Evaluating the utility of Sentinel-1 snow depth in a data assimilation system

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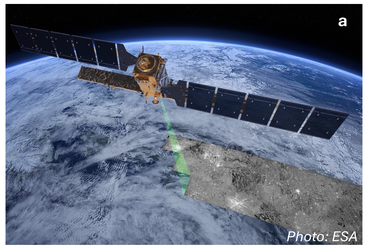
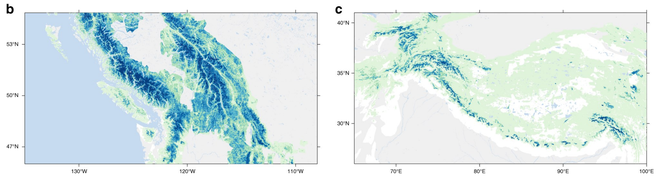
Motivation

Mountain Snowpack Mapping

- Mountain snow depth may be mapped from Sentinel-1 (S1) SAR backscatter at 10^2 to 10^3 m spatial resolution[1,2]
- Independent evaluations [3,4] against lidar and other data suggest large errors in S1 retrieved snow depth





Research Question

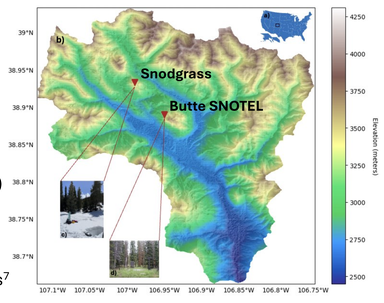
Can Sentinel-1 snow depth data improve estimates of mountain snowpack in space and time relative to a model without snow depth observations?

Data and Experimental Design

Study Area and Period

- **Location:** East River Basin, CO
- **Water Years:** 2018-2021*

  *includes NASA SnowEx



Validation Data

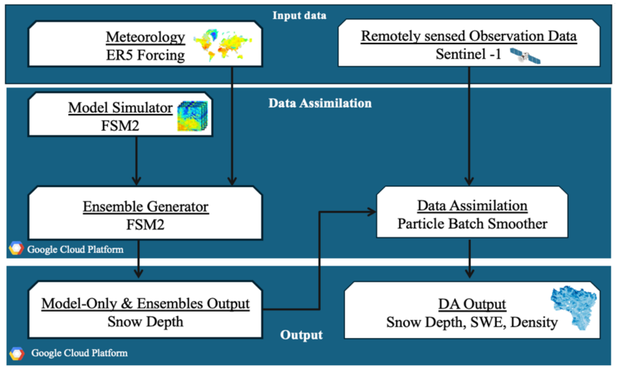
- NRCS SNOTEL Data (Butte station)
- Snodgrass Mountain Field Data[5]
- ASO LiDAR depth[6]
- MODIS Snow disappearance dates[7]

Data Assimilation System

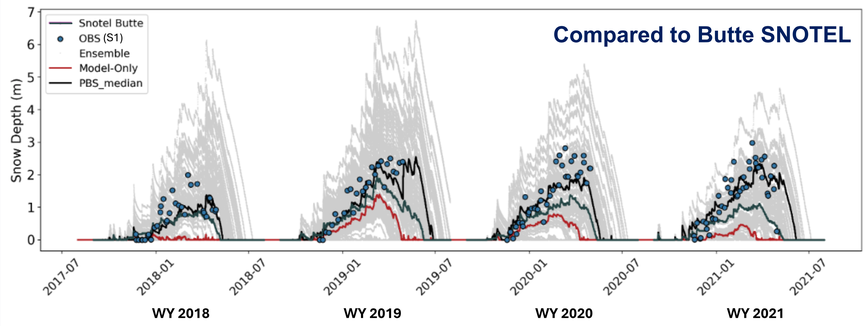
- **Observations:** daily 500m S1 snow depth
- **Snow Model:** FSM2[8]
- **Forcing data:** hourly 9km ERA5-Land[9]
- **Ensemble generator**: MuSA[10] on Google Cloud
- **Ensembles**: 100 by perturbing meteorological forcing
- **DA Approach**: Particle Batch Smoother (PBS)[11,12] with S1 snow depth

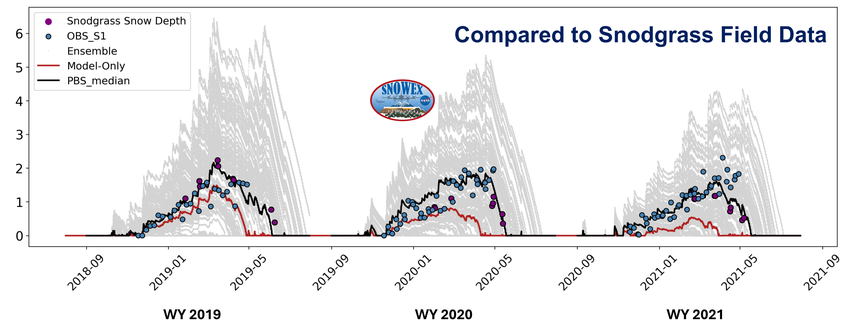
Experiments

- **Control:** Ensemble median
- **PBS Median** (assimilated S1)



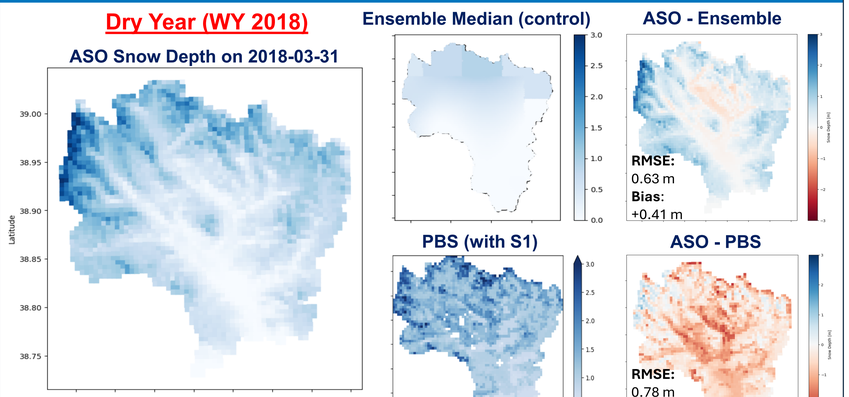
Temporal Results Versus SNOTEL and Field Measurements



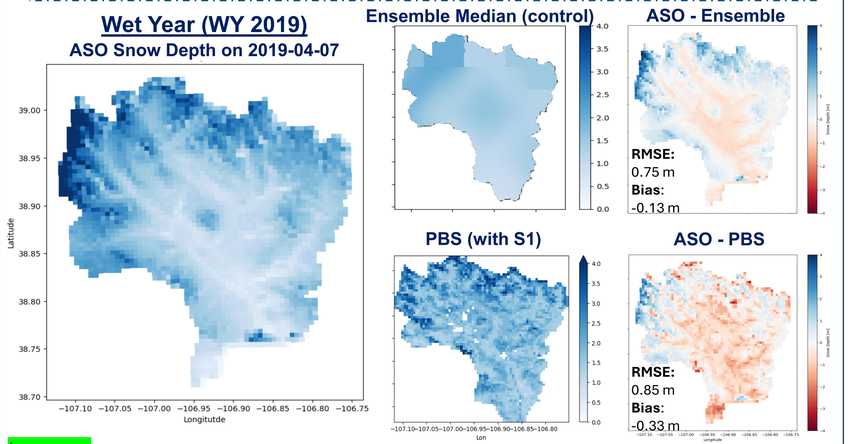


Spatial Results: Snow Depth

Dry Year (WY 2018)



Wet Year (WY 2019)



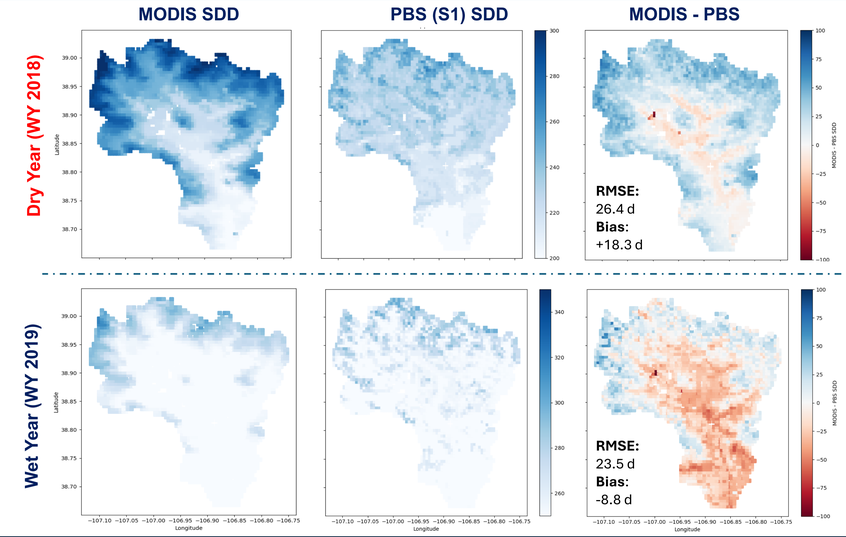
lower error

	MSE	MAE	RMSE	RMAD	Bias
Water Year 2018					
Ens.	0.396	0.476	0.629	0.611	0.412
PBS (S1)	0.610	0.647	0.781	0.830	-0.597
Water Year 2019					
Ens.	0.569	0.536	0.754	0.319	-0.129
PBS (S1)	0.716	0.677	0.846	0.404	-0.326

Summary of Errors (m) by WY

- The ensemble median (control) had lower errors than PBS (S1)
- Similar statistics for PBS when masking out potential wet snow in S1 data (not shown)

Spatial Results: Snow Disappearance Dates (SDD)



Key Takeaways

- In the mountainous East River Basin, assimilation of S1 snow depth in a PBS DA system results in:
  - snow depth **overestimation** in **dry years**
  - snow depth **overestimation** for shallow snow and **underestimation** for deep snow in **wet years**
  - snow disappearance that is **too late** for shallow snow and **too early** for deeper snow across years
- Lower errors in modeled snow depth for control (no S1 assimilation, no downscaling) vs. PBS (w/ S1).
- We find limited utility for S1 retrieved snow depth to improve snowpack mapping in this mountainous basin, consistent with other recent studies[3,4].

References

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Acknowledgements

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