Introduction to LiDAR Technology and Applications in Forest Management

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What is LiDAR?

- LiDAR = Light Detection And Ranging
- Active form of remote sensing
- Measures the distance to target surfaces using narrow beams of near-infrared light (*e.g.*1064 nm).
- Primarily operated on airborne platforms for forestry applications
  - However spaceborne (GLAS) and field based LiDAR instruments have also been developed.

LiDAR is Distance Measurement

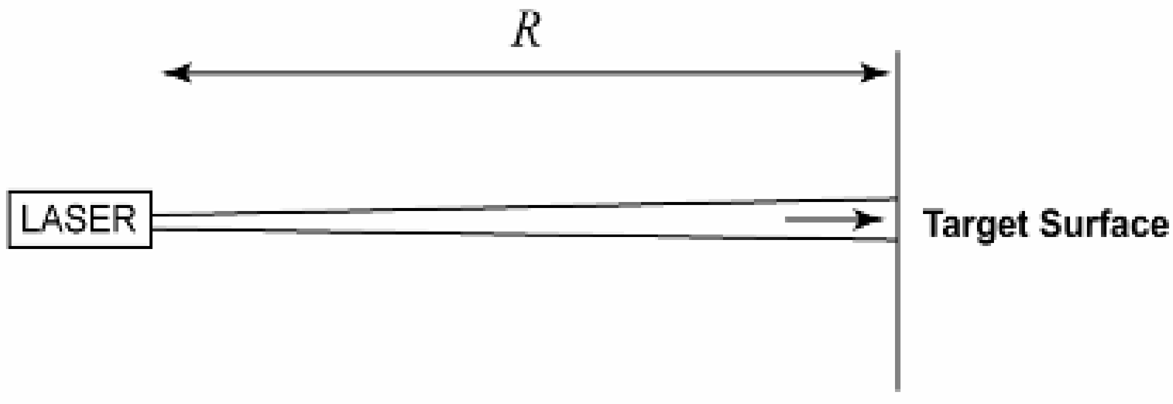
R = Range or distance

c = Speed of light (299 792 km / sec)

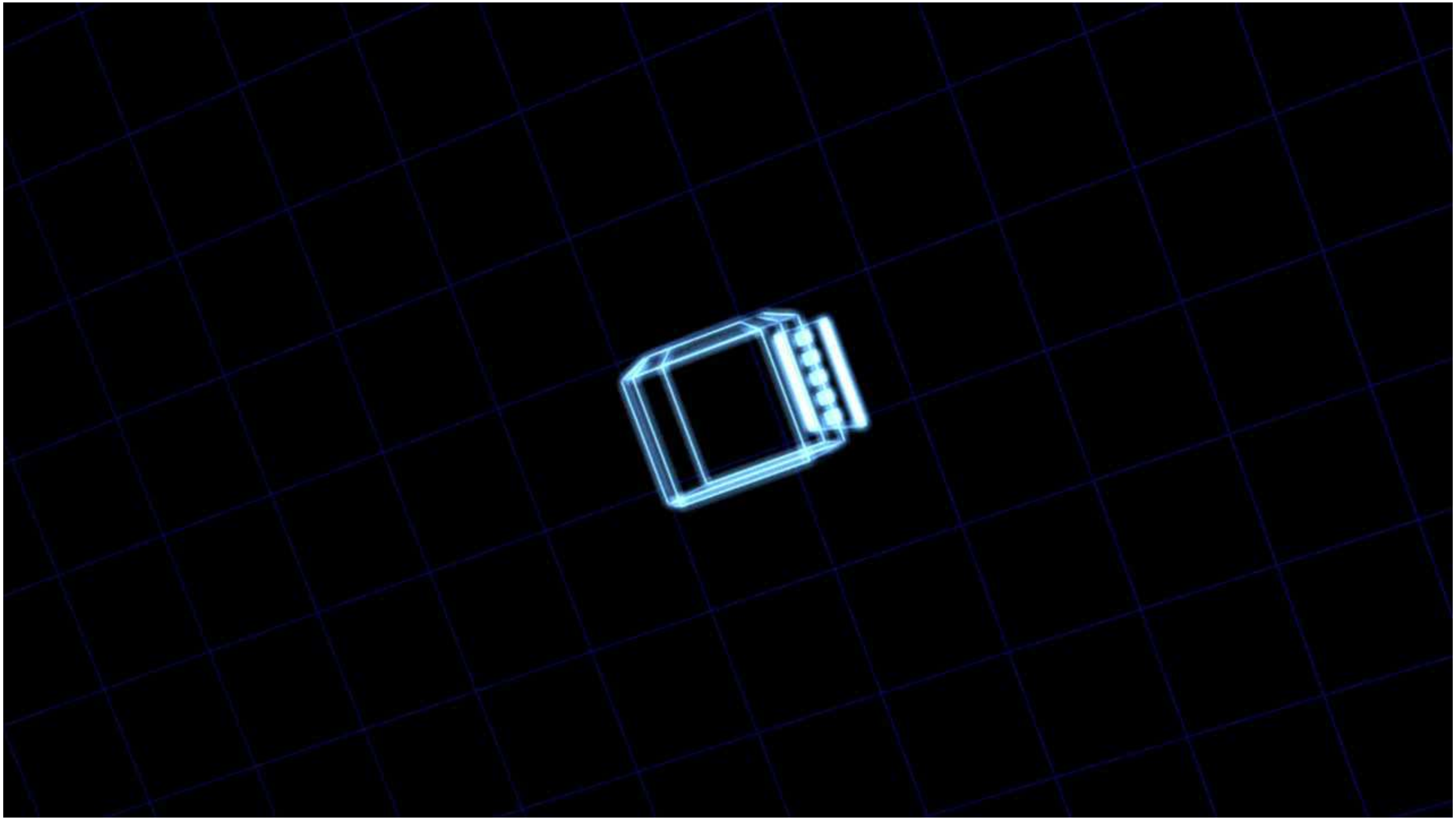
tp = Time the pulse is emitted from the sensor

t = Time the pulse arrives back at the sensor

Divided by 2 to compensate for the round-trip distance



LIDAR from Space (Theoretical)



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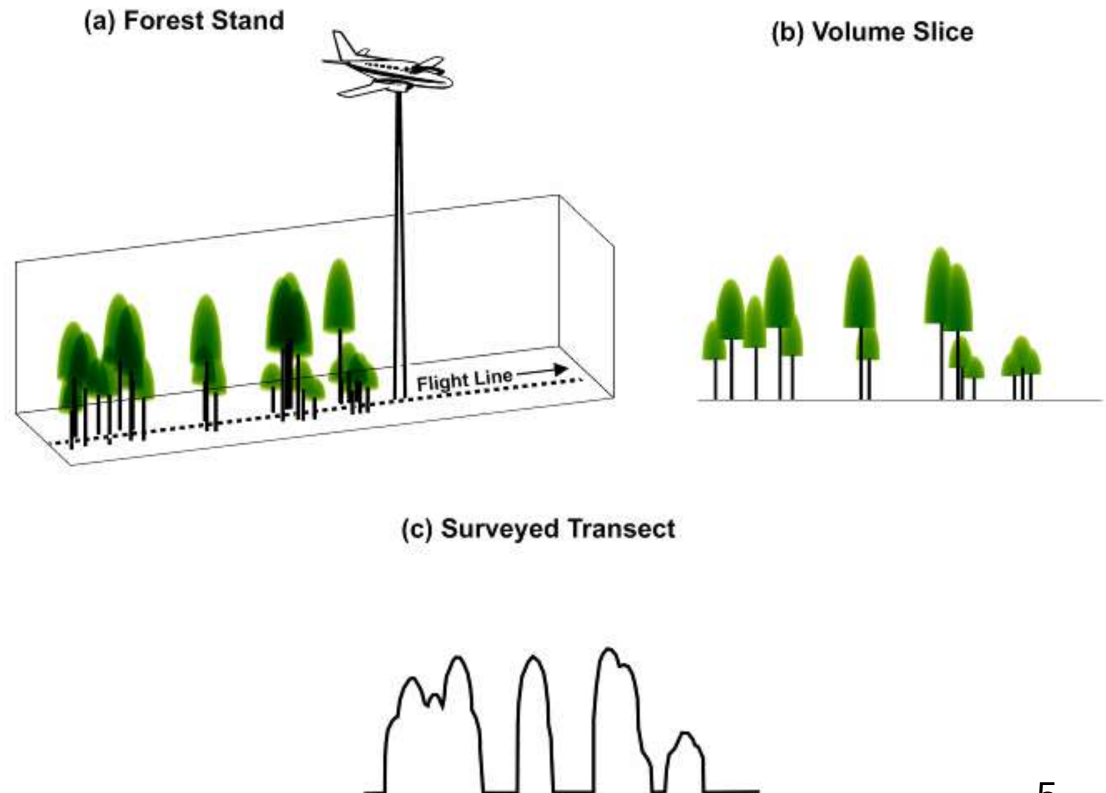
Different Types of LiDAR instruments

- Profiling LiDAR
- Small-footprint LiDAR
- Large-footprint LiDAR
- Ground based LiDAR

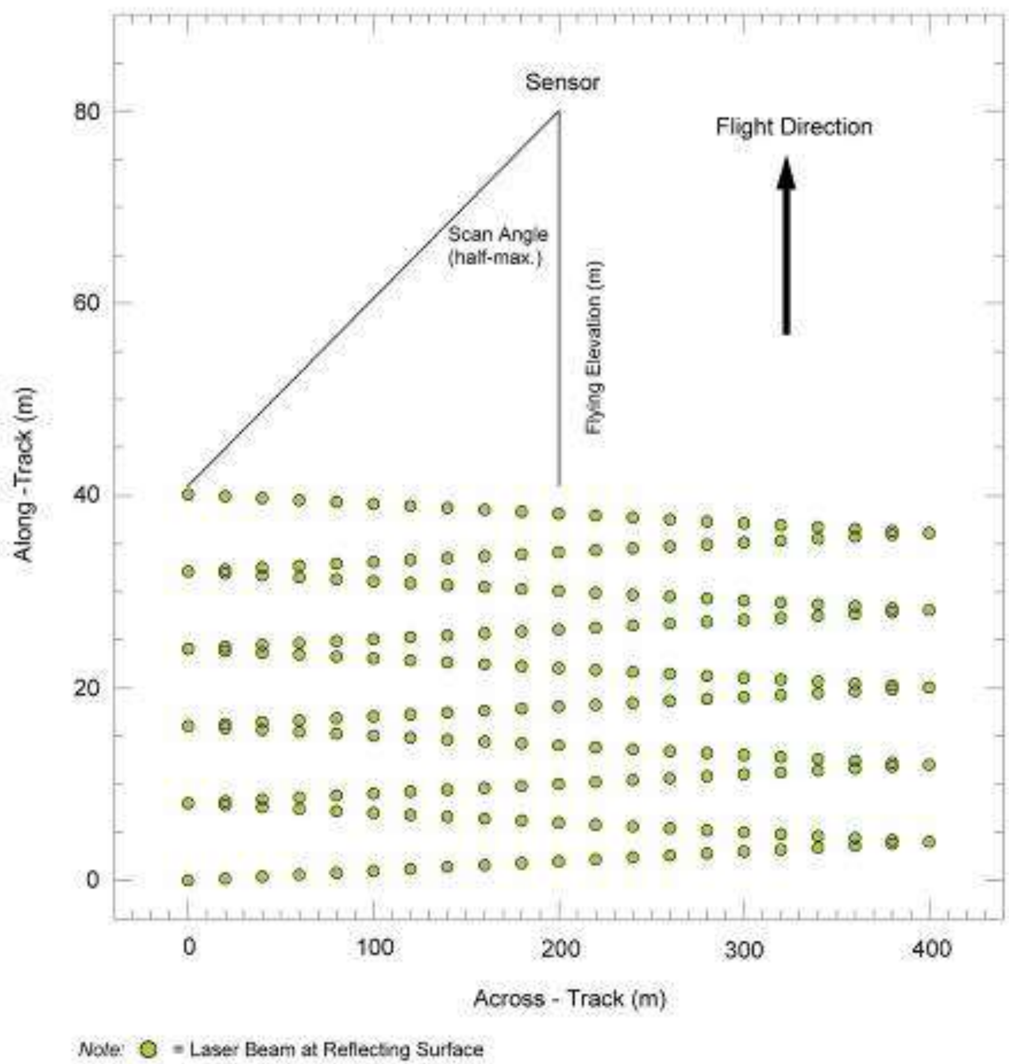
Profiling LiDAR

- Early airborne LiDAR instruments
- Measure height information along single transects with a fixed nadir view angle



- Advantages:
  - Relatively inexpensive technology
  - Great sampling tool
- Limitation:
  - Lack of spatial detail

LiDAR Scanning Pattern



- More advanced scanning systems were later developed (~1990s onwards).
  - Rotating mirror used to direct pulses perpendicular to flight direction
- Both small- and large-footprint LiDAR use this approach

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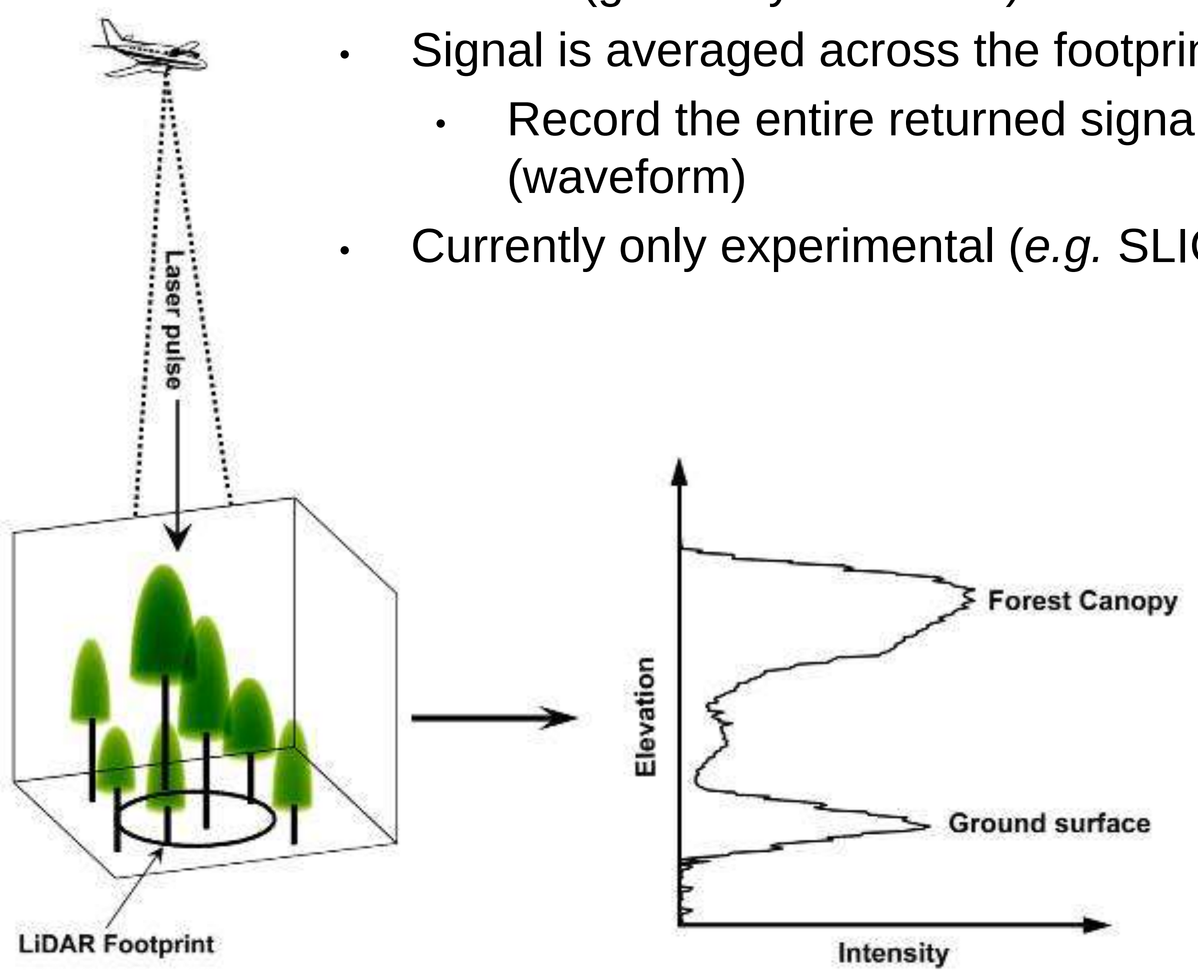
Small-footprint LiDAR

- Beam diameters at intercepting surface < 1 m
- Typically record high sampling densities (>1 / m^2)
- Accuracy ~15 cm vertically and 40 cm horizontally
- Operated on fixed wing or helicopter platforms
- Commercially available
- Sensors now emit up to 260 000 pulses / sec
  - 3 years ago this was closer to 25 000 pulses / sec
- Increase from first / last return combinations to 5 returns per pulse
  - Ability to separate returns by smaller distances (e.g. 2 m intervals)
  - Option to record full waveform is becoming more common

Large-footprint LiDAR

- These instruments use larger beam diameters at intercepting surface (generally 5 to 25 m)
- Signal is averaged across the footprint
  - Record the entire returned signal as a function of time (waveform)
- Currently only experimental (*e.g.* SLICER and LVIS)



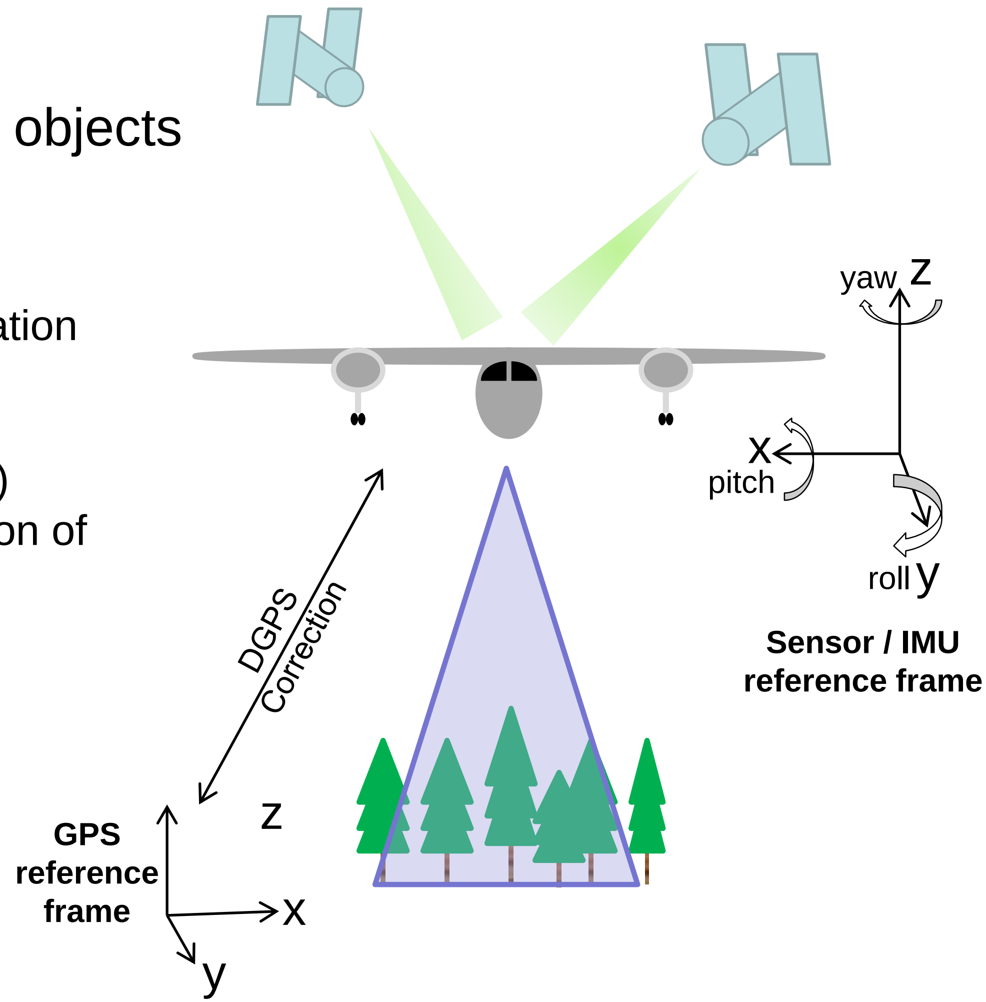
Ground based LiDAR

- Scanner is placed below the forest canopy
- Algorithms are deployed to detect individual tree stems
    - Stems can be occluded by other stems
- Current research aims to make ground based LiDAR an operational inventory tool

Figures provided by Martin van Leeuwen of the University of British Columbia

Airborne Laser Scanning

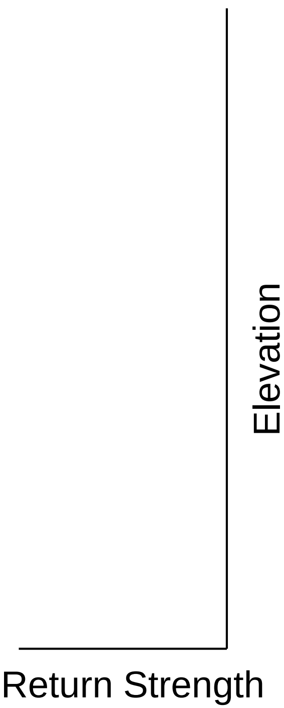
- The coordinates (x, y, z) of target objects are determined by:
  1. Differential GPS (DGPS)
     - Determine precise location of the LiDAR instrument
  2. Inertial Measurement Unit (IMU)
     -Determine the orientation of the LiDAR instrument
  3. LiDAR pulse orientation
  4. Range to target object
     -By recording the time until pulse return



A LiDAR Pulse

A waveform describes the entire return intensity as a function of time for each pulse

LiDAR Echo



[Slide courtesy of ***Darren T. Janzen***
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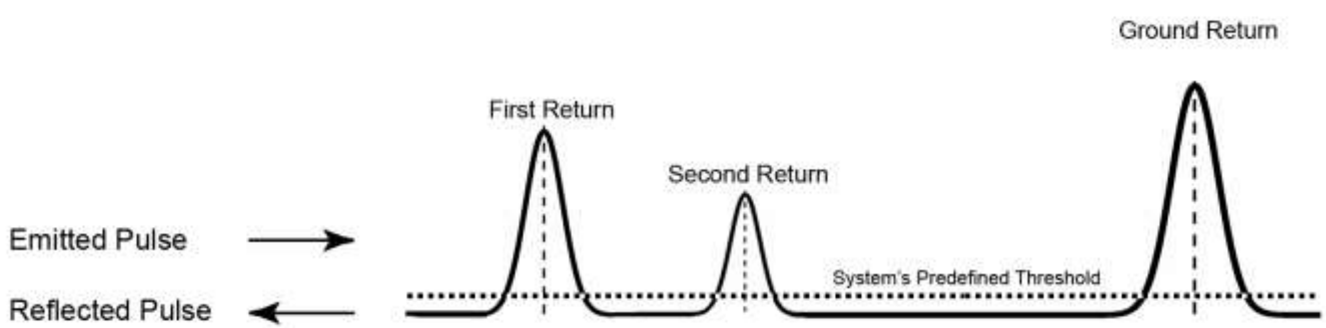
Waveform Data

- Waveform data is less common than discrete return data
  - As technology advances, it is becoming easier to record the full waveform
- Much larger volume of data
- Methods of processing waveform data are not as advanced

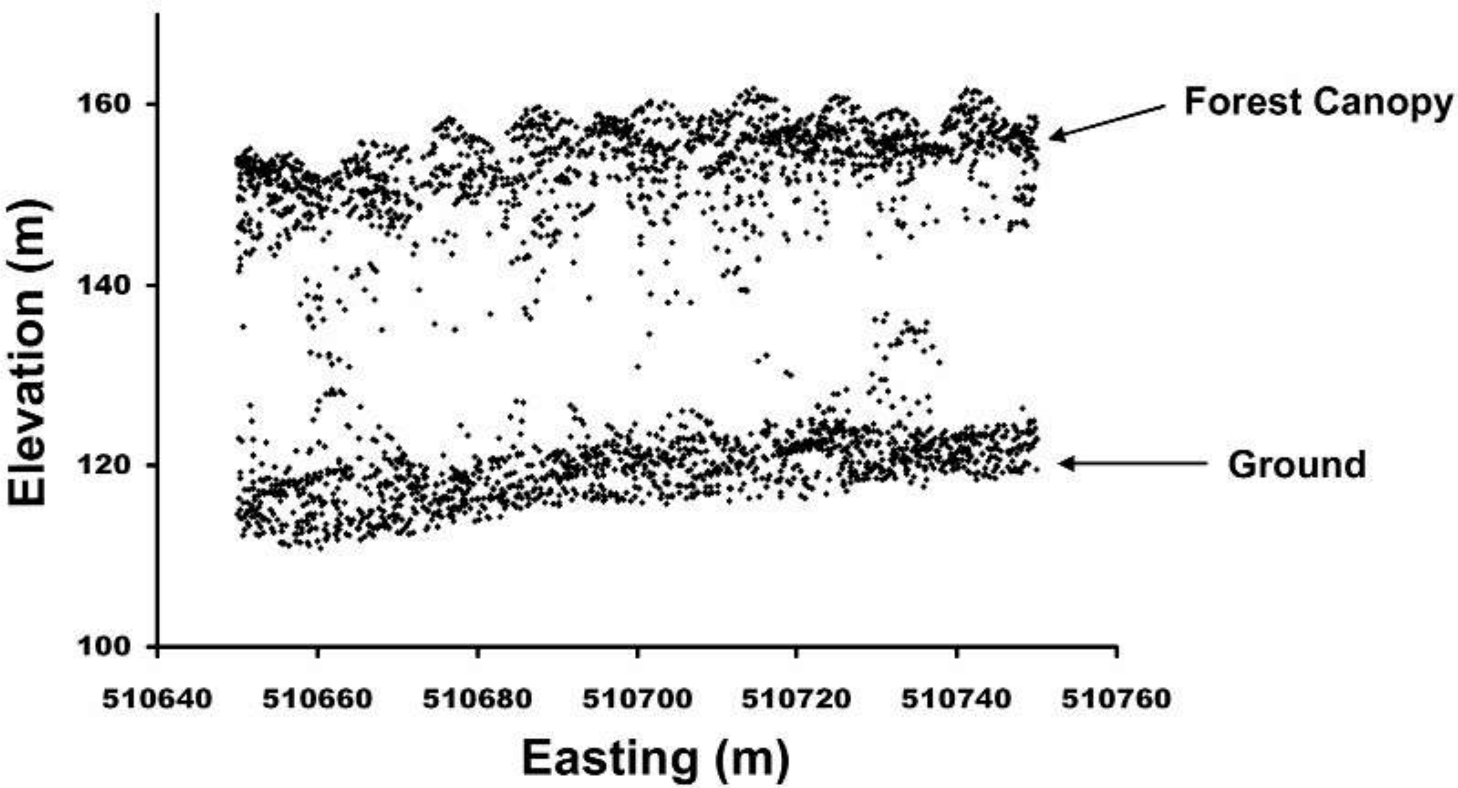
Discrete Return Data

- The returned pulse is classified into one or more discrete returns
  - Returns are recorded when the return energy exceeds the systems predefined threshold
  - Early LiDAR systems were designed to record only the distance to the first target
  - Later systems recorded multiple returns
  - Last returns are particularly important for detecting the ground surface



Discrete Return Data

- Cross-section of discrete return data

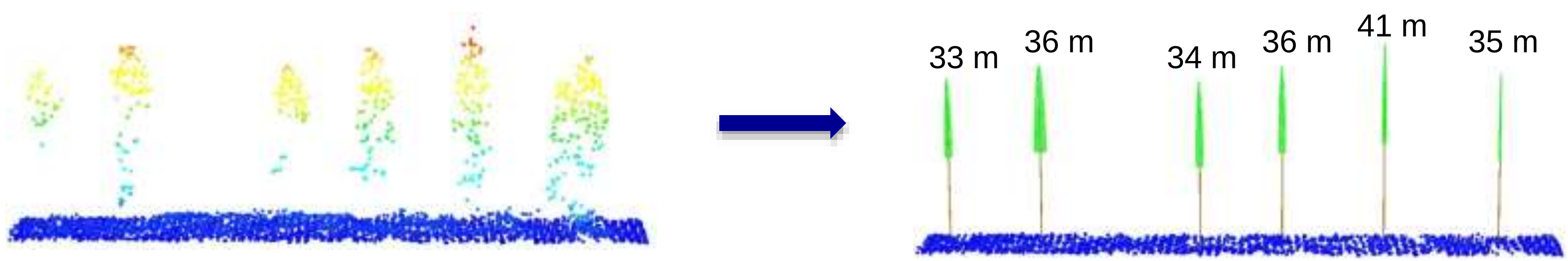


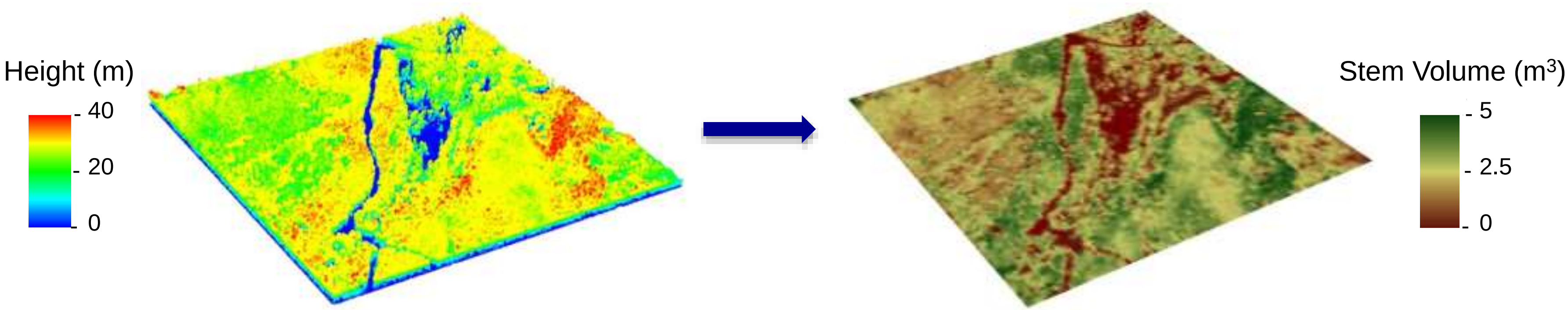
LiDAR Technology

- Advantages of LiDAR technology:
  - Assessment of vertical structure of forests at high spatial resolutions
  - Accurate estimates of surface height
  - Can operate independently of sunlight
- Growing interest in LiDAR in past two decades:
  - In the beginning, primary interest was the development of digital elevation models (DEM)
    - Looking past the vegetation
  - In the past decade, the potential for LiDAR in forestry applications has been realized
    - Measure tree heights to sub-metre levels of accuracy
    - Estimate forest attributes such as stem volume and basal area

Working with Discrete Return LiDAR data

- How do we derive meaningful measurements from a LiDAR point cloud?





LiDAR visualizations produced with FUSION/LDA software – USDA Forest Service

TERRAIN GENERATION

- LIDAR usually has high spatial sampling (0.1 – 4 m).
- Accuracy of 3-D location very good (<20 cm).
- Post-processing is done to ensure
  - Recommend 2 GPS ground receivers with known positions making absolute georeferencing possible
  - Filtering of data to ascertain ground versus non-ground hits.

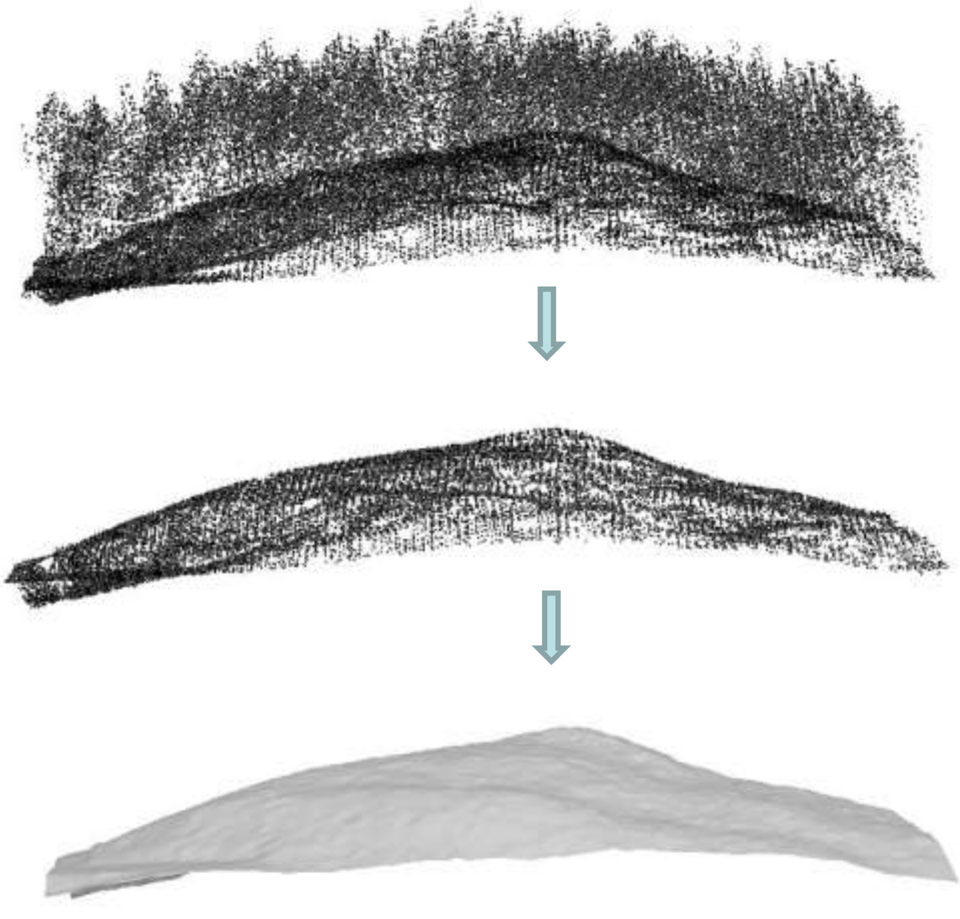
- Typical Accuracies: 15 cm in elevation and horizontal position
- Spot spacing much denser for slower aircraft
- More reliable/accurate DTM through denser spot spacing – more data collected
- Highest accuracy heights at nadir and decrease as swath angle increases

Creating A Digital Elevation Model (DEM)

Step 1: Extract probable ground returns

- Ground points are often classified by LiDAR vendor

Step 2: Create surface from ground returns



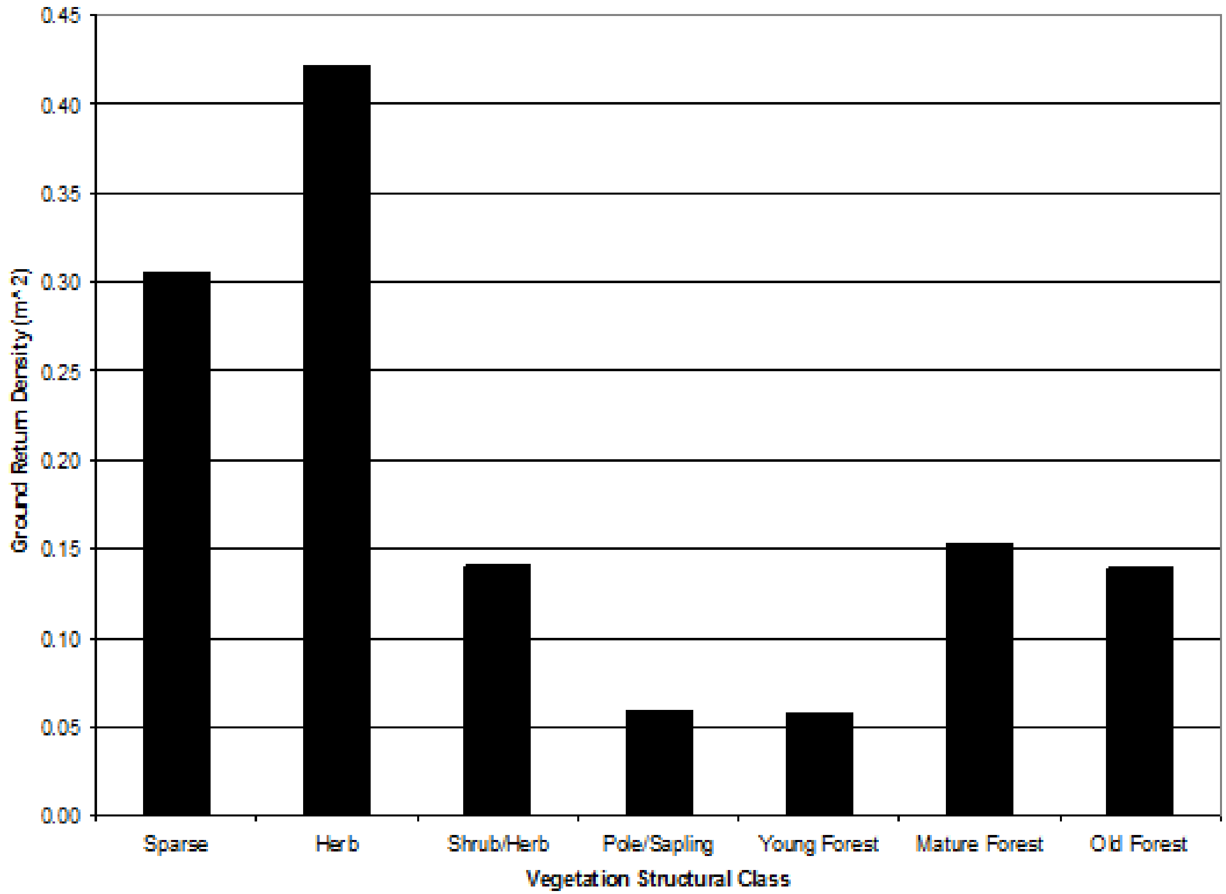
LiDAR visualizations produced with FUSION/LDA software – USDA Forest Service

Creating A Digital Elevation Model (DEM)

- The density of ground points depends on the vegetation structural class

- Fewer pulses will reach the surface under dense canopies

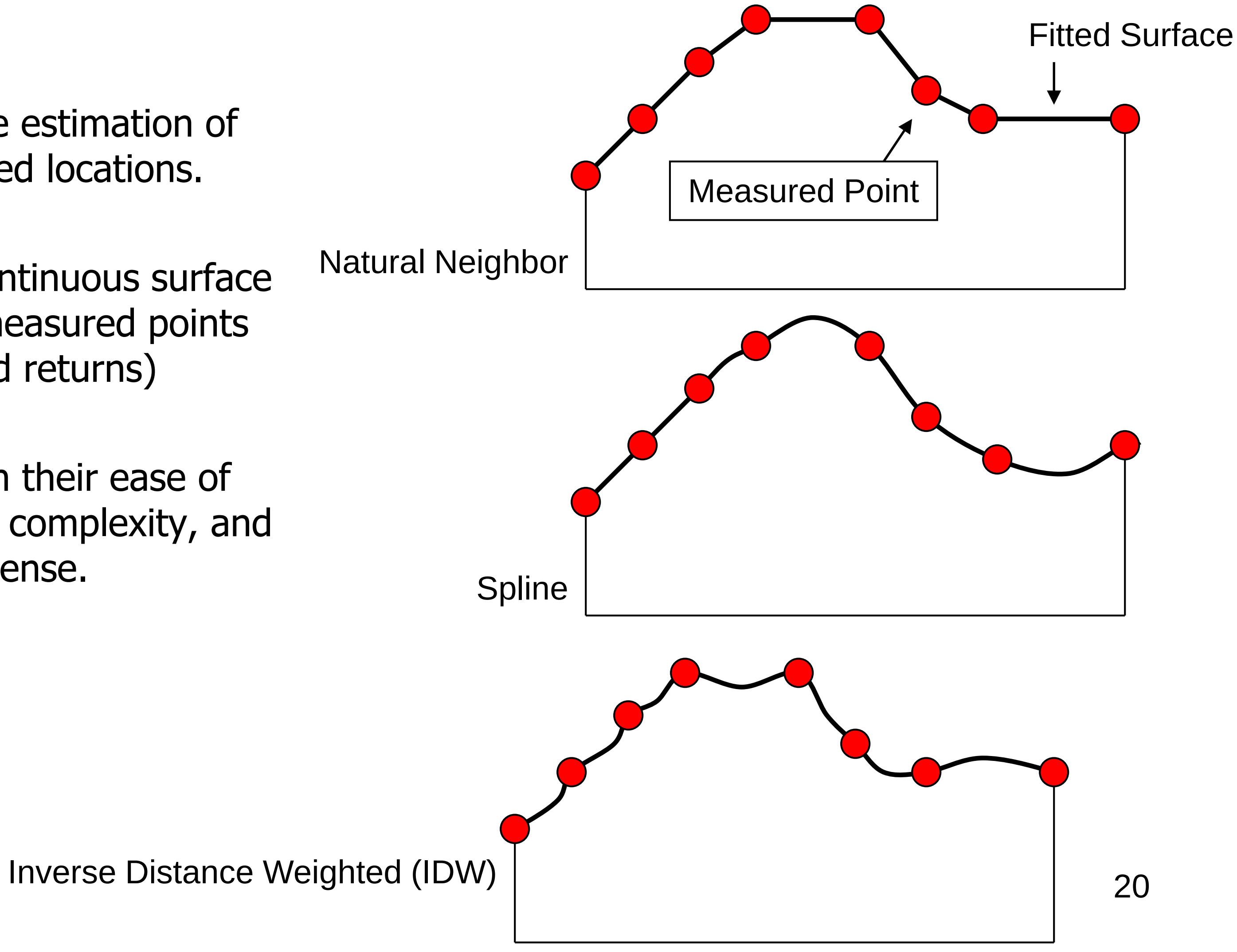
- Methods of interpolation are needed where ground return densities are low



Analysis performed at Pacific Rim National Park, Vancouver Island

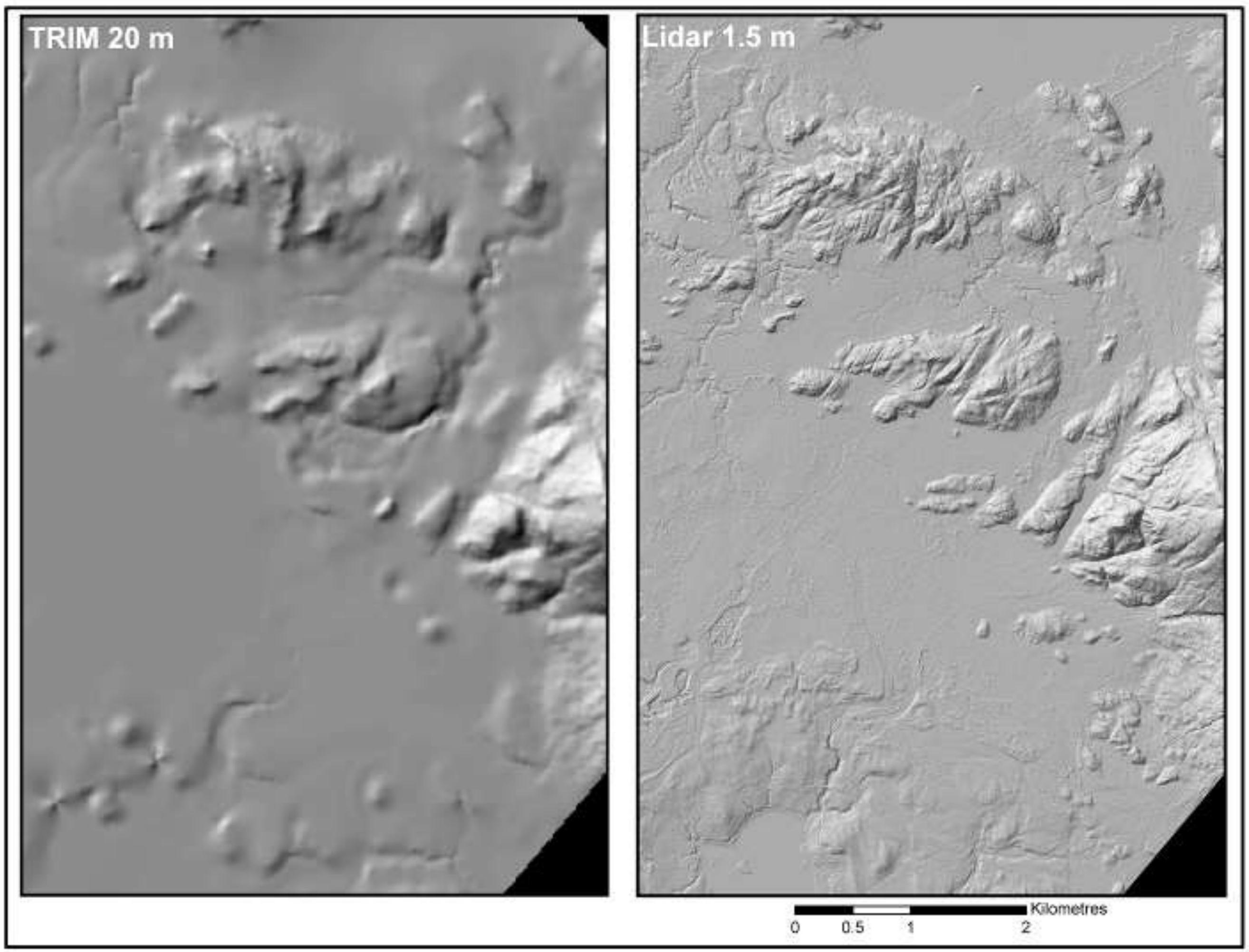
Interpolation Methods

- Interpolation is the estimation of values at unsampled locations.
- Algorithms fit a continuous surface through a set of measured points (e.g. LiDAR ground returns)
- Algorithms differ in their ease of use, mathematical complexity, and computational expense.



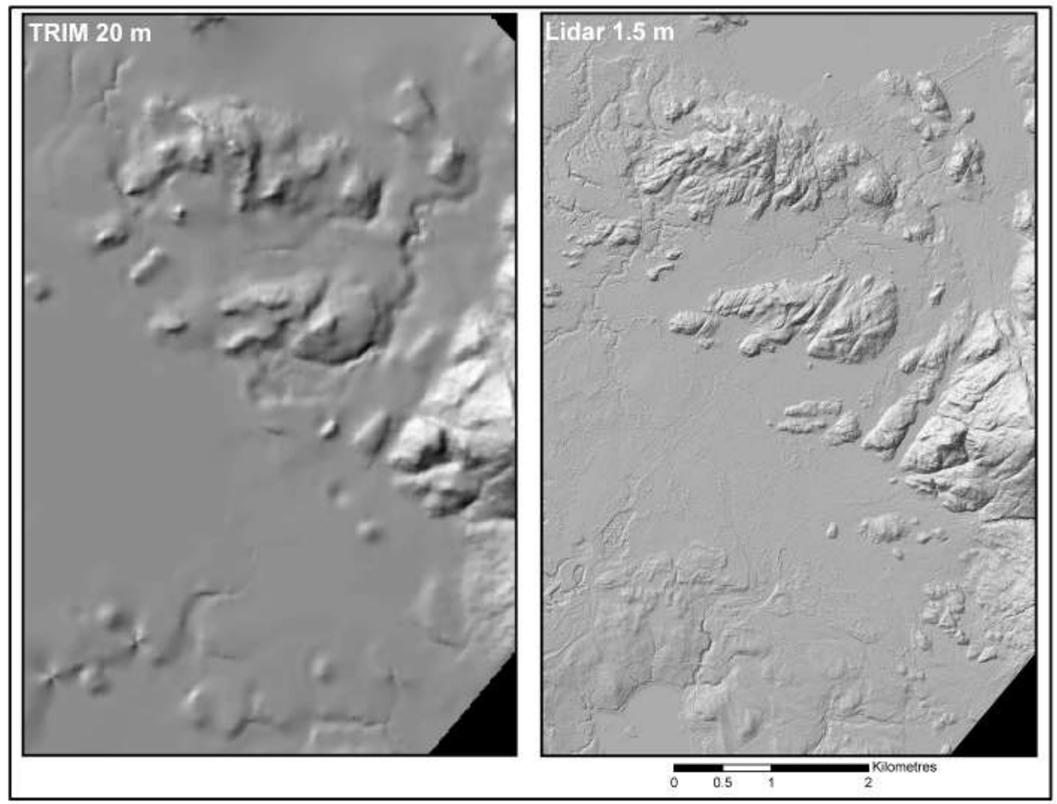
Sources: Johnston *et al.* 2001; Maune *et al. 2001*

Creating A Digital Elevation Model (DEM)

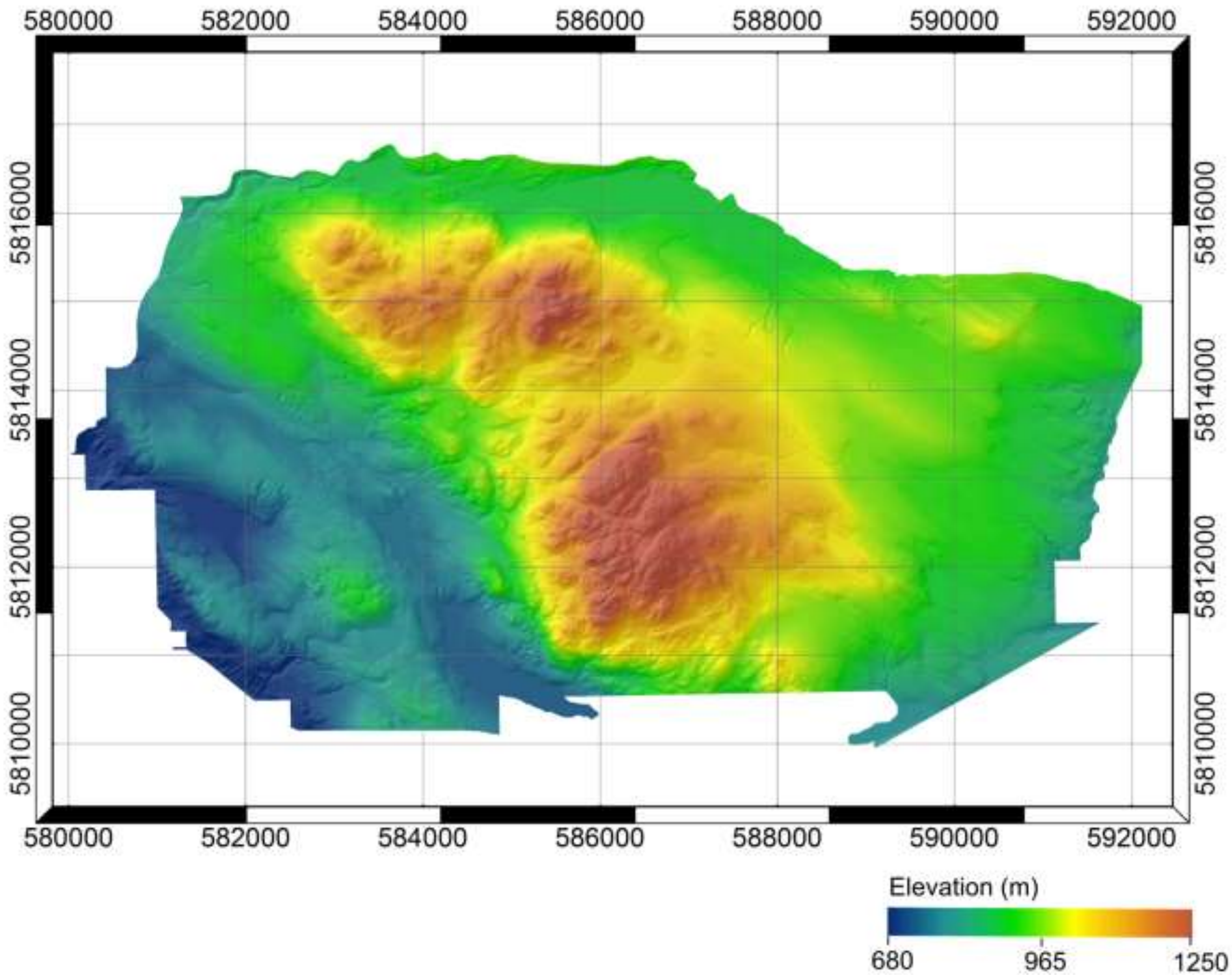


Creating A Digital Elevation Model (DEM)

- Validating DEM
  - Difficult task due to high level of accuracy
  - Differential GPS is affected by vegetation cover (Naesset and Jonmeister, 2002).
  - DEM accuracy may vary spatially across the landscape due to vegetation cover and ground slope
  - Accuracy is generally within 1 m

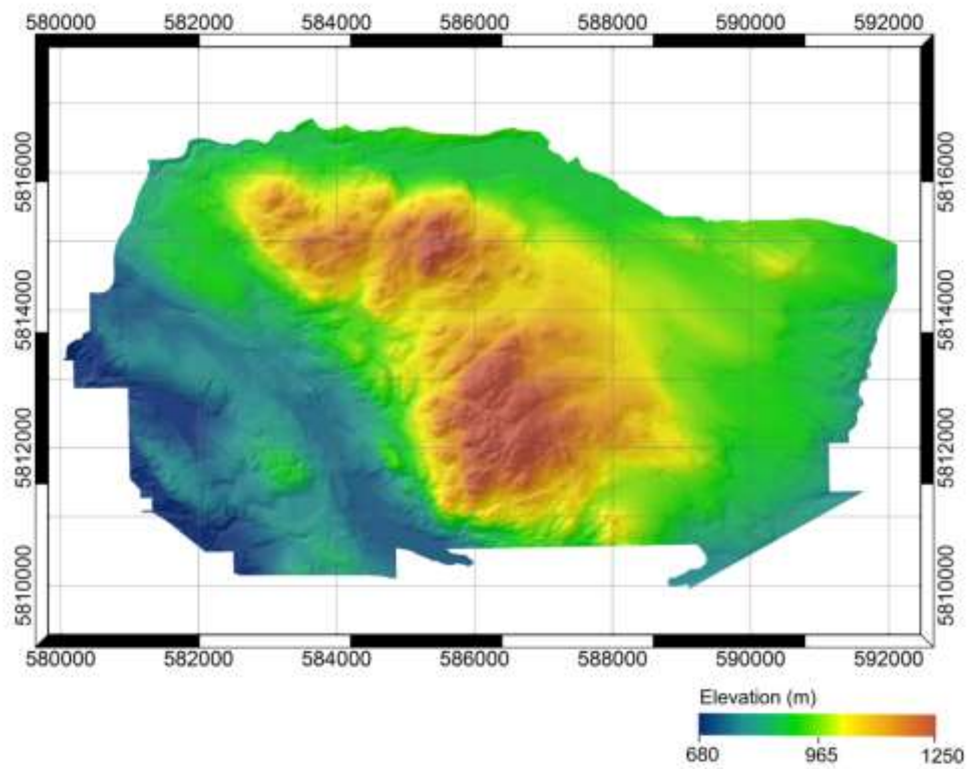


DEM of Alex Fraser Research Forest)

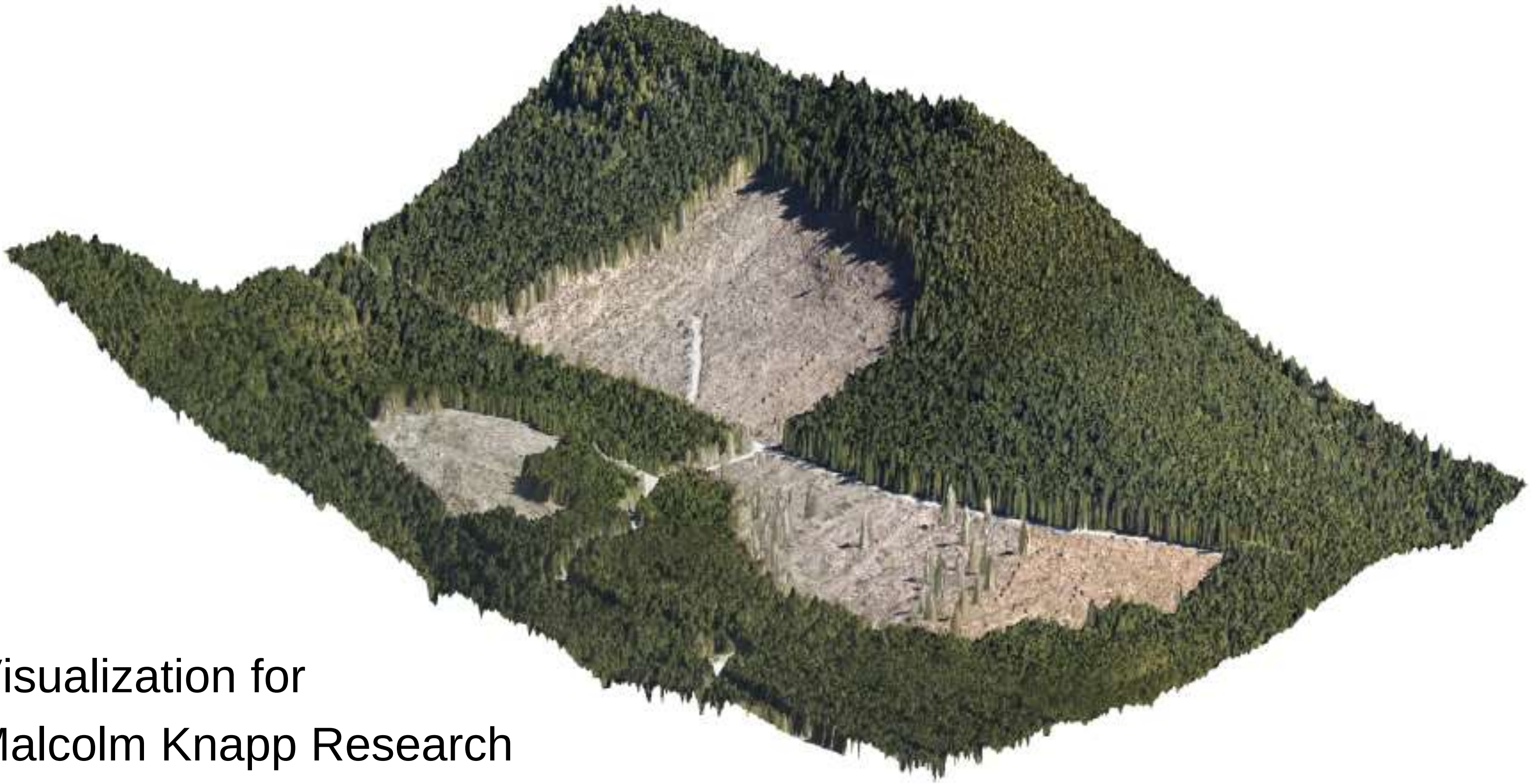


Current uses in operational planning:

- Contour lines
  - Road planning
  - Block boundaries
  - Stream modeling
- Operational slope classes
  - **< 35% slope**: Conventional ground skidding
  - **35-50% slope**: Requires specialized equipment
  - **> 50% slope**: Consider cable yarding

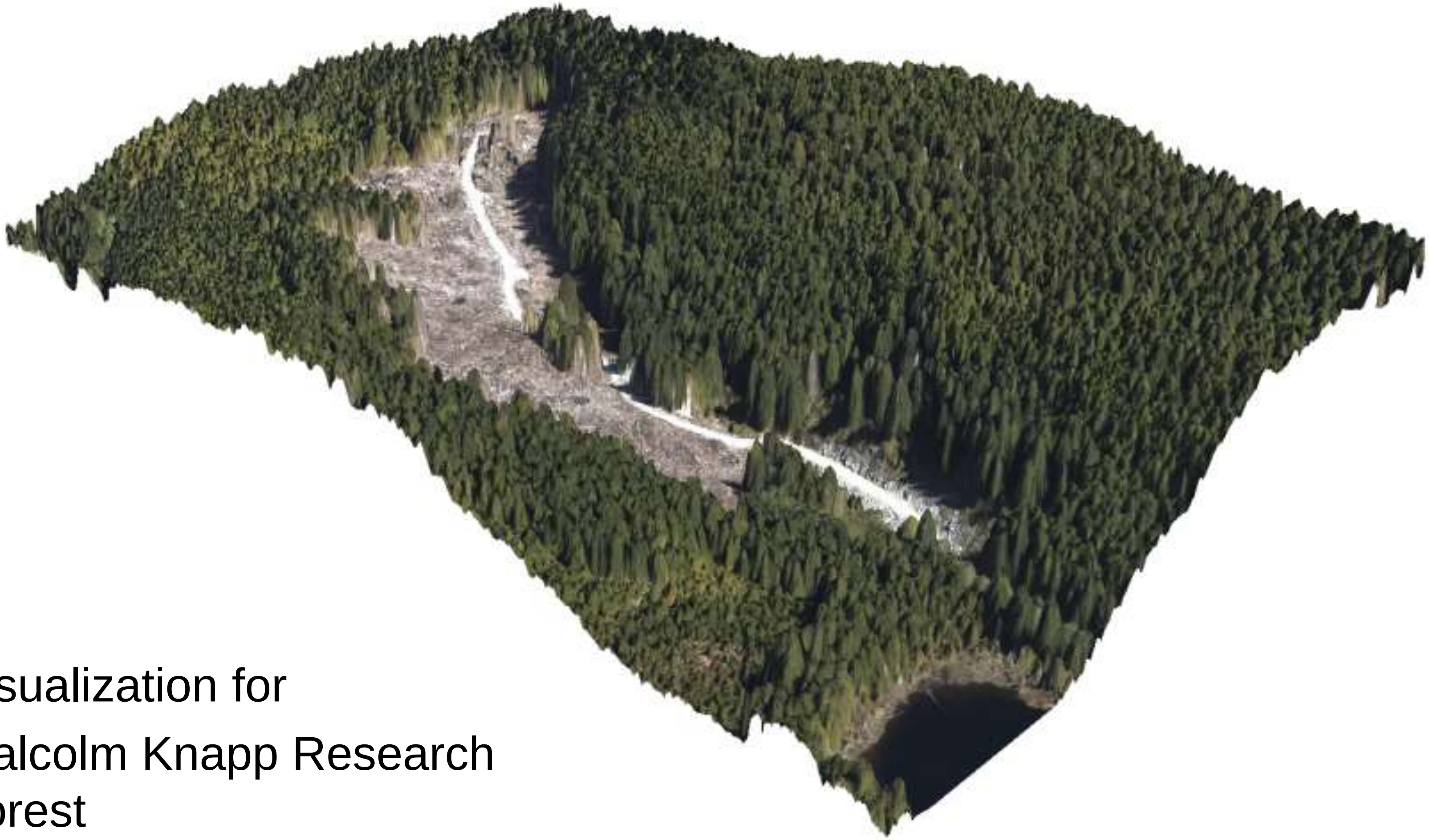


Uses provided by:
Don Skea, AFRF



Visualization for

Malcolm Knapp Research Forest



Visualization for

Malcolm Knapp Research Forest

Lidar visualizations produced with FUSION/LDA software – USDA Forest Service

Derive Heights in Relation to the Surface

Point
elevation

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Derive Heights in Relation to the Surface

Point elevation

Surface elevation

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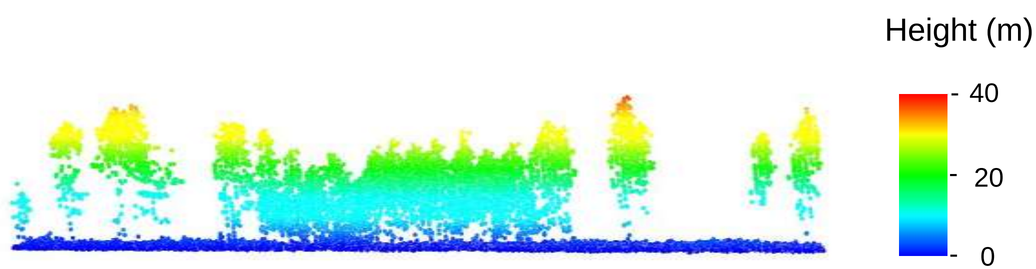
Derive Heights in Relation to the Surface

Point elevation

− Surface elevation

= Point height above surface



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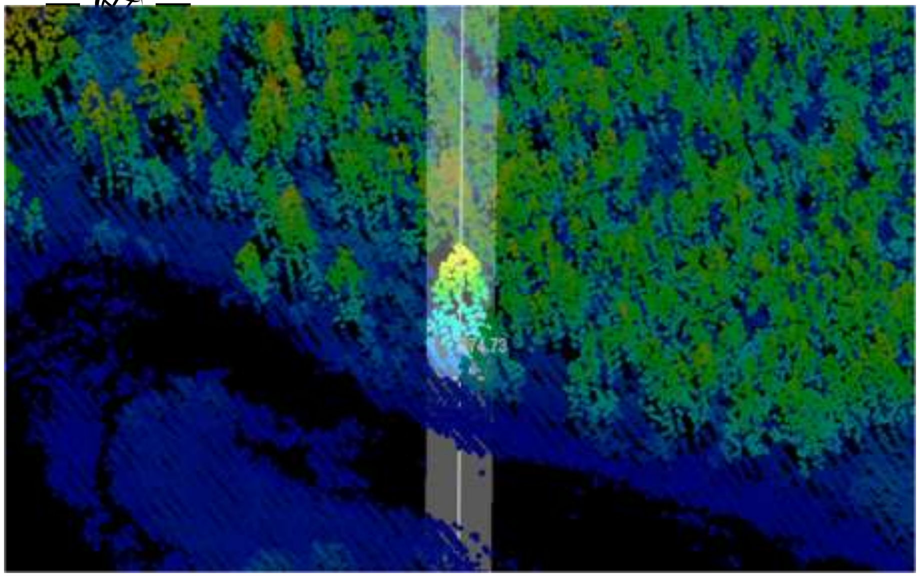

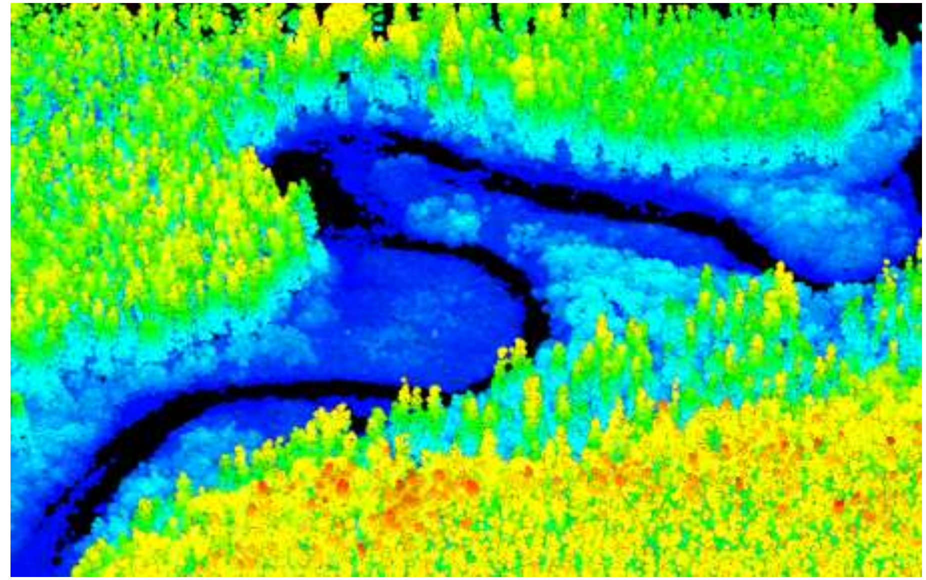

- Two scales of analysis are commonly undertaken
  - Tree scale
    - Individual trees located in the LiDAR data and a range of tree attributes derived (*e.g.* Maximum tree height, crown area, basal area….)
  - Plot scale
    - Attributes are estimated over a defined area (square, rectangular or circular). For example, maximum plot height, basal area, height percentiles

[Slide courtesy of ***Darren T. Janzen***
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