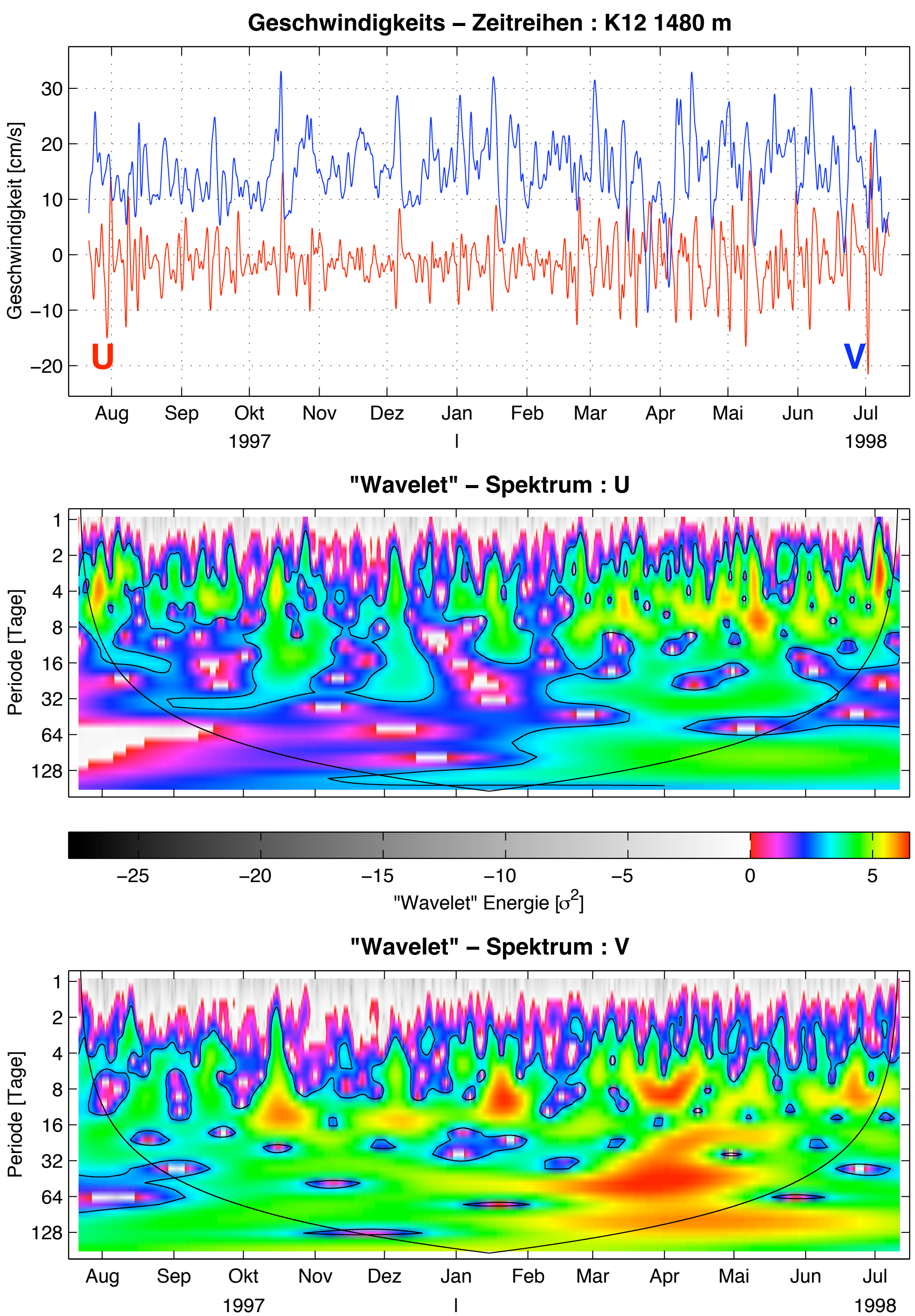
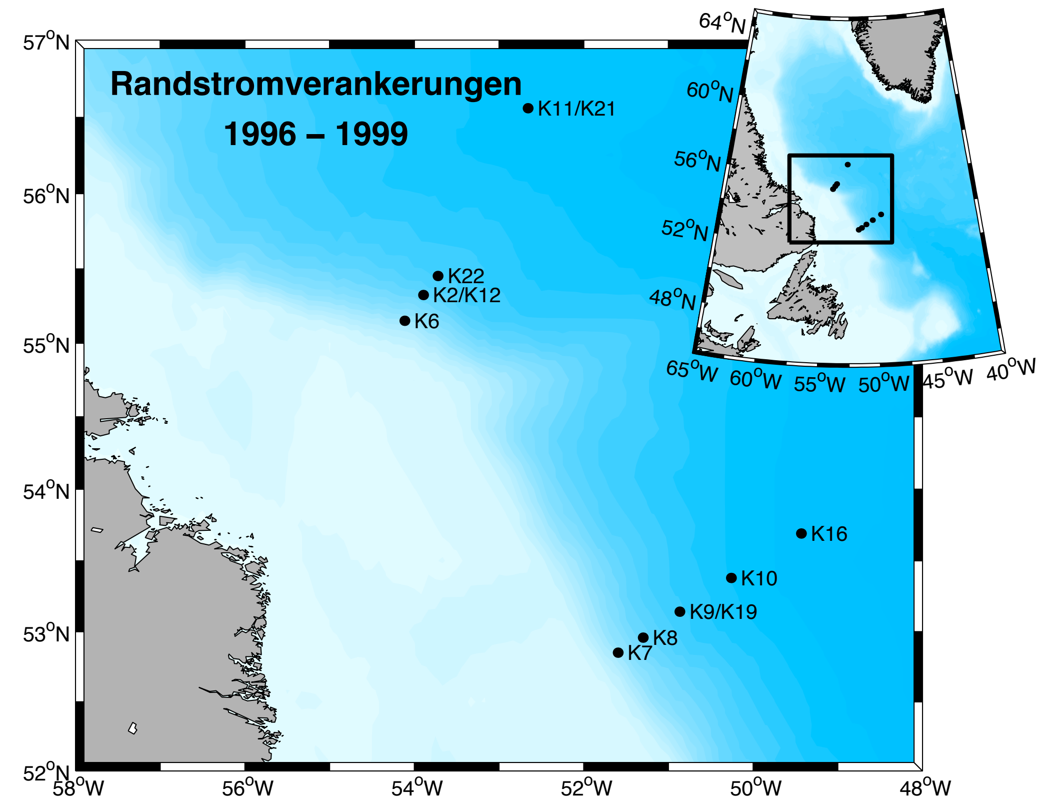
Derivation of structural vegetation information from laser scanning data

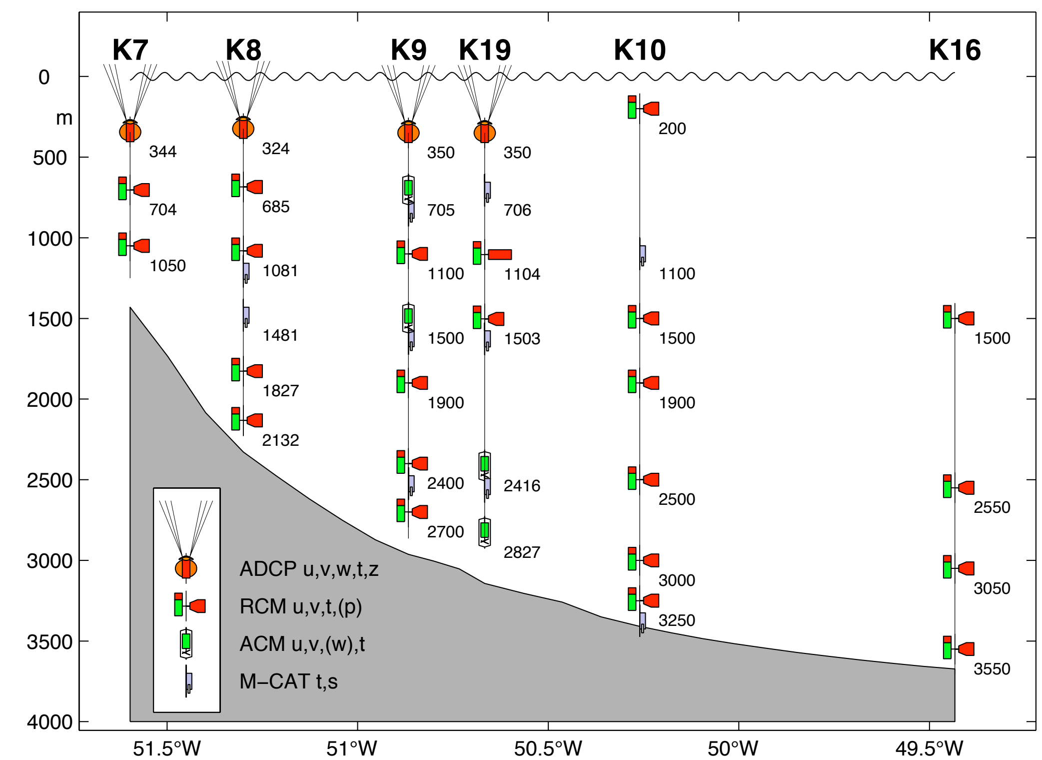
Felix Morsdorf

MetStröm Workshop, Tharandt, 9-10 September 2010

Background in Oceanography ...







Measurement principle - LIDAR

- It is the aim to estimate a 3d coordinate in a known reference system
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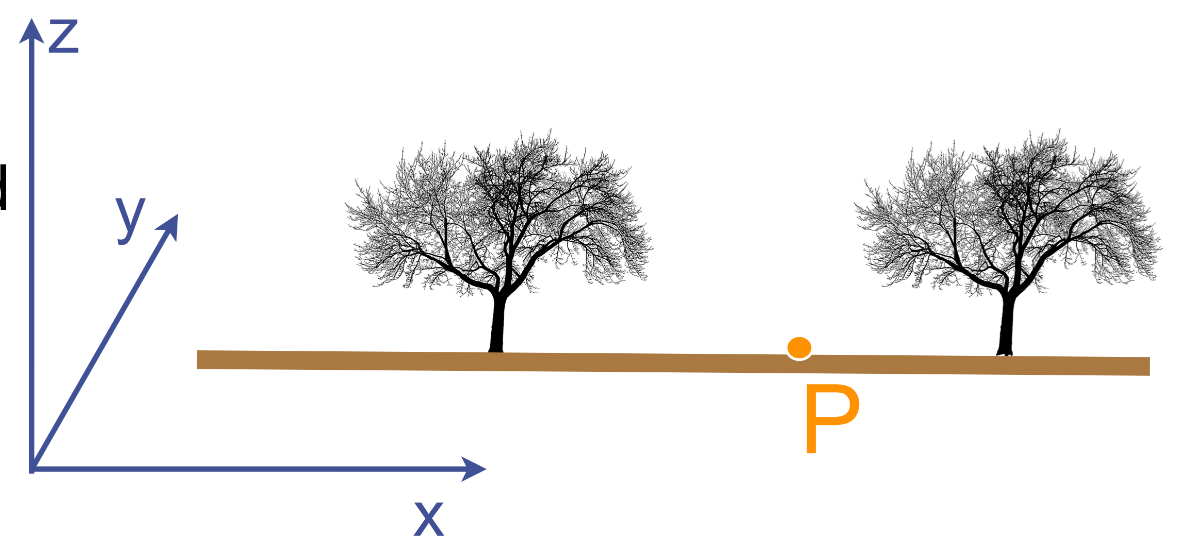
- Position vector $\vec{f}$
  - measured by GPS/INS
- Range vector $\vec{d}$
  - time of flight measurement and calibration of sensor
- Location vector
  - vectorial sum of position and range vectors $\vec{p}$



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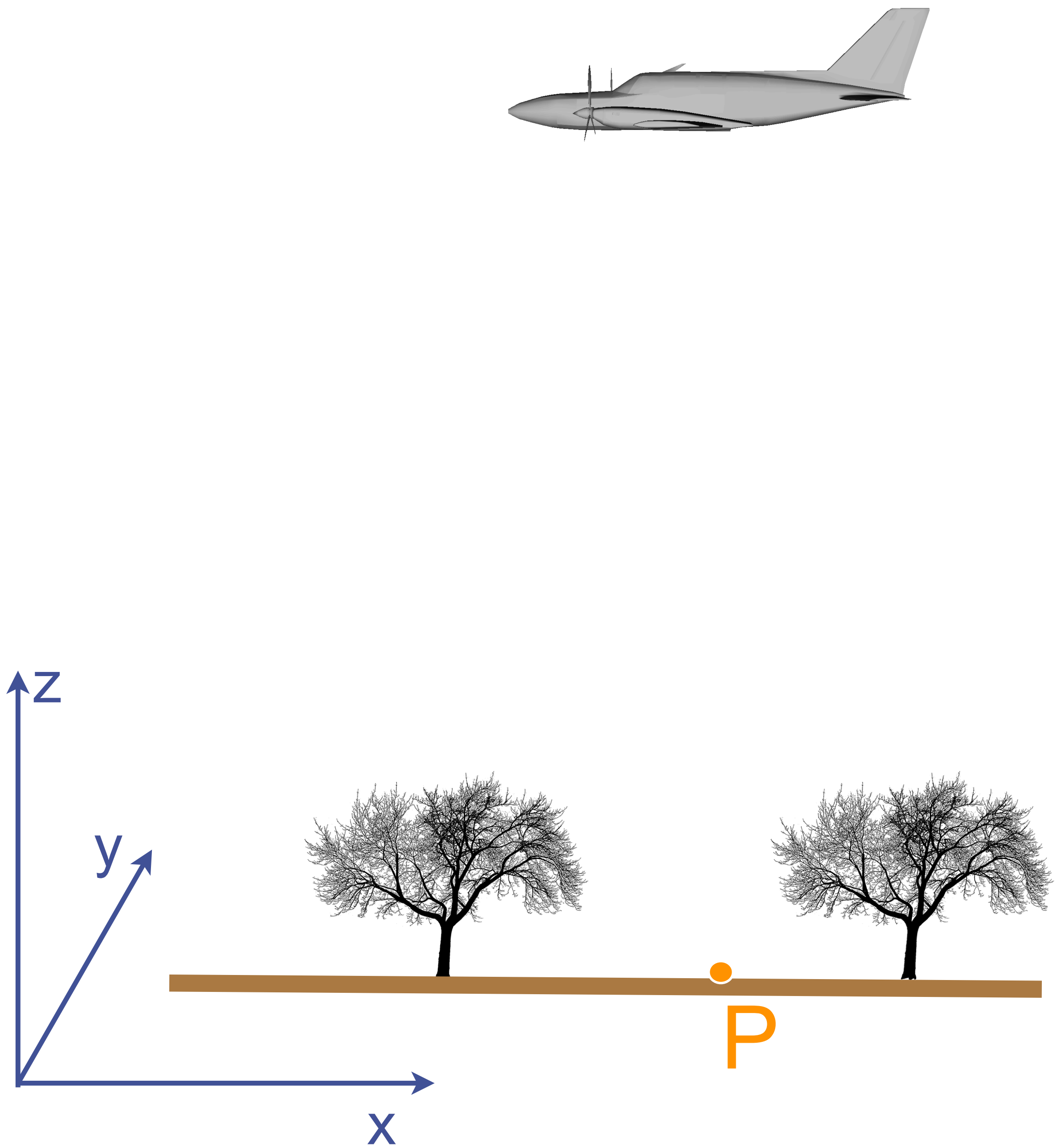

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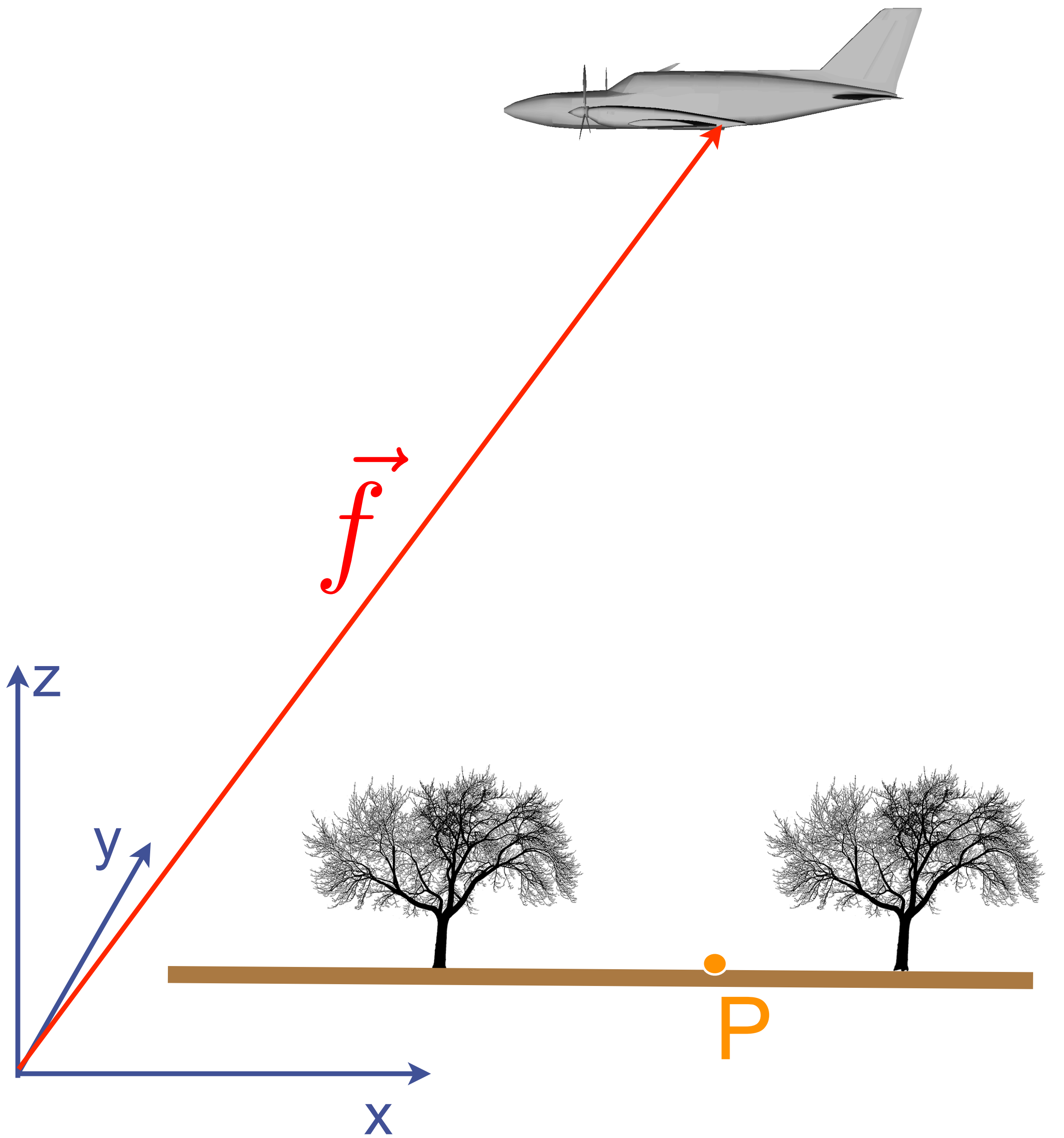

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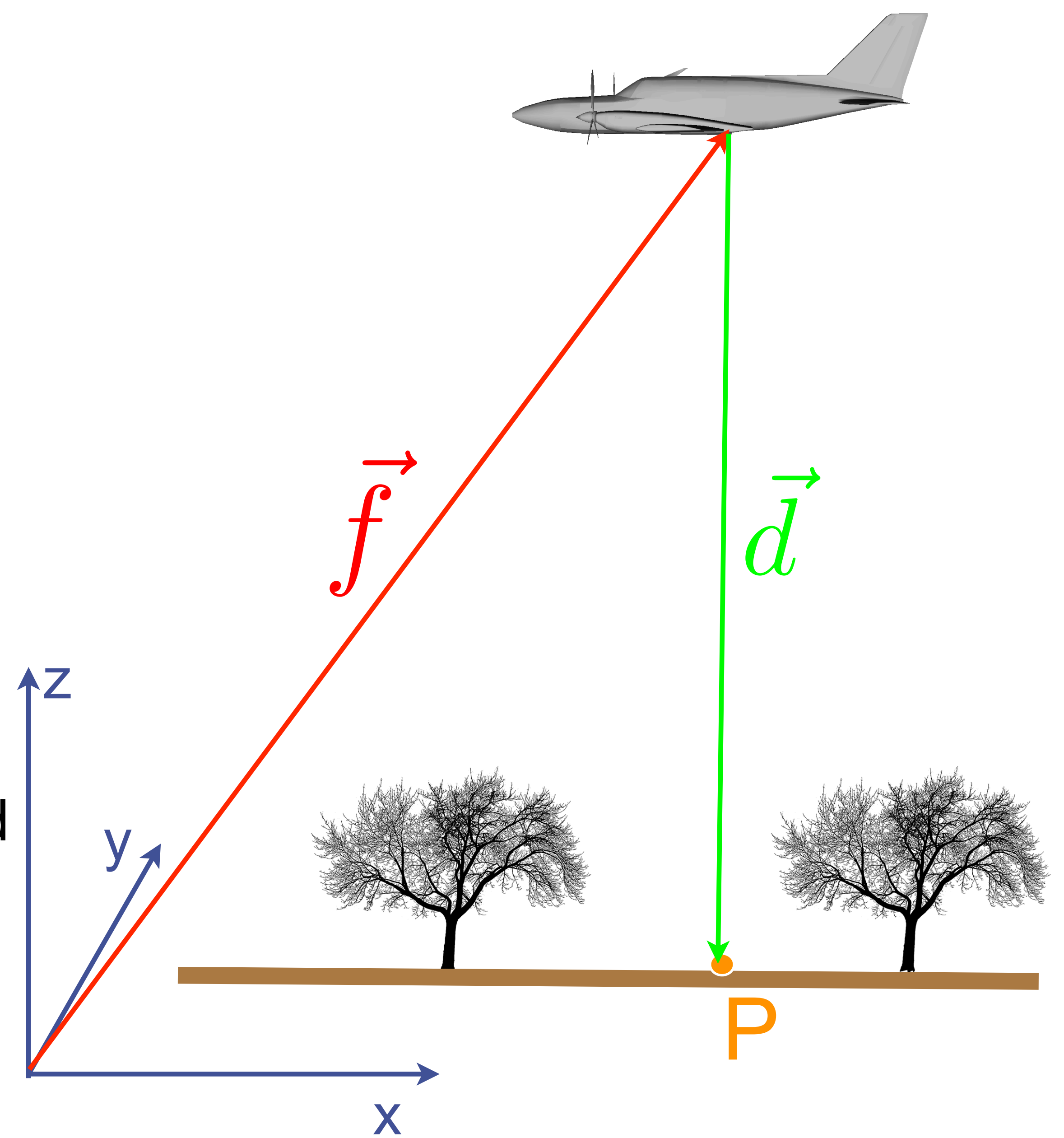

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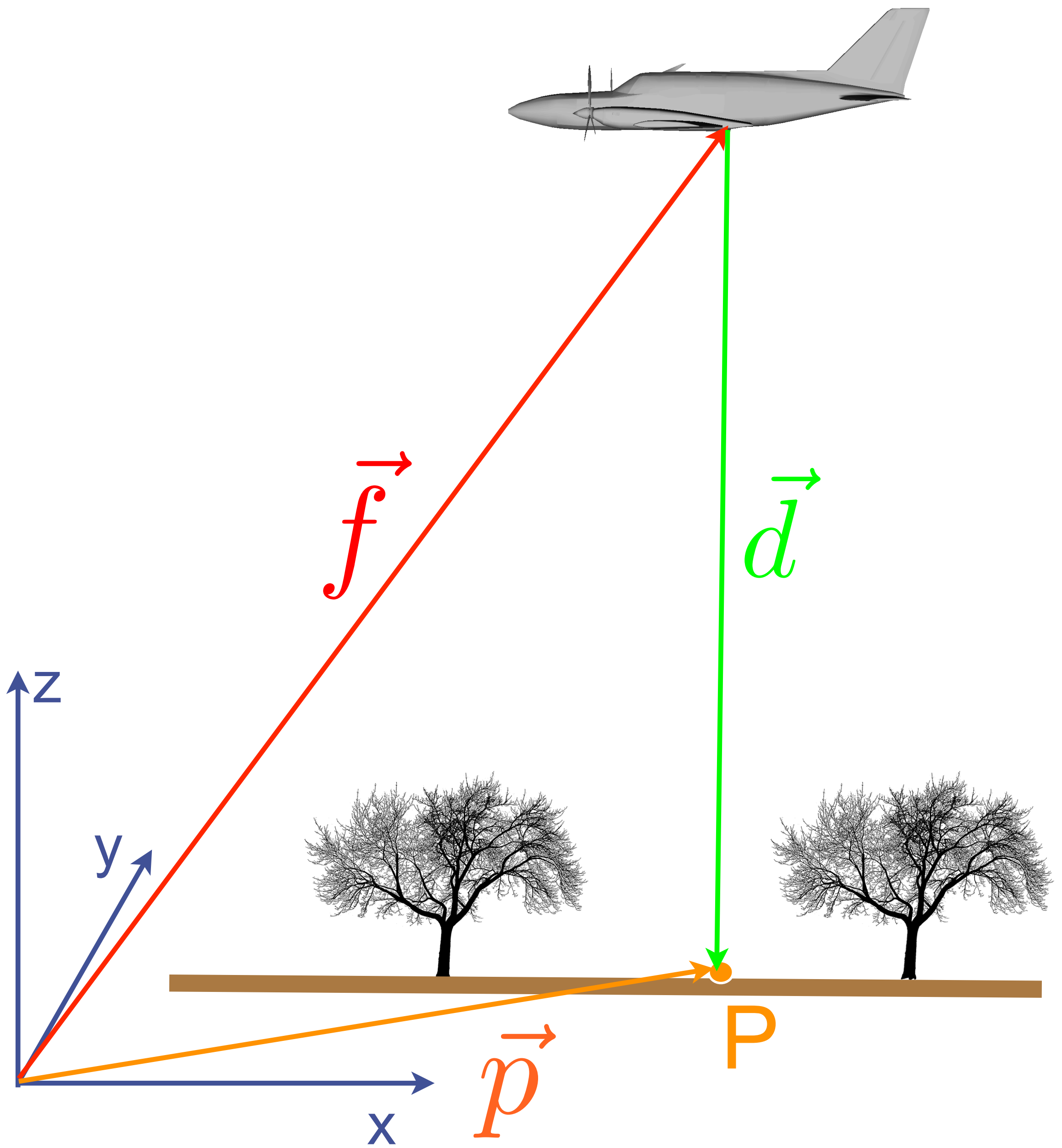

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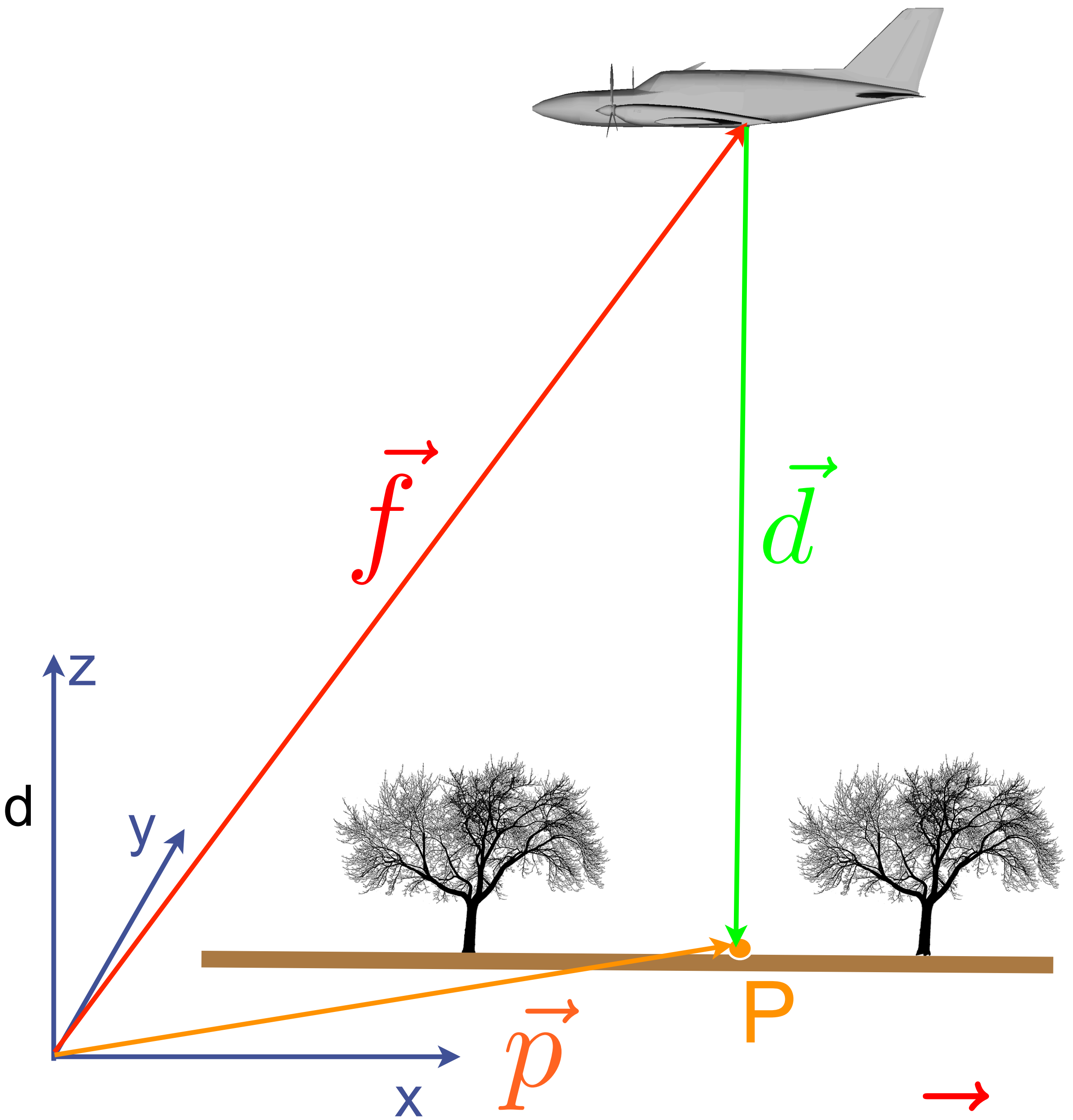

$$\vec{p} = \vec{f} + \vec{d}$$

Technology - LiDAR -> Airborne Laser Scanning (ALS)

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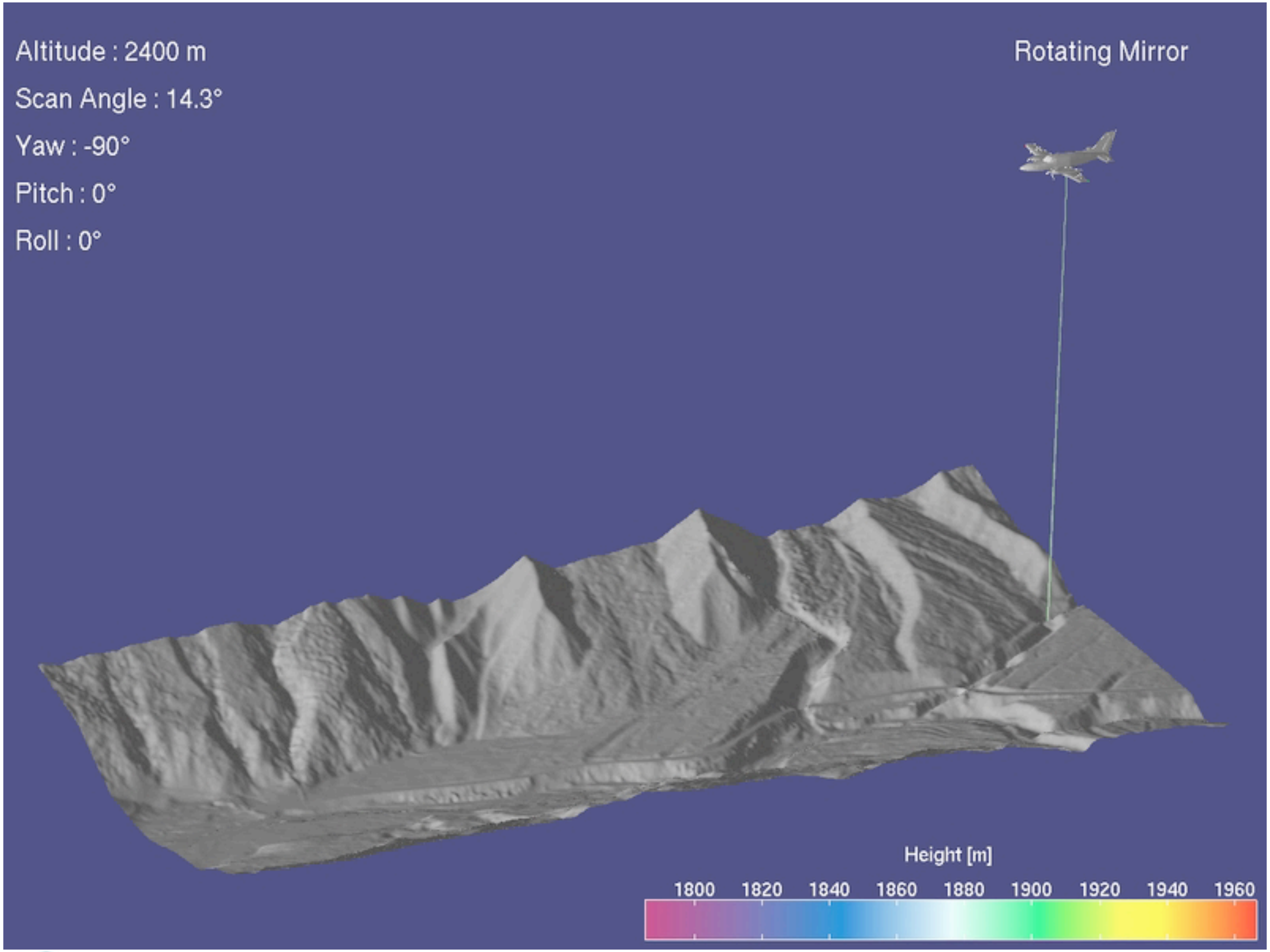
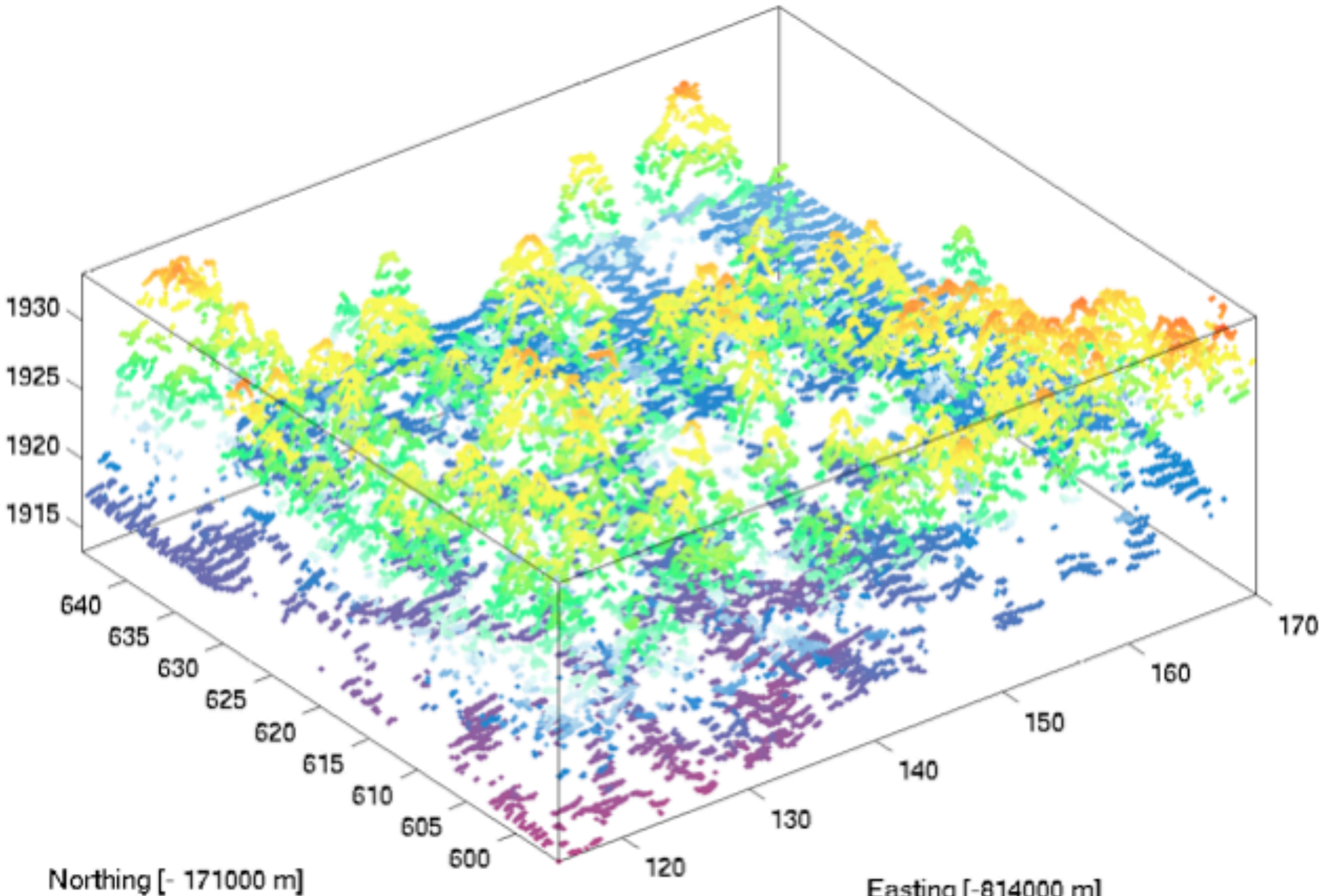


ALS - raw data



1930
1925
1920
1915
640
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Northing [- 171000 m]
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170
Easting [-814000 m]

ALS - general data products

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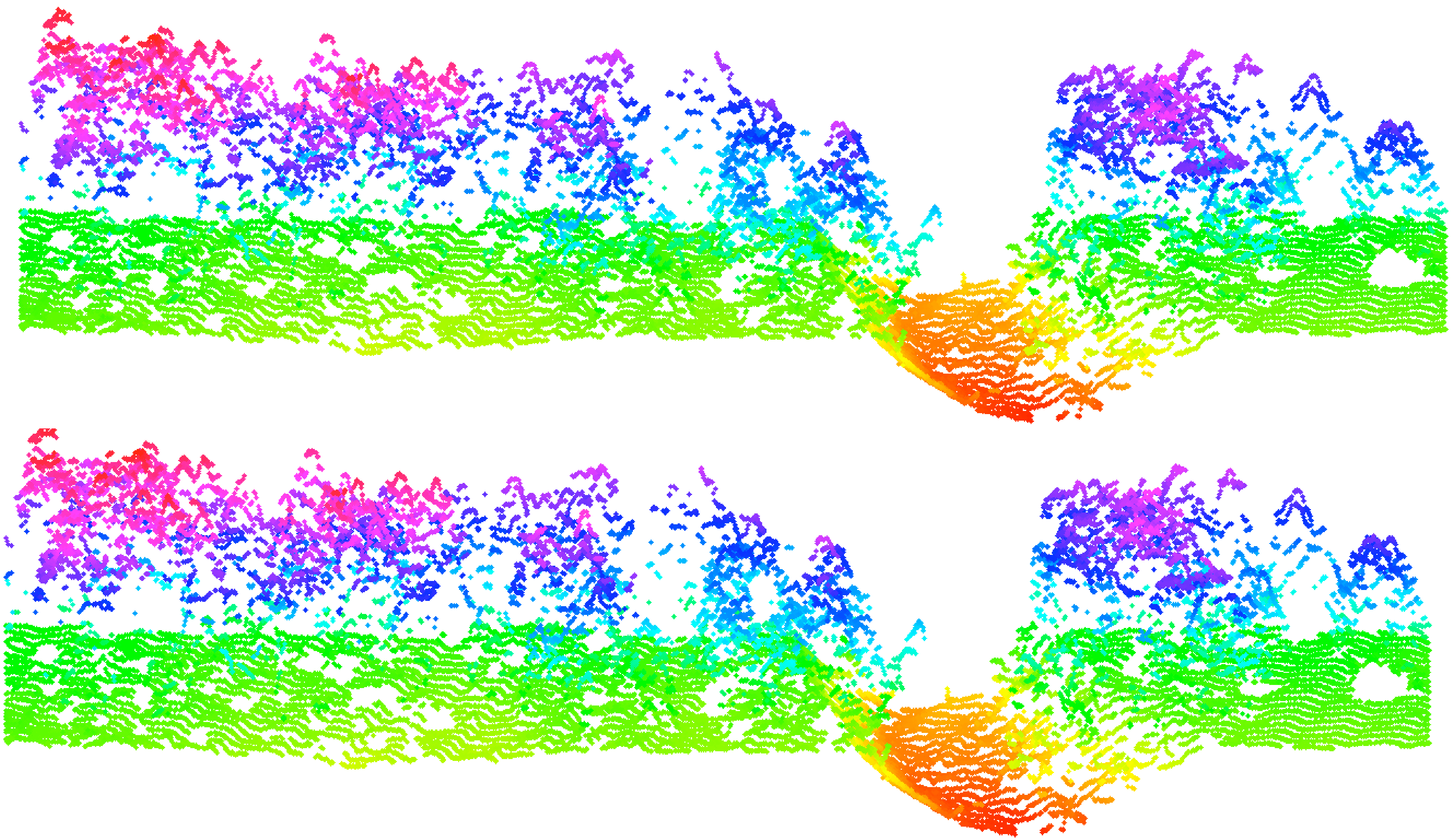

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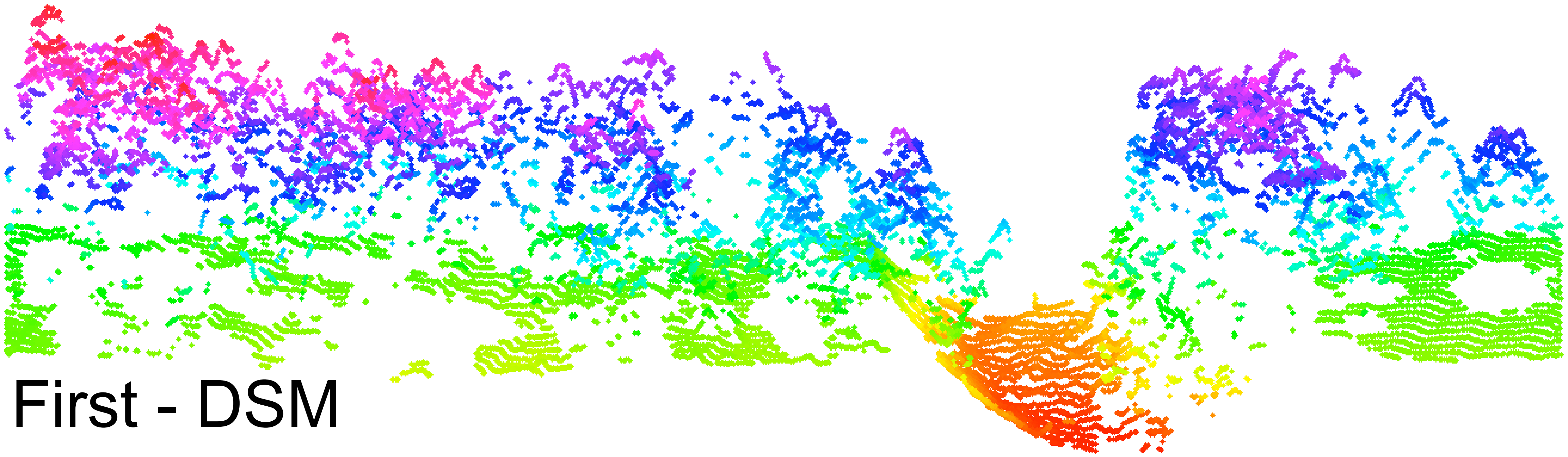
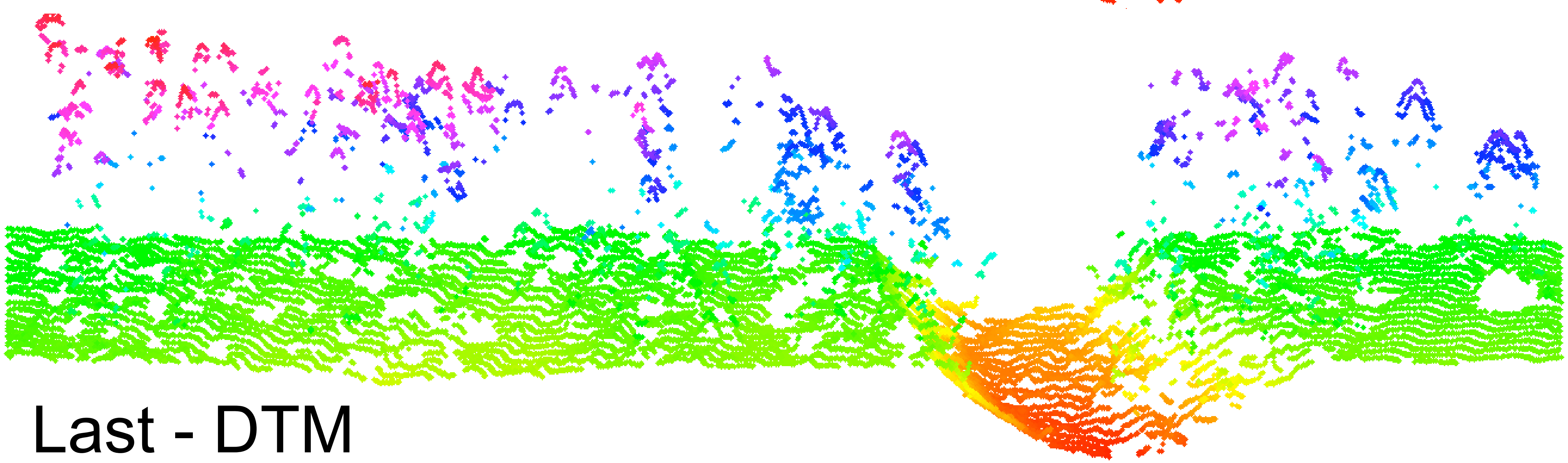


First - DSM



Last - DTM

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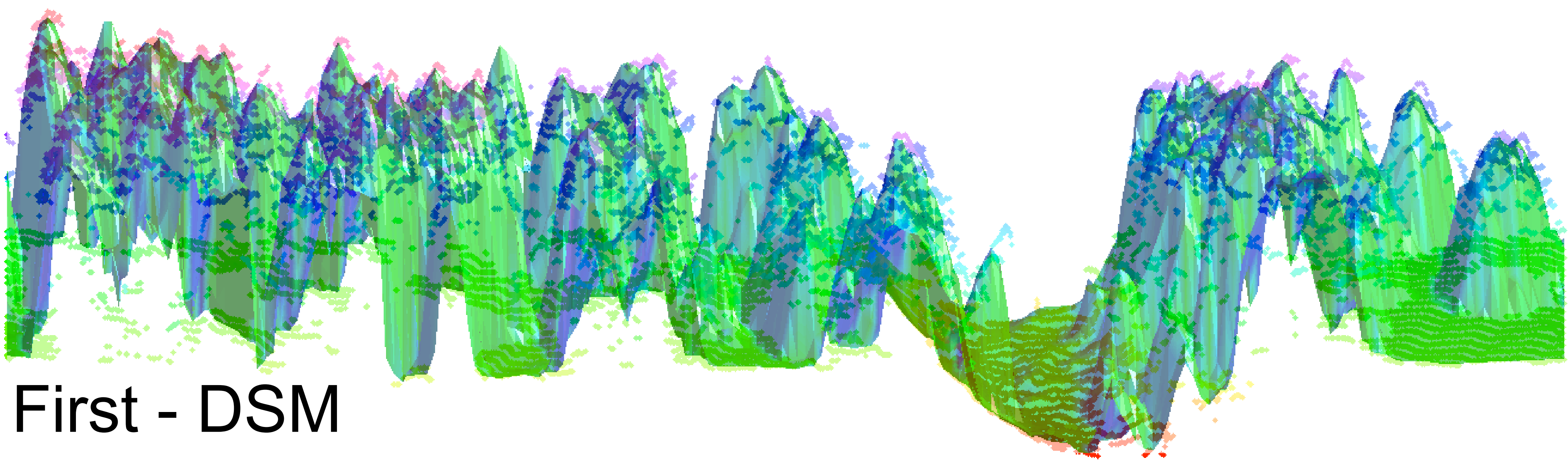

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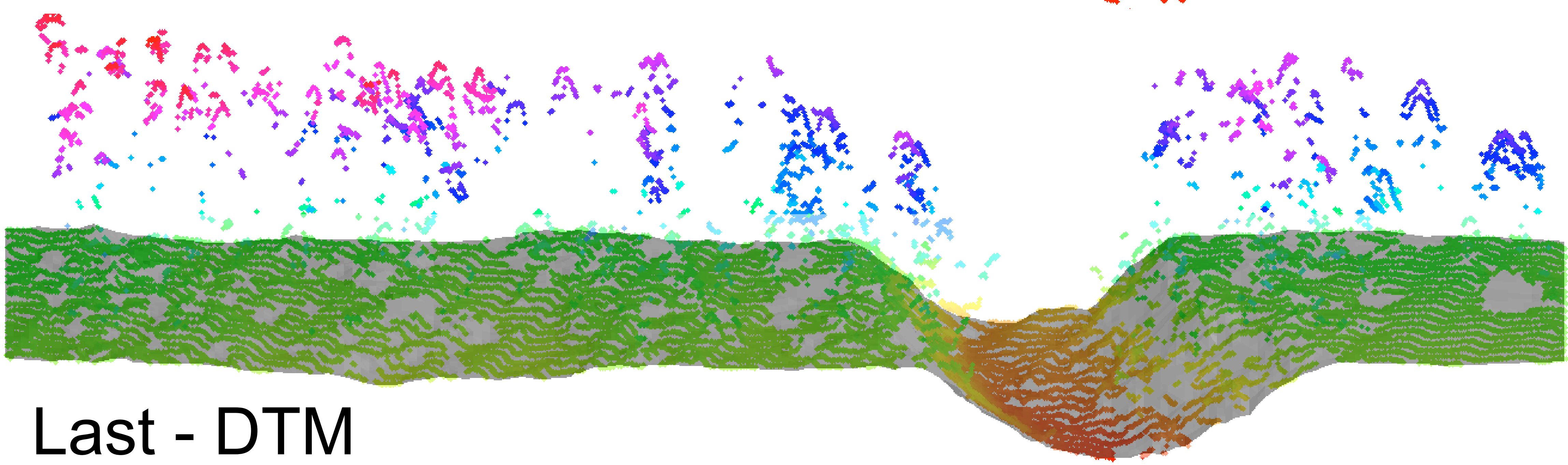
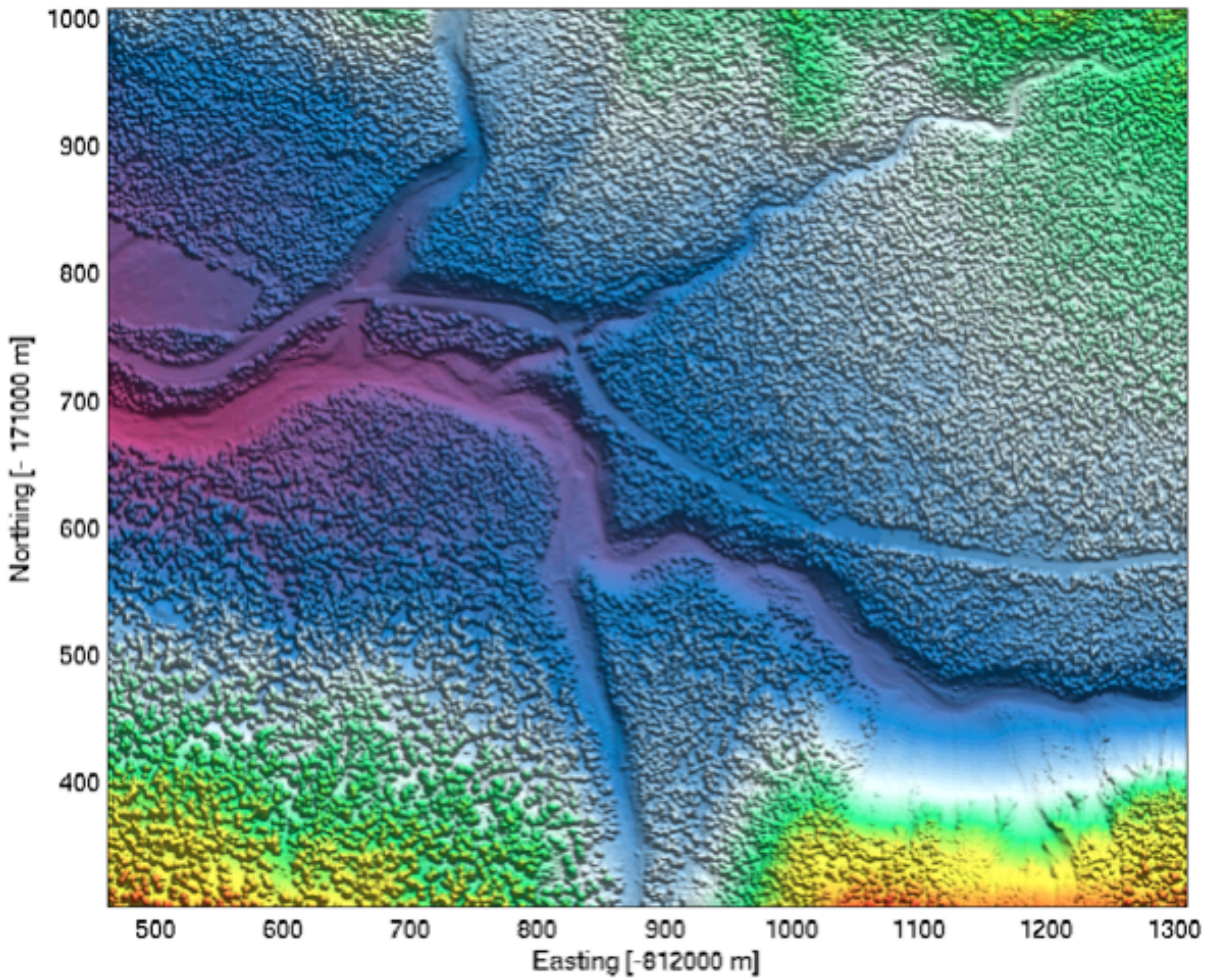


Last - DTM

ALS - DSM vs. DTM



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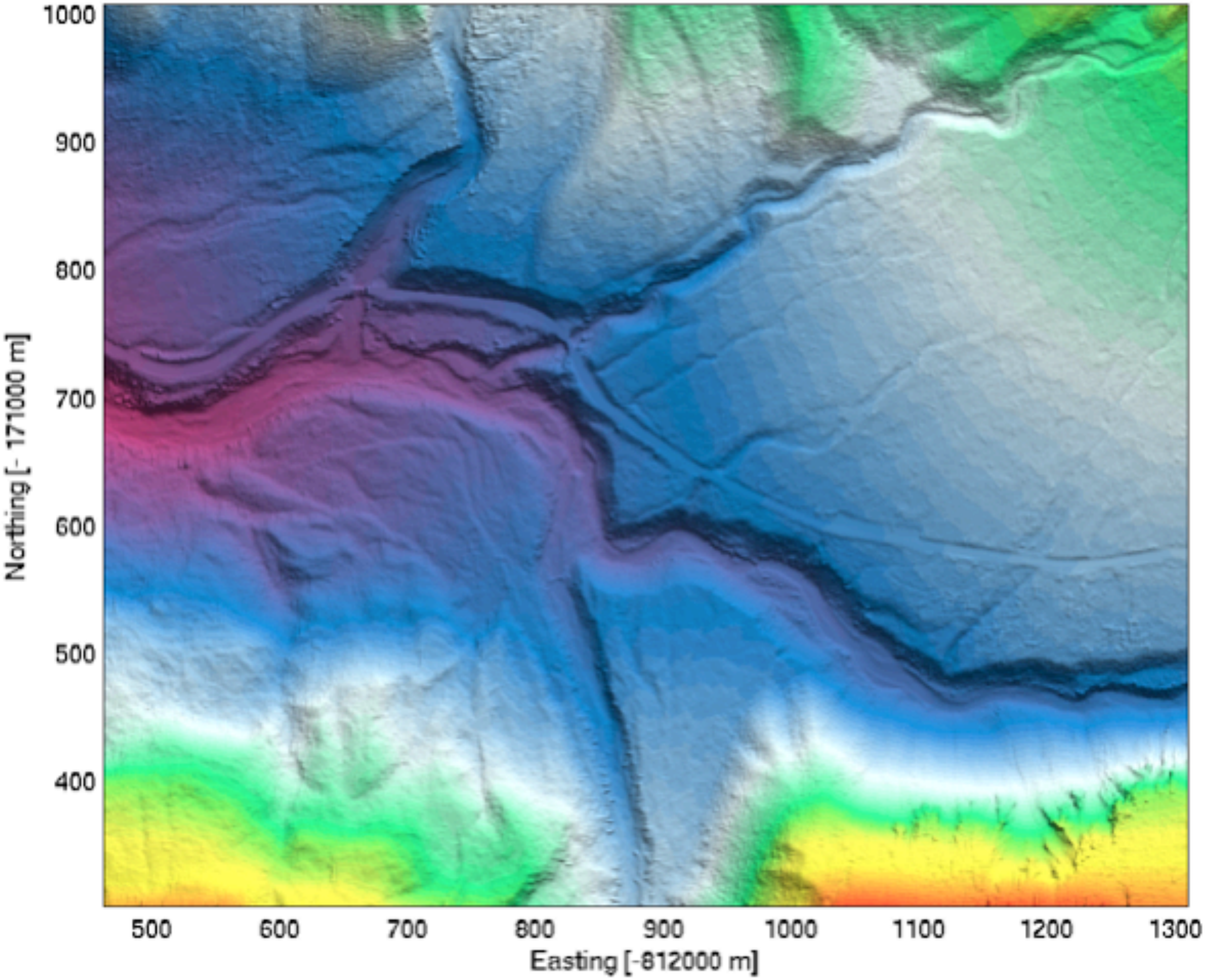
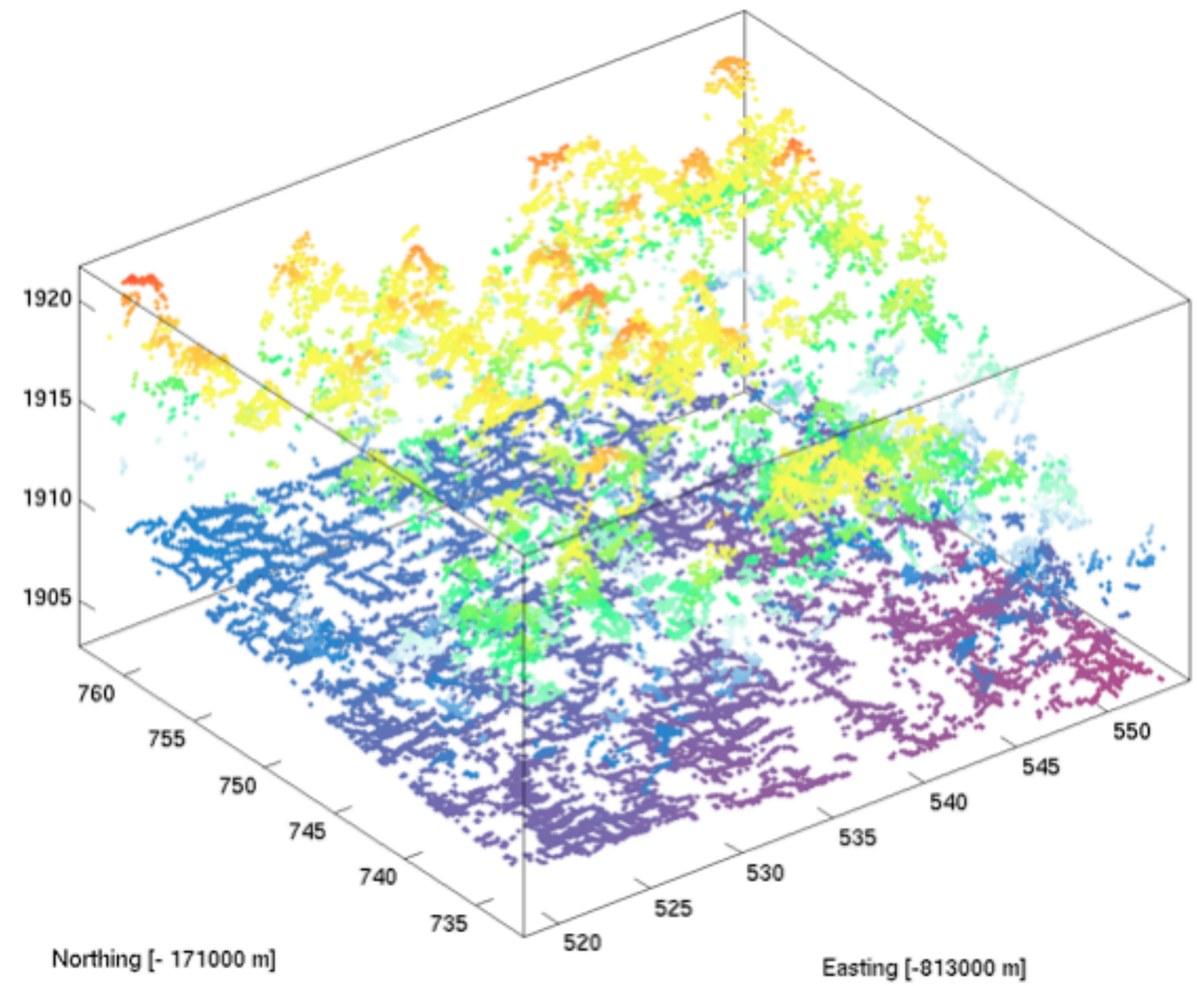


Extraction of single tree geometry - the promise of raw data ...

- why work on raw data:
  - no loss of information by interpolation into raster models
  - 3D structure of vegetation is contained in the point cloud
  - but:
    - Algorithm development and implementation far more complicated than for DSM/DTM
- two step procedure:
  - (1) seed points: local maxima in CHM
  - (2) supervised classification ('cluster-analysis') starting off with seed points from(1)
    - feature space is x,y,z, with z being compressed
    - euclidean distance metric



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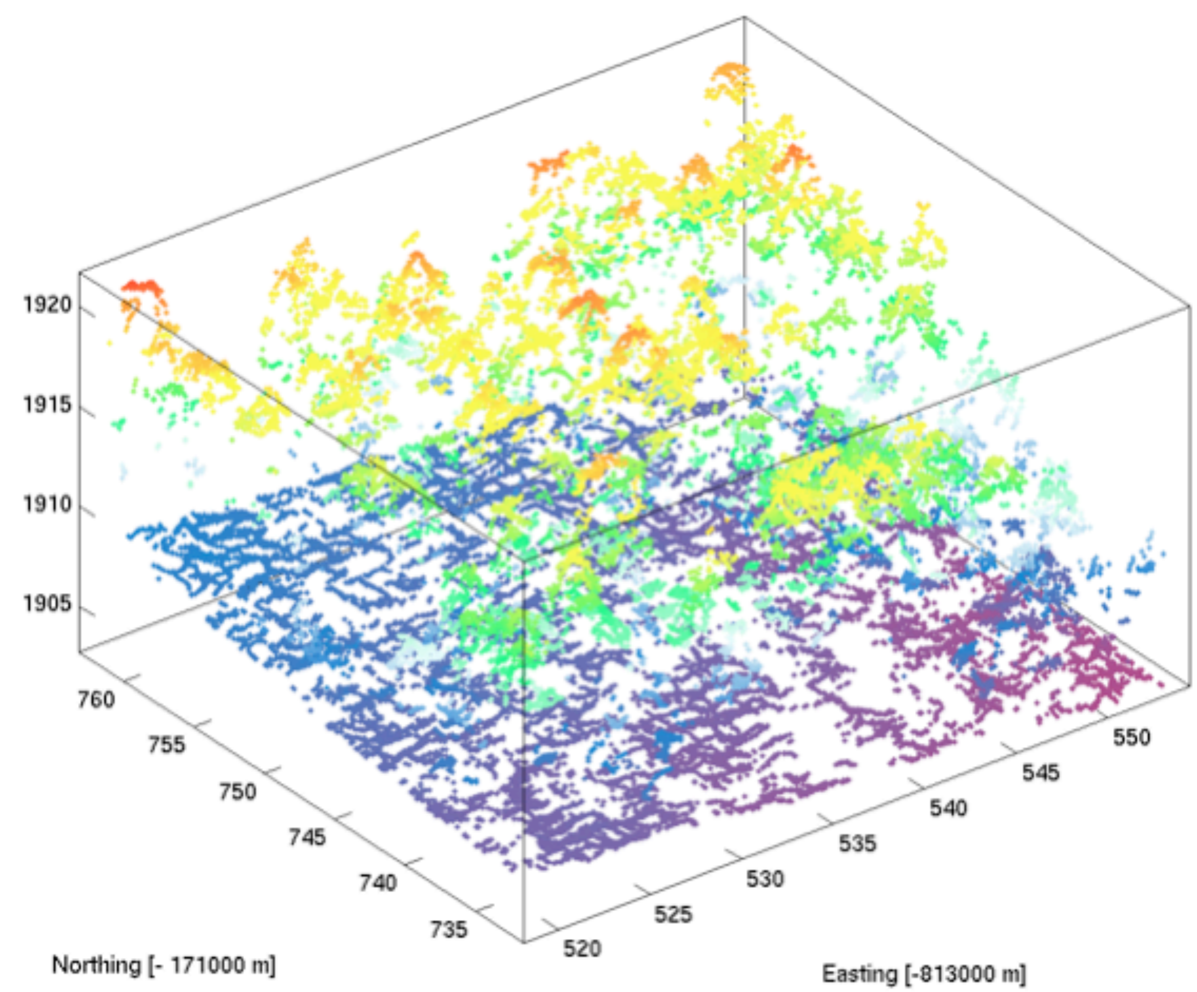
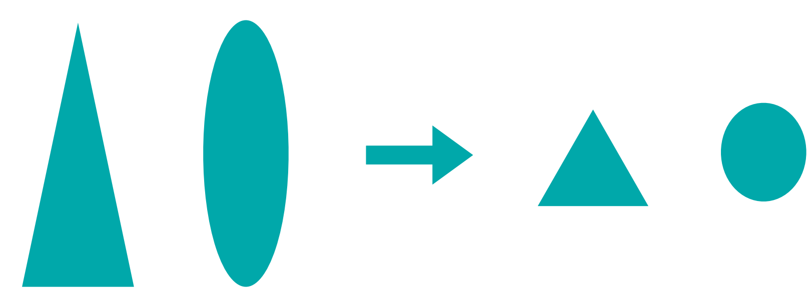
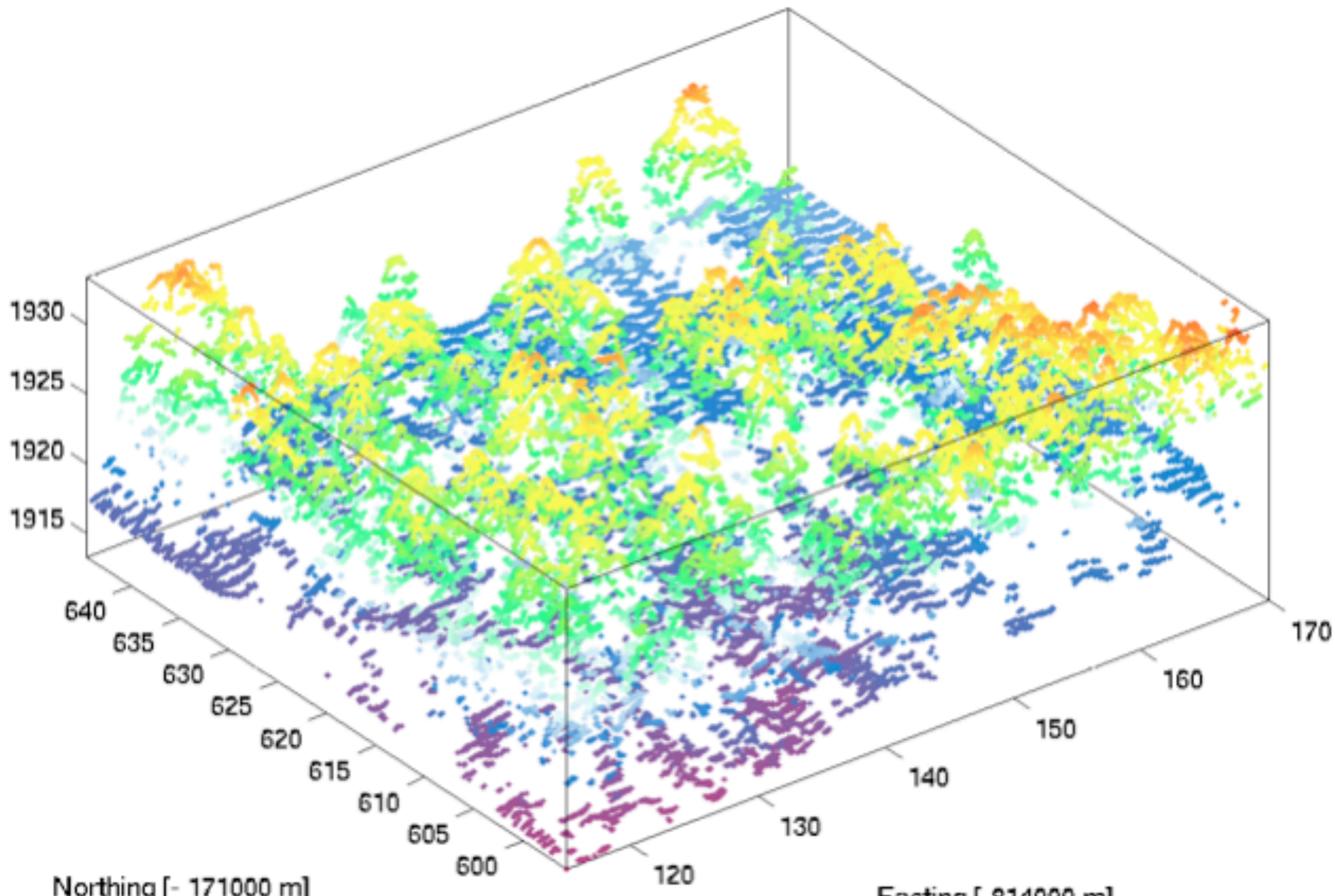




ALS - from raw data to “semantic” information



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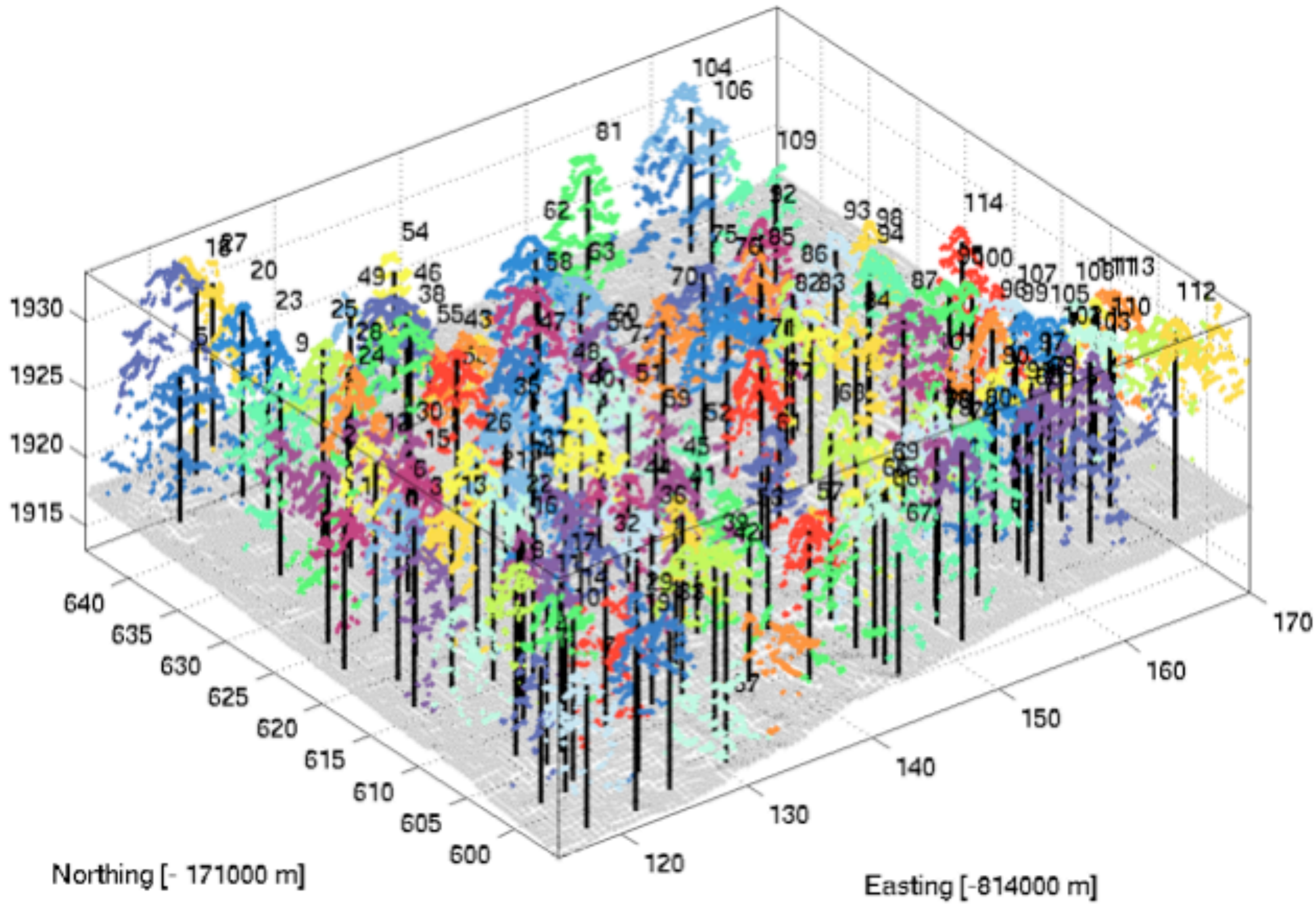
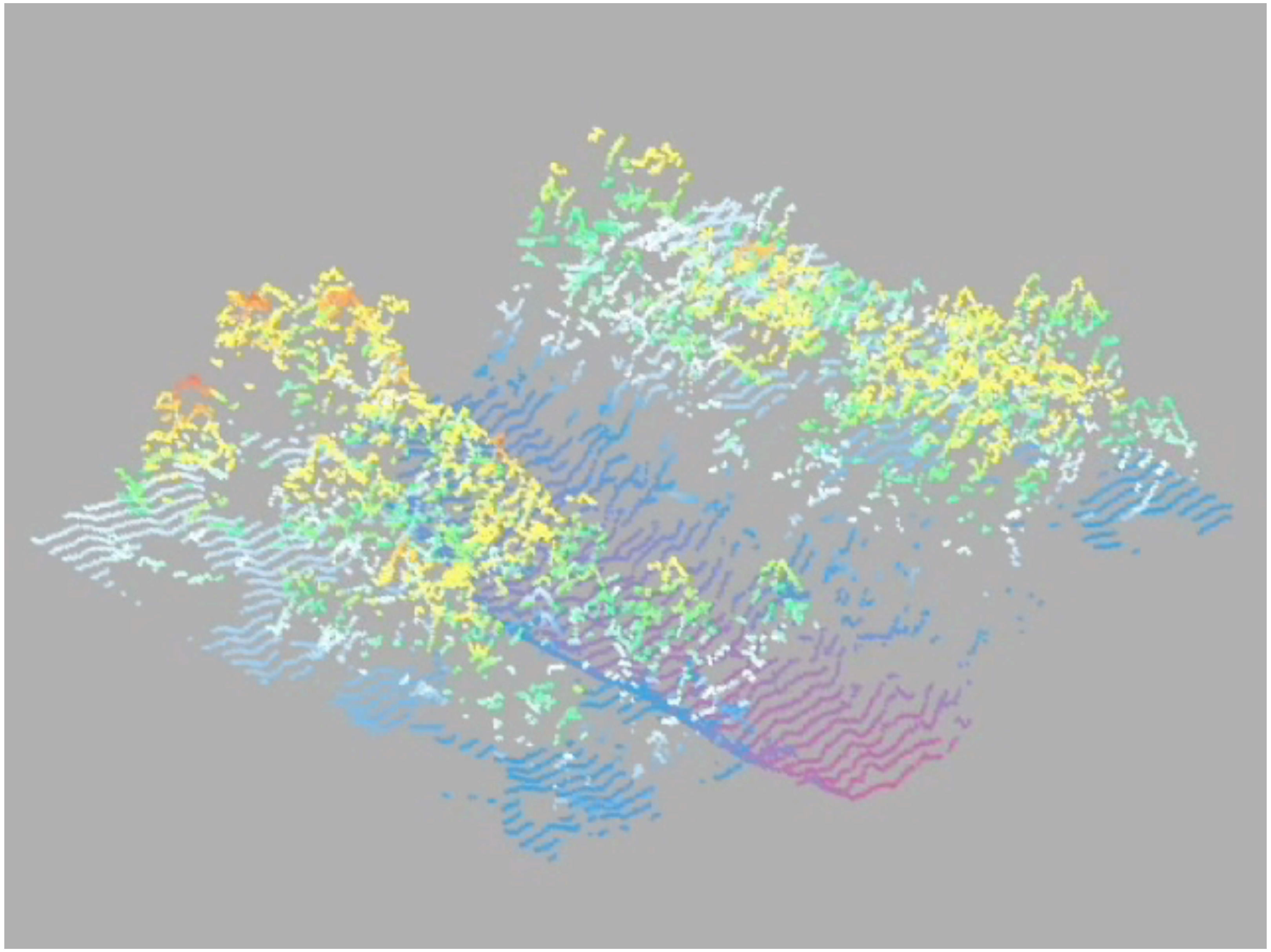


ALS - canopy geometry

- these geometric properties can be derived from segmented clusters:
  - tree position
  - tree height
  - crown diameter
  - crown volume
  - crown base height
- allows for geometric reconstruction of forest scene
- validated with field data
  - 75% of trees, ~ 0.3 m tree height accuracy



Morsdorf, F.; Meier, E.; Kötz, B.; Itten, K.I.; Dobbertin, M. & Allgöwer, B.
LIDAR-based geometric reconstruction of boreal type forest stands at single tree level for forest and wildland fire management
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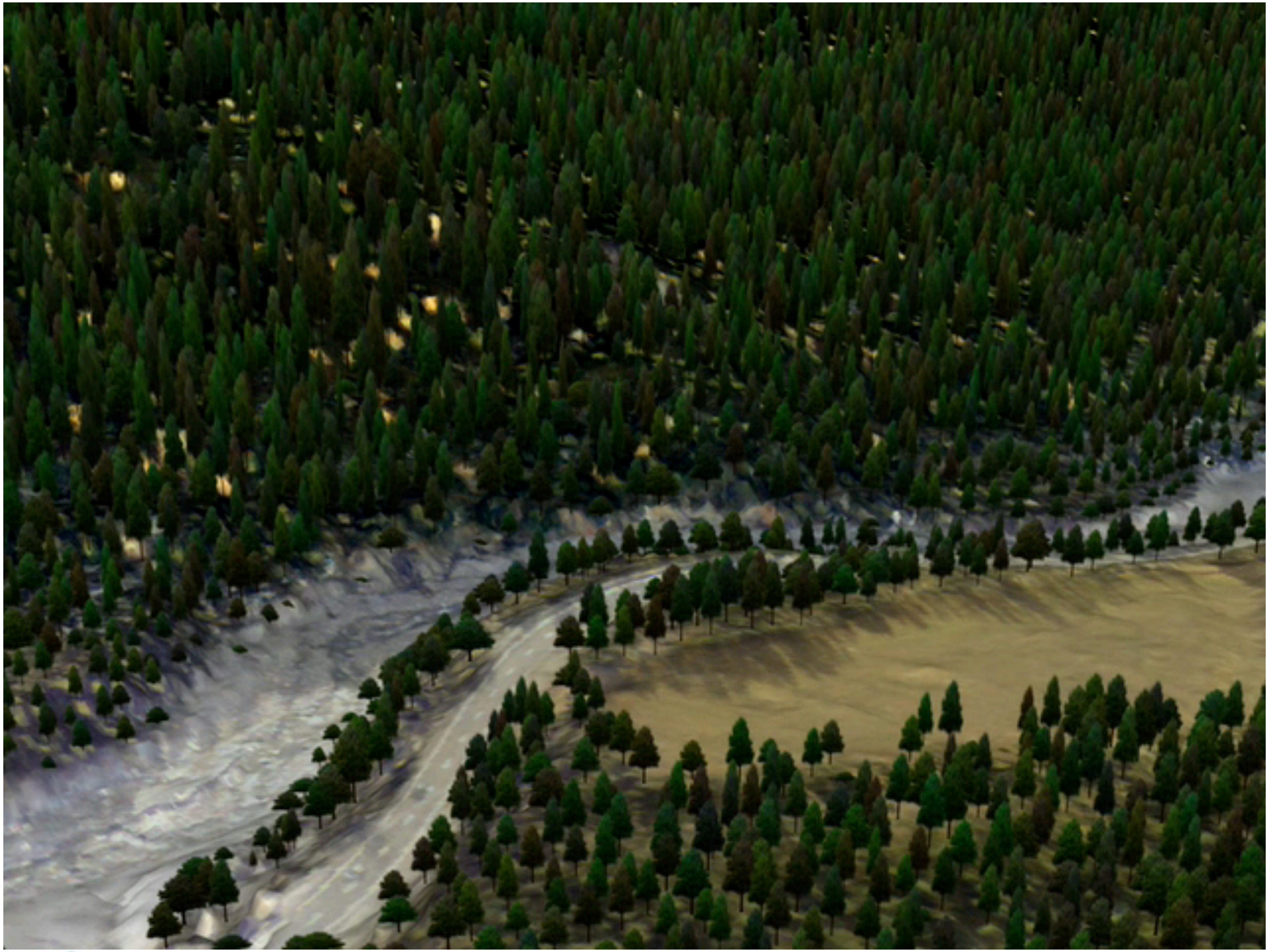
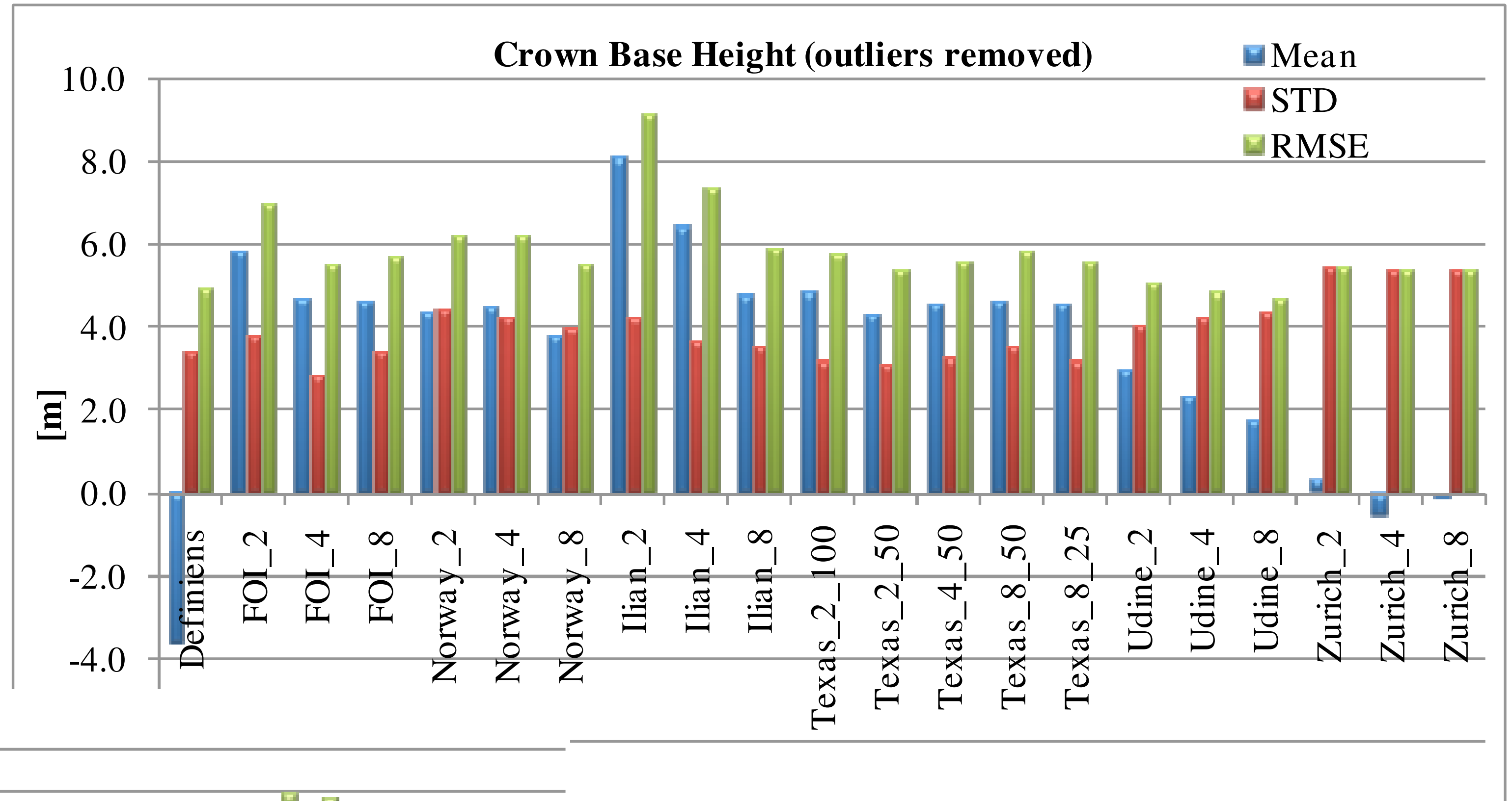
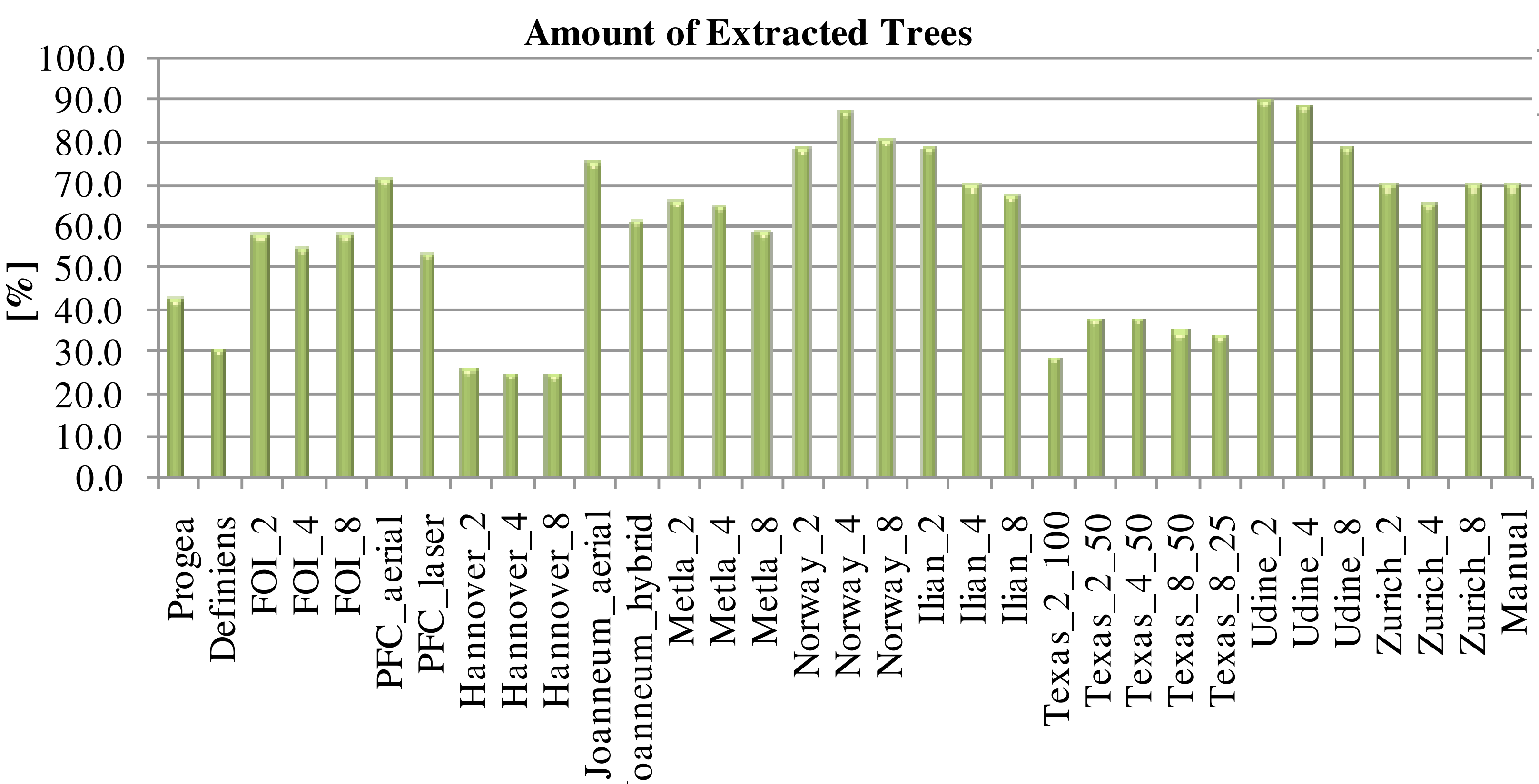


EuroSDR comparison project of tree delineation methods





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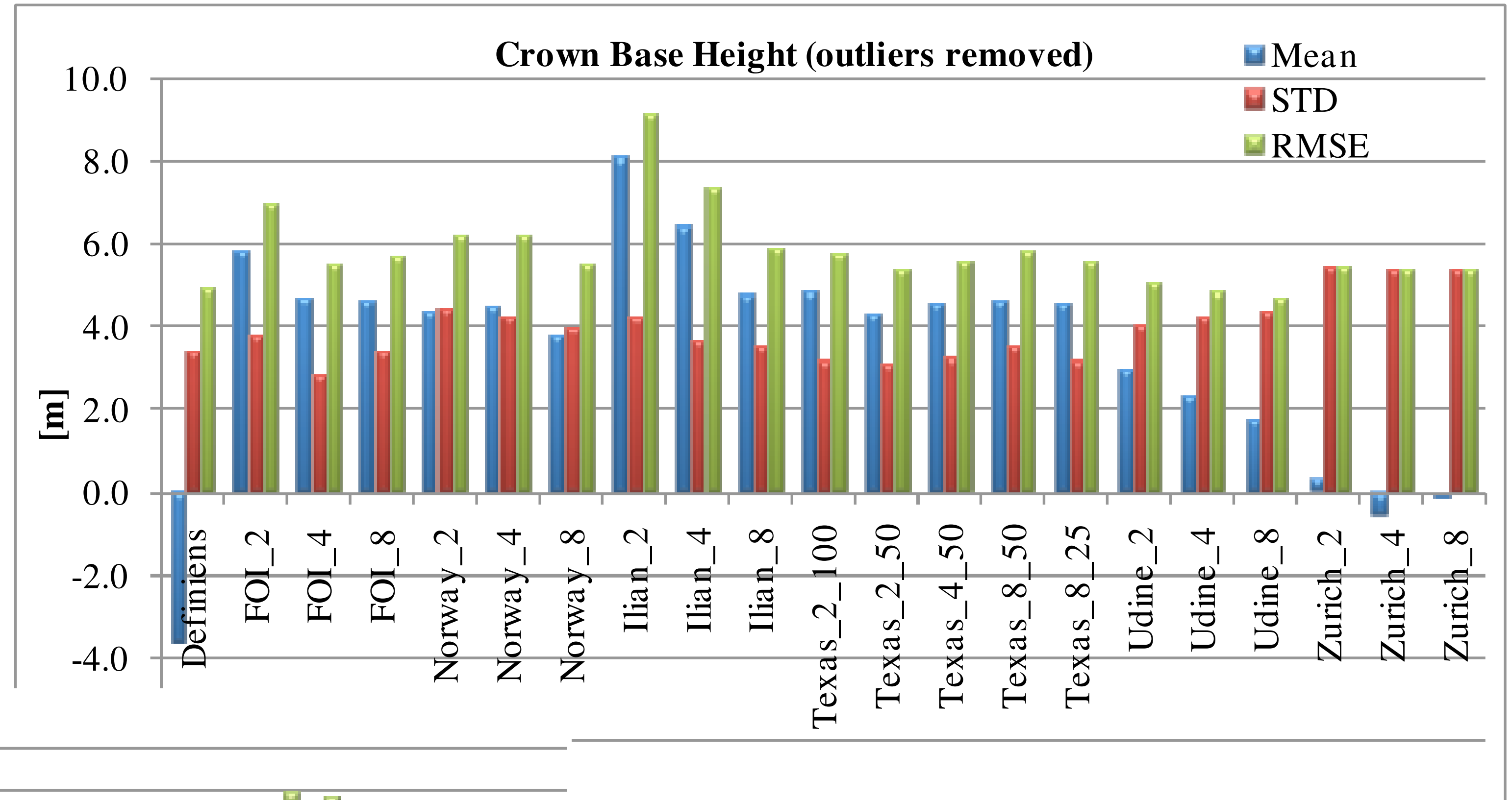
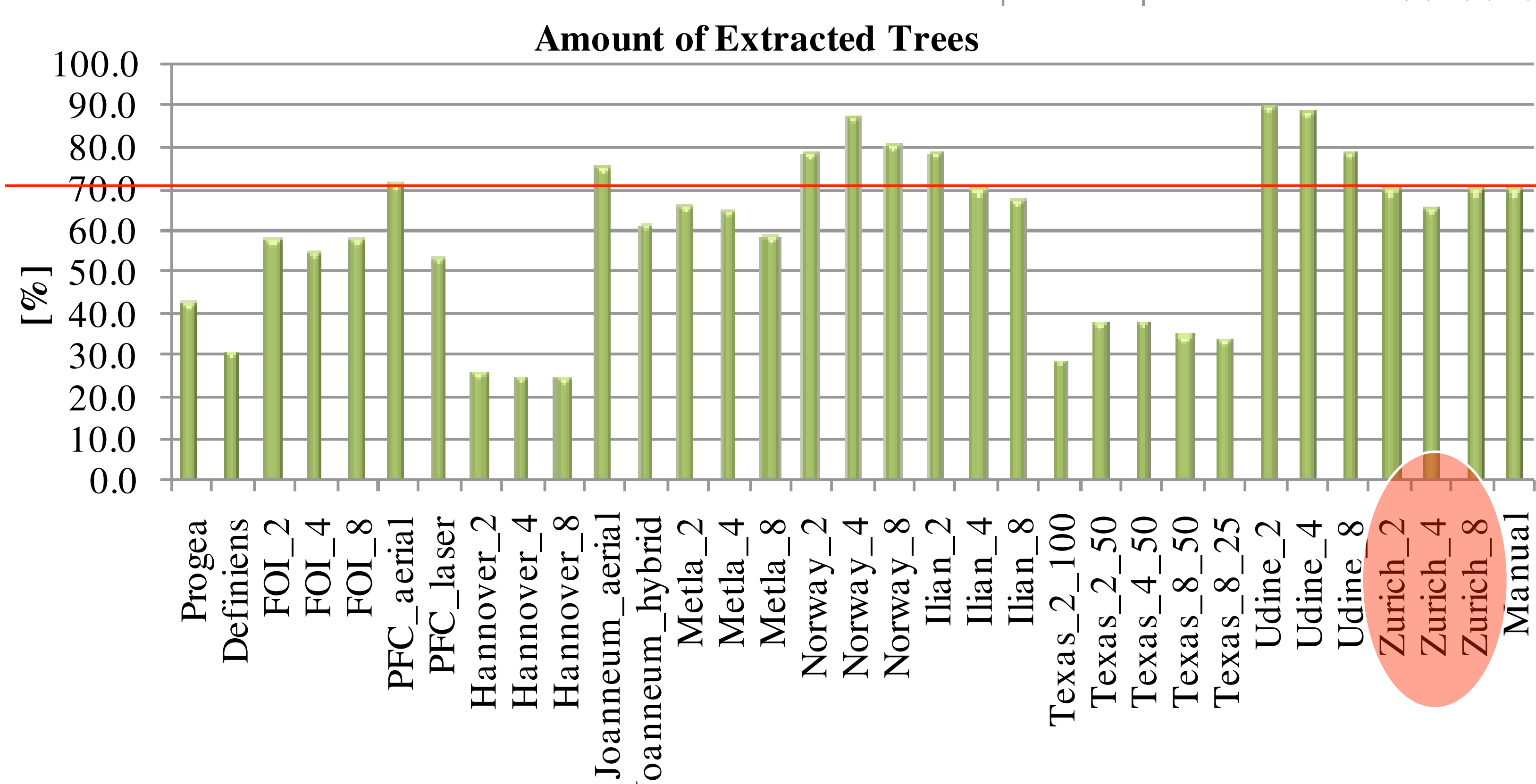
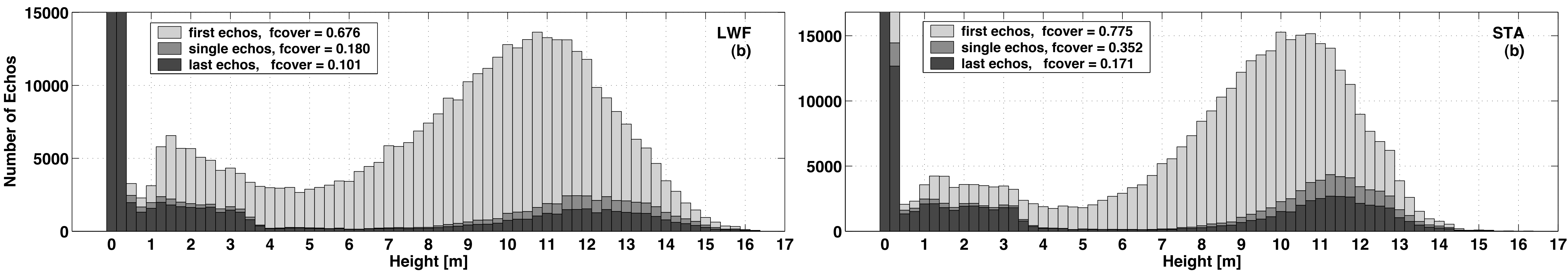




ALS - canopy density

ALS - canopy density (gap fraction)



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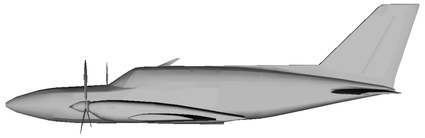
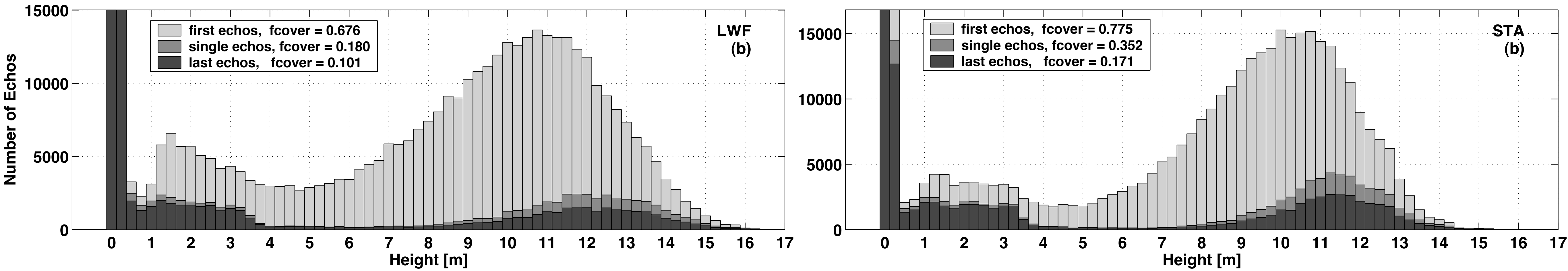


- Computation of canopy density from ALS raw data
  - fractional cover (canopy closure)
    - Sum of echos at a height larger than 1.25m (threshold) divided by the sum of all echos
  - leaf area index (LAI)
    - Relation of single and last echos to number of first echos inside the canopy
    - echos inside vegetation are classied by a height threshold
    - should be a proxy of canopy density when reflectance differences can be neglected



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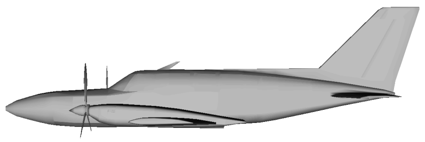

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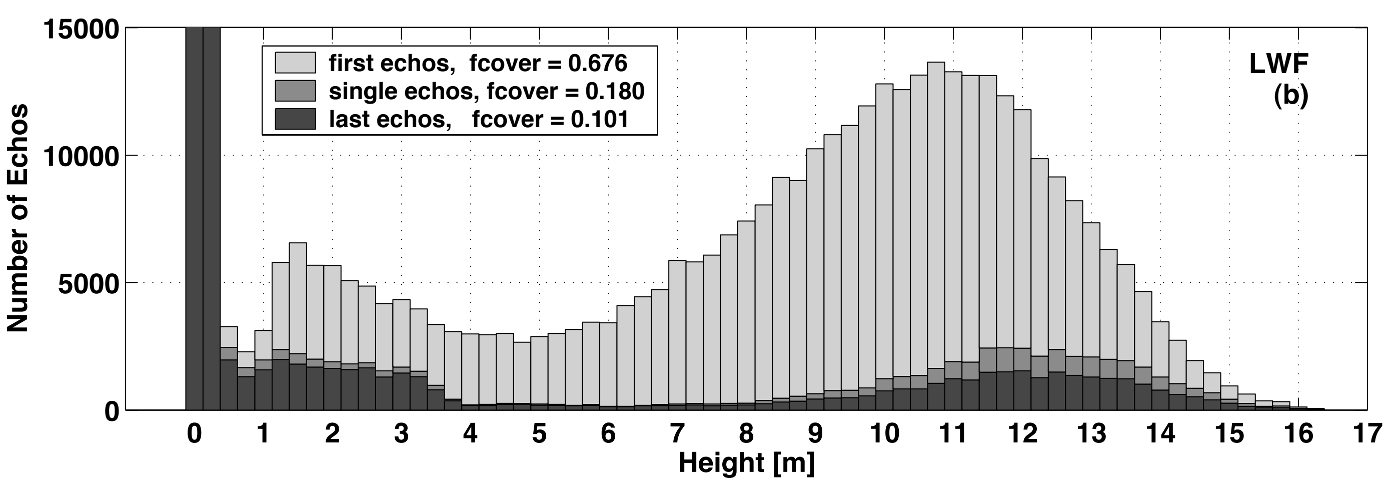
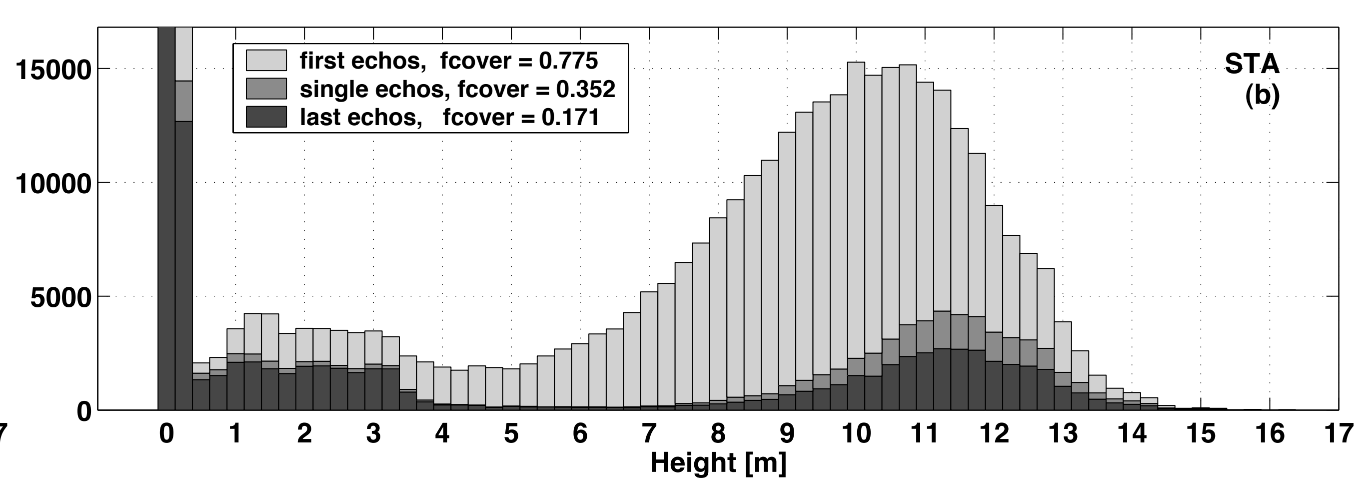
- Validation with field measurements ...
  - which field measurements and ...
  - ... at which scales ?





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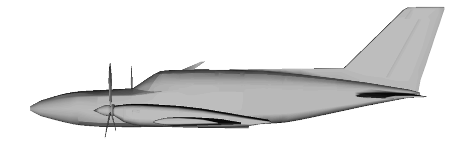
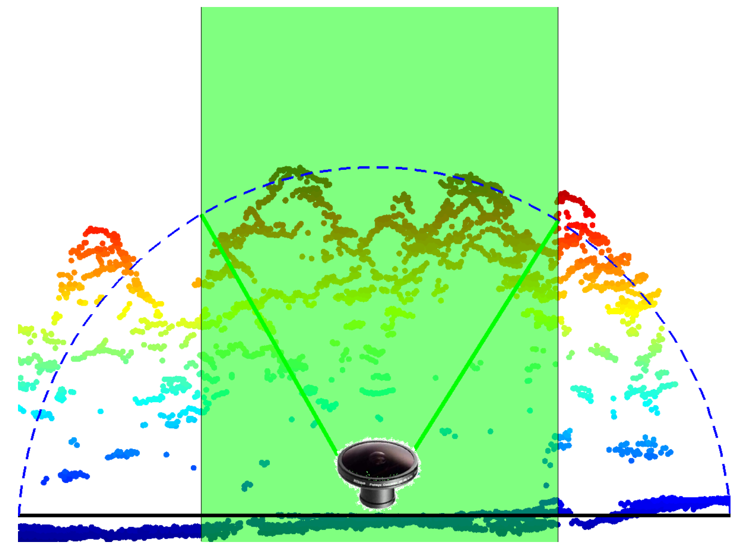
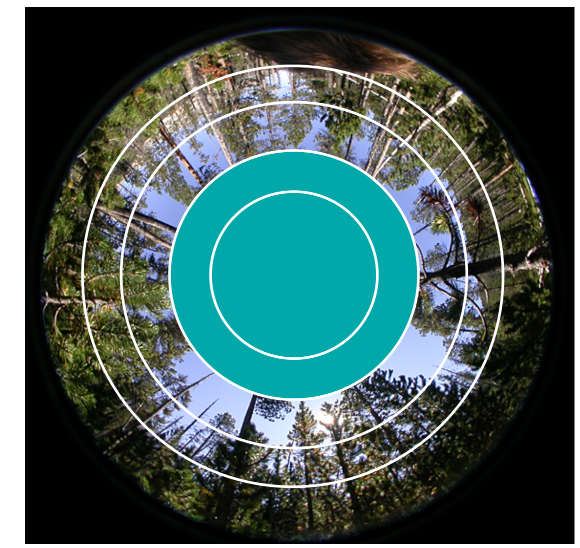
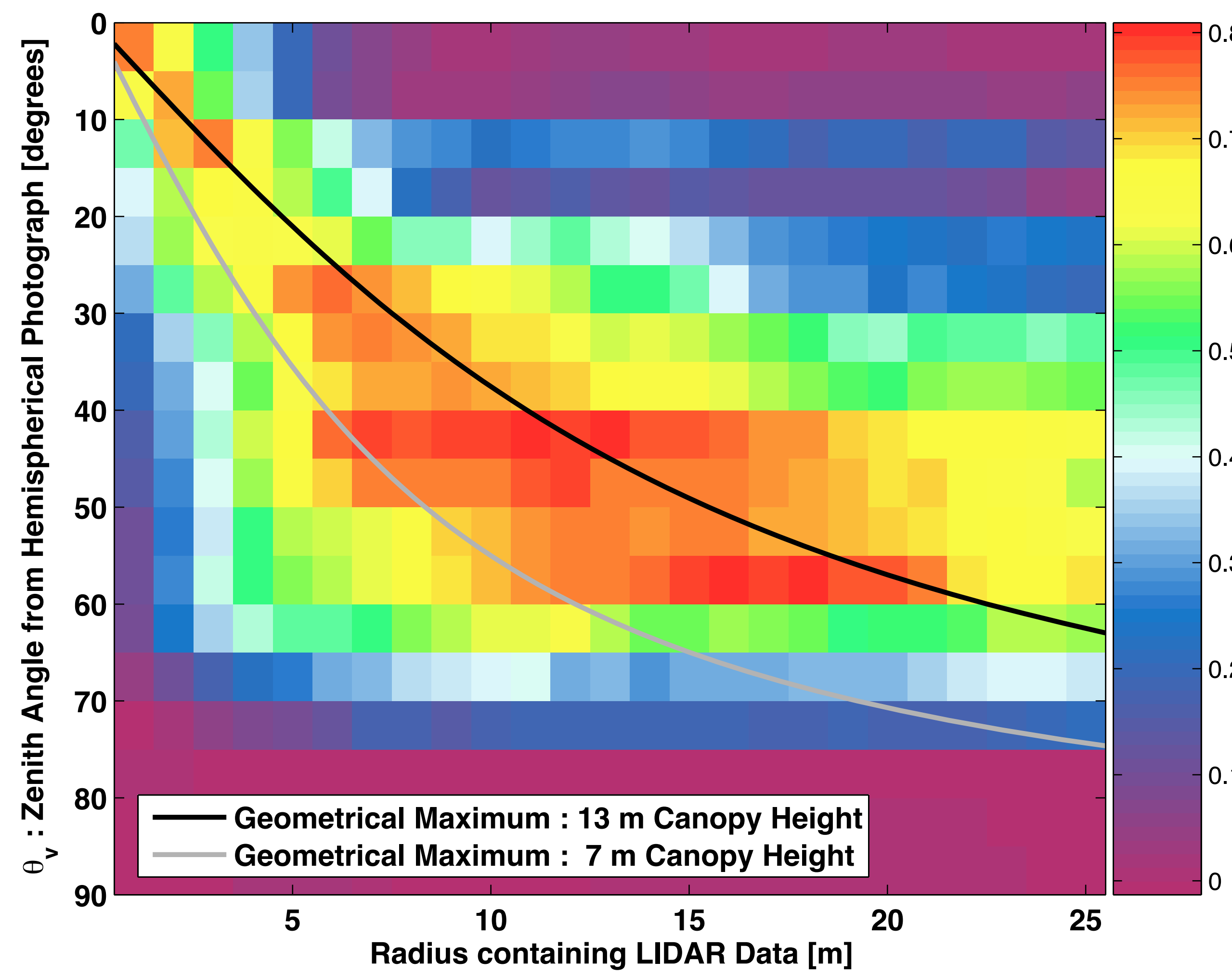


- R^2 for each correlation of "ground truth" and ALS estimates
- two parameters are varied
  - Zenith angle in hemispherical photograph
  - data trap size for ALS data selection to compute proxy
- High correlation at small scales (1-2 m)
  - good enough geolocation of both ALS and field data!

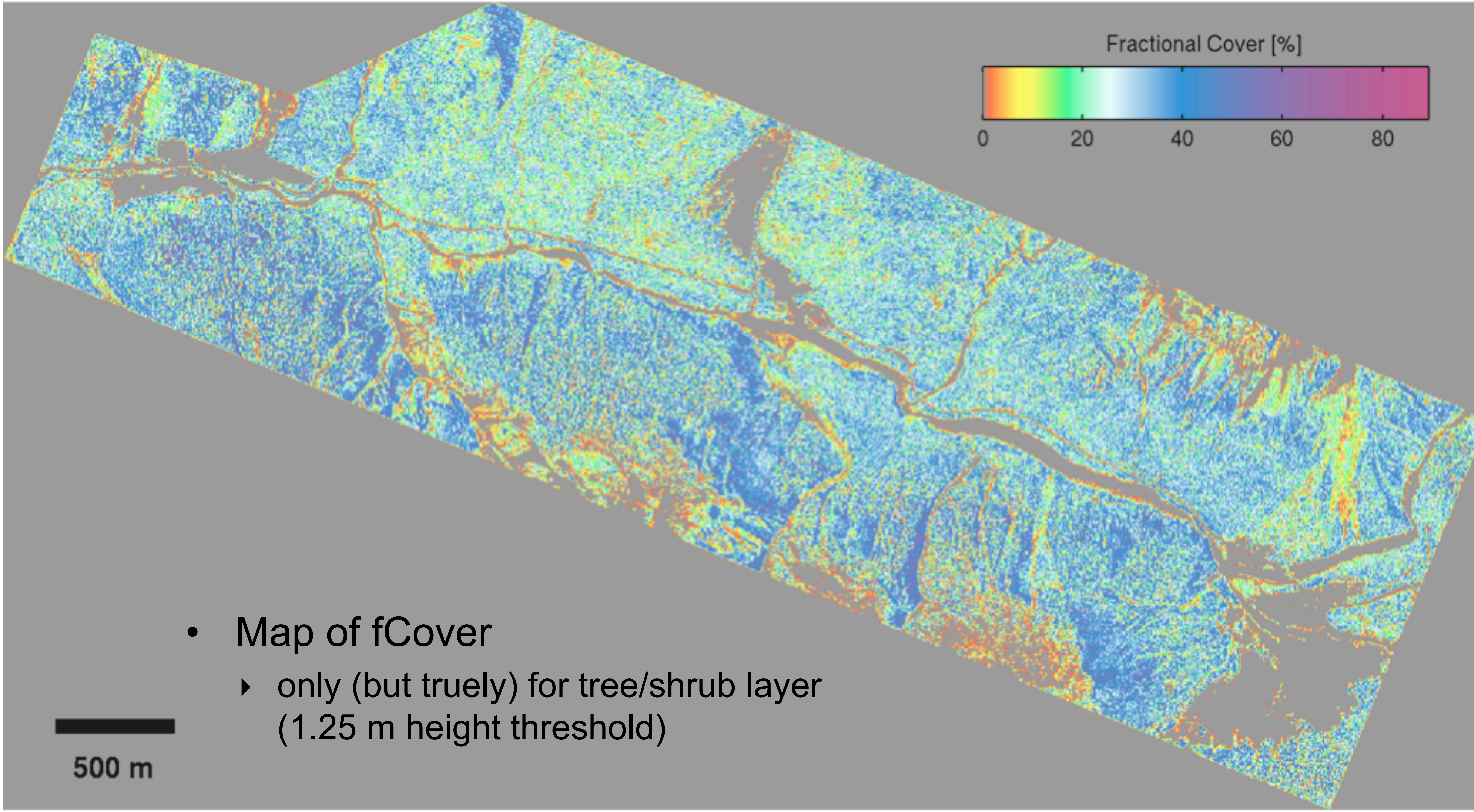






Morsdorf, F.; Kötz, B.; Meier, E.; Itten, K.I. & Allgöwer, B. Estimation of LAI and fractional cover from small footprint airborne laser scanning data based on gap fraction, *Remote Sensing of Environment,* **2006**, *3*, 353-362

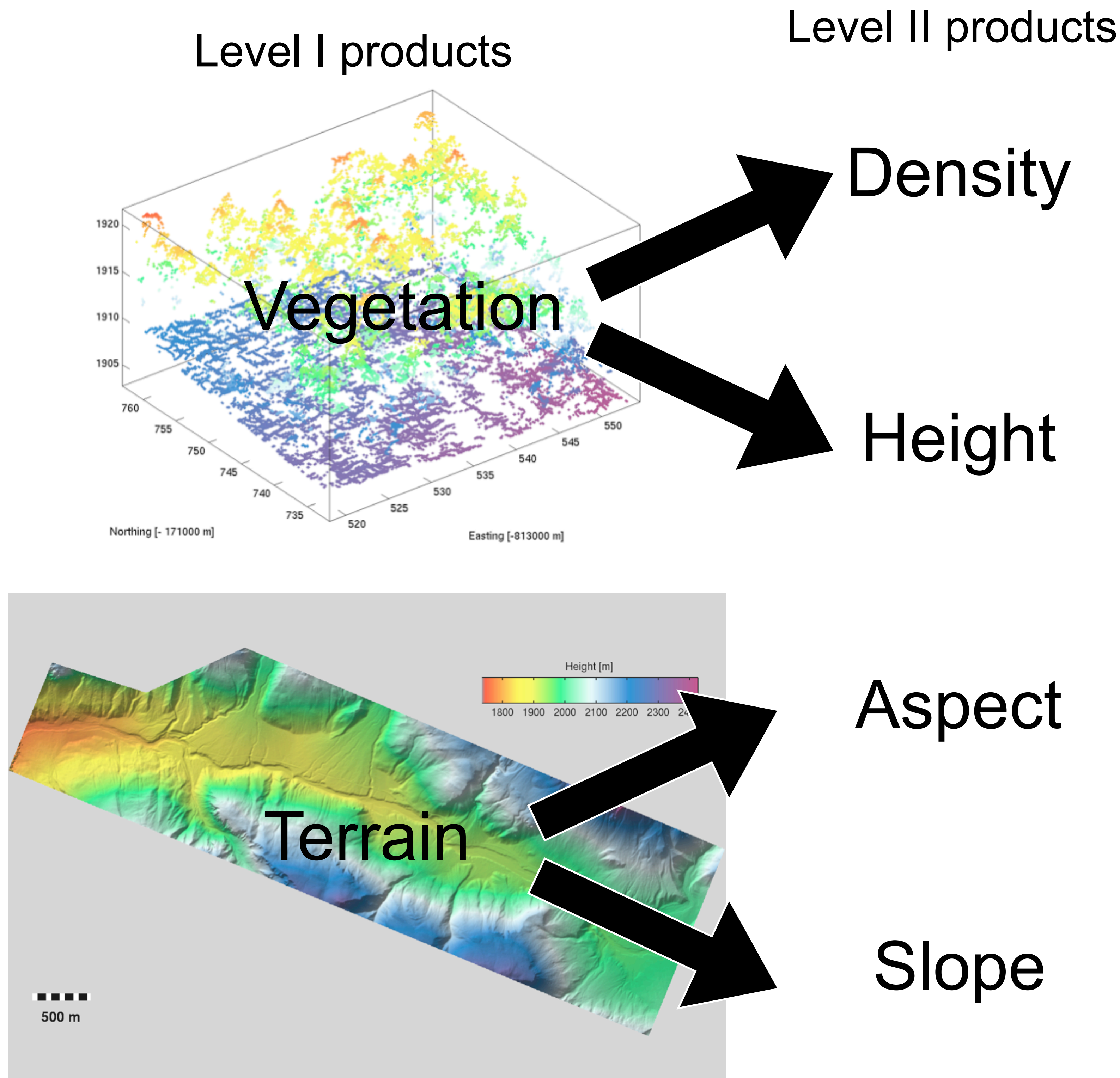
Canopy density - fractional cover



- Map of fCover
  - only (but truely) for tree/shrub layer (1.25 m height threshold)

Application (1): Fire behaviour modelling

- Many relevant input layer for modelling fire behaviour can be derived from ALS data
- High spatial resolution of derived parameters
  - Sensitivity of fire behaviour model ?



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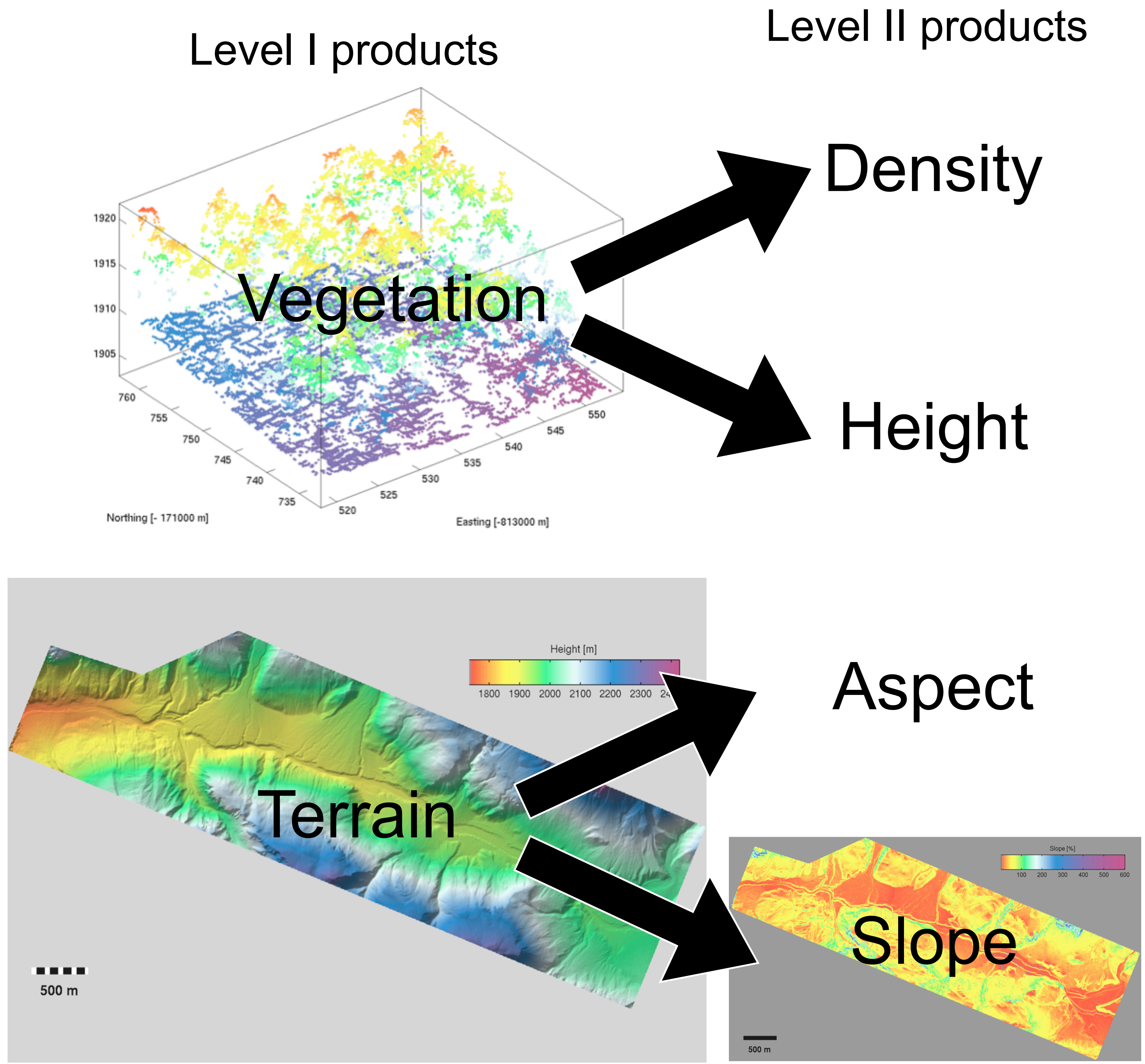

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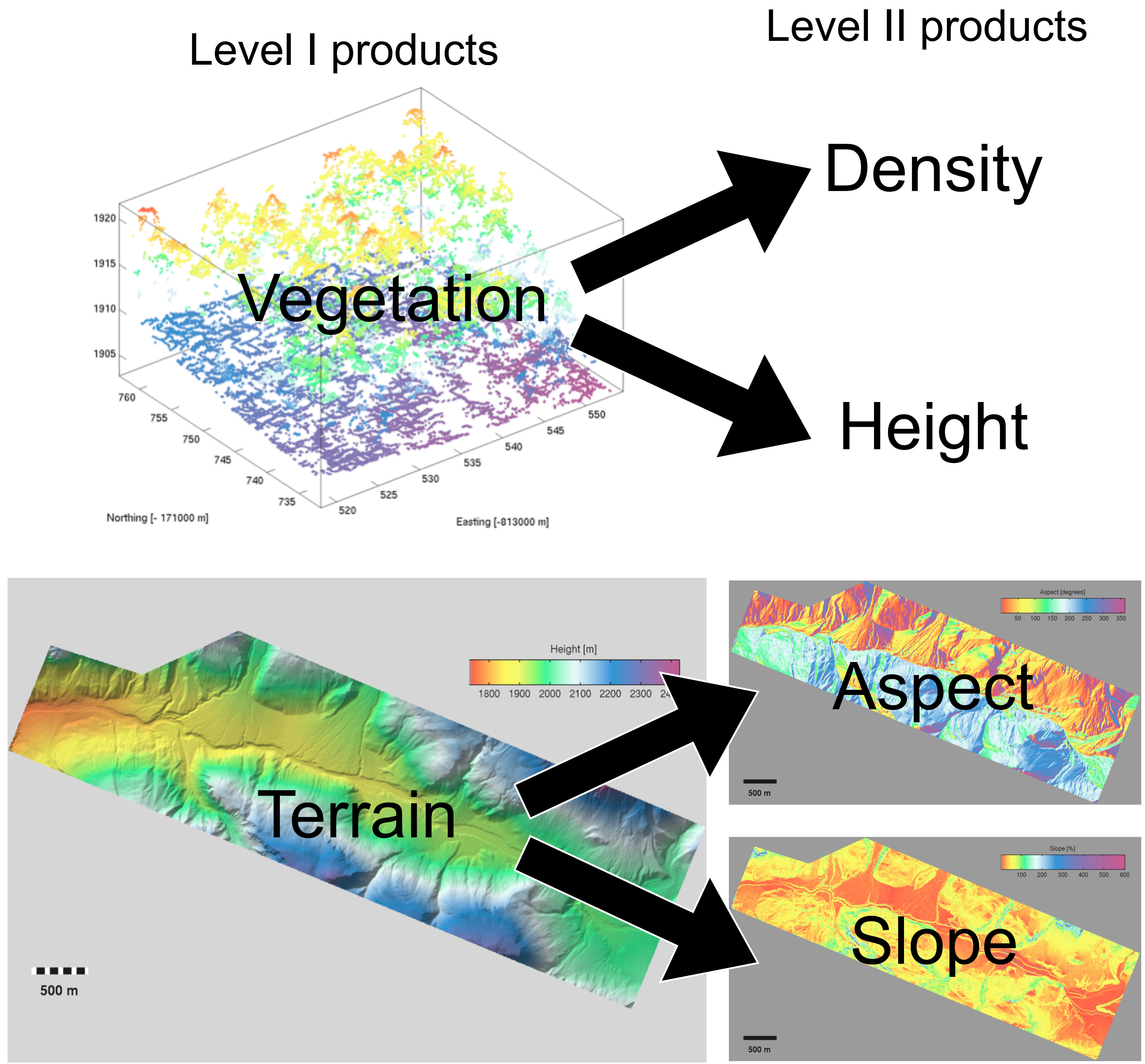

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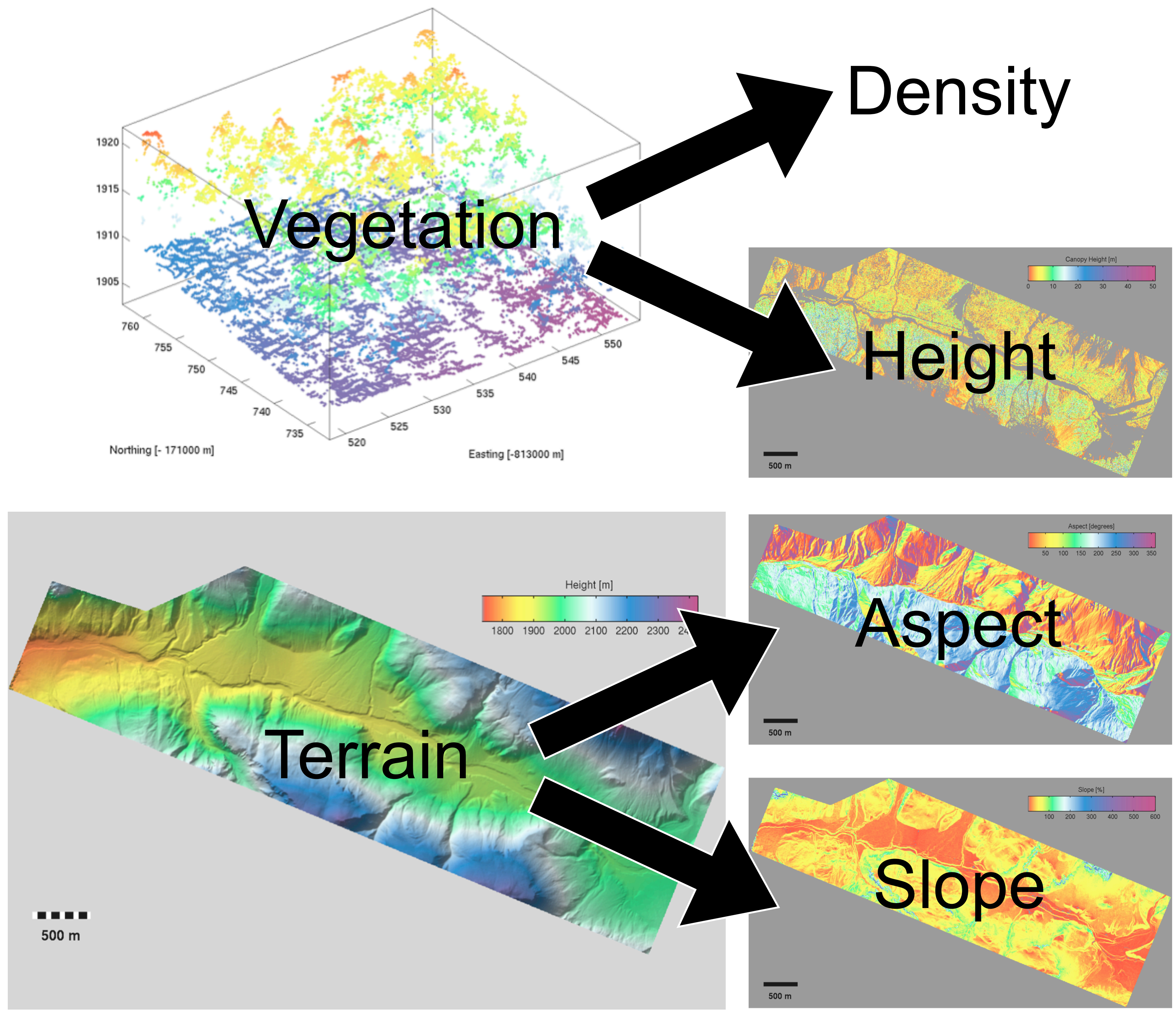

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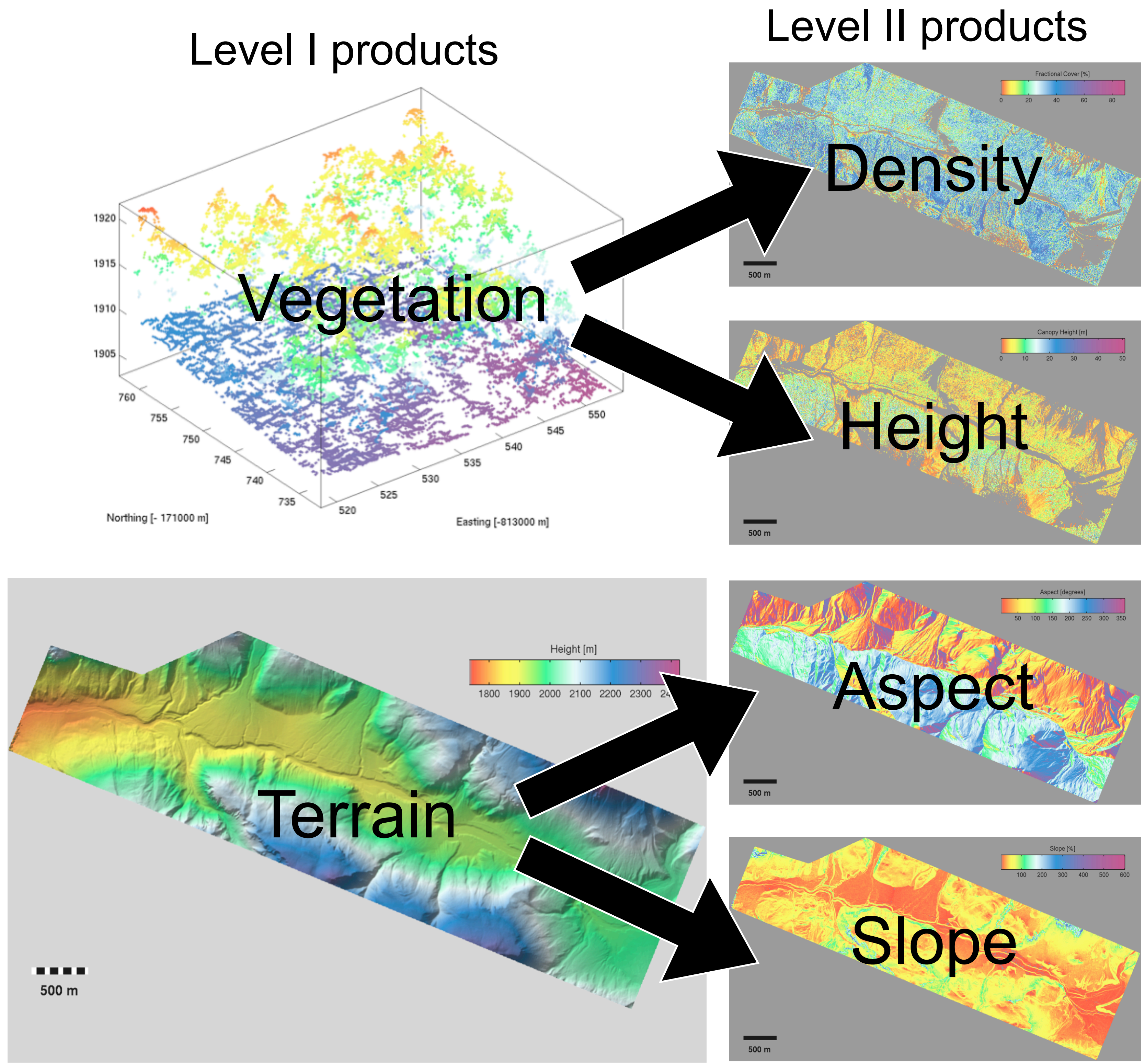
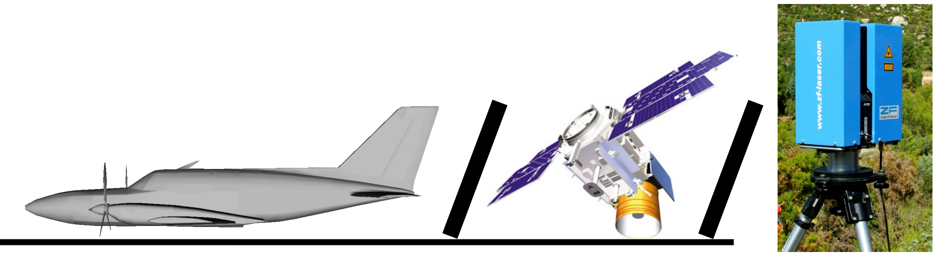
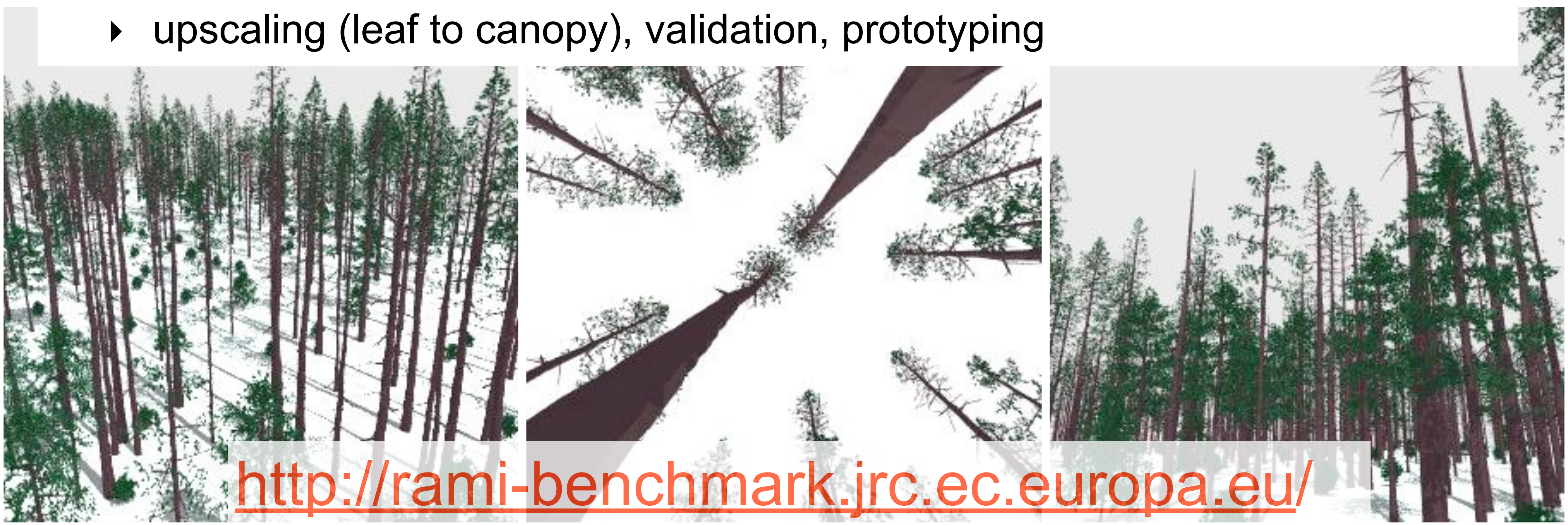




Application (2) : RAMI

- Detailed virtuel characterisation of an actual site (SNP)
  - ALS single tree reconstruction
  - Spectral characterisation of scene elements from field measurements
    - Needle, bark, soil (snow, understorey)
- Structural models of trees and shoots
  - might not be correct for sub-species/site/age !
- Allows forward simulation of RS signals in a RTM
  - upscaling (leaf to canopy), validation, prototyping



http://rami-benchmark.jrc.ec.europa.eu/

ALS - Intensity

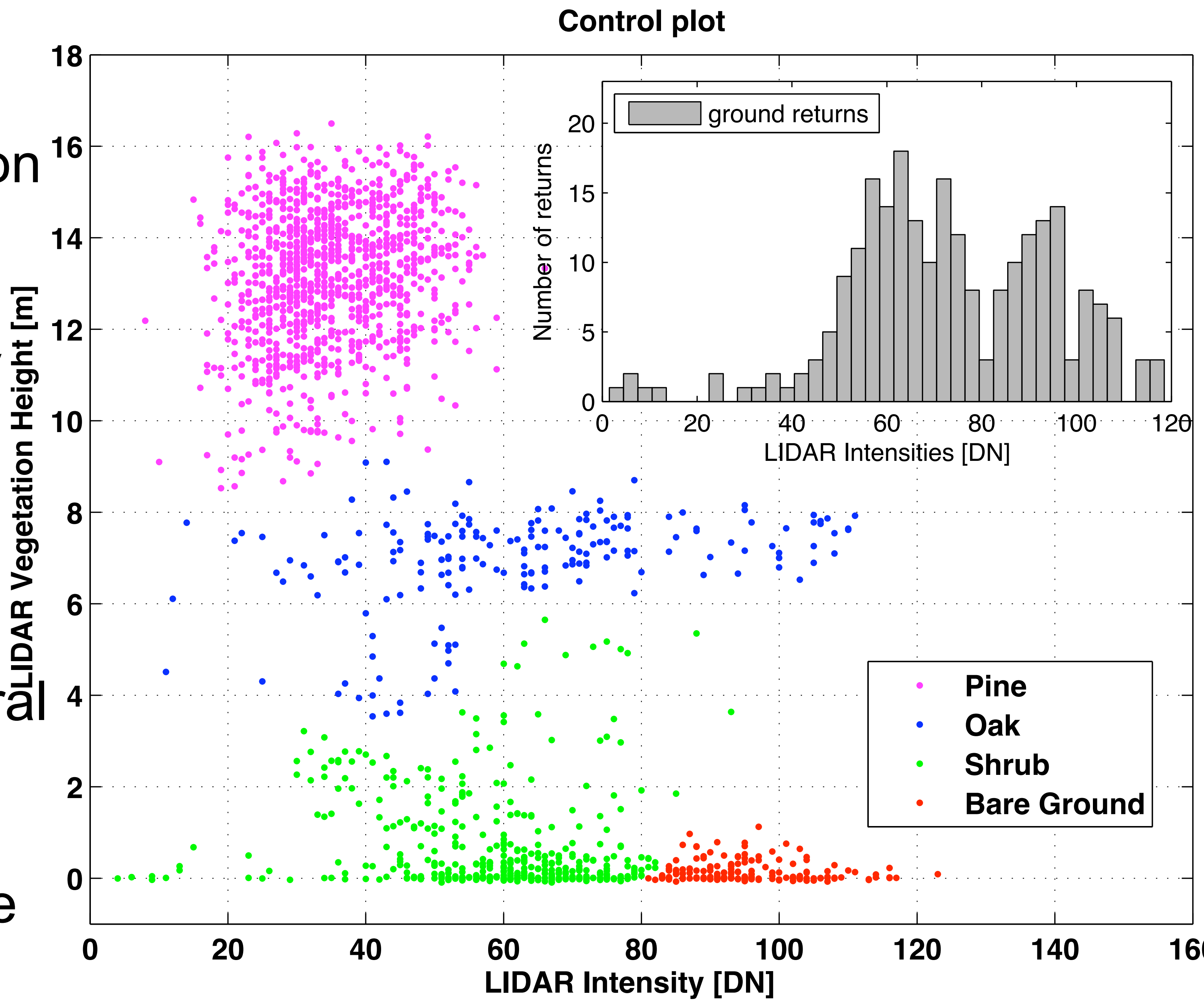
- LiDAR intensity should prove useful
  - no shadows, problem of radiometric calibration (almost) solved

ALS - Intensity - Case study from southern France

- Three layered fire-prone ecosystem close to Lamanon, Provence
  - *pinus halepensis* (alleppo pine)
  - *quercus ilex* (holm oak)
  - *buxus sempervirens* (shrubs)
- Study site comprises four differently treated plots
  - 30x30 (40x30) with 15 m buffer zone
  - **control** - all species, untreated
  - **pine** - only pine
  - **oak** - only oak
  - **mixed** - oak and pine

Use of intensity for species discrimination

- Intensity as second feature for discrimination of vertical strata (species)
- Added value especially close to the ground
- Ability to monitor shrub clearings
- However, intensity is mixed signal of structural and reflectance properties
  - but then: this mixture can be species specific



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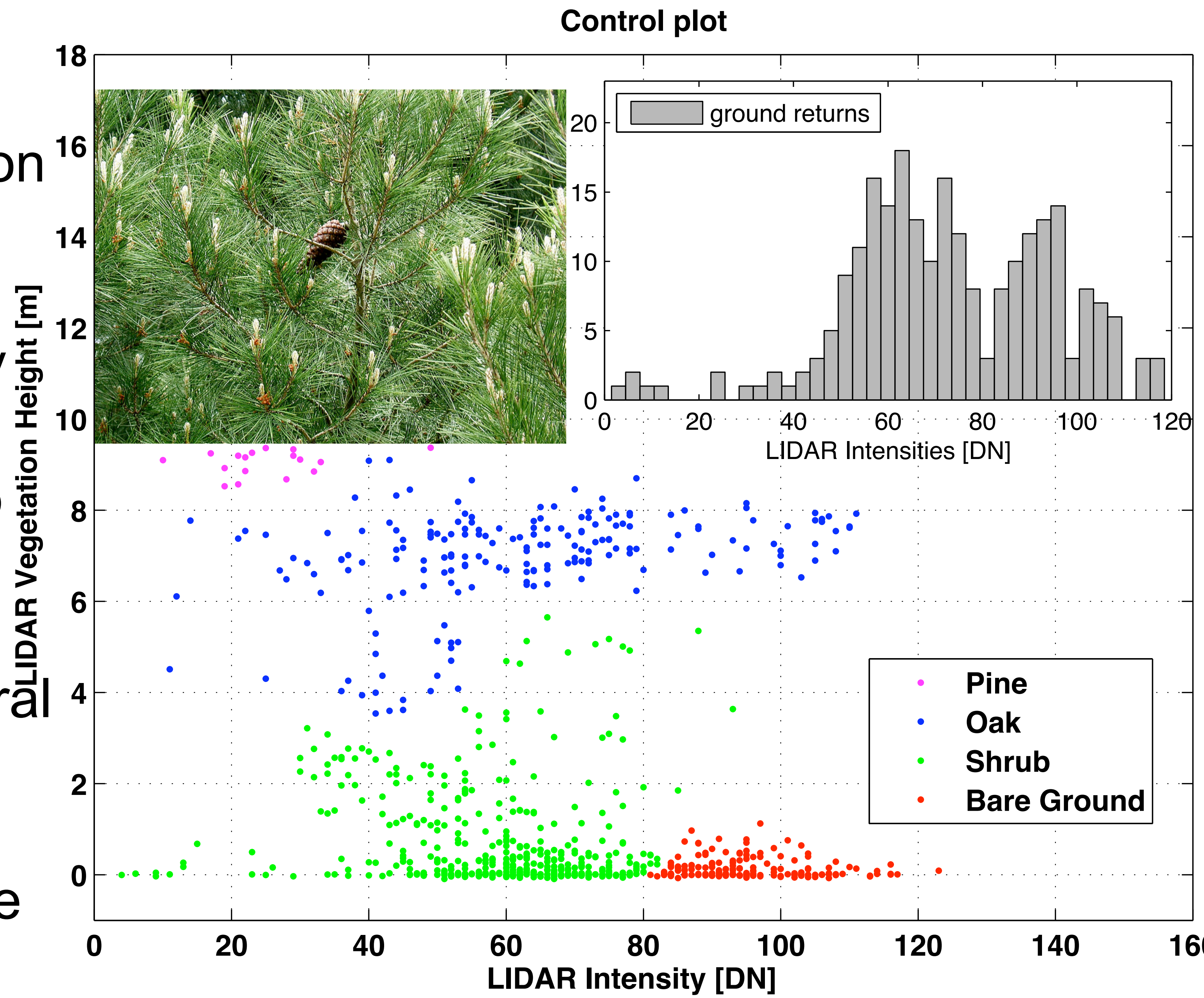

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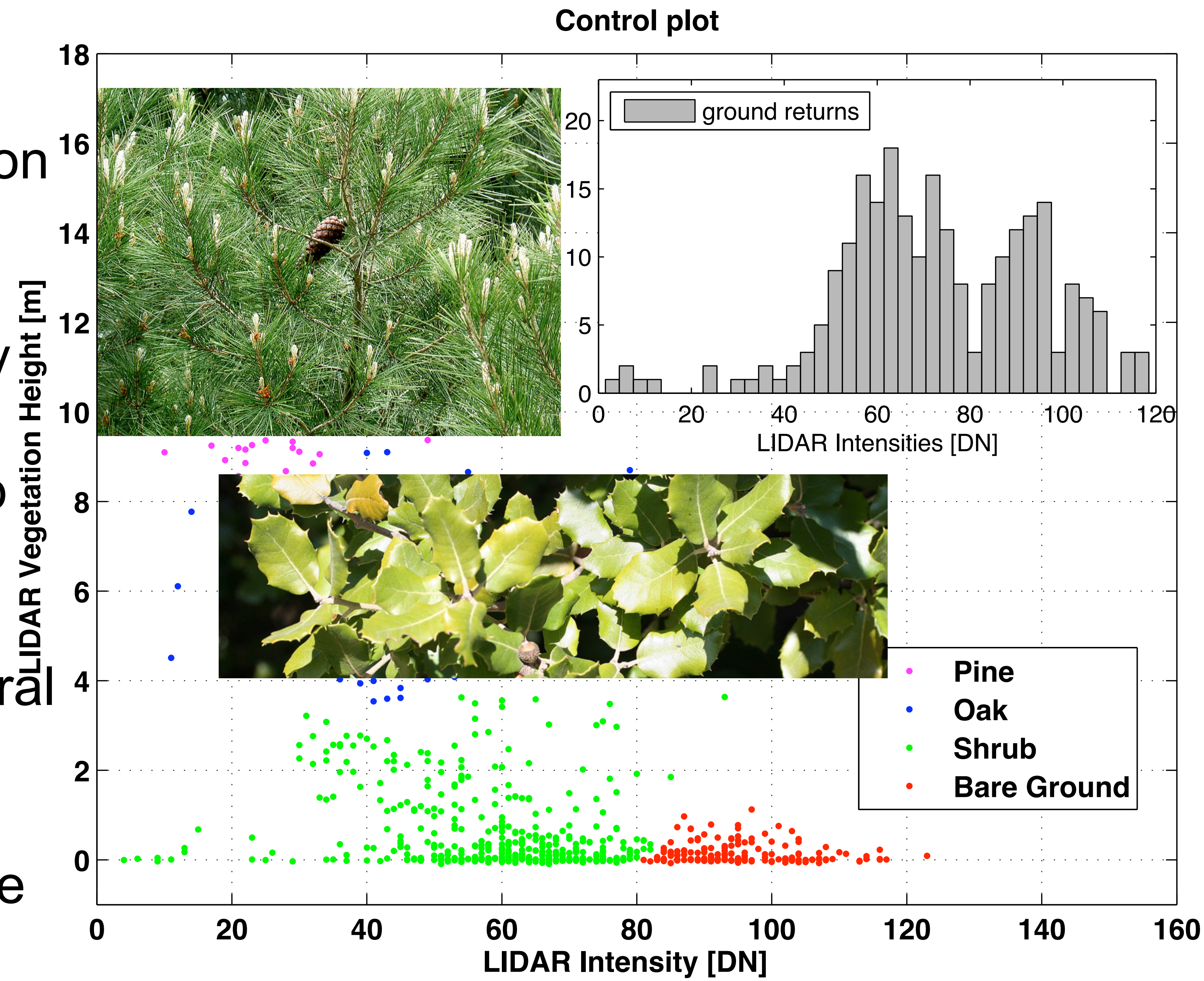

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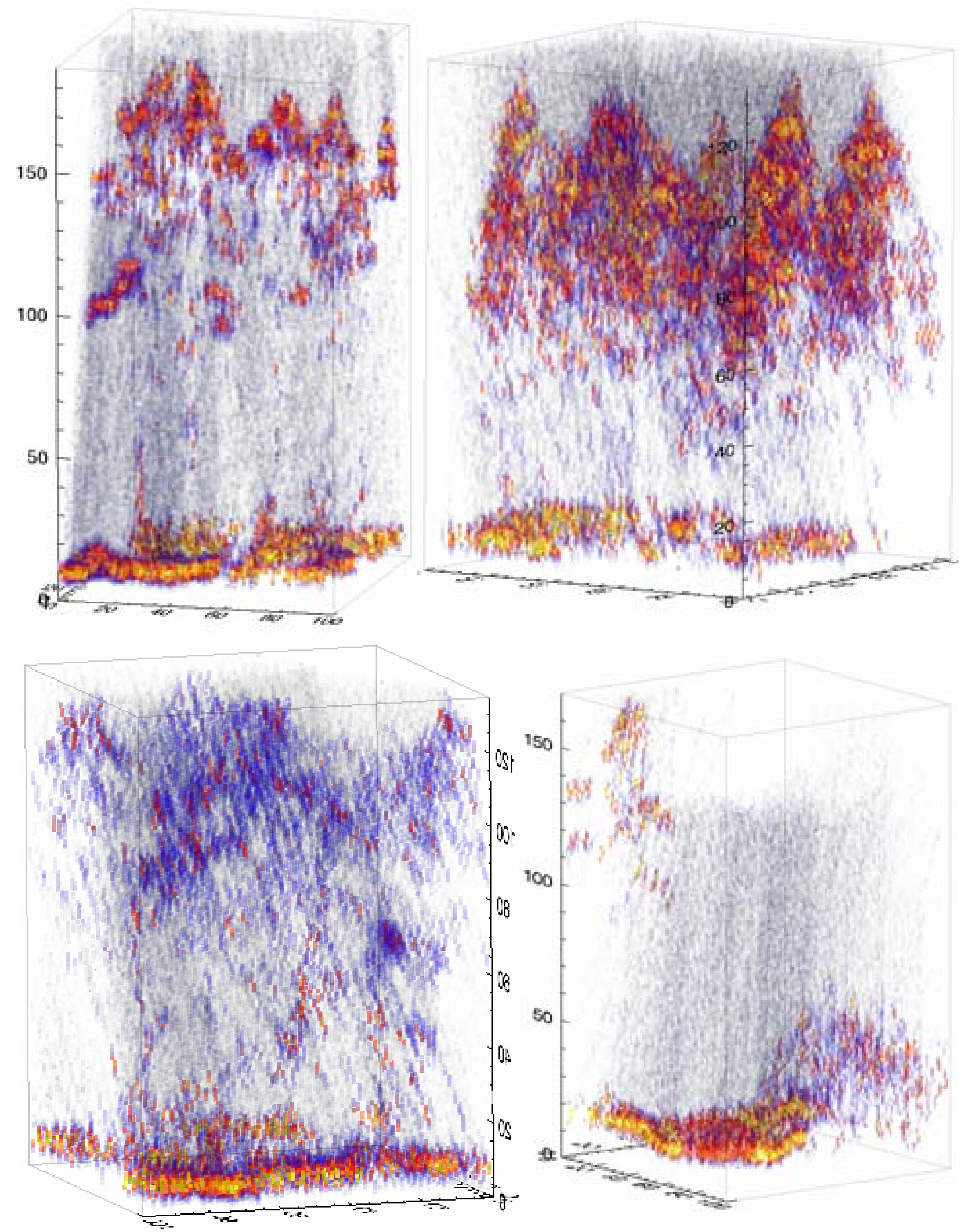
Recent developments

ALS - full waveform

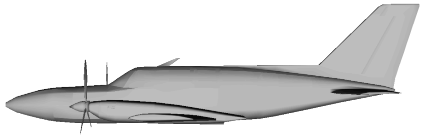
- Higher information content
- Amount of data and it's processing is a tough task
  - Waveform will be recorded along arbitrary lines in 3d space
- First processing attempts were focused on the detection of additional echos
- Cross section is the physical property that can be derived

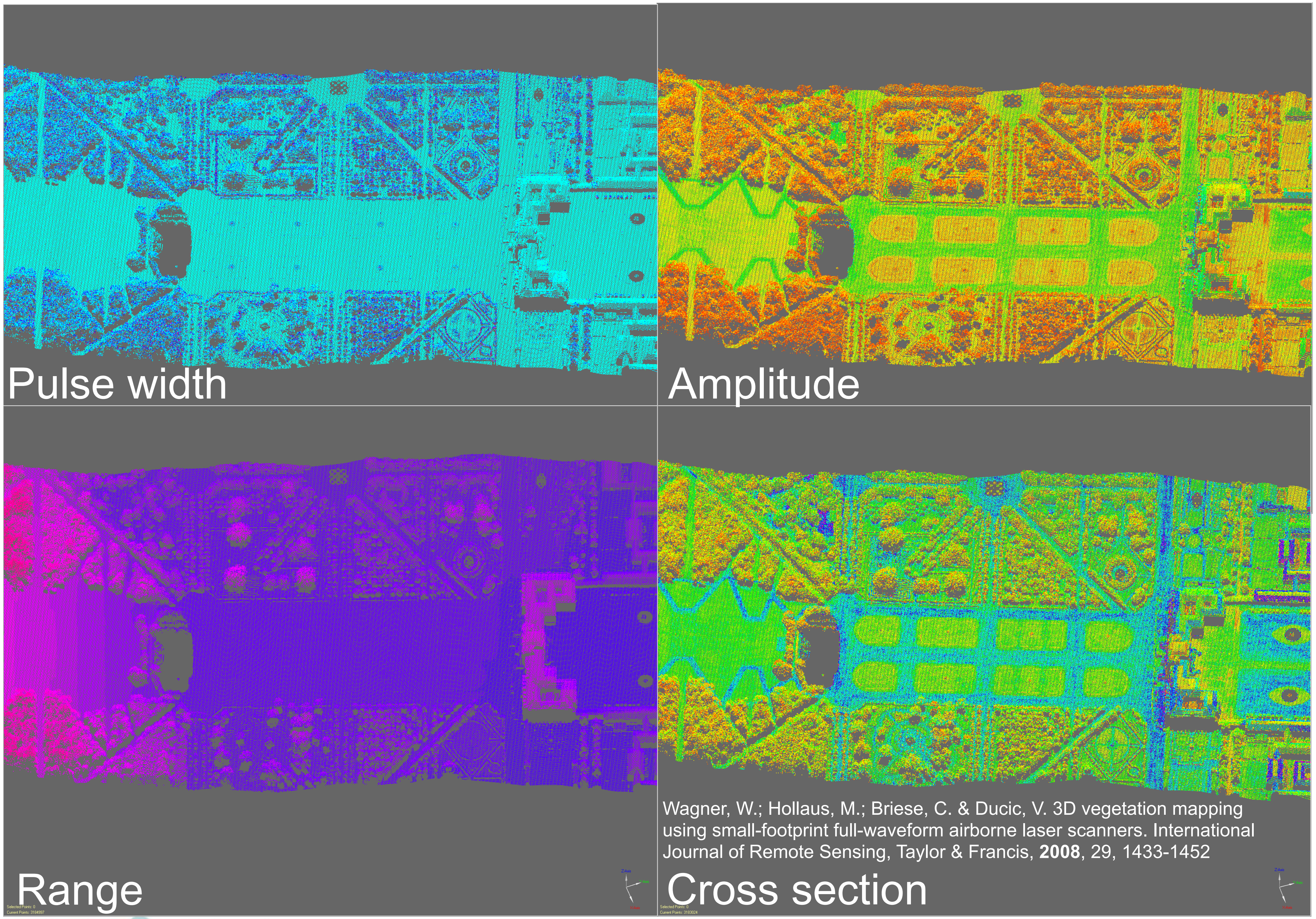
$$\sigma = \frac{4\pi}{\Omega}\rho A_s$$

Persson; Söderman, U.; Töpel, J. & Ahlberg, S.
Visualization and analysis of full-waveform airborne laser scanner data
International Archives of Photogrammetry and Remote Sensing, **2005**, *XXXVI*



ALS - full waveform (Wagner et al.,2008)





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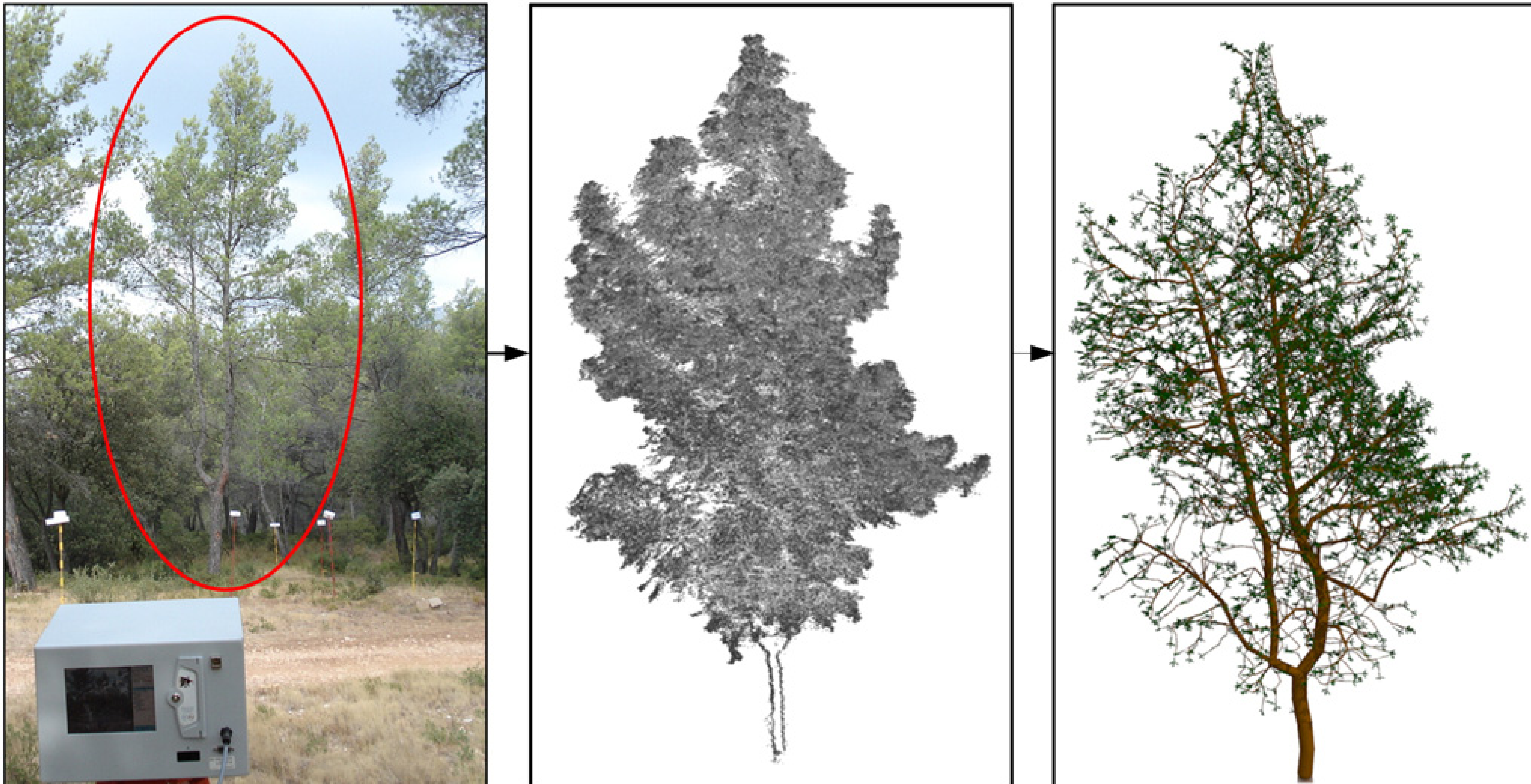
How to generate data for RT models - TLS

In Situ Tree | 3D Point Cloud | Tree Model



Côté, J.-F.; Widlowski, J.-L.; Fournier, R. A. & Verstraete, M. M.
The structural and radiative consistency of three-dimensional tree reconstructions from terrestrial lidar
Remote Sensing of Environment, **2009**, *113*, 1067 - 1081

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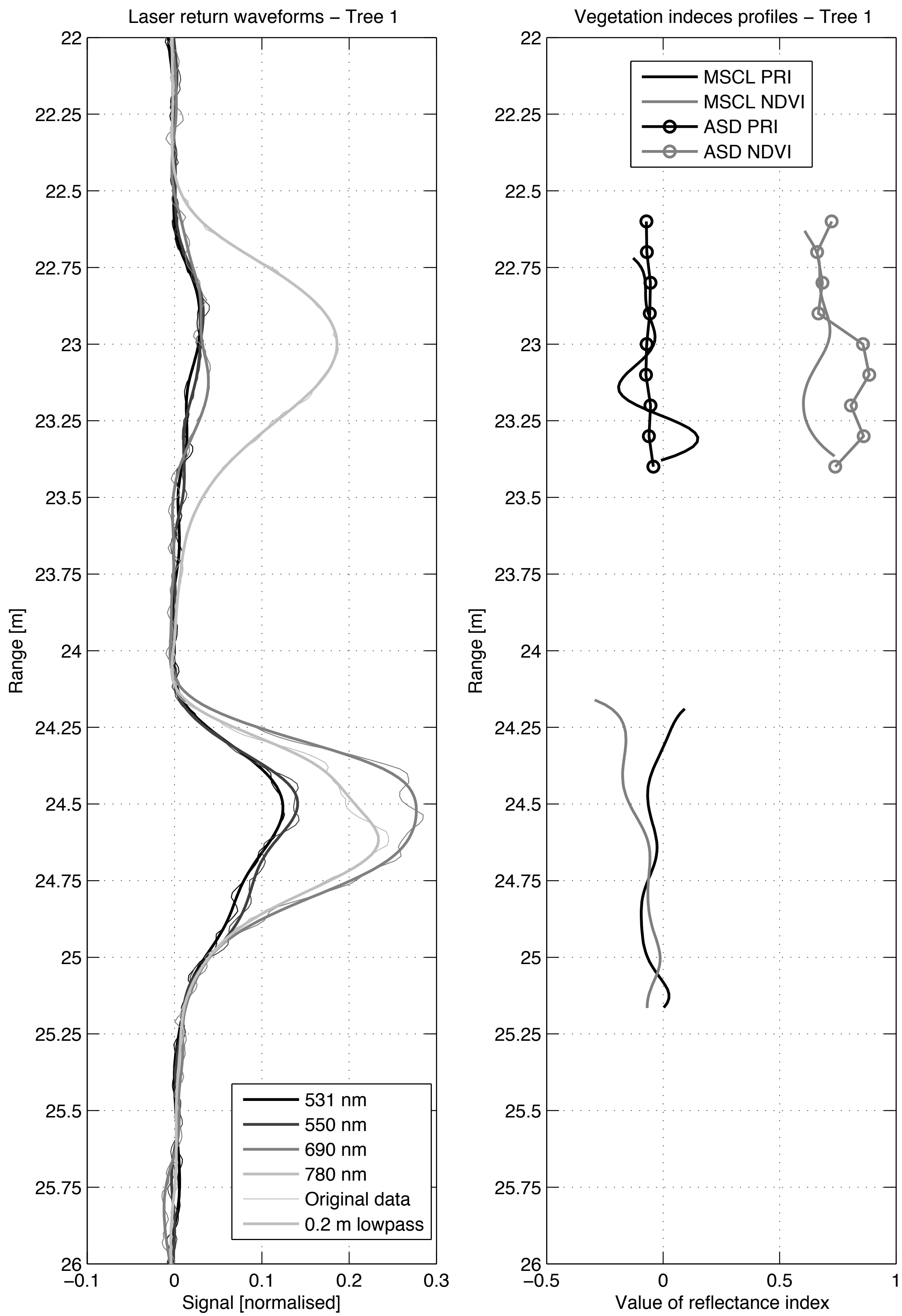
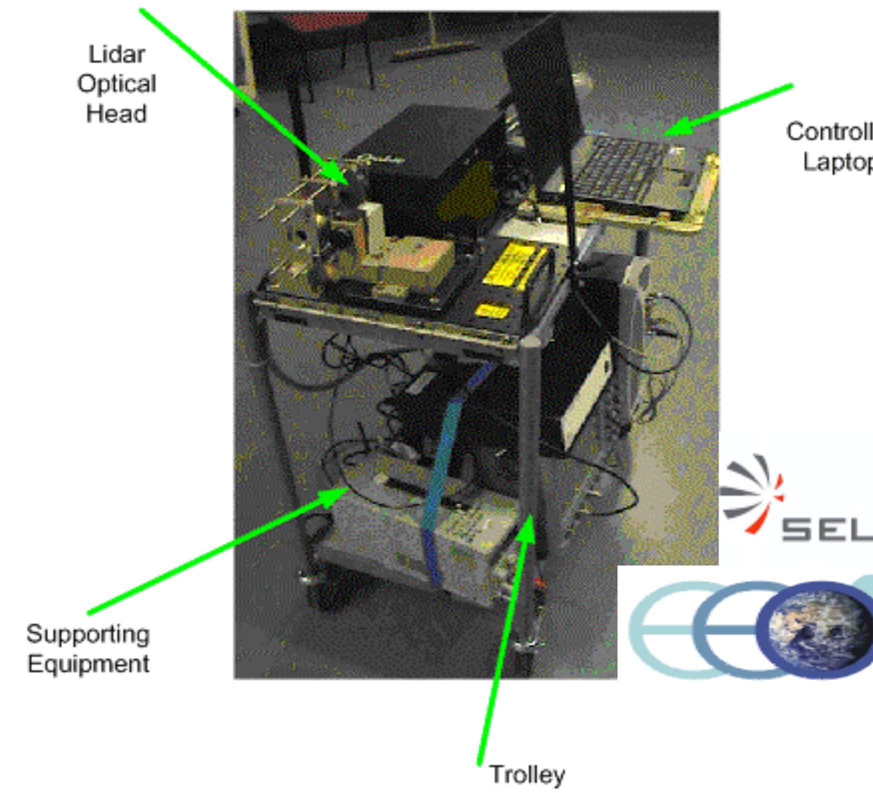
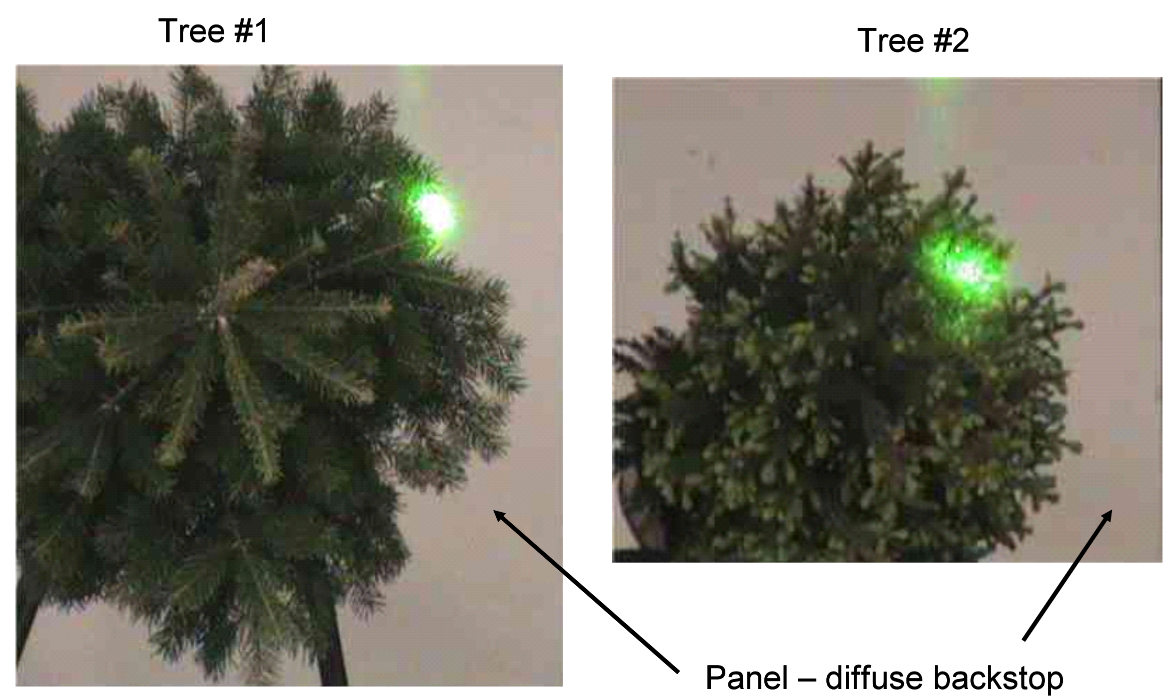
MSL - Multi-Spectral LiDAR



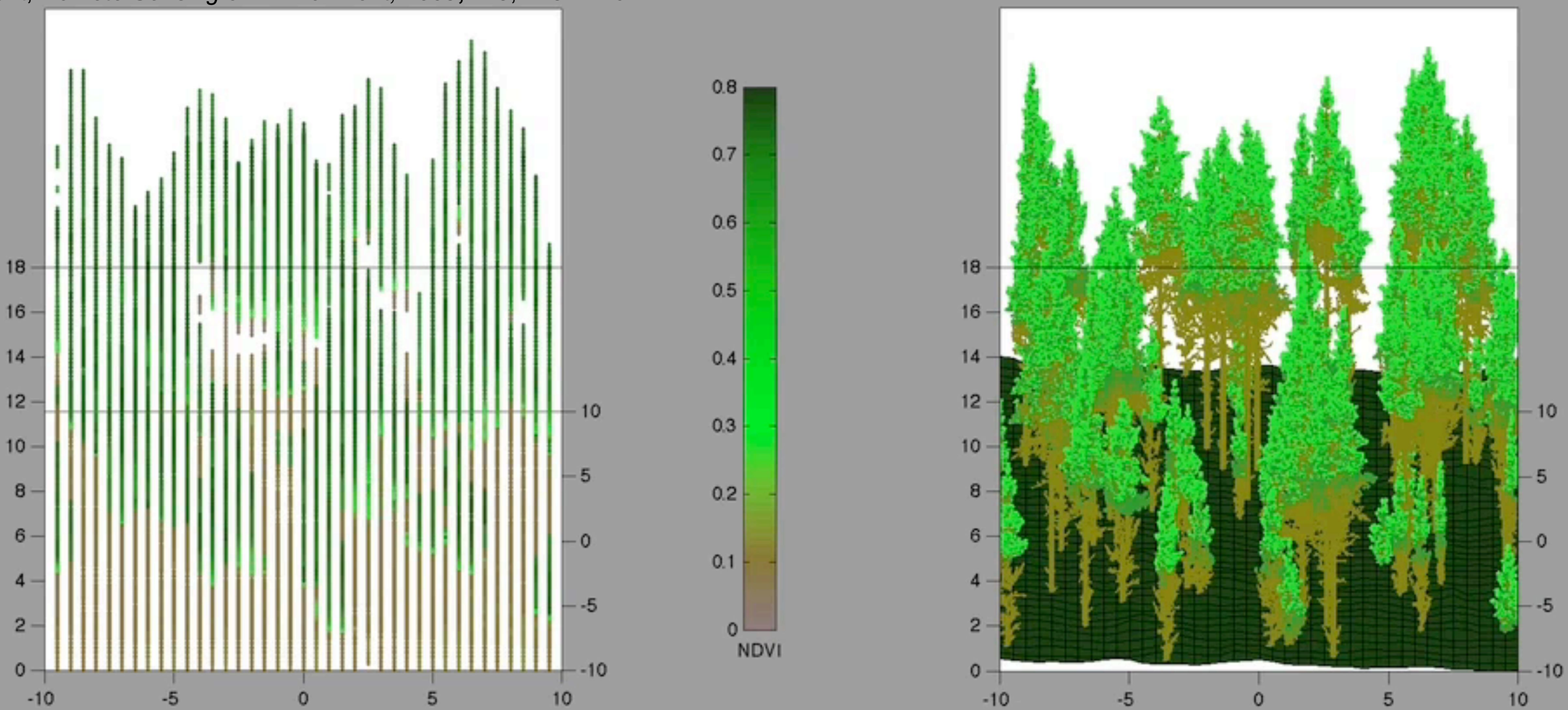




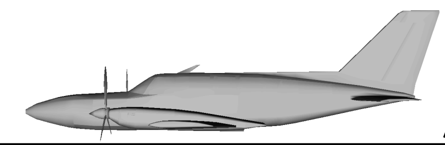
A Multi Spectral Canopy Lidar Demonstrator Project, Iain H Woodhouse, Caroline Nichol, Peter Sinclair, Jim Jack, Felix Morsdorf, Tim Malthus, Genevieve Patenaude, **2010,** Transactions in Geoscience and Remote Sensing, in review.

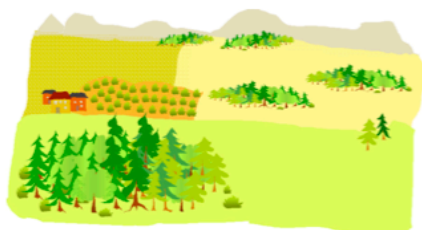
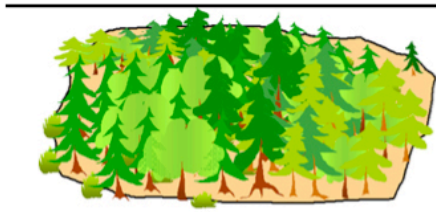
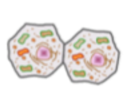
Simulation: an airborne multi-spectral canopy LiDAR (MSCL)

Morsdorf, F.; Nichol, C.; Malthus, T. & Woodhouse, I.H. Modelling multi-spectral LIDAR vegetation backscatter - assessing structural and physiological information content, *Remote Sensing of Environment,* **2009,** 113, 2152-216**.**

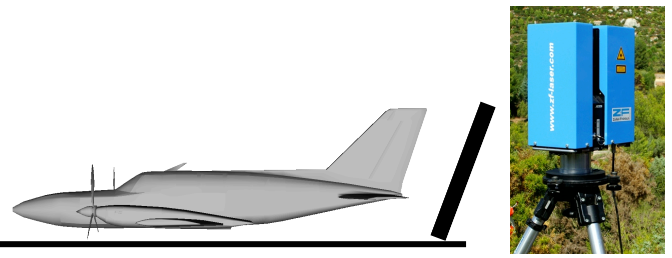


Summing up - scales




Fuel scales / levels	For which fire behaviour model?	Which data acquisition method?	For which purpose?
 Landscape (2D/3D)	▪ Farsite ▪ Fire line rotation model	▪ Satellite images ▪ Aerial photos ▪ Imaging spectroscopy	▪ Fuel type maps ▪ Ignition risk models ▪ Risk maps ▪ Spatial distribution of landscape elements
 Stand (2D/3D)	▪ Behave ▪ Fire line rotation model ▪ Firetec 3D ▪ Canadian Model ▪ McArthur danger meter	▪ Stand inventory and mapping ▪ Aerial photos ▪ LIDAR ▪ Imaging spectroscopy	▪ Input parameters for fire behavior models ▪ Fuel type characterisation ▪ Experimental burns
 Groups, WUI (2D/3D)	▪ Firestar 2D (x,z) ▪ Firetec 3D ▪ NIST	▪ Stand inventory and mapping ▪ Aerial photos ▪ LIDAR ▪ Imaging spectroscopy	▪ Input parameters for fire behavior models ▪3D fuel structures ▪ Biophysical parameters
 Individuals (3D)	▪ Firestar 2D (x,z) ▪ Firetec 3D ▪ CFIS	▪ Cube method ▪ Field sampling ▪ Ground truth	▪ Input parameters for fire behavior models ▪ Fire danger rating system (FMC) ▪ Structural & biophysical parameters
 Particles	▪ Firestar 2D (x,z)	▪ Cube method ▪ Field sampling	▪ Input parameters for fire behavior models ▪ Structural & biophysical parameters
 Cells	…	▪ Biochemical analysis	▪ Input parameters for fire behavior models ▪ Combustion behavior

Summing up - scales



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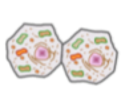
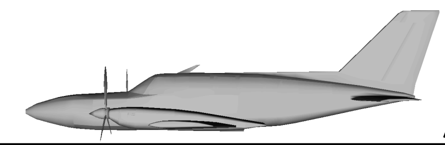
 Cells	…	▪ Biochemical analysis	▪ Input parameters for fire behavior models ▪ Combustion behavior

Airborne laser scanning

ALS

Summing up - scales

 / 

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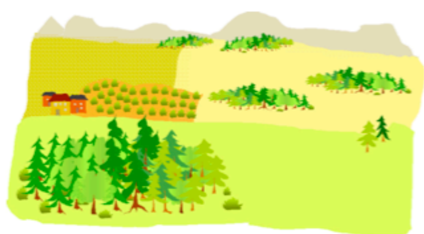 Landscape (2D/3D)	▪ Farsite ▪ Fire line rotation model	▪ Satellite images ▪ Aerial photos ▪ Imaging spectroscopy	▪ Fuel type maps ▪ Ignition risk models ▪ Risk maps ▪ Spatial distribution of landscape elements
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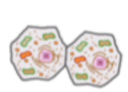 Cells	...	▪ Biochemical analysis	▪ Input parameters for fire behavior models ▪ Combustion behavior

Airborne laser scanning

ALS

Terrestrial laser scanning

TLS

Summary

- Tree geometry and vegetation density can be derived from ALS
- Accuracy of the methods presented are **at least** on the level of traditional field work
  - Validation problem - in theory some ALS based methods may perform better, but how prove it?
- ALS and TLS can provide complementary structural information across a range of scales
  - but to fully exploit this potential, additional reserach is needed
  - e.g. by the integration of structural information derived from ALS and TLS with spectral information and tree models, to be used with RTM ...
    - ... to simulate RS signals - a powerful tool for:
      - Sensor prototyping (e.g. MSCL)
      - Product validation (see above)

Outlook

Outlook

- Challenges
  - automatic extraction of semantic information from point cloud data
  - implementation/validation of methods for higher level products
    - RT is needed to fully understand and exploit full-waveform data
  - e.g. LAI (PAI) from TLS
  - parameterization of sub-scale processes in RT, measurements needed!

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  - automatic extraction of semantic information from point cloud data
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    - RT is needed to fully understand and exploit full-waveform data
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  - parameterization of sub-scale processes in RT, measurements needed!
- Opportunities
  - including ALS intensity and full-waveform information
    - e.g. species discrimination
  - multi-spectral TLS for true LAI estimation
    - ratio of leafy/woody components
  - RT and ALS/TLS based characterisation of actual scenes for upscaling

Thank you for your attention!