Multiscale Very High Resolution Topographic Models in Alpine Ecology: Pros and Cons of Airborne LiDAR and Drone-Based Stereo-Photogrammetry Technologies

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Supplementary material

Summary of supplementary figures and tables

Table S1: Description and parameters for Elevation and 23 digital elevation model (DEM)-derived variables. These variables were selected due to their common usage in ecological studies. Aspect was converted into Eastness and Northness. Each variable was computed at each resolution for LiDAR (50cm, 1m, 2m, 4m, 8m, 16m, 32m) and photogrammetry (6.25cm, 12.5cm, 25cm, 50cm, 1m, 2m, 4m, 8m). Abbreviations with an asterisk (*) in bold type indicate variables that were assessed as uncorrelated at most resolutions with a |r| > 0.8 threshold.

	Variable	Abbv.	Description	Units	Parameters/Reference
	Elevation	**Elev** *	Elevation obtained from DEMs.	m	Interpolated from LiDAR or PG point cloud files; generalized using B-spline wavelet transforms.
Primary attributes	Slope	**Slope***	*Morphometry*. Local morphometric terrain parameters; proxies for water flow, snow movements, erosion, solar radiation, etc. Eastness and Northness represent the sine and cosine of Aspect, respectively. Curvature is important for understanding variations in terrain.	radians	Method = 9 parameter 2nd order polynomial; unit slope = radian; unit aspect = radian
	Aspect	Asp		radians	
	Eastness	**East***		radians	
	Northness	**North***		radians	
	Profile curvature	Vcu		*1/m*	
	Plan curvature	**Hcu***		*1/m*	
	Total Curvature	Tcu		*1/m*	
Secondary attributes	Downslope distance gradient	DDG	*Morphometry*. Quantify downslope controls on local drainage	gradient (degree)	Vertical distance = 5m
	Vector ruggedness measure	**VRM***	*Morphometry*. Quantifies rugosity with less correlation to slope, indicating a combined variability in slope and aspect. 0 = no terrain variation, 1= complete terrain variation	No unit	Radius = 1 cell
	Topographic Openness Positive	TOP	*Lighting*. Expresses the dominance (positive) or enclosure (negative) of a landscape location, to describe how wide a landscape can be viewed from any position.	radians	Radius = 1000; Method = sectors; Multiscale Factor = 3; Number of sectors =16
	Topographic Openness Negative	TON			

Fill Sinks XXL	FIL	*Preprocessing*. To identify and fill surface depressions in DEMs; for use in hydrologic analyses and modelling.	m	Min. slope degree = 0.1
Total Catchment Area	TCa	*Hydrology*. For use in calculating SWI.	m^2	Suction = 10; Type of Area = square root of TCa; Slope type = Catchment slope; Min Slope = 0; Offset Slope = 0.1; Slope Weighting = 1
Catchment Slope	Cslo		%	
Modified Catchment Area	MCa		m^2	
SAGA Wetness Index	**SWI***	*Hydrology*. Modified version of Topographic Wetness Index (TWI), which is a calculation of the slope and MCa. It predicts soil moisture for cells situated on the valley floor.	MCa/Slo	
Sky view factor	**SVF***	*Lighting*. Ratio of the radiation received by a planar surface to the radiation emitted by the entire hemispheric environment	no unit	Max search radius = 10000; Method = sectors; Multi Scale Factor = 3; Number of sectors = 8
Visible Sky	Vis	*Lighting*. Ratio of the sky area over the obstructed area	no unit	
Diffuse Solar radiation in June/December	Df06/ Df12	*Lighting*. Diffuse insolation in summer	kWh/m^2	Solar Constant = 1367 W/m^2; Shadow = flat; Location = constant lat; Latitude=46.407047°; Atmosphere method = Height of Atmosphere and Vapor Pressure; Atmosphere = 12000m; Time period = 30 days; Day step = 6 days; Hour range = 0-24h; Hour step = 1.
Direct Solar radiation in June/December	Di06/ Di12	*Lighting*. Direct insolation in summer		
Total Solar radiation in June/December	**Ti6***/ Ti12	*Lighting*. Sum of direct and diffuse insolation in summer		June date range: 01-30 June 2015 December data range: 01-30 December 2015
Wind Exposition Index	WEX	*Climate*. Calculates the average wind effect for all directions using an angular step. Values <1= shelter and >1 = exposed.	No unit	Search distance = 300km; Angular step size=15.0deg; Acceleration = 1.5

Table S2: Student *t*-tests for MaxEnt analyses. These were used to determine the technology-resolution combination that is able to best discriminate plant occurrence points at **a)** Para (n=146) and **b)** Martinets (n=100) from 10 000 random background points for each variable at each site. Values indicated are *T*-values, with significance represented by $p \leq 0.05$ = *; $p \leq 0.01$ = **; $p \leq 0.001$ = ***. The most significant technology-resolution combination for each variable is highlighted in yellow.

a) Para

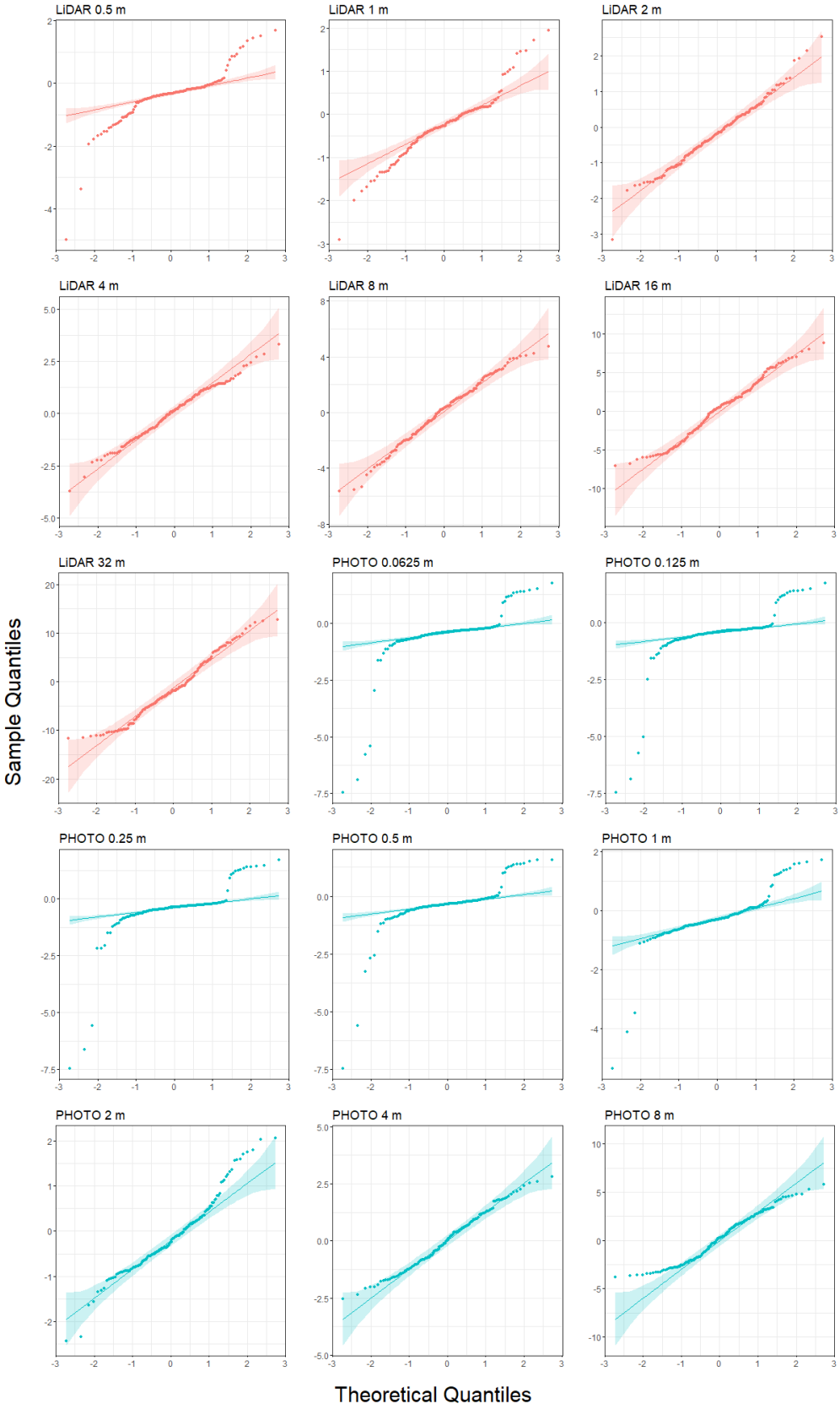
	Photogrammetry								LiDAR						
Variable	**6.25cm**	**12.5cm**	**25cm**	**50cm**	**1m**	**2m**	**4m**	**8m**	**50cm**	**1m**	**2m**	**4m**	**8m**	**16m**	**32m**
Elev	-6.23***	-6.23***	-6.23***	-6.22***	-6.21***	-6.2***	-6.19***	-6.19***	-6.21***	-6.2***	-6.2***	-6.19***	-6.22***	-6.25***	-6.5***
East	3.44***	3.59***	3.69***	3.65***	3.39***	3.6***	2.95**	2.03*	4.8***	5.17***	4.36***	3.14**	1.92	1.67	2.51*
Hcu	0.92	2.03*	3.48***	2.82**	1.67	6.22***	7.75***	9.57***	-0.53	2.75**	7.02***	7.2***	11.05***	10.35***	6.41***
North	-8.06***	-8.3***	-8.39***	-8.59***	-9.55***	-9.64***	-8.82***	-5.41***	-11.35***	-14.1***	-11.04***	-9.91***	-6.54***	-6.17***	-4.38***
Slope	-1.1	-1.84	-2.77**	-3.32**	-3.88***	-4.94***	-6.14***	-7.49***	-3.03**	-3.85***	-5.19***	-6.41***	-7.05***	-7.38***	-8.83***
SVF	4.43***	4.69***	5.03***	5.22***	6.03***	6.35***	6.24***	7.22***	5.35***	5.84***	8.56***	9.33***	11.34***	10.34***	7.9***
SWI	-2.59*	-3.32**	-3.52***	-3.87***	-3.24**	-3.28**	-3.5***	-2.16*	-2.87**	-4.04***	-4.27***	-4.85***	-5.06***	-4.96***	-1.03
Ti06	7.94***	8.36***	8.97***	9.32***	9.48***	9.18***	8.9***	7.59***	10.14***	11.15***	11.19***	11.42***	10.29***	8.76***	7.88***
VRM	-1.16	-1.58	-1.19	-0.29	0.11	-2.37*	-5.28***	-6.47***	0.18	0.48	-1.74	-4.96***	-6.84***	-10.18***	-7.24***

b) Martinets

	Photogrammetry								LiDAR						
Variable	**6.25cm**	**12.5cm**	**25cm**	**50cm**	**1m**	**2m**	**4m**	**8m**	**50cm**	**1m**	**2m**	**4m**	**8m**	**16m**	**32m**
Elev	-3.21**	-3.21**	-3.21**	-3.21**	-3.21**	-3.21**	-3.23**	-3.29**	-3.29**	-3.29**	-3.28**	-3.28**	-3.31**	-3.41***	-3.74***
East	0.07	-0.11	-0.18	0.02	0.08	-0.2	-0.14	-0.21	1.06	1.37	1.29	0.86	0.59	-1.24	-7.34***
Hcu	-2.78**	1.37	1.55	1.08	2.55*	3.27**	4.37***	4.91***	0.24	2.23*	2.77**	6.01***	4.76***	10.42***	11.91***
North	-2.48*	-3.22**	-2.87**	-2.76**	-2.81**	-2.41*	-1.52	-1.15	-4.61***	-4.62***	-3.78***	-2.64**	-1.67	-0.77	3.32**
Slope	0.17	0.25	-0.15	-0.03	-0.79	-2.06*	-2.6*	-0.48	2.09*	1.76	1.03	-0.18	0.75	1.35	3.45***
SVF	2.34*	2.67**	3.33**	3.84***	4.47***	6.08***	6.99***	6.05***	-0.98	0.08	2.19*	3.72***	3.08**	2.04*	-1.32
SWI	-1.28	-5.42***	-4.99***	-4.4***	-5.39***	-4.37***	-3.42***	-4.64***	-8.87***	-7.68***	-6.26***	-4.08***	-5.53***	-9.04***	-6.53***
Ti06	2.1*	2.54*	2.8**	2.88**	3.41***	3.82***	3.46***	1.82	1.55	2.41*	2.66**	2.62*	1.21	-1.15	-5.51***
VRM	0.14	1.75	4.7***	5.73***	3.8***	4.94***	2.93**	-2.54*	10.02***	22.6***	9.98***	0.92	-2.07*	-4.14***	-3.95***

Figure S1: Quantile-quantile (Q-Q) plots for digital elevation model (DEM) vertical error. Error (Δh; meters) was calculated as the difference between the elevation measured at assessment points at **a)** Para (n=157) and **b)** Martinets (n=110) with the elevation estimated from the DEMs acquired from LiDAR or photogrammetry (PHOTO) technologies generalised to multiple resolutions. The technology and resolution for the DEM is noted at the top of each Q-Q plot.

a) Para



b) Martinets

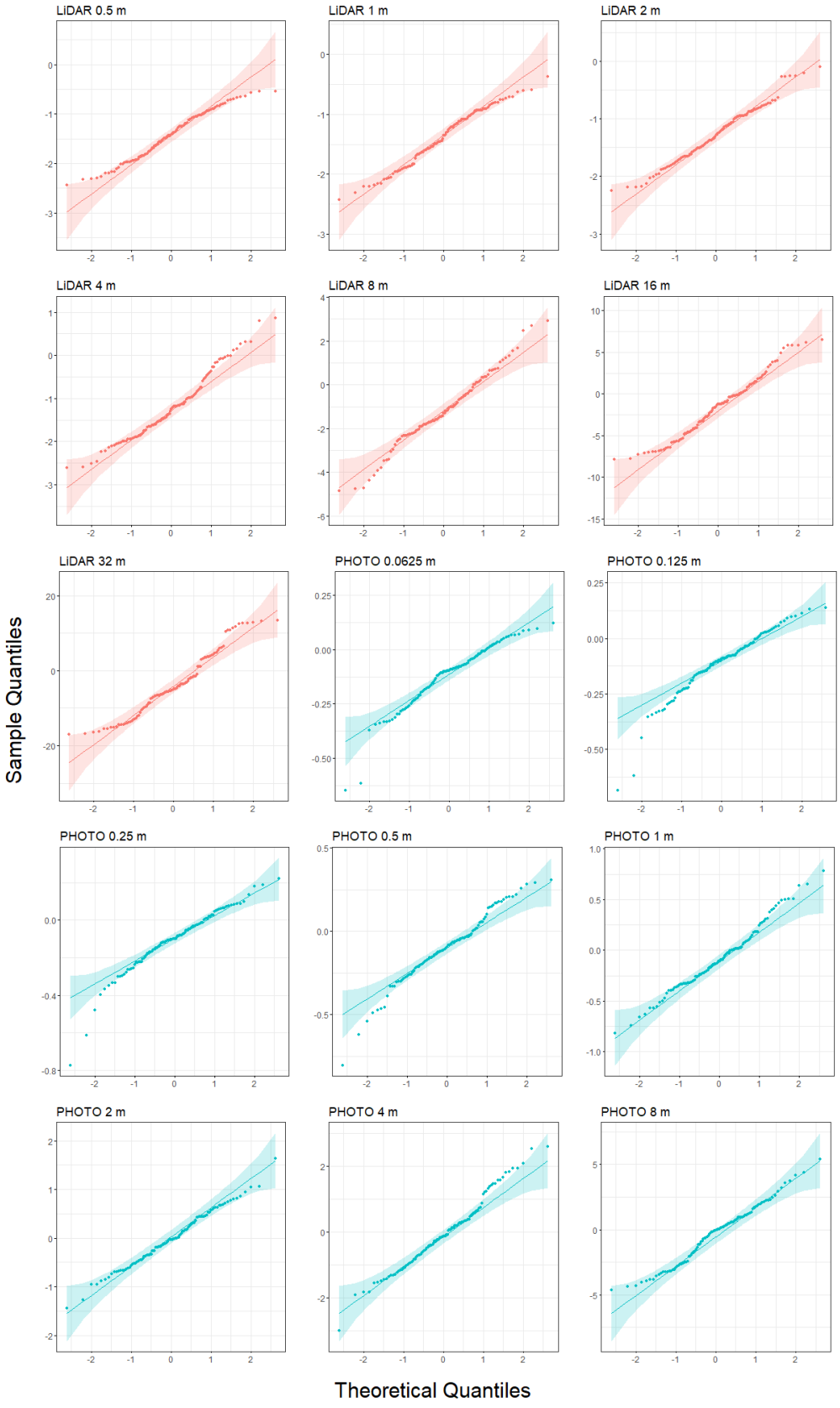

LiDAR 0.5 m
LiDAR 1 m
LiDAR 2 m
LiDAR 4 m
LiDAR 8 m
LiDAR 16 m
LiDAR 32 m
PHOTO 0.0625 m
PHOTO 0.125 m
PHOTO 0.25 m
PHOTO 0.5 m
PHOTO 1 m
PHOTO 2 m
PHOTO 4 m
PHOTO 8 m
Sample Quantiles
Theoretical Quantiles

Table S3: Summary results ranking MaxEnt species distribution models (SDM) to determine optimal parameters. Feature class (FC: L = linear only; LP = linear and product; LQ = linear and quadratic; LPQ =linear, product and quadratic) and regularization multiplier (RM: 1, 2, 5 and 10) were assessed. *Arabis alpina* distribution across the Para and Martinets sites were predicted based on plant presence-only points (Para: n=146; Martinets: n=100) and 10 000 random background points at each site. The optimal spatial resolution for each variable as determined in **Table S2** was used as input environmental variables. Each MaxEnt model was run 20 times (75% training points, 25% testing points) and mean diagnostic values are shown here. Models were assessed using the mean Area Under the Receiver Operating Curve (Fielding and Bell, 1997) based on the test data (AUC_{test}), as well mean sample size corrected Akaike Information Criterion (AICc; Akaike, 1974). For each site, we ranked the FC-RM combination by AUC_{test} and AICc separately, then determined the optimal FC-RM combination as the model resulting in the lowest sum of these ranks (Overall Rank). The top three ranked models at each site are highlighted in yellow.

Site	FC	RM	AUC_{test}		AICc		Rank AUC_{test}	Rank AICc	Sum of ranks	Overall Rank
			mean	sd	mean	sd				
Para	L	1	0.860	0.027	1768.9	12.9	14	13	27	13
	L	2	0.861	0.030	1768.9	11.5	13	14	27	13
	L	5	0.853	0.039	1768.5	15.2	16	12	28	15
	L	10	0.856	0.033	1782.9	12.9	15	16	31	16
	LP	1	0.906	0.022	1710.5	14.1	3	6	9	4
	LP	2	0.886	0.025	1721.3	14.3	6	8	14	7
	LP	5	0.874	0.029	1748.7	12.8	8	11	19	10
	LP	10	0.867	0.032	1772.6	13.5	11	15	26	12
	LQ	1	0.887	0.030	1677.8	13.8	5	3	8	3
	LQ	2	0.884	0.030	1681.5	15.2	7	4	11	6
	LQ	5	0.869	0.026	1713.6	12.2	10	7	17	8
	LQ	10	0.865	0.040	1743.6	18.4	12	10	22	11
	LPQ	1	0.933	0.028	1631.8	11.8	1	1	2	1
	LPQ	2	0.922	0.028	1664.7	12.8	2	2	4	2
	LPQ	5	0.902	0.027	1705.4	13.6	4	5	9	4
	LPQ	10	0.874	0.033	1734.1	13.7	9	9	18	9
Martinets	L	1	0.887	0.027	1178.7	11.3	10	10	20	11
	L	2	0.886	0.028	1181.0	9.2	12	11	23	12
	L	5	0.892	0.028	1189.1	9.3	5	12	17	9
	L	10	0.876	0.030	1192.2	9.8	15	14	29	14
	LP	1	0.887	0.020	1153.9	9.3	9	2	11	5
	LP	2	0.892	0.017	1169.3	10.6	6	6	12	6
	LP	5	0.889	0.018	1175.5	9.4	8	8	16	7
	LP	10	0.878	0.023	1197.7	9.0	13	16	29	14
	LQ	1	0.905	0.022	1156.3	9.1	3	4	7	2
	LQ	2	0.907	0.024	1161.2	11.4	2	5	7	2
	LQ	5	0.887	0.022	1172.6	7.7	11	7	18	10
	LQ	10	0.877	0.031	1192.0	10.0	14	13	27	13
	LPQ	1	0.913	0.023	1150.2	12.3	1	1	2	1
	LPQ	2	0.903	0.019	1154.2	12.7	4	3	7	2
	LPQ	5	0.892	0.027	1178.2	12.6	7	9	16	7
	LPQ	10	0.868	0.029	1193.1	10.5	16	15	31	16

Table S4: Summary statistics of digital elevation model (DEM) vertical error. DEMs were produced using either LiDAR or photogrammetry (PHOTO) technologies and generalized to different spatial resolutions, where DEM vertical error was calculated as the difference between the elevation measured at assessment points at **a)** Para (n=157) and **b)** Martinets (n=110) with the elevation estimated from the DEMs. All values are in meters. Measures of statistics assuming a normal distribution were recalculated with outliers removed, using an outlier threshold of 3*RMSE. *St dev* = standard deviation. *RMSE* = root mean square error. *NMAD* = normalized median absolute deviation.

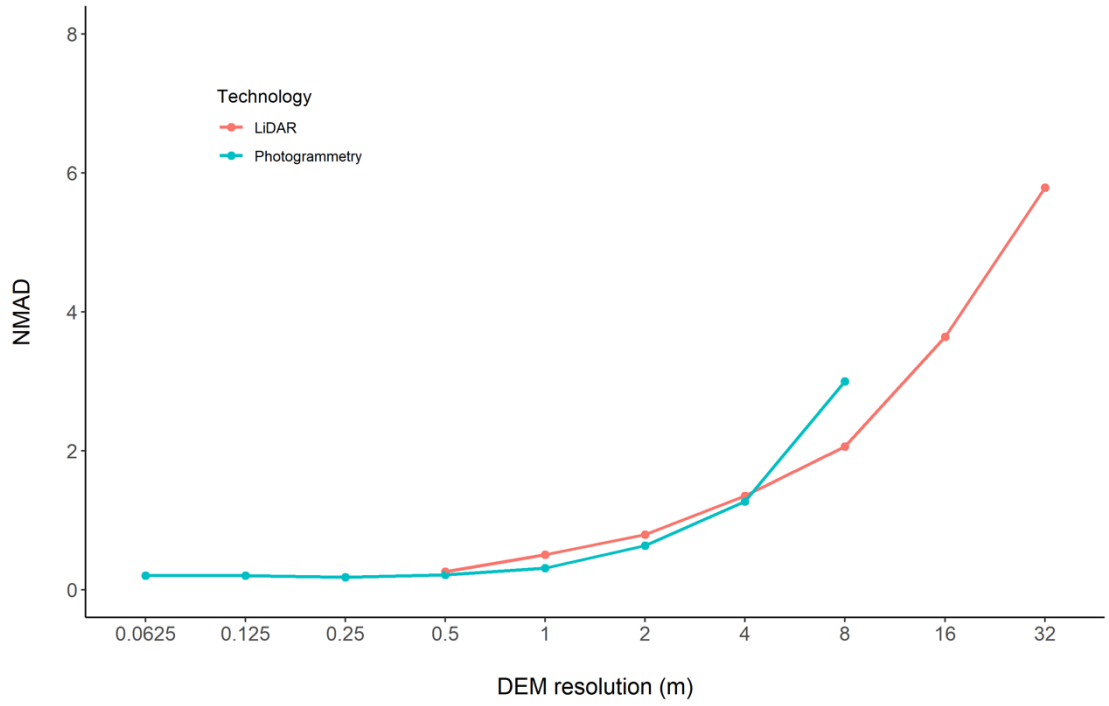
a)

Para (n=157)		**0.0625**	**0.125**	**0.25**	**0.5**	**1**	**2**	**4**	**8**	**16**	**32**
Outliers (n)	LiDAR				2	1	1	1	0	0	0
	PHOTO	4	4	3	3	3	2	0	0		
Minimum	LiDAR				-5.0	-2.9	-3.2	-3.7	-5.7	-7.2	-11.6
	PHOTO	-7.5	-7.5	-7.5	-7.5	-5.4	-2.4	-2.6	-3.8		
Maximum	LiDAR				1.7	1.9	2.5	3.3	4.7	8.7	12.7
	PHOTO	1.7	1.7	1.7	1.6	1.7	2.1	2.8	5.8		
Mean	LiDAR				-0.4	-0.3	-0.2	0.1	0.1	0.1	-1.5
	PHOTO	-0.5	-0.5	-0.5	-0.4	-0.3	-0.2	0.0	0.2		
Mean absolute	LiDAR				0.6	0.5	0.7	1.0	1.7	3.0	5.0
	PHOTO	0.7	0.7	0.7	0.6	0.5	0.6	1.0	2.1		
St dev	LiDAR				0.7	0.7	0.8	1.2	2.1	3.6	5.9
	PHOTO	1.1	1.1	1.0	1.0	0.8	0.8	1.2	2.4		
RMSE	LiDAR				0.8	0.7	0.9	1.2	2.1	3.6	6.1
	PHOTO	1.2	1.2	1.1	1.0	0.8	0.8	1.2	2.4		
Median	LiDAR				-0.3	-0.3	-0.2	0.1	0.3	0.5	-1.9
	PHOTO	-0.4	-0.4	-0.4	-0.4	-0.3	-0.2	0.0	0.3		
NMAD	LiDAR				0.3	0.5	0.8	1.4	2.1	3.6	5.8
	PHOTO	0.2	0.2	0.2	0.2	0.3	0.6	1.3	3.0		

b)

Martinets (n=110)		**0.0625**	**0.125**	**0.25**	**0.5**	**1**	**2**	**4**	**8**	**16**	**32**
Outliers (n)	LiDAR				0	0	0	0	0	0	0
	PHOTO	2	2	2	1	0	1	0	0		
Minimum	LiDAR				-2.4	-2.4	-2.3	-2.6	-4.9	-7.9	-17.0
	PHOTO	-0.7	-0.7	-0.8	-0.8	-0.8	-1.5	-3.0	-4.6		
Maximum	LiDAR				-0.5	-0.4	-0.1	0.9	2.9	6.5	13.4
	PHOTO	0.1	0.1	0.2	0.3	0.8	1.6	2.6	5.4		
Mean	LiDAR				-1.4	-1.4	-1.3	-1.2	-1.2	-1.6	-3.9
	PHOTO	-0.1	-0.1	-0.1	-0.1	-0.1	0.0	-0.1	-0.4		
Mean absolute	LiDAR				1.4	1.4	1.3	1.3	1.6	3.1	7.6
	PHOTO	0.1	0.1	0.1	0.2	0.3	0.4	0.8	1.7		
St dev	LiDAR				0.5	0.5	0.5	0.8	1.5	3.5	8.0
	PHOTO	0.1	0.1	0.2	0.2	0.3	0.5	1.0	2.2		
RMSE	LiDAR				1.5	1.5	1.4	1.4	1.9	3.9	8.9
	PHOTO	0.2	0.2	0.2	0.2	0.3	0.5	1.0	2.2		
Median	LiDAR				-1.4	-1.4	-1.3	-1.3	-1.4	-1.3	-5.0
	PHOTO	-0.1	-0.1	-0.1	-0.1	-0.1	0.0	-0.1	-0.1		
NMAD	LiDAR				0.6	0.5	0.5	0.7	1.3	3.7	7.4
	PHOTO	0.1	0.1	0.1	0.2	0.3	0.6	0.9	2.1		

a) Para



b) Martinets

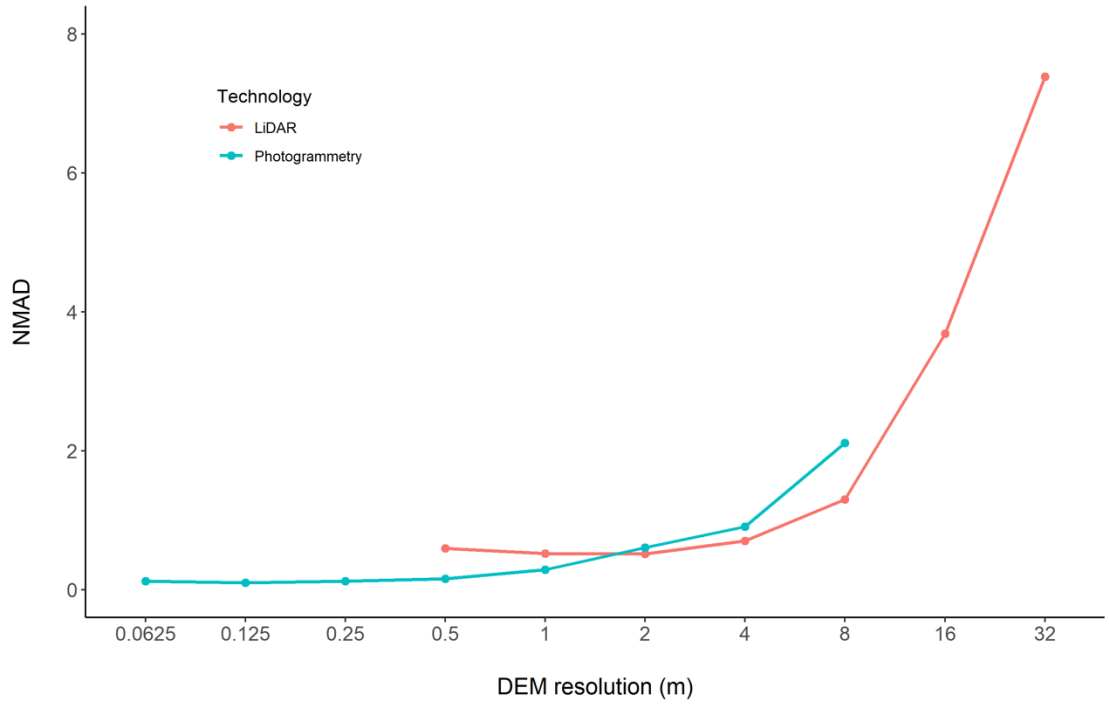


Figure S2: Normalized median absolute deviation (NMAD; meters) of digital elevation model (DEM) vertical error. Error (Δh; meters) was calculated as the difference between the elevation measured at assessment points at **a)** Para (n=157) and **b)** Martinets (n=110) with the elevation estimated from the DEMs acquired from LiDAR or photogrammetry technologies generalized to multiple resolutions.

Table S5: Spearman correlation r_s between pairs of independent derived variables. Variables were derived from LiDAR and photogrammetry DEMs, at a range of spatial resolutions for **a)** Para and **b)** Martinets. Abbreviations are as follows: eastness (East), plan curvature (Hcu), northness (Nrth), slope (Slo), sky view factor (SVF), SAGA wetness index (SWI), total irradiance in June (Ti6), and vector ruggedness measure (VRM). Correlations $|r_s| \geq 0.8$ are highlighted in yellow.

a) Para

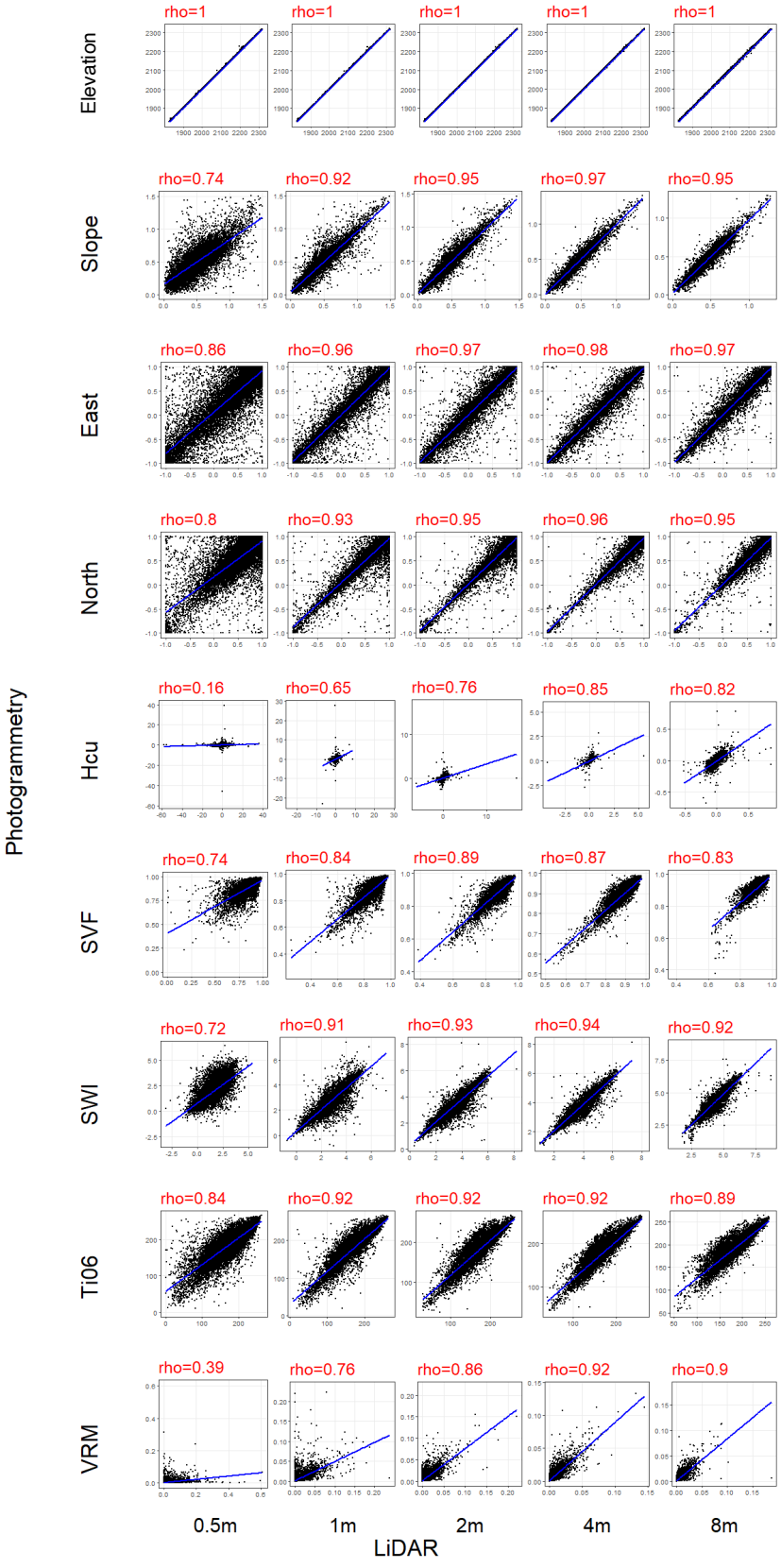
		Photogrammetry								LiDAR						
	Resolution (m)	**0.0625**	**0.125**	**0.25**	**0.5**	**1**	**2**	**4**	**8**	**0.5**	**1**	**2**	**4**	**8**	**16**	**32**
east	Hcu	0.00	0.00	0.01	0.01	0.02	0.03	0.03	0.04	0.00	0.02	0.05	0.06	0.06	0.07	0.11
east	north	-0.64	-0.65	-0.66	-0.66	-0.68	-0.72	-0.76	-0.81	-0.62	-0.69	-0.72	-0.76	-0.82	-0.88	-0.94
east	Slo	-0.05	-0.06	-0.07	-0.08	-0.08	-0.08	-0.07	-0.06	-0.05	-0.06	-0.06	-0.06	-0.04	0.00	0.07
east	SVF	0.10	0.12	0.13	0.15	0.19	0.14	0.05	0.02	0.14	0.16	0.16	0.12	0.11	0.02	-0.16
east	SWI	0.19	0.19	0.19	0.19	0.18	0.16	0.13	0.10	0.18	0.18	0.15	0.14	0.12	-0.04	-0.22
east	Ti06	0.39	0.42	0.45	0.49	0.50	0.52	0.53	0.55	0.49	0.55	0.58	0.60	0.62	0.64	0.64
east	VRM	-0.03	-0.01	-0.06	-0.19	-0.28	-0.35	-0.38	-0.38	-0.14	-0.22	-0.30	-0.34	-0.37	-0.45	-0.33
Hcu	north	-0.01	-0.02	-0.02	-0.02	-0.03	-0.05	-0.04	-0.05	-0.02	-0.02	-0.06	-0.07	-0.07	-0.07	-0.06
Hcu	Slo	0.01	0.03	0.05	0.05	0.07	0.05	0.06	0.09	0.02	0.05	0.06	0.09	0.10	0.09	0.05
Hcu	SVF	0.01	0.03	0.03	0.04	0.04	0.06	0.06	0.09	0.05	0.03	0.04	0.05	0.11	0.17	0.26
Hcu	SWI	-0.10	-0.17	-0.24	-0.30	-0.33	-0.36	-0.41	-0.48	-0.23	-0.27	-0.34	-0.42	-0.50	-0.51	-0.38
Hcu	Ti06	0.01	0.02	0.01	0.01	0.01	0.04	0.03	0.04	0.02	0.01	0.04	0.04	0.06	0.08	0.12
Hcu	VRM	0.01	0.01	0.02	0.01	-0.01	-0.04	-0.05	-0.07	0.00	-0.02	-0.04	-0.06	-0.08	-0.17	-0.39
north	Slo	0.07	0.07	0.08	0.09	0.09	0.09	0.08	0.08	0.04	0.06	0.06	0.06	0.06	0.01	-0.10
north	SVF	0.10	0.11	0.11	0.07	-0.01	0.07	0.13	0.11	0.16	0.12	0.07	0.08	0.04	0.09	0.25
north	SWI	-0.04	-0.03	-0.03	-0.03	-0.04	-0.04	-0.03	-0.02	-0.01	-0.04	-0.04	-0.03	-0.03	0.11	0.25
north	Ti06	-0.52	-0.54	-0.58	-0.61	-0.62	-0.63	-0.62	-0.62	-0.59	-0.63	-0.64	-0.65	-0.66	-0.65	-0.61
north	VRM	0.03	0.02	0.03	0.03	0.12	0.22	0.27	0.30	-0.03	0.06	0.15	0.23	0.29	0.37	0.24
Slo	SVF	-0.75	-0.76	-0.76	-0.75	-0.77	-0.76	-0.76	-0.77	-0.69	-0.66	-0.69	-0.67	-0.65	-0.67	-0.68
Slo	SWI	-0.28	-0.31	-0.35	-0.41	-0.44	-0.46	-0.46	-0.40	-0.36	-0.44	-0.45	-0.45	-0.40	-0.30	-0.29
Slo	Ti06	-0.75	-0.74	-0.72	-0.70	-0.70	-0.70	-0.71	-0.72	-0.64	-0.62	-0.62	-0.62	-0.61	-0.59	-0.56
Slo	VRM	0.55	0.29	0.20	0.14	0.09	0.06	0.05	0.02	0.22	0.15	0.09	0.05	0.02	-0.06	-0.06
SVF	SWI	0.27	0.30	0.32	0.34	0.37	0.30	0.26	0.17	0.34	0.30	0.29	0.24	0.13	0.05	0.04
SVF	Ti06	0.64	0.62	0.60	0.59	0.64	0.56	0.52	0.54	0.54	0.54	0.57	0.54	0.55	0.52	0.38
SVF	VRM	-0.42	-0.24	-0.22	-0.25	-0.24	-0.18	-0.09	-0.07	-0.36	-0.24	-0.17	-0.10	-0.09	-0.07	-0.19
SWI	Ti06	0.25	0.26	0.27	0.29	0.30	0.30	0.29	0.25	0.27	0.29	0.27	0.25	0.19	0.01	-0.12
SWI	VRM	-0.19	-0.17	-0.19	-0.26	-0.24	-0.22	-0.16	-0.08	-0.30	-0.25	-0.23	-0.16	-0.08	0.03	0.09
Ti06	VRM	-0.45	-0.24	-0.18	-0.16	-0.18	-0.21	-0.21	-0.20	-0.21	-0.17	-0.19	-0.20	-0.22	-0.25	-0.24

b) Martinets

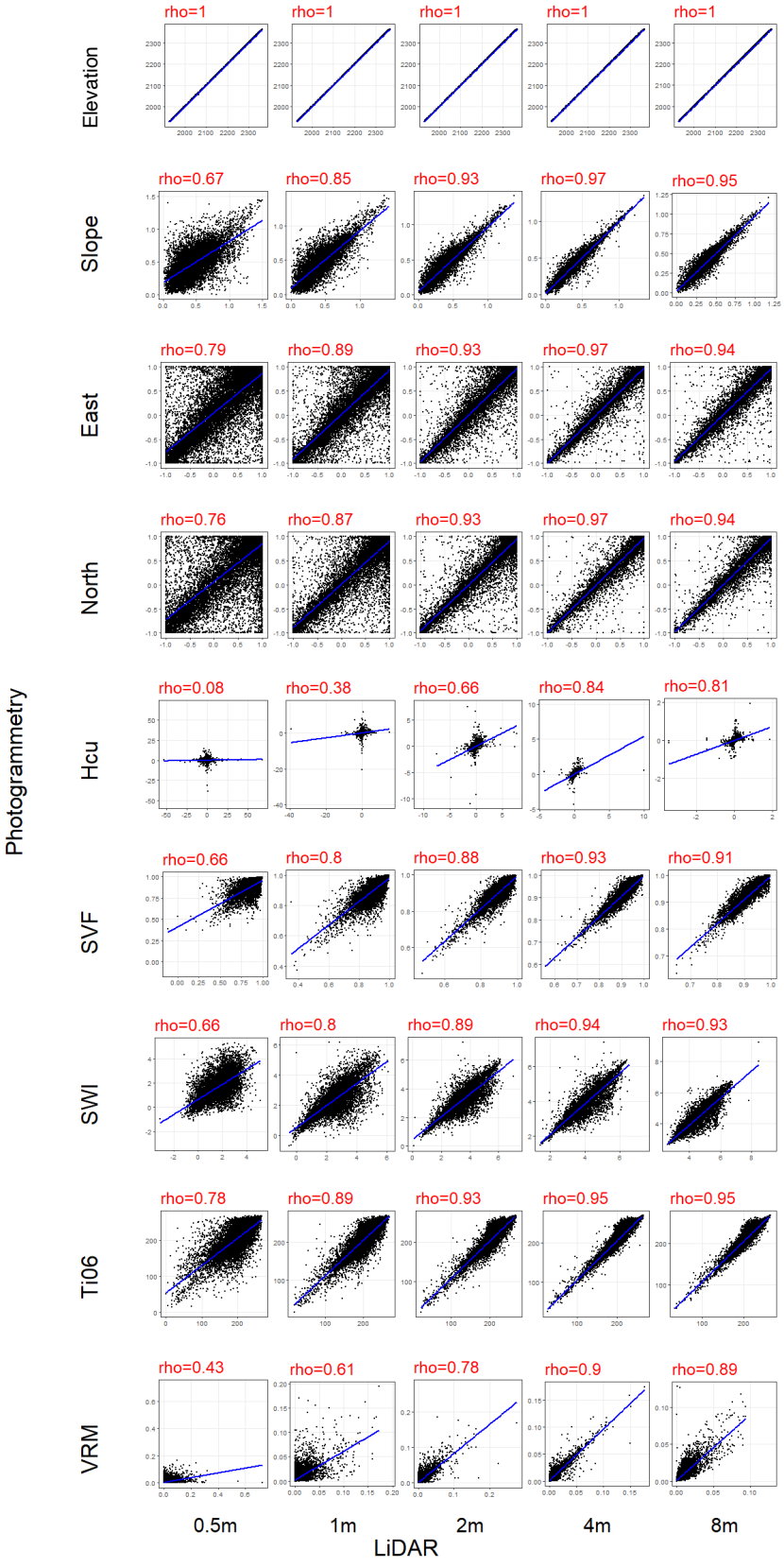
		Photogrammetry								LiDAR						
	Resolution (m)	**0.0625**	**0.125**	**0.25**	**0.5**	**1**	**2**	**4**	**8**	**0.5**	**1**	**2**	**4**	**8**	**16**	**32**
east	Hcu	-0.02	0.00	-0.01	-0.01	-0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.02
east	north	-0.38	-0.41	-0.43	-0.45	-0.49	-0.53	-0.57	-0.63	-0.46	-0.51	-0.55	-0.59	-0.65	-0.73	-0.85
east	Slo	0.01	0.00	0.00	-0.01	-0.03	-0.07	-0.09	-0.14	0.00	-0.02	-0.06	-0.10	-0.14	-0.17	-0.26
east	SVF	0.07	0.06	0.05	0.06	0.06	0.08	0.10	0.12	-0.01	-0.06	-0.02	0.02	0.01	0.03	0.11
east	SWI	-0.08	-0.05	-0.04	-0.01	0.02	0.06	0.07	0.08	-0.08	-0.03	0.03	0.07	0.08	0.10	0.17
east	Ti06	0.32	0.37	0.39	0.42	0.46	0.50	0.53	0.58	0.36	0.40	0.45	0.50	0.54	0.59	0.62
east	VRM	-0.02	0.05	0.09	0.08	0.08	0.10	0.10	0.07	0.13	0.17	0.20	0.16	0.10	0.10	0.15
Hcu	north	0.00	-0.01	-0.01	-0.01	0.00	-0.01	-0.02	-0.03	-0.01	-0.02	-0.02	-0.02	-0.03	-0.01	-0.02
Hcu	Slo	0.00	0.03	0.03	0.04	0.02	0.04	0.05	0.07	0.04	0.06	0.11	0.10	0.08	0.08	0.08
Hcu	SVF	0.06	0.03	0.04	0.05	0.06	0.08	0.11	0.12	0.03	0.01	0.00	0.04	0.08	0.13	0.11
Hcu	SWI	-0.22	-0.25	-0.32	-0.35	-0.34	-0.35	-0.39	-0.43	-0.23	-0.29	-0.38	-0.42	-0.43	-0.45	-0.47
Hcu	Ti06	0.02	0.01	0.01	0.01	0.01	0.01	0.02	0.02	-0.01	-0.01	-0.03	-0.01	0.01	0.03	0.03
Hcu	VRM	0.00	0.01	0.03	0.03	0.01	0.00	-0.01	-0.04	0.01	0.00	0.00	0.00	-0.02	-0.01	-0.04
north	Slo	0.01	-0.02	-0.02	-0.02	-0.02	-0.02	0.01	0.04	-0.07	-0.07	-0.04	0.00	0.05	0.13	0.26
north	SVF	0.17	0.21	0.22	0.21	0.20	0.17	0.15	0.10	0.33	0.34	0.29	0.25	0.22	0.11	-0.06
north	SWI	0.08	0.13	0.13	0.13	0.14	0.12	0.11	0.11	0.23	0.22	0.17	0.13	0.11	0.03	-0.12
north	Ti06	-0.63	-0.67	-0.69	-0.71	-0.72	-0.72	-0.72	-0.73	-0.61	-0.64	-0.66	-0.68	-0.69	-0.72	-0.72
north	VRM	-0.07	-0.12	-0.13	-0.11	-0.09	-0.09	-0.11	-0.11	-0.22	-0.21	-0.20	-0.18	-0.14	-0.14	-0.14
Slo	SVF	-0.76	-0.74	-0.74	-0.75	-0.75	-0.77	-0.78	-0.80	-0.76	-0.78	-0.78	-0.78	-0.79	-0.80	-0.87
Slo	SWI	-0.64	-0.36	-0.39	-0.45	-0.51	-0.55	-0.55	-0.50	-0.50	-0.57	-0.58	-0.55	-0.50	-0.38	-0.17
Slo	Ti06	-0.63	-0.57	-0.56	-0.55	-0.54	-0.54	-0.56	-0.58	-0.55	-0.53	-0.54	-0.55	-0.58	-0.60	-0.71
Slo	VRM	0.44	0.22	0.03	-0.08	-0.17	-0.23	-0.23	-0.19	0.21	0.05	-0.07	-0.13	-0.15	-0.18	-0.32
SVF	SWI	0.56	0.34	0.33	0.33	0.34	0.33	0.31	0.23	0.45	0.46	0.42	0.33	0.27	0.15	-0.05
SVF	Ti06	0.50	0.41	0.38	0.37	0.35	0.37	0.38	0.41	0.34	0.27	0.30	0.31	0.33	0.39	0.53
SVF	VRM	-0.48	-0.37	-0.25	-0.15	-0.05	0.01	0.01	-0.05	-0.40	-0.21	-0.09	-0.07	-0.07	-0.01	0.13
SWI	Ti06	0.39	0.16	0.15	0.16	0.17	0.19	0.19	0.13	0.16	0.17	0.19	0.18	0.14	0.10	0.06
SWI	VRM	-0.41	-0.34	-0.28	-0.17	-0.07	0.03	0.08	0.10	-0.38	-0.25	-0.07	0.03	0.11	0.06	0.15
Ti06	VRM	-0.31	-0.14	0.00	0.06	0.10	0.14	0.14	0.11	-0.05	0.09	0.15	0.16	0.14	0.20	0.31

Figure S3: Scatterplots of Elevation and derived variables from LiDAR and photogrammetry. The values for the eight independent digital elevation model (DEM) derived variables (plot rows) for **a)** Para and **b)** Martinets, produced by LiDAR (*x*-axes) and photogrammetry (*y*-axes) at the common resolutions of 50cm, 1m, 2m, 4m, and 8m (plot columns), as assessed from 15 000 random points. Regression lines are shown in blue, and Spearman r_s (rho) correlation coefficients are marked at the top left-hand corner of plots. All correlations have *p*-values <0.001.

a) Para



b) Martinets


Photogrammetry
Elevation
Slope
East
North
Hcu
SVF
SWI
Ti06
VRM
rho=1
rho=0.67
rho=0.85
rho=0.93
rho=0.97
rho=0.95
rho=0.79
rho=0.89
rho=0.93
rho=0.97
rho=0.94
rho=0.76
rho=0.87
rho=0.93
rho=0.97
rho=0.94
rho=0.08
rho=0.38
rho=0.66
rho=0.84
rho=0.81
rho=0.66
rho=0.8
rho=0.88
rho=0.93
rho=0.91
rho=0.66
rho=0.8
rho=0.89
rho=0.94
rho=0.93
rho=0.78
rho=0.89
rho=0.93
rho=0.95
rho=0.95
rho=0.43
rho=0.61
rho=0.78
rho=0.9
rho=0.89
0.5m
1m
2m
4m
8m
LiDAR