Recent Advancements of the USDA-ARS Snow Modeling Program

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Real-time Model Developments

I. WY 2019 Recap

II. i*Snobal* validation/comparison with *in situ* measurements

III. 10-day SWE and SWI forecasts

IV. Improving vegetation characterization

Project Motivation

- Regression-based SWE-to-streamflow models require statistical stationarity
- Inherent non-stationarity exists in variable climate conditions
- A physics-based snow model:

Opportunities

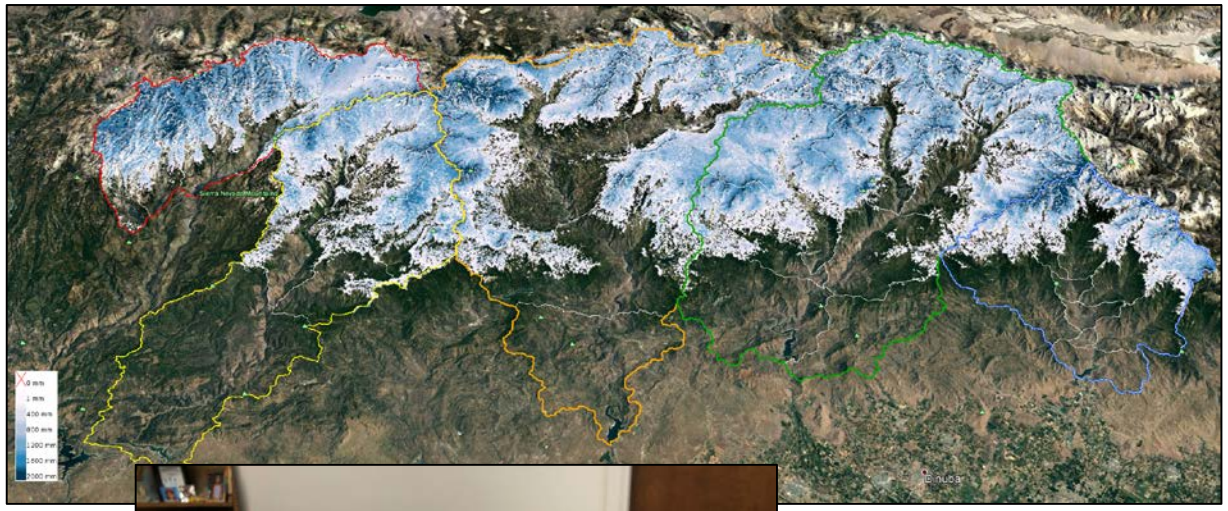
1. circumvents statistical assumptions.
2. provides snowpack information everywhere and all of the time.

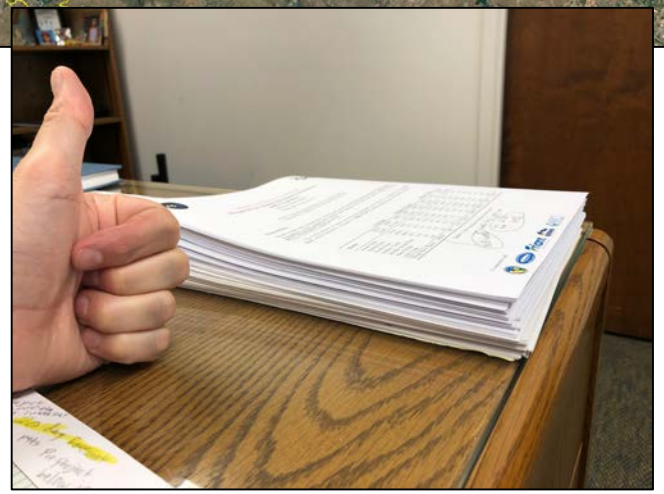
Obstacles

1. requires accurate meteorological forcing data.
2. is computationally expensive.

- The Snow Research Group at the Northwest Watershed Research Center (NWRC) aspires to overcome these obstacles.

I. WY2019 Recap



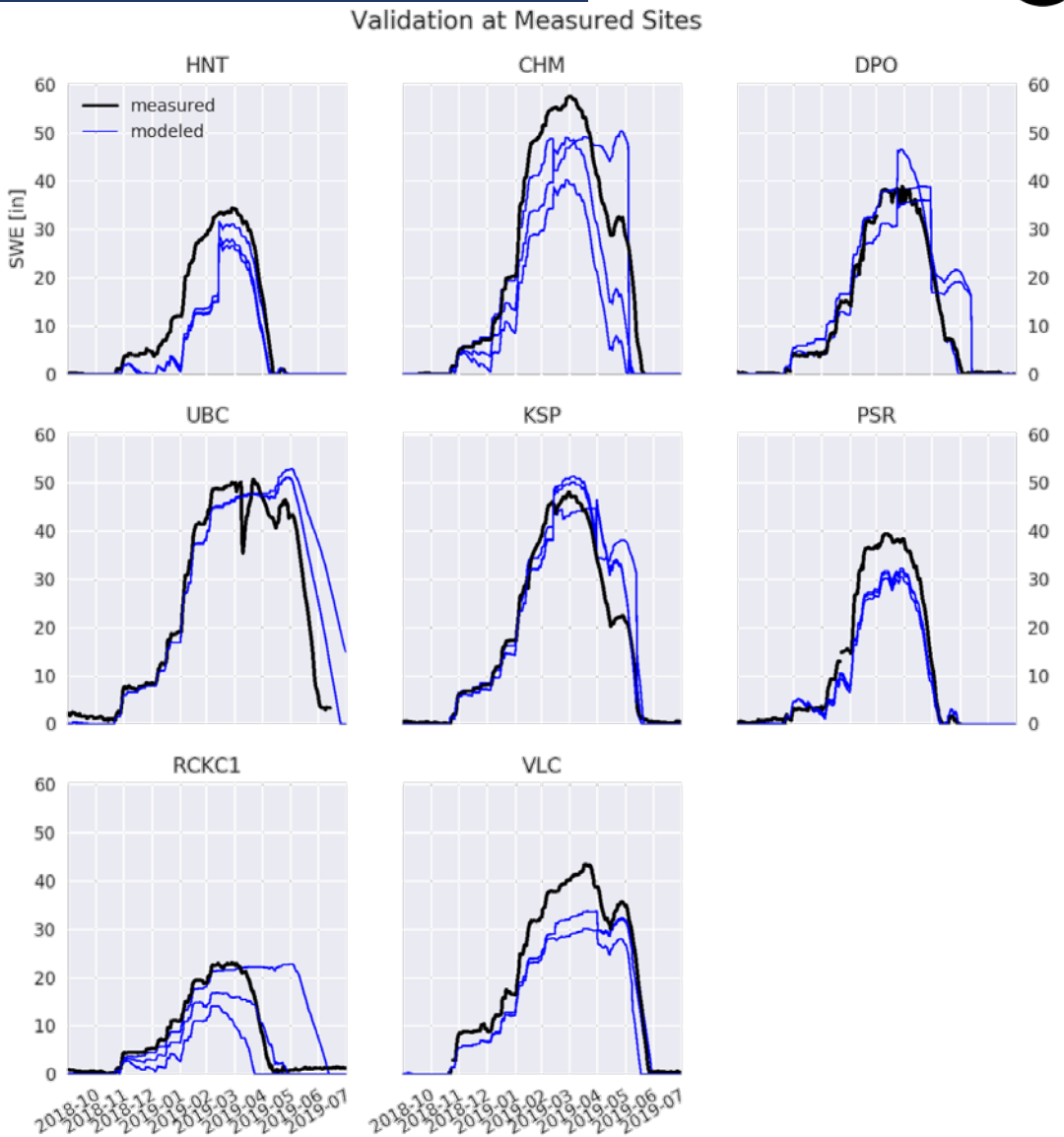


Courtesy of Matt Meadows

- Scaled up from 2 to 6 basins
  - Automated much of the modeling (AWSM)
  - High Resolution Rapid Refresh (HRRR) atmospheric model for inputs
  - 10 day forecast prototype in the SJ
- Reporting
  - New website to host all reports
  - **100** reports delivered
  - 4 teleconferences with 30+ participants to discuss the model results
  - Geoserver to supply spatial results

II. *iSnobal* validation w/ in situ measurements

- Snow pillow sites provide a time series to validate the model in real time
- San Joaquin results showed great agreement with measured SWE
- Vegetation affects around the pillow sites can be seen in the surrounding model pixels



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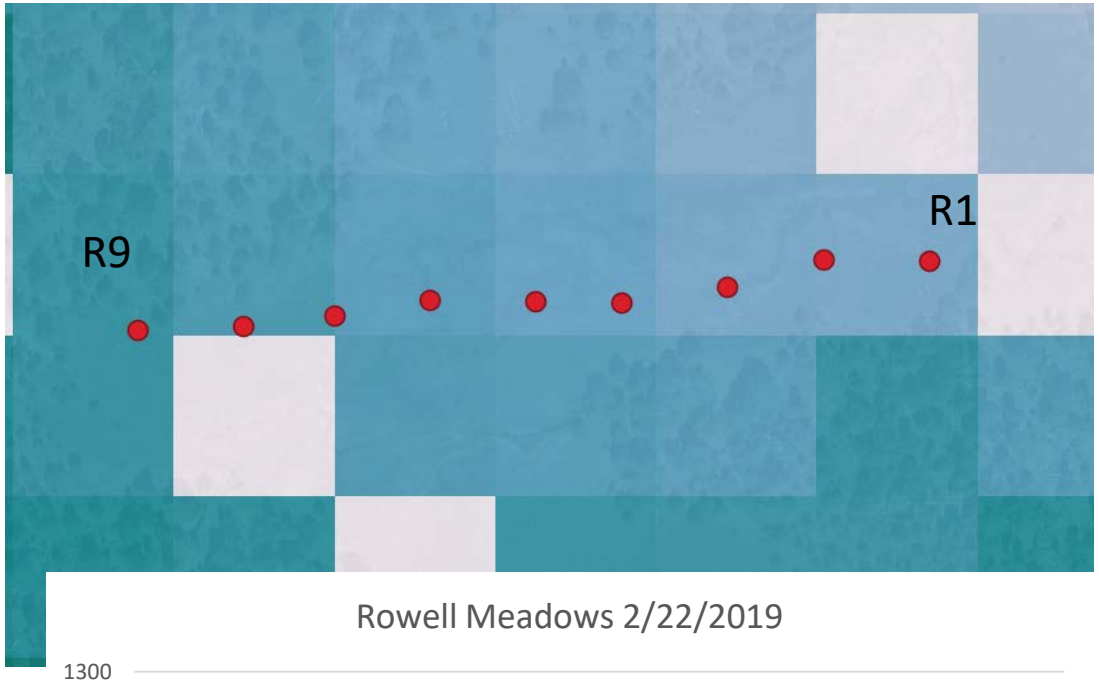
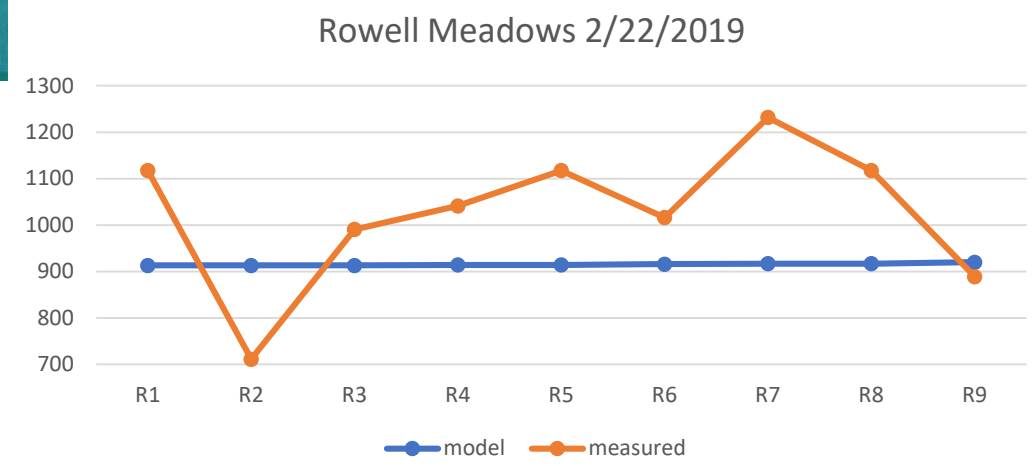
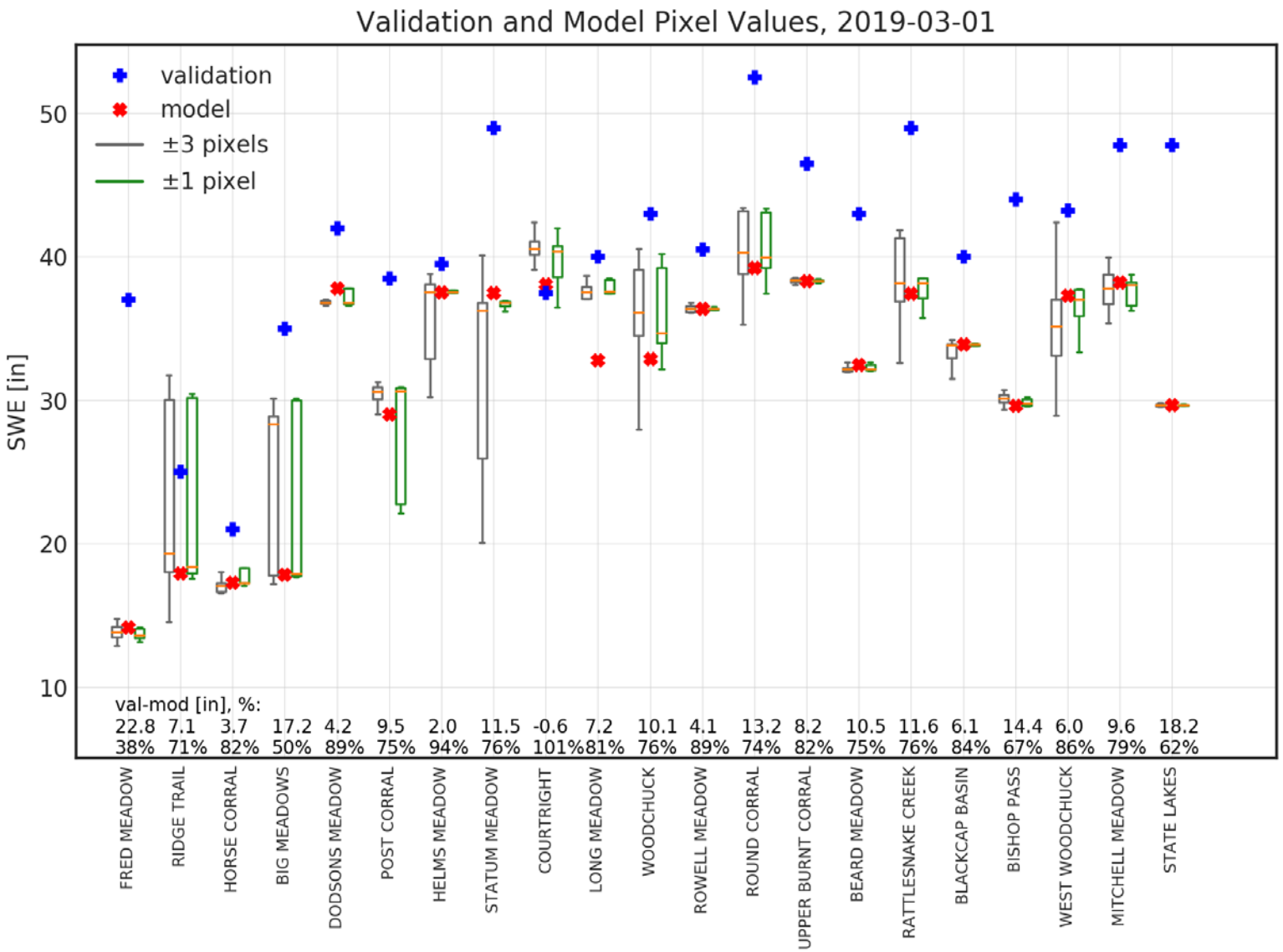




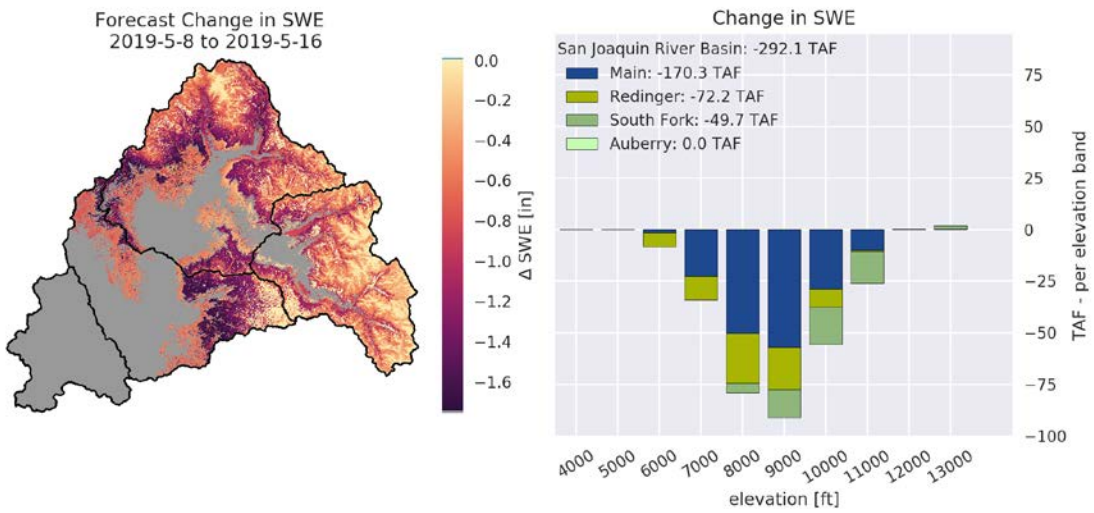
- Snow courses in the Sierra can be upwards of 1-2 km long, spanning multiple pixels
  - Rowell Meadows is 300m long
- Feb 22, 2019
  - Model avg 915 +/- 2 mm
  - Measured avg 1026 +/- 152 mm
- Eventually add an automated bias detection

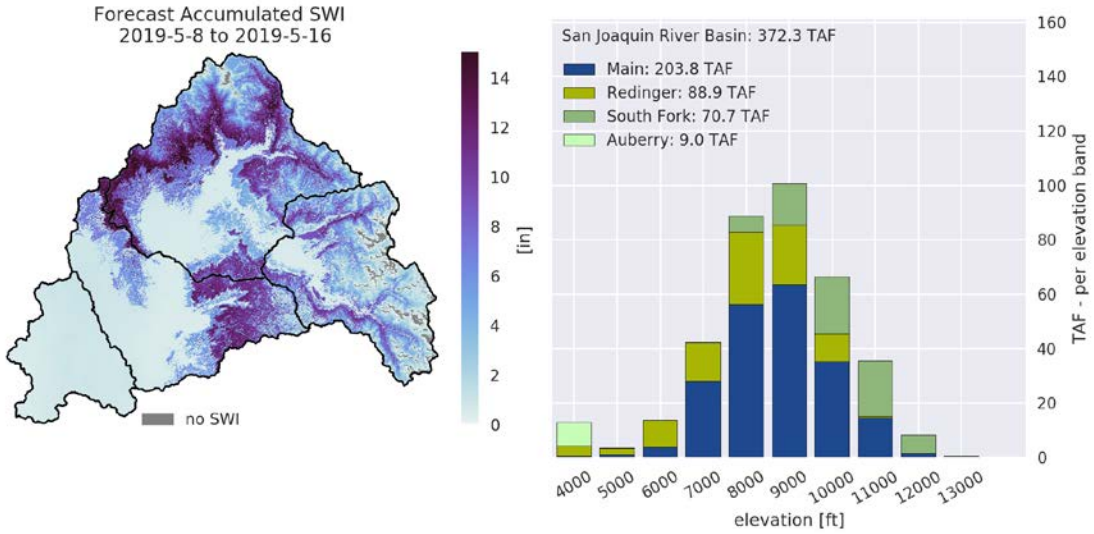
II. *iSnobal* validation w/ in situ measurements



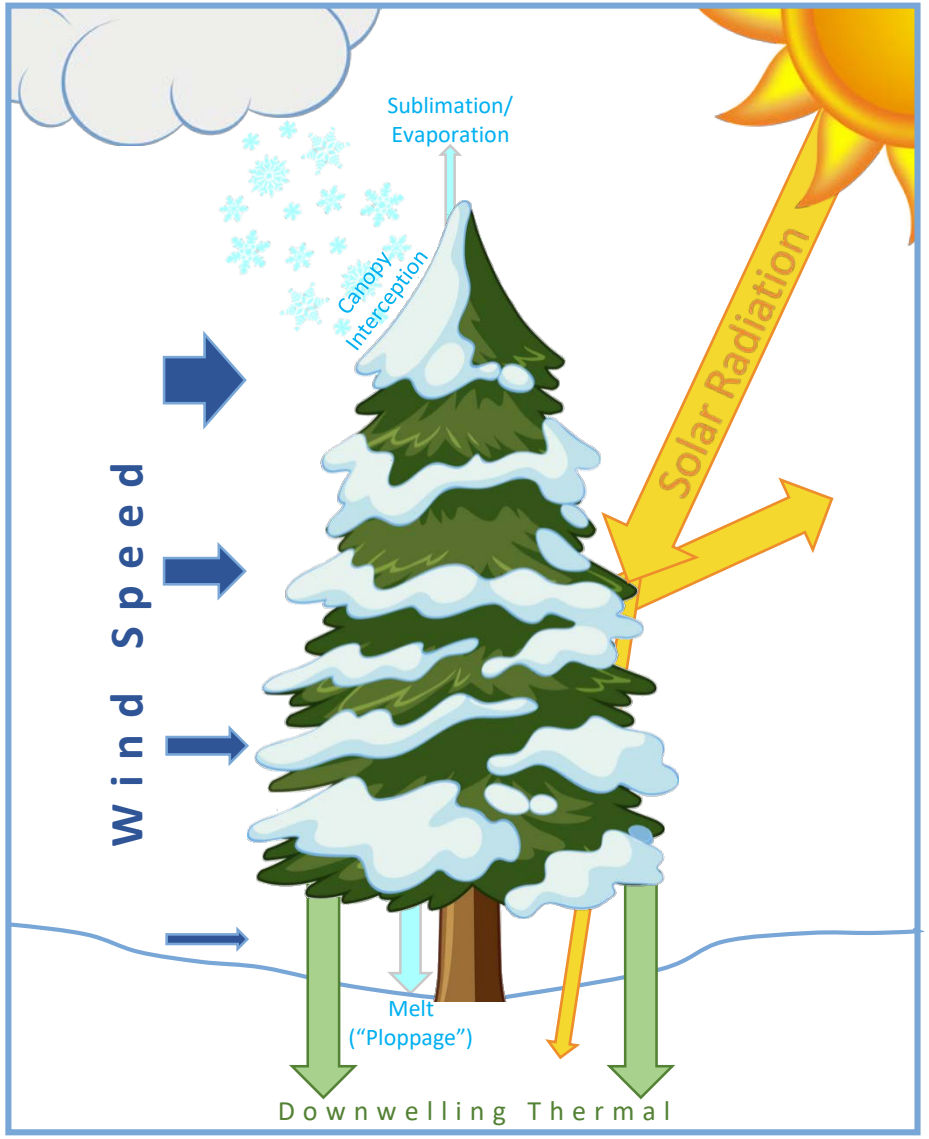
III. 10-day SWE and SWI forecast

- Reclamation-funded Boise State University to provide 10-day atmospheric forecast.
  - Evaluate the usefulness and accuracy of a long range forecast.
- Approximately 6 forecasts were issued to Reclamation.
- Next steps are to evaluate the SWE forecast by comparing with what actually happened.





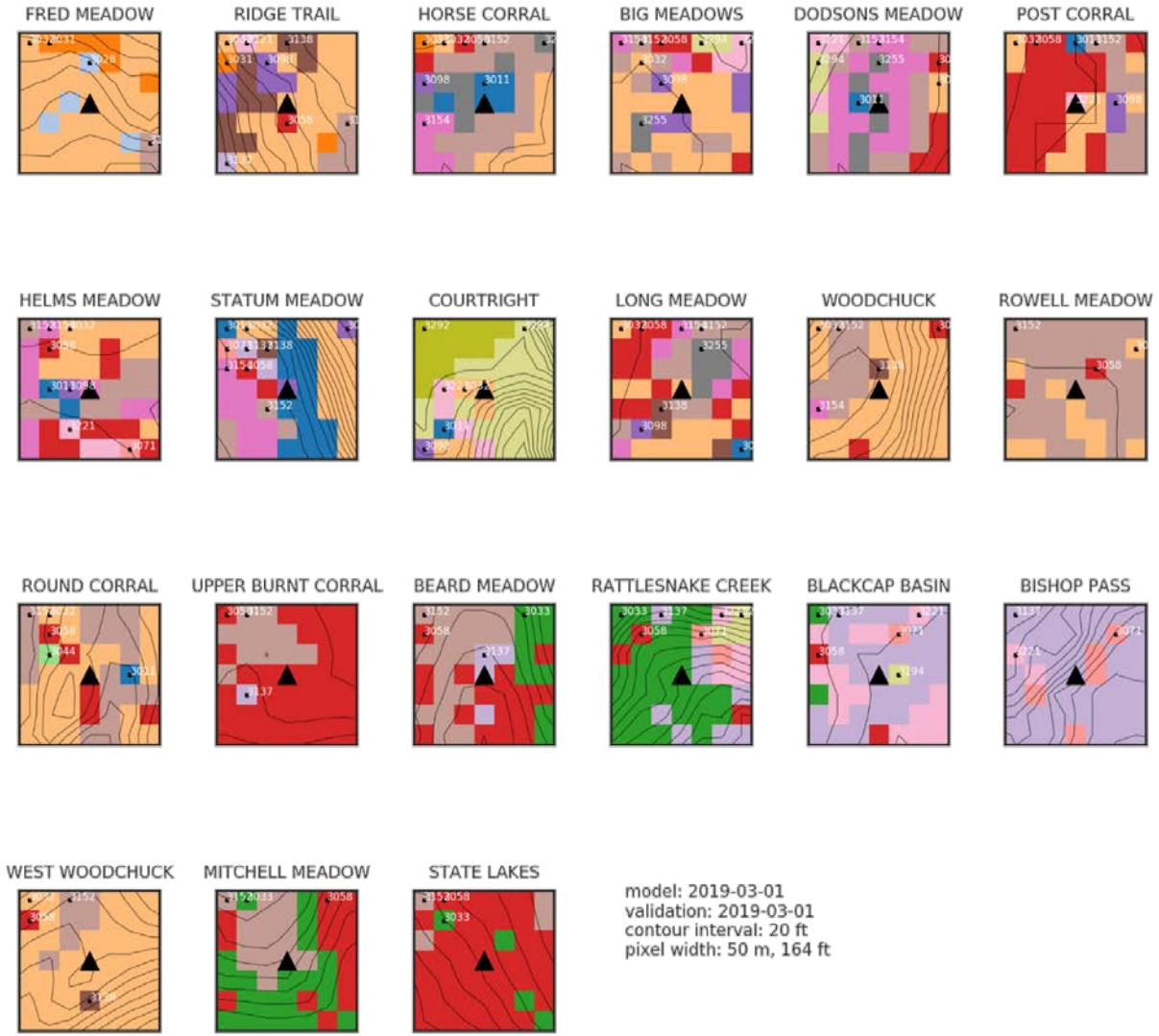
IV. Characterizing Vegetation



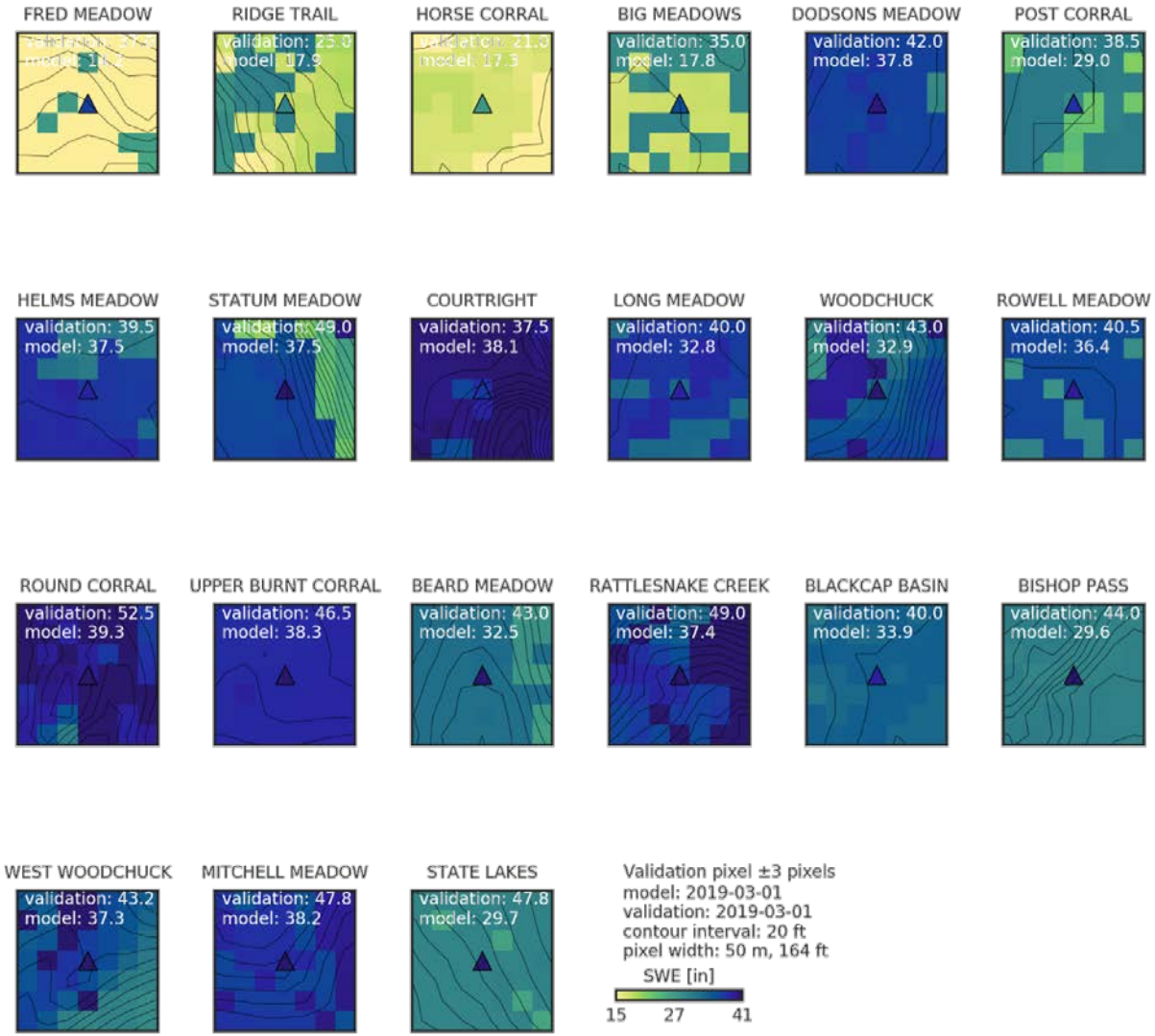
- Forest canopy is crucial to snowpack physics
  - Blocks solar radiation and wind, produces downwelling thermal radiation.
- *iSnobal* pre-processing formerly used simplistic vegetation classification from National Land Cover Database (NLCD).
- Now incorporating LANDFIRE vegetation classification layers
  - Currently testing and evaluating this additional vegetation information.

IV. Characterizing Vegetation

LANDFIRE Classifications



iSnobal SWE Results



Scientific Advancements

I. Estimating annual runoff efficiencies and evapotranspiration

II. Precipitation rescaling using Lidar-measured snow depths

III. Development of a streamflow routing model

IV. Ensemble development of *iSnobal*

I. Estimating Annual Runoff Efficiencies

Hedrick et al., 2019, in review (Hydrological Processes)

Tuolumne Basin Water Balance

2015 – 2017

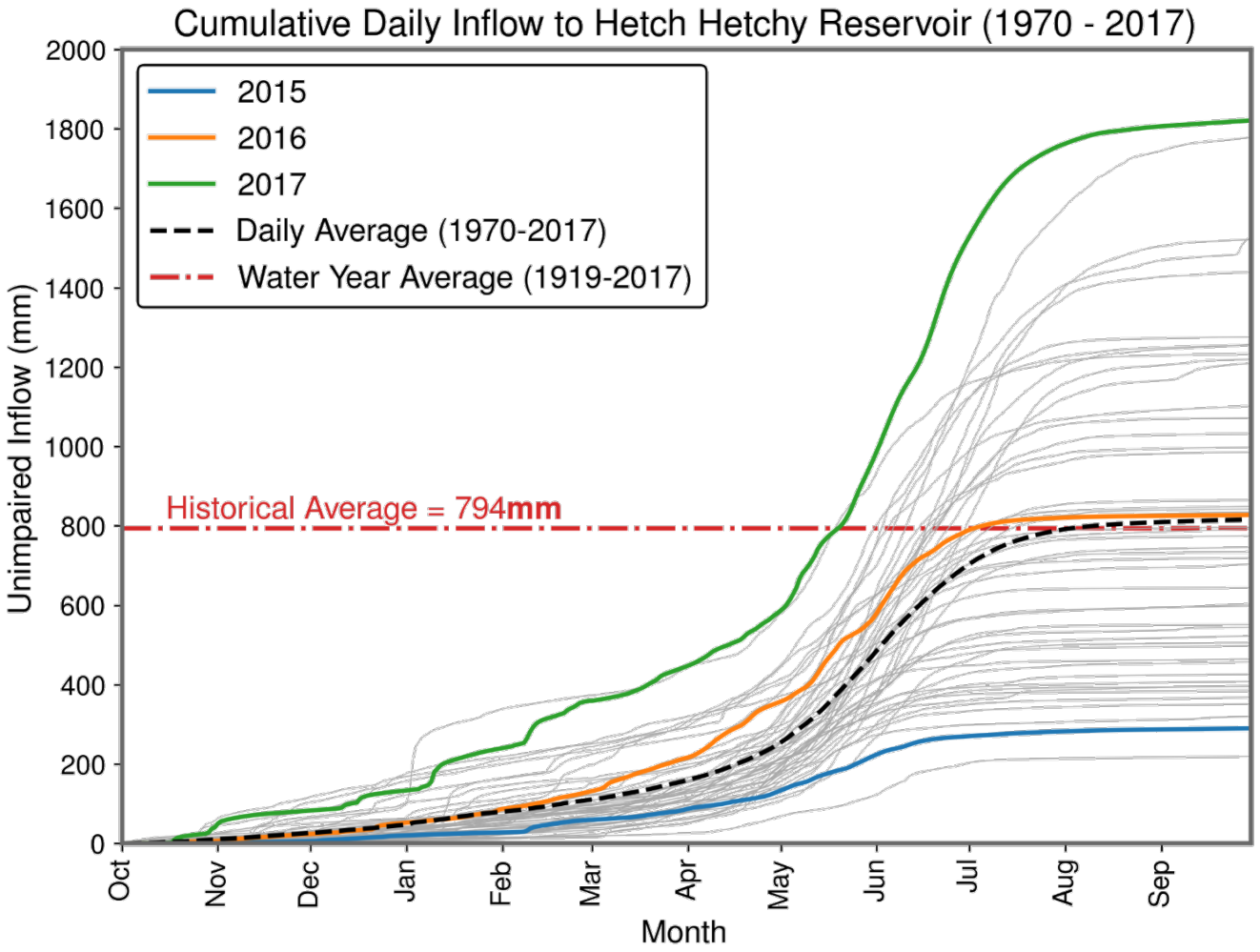
Extremely dissimilar water years

From water balance estimate annual evapotranspiration (ET) totals.

Use ASO + *iSnobal* surface water input (SWI) estimates.

$$\mathbf{SWI} = \mathbf{P_{ASO}} - \mathbf{E_S}$$

$$\mathbf{ET_{WB}} = \mathbf{SWI} - \mathbf{Q} + \epsilon$$

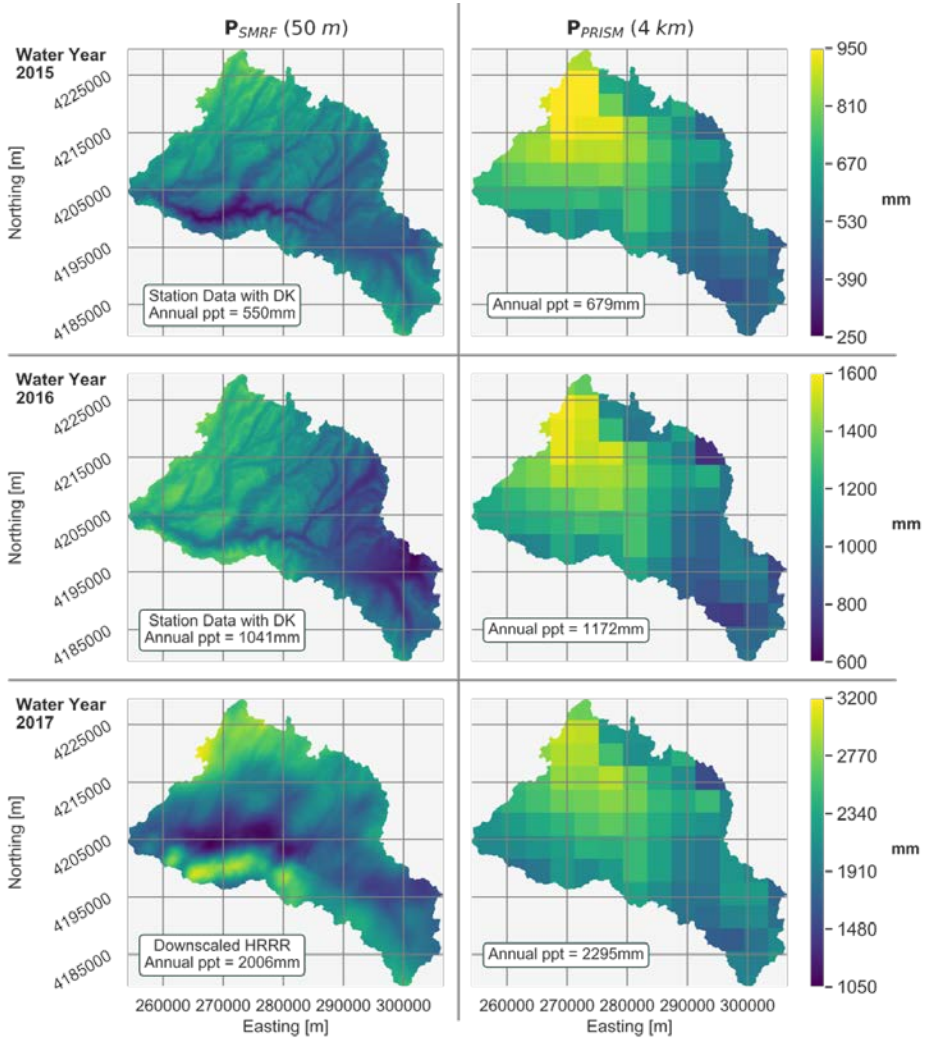


I. Estimating Annual Runoff Efficiencies

Hedrick et al., 2019, in review (Hydrological Processes)

Tuolumne Basin Water Balance

- *iSnobal* requires accurate gridded high resolution precipitation estimates.
- Annual precipitation totals compare well with PRISM reanalysis totals.
- ASO snow depth updates to the model result in even more accurate estimates of input to the water balance.



I. Estimating Annual Runoff Efficiencies

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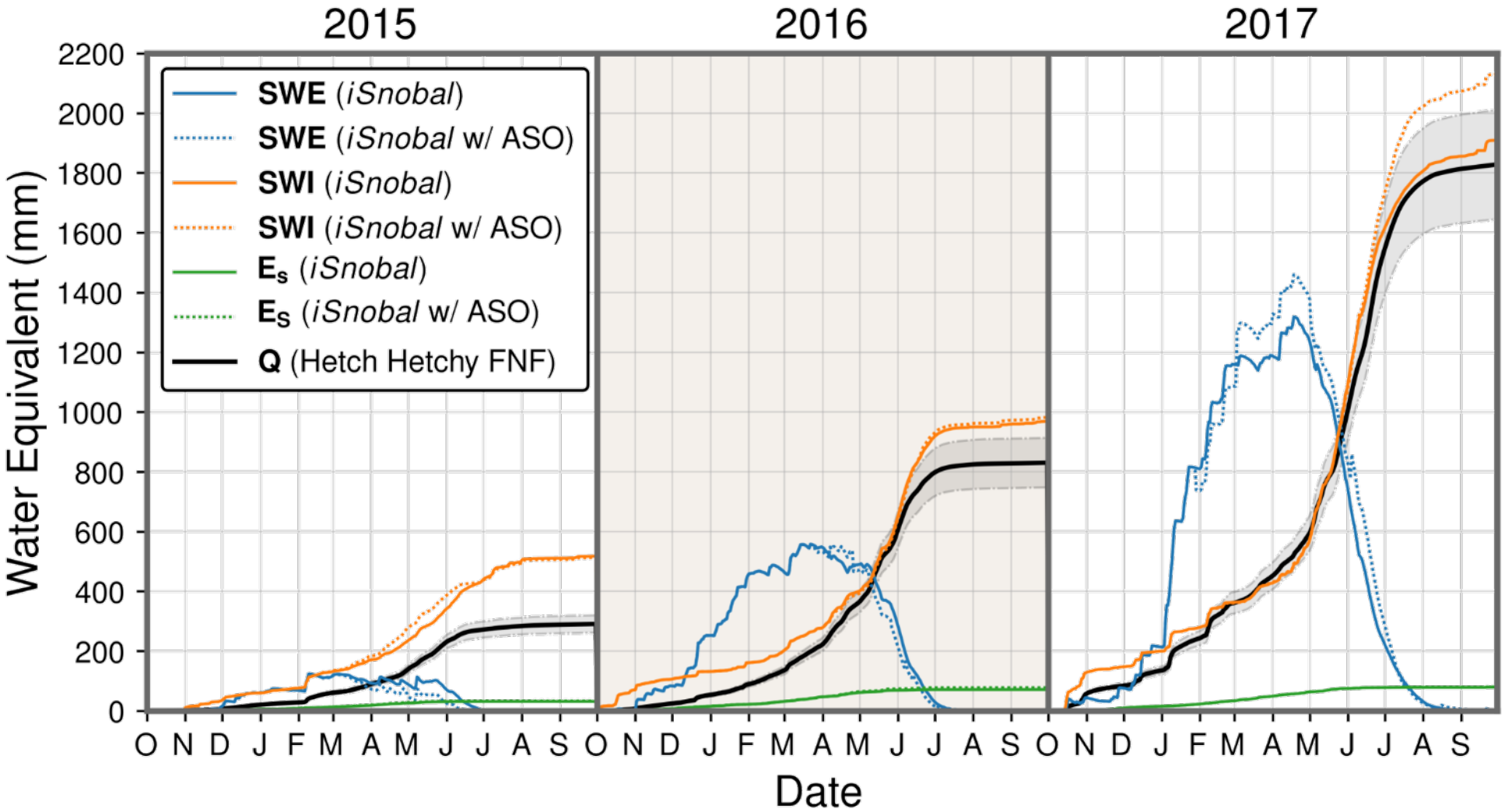

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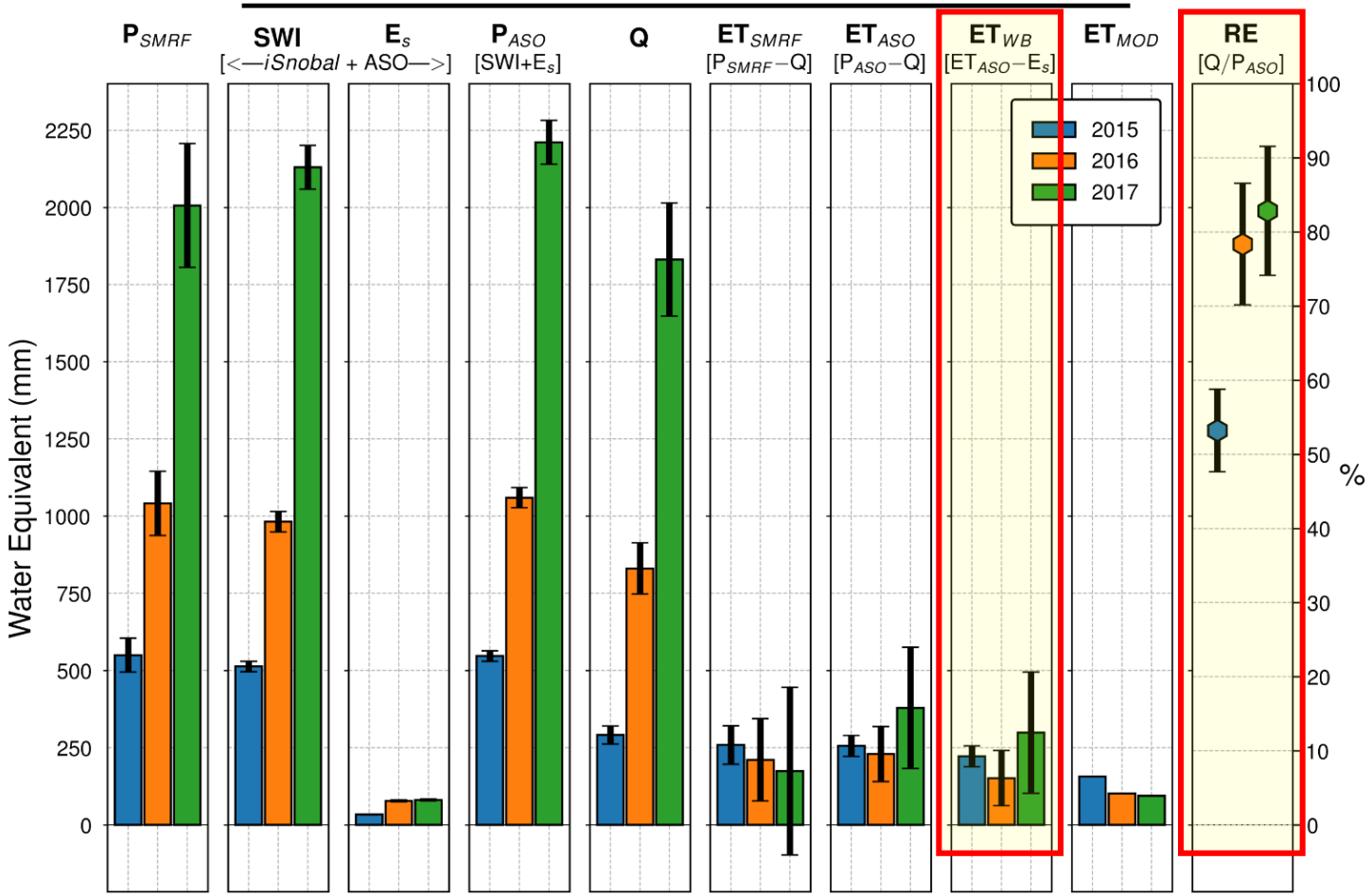

From water balance, estimate evapotranspiration (ET) and runoff efficiency (RE)

I. Estimating Annual Runoff Efficiencies

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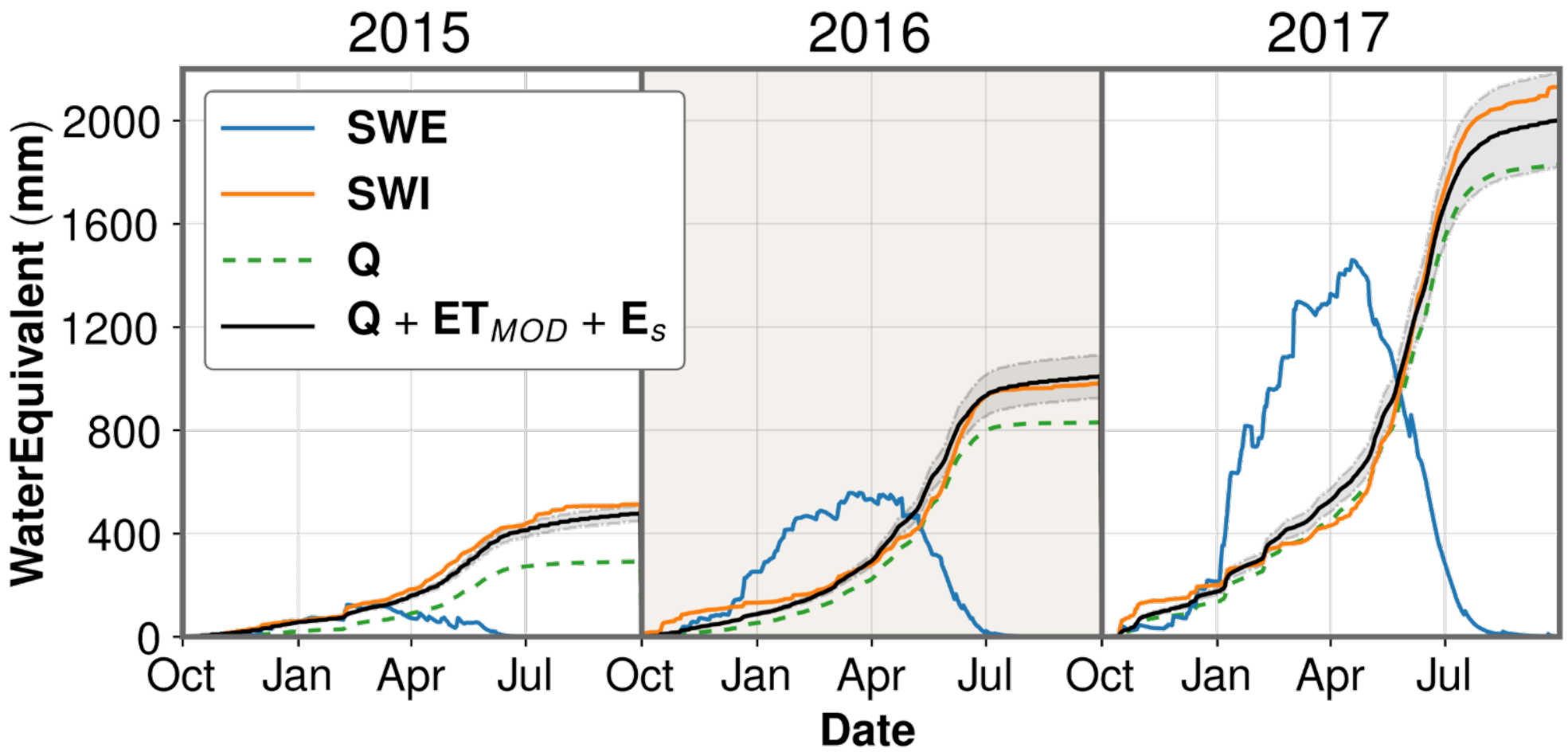
Tuolumne Basin Water Balance

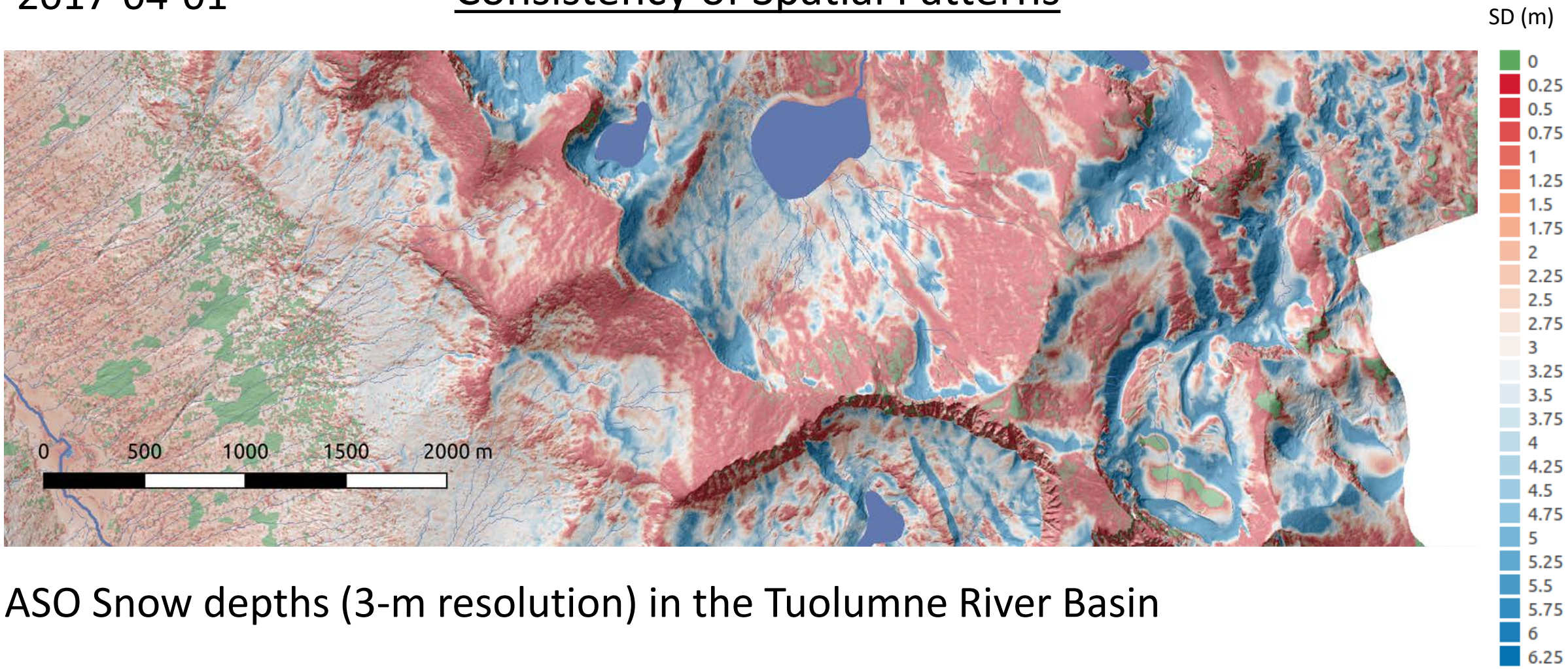


II. Precipitation Rescaling using Lidar

Trujillo et al., 2020a, *In Prep.*

2017-04-01

Consistency of Spatial Patterns



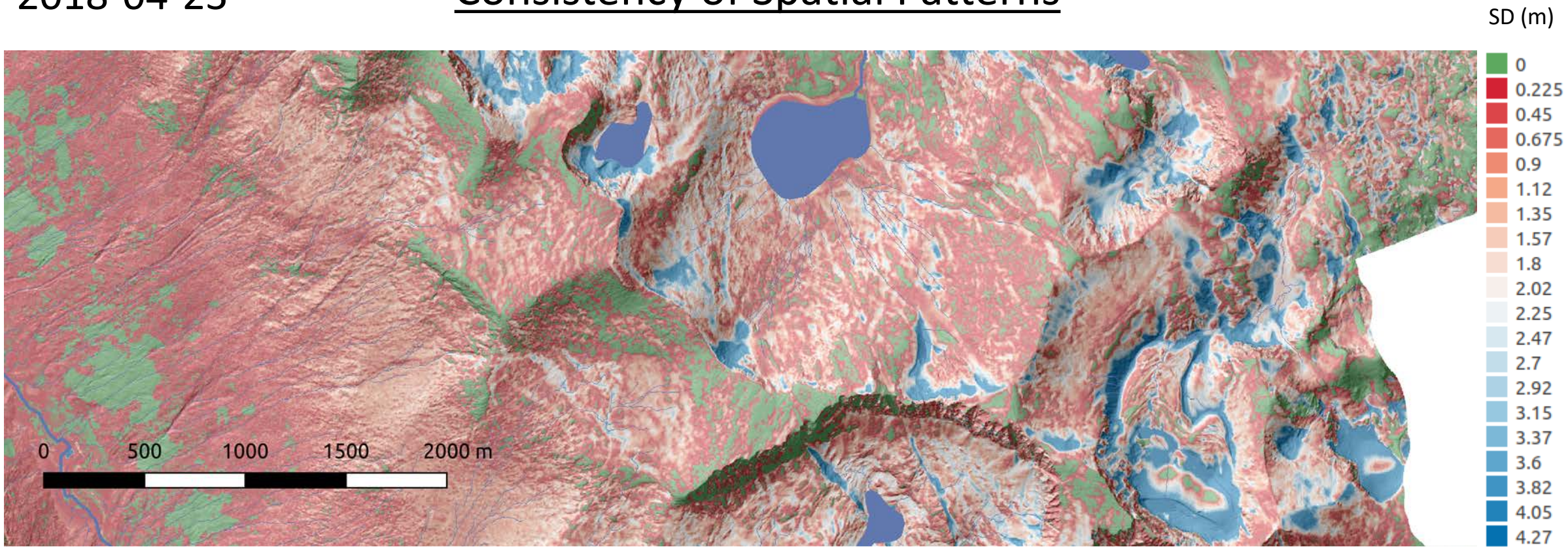
ASO Snow depths (3-m resolution) in the Tuolumne River Basin

II. Precipitation Rescaling using Lidar

Trujillo et al., 2020a, *In Prep.*

2018-04-23

Consistency of Spatial Patterns



ASO Snow depths (3-m resolution) in the Tuolumne River Basin

II. Precipitation Rescaling using Lidar

Trujillo et al., 2020b, *In Prep.*

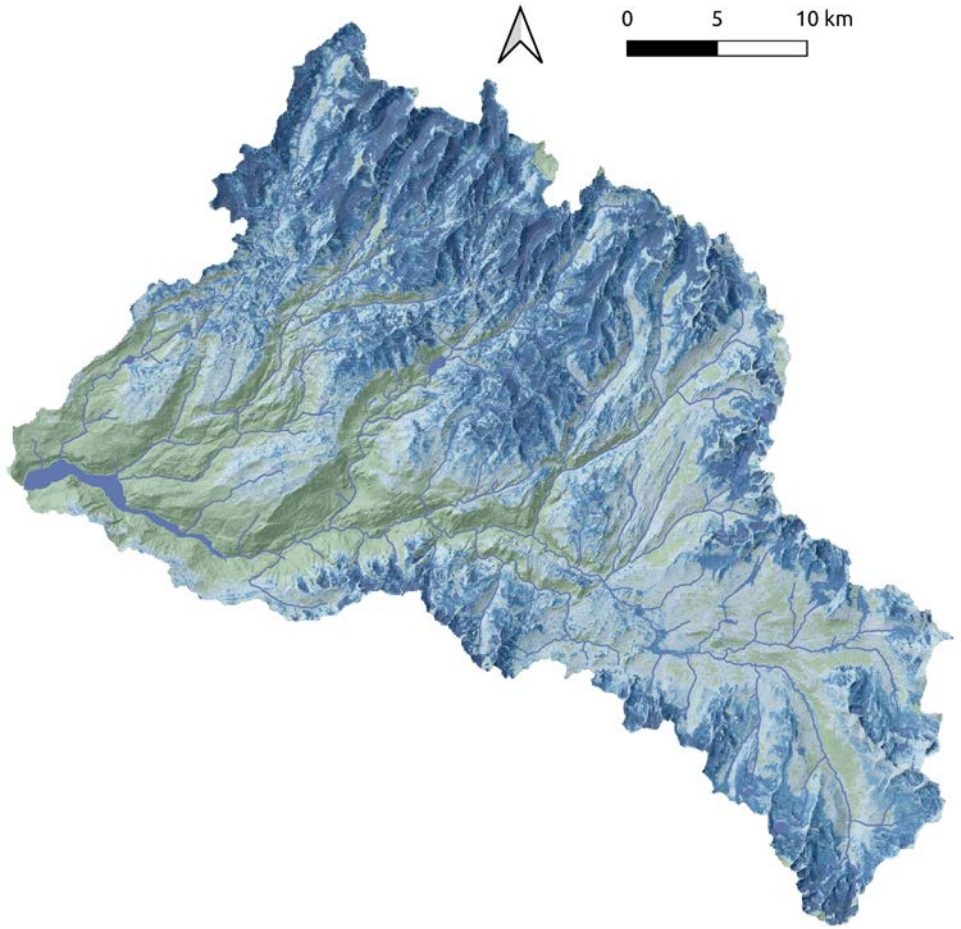
Workplan and Objectives

- Develop a precipitation rescaling method that utilizes snow distribution information over the watershed to inform precipitation interpolation
- The objective is to reproduce the spatial patterns observed, improving the representation of mass and energy balances in *iSnobal*
- More realistic and variable bulk snowpack densities
- The method can utilize distribution information from similar water years relying on the consistency of snow distribution patterns from year to year

II. Precipitation Rescaling (Preliminary results)

Trujillo et al., 2020b, *In Prep.*

2013-04-03 ASO/*iSnobal* SWE

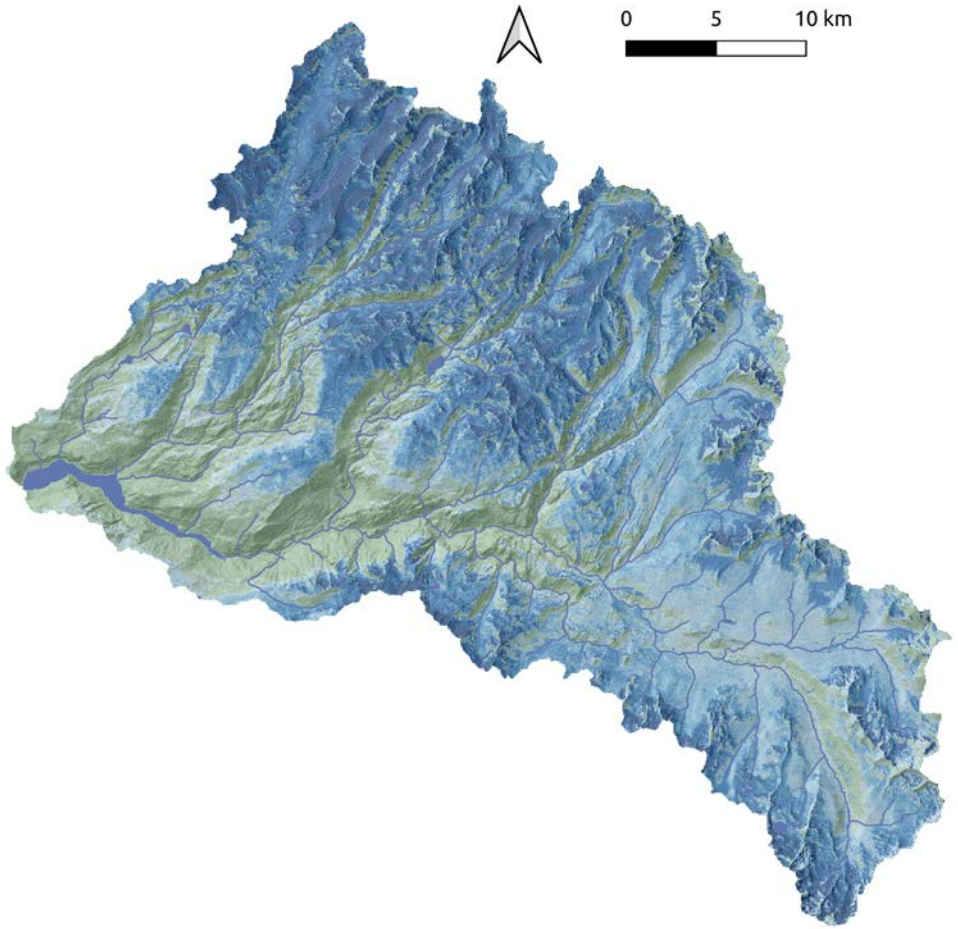


2013-04-03
ASO+*iSnobal* SWE (mm)

- 0 - 0
- 0 - 106
- 106 - 188
- 188 - 235
- 235 - 282
- 282 - 326
- 326 - 364
- 364 - 396
- 396 - 427
- 427 - 474
- 474 - 518
- 518 - 565
- 565 - 628
- 628 - 707
- 707 - 779
- > 779

2013-04-03 *iSnobal* SWE – no updates

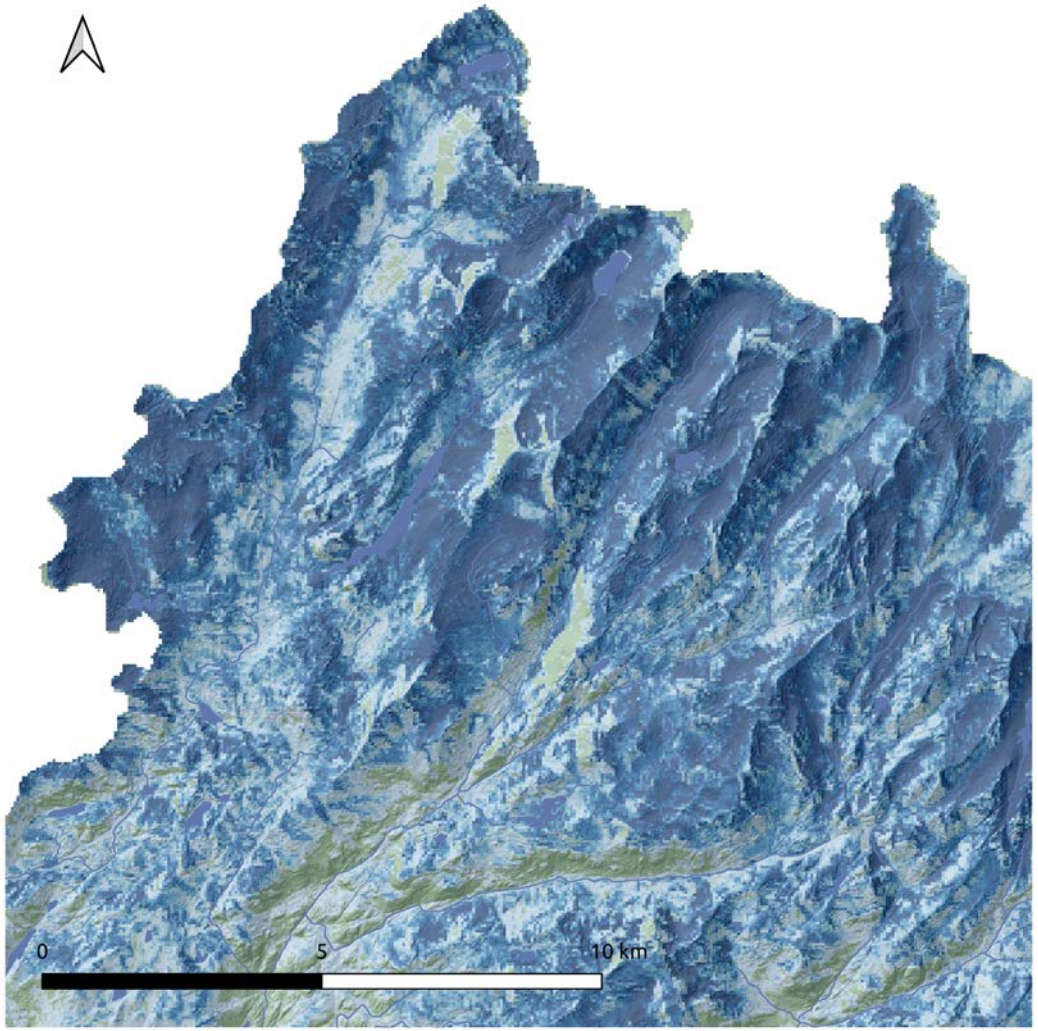
Precip. Rescaling using peak SWE 2016



II. Precipitation Rescaling (Preliminary results)

Trujillo et al., 2020b, *In Prep.*

2013-04-03 ASO/*iSnobal* SWE



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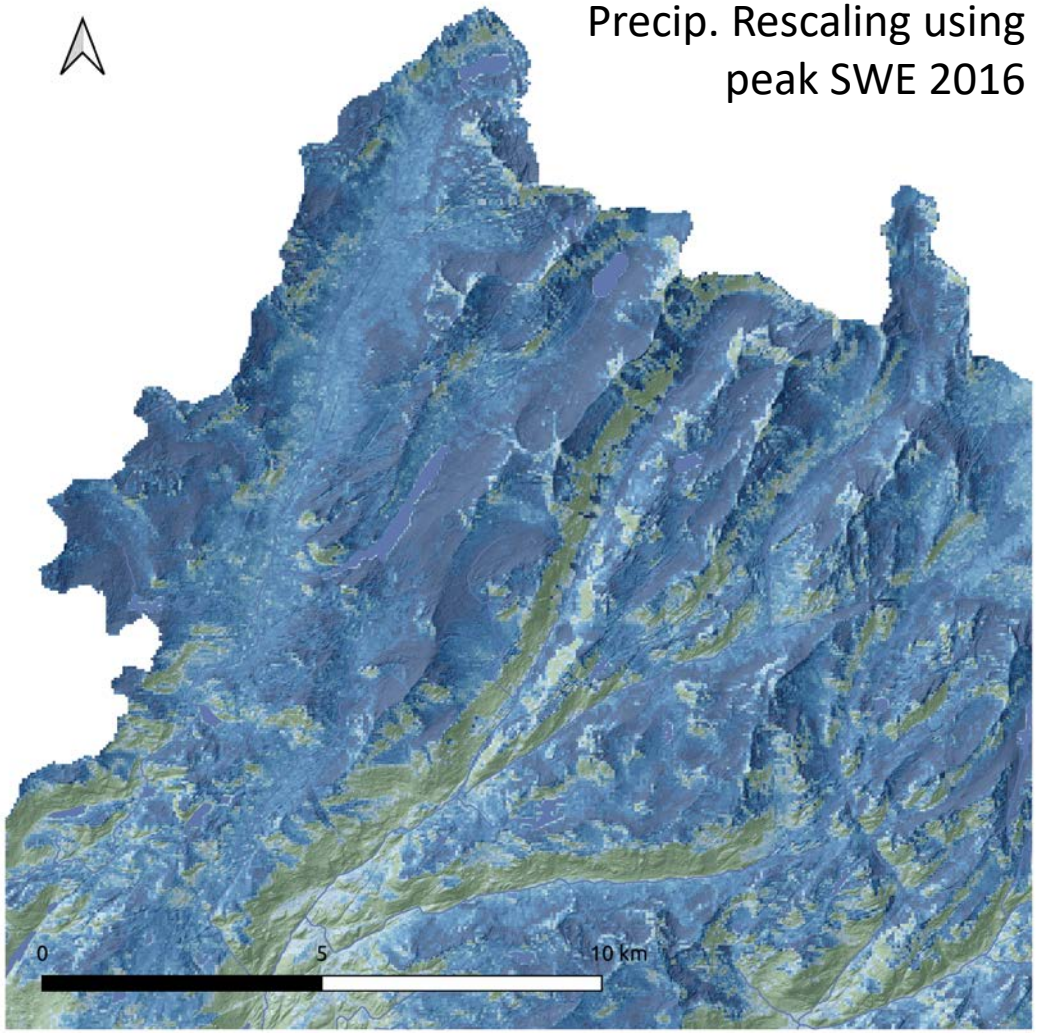
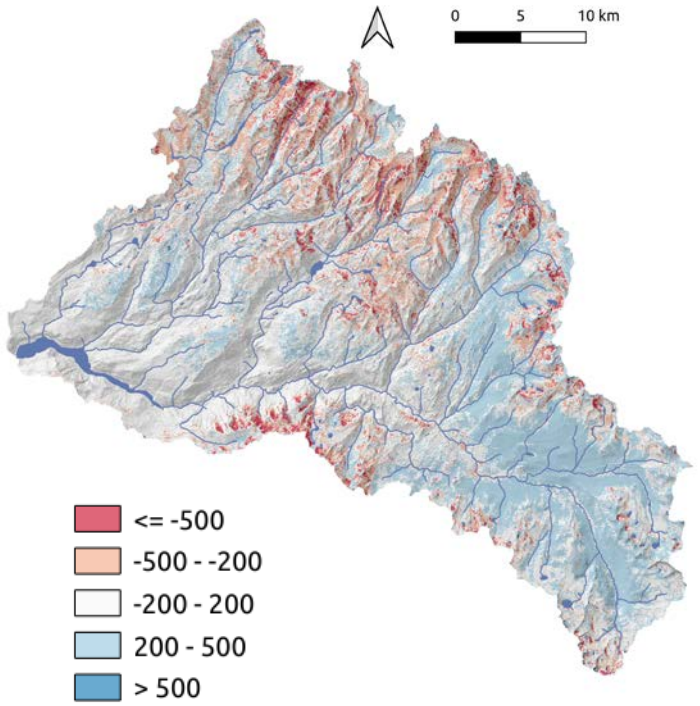


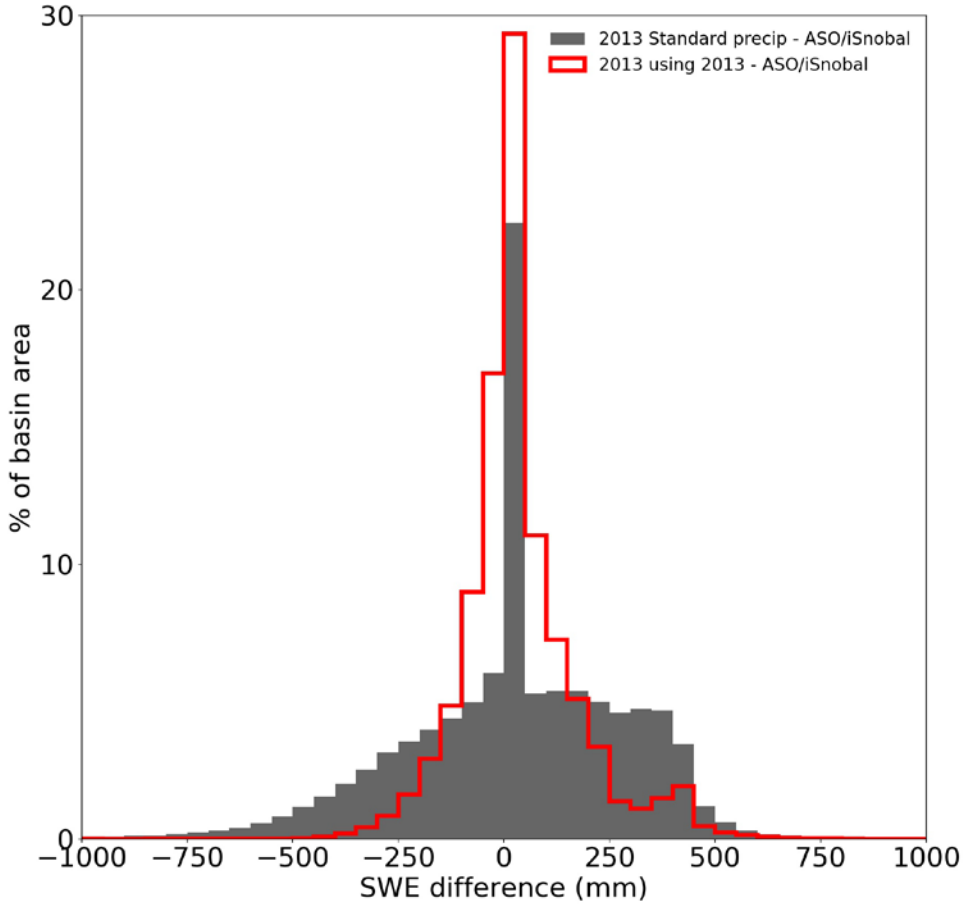
II. Precipitation Rescaling (Preliminary results)

Trujillo et al., 2020b, *In Prep.*

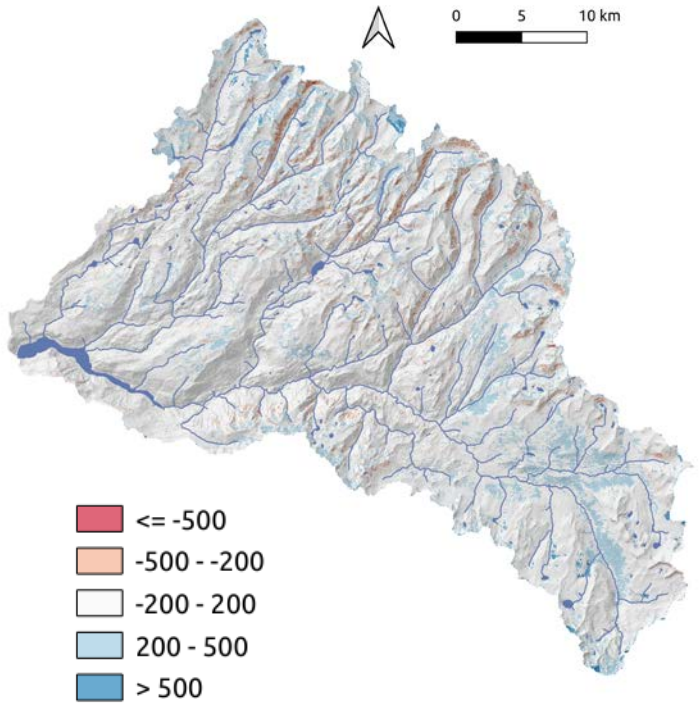
Modeled – ASO/*iSnobal* SWE

Difference
2013-04-03 Std Precip – ASO/*iSnobal*

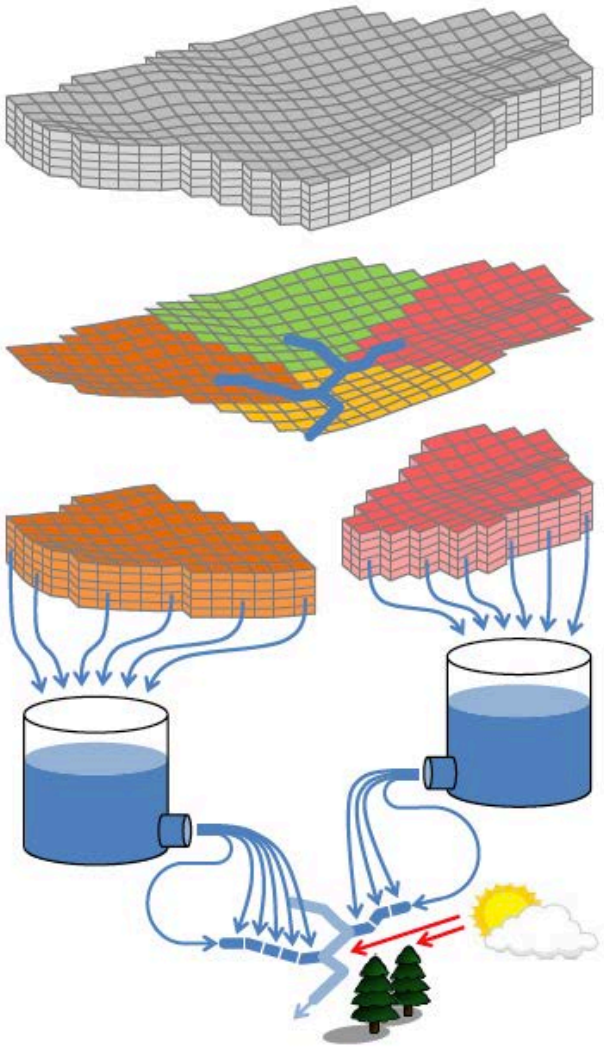




Difference
2013-04-03 using 2013 – ASO/*iSnobal*



III. Streamflow Routing



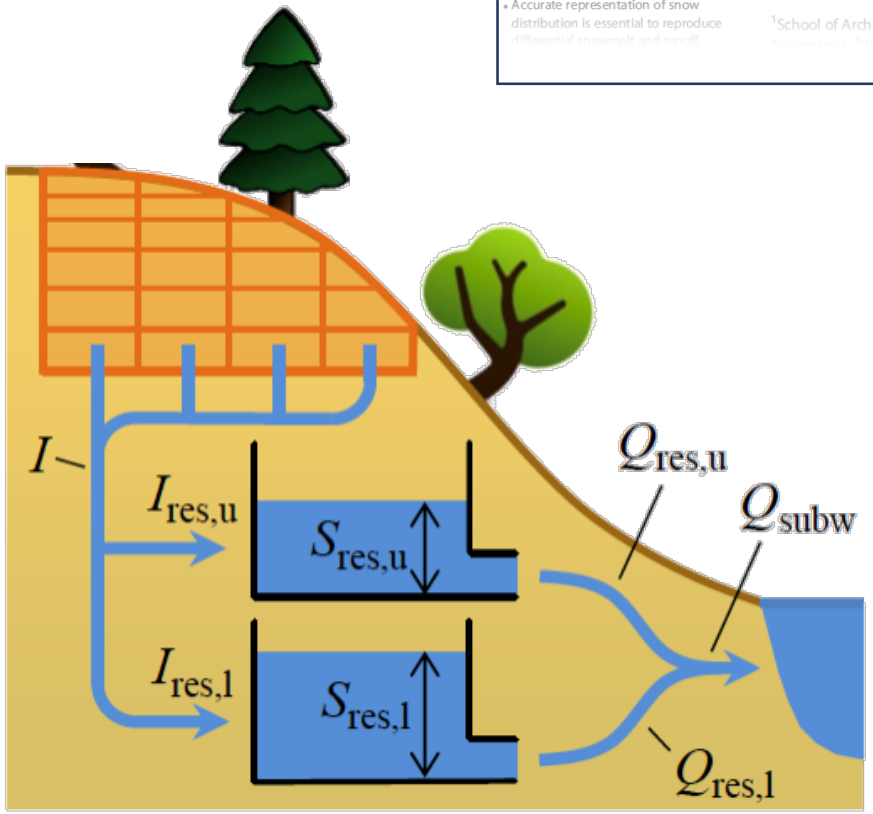
Water Resources Research

RESEARCH ARTICLE
10.1002/2017WR021278

Influence of Slope-Scale Snowmelt on Catchment Response Simulated With the *Alpine3D* Model

Tristan Brauchli[1,2], Ernesto Trujillo[1,2], Hendrik Huwald[1], and Michael Lehning[1,2]

Key Points:
- Accurate representation of snow distribution is essential to reproduce differential snowmelt and runoff



*Muskingum–Cunge for Stream routing

some math…

$$\tau_{res,u} = \overline{\tau}_{res,u}\left(\frac{A_{subw}}{A_{tot}}\right)^{\frac{1}{3}},$$

$$\tau_{res,l} = \overline{\tau}_{res,l}\left(\frac{A_{subw}}{A_{tot}}\right)^{\frac{1}{3}},$$

$$\frac{dS_{res,u}}{dt} = I_{res,u} - \frac{Q_{res,u}}{A_{subw}},$$

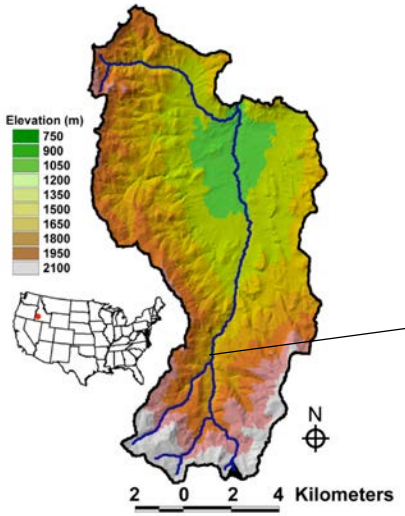
$$\frac{dS_{res,l}}{dt} = I_{res,l} - \frac{Q_{res,l}}{A_{subw}},$$

$$Q_{res,u} = A_{subw}\frac{S_{res,u}}{\tau_{res,u}},$$

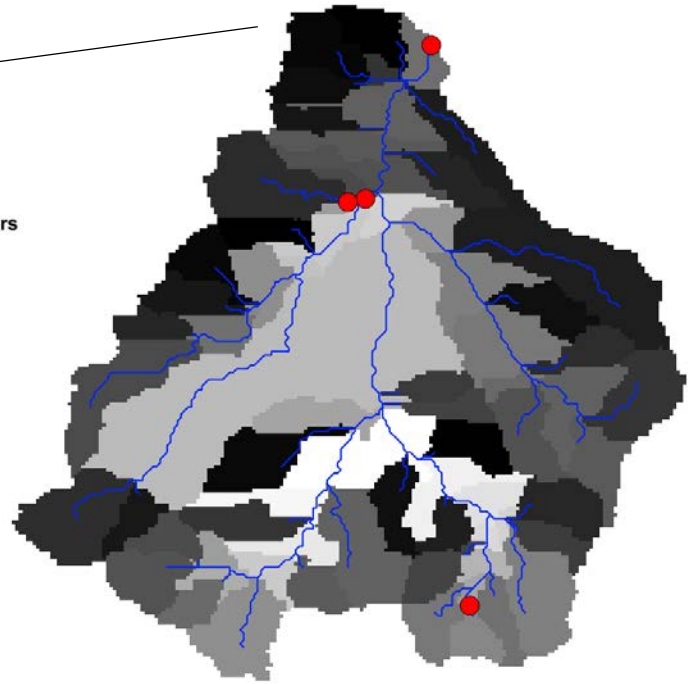
$$Q_{res,l} = A_{subw}\frac{S_{res,l}}{\tau_{res,l}}.$$

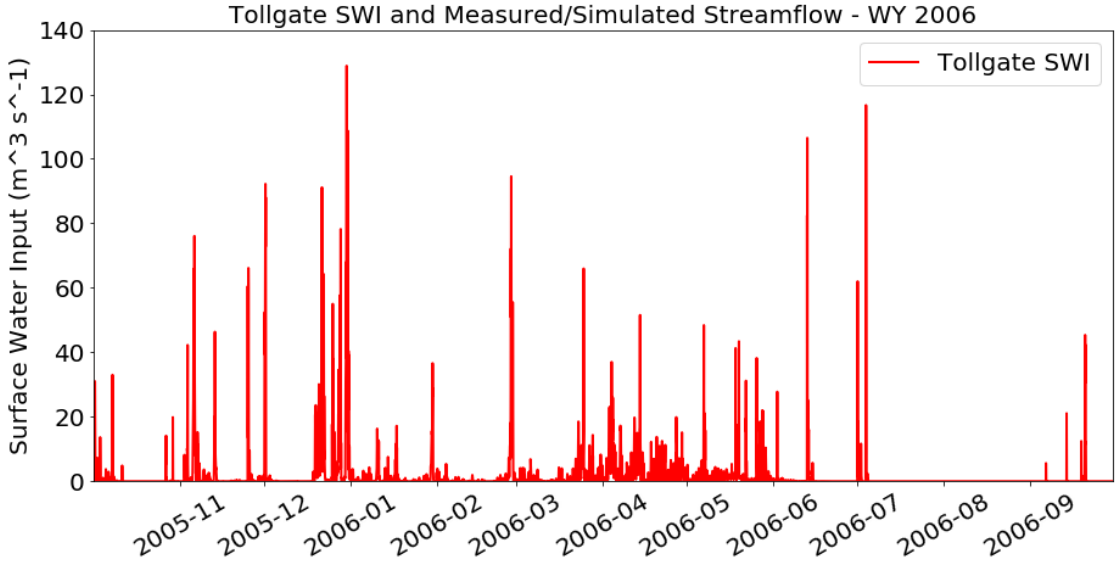
III. Streamflow Routing (Initial Tests)

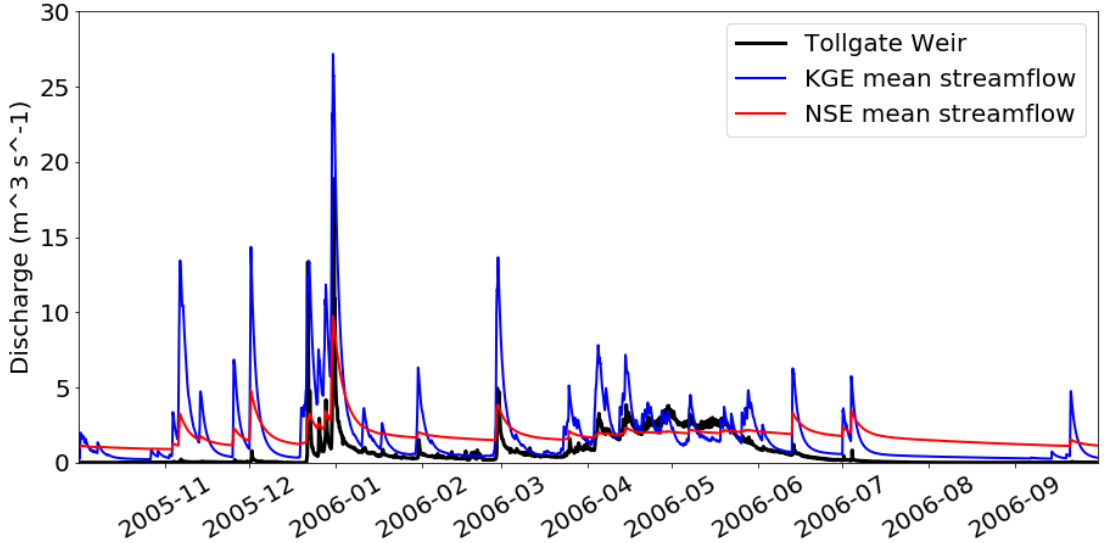
Reynolds Creek, ID



Tollgate Weir contributing area







IV. Long-term *iSnobal* Ensemble

What is the link between the spatial patterns of snow accumulation/melt with hydrological response?

- Use 30-40 year record of hindcast meteorological variables to force model.
  - Reanalysis products (HRRR, NLDAS, etc.)
- Investigate how modeled spatial SWE estimates relate to observed streamflow.
- Develop SWE to streamflow statistical relationships
  - Rather than at a point, use gridded 50m SWE estimates.
  - Instead of <10 regressions per basin, this will lead to ~500,000+ regressions

Conclusions

- Primary Goal → More accurate estimates of reservoir inflow
- ASO is key to this goal, and NWRC is developing scientific applications using the trove of lidar/spectrometer data.
- The new developments shown here are only a few of the more important projects, **however**…
- Major changes to the real-time modeling workflow will only be fully implemented after clearing journal peer review…

…<u>ensuring model results are backed up by the Scientific Method.</u>