Lecture 35. Target Lidar (2)
Laser Rangefinding & Laser Altimeter

- Laser Rangefinding Techniques
  - Time of Flight
  - Geometry-based
  - Interferometry
- Laser Altimeter
- Lidar remote sensing of snow depth
- Summary of Target Lidar

Introduction

- ❑ Lidar remote sensing has two major functions:

➢ One is to measure atmospheric or environmental species, density, temperature, wind, and waves along with their range distributions. These were covered in the first 34 lectures.

➢ Another major function is to determine range - laser range finder. Laser altimeter is a special laser range finder (lectures 35-36).

- ❑ A good reference for laser rangefinding techniques is a paper collection book -- "Selected Papers on Laser Distance Measurements", edited by Brian J. Thompson, SPIE Milestone Series, 1995.

- ❑ Our textbook Chapter 8 "Airborne Lidar Systems" and Chapter 9 "Space-based Lidar" provide references for airborne and spaceborne laser altimeters.

- ❑ Other references could be found through web of science or SPIE related to the new laser altimeter projects.

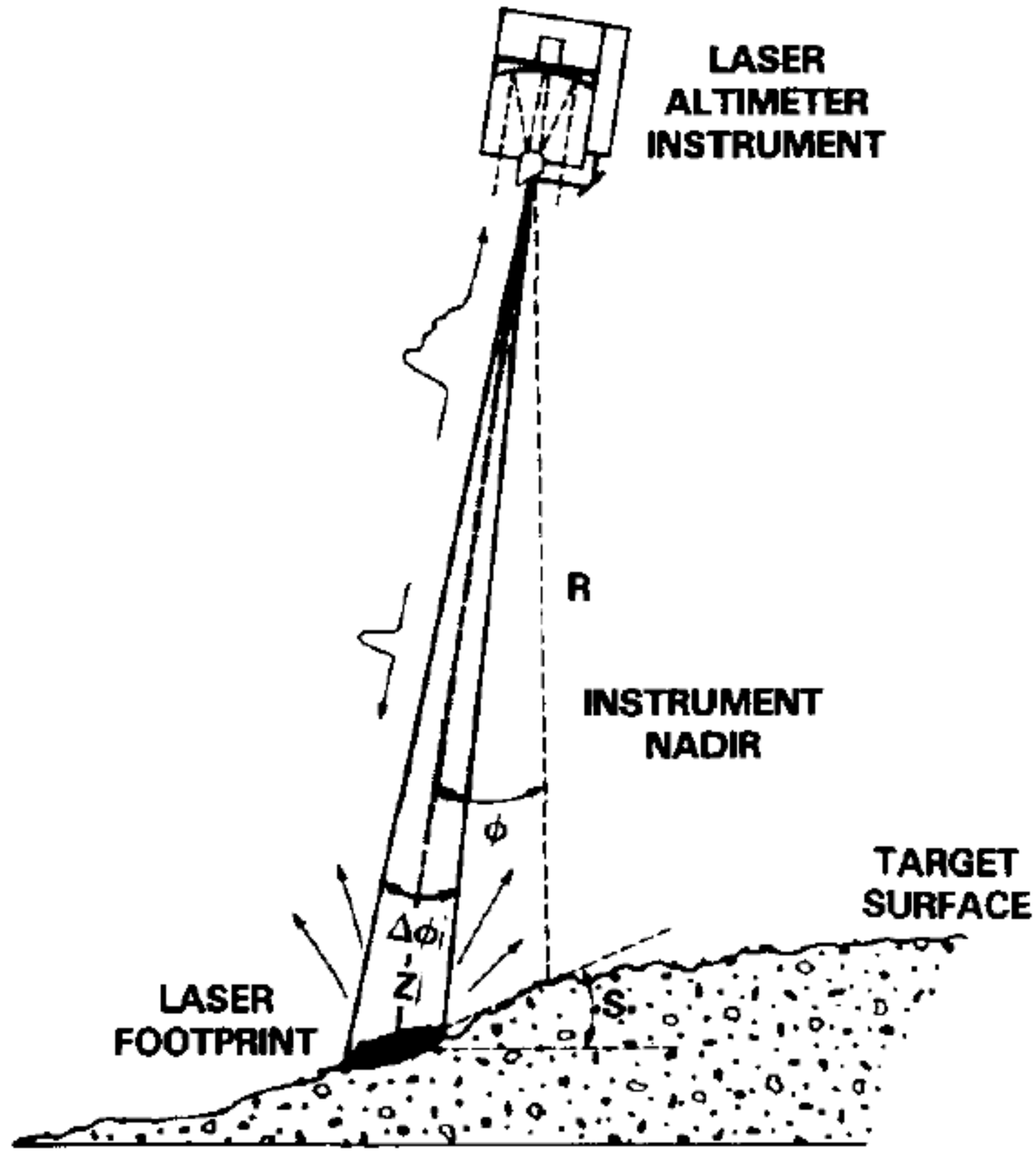
Laser Rangefinding Techniques

- The basic principle of active noncontact rangefinding systems is to project a wave (radio, ultrasonic, or optical) onto an object and process the reflected signal to determine its range. If a high resolution rangefinder is needed, an optical source must be chosen because radio and ultrasonic waves cannot be focused adequately.
- There are mainly three types of rangefinding techniques: (1) Time of flight techniques: this is for the majority of laser range finder; (2) Geometric-based technique: the classical triangulation by projection of a light beam onto a target; (3) Interferometry: using interferometry principle to measure distance to high accuracy.
- Time-of-flight techniques include 1) pulsed laser rangefinding, 2) cw beam amplitude modulation - the phase-shifting rangefinding technique, and 3) chirp pulse compression.
- The main applications of laser rangefinding techniques, in addition to distance measurements, are obstacle detection for autonomous robots or car safety, nondestructive testing, level control, profilometry, displacement measurements, 3-D vision, and so on.

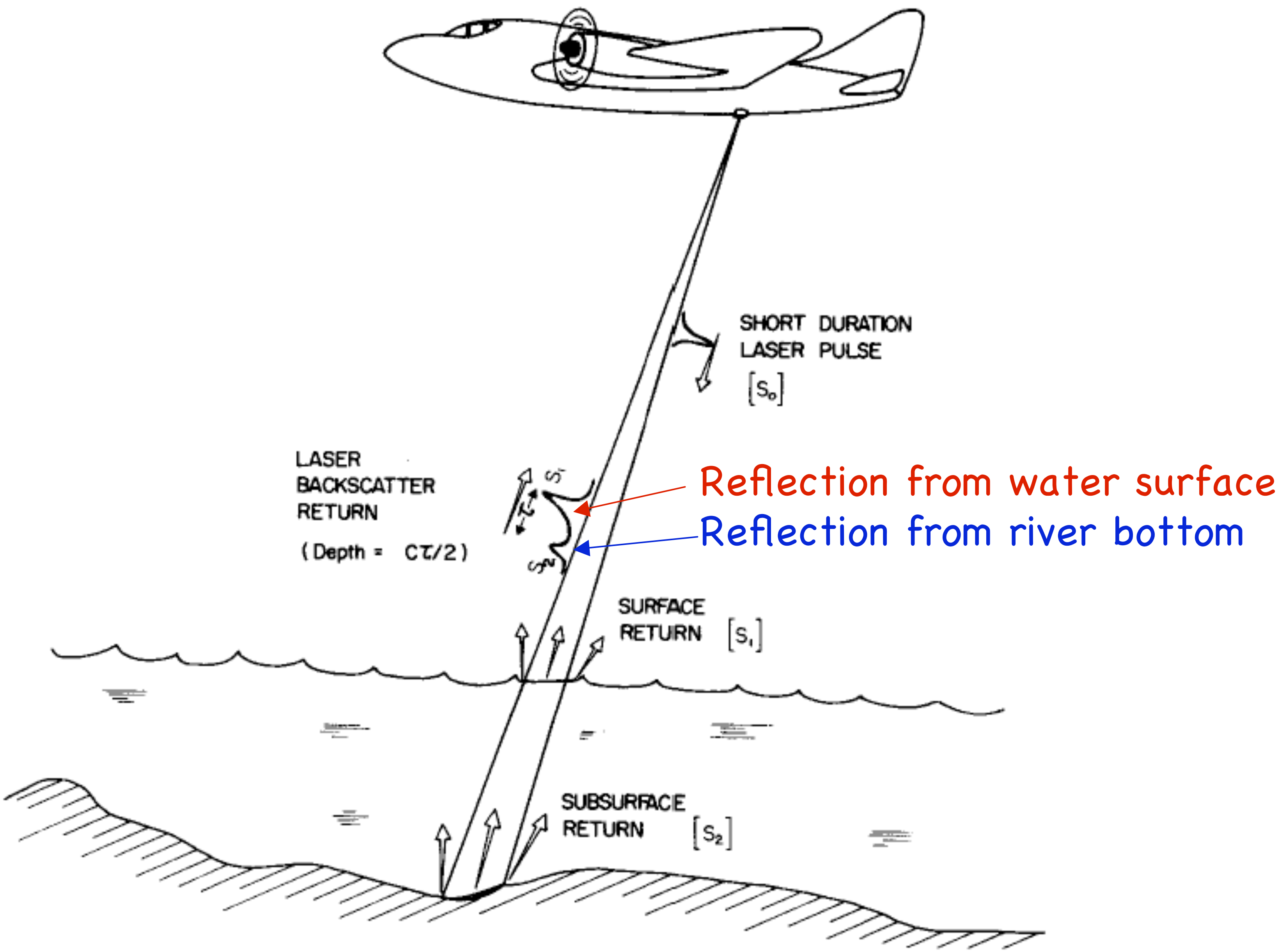
Laser Altimeter (Laser Ranging)

- The time-of-flight information from a lidar system can be used for laser altimetry from airborne or spaceborne platforms to measure the heights of surfaces with high resolution and accuracy.

- The reflected pulses from the solid surface (earth ground, ice sheet, etc) dominant the return signals, which allow a determination of the time-of-flight to much higher resolution than the pulse duration time.



Laser Altimeter for Hydrosphere



Spacebore Laser Altimeter System
ICESat/GLAS

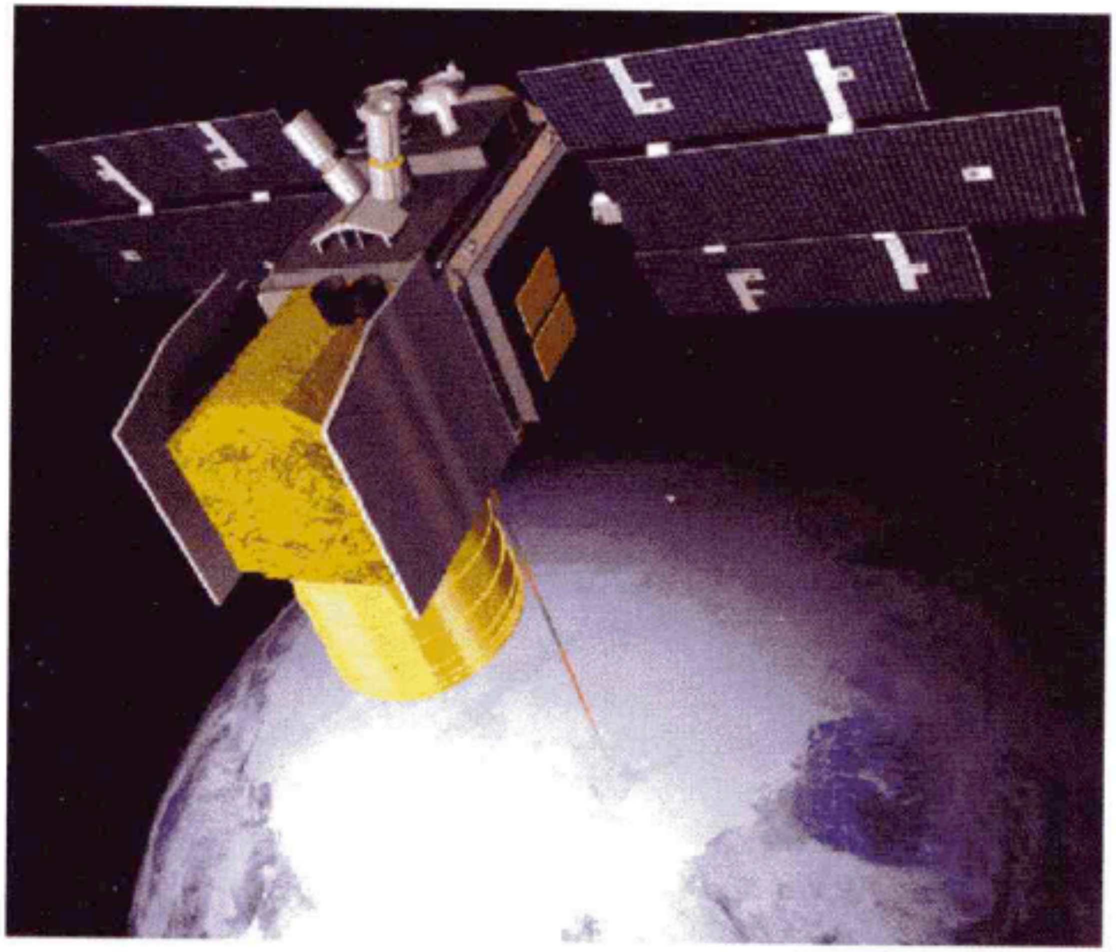
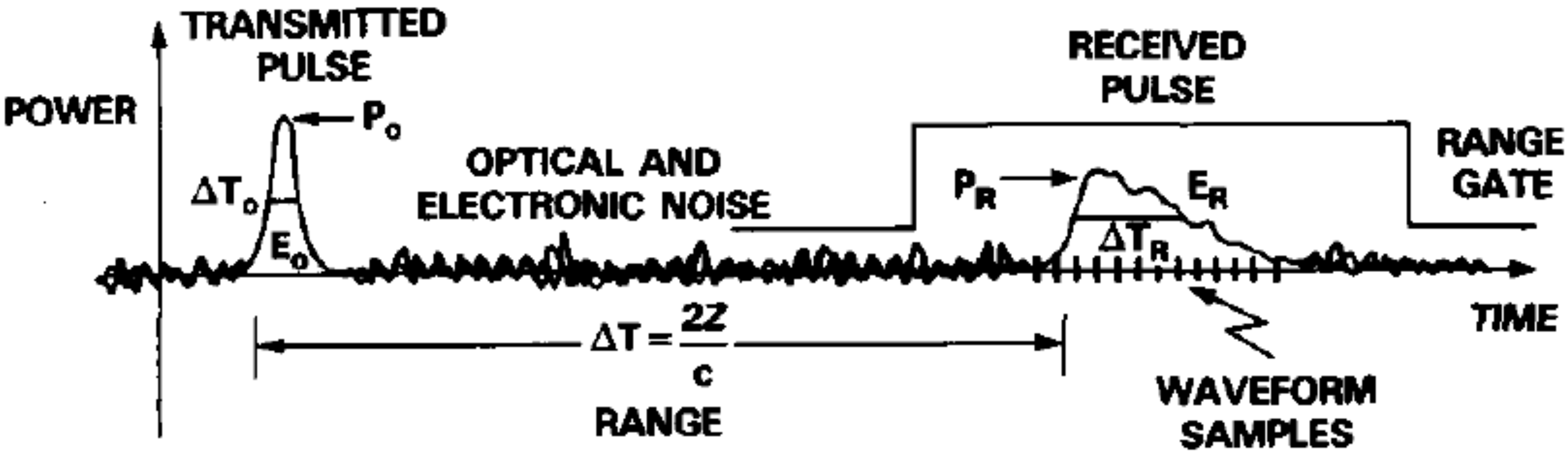


Fig. 13.23. An artist's rendition of the ICESat spacecraft with the GLAS instrument onboard. The 1064 nm and 532 nm laser pulses are shown probing the Earth's atmosphere and polar ice thickness changes. (Courtesy of S.P. Palm.)

Altitude Determination



- The range resolution is now determined by the resolution of the timer for recording pulses, instead of the pulse duration width. By computing the centroid, the range resolution can be further improved.
- Altitude accuracy will be determined by the range accuracy/resolution and the knowledge of the platforms where the lidar is on.
- In addition, interference from aerosols and clouds can also affect the altitude accuracy.

Altitude = Platform Base Altitude - Range ± Interference of aerosols and clouds

Challenges in Laser Altimeter

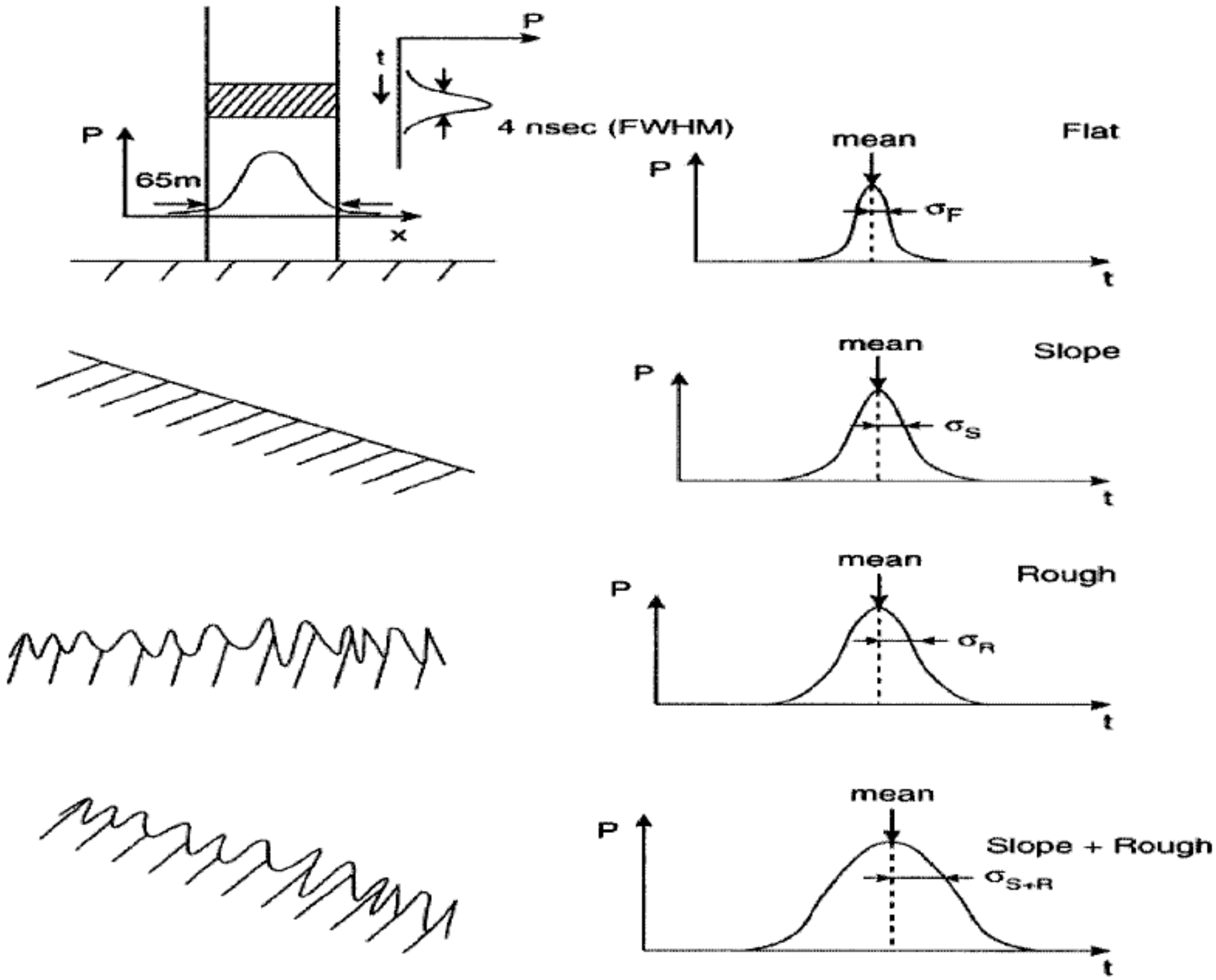
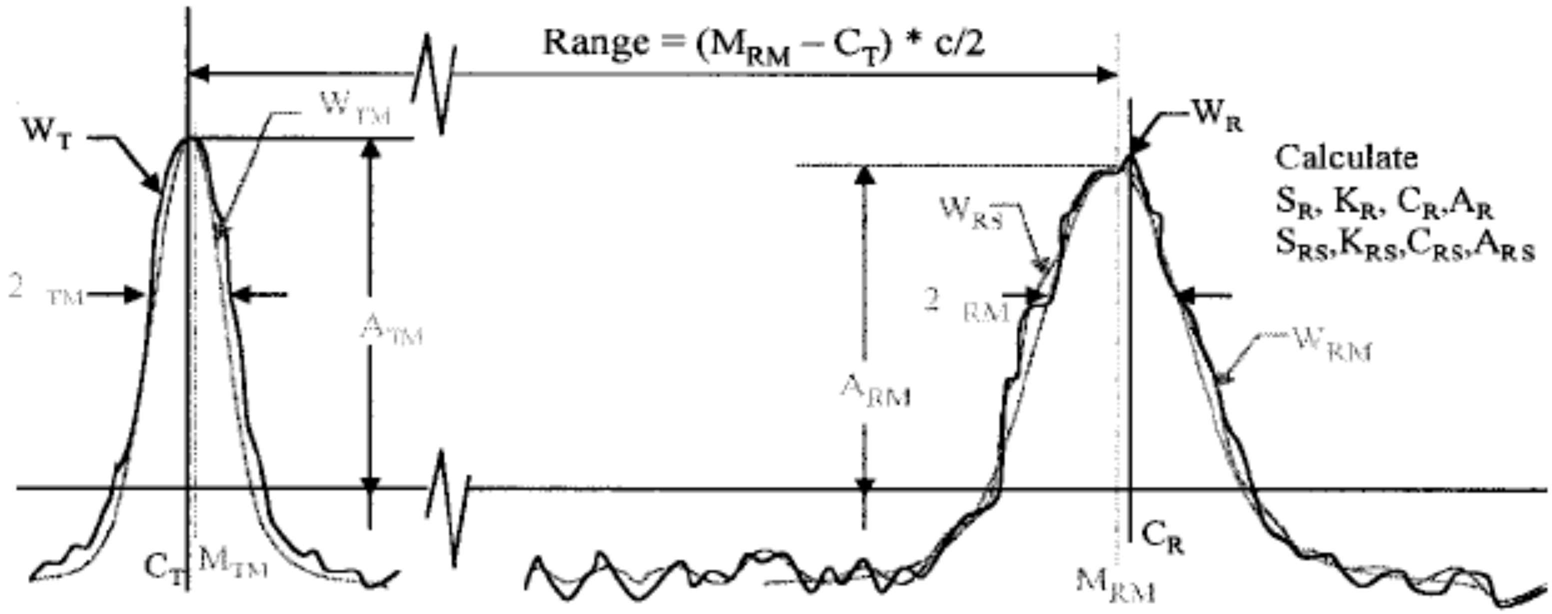


Figure 1 - Characteristics of returned laser pulse as a function of surface type. Presence of surface slope and roughness both broaden the pulse.

Signal Processing in Altimeter



A - Max Amplitude
W - Waveform
M - Gaussian Mean
 - Gaussian 1/e halfwidth
C - Centroid (abscissa value)
S - Skewness
K - Kurtosis

$(\ )_T$ - Transmitted Pulse
$(\ )_{TM}$ - Model of Transmitted pulse
$(\ )_R$ - Return Pulse
$(\ )_{RM}$ - Model of Return Pulse
$(\ )_{RS}$ - Smoothed Return Puls

Figure 3 - Characterization of transmitted and received pulse waveforms

[Brenner et al., GLAS Algorithm Theoretical Basis Document, 2003]

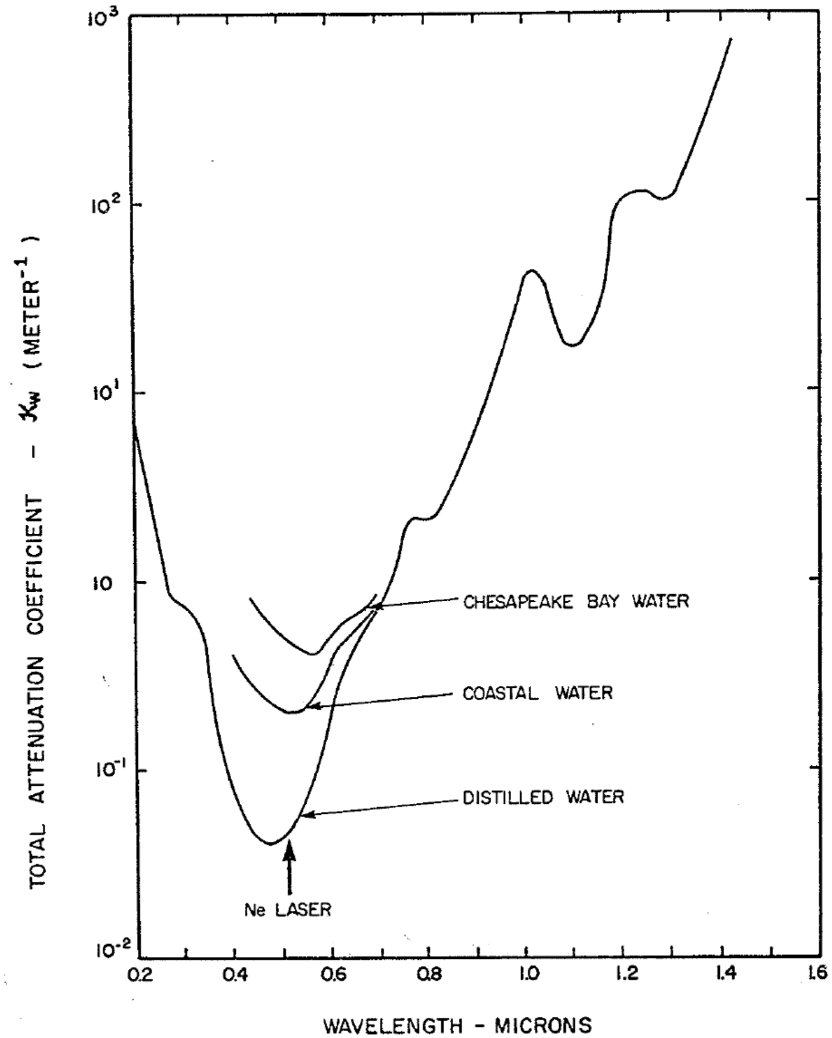
Other Challenges

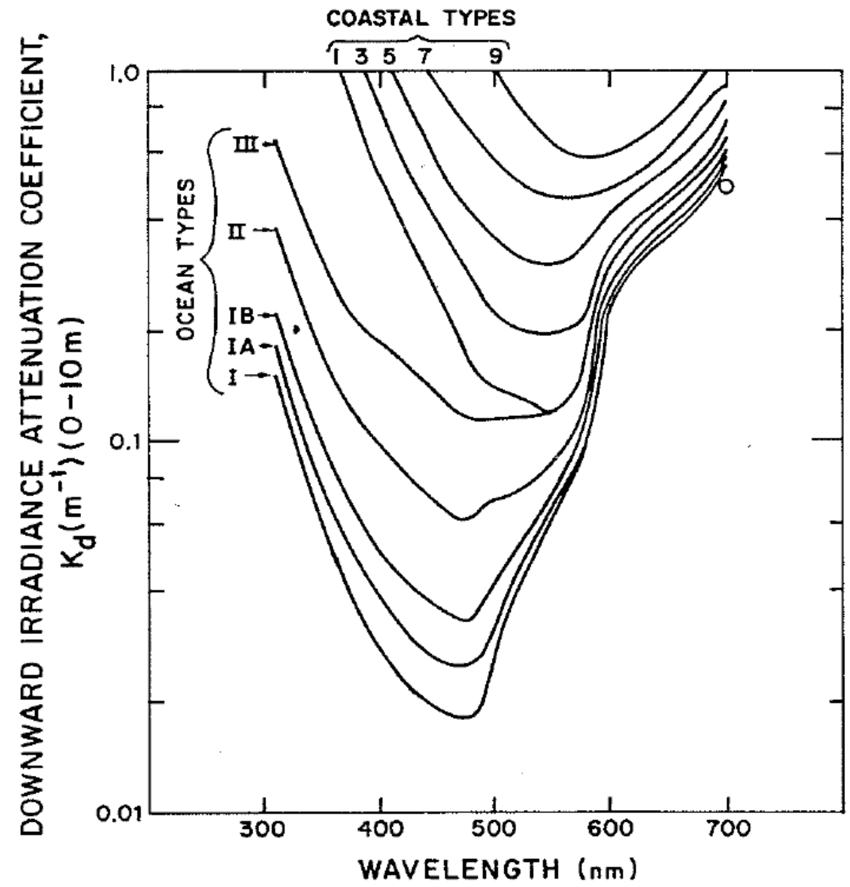
- Besides waveform distortions caused by surface slope and roughness, other factors that could affect the accuracy of laser altimeter include
(1) Orbit and attitude calculations for the platforms
(2) Corrections for atmospheric path-length delays
(3) Corrections for changes in the surface elevations due to tidal effects
(4) ……
(5) How will you have enough penetration and get the reflected signals?

Table 9.10 Ice Altimetry Error Budget

Source	Error type	Magnitude (cm)
Instrument	Single-shot accuracy (3° surface features)	<10
	Range bias	<5
	Laser beam pointing angle uncertainty (1 arcsec, 2° surface)	18
	Radial orbit uncertainty	5
	Clock synchronization (1 μsec)	1
Spacecraft	Distance uncertainty from S/C POD to GLAS zero reference point	0.5
Environment	Atmospheric error (10-mbar error, 0.23 cm/mbar)	2
	RSS error	0.20

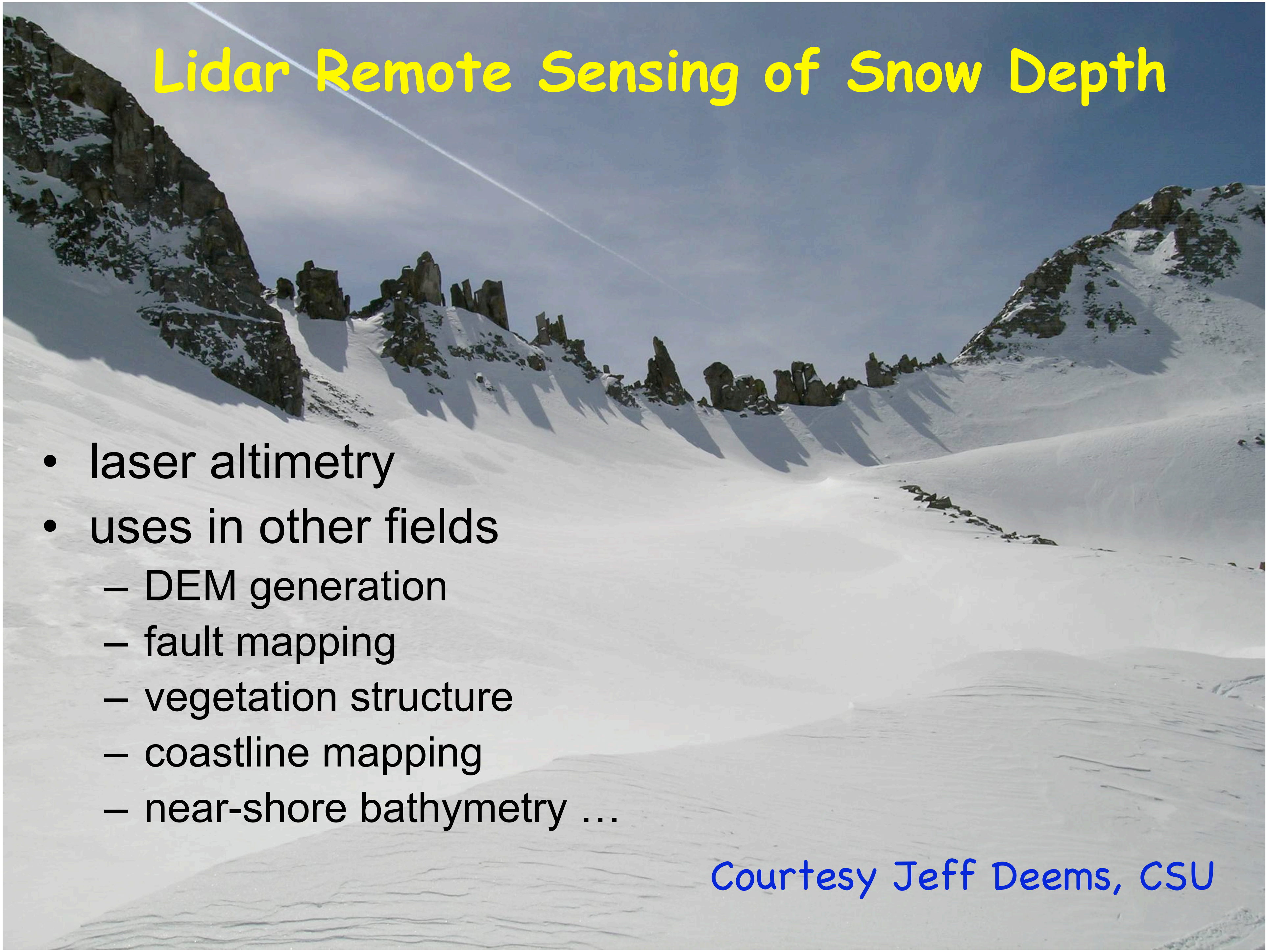
Water Transmission vs. Wavelength





[Measures, Laser Remote Sensing, 1984]

Fig. 10.1. (a) Attenuation coefficient of water (adapted from Tyler and Preisendorfer, 1962). (b) Downward irradiance attenuation coefficient measured by Jerlov (1976) in the first 10 m of depth as a function of wavelength for a variety of deep ocean and coastal water types (Northam et al., 1981).



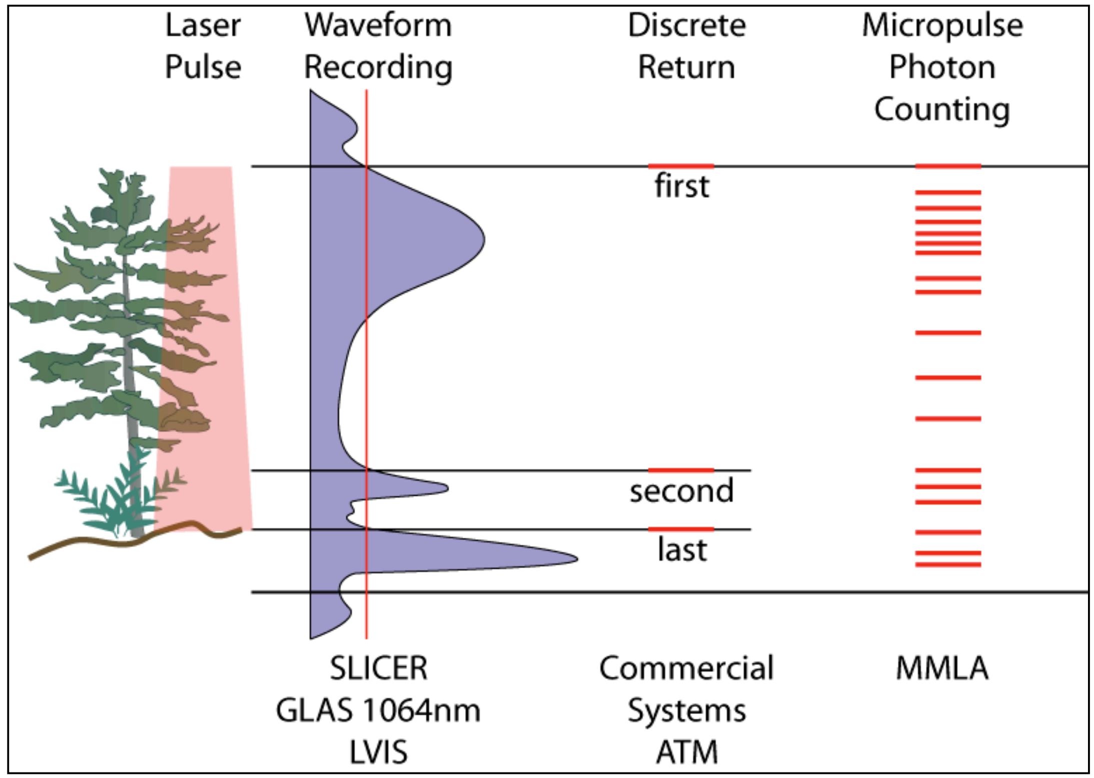
Lidar Remote Sensing of Snow Depth

- laser altimetry
- uses in other fields
  - DEM generation
  - fault mapping
  - vegetation structure
  - coastline mapping
  - near-shore bathymetry …

Courtesy Jeff Deems, CSU

Lidar Ranging Methods

- Discrete return
  - logs time when return intensity exceeds threshold
  - commercial airborne systems
- Waveform recording
  - records entire return intensity profile
  - vegetation, atmospheric applications
- Photon counting
  - digital recording of individual photon returns
  - low power requirements
  - good cloud penetration
- Profiling or scanning
  - scan patterns



courtesy Dave Harding, NASA/GSFC

Some Lidar Sensor Wavelengths

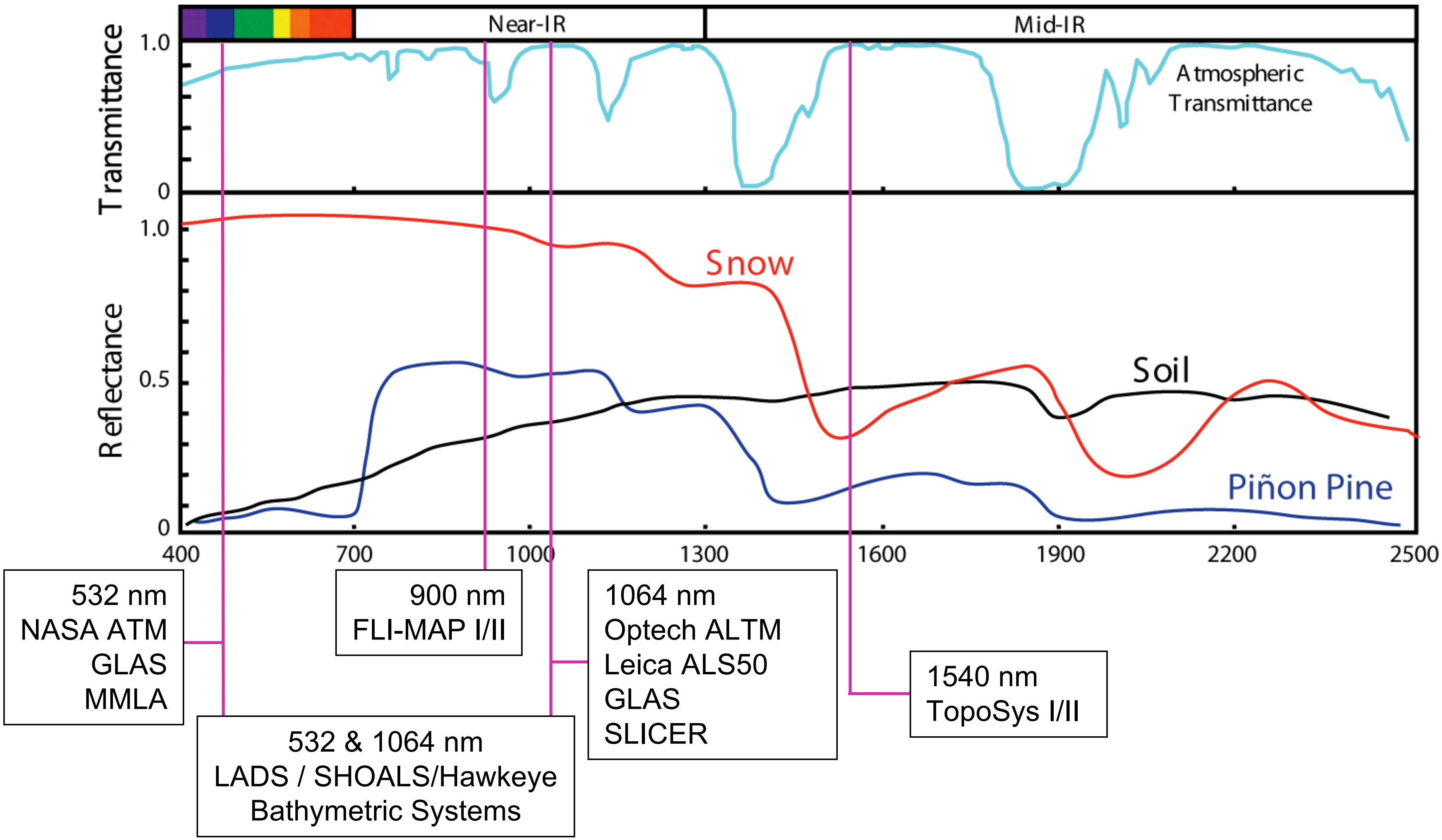
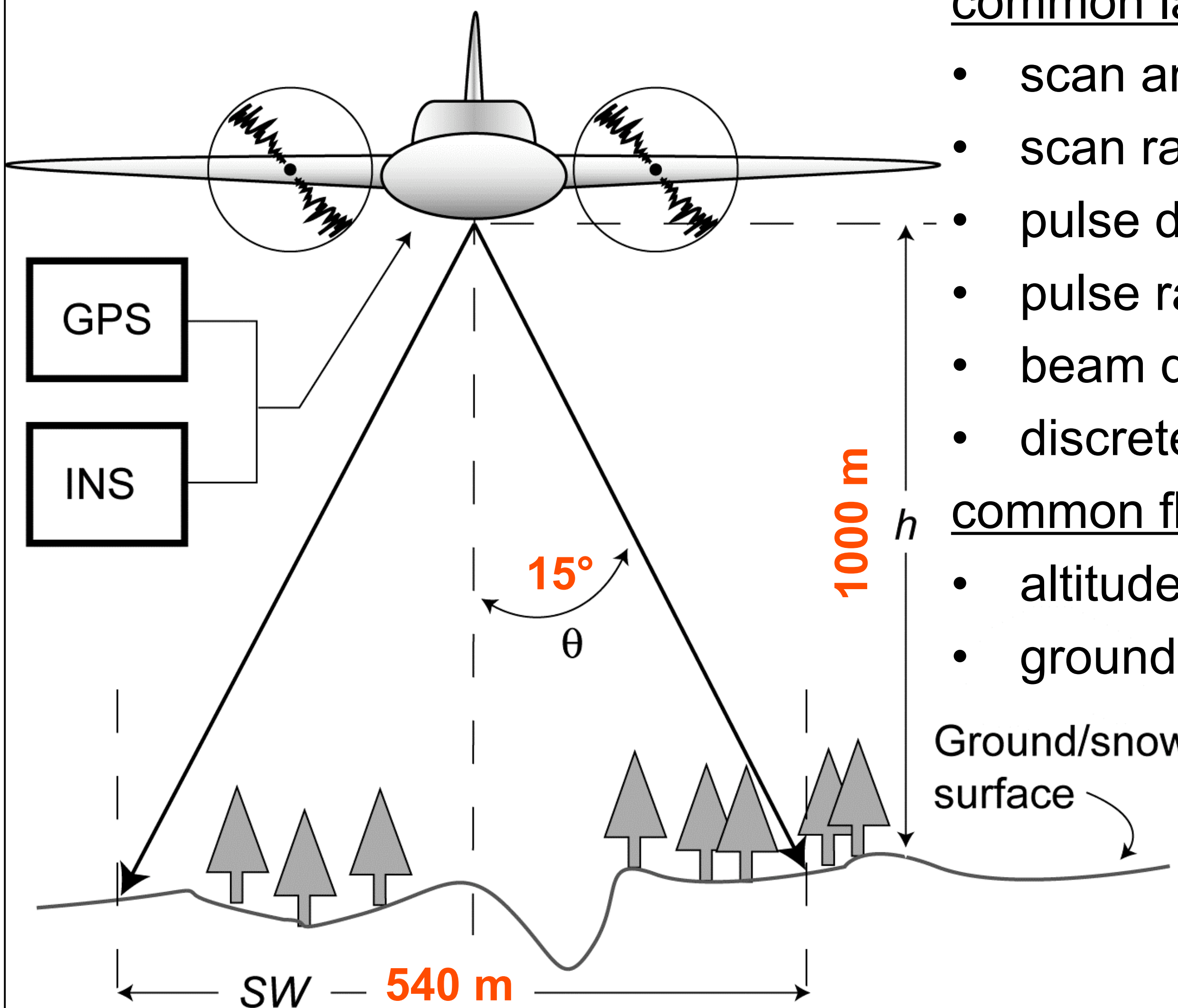


image courtesy Michael Lefsky, CSU

Commercial Airborne Lidar System Components



<u>common laser parameters</u>

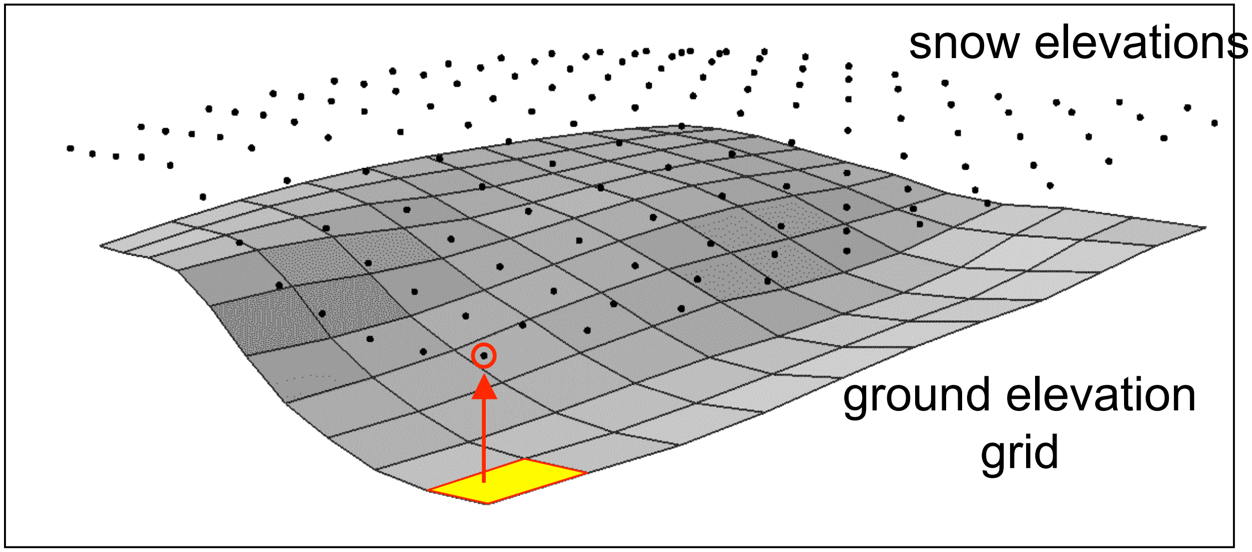
- scan angle: 0-45°
- scan rate: 0-70 Hz
- pulse duration: 6-12 ns
- pulse rate: 4-100 kHz
- beam divergence: 0.25-1mrad
- discrete returns/pulse 4-5

<u>common flight parameters</u>

- altitude AGL1000-1500 m
- ground speed 230 km/h

Lidar Snow Depth Mapping

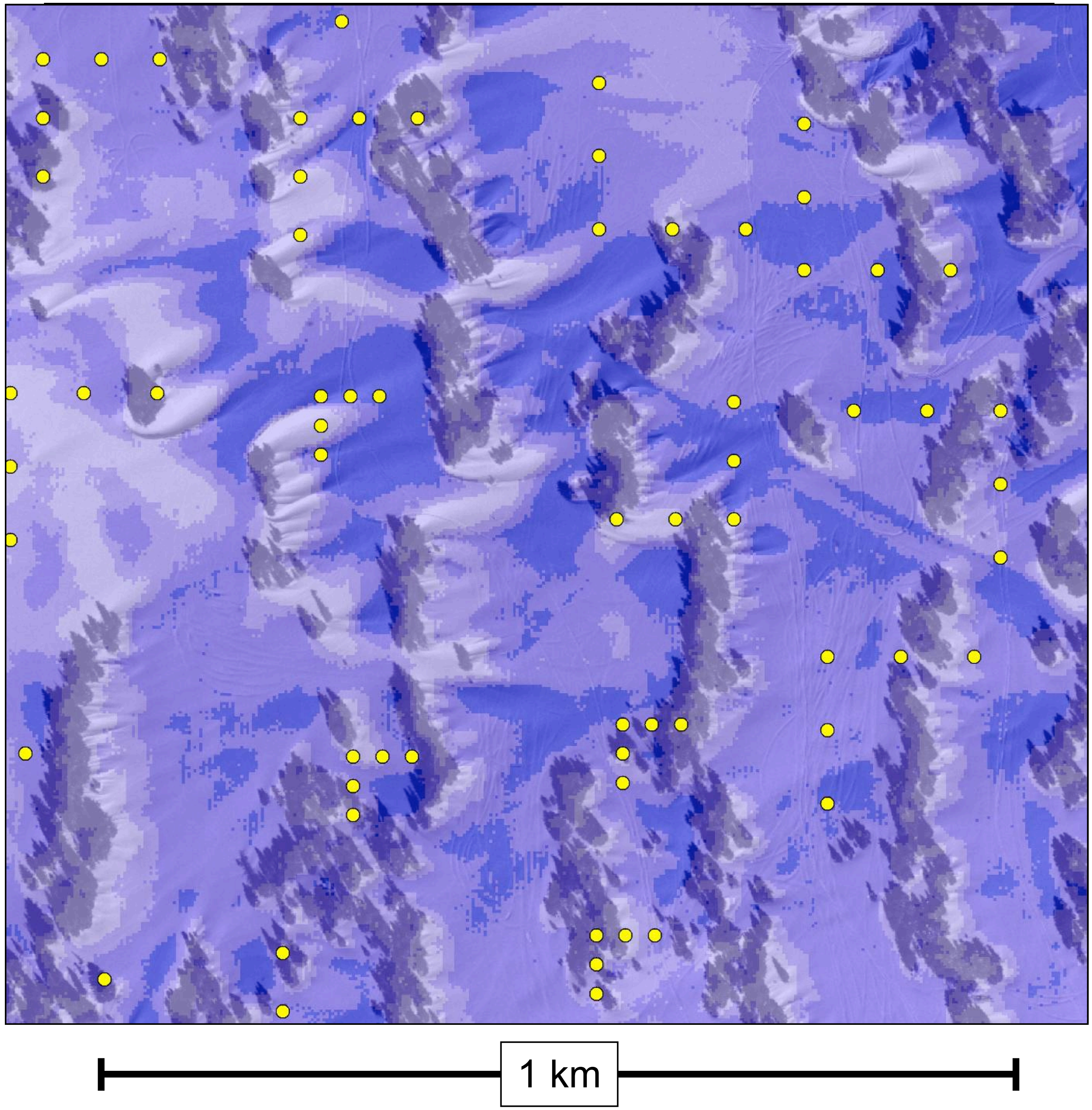
- 2 data collections required
  - snow free & snow covered
- Filter to remove 'not-ground' (vegetation) points
- Convert ground (snow-free) point elevations to grid
- Extract grid values to snow elevation points
- Subtract elevations



Courtesy of Jeff Deems, CSU

CLPX Buffalo Pass ISA

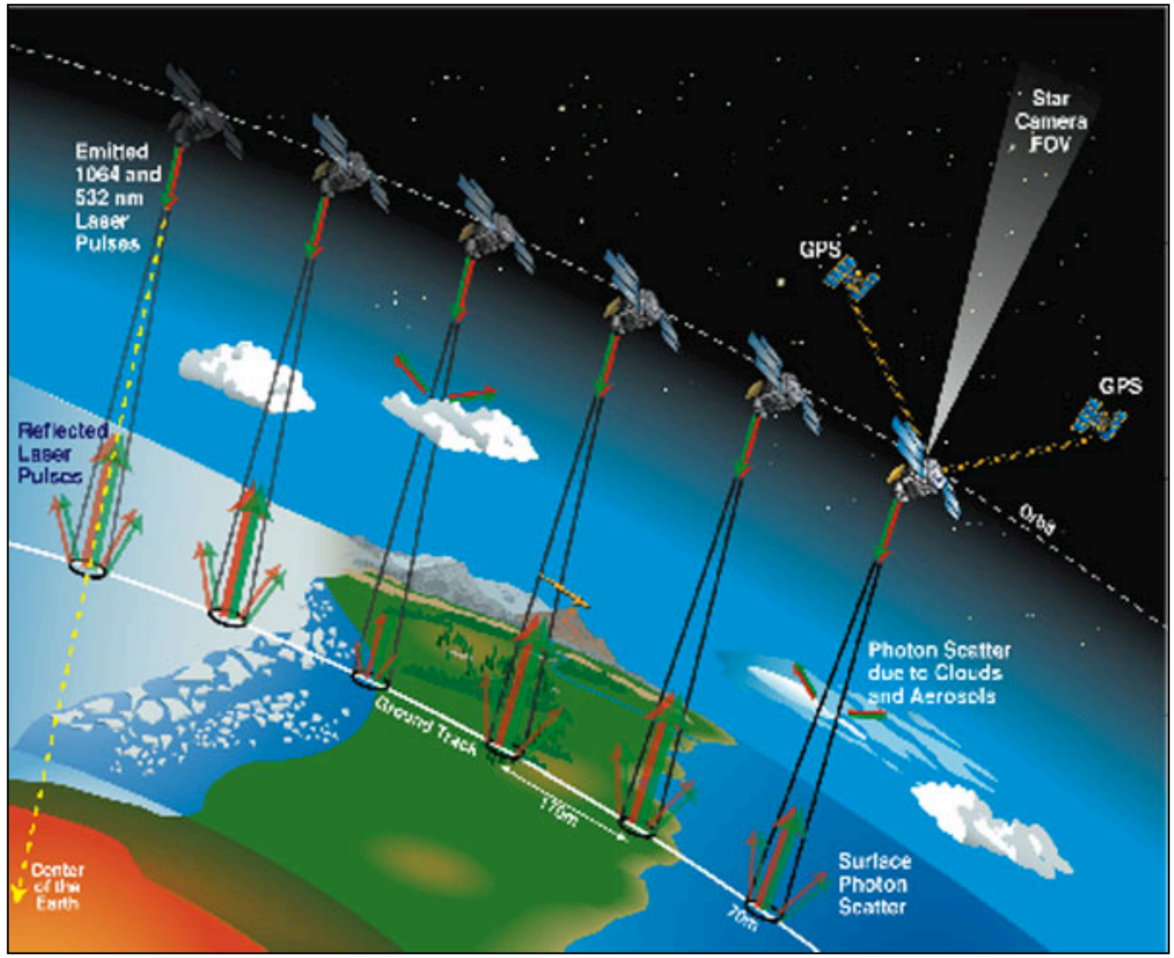
- 9 April 2003
- discrete-return 1064 nm airborne scanning system
- 1.5 m point spacing
- 0.15 m vertical accuracy
- 600k data points



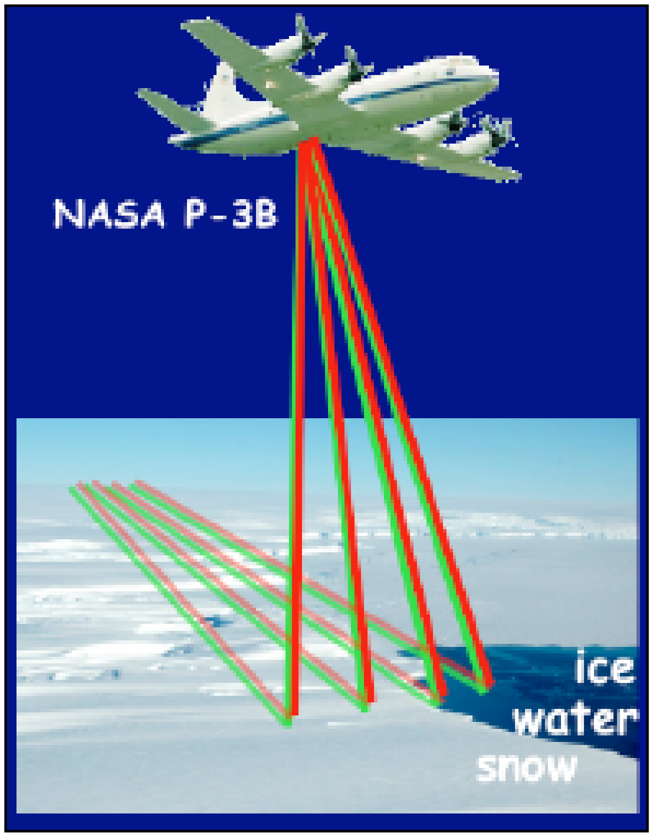
Current Laser Altimeter: ICESat

<u>ICESat</u>

- 532 nm: photon counting atmospheric sounding
- 1064: waveform-recording altimetry
- 70 m laser footprint
- 170 m along-track spacing (due to pulse repetition rate)



Future Laser Altimeter



courtesy Dave Harding, NASA/GSFC

Swath-Imaging Multi-polarization Photon-counting Lidar (SIMPL)

NASA/ESTO IIP

D. Harding, PI 2006-2008

- 532 & 1064 nm micropulse lasers
- 1-beam profile in 2007
- 4-beam pushbroom in 2008 photon-counting
- parallel and perpendicular polarizations
- spaceflight instrument & mission development

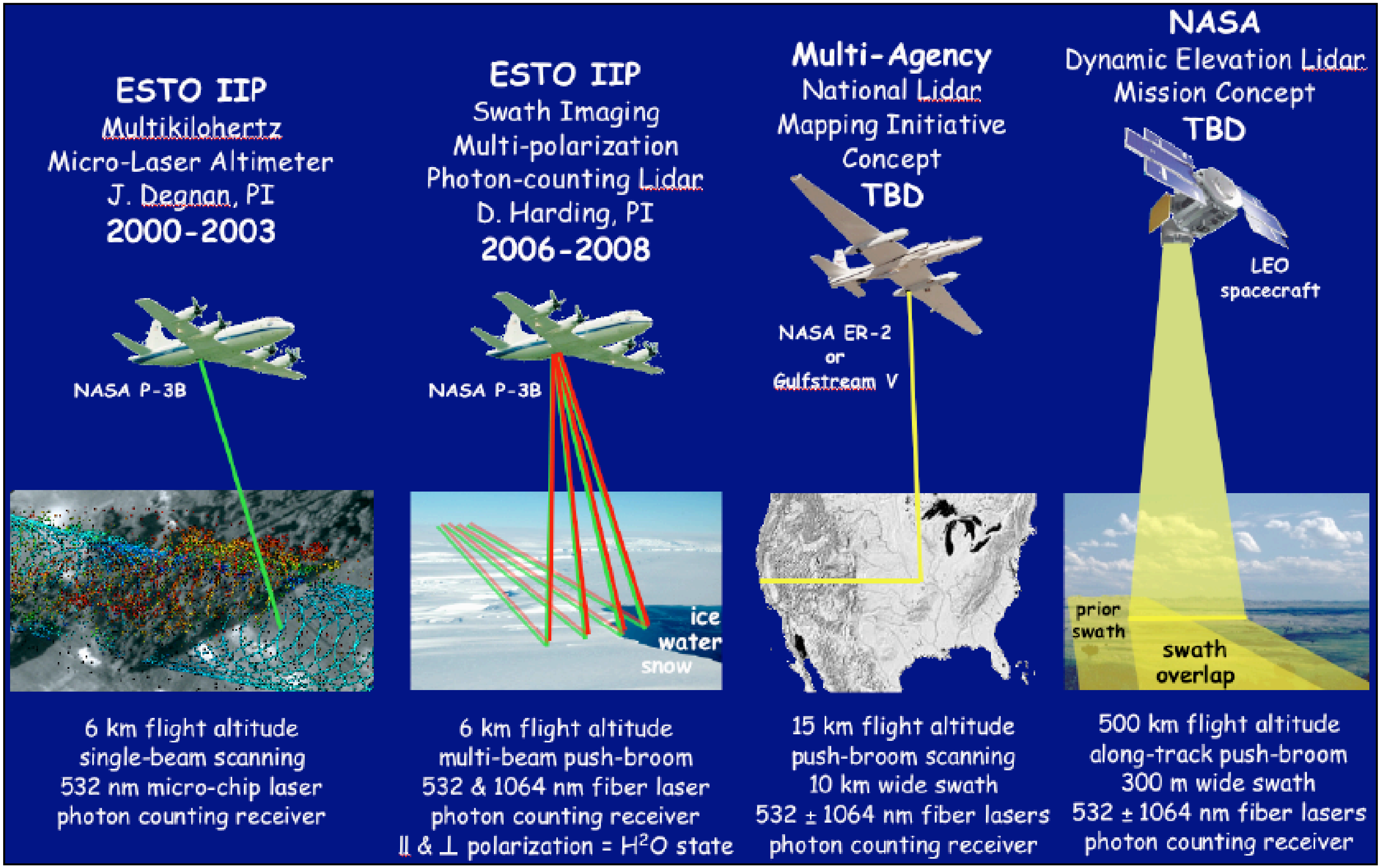
National Lidar Mapping Initiative Concept

- long-duration, long-range aircraft (e.g., ER-2)
  - high altitude enables wide swath (~10 km)
- cross-track scanned push-broom laser altimeter
  - nationally uniform data collection method
  - photon-counting, dual-polarized
- potential for complementary instrumentation
  - MSI/HIS
  - SAR interferometry
- 7-year implementation timeline
  - 4-year refresh interval

courtesy Dave Harding, NASA/GSFC

- base map for extending snow depth mapping to other basins/regions

NASA/GSFC
Lidar Swath Mapping Development



courtesy Dave Harding, NASA/GSFC

Summary of Target Lidar

- Target lidars, including fluorescence lidar, laser altimeter, hydrosphere lidar, ladar, fish lidar, etc, are an variant of atmospheric lidars. They share some of the same techniques used in atmospheric lidars.
- Laser altimeter and ladar use time-of-flight to determine the range of objects or surface. Many factors are involved.
- Fluorescence is used to measure species, organic materials, plants.
- Raman scattering by water is used to normalize the lidar returns.
- Target lidars face some different challenges and difficulties than atmospheric lidars. These challenges and difficulties also determines the growing points in this field.
- Target lidars have been deployed on different platforms for various applications. More efficient and compact target lidars on platforms like UAV, promise more applications.