

Mobilo (dronu) LiDAR datu korelācijas izpēte ar LAI un citiem veģetācijas indeksiem.

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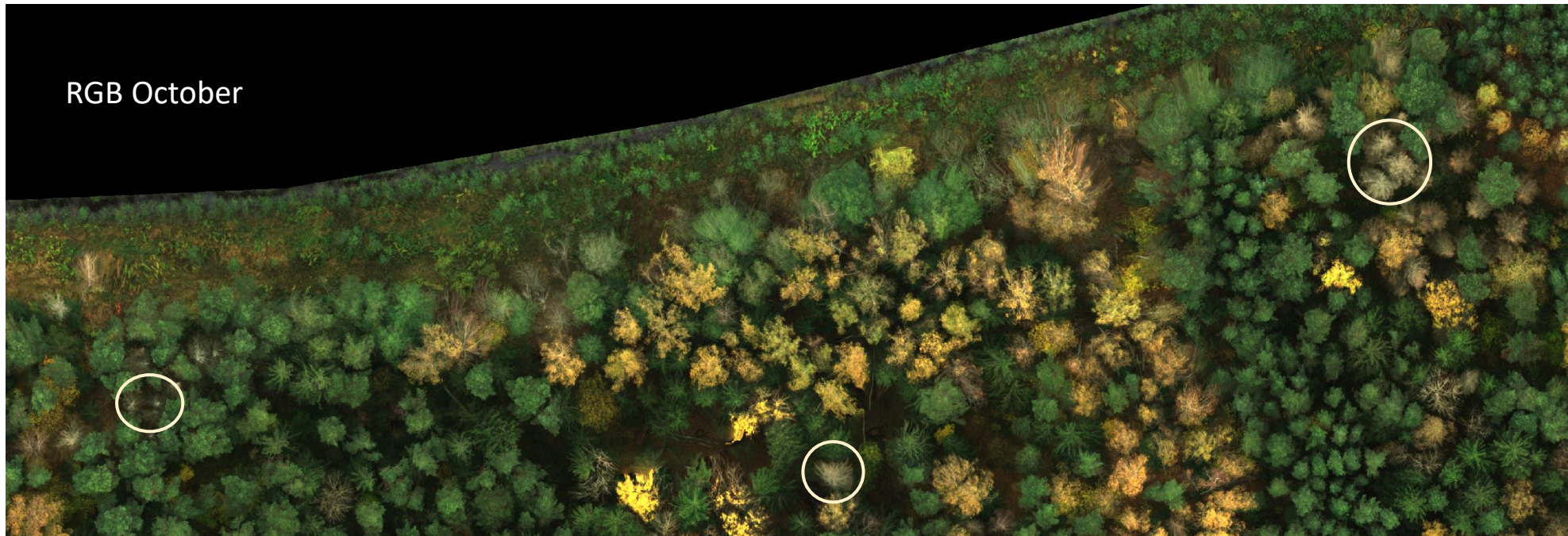
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**“Uz tālīzpēti balstīta meža riska faktoru uzraudzības
sistēma (Forest Risk)”**

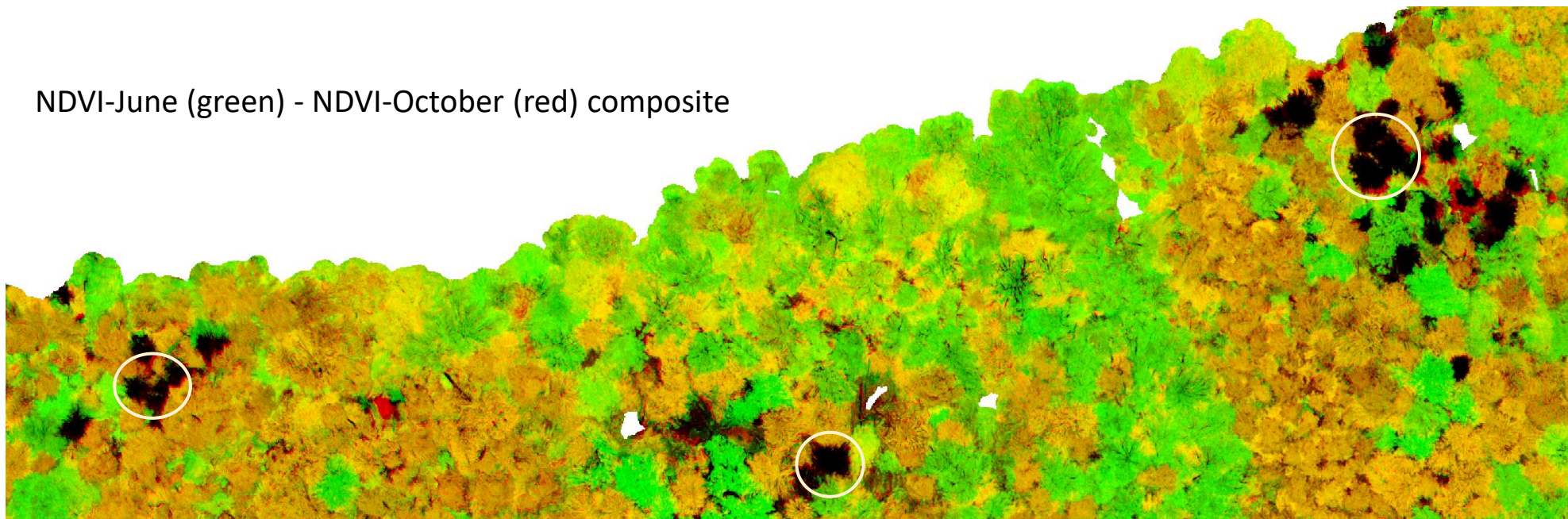
(CFLA) Nr.1.1.1.1/21/A/40

Vegetation indexes vs defoliation

RGB October



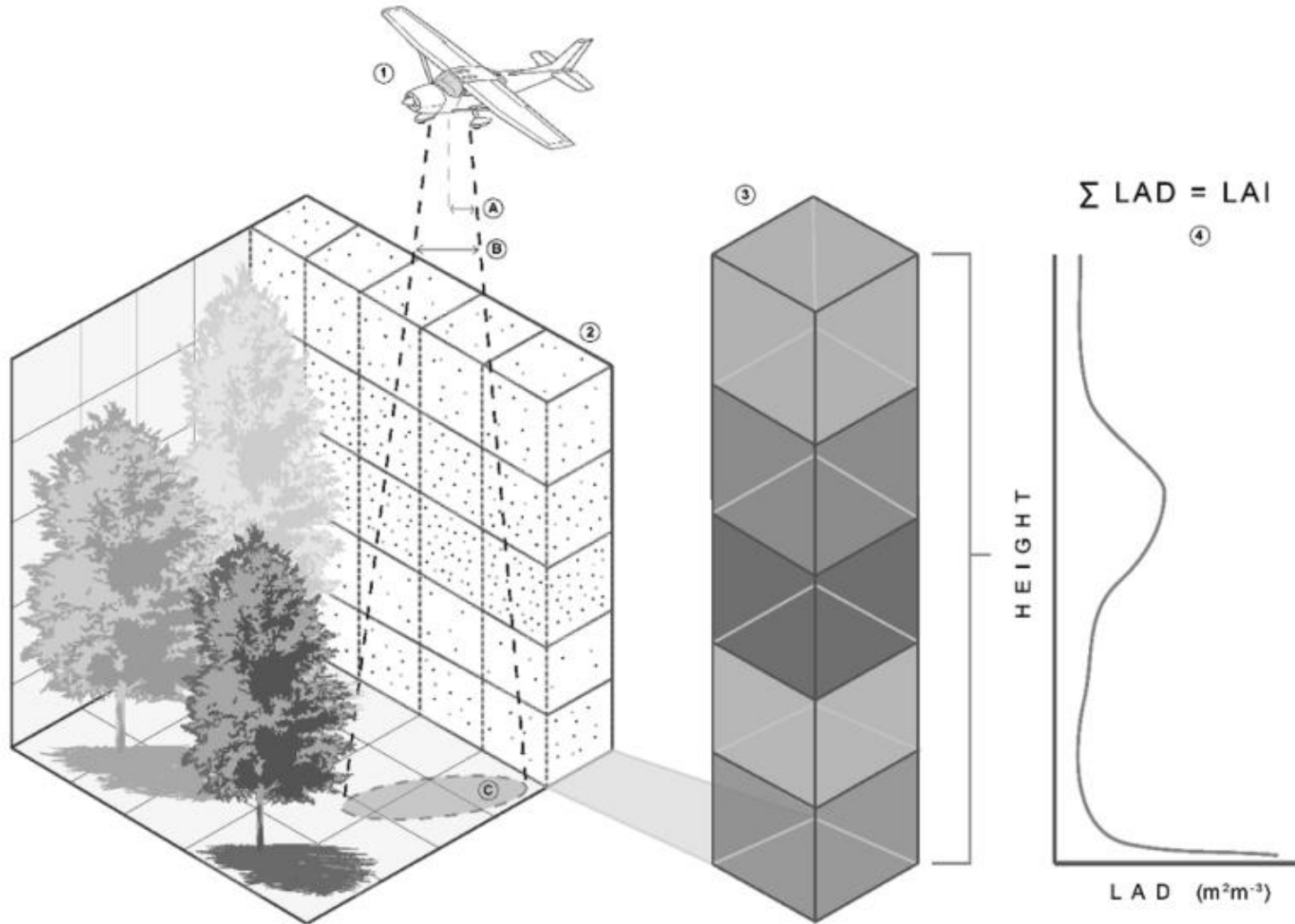
NDVI-June (green) - NDVI-October (red) composite



canopyLazR - R package to estimate leaf area density (LAD), leaf area index (LAI), and forest structural attributes from airborne LiDAR point clouds.

A.G. Kamoske et al.

Forest Ecology and Management 433 (2019) 364–375



Leaf area density (LAD)

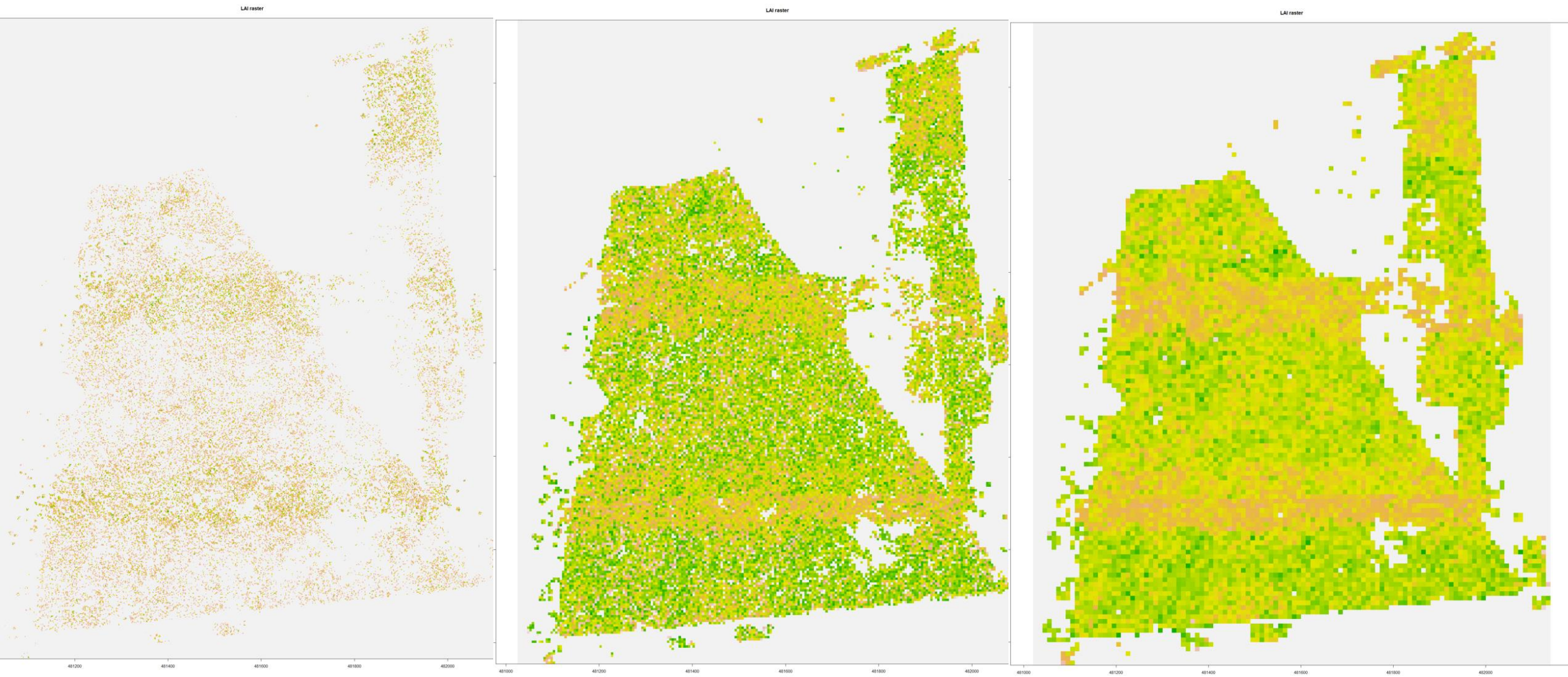
the total leaf area per unit of volume

$$LAD_{i-1,i} = \ln\left(\frac{S_e}{S_t}\right) \frac{1}{k\Delta z}$$

S_e is the number of pulses entering the given voxel
 S_t is the number of pulses exiting the same voxel

Kamoske, Aaron G., Kyla M. Dahlin, Scott C. Stark, and Shawn P. Serbin. "Leaf area density from airborne LiDAR: Comparing sensors and resolutions in a temperate broadleaf forest ecosystem." *Forest Ecology and Management* 433 (2019): 364-375.

LAI - LGIA ALS 7pts/m2

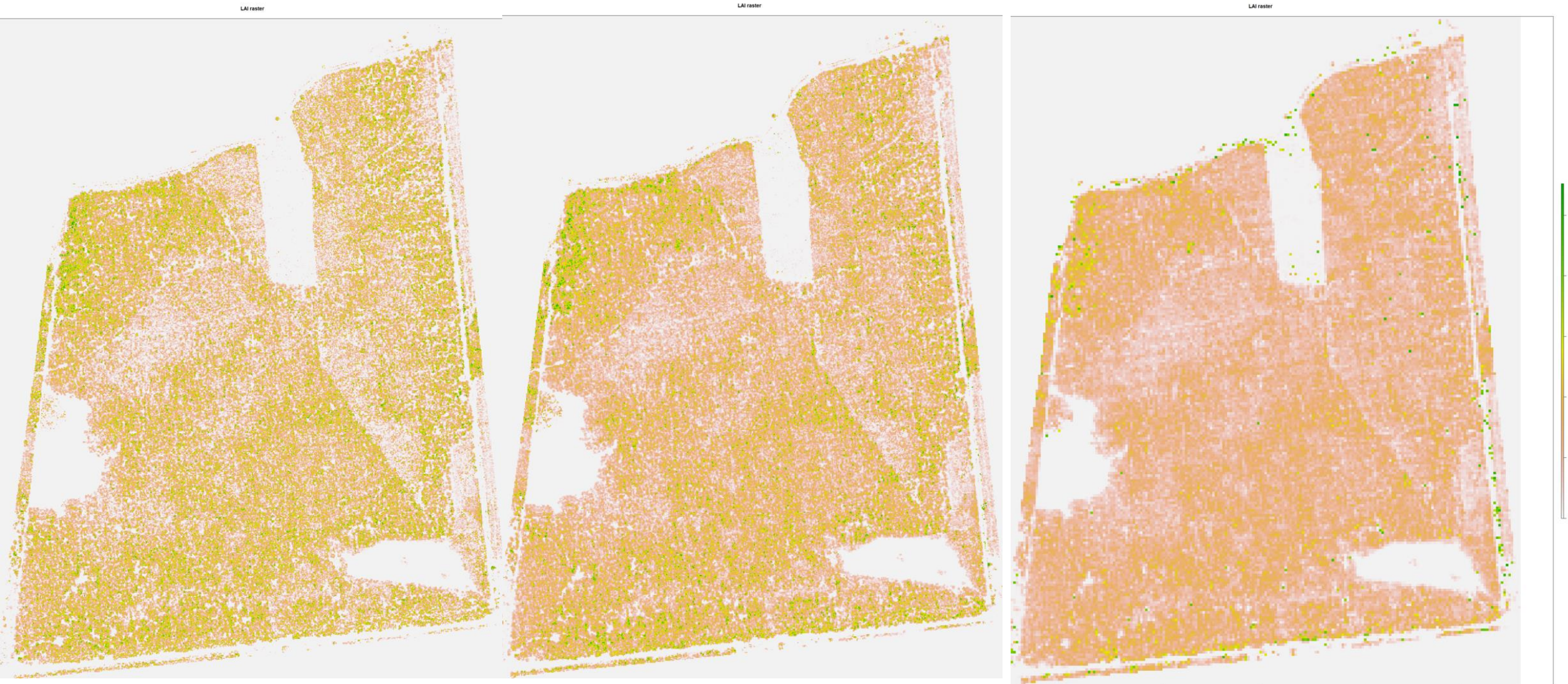


1m x 1m

5 x 5

10 x 10

LAI - UAV ALS_S04_Sept 400pts/m2



1m x 1m

2 x 2

5 x 5

September vs October - *Filled voxel volume raster*

filled voxel volume raster



filled voxel volume raster



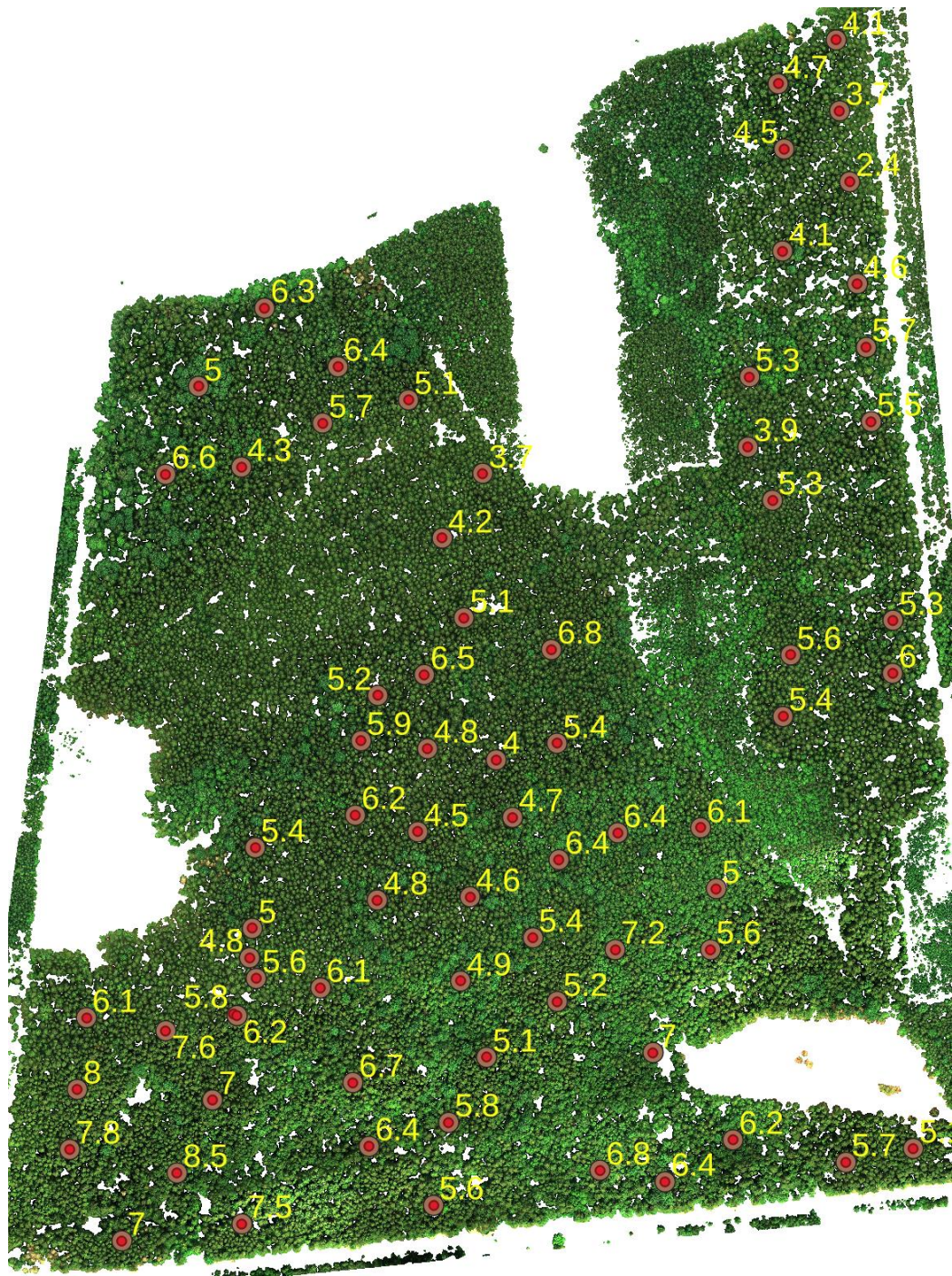
canopyLazR - Total leaf area in the euphotic zone for each column



July

September

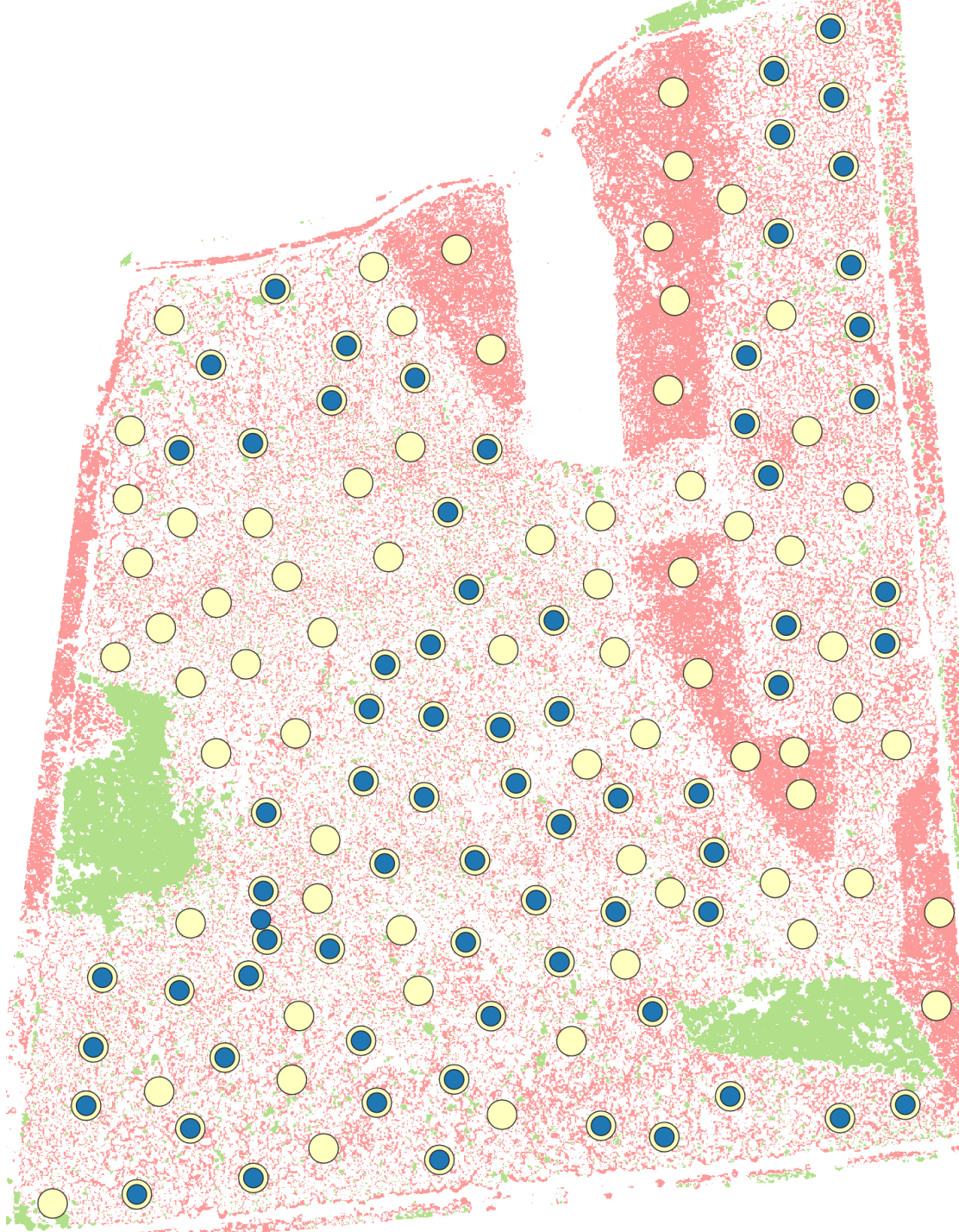
October



LAI field data acquisition

«The LAI-2000 instrument uses five concentric rings centred at zenith angles of 7°, 22°, 38°, 52°, and 68° observing below canopy radiation levels in the blue band (320–490 nm). These data are combined with above canopy readings to compute an estimate of gap fraction (transmittance) from each sensor ring. LAI is then obtained by inversion of the Beer-Lambert law (LICOR, 2015).»

LAI field area: 500 - 1000 m²



Two sets of circular plots:

10 m radius - 300 m²

15 m radius - 700 m²

Collected statistics (mean):

LAI_{voxel} (canopyLazR);

DjiP4 drone imagery indexes (June, July, September);

Sentinel 2 indexes (July, September);



Field LAI plots



Extra plots

Correlation tests - 70 circular plots– 700m²

Coefficients of determination (R²)

Variables	LAI field	ALS_S02_LAI	ALS_S04_LAI
Field LAI	1	0.127	0.180
ALS_S02_LAI (Mean)	0.127	1	0.662
ALS_S04_LAI (MEAN)	0.180	0.662	1
EVI_s01	0.070	0.486	0.261
GDVI_s01	0.022	0.310	0.127
GLI_s01	0.000	0.128	0.003
GNDVI_s01	0.045	0.410	0.193
NDVI_s01	0.024	0.391	0.105
NDVI_s02	0.104	0.481	0.142
NDVI_s04	0.125	0.016	0.001
RVI_s01	0.021	0.383	0.100
SIPI_s01	0.012	0.395	0.131
VARIgpb_s01	0.006	0.253	0.013
VARIgpb_s02	0.001	0.208	0.000
VARIgpb_s04	0.072	0.164	0.025
WDRVI_s01	0.038	0.412	0.120
Sentinel2 21-Jul_NDVI	0.035	0.403	0.121
Sentinel2 09-Sept_NDVI	0.010	0.110	0.164
Sentinel2 21-Jul_RVI	0.035	0.402	0.122
Sentinel2 09-Sept_RVI	0.010	0.110	0.164
Sentinel2 21-Jul_EVI	0.027	0.296	0.058
Sentinel2 09-Sept_EVI	0.013	0.234	0.084
Sentinel2 21-Jul_VARI	0.002	0.102	0.000
Sentinel2 09-Sept_VARI	0.034	0.138	0.020
ALS02_Total leaf area euphotic zone e.c.	0.160		
ALS04_Total leaf area euphotic zone e.c.	0.203		

s01 - June
s02 - July
s04 - September

GNDVI - Green Normalized Difference Vegetation Index

$$GNDVI = (NIR - Green) / (NIR + Green)$$

WDRVI - Wide Dynamic Range Vegetation Index

$$WDRVI = (0.1 * NIR - Red) / (0.1 * NIR + Red)$$

EVI- Enhanced Vegetation Index

$$EVI = 2.5 * (NIR - Red) / (NIR + 6 * Red - 7.5 * Blue + 1)$$

RVI - Ratio Vegetation Index (RVI)

$$RVI = (Red / NIR)$$

SIPI - Structure Insensitive Pigment Index

$$SIPI = (NIR - Blue) / (NIR - Red)$$

GDVI- Green Difference Vegetation Index

$$GDVI = 0.2 * NIR - Green$$

GLI - Green Leaf Index

$$GLI = (2 * Green - Red - Blue) / (2 * Green + Red + Blue)$$

VARI - Visible Atmospherically Resistant Index (VARI)

$$VARI_{green+blue} = (Green - Red) / (Green + Red + Blue)$$

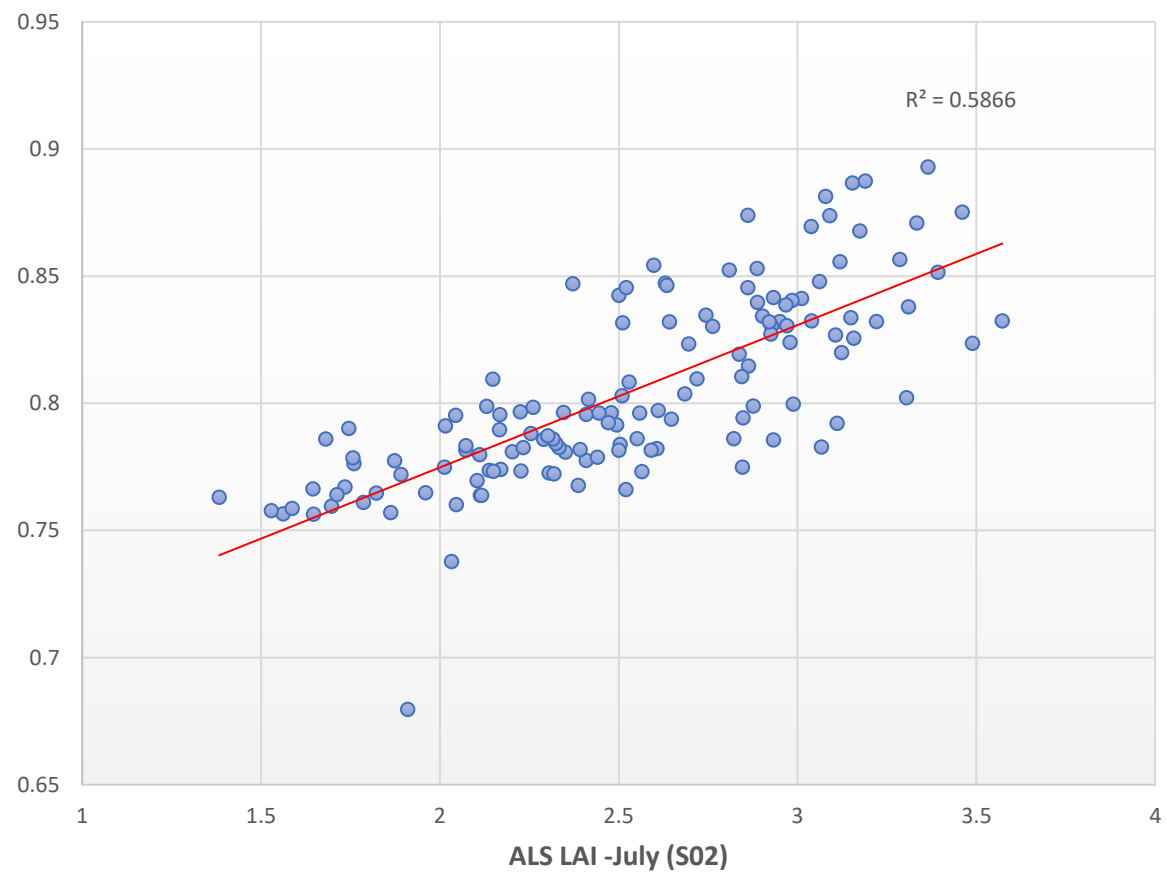
Correlation tests - 138 circular plots– 700m²

s01 - June
s02 - July
s04 - September

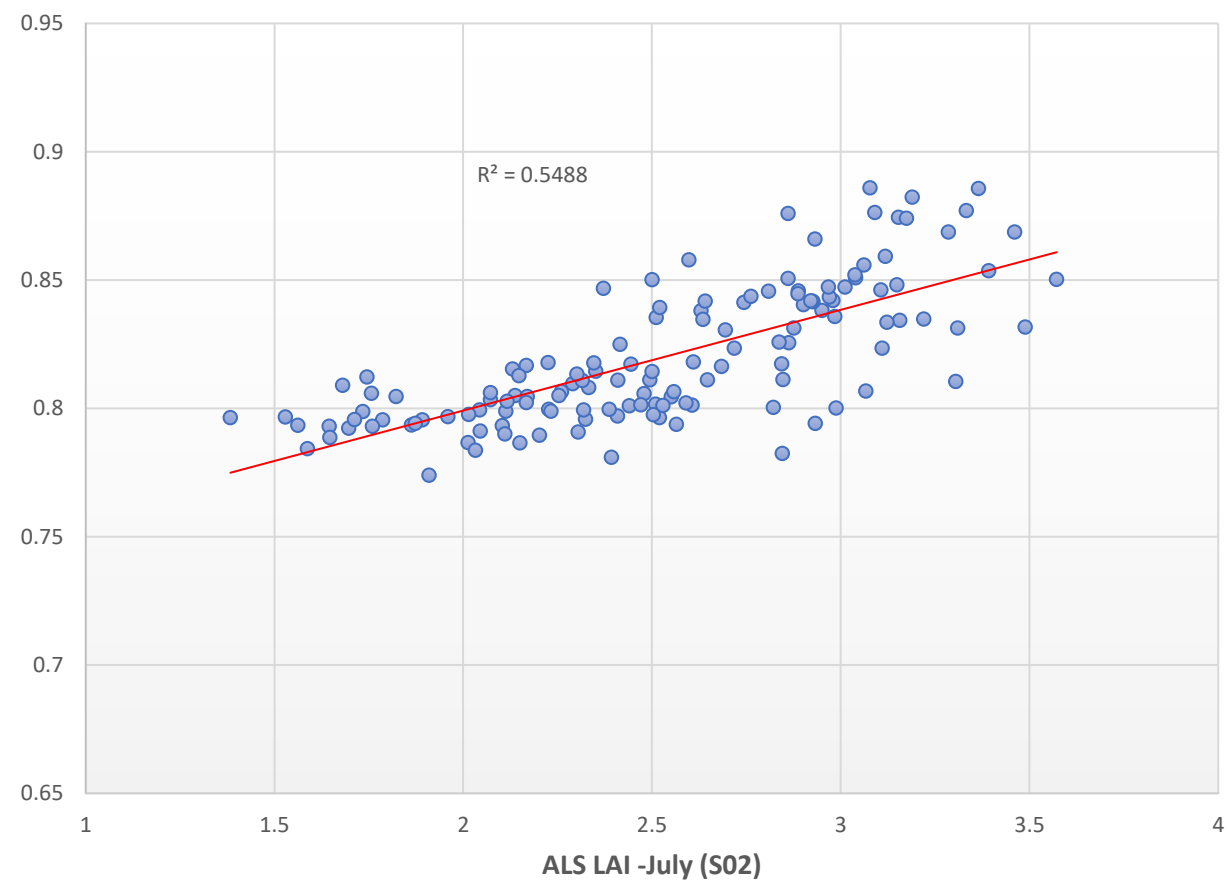
Coefficients of determination (R²)

Variables	ALS_S02_LAI	ALS_S04_LAI	GDVI_s01	GLI_s01	GNDVI_s01	NDVI_s01	NDVI_s02	NDVI_s04	RVI_s01	SIPI_s01	VARI_s01	VARI_s02	VARI_s04	WDRVI_s01
ALS_S02_LAI (Mean)	1	0.67	0.41	0.25	0.51	0.52	0.59	0.04	0.52	0.36	0.41	0.36	0.05	0.53
ALS_S04_LAI (Mean)	0.67	1	0.20	0.02	0.27	0.22	0.25	0.02	0.21	0.11	0.10	0.05	0.03	0.23
GDVI_s01	0.41	0.20	1	0.34	0.96	0.86	0.75	0.13	0.83	0.41	0.57	0.40	0.06	0.91
GLI_s01	0.25	0.02	0.34	1	0.38	0.63	0.64	0.02	0.64	0.48	0.93	0.89	0.09	0.59
GNDVI_s01	0.51	0.27	0.96	0.38	1	0.93	0.84	0.14	0.91	0.50	0.62	0.46	0.07	0.94
NDVI_s01	0.52	0.22	0.86	0.63	0.93	1	0.94	0.13	1.00	0.62	0.84	0.69	0.08	0.98
NDVI_s02	0.59	0.25	0.75	0.64	0.84	0.94	1	0.11	0.95	0.59	0.83	0.76	0.08	0.91
NDVI_s04	0.04	0.02	0.13	0.02	0.14	0.13	0.11	1	0.14	0.16	0.05	0.11	0.35	0.10
RVI_s01	0.52	0.21	0.83	0.64	0.91	1.00	0.95	0.14	1	0.66	0.84	0.71	0.08	0.96
SIPI_s01	0.36	0.11	0.41	0.48	0.50	0.62	0.59	0.16	0.66	1	0.57	0.52	0.02	0.55
VARIgpb_s01	0.41	0.10	0.57	0.93	0.62	0.84	0.83	0.05	0.84	0.57	1	0.88	0.10	0.82
VARIgpb_s02	0.36	0.05	0.40	0.89	0.46	0.69	0.76	0.11	0.71	0.52	0.88	1	0.02	0.64
VARIgpb_s04	0.05	0.03	0.06	0.09	0.07	0.08	0.08	0.35	0.08	0.02	0.10	0.02	1	0.10
WDRVI_s01	0.53	0.23	0.91	0.59	0.94	0.98	0.91	0.10	0.96	0.55	0.82	0.64	0.10	1
Sentinel2 21-Jul_NDVI	0.55	0.20	0.74	0.63	0.79	0.88	0.89	0.10	0.87	0.54	0.80	0.71	0.09	0.87
Sentinel2 09-Sept_NDVI	0.32	0.16	0.41	0.16	0.46	0.45	0.50	0.51	0.46	0.33	0.27	0.36	0.07	0.40
Sentinel2 21-Jul_EVI	0.44	0.11	0.71	0.61	0.71	0.77	0.75	0.06	0.75	0.47	0.73	0.65	0.07	0.79
Sentinel2 09-Sept_EVI	0.38	0.11	0.65	0.45	0.64	0.66	0.64	0.13	0.65	0.42	0.57	0.53	0.01	0.67
Sentinel2 21-Jul_VARI	0.21	0.01	0.26	0.65	0.29	0.44	0.49	0.04	0.45	0.30	0.60	0.70	0.02	0.41
Sentinel2 09-Sept_VARI	0.02	0.01	0.01	0.00	0.01	0.00	0.00	0.22	0.00	0.00	0.00	0.01	0.30	0.01

DjiP4 NDVI - July



Sentinel2 NDVI - July



Type abbreviation	Returns	Return number	Number of returns
AR	All returns	1, 2, 3, 4	1, 2, 3, 4
SR	Single returns	1	1
FMR	First of many returns	1	> 1
FR (= SR + FMR)	First returns	1	1, 2, 3, 4
INR	Intermediate returns	2, 3, 4	> return number
LR (= SR + LMR)	Last returns	= number of returns	1, 2, 3, 4
LMR	Last of many returns	= number of returns	2, 3, 4

LiDAR cloud metrics.

Pearse, Grant D., Justin Morgenroth, Michael S. Watt, and Jonathan P. Dash. "Optimising prediction of forest leaf area index from discrete airborne lidar." *Remote Sensing of Environment* 200 (2017): 220-239.

Table 4

Summary of ratio metrics computed at a range of plot radii and height thresholds (HT) (see Section 3.2) and used to develop ALS-LAI models. VegMean and VegMode were precursor metrics only. Intensity metrics IR and IR_{BL} used raw intensity values. All other metrics used counts of returns by type and position relative to the HT as defined in Table 2. Sources including FUSION or LAsTools indicate metrics available as standard outputs from software tools of the same name. Subscripts A and B are added to denote returns with heights above and below a chosen height threshold HT.

Metric/variable name	Sources	Name in source	Metric details	Notes
CCov	FUSION, LAsTools, Beets et al. (2011), Morsdorf et al. (2006)	Canopy cover, FCLidar(FR)	FR _A /FR	Equivalent to FCI (Korhonen et al., 2011) when FR _A = SR _A + FMR _A
CDens	FUSION, LAsTools, Riaño et al. (2004), Hopkinson and Chasmer (2009)	Canopy density, FCLidar(RR)	AR _A /AR	
FaZ_All	Pope and Treitz (2013)	DV	FR _A /AR	
IR	Hopkinson and Chasmer (2009, 2007)	Intensity ratio		
IR _{BL}	Hopkinson and Chasmer (2009, 2007)	Beer's law intensity ratio	$1 - \left(\frac{\left(\frac{\sum SR_B}{\sum AR} \right) + \sqrt{\frac{\sum LR_B}{\sum AR}}}{\left(\frac{\sum FR + \sum SR}{\sum AR} \right) + \sqrt{\frac{\sum INR + \sum LR}{\sum AR}}} \right)$	See Appendix A.2.3 for details
LCI	Korhonen et al. (2011)	Last echo cover index	LR _A /LR	
lnSD	Solberg et al. (2006), Richardson et al. (2009)	ln(Na/Nb), -ln(Rg/Rt)	-ln(FR _B /FR)	
MLP	Morsdorf et al. (2006)	N LAI, canopy	FR _A /LR _A	Canopy returns only
NaMean_First	Adapted from FUSION	Num above VegMean as % of first	AR _A /FR, HT = VegMean	See Appendix A.2.1 for details.
NaMode_First	Adapted from FUSION	Num above VegMode as % of first	AR _A /FR, HT = VegMode	See Appendix A.2.2 for details.
NaZ_First	FUSION	Num above HT as % of first	AR _A /FR	
nLAI	Morsdorf et al. (2006)	N LAI, scene	MLP fCover	See Appendix A.2.4 for details.
PAaVegMean	Adapted from FUSION	% all above VegMean	AR _A /AR, HT = VegMean	See Appendix A.2.1 for details.
PAaVegMode	Adapted from FUSION	% all above VegMode	AR _A /AR, HT = VegMode	See Appendix A.2.2 for details.
PFaVegMean	Adapted from FUSION	% first above VegMean	FR _A /FR, HT = VegMean	See Appendix A.2.1 for details.
PFaVegMode	Adapted from FUSION	% first above VegMode	FR _A /FR, HT = VegMode	See Appendix A.2.2 for details.
SCI	Solberg et al. (2009), Korhonen et al. (2011), Heiskanen et al. (2015)	P, SCI	SR _B + λ (FMR _B + LMR _B) / SR + λ (FMR + LMR)	λ = 0.5, see Appendix A.2.5 for details.
VegMean		Mean height of returns above HT	Mean height of AR ≥ HT	See Section 3.2 for HT values.
VegMode		Modal height of returns above HT	Modal height of AR ≥ HT	Mode described in Table 3. See Section 3.2 for HT values.
ZP_Rg_p	Zhao and Popescu (2009)	r grd/pulse	AR _B /FR	See Appendix A.2.6 for details.
ZP_Rig_p	Zhao and Popescu (2009)	r in + grd / pulse	(INR _A + AR _B) / FR	See Appendix A.2.6 for details.
ZP_Rig_t	Zhao and Popescu (2009)	r in + grd / total	(INR _A + AR _B) / AR	
ZP_Rsrg_p	Zhao and Popescu (2009)	r sr^grd/pulse	SR _B /FR	See Appendix A.2.6 for details.
ZP_Rsrg_t	Zhao and Popescu (2009)	r sr^grd/total	SR _B /AR	

ALS-s04 (September) cloud metrics > 138 circular plots - 700m²

Correlation tests - Coefficients of determination (R²)

Variables	EVI_s01	GDVI_s01	GLI_s01	GNDVI_s01	NDVI_s01	NDVI_s02	NDVI_s04	RVI_s01	SIPI_s01	VARI_s01	VARI_s02	VARI_s04	WDRVI_s01	Sent NDVI-Jul	Sent NDVI-Sept	Sent EVI-Jul	Sent EVI-Sept
FR ab 15 %	0.035	0.145	0.183	0.122	0.141	0.154	0.136	0.132	0.074	0.176	0.258	0.063	0.155	0.206	0.190	0.327	0.318
AR ab 15 %	0.025	0.117	0.184	0.097	0.120	0.132	0.117	0.114	0.068	0.164	0.251	0.056	0.129	0.182	0.161	0.302	0.286
AR a15 / FR %	0.025	0.120	0.184	0.099	0.122	0.133	0.128	0.116	0.075	0.163	0.256	0.062	0.129	0.187	0.171	0.308	0.294
AR a m/FR	0.006	0.018	0.045	0.010	0.018	0.017	0.055	0.016	0.005	0.040	0.063	0.037	0.024	0.015	0.030	0.018	0.005
INR / FR a Mean	0.010	0.055	0.018	0.056	0.046	0.054	0.118	0.051	0.062	0.020	0.067	0.071	0.034	0.112	0.194	0.167	0.252
INR / SR	0.016	0.069	0.046	0.063	0.062	0.068	0.171	0.065	0.071	0.047	0.121	0.107	0.053	0.131	0.223	0.179	0.226
AR / FR	0.020	0.081	0.054	0.076	0.075	0.083	0.192	0.077	0.074	0.056	0.138	0.117	0.065	0.149	0.250	0.210	0.267
INR/AR	0.021	0.084	0.056	0.080	0.079	0.088	0.198	0.080	0.074	0.058	0.143	0.120	0.069	0.154	0.258	0.220	0.281
INR/FRg	0.098	0.202	0.063	0.221	0.192	0.199	0.041	0.178	0.101	0.124	0.091	0.034	0.210	0.185	0.123	0.178	0.212
INR/ARg	0.063	0.086	0.002	0.109	0.077	0.079	0.005	0.069	0.024	0.025	0.006	0.079	0.087	0.054	0.033	0.023	0.029
AR/ARg	0.084	0.130	0.008	0.158	0.118	0.123	0.024	0.108	0.048	0.046	0.022	0.050	0.129	0.100	0.080	0.061	0.076
FR a m/FRg	0.112	0.247	0.111	0.267	0.246	0.265	0.086	0.231	0.141	0.179	0.167	0.004	0.260	0.275	0.213	0.297	0.358

Type abbreviation	Returns	Return number	Number of returns
AR	All returns	1, 2, 3, 4	1, 2, 3, 4
SR	Single returns	1	1
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FR (= SR + FMR)	First returns	1	1, 2, 3, 4
INR	Intermediate returns	2, 3, 4	> return number
LR (= SR + LMR)	Last returns	= number of returns	1, 2, 3, 4
LMR	Last of many returns	= number of returns	2, 3, 4

AR=FR+INR
 FR=SR+FMR
 Return 2 count= FMR
 SR=FR-FMR
 INR=AR-FR
 MR=AR-SR
 FR= Pulses

ALS-s02 (July) cloud metrics > 138 circular plots - 700m²

s01 - June
s02 - July
s04 - September

Correlation tests - Coefficients of determination (R²)

Variables	DJIP4 imagery indexes													Sentinel-2						
	EVI_s01	GDVI_s01	GLI_s01	GNDVI_s01	NDVI_s01	NDVI_s02	NDVI_s04	RVI_s01	SIPI_s01	VARI_s01	VARI_s02	VARI_s04	WDRVI_s01	NDVI-July	NDVI-Sept	RVI-July	RVI-Sept	EVI-July	EVI-Sept	VARI-July
FR a 15 %	0.026	0.138	0.159	0.109	0.121	0.130	0.133	0.109	0.049	0.154	0.225	0.062	0.141	0.188	0.175	0.181	0.163	0.317	0.316	0.212
AR a 15 %	0.011	0.094	0.131	0.068	0.079	0.085	0.114	0.071	0.030	0.113	0.183	0.063	0.093	0.137	0.136	0.131	0.126	0.257	0.254	0.195
AR a15 / FR %	0.021	0.114	0.169	0.089	0.107	0.115	0.122	0.098	0.055	0.149	0.234	0.053	0.121	0.175	0.154	0.169	0.144	0.306	0.297	0.236
P AR a m/FR	0.004	0.028	0.075	0.016	0.025	0.025	0.063	0.019	0.006	0.062	0.103	0.034	0.038	0.040	0.045	0.037	0.040	0.071	0.048	0.069
INRam/SR	0.048	0.083	0.160	0.092	0.124	0.147	0.123	0.132	0.182	0.141	0.273	0.043	0.103	0.194	0.192	0.191	0.188	0.275	0.293	0.304
INR / FR a Mean	0.106	0.161	0.171	0.203	0.232	0.270	0.130	0.244	0.277	0.191	0.302	0.016	0.192	0.317	0.290	0.318	0.287	0.361	0.418	0.307
INR / AR	0.103	0.184	0.232	0.207	0.244	0.281	0.167	0.242	0.217	0.247	0.378	0.029	0.229	0.349	0.309	0.345	0.299	0.422	0.451	0.339
INR / SR	0.110	0.151	0.219	0.182	0.226	0.259	0.132	0.231	0.266	0.232	0.344	0.015	0.202	0.307	0.251	0.305	0.245	0.346	0.357	0.295
FMR/SR	0.114	0.154	0.203	0.187	0.227	0.262	0.133	0.233	0.263	0.220	0.330	0.016	0.200	0.308	0.263	0.307	0.258	0.341	0.359	0.289
AR / FR	0.107	0.175	0.235	0.201	0.242	0.277	0.155	0.242	0.236	0.249	0.376	0.022	0.224	0.340	0.287	0.336	0.279	0.403	0.424	0.330
AR/Arg	0.236	0.406	0.219	0.469	0.459	0.505	0.082	0.436	0.297	0.358	0.319	0.010	0.483	0.501	0.310	0.499	0.302	0.439	0.421	0.215
FR/FRg	0.092	0.231	0.235	0.230	0.251	0.295	0.133	0.236	0.134	0.266	0.338	0.024	0.268	0.376	0.322	0.368	0.309	0.459	0.496	0.343
INR/ARg	0.169	0.255	0.090	0.311	0.287	0.310	0.012	0.271	0.173	0.195	0.119	0.046	0.309	0.265	0.119	0.266	0.118	0.179	0.153	0.053
INR/FRg	0.132	0.306	0.220	0.310	0.313	0.355	0.101	0.292	0.160	0.290	0.309	0.004	0.342	0.423	0.310	0.416	0.299	0.480	0.511	0.306
SR/FRg	0.079	0.204	0.229	0.202	0.226	0.269	0.137	0.213	0.122	0.249	0.332	0.032	0.239	0.350	0.314	0.342	0.301	0.435	0.473	0.340
FMR/FRg	0.128	0.305	0.230	0.306	0.312	0.354	0.108	0.291	0.162	0.295	0.322	0.006	0.340	0.426	0.317	0.418	0.306	0.490	0.521	0.318
FR a15/FRg	0.113	0.152	0.044	0.182	0.161	0.174	0.006	0.152	0.107	0.100	0.066	0.032	0.172	0.178	0.081	0.178	0.081	0.134	0.148	0.058
AR a15/Arg	0.067	0.034	0.003	0.065	0.060	0.066	0.010	0.059	0.055	0.027	0.004	0.079	0.058	0.039	0.003	0.041	0.004	0.004	0.002	0.001
FR a m/FRg	0.095	0.224	0.247	0.227	0.254	0.303	0.124	0.240	0.138	0.276	0.348	0.025	0.268	0.386	0.318	0.377	0.305	0.468	0.507	0.359
AR a m/ARg	0.234	0.370	0.215	0.444	0.442	0.492	0.068	0.424	0.304	0.344	0.311	0.011	0.453	0.495	0.291	0.494	0.286	0.434	0.429	0.222
FR a m/ARg	0.234	0.382	0.237	0.452	0.454	0.510	0.084	0.436	0.317	0.361	0.349	0.005	0.463	0.528	0.328	0.526	0.321	0.487	0.489	0.270
INR a m/Arg	0.128	0.157	0.046	0.207	0.192	0.198	0.001	0.180	0.116	0.123	0.050	0.069	0.206	0.149	0.045	0.151	0.045	0.070	0.054	0.006

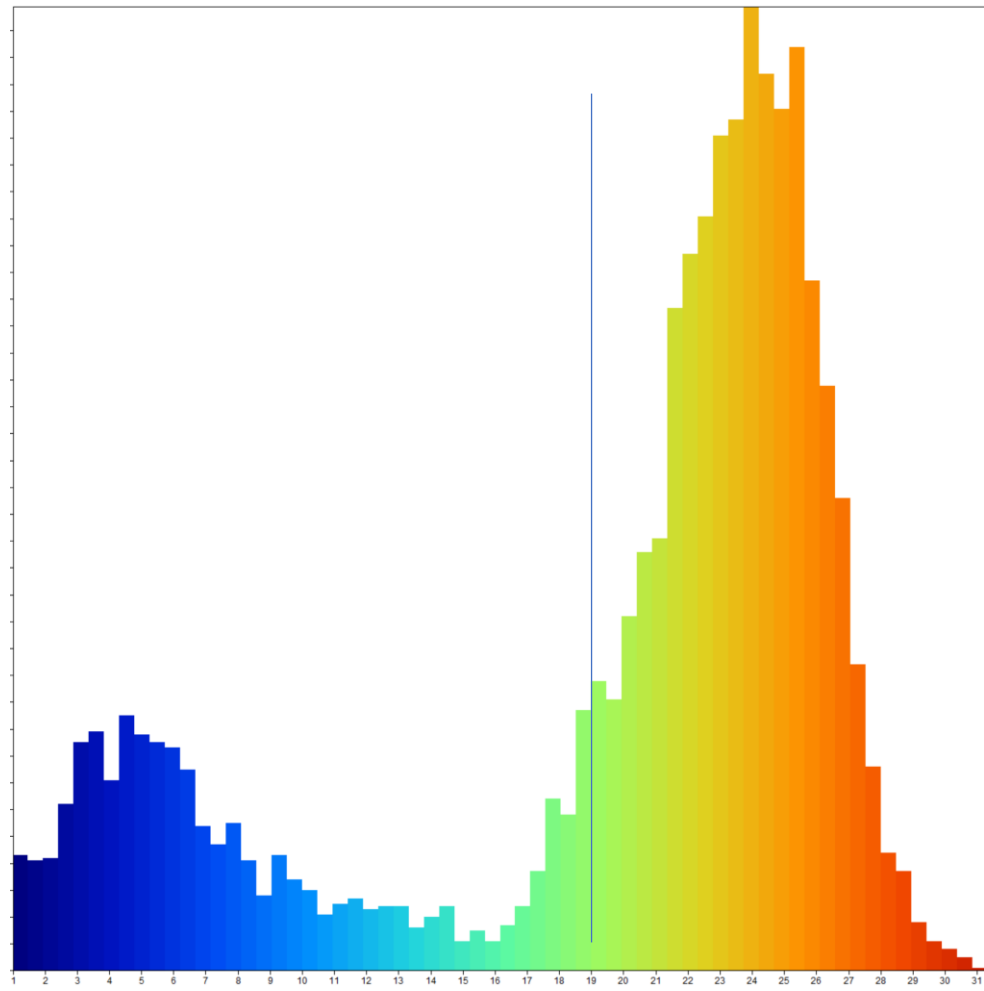
LGIA LiDAR (30.09.2014) Cloud Metrics > 70 circular plots - 700m²

Correlation tests - Coefficients of determination (R²)

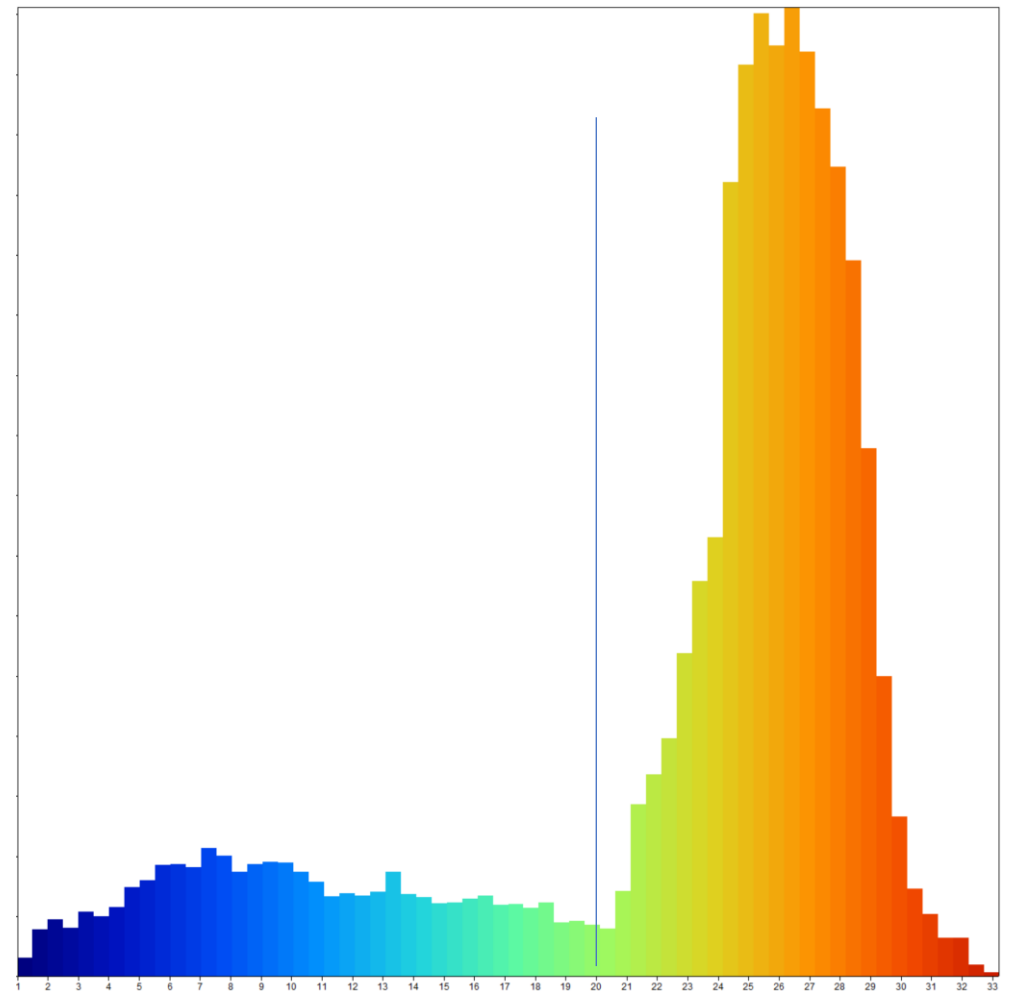
Variables	EVI_s01	GDVI_s01	GNDVI_s01	NDVI_s01	NDVI_s02	NDVI_s04	RVI_s01	SIPI_s01	VARI_s01	VARI_s02	VARI_s04	Sent NDVI-Jul	Sent NDVI-Sept	Sent RVI-Jul	Sent RVI-Sept	Sent EVI-Jul	Sent EVI-Sept
P FR ab 15	0.002	0.001	0.002	0.051	0.059	0.001	0.053	0.036	0.178	0.287	0.008	0.028	0.026	0.028	0.027	0.008	0.029
P AR ab 15	0.069	0.079	0.091	0.216	0.258	0.026	0.220	0.169	0.372	0.497	0.166	0.202	0.010	0.200	0.010	0.170	0.015
AR a15 / FR %	0.002	0.003	0.002	0.020	0.026	0.002	0.021	0.009	0.121	0.247	0.003	0.009	0.031	0.009	0.032	0.002	0.039
AR a15/FR a15	0.066	0.051	0.047	0.010	0.008	0.007	0.008	0.021	0.003	0.059	0.005	0.008	0.014	0.008	0.014	0.004	0.021
P FR a Mean	0.009	0.026	0.022	0.000	0.000	0.008	0.000	0.000	0.052	0.098	0.013	0.009	0.087	0.009	0.088	0.032	0.150
P AR a Mean	0.060	0.048	0.058	0.158	0.185	0.061	0.157	0.110	0.311	0.368	0.140	0.107	0.076	0.105	0.077	0.087	0.000
INRRam/INR	0.067	0.088	0.101	0.153	0.208	0.209	0.152	0.092	0.207	0.253	0.309	0.160	0.046	0.157	0.046	0.230	0.085
INRRam/SR	0.424	0.500	0.502	0.445	0.481	0.197	0.438	0.428	0.277	0.150	0.593	0.518	0.017	0.515	0.017	0.580	0.461
INR / FR a Mean	0.391	0.466	0.474	0.537	0.607	0.251	0.527	0.466	0.497	0.399	0.612	0.553	0.002	0.548	0.002	0.611	0.319
INR / AR	0.388	0.496	0.500	0.419	0.493	0.233	0.411	0.394	0.243	0.139	0.577	0.516	0.027	0.513	0.028	0.624	0.522
INR / SR	0.447	0.526	0.534	0.525	0.583	0.286	0.517	0.470	0.393	0.266	0.752	0.598	0.002	0.593	0.002	0.692	0.480
FMR/SR	0.426	0.510	0.516	0.500	0.560	0.287	0.492	0.450	0.367	0.245	0.740	0.576	0.002	0.572	0.003	0.673	0.475
AR / FR	0.434	0.535	0.543	0.485	0.554	0.254	0.476	0.447	0.313	0.194	0.651	0.576	0.017	0.572	0.017	0.679	0.530
FR/FRg	0.071	0.070	0.074	0.018	0.019	0.001	0.015	0.015	0.003	0.043	0.002	0.020	0.041	0.020	0.041	0.029	0.091
INR/ARg	0.049	0.034	0.038	0.001	0.007	0.003	0.001	0.004	0.027	0.095	0.000	0.011	0.077	0.011	0.078	0.011	0.071
FMR/FRg	0.118	0.134	0.137	0.056	0.057	0.007	0.052	0.048	0.002	0.015	0.025	0.061	0.041	0.061	0.041	0.078	0.147
FR a m/FRg	0.068	0.069	0.072	0.015	0.016	0.000	0.013	0.013	0.005	0.049	0.002	0.020	0.046	0.021	0.047	0.030	0.099
AR a m/Arg	0.002	0.009	0.008	0.066	0.054	0.020	0.069	0.043	0.185	0.285	0.083	0.038	0.070	0.037	0.071	0.043	0.001
FR a m/Arg	0.012	0.031	0.029	0.110	0.093	0.025	0.114	0.083	0.240	0.330	0.118	0.073	0.056	0.071	0.057	0.076	0.001

Type abbreviation	Returns	Return number	Number of returns
AR	All returns	1, 2, 3, 4	1, 2, 3, 4
SR	Single returns	1	1
FMR	First of many returns	1	> 1
FR (= SR + FMR)	First returns	1	1, 2, 3, 4
INR	Intermediate returns	2, 3, 4	> return number
LR (= SR + LMR)	Last returns	= number of returns	1, 2, 3, 4
LMR	Last of many returns	= number of returns	2, 3, 4

	All returns	Return 1 count	Return 2 count	Return 3 count	Return 4 count	Return 5 count	Return 6 count	Elev mean	Elev skewness	Elev kurtosis	Elev P10	Elev P20	Elev P25	Elev P30	Elev P40	Elev P50	Elev P60	Elev P70	Elev P75	Elev P80	Elev P90	Elev P95	Elev P99
LGIA ALS	7414	4226	2373	715	94	6	0	16.18	-0.59	1.66	0.10	3.02	5.06	7.50	18.82	21.45	22.76	23.85	24.37	24.89	26.02	26.89	28.53
ALS_s04	516884	375468	141416	0	0	0	0	20.66	-1.17	2.92	3.06	10.80	15.51	21.24	23.97	25.00	25.81	26.63	27.05	27.47	28.45	29.12	30.71



LGIA LiDAR



Drone ALS s04

Conclusions:

- LiDAR Voxel-based (plots 700 m²)

$$\text{LAI}_{\text{field}} \neq \text{LAI}_{\text{LiDAR}} \neq \text{Indexes}_{\text{Imagery-based}}$$

$$\text{LAI}_{\text{LiDAR-July}} \approx \text{Indexes}_{\text{June-July}} \quad (\text{NDVI } R^2 = 0.5)$$

- LiDAR CloudMetrics-based (plots 700m²)

$$\text{LAI}_{\text{field}} \neq \text{CloudMetrics}_{\text{LiDAR(Drone)}} \text{ ratios} \neq \text{Indexes}$$

$$\text{CloudMetrics}_{\text{LiDAR-Drone(July)}} \text{ ratios} \approx \text{Indexes} \quad (\text{NDVI, EVI } R^2 = 0.4 - 0.5)$$

$$\text{CloudMetrics}_{\text{LiDAR(LGIA)}} \text{ ratios} \approx \text{Indexes} \quad (\text{NDVI, VARI } R^2 = 0.5 - 0.7)$$

- $\text{Indexes}_{\text{Drone-based}} = \text{Indexes}_{\text{Sentinel-2}} \quad R^2 = 0.8$ (only summer months, except deadwood)

***Paldies par uzmanību un
sadarbību!***