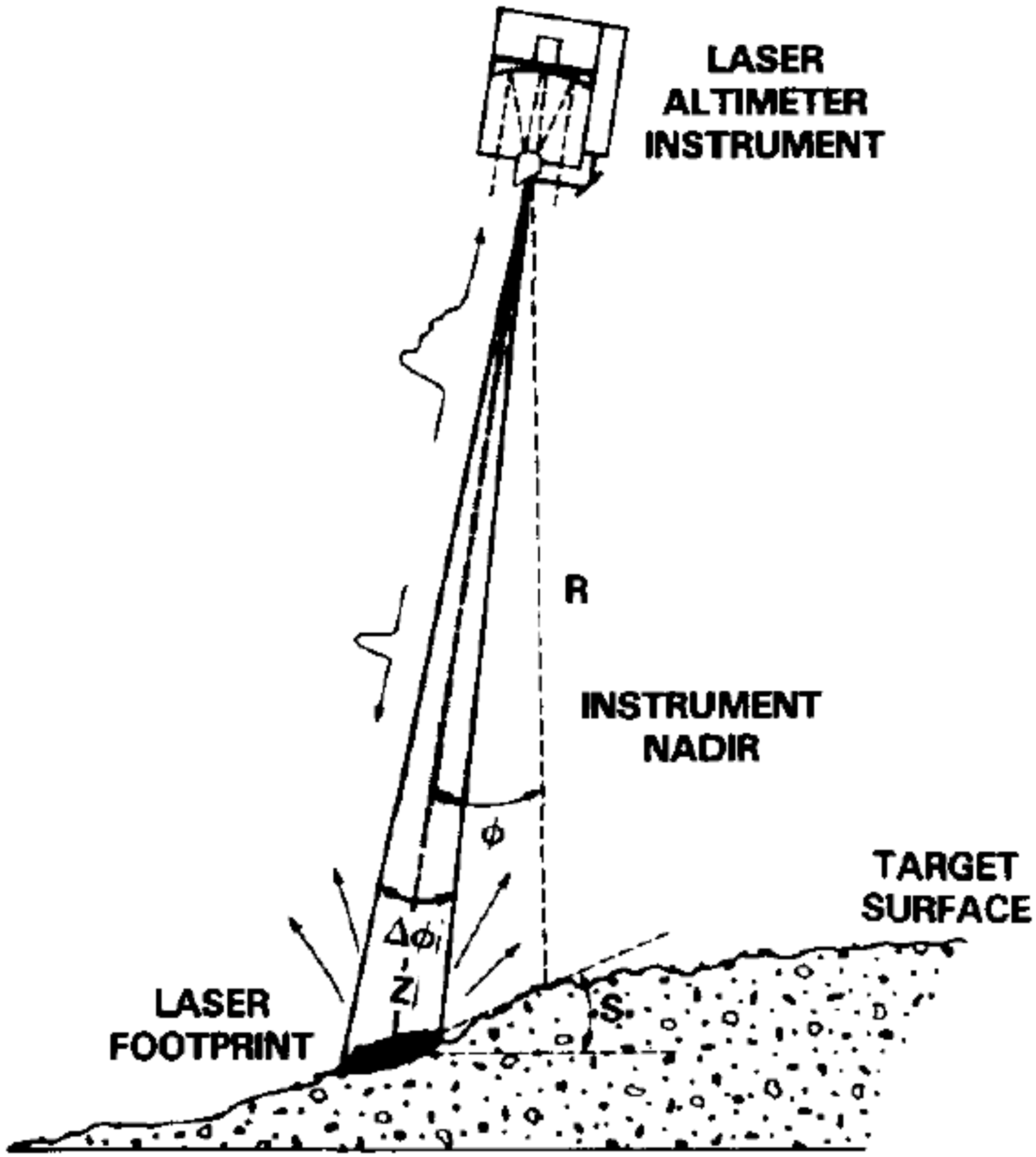
Lecture 33. Target Lidar (2)
Laser Altimeter

- Laser Altimeter
- GLAS on ICESat
- Lidar remote sensing of snow depth
- Summary of Target Lidar

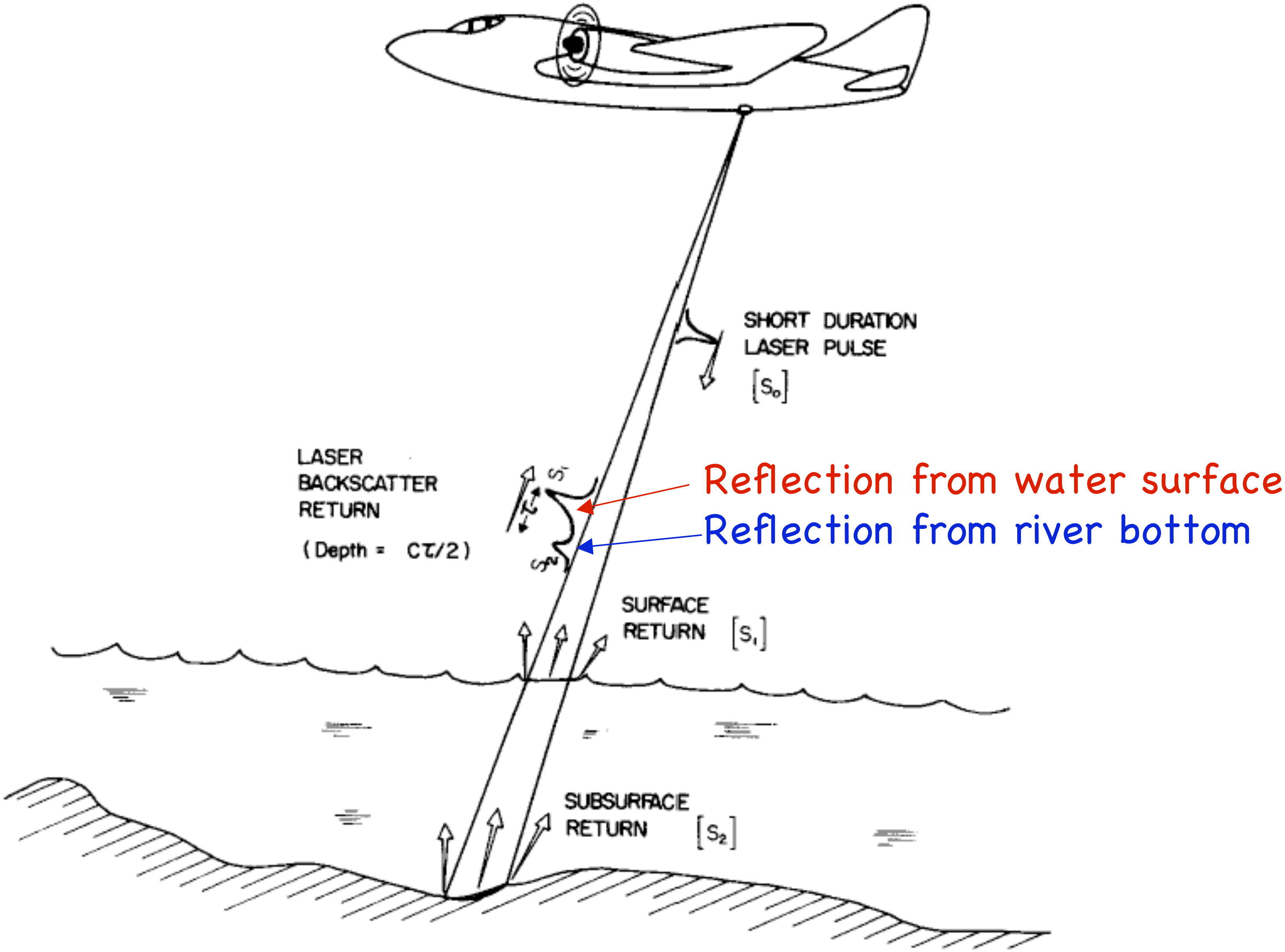
Laser Altimeter (Laser Ranging)

- 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.

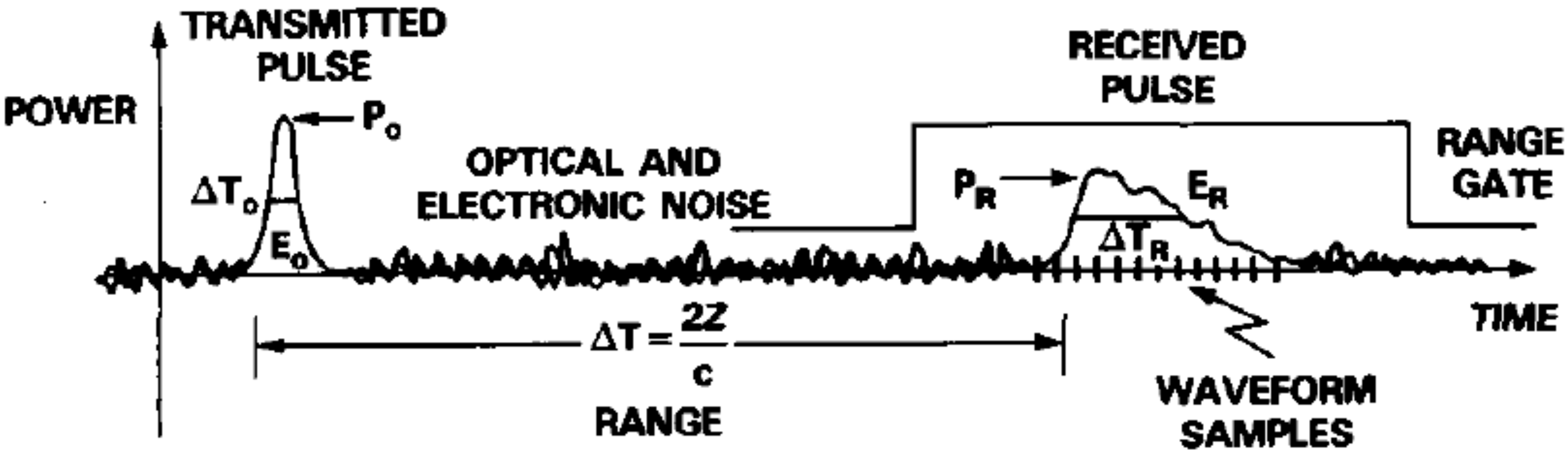
- The reflected pulses from the solid surface (earth ground, ice sheet, etc) dominant the return signals, which allow a determination of the time-of-flight to much higher resolution than the pulse duration time.



Laser Altimeter for Hydrosphere



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

Geoscience Laser Altimeter System (GLAS) on the ICESat

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.)

GLAS Objectives and Specifications

- The primary purpose of GLAS is to detect ice elevation changes by precision profiling of ice surface elevations over the Greenland and Antarctic ice sheets, that are indicative of changes in ice volume (mass balance) over time.
- Other objectives include measurements of sea ice, ocean, and land surface elevations; ice, water, and land surface roughness; multiple near-surface canopy heights over land; and cloud and aerosol layer heights.
- Diode-pumped Nd:YAG laser at 1064 nm for surface topography measurements.
- Frequency-doubled laser at 532 nm for cloud/aerosol and atmospheric study.

Table 13.2. System parameters for the spaceborne GLAS lidar (Courtesy of S.P. Palm.)

Parameter	532-nm Channel	1064-nm Channel
Orbit altitude	600 km	600 km
Laser energy	36 mJ	73 mJ
Laser divergence	110 μrad	110 μrad
Laser repetition rate	40 Hz	40 Hz
Effective telescope diameter	0.95 m	0.95 m
Receiver field of view	160 μrad	475 μrad
Detector quantum efficiency	70%	35%
Detector dark current	3.0×10^{-16} A	50×10^{-12} A
RMS detector noise	0.0	20×10^{-12} A
Electrical bandwidth	1.953×10^6 Hz	1.953×10^6 Hz
Optical filter bandwidth	0.030 nm	1.00 nm
Total optical transmission	30%	55%

GLAS on ICESat

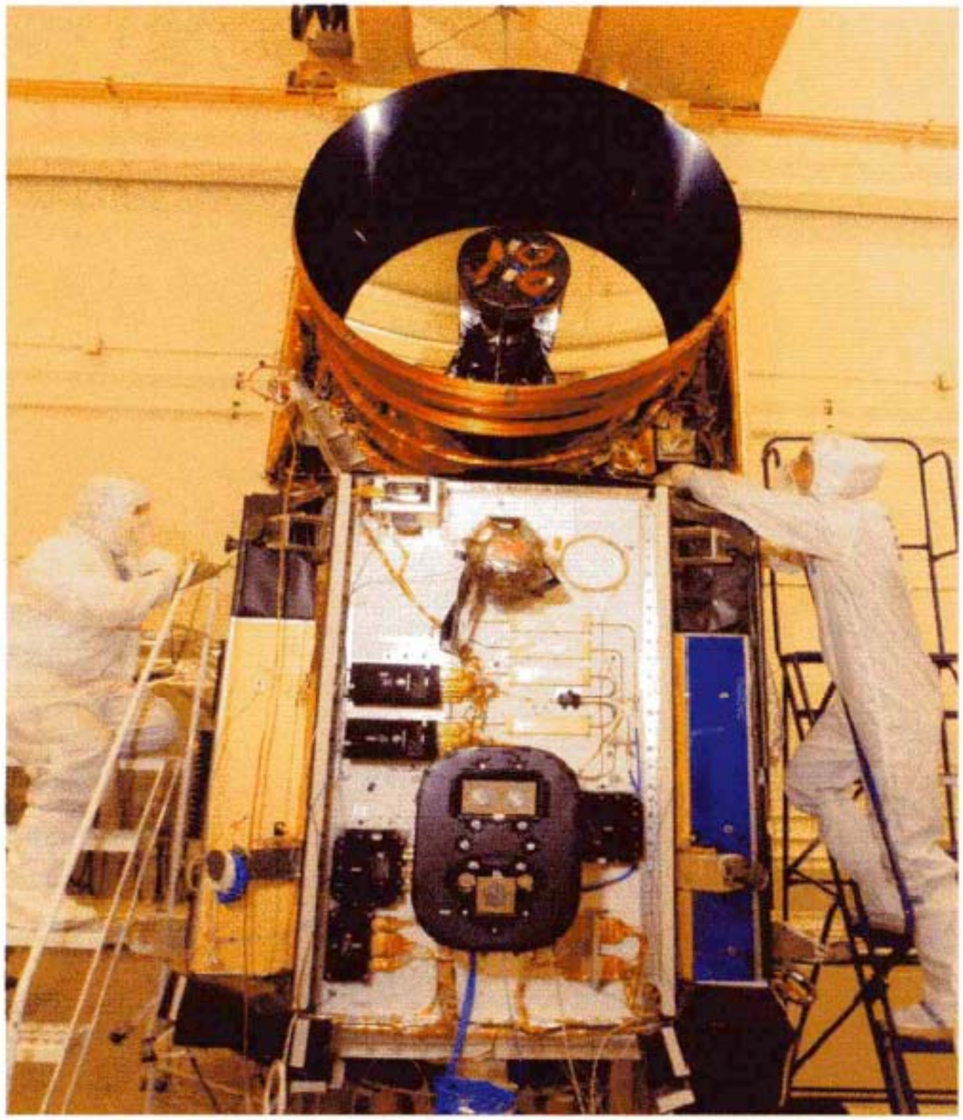


Fig. 13.22. Shows the ICESat during fabrication in a clean room at Ball Aerospace and Technologies Corporation, Boulder, Colorado. ICESat was launched on a Boeing Corporation Delta II launch vehicle, January 2003.

University of Colorado NSIDC is also involved in the ICESat. (National Snow and Ice Data Center)

Challenges in Laser Altimeter

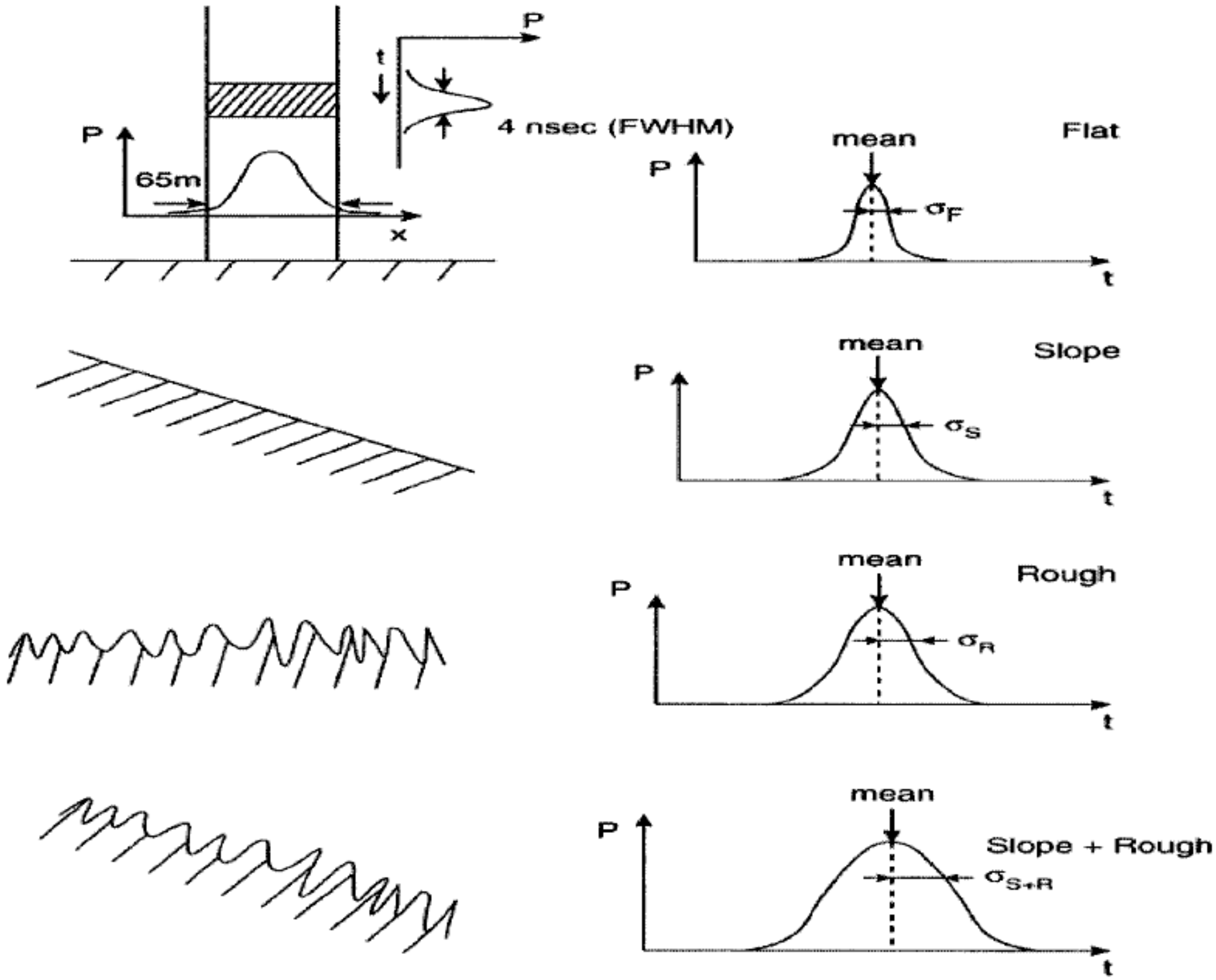
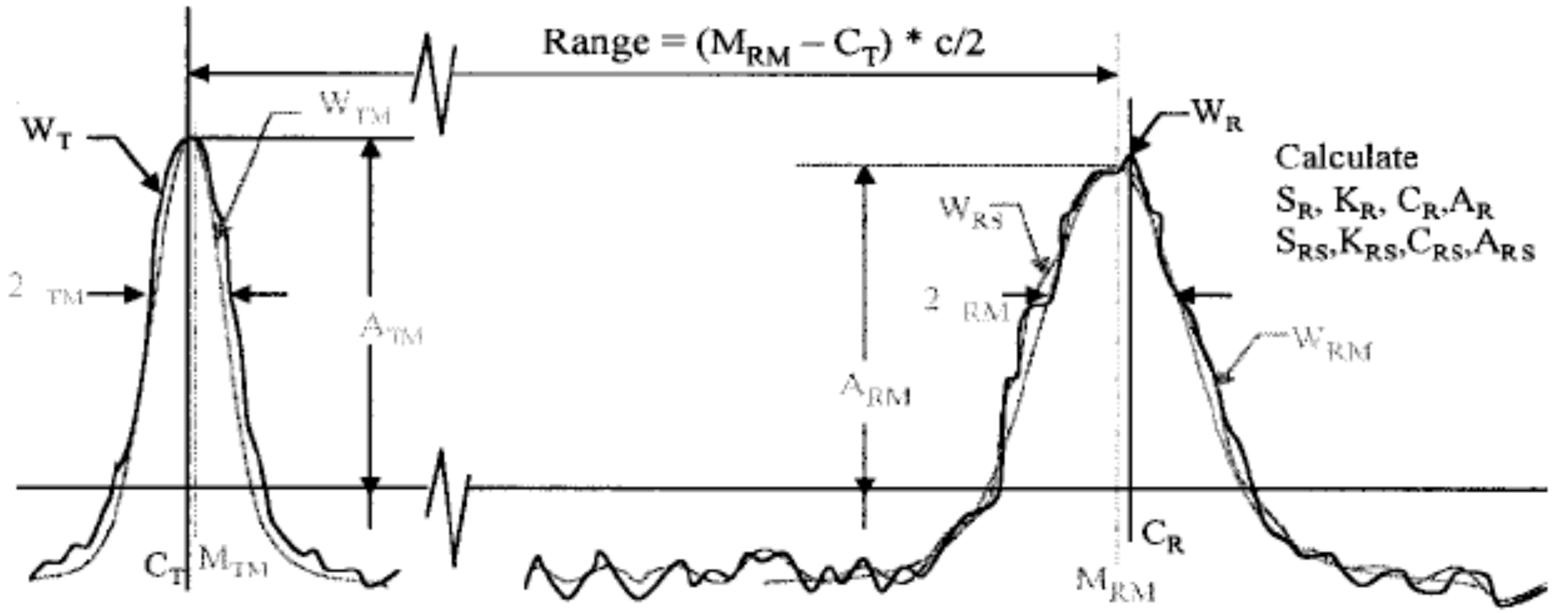


Figure 1 - Characteristics of returned laser pulse as a function of surface type. Presence of surface slope and roughness both broaden the pulse.

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

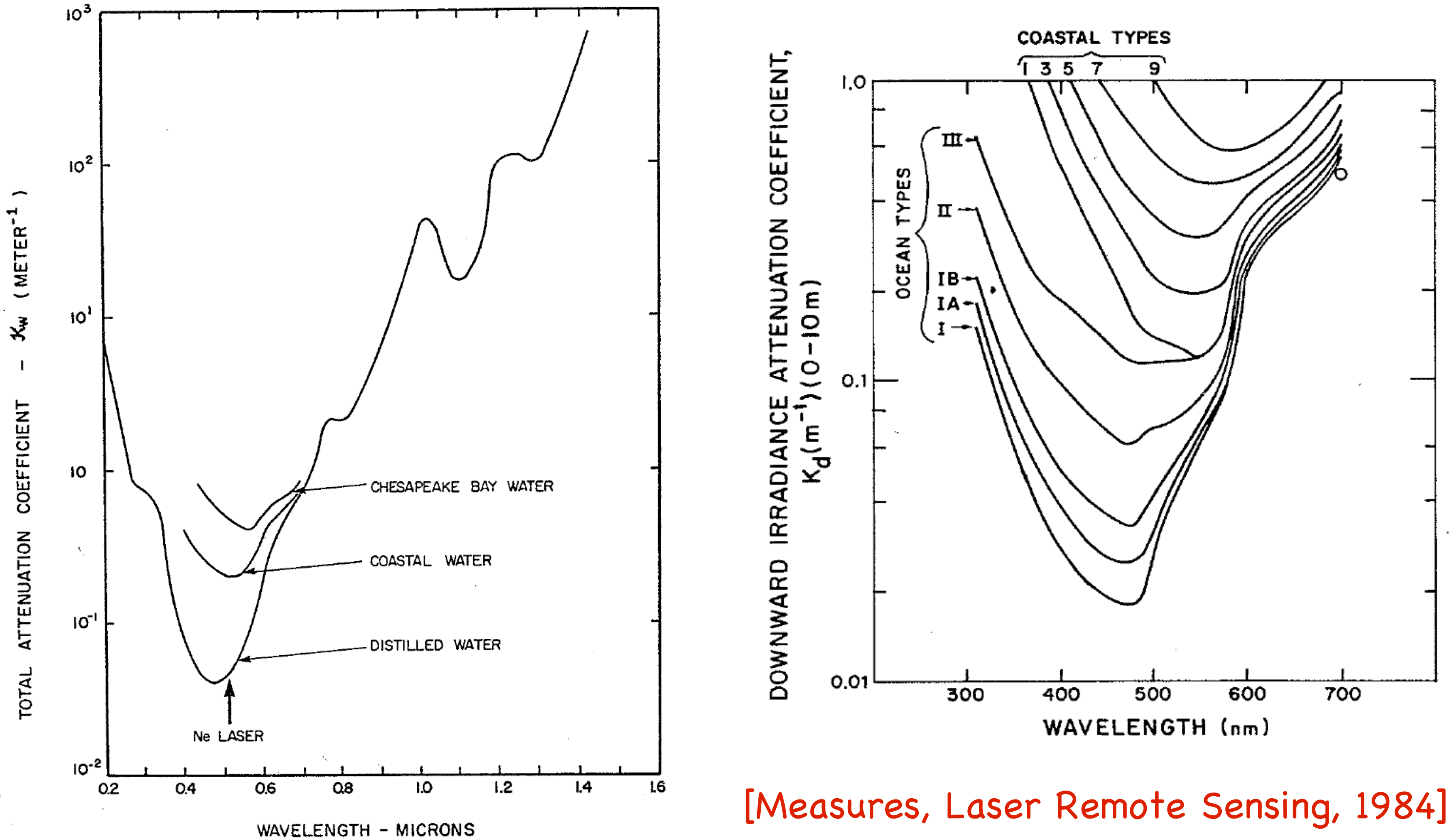
- Besides the analysis of waveform distortions caused by surface slope and roughness, other factors that can affect the accuracy of laser altimeter include

(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) Conversion ranges into absolute surface elevations with respect to the geoid.

Table 9.10 Ice Altimetry Error Budget

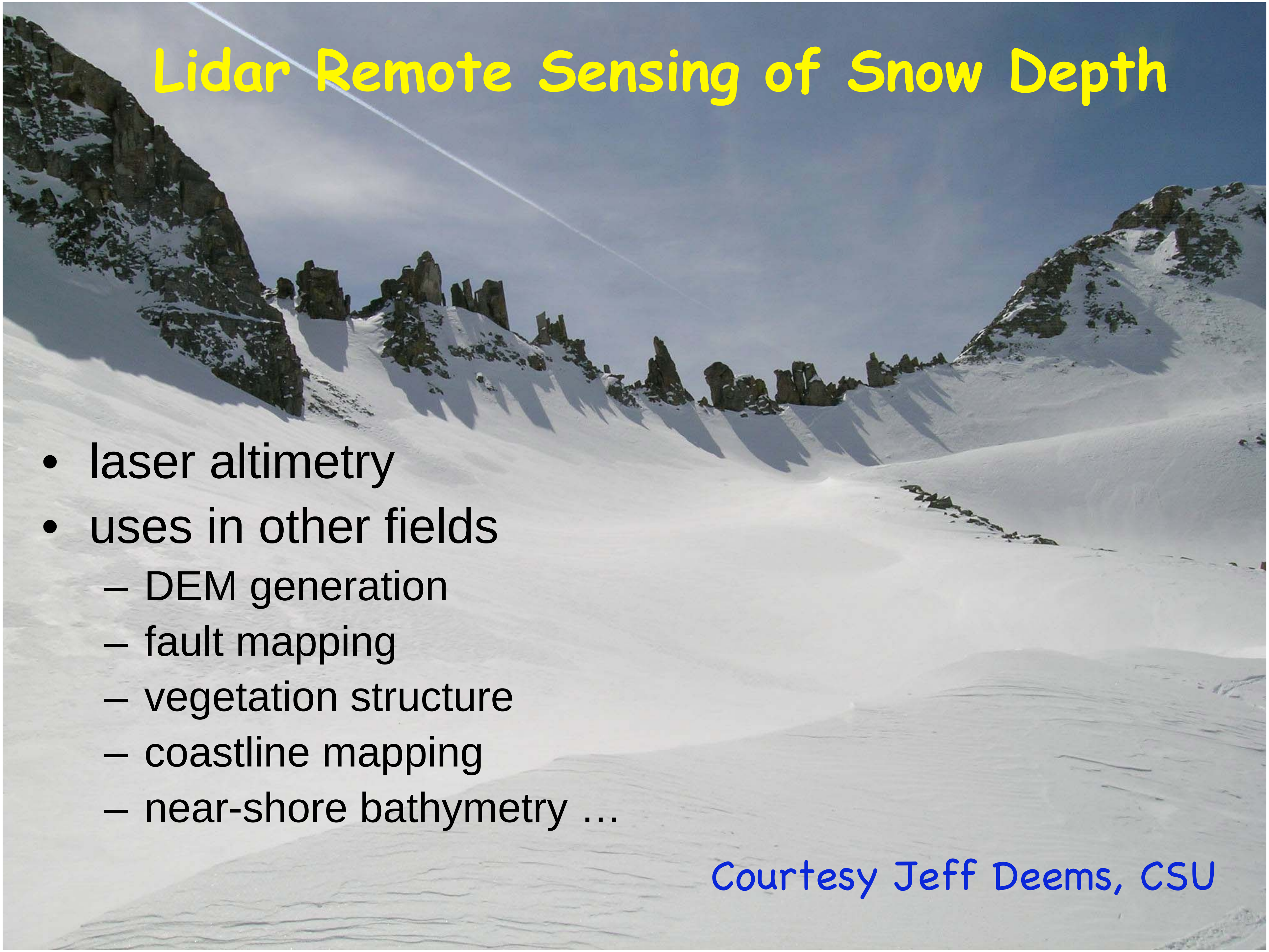
Source	Error type	Magnitude (cm)
Instrument	Single-shot accuracy (3° surface features)	<10
	Range bias	<5
	Laser beam pointing angle uncertainty (1 arcsec, 2° surface)	18
	Radial orbit uncertainty	5
	Clock synchronization (1 μsec)	1
Spacecraft	Distance uncertainty from S/C POD to GLAS zero reference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



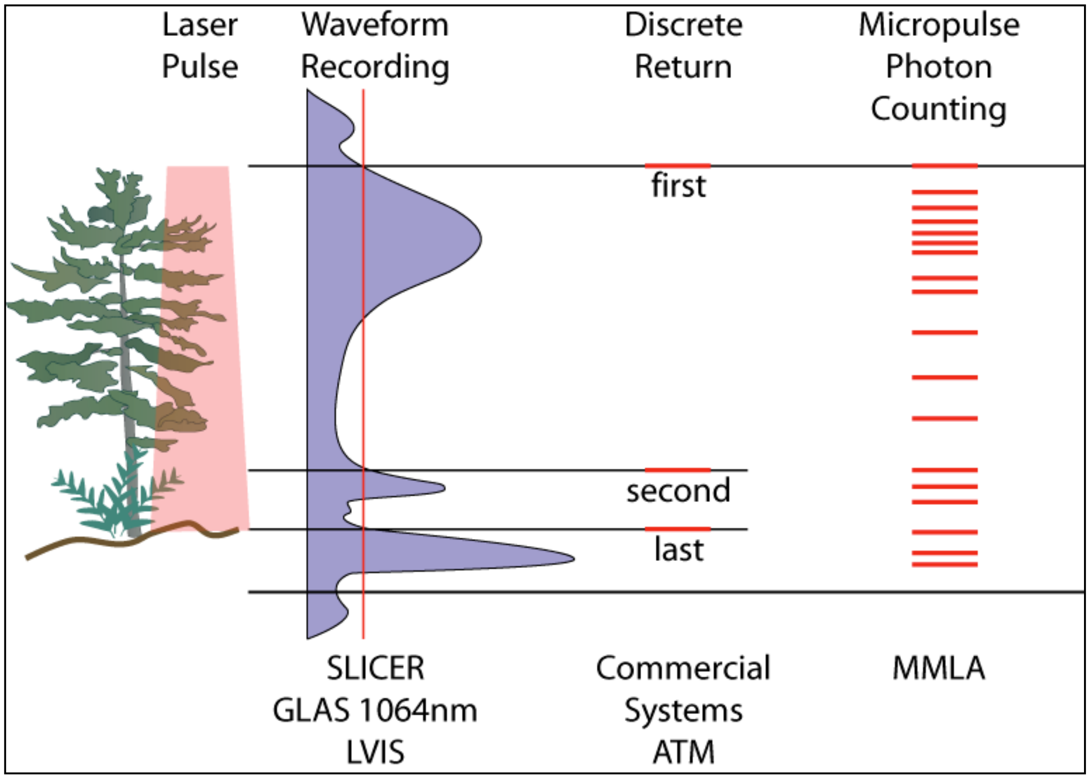
Lidar Remote Sensing of Snow Depth

- 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

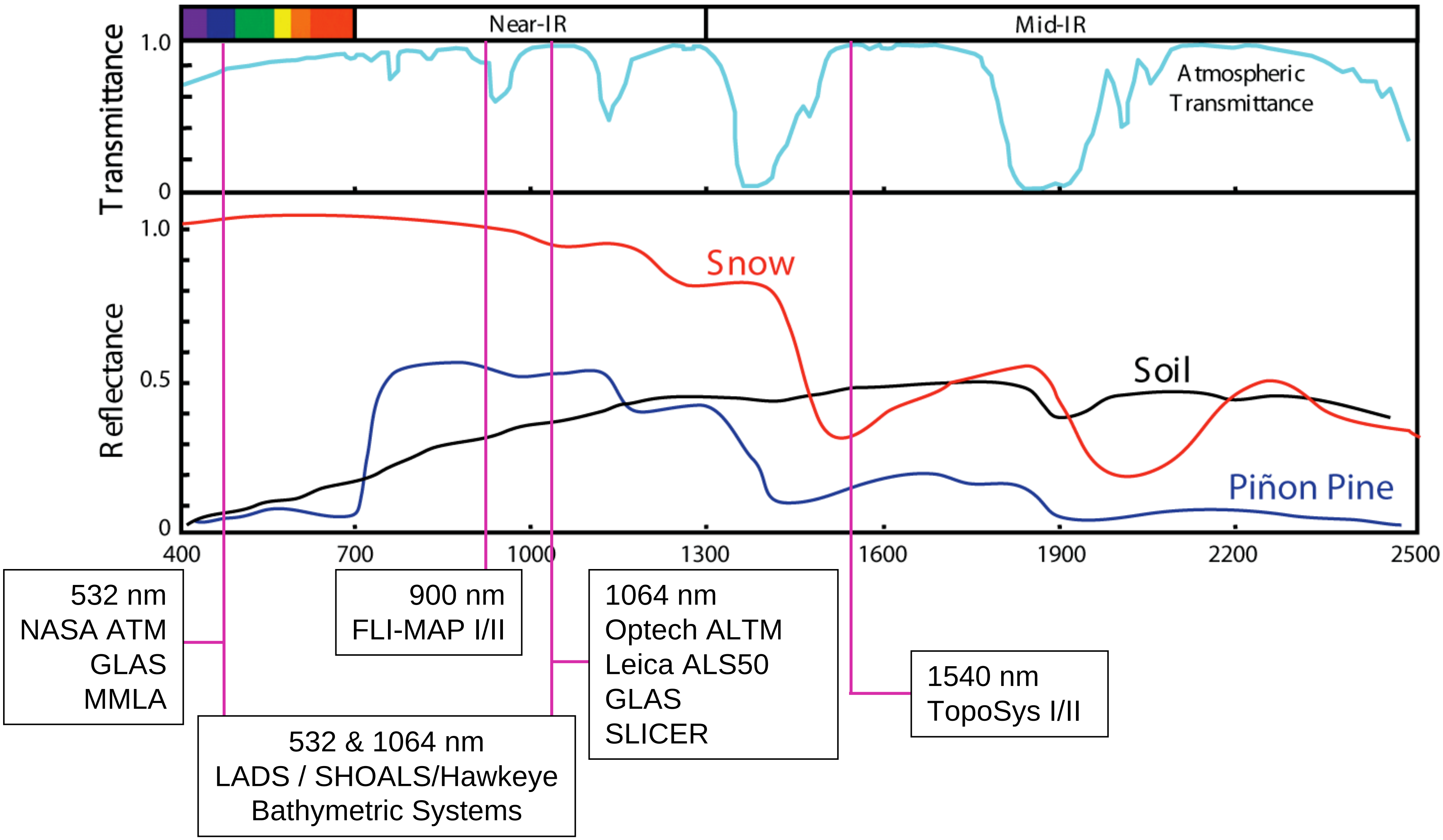
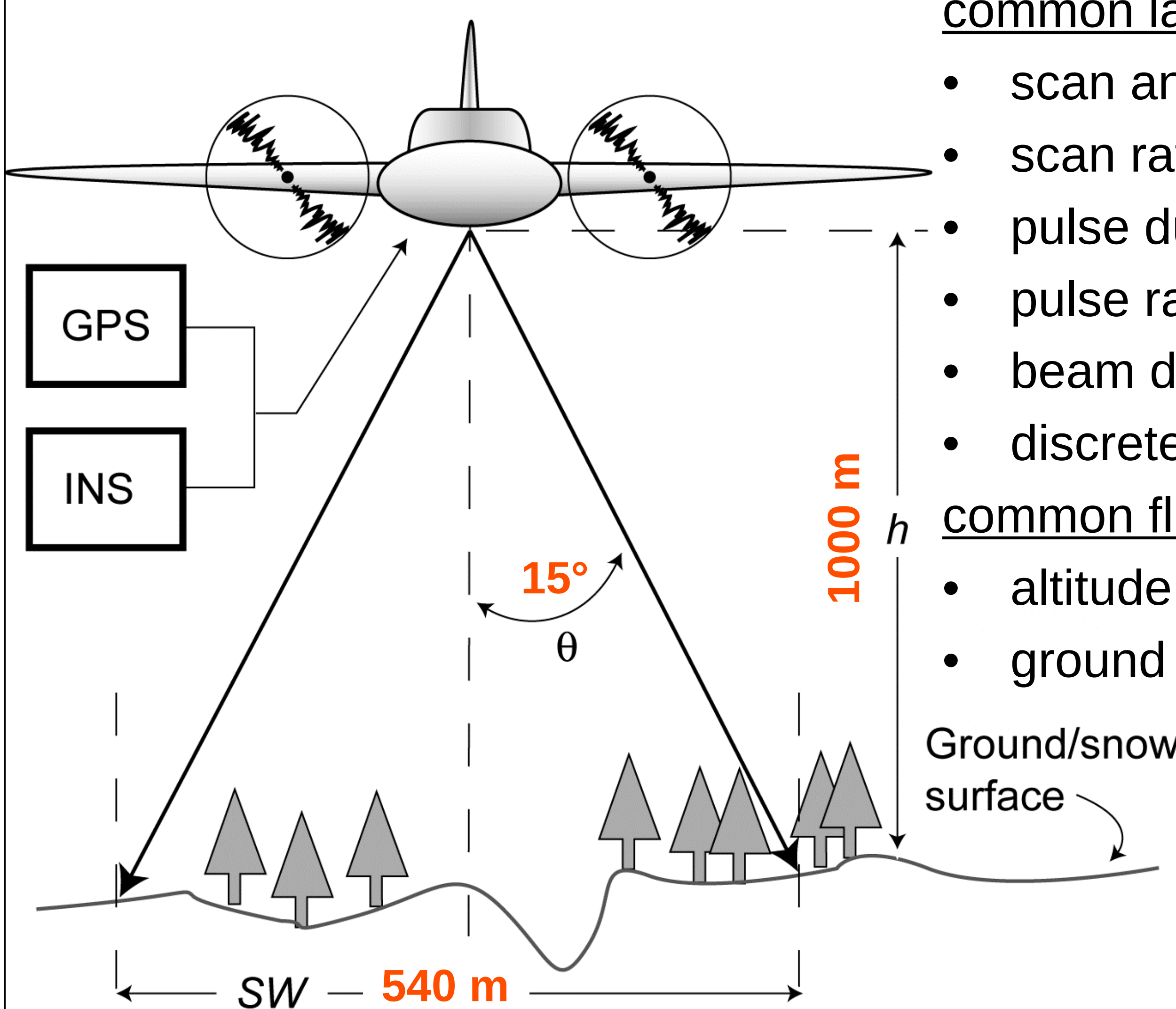


image courtesy Michael Lefsky, CSU

Commercial Airborne Lidar System Components



common laser parameters

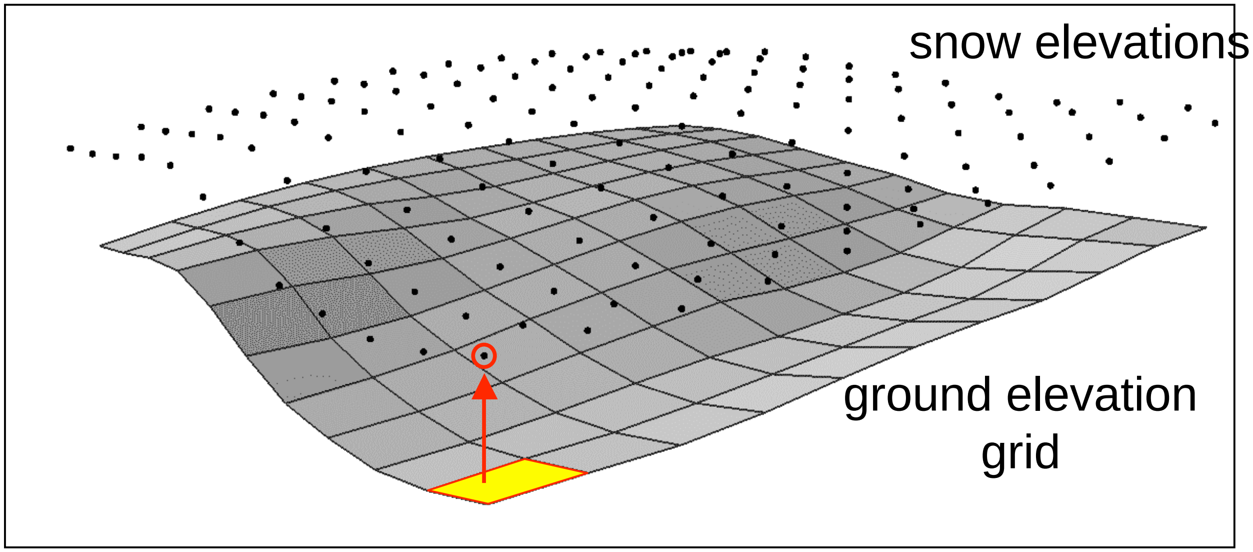
- scan angle: 0-45°
- scan rate: 0-70 Hz
- pulse duration: 6-12 ns
- pulse rate: 4-100 kHz
- beam divergence: 0.25-1mrad
- discrete returns/pulse 4-5

common flight parameters

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

Lidar Snow Depth Mapping

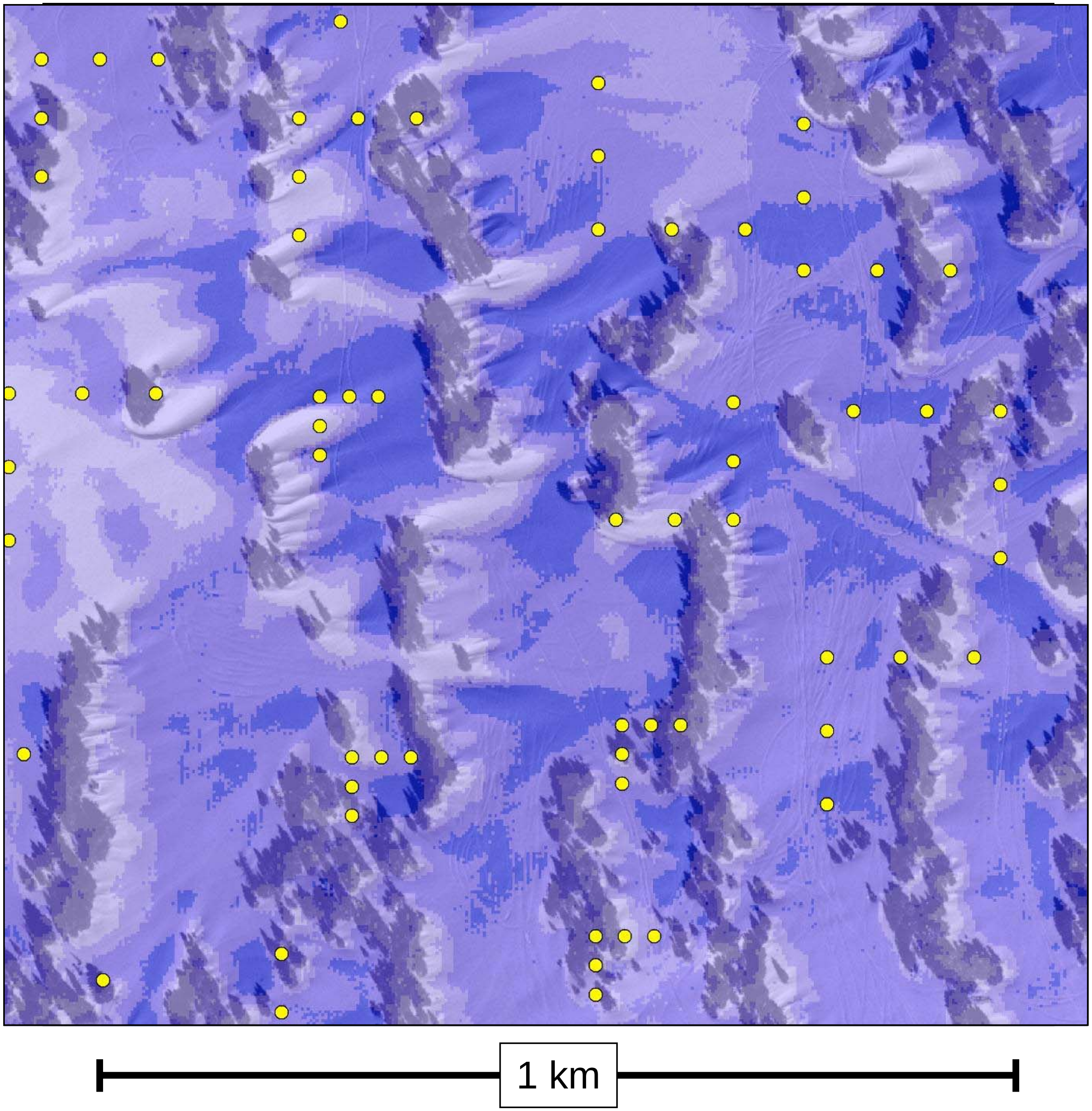
- 2 data collections required
  - snow free & snow covered
- Filter to remove 'not-ground' (vegetation) points
- Convert ground (snow-free) point elevations to grid
- Extract grid values to snow elevation points
- Subtract elevations



Courtesy of Jeff Deems, CSU

CLPX Buffalo Pass ISA

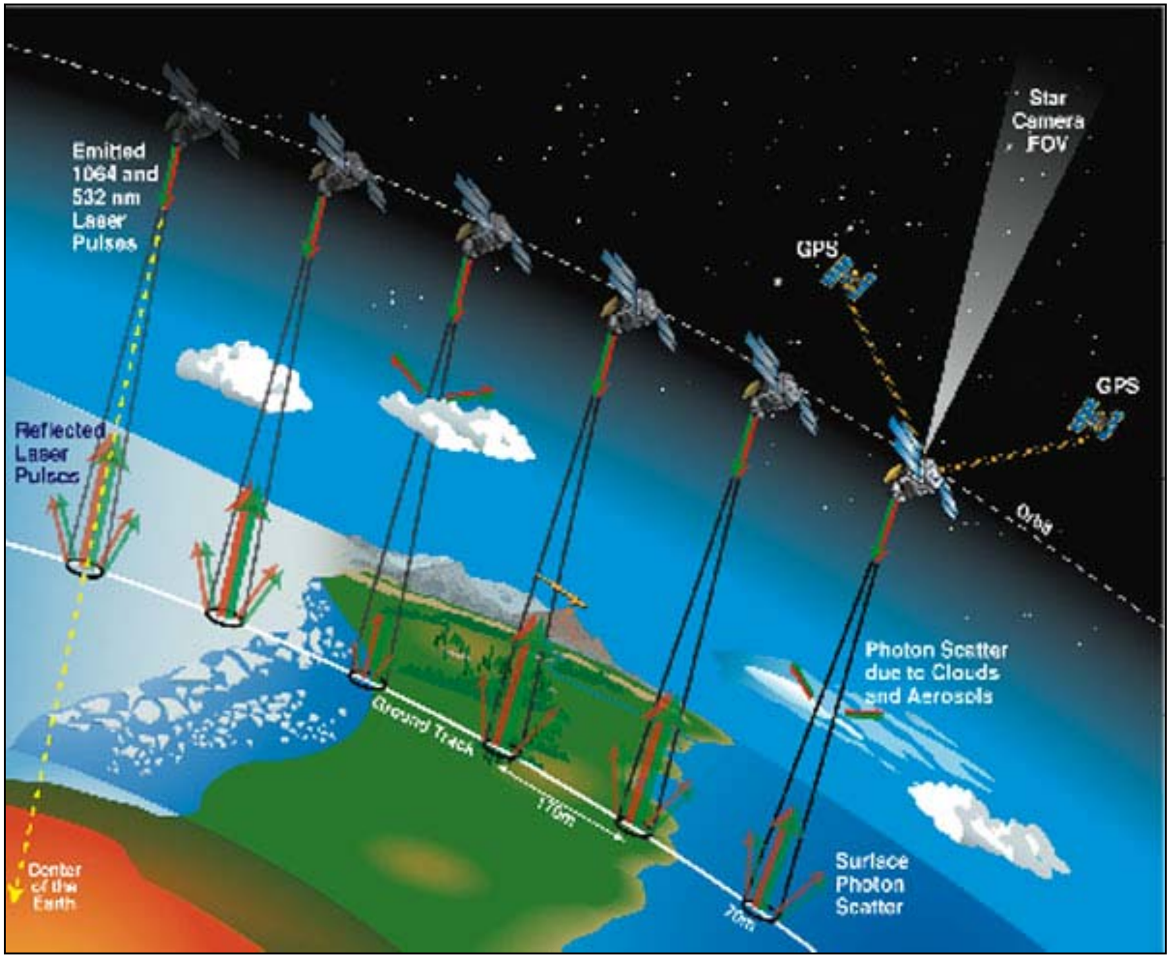
- 9 April 2003
- discrete-return 1064 nm airborne scanning system
- 1.5 m point spacing
- 0.15 m vertical accuracy
- 600k data points



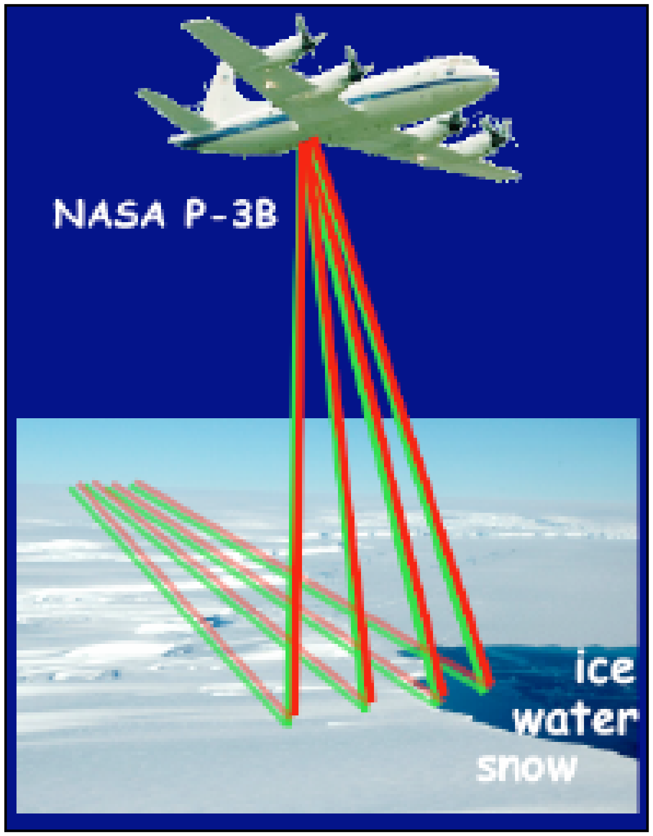
Current Laser Altimeter: ICESat

ICESat

- 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

<u>Swath-Imaging Multi-polarization Photon-counting Lidar (SIMPL)</u>

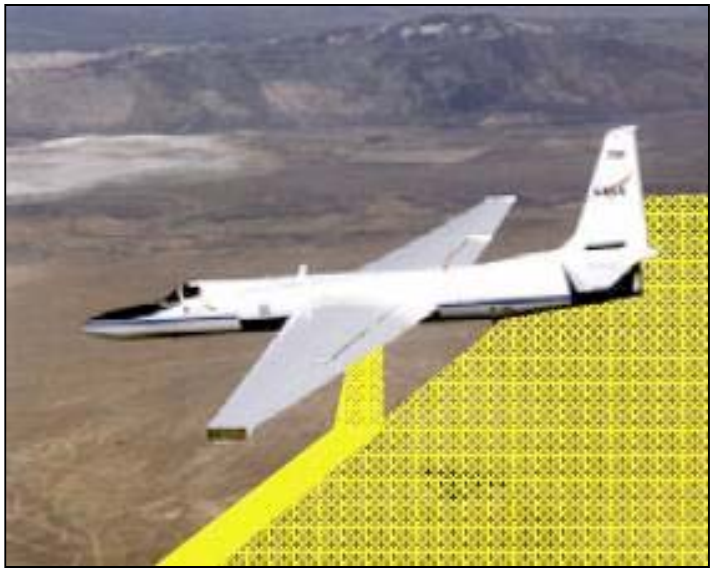
NASA/ESTO IIP

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

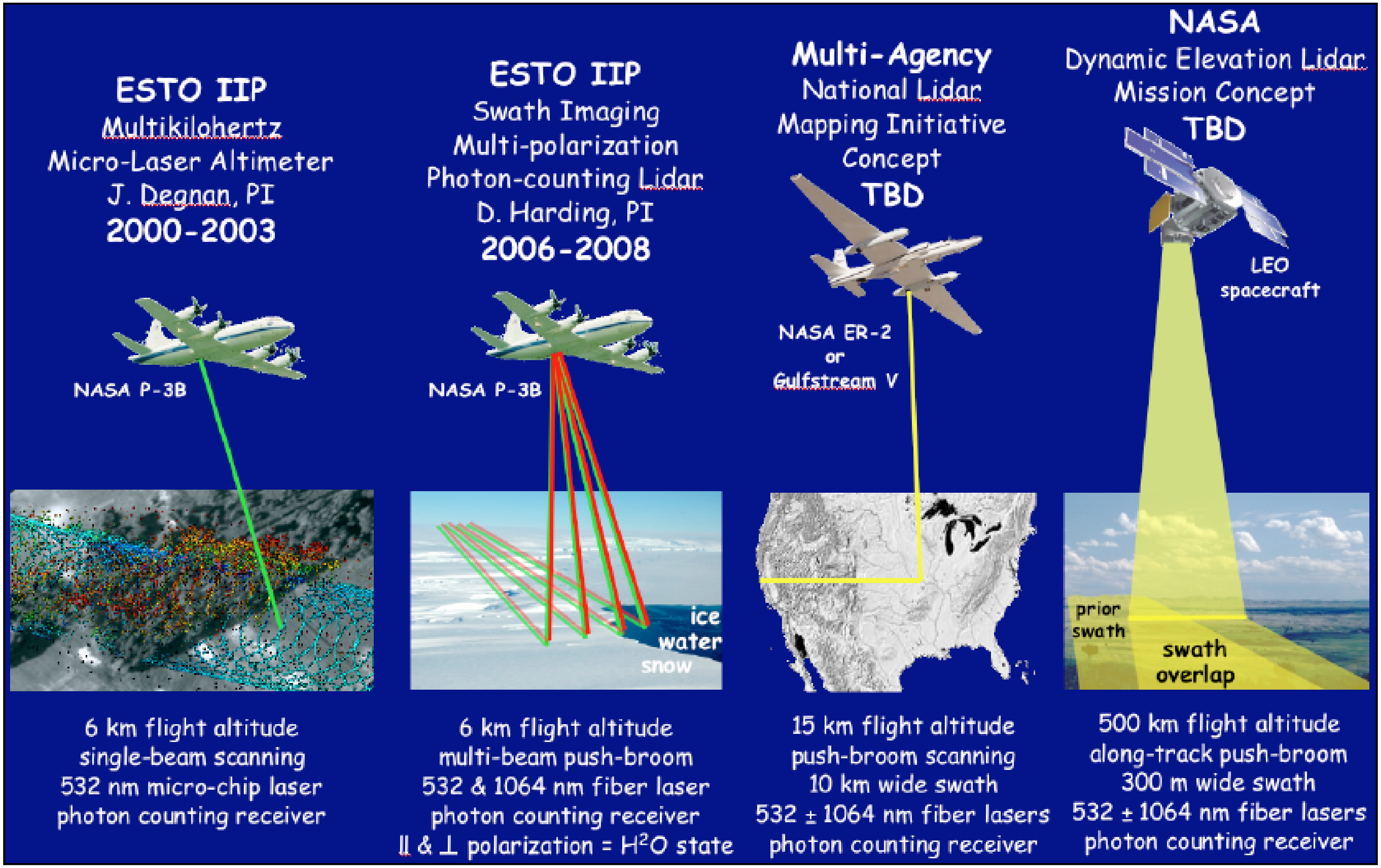
- long-duration, long-range aircraft (e.g., ER-2)
  - high altitude enables wide swath (~10 km)
- cross-track scanned push-broom laser altimeter
  - nationally uniform data collection method
  - photon-counting, dual-polarized
- potential for complementary instrumentation
  - MSI/HIS
  - SAR interferometry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