

# Lecture 36. Target Lidar (4)
# Laser Rangefinder - TOF Techniques

- Review Rangefinding Techniques and Principles
  1) Time of Flight; 2) Geometry-based
  3) Interferometry / Diffraction ranging
- Review Time of Flight Techniques
  1) Pulsed laser rangefinding 2) CW laser amplitude modulation
  3) CW laser chirp / Chirp pulse compression
- TOF: Altitude Determination and Error Budget
  1) Laser altimeter and Lidar bathymetry
  2) Waveform recording vs. micropulse photon counting
- Application examples



# Review: Rangefinding Techniques

- There are several different approaches to determine range, including the triangulation method with a very long history. We introduce mainly four types of rangefinding techniques:

- (1) Time of flight technique is used for the majority of laser range finder including laser altimeter and lidar bathymetry;

- (2) Geometric-based rangefinding technique is a generalization of the classical triangulation method. By projection of a light beam onto a target, the range can be calculated from known geometry.

- (3) Interferometry: using interferometry principle to measure distance to high accuracy,

- (4) Diffraction range measurement techniques, like speckle tech. and diffraction imaging.



# Review: TOF Rangefinding

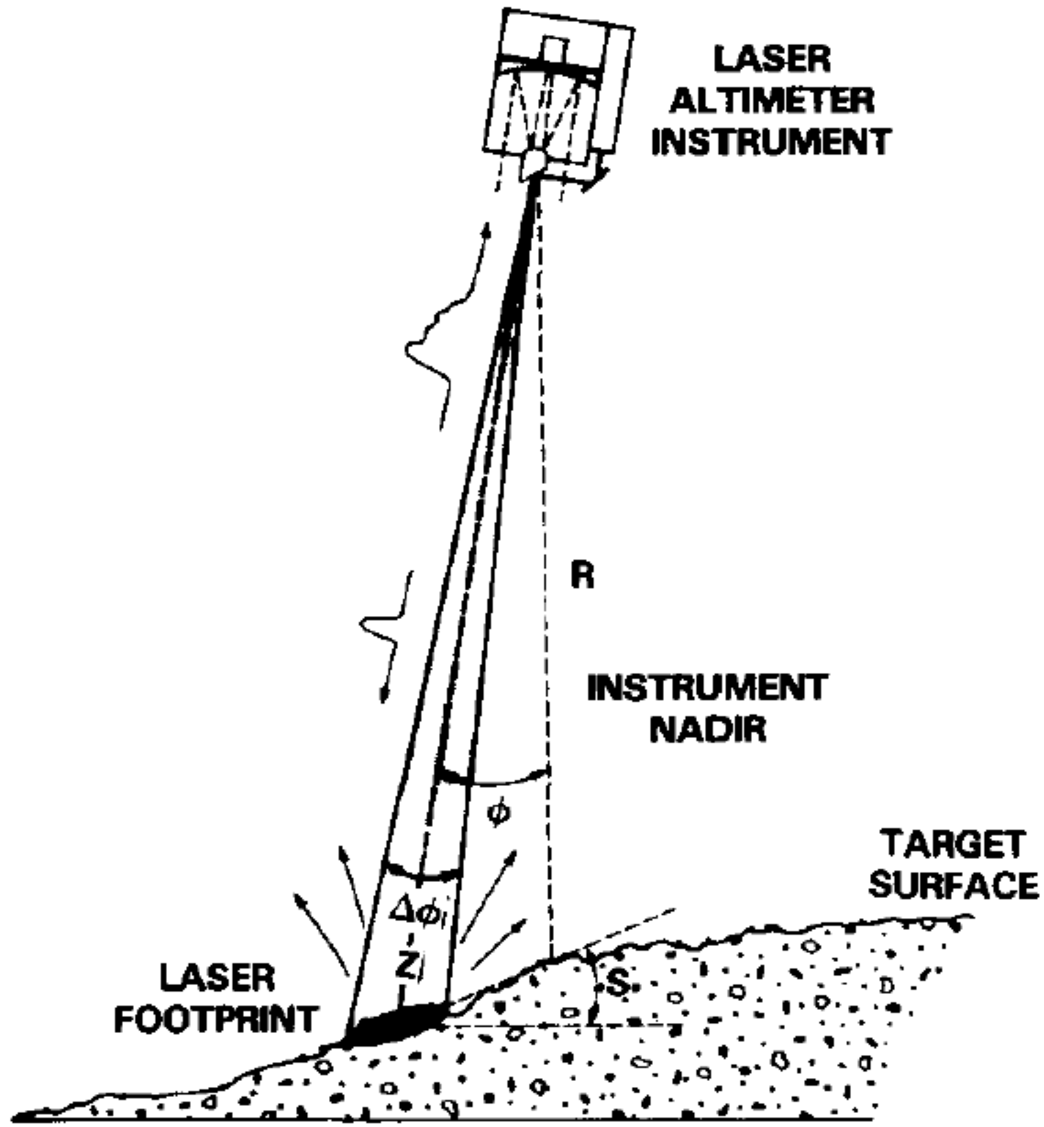
- Time-of-flight techniques include
- 1) pulsed laser TOF rangefinding,
- 2) cw laser amplitude modulation - the phase-shifting rangefinding technique, and
- 3) cw laser chirp: linear variation of frequency with time, and then take the beat frequency to determine TOF



# Laser Altimeter (Laser Ranging)

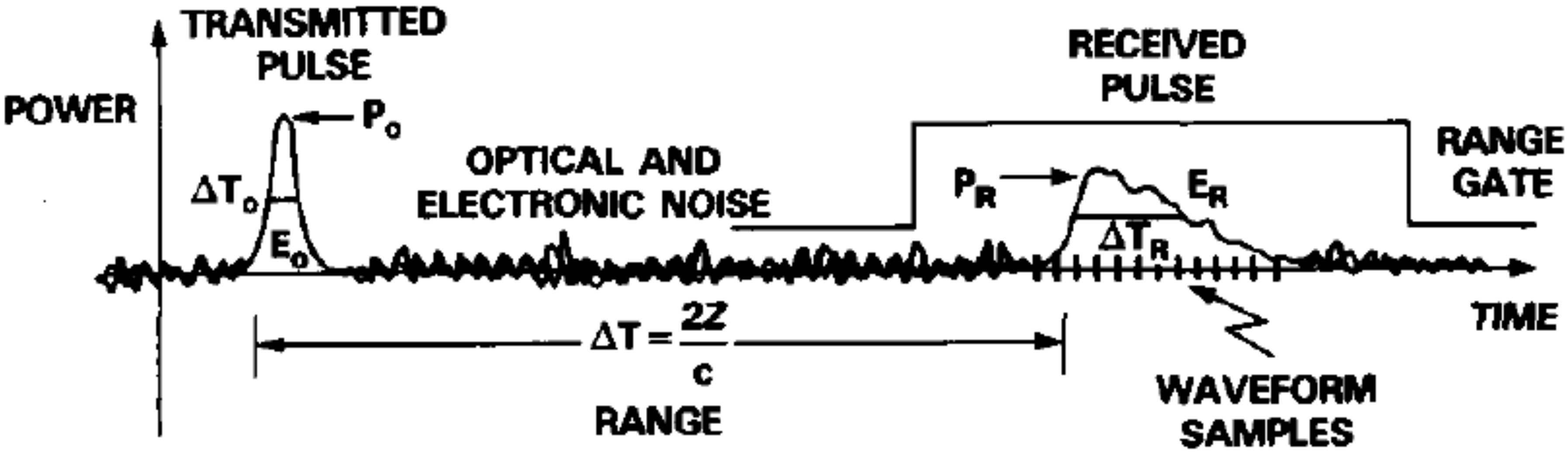
- The time-of-flight information from a lidar system can be used for laser altimetry from airborne or spaceborne platforms to measure the heights of surfaces with high resolution and accuracy.

- 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.





# 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

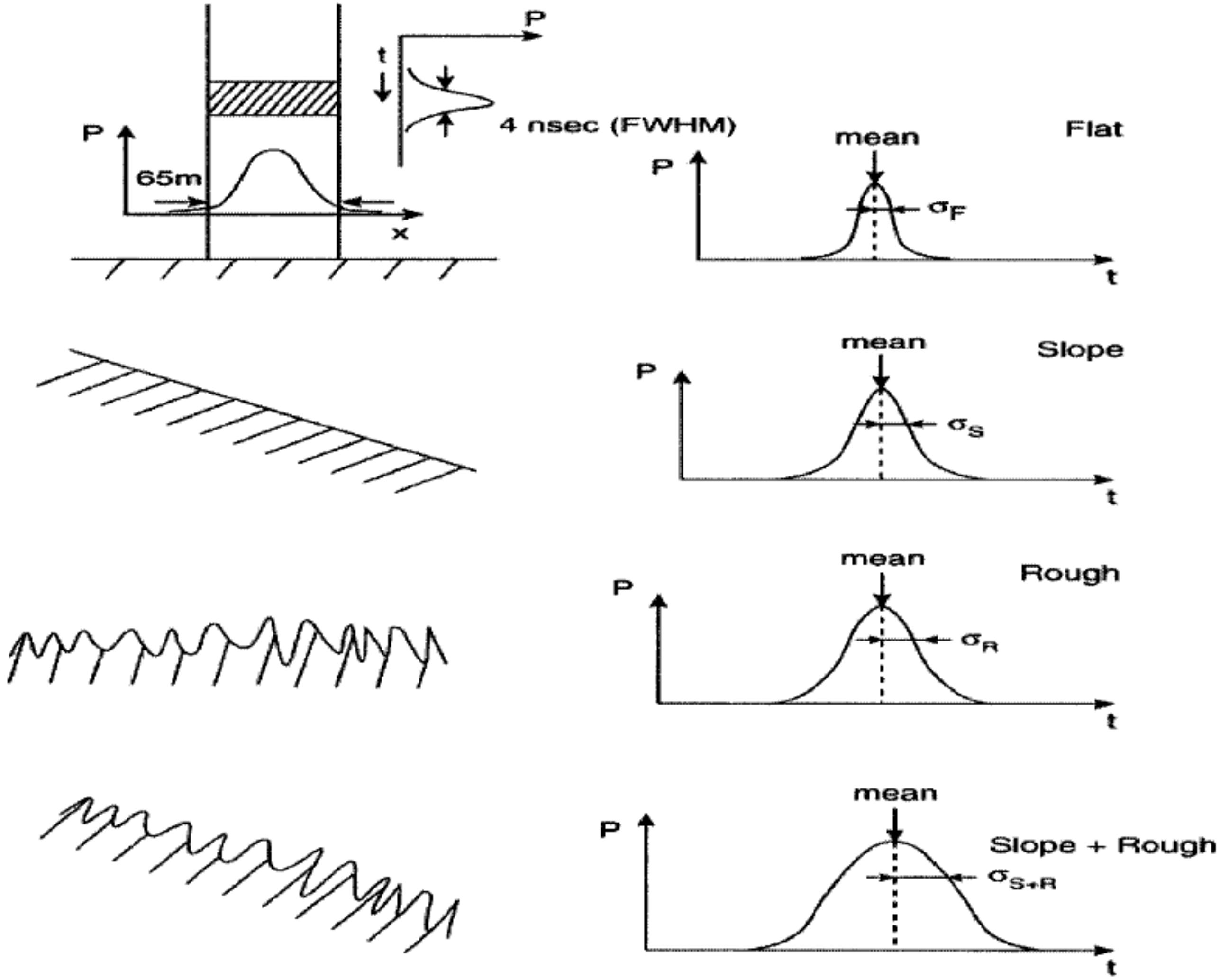
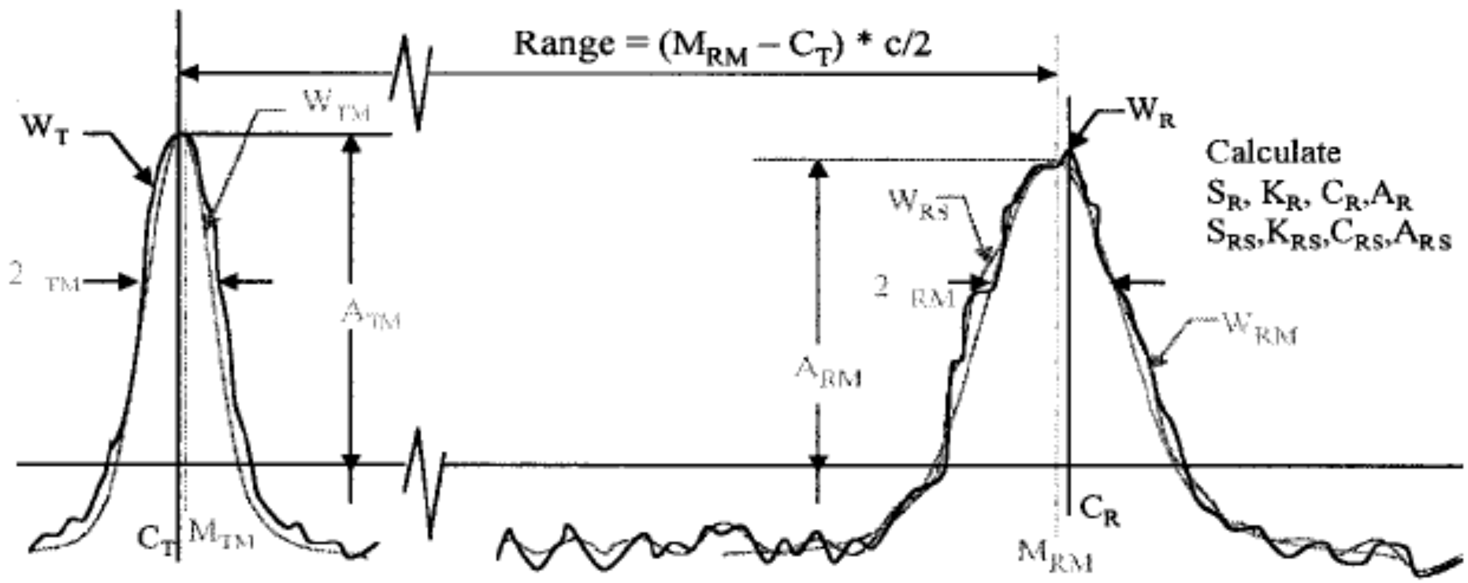



**Figure 1 - Characteristics of returned laser pulse as a function of surface type. Presence of surface slope and roughness both broaden the pulse.**



# 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

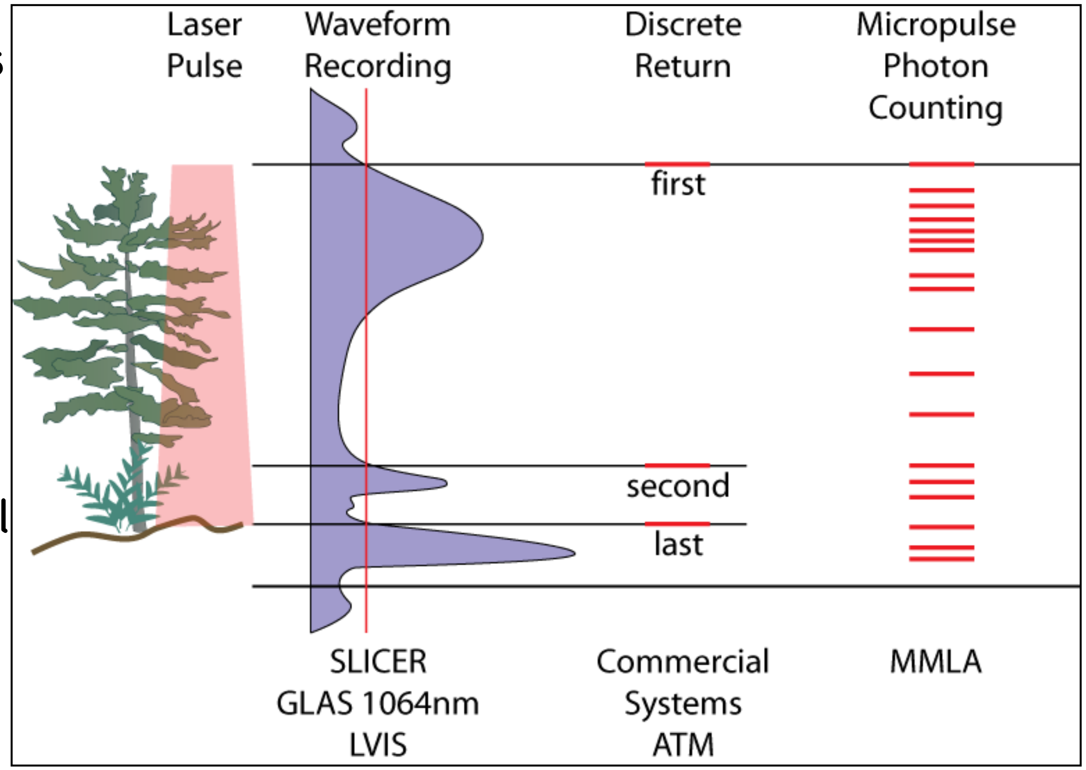
- Besides waveform distortions caused by surface slope and roughness, other factors that could affect the accuracy of laser altimeter include
(1) Orbit and attitude calculations for the platforms
(2) Corrections for atmospheric path-length delays
(3) Corrections for changes in the surface elevations 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 |

# Lidar Ranging Methods

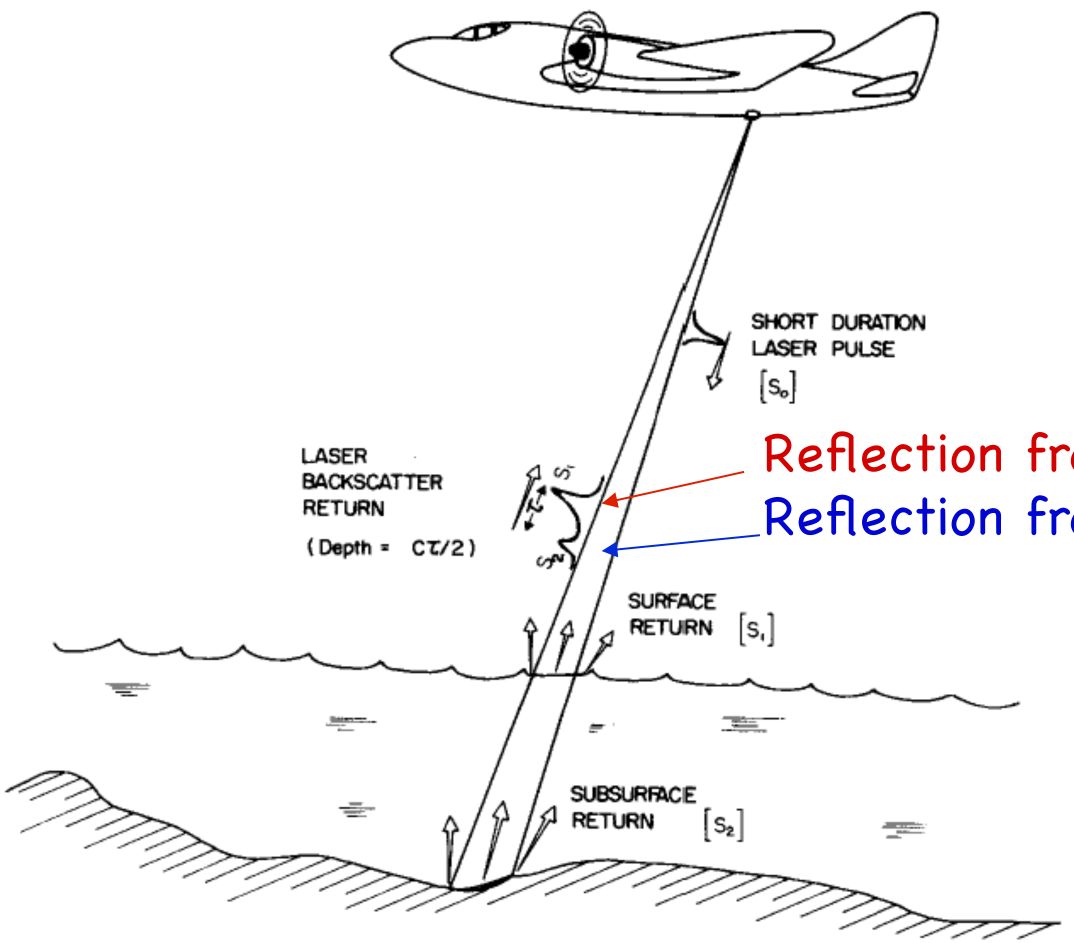
- Discrete return
  - logs time when return intensity exceeds threshold
  - commercial airborne systems
- Waveform recording
  - records entire return intensity profile
  - vegetation, atmospheric applications
- Photon counting
  - digital recording of individual photon returns
  - low power requirements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




courtesy Dave Harding, NASA/GSFC

# TOF in Lidar Bathymetry

- Time of flight techniques: this is for the majority of laser range finder;





# Lidar Bathymetry

- To obtain better resolutions in lidar bathymetry (better than the pulse width-limited depth resolution), several methods could be used, including waveform digitizing and signal distinguishing.

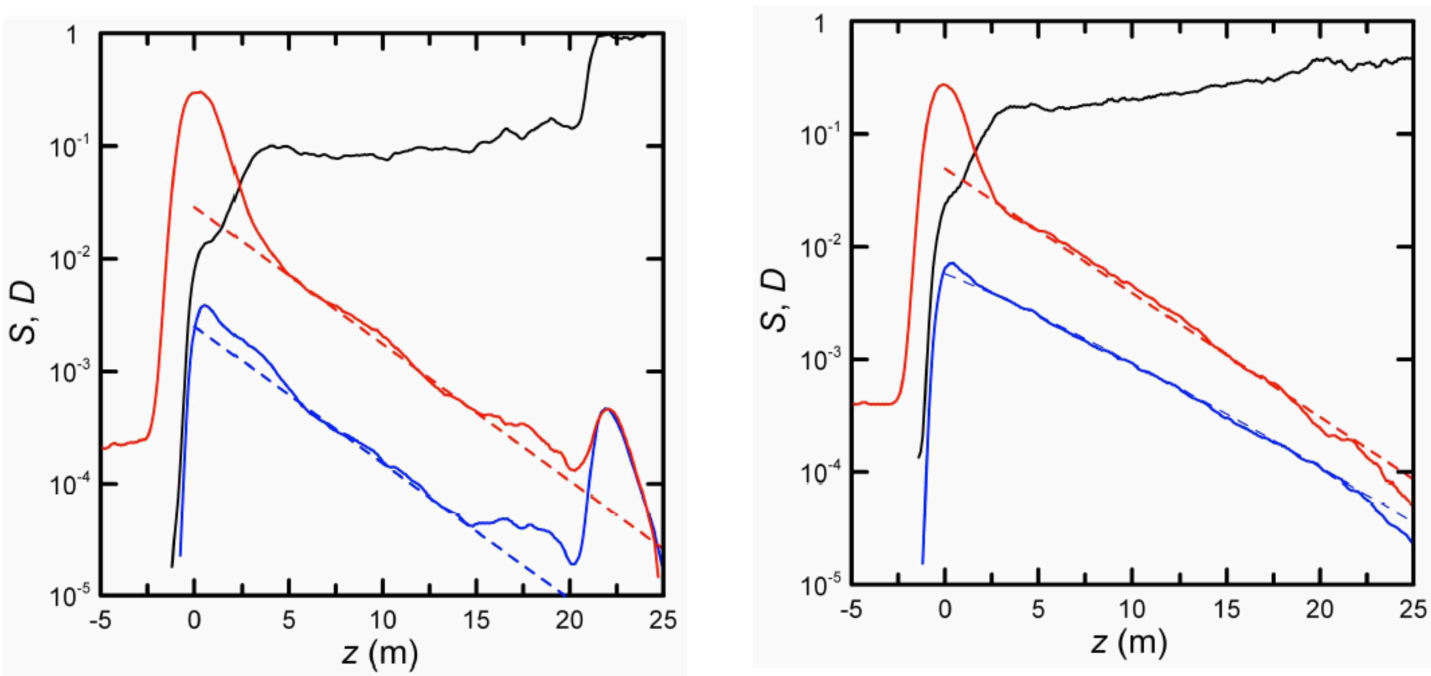



Fig.4. Typical depth profiles of the co-polarized return $S_C$ (red), cross-polarized return $S_X$ (blue), and depolarization $D$ (black). The solid lines are measured values, and the dashed lines are the theoretical profiles from Eq. (8). The left panel is from the near-shore region. The large, unpolarized return at 22 m depth is the bottom of the ocean. The right panel is from the off-shore region.

[Churnside, Polarization effects on ocaneographic lidar, Optics Express, 16, 1196-1207, 2008]

# More Considerations on Bathymetry

- Waveform recoding and digitizing

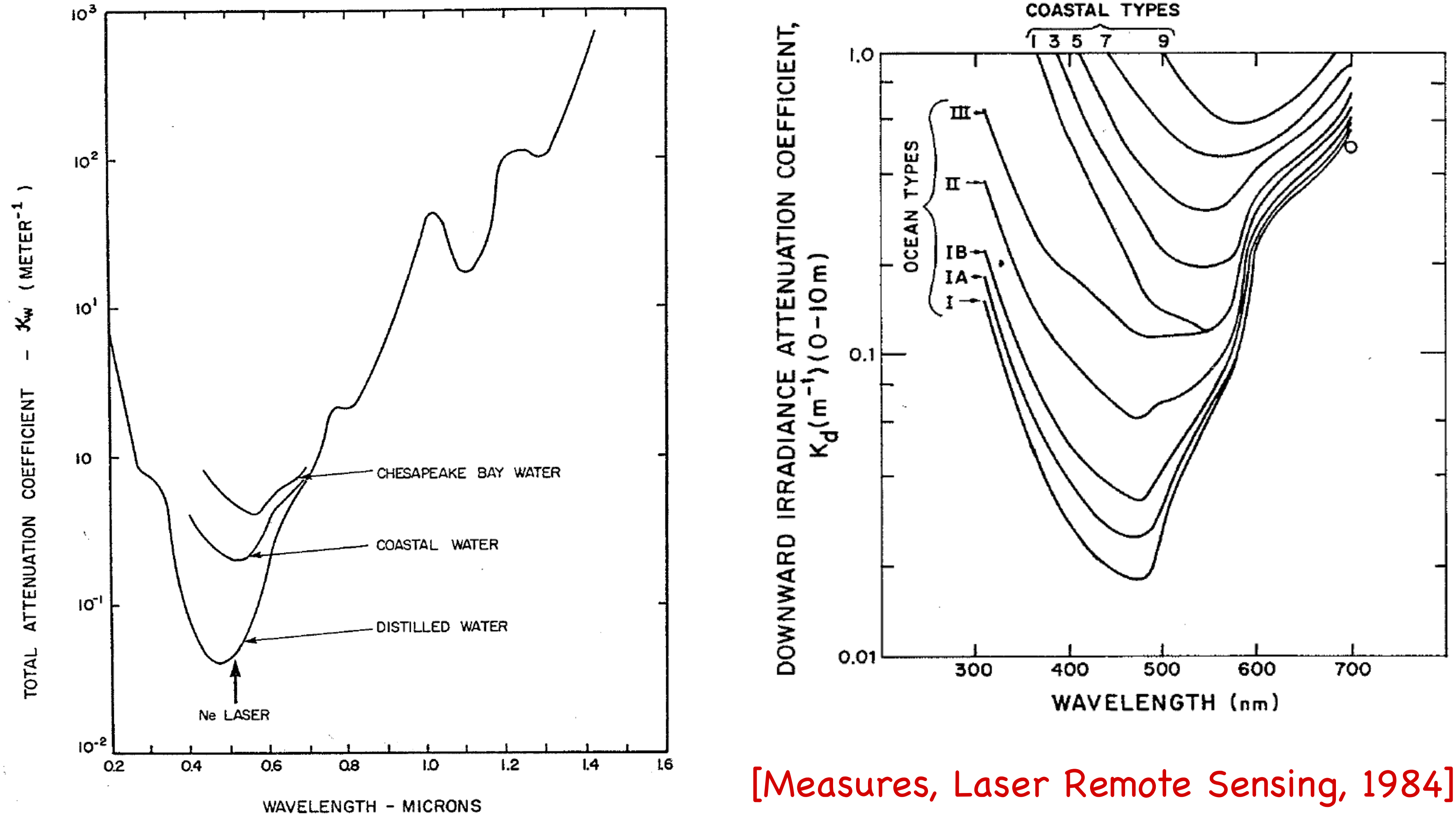
- Polarization applications in bathymetry [Churnside, Optics Express, 2008; Mitchell et al., Applied Optics, 2010]

- Both methods mentioned above are ultimately limited by the receiver bandwidth and pulse width …

- Potential improvement: combination of polarization detection with CW laser chirp technique



# Water Transmission vs. Wavelength

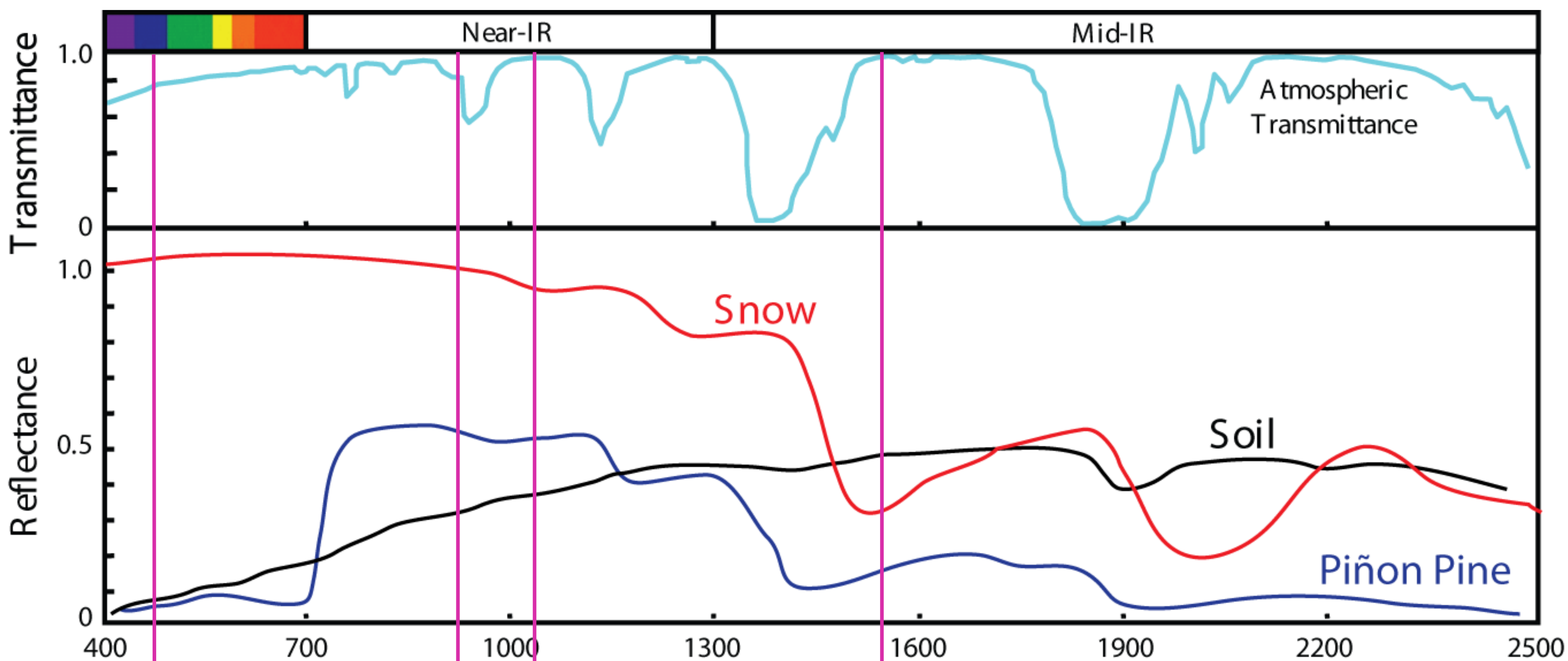



[Measures, Laser Remote Sensing, 1984]

**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).



# Some Lidar Sensor Wavelengths




532 nm
NASA ATM
GLAS
MMLA

900 nm
FLI-MAP I/II

1064 nm
Optech ALTM
Leica ALS50
GLAS
SLICER

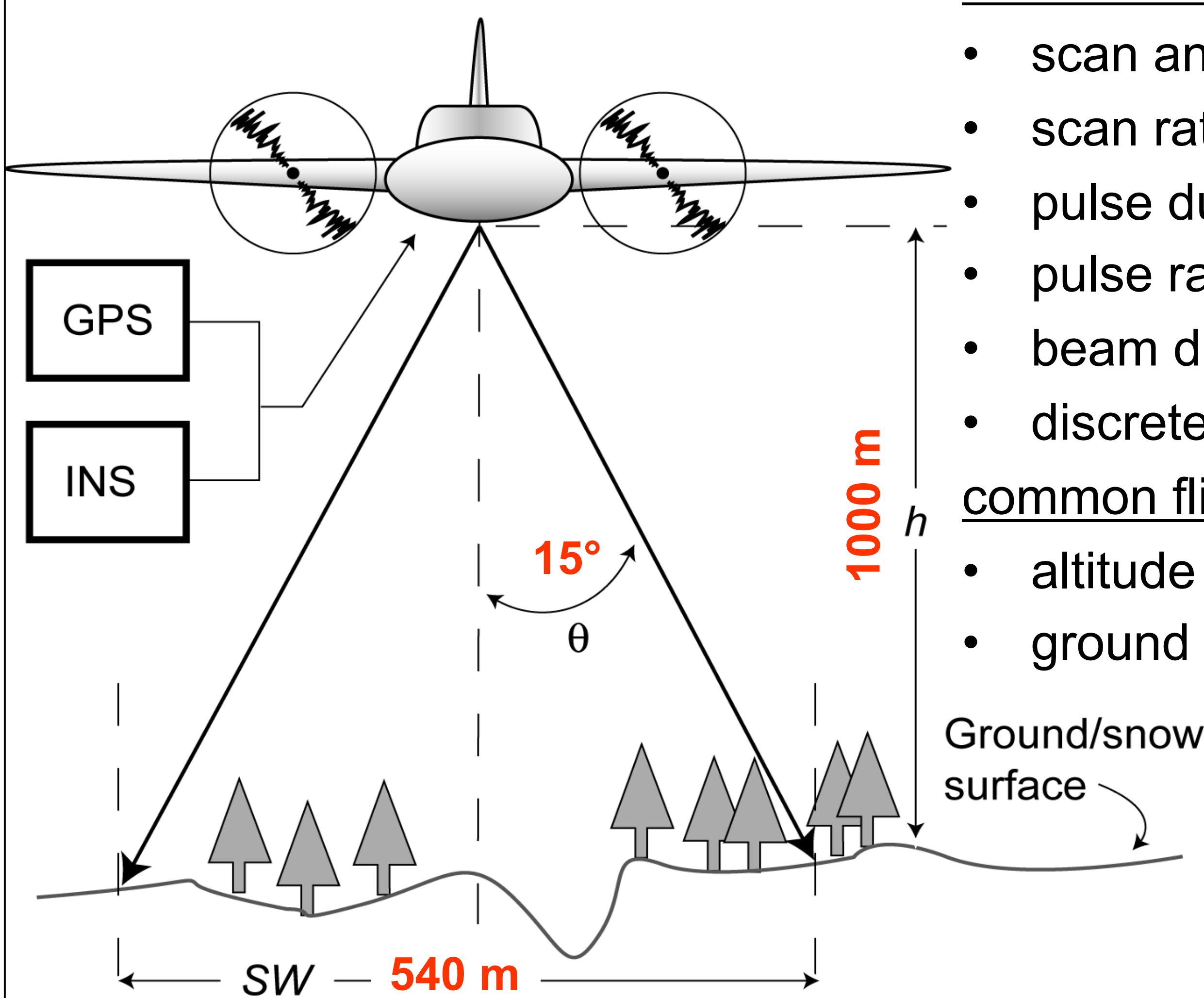
1540 nm
TopoSys I/II

532 & 1064 nm
LADS / SHOALS/Hawkeye
Bathymetric Systems

*image courtesy Michael Lefsky, CSU*



# Commercial Airborne Lidar System Components





<u>common laser parameters</u>

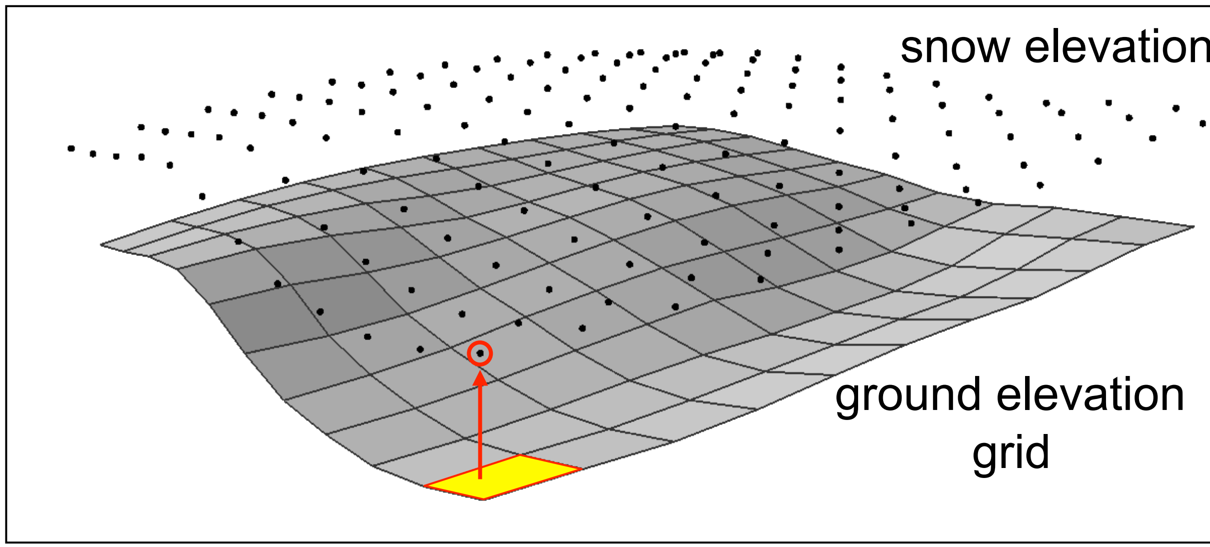
- scan angle: 0-45°
- scan rate: 0-70 Hz
- pulse duration: 6-12 ns
- pulse rate: 4-100 kHz
- beam divergence: 0.25-1mrad
- discrete returns/pulse 4-5

<u>common flight parameters</u>

- altitude AGL 1000-1500 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



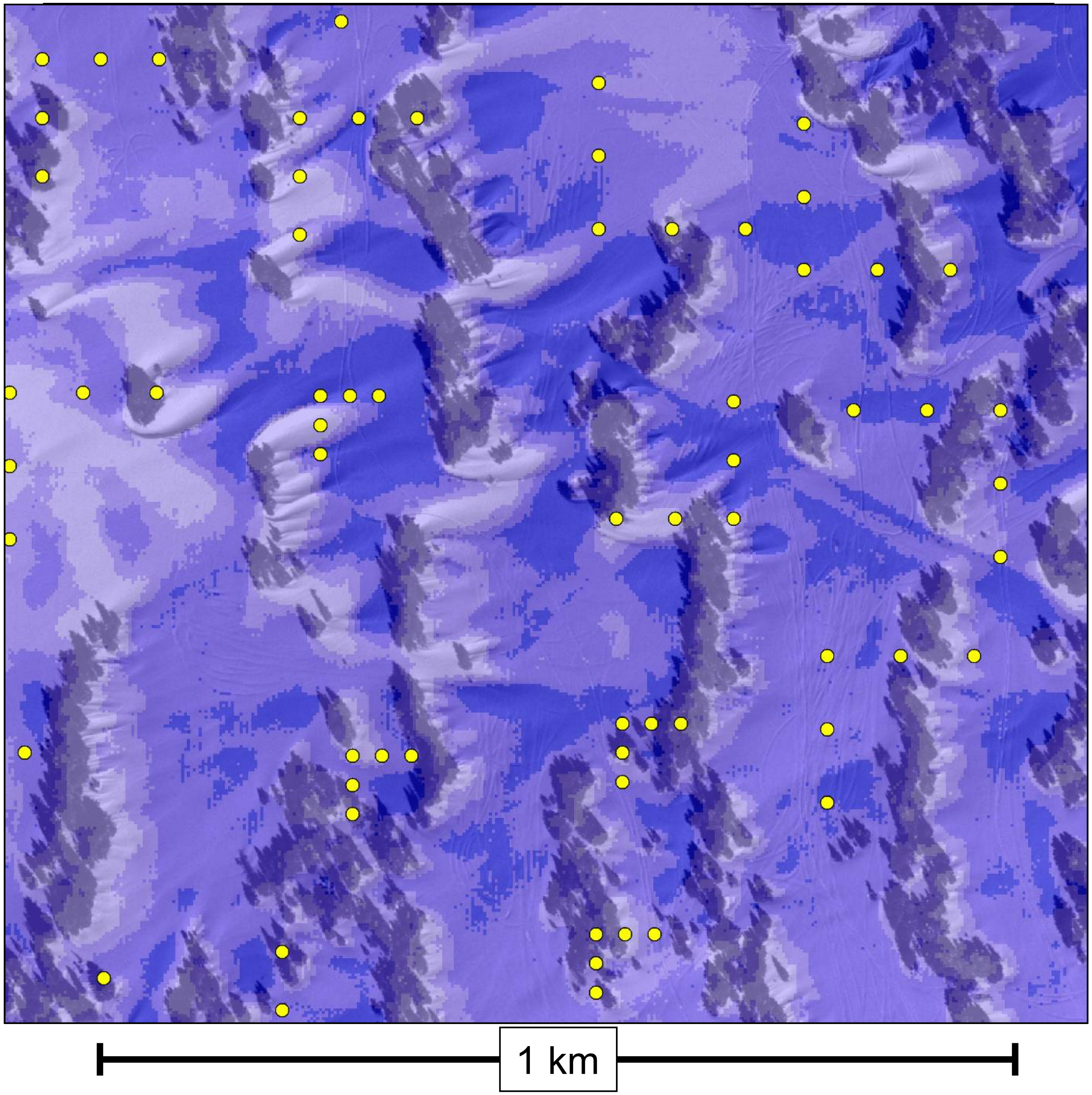

Courtesy of Jeff Deems, CSU



**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

Courtesy of Jeff Deems, CSU

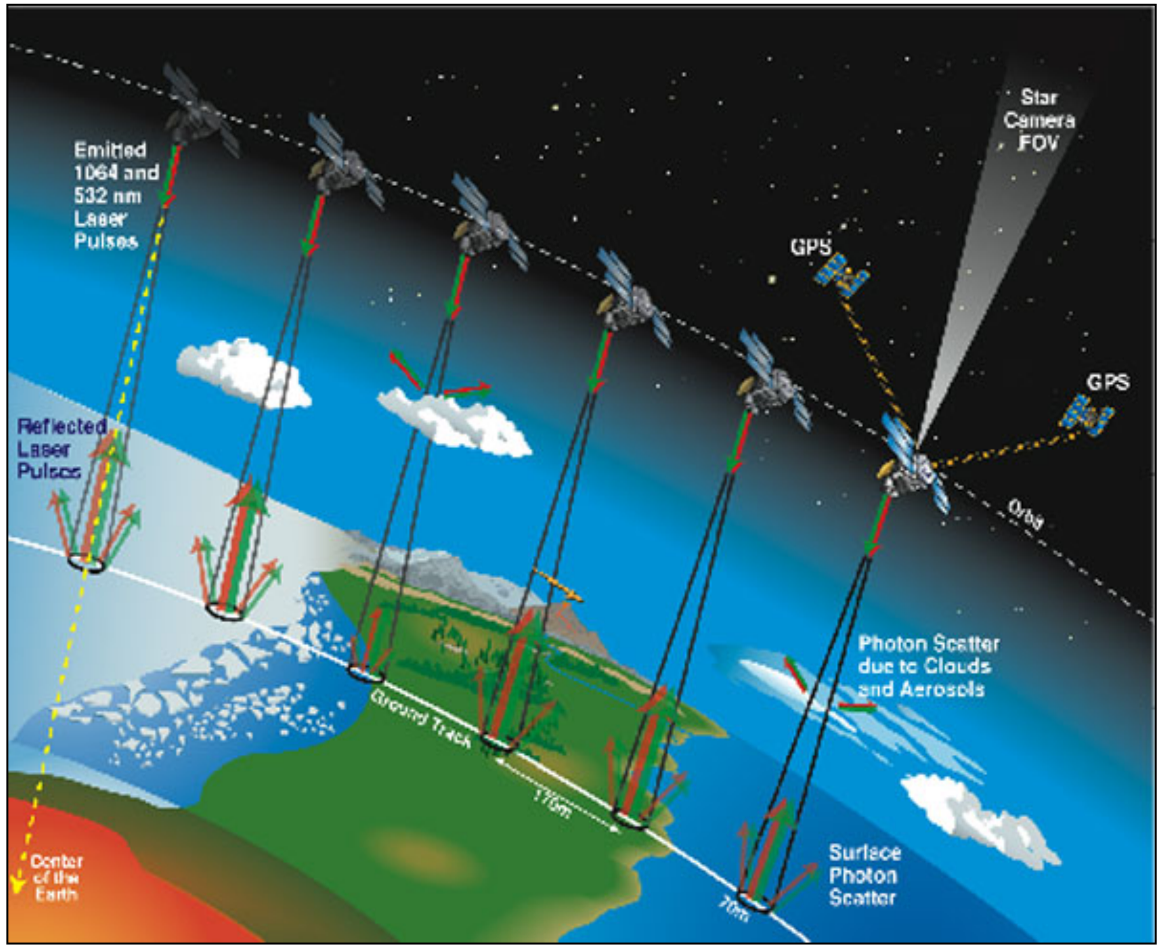




# Current Laser Altimeter: ICESat

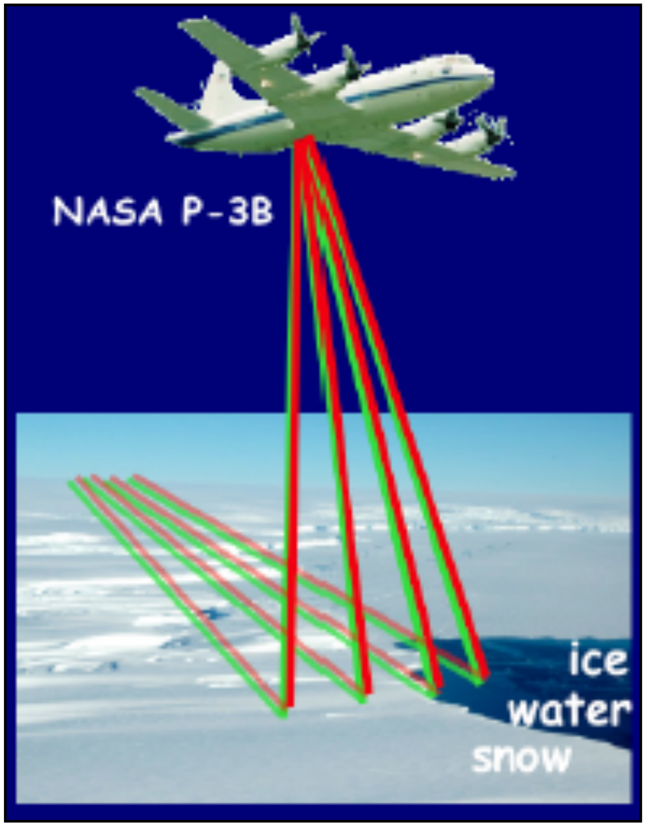
<u>ICESat</u>

- 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



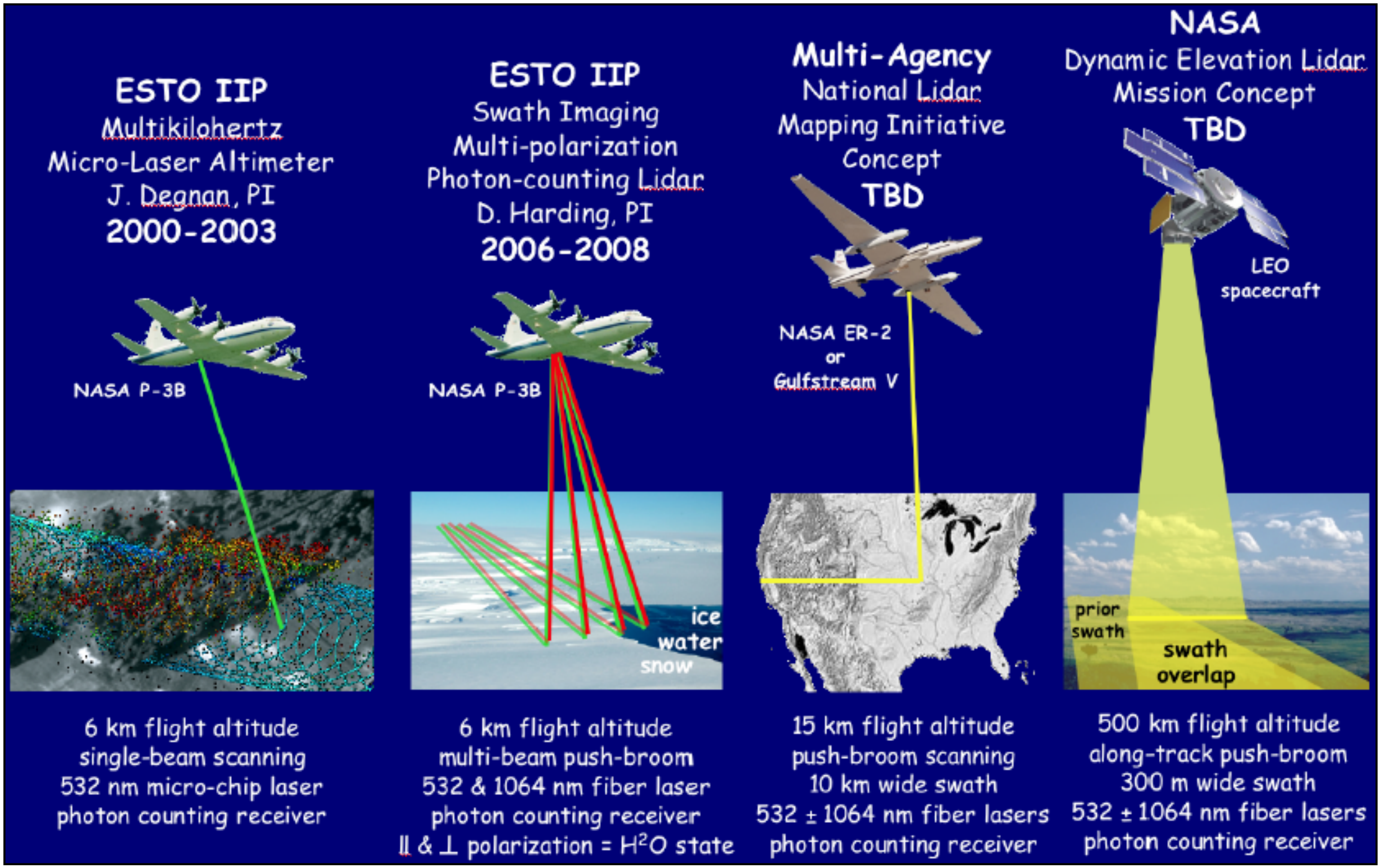
# National Lidar Mapping Initiative Concept

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

*courtesy Dave Harding, NASA/GSFC*



# 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.