Estimation of Seasonal Snow Water Equivalent Using Landsat Observations

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AGU Fall Meeting 2018

Washington DC, Dec. 10-14, 2018

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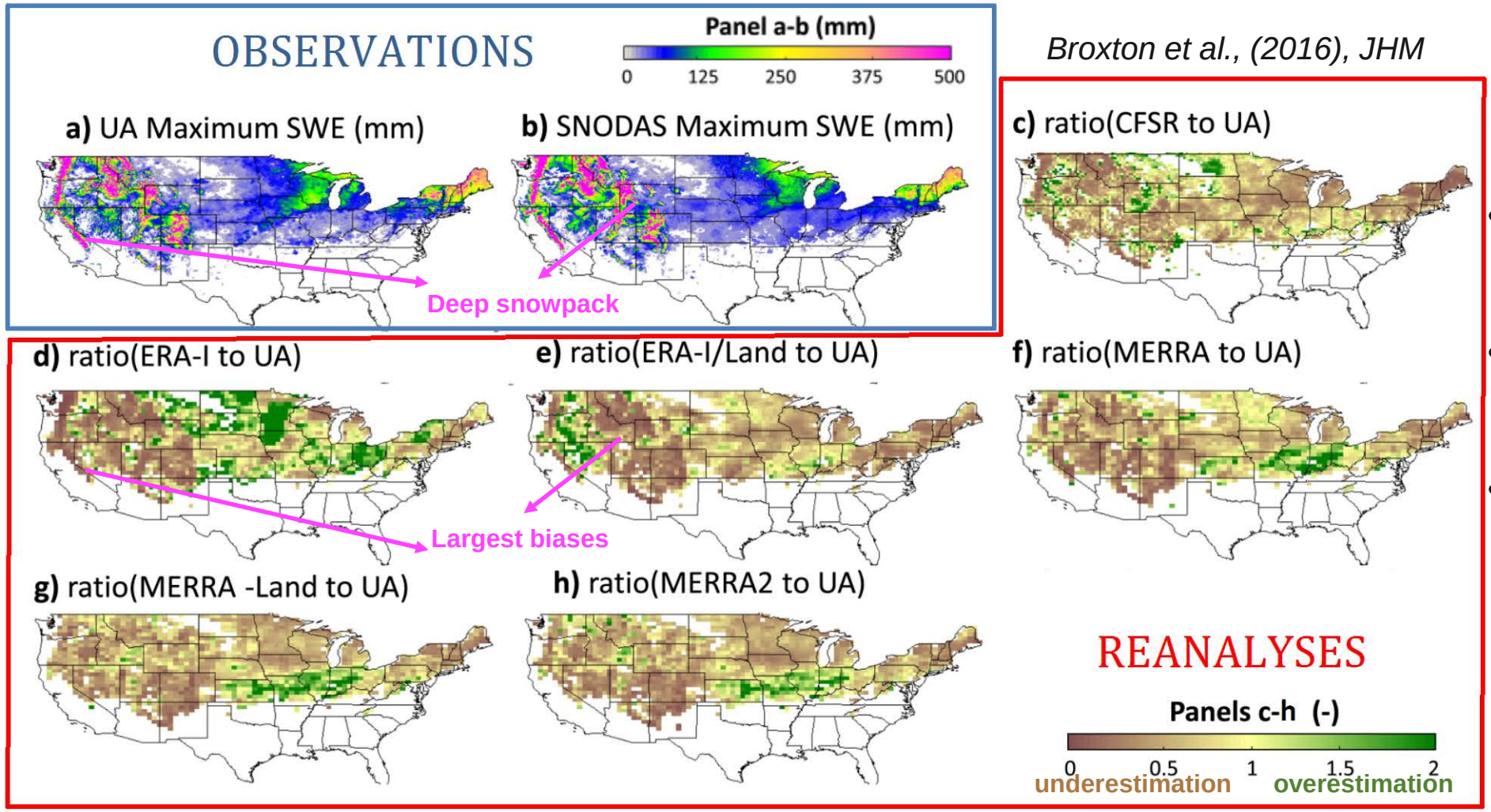
Snow is Biased in Reanalysis Datasets



Broxton et al., (2016), JHM

- Reanalyses are used to investigate snow processes [e.g., time/magnitude]
- But SWE is typically underestimated
- Larger biases in deep snowpack
- Biases partially explained by spatial resolution and snowfall biases

Need to provide unbiased reanalysis estimates of SWE

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Presentation outline

- Motivations
- **A Method for Snow Reanalysis**
- Proof of Concept: Sierra Nevada Case
  - Validation
  - Climatology
- Conclusions

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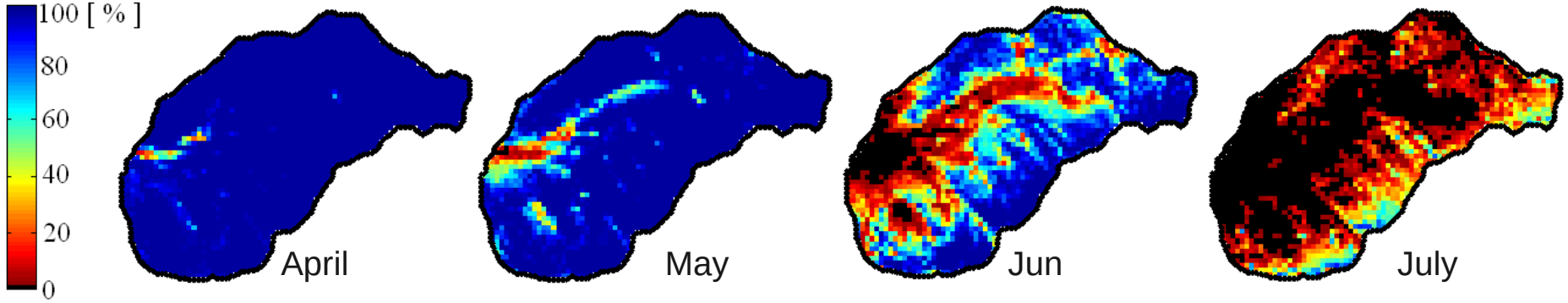
Snow Reanalysis Concept

Example FSCA depletion (Tokopah Watershed, California)



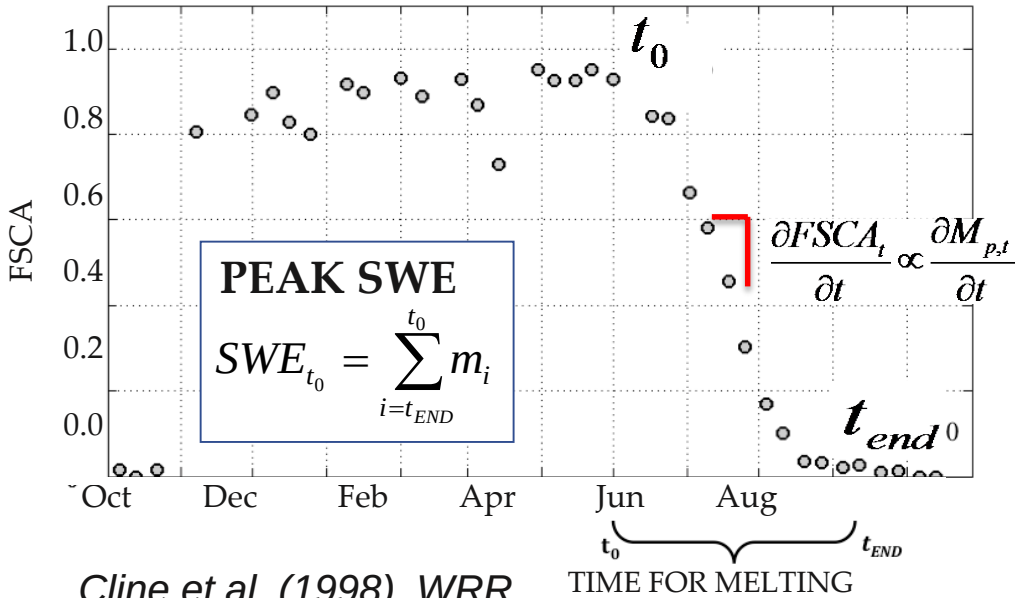
*Vis/NiR provides no direct estimate of SWE, but….

Reconstruction of SWE from:

- Depletion of fractional snow covered area [***FSCA***]
- Space/Time continuous energy fluxes
- SWE as a sum of melt (m_i) events

Use satellite observed FSCA to estimate SWE!!

Girotto et al. (2014); HP



Cline et al. (1998), WRR

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Snow Reanalysis Concept

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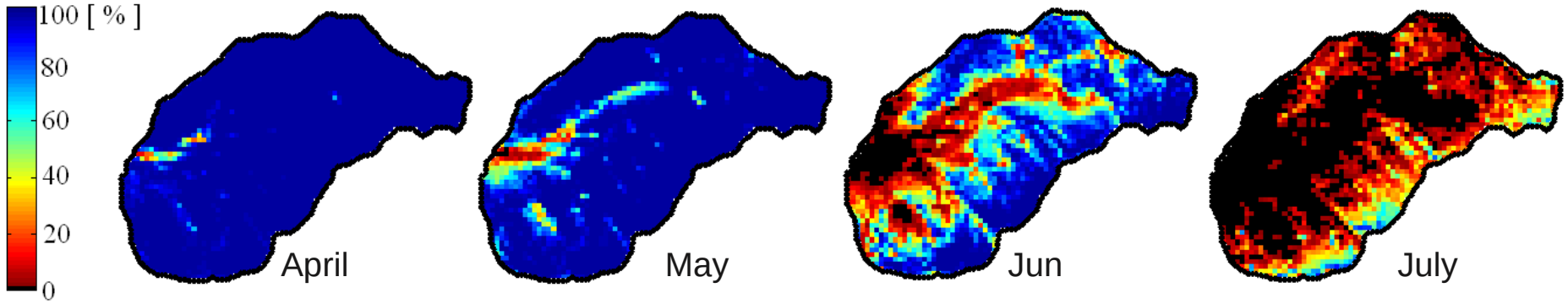

Reconstruction of SWE from:

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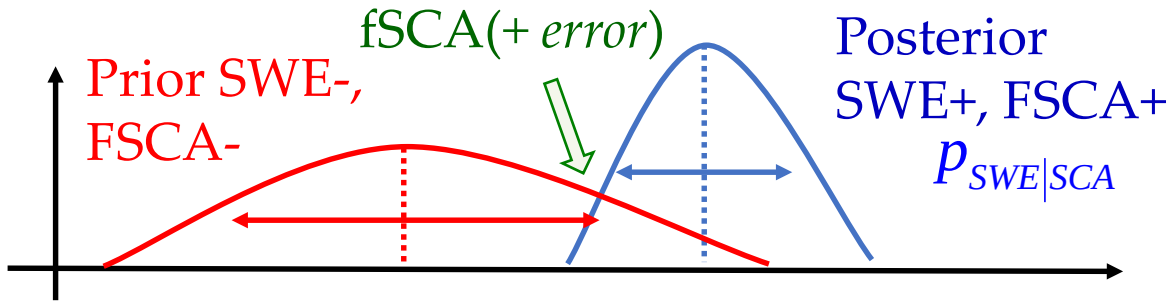
Probabilistic Approach
(Ensemble Kalman Smoother, Particle Smoother)



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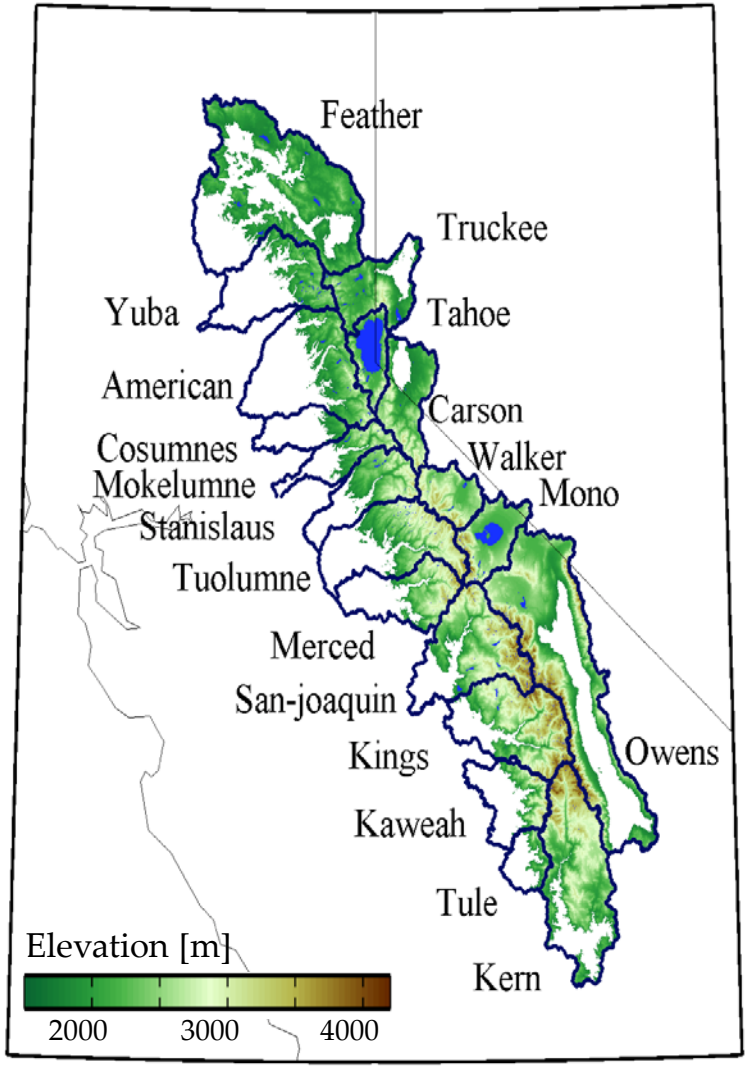
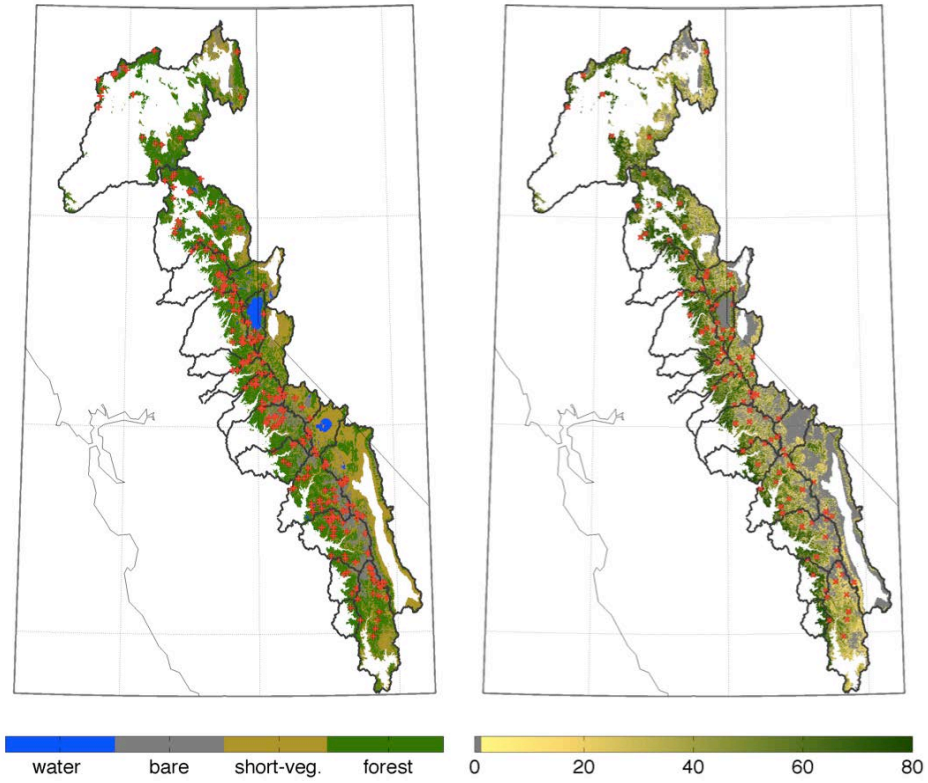
The Sierra Nevada: Validation

- Landsat observations
  (Landsat 5-8 record)
- Forcings: NLDAS
- Temporal Extent: **31 years**
- Spatial resolution: **90 m**
- Temporal resolution: **daily**
- Analysis: Particle Smoother
- Maritime snowpack (max. SWE ~1-2m)



- Validation:
- 108 snow-pillow
- 202 snow-courses



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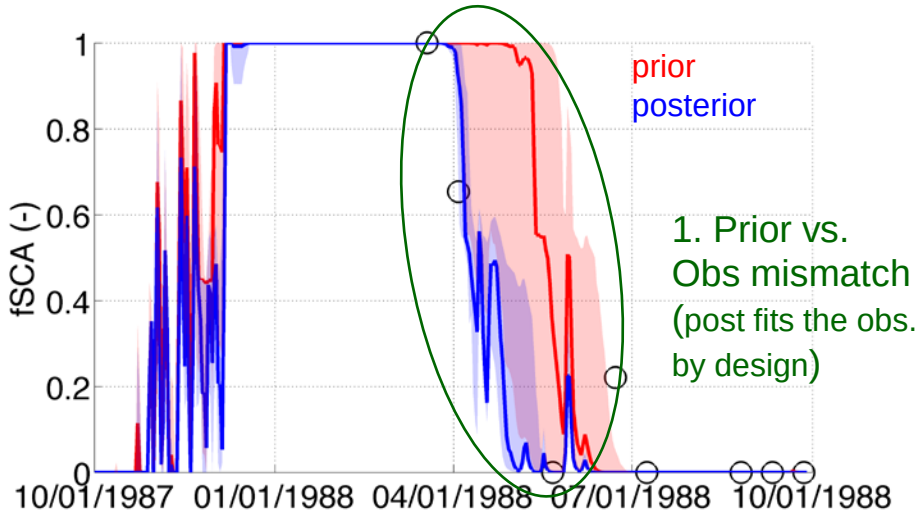
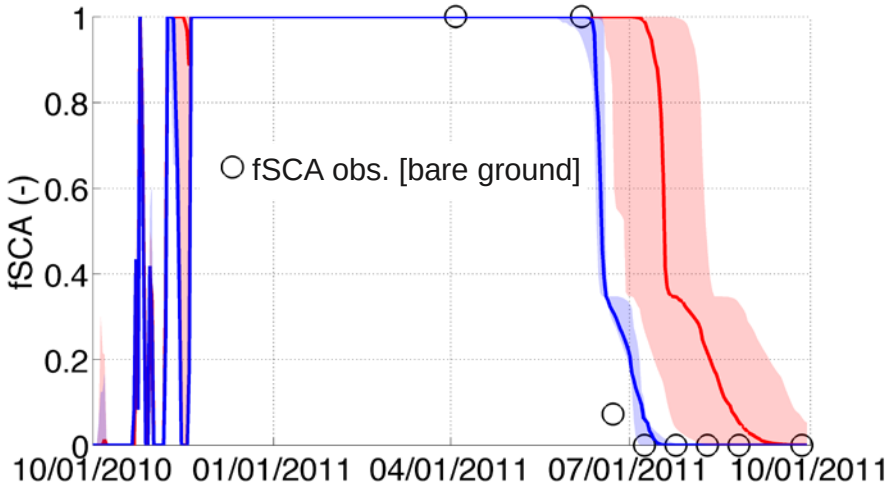
The Sierra Nevada: Validation

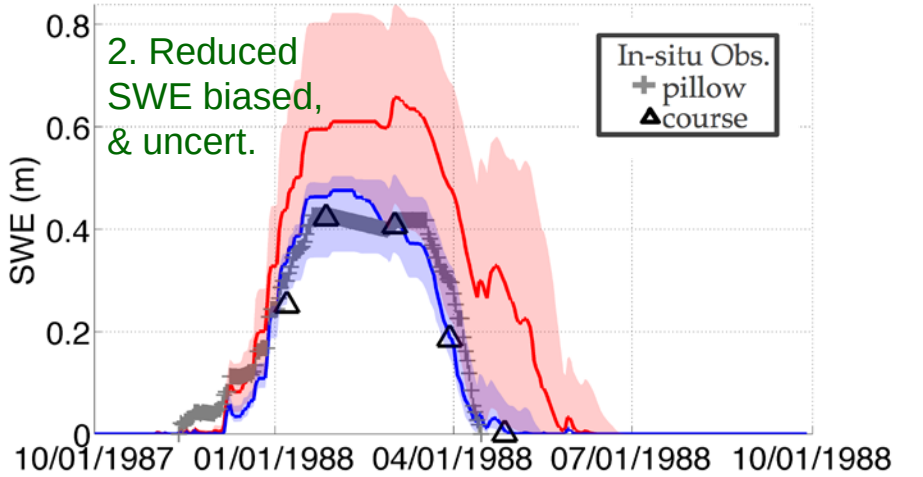


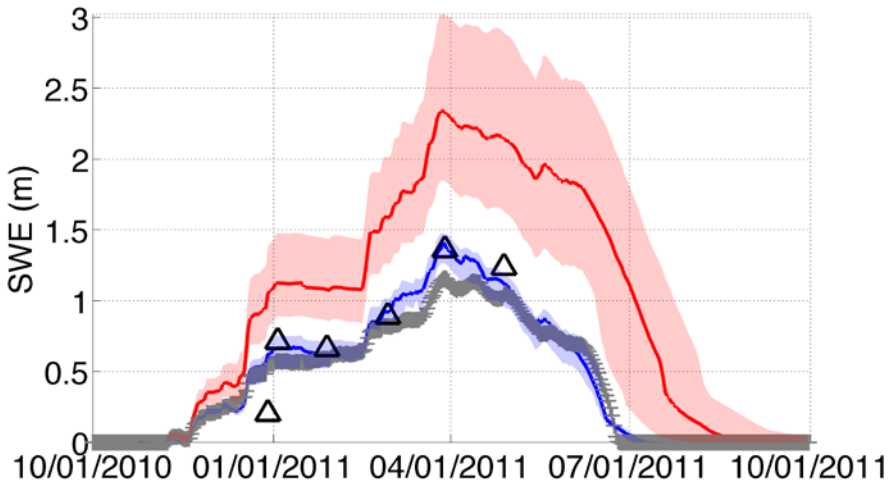
1. Prior vs. Obs mismatch (post fits the obs. by design)

dry year



wet year





Example: American River Watershed:

- fveg = 52%,
- elev=2400 m;
- co-located pillow/snow course data

(Margulis et al. 2016; JHM)

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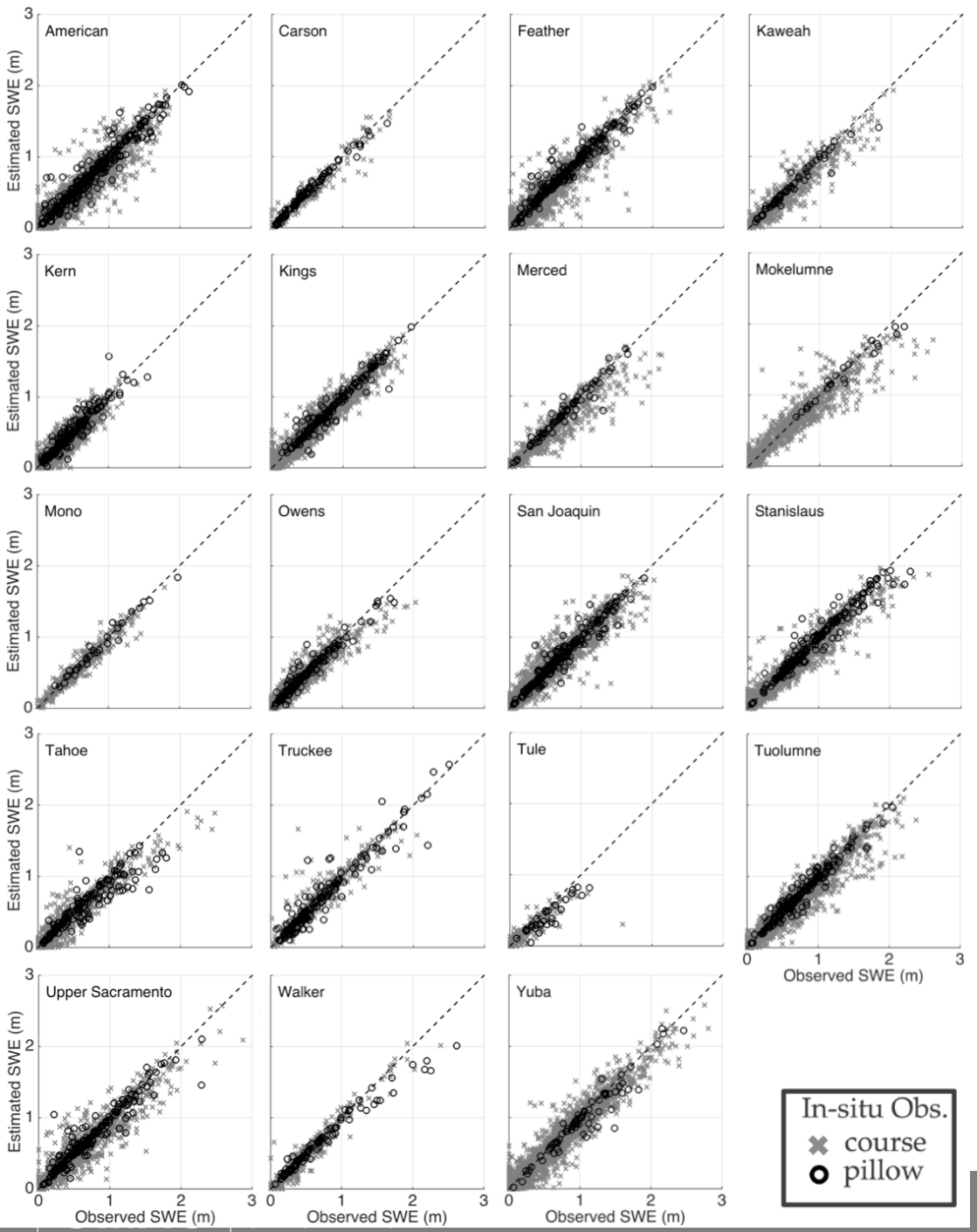
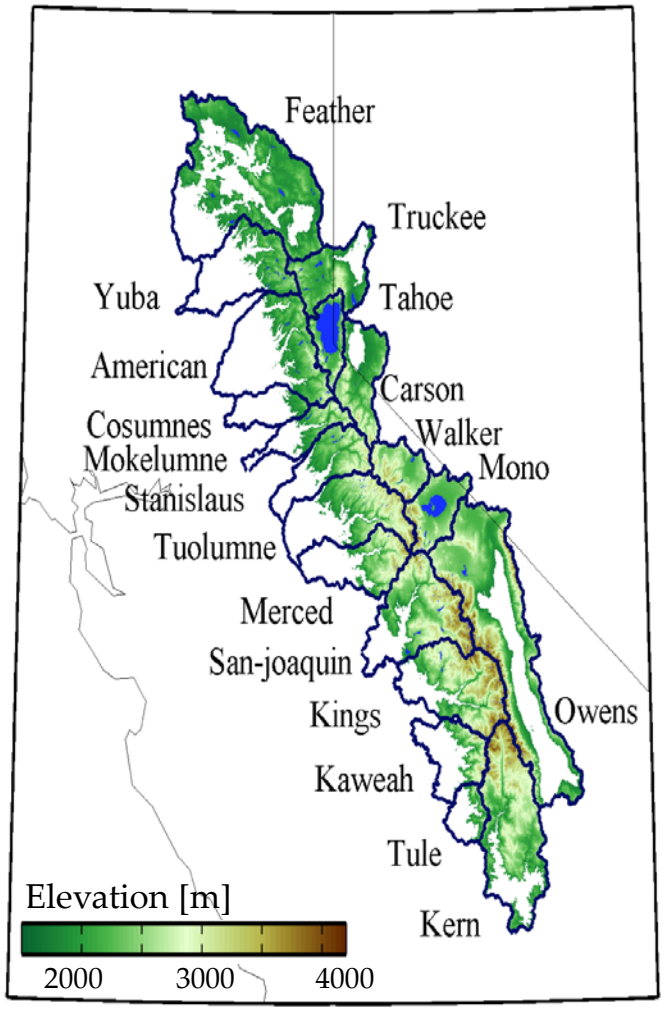
The Sierra Nevada: Validation



SWE estimates validated against >9000 station-years (snow pillow & snow course data)

SWE statistics show encouraging results:

- ME ~ -2 cm
- RMSE ~ 12 cm
- Corr. ~ 0.96



(Margulis et al. 2016; JHM)

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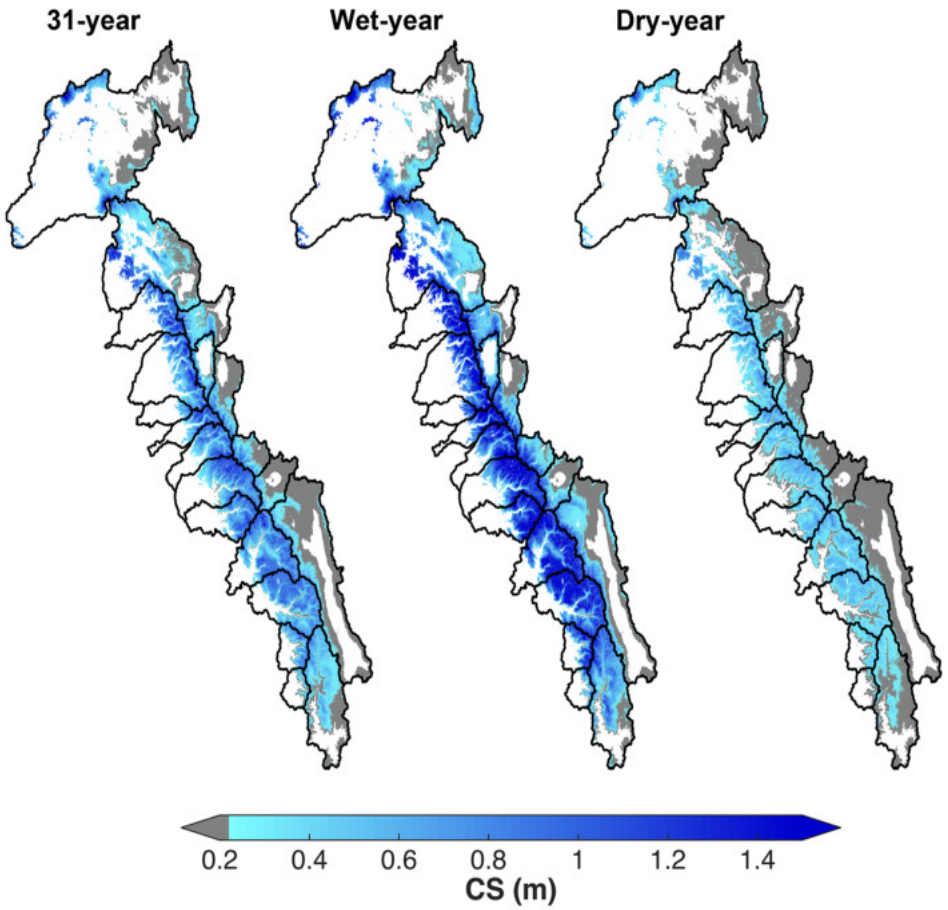
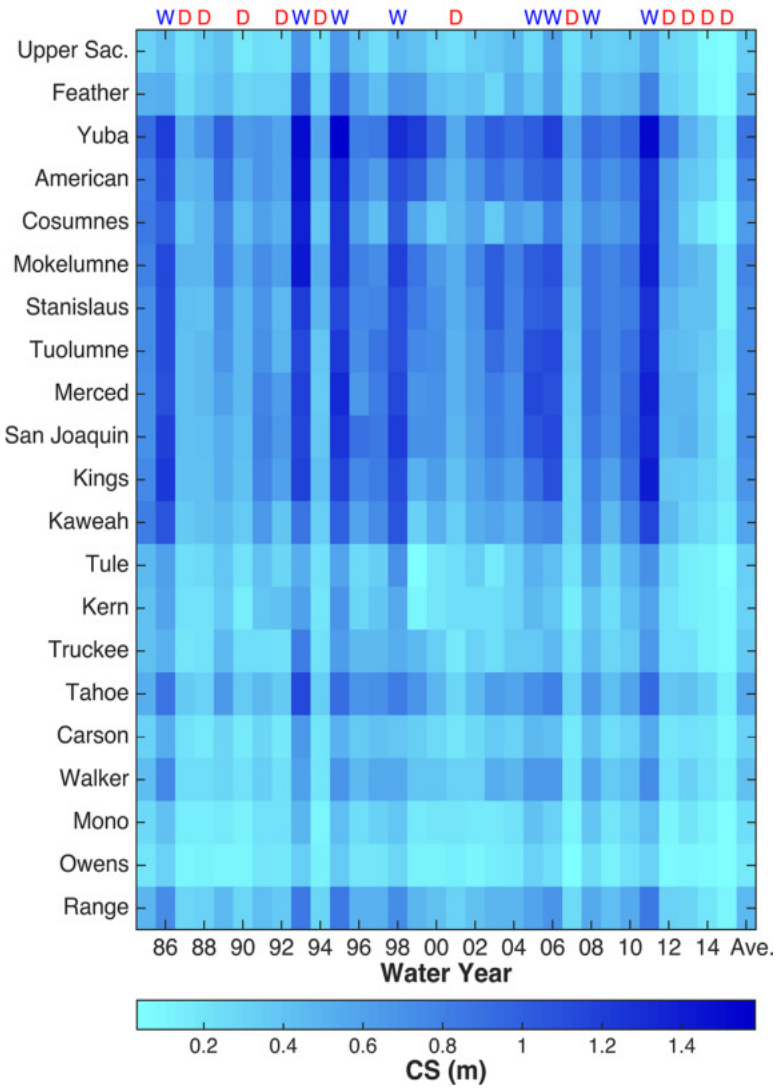
The Sierra Nevada Example: Spatial Analysis

Cumulative Snowfall (CS):

Accumulated increases in SWE (reanalysis)

- West accumulates more than East
- Higher elevations more CS
- Very high degree of spatial and interannual variability
- Sierra Nevada is a story of Wet/Dry Years





(Huning and Margulis 2017; WRR)

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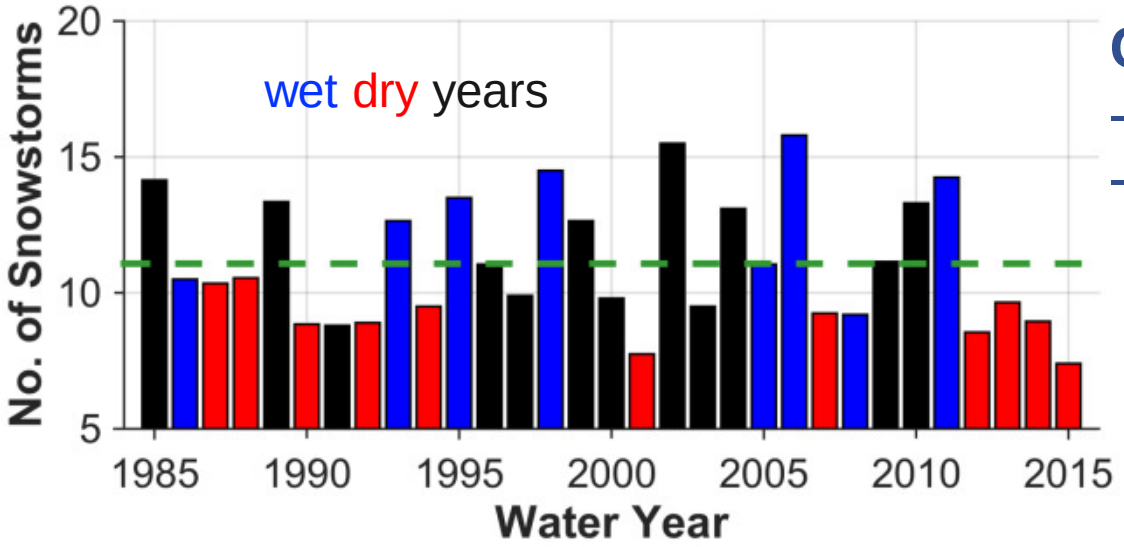
The Sierra Nevada Example: Temporal Analysis

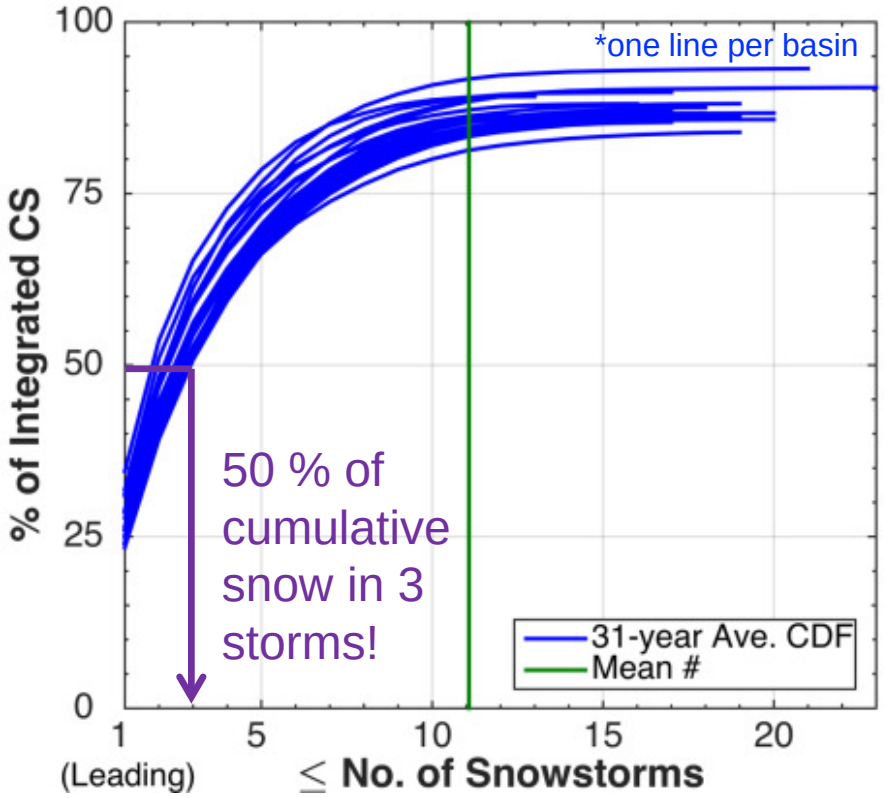


Climatology of Sierra Nevada snowstorms

- On average 11 snowstorms each winter
- More events for wet years (13) less for dry years (9)

Storm contribution to the total cumulative snow

- 50 % of the cumulative snow accumulates within 3 snow storms
- Each wintertime storm matters!
- The climatological rate of snowfall accumulation has a similar response over the entire Sierra Nevada range



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Conclusions & Future Directions

- This SWE reanalysis provides **unbiased** estimates of SWE even for **large snowpacks** (at least for the Sierra Nevada Mountains)
- SWE reanalysis provides a **unique** dataset in terms of large spatial/temporal extent, high spatial/temporal resolution, accuracy
- Climatology of the Sierra Nevada:
  - Higher cumulative snow for higher elevation, more cumulative snow in the west
  - Very high degree if spatial and interannual variability
  - Only a few storms to get the annual cumulative snow --> each storm is important
  - Coherence of events across the Sierra mountain range

Next/ongoing steps:

- Extend this method and analysis to other regions/longer times (e.g., Andes, High Mountain Asia, or in a context of a global reanalysis dataset)

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Thanks!!!

Funding provided by:

- NASA Terrestrial Hydrology Program
- NASA Earth and Space Science Fellowship (NESSF)
- NSF Earth Sciences (EAR)

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