Green, waveform lidar in topo-bathy mapping – Principles and Applications

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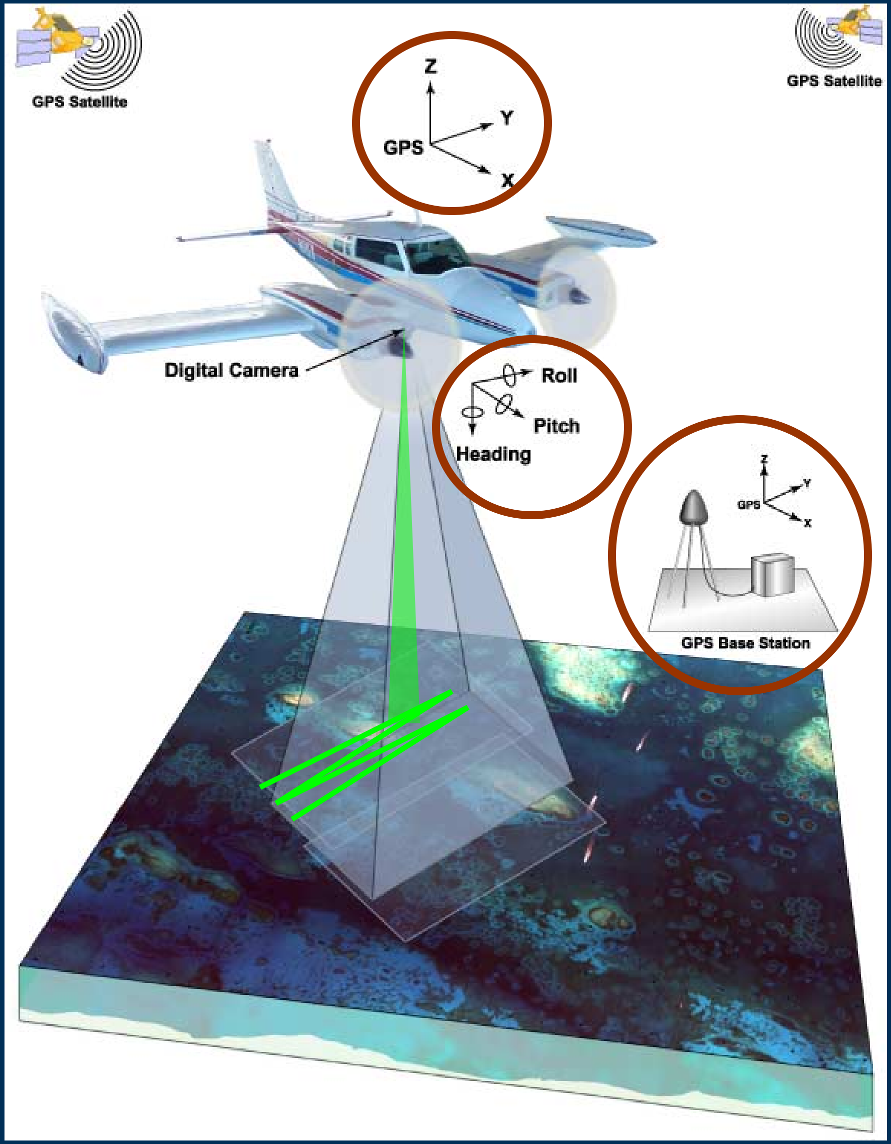
U.S. Department of the Interior
U.S. Geological Survey

Airborne 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)
- Data System



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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 laser which can produce radiation at an IR wavelength of 1064 nm
  - Easily absorbed at the water surface (unreliable water surface reflections).
  - Wavelengths utilized: 1000 – 1500 µm
- Blue-Green Wavelength
  - Used by all airborne bathymetric and “topo-bathy” systems
  - Solid-state IR laser output is frequency doubled to produce output at 532 nm
  - Can penetrate water, but signal strength attenuates exponentially through the water column

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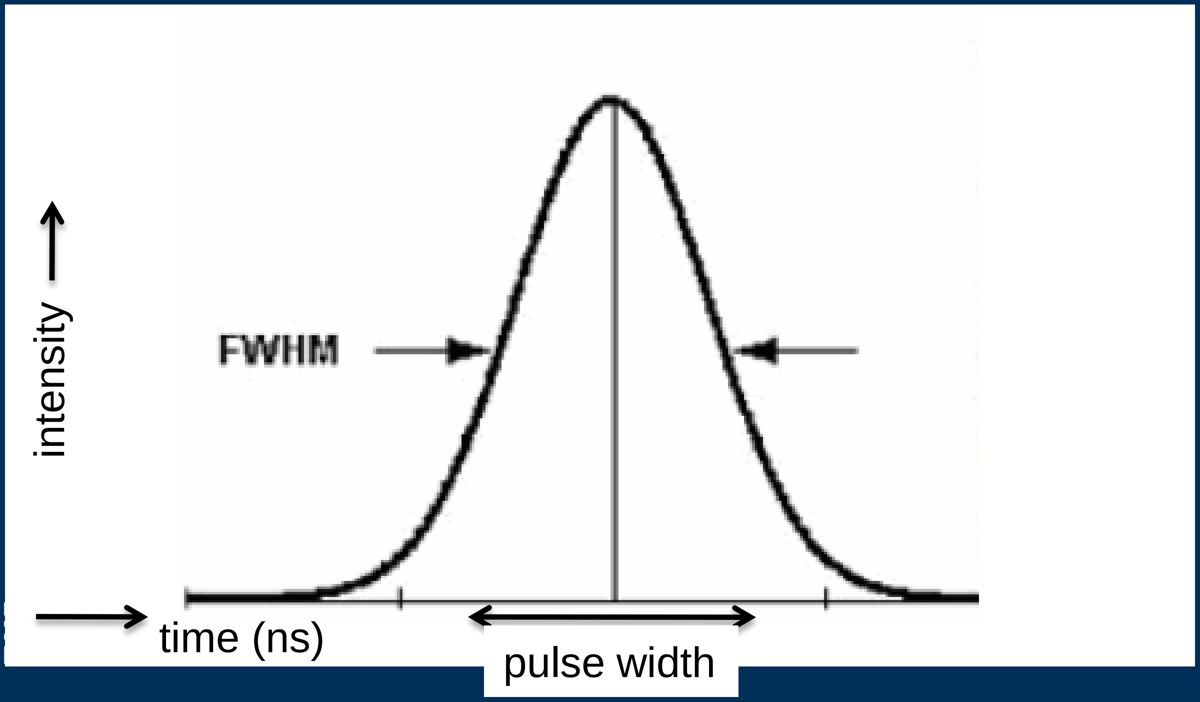
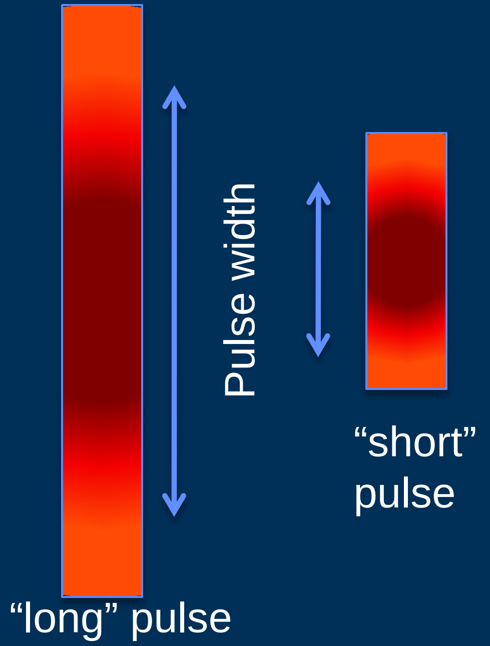
Laser system characteristics – Pulse width

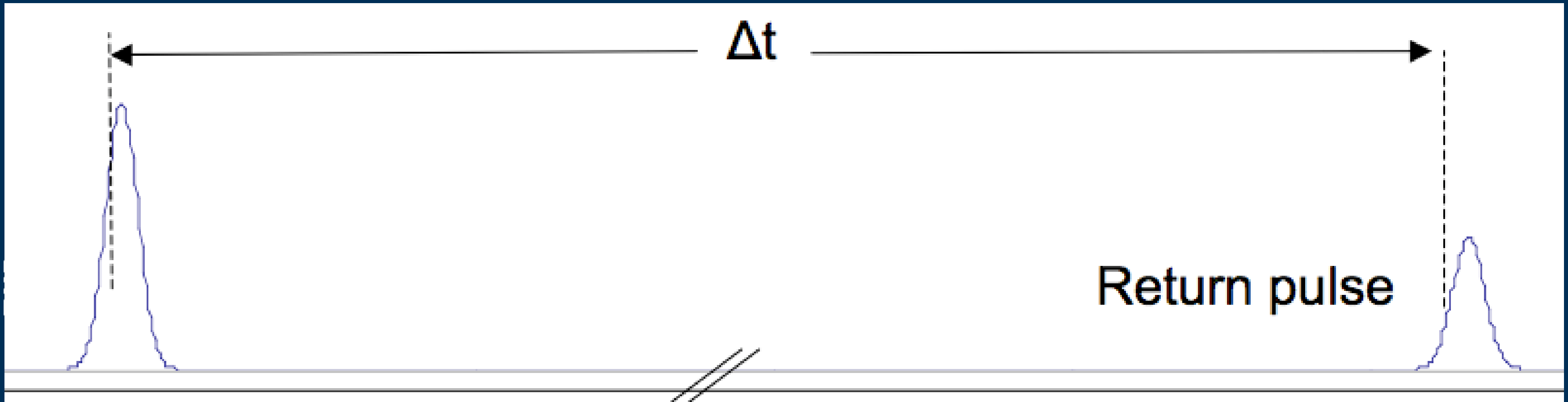
- Pulse width (or duration) is usually defined as the time during which the laser output pulse power remains continuously above half its maximum value (FWHM)..





Laser system characteristics – Pulse energy, shape and footprint

- Pulse energy – total energy content of a pulse
  - typically < 50 µJ for land topography and < 5 mJ for bathymetry
- Laser beam is typically a diverging Gaussian beam (“waveform”)
- Spot size (footprint) at given range is given as a radius or diameter of the contour where the intensity has fallen to either 1/e or $1/e^2$ of the intensity of the peak.
- Return pulse shape is the result of the interaction of the transmit beam
- Target characteristics influence shape of the return pulse
  - Sloping or rough terrain produces wider return pulses
  - Multiple targets separated by small distances produce complex waveforms



Different Laser Ranging Methods

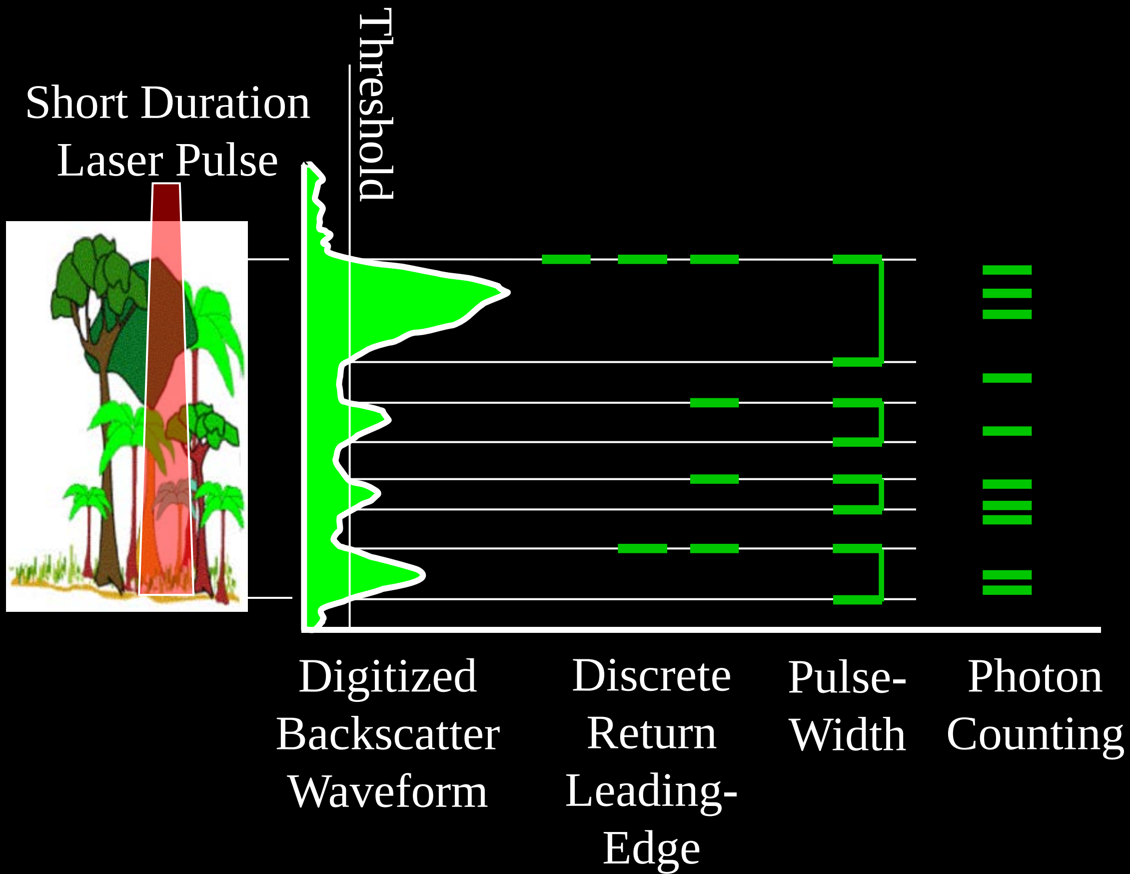
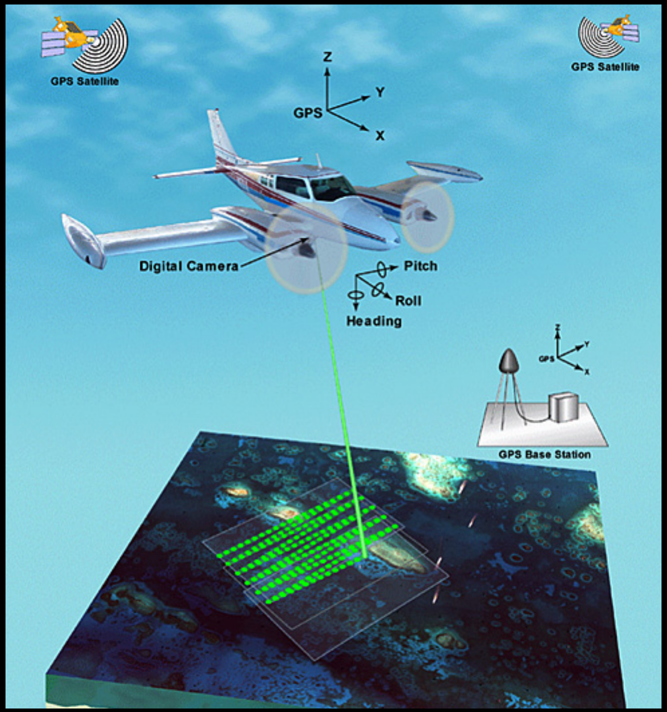
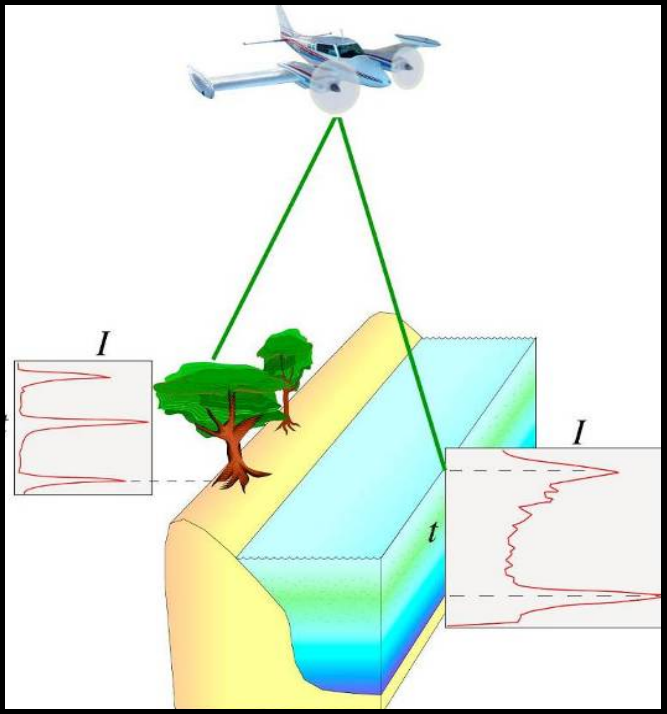


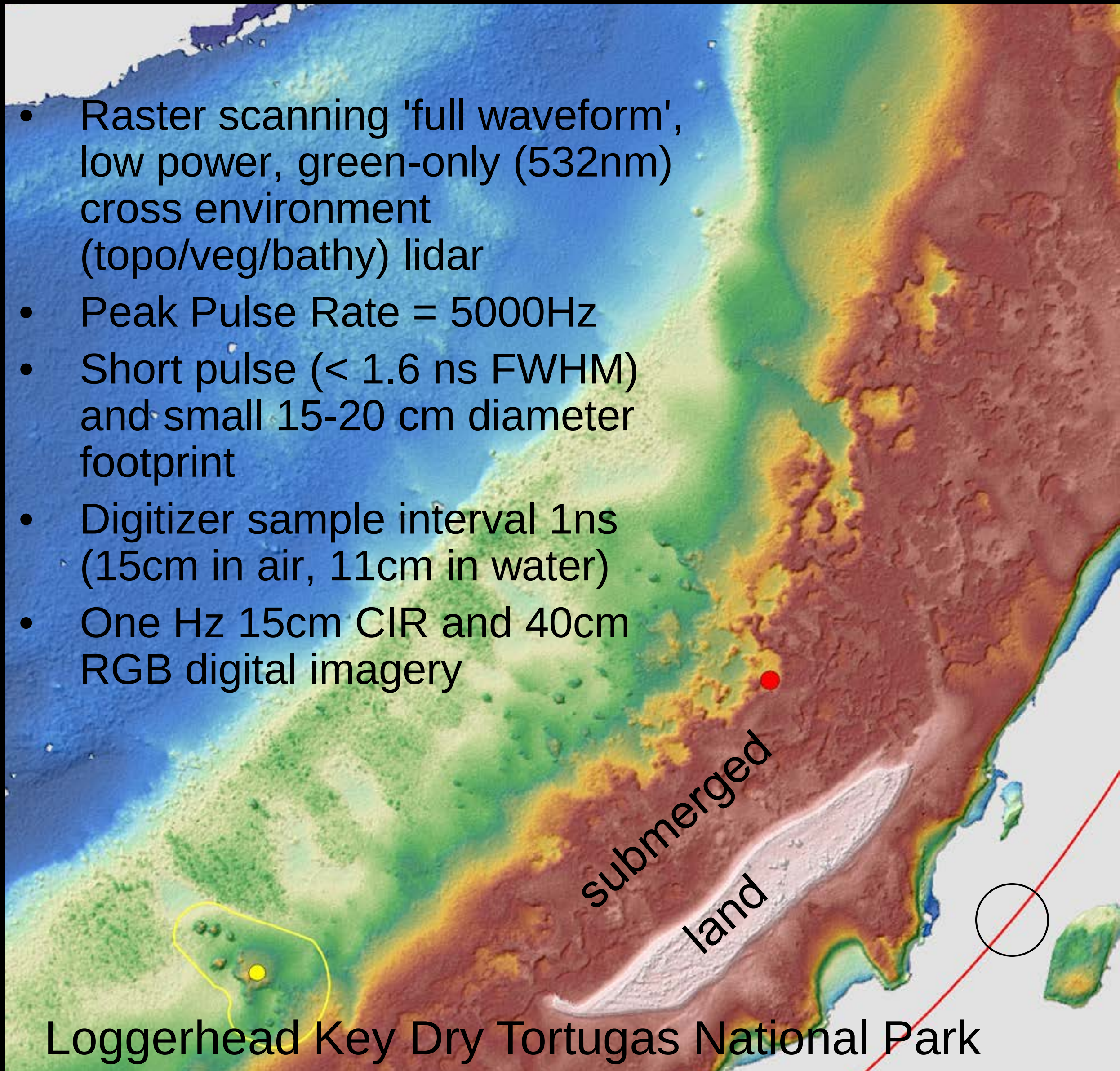
Image courtesy Dave Harding, NASA

Experimental Advanced Airborne Research Lidar (EAARL) – An example topo-bathy system

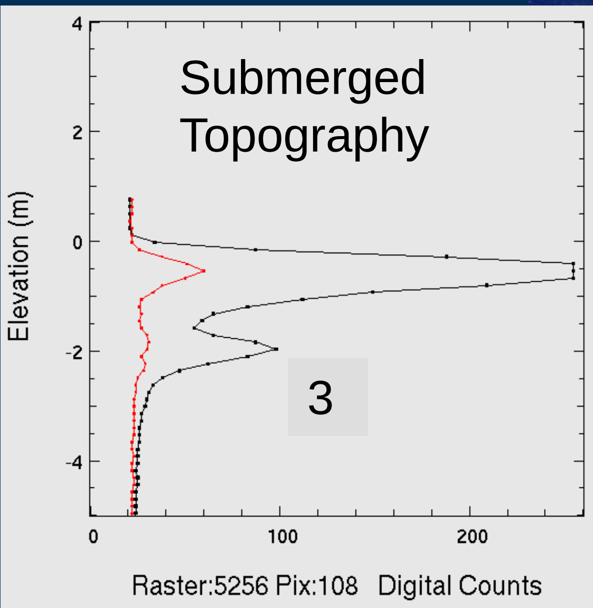


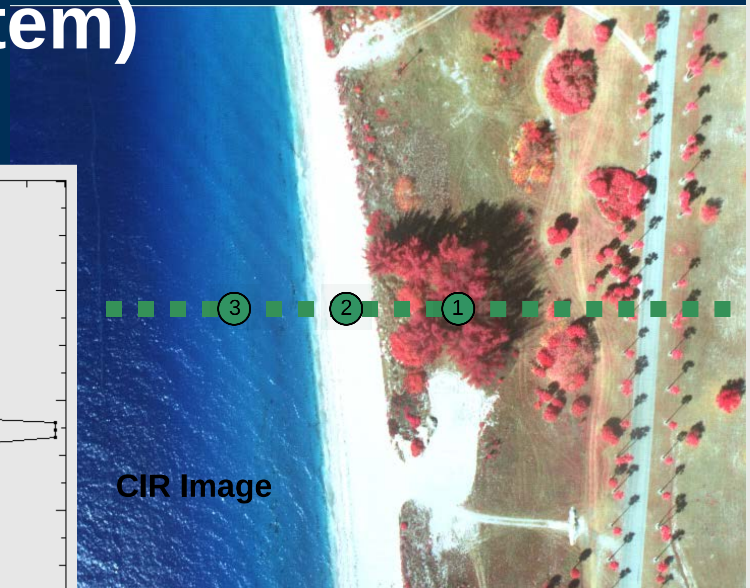


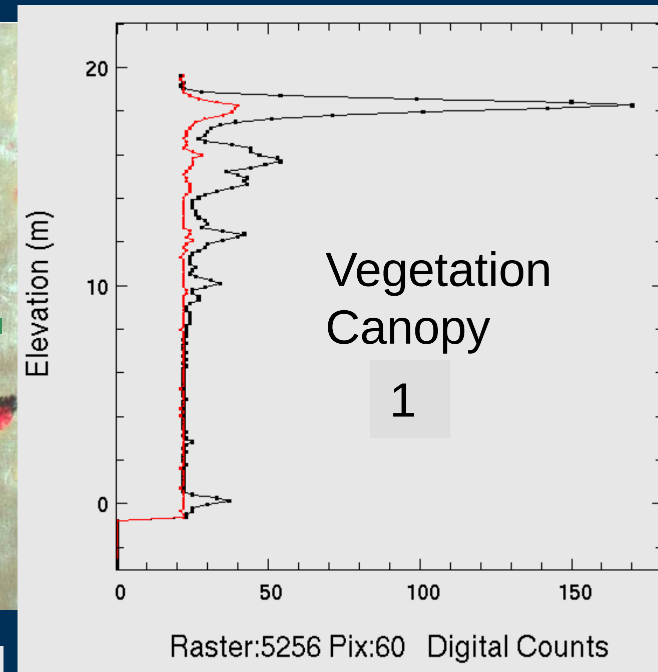
- Raster scanning 'full waveform', low power, green-only (532nm) cross environment (topo/veg/bathy) lidar
- Peak Pulse Rate = 5000Hz
- Short pulse (< 1.6 ns FWHM) and small 15-20 cm diameter footprint
- Digitizer sample interval 1ns (15cm in air, 11cm in water)
- One Hz 15cm CIR and 40cm RGB digital imagery

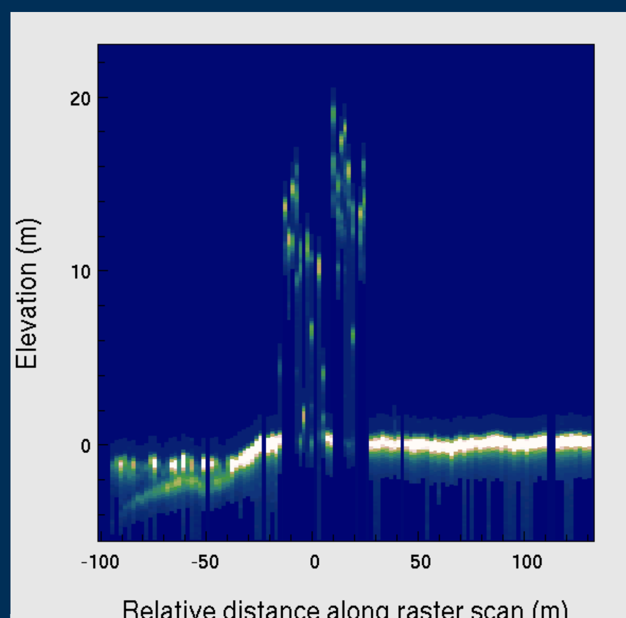


Sample topo-bathy waveforms (from the EAARL system)

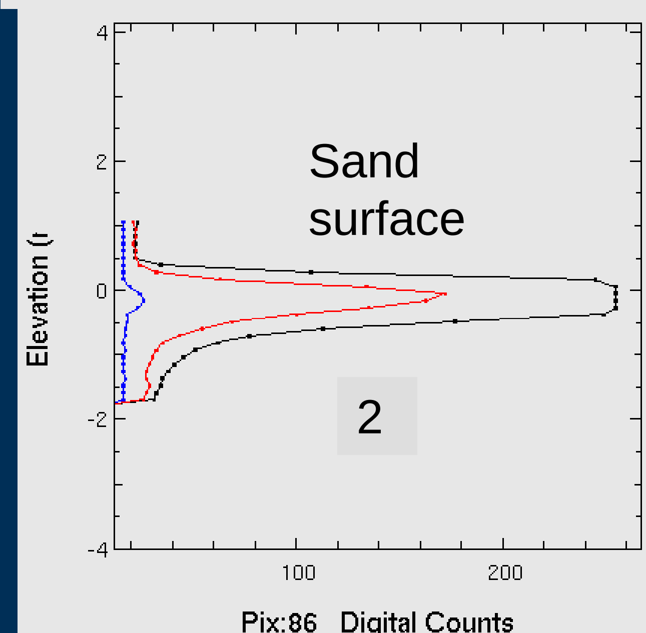








Lidar backscatter along scan



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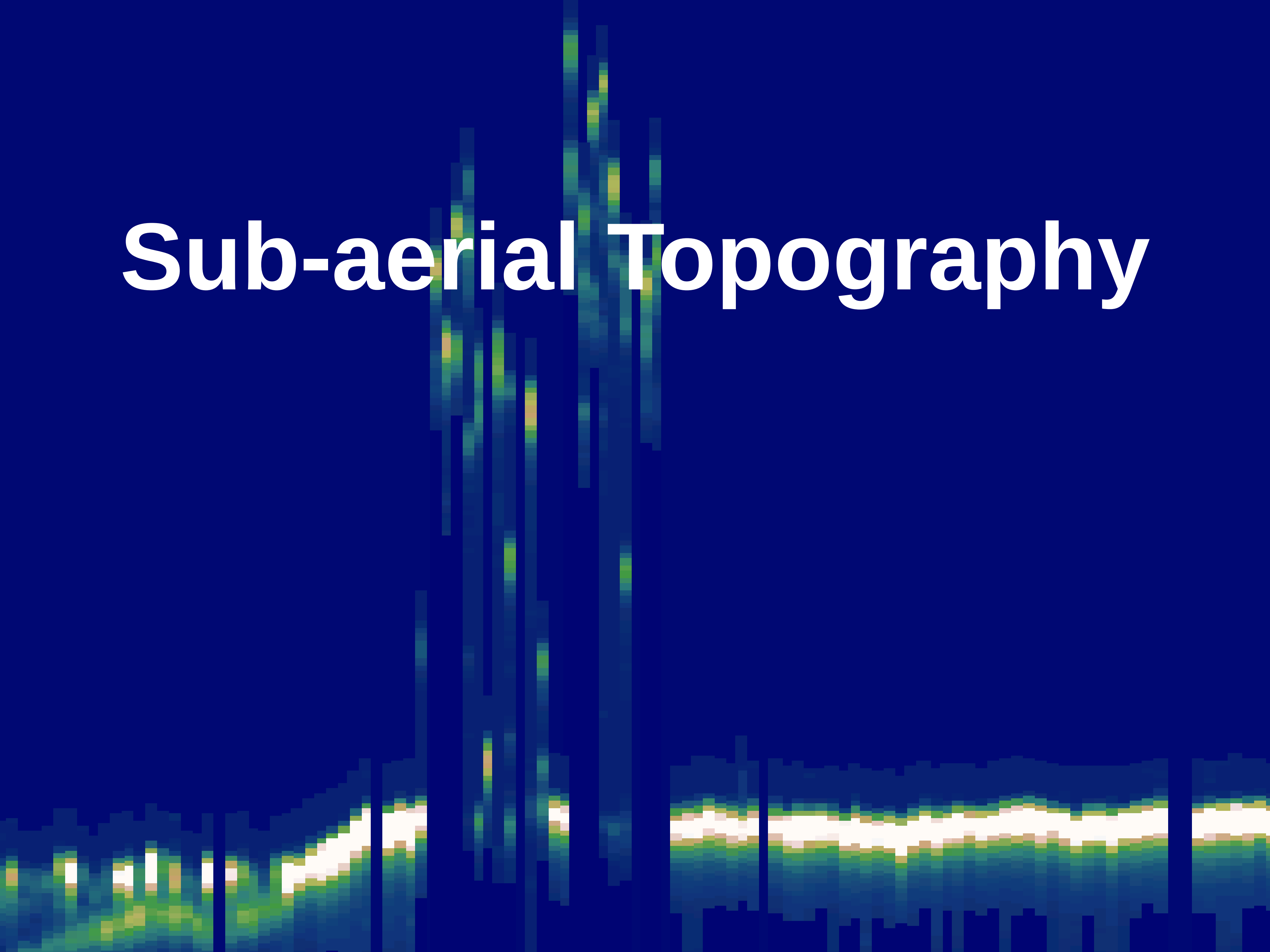
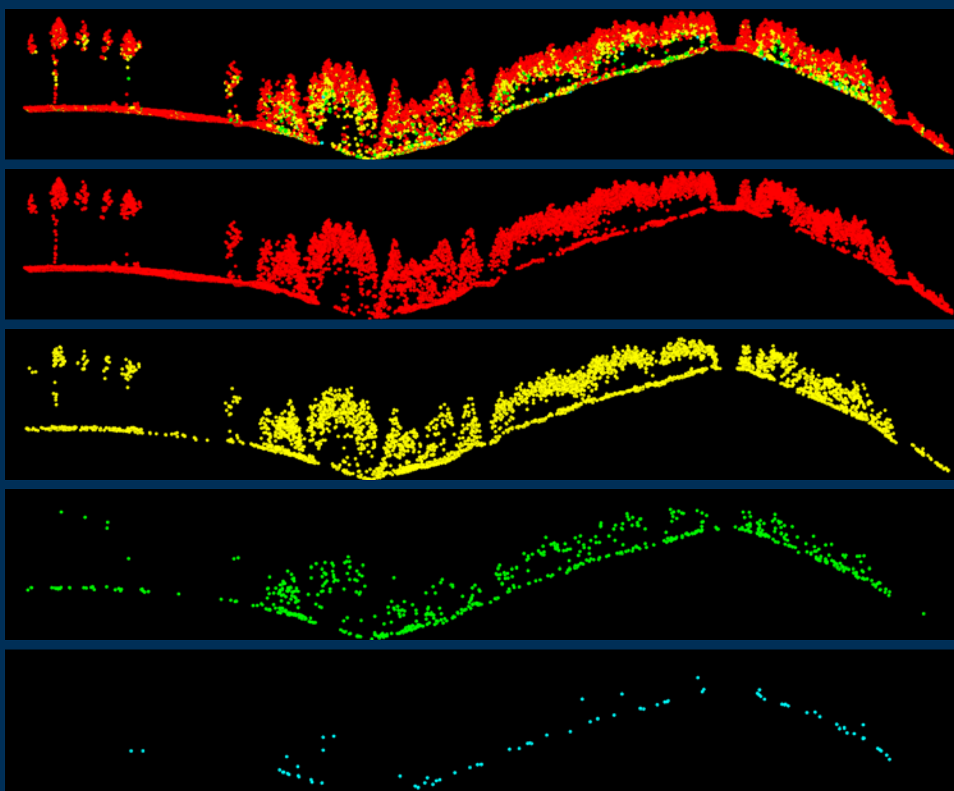
Sub-aerial Topography



Multiple (discrete) return lidar data from a vegetated terrain



All returns (16,664 pulses)

1st returns (11,469 pulses, 69%)

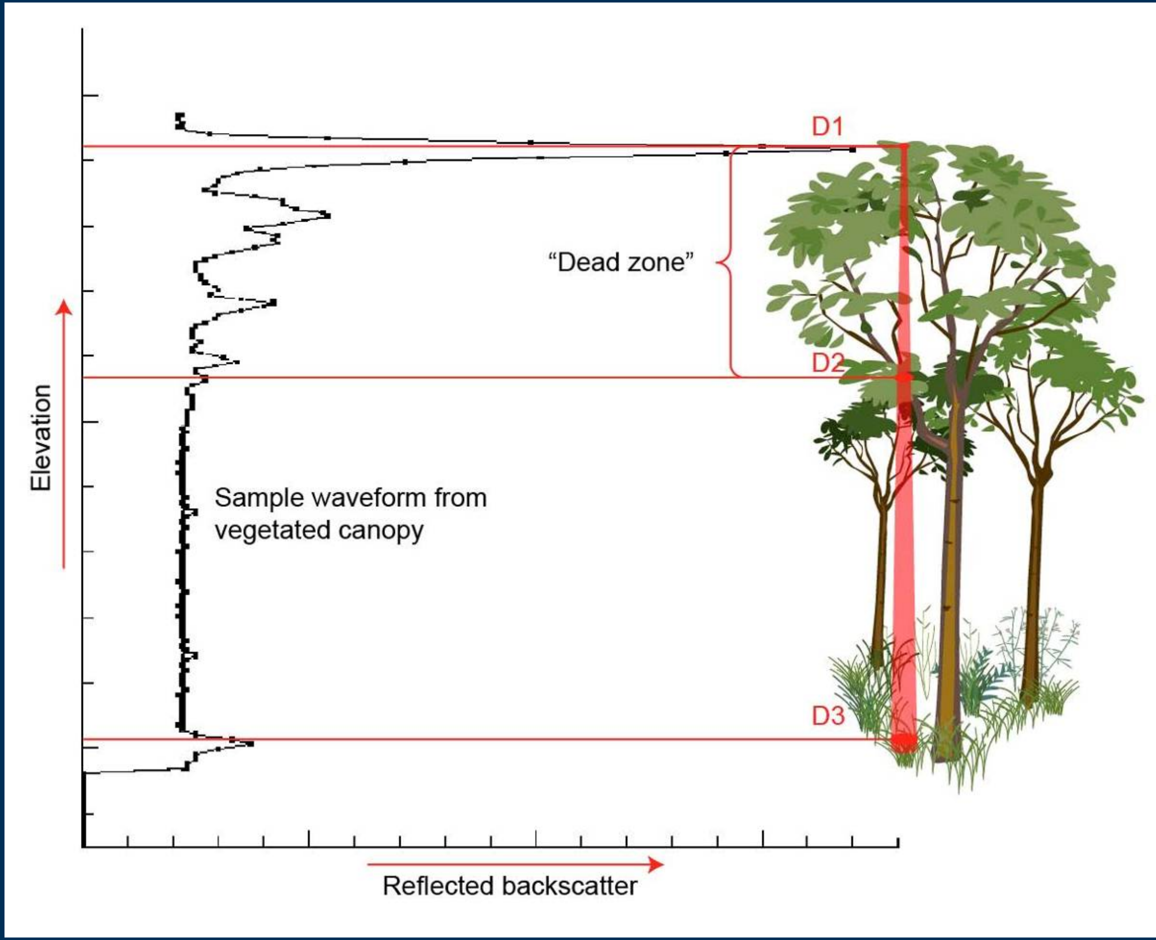
2nd returns (4,385 pulses, 26%)

3rd returns (736 pulses, 4%)

4th returns (83 pulses, <1%)

Image courtesy Hans-Erik Anderson

Discrete return vs. waveform-resolving and the “dead zone” effect

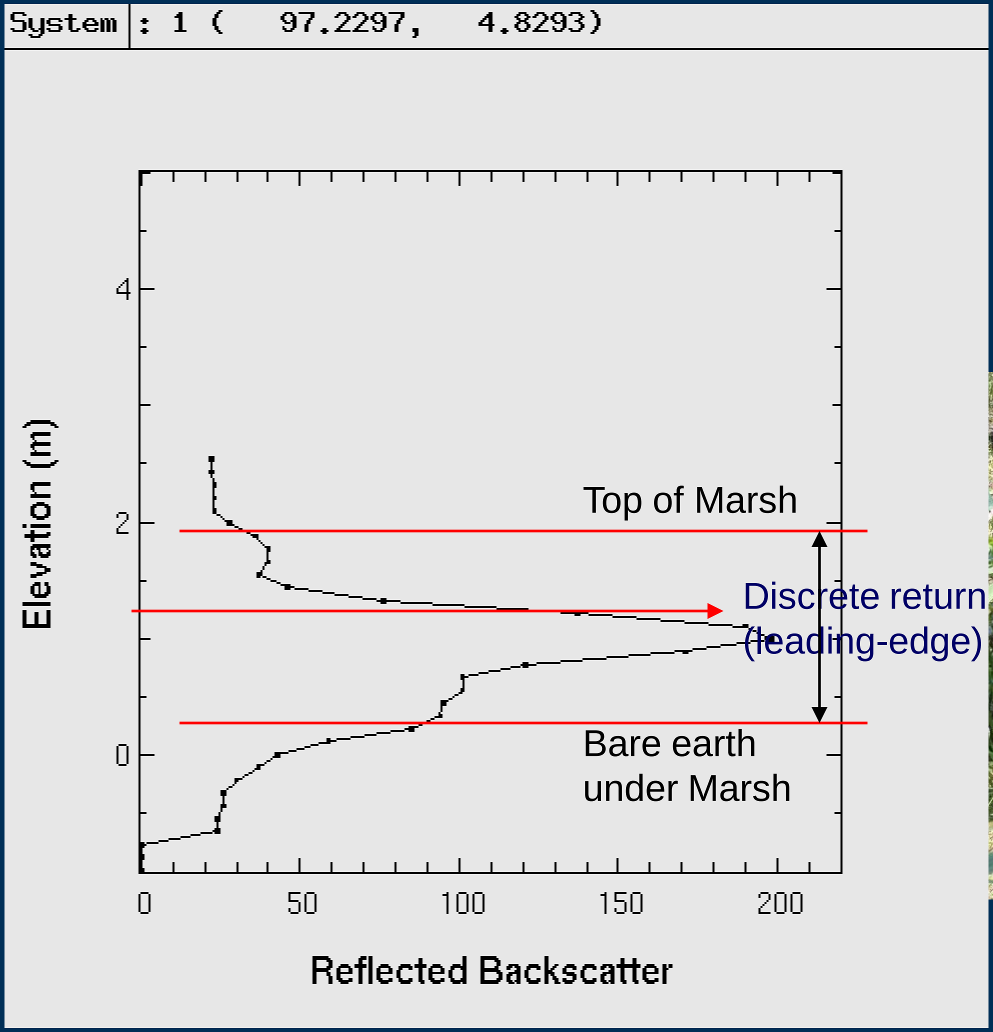


Discrete-return lidar

Waveform-resolving lidar

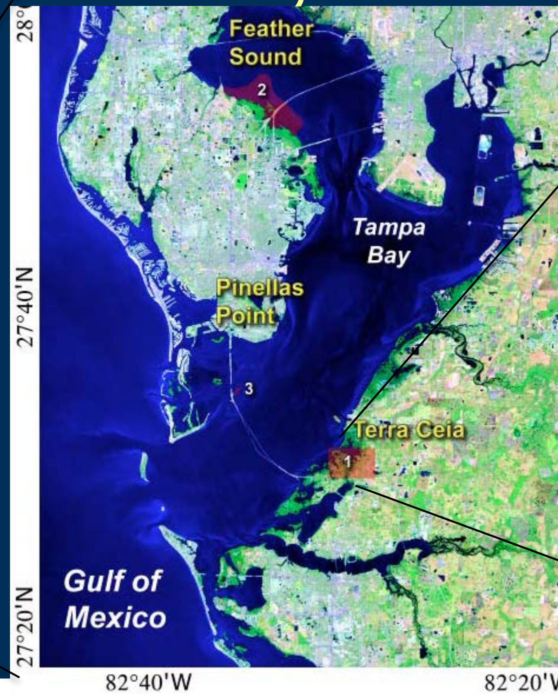
“minimum object separation” in discrete-return lidars can be 1-6m

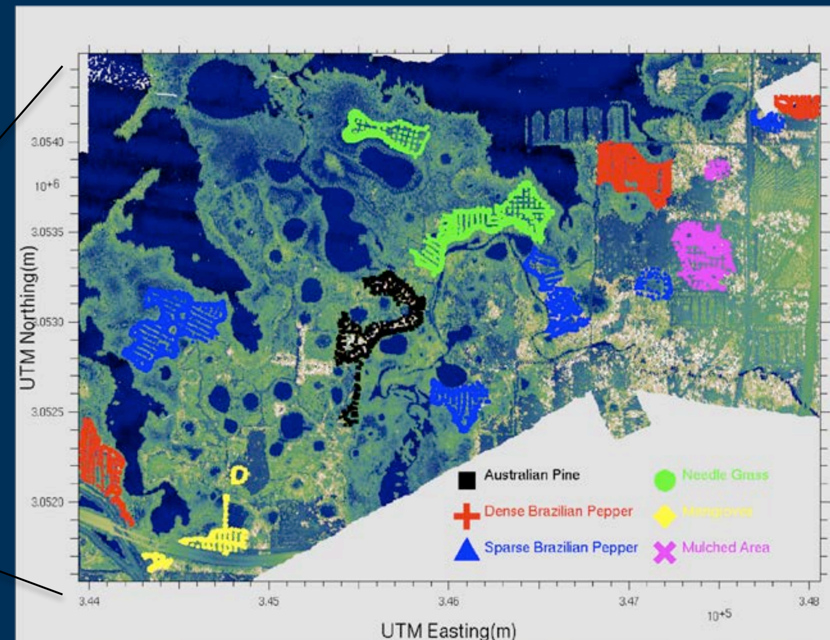
Sample small-footprint, short-pulse waveform in wetland environments

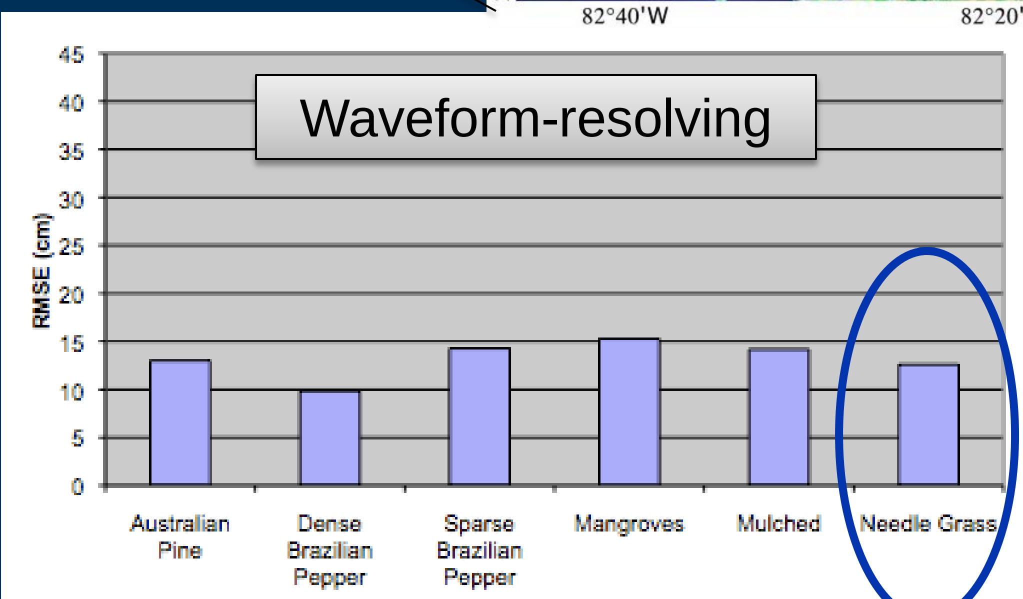


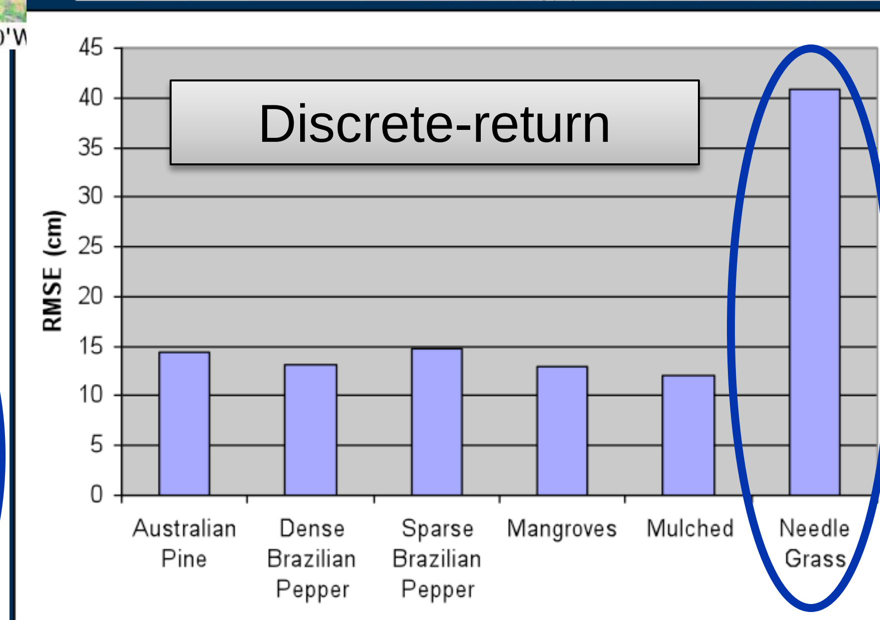
Waveforms allow various ranging methods to be used in post-flight processing software

Accuracy analysis in deriving bare earth under vegetation, Terra Ceia, FL

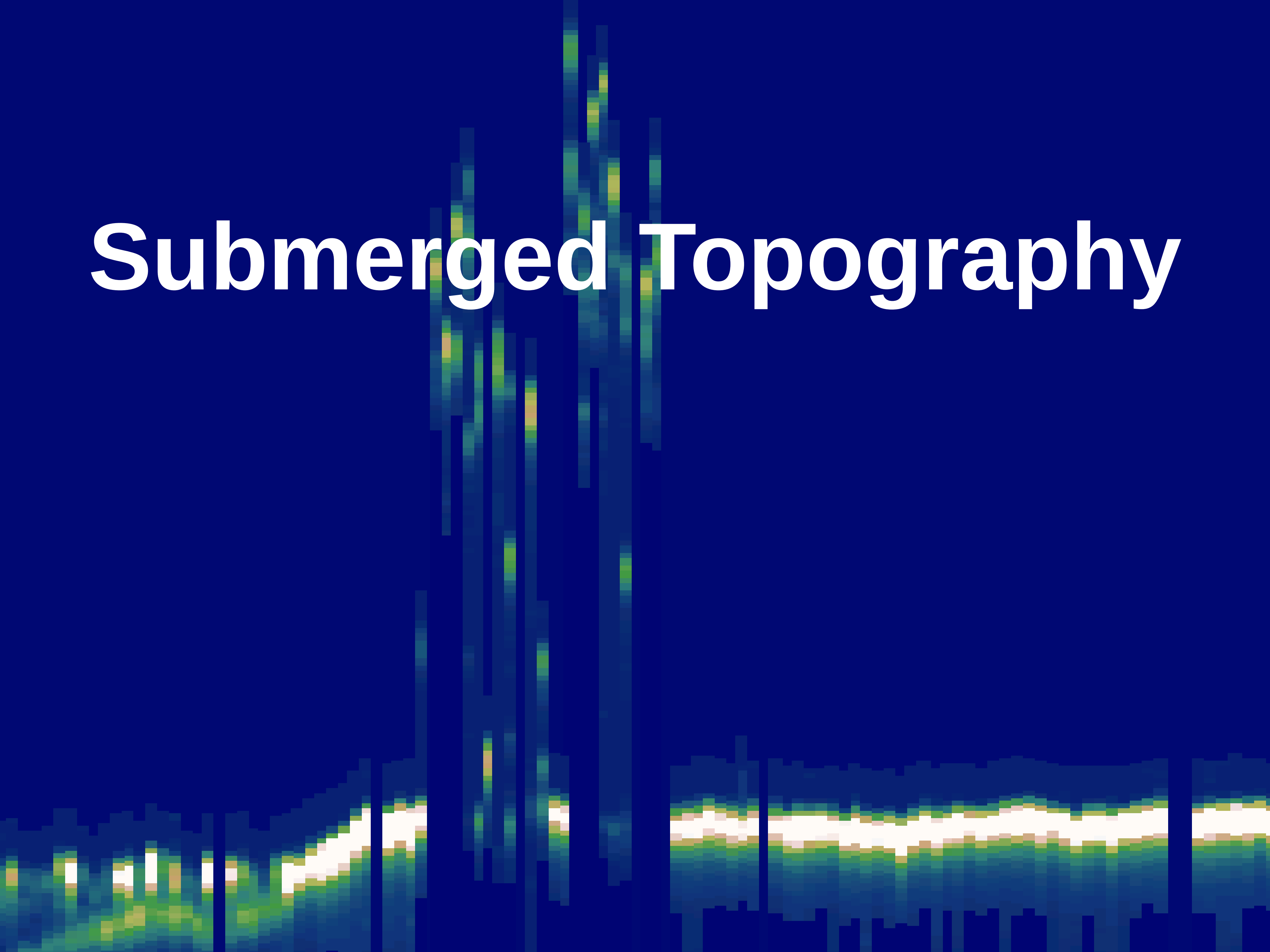






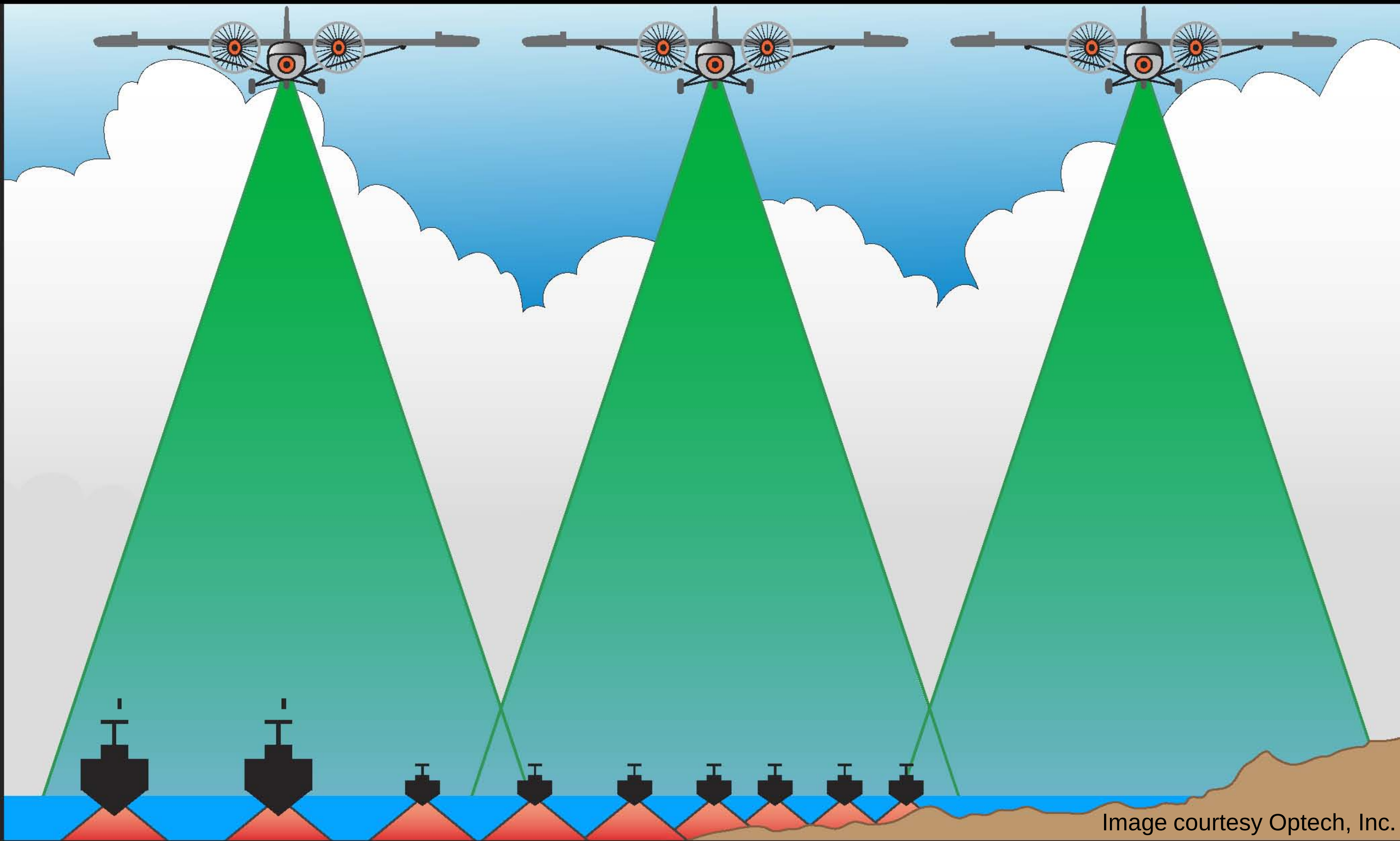


Submerged Topography

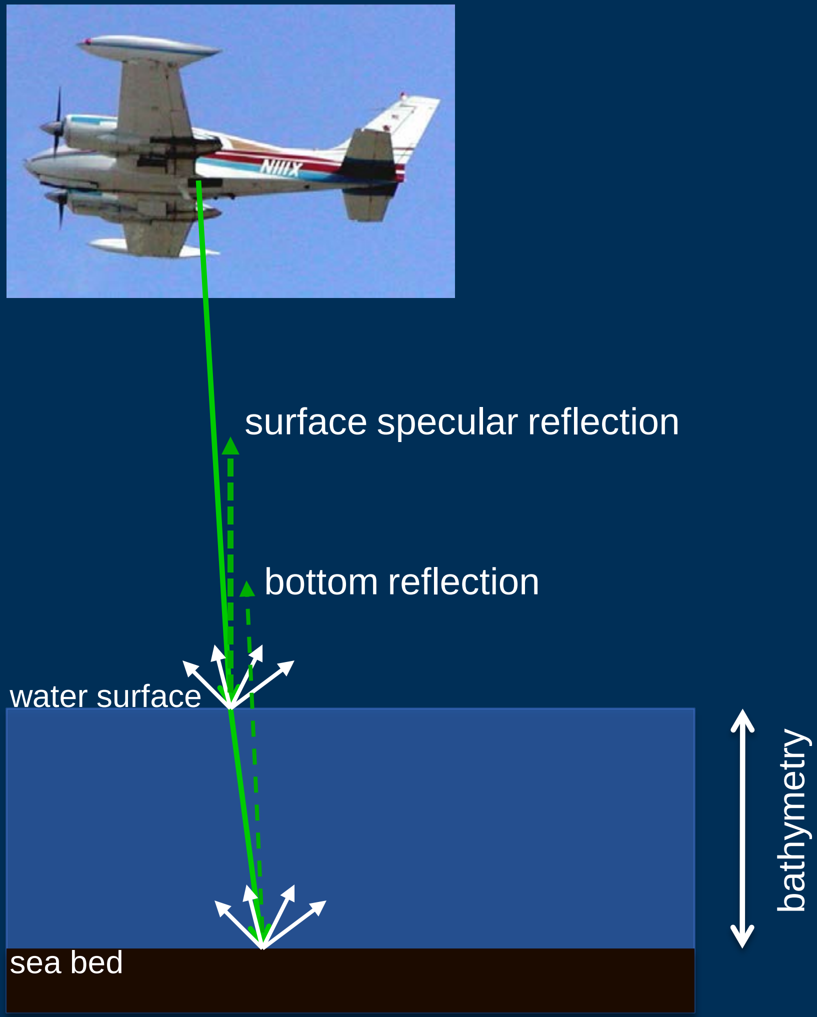


Why lidar?

Airborne bathymetric (subaqueous) lidar is of high value in filling the “0 to -10m” depth gap in coastal mapping:



How bathymetric lidars work



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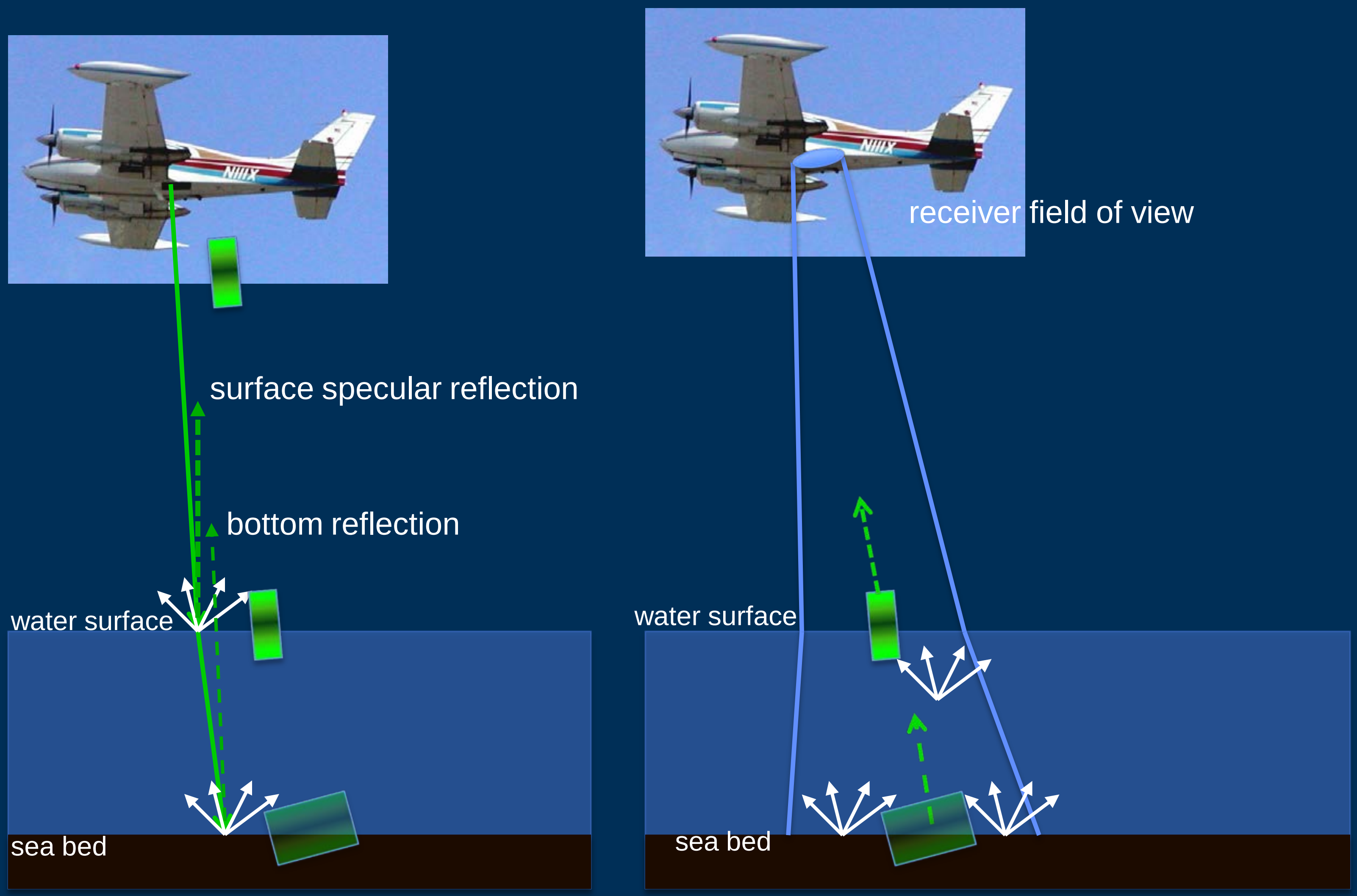
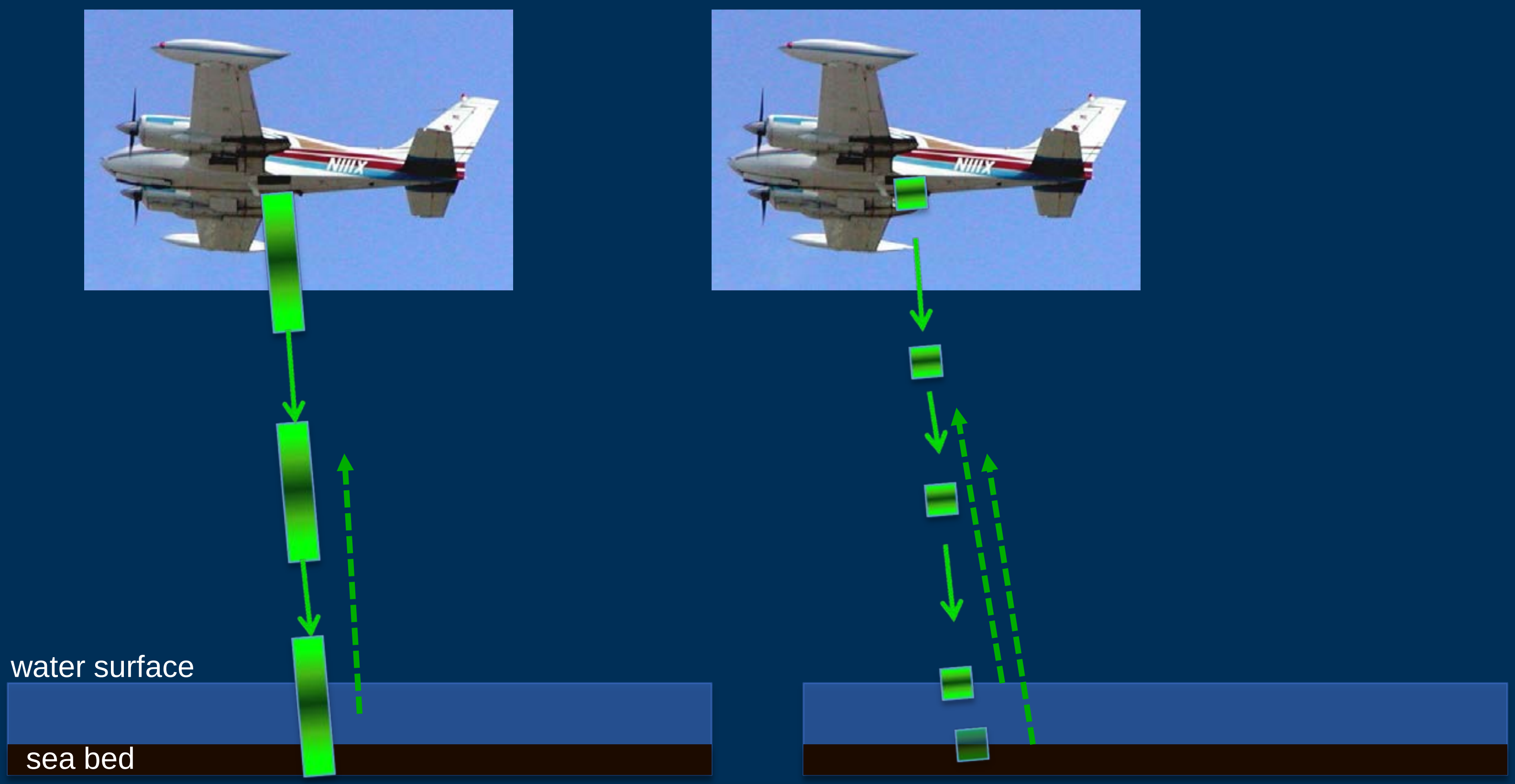
How bathymetric lidars work



Effect of pulse width on determining shallow submerged topography



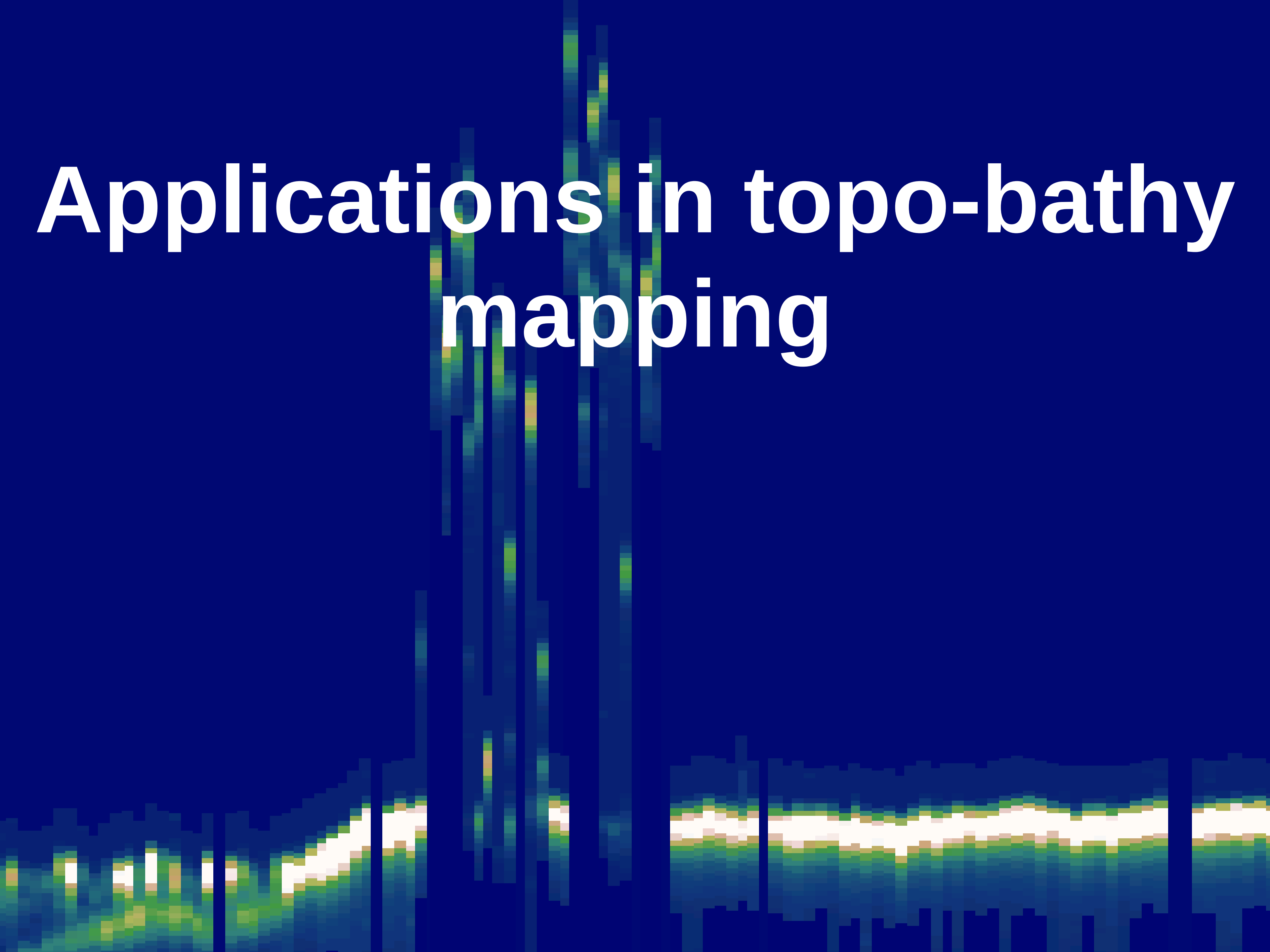
“long” pulse

cannot differentiate between surface and bottom return

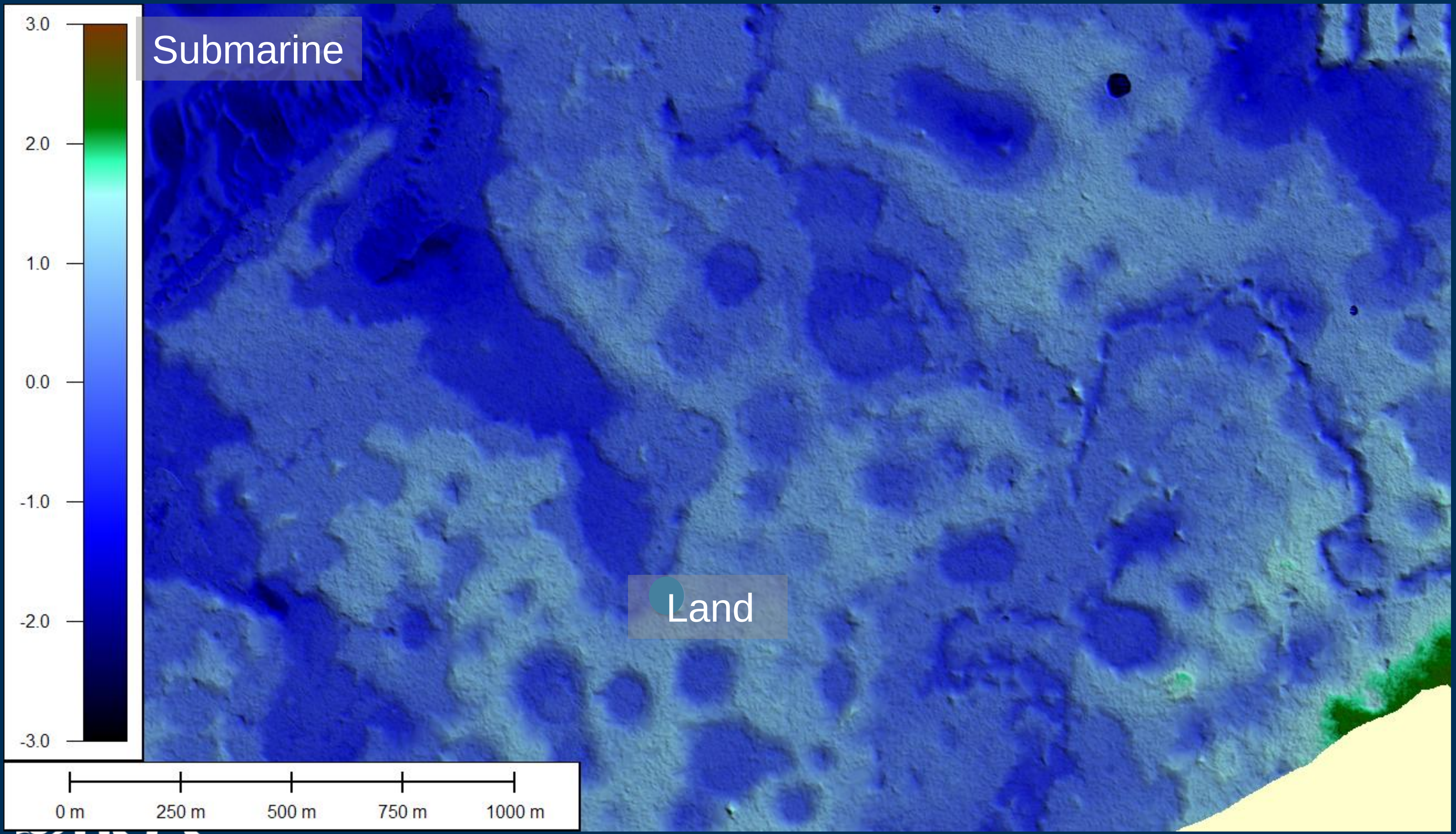
“short” pulse

surface and bottom return is separate or convolved

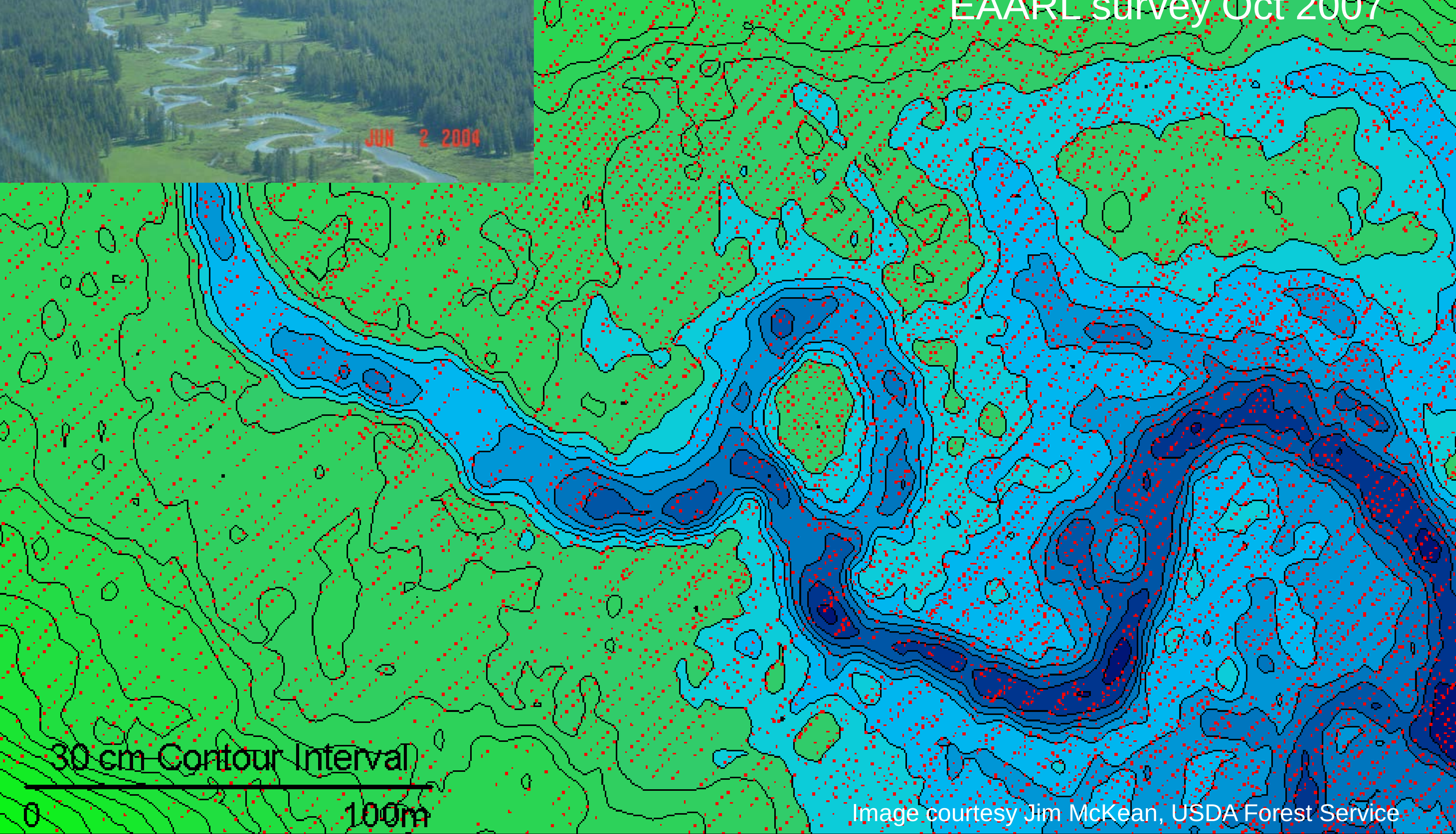
Applications in topo-bathy mapping



Integrated Topo-bathy Mapping using EAARL
Terra Ceia, Tampa Bay



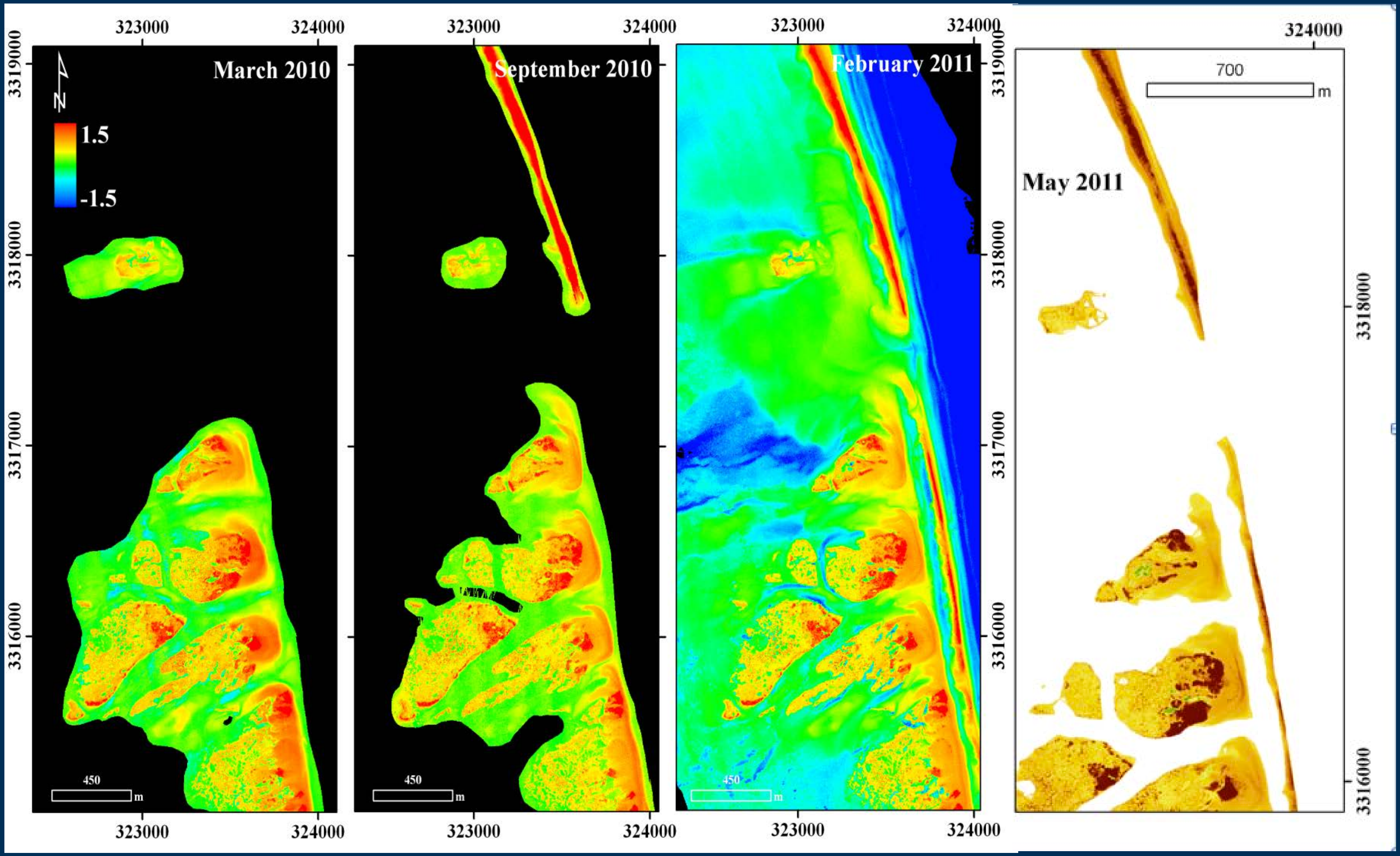
Fluvial Channel and Floodplain Mapping



Mapping barrier islands for storms response studies

Lidar imagery used to document berm construction and evolution of Chandeleur Islands, LA

1. Used to initialize numerical models that predict berm and island response to storms
2. Used to characterize changes in morphologic features
3. Submerged topographic data (Feb. 2011) used to quantify sediment budget



Concluding remarks

- Short-pulse, waveform-resolving lidar systems have greater potential to separate low vegetation from ground
- Green-wavelength lasers can penetrate through water to provide submerged topography
- For bathymetric lidars, tradeoffs exist between laser power, pulse width, and footprint size.
- Absorption and scattering cause an exponential decay of light intensity with increasing depth.
- Habitat spectra / bottom composition (sand vs. sea grass vs. mud) also influences the ability to determine submerged topography.

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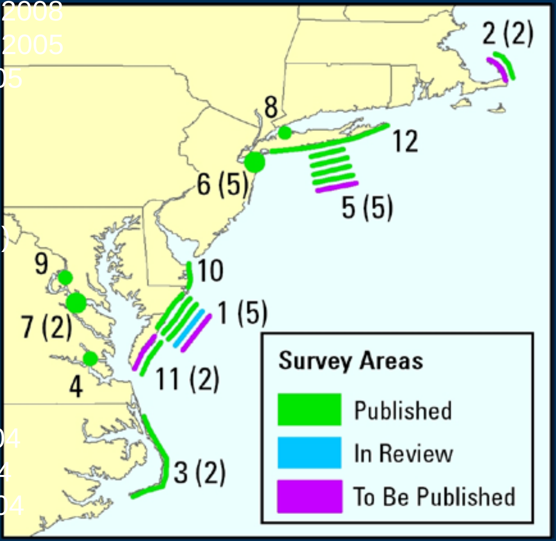
Published Lidar Data Products

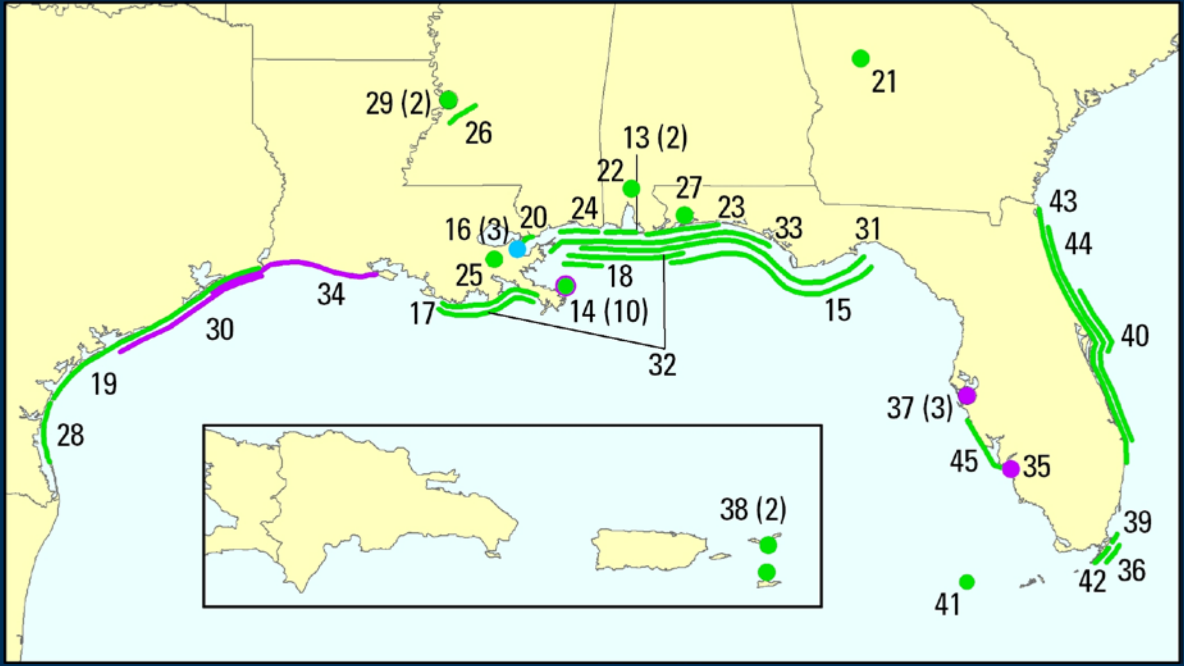
NORTHEAST
1. Assateague Island NS; 2002, 2004, 2008, 2009, 2010 (5)
2. Cape Cod NS; 2002, 2005 (2)
3. Cape Hatteras NS; 2003, 2009 (2)
4. Colonial NHS; 2005
5. Fire Island NS; 2002, 2005, 2007, 2009 (5)
6. Gateway NP/Sandy Hook; 2002, 2005, 2007, 2009 (5)
7. George Washington Birthplace NM; 2005, 2008 (2)
8. Sagamore Hill NHS; 2005
9. Thomas Stone NHS; 2005
10. Maryland and Delaware Coast; 2009
11. NE Virginia Coast; 2003, 2009 (2)
12. NE Barrier Islands; 2007

GULF COAST
13. Alabama Coast; 2001, 2007 (2)
14. Chandeleur Islands; 2005, 2006, 2007, 2008, 2010, 2011 (10)
15. Florida Coast; 2001
16. Louisiana Central Wetlands, North Shore, Alligator Point; 2010 (3)
17. Louisiana Coast; 2001
18. Mississippi Coast; 2001
19. Texas Coast; 2001
20. Pearl River Delta; 2008
21. Potato Creek Watershed; 2010
22. Three Mile Creek/Mobile-Tensaw Delta; 2010
23. Gulf Islands NS-FL; 2007, 2008 (2)
24. Gulf Islands NS-MS; 2007, 2008 (2)
25. Jean Lafitte NHP&P; 2006
26. Natchez Trace Pkwy; 2007
27. Naval Live Oaks, 2007
28. Padre Island NS; 2005
29. Vicksburg NMP; 2007, 2008 (2)
30. Post-Ike, Northeast Texas Coast; 2008
31. Post-Ivan, Alabama and Florida Coast; 2004
32. Post-Gustav, Louisiana to Florida Coast; 2008
33. Post-Katrina, Louisiana to Florida Coast; 2005
34. Post-Rita, Texas to Louisiana Coast; 2005

FLORIDA and the CARIBBEAN
35. Ft. Meyers, Florida; 2003
36. North Florida Reef Tract; 2001-2002
37. Tampa Bay, Florida; 2002, 2005, 2007 (3)
38. U.S. Virgin Islands; 2003 (2)
39. Biscayne NP; 2001-2002
40. Canaveral NS; 2009
41. Dry Tortugas NP; 2004
42. Florida Keys NMS; 2006
43. Post-Frances, Eastern Florida Coast; 2004
44. Post-Jeanne, Eastern Florida Coast; 2004
45. Post-Charley, Western Florida Coast; 2004

TOTAL PRODUCTS = 80





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Research lidar surveys, data analysis, and products

Available on DVD (upon request) and online at http://coastal.er.usgs.gov/remote-sensing

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Thank you.

Questions?