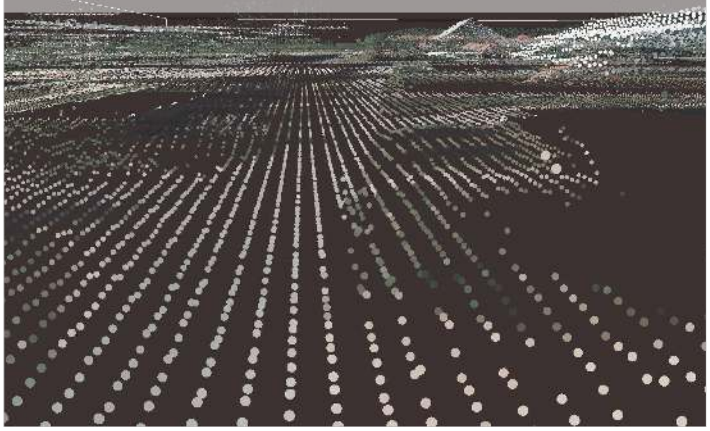
IITGn Workshop Quantitative Geomorphology:
Lidar



Active Remote Sensing

- active sensors *emit* EMR in certain wavelengths and then detect the returning signal
- Active sensors are much more complex than passive sensors, both in their technology and the interpretation of the signal.
  - **RADAR** (Radio Detection and Ranging) use pulses of long wave EMR in the radio spectrum (~1 mm – 1 m) to illuminate the terrain to determine the distance and angular position of objects
  - **LIDAR** (Light Detection and Ranging) measures the time for a laser pulse (usually visible or near IR) to return to generate distance measurements and highly detailed 3-d models
  - **SONAR** (SOund Navigation and Ranging)

LIDAR – Light Detection and Ranging principles

1. Light travels at a constant speed through air (c = ~3 x 10^8 m/s).
2. LIDAR emits a narrow pulse of laser light (narrow spatially and spectrally)and record the amount of time it takes for the laser light to return (t):

   *distance = c * t/2*
3. Several factors must be known to accurately determine the geographical position of each laser return:
   a) LIDAR calculated distance
   b) position of the sensor
   c) angle of laser pulse
   d) atmospheric effects on *c*
   e) attitude of the platform (pitch, roll, yaw).

LiDAR – Why use a laser?

ALS (Airborne Lidar System) take advantage of two of the unique properties of laser light:

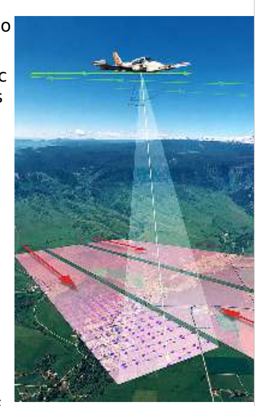
1. The laser is **monochromatic**. It is one specific wavelength of light. The wavelength of light is determined by the lasing material used, usually 532 or 1064nm.

Advantage: We know how specific wavelengths interact with the atmosphere and with materials.

2. The light is accurate and **directional**. A laser has a very narrow beam which remains concentrated over long distances. A flashlight (or Radar) on the other hand, releases energy in many directions, and the energy is weakened by diffusion.

Advantage: The beam maintains its strength over long distances.

3mrad divergence = 30 cm at 1 km and 1.5m at 5 km



Radians

- A full angle is 2π radians, so there are 360° per 2π radians, equal to 180°/π or 57.29° / radian.
- A milliradian (mrad) is 1/1000 radian.
- 3 mrad = 3*0.05729°
  - tan α = x/(flight height)
  - At 1km flight height …

LIDAR – Two distinct types of ALS systems

Discrete-return systems (a.k.a. small-footprint)

SAMPLES the returned energy from each outgoing laser pulse in the vertical plane (Z) *(if the return reflection is strong enough)*

Most commercial lidar systems are discrete return, many different types are available

Waveform systems (a.k.a. large-footprint)

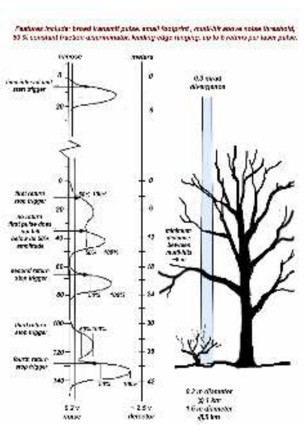
Records the **COMPLETE** range of the energy pulse (intensity) reflected by surfaces in the vertical dimension

Samples transects in the horizontal (X,Y) plane

Waveform systems designed to capture vegetation information are not widely available

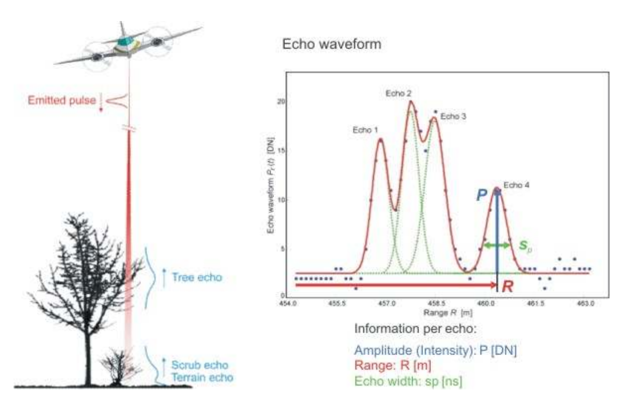
Waveform systems include SLICER, LVIS, ICESat

Discrete Return LIDAR

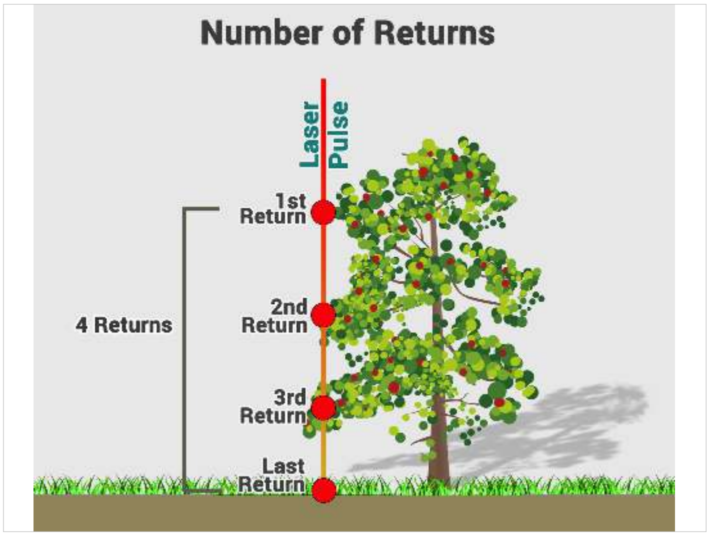


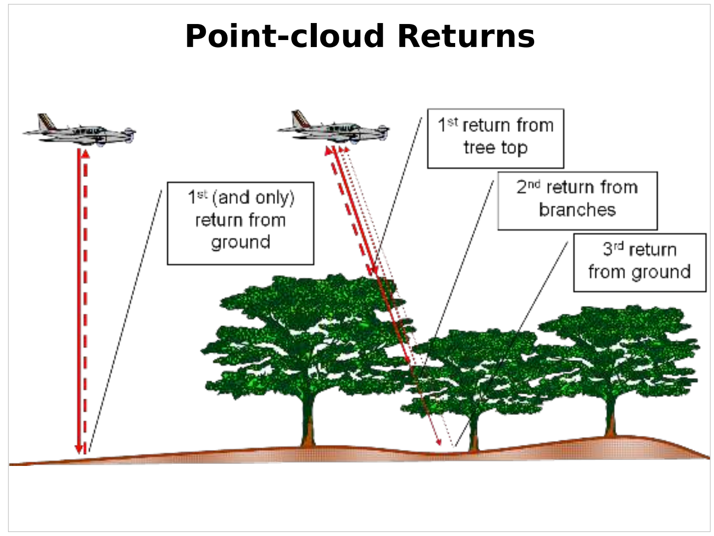
- Records data as X,Y,Z points
- Spatial resolution is expressed in terms of “post spacing” which is the avg. horizontal distance between points
- However, you *can* have multiple returns within the same pulse
- Returns are “triggered” if the laser reflects from a surface large enough to exceed a pre-set energy threshold
- New capability to record the intensity of point returns.

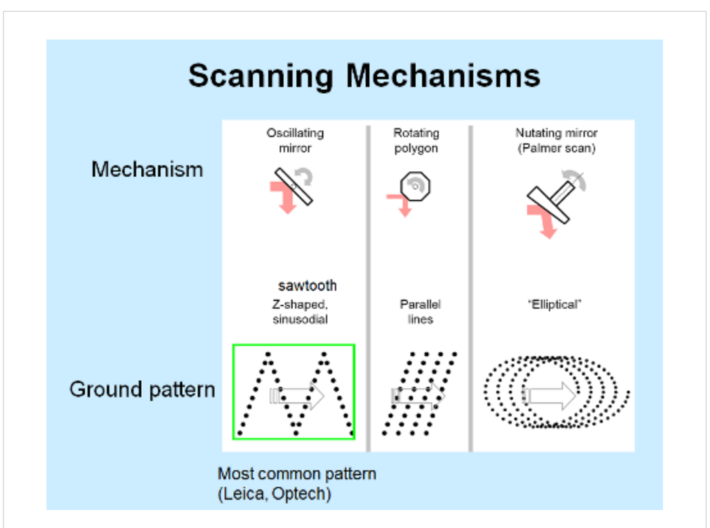
Full WaveForm (FWF) Lidar

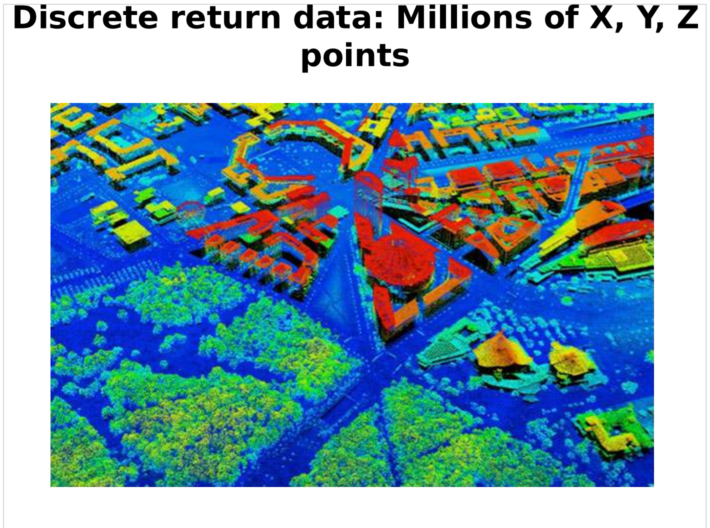


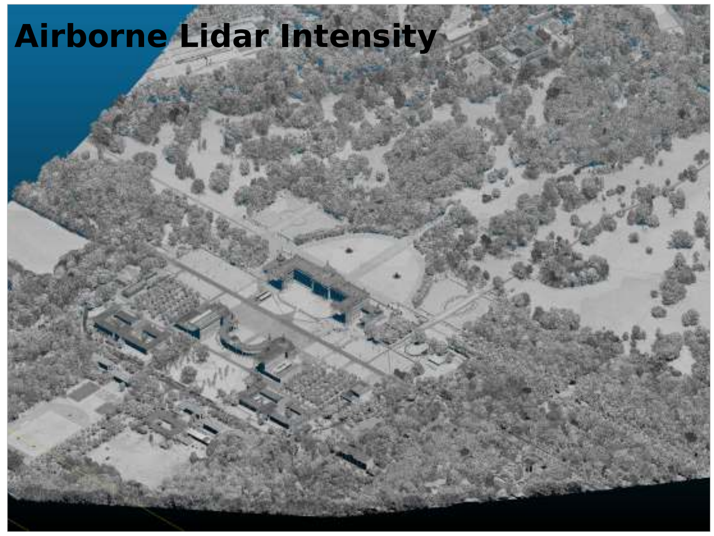
OPALS, TU Wien

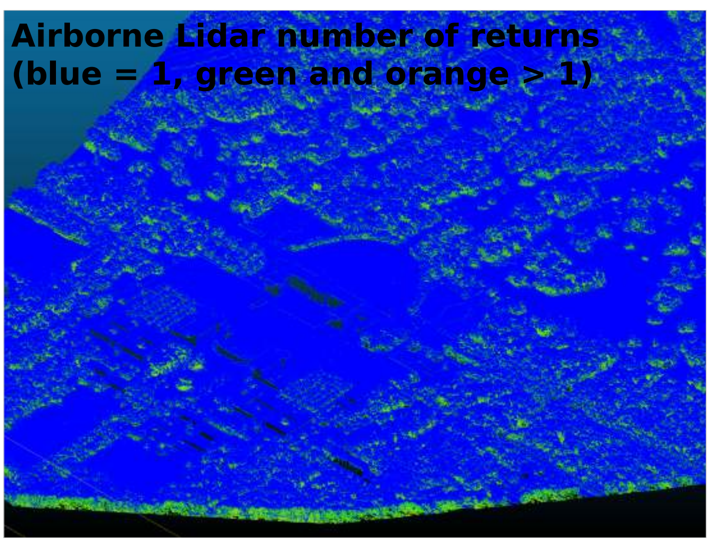

Number of Returns
Laser Pulse
1st Return
2nd Return
3rd Return
Last Return
4 Returns

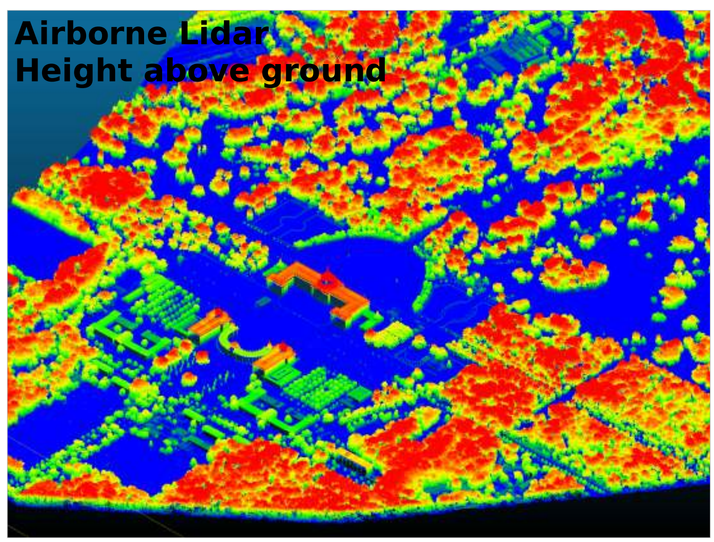

Point-cloud Returns
1st (and only) return from ground
1st return from tree top
2nd return from branches
3rd return from ground


Scanning Mechanisms
Mechanism
Oscillating mirror
Rotating polygon
Nutating mirror (Palmer scan)
sawtooth
Z-shaped, sinusodial
Parallel lines
"Elliptical"
Ground pattern
Most common pattern (Leica, Optech)

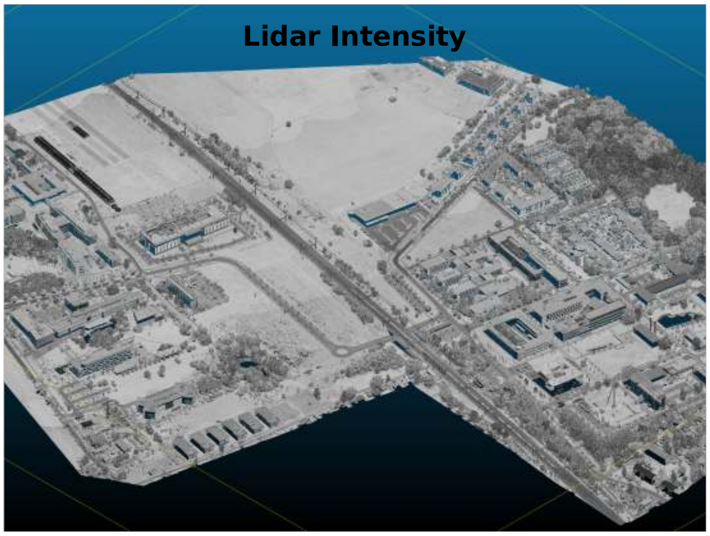

Discrete return data: Millions of X, Y, Z points


Airborne Lidar Intensity


Airborne Lidar number of returns
(blue = 1, green and orange > 1)

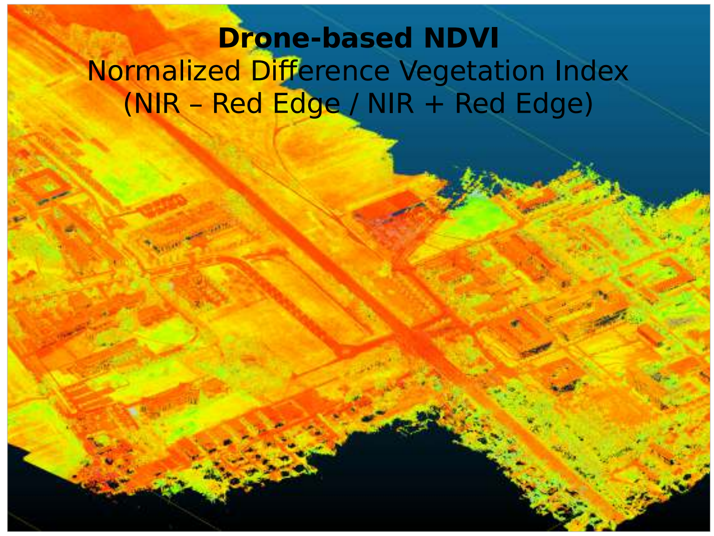

Airborne Lidar
Height above ground

Lidar Intensity

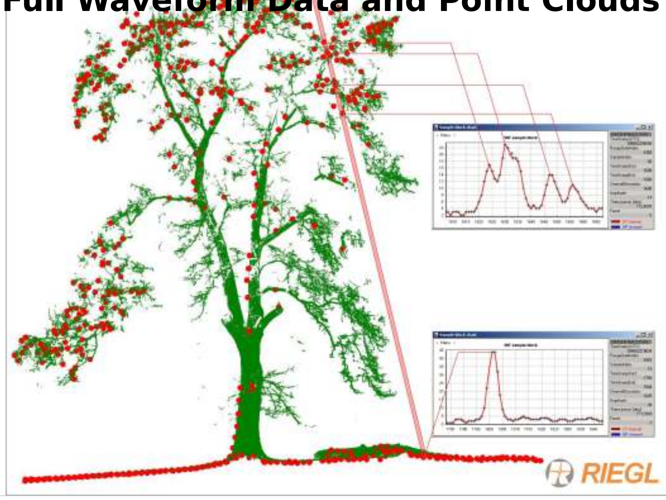


Drone-based NDVI

Normalized Difference Vegetation Index
(NIR – Red Edge / NIR + Red Edge)



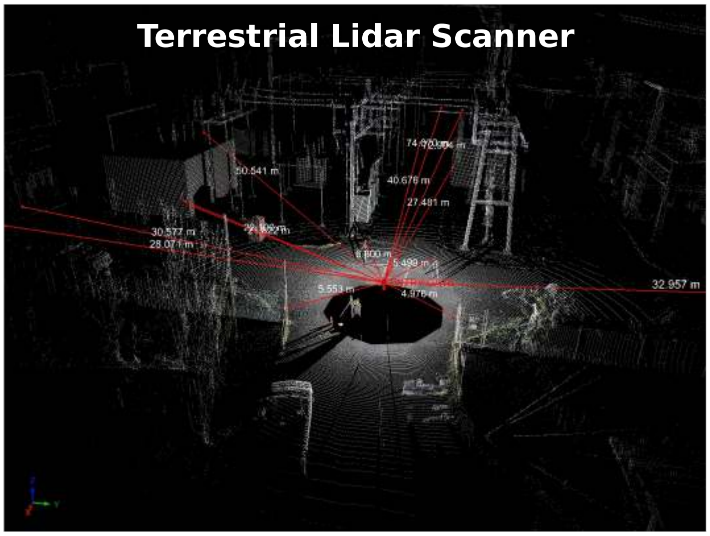
Full Waveform Data and Point Clouds



Terrestrial LiDAR – Applications

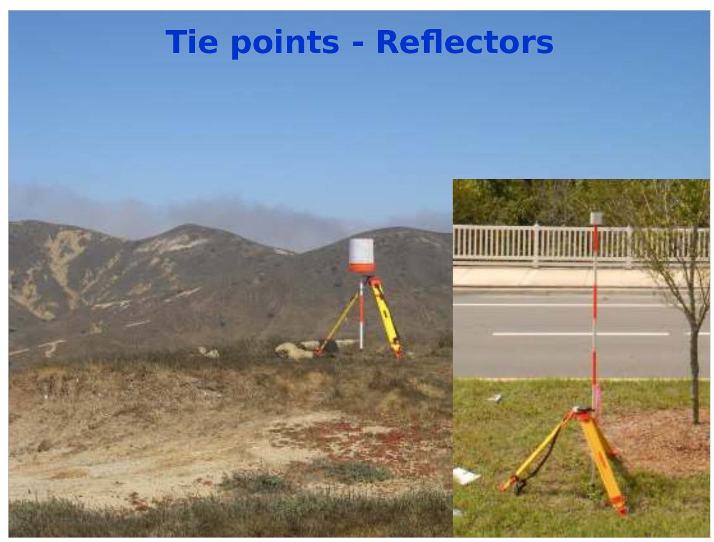
Riegl Model LMS-Z420i terrestrial LiDAR scanner

- ~1000 m Range
- 10 mm accuracy
- Near-infrared wavelength
- 0.25 mrad beam divergence

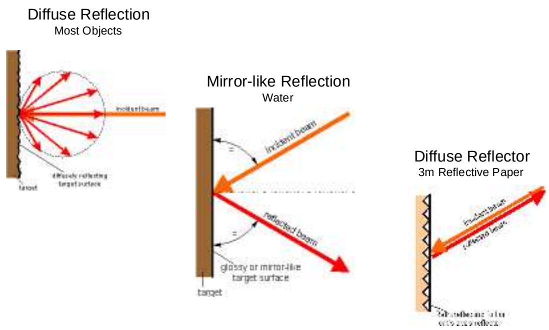

Terrestrial Lidar Scanner
50.541 m
40.676 m
27.481 m
30.577 m
28.071 m
5.553 m
4.976 m
32.957 m


RIEGL


Scanner Position


Tie points - Reflectors

Typical Reflectivity 1



Typical Reflectivity 2

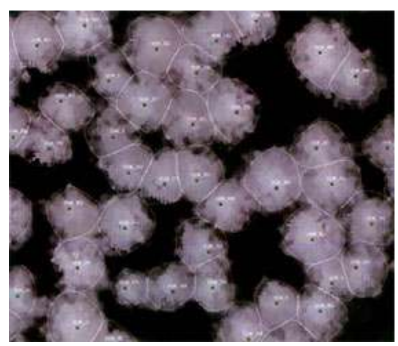
- The amount of light that is returned from a target's surface is characterized by the reflection coefficient ρ.
- For a diffusely reflecting target, the maximum value of ρ is 100 %.
- A list of diffuse materials at 900nm wavelength

Glossy, mirror-like or retro-reflecting surfaces / material:	
MATERIAL	**REFLECTIVITY**
Reflecting foil 3M2000X3	1250%
Opaque white plastic	110%
Opaque black plastic	17%
Clear plastic	50%

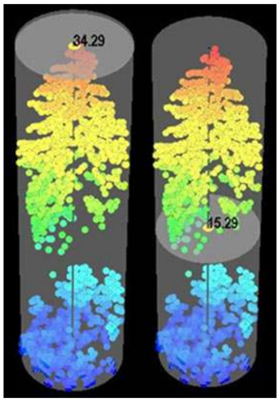
Diffusely reflecting surfaces / materials:	
MATERIAL	**REFLECTIVITY**
White paper	up to 100%
Dimension lumber (pine, clean, dry)	94%
Snow	80-90%
White masonry	85%
Limestone, clay	up to 75%
Carbonate sand (dry)	57%
Carbonate sand (wet)	41%
Beach sands, dessert typ.	50%
Rough wood pallet (clean)	25%
Concrete, smooth	24%
Asphalt with pebbles	17%
Lava	8%
Black neoprene	5%
Black rubber tire wall	2%

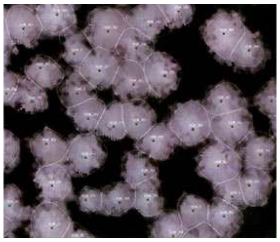
Lidar Applications

Lidar Applications



Lidar Applications





Terrestrial Lidar - Applications

- Vegetation structure (Clawges et al. 2007)

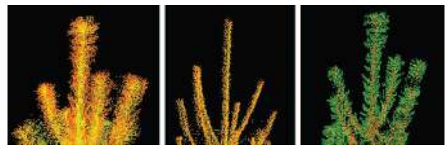
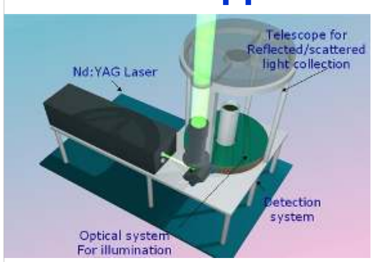
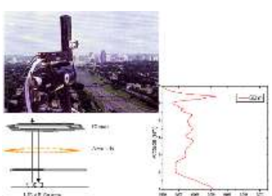


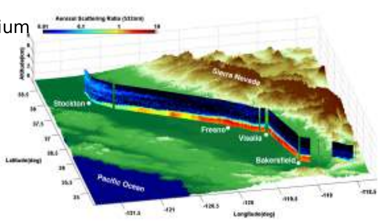
Figure 2. Laser returns for the top of Tree A with (*a*) leaf-on, (*b*) with leaf-off, and (*c*) categorized using return intensity values for leaf-on.

LIDAR applications - scattering





neodymium-doped yttrium aluminium garnet; Nd:$Y_3Al_5O_{12}$
1064 nm in the infrared spectrum

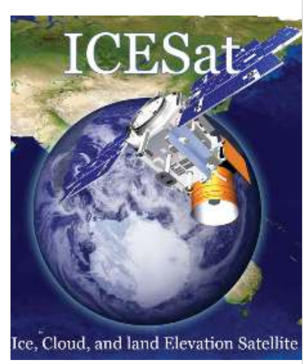


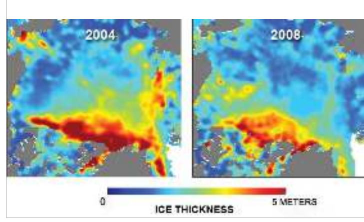
Spaceborne LIDAR: ICESat and ICESat2

Spaceborne waveform LIDAR systems

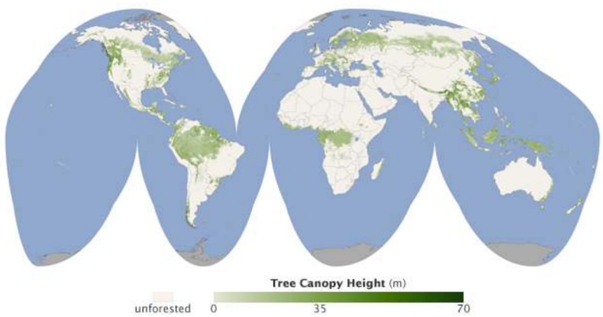
ICEsat launched in 2003 for survey of topography and polar ice, but stopped working in 2010

ICESat 2 is planned for 2016





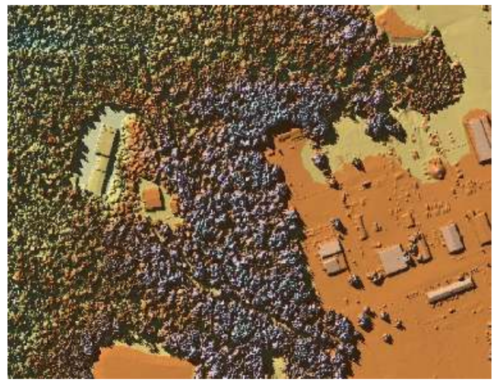
Global Tree Heights from Lidar



Developed with ICESat data by Michael Lefsky (2010)
http://www.nasa.gov/topics/earth/features/forest-height-map.html

Bare Earth DEM Calculations

1. Identify man made structures
   - Determine ground elevation at edges
2. Identify vegetated areas
   - Search for ground points within area
3. Identify open areas
4. Interpolate between available points
5. Filtering and clean-up

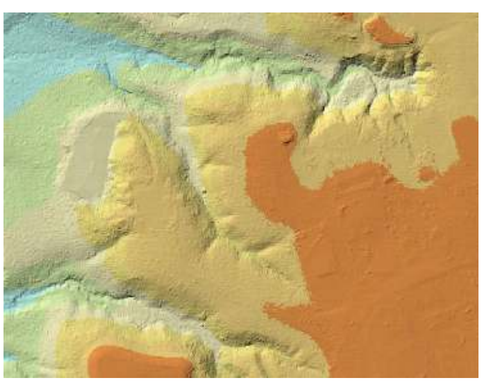


First Return DEM

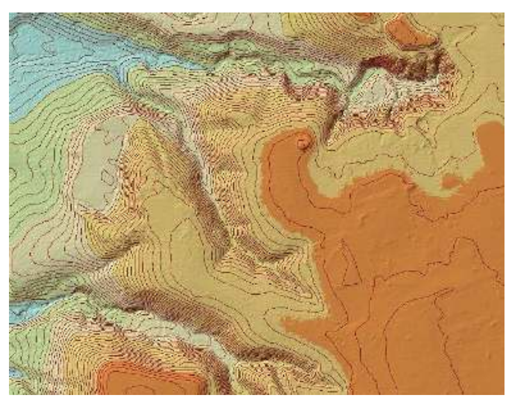
Automatically extracted Bare Earth DEM

• Ground surface with vegetation and man-made structures removed

• Critical for terrain and hydrology modeling

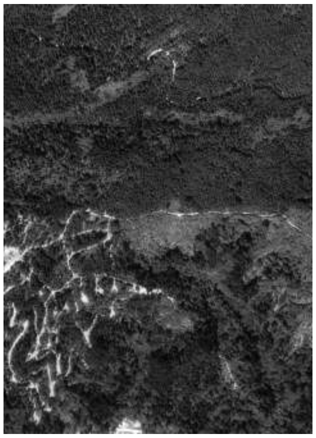


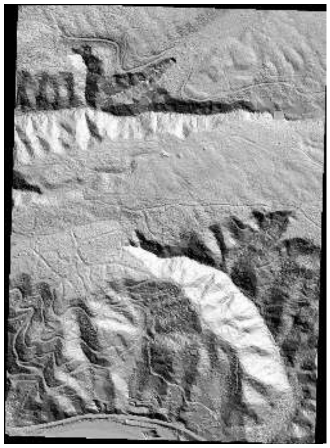
Bare Earth DEM



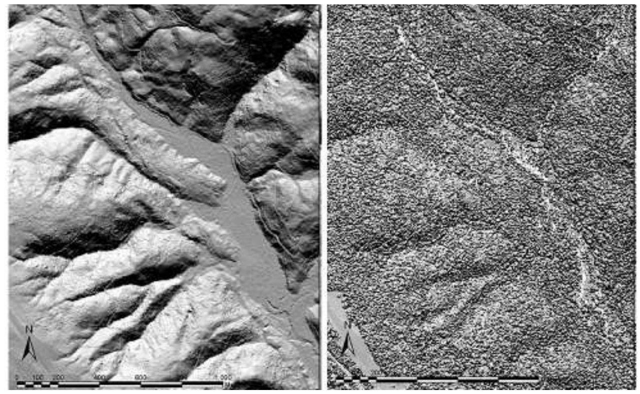
Bare Earth DEM with 1 meter contours

LIDAR Surfacing





LIDAR Surfacing: San Andreas Fault Zone

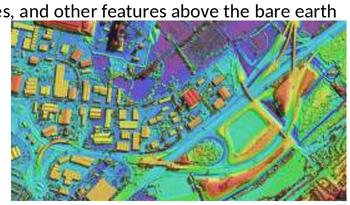


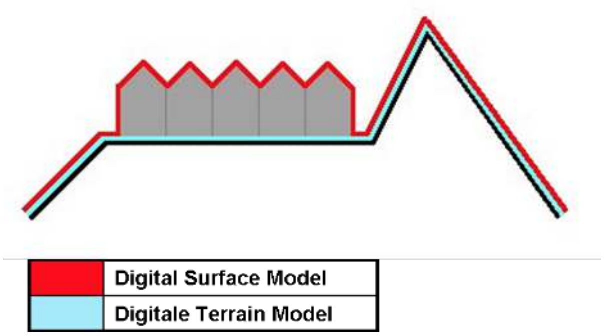
Digital Elevation Data

Definitions paraphrased from Maune et al, 2nd edition DEM Users Manual

(Terms often used interchangeably)

- DEM = Digital Elevation Model; Typically Bare Earth or terrain
- DTM = Digital Terrain Model; Similar to DEM with the addition of some elevations for significant topographic features on the land defined by mass points or break lines
- DSM = Digital Surface Model; Similar to a DEM or DTM, but shows the tops of all surfaces including buildings, trees, and other features above the bare earth



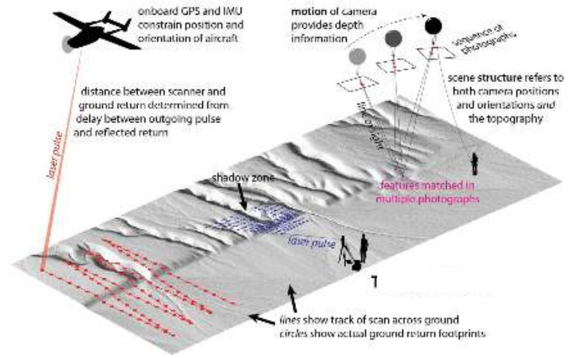


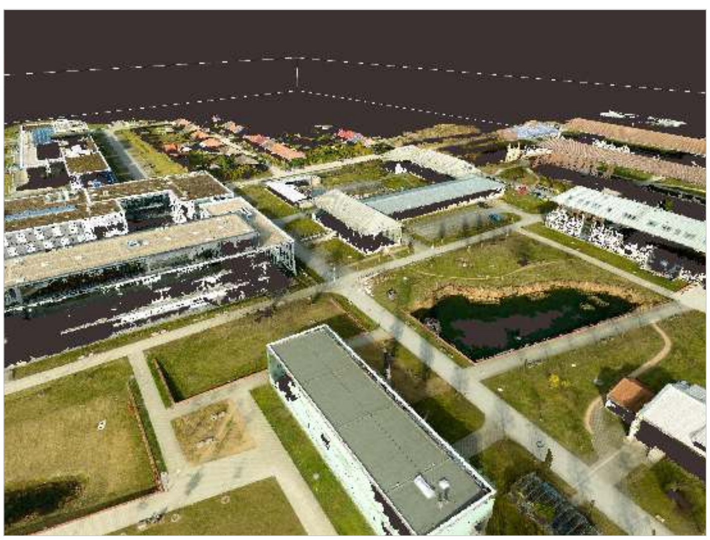
http://en.wikipedia.org/wiki/Digital_elevation_model

Point cloud classification

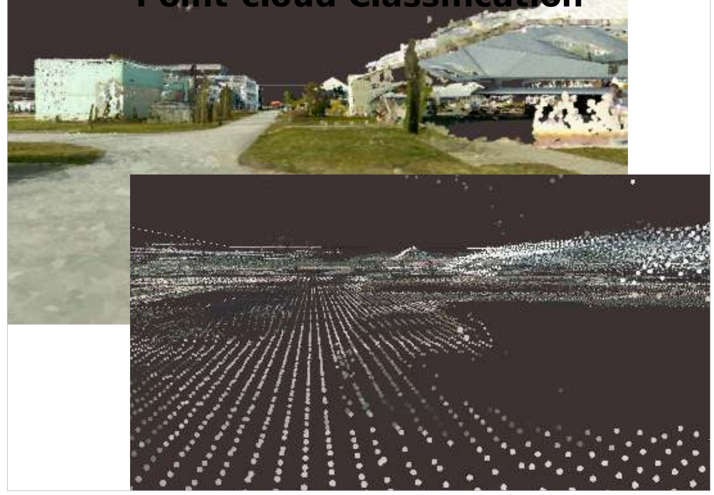
Classification Value (Levels)	Meaning
0	Created, Never Classified
1	Unclassified 1
2	Ground
3	Low Vegetation
4	Medium Vegetation
5	High Vegetation
6	Building
7	Low Point (noise)
8	Model Key Point (mass point)
9	Water
10	Reserved for ASPRS Definition
11	Reserved for ASPRS Definition
12	Overlap Points 2
13-31	Reserved for ASPRS Definition

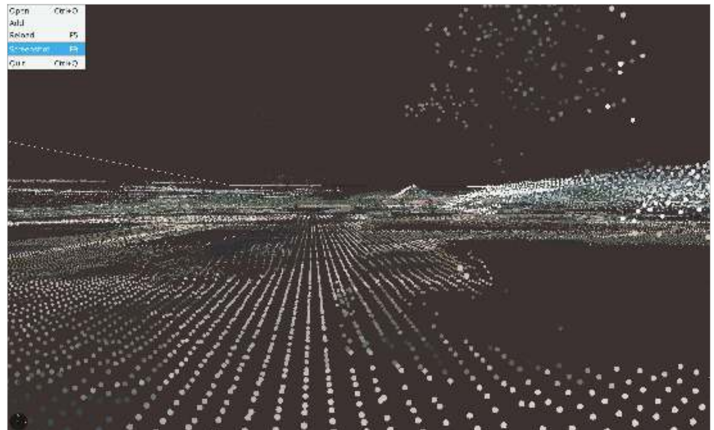
Lidar (ALS, TLS, MLS)	**Structure-from-Motion**
•Expensive laser equipment required	•Requires only a cheap camera
• Works in densely-vegetated landscapes	• Coloured points & orthophoto for texture mapping
•Uses precise time-of-flight measurements but prone to artifacts from GPS and IMU	•Back-solves for camera parameters; warping artifacts are a common problem but easily mitigated



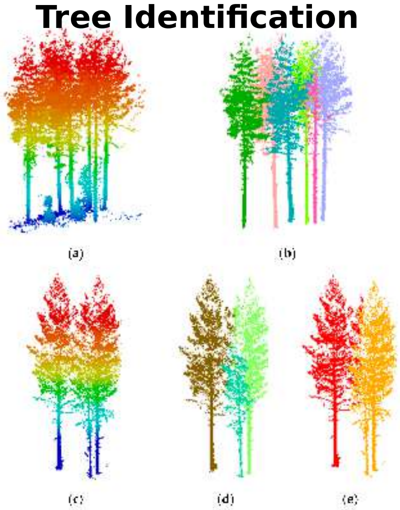


Point-cloud Classification

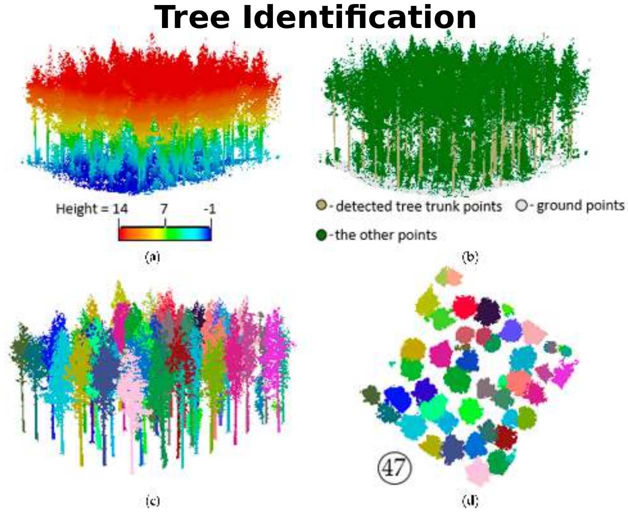




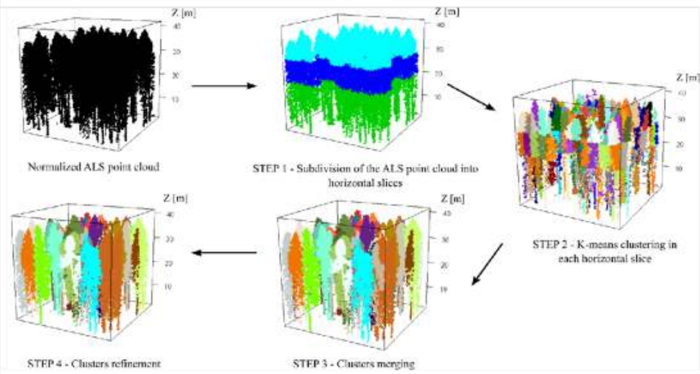
Tree Identification



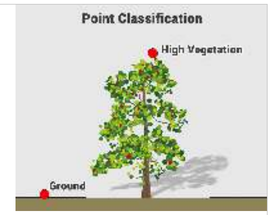
Tree Identification

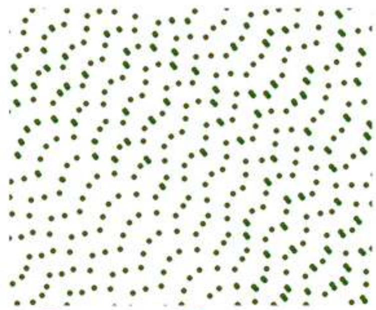


Tree Identification



Point-cloud Classification





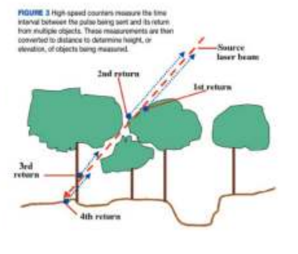
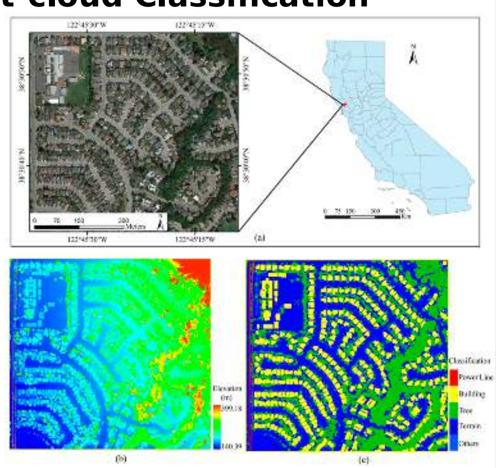


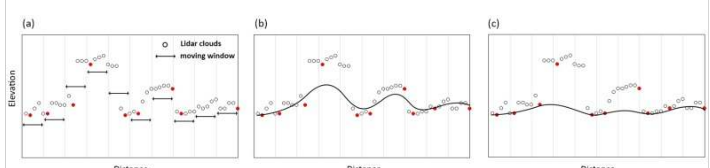
Image from LIDAR primer, Geospatial solutions 2002

Point-cloud Classification



Ao, Z. et al. (2017): One-class Classification of …, Remote Sensing, 9(10)

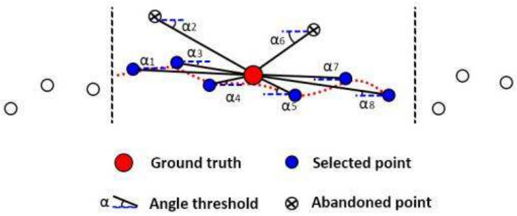
Point-cloud Classification



Schematic diagram of surface-based DTM generation methods. (**a**) A lowest point is selected for each cell; (**b**) A coarse surface is produced based on these pre-selected points; (**c**) A refined DTM is generated based on the residue between the coarse surface and the elevation of rest points.

Chen, Z., Gao, B., & Devereux, B. (2017). State-of-the-Art: DTM Generation Using Airborne LIDAR Data. *Sensors (Basel, Switzerland)*, *17*(1), 150.

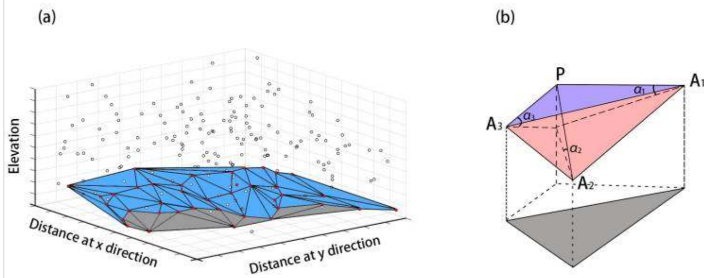
Point-cloud Classification



Schematic diagram of morphology-based DTM generation method: If the slope between the ground point and a candidate point is smaller than a (global or local) slope threshold, then this candidate point is set as a ground point. Otherwise, this candidate point is set as a non-ground point.

Chen, Z., Gao, B., & Devereux, B. (2017). State-of-the-Art: DTM Generation Using Airborne LIDAR Data. *Sensors (Basel, Switzerland)*, *17*(1), 150.

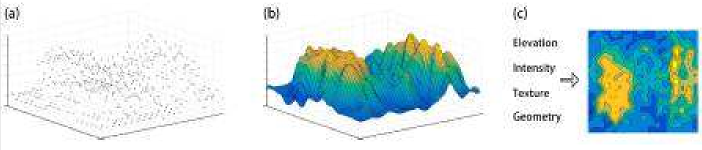
Point-cloud Classification



Schematic diagram of morphology-based DTM generation method. (**a**) Some of the lowest points are selected as preliminary ground points and form a coarse TIN; (**b**) Rest points are examined using triangles within this TIN model. (used in TerraScan and lasground)

Chen, Z., Gao, B., & Devereux, B. (2017). State-of-the-Art: DTM Generation Using Airborne LIDAR Data. *Sensors (Basel, Switzerland)*, *17*(1), 150.

Point-cloud Classification



Schematic diagram of segmentation and classification-based DTM generation method. (**a**) Raw Lidar points; (**b**) Raster images produced using raw Lidar points; (**c**) After-image segmentation, unclassified segments are categorized into different land cover types by employing a diversity of features.

Chen, Z., Gao, B., & Devereux, B. (2017). State-of-the-Art: DTM Generation Using Airborne LIDAR Data. *Sensors (Basel, Switzerland)*, *17*(1), 150.