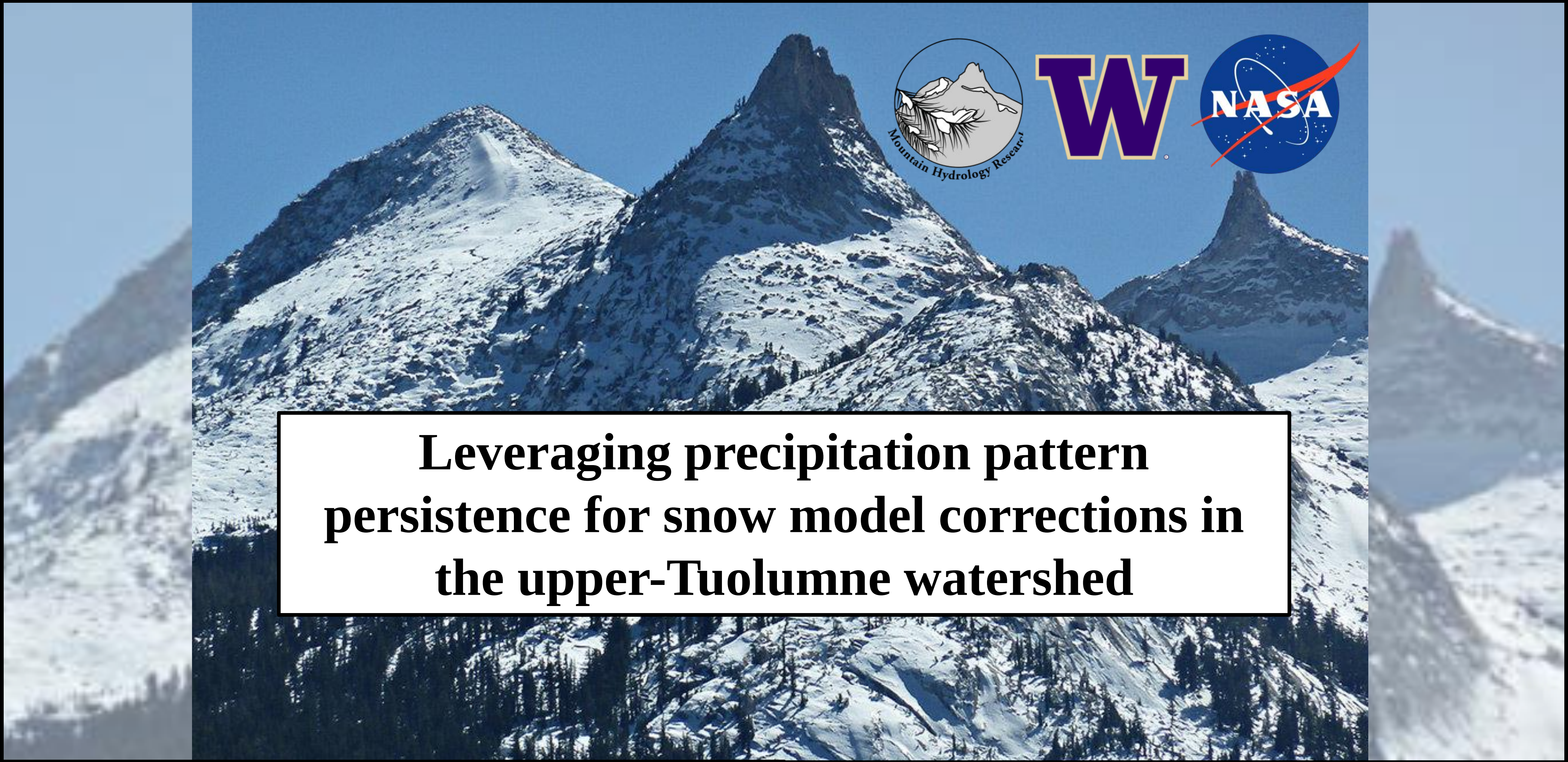

Leveraging precipitation pattern persistence for snow model corrections in the upper-Tuolumne watershed

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Department of Civil and Environmental Engineering,
University of Washington

AMS Conference on Mountain Meteorology
July 6, 2020
Park City, UT

Snowfall distribution

ATMOSPHERIC SIMULATION RESOLUTION

SNOW DEPTH

Windward-versus-leeward precipitation

Snowfall distribution

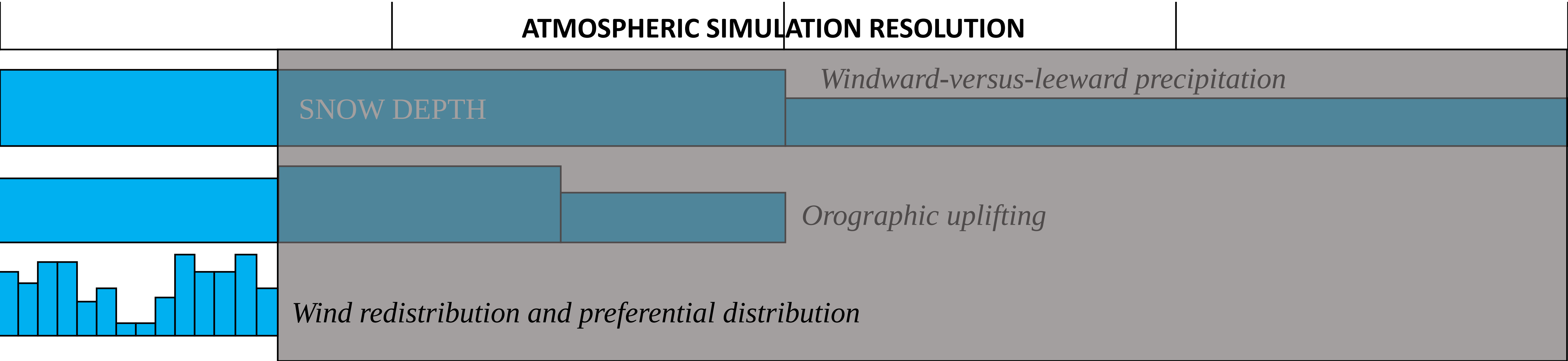
ATMOSPHERIC SIMULATION RESOLUTION

SNOW DEPTH

Windward-versus-leeward precipitation

Orographic uplifting

Snowfall distribution



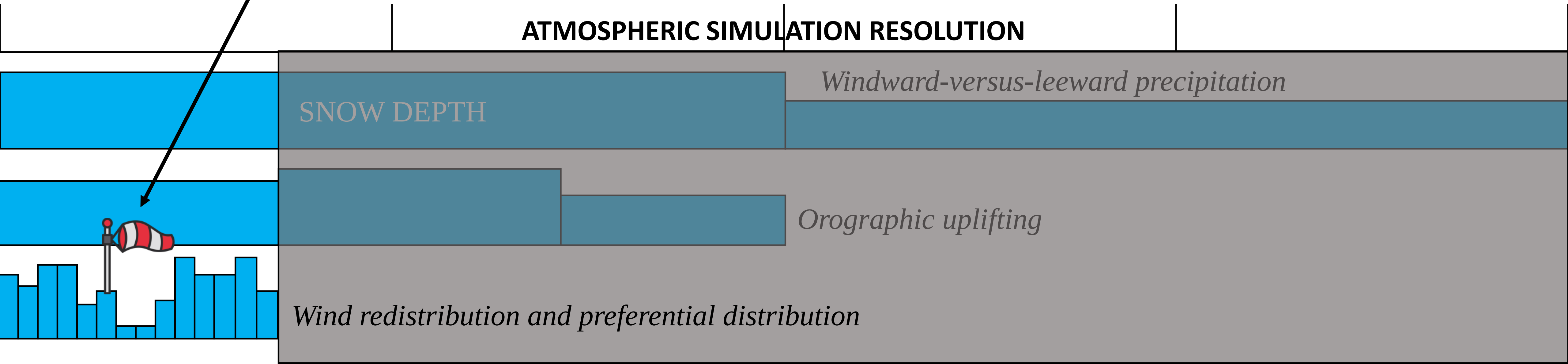
Snowfall distribution

Meteorologist

"How well are we simulating snowfall?"

Snow hydrologist

"How well can we forecast streamflow?"



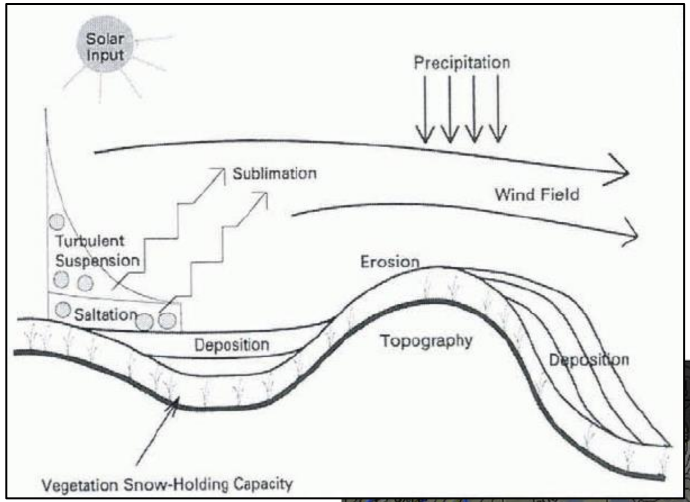


Figure from: Liston and Sturm (1998)

Modeling snowpack spatial distribution

- Snow models have progressed to represent drivers of snow accumulation. However, accuracy is constrained by:
  - Systematic model uncertainty
  - Spatial resolution necessary to resolve snow heterogeneity (< 10 m)

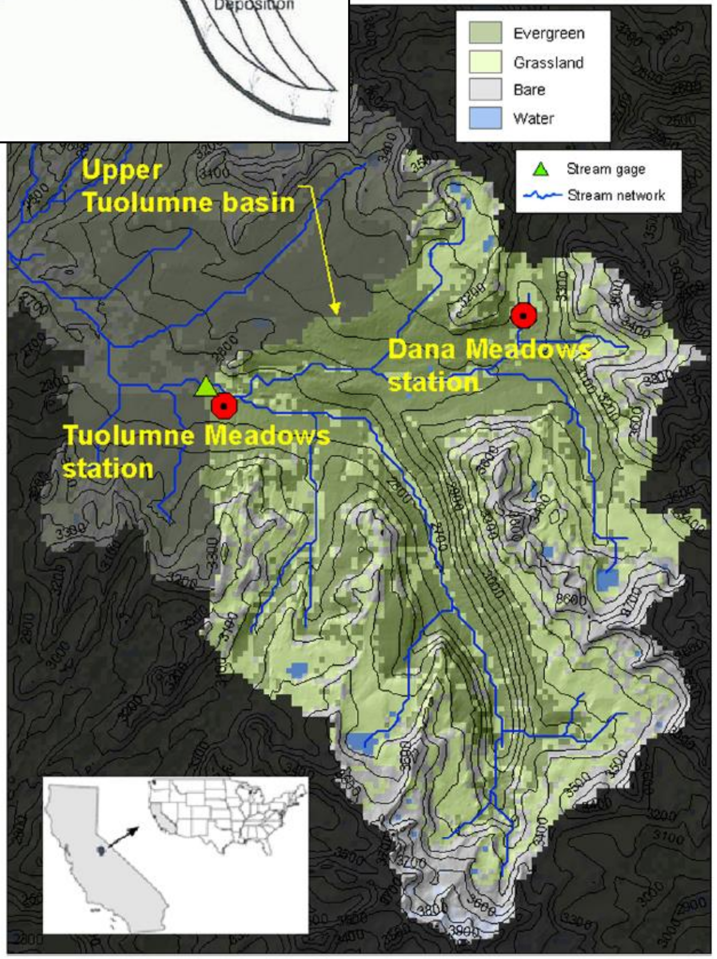
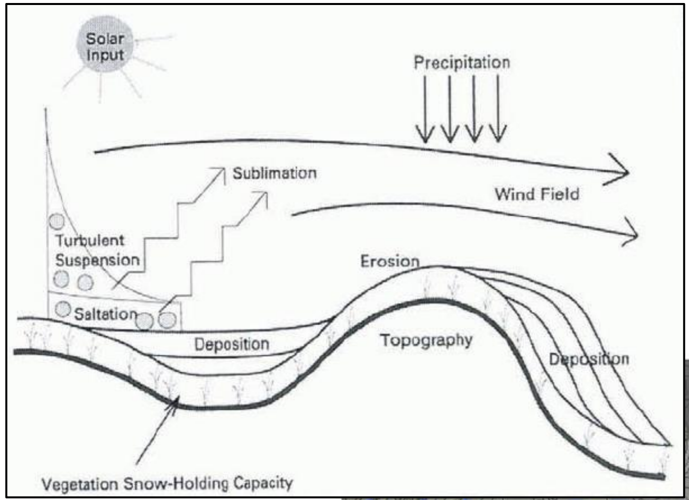


Figure adapted from: Cristea et al. (2017)



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Modeling snowpack spatial distribution

- Snow models have progressed to represent drivers of snow accumulation. However, accuracy is constrained by:
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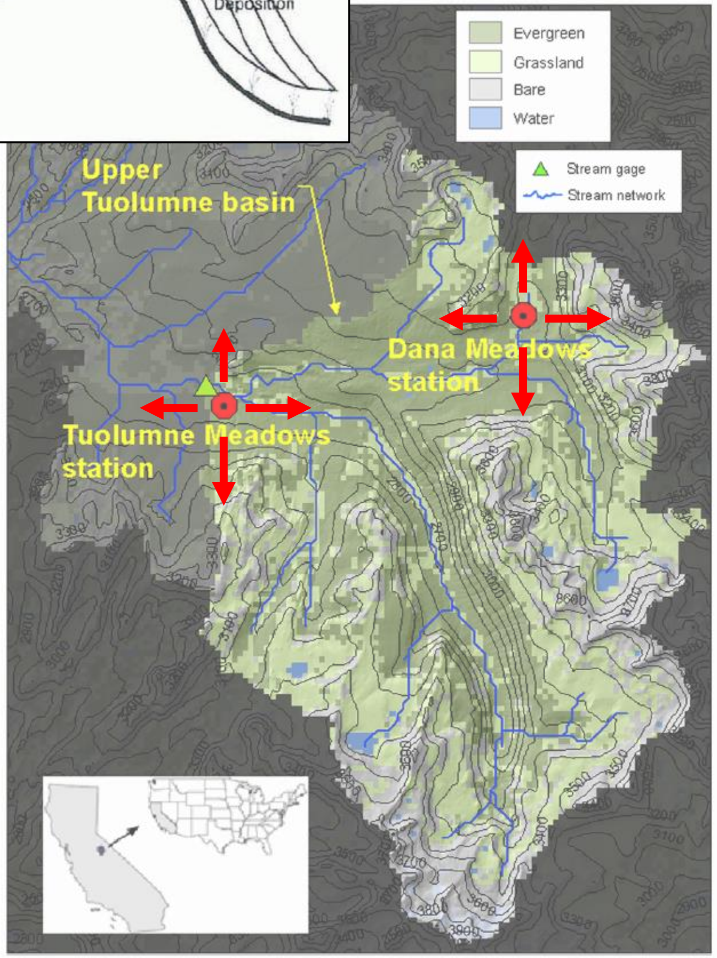

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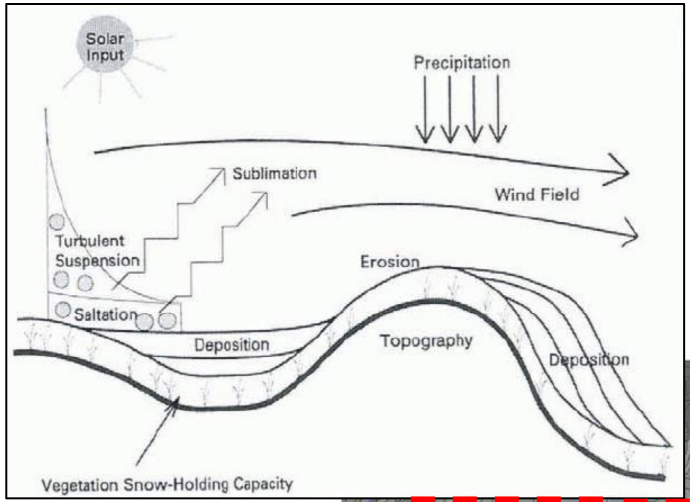

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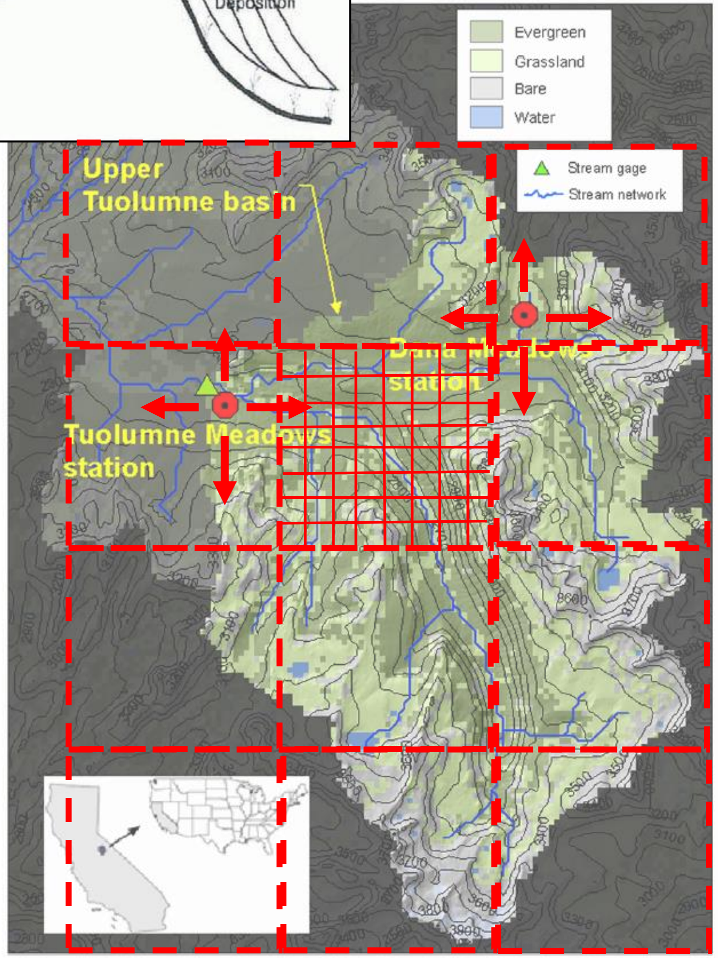

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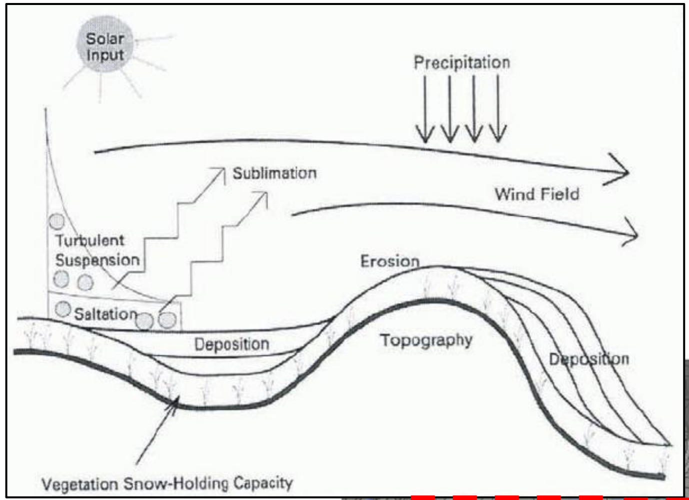
Modeling snowpack spatial distribution



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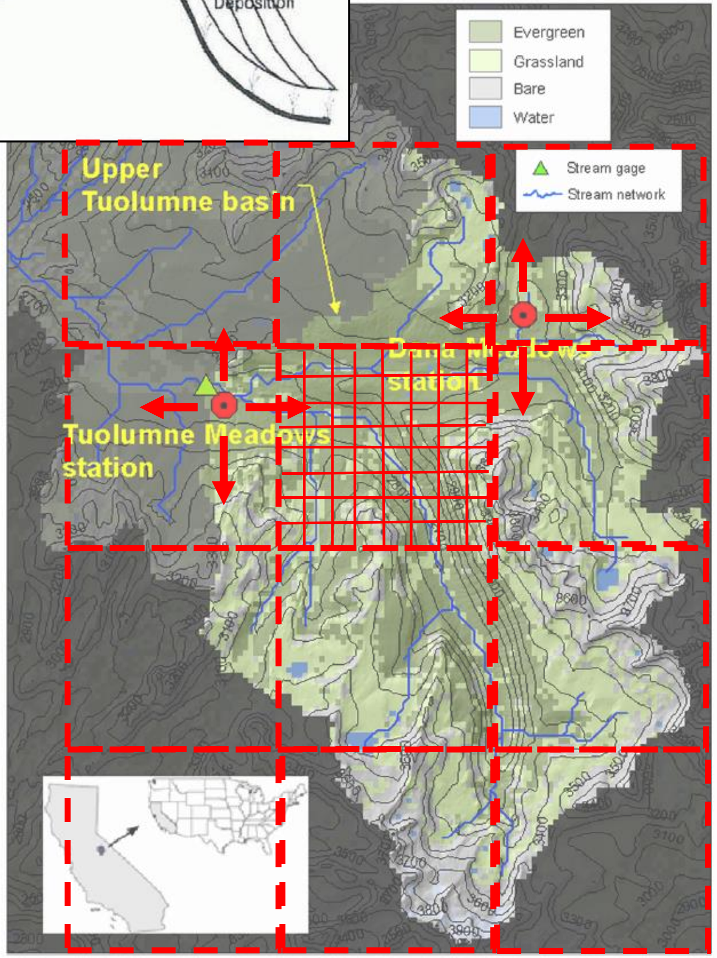
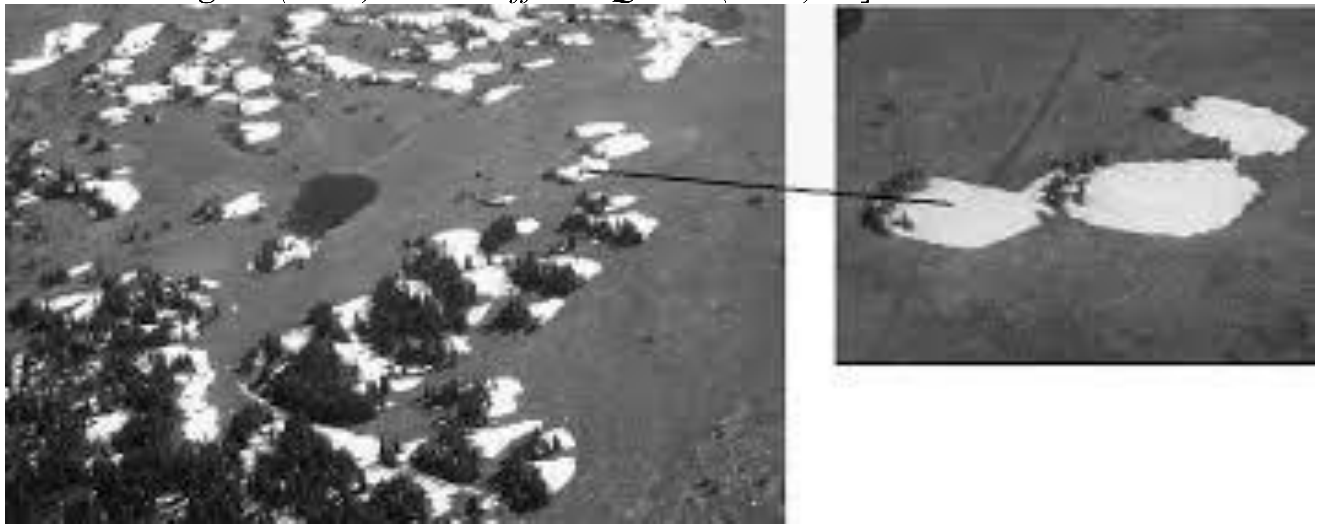


Figure adapted from: Cristea et al. (2017)

- Snow models have progressed to represent drivers of snow accumulation. However, accuracy is constrained by:
  - Systematic model uncertainty
  - Spatial resolution necessary to resolve snow heterogeneity (< 10 m)
  - Fine-scale meteorology
- Fortunately, snow patterns at times near peak-snowpack can be repeatable interannually *[Deems et al. (2008); Schirmer and Lehning (2011); Sturm and Wagner (2010); Woodruff and Qualls (2019); …]*



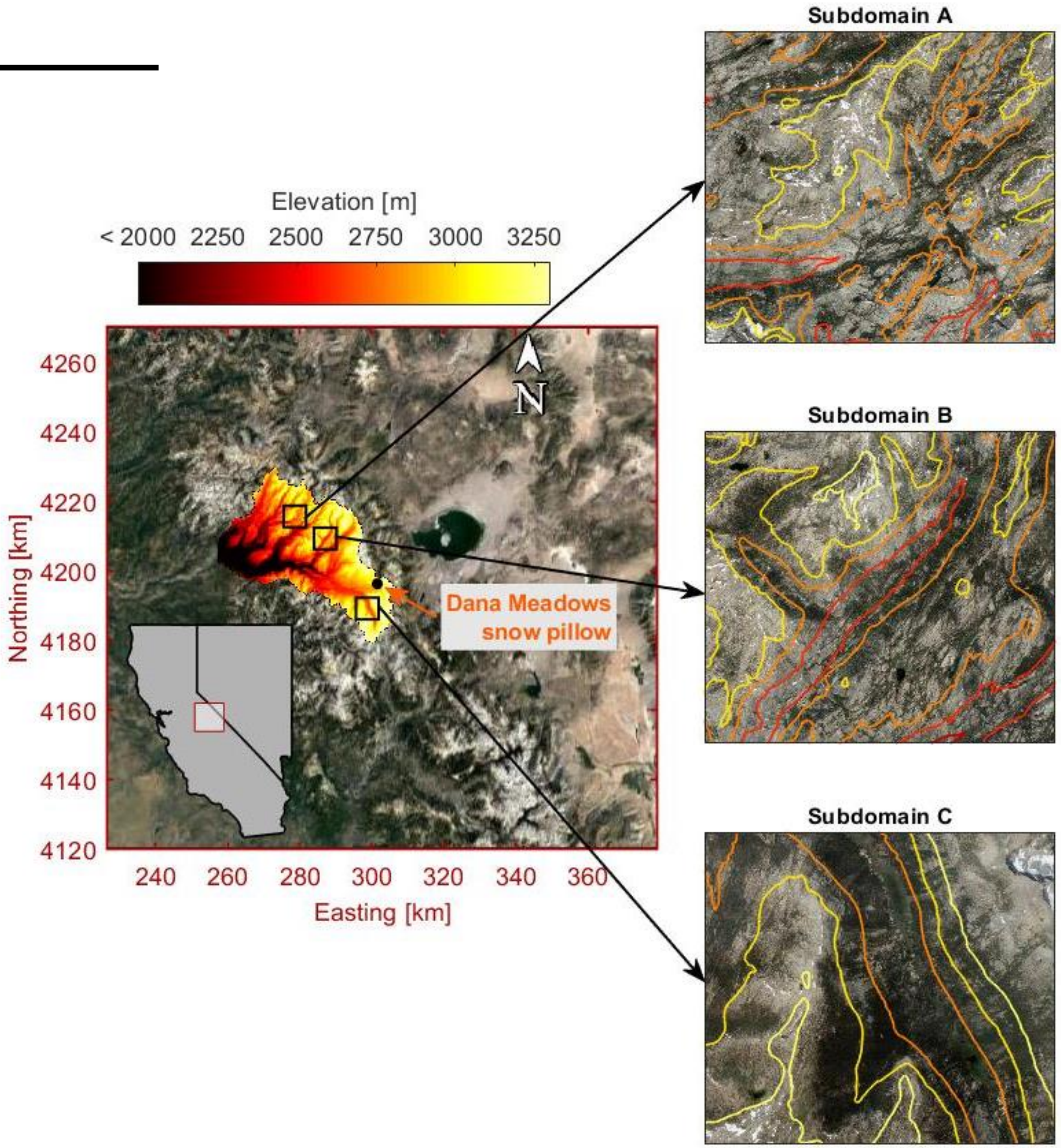
QUESTIONS:

1. **What types of observations and products can be used to infer historic snowpack distribution patterns?**
2. **How can repeatable patterns compensate for precipitation uncertainty and modeling constraints?**

Study domain

Tuolumne watershed, CA:

- Snow cover from ~700m – 3900 m elevation
- Subdomains:
    - A: Highest elevation; steep slopes with various aspects
    - B: Mid-elevation; various forest densities
    - C: Mid-elevation; valley bordered by ridges with drifting and avalanching



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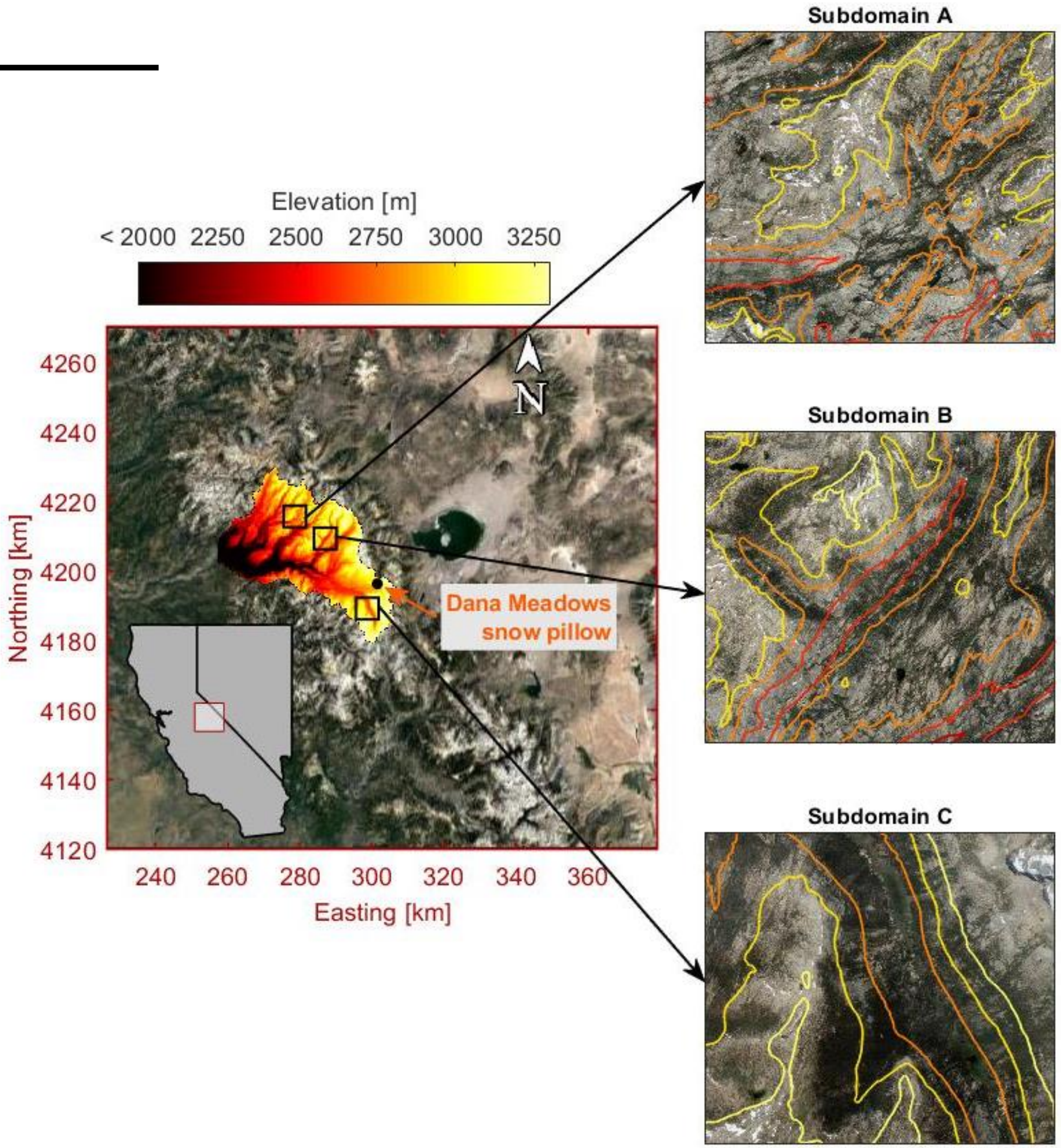
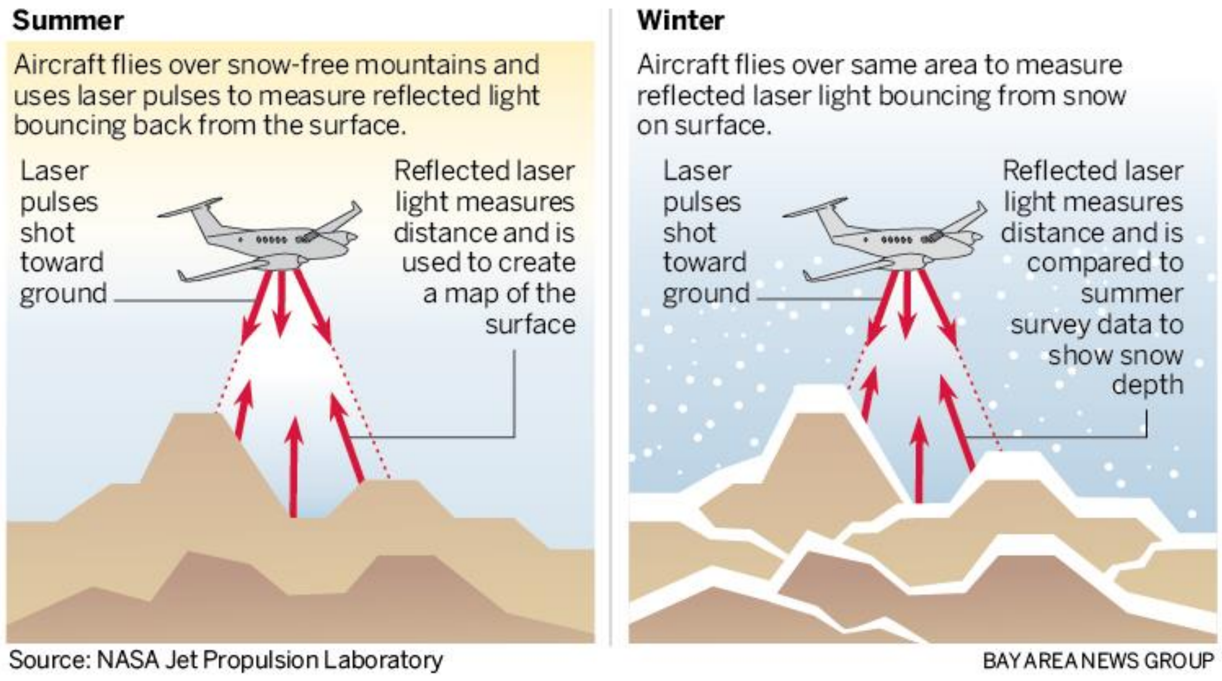
~ resolution of gridded atmospheric products

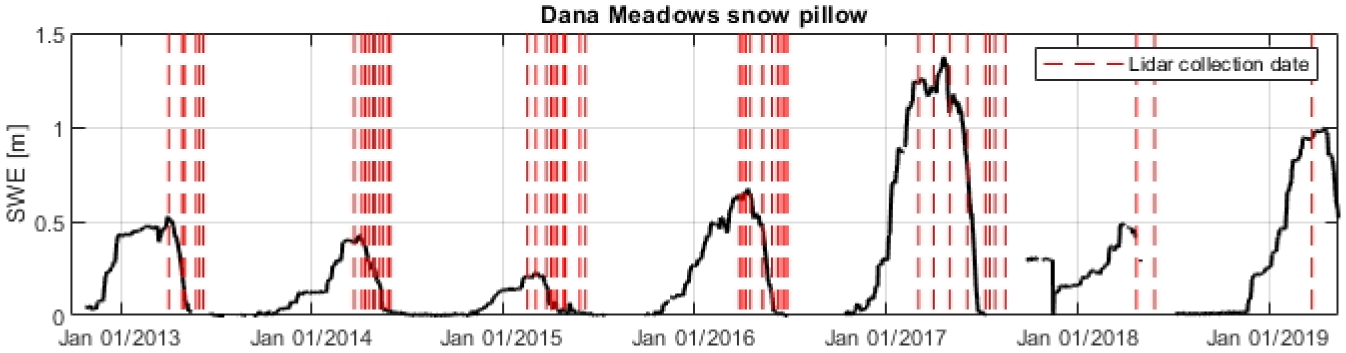


Airborne lidar snow depth retrievals

Airborne Snow Observatory lidar:

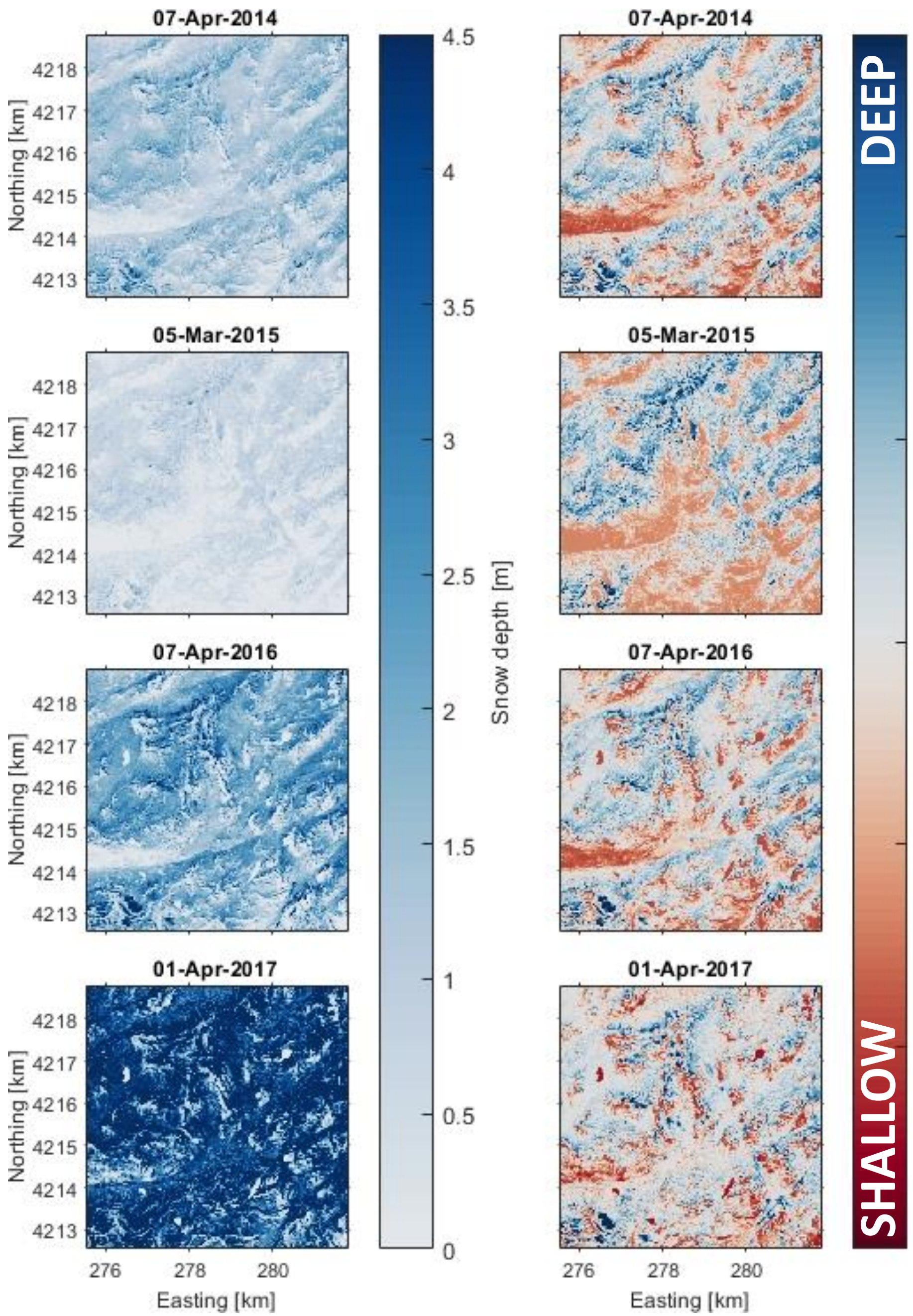
- 3m gridded estimates of co-registered snow-free and snow-present flights: distribution and total volume
- $\pm$ 8 cm snow depth accuracy in forested and open areas
- Included seasons with abnormally-shallow and abnormally-deep snowpack





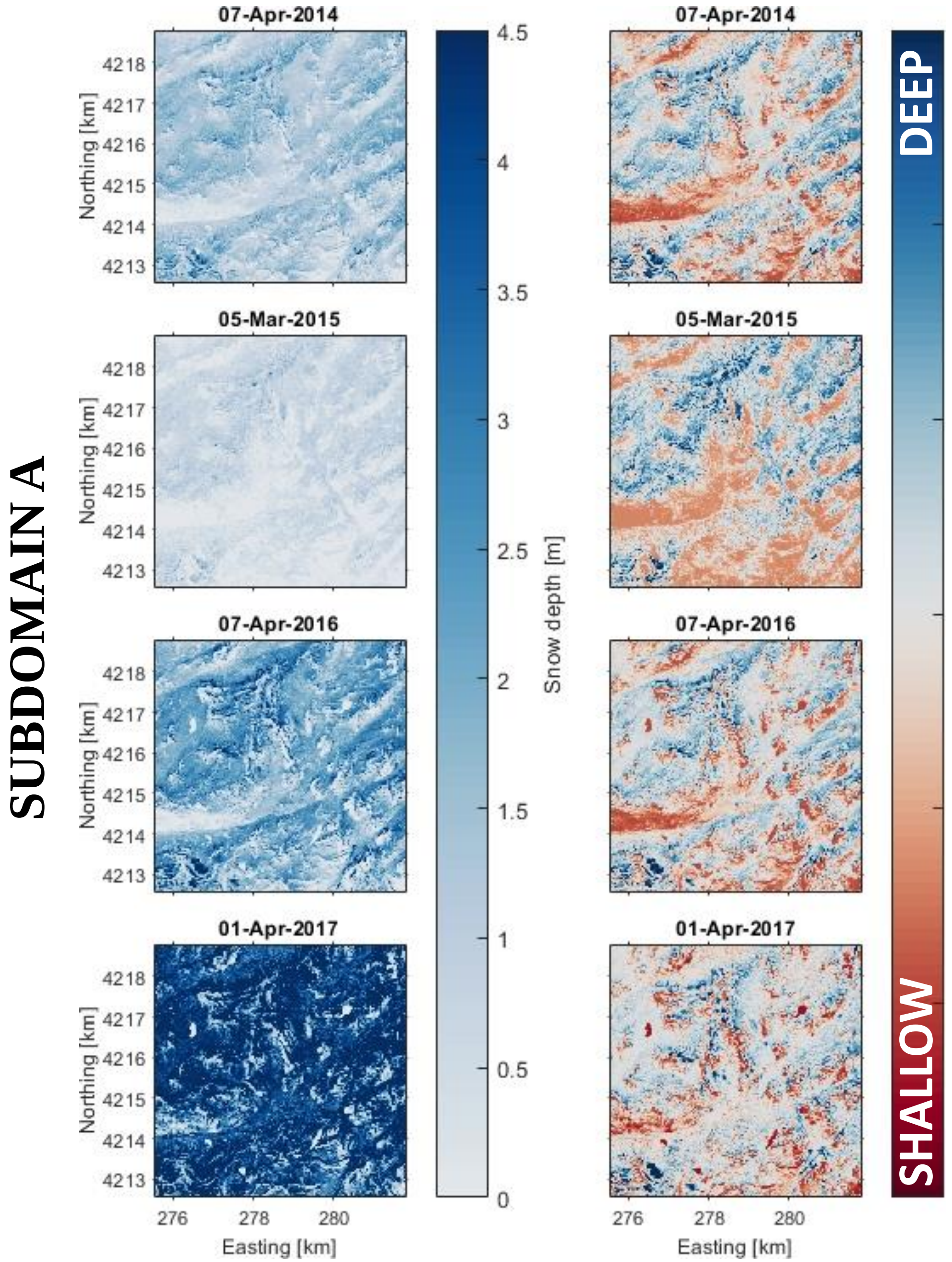
Snow pattern repeatability

SUBDOMAIN A



Snow pattern repeatability

The spatial coefficient of correlation (r) of snow patterns at times near peak snowpack ranged from ***r = 0.80 to 0.91***

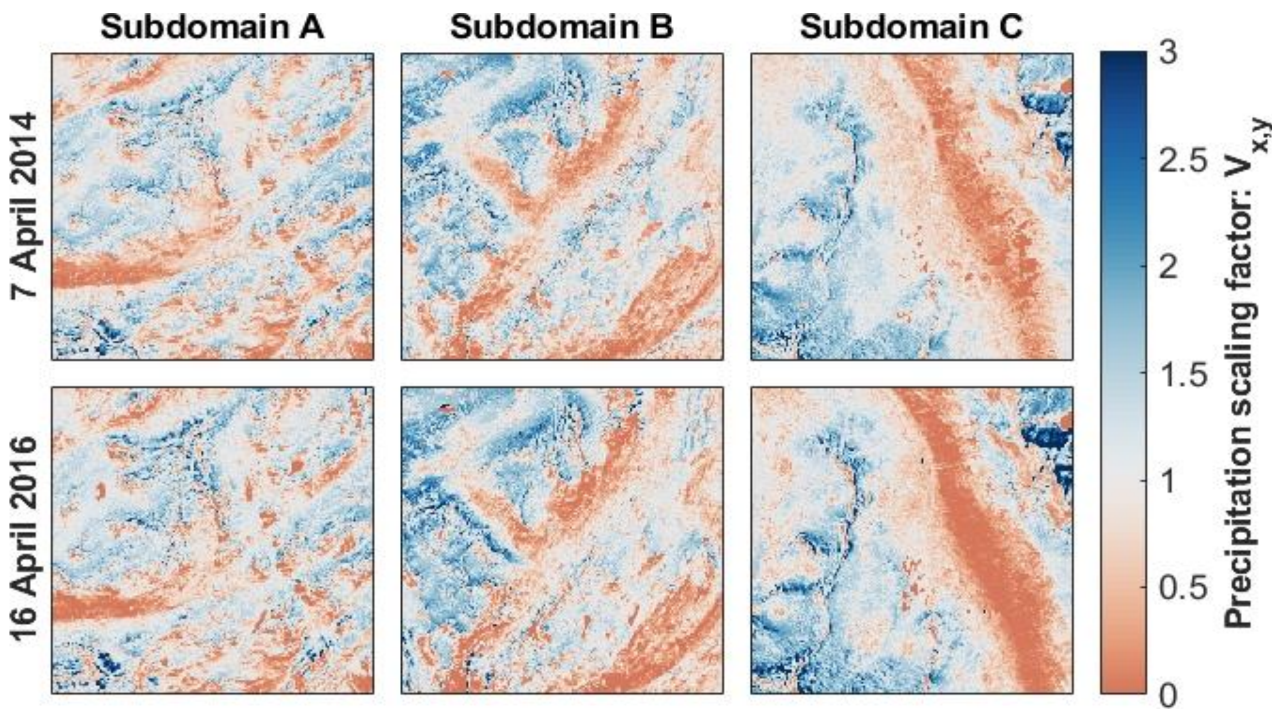


Snow precipitation scaling [Vogeli et al. (2016)]

Distributed snow depth

$$V_{x,y} = \frac{d_{x,y}}{\mu_d}$$

Domain mean snow depth



Snow precipitation scaling [Vogeli et al. (2016)]

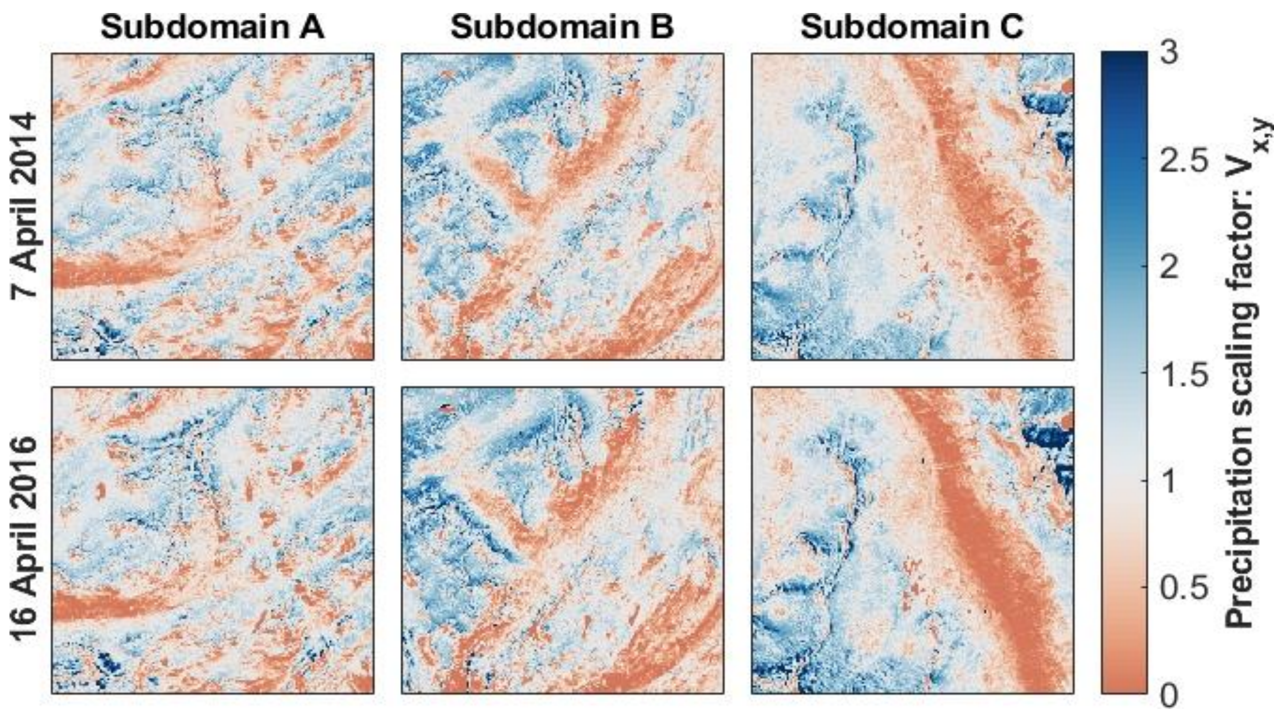
$$V_{x,y} = \frac{d_{x,y}}{\mu_d}$$

Distributed snow depth

Domain mean snow depth

$$p^i_{x,y} = V_{x,y} \times \mu^i_p$$

Domain mean precip. at time *i*

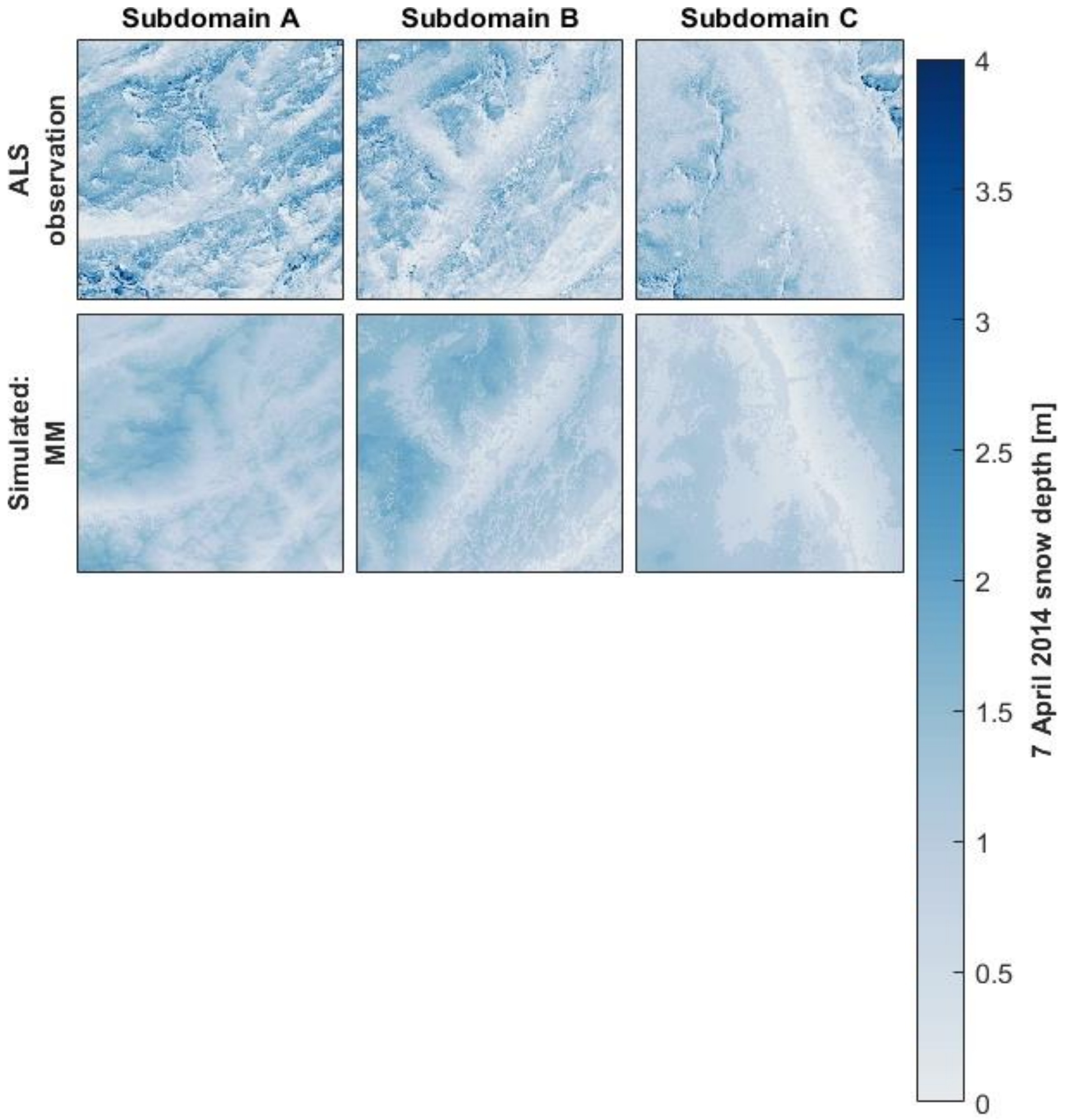


Assumes:

- *Linear relationship between precipitation and snow depth*
- *Unbiased domain mean precipitation*
- *Pattern is influenced by only snowfall*

Default simulations

- **25 m resolution** simulations
- WY2014 forcing from **6 km WRF** with boundary conditions from the North American Regional Reanlaysis (NARR)
- Precipitation distributed to the model gridcell using **MicroMet** *[Liston and Elder (2006a)]*
  - Meteorological interpolation routine
  - Elevation-based lapse-rate
- Snow simulated using **SnowModel** *[Liston and Elder (2006a)]*



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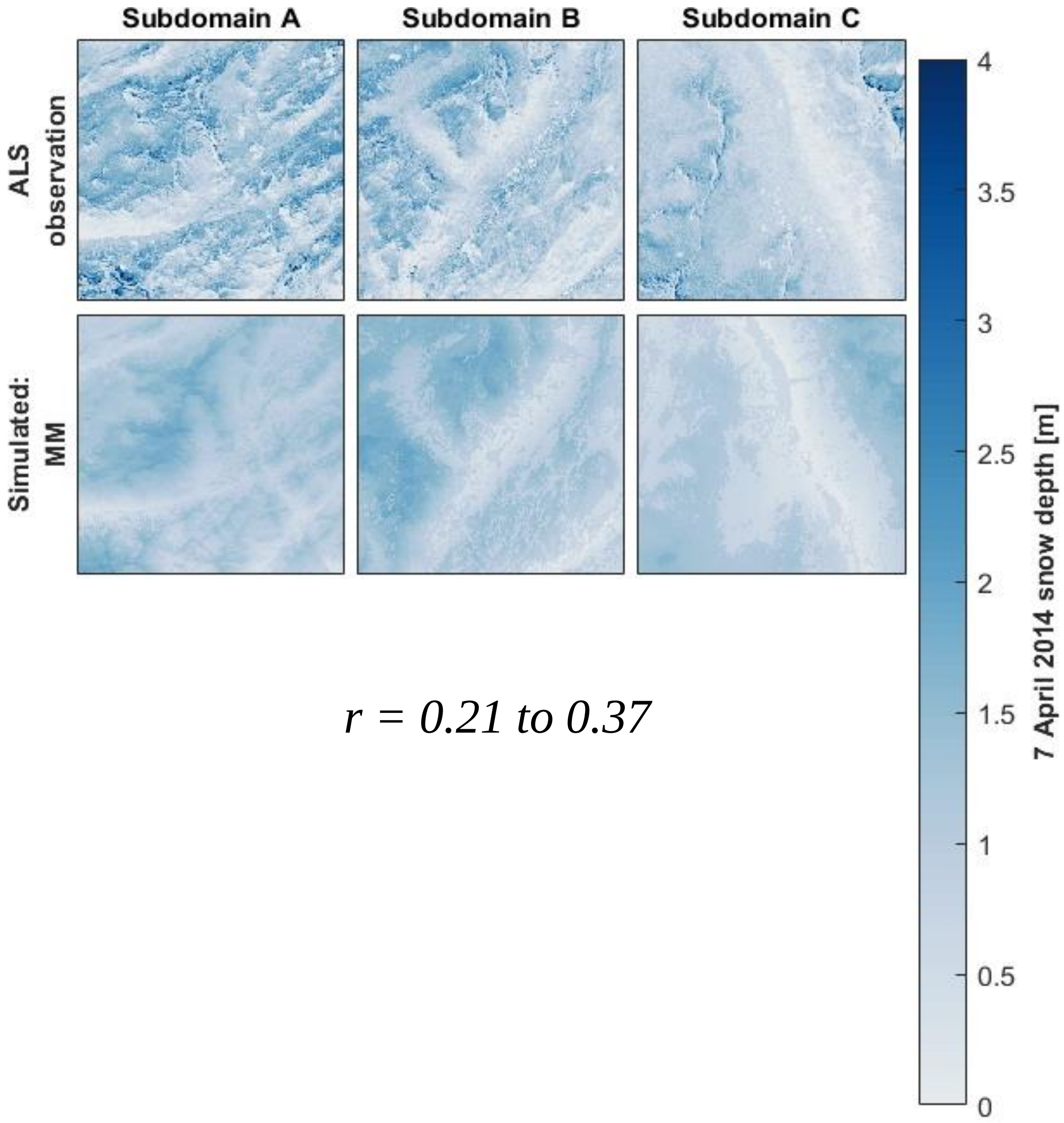


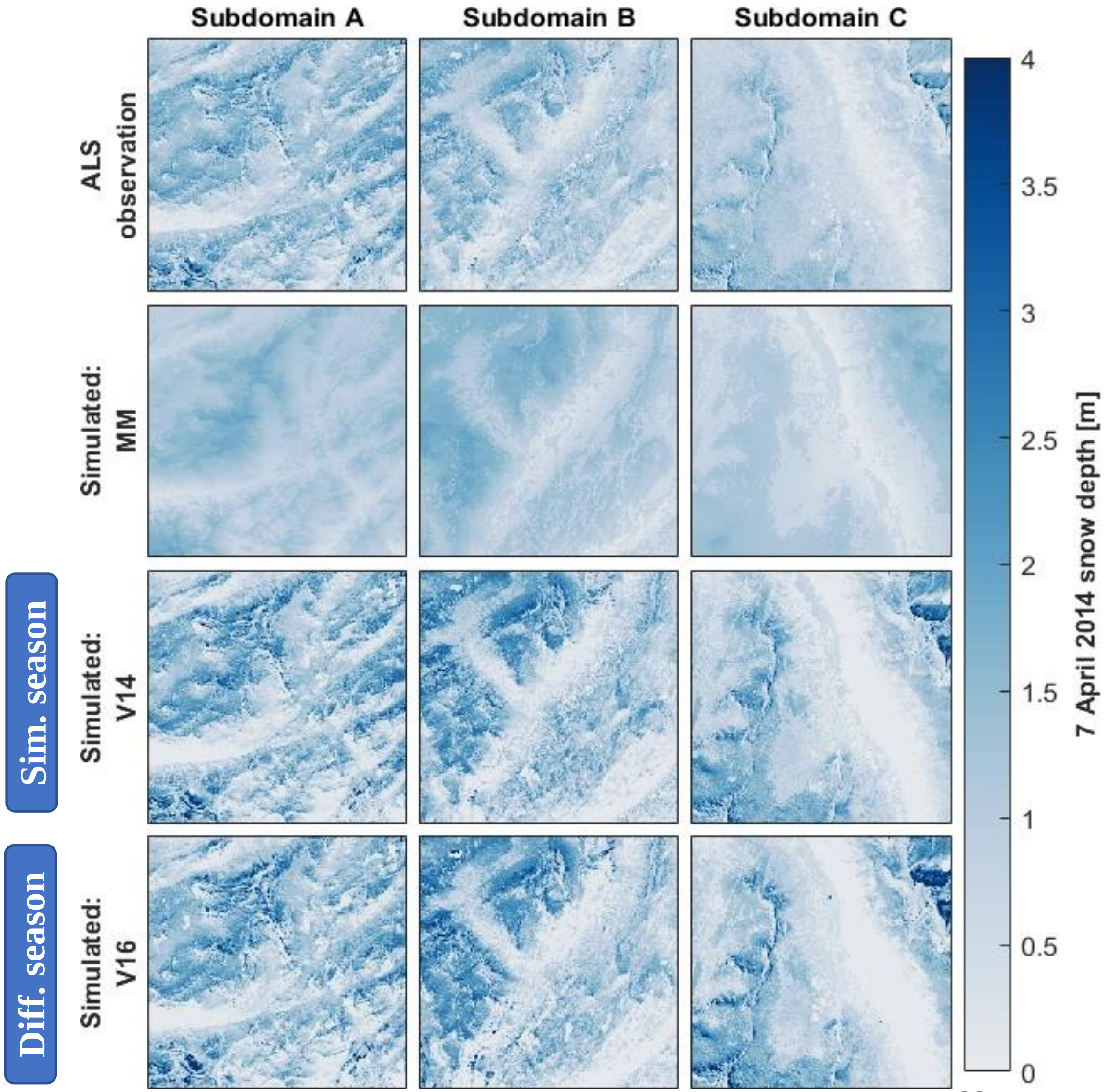
r = 0.21 to 0.37

Scaled simulations

$r \approx 0.21 \rightarrow 0.37$ | $MAE \approx 0.23 \rightarrow 0.42\ m$

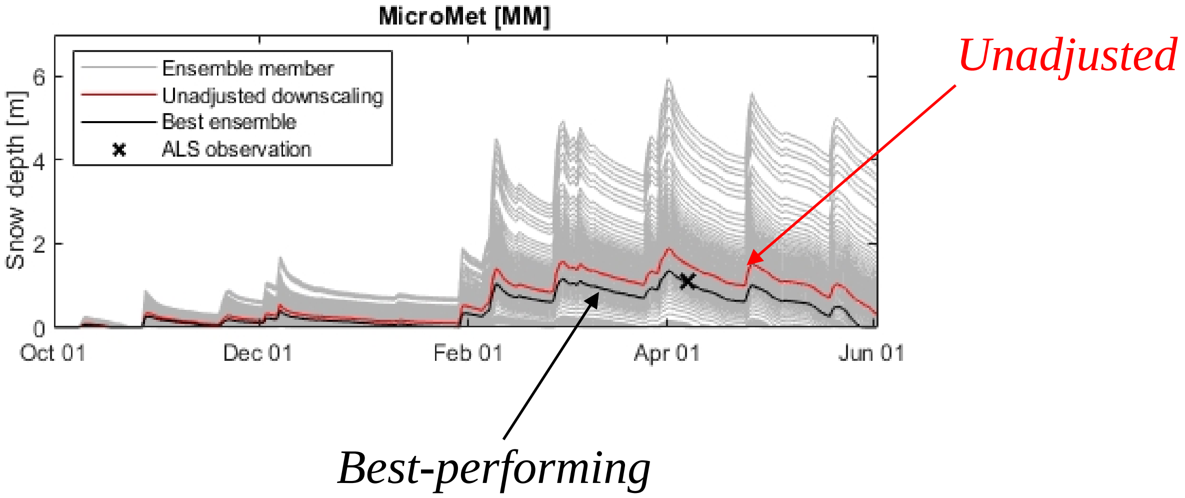
$r \approx 0.63 \rightarrow 0.83$ | $MAE \approx 0.20 \rightarrow 0.27\ m$

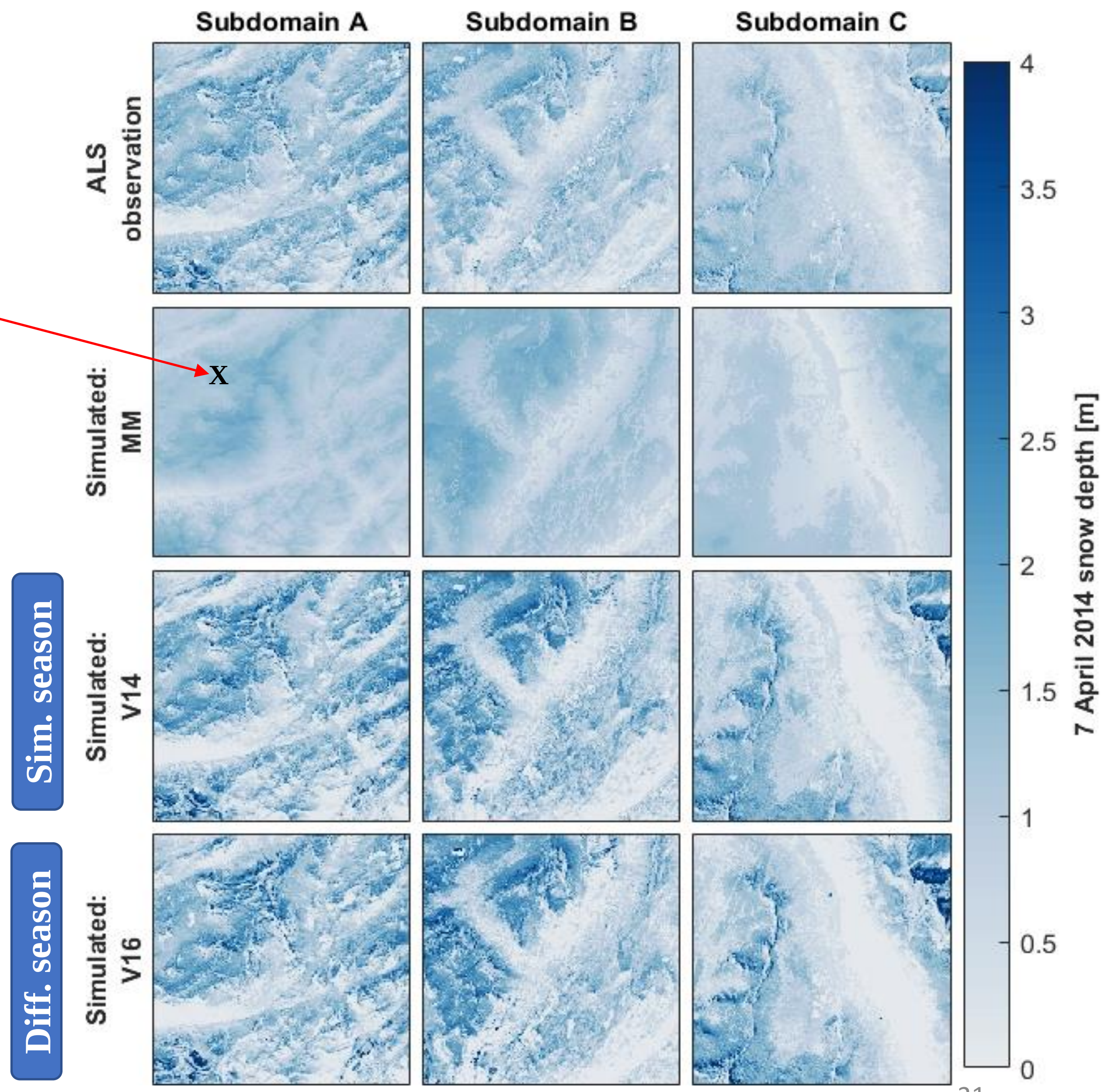
$r \approx 0.50 \rightarrow 0.67$ | $MAE \approx 0.27 \rightarrow 0.41\ m$



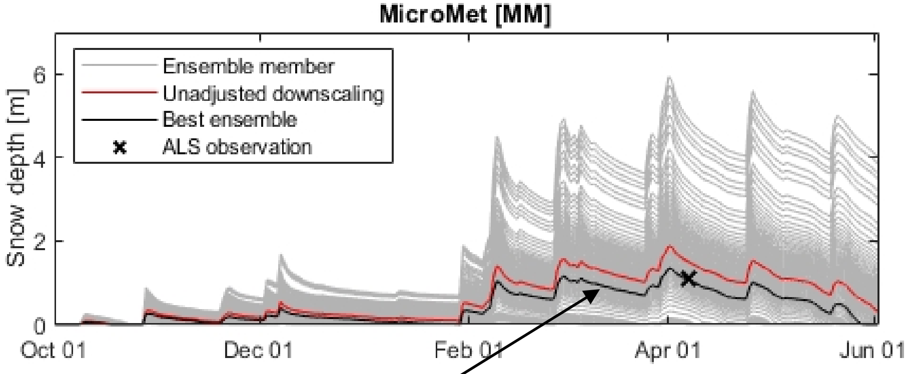
Scaled simulations

Ensemble of simulations using array of precipitation multipliers:

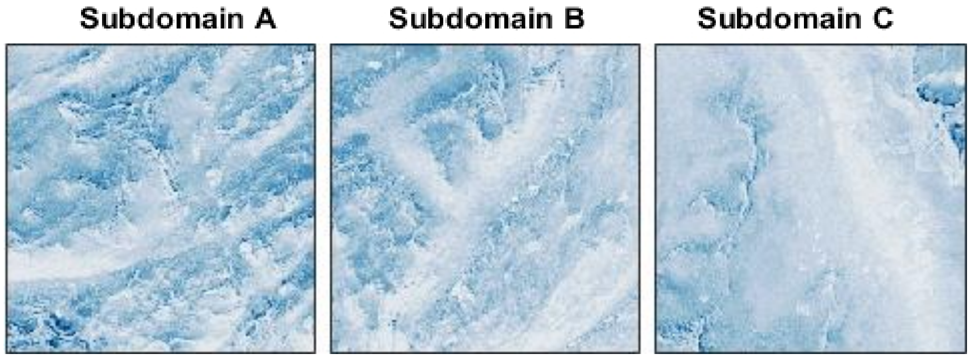




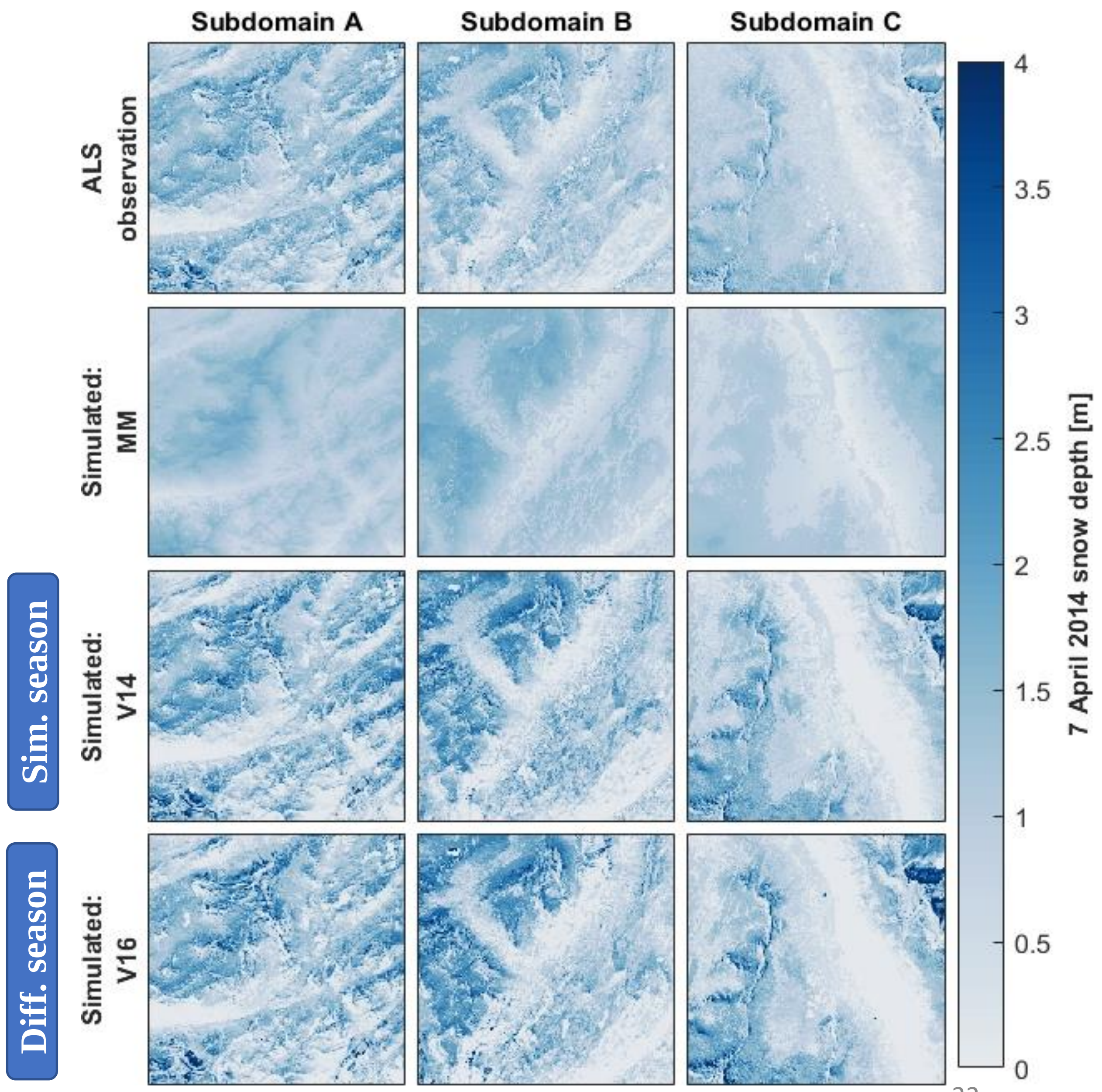
Scaled simulations



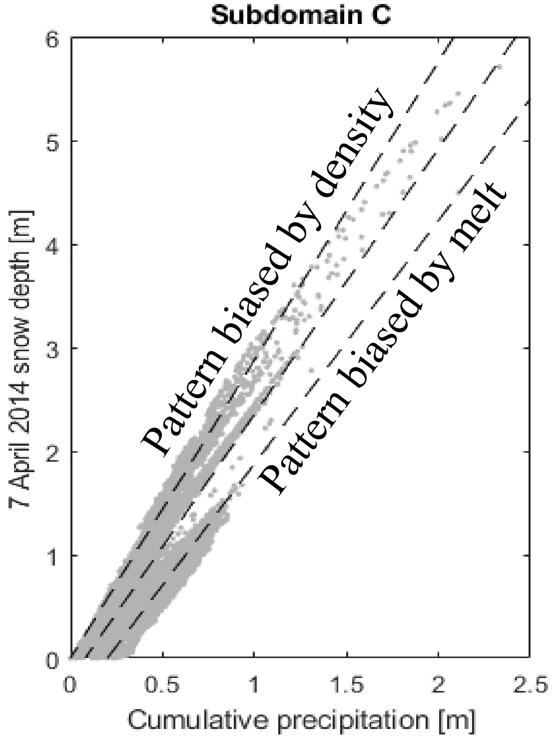
Best-performing

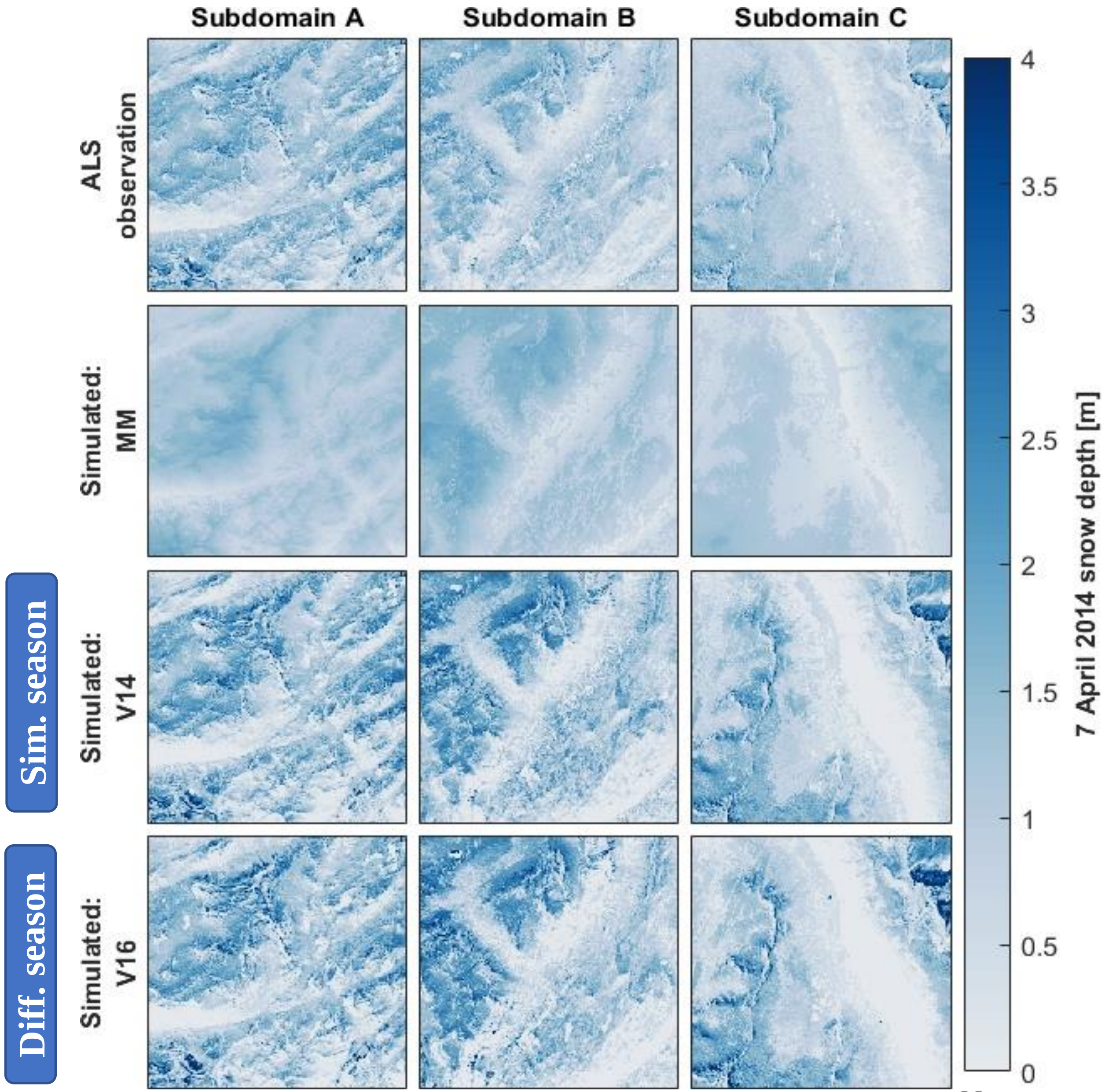


$$r \approx 0.99, MAE \approx 0.01\ m$$



Scaled simulations





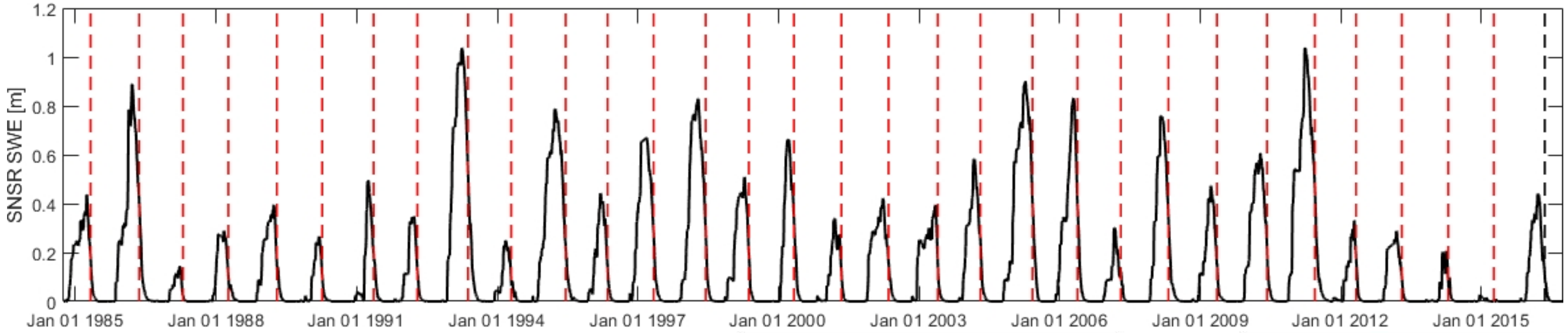
Recall, precipitation scaling assumes:

- *Linear relationship between precipitation and snow depth*
- *Pattern is influenced by only snowfall*
- *Unbiased domain mean precipitation*

Continuing work

Sierra Nevada Snow Reanalysis (SNSR) [Margulis et al. (2016)]:

- SWE at ~100 m spatial resolution
- 1985 – 2016
- Retroactively reconstructs SWE using a fully-Bayesian assimilation of Landsat-observed fractional snow-covered area



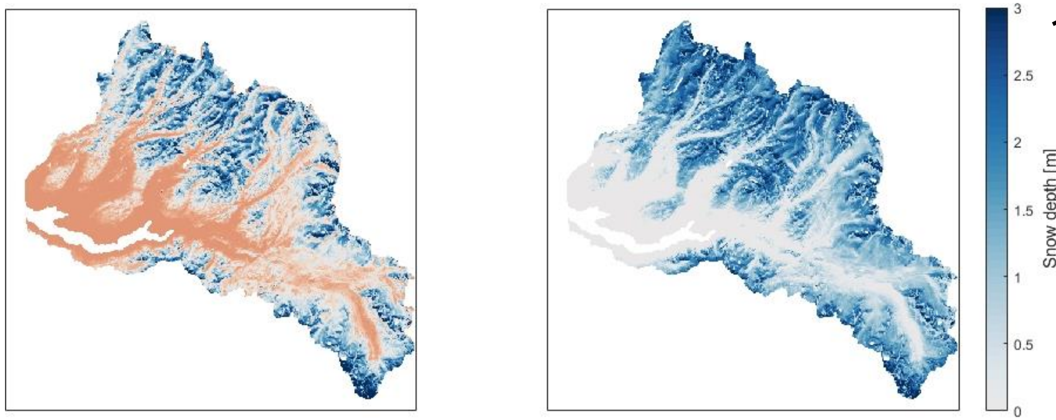


Figure from: Margulis et al. (2016)

Conclusions

- Snow precipitation patterns in the Tuolumne watershed are persistent between seasons
- Correcting precipitation heterogeneity using patterns is challenged more by commonly-used modeling assumptions, as opposed to the prevalence of snow patterns
- Future work should consider precipitation pattern scaling that includes the effect of snowmelt and snow density
- Snowpack reconstructions are a promising path forward for snow pattern investigation in domains without lidar

Thank you. Questions?

Question session: Thursday, 16 July at 10:50 AM (mountain time)

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University of Washington Civil and Environmental Engineering