

Approach

No assimilation

Observed precipitation, temperature, wind

↓

VIC hydrology model

↓

Simulated daily flow

SNOTEL SWE assimilation

Observed precipitation, temperature, wind

↓

VIC hydrology model ← SWE assimilation Weighted average

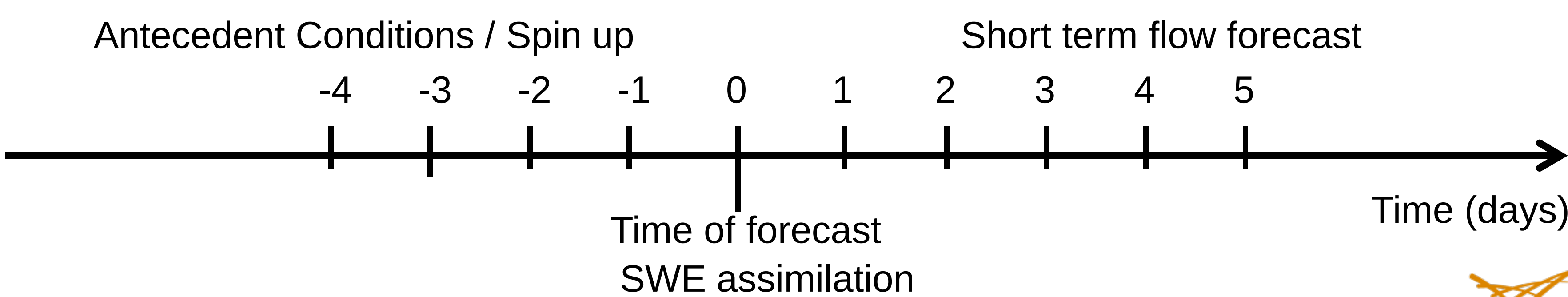
↓

Simulated daily flow

Perfect forecast scenario

Daily 1/8th degree simulations

Flow forecast verification with respect to observed daily (naturalized) flow



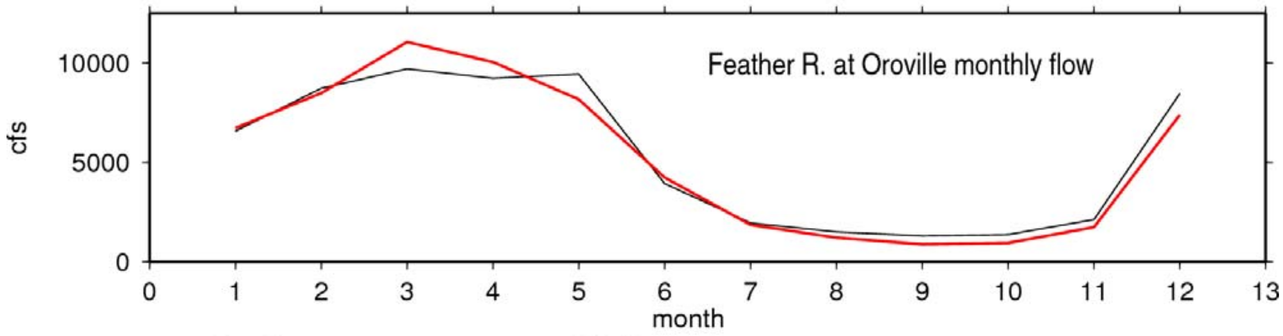
Pacific Northwest NATIONAL LABORATORY

Approach

- Experiments:
  - “Perfect forecast” scenario; estimate only assimilation
  - For different weights between simulated and observed SWE anomalies: uncertainties due to the static weights

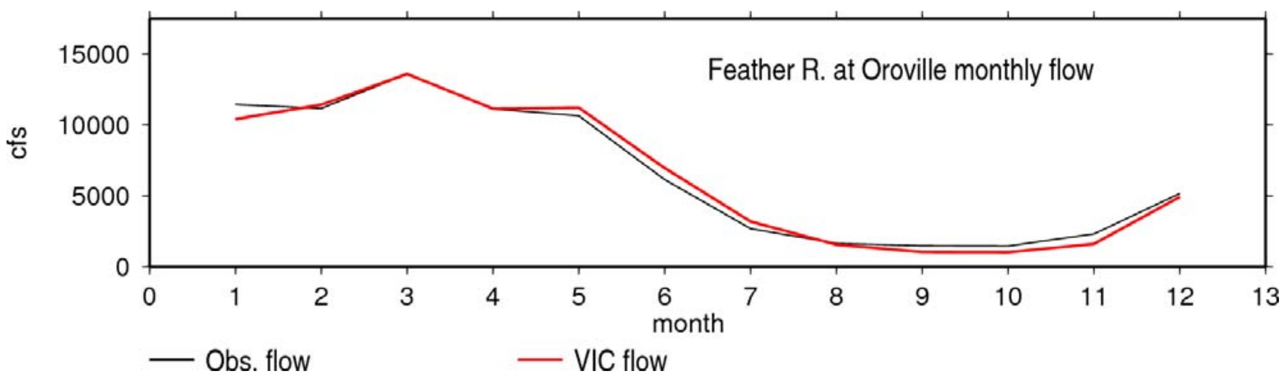
- Analysis
  - Daily streamflow forecast verification for the 1990-2005 period
  - For different months: accumulation vs ablation period
  - Streamflow forecast categories based on observations
  - Accuracy skills assessment: biases, RMSE, correlation

Feather – VIC calibration



Mean monthly flow
Calibration period
2000-2005

Daily NSE: 0.81
Annual bias: 0



Mean monthly flow
Validation period
1990-2000

Daily NSE: 0.84
Annual Bias: 0

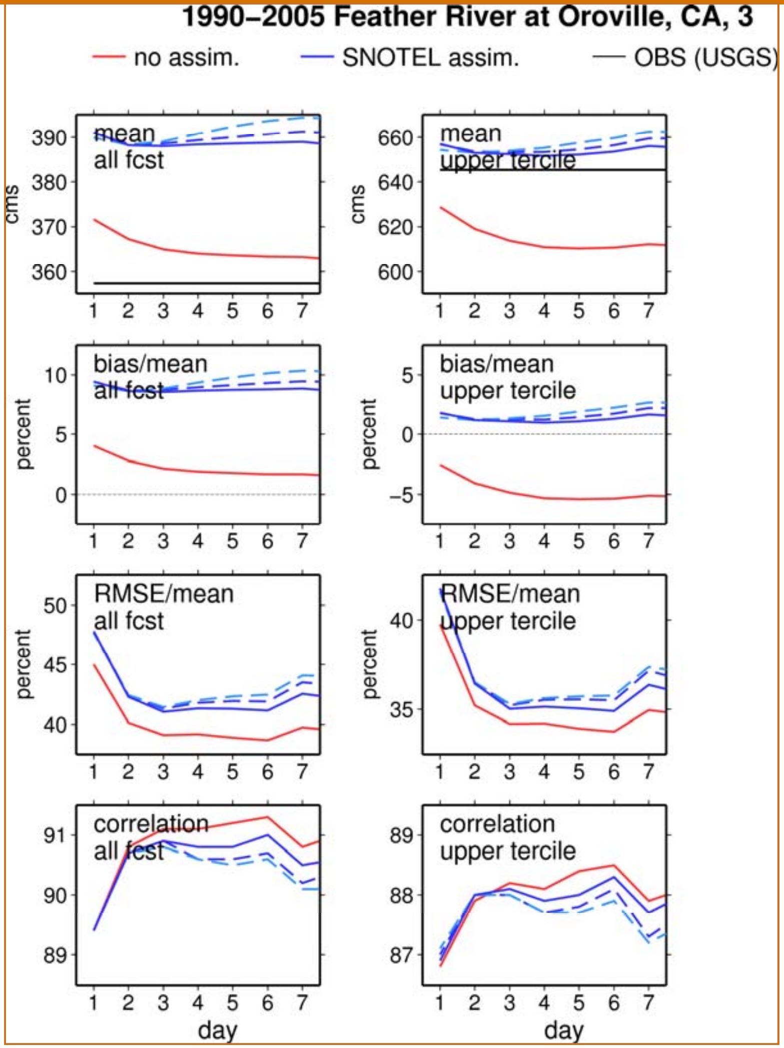
Pacific Northwest
NATIONAL LABORATORY

Results - March

1990-2005 period
496 forecasts
Observed flow categories

For all lead times:

-Overall higher bias and RMSEs, decreased bias during high flows
-Status quo

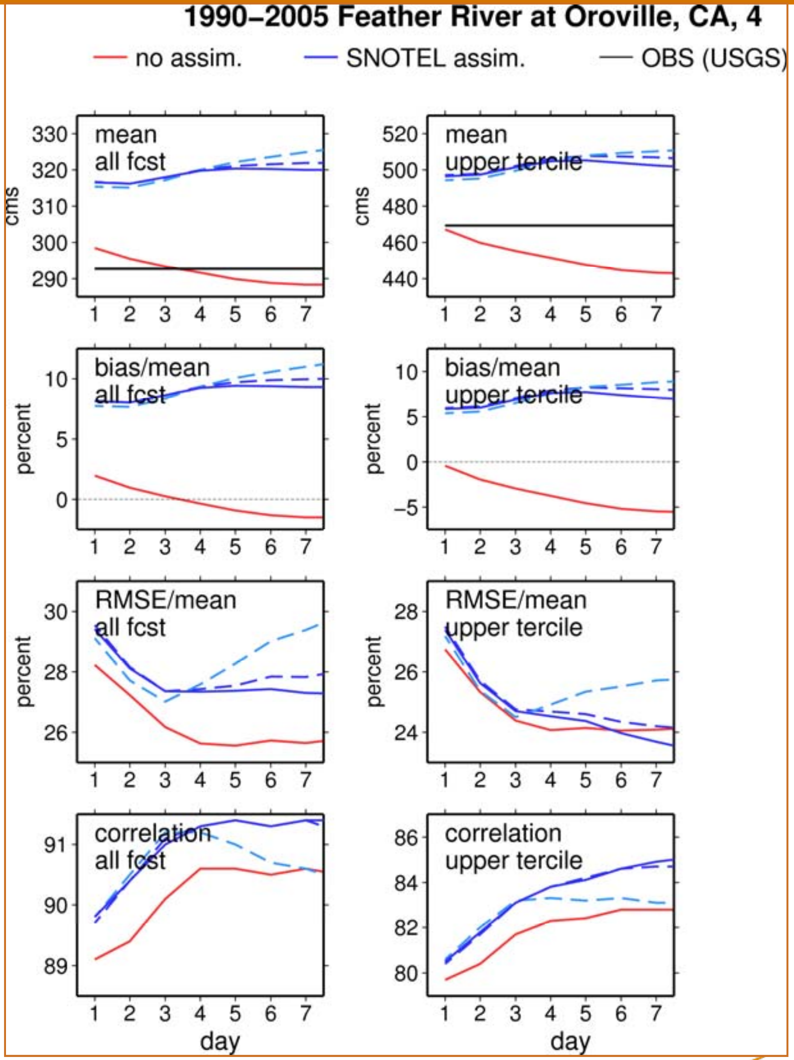


Elevation -based SWE assim
Distance-based SWE assim
Elevation and distance-based SWE assim
No assimilation

Pacific Northwest
NATIONAL LABORATORY

Results - April

1990-2005 period
480 forecasts
Observed flow categories



For all lead times:

•Increased bias and RMSE
•Status quo

Elevation -based SWE assim
Distance-based SWE assim
Elevation and distance-based SWE assim
No assimilation

Pacific Northwest
NATIONAL LABORATORY

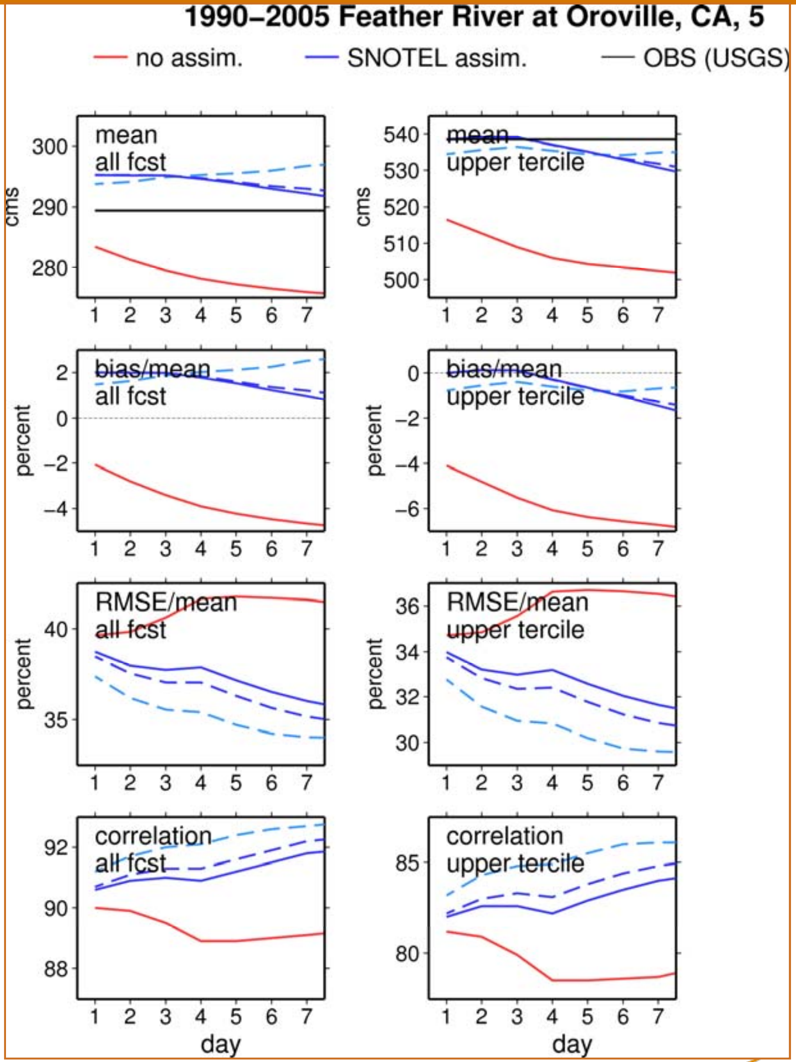
Results - May

1990-2005 period
496 forecasts
Observed flow categories

For all lead times:

- Decreased RMSE
- Decreased bias for high flows
- Increased correlation
- Increased sensitivity to weights: largest at end of snowmelt period

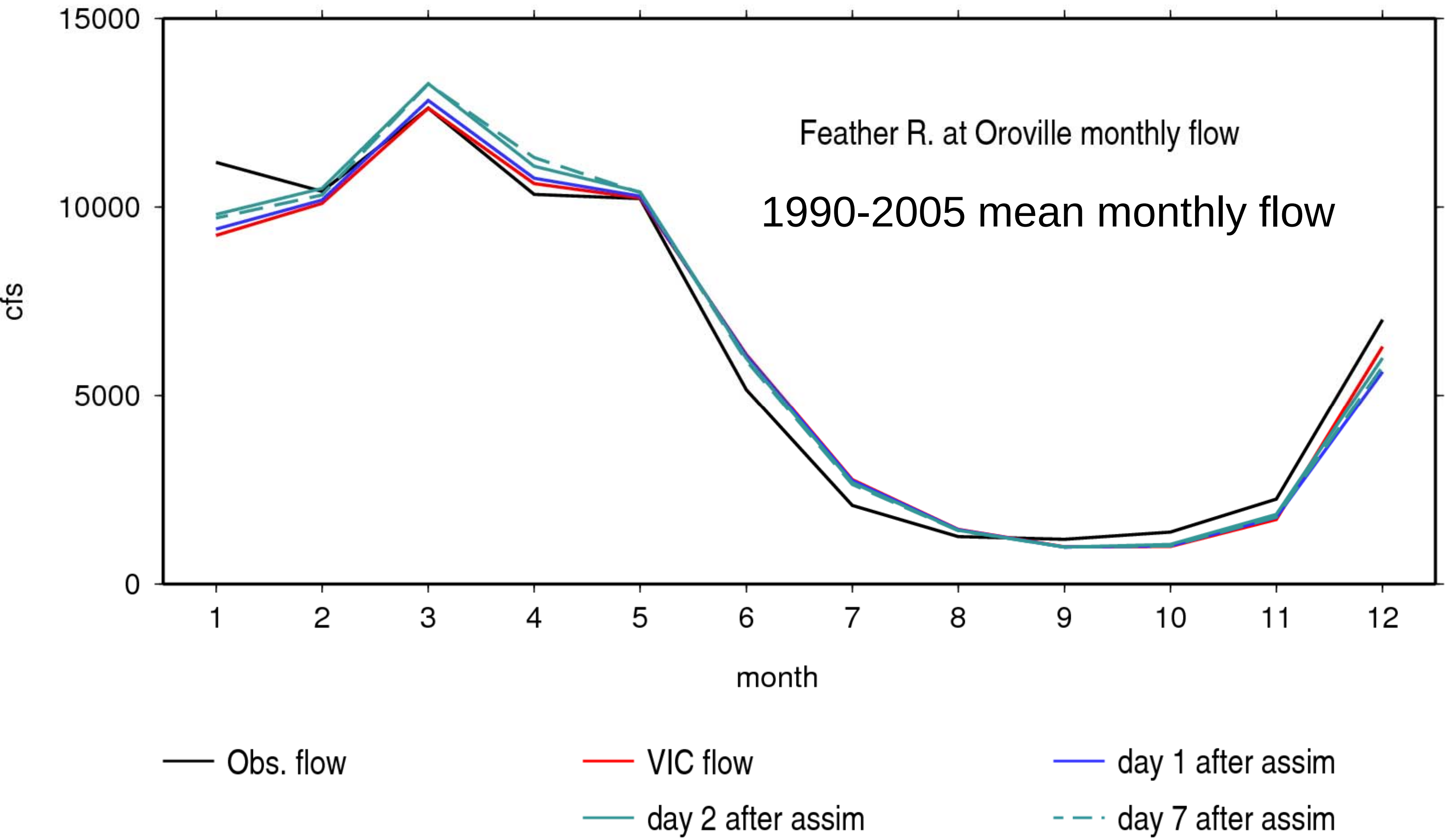
- Not shown: both high and low flow improved by SWE DA



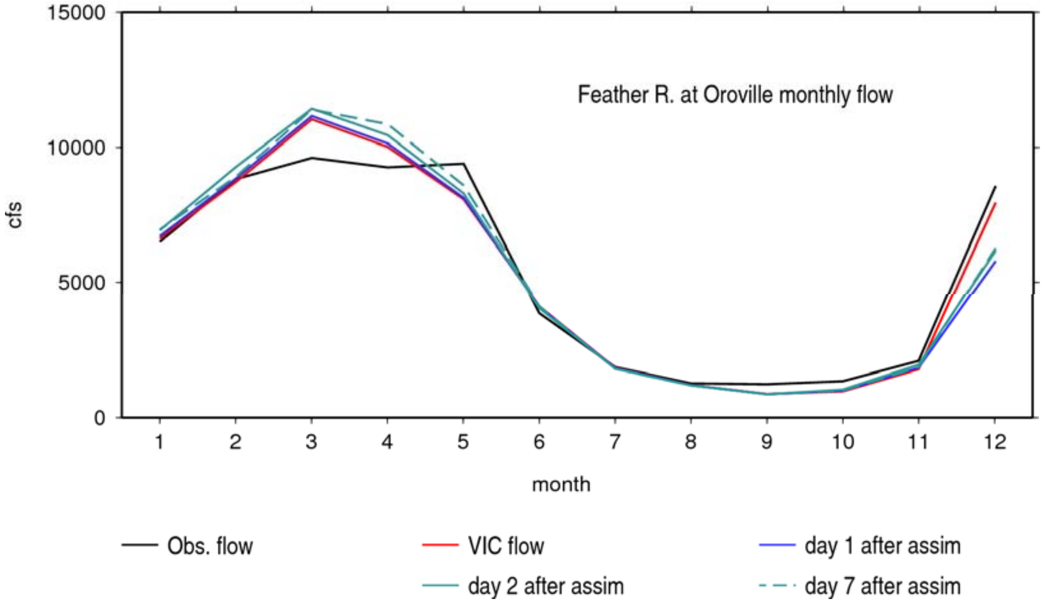
Elevation -based SWE assim
Distance-based SWE assim
Elevation and distance-based SWE assim
No assimilation

Pacific Northwest NATIONAL LABORATORY

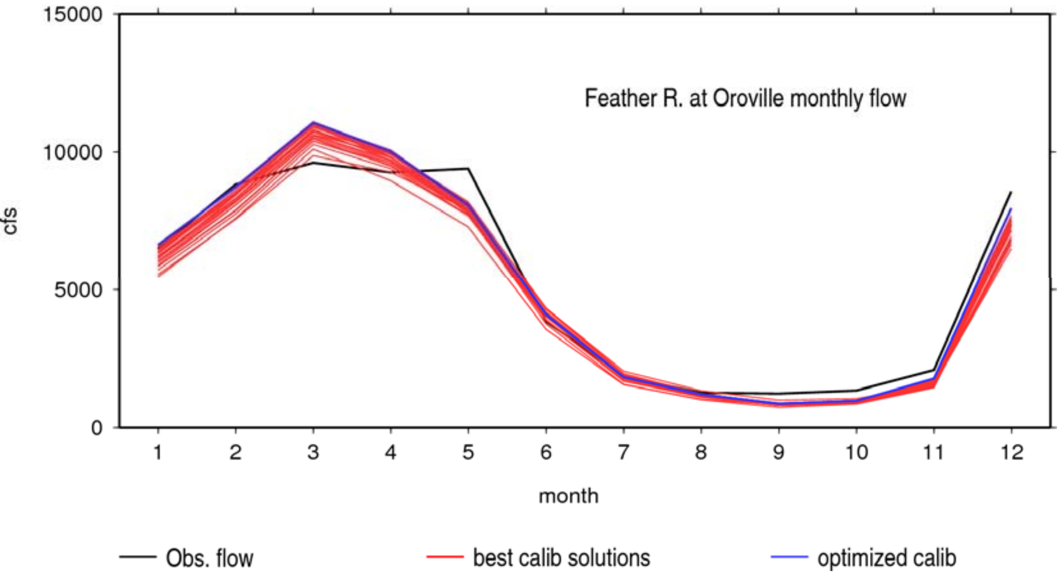
Effect of SWE assim. on the calibrated water balance (model parameterization)



SWE uncertainty vs model uncertainty



i) Uncertainty in precipitation forcing
ii) (not shown) small differences between different weight scenarios – small uncertainty due to different weighting scenarios



Parameter uncertainty:

Best 25 parameterization solutions for the VIC-routing model.
- Annual bias varies 0-12%.
- For equivalent NSE values

Pacific Northwest
NATIONAL LABORATORY

Conclusions

- SWE assimilation can improve short term flow forecasts volume during ablation period.
- Largest improvement for lead times longer than time of concentration.
- Uncertainties related to elevation-based and distance-based weights increased at the end of the snowmelt period.
  - Need to calibrate the weights – calibrate the spatial disaggregation of the SNOTEL SWE for basins with different hydro-climatic conditions
- Over the Feather RB: parameterization uncertainties larger than the precipitation forcing uncertainty.

Future direction

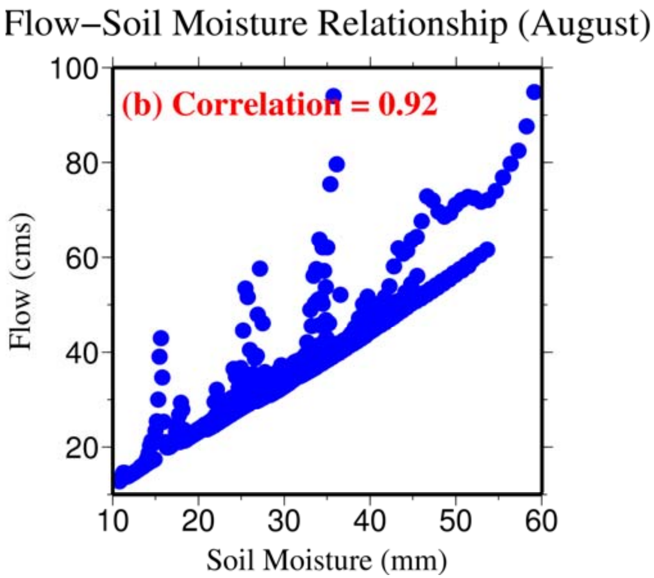
- Future direction: merge a pre-processor with a SWE DA.
  - Should we also calibrate the SWE DA for probabilistic forecast?
  - How to merge it with the pre-processor.

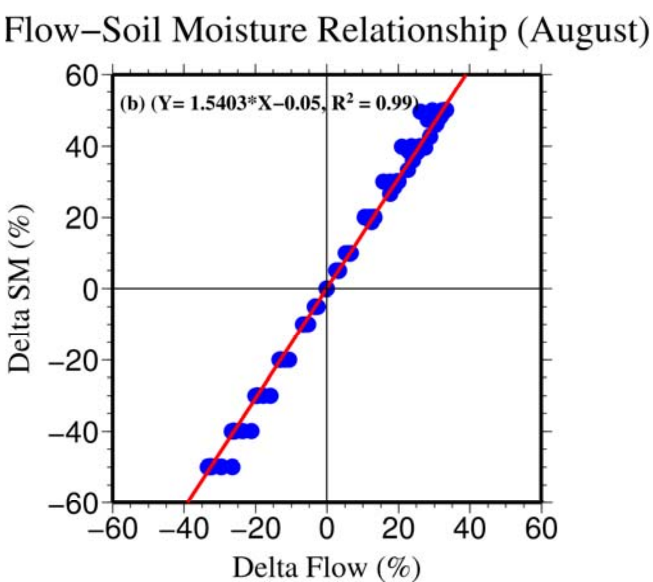
River flow – Soil Moisture Assimilation Approach

- Direct insertion of soil moisture initial state information
- Initial state information was obtained from relationship between weekly mean soil moisture and flow differences through an empirical relationship
  - High flow period (Oct-June) -- SM (LYR1+LYR2)
  - Low flow period (July-September) -- SM (LYR3)

Pacific Northwest NATIONAL LABORATORY

River flow – Soil Moisture Assimilation Approach



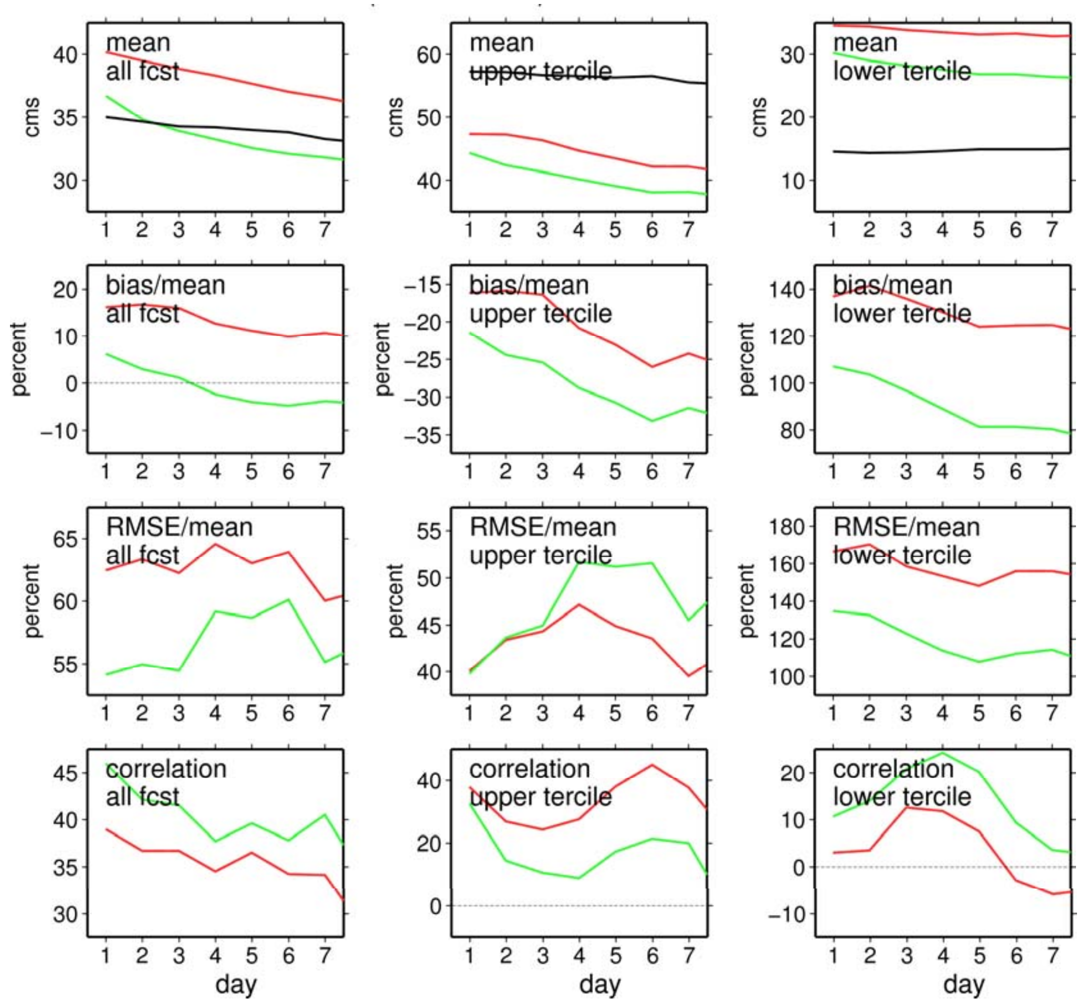


- Developed relationship between change in weekly flow and weekly soil moisture (layer 3)
- Linear relationship was found suitable for August

Pacific Northwest
NATIONAL LABORATORY

River flow – Soil Moisture Assimilation Results

AUGUST
1990-2005 period
400 forecasts
Observed flow categories



- overall improvement
- slow flow sensitive to DA

Soil Moisture Assimilation – Bottom Soil Layer
No assimilation

River flow – Soil Moisture Assimilation

Future work

- Improve results for high flows: use a shorter spatial window of previous observed flow conditions for assimilation
- Apply assimilation over several soil layers depending on previous flow conditions
- Merge SWE and soil moisture assimilation using an ensemble Kalman Filter.

Thank you!

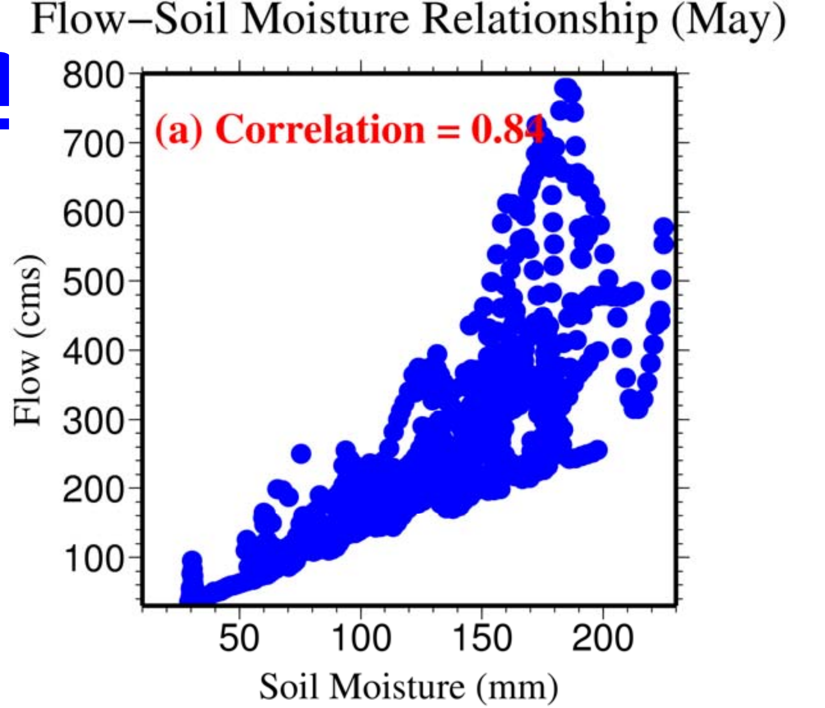
Pacific Northwest
NATIONAL LABORATORY

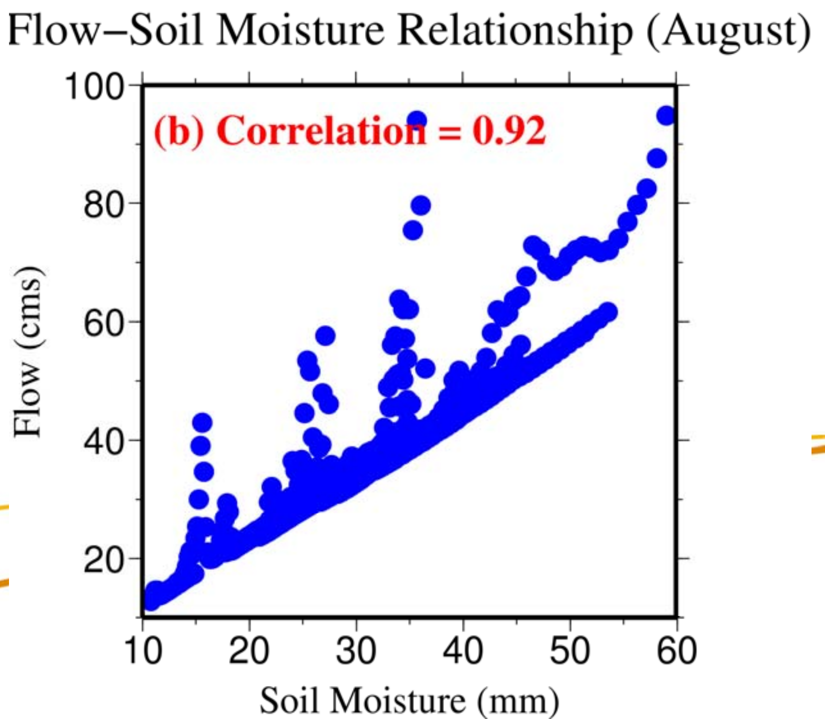
Extra slides

Assimilation Approach

Period : 1961 -1990

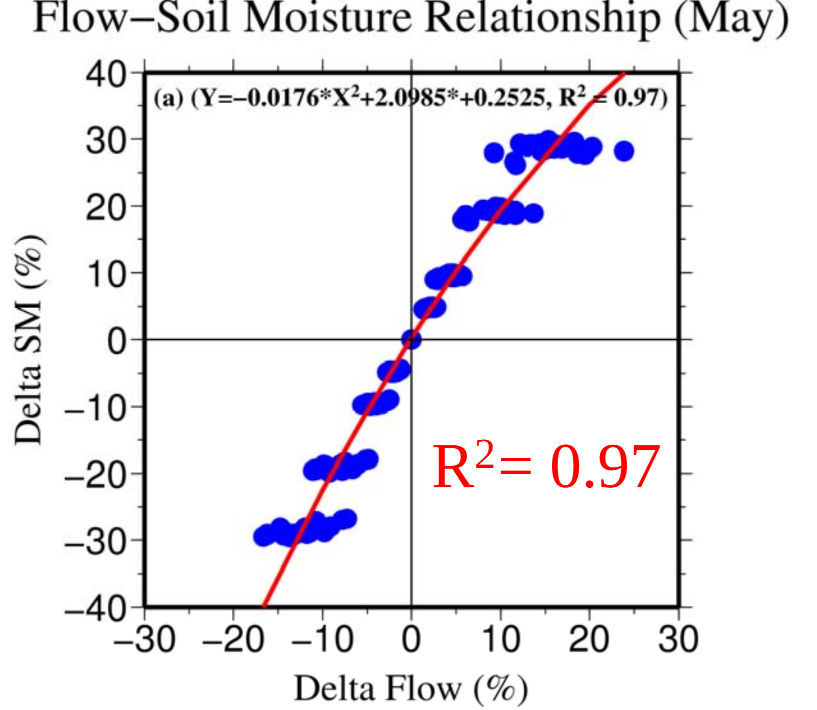
- Soil moisture (Layer 3) – May flow correlation 0.84
- Soil moisture (Layer 3) – August correlation 0.92
- Tested relationship for other layers but moisture from layer 3 provided best skill for flow prediction

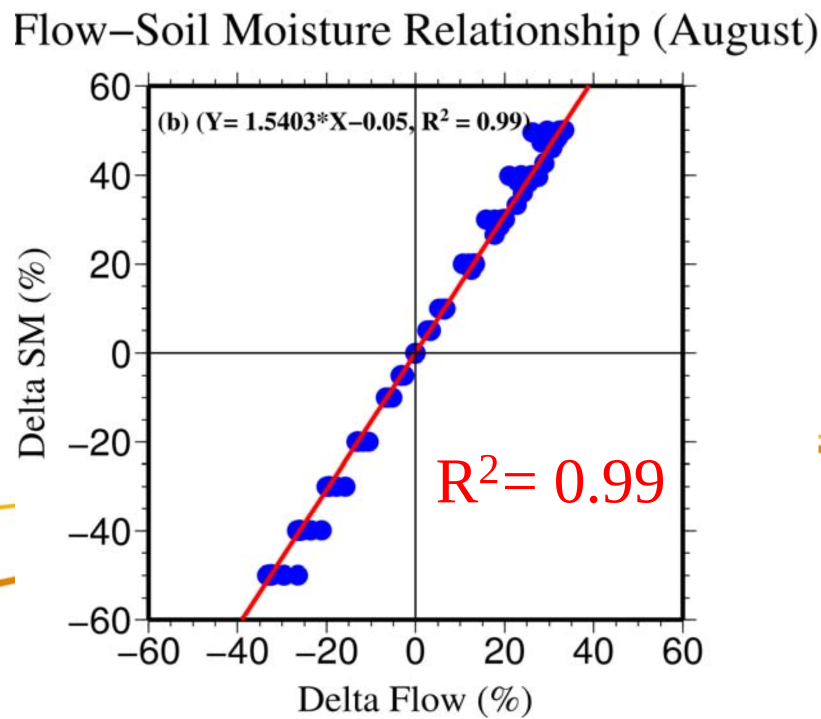




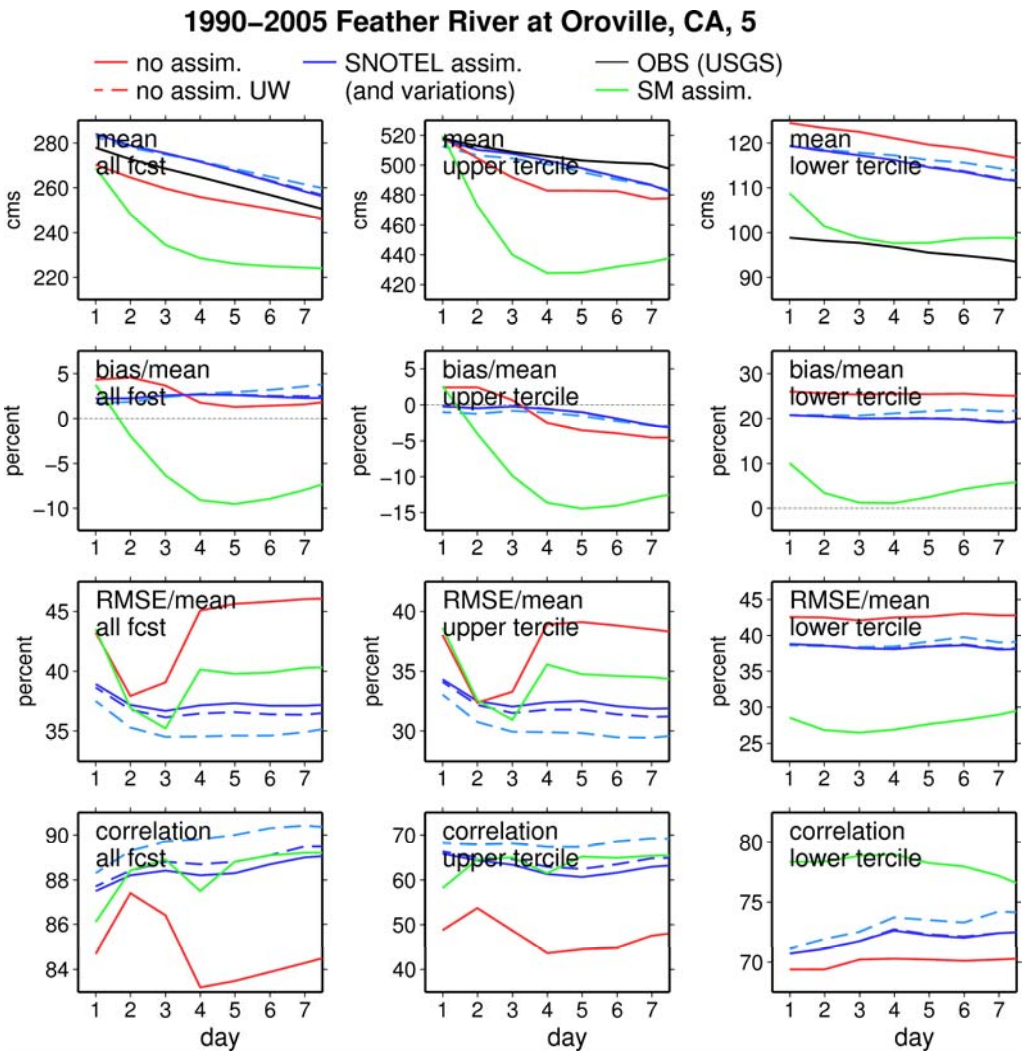
Assimilation Approach

- Developed relationship between change in weekly flow and weekly soil moisture (layer 3)
- Second order polynomial was used to estimated change in soil moisture state for May
- Liner relationship was found suitable for August





SWE DA - May



1990–2005 Feather River at Oroville, CA, 5
no assim.
no assim. UW
SNOTEL assim.
(and variations)
OBS (USGS)
SM assim.
mean
all fcst
mean
upper tercile
mean
lower tercile
bias/mean
all fcst
bias/mean
upper tercile
bias/mean
lower tercile
RMSE/mean
all fcst
RMSE/mean
upper tercile
RMSE/mean
lower tercile
correlation
all fcst
correlation
upper tercile
correlation
lower tercile
cms
percent
day

Approach – SWE assimilation

- Direct insertion
  - SNODAS: direct insertion of SWE observation at the discretion of the forecaster (SNTHERM high spatial resolution snow model)

  Incoherency between assimilated SWE and subsequent hydrologic model

- Assimilation
  - Weighted average of spatially distributed simulated and point-based observed anomalies (Wood and Lettenmaier 2006)
  - Ensemble Kalman Filter of simulated and interpolated SWE anomalies (Z-score, Slater and Clark 2006)

  Coherent with hydrologic model parameterization and structure.

Background – snow data assimilation

Snow Water Equivalent (SWE) or Snow Coverage (SCA)?

- SCA assimilation has shown some ability to reduce weekly and seasonal streamflow forecast errors in previous work (Clark and Slater 2006, Tang et al. 2010, McGuire et al. 2006, Andreadis et al. 2006, etc)
  - Not a model state variable, SWE (reflects water storage) may be weakly linked to SCA
  - Uncertainties in cloud-no cloud conditions
- SWE assimilation can correct for:
  - Errors in precipitation input leading to errors in model SWE
  - Errors in snow/rain differentiation and spatial distribution over the model grid cell which also lead to model SWE errors
- Point observations vs spatial average model predictions lead to complications

Pacific Northwest
NATIONAL LABORATORY

Background – SWE assimilation

- Direct insertion
  - SNODAS: direct insertion of SWE observation at the discretion of the forecaster (SNTHERM high spatial resolution snow model)

  Incoherency between assimilated SWE and subsequent hydrologic model

- Assimilation
  - Weighted average of spatially distributed simulated and point-based observed anomalies (Wood and Lettenmaier 2006)
  - Ensemble Kalman Filter of simulated and interpolated SWE anomalies (Z-score, Slater and Clark 2006)

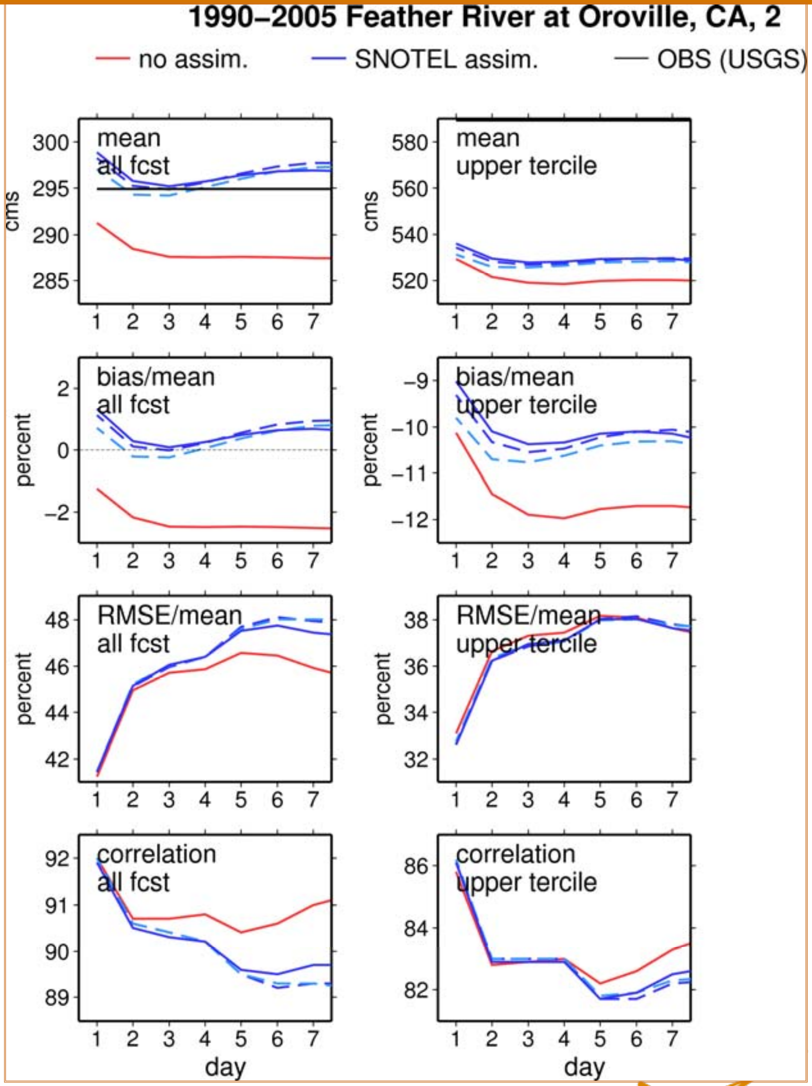
  Coherent with hydrologic model parameterization and structure.

Results - February

1990-2005 period
452 forecasts
Observed flow categories

Status quo

Note: no improvement during accumulation period



Elevation -based SWE assim
Distance-based SWE assim
Elevation and distance-based SWE assim
No assimilation

Status quo

Pacific Northwest
NATIONAL LABORATORY