Estimation of Seasonal Snow Water Equivalent Using Landsat Observations

Manuela Girotto[1,2], Laurie Huning[3], Steven A. Margulis[4], Gonzalo Cortés[4], Michael Durand[5]

[1]Global Modeling and Assimilation Office, NASA Goddard Space Flight Center, Greenbelt, MD, USA
[2]GESTAR, Universities Space Research Association, Columbia, MD, USA
[3]Department of Civil and Environmental Engineering, University of California, Irvine, CA, USA
[4]Department of Civil and Environmental Engineering, University of California, Los Angeles, CA, USA
[5]School of Earth Sciences, and Byrd Polar Research Center, The Ohio State University, Columbus, Ohio, USA

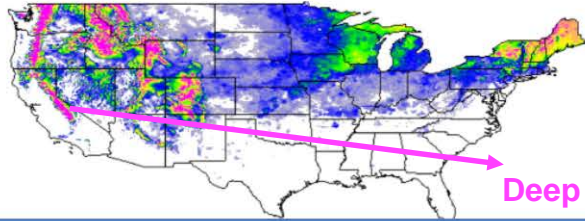AGU Fall Meeting 2018

Washington DC, Dec. 10-14, 2018
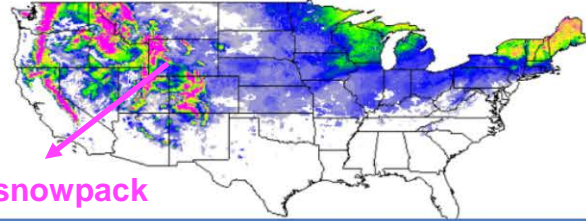
Snow is Biased in Reanalysis Datasets

Broxton et al., (2016), JHM
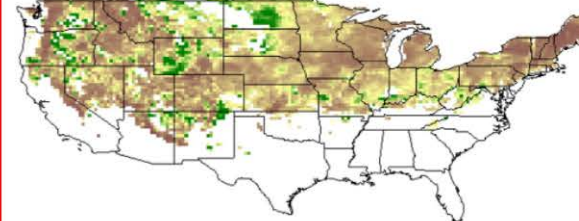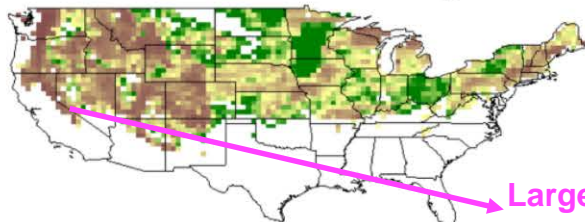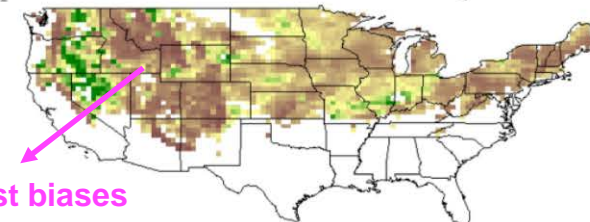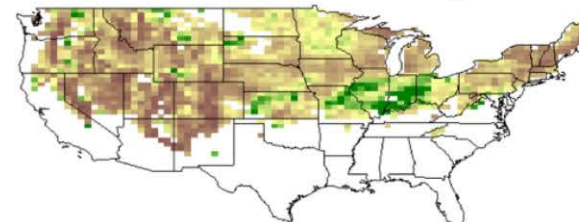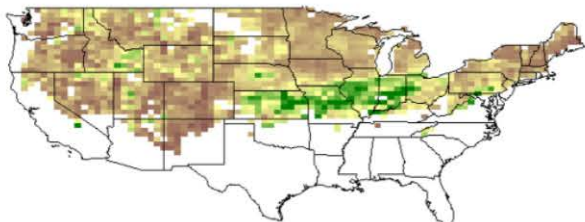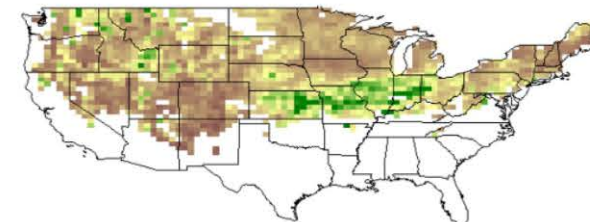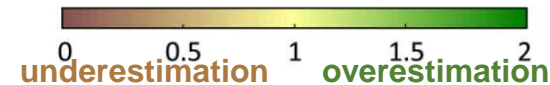
- Reanalyses are used to investigate snow processes [e.g., time/magnitude]

- 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

Presentation outline

- **Motivations**

- **A Method for Snow Reanalysis**

- **Proof of Concept: Sierra Nevada Case**
  - **Validation**
  - **Climatology**

- **Conclusions**

Snow Reanalysis Concept

Example FSCA depletion (**Tokopah Watershed, California**)

April   May   Jun   July

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

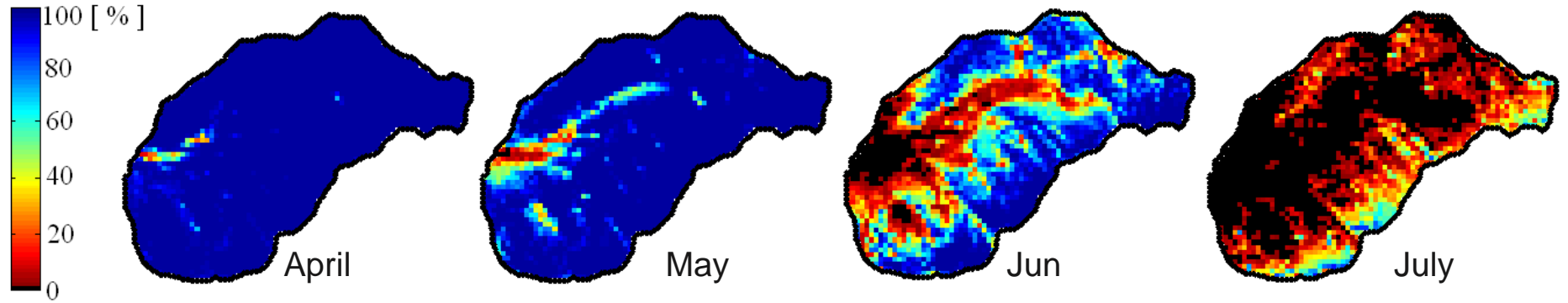## Reconstruction of SWE from:

- 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!!
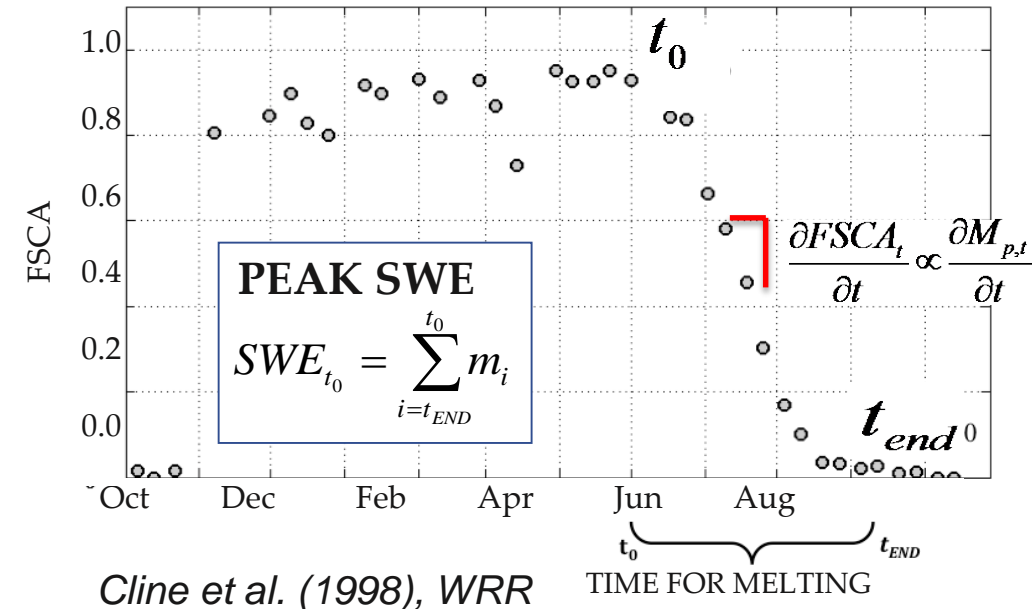
Girotto et al. (2014); HP

PEAK SWE

$$SWE_{t_0} = \sum_{i=t_{END}}^{t_0} m_i$$

$$\frac{\partial FSCA_t}{\partial t} \propto \frac{\partial M_{p,t}}{\partial t}$$

t_0

t_{end}

Oct   Dec   Feb   Apr   Jun   Aug

t_0 TIME FOR MELTING t_{END}

Cline et al. (1998), WRR

manuela.girotto@nasa.gov

Snow Reanalysis Concept

Example FSCA depletion
(Tokopah Watershed, California)
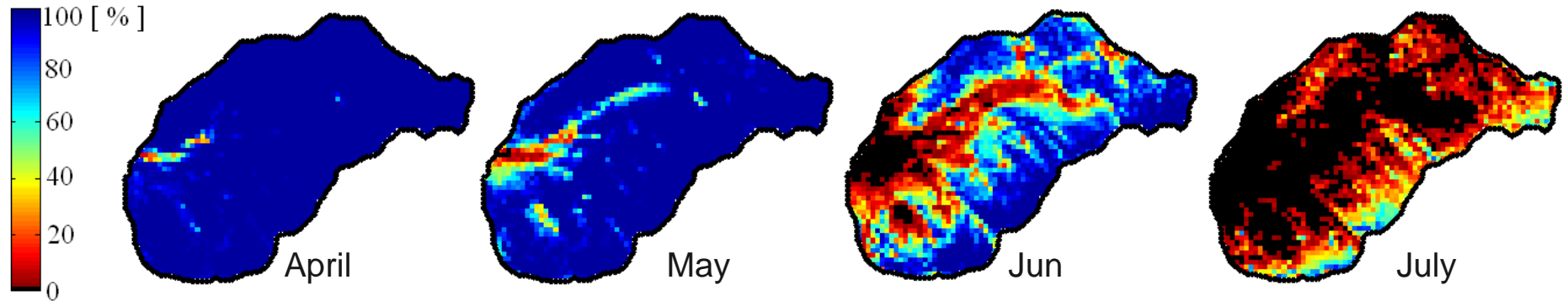
Reconstruction of SWE from:

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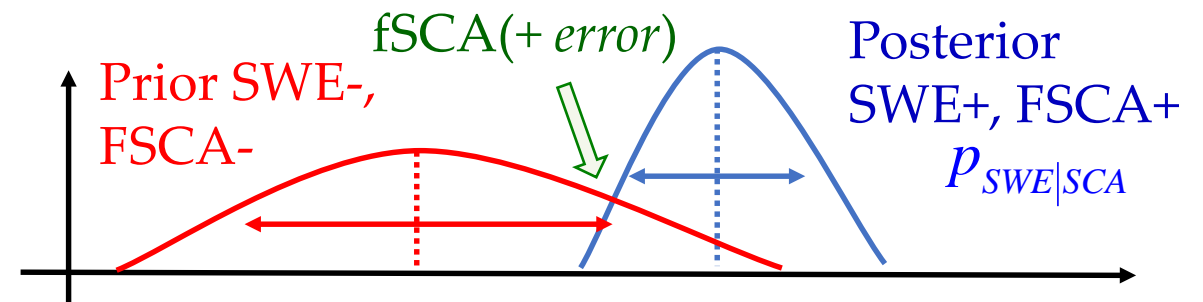- SWE as a sum of melt (m_i) events

Probabilistic Approach
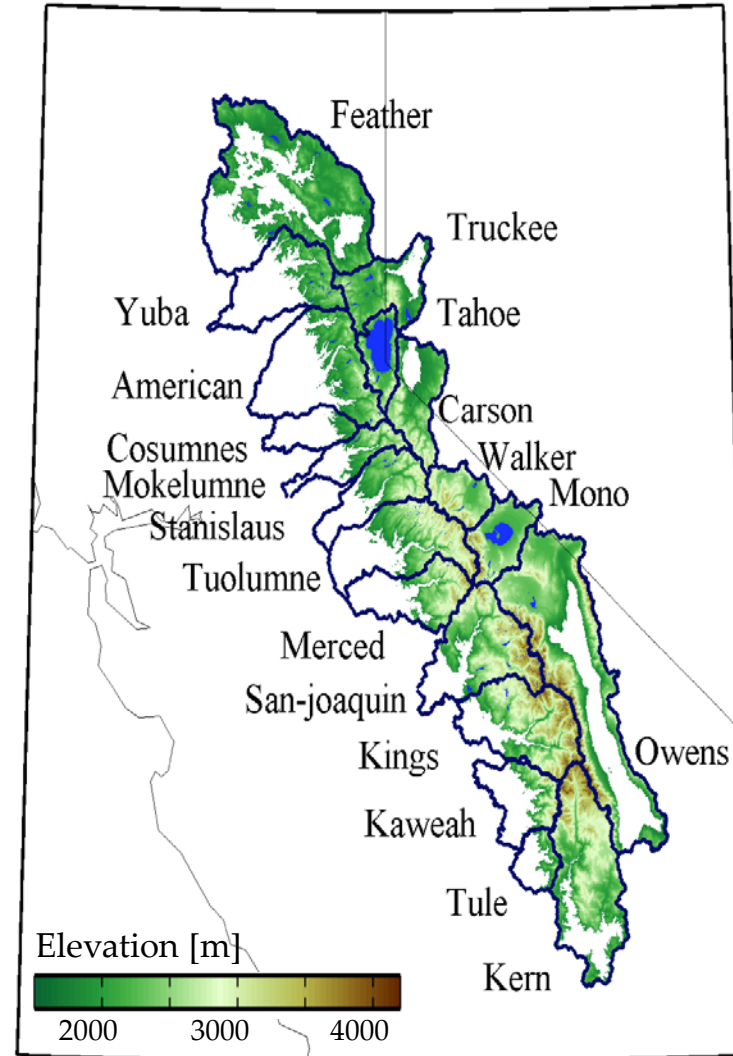(Ensemble Kalman Smoother, Particle Smoother)
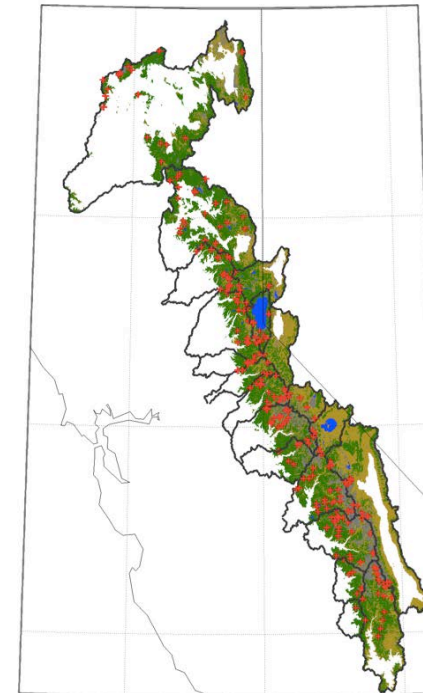

Girotto et al. (2014); HP

Presentation outline

- **Motivations**

- **A Method for Snow Reanalysis**

- **Proof of Concept: Sierra Nevada Case**
  - **Validation**
  - **Climatology**

- **Conclusions**

The Sierra Nevada: Validation
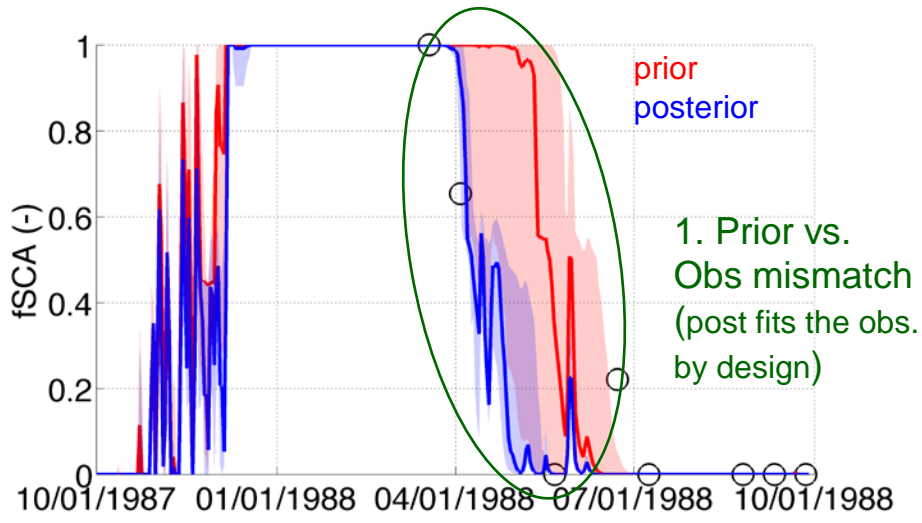
- Landsat observations
  (Landsat 5-8 record)

- Forcings: NLDAS

- Temporal Extent: **31 years**

- Spatial resolution: **90 m**

- Temporal resolution: **daily**

- Analysis: Particle Smoother

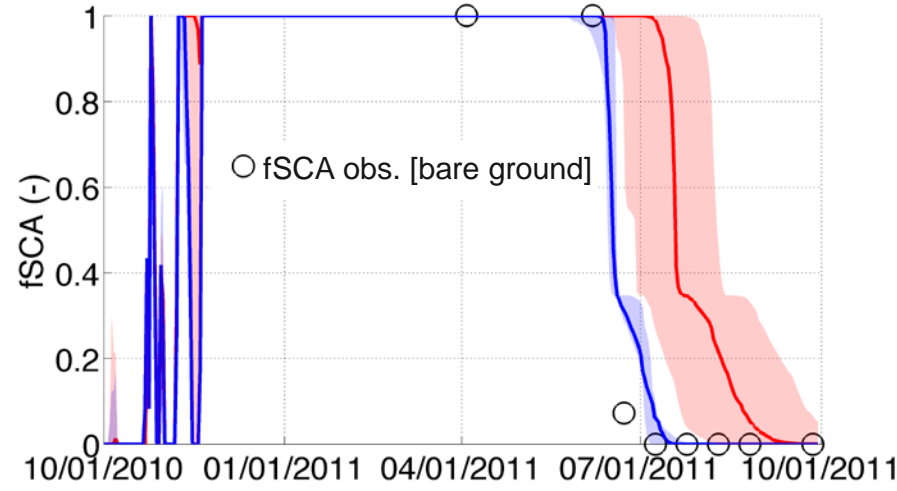- Maritime snowpack (max. SWE ~1-2m)

Elevation [m]
2000 3000 4000

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

water   bare   short-veg.   forest   0   20   40   60   80

The Sierra Nevada: Validation

prior
posterior

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

fSCA obs. [bare ground]

dry year

wet year

2. Reduced
SWE biased,
& uncert.

In-situ Obs.
+ pillow
△ course
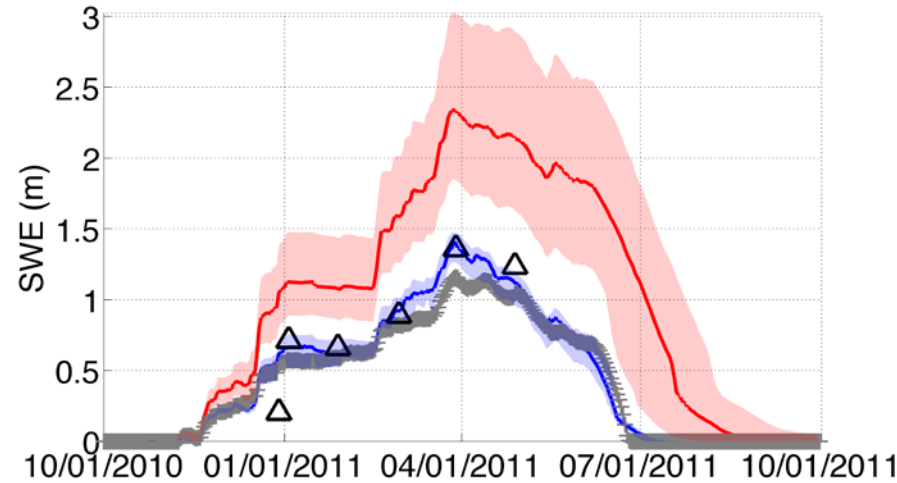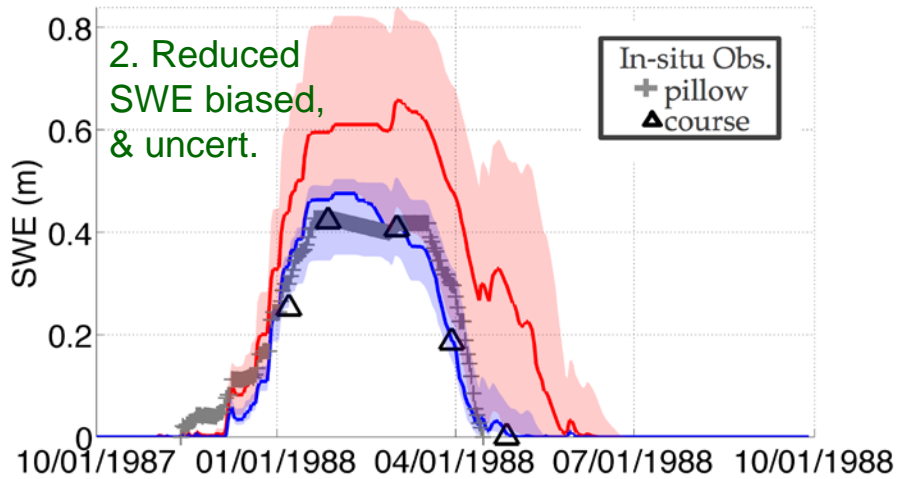
Example: American River
Watershed:
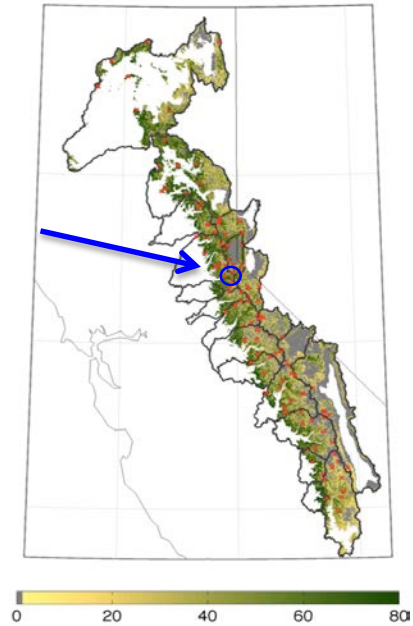• fveg = 52%,
• elev=2400 m;
• co-located pillow/snow
  course data

(Margulis et al. 2016; JHM)

The Sierra Nevada: Validation
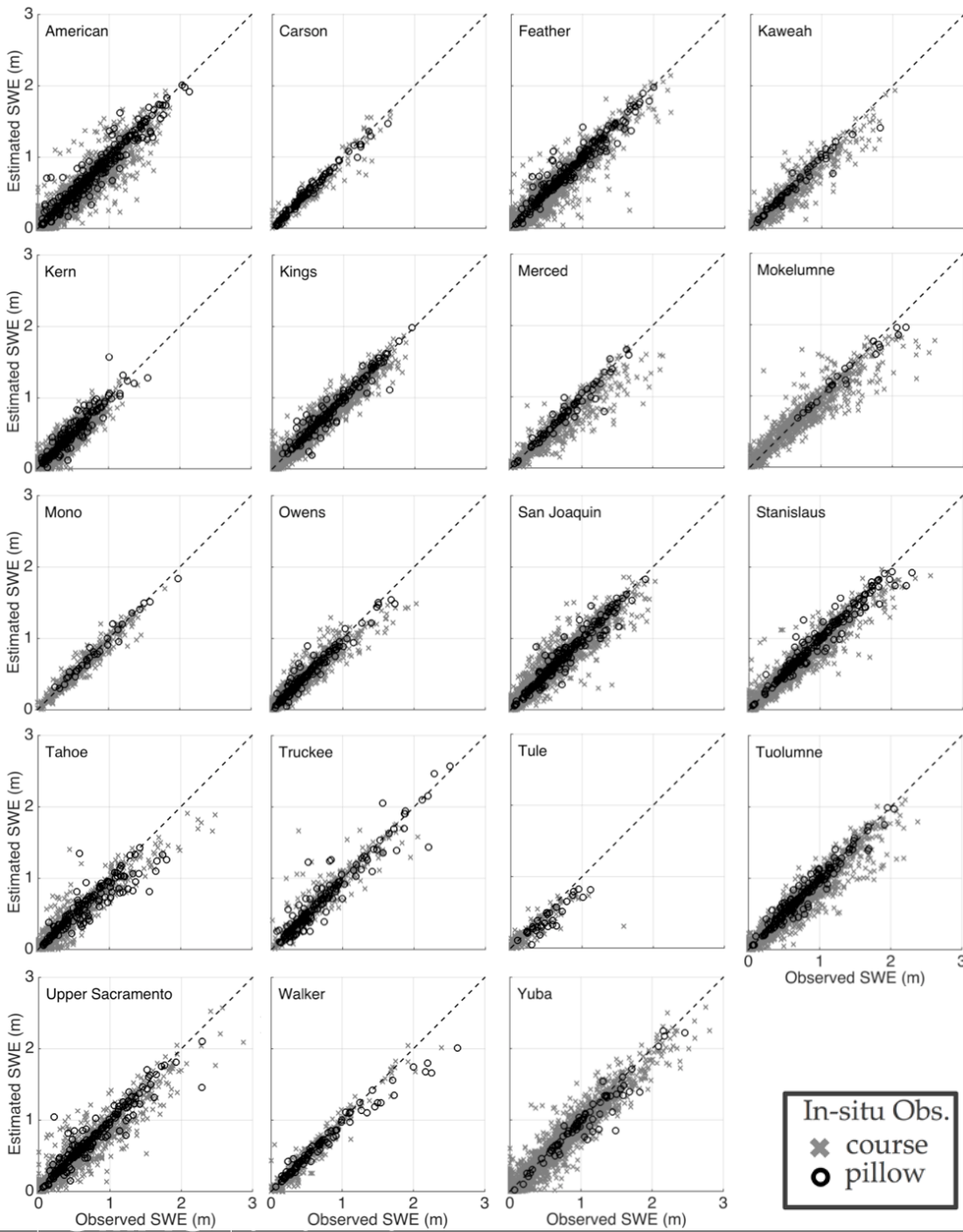
SWE estimates validated against >9000 station-years (snow pillow & snow course data)

SWE statistics show encouraging results:

- ME ~ -2 cm
- RMSE ~ 12 cm
- Corr. ~ 0.96
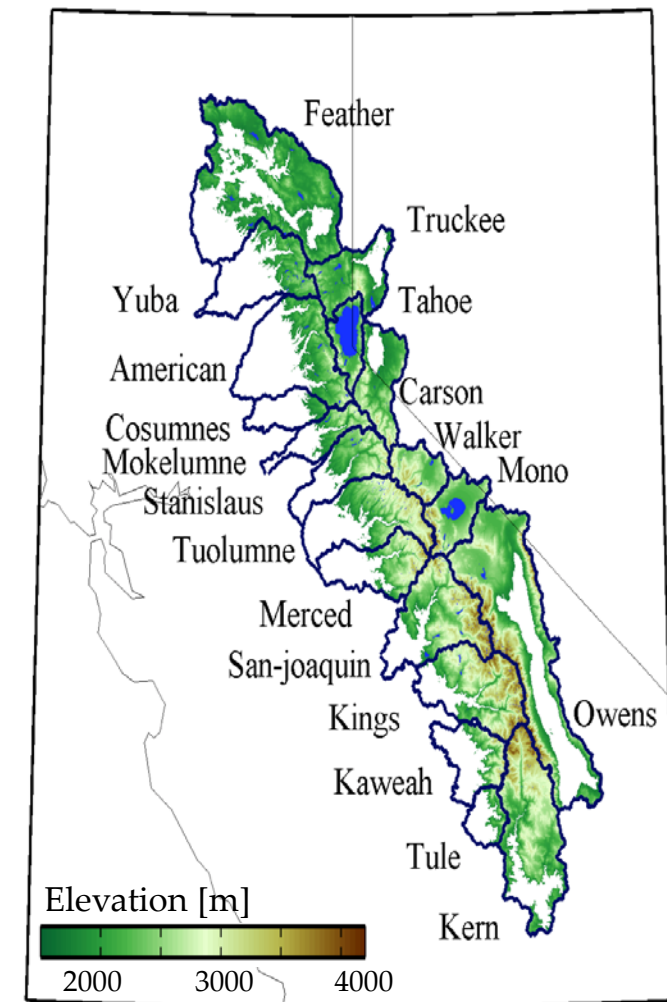
(Margulis et al. 2016; JHM)

manuela.girotto@nasa.gov

Presentation outline

- **Motivations**

- **A Method for Snow Reanalysis**

- **Proof of Concept: Sierra Nevada Case**
  - **Validation**
  - **Climatology**

- **Conclusions**

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)

The Sierra Nevada Example: Temporal Analysis

wet dry years

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

*one line per basin

50 % of cumulative snow in 3 storms!

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
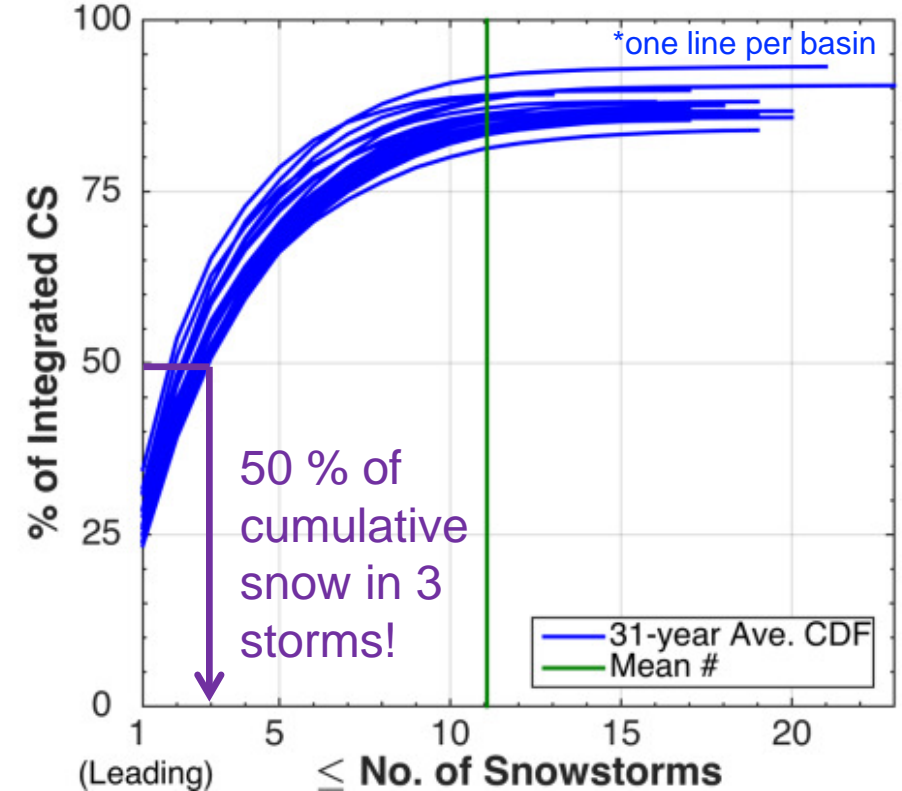
(Huning and Margulis 2017; WRR)

Presentation outline
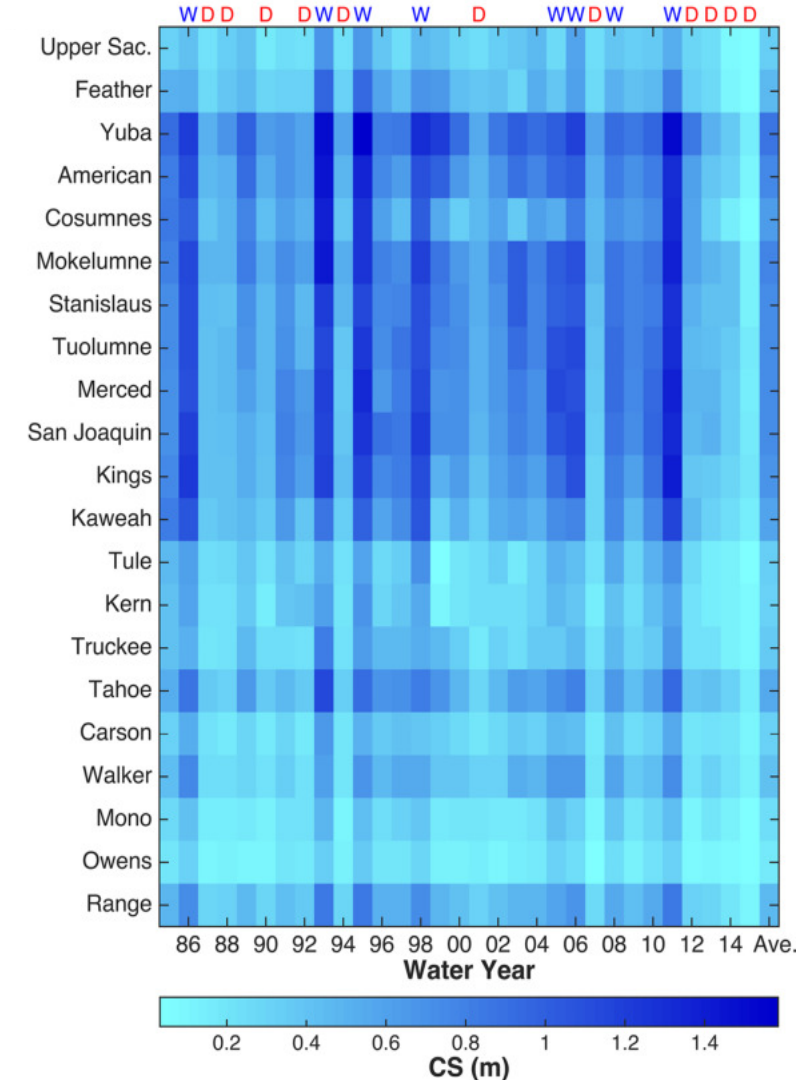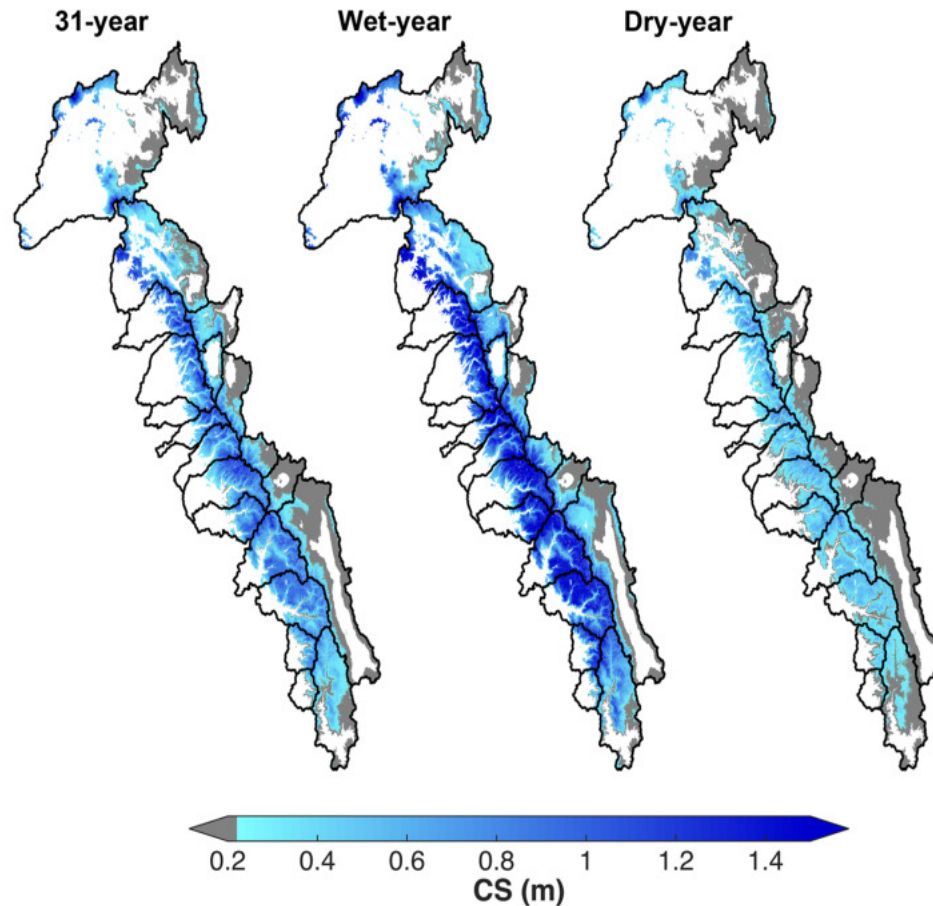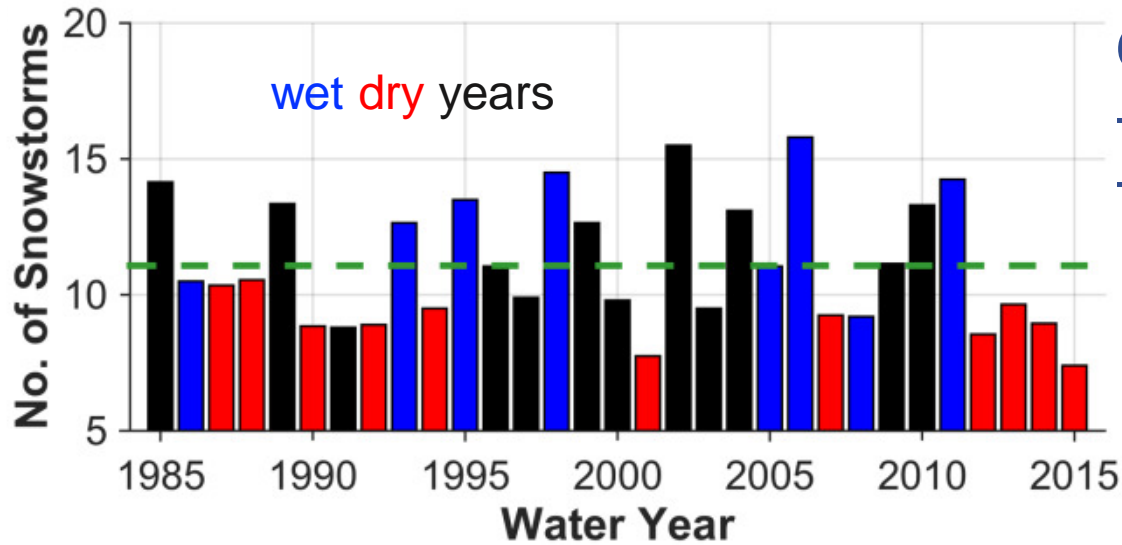
- **Motivations**

- **A Method for Snow Reanalysis**

- **Proof of Concept: Sierra Nevada Case**
  - **Validation**
  - **Climatology**

- **Conclusions**

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)

manuela.girotto@nasa.gov

Thanks!!!

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

manuela.girotto@nasa.gov