



Supplement of

Characterizing the spatial distribution of field-scale snowpack using unpiloted aerial system (UAS) lidar and structure-from-motion (SfM) photogrammetry

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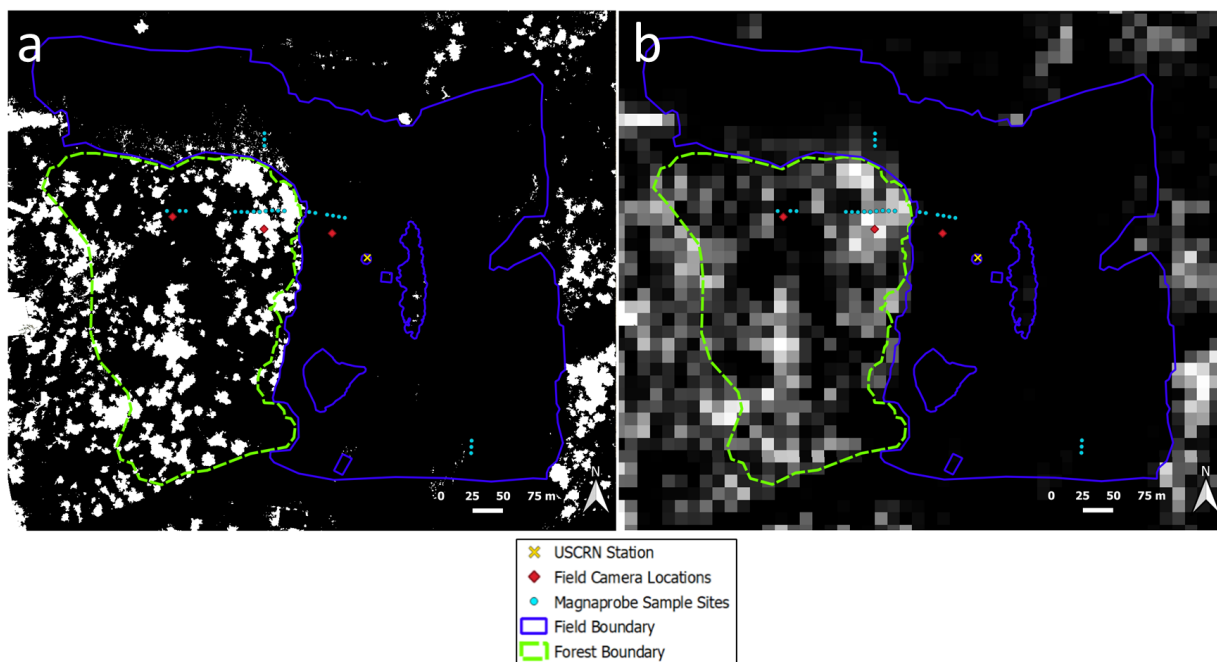


Figure S1 Map of binary Green Leaf Index (GLI) 3 x 3 cm output (a) and 10 m x 10 m coarsened output (b) for study area at Thompson Farm in Durham, NH, USA.

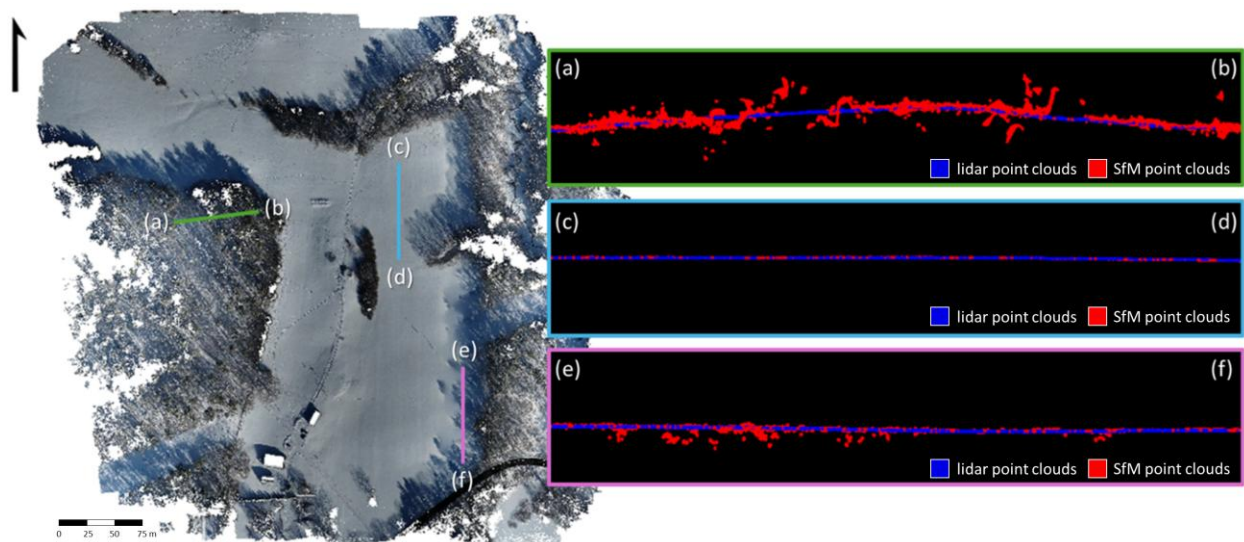


Figure S2 Comparison of ground surface returns for SfM and lidar surveys from February 10, 2021. Panels on the right-side show profile views of the ground returns from lidar (blue points) and SfM (red points) point clouds. The green transect (a – b) shows the greater variability in SfM ground elevations compared to the lidar in the forest. The blue transect (c – d) shows that SfM and lidar agree well in the field when the SfM software identifies an adequate number of tie points. The purple transect (e – f) shows how fewer SfM tie points in the field results in poor dense cloud reconstruction in those areas.

Table S1 Number of magnaprobe sample locations (1 x 1 m grid cells) by land cover type for each snow-on UAV flight over the field campaign period in 2021. Each grid cell was comprised of nine, evenly spaced magnaprobe snow depth measurements and one snow tube snow water equivalent (SWE) measurement. Forest type was determined based on the binary Green Leaf Index (GLI) output within a 10 m x 10 m grid around the sample point (deciduous < 40% leaf on, mixed 40 – 60% leaf on, coniferous > 60% leaf on).

Date	Number of sample locations (Field)	Number of sample locations (Coniferous)	Number of sample locations (Deciduous)	Number of sample locations (Mixed)
Feb 4 th	9	1	2	1
Feb 10 th	9	0	3	1
Feb 20 th	9	1	3	2
Feb 23 th	9	1	3	2
Feb 24 th	9	1	3	2
Feb 28 th	9	1	3	2
Mar 3 rd	8	1	2	2
Mar 7 th	3	1	3	2

Table S2 Summary statistics of in-situ magnaprobe (MP) snow depths as compared to co-located UAS lidar and structure-from-motion (SfM) photogrammetry snow depth values at MP sampling locations from February 4th to March 7th.

		Mean	Mean	Bias	Std Dev	Std Dev	N	a (Intercept)	b (Slope)	r ²	MAD	RMSD
Method	Location	MP	UAS		MP	UAS						
Lidar	Field	13.6	15.1	-1.50	6.16	7.52	65	0.93	1.04	0.73	3.53	4.17
	Forest	14.7	8.42	6.28	5.01	5.82	36	-5.88	0.97	0.70	6.29	7.02
SfM	Field	13.6	14.9	-1.31	6.21	9.61	64	-0.13	1.11	0.51	4.00	6.83
	Forest	14.9	41.1	-26.2	4.94	67.5	37	9.76	2.10	0.02	31.4	71.1

**The terms N , b , r^2 , and p are dimensionless, all other terms have dimensions of cm.*

Table S3 Lidar ground return point count (number of ground returns per 1 m x 1 m pixel) statistics by land cover type. The flight on 4/2/2021 was the snow-off baseline flight.

Location	Date	Mean	Median	Standard Deviation	75th Percentile	25th Percentile
Field	2/10/2021	1231.7	1272	197.7	1373	1116
Field	2/20/2021	1062.8	1080	170.2	1179	965
Field	2/23/2021	900.6	911	164.3	1006	812
Field	2/24/2021	851.2	873	173.1	962	770
Field	2/28/2021	893.1	930	207.9	1021	817
Field	2/4/2021	1059.2	1080	183.9	1187	951
Field	3/3/2021	527.1	566	207.1	668	430
Field	3/7/2021	748.5	801	258.3	930	620
Field	4/2/2021	664.1	669	218.6	803	537
Forest	2/10/2021	442.2	440	186.9	580	299
Forest	2/20/2021	299.7	289	151.0	402	183
Forest	2/23/2021	215.2	199	130.0	299	114
Forest	2/24/2021	179.8	164	116.4	255	87
Forest	2/28/2021	145.7	127	105.1	212	61
Forest	2/4/2021	264.0	252	139.4	357	156
Forest	3/3/2021	125.1	111	83.8	177	59
Forest	3/7/2021	187.0	174	108.1	257	103
Forest	4/2/2021	178.3	162	112.0	251	89

Table S4 SfM ground return point count (number of ground returns per 1 m x 1 m pixel) statistics from derived point clouds by land cover type. Accuracy of SfM point clouds depends on the RTK geotagging as well as the software's ability to reconstruct the 3D model from tie points. The flight on 4/2/2021 was the snow-off baseline flight.

Location	Date	Mean	Median	Standard Deviation	75th Percentile	25th Percentile
Field	2/4/2021	390.6	331	249.6	461	325
Field	2/10/2021	322.4	318	39.5	319	317
Field	2/20/2021	238.2	308	116.4	311	183
Field	2/23/2021	322.5	312	69.3	315	310
Field	2/24/2021	309.2	307	21.2	308	306
Field	2/28/2021	319.8	315	51	317	314
Field	3/3/2021	325.5	317	48.5	319	316
Field	3/7/2021	317	315	37.2	316	314
Field	4/2/2021	327.6	323	46.4	324	321
Forest	2/4/2021	369.6	132	487	640	0
Forest	2/10/2021	525.8	453	265	656	341
Forest	2/20/2021	27.5	0	75.5	1	0
Forest	2/23/2021	692.6	639.5	459.6	907	406
Forest	2/24/2021	148.3	135	124.5	281	16
Forest	2/28/2021	1053.6	909	798	1471	438
Forest	3/3/2021	616.6	492	372.3	775	339
Forest	3/7/2021	743	569	496.7	965	360
Forest	4/2/2021	477.7	415	260.6	601	328

Table S5 Lidar ground return point count (number of ground returns per 1 m x 1 m pixel) statistics by forested land cover type. The flight on 4/2/2021 was the snow-off baseline flight.

Location	Date	Mean	Median	Standard Deviation	75th Percentile	25th Percentile
Deciduous	2/10/2021	485.7	487	173.8	612	356
Deciduous	2/20/2021	333.4	325.5	143.3	430	228
Deciduous	2/23/2021	240.9	228	127.8	323	145
Deciduous	2/24/2021	203.3	192	114.8	278	117
Deciduous	2/28/2021	167.3	154	104.7	233	86
Deciduous	2/4/2021	292.9	284	134.6	381	192
Deciduous	3/3/2021	138.8	128	83.8	192	74
Deciduous	3/7/2021	206.3	195	106.4	276	125
Deciduous	4/2/2021	198.8	187	111	272	113
Coniferous	2/10/2021	291	273	147.7	380	182
Coniferous	2/20/2021	182.4	162	114.1	250	96
Coniferous	2/23/2021	126	106	92.8	174	57
Coniferous	2/24/2021	98.2	79	78.9	136	40
Coniferous	2/28/2021	71	54	64.5	99	24
Coniferous	2/4/2021	163.5	143	104.6	223	86
Coniferous	3/3/2021	77.3	61	63.8	108	30
Coniferous	3/7/2021	120.3	101	84.8	165	57
Coniferous	4/2/2021	107.4	88	82.4	149	46

Table S6 SfM ground return point count (number of ground returns per 1 m x 1 m pixel) statistics from derived point clouds by forested land cover type. Accuracy of SfM point clouds depends on the RTK geotagging as well as the software's ability to reconstruct the 3D model from tie points. The flight on 4/2/2021 was the snow-off baseline flight.

Location	Date	Mean	Median	Standard Deviation	75th Percentile	25th Percentile
Deciduous	2/10/2021	512.9	434	252.9	637	336
Deciduous	2/20/2021	32	0	80.9	4	0
Deciduous	2/23/2021	666.4	619	437	878	392
Deciduous	2/24/2021	164.8	172	123.7	294	33
Deciduous	2/28/2021	1035.6	892	788.2	1456	428
Deciduous	2/4/2021	378.5	159	481.9	658	0
Deciduous	3/3/2021	624	504	369.5	790.75	342
Deciduous	3/7/2021	732.7	549	497.9	950	351
Deciduous	4/2/2021	480.9	413	252.3	602	328
Coniferous	2/10/2021	570.6	521	299	718	370
Coniferous	2/20/2021	12	0	49.4	0	0
Coniferous	2/23/2021	782.6	709	519.9	1001	463
Coniferous	2/24/2021	90.6	35	108.9	166	0
Coniferous	2/28/2021	1116.1	967	828.4	1522.75	486
Coniferous	2/4/2021	339	72	503	559	0
Coniferous	3/3/2021	591	457	380.9	720.75	329
Coniferous	3/7/2021	779.1	635	490.9	1000	400.5
Coniferous	4/2/2021	466.6	425	287.4	600	327

Table S7. Results of Kruskal-Wallis test (so-called “one-way ANOVA on ranks”) for the mean relative difference of snow depth and physical variables for combined, field, and forest, respectively.

	Combined		Forest		Field	
variable	Chi-squared	p-value	Chi-squared	p-value	Chi-squared	p-value
Slope	23462	0.00**	643	0.00**	7	0.00**
Shadow hrs	17346	0.00**	83	0.00**	7705	0.00**
Veg type	29515	0.00**	1293	0.00**	2386	0.00**
K sat	15781	0.00**	641	0.00**	91	0.00**
Soil Organic Matter	17227	0.00**	1540	0.00**	2720	0.00**

Table S8. Results of the Tukey test for the mean relative difference of snow depth with physical variables across all subgroups for combined, field, and forest, respectively.

<i>Combined</i>	Slope	Shadow hrs	Veg type	Ksat	Soil Organic Matter
Group 1 vs. 2	0.00**	0.00**	0.00**	0.079	0.00**
Group 1 vs. 3	0.00**	0.00**	0.00**	0.00**	0.00**
Group 1 vs. 4	0.00**	0.00**	0.00**	0.00**	0.00**
Group 1 vs. 5	0.00**	0.00**	-	0.675	0.00**
Group 2 vs. 3	0.00**	0.00**	-	0.00**	0.00**
Group 2 vs. 4	0.00**	0.00**	-	0.00**	0.00**
Group 2 vs. 5	0.00**	0.00**	-	0.264	0.00**
Group 3 vs. 4	0.00**	0.00**	-	0.00**	0.00**
Group 3 vs. 5	0.052	0.00**	-	0.00**	0.00**
Group 4 vs. 5	0.539	0.00**	-	0.00**	0.00**

<i>Forest</i>	Slope	Shadow hrs	Veg type	Ksat	Soil Organic Matter
Group 1 vs. 2	0.00**	0.44	0.00**	0.00**	0.00**
Group 1 vs. 3	0.00**	0.34	-	0.00**	0.00**
Group 1 vs. 4	0.00**	0.99	-	0.00**	0.00**
Group 1 vs. 5	0.00**	0.00**	-	0.00**	0.00**
Group 2 vs. 3	0.00**	1.00	-	0.00**	0.00**
Group 2 vs. 4	0.06	0.00**	-	0.00**	0.00**
Group 2 vs. 5	0.90	0.00**	-	0.00**	0.00**
Group 3 vs. 4	0.76	0.00**	-	0.00**	0.00**
Group 3 vs. 5	0.18	0.00**	-	0.00**	0.00**
Group 4 vs. 5	0.78	0.00**	-	0.73	0.00**

<i>Field</i>	Slope	Shadow hrs	Ksat	Soil Organic Matter
Group 1 vs. 2	0.00**	0.00**	0.56	0.30
Group 1 vs. 3	0.00**	0.00**	0.99	0.79
Group 1 vs. 4	0.00**	0.00**	0.22	0.00**
Group 1 vs. 5	0.00**	0.00**	1.00	0.00**
Group 2 vs. 3	0.00**	0.00**	0.76	0.86
Group 2 vs. 4	0.00**	0.00**	0.84	0.00**
Group 2 vs. 5	0.00**	0.00**	0.09	0.00**
Group 3 vs. 4	0.00**	0.00**	0.33	0.00**
Group 3 vs. 5	0.00**	0.00**	0.96	0.00**
Group 4 vs. 5	0.22	0.00**	0.03	0.00**