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Supplement of

Evaluating the utility of Sentinel-1 in a Data Assimilation System for estimating snow depth in a mountainous basin

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This supplement contains figures of additional analyses which are supplemental to the main publication.

DA Methods Comparison

We evaluated three data assimilation (DA) methods: the Particle Batch Smoother (PBS), which assimilates observations in temporal batches; the standard Particle Filter (PF) with constant observation uncertainty; and a PF variant with dynamically varying uncertainty. For both PBS and the constant-uncertainty Particle Filter (PF_{cons}), we used a fixed observation error of 0.4 m, corresponding to the average RMSE of S1 snow depth against 12 SNOTEL sites. For the variable-uncertainty Particle Filter (PF_{var}), we also set the baseline error to 0.4 m, but allowed it to vary dynamically over time: the uncertainty started at 0 and increased incrementally up to 0.4 m as the season progressed. The PF operates sequentially, updating the state estimate with each incoming observation, and was implemented using MuSA. Example results from a single year at one SNOTEL site and the independent Snodgrass site are shown in Figure S1, while summary statistics averaged across all sites and water years are presented in Table S1. The comparisons show that PBS achieves the best performance for all five error metrics considered.

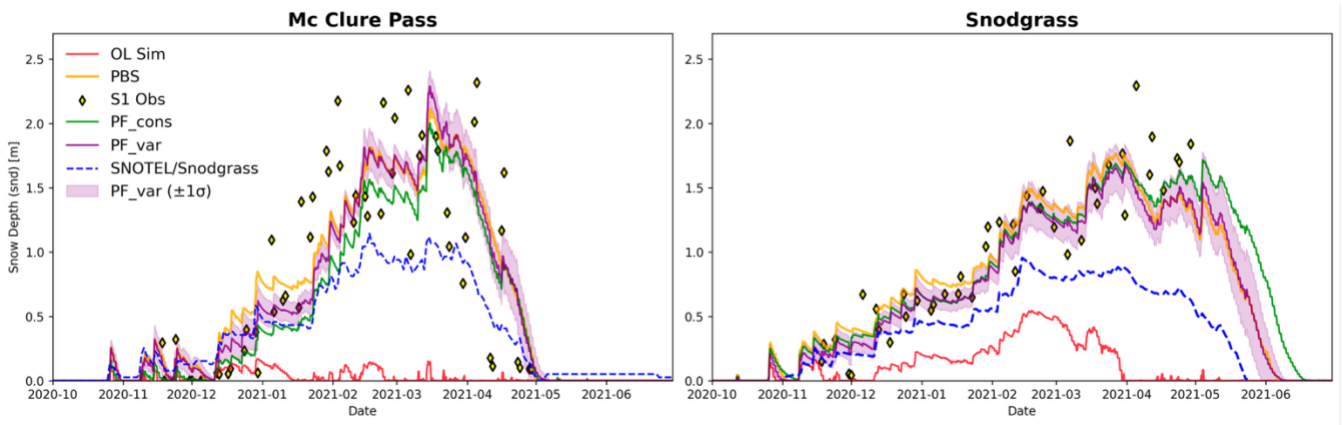

Figure S1: McClure SNOTEL and Snodgrass independent site showing comparison of PBS, PFcons, and PFvar approaches. Shaded purple shows the posterior uncertainty of PFvar.

Table S1: Comparison of different DA approaches. Metrics are averaged across all temporal evaluation sites and across four years

Model	R^2	Bias (m)	RMSE (m)	MAE (m)	RMAD
PBS	0.82	0.05	0.29	0.18	0.38
PFcons	0.76	0.07	0.34	0.21	0.44
PFvar	0.80	0.08	0.32	0.19	0.43

CRPS Results

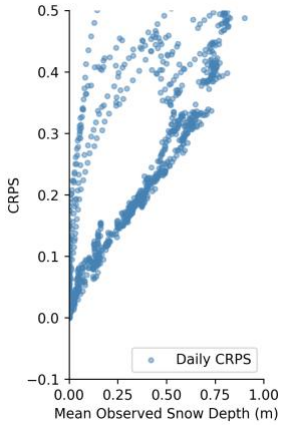

Figure S2: CRPS comparison with observed snow depth averaged over the stations.

Model-Only Results:

Temporal plots are shown with prior mean (model-only), supplementary for Figures 5 and 8 of the main paper.

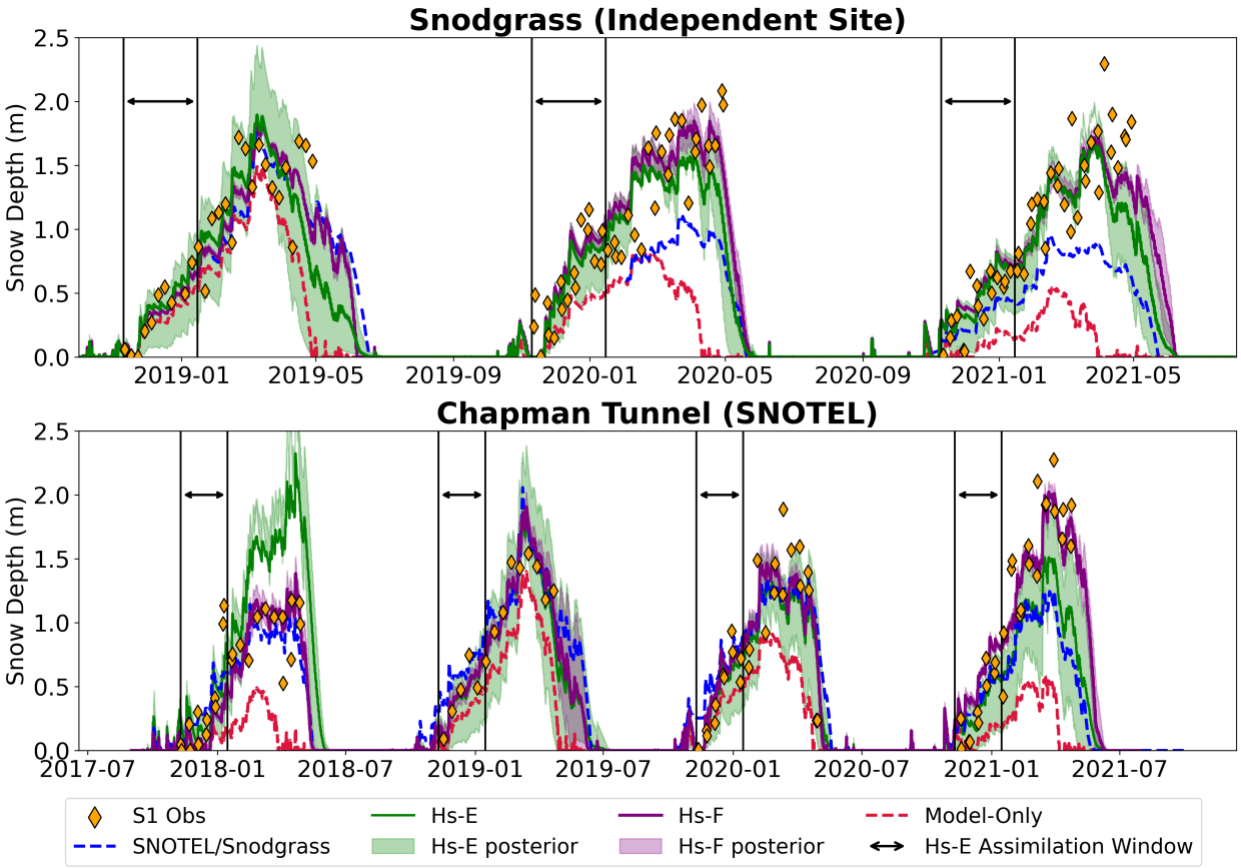

Figure S3: Temporal analysis results at (top) Snodgrass and (bottom) Chapman Tunnel. Hs-F (purple line) and Hs-E (green line) represent the posterior mean of full and early window experiments. SNOTEL, Model-only (red line) represents prior mean, and Snodgrass station data (blue dashed line) provide snow depth evaluation data. Orange diamonds represent S1 snow depth observations. Shading of respective color indicates one standard deviation of posterior particle spread, and the solid black lines represent the early assimilation window.

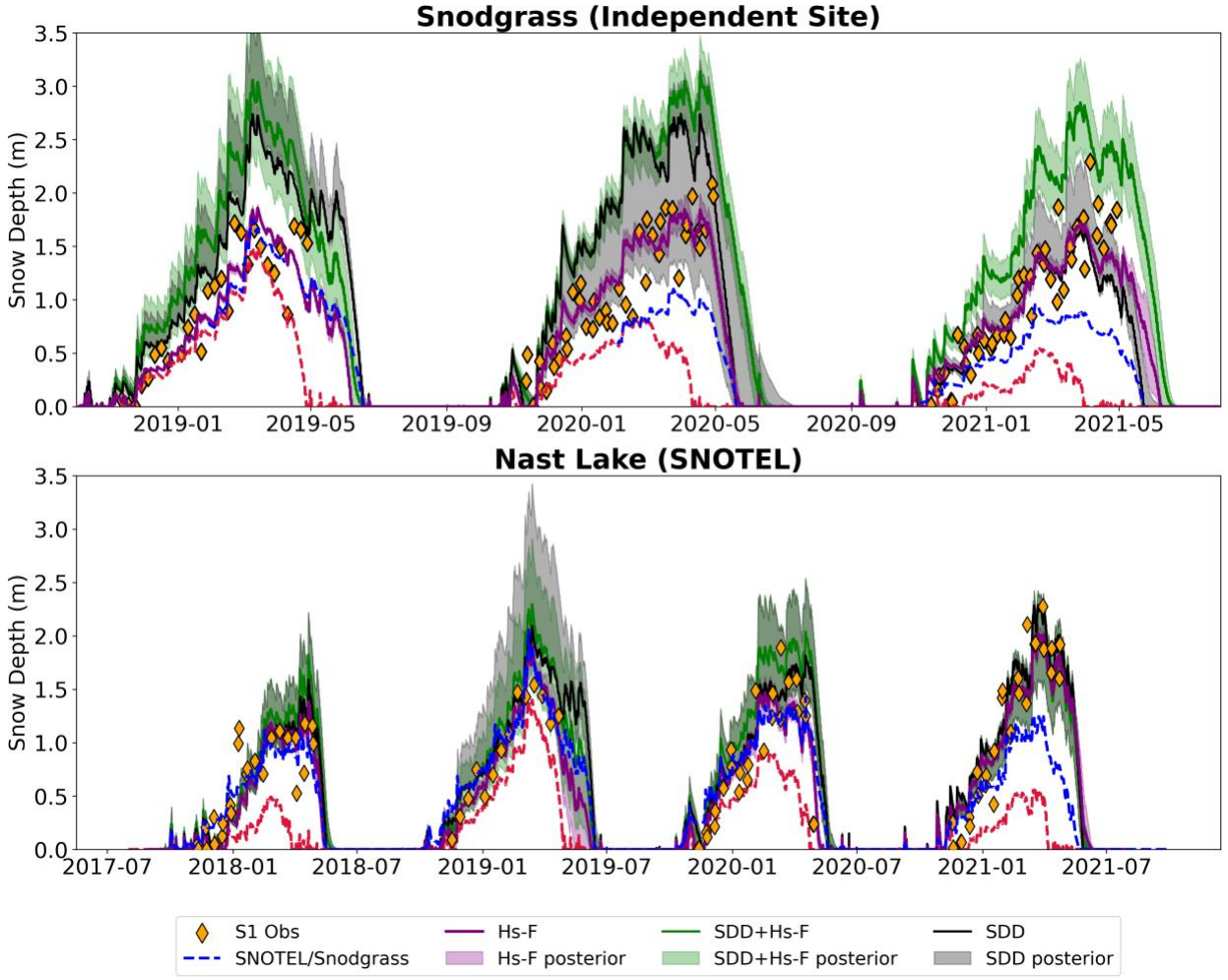

Figure S4: Example results of the joint assimilation experiments at (a) Snodgrass and (b) Nast Lake. Hs-F (purple line) and SDD+Hs-F (green line) represent the posterior mean for each experiment. SDD (black line) is the posterior snow depth based on assimilating only SDD, and Model-only (red line) represents the prior mean. SNOTEL and Snodgrass in situ (blue dashed line) provide snow depth evaluation data. Orange diamonds represent S1 snow depth observations. Shading of respective color indicates one standard deviation of posterior particle spread

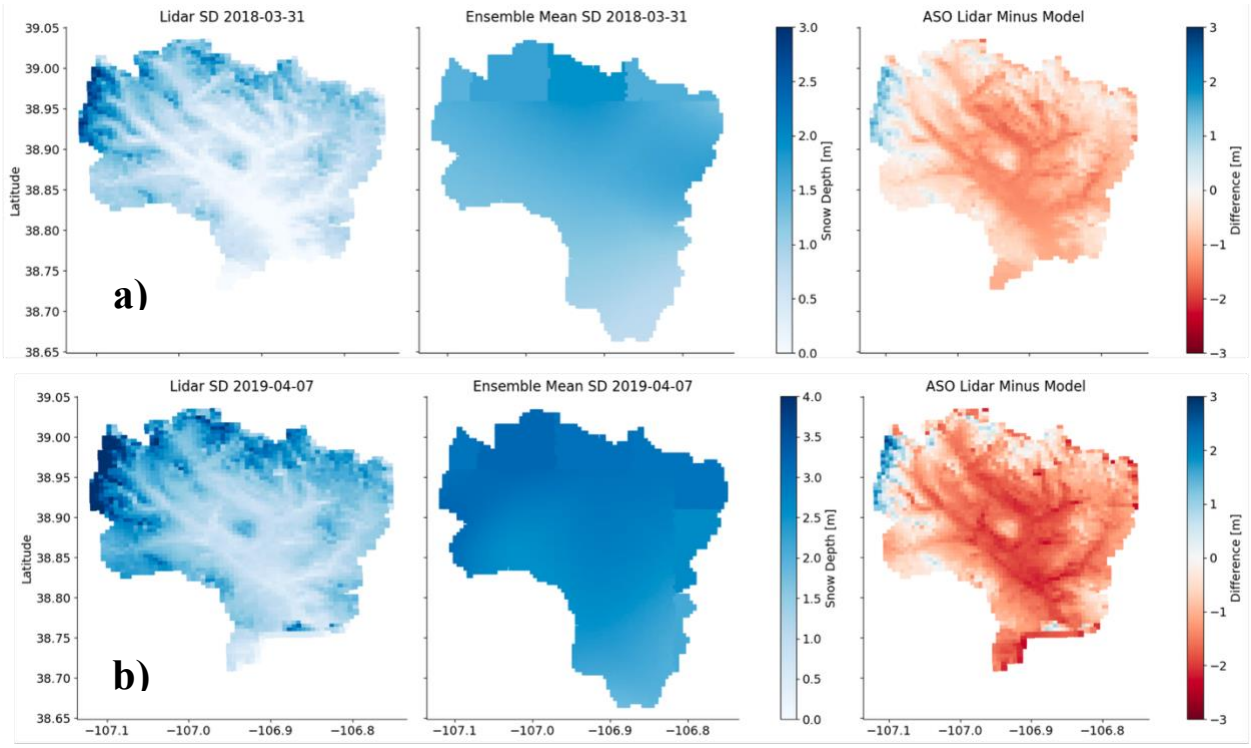

Figure S5: The first column in panels a and b shows snow depth from airborne LiDAR near peak snow accumulation. The second column in panels a and b shows the prior mean snow depth, and the third column shows the difference between LiDAR and prior.

Table S2: Error metrics of posterior mean of all experiments. Metrics are averaged across all temporal sites.

Metrics	Experiments				
	Model-Only	Hs-E	Hs-F	SDD+Hs-F	SDD
R^2	0.62	0.86	0.88	0.92	0.92
RMSE	0.43	0.35	0.29	0.28	0.28
Mean Bias	-0.29	0.09	0.07	0.15	0.14
MAE	0.29	0.23	0.20	0.19	0.19
RMAD	0.63	0.63	0.46	0.42	0.43
CRPSS	-	0.082	0.16	0.19	0.22

Table S3: Table comparing error metrics of posterior mean snow depth of all DA experiments, including Hs-F, Hs-E, SDD+Hs-F, SDD, and **prior mean (model-only)** when evaluated against four LiDAR surveys.

LiDAR Survey	**Exp**	**R^2**	**RMSE (m)**	**Mean Bias (m)**	**MAE (m)**	**RMAD (m)**
2018-03-31	Hs-F	0.51	0.48	-0.21	0.35	0.45
	Hs-E	0.29	1.24	-1.15	1.15	1.48

	SDD+Hs-F	0.58	0.65	0.55	0.55	0.71
	SDD	0.74	0.32	-0.25	0.33	0.42
	Model Only	**0.06**	**0.91**	**-0.74**	**0.62**	**2.63**
	Hs-F	0.33	0.39	0.08	0.21	0.88
	Hs-E	0.37	0.78	-0.59	0.69	2.55
2018-05-24	SDD+Hs-F	0.69	0.71	0.55	0.62	0.35
	SDD	0.70	0.68	-0.48	0.54	0.32
	Model Only	**0.04**	**0.68**	**0.55**	**0.62**	**2.64**
	Hs-F	0.33	0.73	-0.08	0.52	0.31
	Hs-E	0.47	0.85	-0.52	0.66	0.40
2019-04-07	SDD+Hs-F	0.69	0.71	0.55	0.62	0.35
	SDD	0.70	0.68	-0.48	0.54	0.32
	Model Only	**0.28**	**1.34**	**-1.14**	**1.23**	**0.73**
	Hs-F	0.08	1.06	0.44	0.60	0.83
	Hs-E	0.57	0.77	-0.21	0.52	0.63
2019-06-10	SDD+Hs-F	0.49	1.0	0.71	0.71	0.85
	SDD	0.76	0.52	-0.09	0.34	0.40
	Model Only	**0.14**	**1.55**	**-1.30**	**1.41**	**1.69**
	Hs-F	**0.31**	**0.66**	**0.05**	**0.42**	**0.61**
	Hs-E	**0.42**	**0.91**	**-0.61**	**0.75**	**1.2**
Average	**SDD+Hs-F**	**0.46**	**0.70**	**0.51**	**0.52**	**0.72**
	SDD	**0.72**	**0.41**	**0.20**	**0.33**	**0.42**
	Model-Only	**0.13**	**1.12**	**-0.65**	**9.87**	**1.92**