Online Resource: Supplementary Information

Applications of Snow-Covered Areas from Unoccupied Aerial Systems (UAS) Visible Imagery in Southeastern New Hampshire

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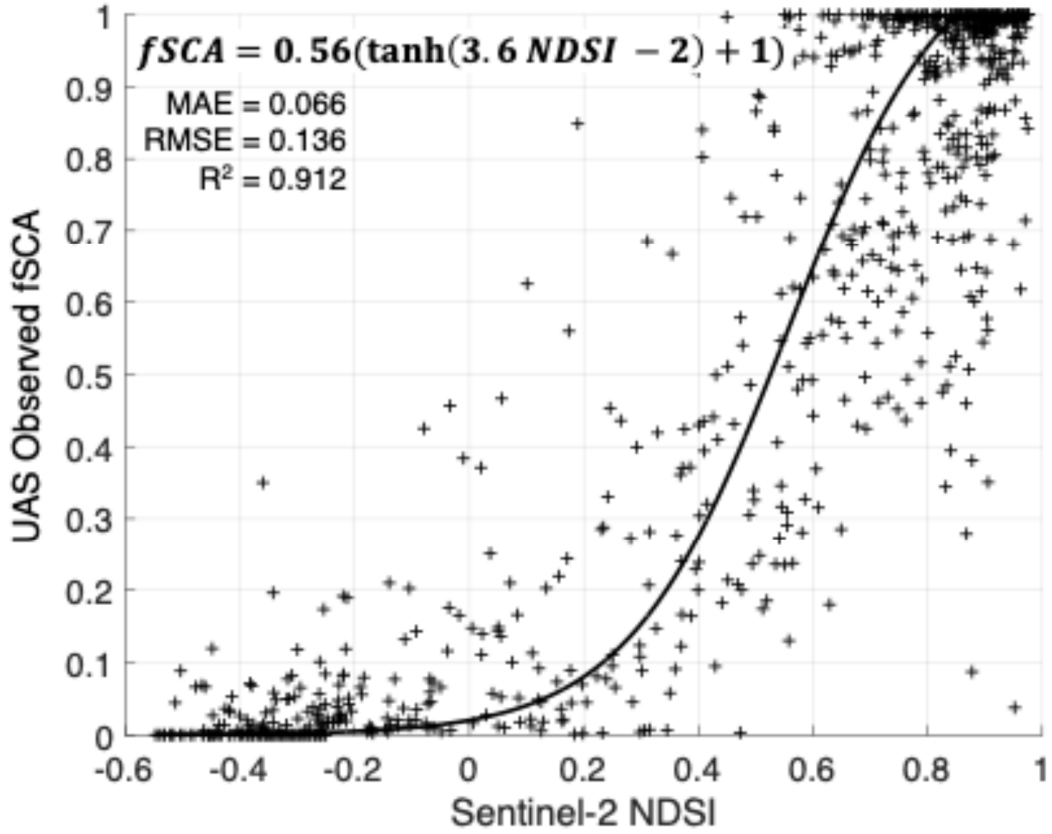

Figure S1 – Sentinel-2 observed NDSI compared to UAS-RGB-SCA fractional snow-covered area (fSCA) within each corresponding 20 m Sentinel-2 pixel (n = 1,092; 182 pixels within the field boundary x 6 dates). The solid black line shows the optimized NDSI to fSCA hyperbolic tangent function. The function and associated performance metrics, mean absolute error (MAE), root-mean-squared error (RMSE), and coefficient of determination (R^2), are also included.

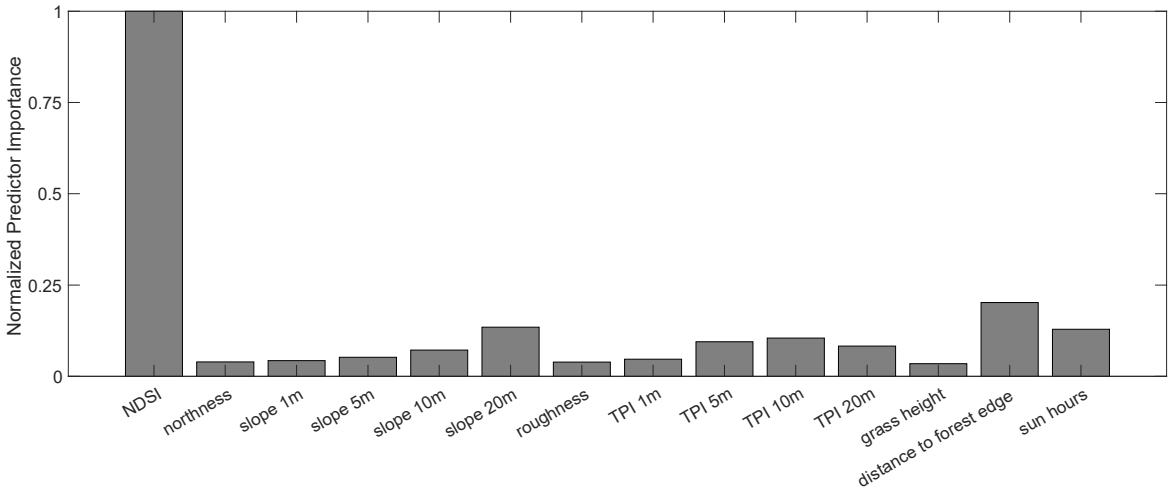

Figure S2 – Normalized fine-scale snow-covered area predictor importance from the trained random forest model considering all 14 input predictors. Hyperparameters of NumPredictors = 4, MinLeafSize = 0.01%, and NumLearners = 500 were used.

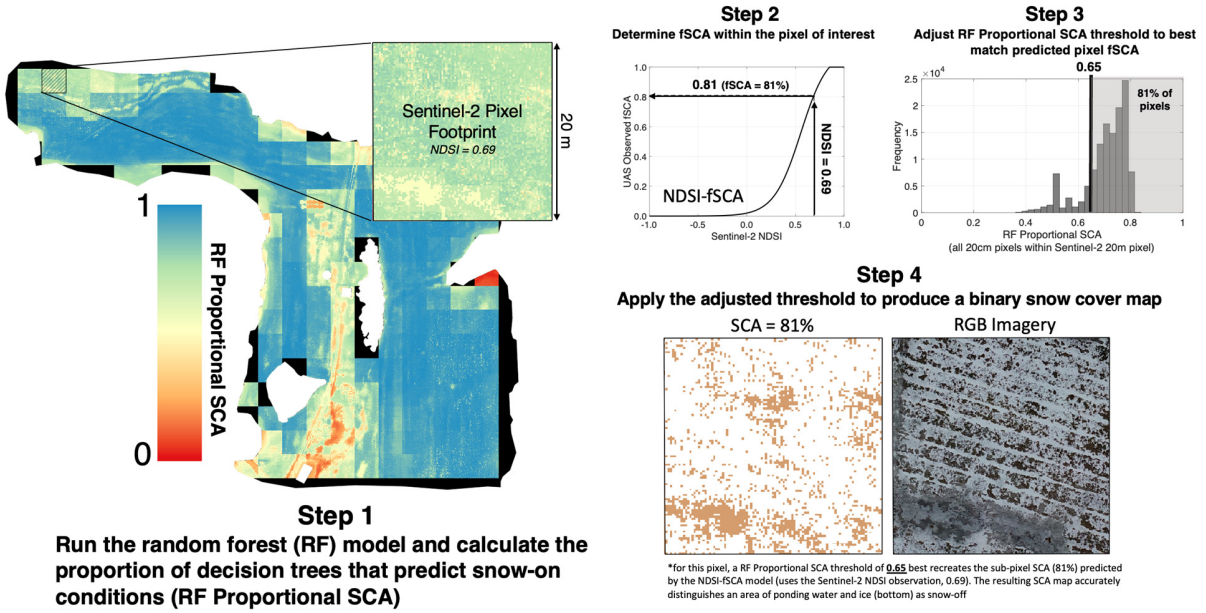

Figure S3 – Detailed Random Forest (RF) modeling workflow for the RF SCA model over a single pixel of interest indicated by the black hatched area in the top left of the field. This example uses observations and model outputs from March 3, 2021.

Table S1 Summaries of UAS and satellite snow cover products and UAS LiDAR snow depth for all study dates. Only dates with observations from at least one product are included.

date	UAS-RGB-SCA (% cover)				UAS-LIDAR-fSCA (snow depth > 0 cm)	UAS-LIDAR mean snow depth (cm)	Landsat fSCA	Landsat NDSI	Sentinel-2 fSCA	Sentinel NDSI	MODIS NDSI	VIIRS NDSI
	snow	ice	shadow	bare earth								
2021-01-24	--	--	--	--	--	--	0.00	0.0	0.00	0.0	0.0	0.0
2021-01-25	--	--	--	--	--	--	--	--	--	--	0.0	0.0
2021-01-30	--	--	--	--	--	--	--	--	--	--	--	0.0
2021-01-31	--	--	--	--	--	--	--	--	--	--	1.4	24.1
2021-02-03	--	--	--	--	1.00	16.2	--	--	--	--	--	--
2021-02-04	99.8%	0.0%	0.0%	0.2%	1.00	16.3	--	--	--	--	--	--
2021-02-05	--	--	--	--	1.00	16.0	--	--	--	--	--	--
2021-02-06	--	--	--	--	1.00	17.7	--	--	0.98	89.2	--	--
2021-02-08	--	--	--	--	1.00	22.0	--	--	0.70	62.8	18.4	47.5
2021-02-10	84.8%	0.0%	14.7%	0.5%	1.00	24.3	--	--	--	--	--	34.5
2021-02-11	--	--	--	--	--	--	--	--	--	--	--	34.4
2021-02-12	--	--	--	--	1.00	21.3	--	--	--	--	--	41.6
2021-02-13	--	--	--	--	--	--	--	--	0.76	66.2	--	43.7
2021-02-17	--	--	--	--	--	--	0.99	63.4	--	--	51.5	34.8
2021-02-20	93.1%	0.0%	6.7%	0.2%	1.00	23.7	--	--	--	--	49.0	41.0
2021-02-21	--	--	--	--	--	--	--	--	0.94	78.7	46.5	42.9
2021-02-23	99.5%	0.0%	0.0%	0.5%	1.00	17.2	--	--	0.97	85.3	--	--
2021-02-24	91.4%	0.0%	7.2%	1.3%	1.00	12.9	--	--	--	--	--	--
2021-02-25	--	--	--	--	--	--	0.94	54.7	--	--	52.4	--
2021-02-26	87.1%	0.0%	8.8%	4.1%	0.97	8.3	--	--	0.96	89.9	40.0	42.4
2021-02-28	90.6%	5.5%	0.0%	3.9%	0.99	12.2	--	--	--	--	--	--
2021-03-01	78.8%	11.9%	0.0%	9.3%	--	--	--	--	--	--	--	--
2021-03-02	--	--	--	--	--	--	--	--	--	--	40.0	48.6
2021-03-03	77.4%	13.9%	0.0%	8.7%	0.92	5.4	--	--	0.88	78.3	--	--
2021-03-04	--	--	--	--	--	--	--	--	--	--	--	31.3
2021-03-05	--	--	--	--	--	--	0.88	29.3	--	--	--	--
2021-03-06	--	--	--	--	--	--	--	--	--	--	--	27.4
2021-03-07	47.1%	22.4%	0.0%	30.6%	0.84	4.3	--	--	--	--	22.3	27.5
2021-03-08	38.1%	23.0%	0.0%	38.9%	0.92	4.7	--	--	0.63	58.4	14.8	13.1
2021-03-09	19.3%	0.0%	0.0%	80.7%	0.38	1.3	--	--	--	--	10.8	2.8
2021-03-10	10.3%	0.0%	0.0%	89.7%	--	--	--	--	0.10	11.8	0.0	0.0
2021-03-11	9.3%	0.0%	0.0%	90.7%	0.44	1.1	--	--	--	--	--	0.0
2021-03-12	--	--	--	--	--	--	--	--	--	--	0.0	0.0
2021-03-13	--	--	--	--	--	--	0.00	0.0	0.00	0.02	0.0	0.0
2021-03-15	--	--	--	--	--	--	--	--	0.00	0.0	0.0	0.0
2021-03-17	--	--	--	--	--	--	--	--	--	--	0.0	0.0
2021-03-19	--	--	--	--	--	--	--	--	--	--	0.0	0.0
2021-03-20	--	--	--	--	--	--	--	--	0.00	0.0	0.0	0.0
2021-03-21	--	--	--	--	--	--	0.00	0.0	--	--	0.0	0.0
2021-03-22	--	--	--	--	--	--	--	--	--	--	0.0	0.0
2021-03-23	--	--	--	--	--	--	--	--	0.00	0.0	0.0	0.0
2021-03-27	--	--	--	--	--	--	--	--	--	--	--	0.0
2021-03-29	--	--	--	--	--	--	0.00	0.0	--	--	--	0.0
2021-03-30	--	--	--	--	--	--	--	--	0.00	0.0	0.0	0.0
2021-04-02	0%	0%	0%	100%	0.00	0.0	--	--	0.00	0.0	--	--
2021-04-03	--	--	--	--	--	--	--	--	--	--	0.0	0.0
2021-04-04	--	--	--	--	--	--	--	--	0.00	0.0	0.0	0.0
2021-04-06	--	--	--	--	--	--	0.00	0.0	--	--	--	--
2021-04-08	--	--	--	--	--	--	--	--	--	--	--	0.0
2021-04-09	--	--	--	--	--	--	--	--	--	--	0.0	0.0
2021-04-10	--	--	--	--	--	--	--	--	--	--	0.0	0.0

Table S2 Performance metrics (precision, recall, F1 score, and overall accuracy) for UAS-derived cover classes overall and by cover class (bare earth, snow, shadow, and ice) compared to the manual classification.

		all classes			
date	**test area**	accuracy (correct/all)	mean precision	mean recall	mean F1score
2021-02-20	North	89.5%	0.89	0.88	0.88
	Central	97.3%	0.50	0.68	0.71
	South	100.0%	1.00	1.00	1.00
2021-02-24	North	93.6%	0.95	0.56	0.88
	Central	92.1%	0.65	0.53	0.59
	South	99.9%	0.91	0.60	0.66
2021-02-28	North	95.8%	0.63	0.78	0.84
	Central	87.5%	0.64	0.71	0.79
	South	94.9%	0.81	0.43	0.49
2021-03-03	North	80.2%	0.72	0.52	0.55
	Central	77.3%	0.63	0.59	0.60
	South	79.0%	0.65	0.44	0.48
2021-03-07	North	32.6%	0.33	0.34	0.34
	Central	82.9%	0.66	0.65	0.62
	South	56.5%	0.54	0.46	0.48
2021-03-11	North	88.1%	0.53	0.76	0.61
	Central	77.7%	0.55	0.73	0.53
	South	99.0%	0.50	0.99	1.00

		bare earth					snow				
		% of coverage in indicated test area					% of coverage in indicated test area				
		manual reference	UAS-RGB-SCA	precision	recall	F1score	manual reference	UAS-RGB-SCA	precision	recall	F1score
2021-02-20	North	0.0%	0.0%	--	--	--	36.5%	32.8%	0.90	0.81	0.85
	Central	0.0%	0.0%	0.00	--	--	97.2%	98.0%	0.98	0.99	0.99
	South	0.0%	0.0%	--	--	--	100.0%	100.0%	1.00	1.00	1.00
2021-02-24	North	0.0%	0.0%	--	--	--	83.4%	89.1%	0.93	1.00	0.96
	Central	3.4%	0.4%	0.98	0.12	0.21	96.6%	92.9%	0.99	0.95	0.97
	South	0.0%	0.0%	--	--	--	99.8%	100.0%	1.00	1.00	1.00
2021-02-28	North	0.0%	0.0%	0.00	--	--	91.4%	94.7%	0.96	1.00	0.98
	Central	15.6%	7.6%	0.96	0.47	0.63	84.4%	82.7%	0.97	0.95	0.96
	South	0.6%	0.1%	0.98	0.16	0.27	94.5%	98.4%	0.96	1.00	0.98
2021-03-03	North	4.0%	0.7%	0.56	0.09	0.16	67.1%	81.8%	0.80	0.98	0.88
	Central	39.2%	28.5%	0.97	0.70	0.81	54.9%	56.3%	0.87	0.89	0.88
	South	5.6%	1.6%	0.89	0.25	0.39	82.2%	78.6%	0.97	0.92	0.94
2021-03-07	North	3.6%	28.8%	0.05	0.44	0.10	33.1%	32.7%	0.81	0.80	0.80
	Central	60.3%	61.6%	0.94	0.96	0.95	35.9%	25.4%	0.93	0.66	0.77
	South	18.7%	21.6%	0.65	0.75	0.70	74.5%	43.2%	0.97	0.56	0.71
2021-03-11	North	79.4%	89.3%	0.88	0.99	0.93	2.2%	10.7%	0.18	0.87	0.30
	Central	96.3%	76.4%	0.98	0.78	0.87	3.7%	23.6%	0.11	0.68	0.18
	South	100.0%	99.0%	1.00	0.99	1.00	0.0%	1.0%	0.00	--	--

		shadow					ice				
		% of coverage in indicated test area					% of coverage in indicated test area				
		manual reference	UAS-RGB-SCA	precision	recall	F1score	manual reference	UAS-RGB-SCA	precision	recall	F1score
2021-02-20	North	63.5%	67.2%	0.89	0.95	0.92	0.0%	0.0%	--	--	--
	Central	2.8%	1.9%	0.53	0.36	0.43	0.0%	0.0%	--	--	--
	South	0.0%	0.0%	--	--	--	0.0%	0.0%	--	--	--
2021-02-24	North	15.5%	10.9%	0.96	0.67	0.79	1.1%	0.0%	--	0.00	--
	Central	0.0%	6.7%	0.00	--	--	0.0%	0.0%	--	--	--
	South	0.2%	0.0%	0.82	0.20	0.32	0.0%	0.0%	--	--	--
2021-02-28	North	0.0%	0.0%	--	--	--	8.6%	5.3%	0.92	0.56	0.70
	Central	0.0%	0.0%	--	--	--	0.0%	9.8%	0.00	--	--
	South	0.0%	0.0%	--	--	--	4.9%	1.5%	0.48	0.15	0.23
2021-03-03	North	0.0%	0.0%	--	--	--	28.9%	17.5%	0.81	0.49	0.61
	Central	0.0%	0.0%	--	--	--	5.9%	15.3%	0.07	0.17	0.09
	South	0.0%	0.0%	--	--	--	12.3%	19.8%	0.08	0.14	0.10
2021-03-07	North	30.8%	0.0%	--	0.00	--	32.5%	38.4%	0.12	0.14	0.13
	Central	0.0%	0.0%	--	--	--	3.8%	12.9%	0.10	0.32	0.15
	South	0.0%	0.0%	--	--	--	6.7%	35.2%	0.01	0.08	0.02
2021-03-11	North	0.0%	0.0%	--	--	--	18.4%	0.0%	--	0.42	--
	Central	0.0%	0.0%	--	--	--	0.0%	0.0%	--	--	--
	South	0.0%	0.0%	--	--	--	0.0%	0.0%	--	--	--

Table S3 Pixel counts and chi-squared test statistics for detecting statistically significant differences between the random forest snow covered area model (RF SCA) and Sentinel-2 NDSI single-threshold-based SCA (Sentinel-2 SCA). Significant results ($\alpha < 0.05$) are indicated with an asterisk (*). Correct classifications are defined as those agreeing with the UAS snow cover reference product (UAS-RGB-SCA). Correct classifications are considered to be those when RF SCA or Sentinel-2 SCA defines snow (or non-snow) and UAS-RGB-SCA is snow or ice (bare earth).

		Sentinel-2 SCA (0.52 NDSI threshold)				RF SCA		Chi-squared test statistics		
	date	correctly classified	total classified	correctly classified (reduced)	total classified (reduced)	correctly classified	total classified	pooled estimate of proportion	χ^2	p-value
overall	2021-02-23	21,285,762	21,398,612	181	182	20,931,251	21,398,612	0.98	2.28	0.13
	2021-02-26	18,672,763	19,864,759	171	182	18,760,137	19,864,759	0.94	0.08	0.78
	2021-03-03	19,667,795	21,811,239	164	182	19,735,254	21,811,239	0.90	0.03	0.86
	2021-03-08	15,508,200	22,004,730	128	182	16,047,001	22,004,730	0.73	0.62	0.43
	2021-03-10	19,803,046	21,931,124	164	182	19,523,700	21,931,124	0.89	0.22	0.64
	2021-04-02	21,931,124	21,931,124	182	182	21,931,124	21,931,124	1.00	--	--
UAS snow/ice	2021-02-23	21,285,757	21,286,540	182	182	20,930,178	21,286,540	0.98	3.10	0.08
	2021-02-26	18,599,952	19,065,133	178	182	18,669,522	19,065,133	0.98	0.01	0.91
	2021-03-03	19,226,691	19,955,809	175	182	18,869,246	19,955,809	0.95	0.90	0.34
	2021-03-08	10,780,188	13,639,951	144	182	10,956,107	13,639,951	0.80	0.17	0.68
	2021-03-10	681,806	2,077,774	60	182	857,585	2,077,774	0.41	5.18	0.02*
	2021-04-02	0	0	--	182	0	0	--	--	--
UAS bare earth	2021-02-23	5	112,072	0	182	1,073	112,072	0.01	1.76	0.18
	2021-02-26	72,811	799,626	17	182	90,615	799,626	0.11	0.72	0.40
	2021-03-03	441,104	1,855,430	43	182	866,008	1,855,430	0.47	38.84	<0.01*
	2021-03-08	4,728,012	8,364,779	103	182	5,090,894	8,364,779	0.61	1.39	0.24
	2021-03-10	19,121,240	19,853,350	175	182	18,666,115	19,853,350	0.94	1.47	0.22
	2021-04-02	21,931,124	21,931,124	182	182	21,931,124	21,931,124	1.00	--	--