Remote Sensing 1: GEOG 4/585

Lecture 6.1.

Active remote sensing: LiDAR

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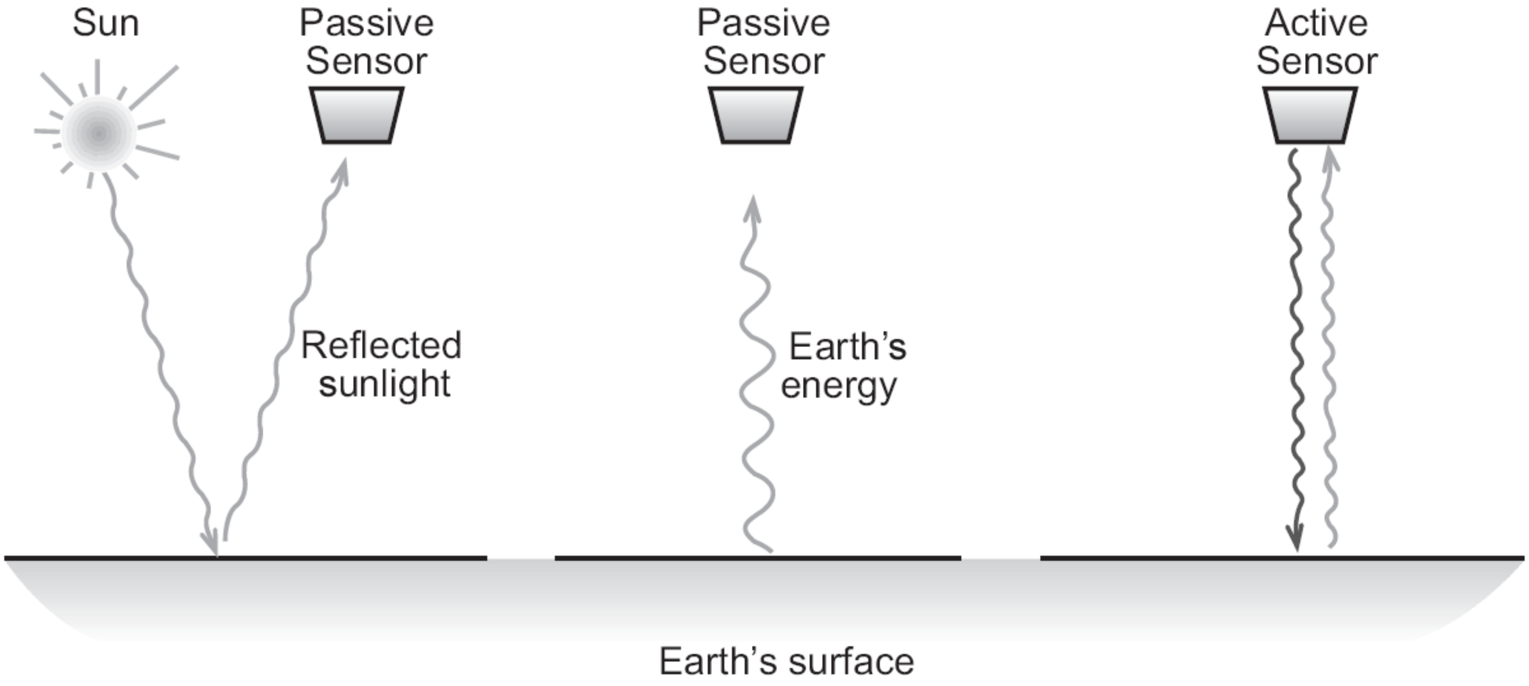
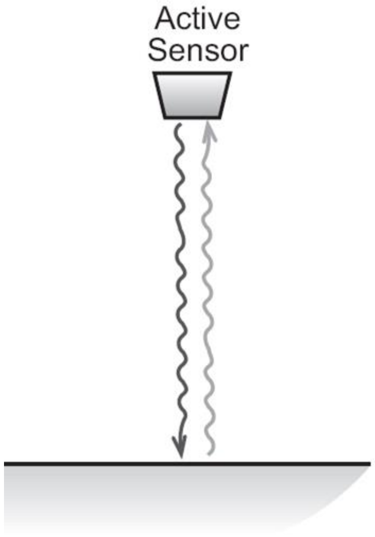
Required reading:
Principles of Remote Sensing pp 345-406

Classification of sensing systems



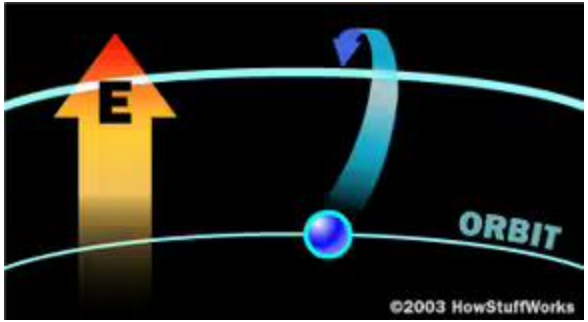
Two main types of active remote sensing systems

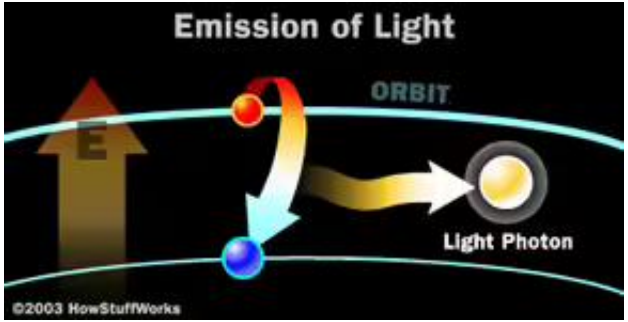
- RADAR (RAdio Detection And Ranging)
    - Sometimes called “active microwave remote sensing”
    - Transmits long-wavelength microwaves (~1 – 100 cm) through the atmosphere and records energy backscattered from the terrain
- LiDAR (Light Detection And Ranging)
    - Transmits relatively short-wavelength *laser* light (visible/infrared, commonly 532 and 1064 nm) and records energy back-scattered from the terrain



What is a laser?

- Light Amplification by the Stimulated Emission of Radiation
- Lasing medium is "pumped" using very intense flashes of light or electrical discharges to get the atoms into an excited state (higher-energy orbit)
- When the electrons relax to lower-energy orbit, they release energy in the form of photons (light energy)



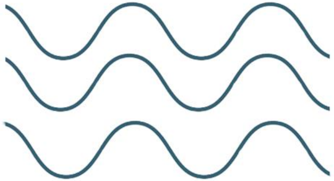


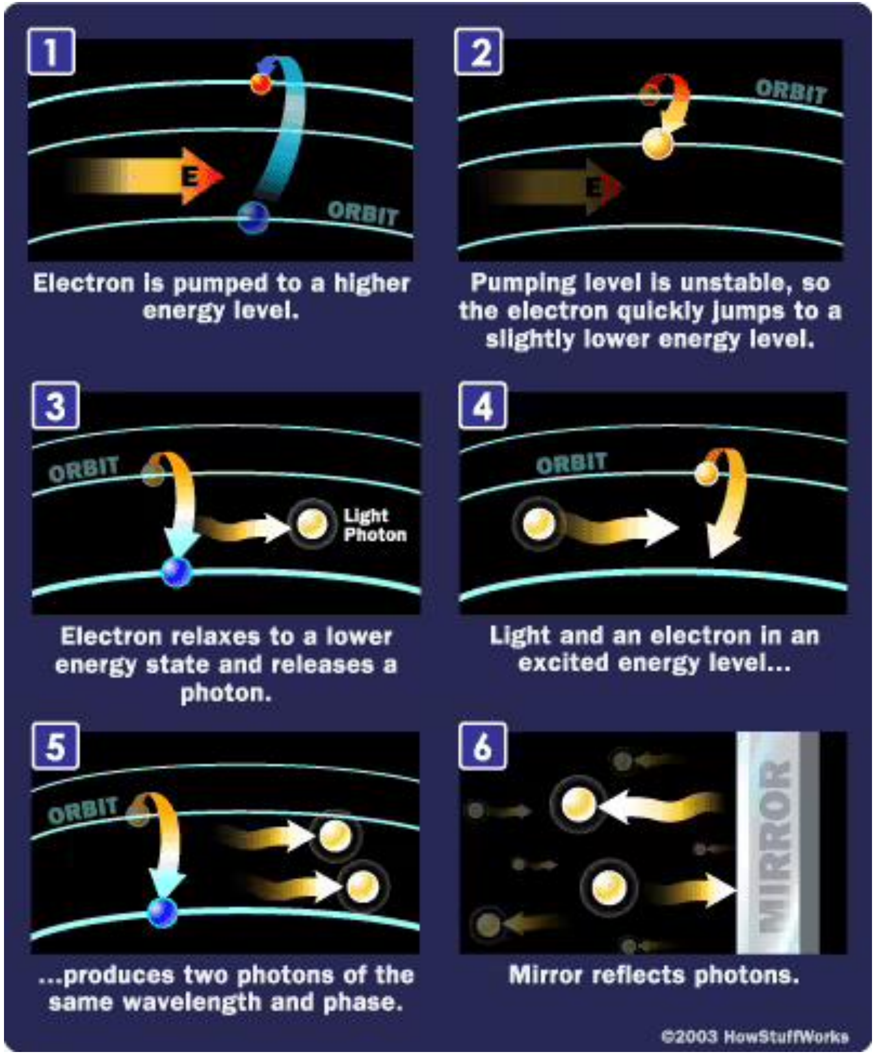
Laser light

Laser light has different different properties to normal light:

- The light released is ***monochromatic***
  - It contains one specific wavelength (color) of light dependent on the amount of energy released by “relaxing” electrons

- The light is very ***directional***
  - A laser light has a very tight beam and is very strong and concentrated
- The light released is ***coherent***
  - It is “organized” - each photon moves in step with the others





Laser wavelengths

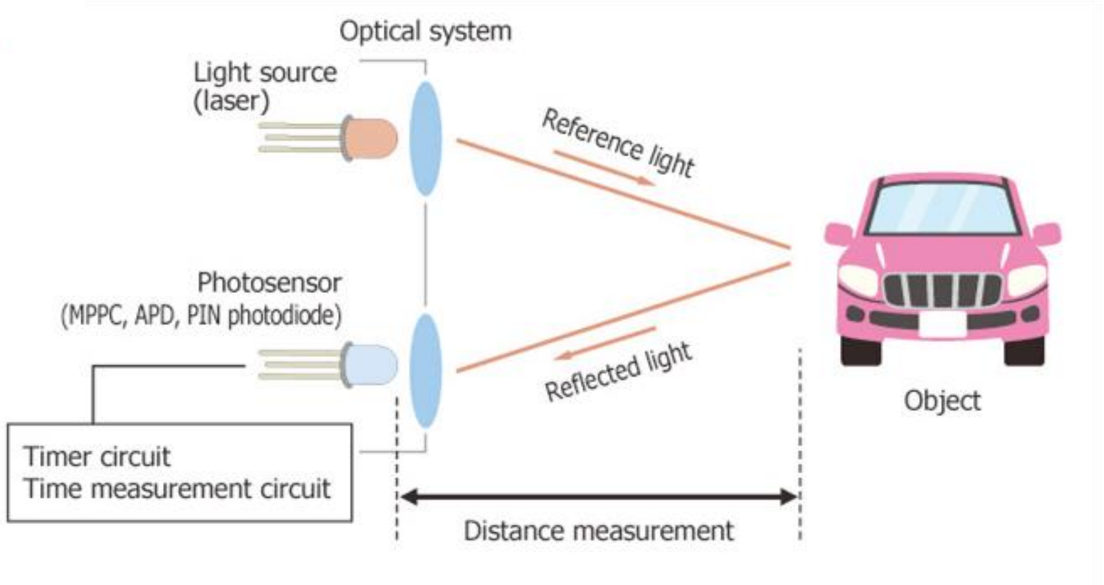
Some typical lasing mediums and their emission wavelengths (in nanometers):

- Argon fluoride (UV): 193
- Krypton fluoride (UV): 248
- Xenon chloride (UV): 308
- Nitrogen (UV): 337
- Argon (blue): 488
- Argon (green): 514
- Helium neon (green): 543
- Helium neon (red) 633
- Rhodamine 6G dye: 570-650
- Ruby (CrAlO3) (red): 694
- Nd:Yag (NIR): 1064
- Carbon dioxide (FIR): 10600

Goldfinger’s industrial laser

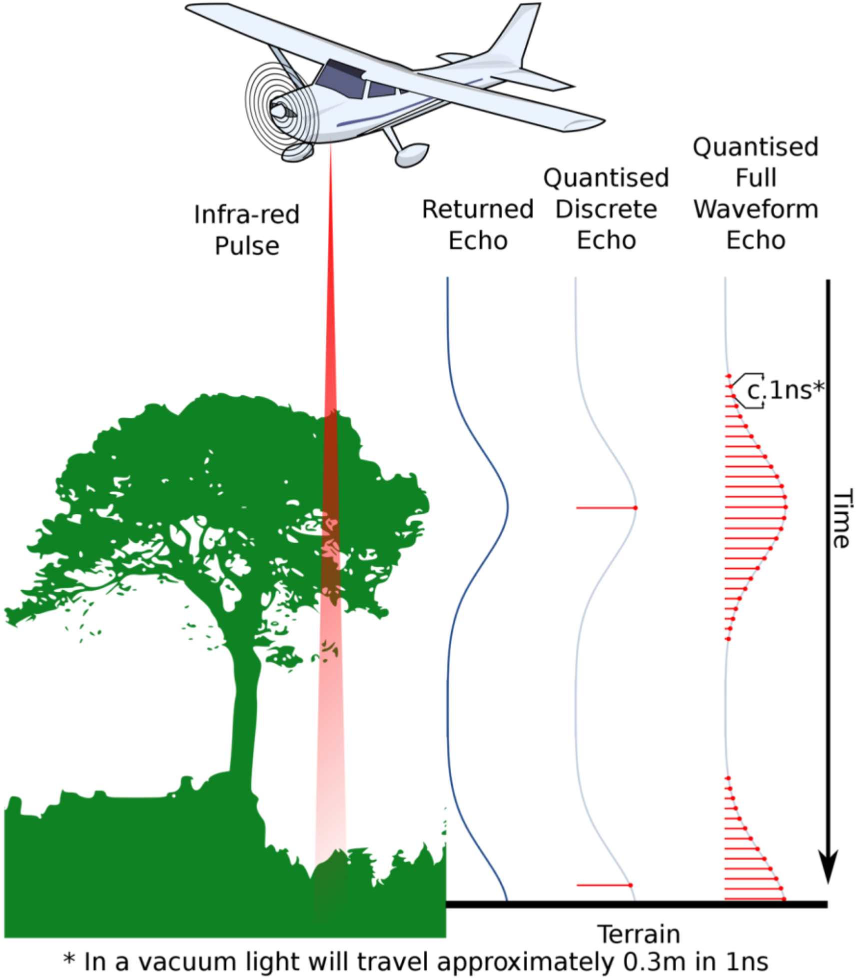
What is a LiDAR?

1. Laser generates a pulse of light
2. Pulse reflects off an object and returns to the system receiver
3. High-speed counter measures the time of flight from the start pulse to the return pulse
4. Time measurement is converted to a distance (because we know speed-of-light)



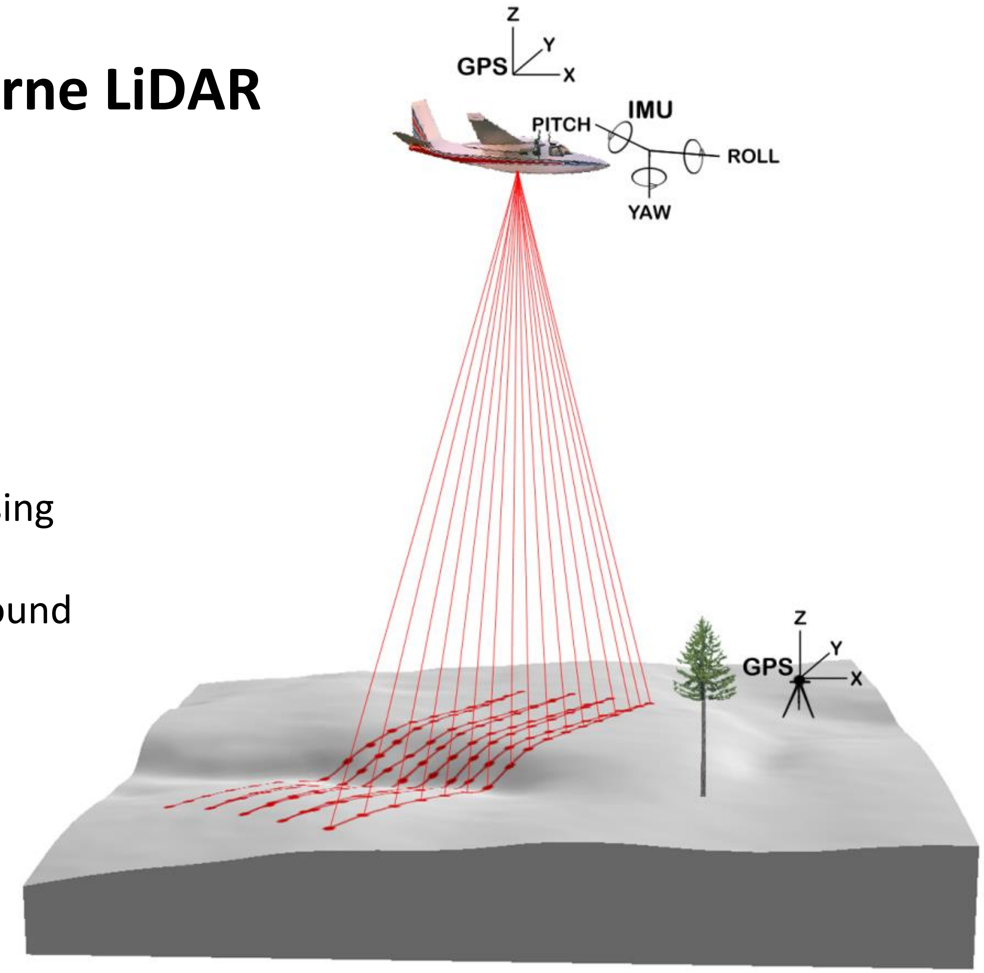
How does LiDAR work?

- Laser emits up to 200,000+ pulses/second
- Receiver measures returned energy of each pulse
- ***Discrete Return LiDAR System*** samples the returned energy of each laser pulse
- ***Full Waveform LiDAR System*** continuously samples the intensity of returned laser pulse energy
    - Providing more information about the structure and the physical backscattering characteristics of illuminated targets



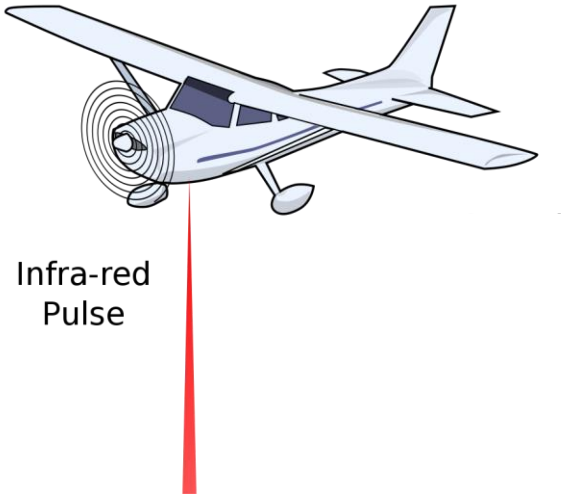
Airborne LiDAR

- Scanning laser emitter-receiver unit
- Differentially-corrected GPS
- Inertial measurement unit (IMU)
- Onboard computer for storage and processing
- Elevation = aircraft altitude - distance to ground



Profiling LiDAR

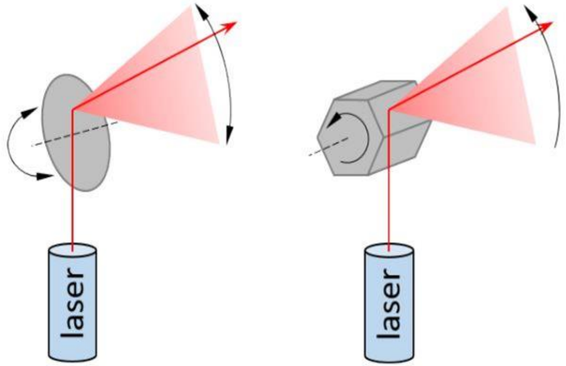
- Fixed at nadir, sends out individual pulses in one line
- Measures height along a single transect
- Old technology (1980s) but still in use
    - Drones for altitude control
    - Measuring yardage in golf



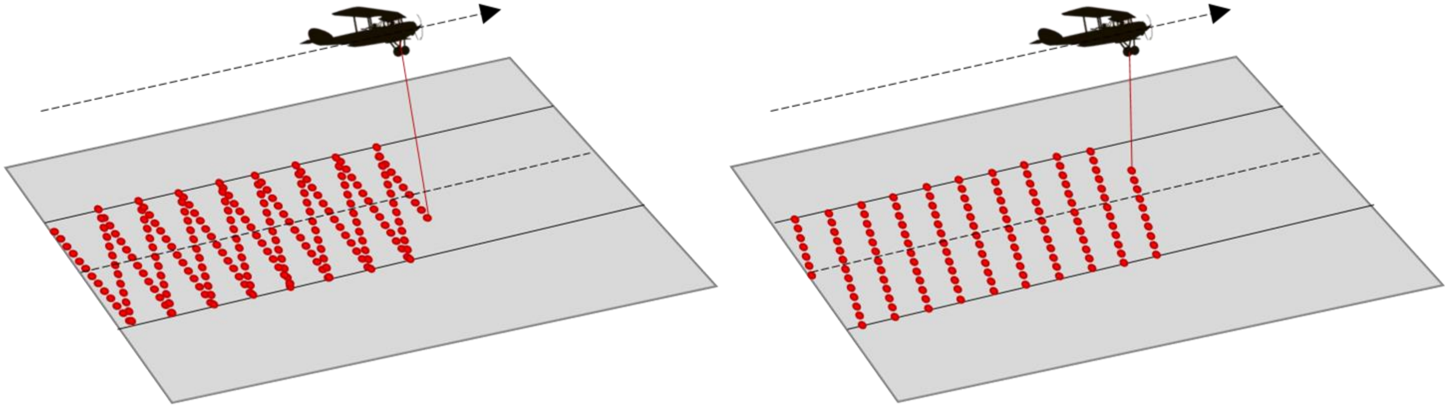
Scanning mechanisms

a) Oscillating mirror
- Produces a jagged pattern on the ground

b) Rotating polygon mirror
- Produces parallel lines oblique to the direction of the platform's progression



(a) (b)



(a) (b)

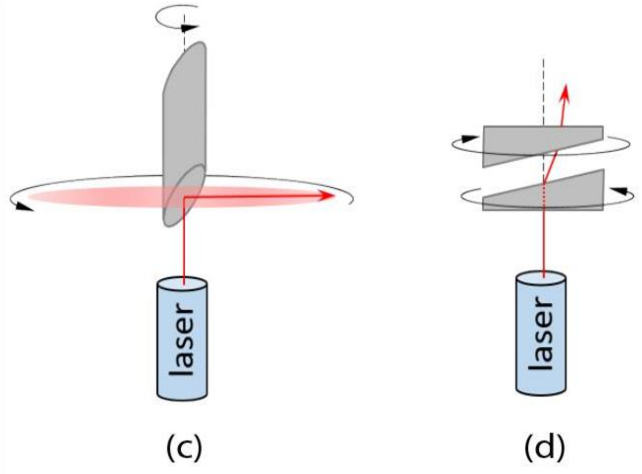
Scanning mechanisms

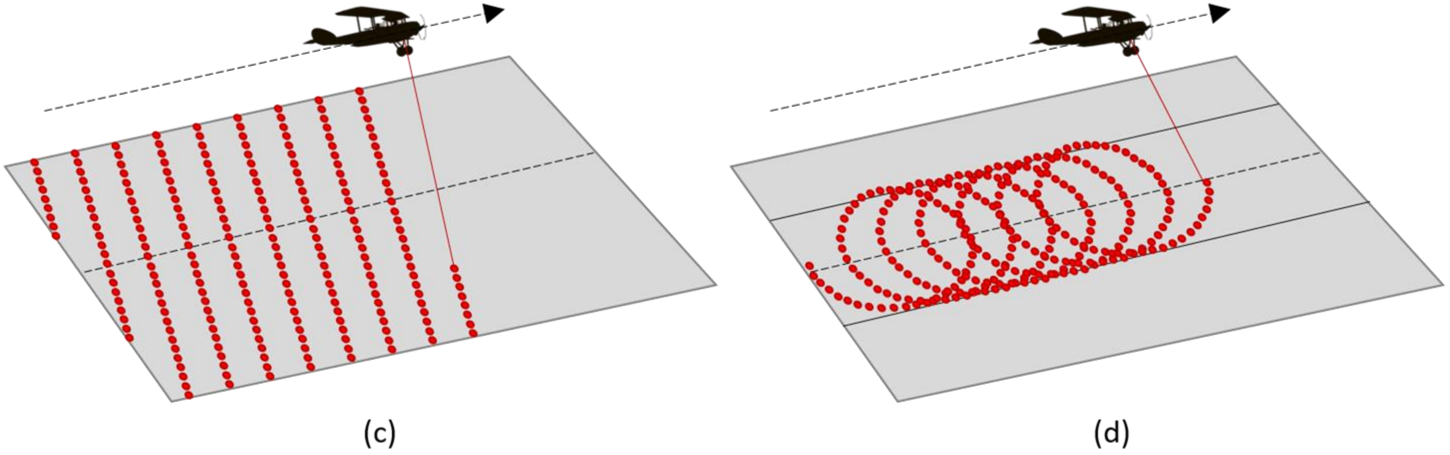
c) Rotating mirror

- Makes it possible to scan almost 360°

d) Dispersive prisms or gratings

- Rotate around the same axis to generate roses-like scanning patterns



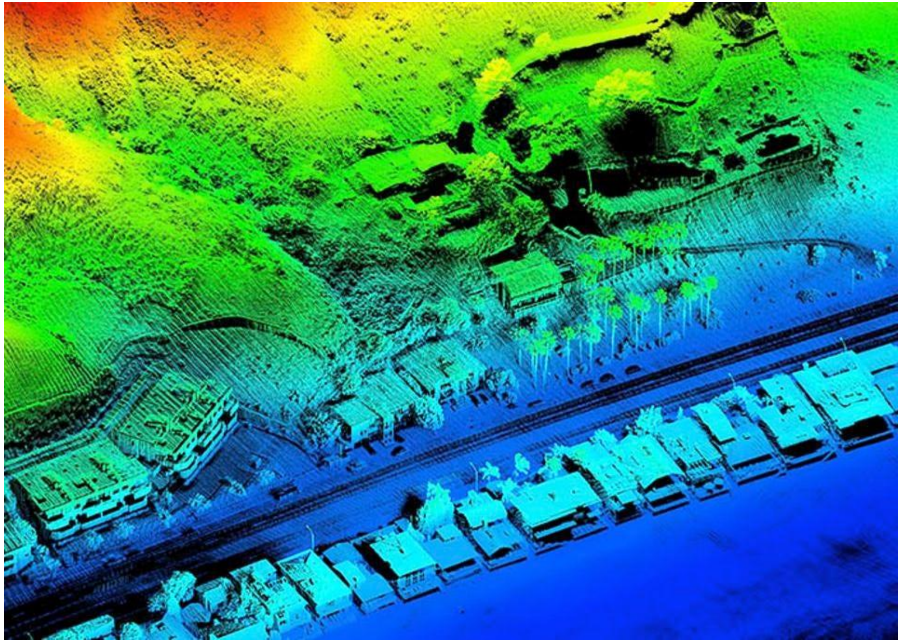


Airborne LiDAR systems

System	Optech ALTM 3100EA	Riegl LMS-Q560	TopoSys Falcon II
Laser	1064 nm	near IR	1540 nm
Altitude	80 – 3500 m	30 – 1500 m	60 – 1600 m
Range measurements	up to 4	full waveform	first and last
Scan frequency	max. 70 Hz	max. 160 Hz	max. 630 Hz
Scan angle	max. ± 25°	max. ± 30°	± 7° (fixed)
Pulse rate	max. 100 kHz	max. 100 kHz, 50 kHz @ ± 22.5°	83 kHz
Beam divergence	0.3 mrad	0.5 mrad	0.5 mrad
Beam pattern	oscillating, sawtooth	rotating polygon, parallel	fiber switch, parallel

LiDAR data

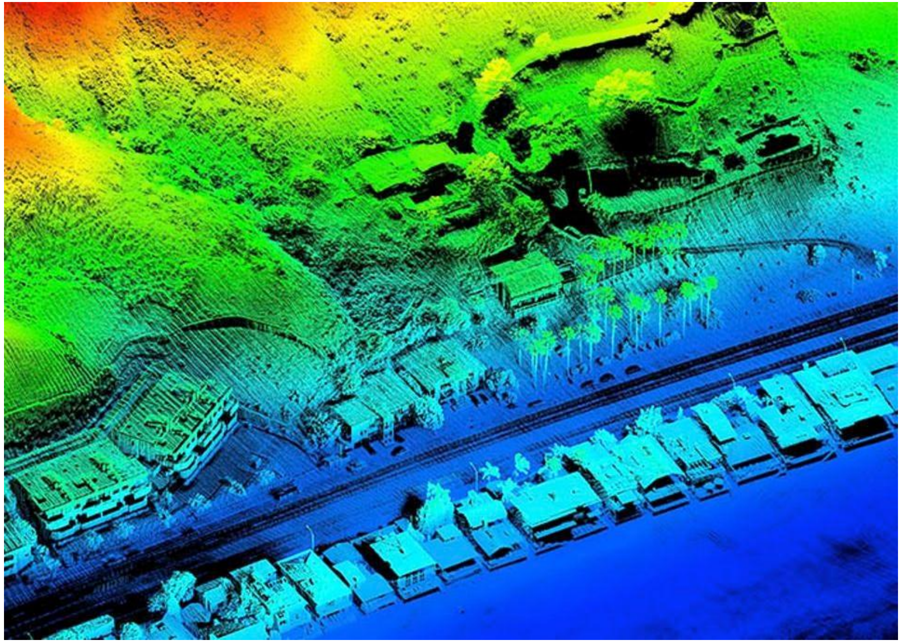
- Raw return data are XYZ points
- High spatial resolution
  - Laser footprint on ground ≤ 0.50 meters
  - Typical density is 0.5 to 20+ pulses/m^2
- Large volume of data
  - 5,000 to 60,000+ pulses/hectare
  - 10 to100+ thousands of returns/hectare
  - 0.4 to 5.4+ MB/hectare



Digital surface models

- We can produce digital surface models (DSM) using LiDAR data

- Colors represent height above some datum (e.g. mean sea level)



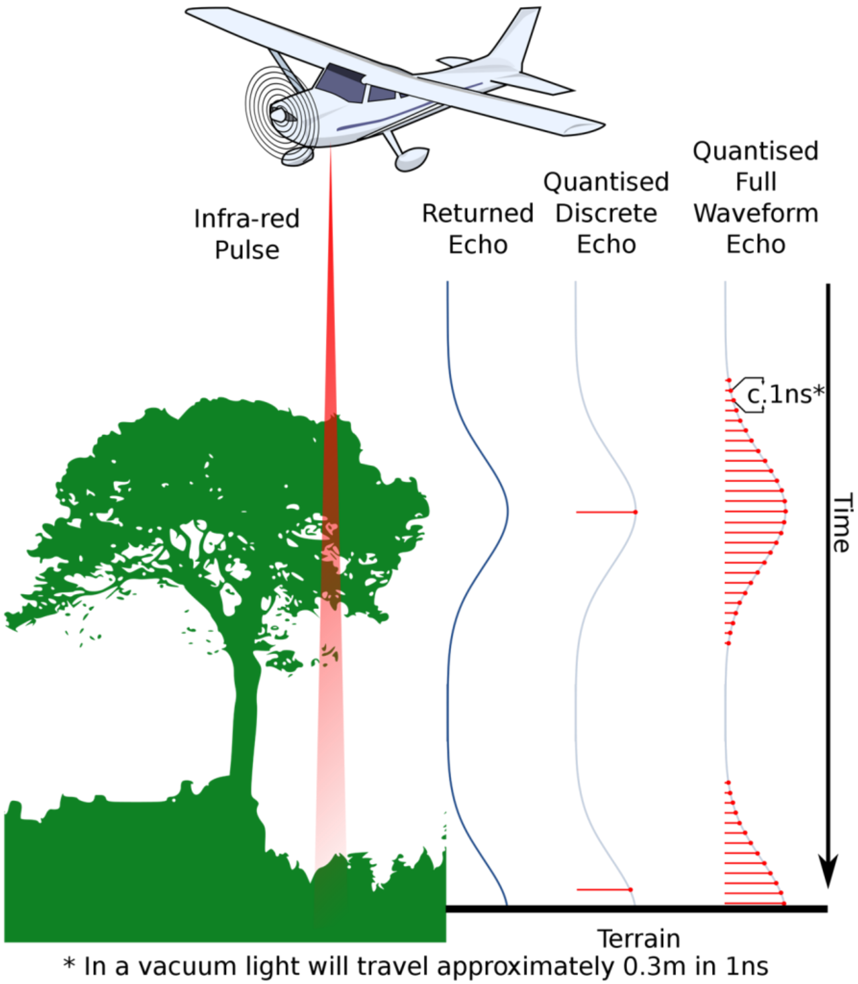
Reflectivity

- The strength of LiDAR returns depends on the reflectivity of an illuminated object
- The reflective percentages are referred to as LiDAR intensity
- Light intensity is particularly useful in distinguishing features in land use/cover
    - e.g. impervious surfaces stand out in light intensity images.

MATERIAL	**REFLECTIVITY @ λ = 900 nm**
Dimension lumber (pine, clean, dry)	94%
Snow	80-90%
White masonry	85%
Limestone, clay	up to 75%
Deciduous trees	typ. 60%
Coniferous trees	typ. 30%
Carbonate sand (dry)	57%
Carbonate sand (wet)	41%
Beach sands, bare areas in desert	typ. 50%
Rough wood pallet (clean)	25%
Concrete, smooth	24%
Asphalt with pebbles	17%
Lava	8%
Black rubber tire wall	2%

Multiple returns

- Often the receiver will record more than one return from the same place on the ground.
- These multiple returns provide more information about the structure and the physical backscattering characteristics of illuminated targets
- Enables mapping of sub-canopy terrain, and therefore canopy height

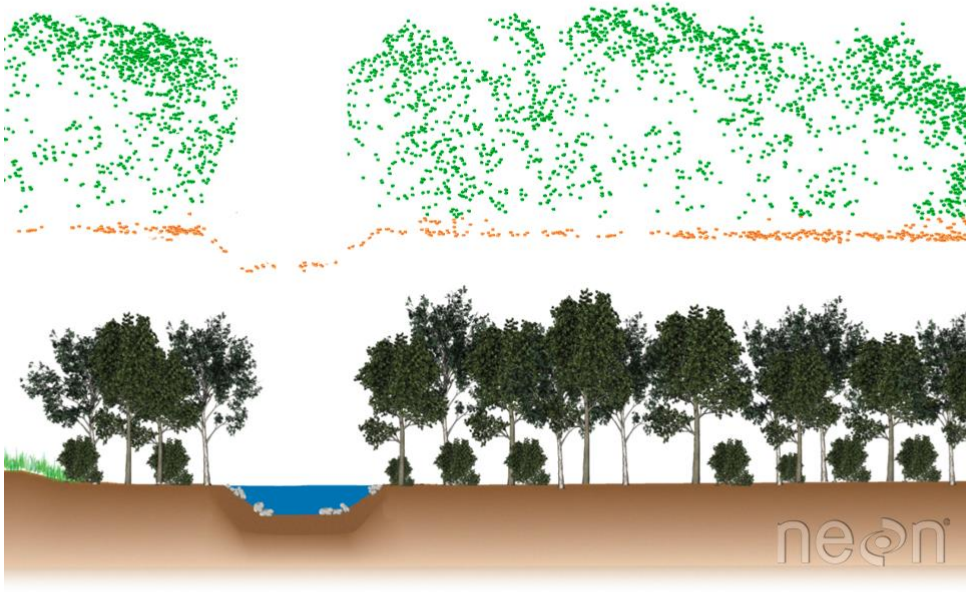


Digital terrain (or “bare earth”) models

- First step for quantifying canopy height is to separate ground from non-ground returns

- Usually achieved by classifying our point cloud either manually or with an automatic filtering approach

- Often use fixed kernel sizes and assume:
    - Ground returns are local minimums within the point cloud or,
    - Ground cannot exhibit slopes steeper than a set angle



Point cloud classification

- There are pre-defined classification schemes defined by the American Society for Photogrammetry and Remote Sensing (ASPRS)

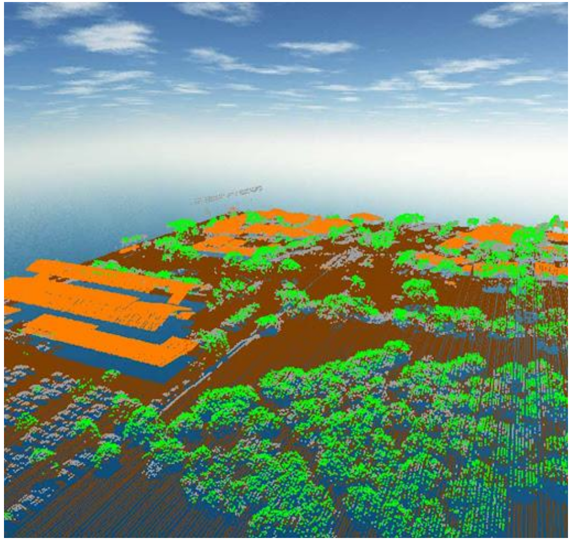
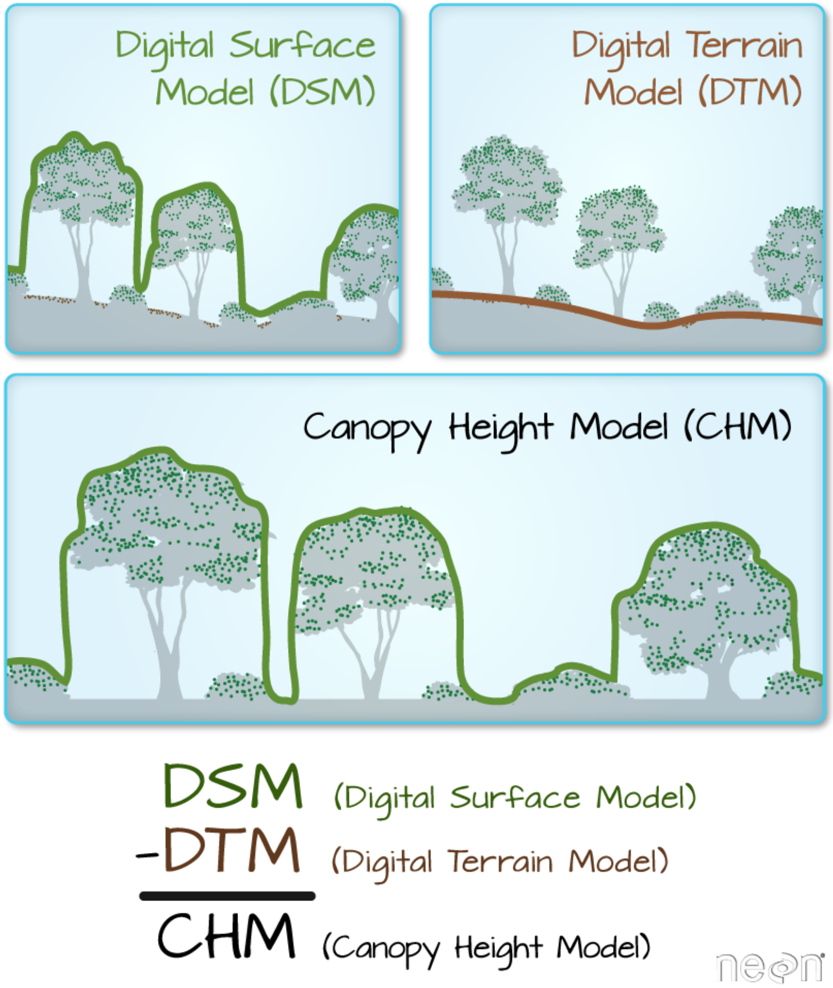


Table 1. ASPRS Standard LIDAR Point Classes

Classification Value (bits 0:4)	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



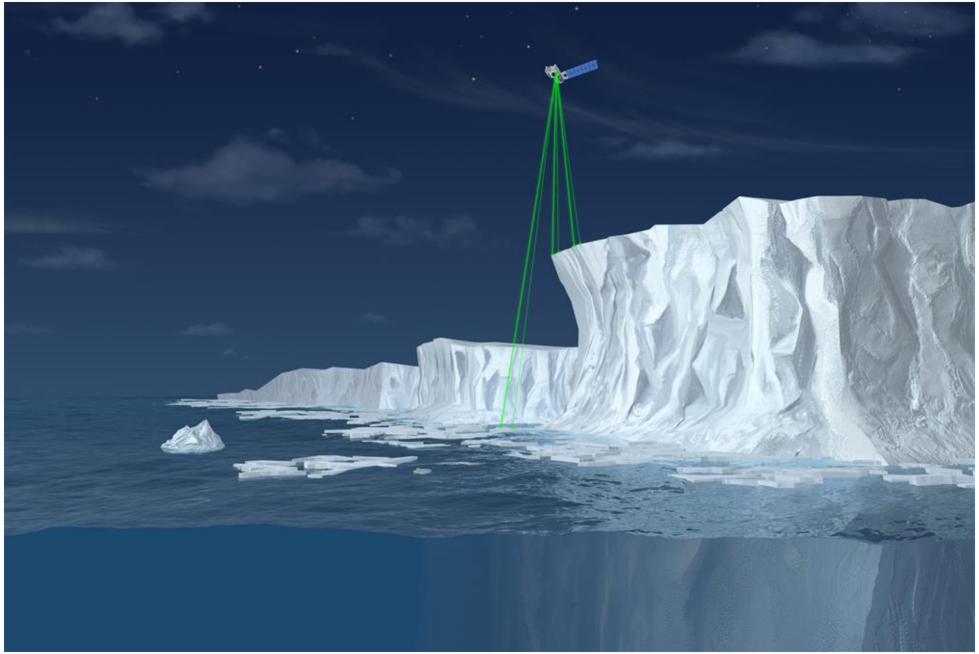
Canopy height model

- By subtracting a digital surface model (DSM) from “bare earth” digital elevation model (DEM) we can produce a map that represents the height of features (e.g. trees) that from the ground.

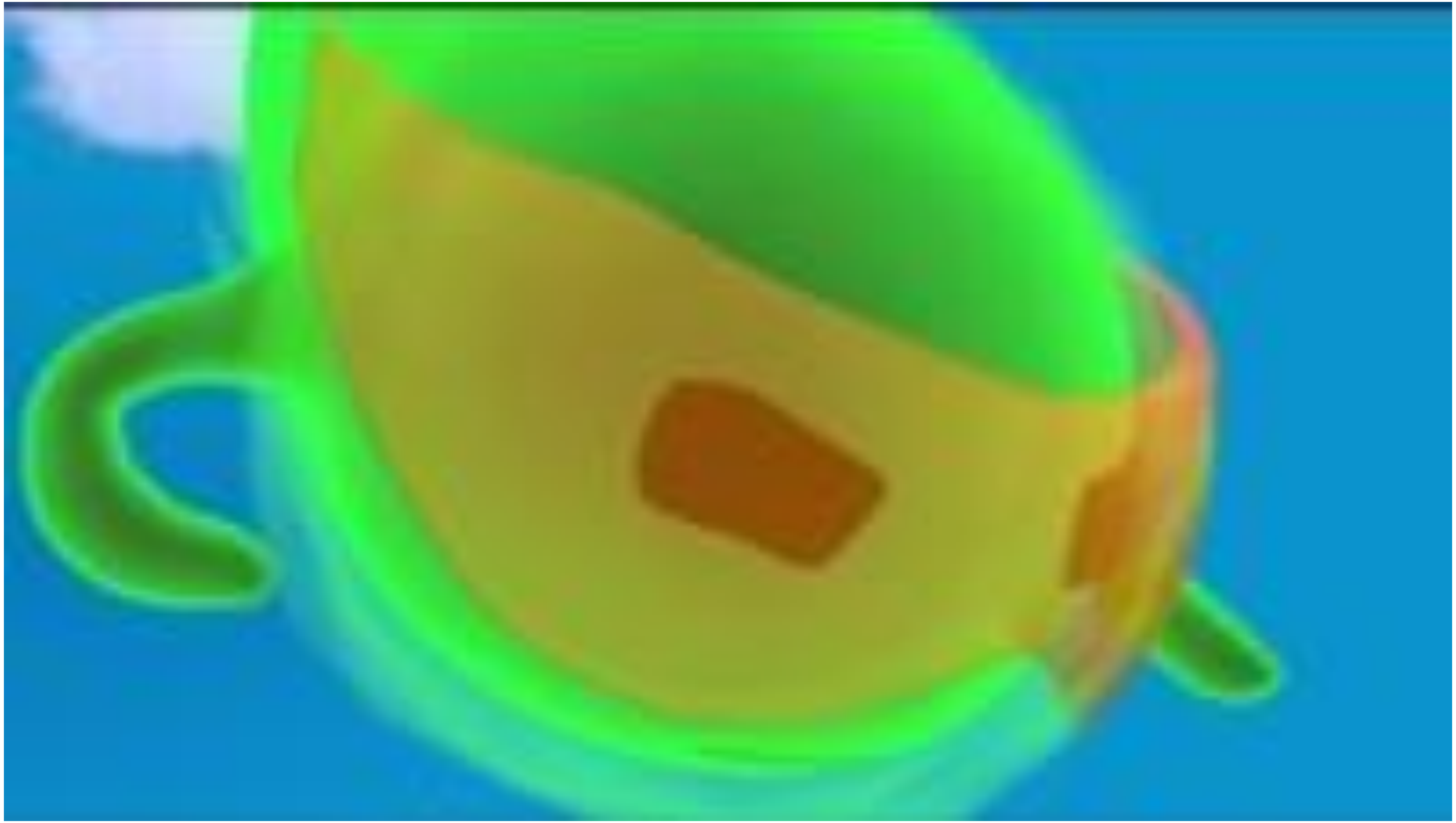
LiDAR in space

- ICESat (2003-2010)
  - Carried the Geoscience Laser Altimeter System (GLAS)
  - One infrared laser (1064 nm)
  - Ground footprint of 70 m

- ICESat-2 (2018-present)
  - Carries the Advanced Topographic Laser Altimeter System (ATLAS)
  - Photon-counting LiDAR
  - One green laser (532 nm) split into six beams
  - Ground footprint of 13 m

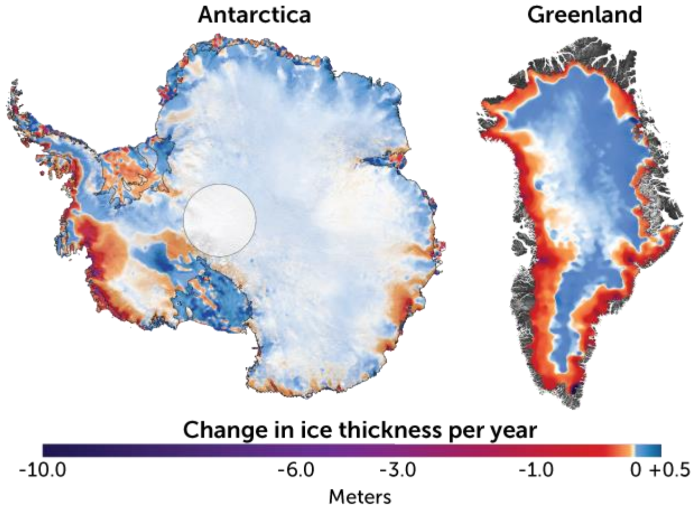


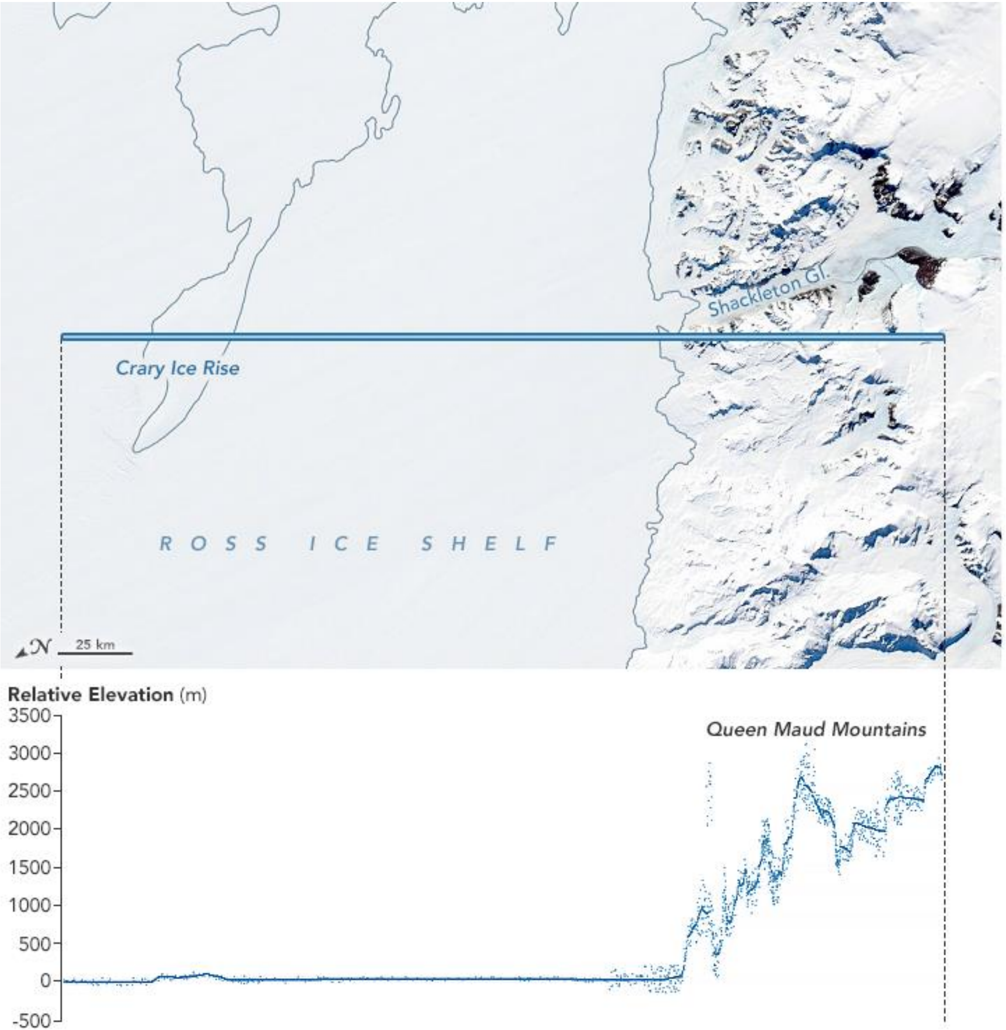
Pho the Photon



ICESat-2

- Main objective is to measure volumetric changes in Earth's ice sheets and their contributions to sea level rise

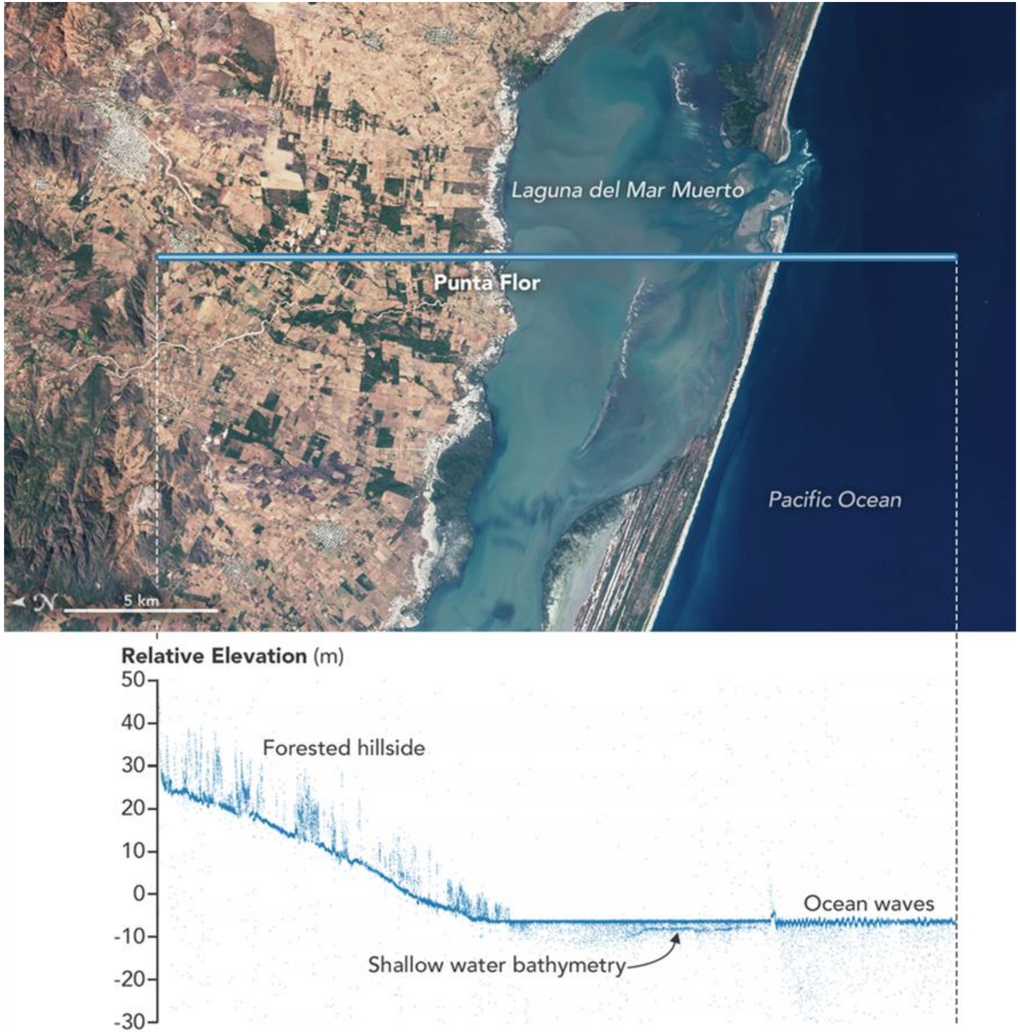




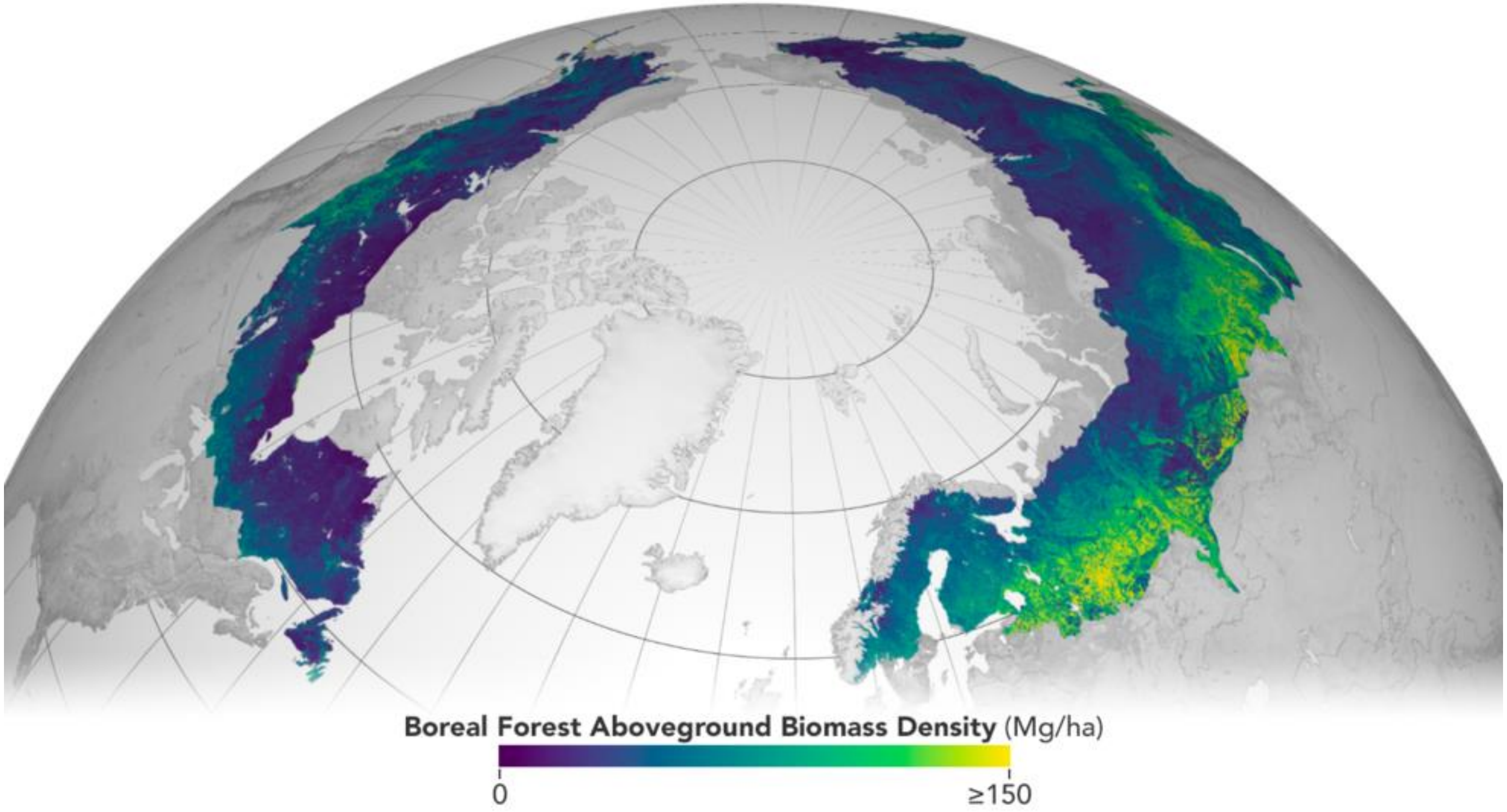
ICESat-2 beyond the poles

As well as measure elevational changes of the Earth's cryosphere, ICESat-2 will also:

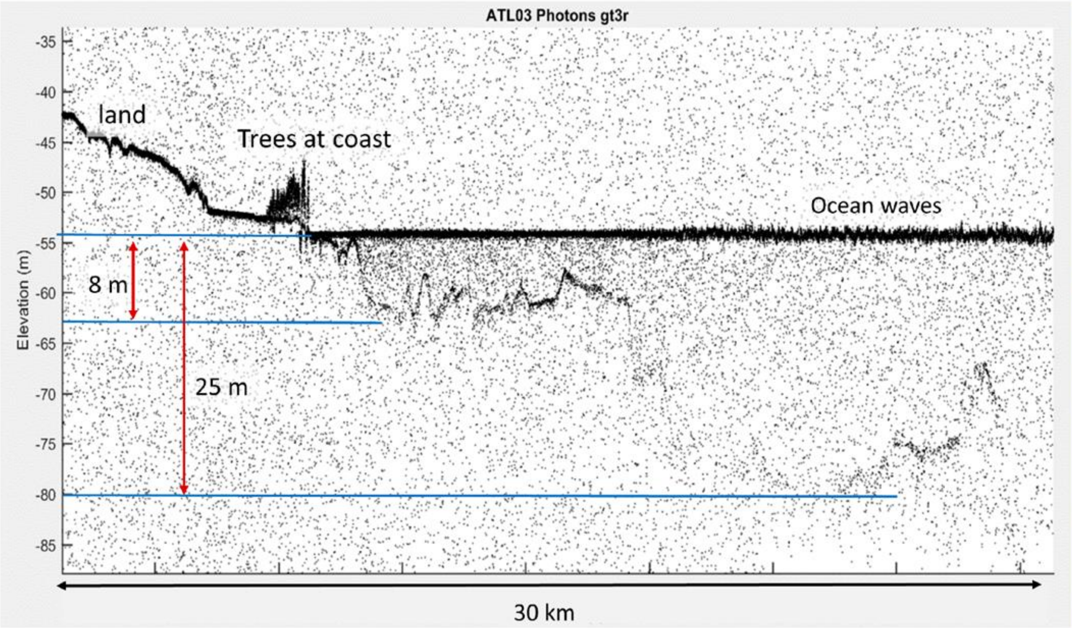
- survey heights of the world's forests
- survey bathymetry of shallow water water bodies and coasts

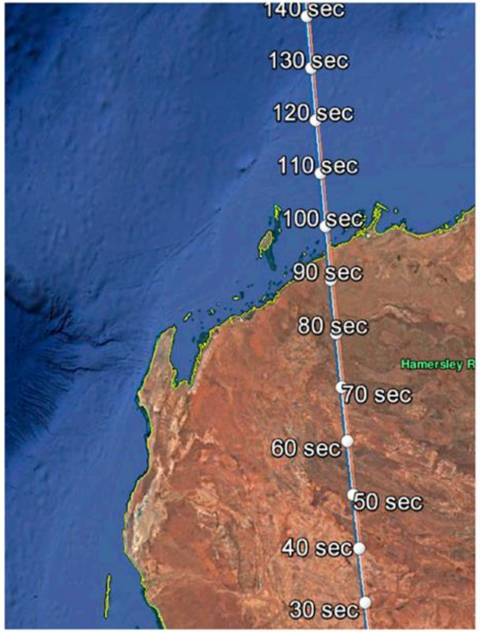


Aboveground biomass in boreal region



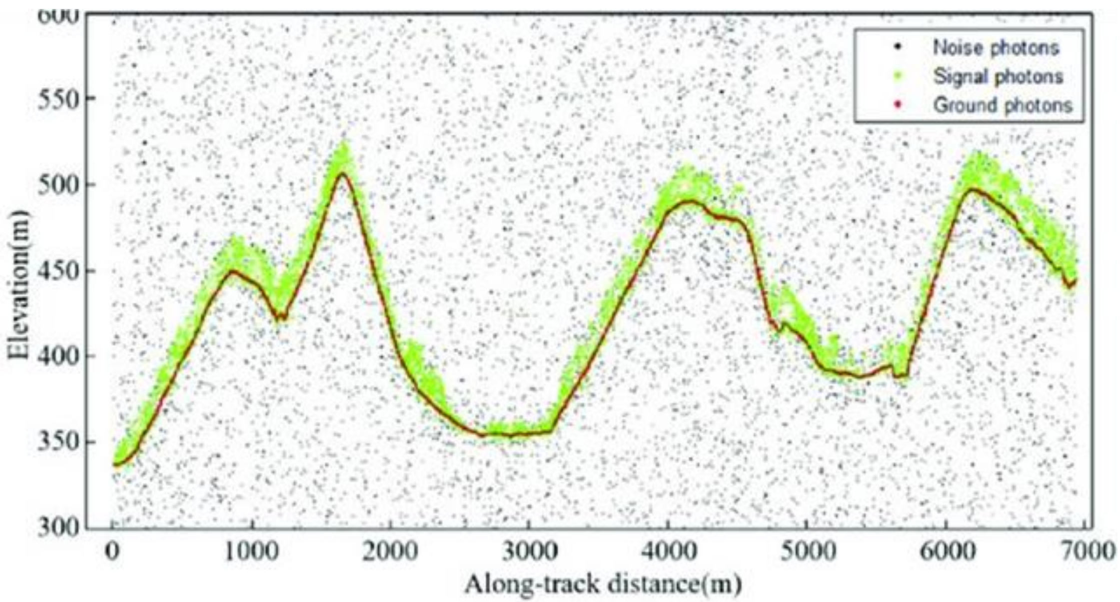
Bathymetric mapping by LiDAR





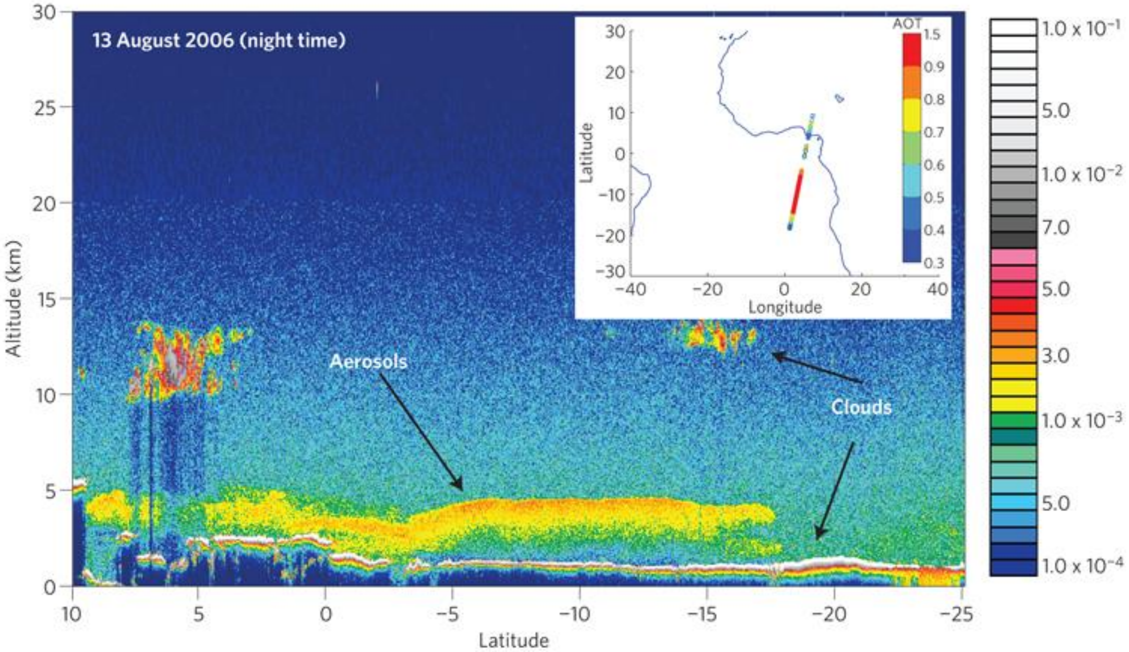
Aerosols and water vapor

- Laser measurements can be weakened by interacting with dust and vapor particles, which scatter the laser beam and the signal returning from the target



Atmospheric LiDAR

- Vertical profiles of cloud and aerosol layers produced by NASA's Cloud Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) mission



Summary

- Airborne LiDAR is a very popular tool, especially in forestry, glaciology, and archeology
- LiDAR is most accurate technique for acquiring elevation data
- Spaceborne LiDAR now being used very successfully (e.g. ICESat-2)
- But lasers are blocked by clouds and aerosols
- Since the beam is so narrow, LiDAR has relatively sparse data coverage compared to multispectral imagery and radar

How does LiDAR work?

- Laser Pulse Generators
    - Airborne topographic mapping lidars use 1064 nm (infrared) diode-pumped YAG lasers
- Nd:YAG (neodymium-doped yttrium aluminum garnet; $Nd{:}Y_3Al_5O_{12}$) is a crystal that is commonly used as a lasing medium for solid-state lasers