Lidar Technology Overview

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Lidar Workshop Objectives

- Educational component
- Compile information on applications of lidar data in the Northern Gulf of Mexico
- Where is the gap in data coverage, and where can this technology be used.
- Allow workshop attendees to explore partnerships in data acquisition, processing, and applications.

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Lidar Definition

- LIDAR (***Li***ght ***D***etection ***a***nd ***R***anging) is an optical remote sensing technology which measures properties of scattered light to find range and/or other information of a distant target.
- The prevalent method to determine distance to an object or surface is to use laser pulses.
- Similar to radar technology, which uses radio waves instead of light, the range to an object is determined by measuring the time delay between transmission of a pulse and detection of the reflected signal.

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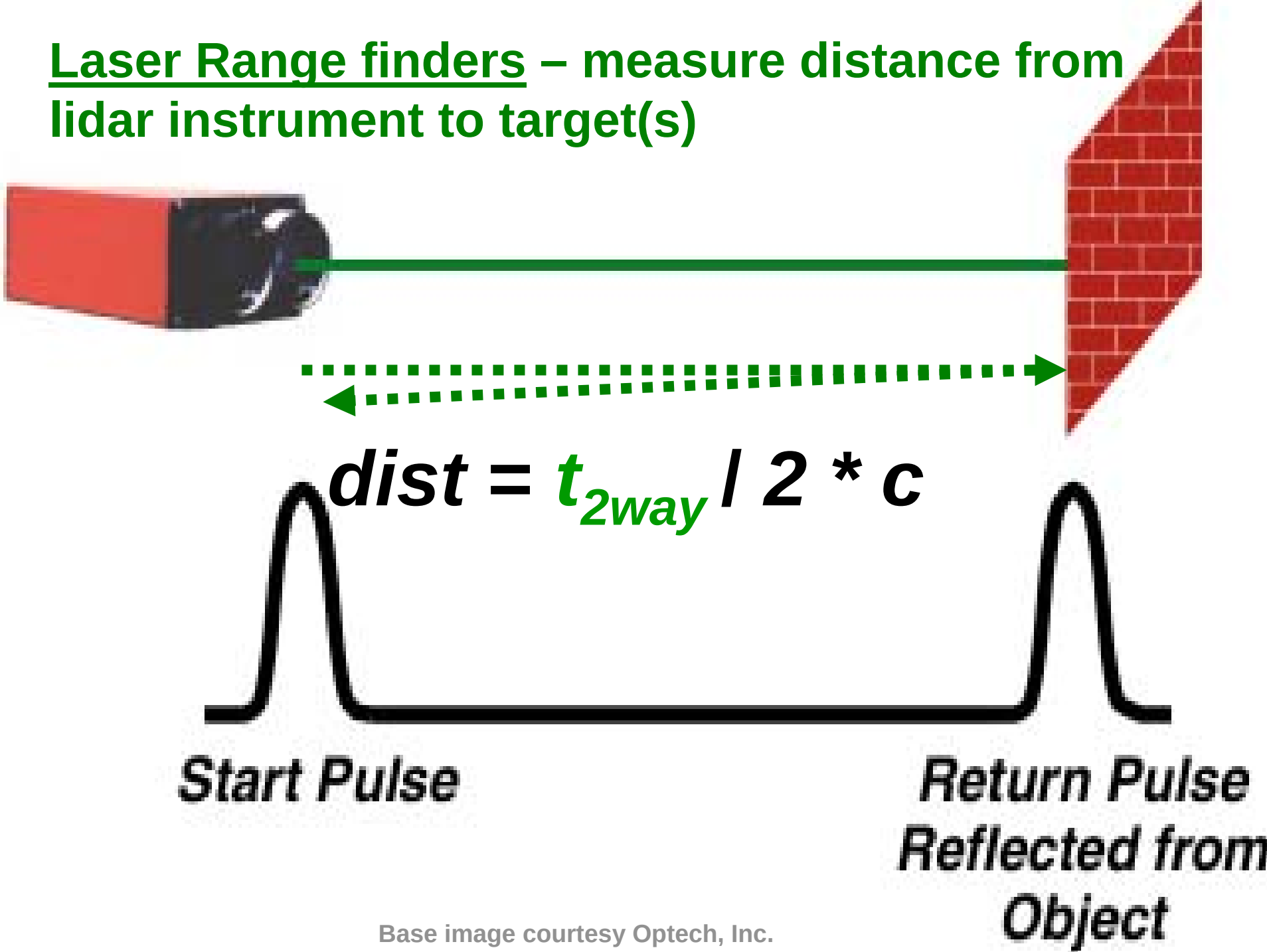
http://en.wikipedia.org/lidar

Laser Range finders – measure distance from lidar instrument to target(s)



Base image courtesy Optech, Inc.

Airborne Lidar System (ALS)

Consists of the following separate components that are basically operating independently:

1. Laser ranging device
2. GPS positioning device
3. Inertial System
4. Digital Camera (RGB or CIR) (Optional)

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http://en.wikipedia.org/lidar

Types of Airborne Lidar Sensors

- Laser operating principles (Pulsed, CW)
- Operating wavelengths (near-infrared, blue-green)
- Laser system characteristics: Power, Pulse Repetition Frequency (PRF), Scanning Pattern, Footprint Size, etc.
- Number of returns
  - Single Return
  - Multiple Return
  - Waveform-resolving
- Application: Sub-aerial OR Submerged Topography

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Laser Operating Principles

- Pulsed Lasers
  - Most commonly used for ranging applications
  - Consists of a pulsed laser transmitter, an optical telescope receiver that amplifies the backscatter, and photomultiplier tube to convert optical energy into electrical impulses.
  - Distance to object is determined by recording the time taken by the transmitted pulse to the target and back (at the speed of light)
- Continuous Wave (CW) Lasers
  - Transmits a continuous signal, and ranging is carried out by modulating the intensity of the laser light.
  - Travel time is directly proportional to the phase difference between the received and transmitted sinusoidal signal.

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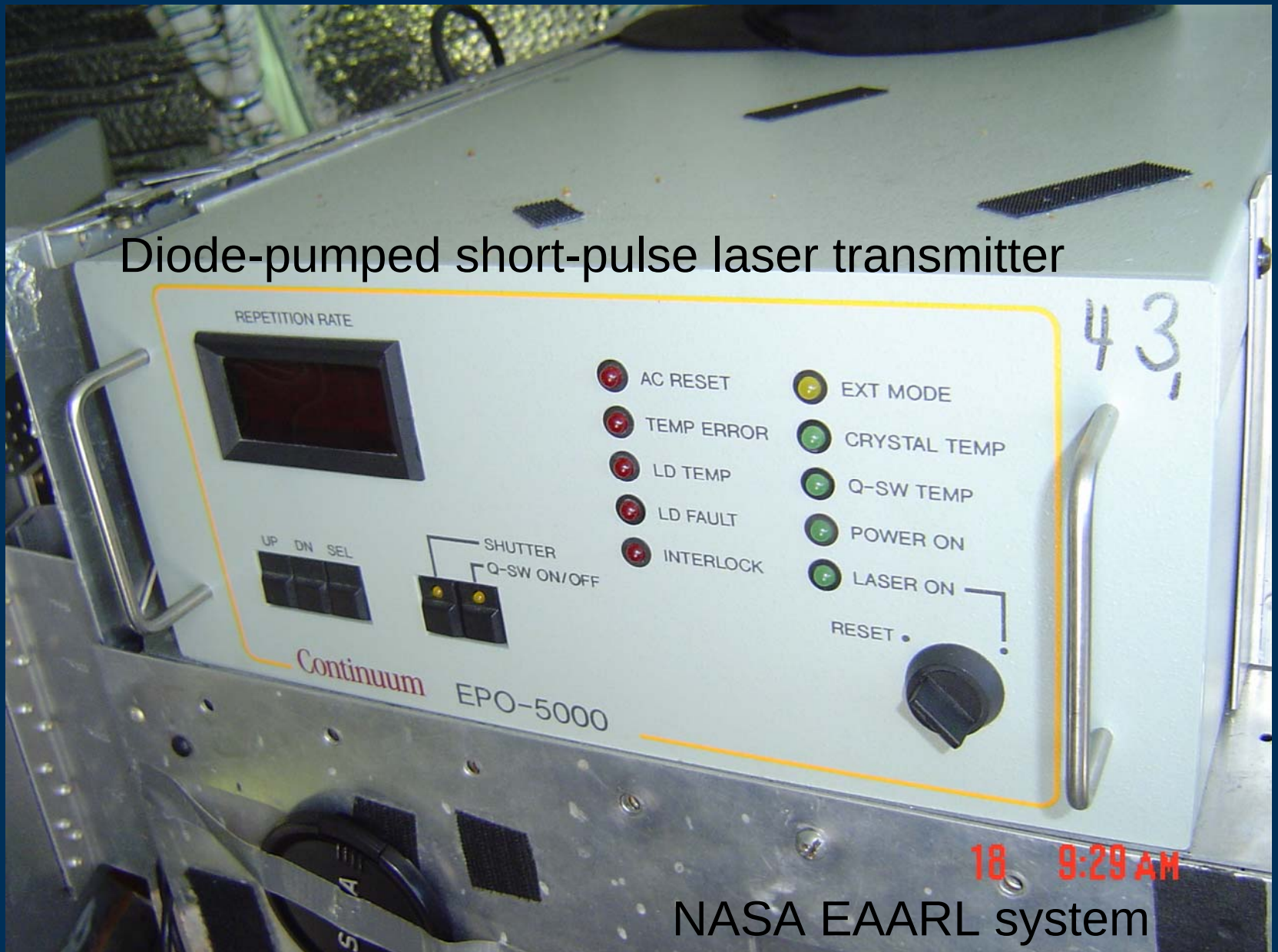
Pulsed Laser Transmitter



Diode-pumped short-pulse laser transmitter

NASA EAARL system

Operating Wavelengths

- In theory, any light source can be used to create a lidar instrument
- Near-Infrared wavelength
  - Used by most airborne terrestrial lidar systems
  - The most common laser is the solid-state Nd:YAG laser which produces radiation at an IR wavelength of 1064 nm
  - Easily absorbed at the water surface (unreliable water surface reflections)
- Green Wavelength
  - Used by all airborne bathymetric and topo-bathy systems
  - Nd:YAG IR laser output is frequency doubled to produce output at 532 nm
  - Can penetrate water

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Laser system characteristics

- Pulse energy – total energy content of a pulse (typically 100 µJ for ALS and 5 mJ for ALB).
- Pulse duration is usually defined as **the time during which the laser output pulse power remains continuously above half its maximum value (**FWHM). (typically 10 ns).
- Pulse repetition frequency (PRF) (kHz) – number of emitted pulses per second (ranges from 1 to 200 kHz)
- Scan rate – number of times per second a scanning device samples its field of view (25 – 90 Hz)

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Laser system characteristics (contd.)

- Scan Pattern – zig-zag, parallel, elliptical, etc.
  - Usually zig-zag (oscillating mirror)
  - Can create large population of data towards edge of swath
- Scan Angle (up to 75°)
- Spot size of laser pulse
  - Beam Divergence (0.25 to 2 milliradian)
  - Laser footprint (0.2 – 2 m)
  - Receiver field-of-view (FOV) (0.2 – 5 m)

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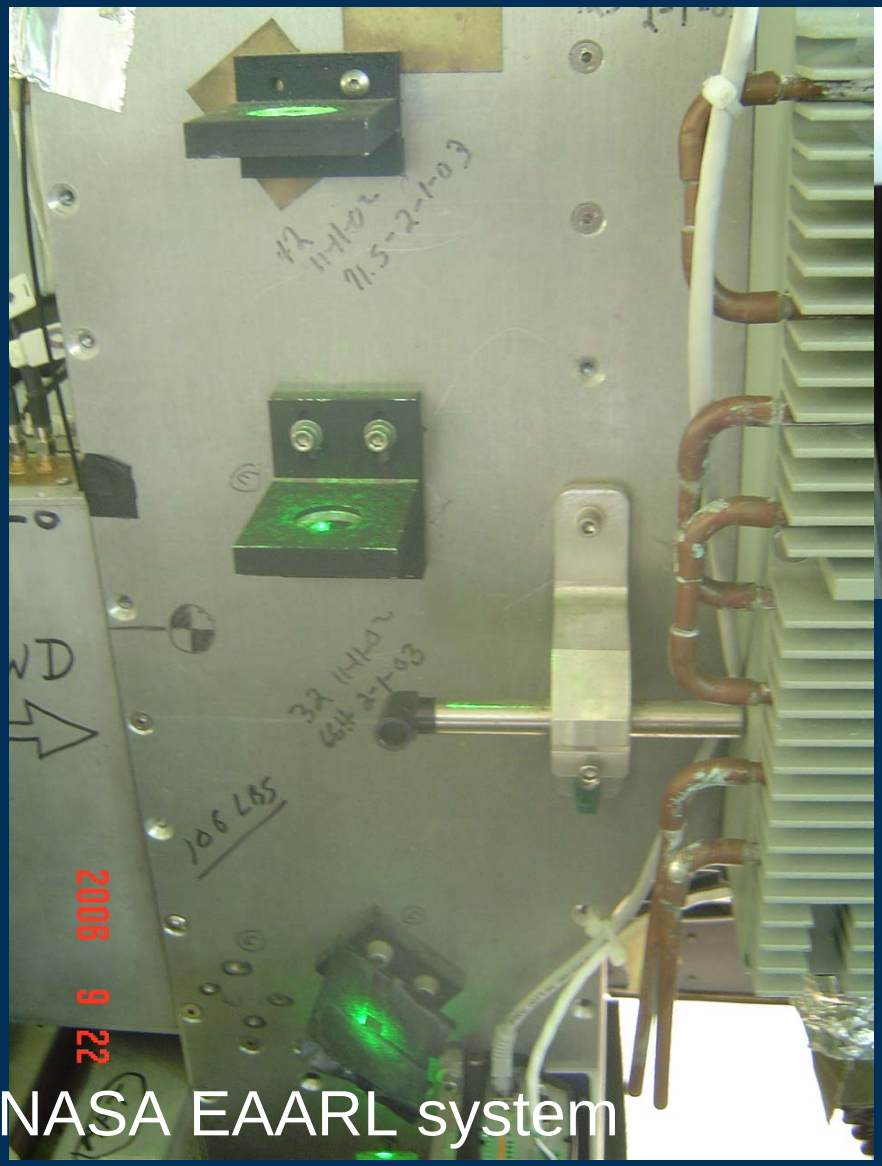
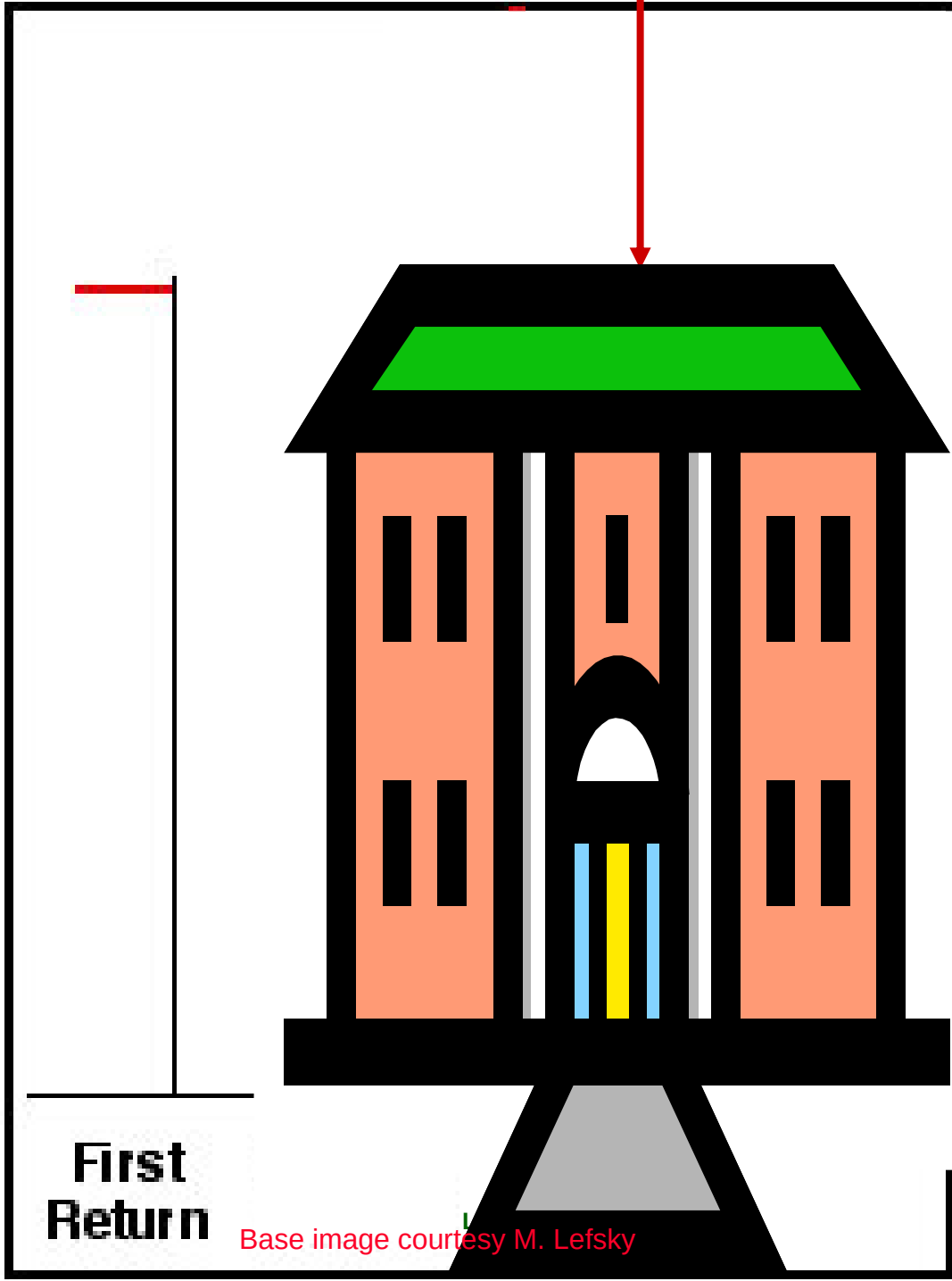
Mirrors, lenses and scan



“First-return” lidars

→

measure the distance to the *first* target encountered by the laser pulse



Base image courtesy M. Lefsky

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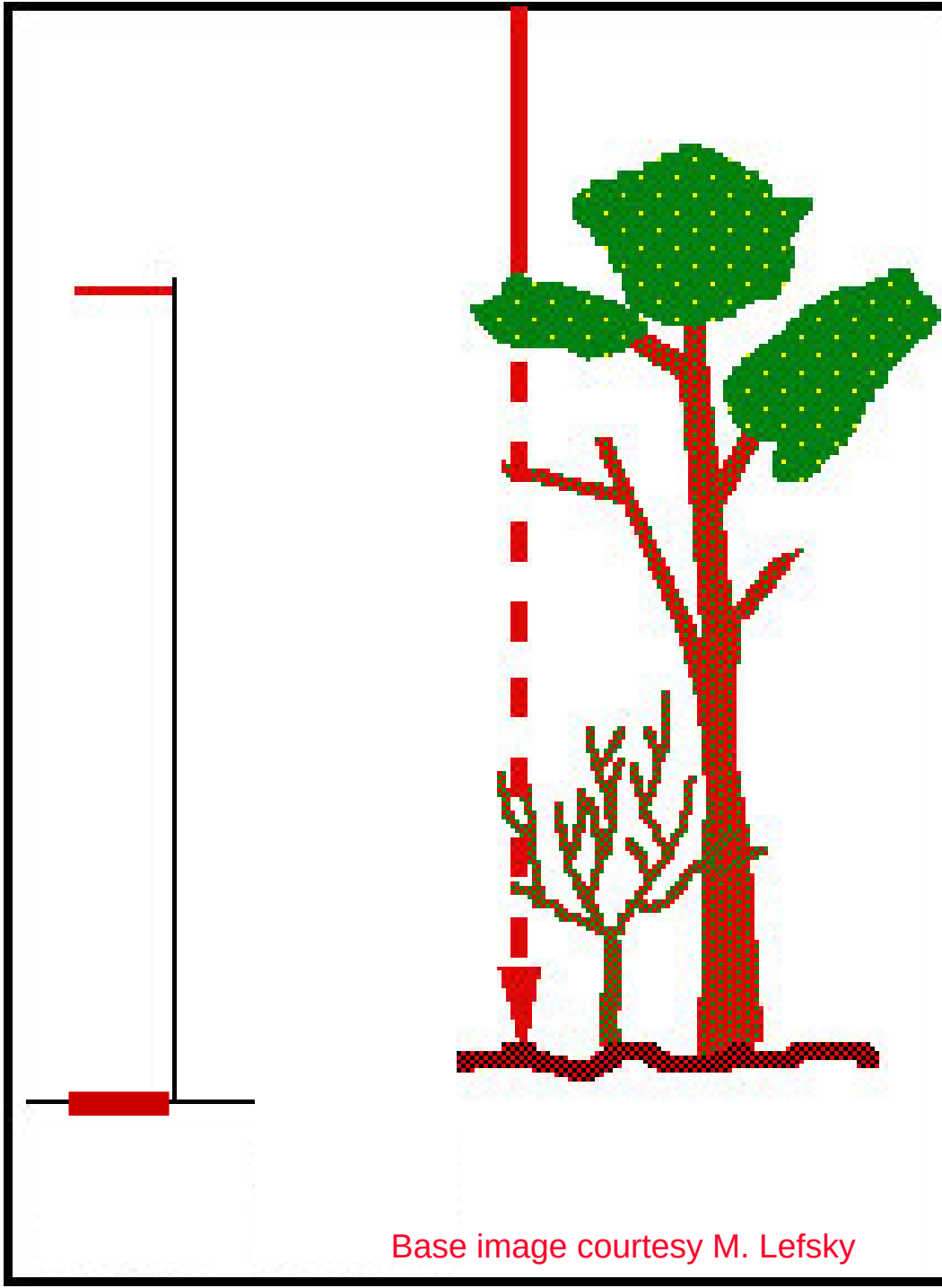
“Two-stop” lidars

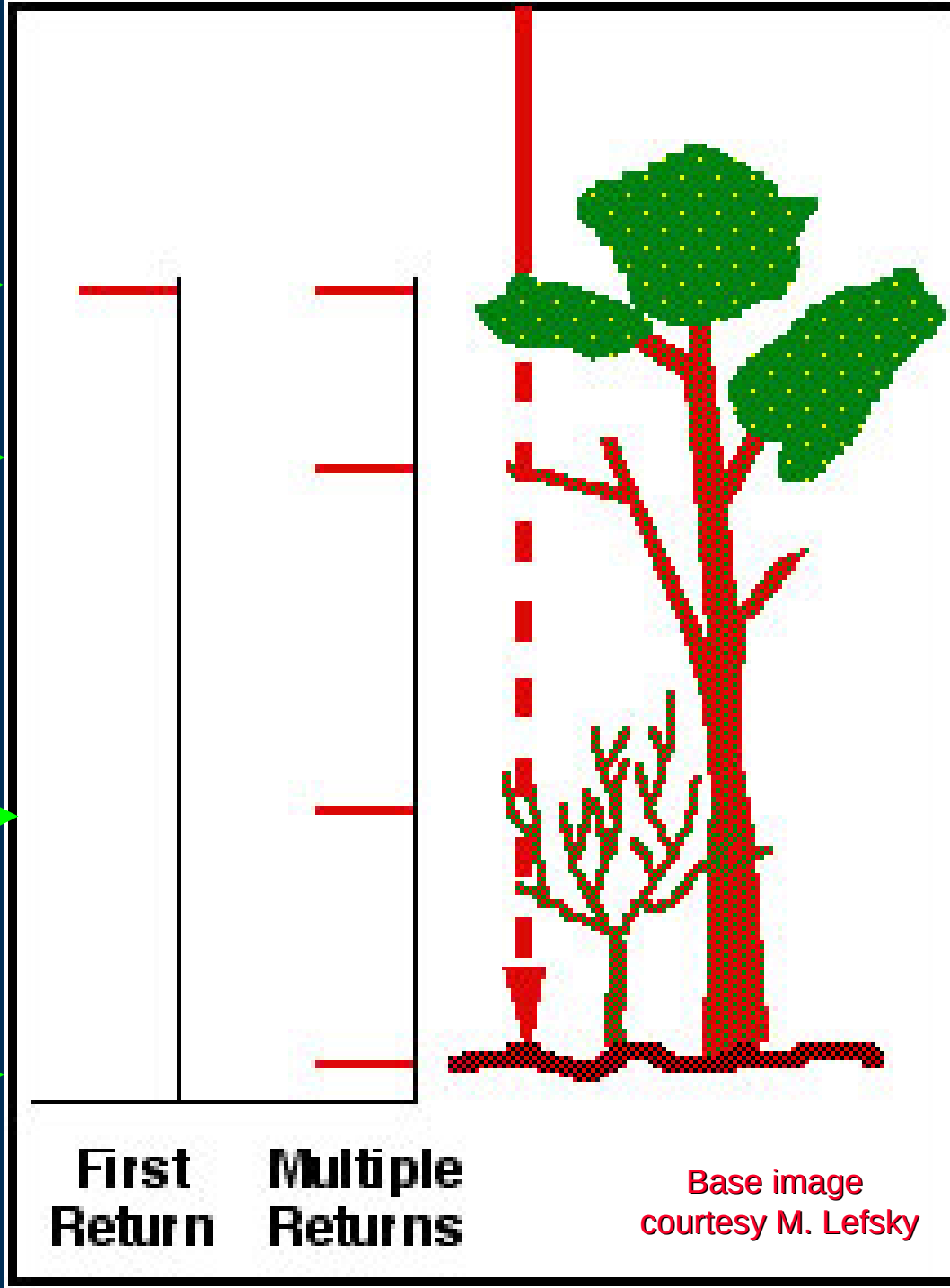
measure the distance to the *first* and *last* targets encountered by the laser pulse



Base image courtesy M. Lefsky

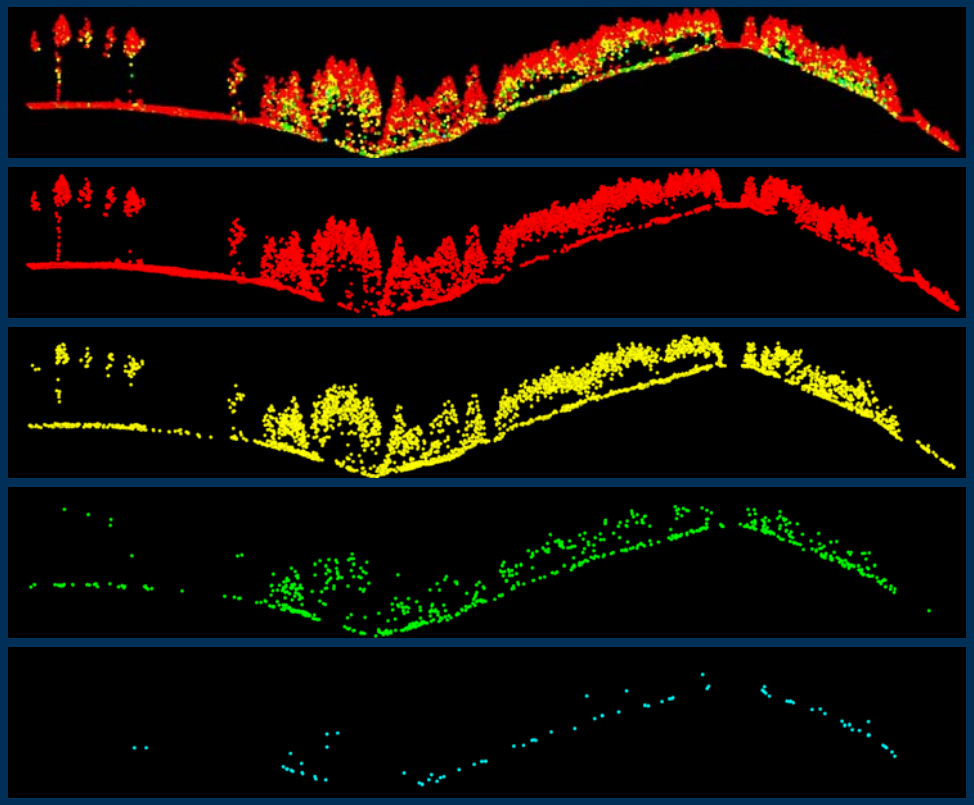
“Multi-Stop” lidars

measure the distances to *multiple* targets ($n \leq 5$) encountered by the laser pulse



Base image courtesy M. Lefsky

Multiple Return lidar systems



All returns (16,664 pulses)

1st returns

2nd returns (4,385 pulses, 26%)

3rd returns (736 pulses, 4%)

4th returns (83 pulses, <1%)

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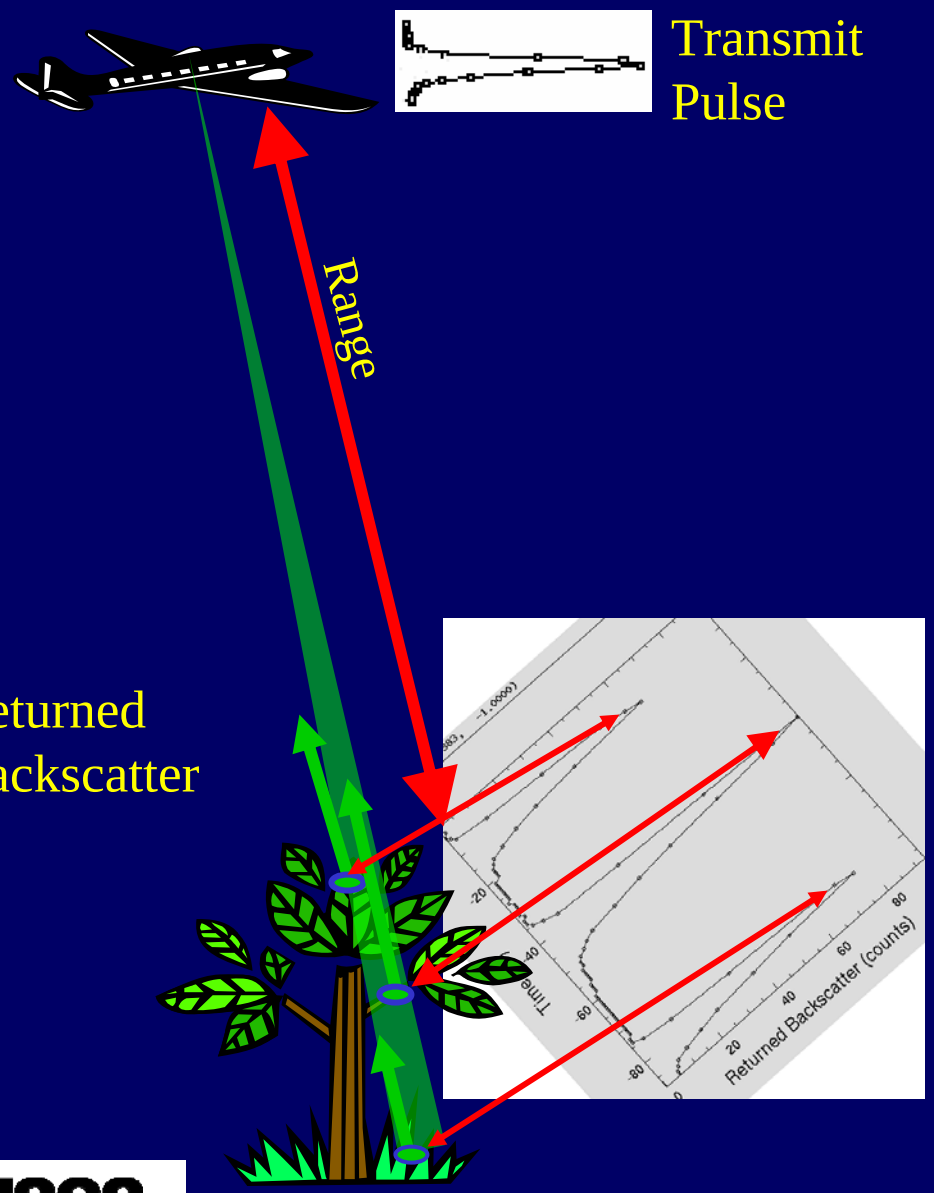
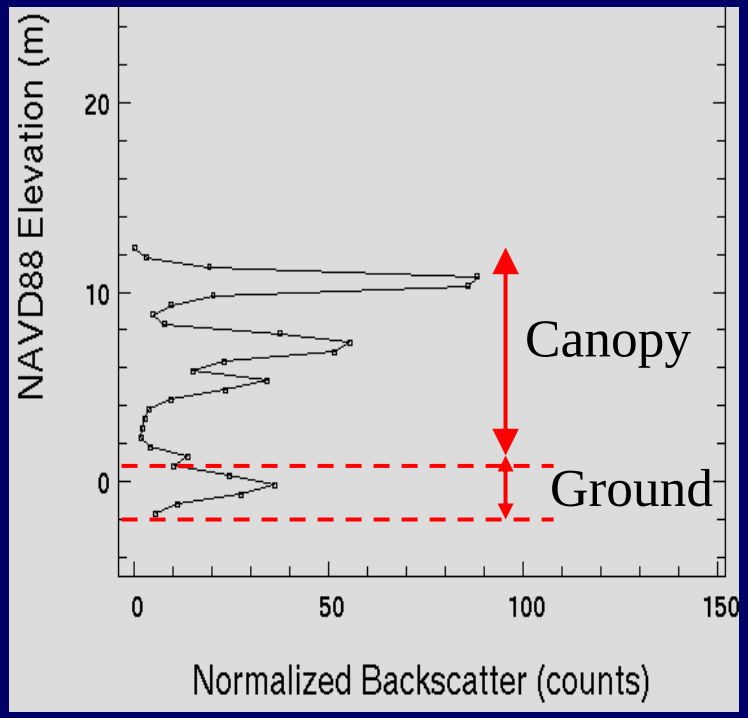
Image courtesy Hans-Erik Anderson

Small-footprint waveform-resolving lidar





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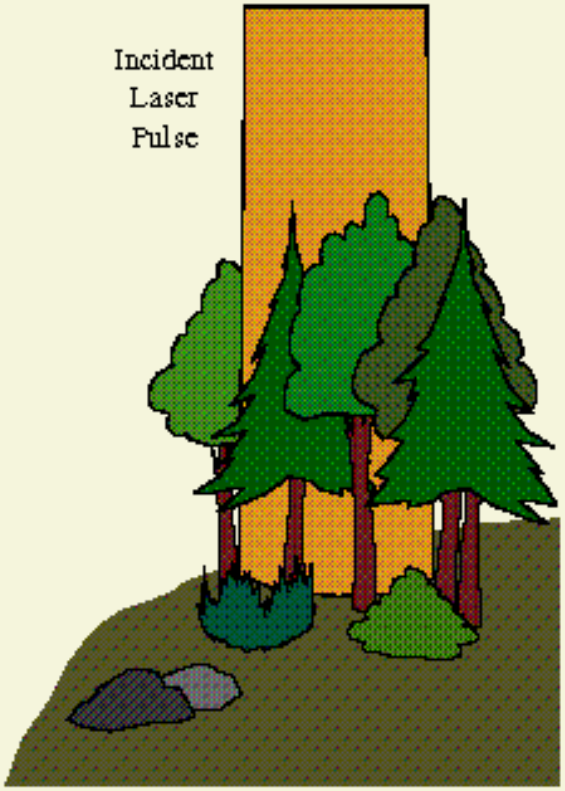
Large-footprint “waveform-resolving” lidars

measure a nearly continuous profile



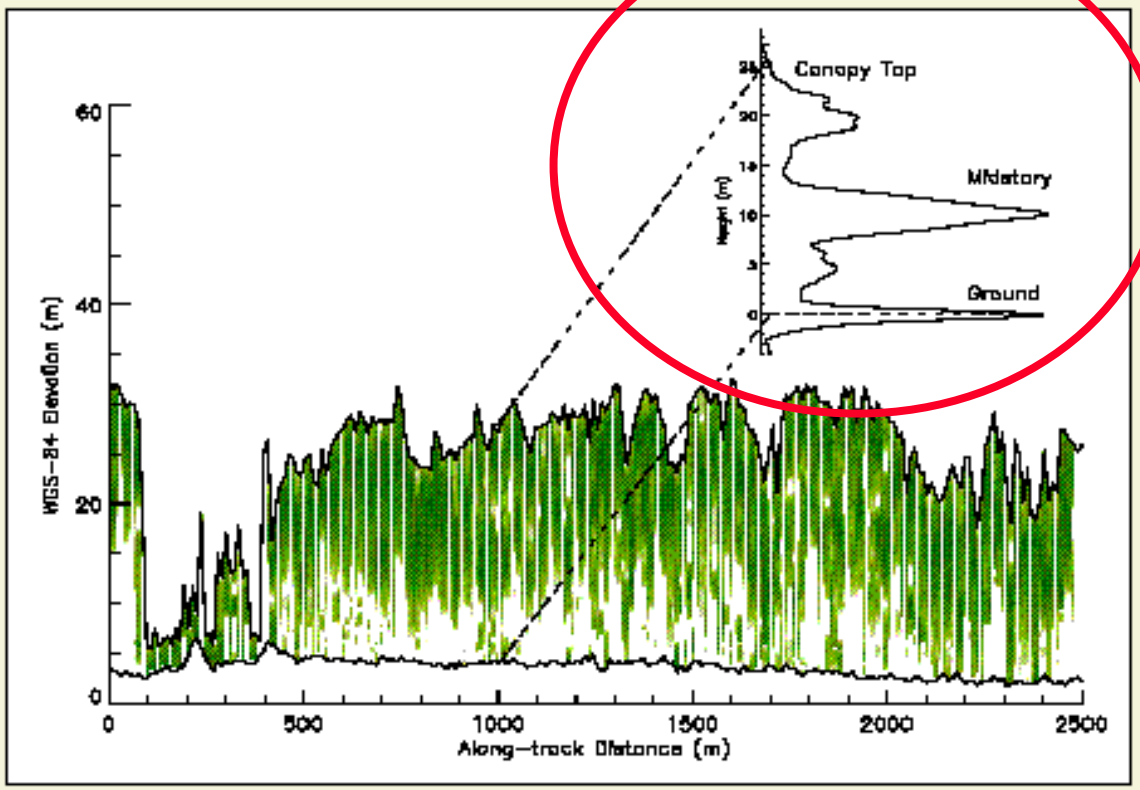
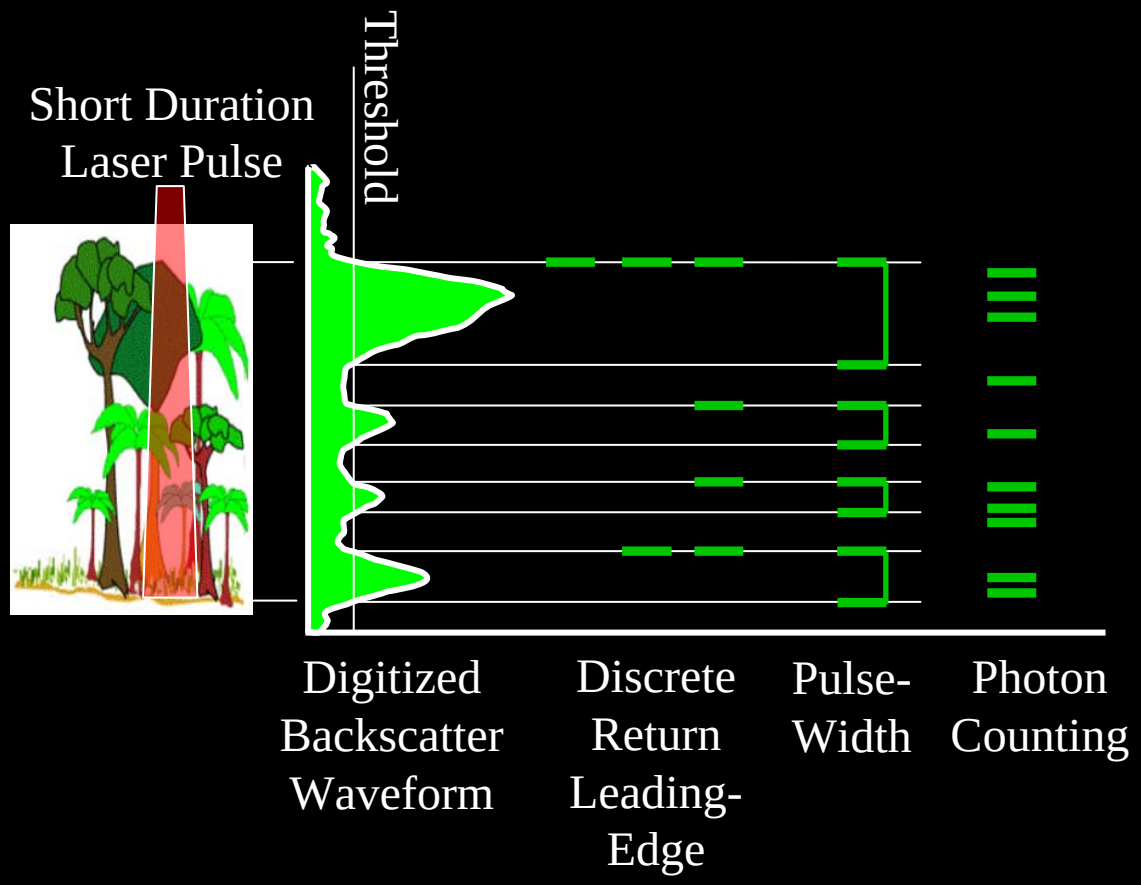
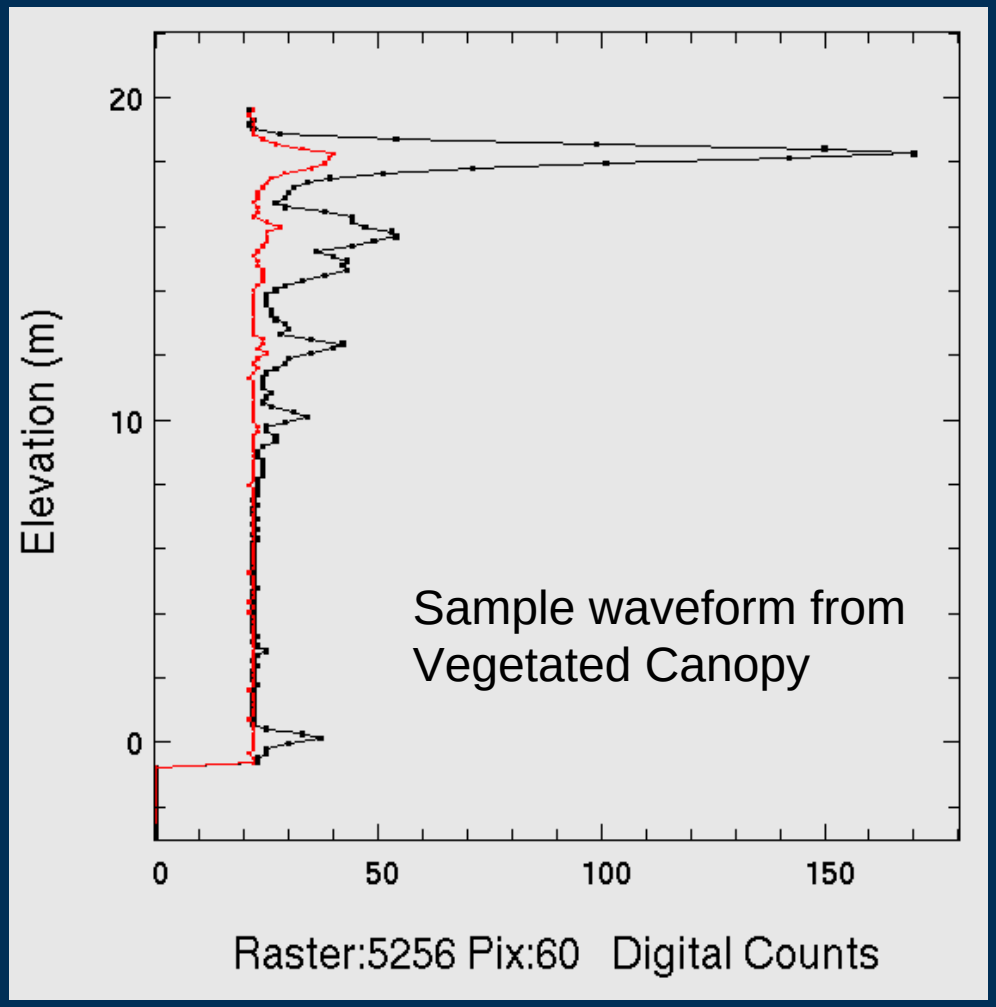


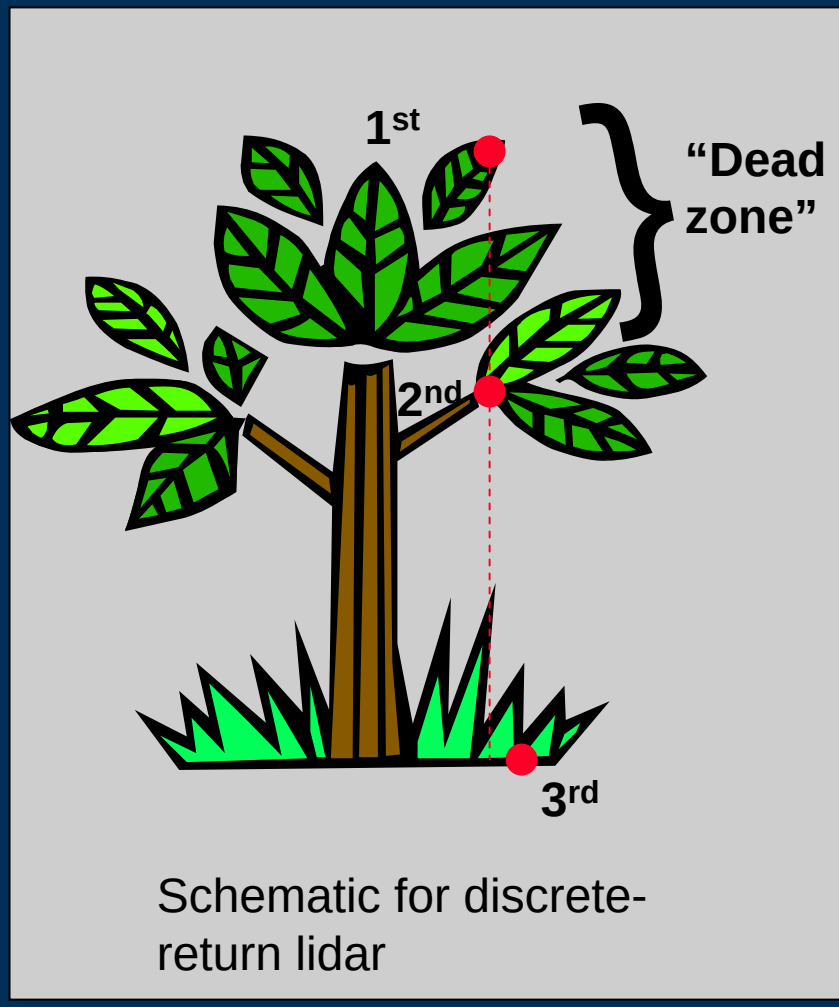
Image courtesy B. Blair, NASA

Different Laser Ranging Methods



Waveform-digitizing vs. Discrete-return





Schematic for discrete-return lidar

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Multiple Returns

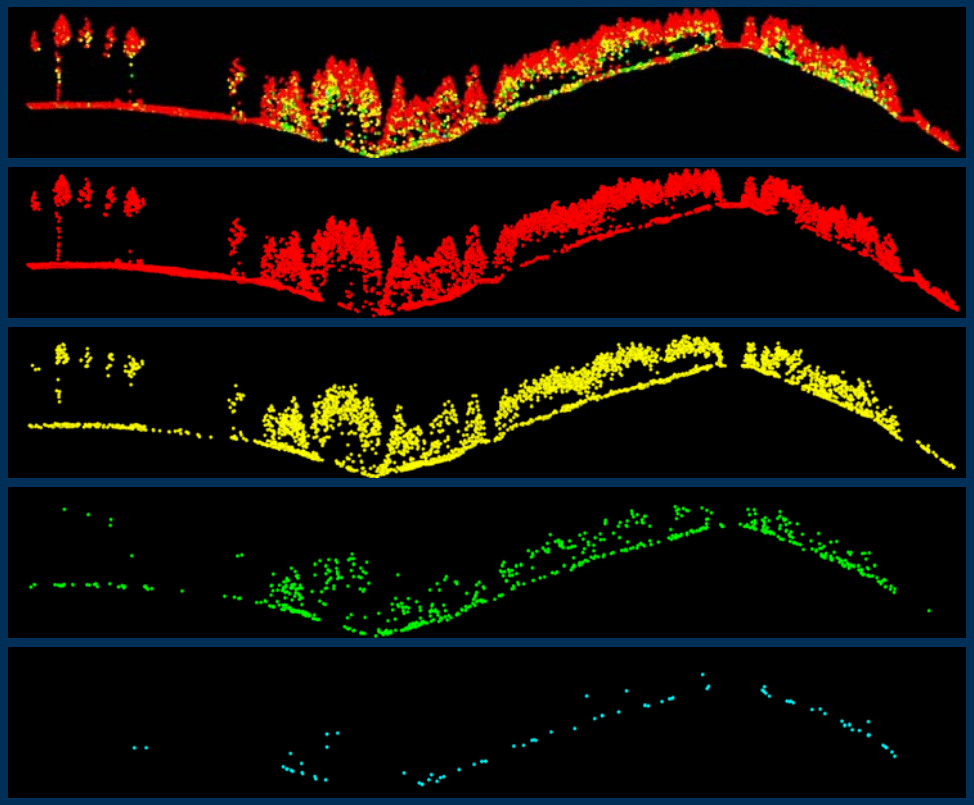

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Image courtesy Hans-Erik Anderson

Can Lidar can “see” through trees??

Reality:

Lidar can “see” through *gaps* in canopy-forming trees

Rule of thumb:

On a bright sunny day, if you can see sunlight on the ground, lidar will map it.

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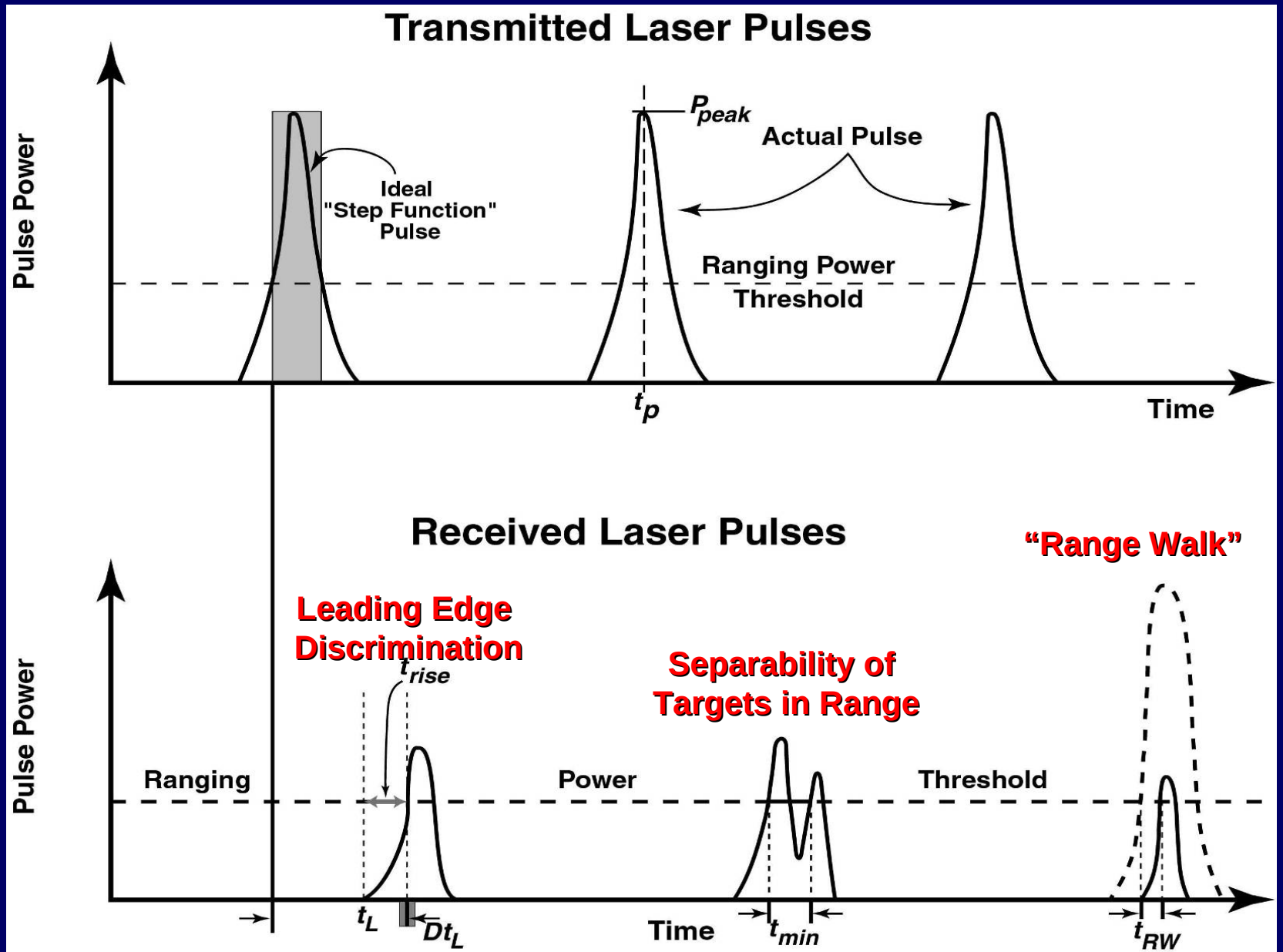
Accuracy and Resolution in Laser Ranging



Error Source 1:
Laser Ranging Accuracy

Ground tests and calibration conducted by airborne laser manufacturers suggest that the laser ranging is accurate to 1 – 5 cm.

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Lidar System Electronics and Design

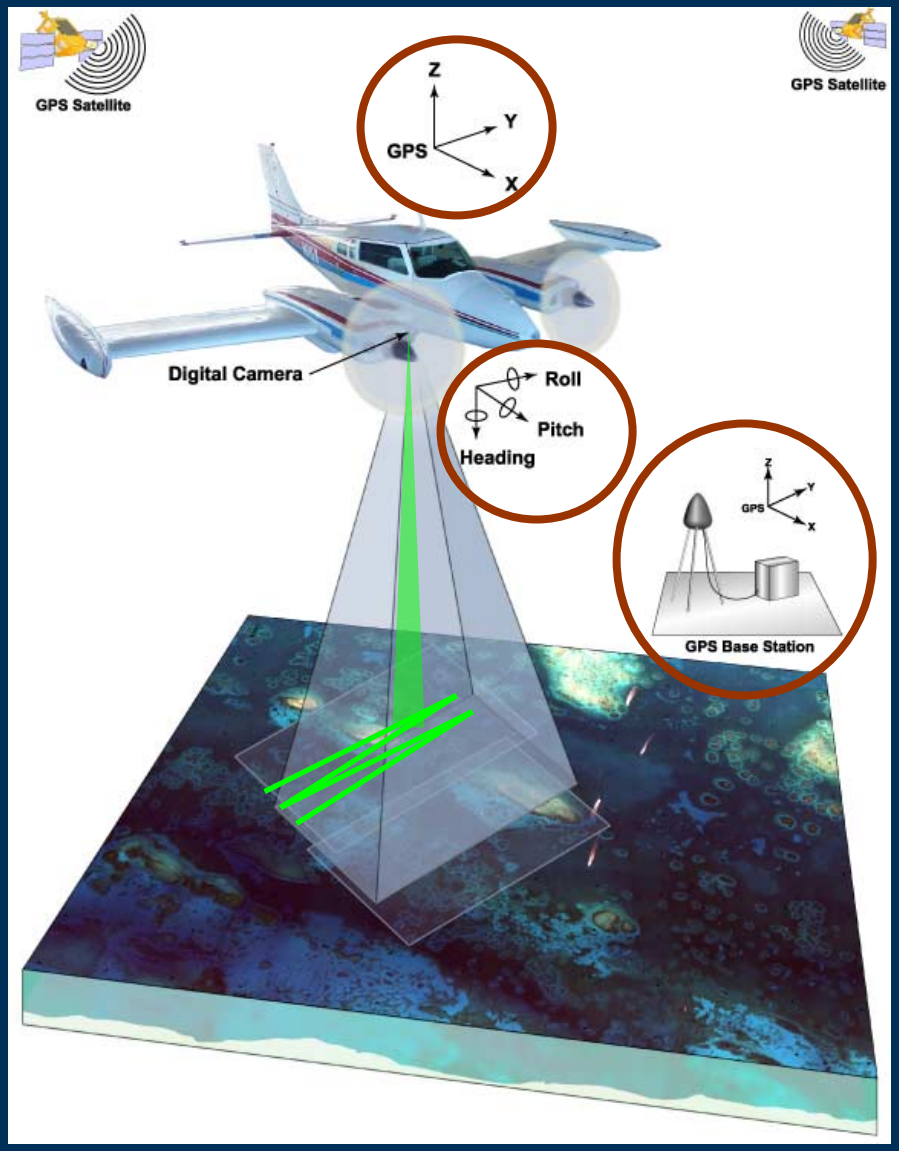
You gotta be kidding me!!!!!!!

Let’s just assume it works.

Enabling Technologies: Aircraft Position and Attitude Determination

Lidar System Components

- Lidar Transmitter, Scanner, and Receiver
- Aircraft Positioning – Differential GPS (with post-processing)
- Aircraft Attitude – Pitch, Roll, Yaw – Inertial Navigation System (GPS-Aided)



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Positioning using GPS

1. Space Segment
   - 24 satellites that orbit the earth 20,200km above the earth in 6 orbital places with 12-hour orbital period.
   - Design puts a minimum of 4 satellites in view at any time anywhere on the earth.
   - Satellites transmit L1 and L2 signals
2. Control Segment
   - Comprises MCS (in Colorado) and 4 other tracking stations throughout the world.
   - Controlling the operation of satellites and calibrating their orbits
   - Periodically uploads navigation and satellite clock correction parameters to satellites

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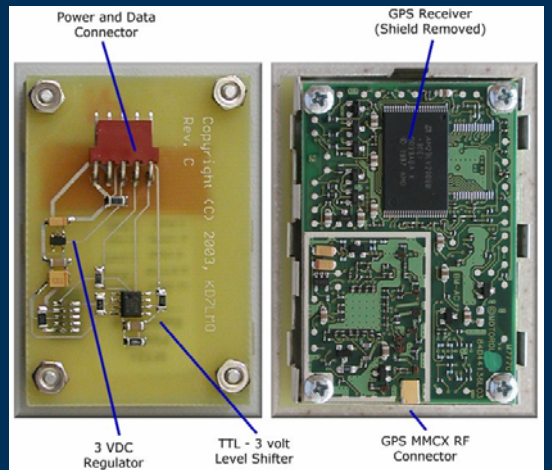
Positioning using GPS

3. User Segment

- GPS receivers
- **The receiver identifies each satellite's signal by its distinct C/A code pattern, then measures the time delay for each satellite.**
- Requires a minimum of 4 pseudoranges to solve for 4 unknowns: 3-D position and time solution error.
- Accuracy depends on GDOP – satellites used in the solution are uniformly distributed across the visible sky.



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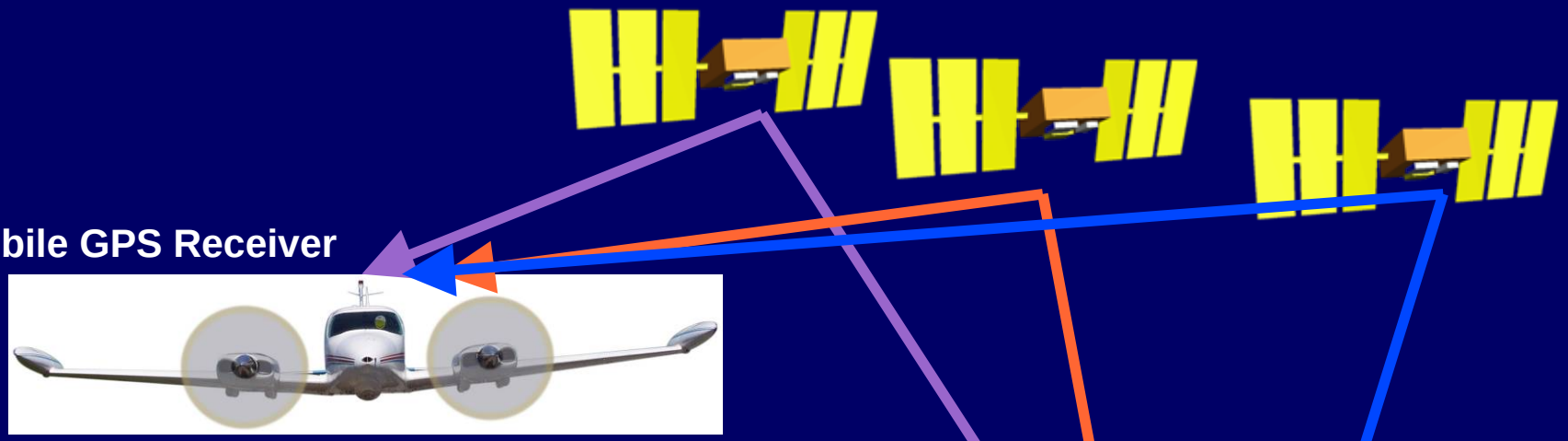
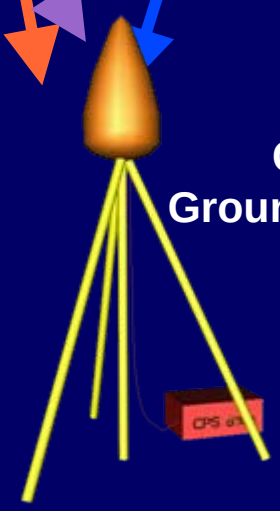
Positioning using GPS

GPS method	Description	Positional accuracy
Single Frequency	tracks only the CA pseudoranges and carrier phases of L1 carrier	8 – 20 m
Differential GPS	tracks L1 CA and carrier phase, and computes a derived L2; requires base station	1 – 3 m
Satellite-based Augmentation Systems	25 reference receivers in US; real-time diff. GPS correction	1 – 3 m
Precise phase interferometry processing	Differential GPS + Kinematic Ambiguity Resolution (KAR)	Up to 10 cm
Network Differential GPS	Network of base stations	Improves accuracy



- Differential GPS aircraft positioning.
- Post-processing of GPS ground and aircraft data
- Uses the difference in the dual frequency (L1, L2) carrier phase-derived ranges for the ground and aircraft.
- Provides aircraft position at submeter accuracy.



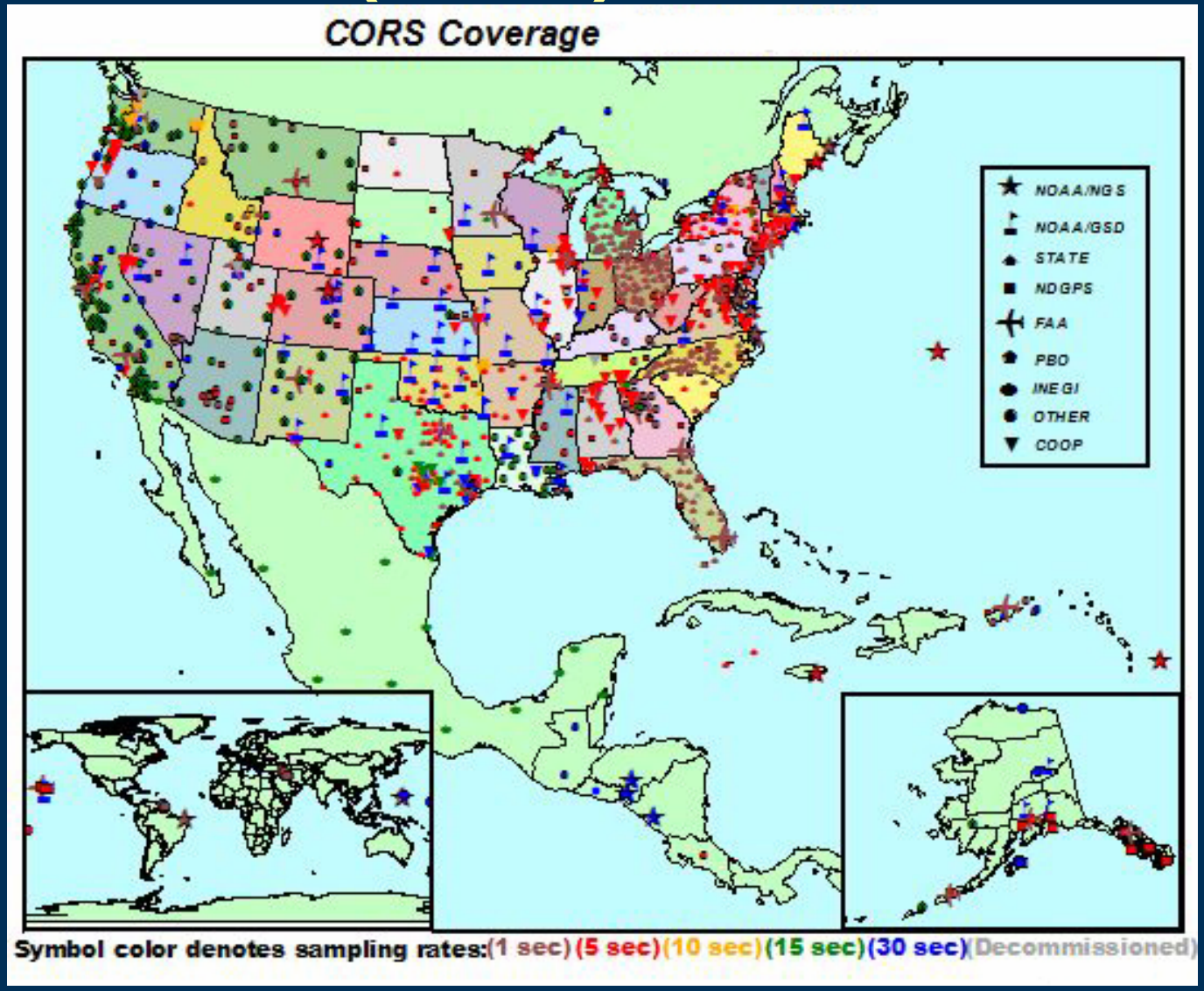
Typical Airborne DGPS Relative Positioning Errors:

Error Source	Error for 50 Km Baseline (m)
Orbital	0.05
Ionospheric	0.05 – 0.50
Tropospheric	0.10
Signal Multipath	0.05
Receiver Noise	<0.025
Total Error	0.1 – 0.5 (Maune, 2001)

Clear Horizon

Base Station at Staging Airport

Continuously Operating Reference Stations (CORS) Network



Planning Considerations

- Time of day of mission
  - Low PDOP values
  - Ionosphere activity is quieter at night
- Use choke ring antenna when possible
  - Reduces multipath error
- Baseline length must not exceed 25-30 km
  - Use multiple base stations when possible
- Find out about any surrounding activity
  - Lajas Aerostat (radar balloon) in PR
- Post-processing of GPS trajectories
  - Rapid solution (same day)
  - Ephemeris solution (next day)
  - Precision solution (2 weeks later)

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Error Source 2:
GPS positioning error

- Horizontal (XY) positioning error up to 1 meter
- Vertical (Z) error is much higher in sloping terrains (usually less than 10 cm)

GPS error contributes most to the Error Budget

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GPS-Aided Inertial Navigation System

- GPS Receiver (DGPS solution)
- Inertial Measurement Unit
  - Comprises 3 accelerometers and 3 gyros arranged in an orthogonal triad
  - Measures the local gravity vector, acceleration vector, and angular rate vector experienced by IMU
  - Typical sampling rate = 200 Hz
- Post-processing GPS-IMU software
  - Converts measured accelerations and angular rates along with GPS positioning to Pitch, Roll, and Heading

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Planning Considerations

- GPS planning as discussed earlier
- Inertial Navigator alignment
  - Stationary ground alignment
  - In-flight alignment
- Quality Control
  - Needs to be combined with lidar data for QA/QC

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Error Source 3:
Aircraft Attitude positioning error

If properly calibrated:

- Horizontal (XY) positioning error about 10-50 cm
- Vertical (Z) error usually less than 5 cm

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Boresight Calibration

- Corrects for mounting misalignment between the IMU and lidar reference frame.
- Typically requires airborne calibration using a reference surface test.
- Need to correct for pitch, roll, and heading offsets

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Roll bias correction

- Flight lines flown with overlap over runway or parking lot in opposing directions is used for roll bias correction.
- Roll misalignment angle will cause the cross sections to look like an ‘X’ when they are overlaid.

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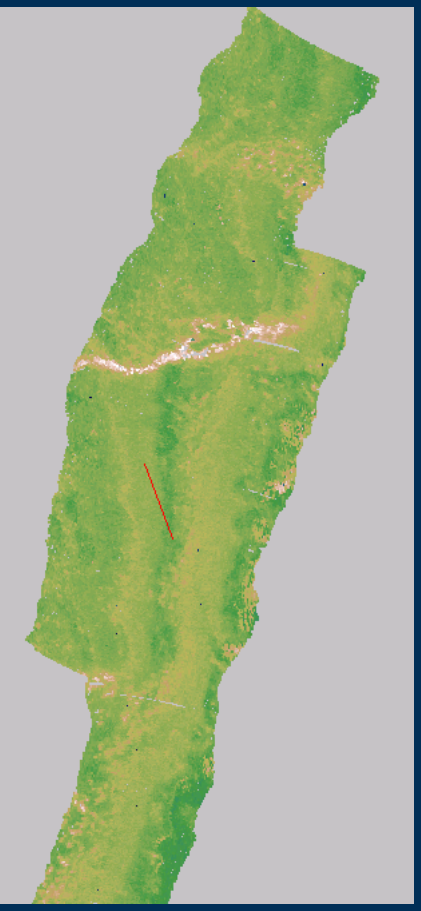
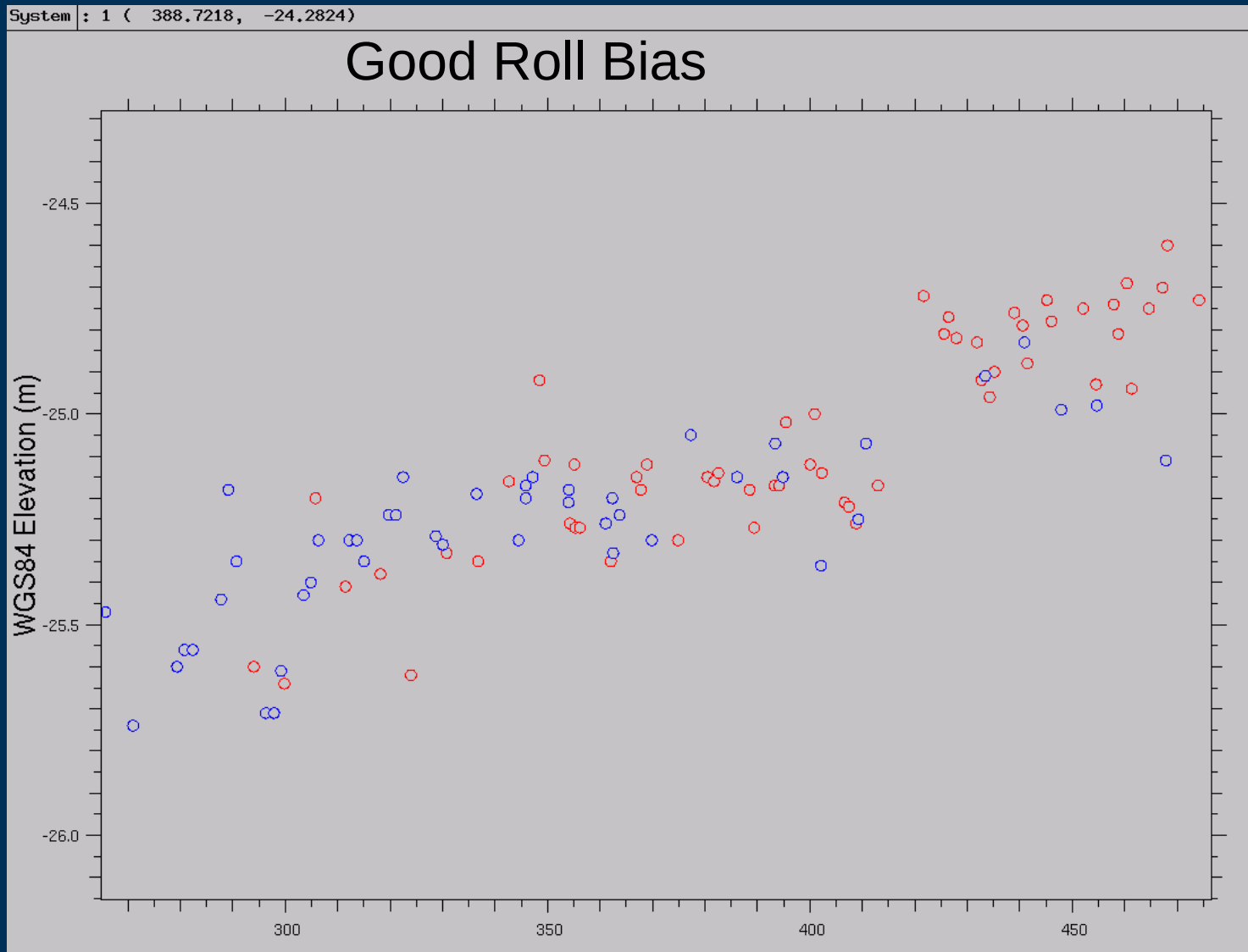
Good Roll Bias Values

Roll bias correction

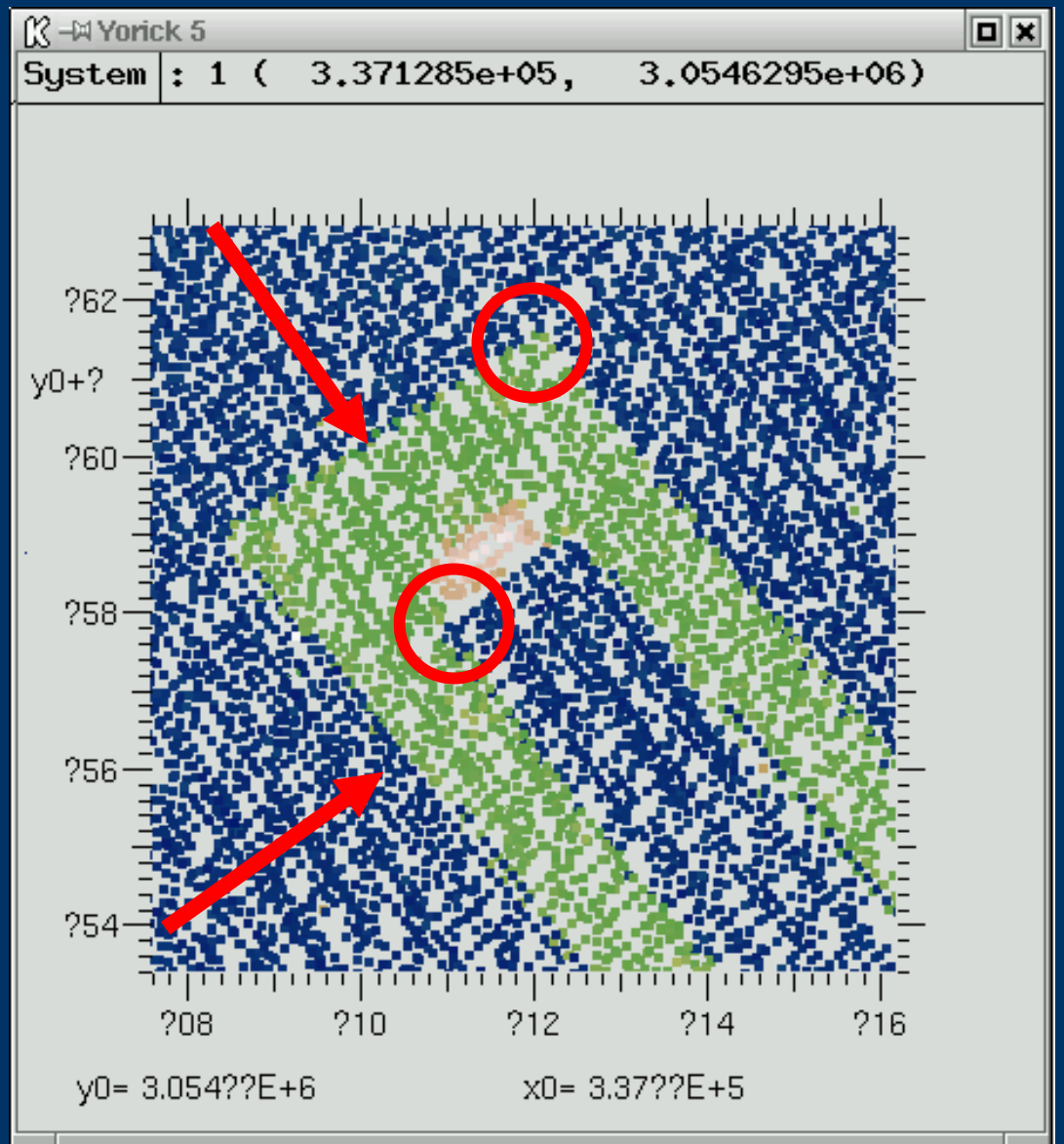




Boresight Calibration

This Hanger was Surveyed By 2 Overpasses at 90º

Note the flightline-to-flightline agreement In Edge Discrimination



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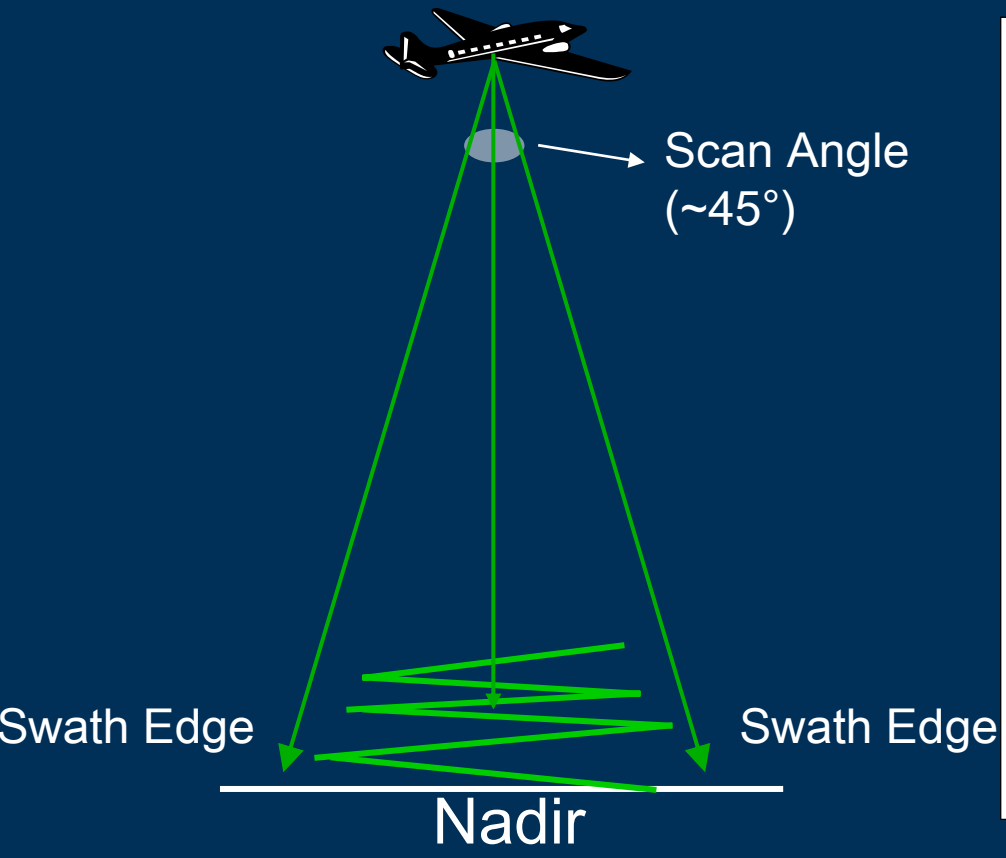
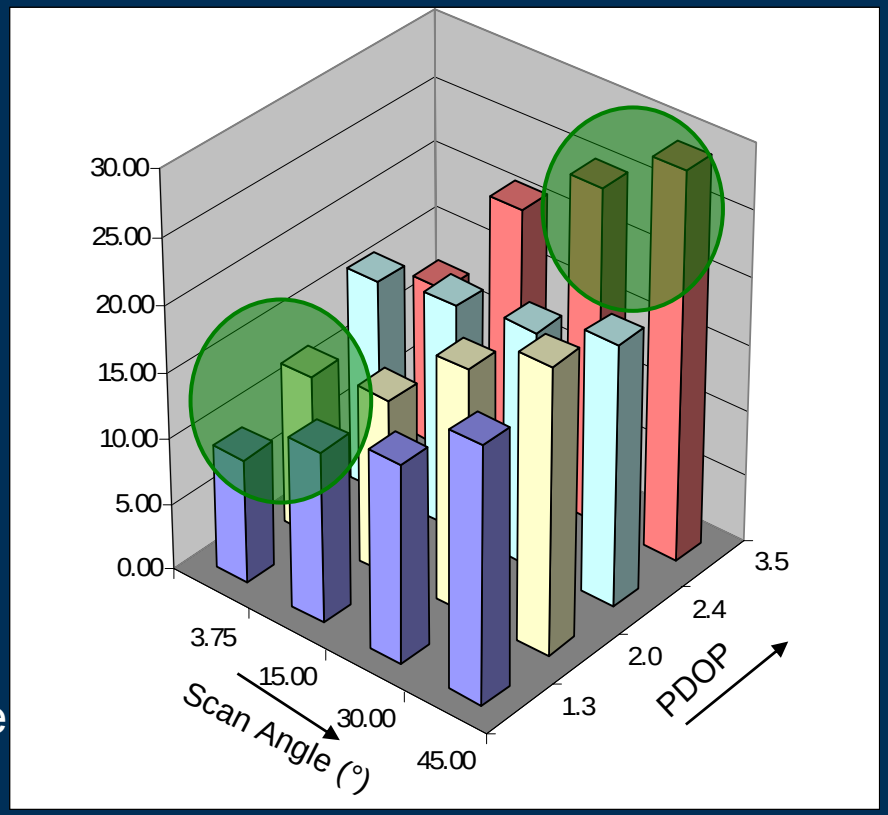
Effect of GPS and Scan Angle on vertical accuracy





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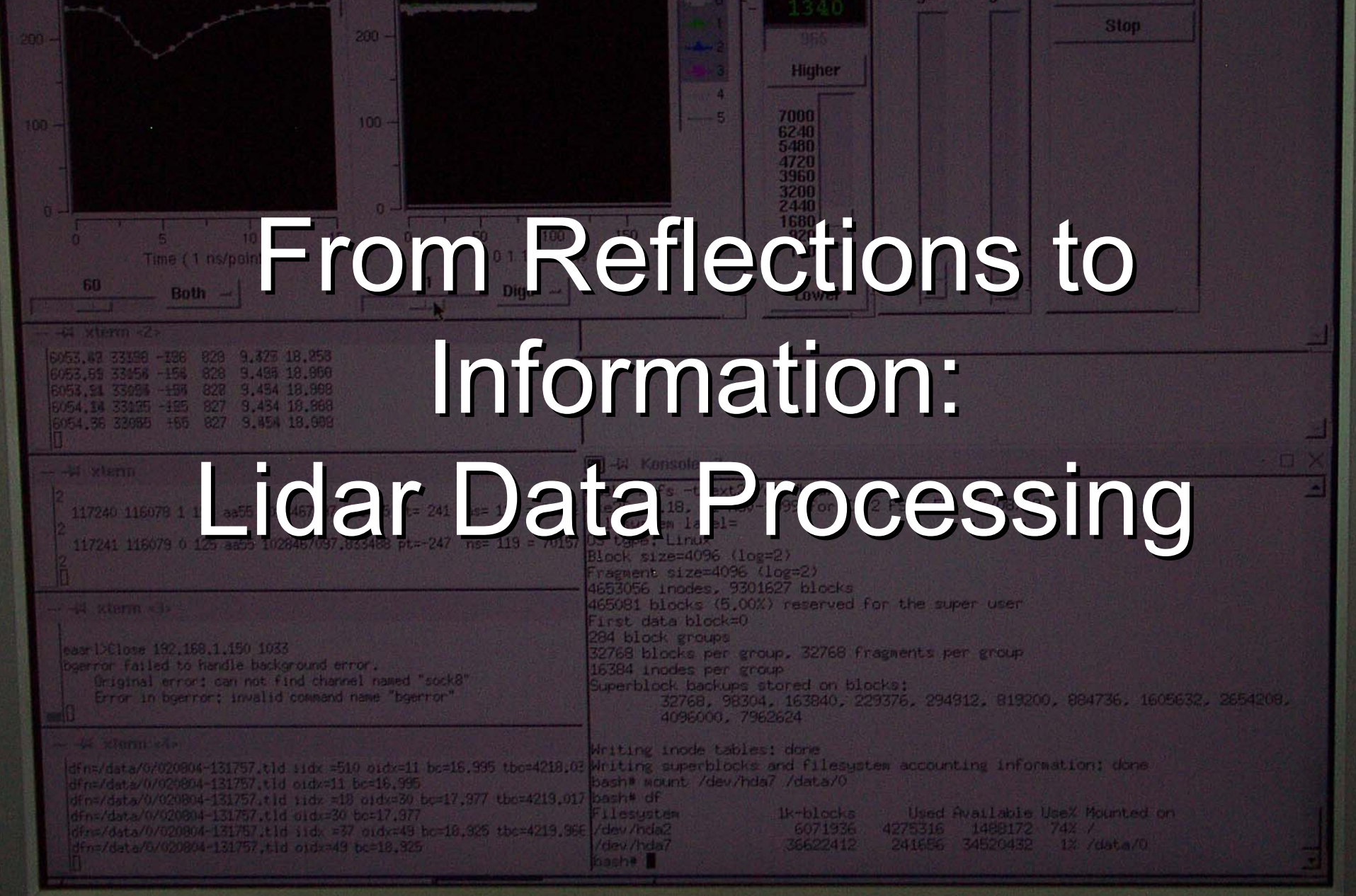
From Reflections to Information: Lidar Data Processing



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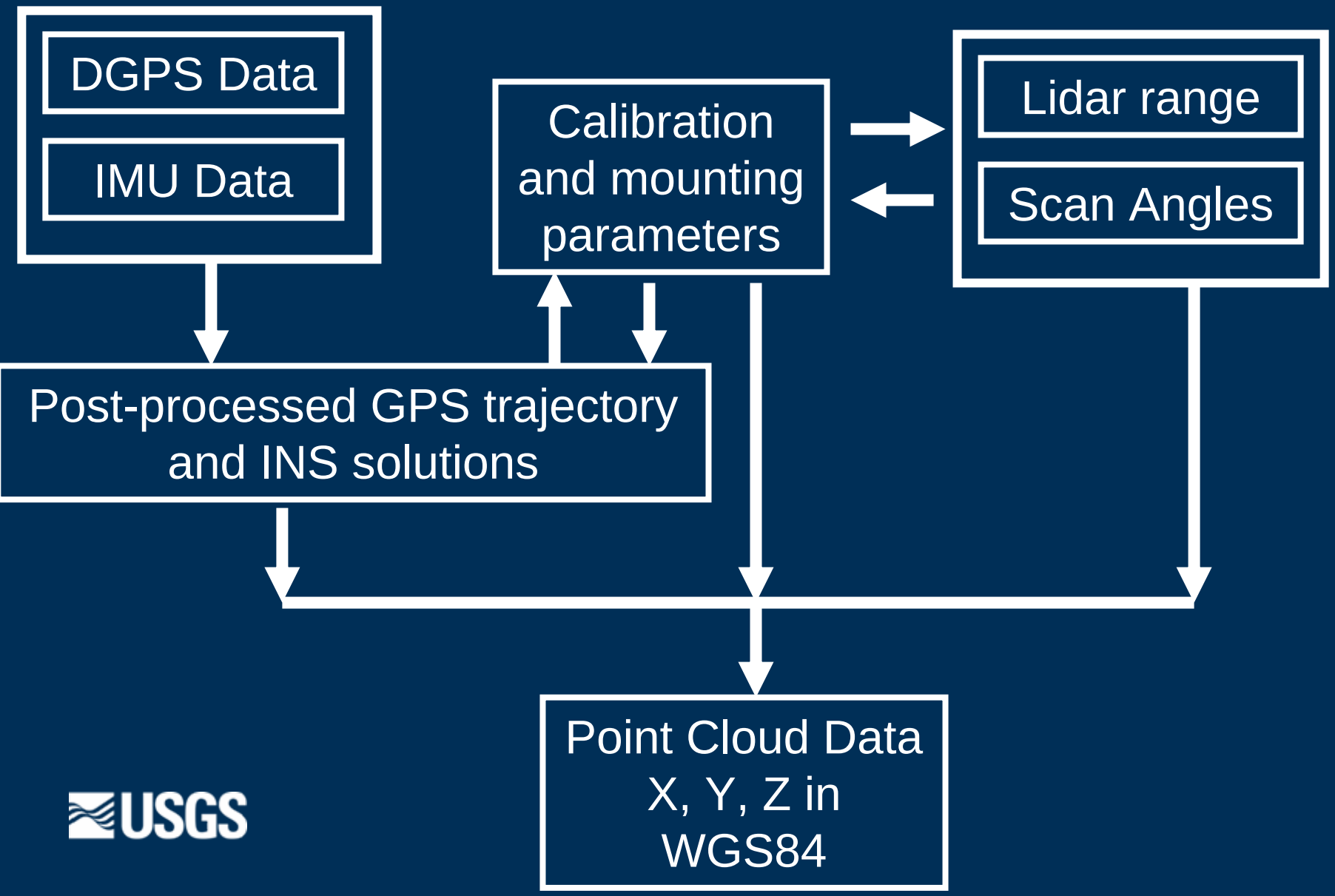
Lidar Data Processing



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Lidar “point cloud” data

- Points may be first, intermediate or last returns
- Erroneous (outlier) points might include reflections from objects such as birds, atmospheric effects (dust, moisture), multiple reflections, very bright points.
- Data may be stored in text format or in binary (LAS) format
- 2 km x 2 km (~990 acres) area with 3-4 points / m^2 will contain 9 – 12 million points.

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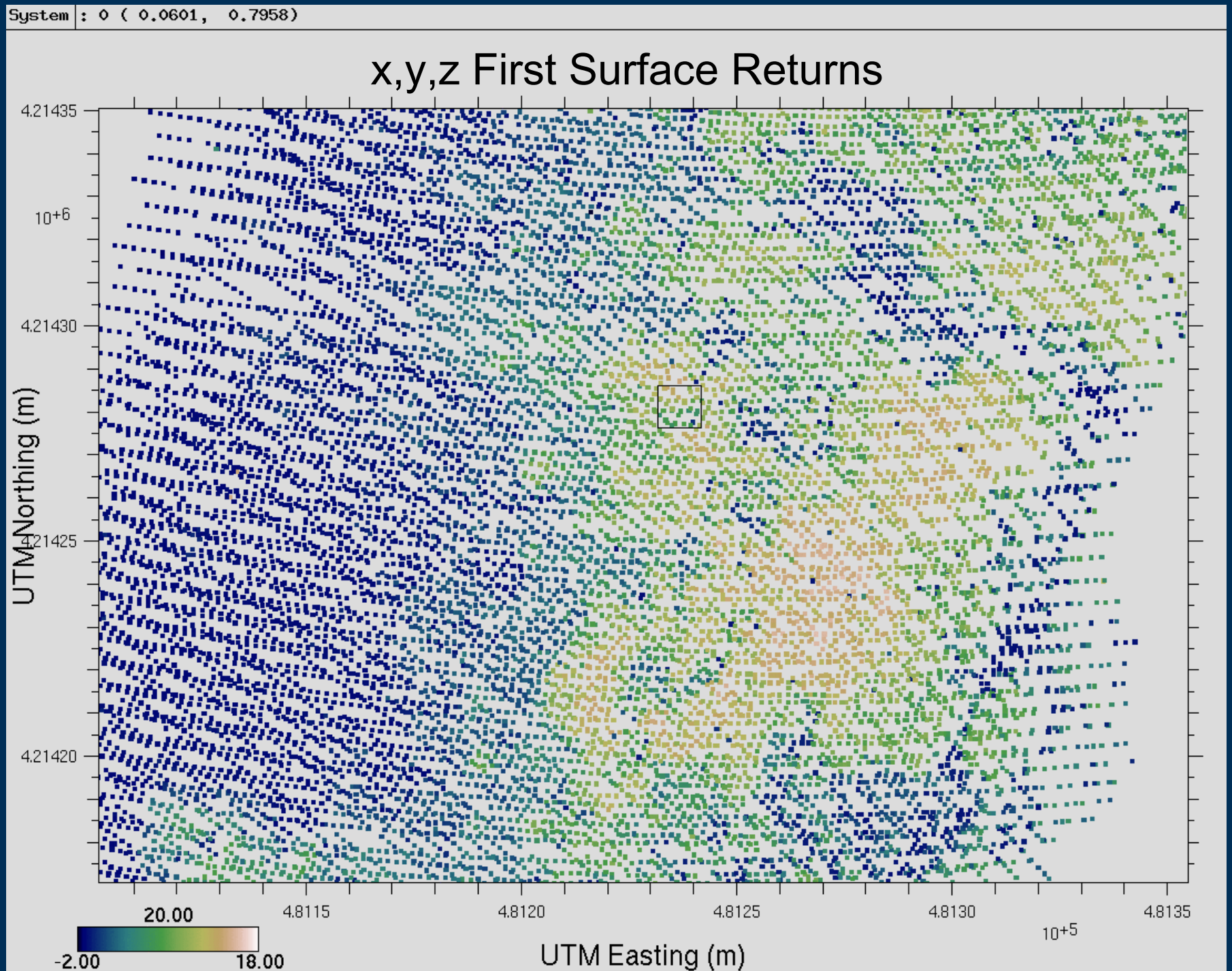
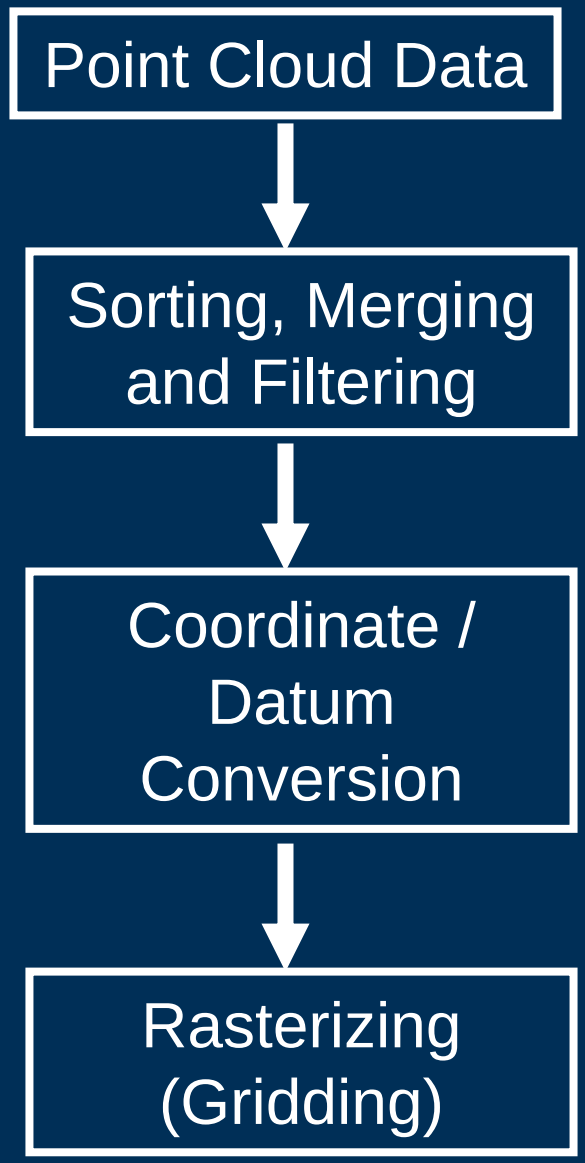

System : 0 (0.0601, 0.7958)
x,y,z First Surface Returns
4.21435
10+6
4.21430
4.21425
4.21420
UTM Northing (m)
4.8115
4.8120
4.8125
4.8130
4.8135
10+5
UTM Easting (m)
20.00
-2.00
18.00

Lidar Data Processing



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Output data types

- Canopy-top (first return) elevations
- Bare-Earth elevations
- Building models
- Vegetation metrics (multiple return or waveform-resolving systems)
- Intensity returns

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Laser Intensity Image of NASA Wallops Flight Facility

Filtering for bare-Earth

- Almost all algorithms are proprietary
- Software available to classify lidar data (ground, vegetation, buildings, etc.)
- Automated processing algorithms typically remove 90-95% of non-ground points, the remaining 10% may consume 90% of the budget.

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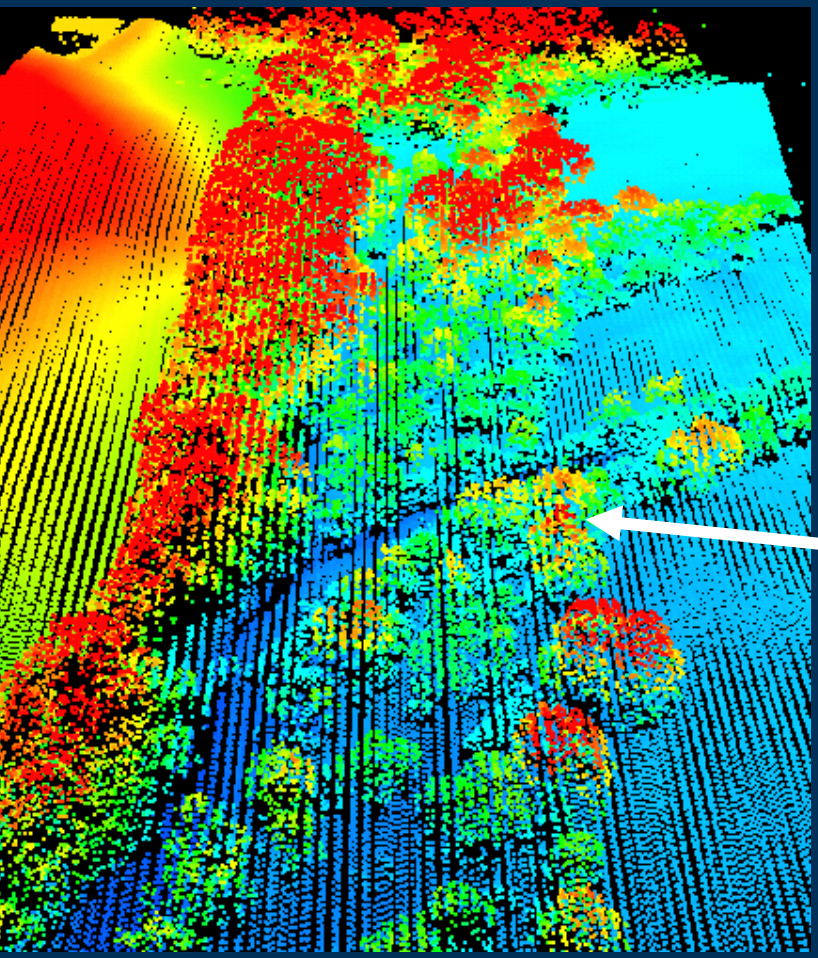
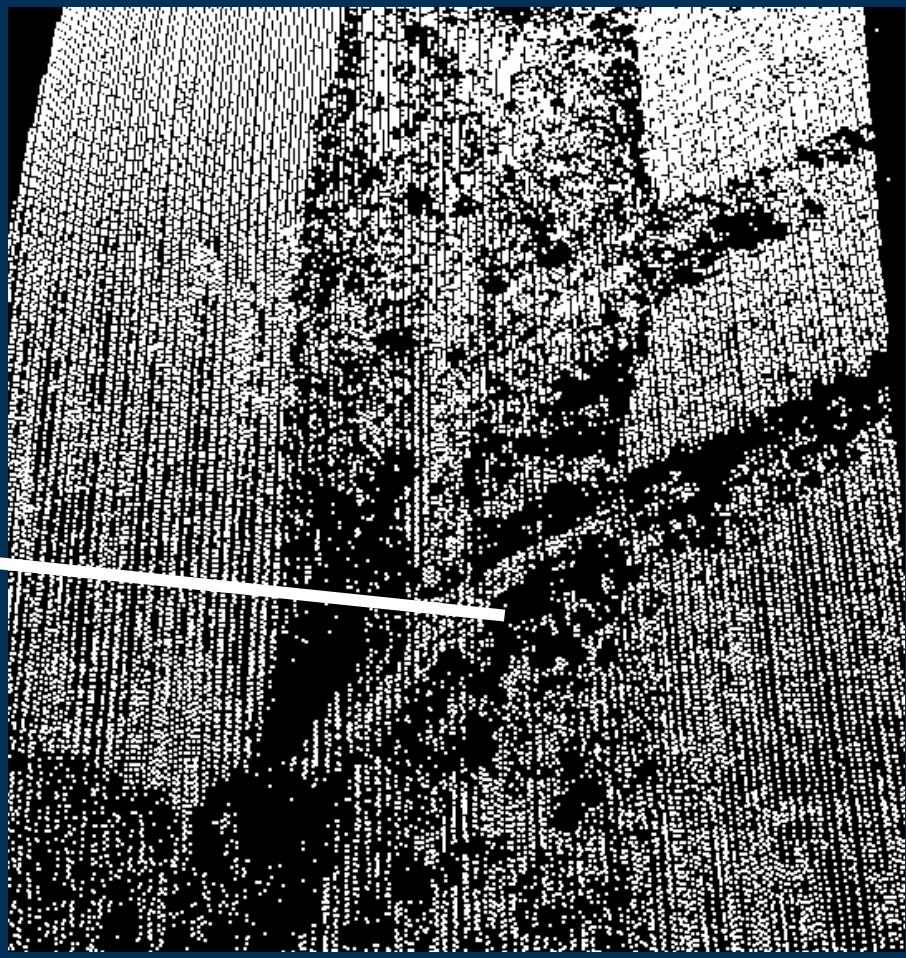
Vegetation Effects on Terrain Model

Point Cloud Elevation Stretch

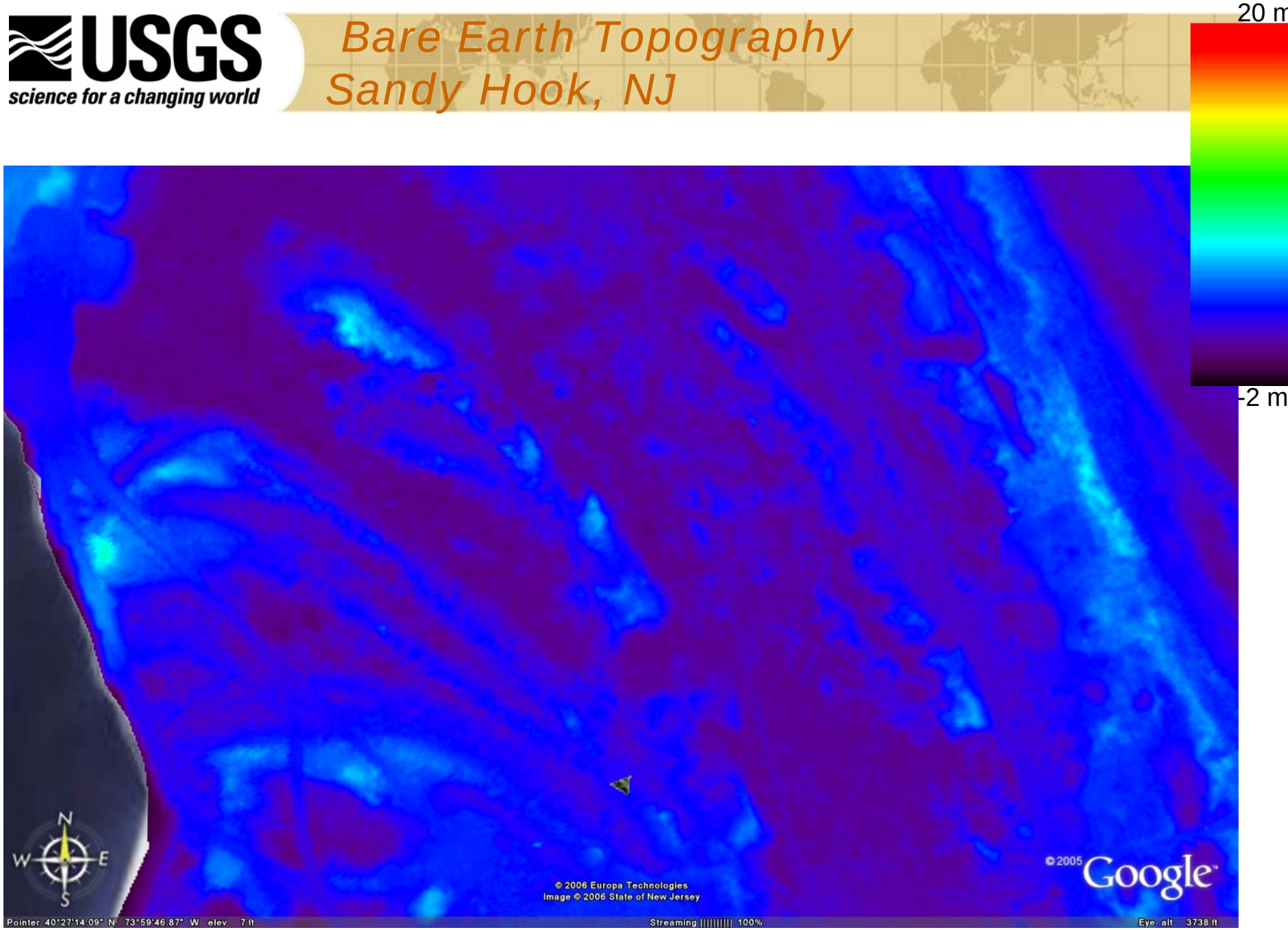


Bare Earth Points used to create surface



Images courtesy Hans Erik Anderson

Bare Earth Topography
Sandy Hook, NJ



Error Source 4:
Filtering / Processing error

- “Vegetation” noise
- Bare Earth under short grasses are much harder to determine (“dead zone” effect)
- Error depends on the type of surface being mapped – ranges from a few cm in open canopies to up to several meters in closed canopies and sloping terrains.

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Coordinate / Datum Conversions

- GPS data are processed in WGS84 coordinate system using the ITRF00
- Data are usually converted to NAD83, based on the GRS80 ellipsoid
- Horizontal offset between WGS84 and GRS80 is minimal; but vertical offset can exceed 1 m.

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Vertical Datums

- Conversion of ellipsoid heights to orthometric heights using the GEOID model (NAD83 to NAVD88)
- Geoid is a specified equipotential surface which best fits, in a least squared sense, to global mean sea level.
- GEOID is NOT a local mean sea level datum, nor is it a tidal datum.
- Users should reference their products to the latest National Vertical Datum (i.e. NAVD88 using GEOID03)

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Error Source # 5: Datum / Coordinate Conversion Errors

- Minimize datum / coordinate conversions especially when comparing data sets.
- NOAA NGS VDatum Tool can be used in coastal regions
- 1 – 5 cm may be added with each datum transformation.

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Rasterizing Point Cloud Data

- Point cloud data converted to a regular grid
- Typically uses Delaunay Triangulation followed by interpolation
- Output data type is usually a Geotif file (32-bit floating point format)
- Geotif includes geo-referencing information in the same file
- Should be careful when interpolating over gaps in bare earth under dense canopies.

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Error Budget

1.	Laser ranging accuracy	1 – 5 cm
2.	GPS positioning error	5 – 100 cm
3.	Attitude system error	3 – 15 cm
4.	Terrain type (vegetation “noise”)	1 – 100 cm
5.	Coordinate / Datum conversions	1 – 10 cm
6.	Rasterizing (Gridding)	?
7.	Time synchronization errors	?

Total Error 11 – 230 cm

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Error Budget

- Expect the overall vertical accuracy to be about 15 cm (6 inches)
- Expect the overall horizontal accuracy to be sub-meter.
- There are ways to improve this accuracy:
  - Multiple base stations in study area
  - GPS / IMU post-processing
  - Boresight calibration
  - A few high-accurate GPS ground control points can help reduce offsets

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Determining lidar errors

- Root Mean Square Error (RMSE) DOES NOT account for offsets in data.
- Mean Error (ME) is a good indicator of any offsets in data.
- Use GPS ground control points to improve the overall accuracy by reducing the offsets.

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Commercial Lidar Processing and Visualization Software

- Terrasolid's TerraScan and TerraModeler
  - $6K for TerraScan, $4K for Modeler, $300 for viewer
- Merrick's Advanced Remote Sensing (MARS) Software
  - Free viewer, Explorer, Explorer Pro, Tool Suites
- QT Modeler (Tinning and visualization)
  - Free viewer, $3K
- Lidar Explorer Version 2.0 for ArcGIS (9.x)
  - Free lidar viewer, $2K for license
- Interactive Data Language (IDL) for custom routines

Commercial Lidar Visualization and Analysis Software

- Any GIS software package can be used to visualize and analyze gridded (geotif) data
- Global Mapper is my favorite
  - $300!!!!!
  - Direct access to Terra Server Imagery
  - Excellent support service
- ITT VIS ENVI / IDL (build your own custom applications)
- Google Earth

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Major advantages of Lidar

- Lots of data points; makes for a very good approximation of the surface
- Can penetrate through gaps in trees and provide detailed topography of bare Earth
- Can provide detailed information of vertical distribution of canopies
- High-resolution submerged topography in relatively clear and shallow water
- The accuracy will improve with enhancements in GPS technology

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Thank you.