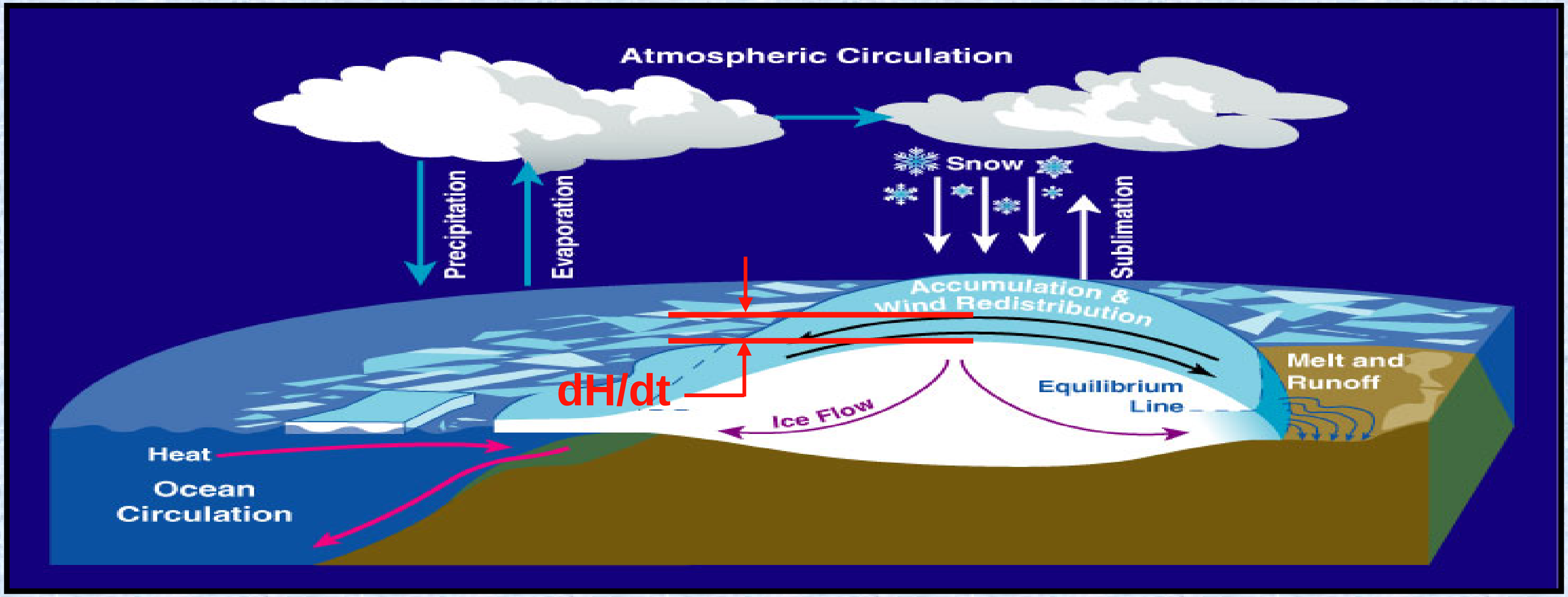
ICESat's Observations of Arctic Sea Ice Freeboard/Thickness and NASA's plans for ICESat-2

Jay Zwally, ICESat-1 Project Scientist

Space and the Sweden
October 20, 2009

Ice Sheet Mass Balance Primary Objective of ICESat

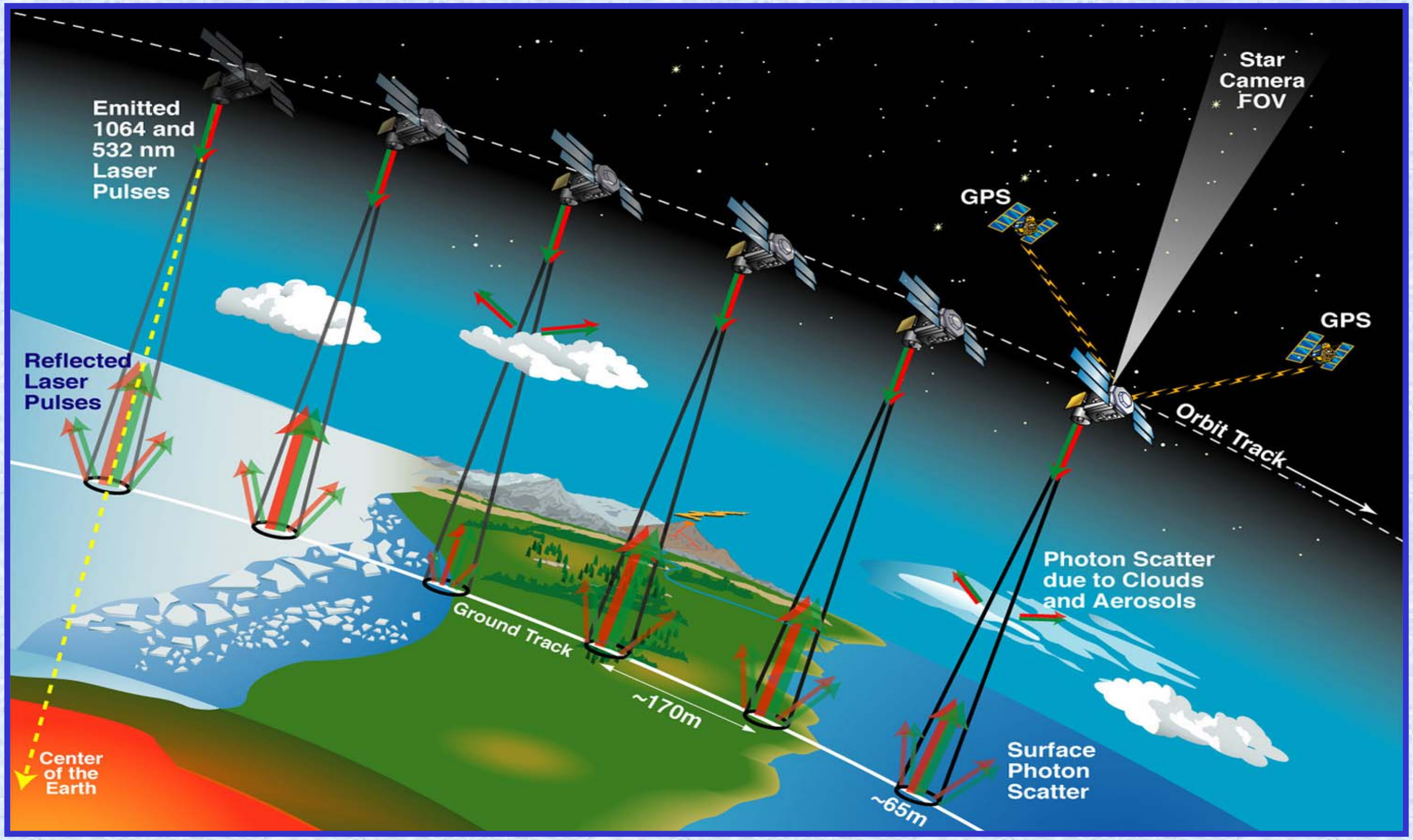


- ❑ Measure ice-surface elevation changes (dH/dt) from repeat measurements of elevation <u>profiles</u> along precise repeat tracks (minimal cross-track spacing) and at orbital crossovers.

- ❑ Derive <u>spatially averaged</u> elevation changes (dH/dt).

- ❑ Convert <u>volume changes</u> (dH/dt x area) to <u>mass changes</u> (dM/dt).
  - ❑ Correct for variable firn compaction (temperature driven).
  - ❑ Calculate effective density for dH(A(t))/dt due to trends in precipitation.
  - ❑ Correct for modeled bedrock motion dB/dt.

ICESat-1: Geoscience Laser Altimeter System (GLAS)



- 1064 nm (red) laser beam for surface altimetry (10 cm accuracy and 2 cm precision) and clouds and aerosols (75 m)
- GPS for precision orbits (2 cm)
- Precision laser attitude system (2 arc sec, 6 m horizontal)
- ~ 65 m footprint spaced at 172 m (50 HZ PRF)
- 532 nm laser beam for thin clouds and aerosols

ICESat was designed to operate a laser continuously for 3 to 5 years

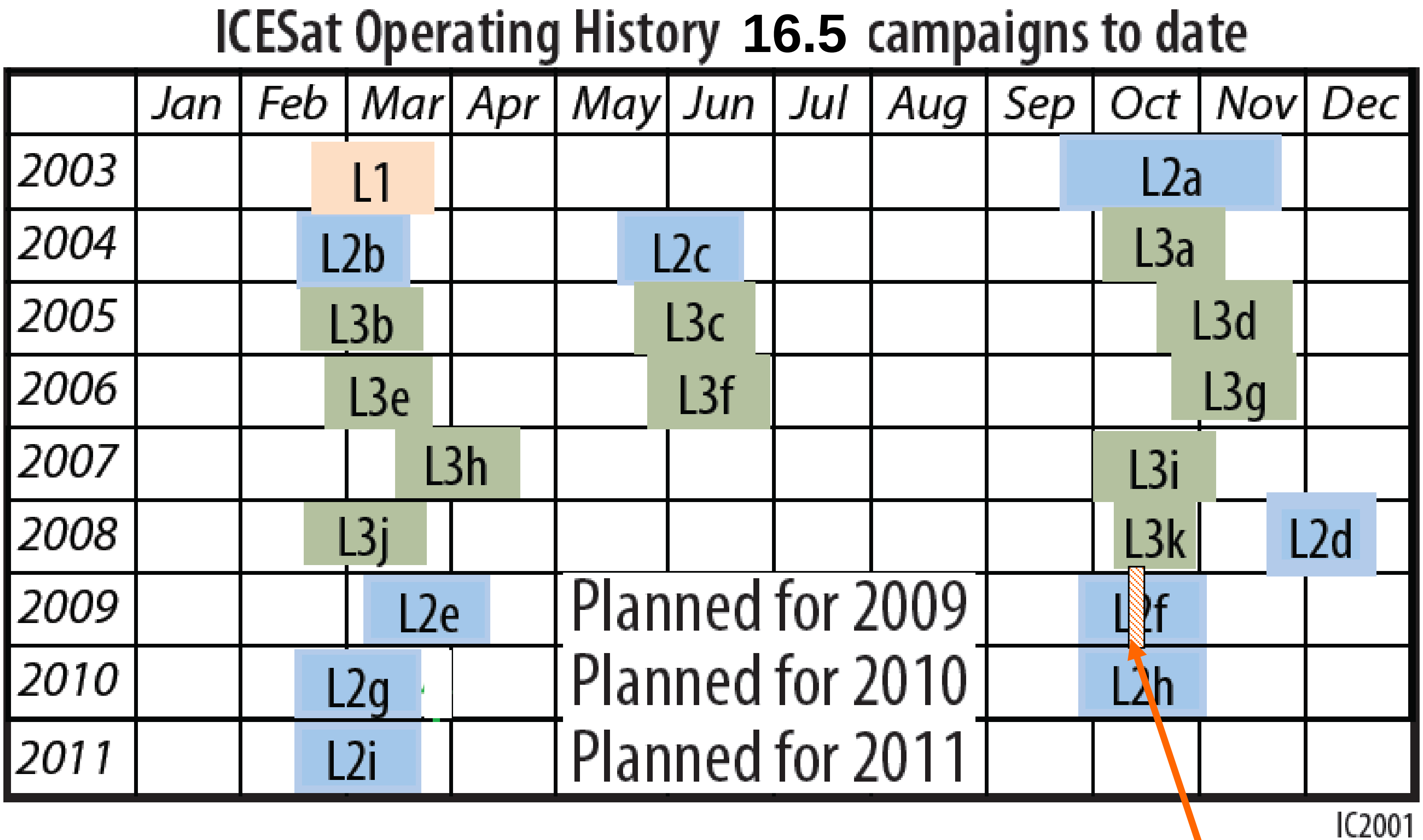
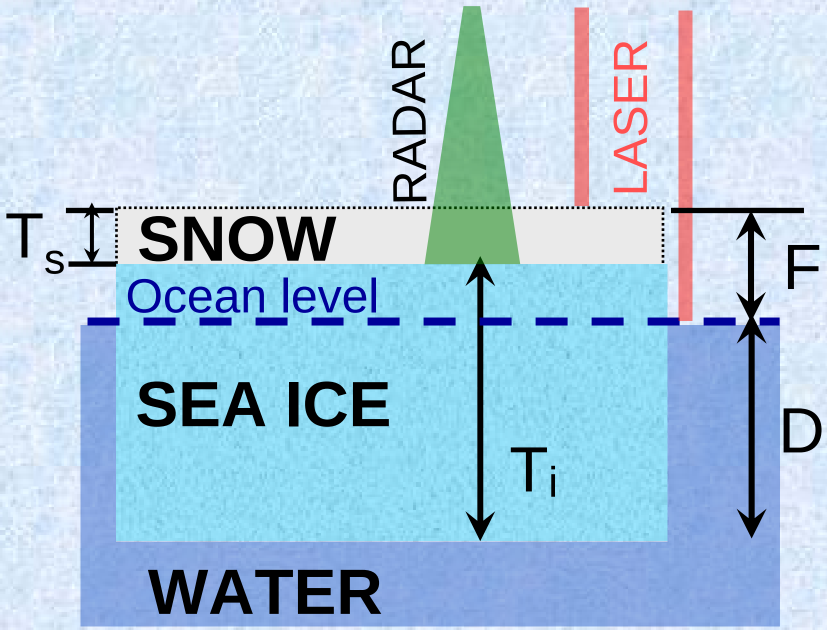


Figure 23: Completed and Planned Campaigns

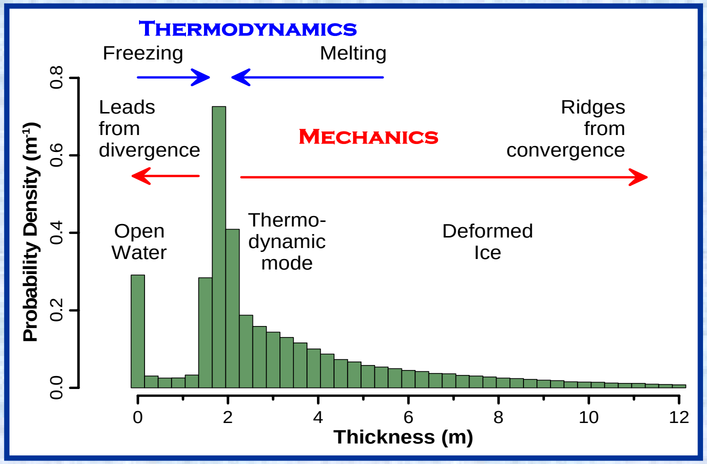
Laser stop fire anomaly

Sea Ice Freeboard and Thickness from Altimetry

- ❑ Laser accurately measures total freeboard (F), i.e. elevation of snow and ice above ocean reference level.
- ❑ Sea ice thickness (T_i) is estimated from freeboard using estimates of snow cover and buoyancy calculations.
- ❑ CRYOSAT radar altimetry will provide similar measurements mostly to snow/ice interface and ocean reference.



- ❑ Obtaining sea ice thickness has been major challenge in sea ice science.
- ❑ ICESat has been providing comprehensive mapping of sea ice freeboards and estimates of sea ice thickness distributions.



Freeboard and Thickness from Satellite Radar Altimetry

High interannual variability of sea ice thickness in the Arctic region

Seymour Laxon[1], Neil Peacock[1] & Doug Smith[2]

NATURE | VOL 425 | 30 OCTOBER 2003 | www.nature.com/nature

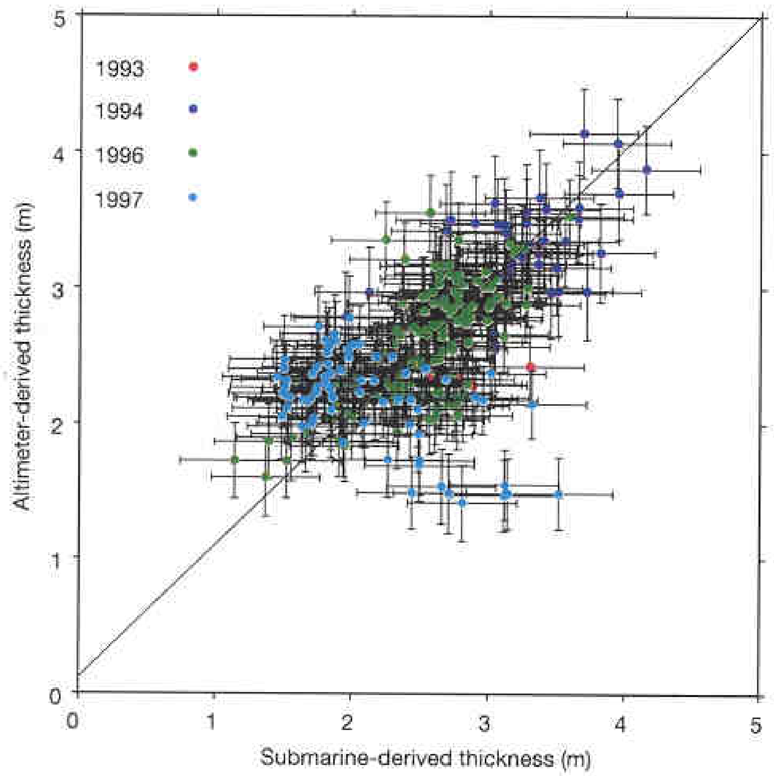


Figure 2 Comparison between satellite altimeter- and submarine-derived ice thickness in the Beaufort Sea during the 1990s. Submarine thicknesses are shown for each of the 50-km segments gathered during the four missions during the 1990s. Altimeter thickness

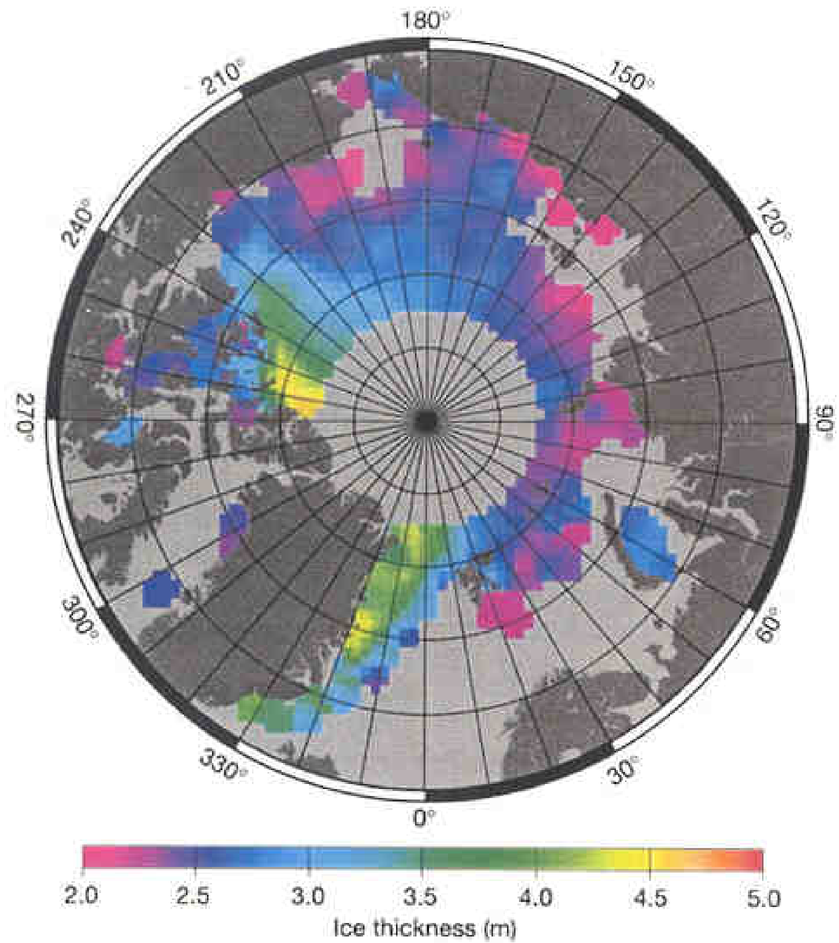
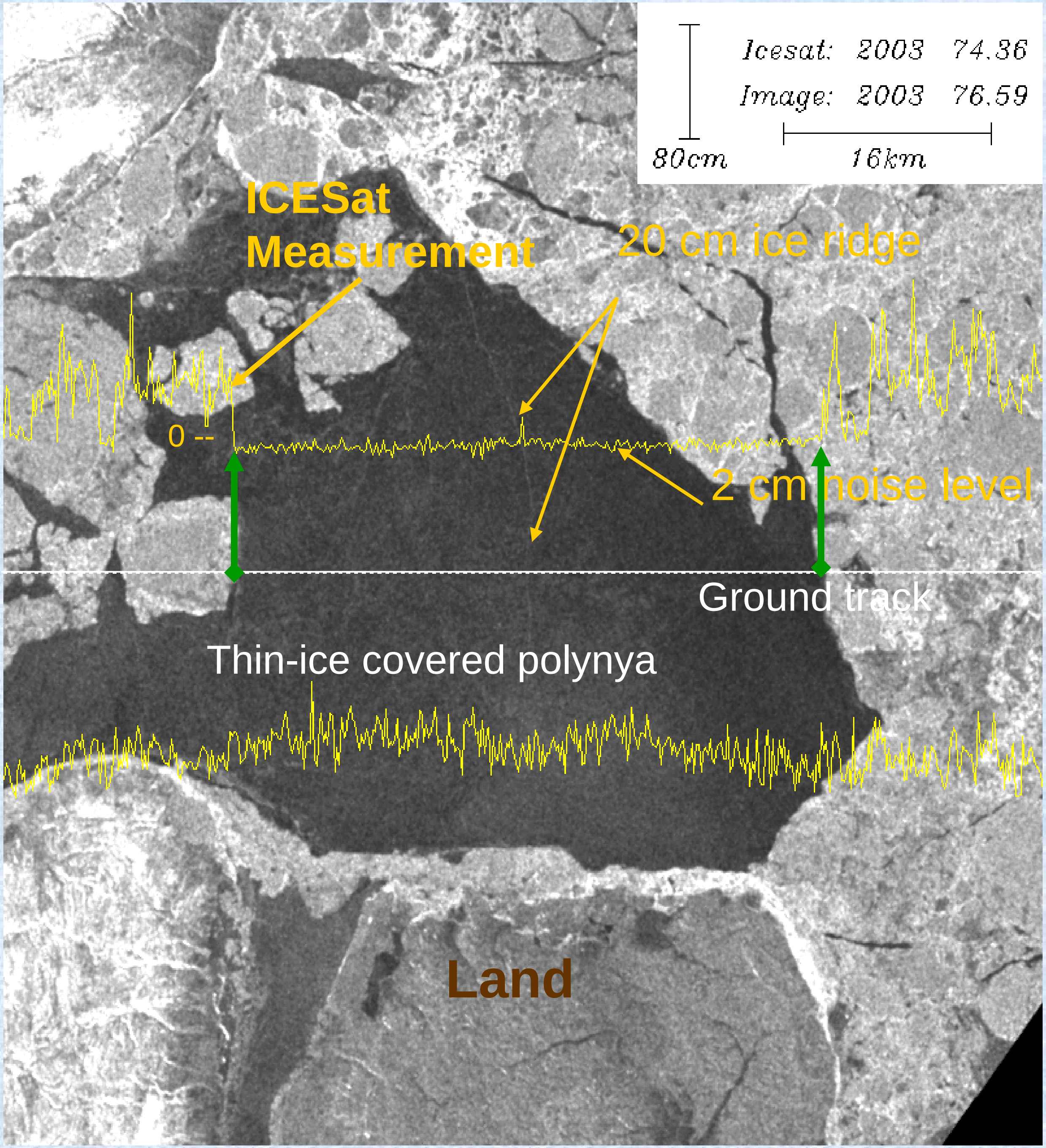
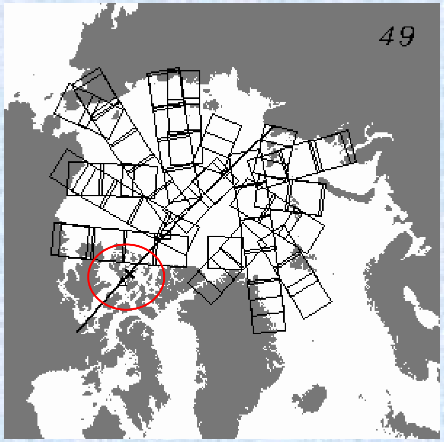


Figure 1 Average winter (October to March) Arctic sea ice thickness from October 1993 to March 2001 from satellite altimeter measurements of ice freeboard. Data are not available in the marginal ice zone, or above the ERS latitudinal limit of 81.5° N. Ice freeboard is converted to thickness using fixed ice, snow and water densities and regional monthly snow depth[22]. The mean thickness excludes thin ice (less than 0.5–1 m) and open water.



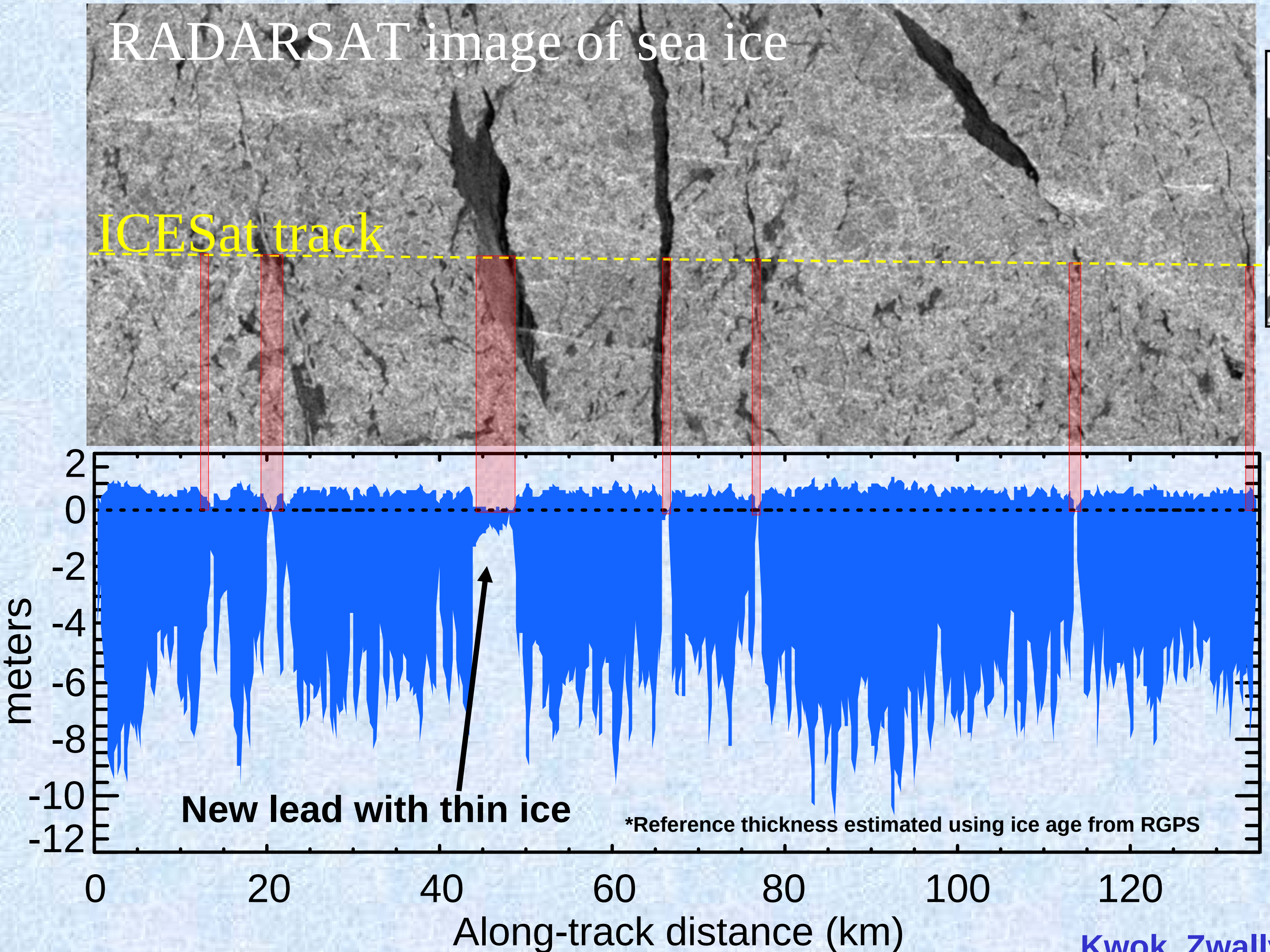
ICESat sea ice elevations

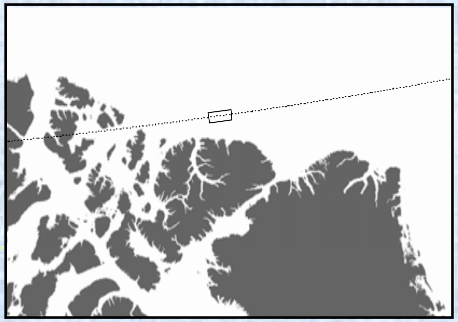
- Illustrates 2 cm range precision of ICESat.
- Precision is important, because mean freeboard is about 30 cm.



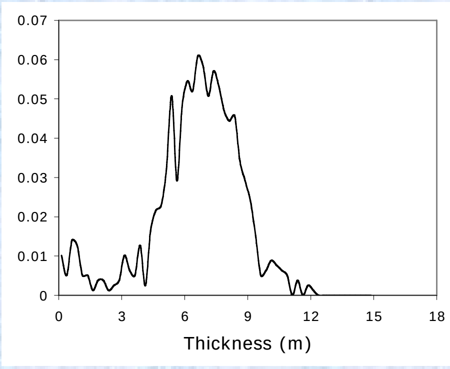
Ron Kwok, JPL

Near-coincident ICESat and RADARSAT Data Over Arctic Sea Ice

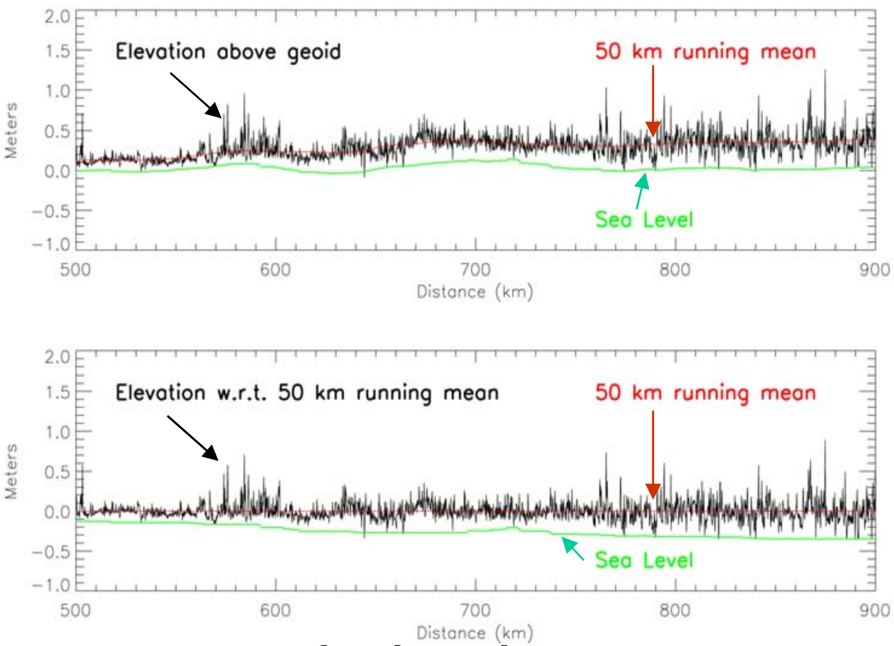




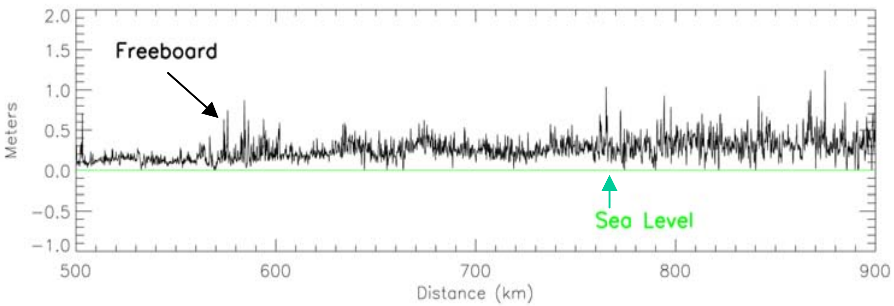
Δt = 1.2 days

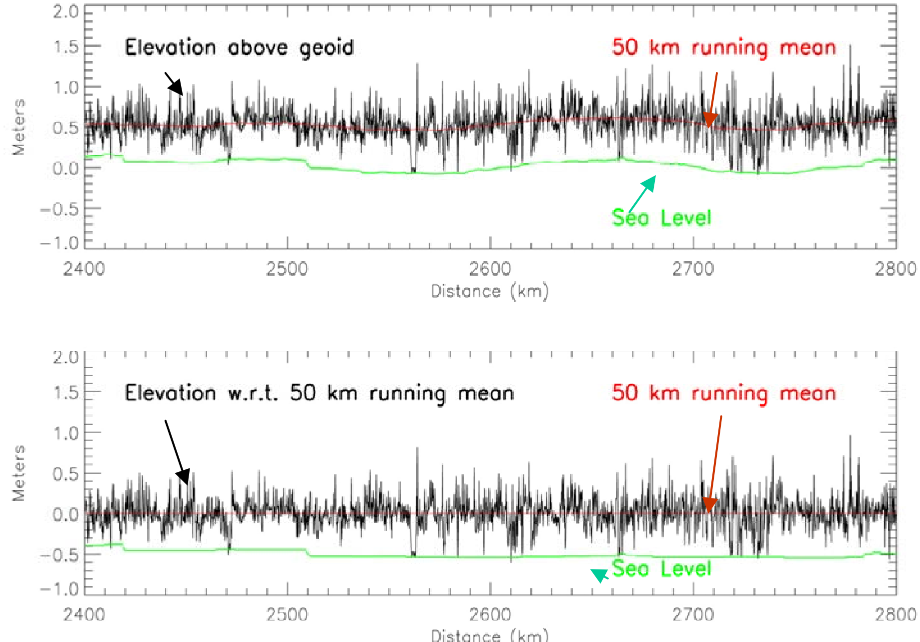


Kwok, Zwally, & Yi, GRL Aug 2004

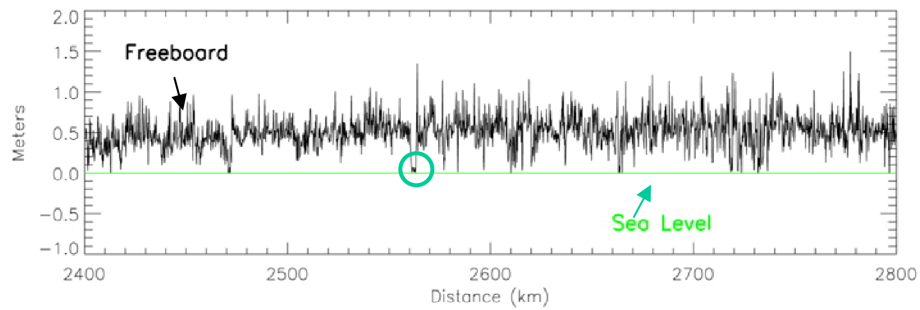


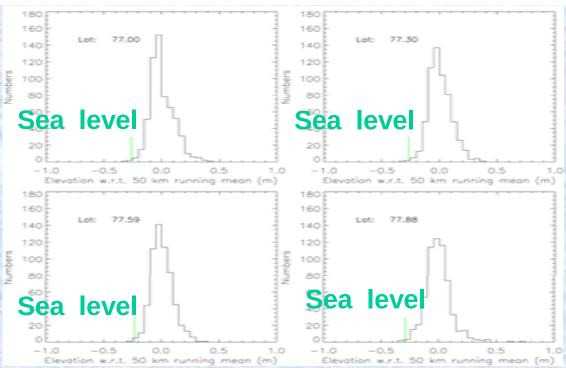
mean freeboard: 0.258 m



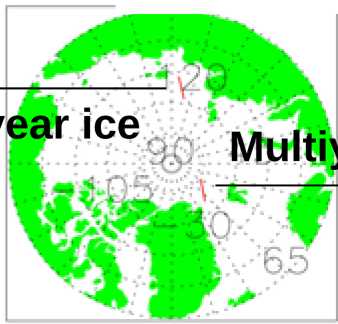


mean freeboard: 0.506 m

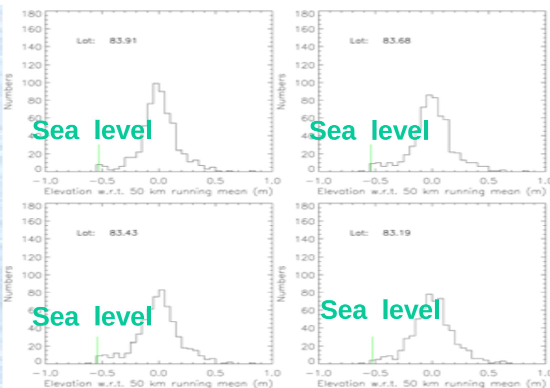




First year ice



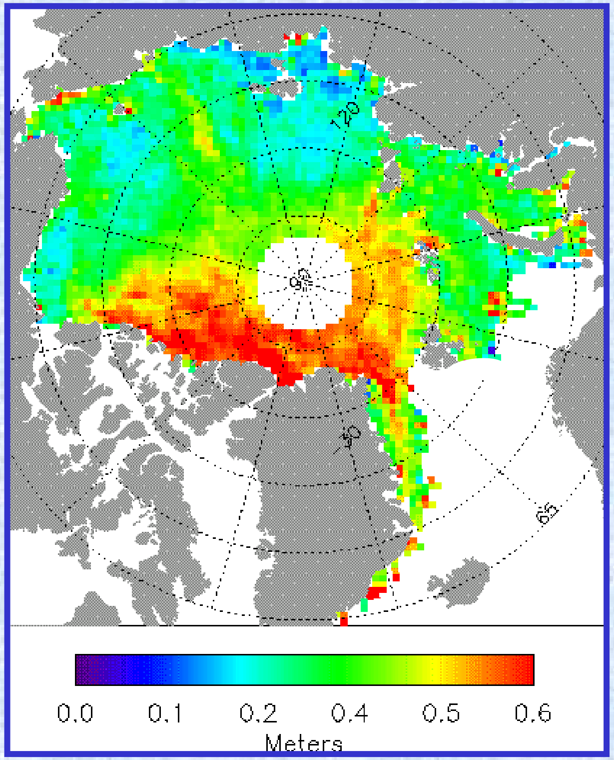
Multiyear ice

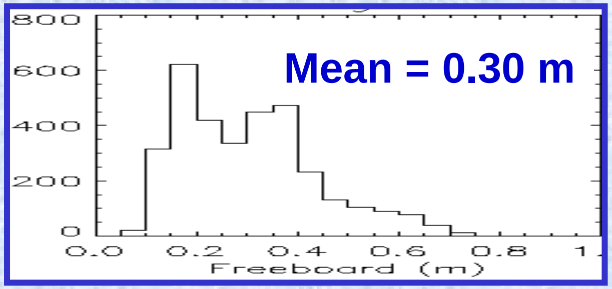


ICESat-1 Sea Ice Measurements

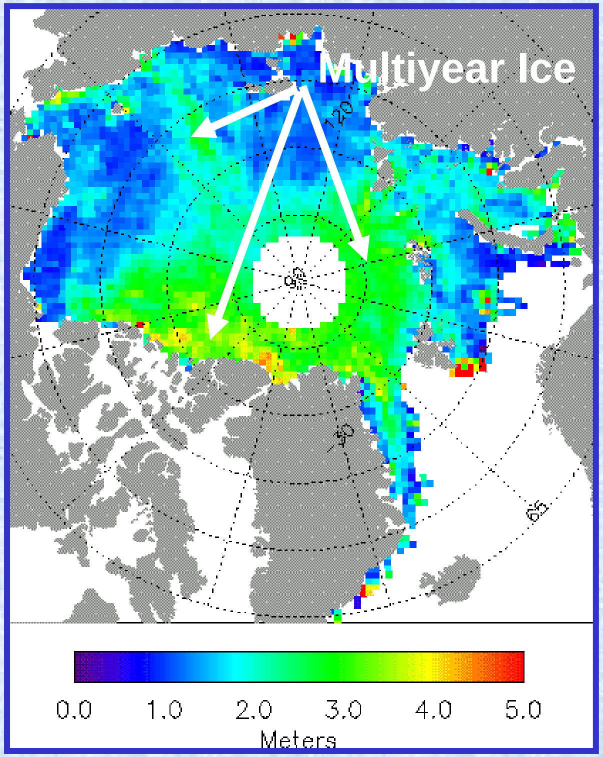
Feb 20-Mar 29, 2003

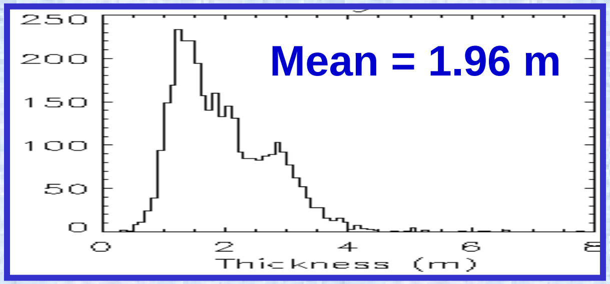
Freeboard



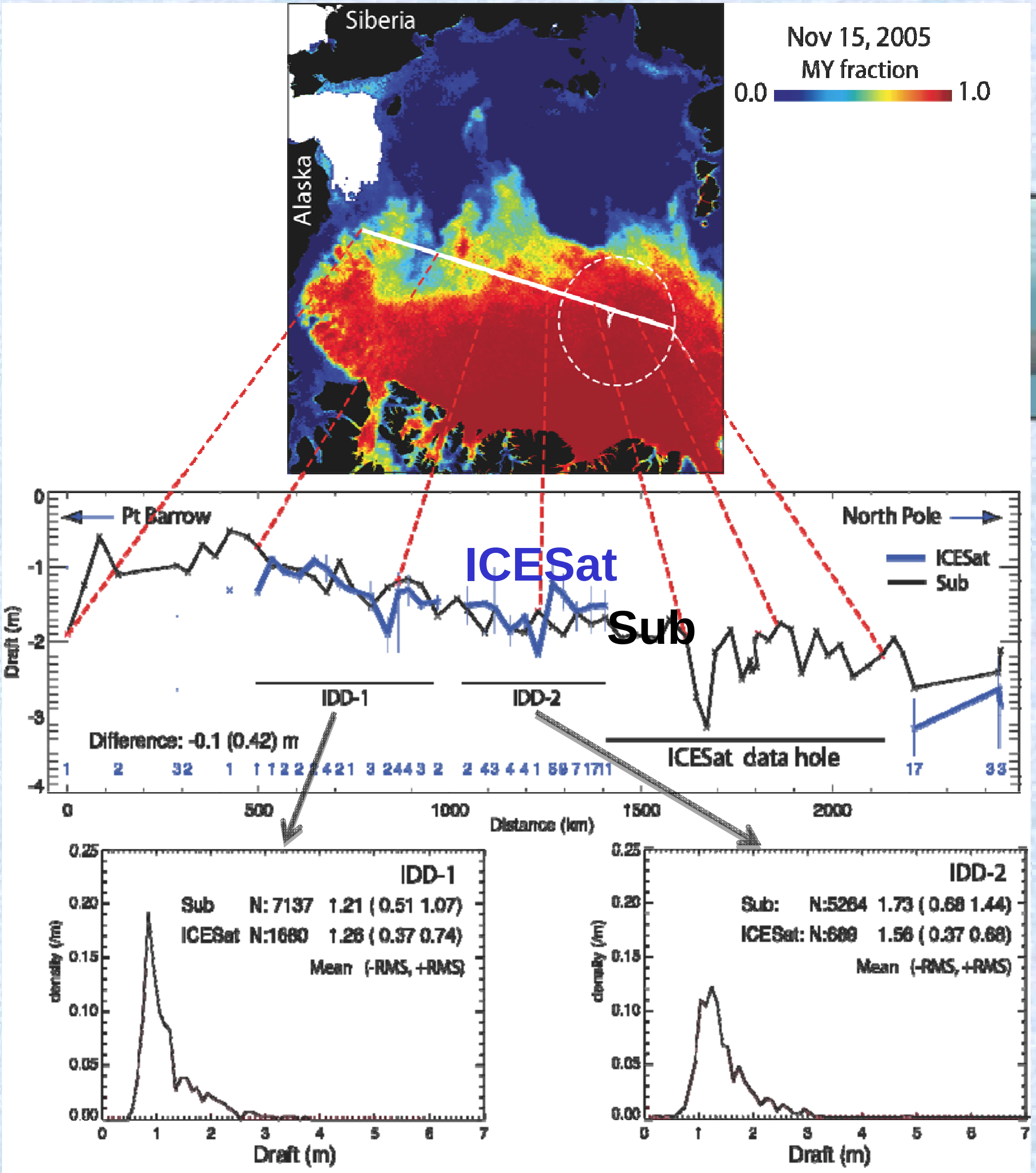


Thickness

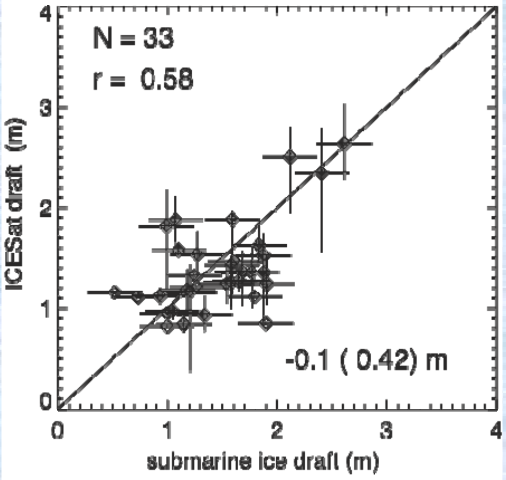




Comparison with ice draft along submarine track (Nov 2005)



Ice Draft Distributions (IDDs)

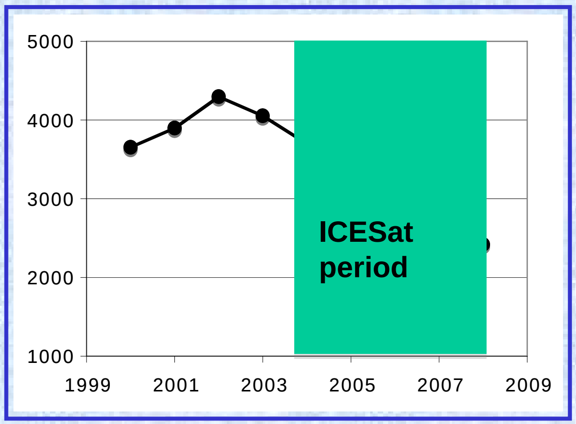


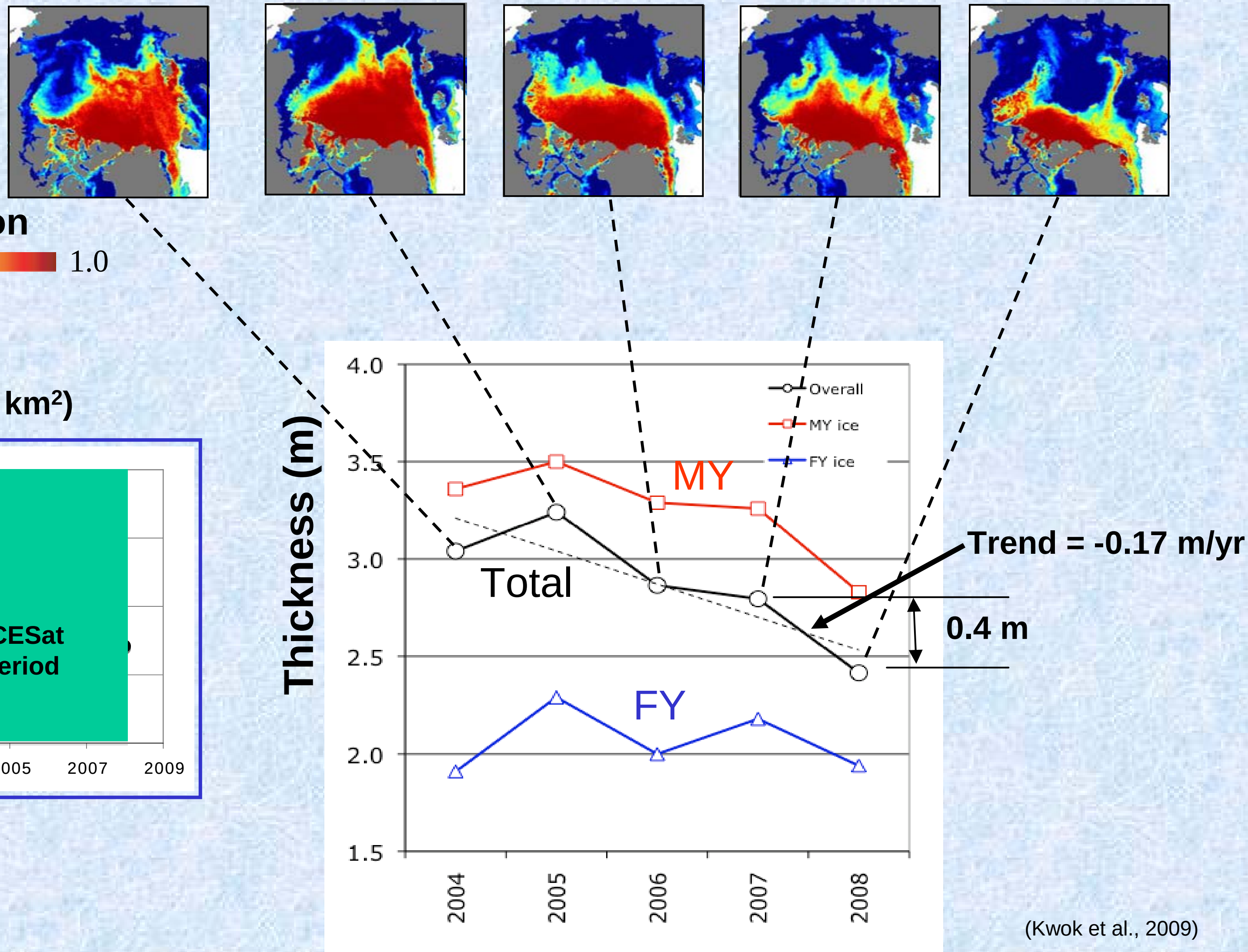
Kwok, R., M. Wensnahan, I. Rigor, H. J. Zwally, and D. Yi (2009), Thinning and volume loss of Arctic sea ice: 2003-2008, *J. Geophys. Res*., doi:10.1029/2009JC005312.

Trends in winter sea ice thickness from ICESat

MY fraction

MY Area (10^3 km^2)

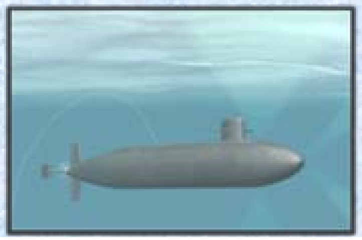


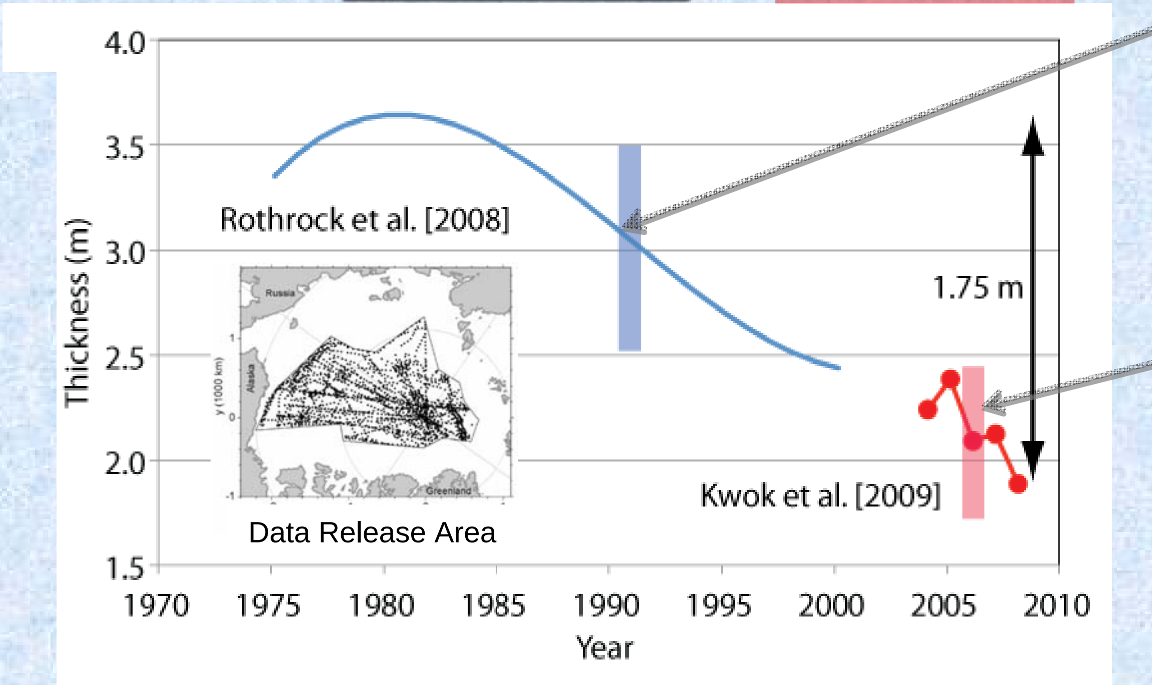


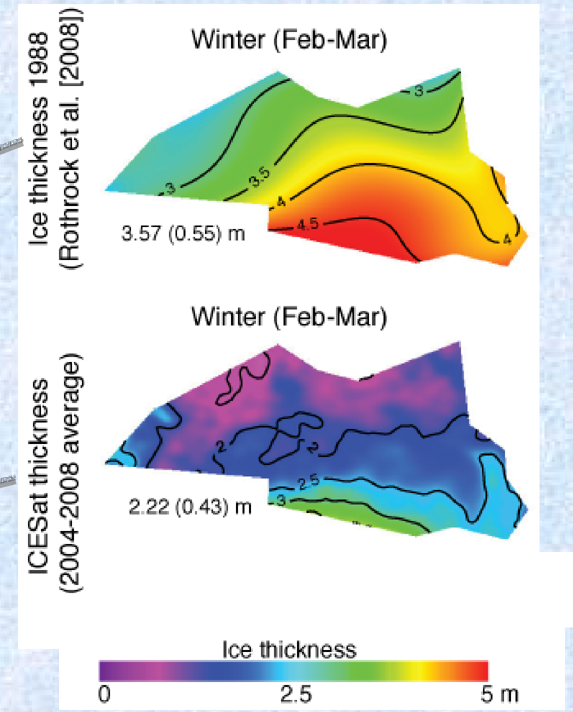
(Kwok et al., 2009)

Ice volume is decreasing faster than ice area because both thickness and area are decreasing.

ICESat thickness estimates extend the record previously obtained by submarine sonar showing major loss in ice thickness in central Arctic Ocean.







(from Kwok and Rothrock, 2009)

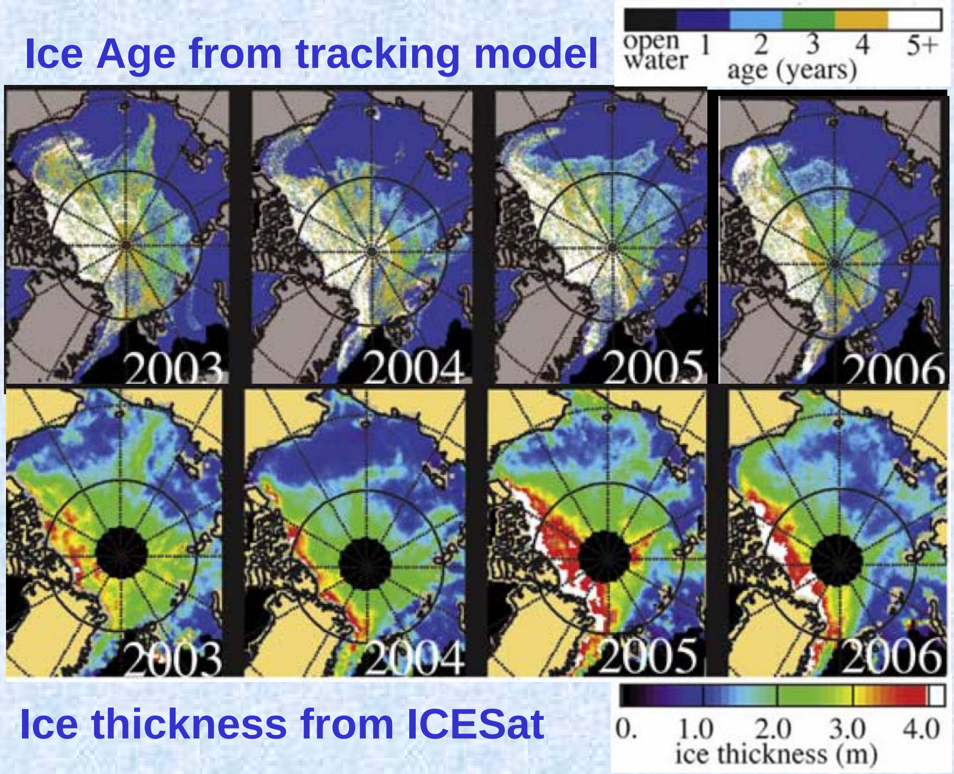
Decline in Age and Thickness of Arctic Sea Ice

A younger, thinner Arctic ice cover: Increased potential for rapid, extensive sea-ice loss, *GRL Dec 2007,*
J. A. Maslanik, C. Fowler, J. Stroeve, S. Drobot, J. Zwally, D. Yi, and W. Emery, U. Colorado and NASA Goddard

- ❑ **Oldest and thickest multiyear ice has declined significantly.**

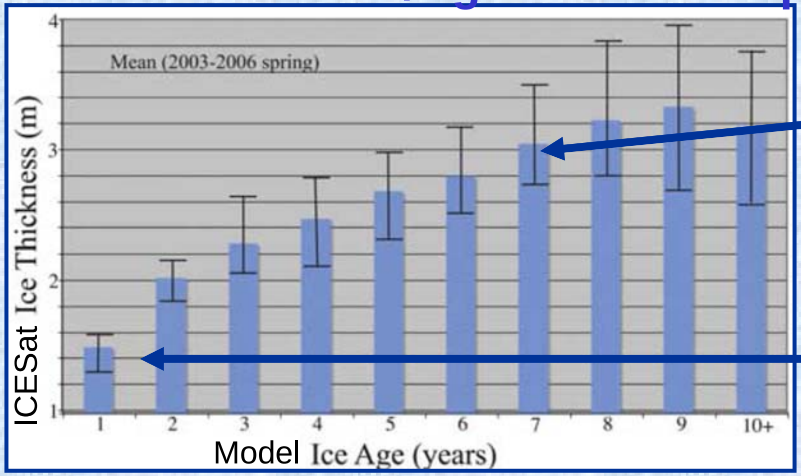
- ❑ **Remaining ice is thinner and more vulnerable to increasing summer melting.**

Ice Age from tracking model



Ice thickness from ICESat

Sea Ice Thickness/Age Relationship



Takes about 7 years to grow 3 to 4 m multiyear ice.

Thinner ice is only 1 to 2 years old.

Summary of Arctic Sea Ice Changes

While the <u>area of sea ice</u> at the end of the summer has been <u>declining at an increasing rate (-4.7%/yr)</u>, the <u>thickness has been decreasing at a similar rate (-5.3%/yr)</u> (2003 to 2007 rates).

Therefore, the <u>volume</u> of sea ice has been <u>decreasing even faster (-8.8%/yr) than the area</u>. (2003 to 2007 rates).

A large area of former perennial ice pack from the Beaufort to Laptev Seas is now a seasonal sea ice zone.

Most of the sea ice thicker than 2 m has disappeared throughout the Arctic Ocean.

Remaining perennial pack is thinner and more vulnerable to disappearance in summer.

In 2008 and 2009 sea ice AREA has rebounded some, but not THICKNESS in 2008 and ??2009??

NAS Decadal Survey to ICESat-2 Science Objectives

Decadal Survey Objectives

Sustained measurements to distinguish short-term variability from long-term trends

Trends to calibrate climate models that predict future changes in sea level and in other climate variables

Ongoing, continuous measurements of both land ice and sea ice volume to observe trends, update assessments and test climate models

Trends in sea ice thicknesses

Support estimating changes in terrestrial biomass

ICESat-2 Science Objectives

Quantify polar ice sheet mass balance to determine contributions to sea level rise and the linkages to changing climate.

Determine seasonal changes, interannual variability, and long-term trends.

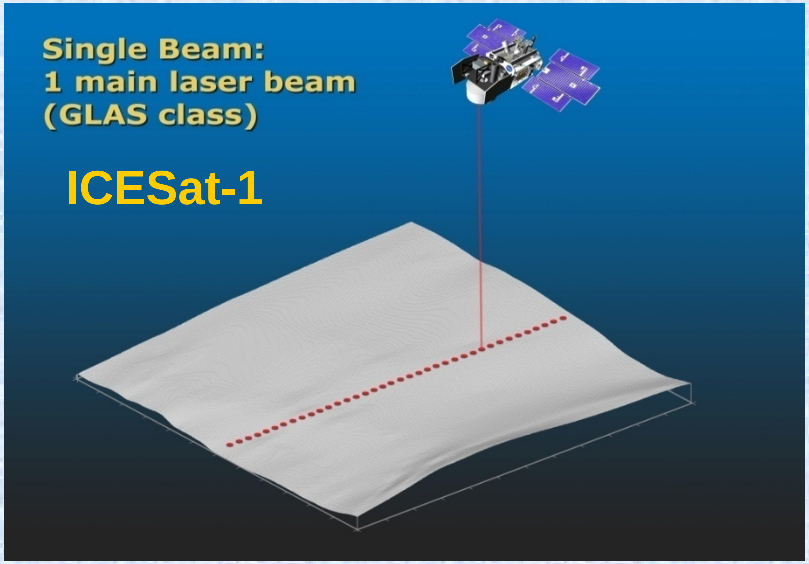
Determine topographic character of ice sheet changes to assess mechanisms driving ice change and improve predictive ice sheet models.

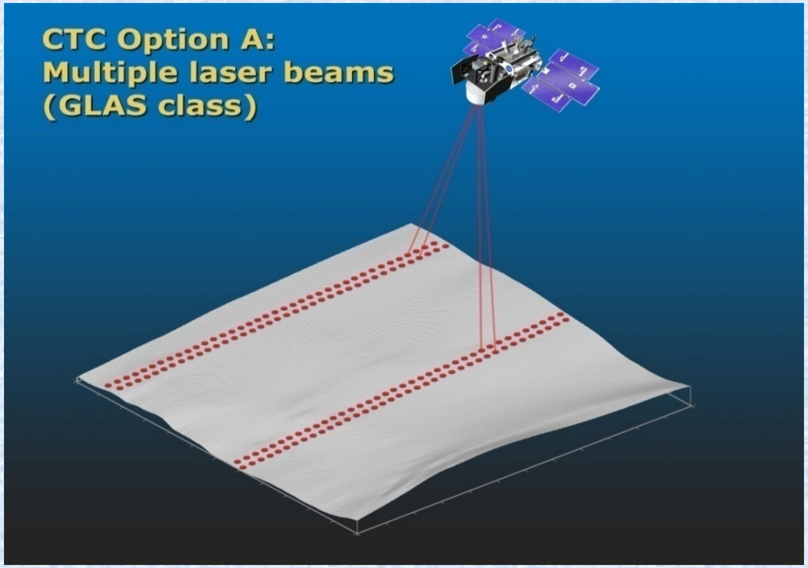
Estimate sea ice thickness to examine ice/ocean/atmosphere exchanges of energy, mass and moisture.

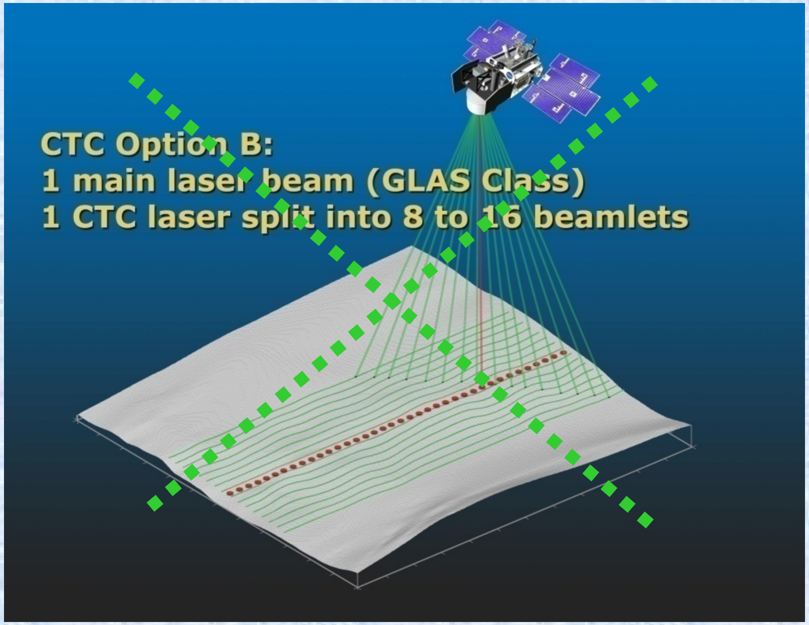
Determine seasonal changes, inter-annual variability, and long-term trends.

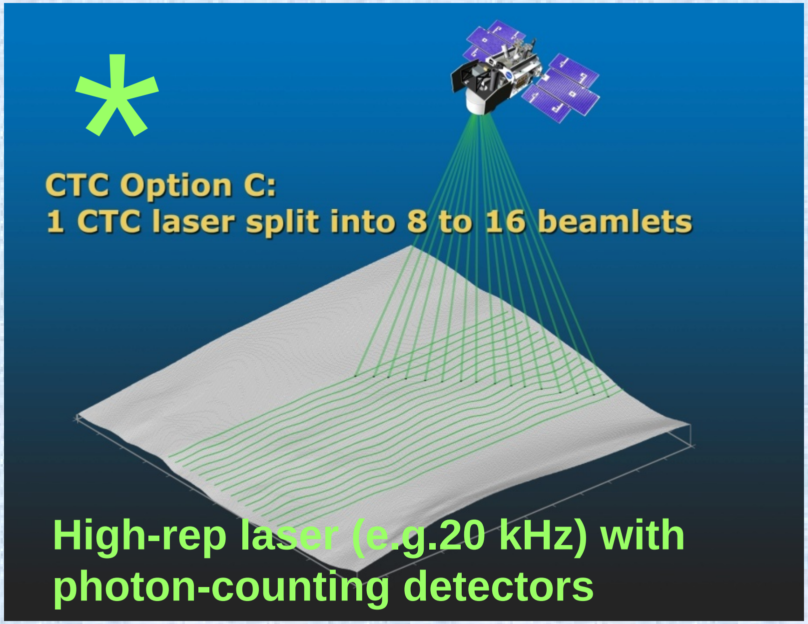
Measure vegetation canopy height for estimating large-scale land biomass and biomass change.

ICESat-2 Laser Measurement Options

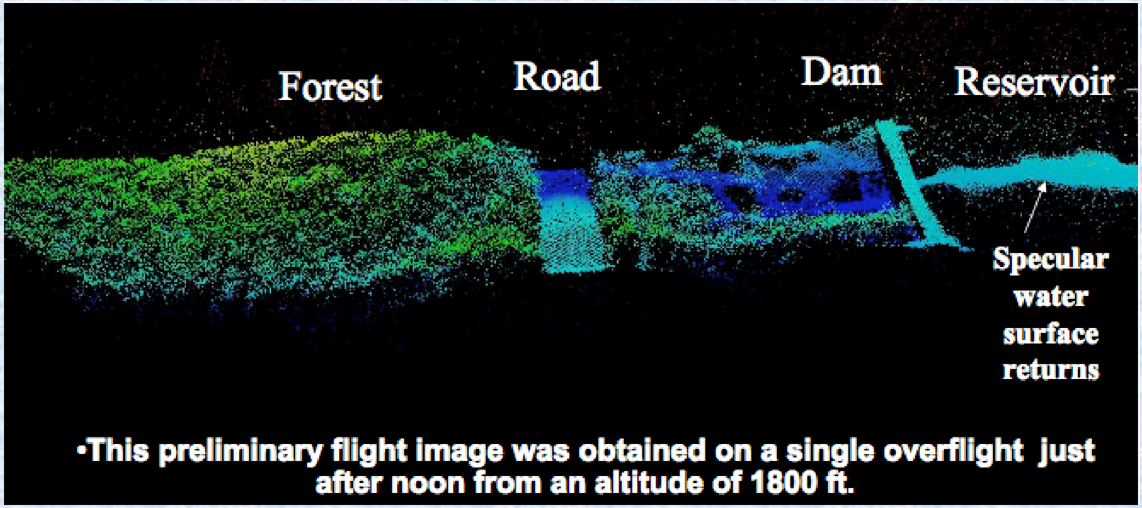


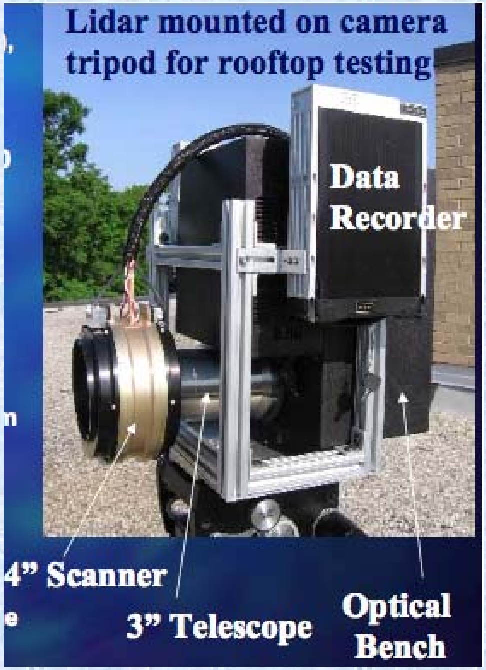


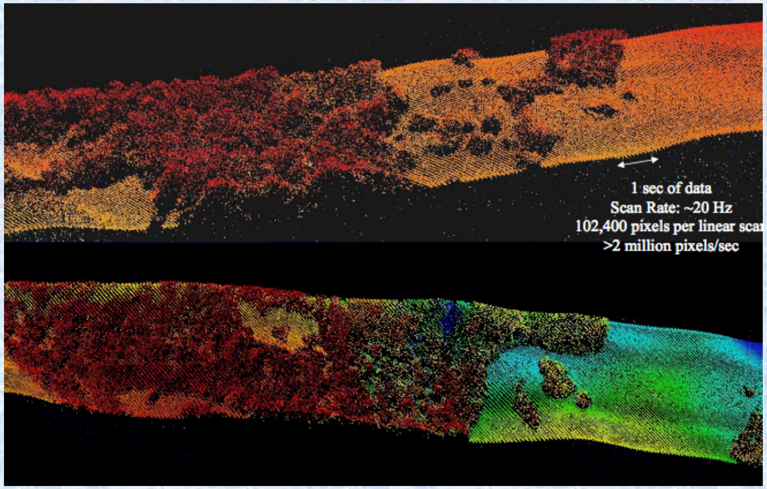


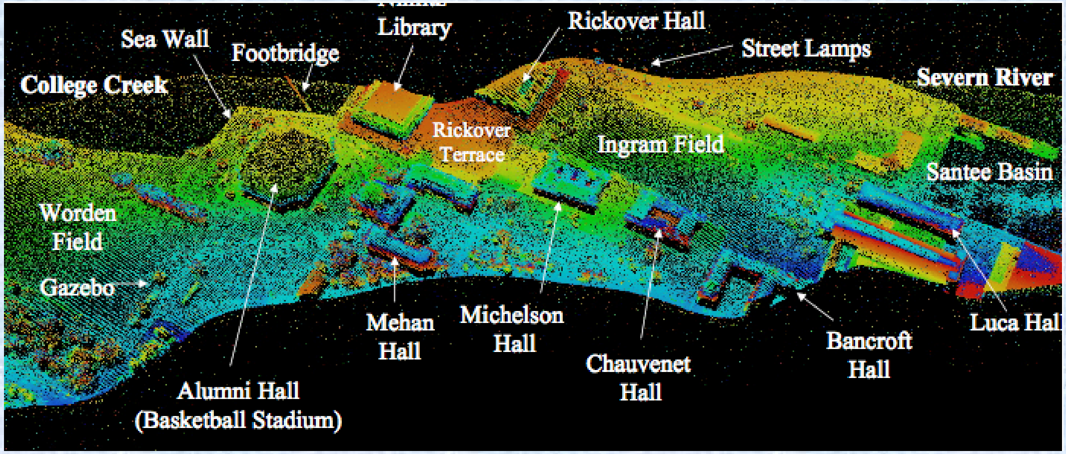


Airborne Scanning Lidar (Sigma Space Corp.)










ICESat-1 (2003 – 2009?)
ICESat-2 (2015 – 2020)
Unique Laser Missions for
Multidisciplinary Earth Science