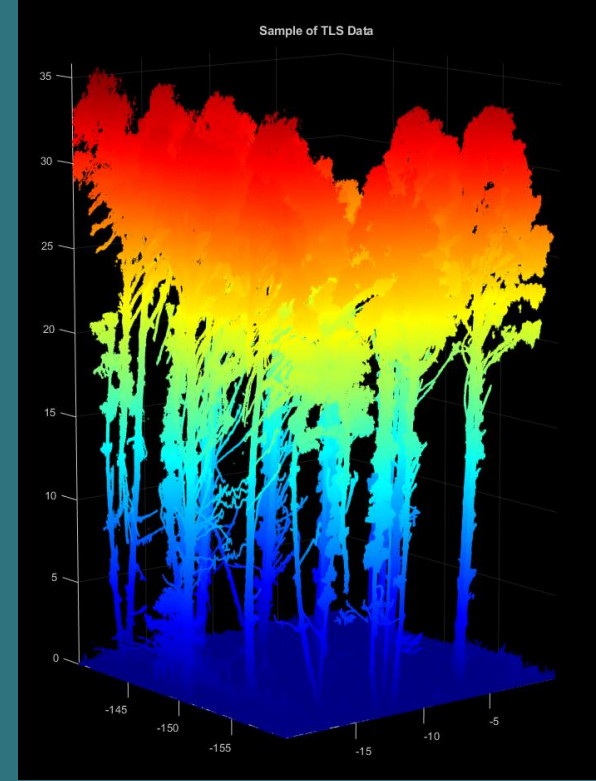


Stem Attribute Imputation from Fused Aerial and Terrestrial LiDAR Scans

Prof Anthony Finn

Tuesday, 10th Sept 2024



Talk Overview

Trials Equipment & Sites

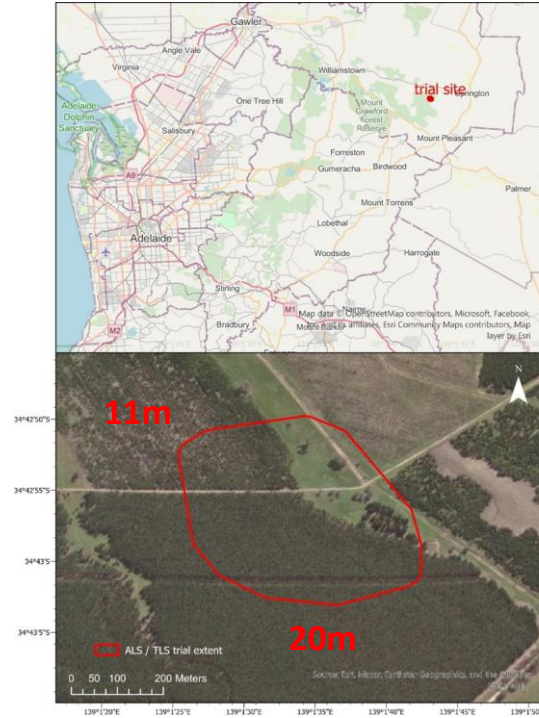
Results & Analysis

- Point Cloud Structure
- Tree Location Accuracy
- Stem Attribute Extraction
- MRG/ALS Imputation

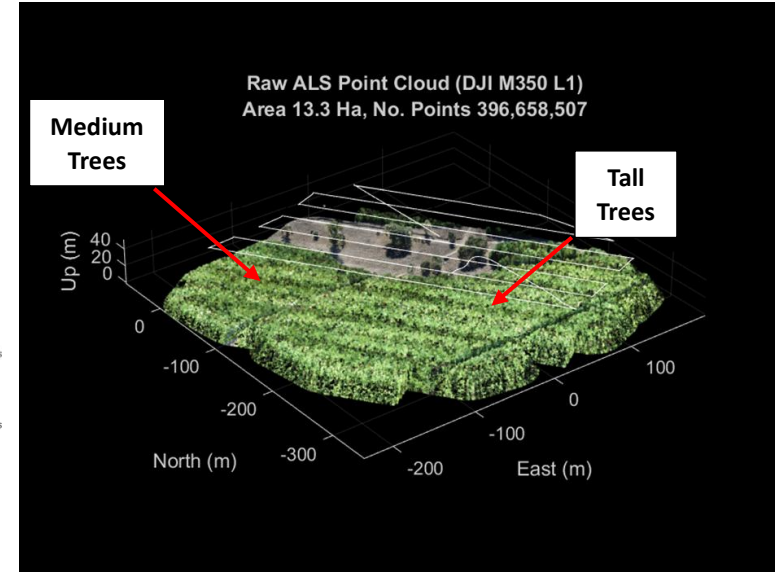
Results obtained for L1 & L2 LiDARs and High and low-resolution point clouds and Tall (21m) & medium-sized (13m) trees and Radiata Pine & Eucalyptus trees. Focus on Tall Radiata Pine Tree data presented here.



Trials Site – Mount Crawford



Height of Tall Pine Trees – 21 m



ALS Data

Also, data from Cradoc, TAS and Chain of Ponds, SA (Eucalyptus)

ALS & TLS Instruments

Terrestrial LiDAR (TLS)

GeoSLAM Zeb-Horizon
10 – 15 mins (loop closure)
300,000 points per second
Only fiducial references
Coverage (approx.) 2 ha

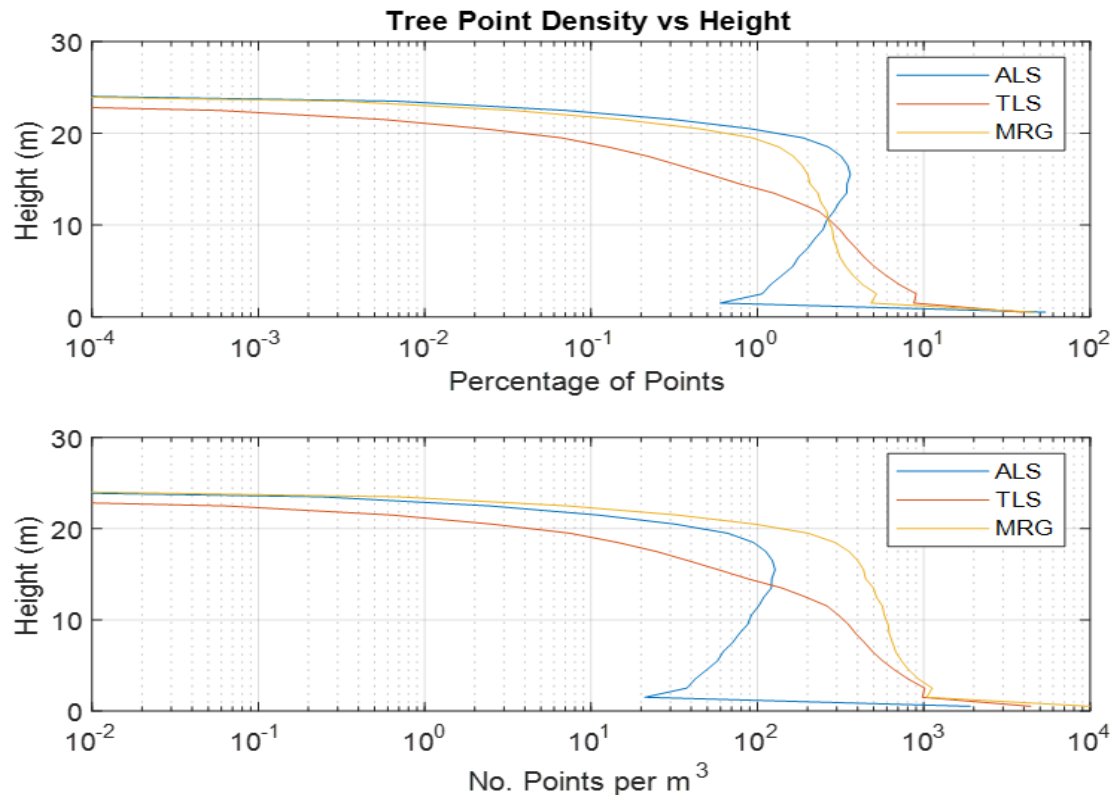
Aerial LiDAR (ALS)

Zenmuse L1 & DJI M350
10 – 15 mins flight time
160,000 points per second
RTK CP DGNSS (< 10cm)
Coverage (approx.) 13 ha

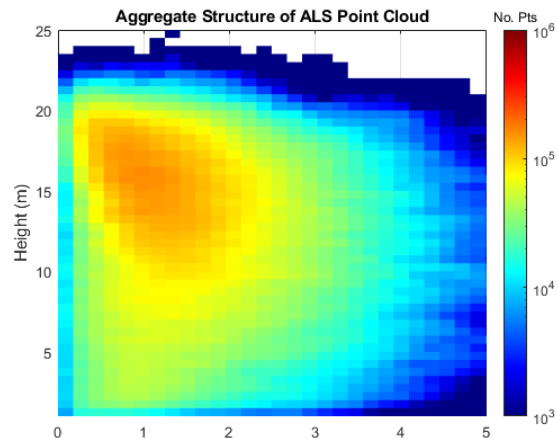


Trial Strategy: Approximately match (and minimise) operational effort for ALS & TLS

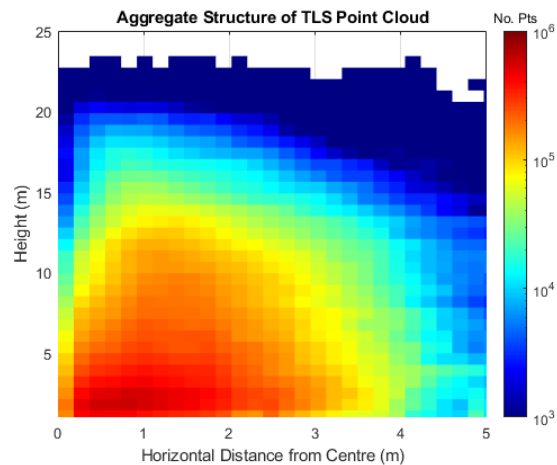
Point Cloud Structure



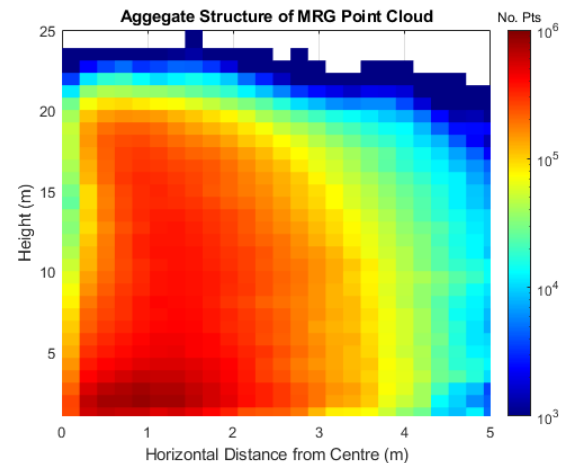
Point Cloud Structure (2D)



ALS



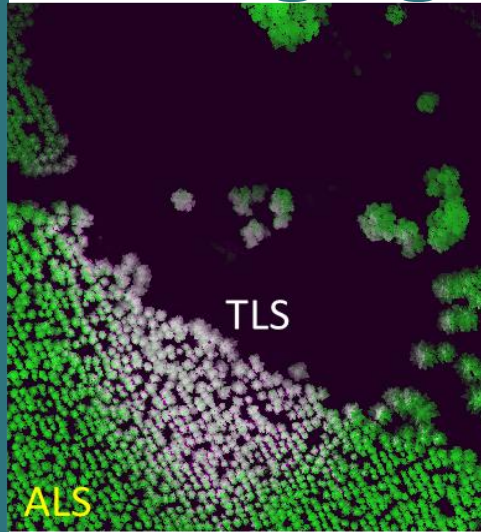
TLS



MRG



Merging the Point Clouds

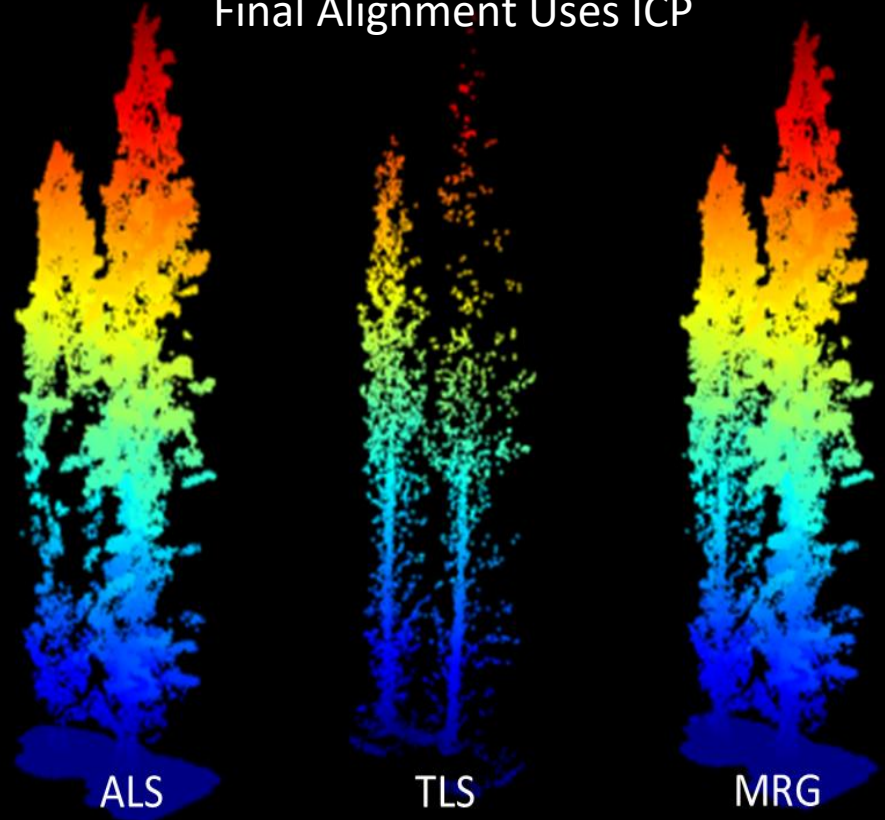


Normalise Ground

Create CHM Images

Preliminary Alignment
Uses CHM Correlation

Final Alignment Uses ICP



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Stem Attribute Extraction (Pine)

Goat Farm Site, Mt Crawford, SA

95 Field Obs.

Attribute	ALS High Res	ALS Low Res	MLS	Merged	Field
All Tall Trees (cm)					
H_T (m)	20.8 ± 3.7	19.8 ± 3.0	19.8 ± 5.0	20.8 ± 3.8	20.5 ± 1.6
DBH (cm)	28.1 ± 3.1	27.9 ± 0.4	24.5 ± 3.9	26.6 ± 3.0	25.4 ± 4.8
All Medium Trees (cm)					
H_T (m)	11.2 ± 2.4	---	11.0 ± 2.7	11.3 ± 1.9	11.4 ± 1.1
DBH (cm)	16.2 ± 5.2	---	13.6 ± 3.7	12.5 ± 2.9	13.1 ± 2.5

CHM & Regression
Model

TreeLS

Errors (wrt Field Obs.)

 H_T : 1% - 3.5%DBH_{TreeLS}: 2.5% - 3.5%DBH_{Regression}: 10% - 23%

Whole Site

20 Medium
Trees Observed
by TLS & ALS35 Tall Trees
Observed by
TLS & ALS20 Medium
Trees Observed
Only by ALS20 Tall Trees
Observed
Only by ALS

Eucalyptus

 H_T = similarDBH_{TreeLS} = similarDBH_{Regression} = worse

Attribute Extraction

Pine

Total Tree Height	Field Obs	TreeLS			Regression		
		ALS	TLS	MLS	ALS	TLS	MLS
TLS Trees, Tall	20.3 ± 1.5	19.1	20.4	20.3	20.7	19.4	20.8
ALS-only Trees Tall	20.6 ± 1.6	-	-	-	20.8	-	20.8
TLS Trees Medium	11.8 ± 0.6	11.9	10.9	11.9	11.9	10.5	11.9
ALS-only Trees Medium	10.9 ± 1.6	-	-	-	11.9	-	11.9
Diameter Breast Height	Field Obs	TreeLS			Regression		
		ALS	TLS	MLS	ALS	TLS	MLS
TLS Trees, Tall	25.4 ± 5.3	26.4	26.3	25.9	28.4	24.5	28.2
ALS-only Trees Tall	22.1 ± 2.7	-	-	-	27.7	-	27.4
TLS Trees Medium	16.6 ± 1.3	25.5	18.2	17.9	13.6	12.5	13.1
ALS-only Trees Medium	15.8 ± 3.1	-	-	-	12.8	-	12.7

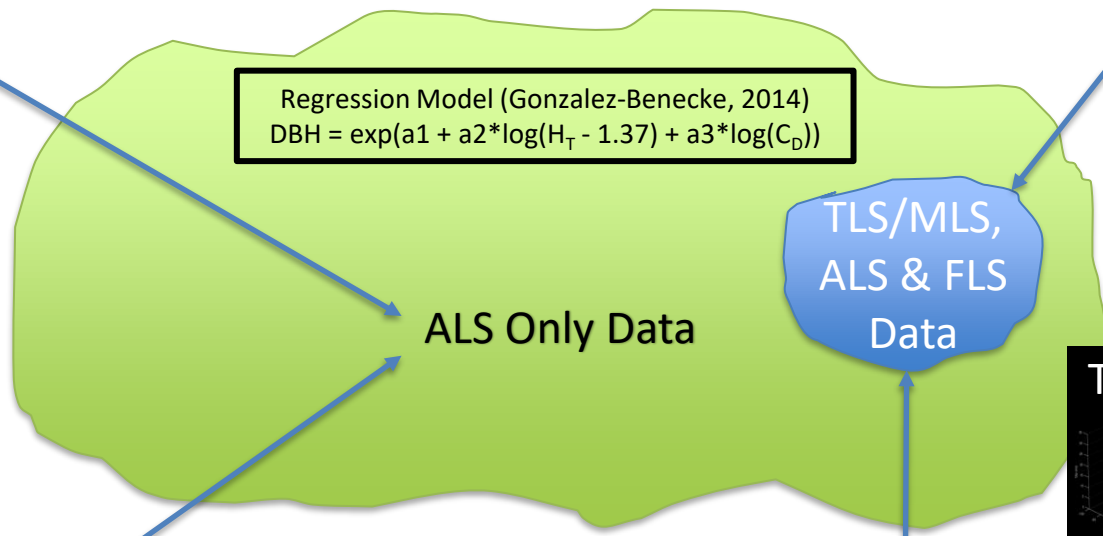
Eucalyptus

Attribute	L1 ALS	L2 ALS	TLS	L1 Merged	L2 Merged	Field Obs
H _T (m)	32.1 ± 2.8	32.4 ± 3.0	30.9 ± 5.0	31.1 ± 3.8	32.2 ± 3.8	--
DBH (cm)	34.4 ± 3.1	41.5 ± 0.4	37.5 ± 3.9	35.0 ± 3.0	41.6 ± 3.6	36.9 ± 13.8

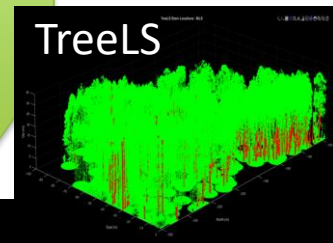
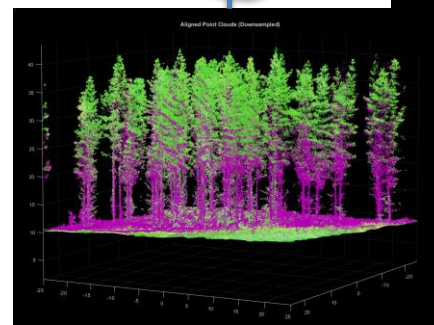
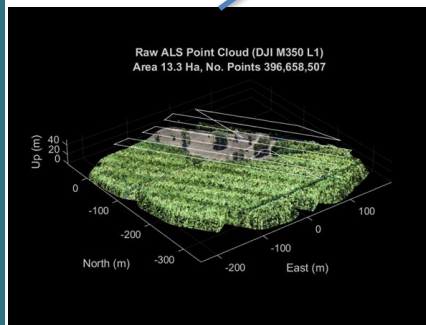


Stem Imputation Modelling

Cannot Use
Sophisticated Stem
Extraction Tools
(No Stem Data), So
Apply Corrected
Regression Model



Apply TreeLS
& Regression
Model and
Compute
Corrected
Model



Stem Imputation Modelling

Accurate total tree height estimates can be derived from ALS or MLS.

Accurate stem locations and attributes can be derived from TLS or MLS.

Want better estimates of stem attributes in the region observed solely by the ALS (for which there is limited stem data), so ...

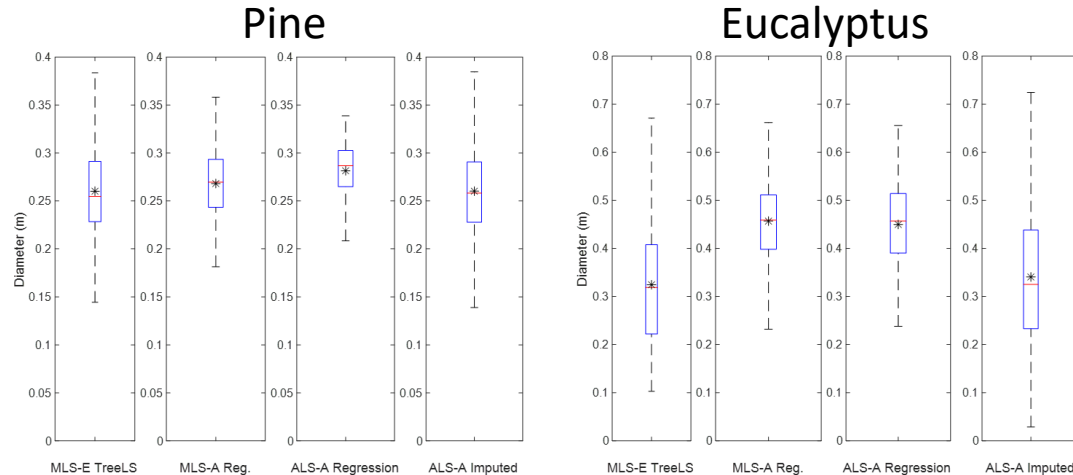
- (i) Apply accurate stem attribute extraction tools to MLS data
- (ii) Compare the outcomes of (i) to regression model estimates of the same trees obtained using just the ALS component of MLS data set
- (iii) Adjust regression model estimates so they match TreeLS estimates
- (iv) Apply the corrected model developed in step (iii) to the (much larger) section of forest observed only by the ALS



Errors reduce from
12 – 28% without
imputation to
2 – 6% with
imputation

DBH Imputation Modelling

Observation or Imputation Strategy	Tree Set		
	Tall Pine	Medium Pine	Tall Eucalypt
Field Observations (Target)	25.4 ± 5.3	18.8 ± 1.3	36.9 ± 18.8
Strategy 1 $x_{Imp} = \beta_{TreeLS}^{-1}(\beta_{ALS-E}(x_{ALS-E}))$	25.9	20	35.1
Strategy 2 $x_{Imp} = \beta_{TreeLS}^{-1}(\beta_{Corr}(x_{ALS-E}))$	28.3	17.4	42.1
Strategy 3 $x_{Imp} = \beta_{TreeLS}^{-1}(k_{Corr}(x_{ALS-E}))$	26.7	19.8	42.7
Strategy 4 Strategy 3 but $\Delta(y) = y_{TreeLS}/y_{MLS-A}$	26.9	20	38.5
Strategy 5 PDFs then $x_{Imp} = \beta_{TreeLS}^{-1}(k_{Corr}(x_{ALS-E}))$	26.3	40	34.6
Strategy 6 $y = k(x)$ replaced by $y = k'(x_1, x_2)$	32.1	16.9	22.3
Regression Model (No Imputation)	28.2	13.6	47.4



Note: Reg.
Model Not
Species
Appropriate
to Eucalyptus

Stem Imputation Modelling

Limitations of current imputation study

- Simple mathematical (imputation) models
- One TLS region, one ALS region (multiple?)
- “Arbitrary” regression model (better ones?)
- Regression models based on DBH (voxels?)
- One density of ALS point clouds (higher/lower?)
- Can tree location estimate also be improved?
- Use voxel-based techniques?



Summary

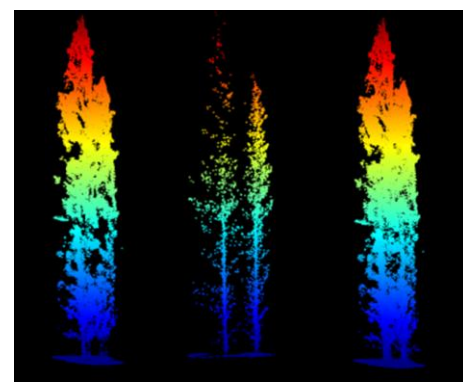
No major surprises in sensor data

- Reduction in returns with increasing distance

Point clouds more expensive (higher 'cost per dot')

But merged point clouds deliver

- Improved point cloud structure of trees
 - Propagation studies, light interception, hydrology, microclimates, forest resilience, etc.
- Improved location accuracy of trees (TLS data set)
- Improved stem attribute extraction
- Significant imputation opportunities
 - Without too much additional field time (~15 mins?)



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“Geospatial Positioning & Fusion: is real-time sub-metre, accuracy operationally feasible in forestry environments?”

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