Operational Forest Inventory of Mature Douglas-fir Stands Using Mobile Lidar

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Forest Inventory Approaches

- Entity
  - Stand level
  - Tree level
- Data
  - Two-dimensions:
    - Example: multispectral (indices) & elevation data
    - Cons: limited information from bird view
  - Three-dimensions
    - Pros: more information describing forest
    - Cons: noise, giant data size

Terrestrial lidar

- Game changer
  - Accurate
  - Fast (some)
- Types
  - Stationary
  - Mobile
    - Vehicle
    - Handheld / backpack

Leica P50

Faro S70

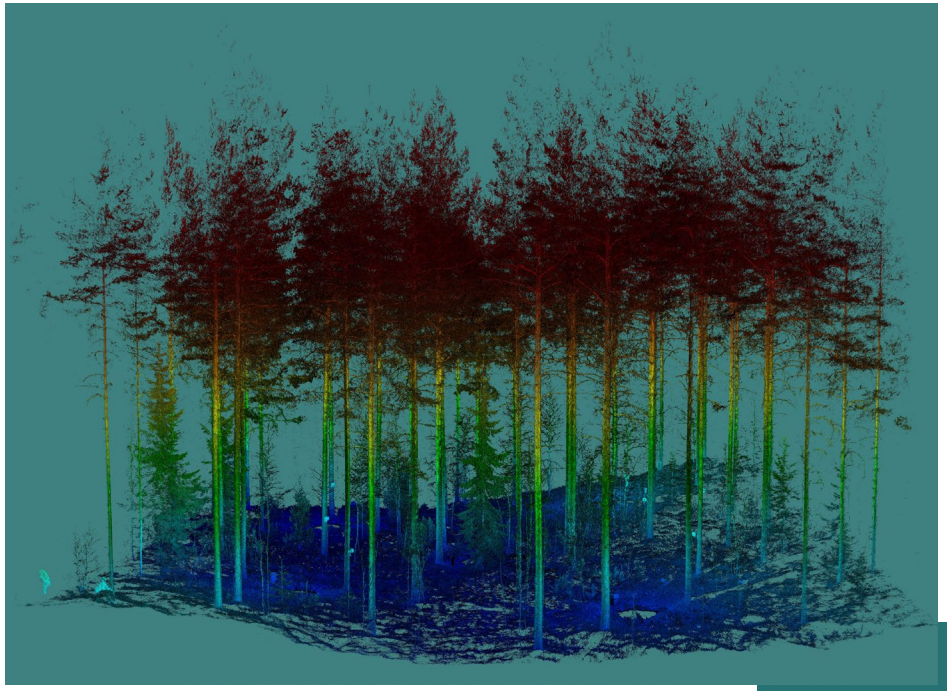
GeoSlam Horizon

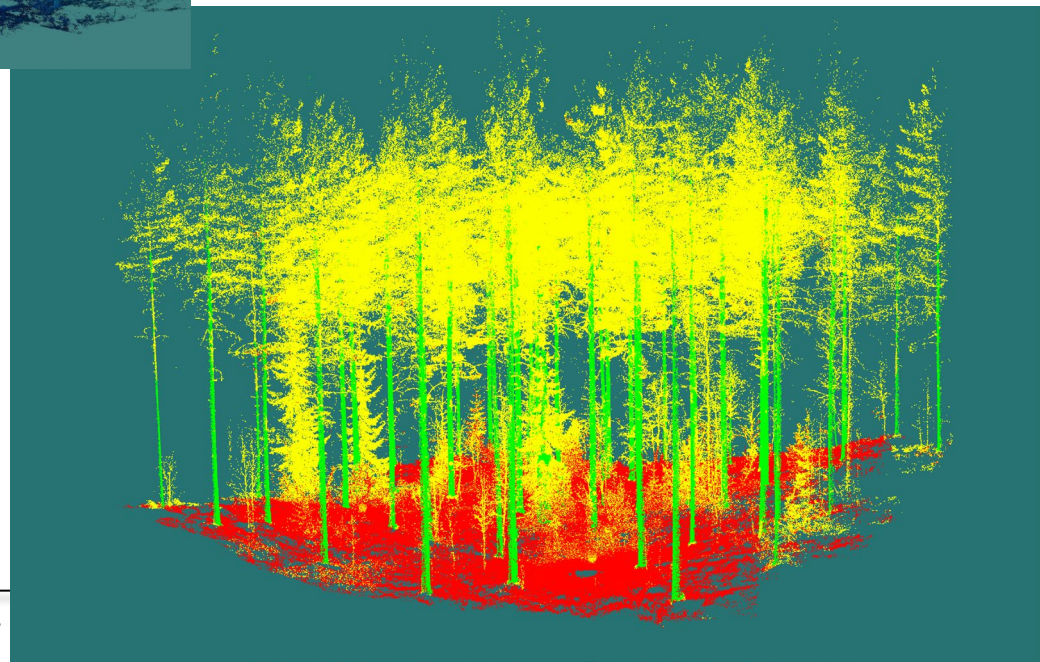
Kaarta Sencil2

- Allow individual tree forest inventory

Individual trees forest inventory

- Two steps
  - Identify trees
  - Measure trees
- Point clouds
  - 3D stem detection
  - 3D stem modeling





3-D Stem Detection Methods

1. Create multiple layers and count point density
2. Transfer point cloud into voxel, check flatness and distance
3. Detect clusters to identify trees

Problems:

- No pre-knowledge on stem location

3-D Stem Modeling

- Cylinder fitting:
  - RANSAC model: difficult in shrubby areas

- Circle fitting:
  1. Hough transform: required pre-knowledge of circle radius
  2. Least squares: influenced by outliers
  3. RANSAC: not the optimal solution

Objective

Develop an algorithm that

- classifies points as stems, ground, and crown
- locates individual trees
- computes stem attributes

Data#1: International Benchmark TLS Data

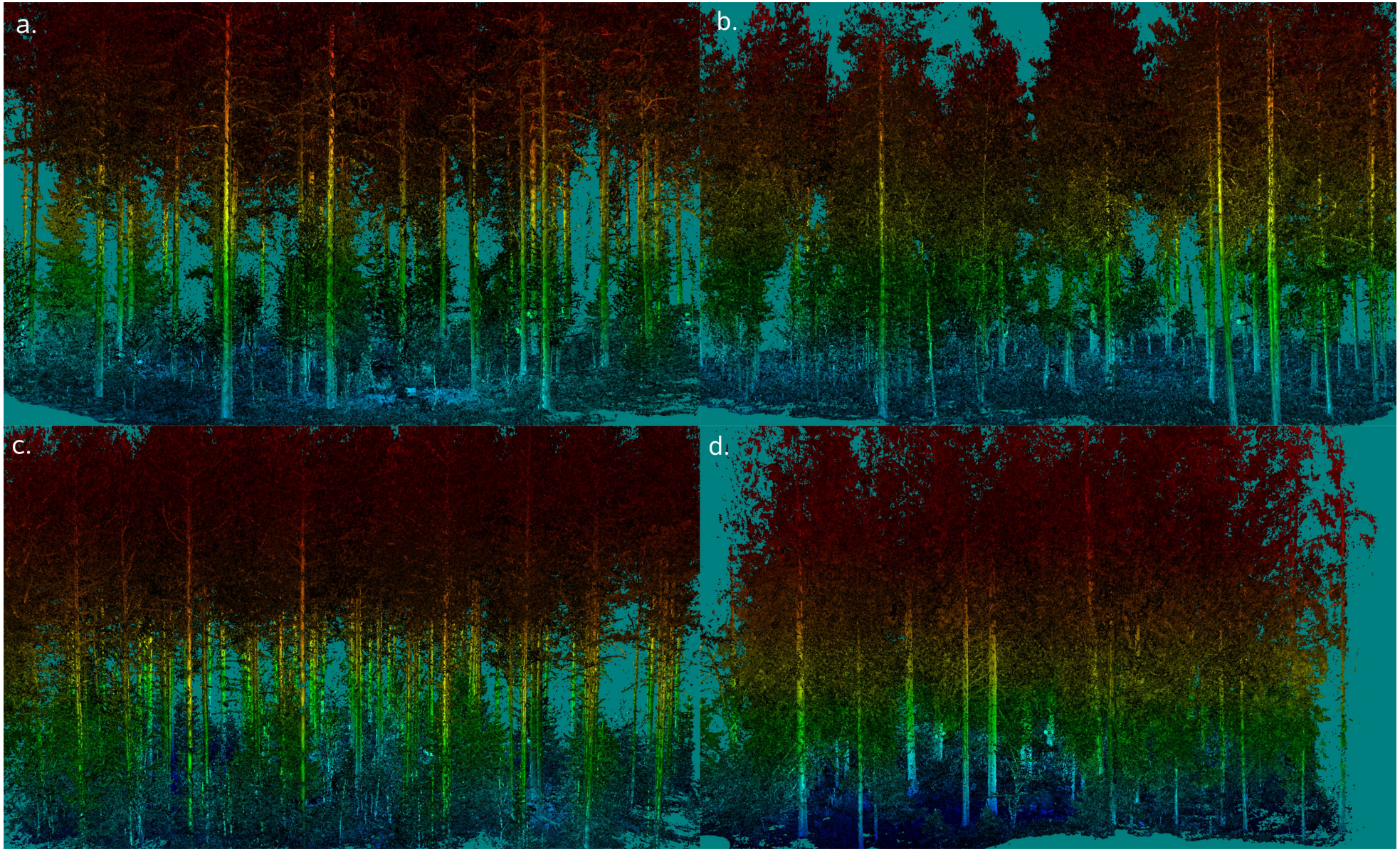
- Boreal forest in Finland: 2014
- Species: Scots Pine, Norway Spruce and Downy Birches
- Complexity: Easy plot, Medium plots and Difficult Plots,
- Area: $32\ m \times 32\ m$ (~1/4 ac)
- Scanning from 5 locations
- Leica HDS6100

Data#1: International Benchmark TLS Data

Plot	Plot label	Tree Density stem/ha	DBH cm	Tree height m	# Points Million
1	Easy	498	22.8±6.6	18.7±3.9	111.1
2	Easy	820	15.9±6.9	13.7±4.0	113.7
3	Medium	1445	14.8±7.3	15.4±6.8	119.9
4	Medium	761	19.6±14.1	16.1±10.2	129.4
5	Hard	1279	14.3±13.1	13.0±7.0	124.5
6	Hard	2304	12.2±5.5	13.0±6.3	111.1

(Liang et al., 2018)

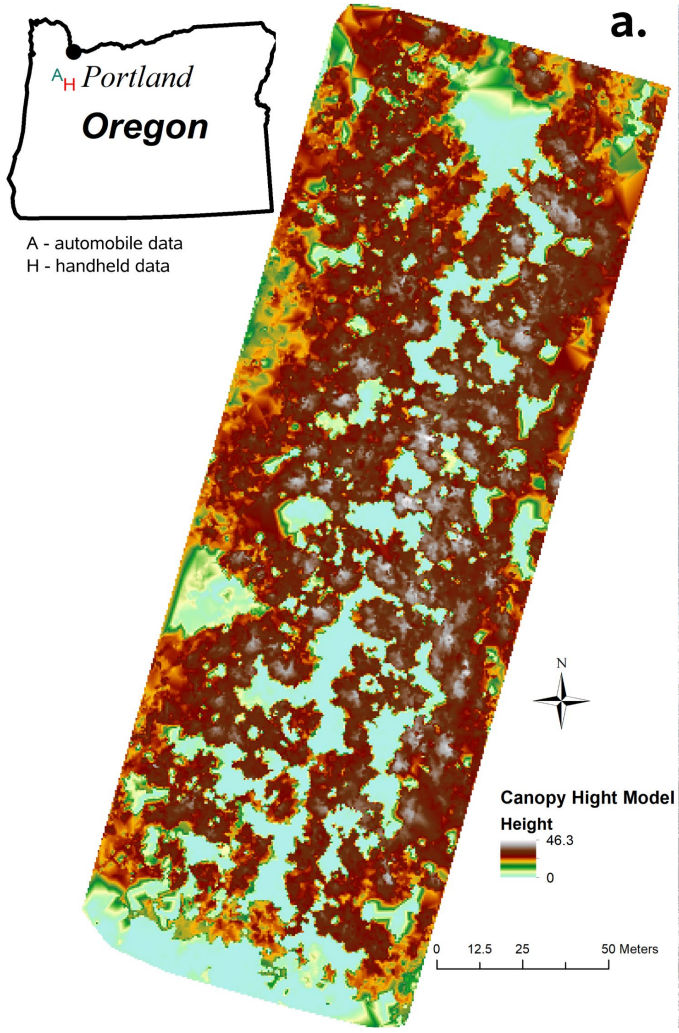
Data#1: International Benchmark TLS Data



Data#2: McDonald-Dunn Forests MLS Data

- McDonald-Dunn Research Forest (near Corvallis OR)
  - Mature Douglas Fir
- Acquired in March 2018
  - Velodyne HDL-64E on a Toyota Tacoma Truck.
- Scanned 2.7 ha with more than 81 million points.
- 86 tree: average DBH is 73 cm and 41 m height

Data#2: McDonald-Dunn Forests MLS Data

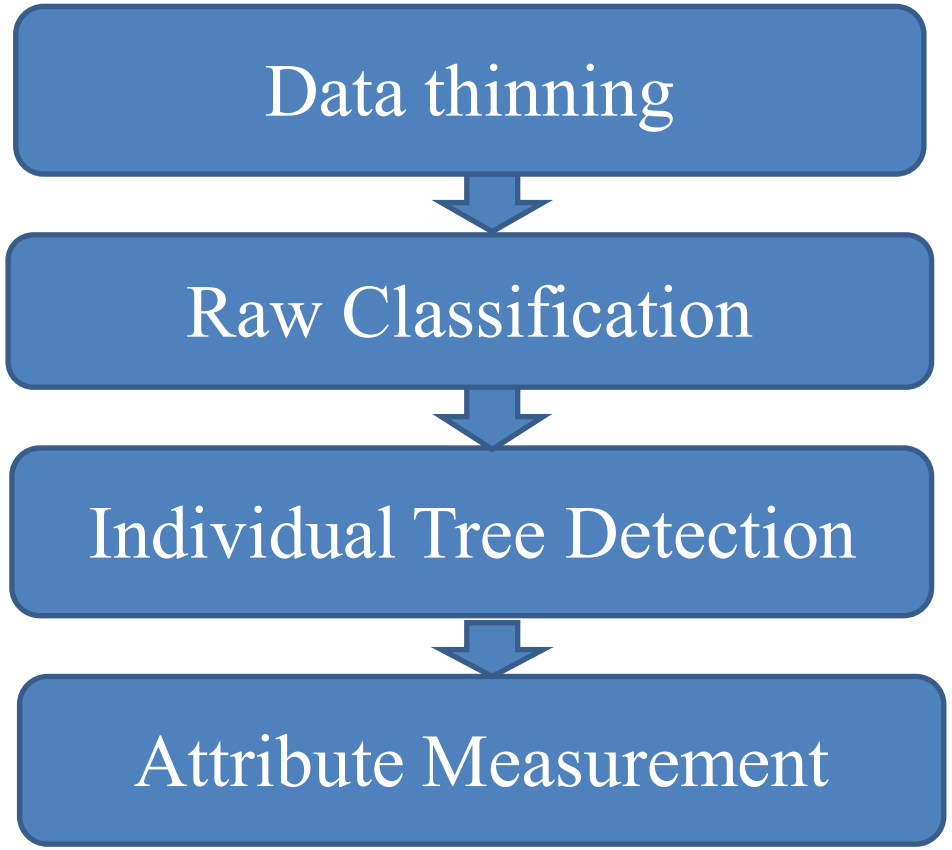


Data#3: McDonald-Dunn Forests HLS Data

- McDonald – Dunn Forest, Feb 2021
  - Mature Douglas – Firs
- Handheld lidar unit GeoSlam Zeb Horizon
  - Velodyne Puck (VLP -16)
- Area: 1.0 ha with 46.6 million points
- 153 trees
  - Height 35.4 m
  - DBH: 39.1 cm

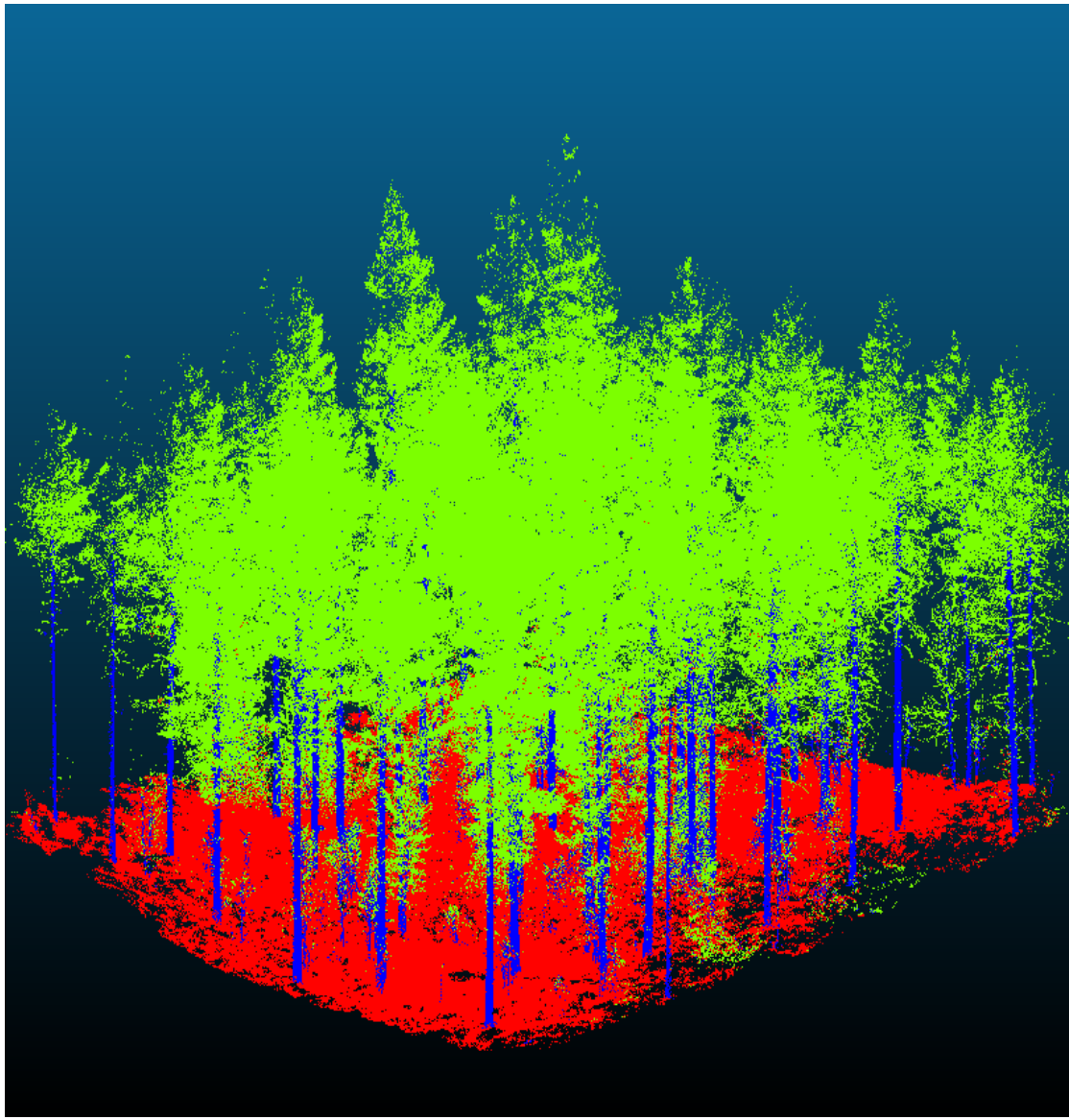
Data#3: McDonald-Dunn Forests HLS Data

Method: Overview



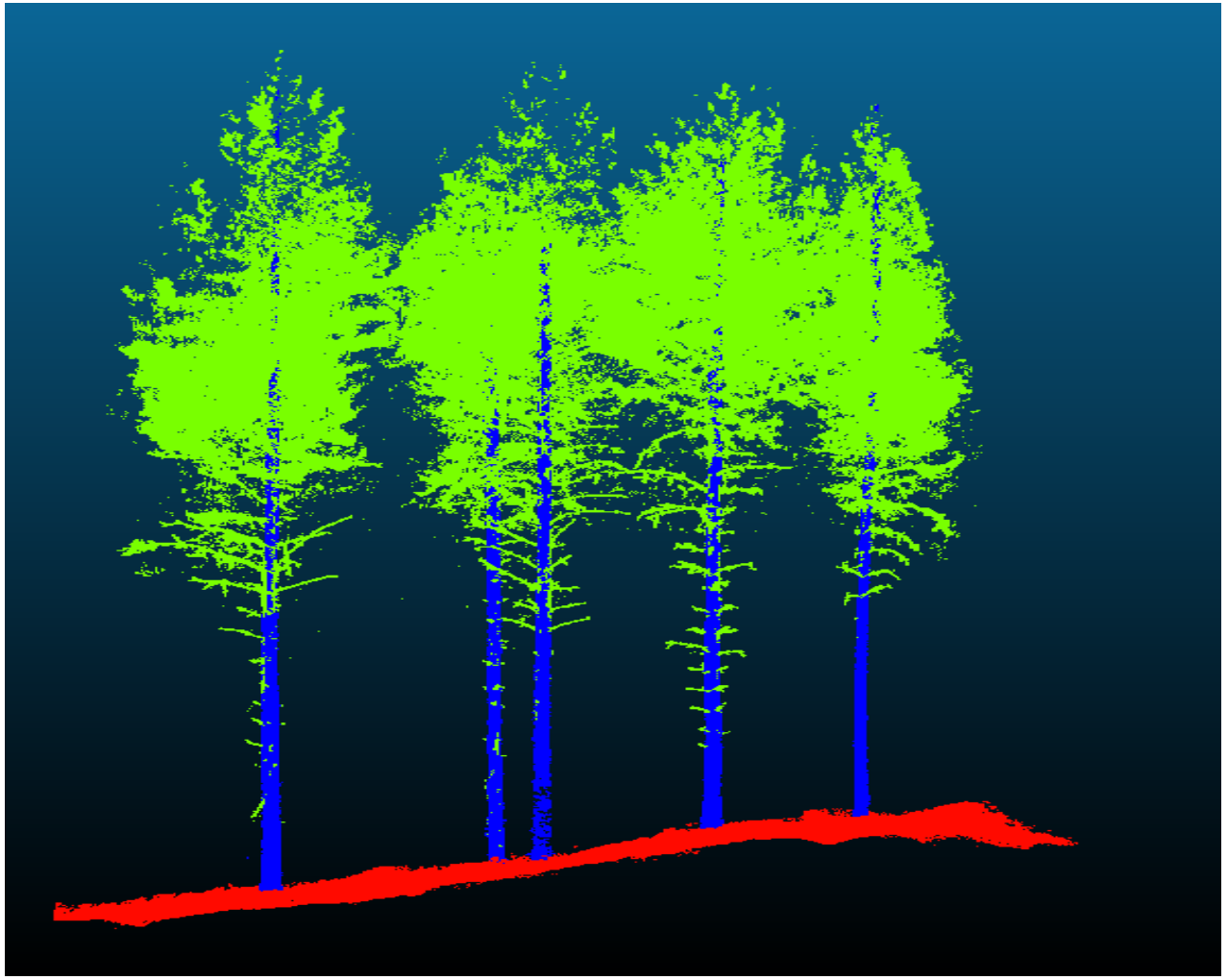
Raw classification

- Classify the points as
  - Stem
  - Ground
  - Crown (non-stem/ground)
- Point Net++
  - ANN Multilayer Perceptron algorithm
  - Adjusted to forestry settings



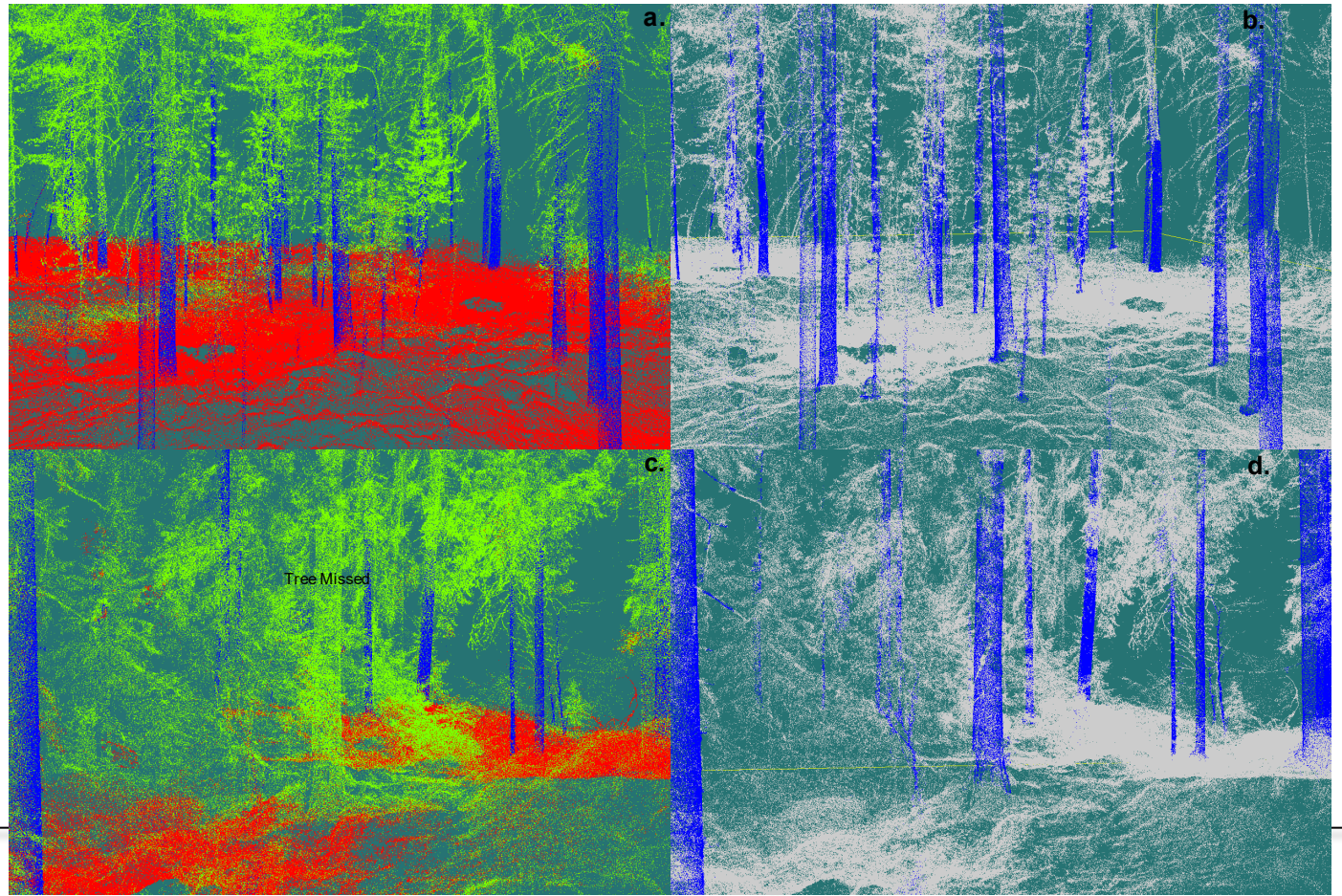
Training Data

- 10 Trees
- 3 classes:
  - Ground
  - Stem
  - Crown



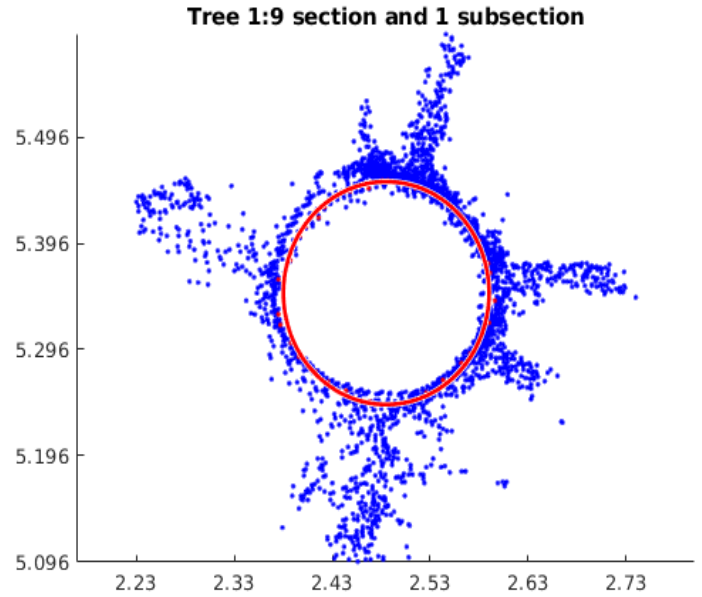
Individual Tree Detection

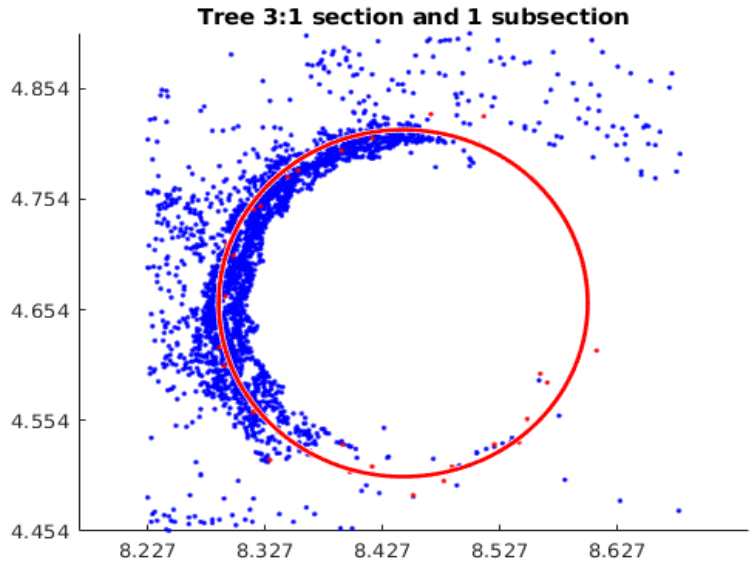
2-D Projection of stem points → Cluster Points: fine classification → Identify trees and their crown class position



Estimation of tree attributes

- Trees Verticalization
- Remove Outliers
- Segment the Stem in Sections
- Sections Projected on 2D
- Computation of Important Points
- Compute Attributes



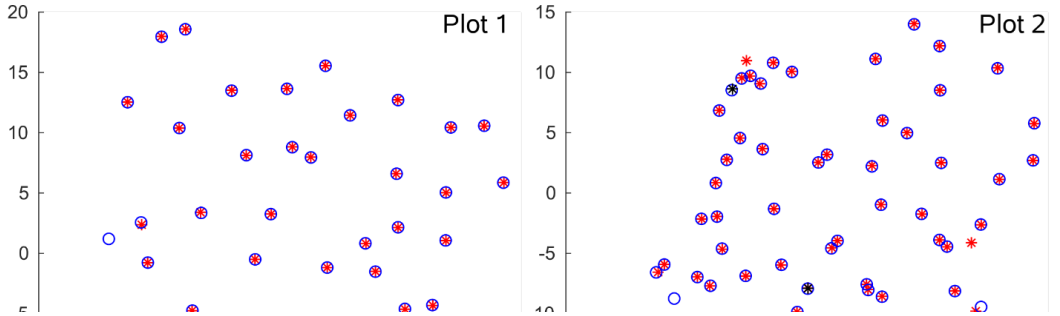


Results

- Individual tree detection
  - Completeness, Correctness
- Location
- Diameter at breast height (DBH)
- Total tree height

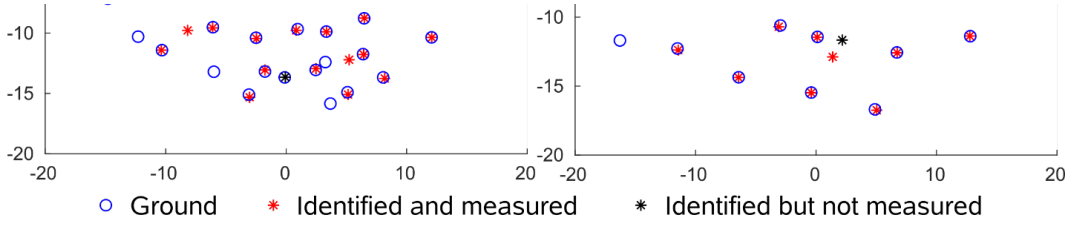
Benchmark Data: Individual Tree Detection

Plot	Completeness [%]		Correctness [%]	
	All Trees	Dominant	All Trees	Dominant
1	92.16	97.83	100	100
2	91.9	96.5	100	94.9
3	80.8	94.2	98.8	95.3
4	74.1	84.6	95.2	91.7
5	55.7	62.8	94.8	79.4
6	43.6	52.6	100	71



Best Benchmark results:

- Easy: 90.4 / 93.6
- Medium: 88 / 89.2
- Hard: 62.5 / 100



Benchmark Data: DBH

Plot	Bias [mm] ([%])	
	All Trees	(Co)Dominant
1	2.7 (1.1)	2.9 (1.2)
2	-5.5 (3.1)	-6.2 (3.2)
3	2.0 (1.0	1.2 (6.4)
4	0.5 (0.2	0.3 (0.1)
5	-2.1 (1.0)	-8.2 (3.5)
6	2.5 (1.8)	2.4 (1.5)

Best Benchmark results:

- Easy: -1
- Medium: 0.8
- Hard: -1

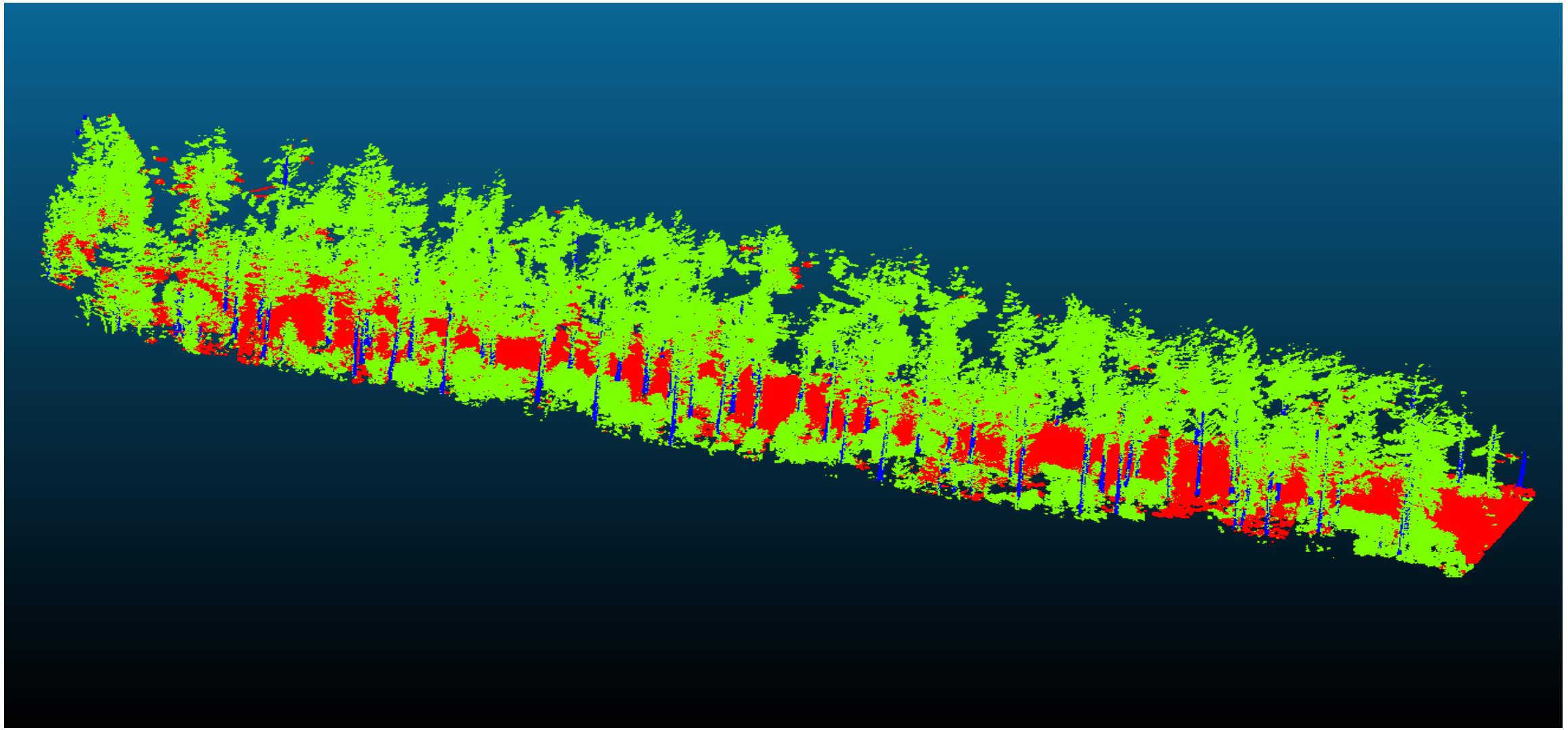
Benchmark Data: Height

Plot	Bias [mm] ([%])	
	All Trees	(Co)Dominant
1	-0.66 (-3.4)	-0.89 (-4.4)
2	-0.87 (-5.9	-1.27 (-8.1)
3	-1.35 (-6.8)	-1.75 (-5.6)
4	-2.4 (-11.2)	-4.16 (-16.6)
5	1.22 (7.7)	0.96 (5.3)
6	0.29 (1.9)	-2.0 (-11.1)

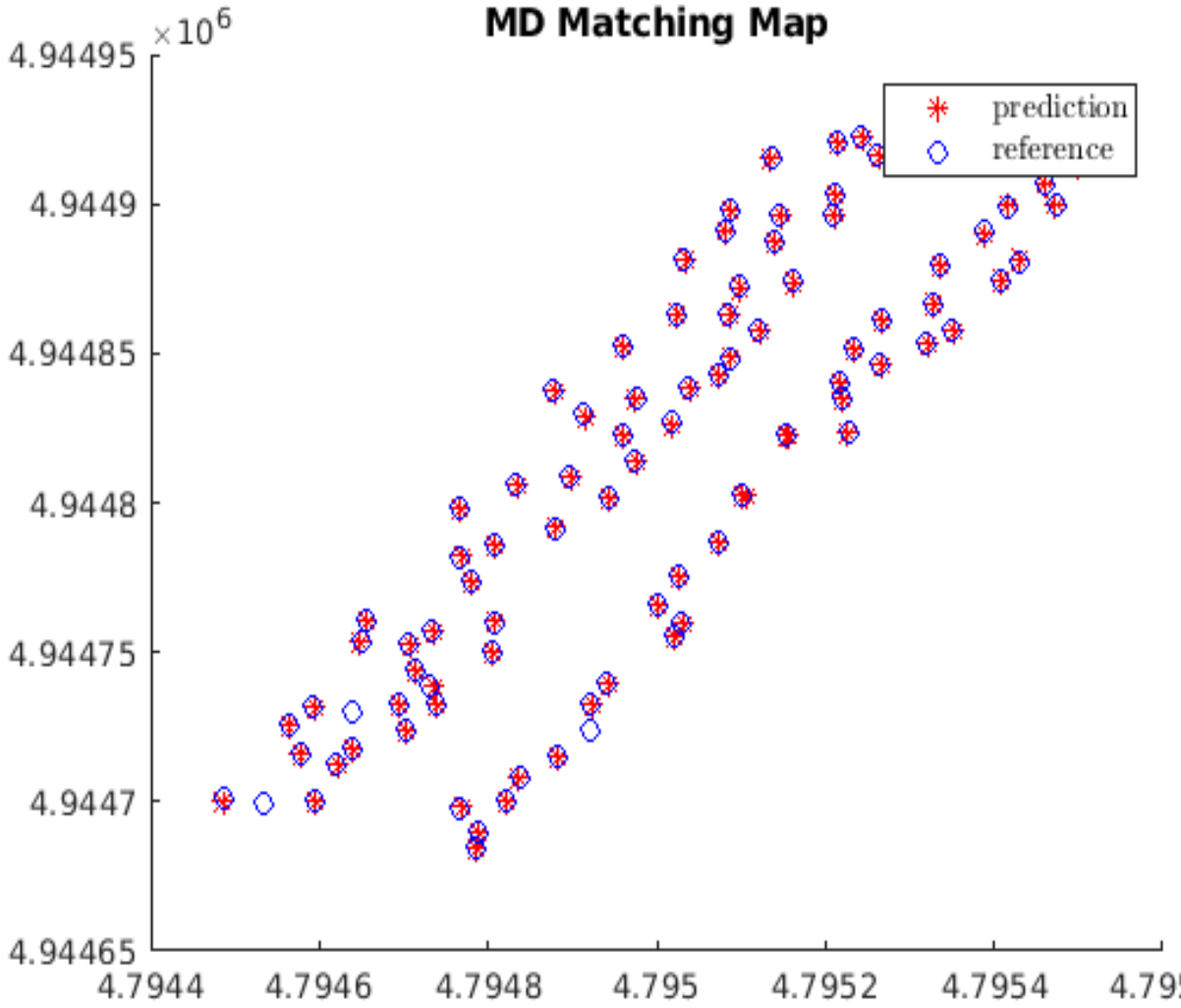
Best Benchmark results:

- Easy: -2.2
- Medium: -2.2
- Hard: -0.1

McDonald–Dunn Data: MLS (truck)

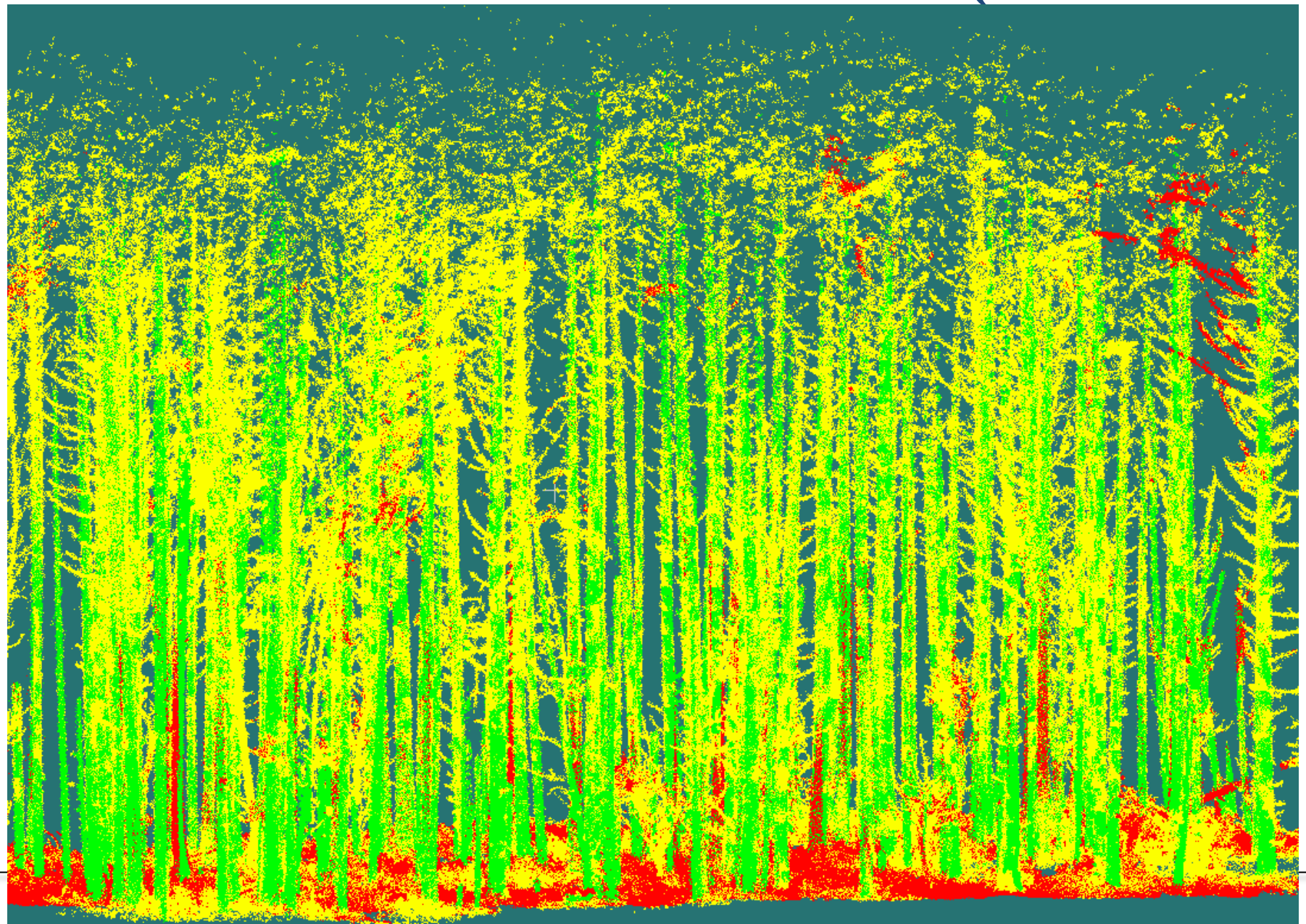


McDonald–Dunn Data MLS: Assessment

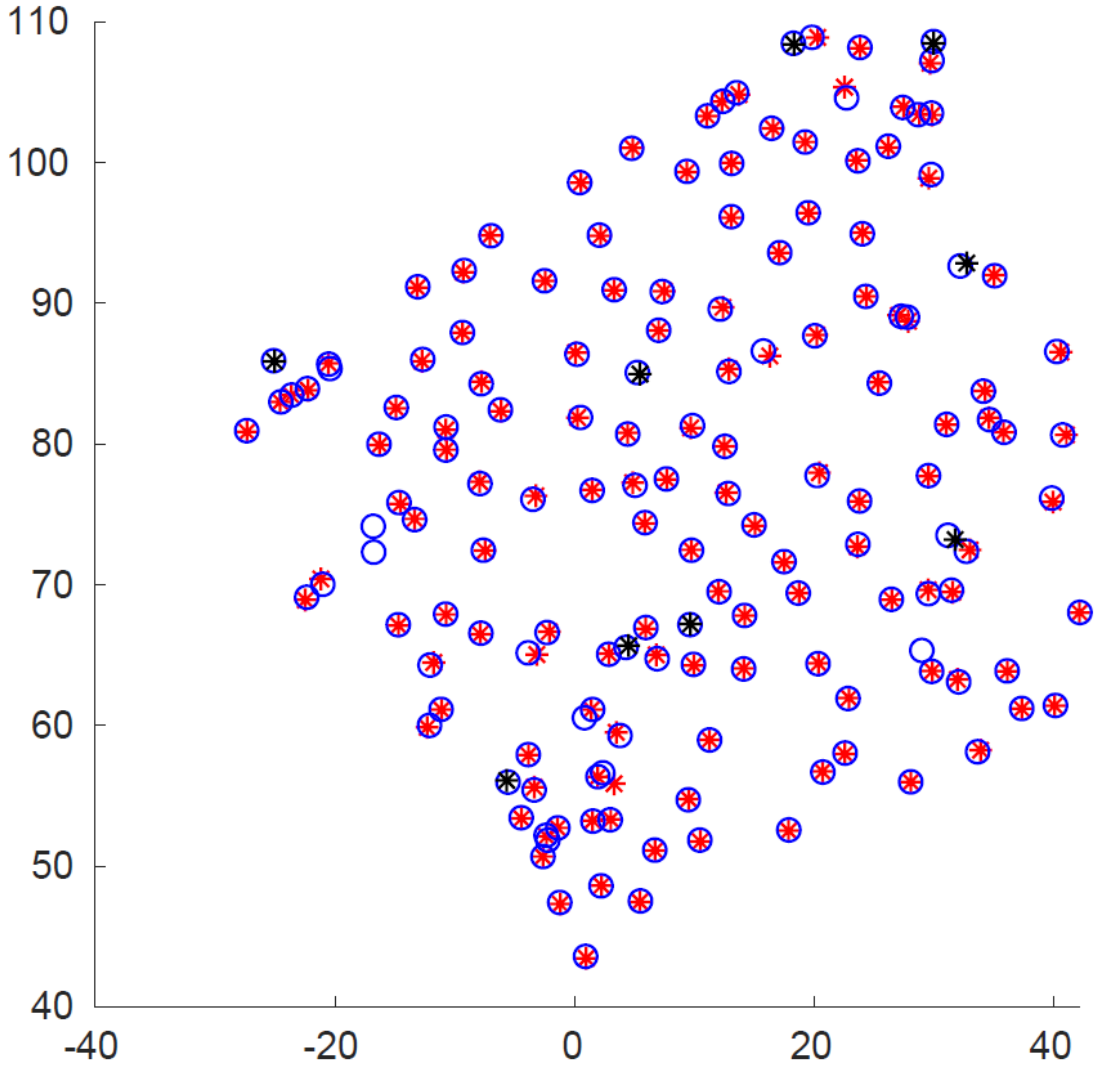


Variable	Value at 1.5m	Value at 2.5m
Completeness	94.25%	94.25%
Correctness	96.47%	96.47%
Bias Location	14 cm	14 cm
Diameter Bias	**8.4 mm**	**-2.5 mm**
Height Bias	-11.08	-11.08

McDonald–Dunn Data: MLS (handheld)



McDonald–Dunn Data (HLS): Assessment



Variable	Value at 1.5m
Completeness	92.1%
Correctness	95.9%
Bias Location	1 cm
Diameter Bias	3.8 mm
Height Bias	>10 m

Conclusion

- Computation time: aprox.1 hour / 100 trees with “normal” PC
- Accuracy depends on two factors:
  - Forest
  - Lidar device
- Point classification:
  - Subsequent attributes: branches, leaves

Conclusion

- Mature forest (commercial thinning and older):
  - Tree identification: >92% completeness & >95% correctness (exception one)
- Precommercial thinning: challenges (<65% completeness)
- Dimensional measurements:
  - Location: < 15 cm
  - DBH bias: < 3 mm (majority of cases)
  - Height bias: < 2 m (majority of cases)