Application of Sentinel-2 Satellite Data in Forestry

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Outline

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  - Sentinel satellite series
- Background
  - Uses of Sentinel
  - Measuring and understanding forest health
- Study site
- Methods
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  - Analysis in ArcMap
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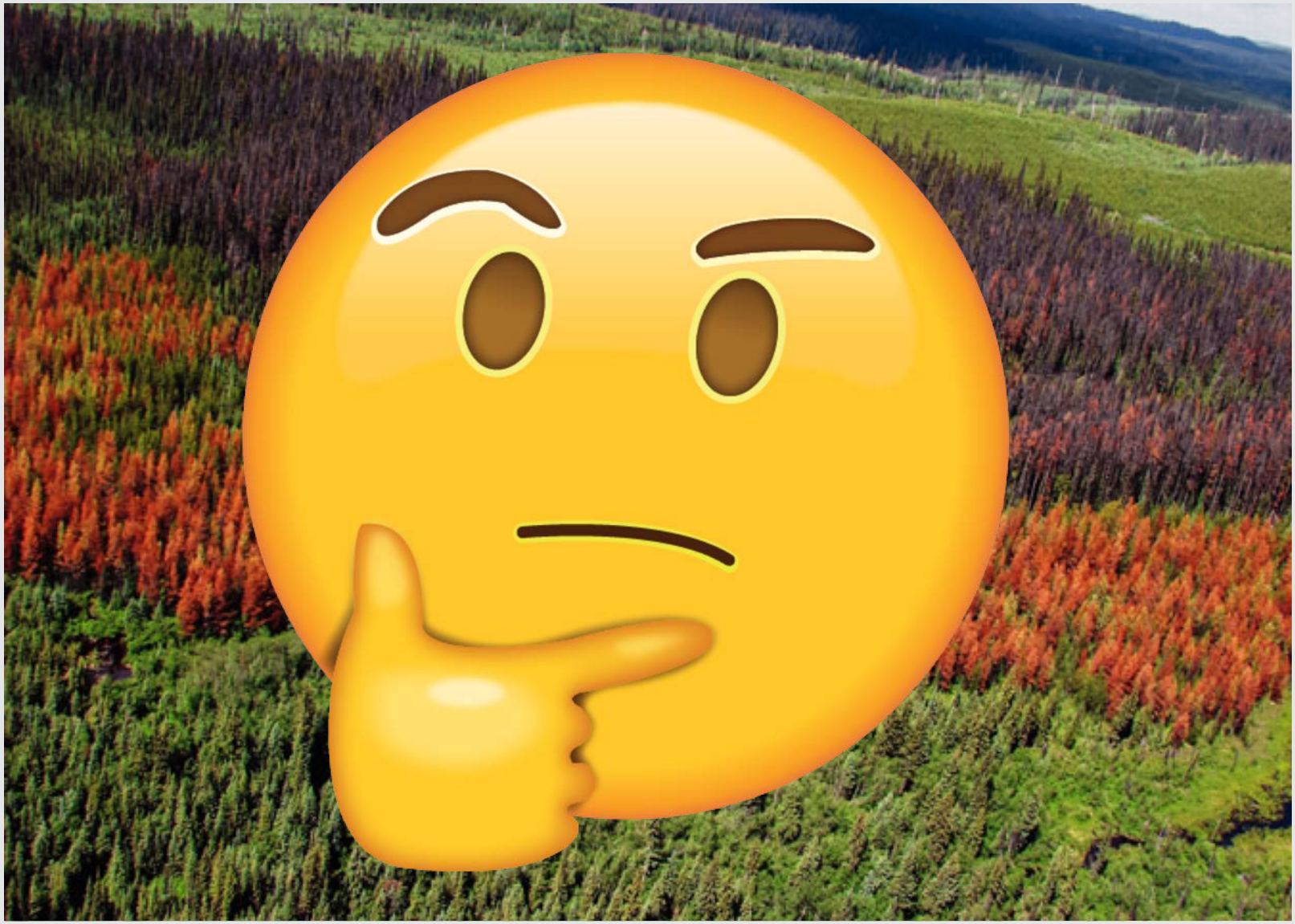
Introduction

Sentinel overview

- Part of Copernicus (European Space Agency)
- 5 missions so far, Sentinel-1 to Sentinel-5
- Sentinel-2 provides RGB bands at 10m resolution, other spectral bands at 20-60m
  - Sentinel-2A > 23 June 2015
  - Sentinel-2B > 07 March 2017
  - Land observation, land use and detection maps, disaster relief support
  - Orbit height: 786km
  - Swath: 290km
  - Repeat cycle: 10 days with 1 satellite and 5 days with 2 satellites
- FREE!

Uses of Sentinel in Forestry



Background

Forest health

Numerous definitions!

Understanding the relationships between drivers, stress, and ecosystems spatially and over time to allow better forest management decisions

Help the trees be the best they can be!

Leaf area index (LAI)

- Ratio of leaf area per unit ground surface area
- A healthier tree with more foliage will have a higher LAI, while a less-healthier tree with minimal foliage will have a lower LAI
- Field = slow
- Remote sensing = faster?

Leaf area index (LAI)

- Provide an understanding of changes in productivity (Zheng and Moskal, 2009)
- LAI can give an overall picture of the forest to assist tree management decisions (fertilization)

Leaf area index (LAI)

Study Site

Study site

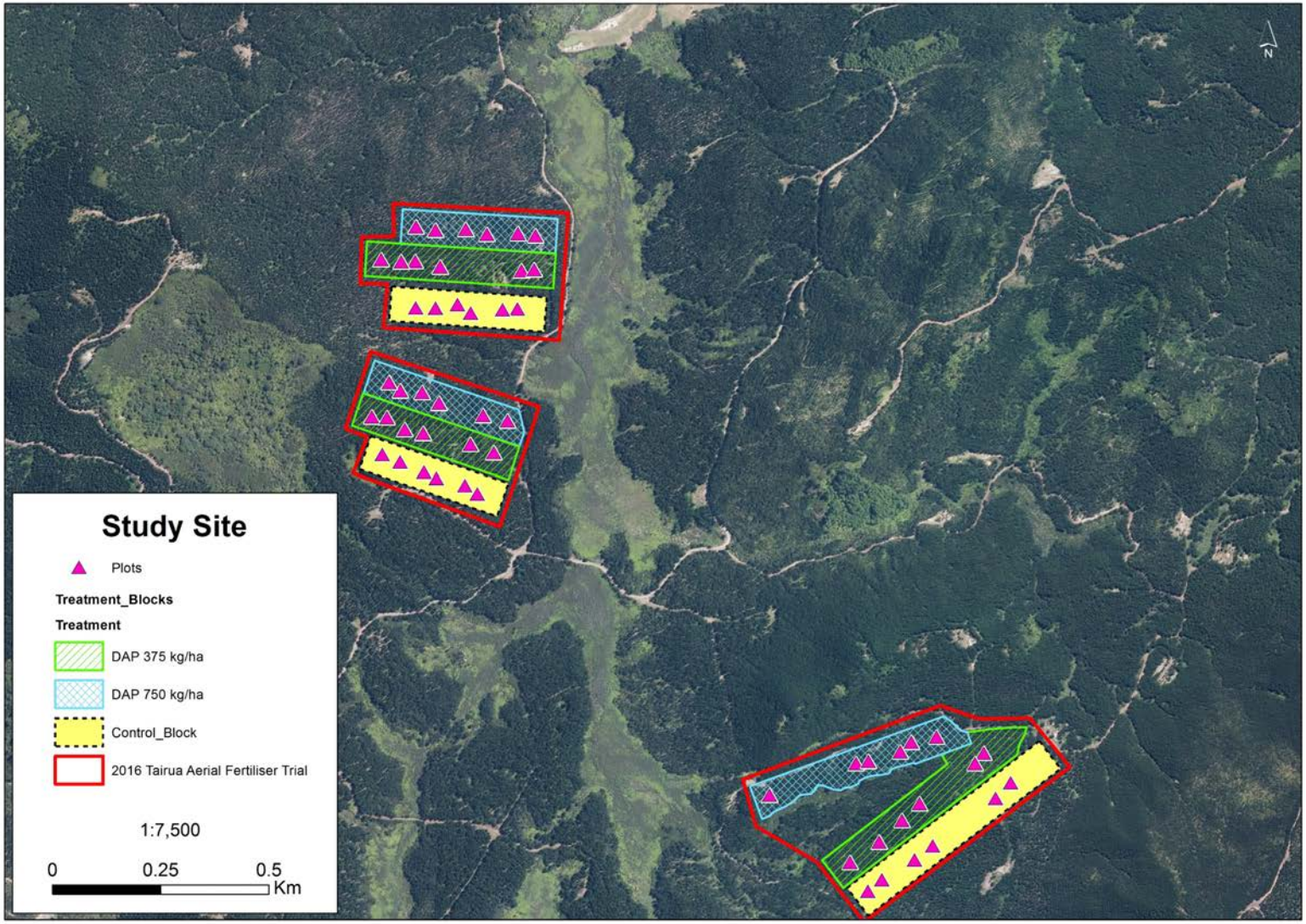
- Tairua Forest
- Eastern Bay of Plenty
- Operational aerial fertilizer trial (2016)
- Multiple sets of field/lab data:
  - Foliage samples (chemistry)
  - Soil samples (chemistry)
  - Growth measurements
  - LiDAR surveys

Study site

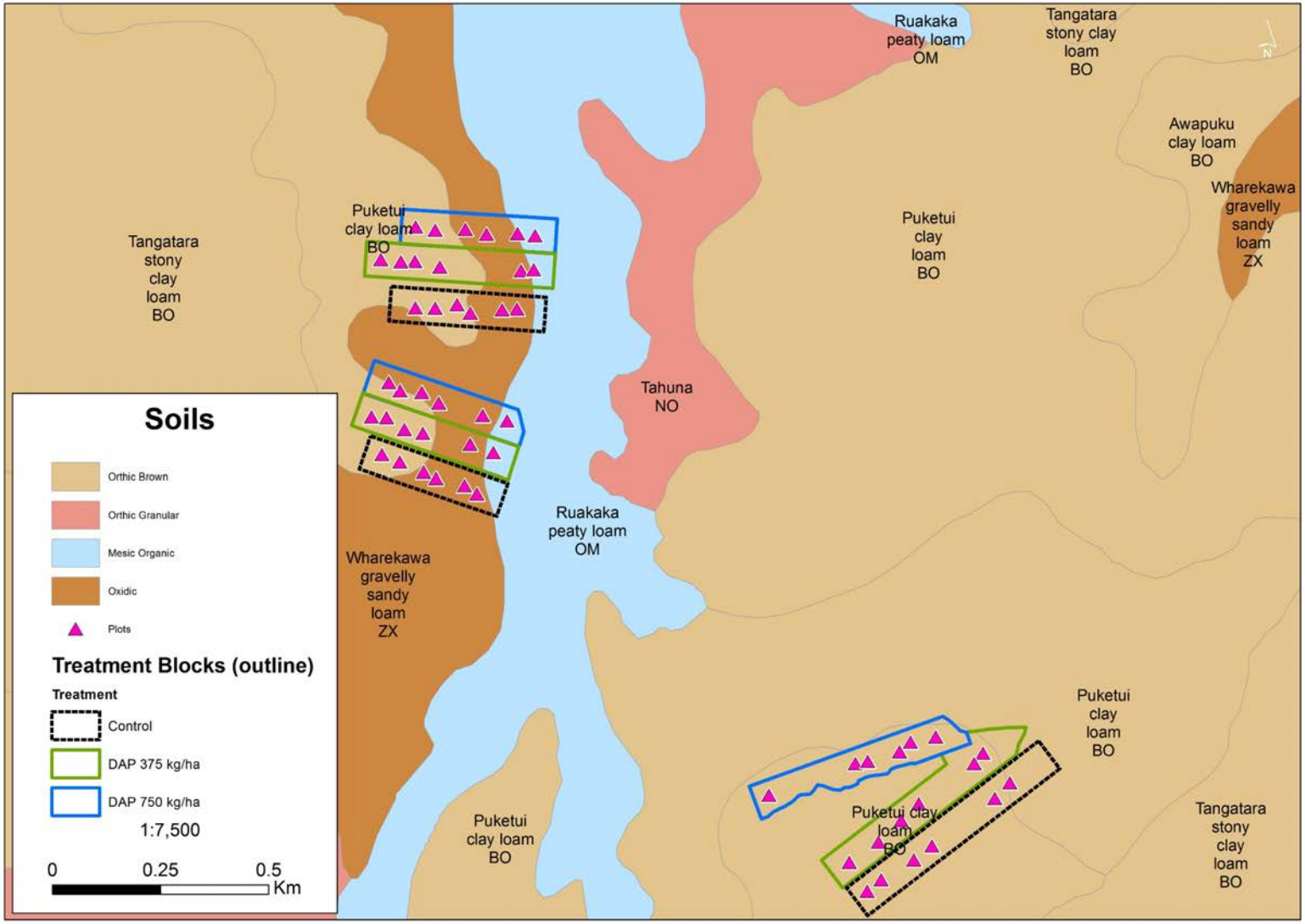
- Phosphorus deficient
  - Short needles
  - Narrow crowns

Davis et al. 2010

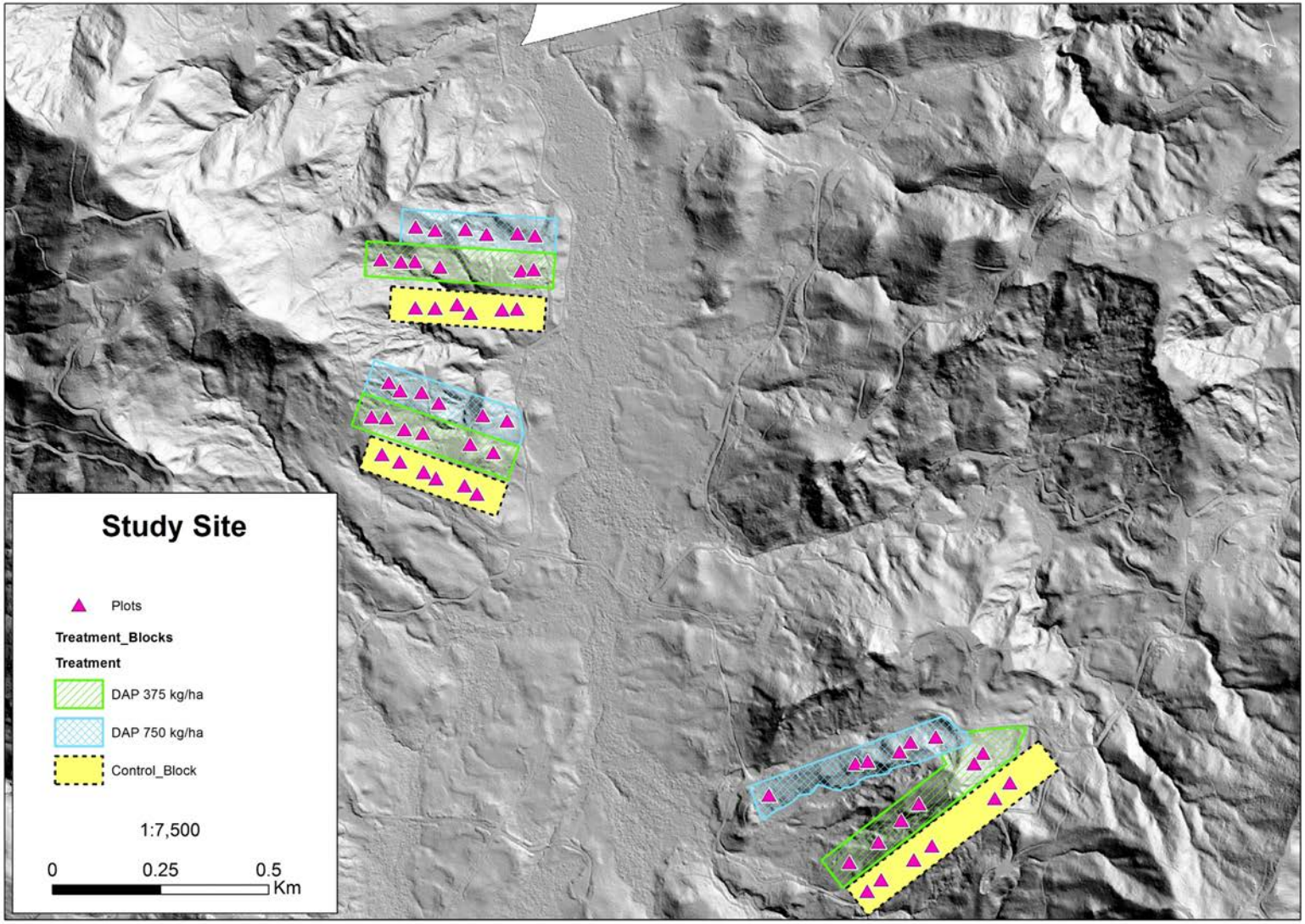
Study Site
Aerial Fertiliser Trial - DAP



Study Site
Soils

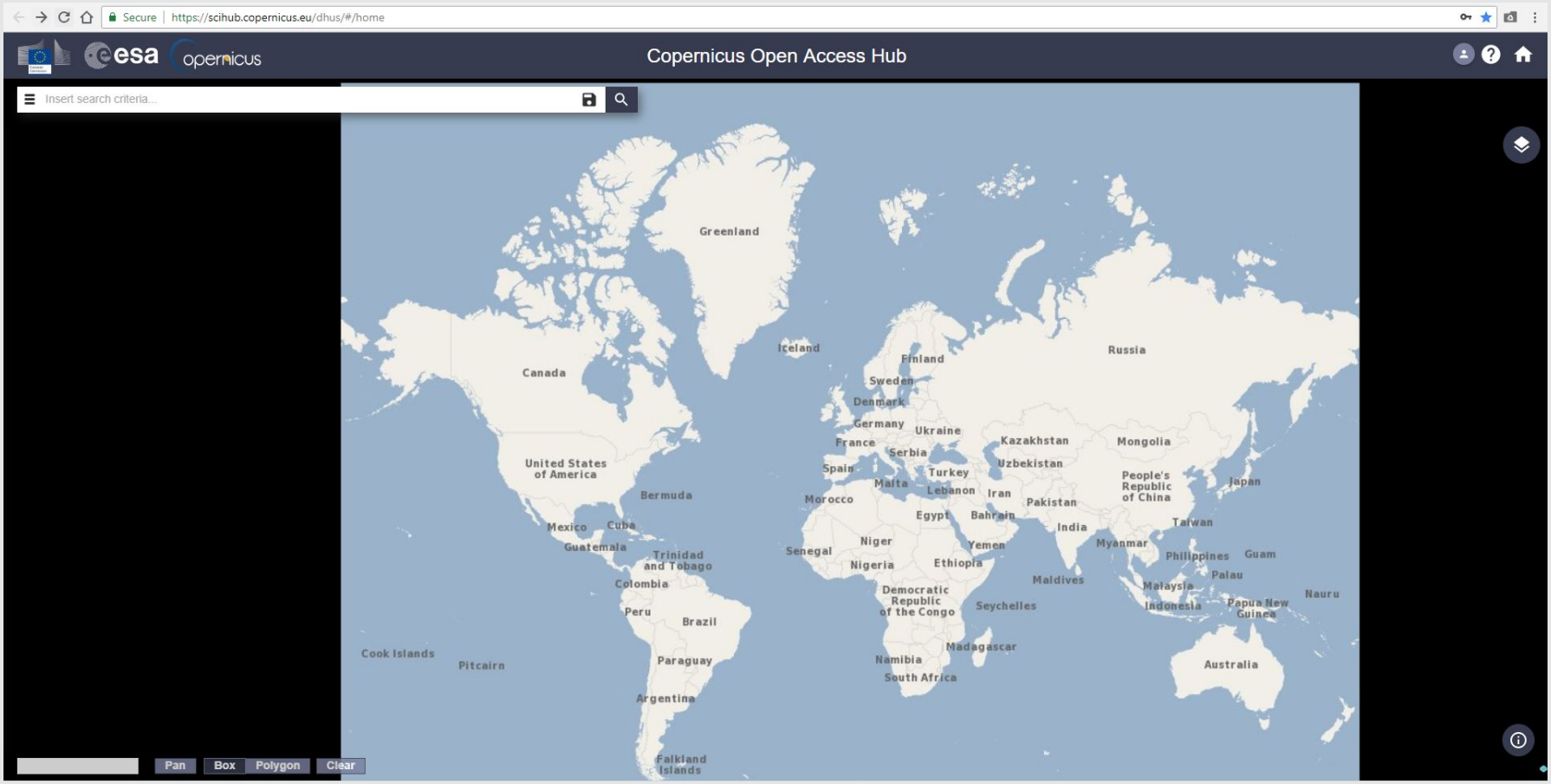


Study Site Terrain

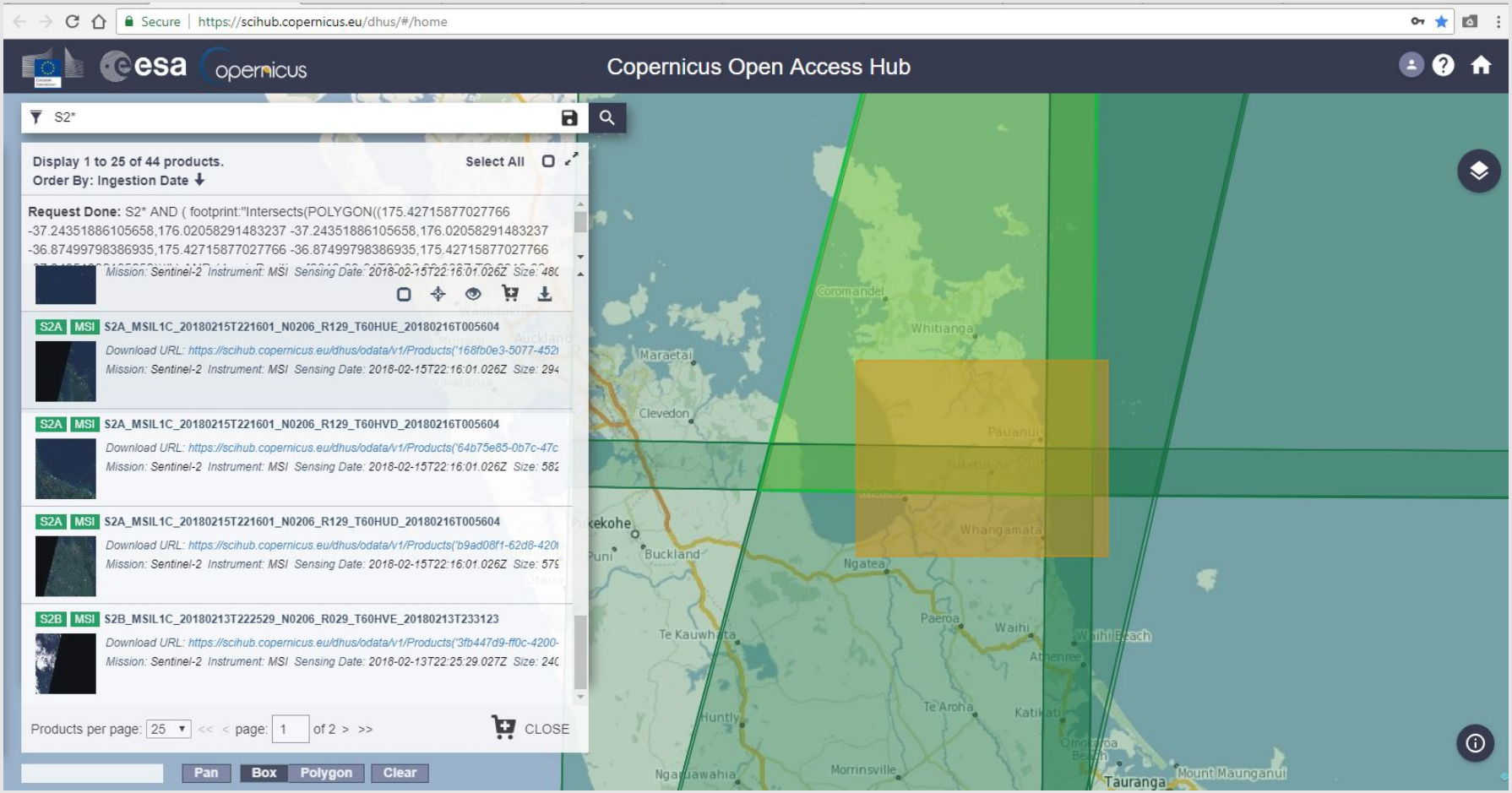


Methods
Sentinel Processing

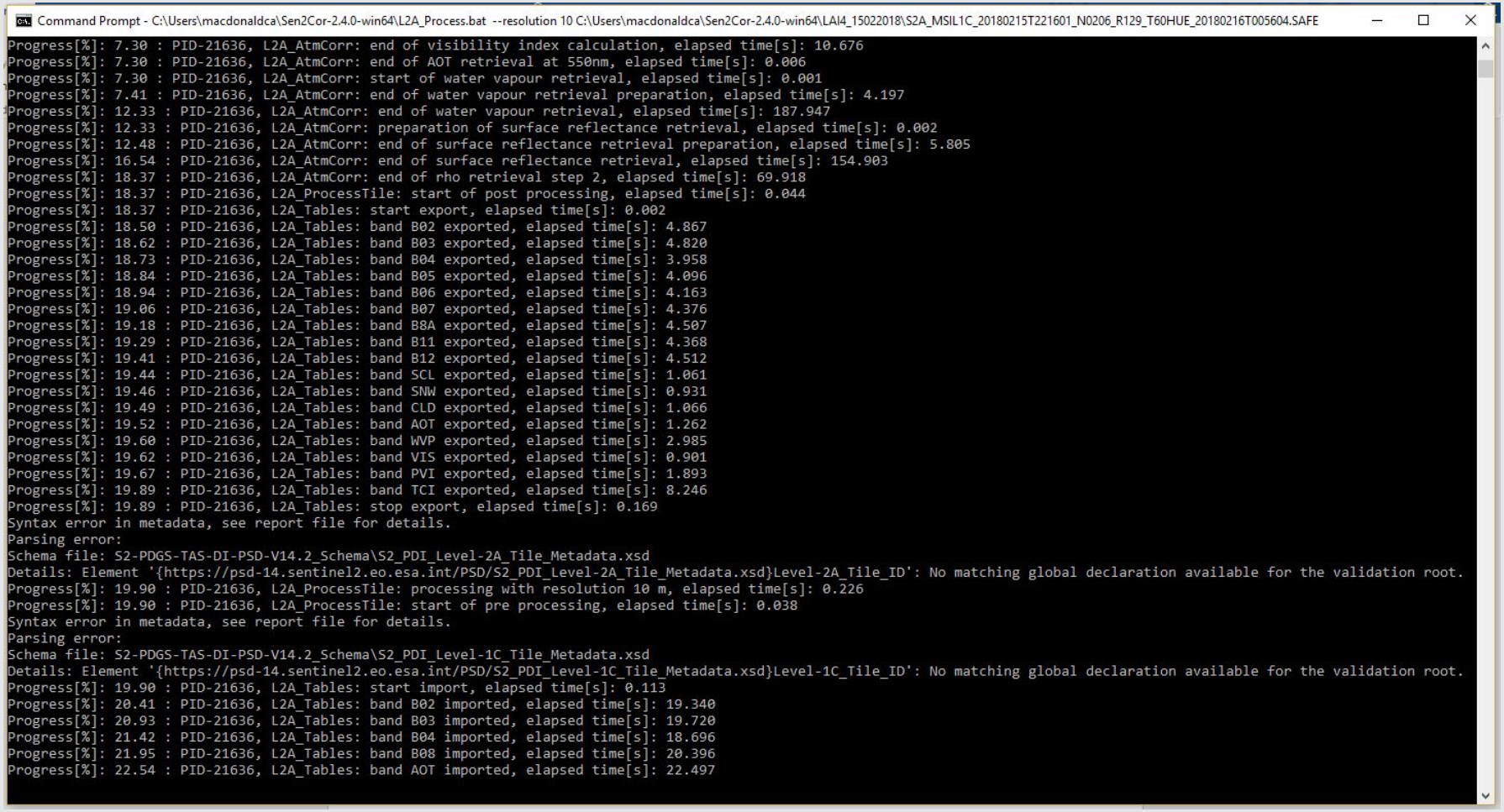
Sentinel Processing



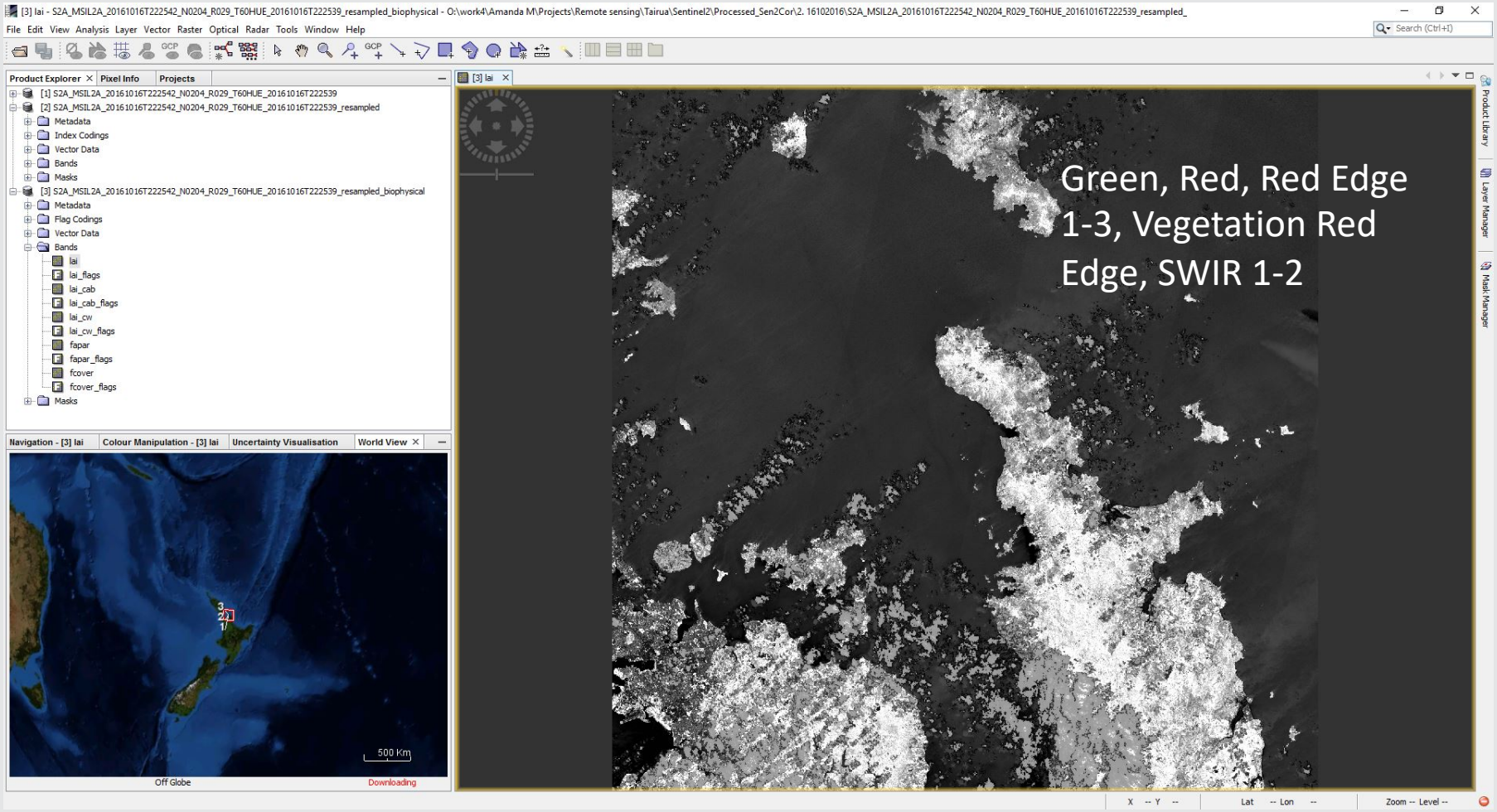
Sentinel Processing



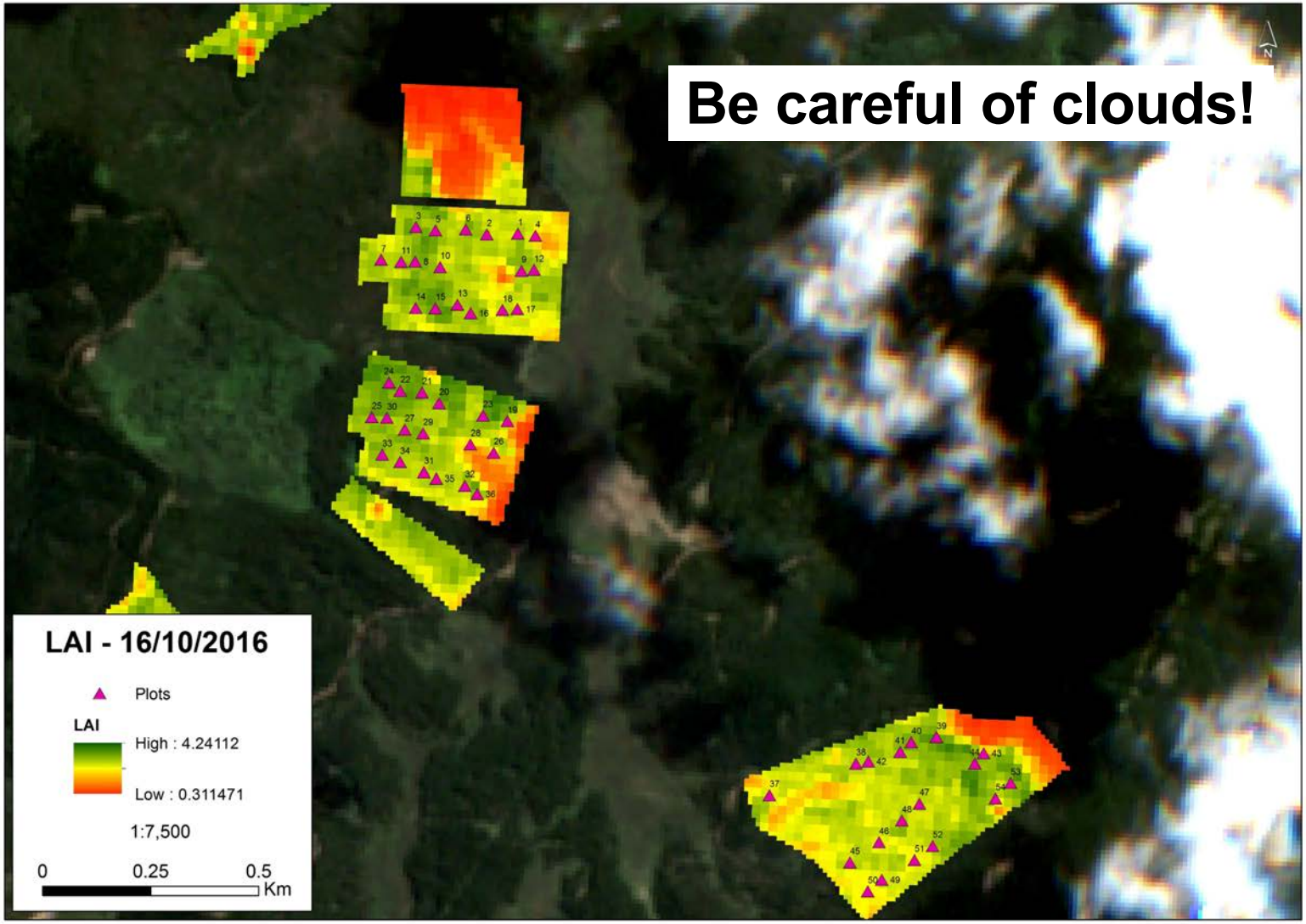
Sentinel Processing

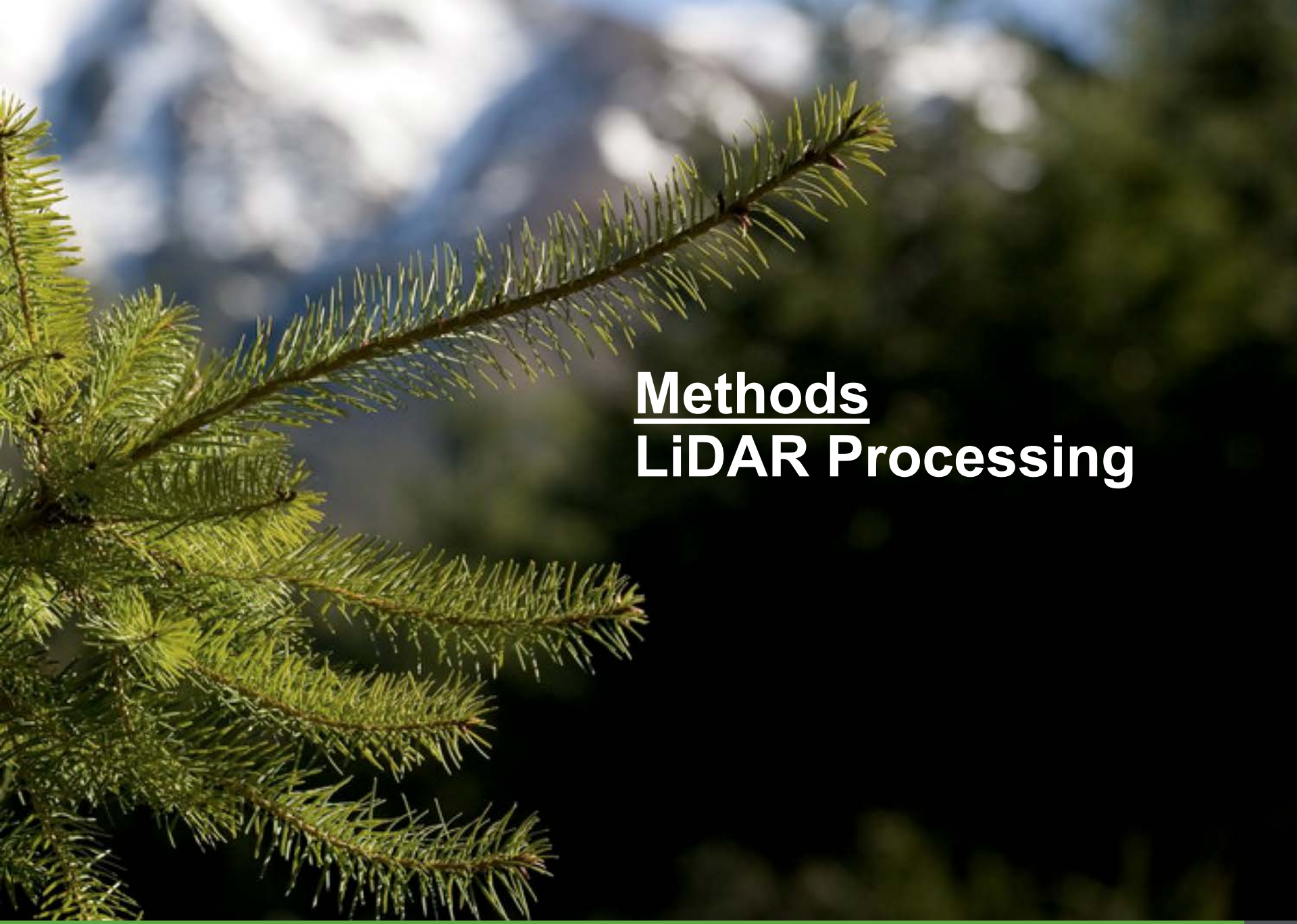


Sentinel Processing



Sentinel Processing

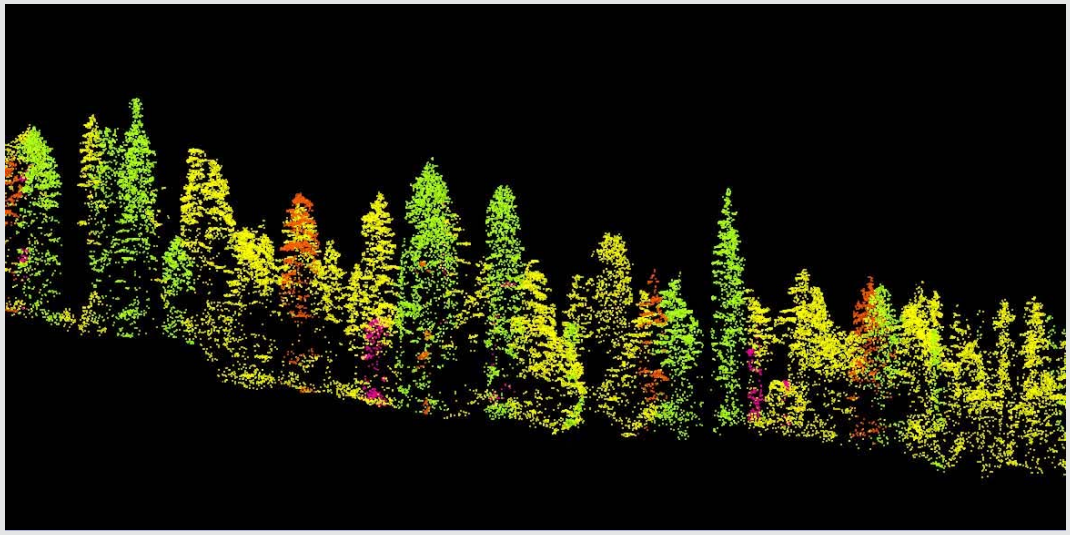




Methods
LiDAR Processing

LiDAR Processing

Light Detection And Ranging (LiDAR) refers to an active laser-scanning technology that allows accurate 3-D measurement of forest vegetation and the ground surface based on laser pulse return times.

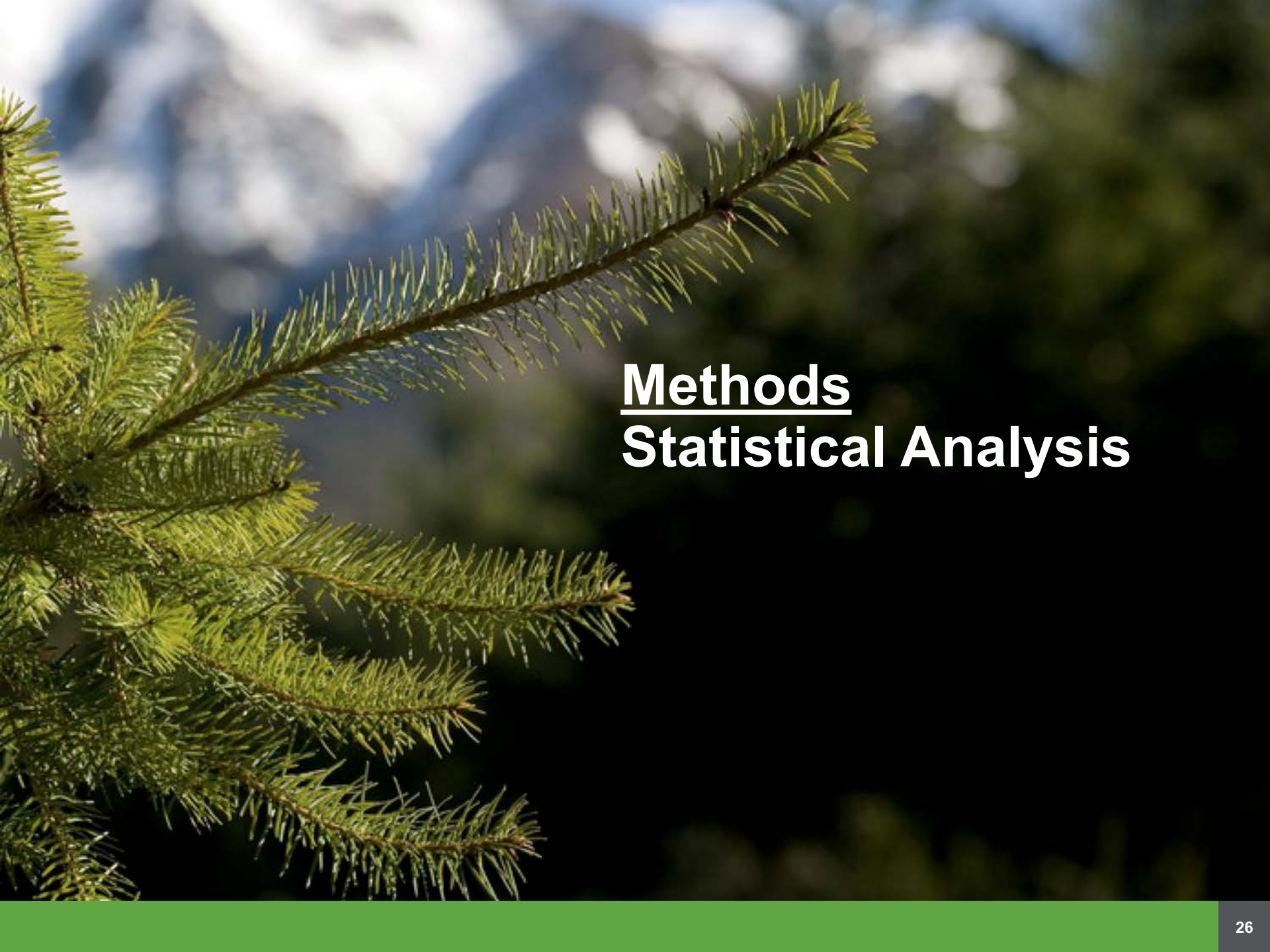


- P50fp: height above ground corresponding with the 50th percentile of the point cloud above a base height (0.5m)
- %veg: percentage of first returns above a base height – it is an estimate of canopy cover

LiDAR Processing

LiDAR processing (LasTools)

- Remove low and high outliers (lasnoise)
- Classify ground and non-ground points (lasground)
- Create a normalized point cloud (lasheight)
- Create forest metrics (lascanopy)



Methods
Statistical Analysis

Statistical Analysis

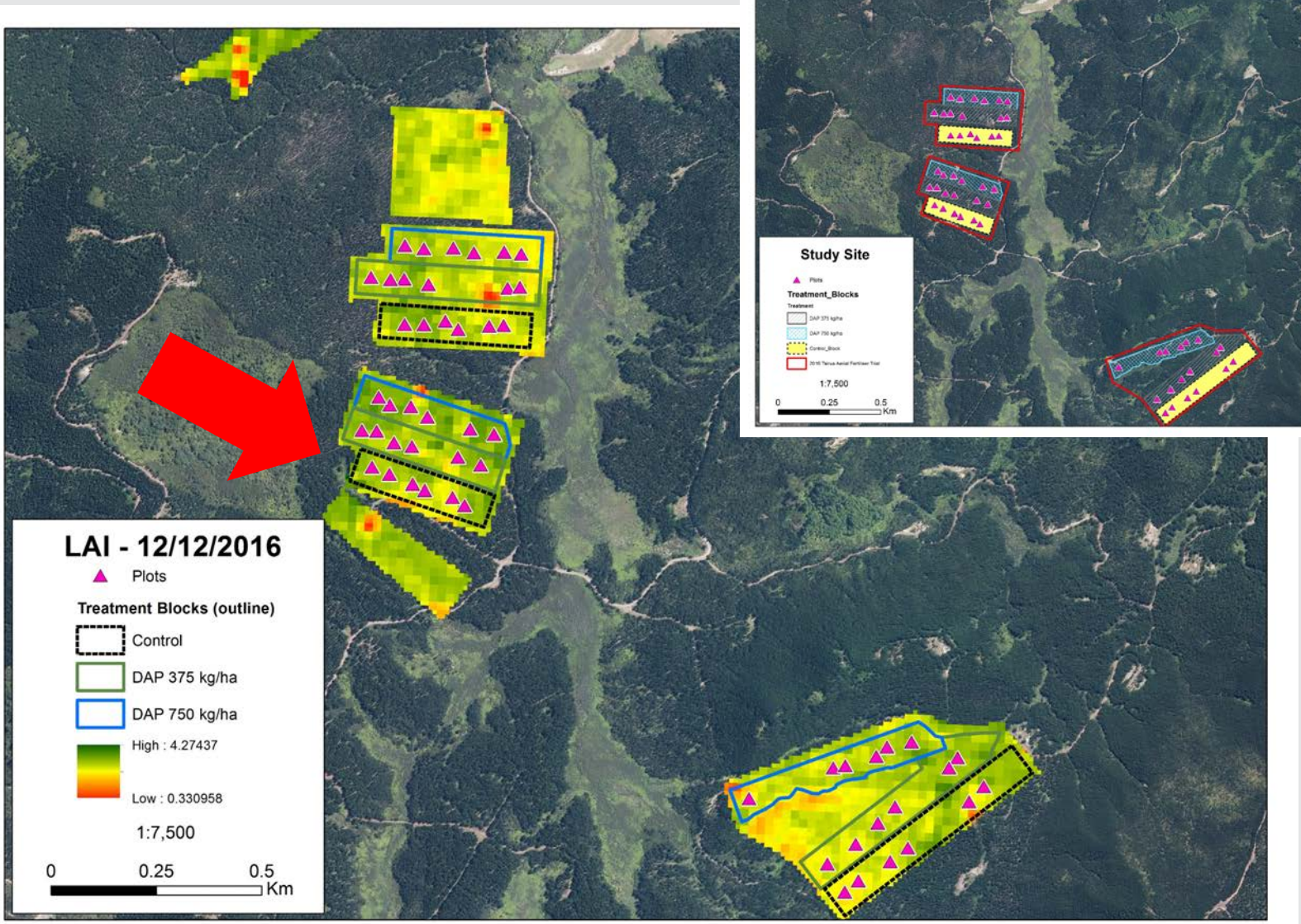
- ArcMap
  - Zonal statistics (mean) from plot 5m buffer
  - Extract values from rasters (Sentinel LAI, LiDAR p50fp, %veg, elevation, slope and aspect)

Statistical Analysis

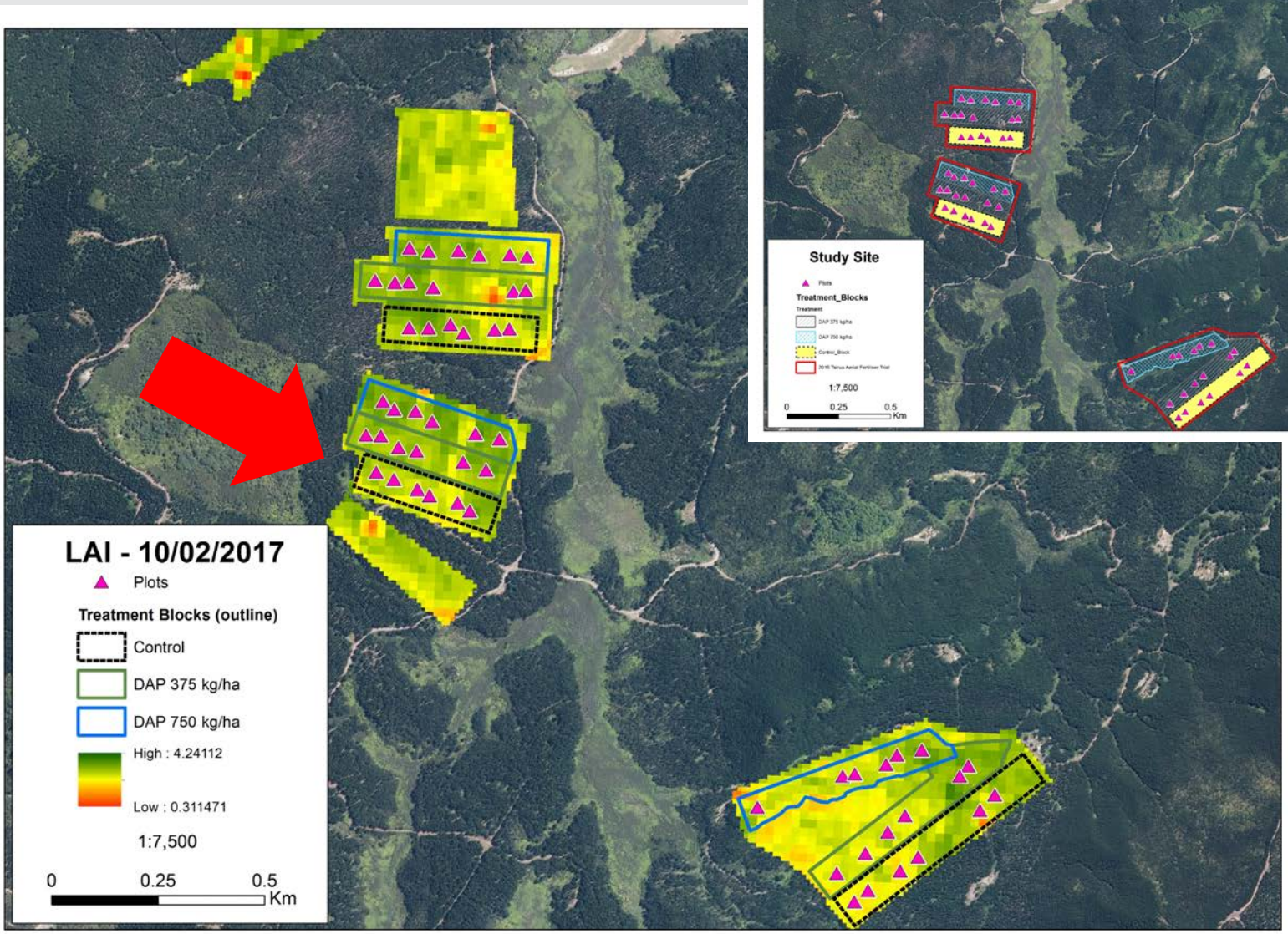
- Multivariate analysis using stepwise regression (Minitab)
  - 54 plots
  - 37 variables
    - Growth measurements (DBH, BA, Total Height, Crown Height, Crown Length)
    - Foliage (C, N, B, Ca, Cu, Fe, K, K-Mg ratio, Mg, Mn, P, Zn, Fasicle weight)
    - Soils (pH, C, N, P, B, Al, Na, Mg, P, K, Ca, Mn, Fe, Cu, Zn)
    - Terrain (Elevation, Aspect, Slope)


Results
Sentinel

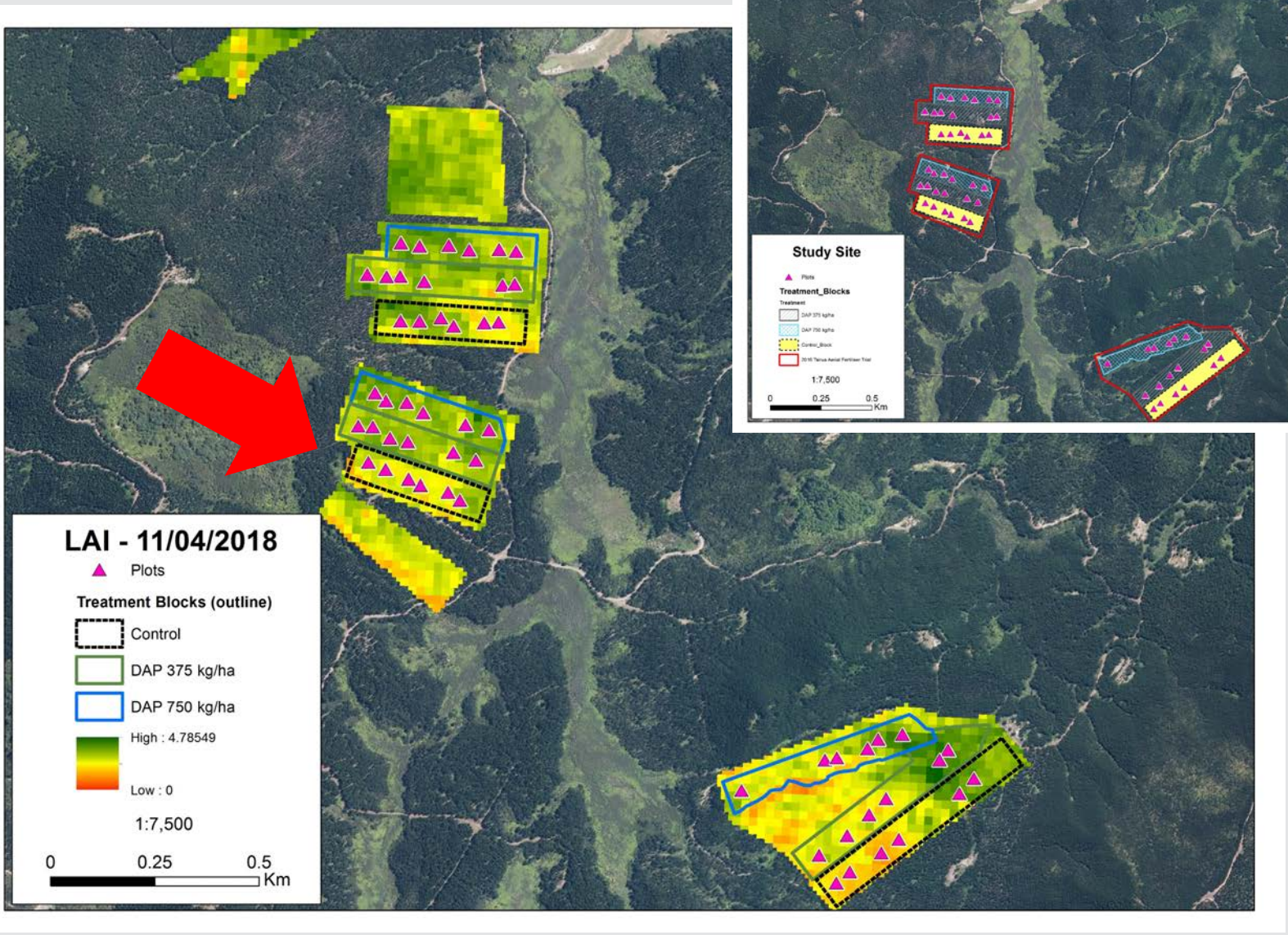
Sentinel Results – 2016



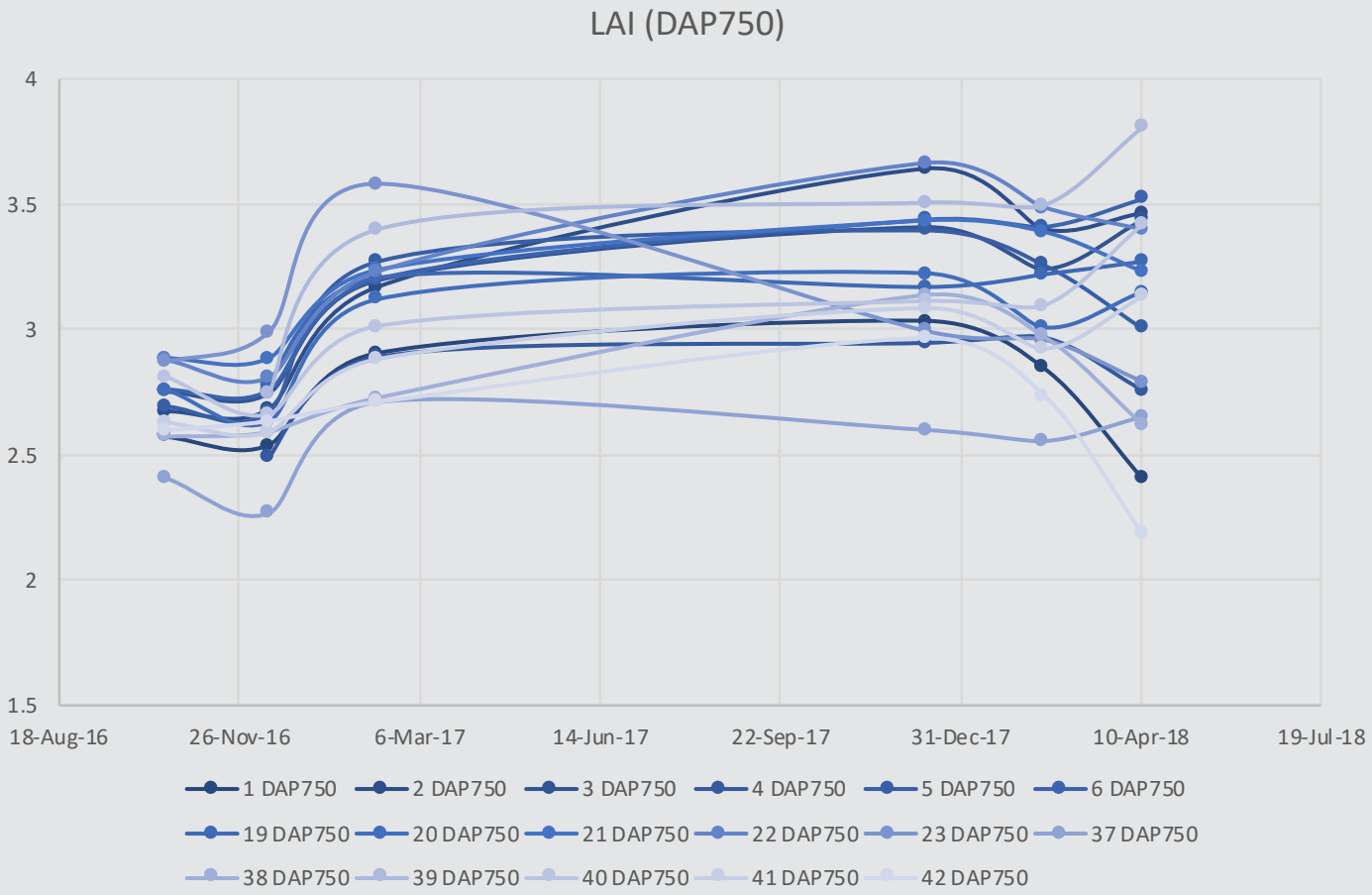
Sentinel Results – 2017



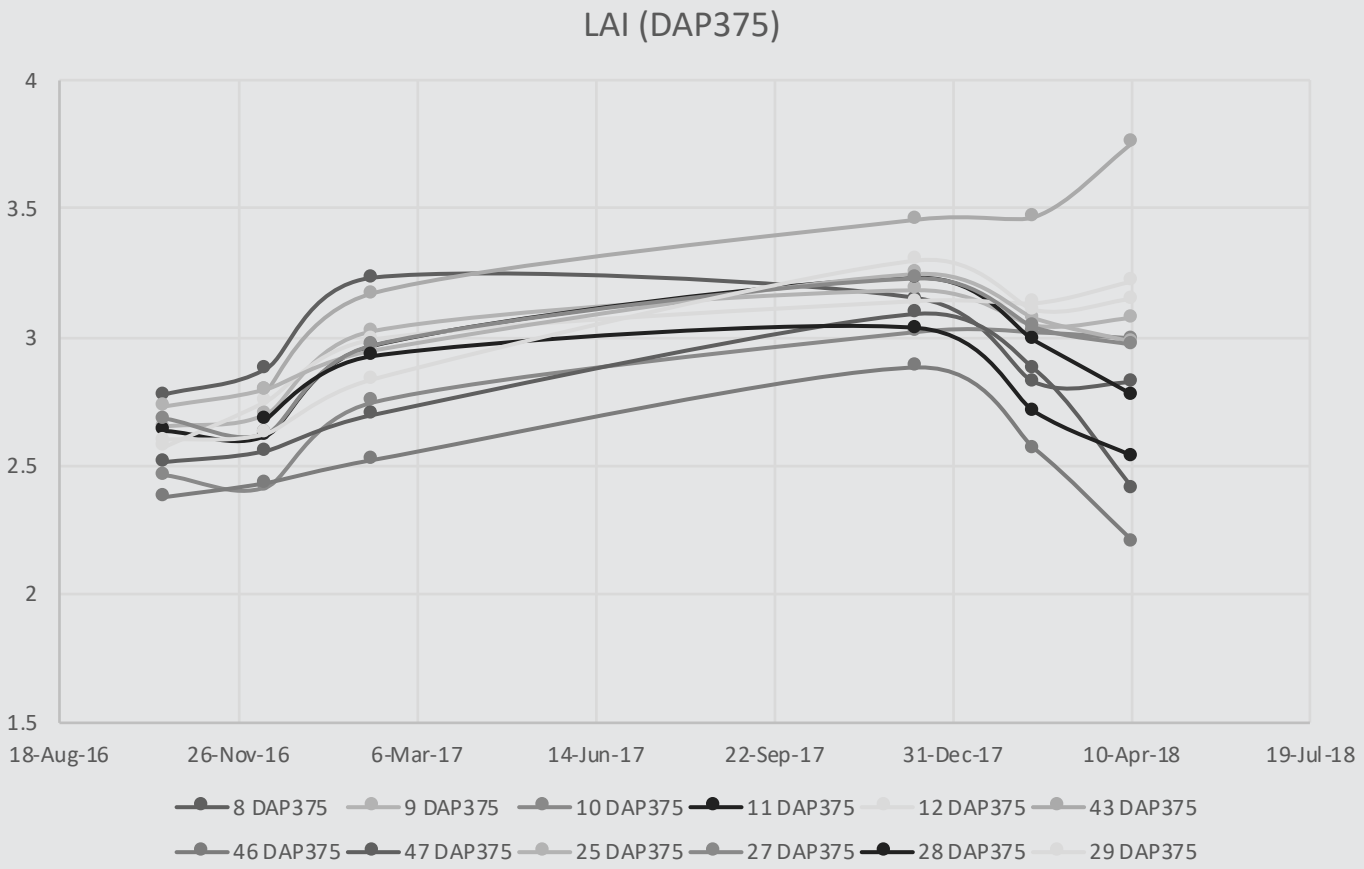
Sentinel Results – 2018



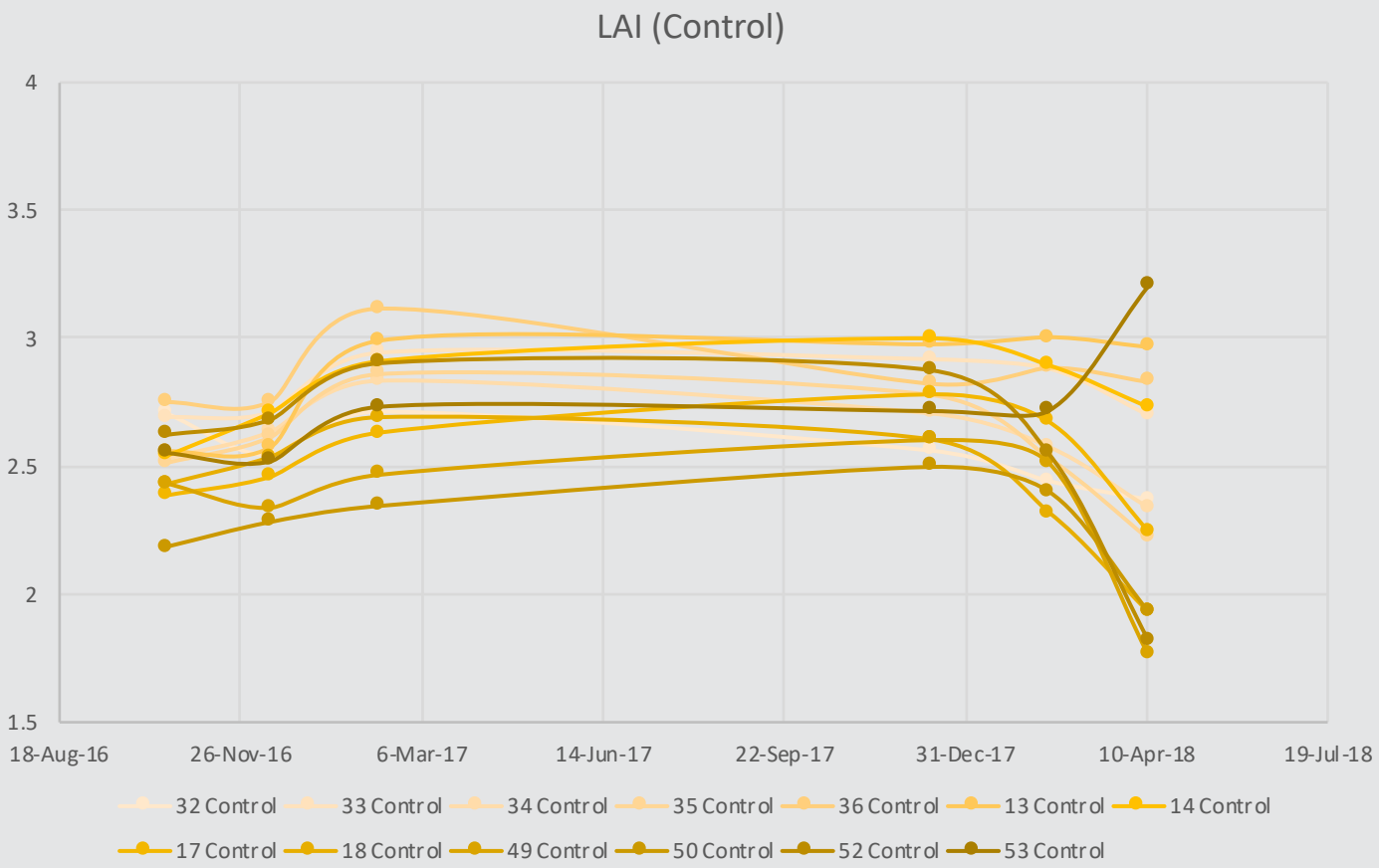
LAI over time



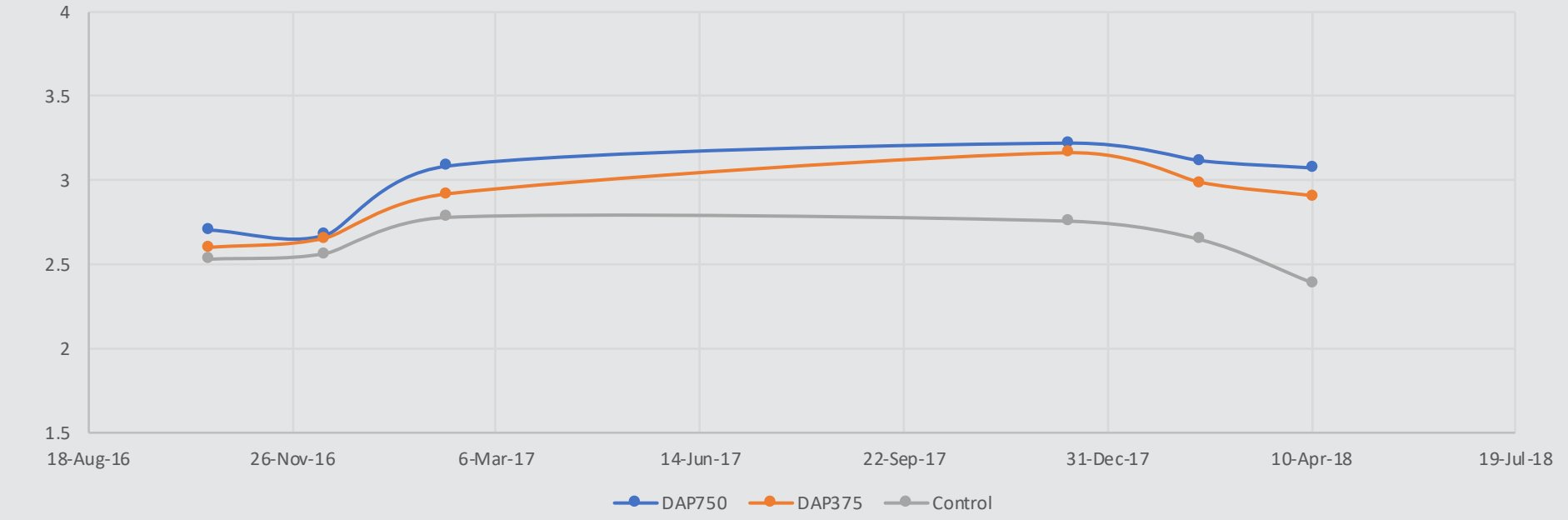
LAI over time

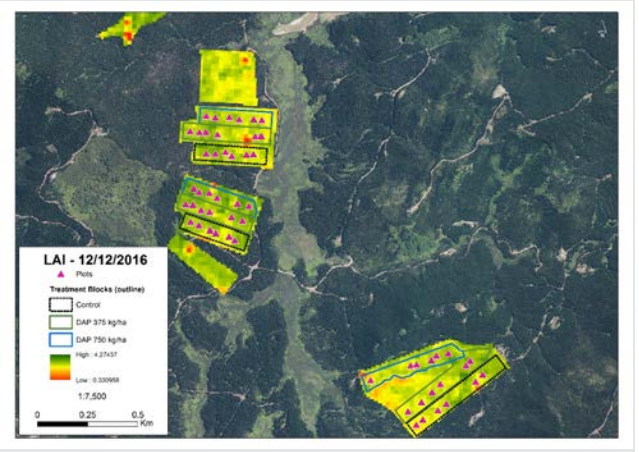


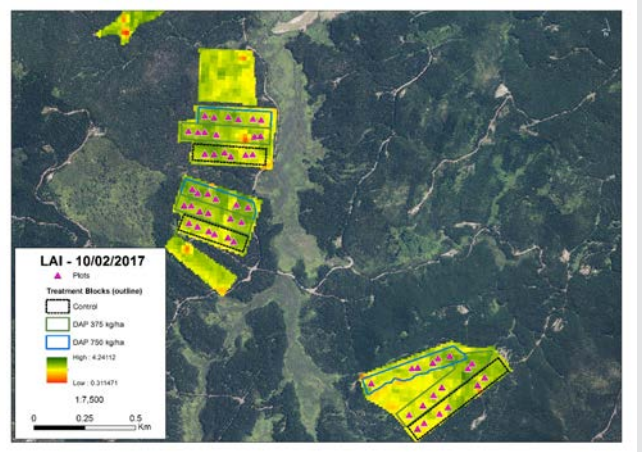
LAI over time

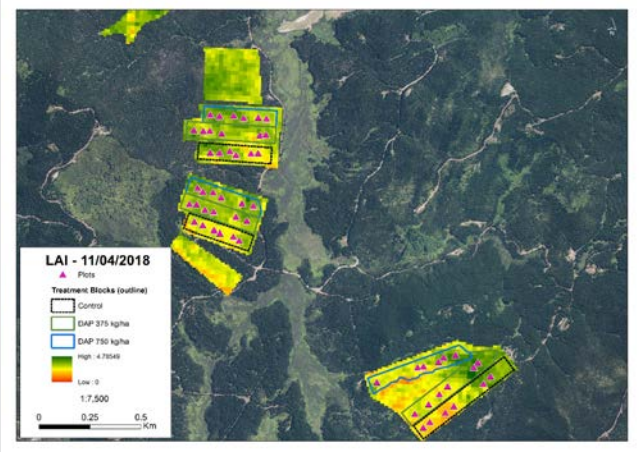


LAI over time



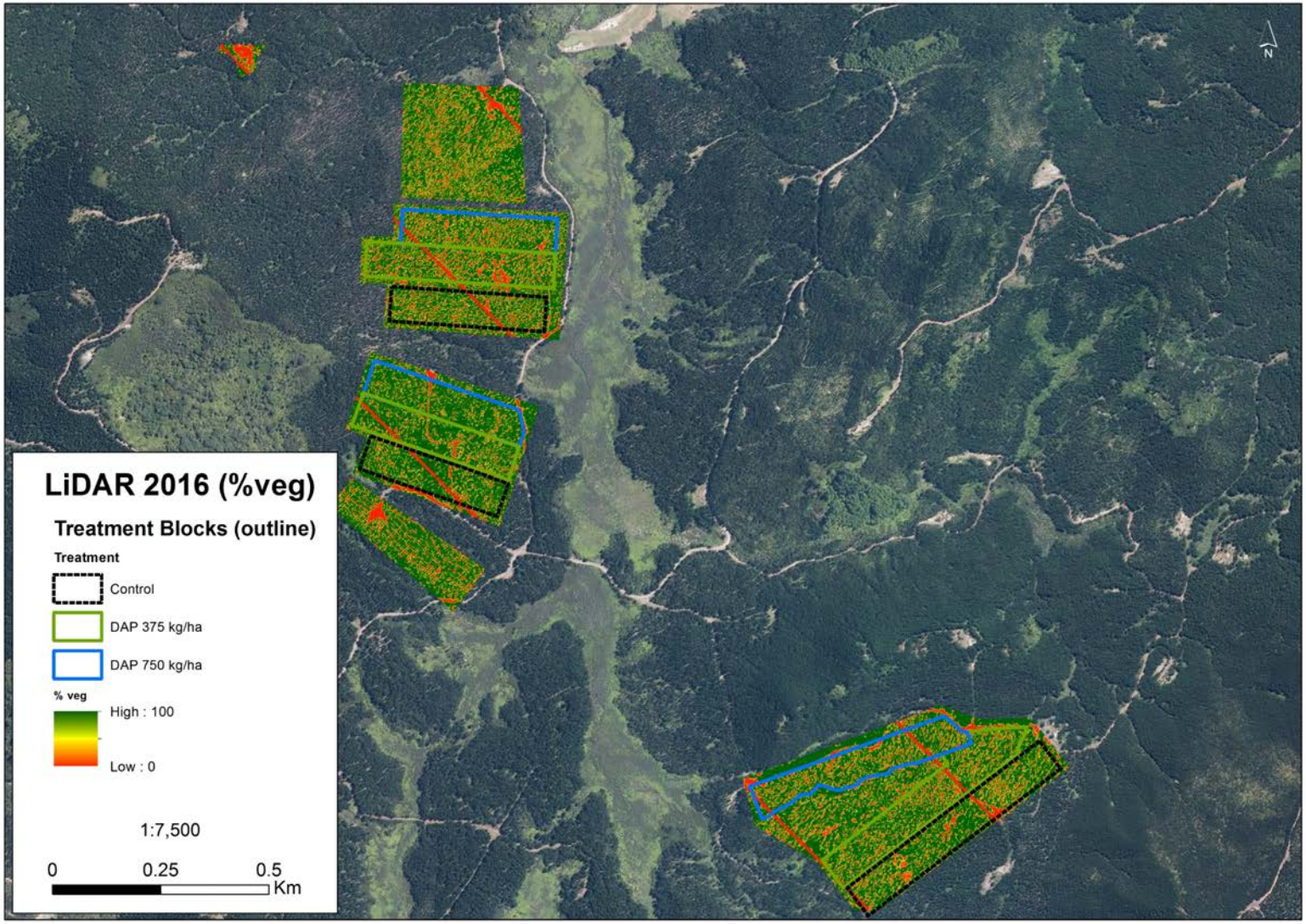






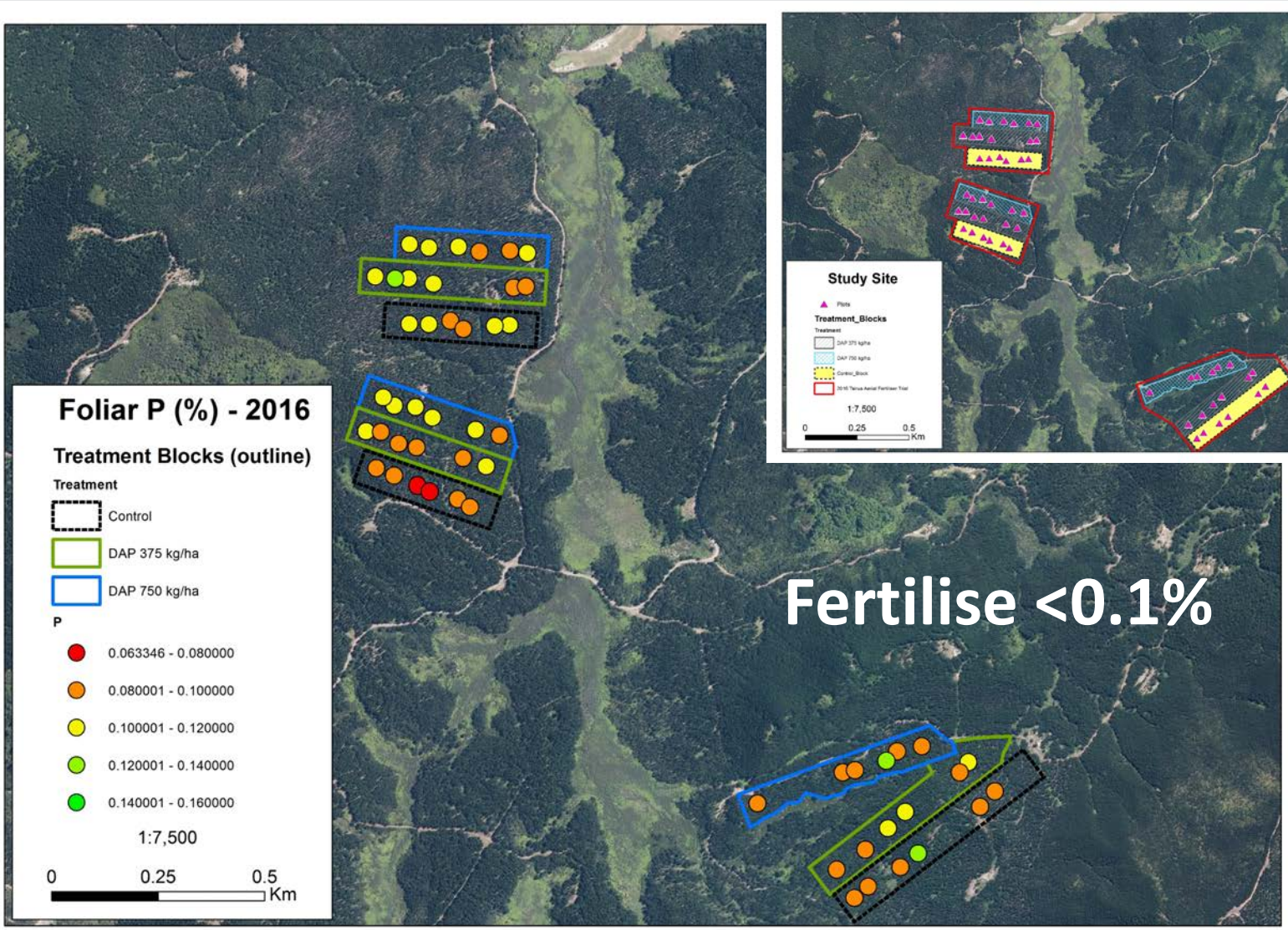
Results
LiDAR

LiDAR Results – 2016
Percentage of vegetation cover

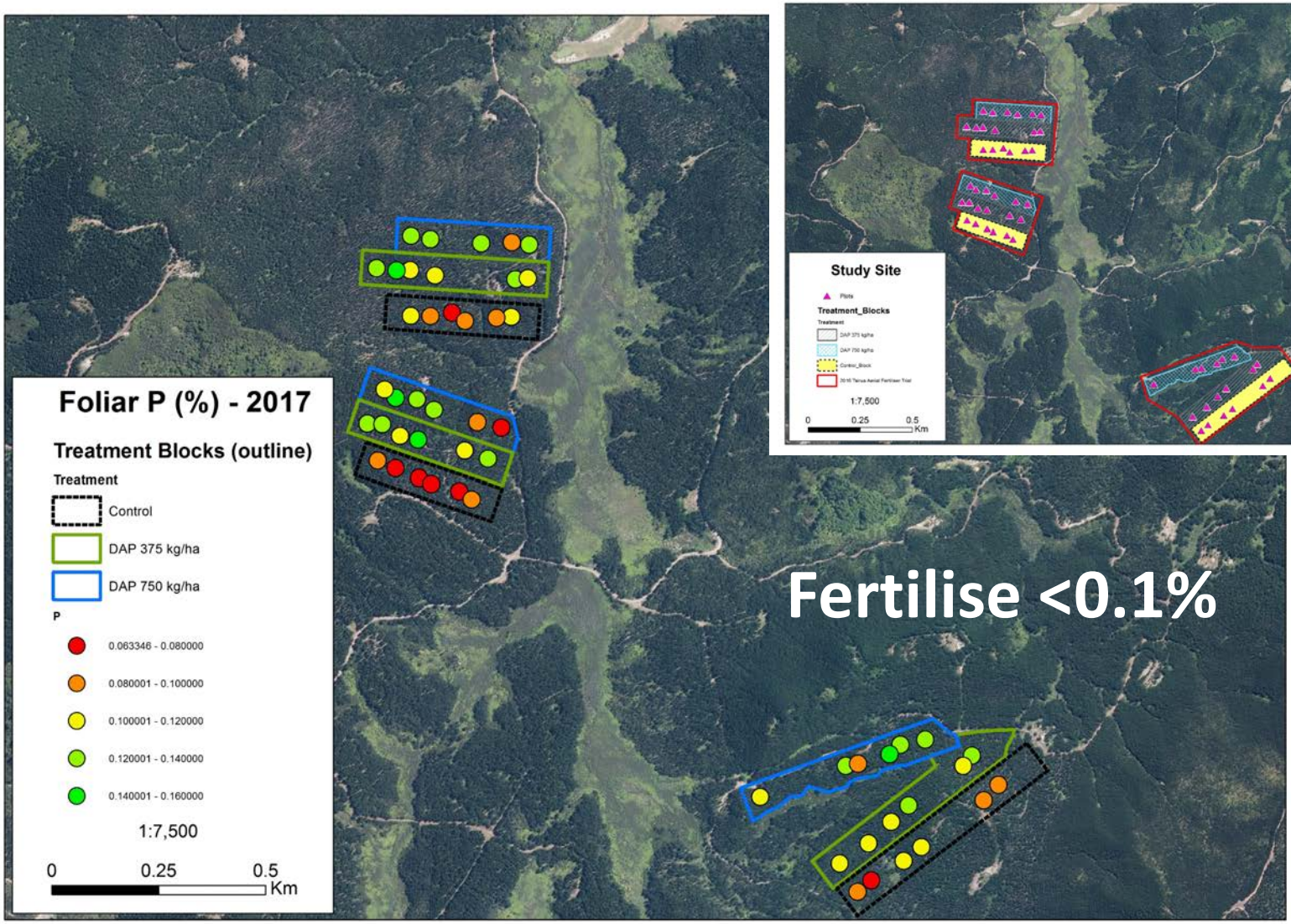


Results
Field and Lab

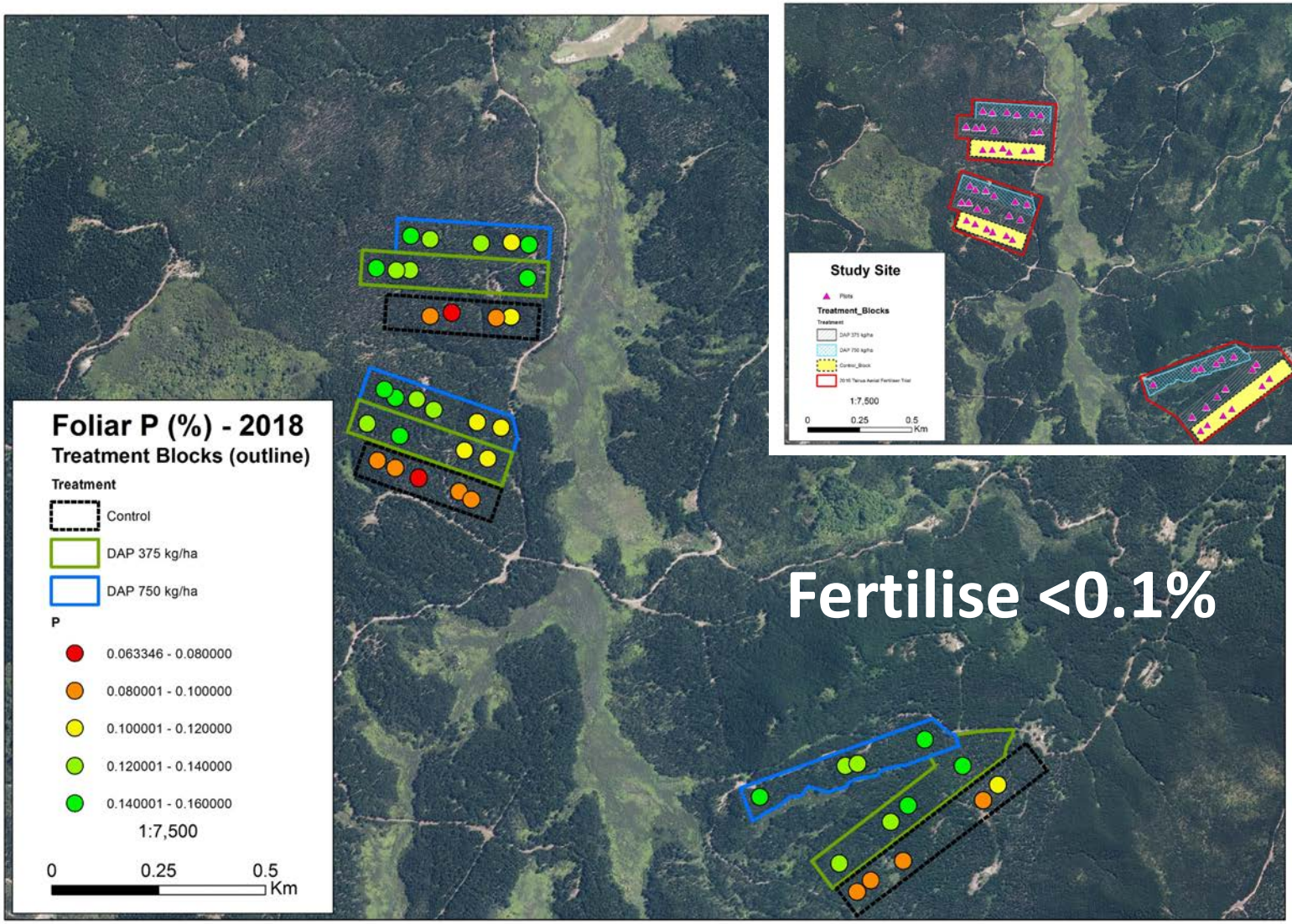
Laboratory Results
Foliar (P) - 2016



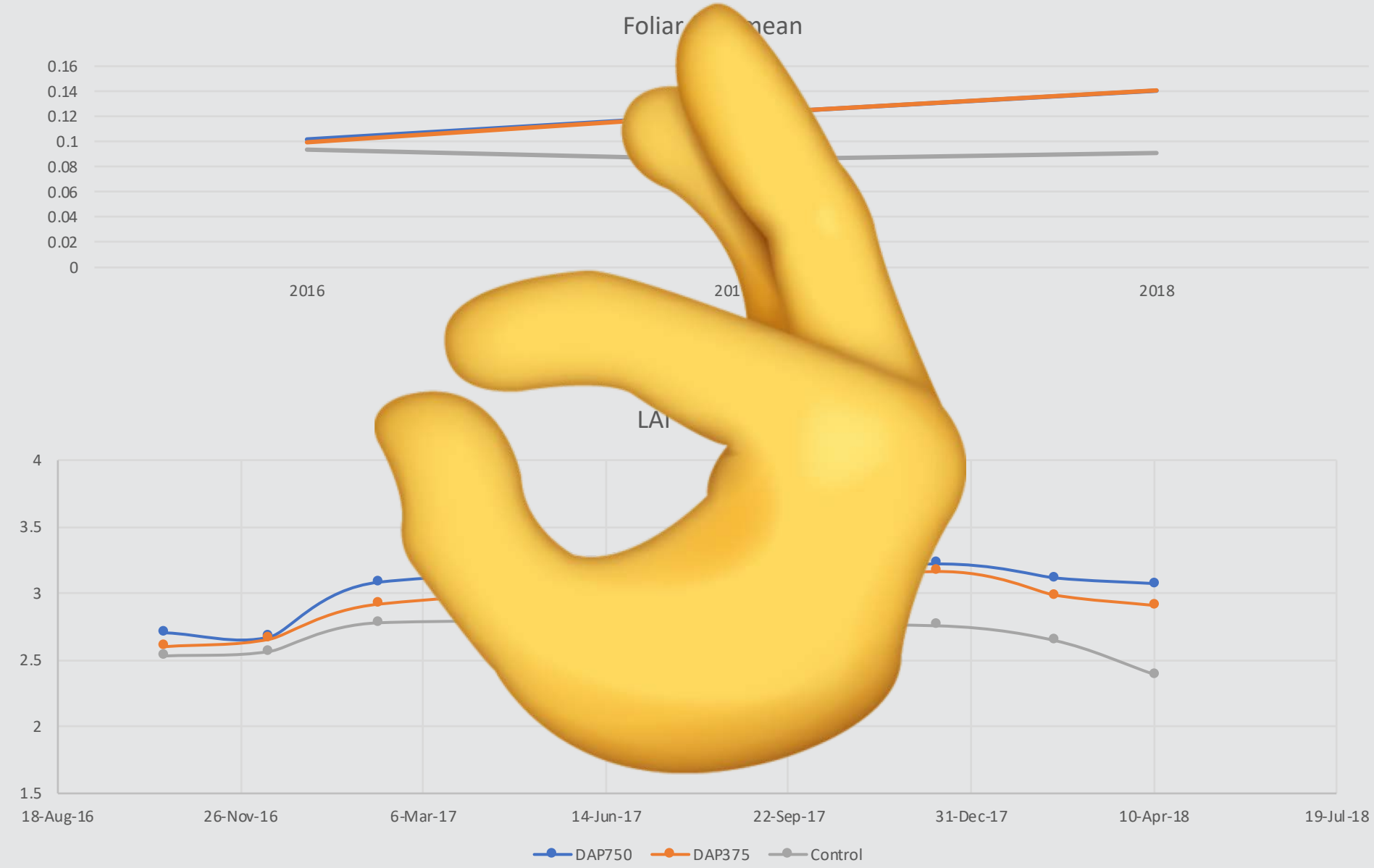
Laboratory Results
Foliar (P) - 2017



Laboratory Results
Foliar (P) - 2018



Foliar (P) over time

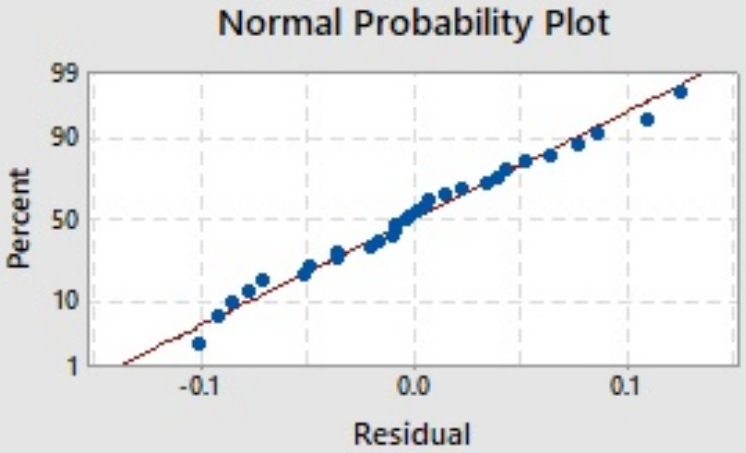


Results
Statistics

Statistical Analysis

LAI (Sentinel-2) vs other variables

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	10	0.45796	0.045796	8.78	0.000
DBH	1	0.08430	0.084301	16.15	0.001
C_foliage	1	0.03530	0.035303	6.76	0.018
B_foliage	1	0.01198	0.011979	2.30	0.146
K_foliage	1	0.01927	0.019269	3.69	0.070
Mg_foliage	1	0.05165	0.051651	9.90	0.005
Mn_foliage	1	0.10593	0.105926	20.30	0.000
Fasicle_Weight_foliage	1	0.03931	0.039315	7.53	0.013
Total P mg/kg_soil	1	0.02796	0.027964	5.36	0.032
Mg_soil	1	0.03804	0.038040	7.29	0.014
K_soil	1	0.17793	0.177931	34.09	0.000
Error	19	0.09916	0.005219		
Total	29	0.55712			



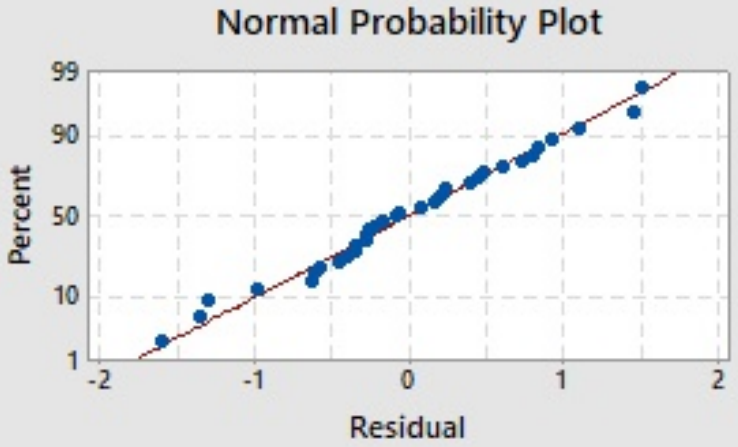
R-sq(adj)
72.83%

LAI = 6.20 + 0.002447 DBH - 0.0898 C_foliage + 0.01489 B_foliage + 0.388 K_foliage + 2.658 Mg_foliage + 0.000317 Mn_foliage - 0.0623 Fasicle_Weight_foliage - 0.001924 Total P mg/kg_soil + 0.001818 Mg_soil - 0.003189 K_soil

Statistical Analysis

LiDAR (p50fp) vs other variables

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	10	109.738	10.9738	13.59	0.000
CrownHeight	1	12.514	12.5143	15.50	0.001
C_foliage	1	11.934	11.9339	14.78	0.001
N_foliage	1	12.118	12.1183	15.01	0.001
Cu_foliage	1	2.079	2.0787	2.57	0.122
Fe_foliage	1	10.830	10.8299	13.41	0.001
P_foliage	1	6.034	6.0337	7.47	0.012
Total C (%)_soil	1	19.278	19.2780	23.88	0.000
Al_soil	1	12.622	12.6223	15.63	0.001
Mg_soil	1	4.556	4.5564	5.64	0.026
P_soil	1	4.288	4.2883	5.31	0.031
Error	23	18.568	0.8073		
Total	33	128.306			



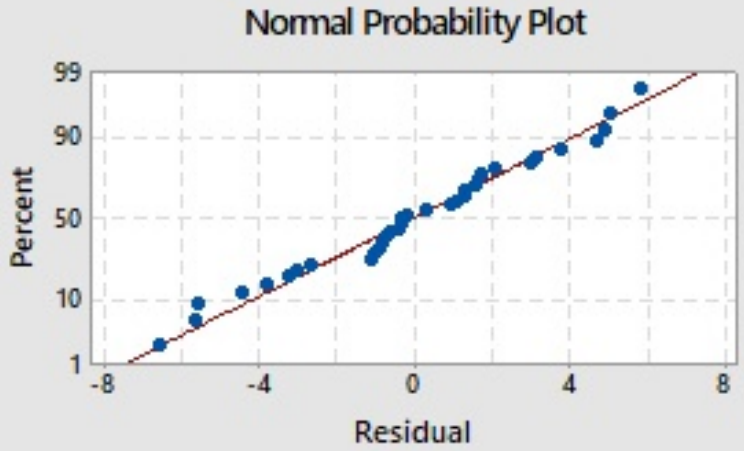
R-sq(adj)
79.24%

LiDAR (p50fp)	=	81.6 + 0.800 CrownHeight - 1.587 C_foliage + 6.61 N_foliage + 0.571 Cu_foliage - 0.1649 Fe_foliage - 50.9 P_foliage - 1.374 Total C (%)_soil + 0.002902 Al_soil + 0.01035 Mg_soil + 0.346 P_soil

Statistical Analysis

LiDAR (% veg) vs other variables

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	10	2039.93	203.99	14.21	0.000
CrownHeight	1	528.14	528.14	36.78	0.000
Cu_foliage	1	292.81	292.81	20.39	0.000
Fe_foliage	1	211.15	211.15	14.71	0.001
K_foliage	1	164.18	164.18	11.43	0.003
Mn_foliage	1	134.36	134.36	9.36	0.006
Total C (%)_soil	1	47.82	47.82	3.33	0.081
Total N (%)_soil	1	102.88	102.88	7.17	0.013
Mg_soil	1	132.18	132.18	9.21	0.006
Ca_soil	1	81.82	81.82	5.70	0.026
Zn_soil	1	122.81	122.81	8.55	0.008
Error	23	330.23	14.36		
Total	33	2370.16			



R-sq(adj)
80.01%

LiDAR (% veg)	=	105.0 - 3.665 CrownHeight + 6.25 Cu_foliage - 0.600 Fe_foliage - 26.95 K_foliage + 0.01288 Mn_foliage - 5.77 Total C (%)_soil + 161.5 Total N (%)_soil + 0.1330 Mg_soil - 0.0496 Ca_soil - 7.54 Zn_soil

Discussion

Discussion

- Statistical analysis shows a good relationship with LAI and field/lab data
- LAI trends over time show the potential to keep track of forest health using satellite data with some confidence
- On a broader scale, allows better forest management decisions to be made about fertilizer application type and areas where fertilizer need to be applied

Issues

- Not a great correlation between LAI (Sentinel) vs LiDAR metrics
  - Dataset too small?
  - Too much noise in the Sentinel data.
  - Different algorithms?
- Regression analysis highlights the complexity of factors that affect forest health

Conclusions/Further work

- Remote sensing using Sentinel-2 shows the potential to measure forest health objectively, accurately and cheaply

- Get monthly LAI from Sentinel and identify any seasonal variation
- Larger dataset

Questions??

Thanks to Charles Hosking and Paul Adams at Rayonier for discussions on forest nutrition and also, European Space Agency for the free satellite data!