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Predictability of Alpine Snowpack: A case study in the Tuolumne Alpine Research Catchment

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INARCH – Oct. 18, 2021 Virtual Meeting

AS 



Motivation: Merging advances in technology



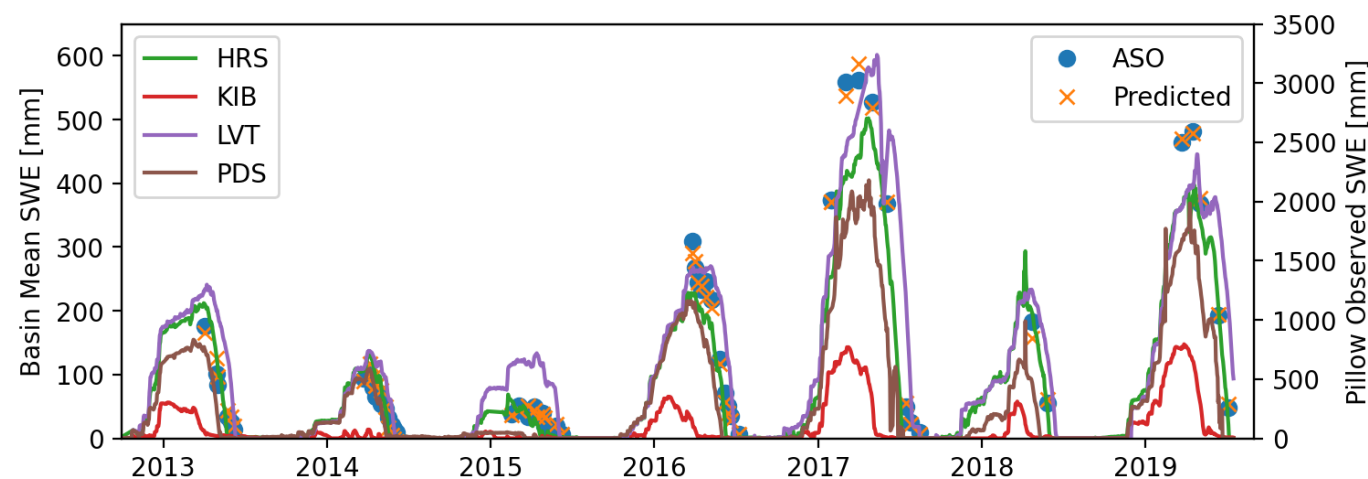
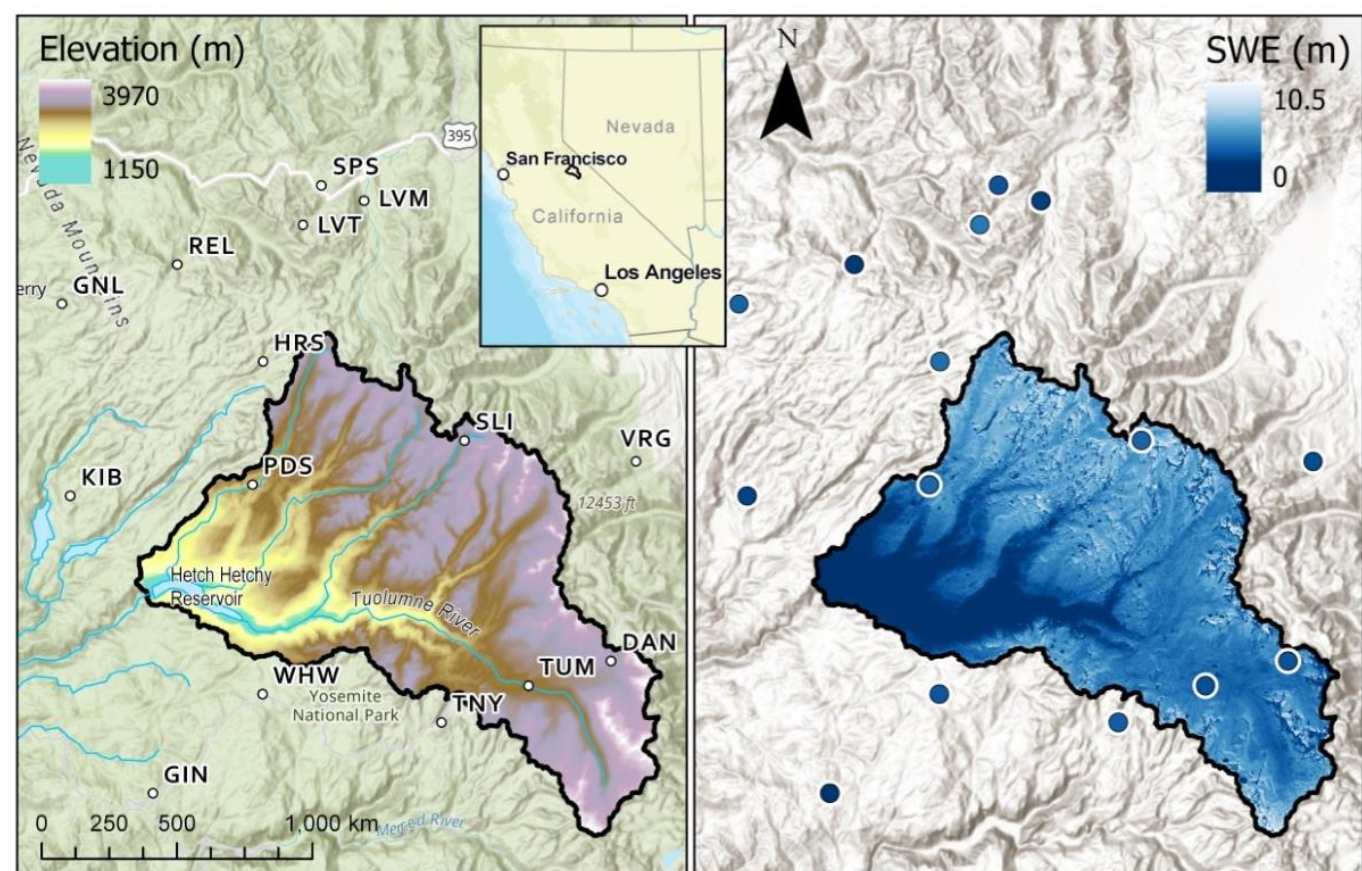
https://www.nrcs.usda.gov/wps/portal/nrcs/detail/ut/newsroom/photos/?cid=nrcs141p2_034312

<https://www.jpl.nasa.gov/spaceimages/details.php?id=PIA17771>

Datasets & Analysis

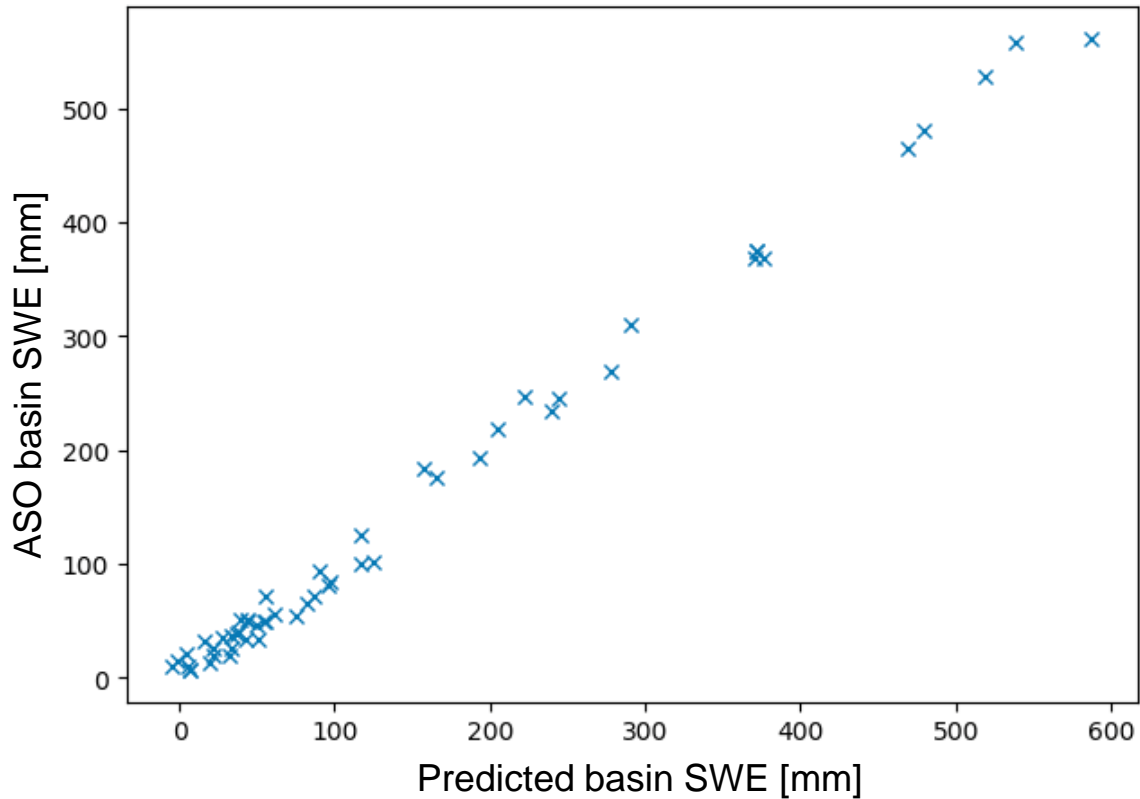
Multiple linear regression using snow pillows to predict basin-averaged ASO SWE

- Ground measurements: 15 snow pillows
- ASO images: 53 flights
- Assumptions inherent to linear regression and stationarity.



Basin average SWE from ASO is reasonably predicted by snow pillows and common regression statistics.

Multiple Linear Regression (RMSE 12mm)



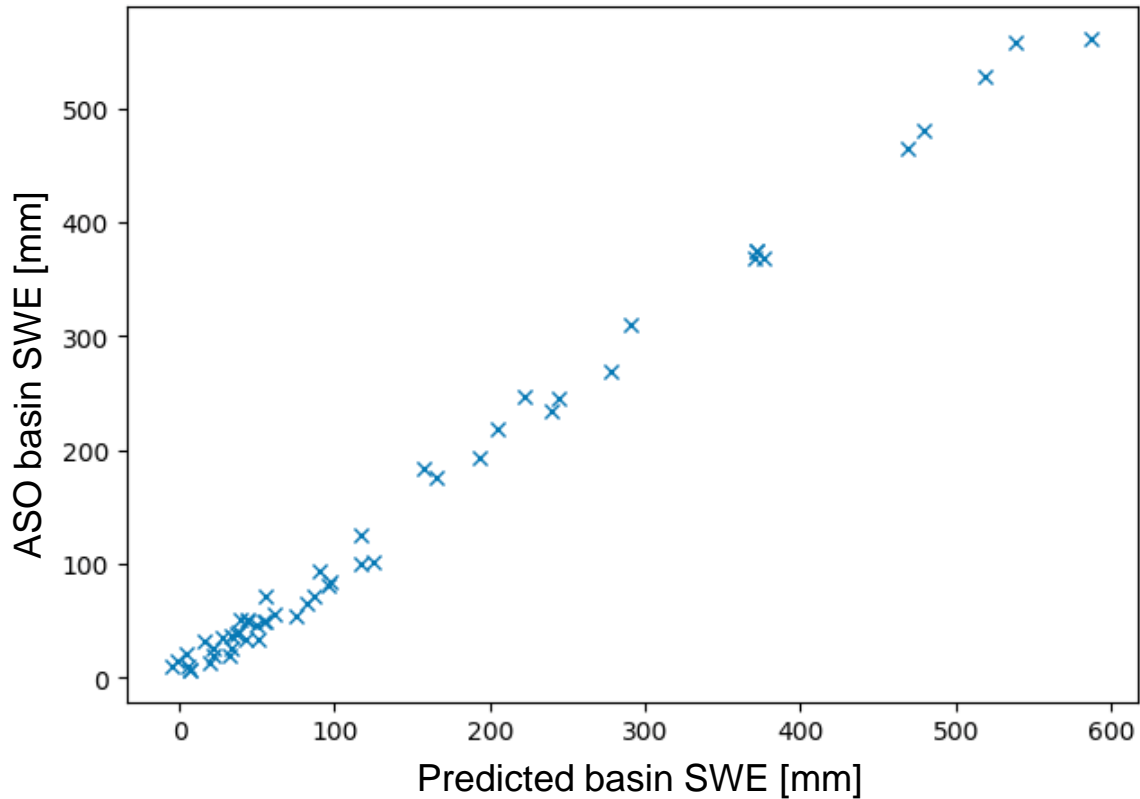
Ground measurements: 15 snow pillows

ASO images: 53 flights (through 2019)

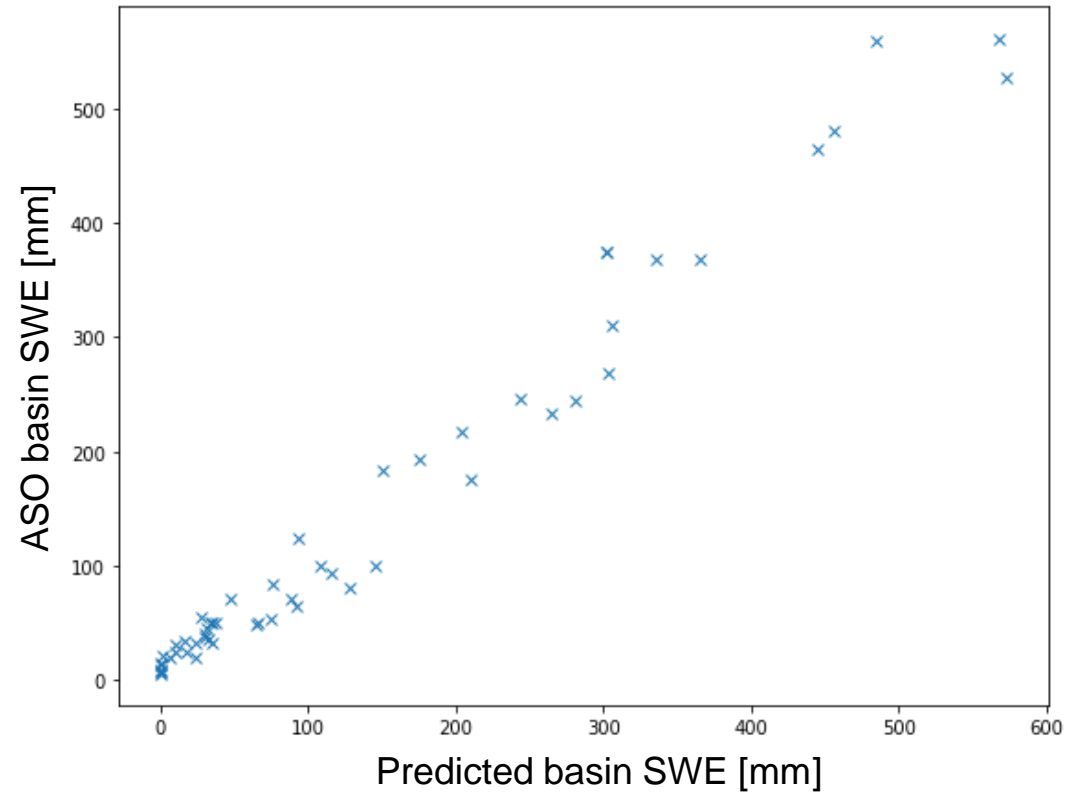
Many possible combinations of stations and flights!

Basin average SWE from ASO is reasonably predicted by snow pillows and common regression statistics.

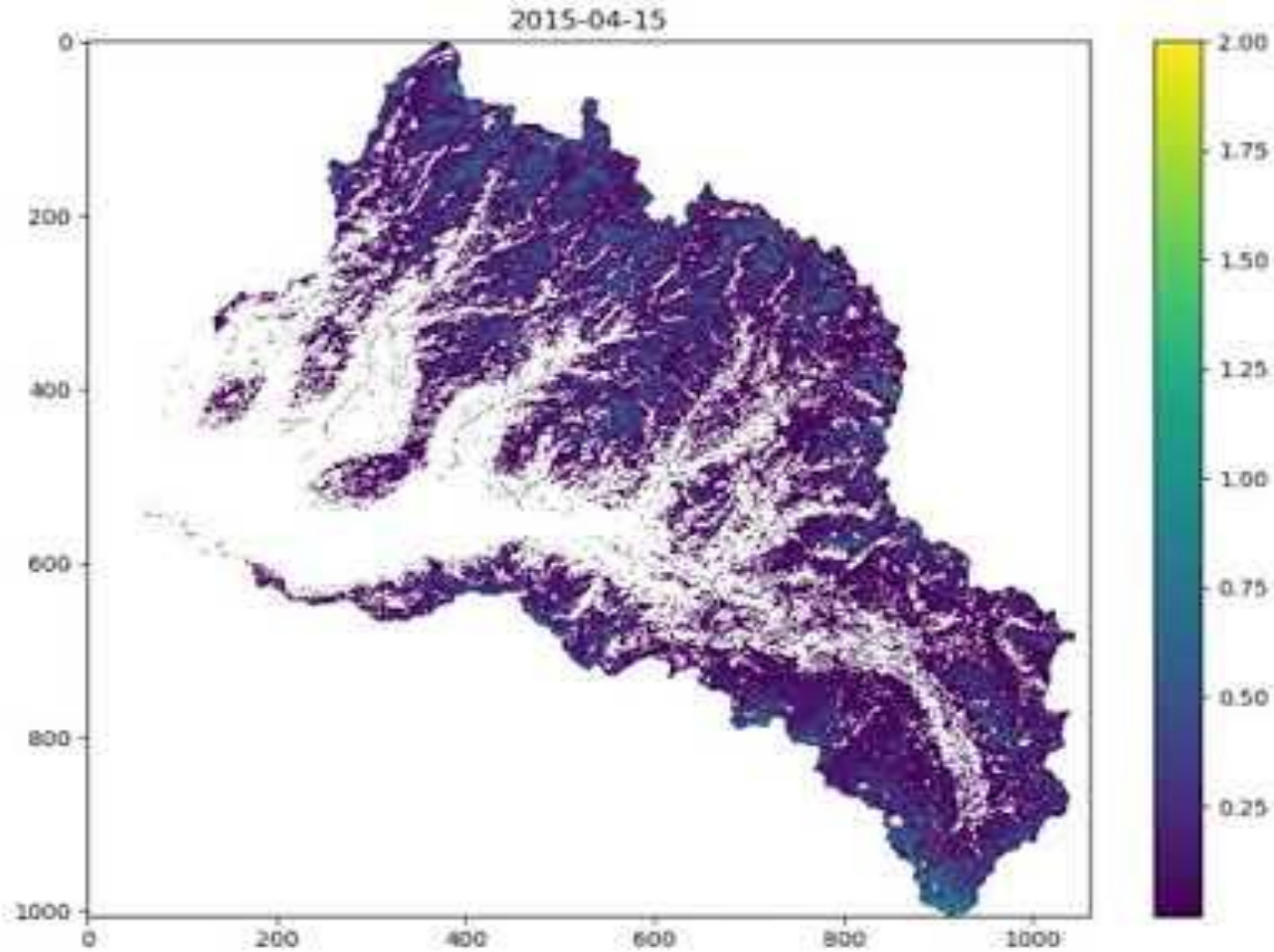
Multiple Linear Regression (RMSE 12mm)



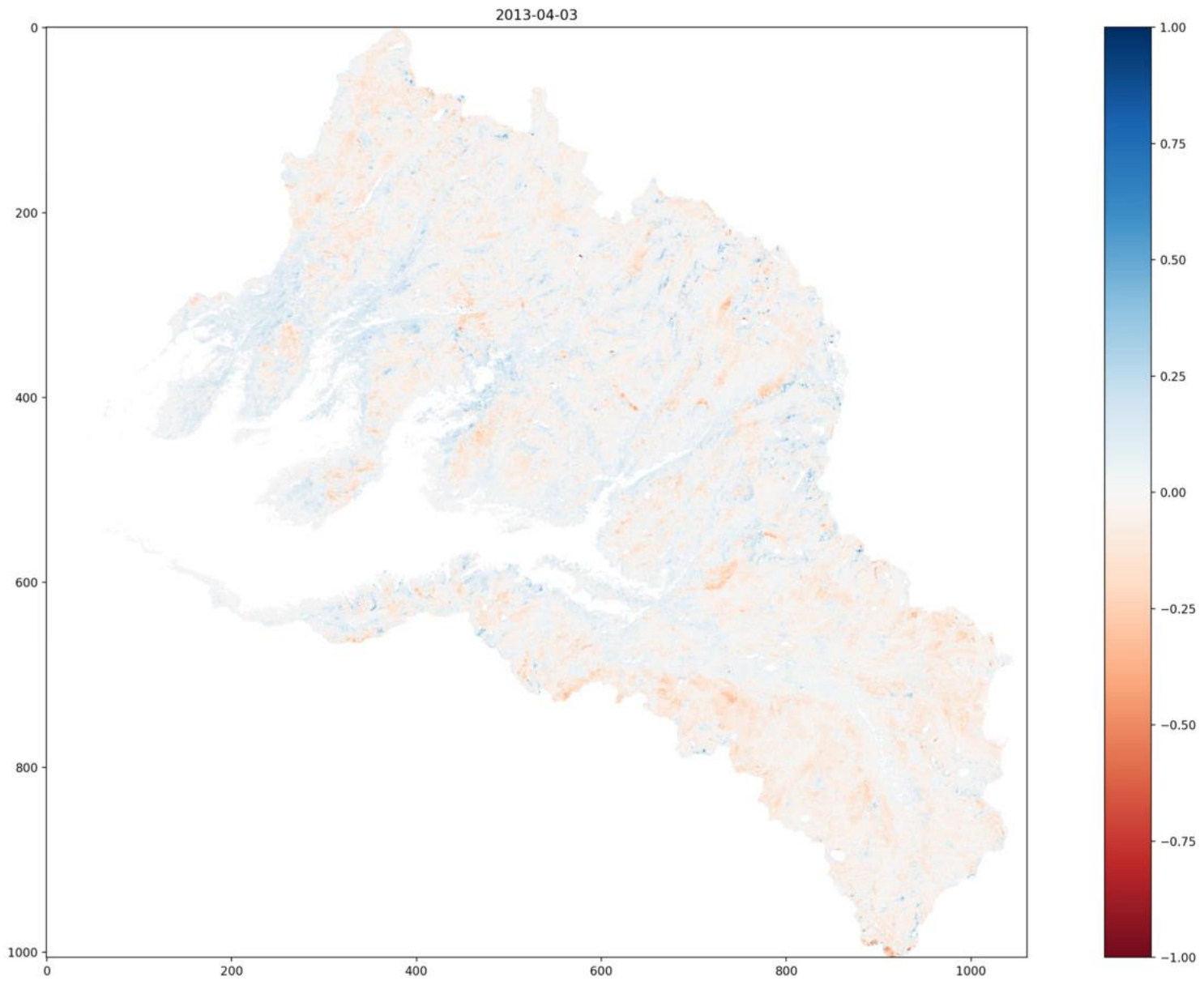
Example Leave 1 year out MLR



ASO-like Grid-cell by Grid-cell statistical SWE prediction



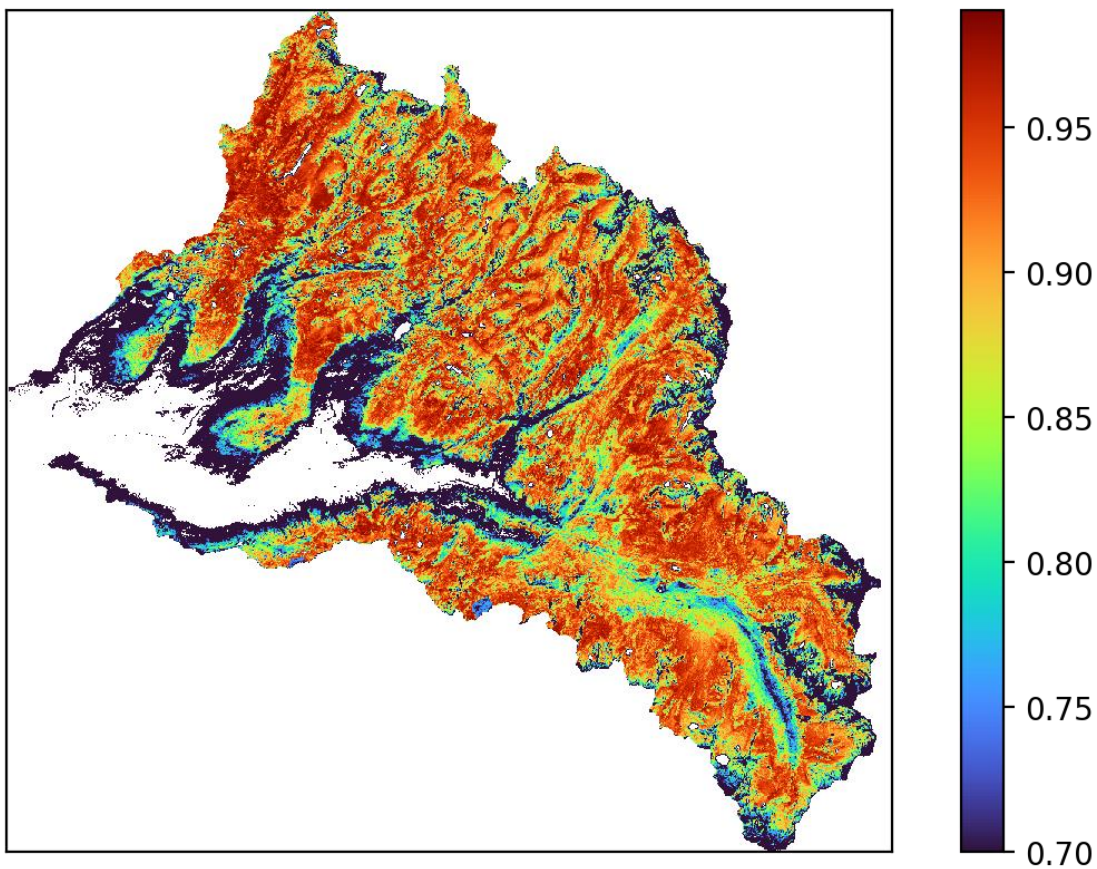
Difference in ASO SWE and statistical prediction ('ASO-like SWE')



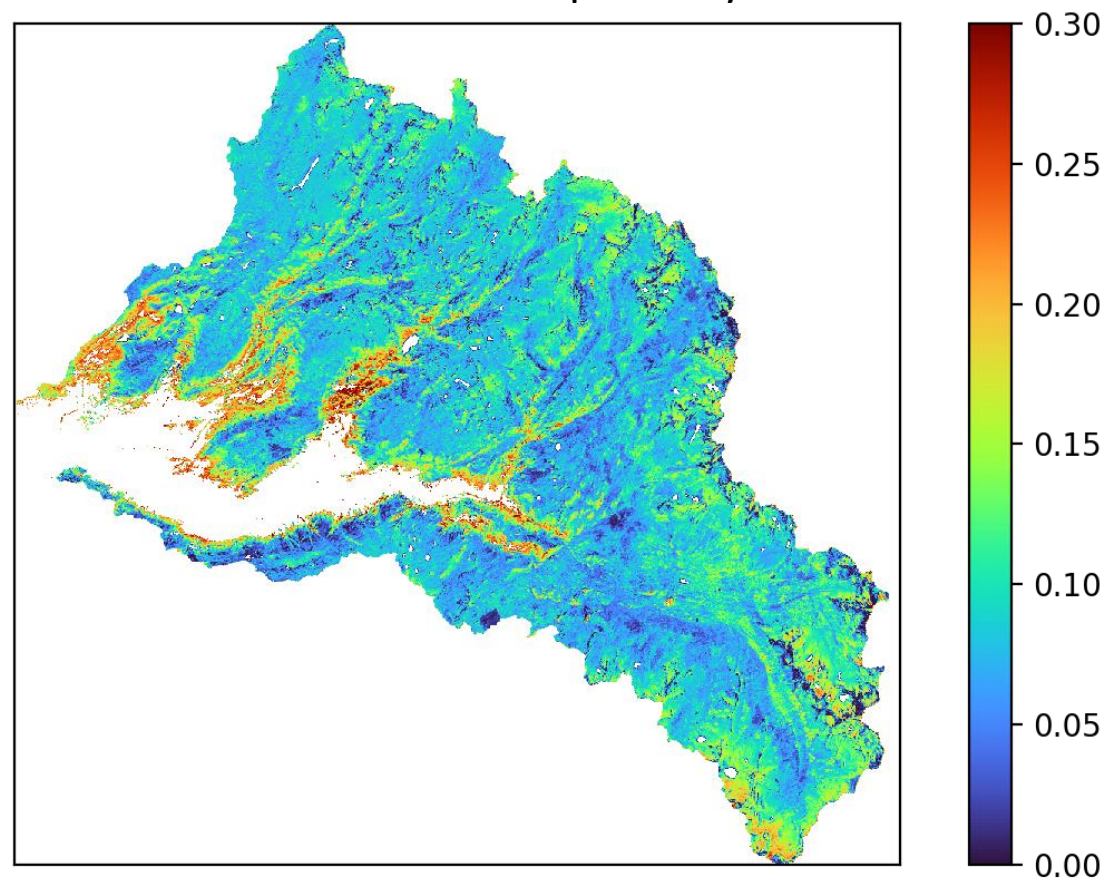
Where Should You put a New Station?

Correlation between each 50 m ASO grid cell and basin mean (r^2)

Most mid-elevation points have very high-correlation



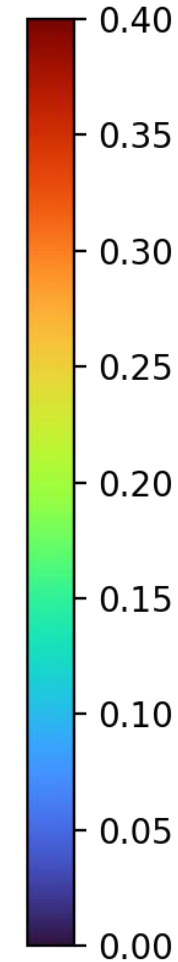
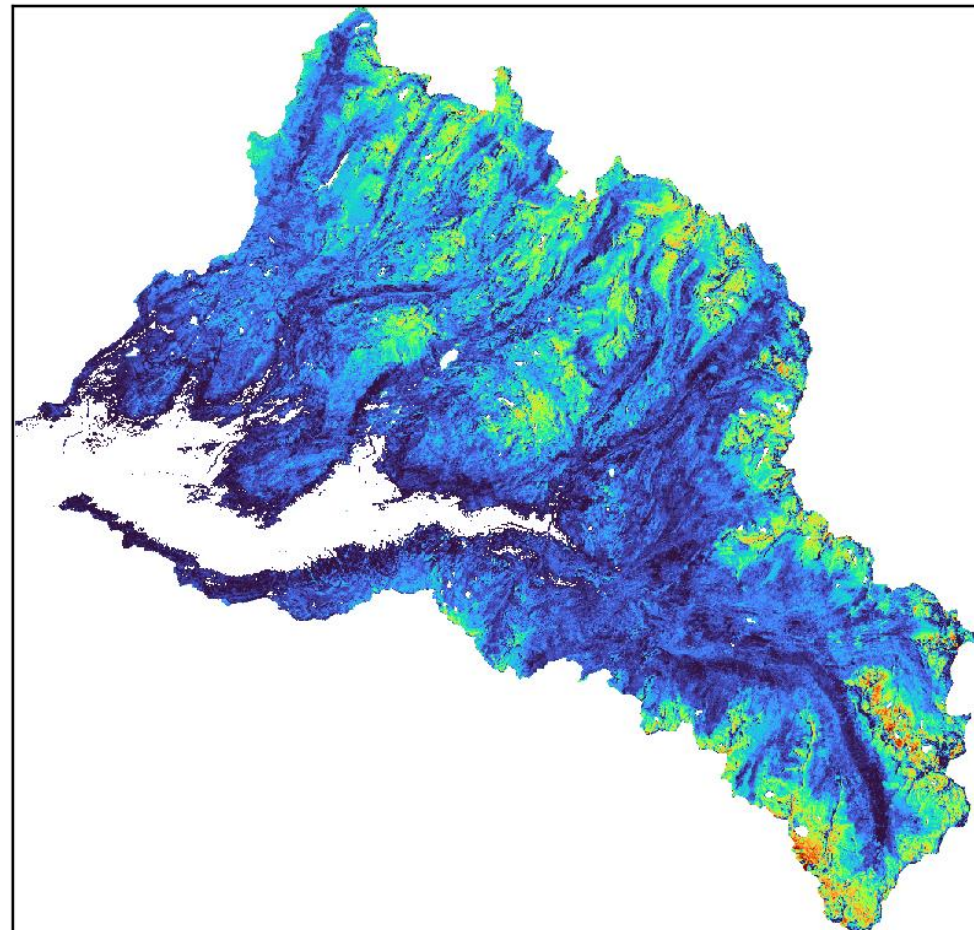
The second order variance is primarily in low-elevations



Where Should You put a New Station?

Correlation between each 50 m ASO grid cell and basin mean residual (r^2)

Variance unexplained by existing station network primarily at high-elevations



This result is very sensitive to the available station network.

In other basins, with other stations your results may vary

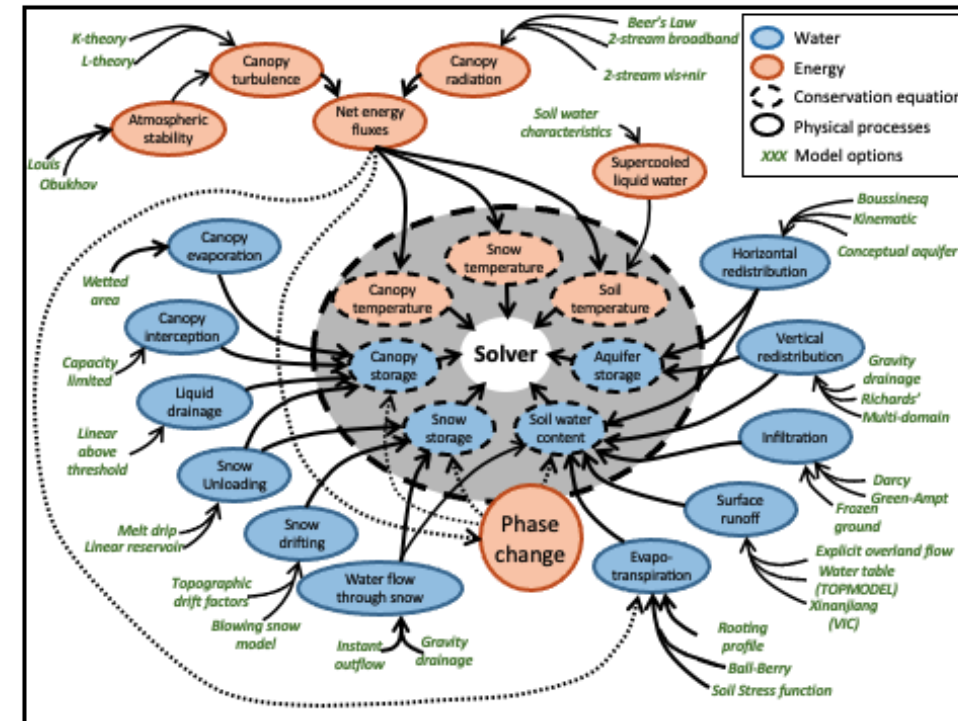
Watershed modeling & forecasting with SUMMA

- SUMMA and mizuRoute
 - Flexible framework with multi-physics options
 - SUMMA has better numerics than other options (eg VIC)
 - MizuRoute is efficient and also has flexible physics
- Watershed models are a workhorse for seasonal water supply prediction, and can assimilate snow observations... how much does that help?

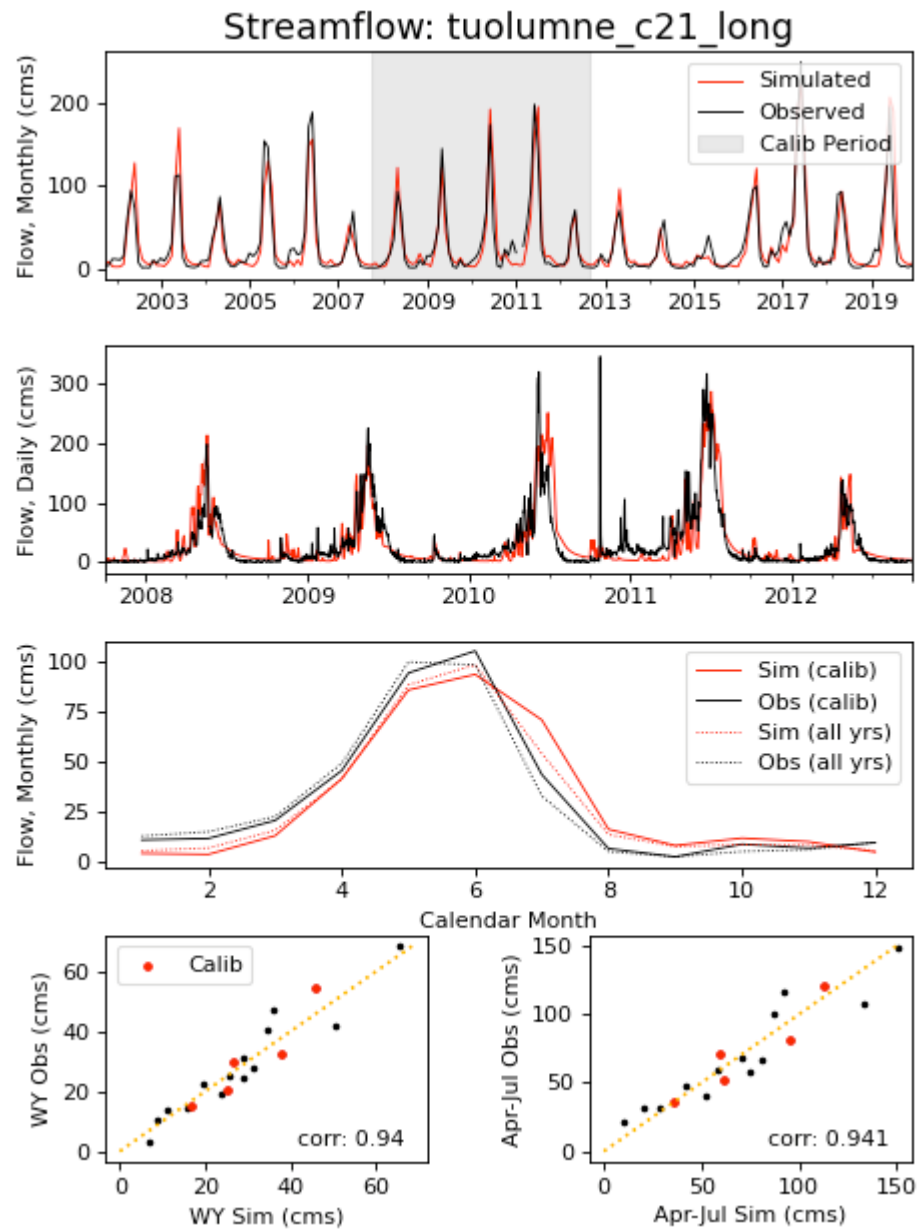
MizuRoute modeling



SUMMA Framework

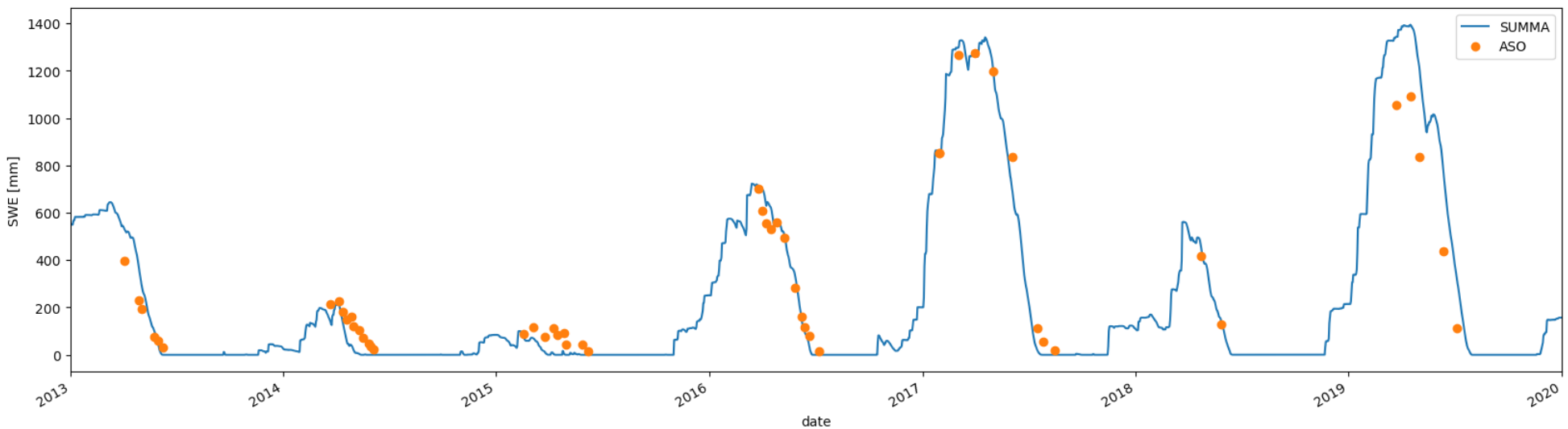
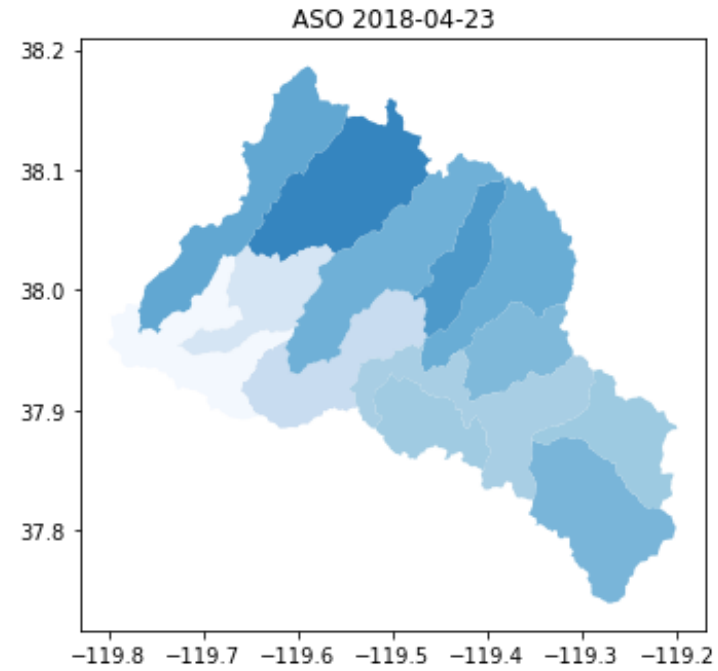
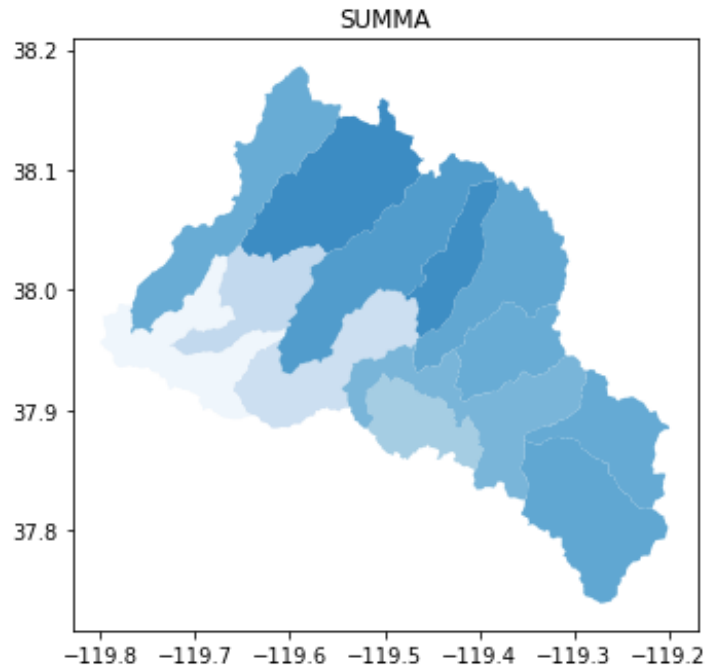


Tuolumne Basin cutout for ASO / water supply forecasting assessment

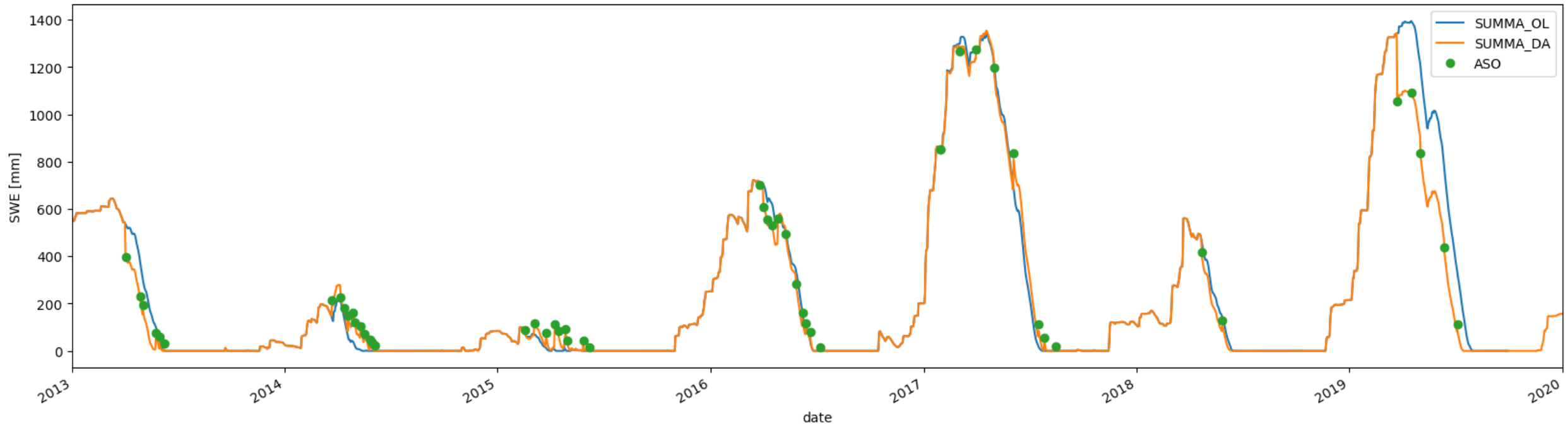


Assessment versus ASO-based snow data

- SUMMA is calibrated for streamflow -- but simulates snow (SWE) well
- Spatial patterns are realistic (though coarse)
- Year to year variability is discriminated well

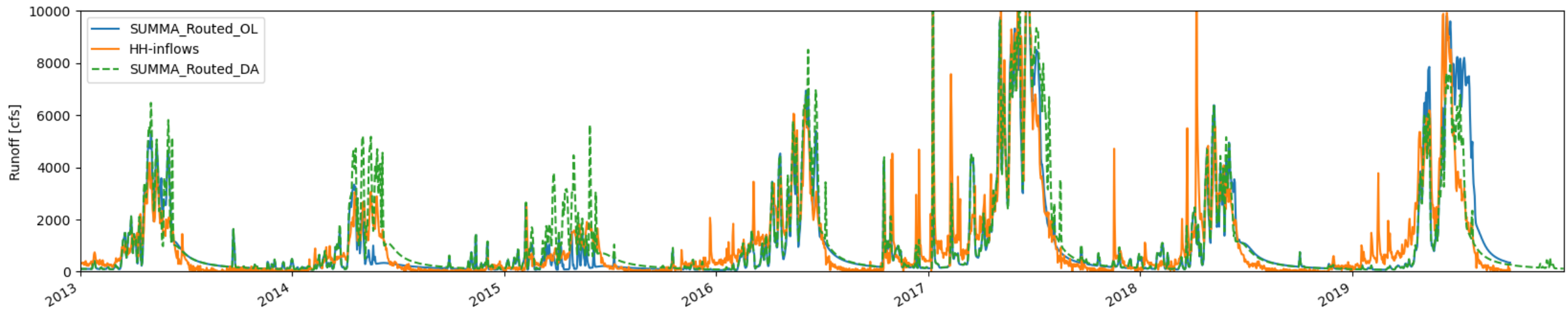


Snow Data Assimilation Results



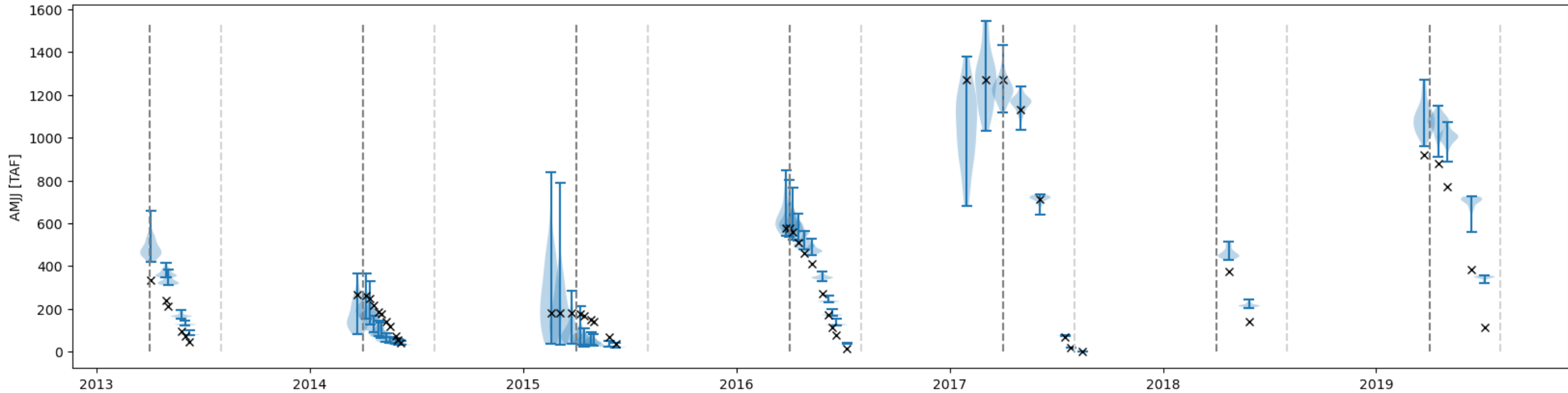
- DA run sometimes has lower SWE (2013, 2019)
- DA run sometimes has more SWE (2014, 2015 and late season)
- After first DA update, subsequent cycles have less effect (see 2013, 2019)

Baseline SUMMA with sequential ASO DA



- DA (green) improves low bias in some years (2014,2015)... but might make it too high
- DA improves high bias in other years (2019)
- Minimal effect in years that were well simulated (as you want)

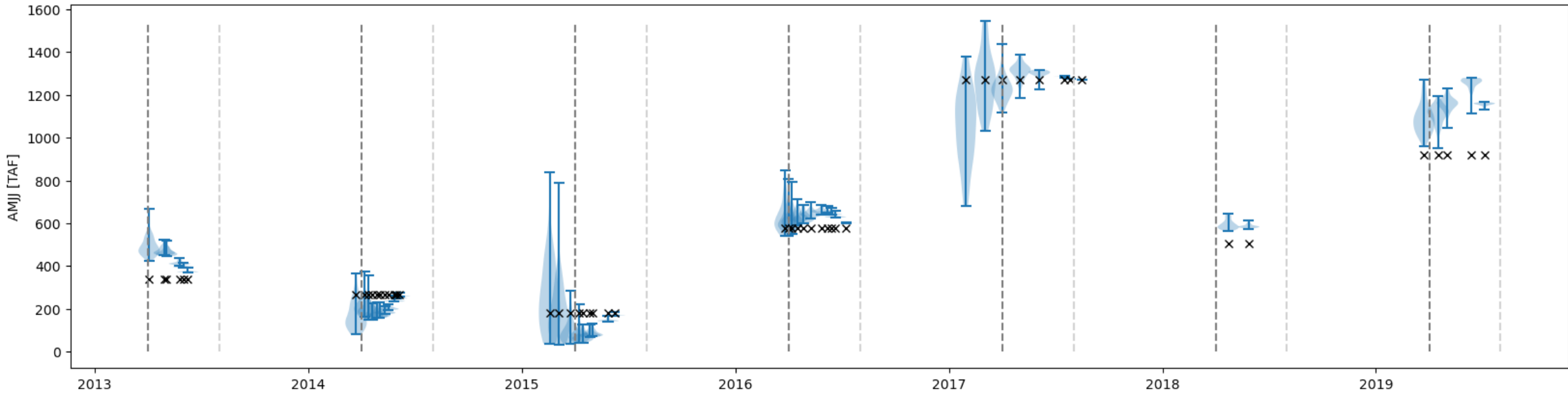
ESP Forecast Results



- SUMMA run with observed forcing to forecast date (ASO flight dates)
- Forecast with ensemble of historical weather sequences
- X marks observed April-July 31 volume (or forecast date to July 31)

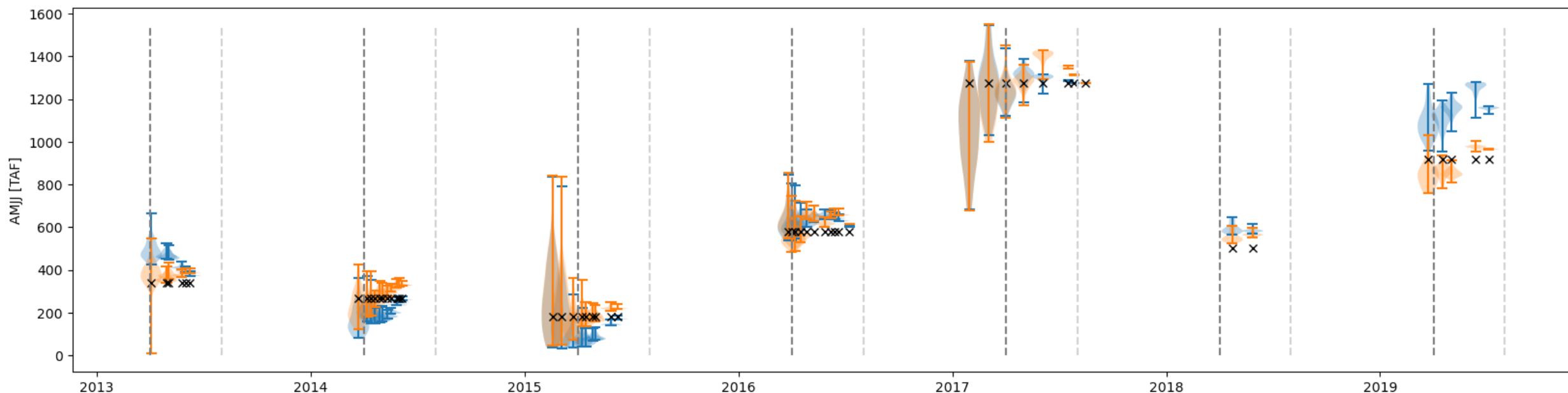
ESP Forecast Results

Adding in observed prior to forecast date



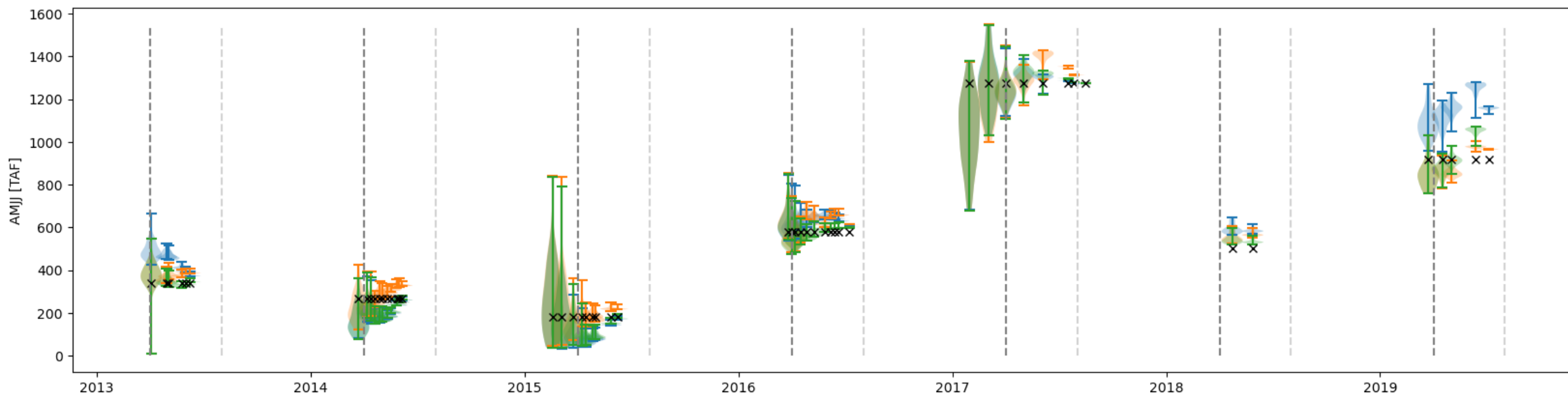
- SUMMA run with observed forcing to forecast date (ASO flight dates)
- Forecast with ensemble of historical weather sequences
- X marks observed April-July 31 volume

ESP Forecast Results with sequential DA



- SUMMA run with observed forcing to forecast date (ASO flight dates)
- Assimilating all available ASO data (orange violins)
- Forecast with ensemble of historical weather sequences
- X marks observed April-July 31 volume

ESP Forecast Results with ~April 1 DA



- Open Loop ESP (Blue)
- Sequential DA (Orange)
- ~April 1 only DA (green)
- Observed Volume (black x)

ESP median forecast statistics

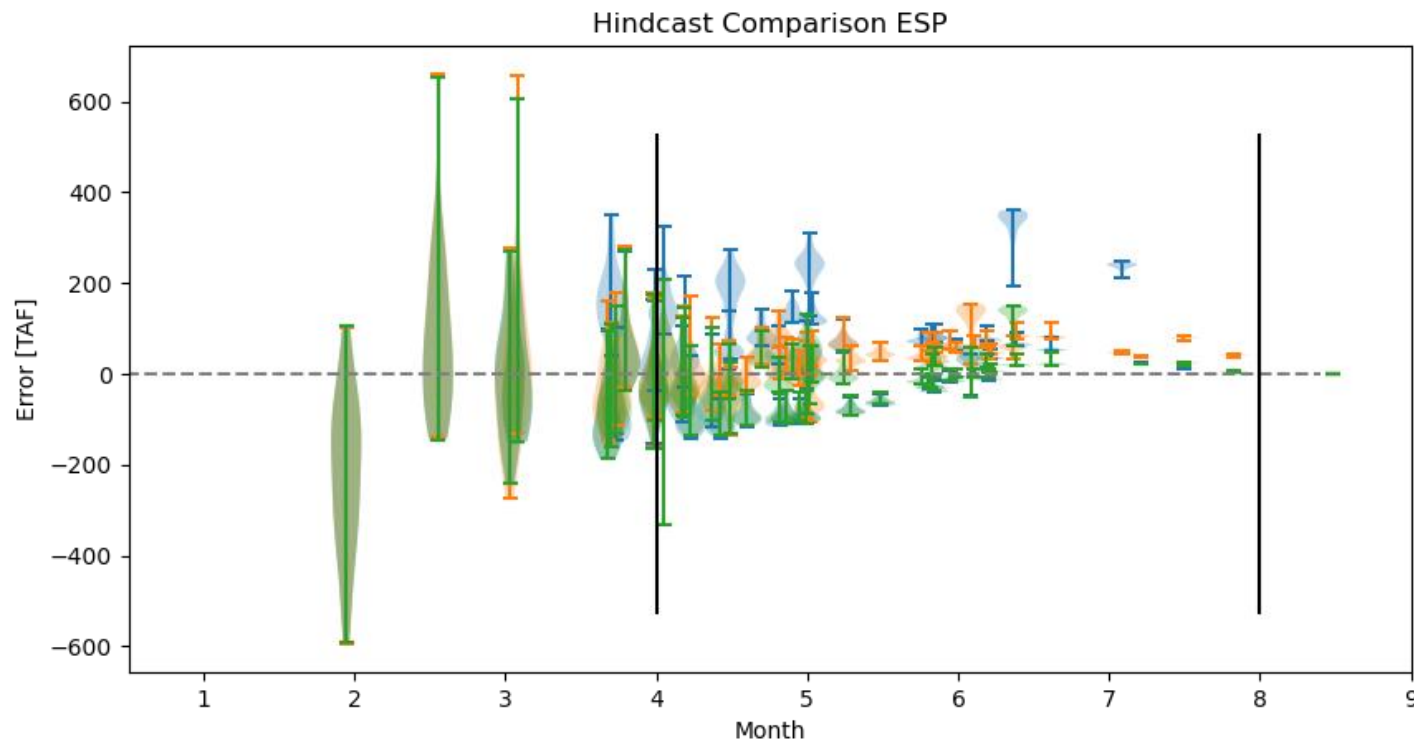
$r^2=0.94$: Open Loop

$r^2=0.98$: Sequential DA

$r^2=0.98$: ~April 1 only non-sequential DA

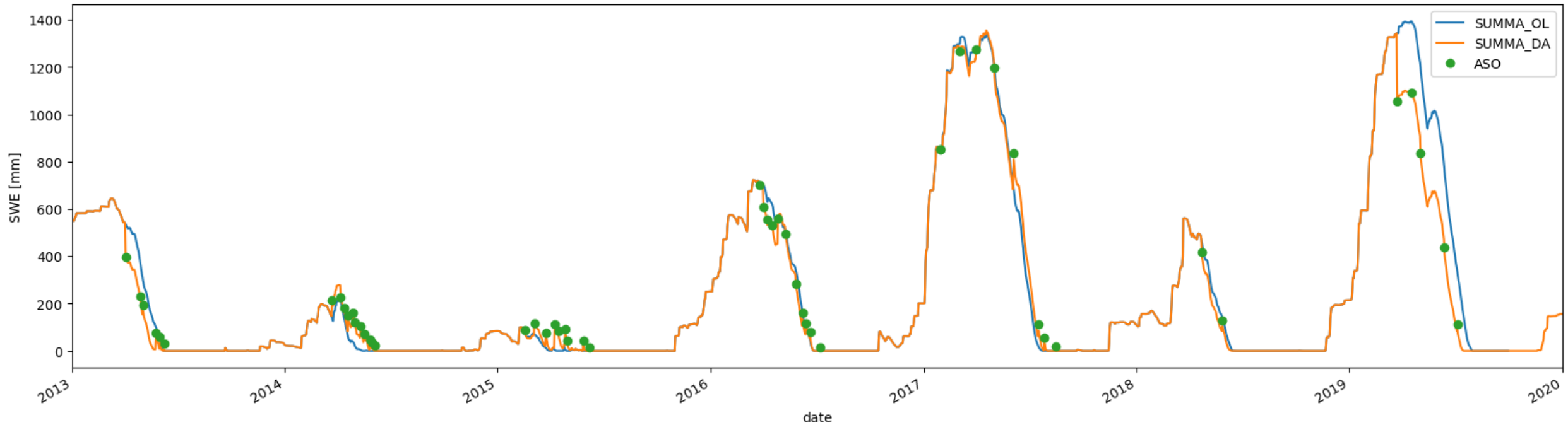
ESP Forecast Results: Seasonality of Errors

- Early Season may have little value
 - before mid-March
- Full sequential DA has larger errors than OL after mid-June
 - Other locations, e.g. Colorado will be different!
- April 1 DA is almost as good, smaller errors in late season



Open Loop ESP (Blue)
Sequential DA (Orange)
~April 1 only non-sequential DA (green)

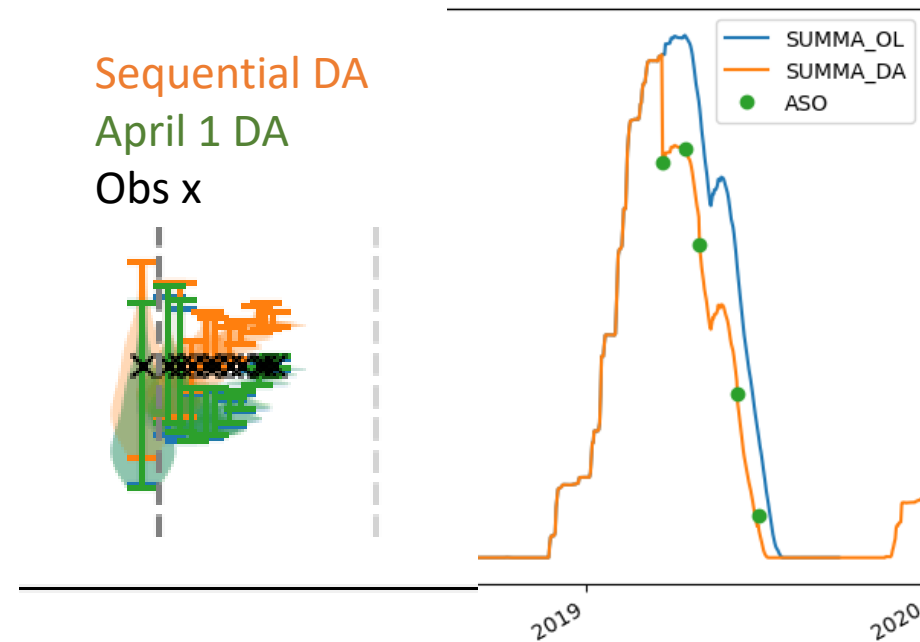
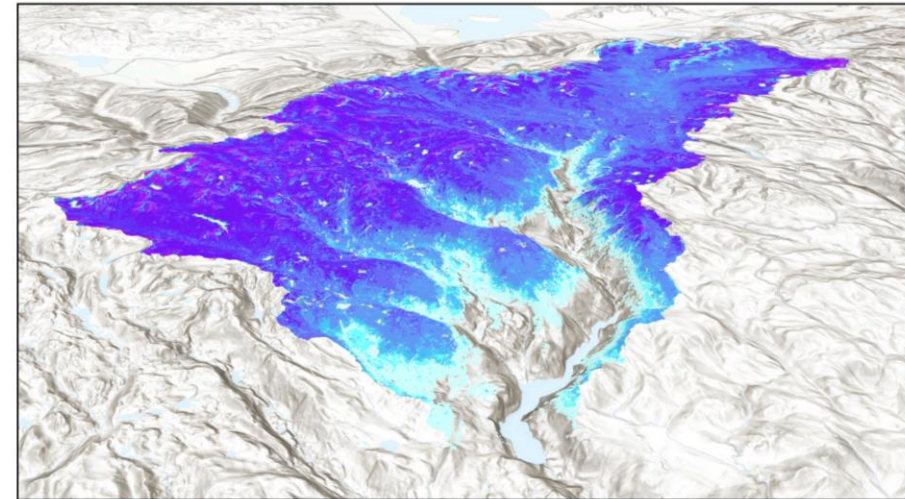
Snow Data Assimilation Results



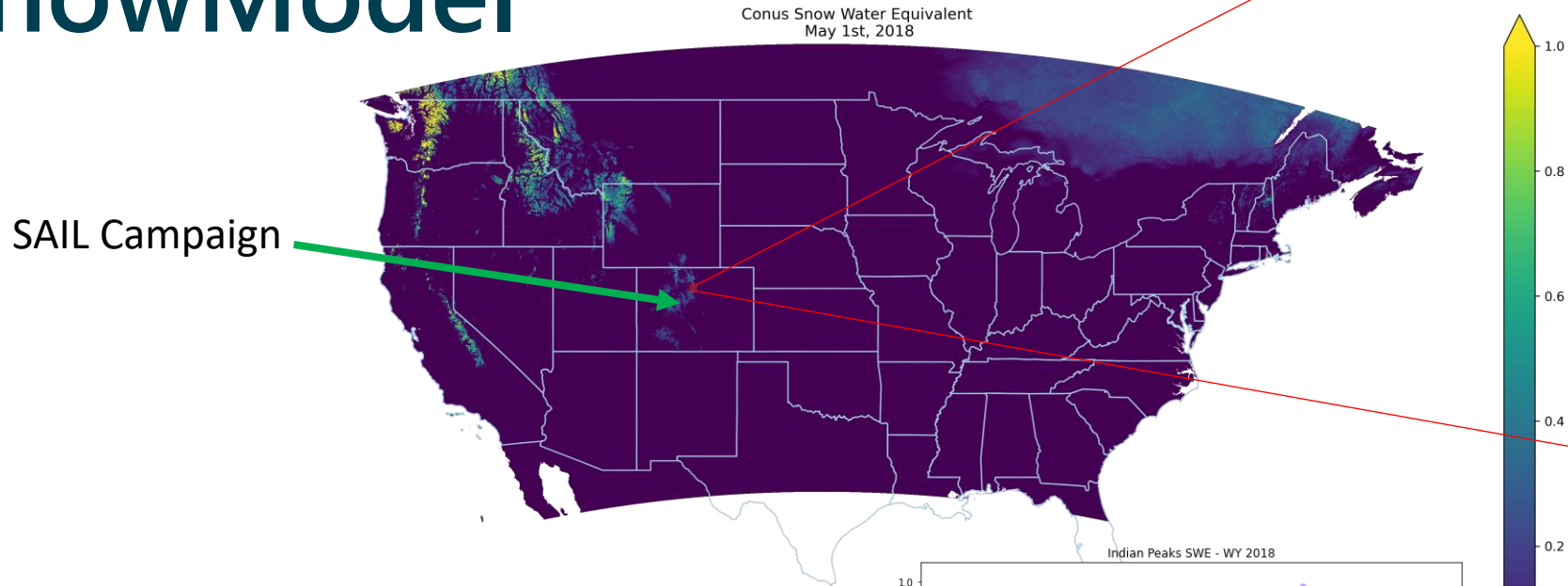
- DA run sometimes has lower SWE (2013, 2019)
- DA run sometimes has more SWE (2014, 2015 and late season)
- After first DA update, subsequent cycles have less effect (see 2013, 2019)

Alpine Snowpack Observations and Forecasting

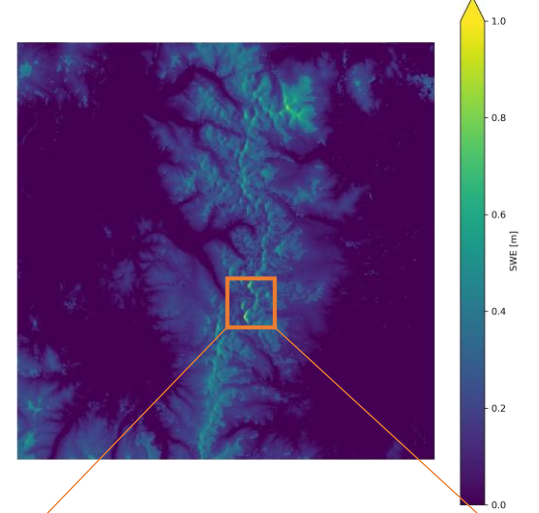
- High degree of statistical predictability in basin mean SWE
 - once you have enough data points
- Existing monitoring network needs more high-elevation stations
- ASO DA in a calibrated watershed model improves model volume forecasts
 - Flights near peak SWE correct errors in winter precipitation
 - Late season DA can make the model worse!
 - Improving late season (high elevation) model snow will improve late season DA
- **Caveat:** Evidence is from one basin for limited forecasts, thus is not general. CA is a good location for snow DA due to seasonal climate.
 - 90% of Tuolumne precipitation falls between Oct. and Apr.



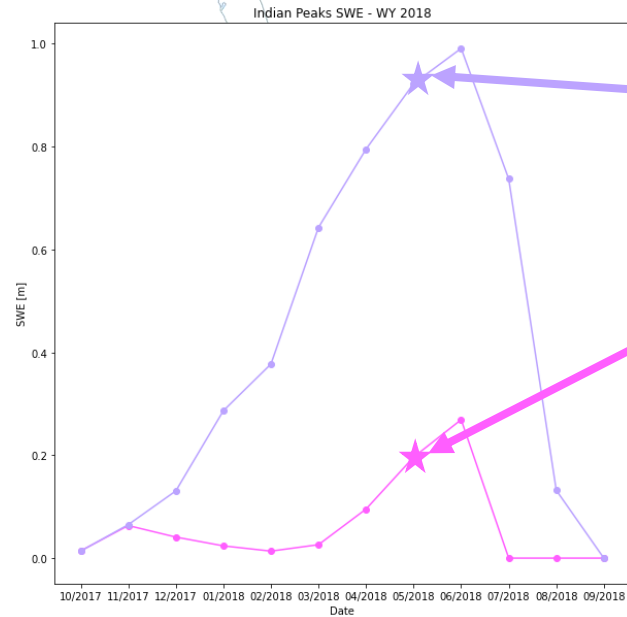
Continental Snow Drift Resolving SnowModel



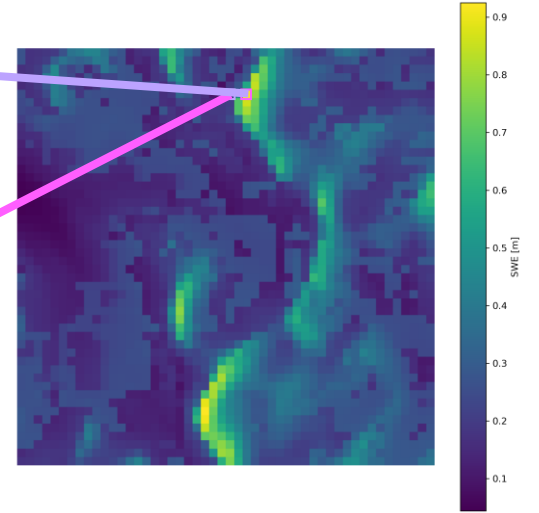
Domain Zoom 2500 km²



- SnowModel (Liston et al)
- Parallelized on 1800 cores
- 100 m grid
- 24,000 x 54,000 gridcells



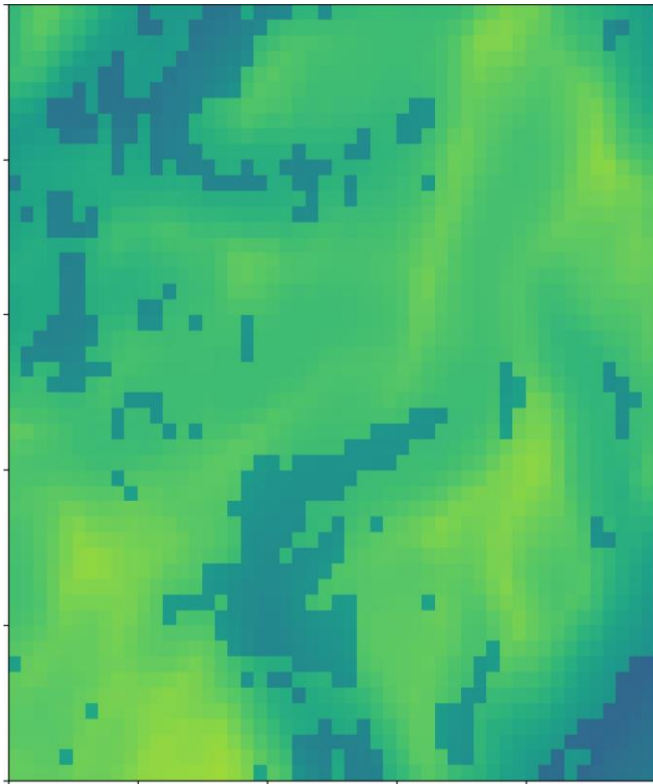
Domain Zoom 25 km²



Modeled heterogeneity vs. ASO Lidar

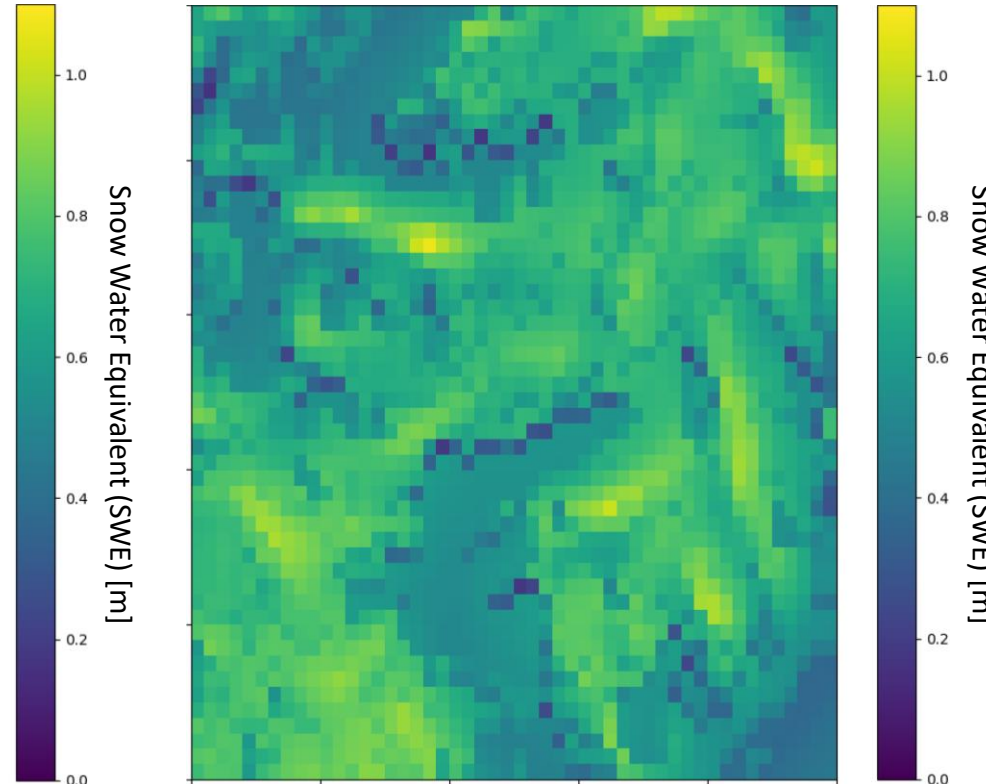
April 17th, 2019

SnowModel – No SnowTran



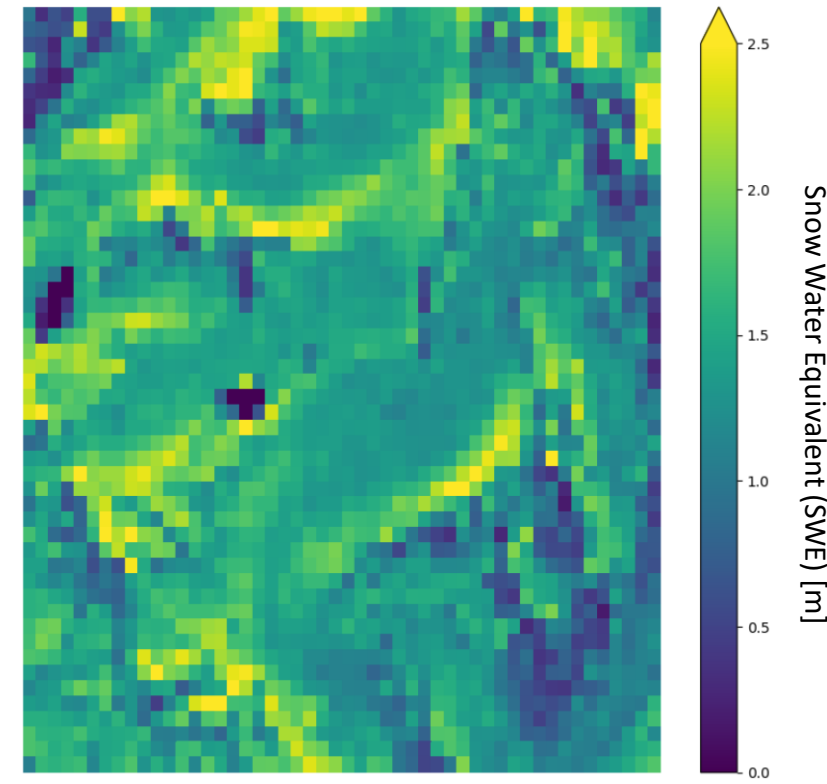
Too much canopy sublimation loss
No Drifts, No redistribution

SnowModel – w/ SnowTran



Drifts aren't deep enough (winds too weak)
Not enough total snow (likely a precip error)

ASO Lidar



Note change in color scale!