Comparing CryoSat, ICESat, and AMSR-E Measurements over Antarctic Sea Ice

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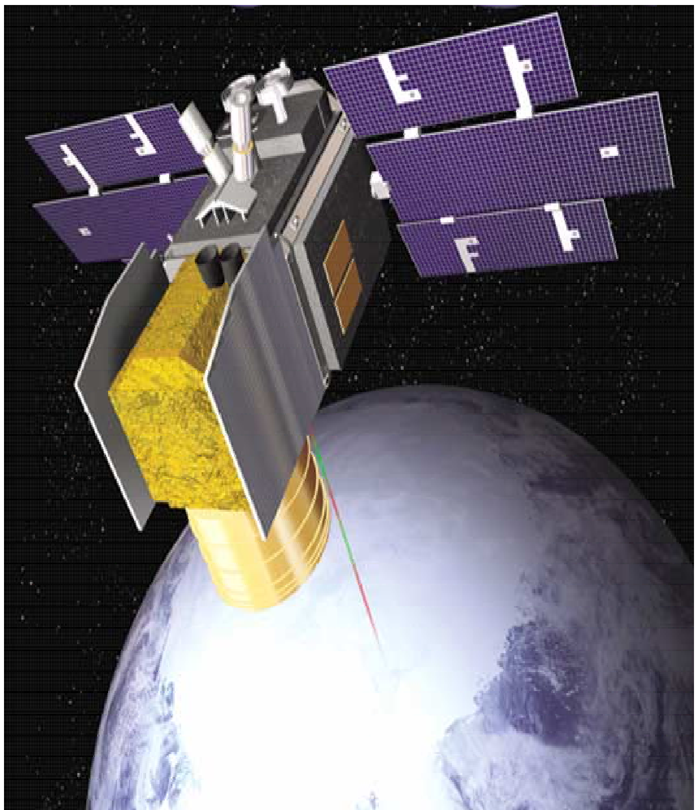
Ice, Cloud, and Land Elevation Satellite (ICESat)



Instrument: Geoscience Laser Altimeter System (GLAS)

Launch Time: January 12, 2003

Orbit Height: 600 km

Inclination: 94°

Laser Wavelength: 1064 nm and 532 nm

Orbit Repeat: 8 day and 91 day

Transmitted Pulse FWHM : 5 ns

Laser Footprint Diameter on the ground: 70 m

Sample interval on the ground: 170 m

Sample Rate: 40 laser shots per second.

ICESat Objectives

Primary purpose:

Detection of ice sheets elevation changes that are indicative of changes in ice volume over time.

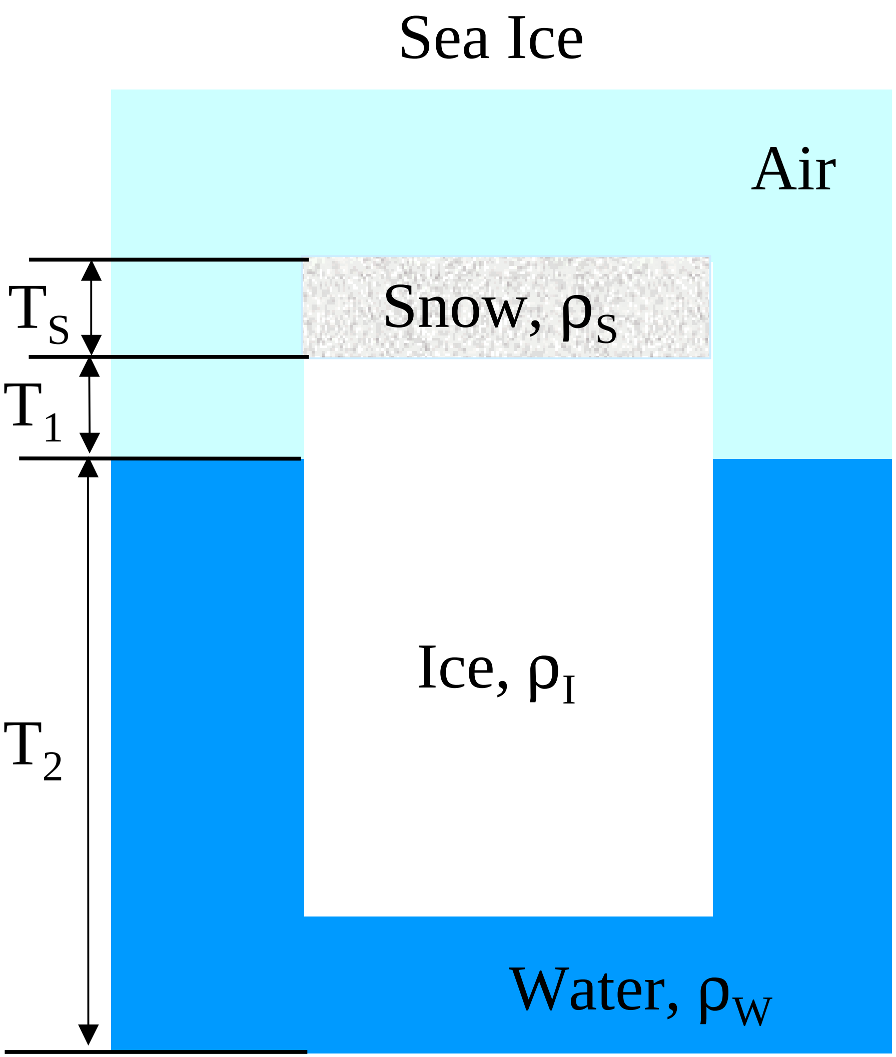
Other objectives include:

Measurements of sea ice, ocean, and land surface elevations and surface roughness; multiple near-surface canopy heights over land; and cloud studies.

ICESat Laser Operating Periods

	Operating Time	Orbit
Laser 1	02/20/2003 - 03/29/2003	8-day
Laser 2a	09/25/2003 - 11/19/2003	8-day/91-day
Laser 2b	02/17/2004 - 03/21/2004	91-day
Laser 2c	05/18/2004 - 06/21/2004	91-day
Laser 3a	10/03/2004 - 11/08/2004	91-day
Laser 3b	02/17/2005 - 03/21/2005 ?	91-day

Comparing CryoSat, ICESat, and AMSR-E Measurements



Sea Ice Thickness ($T_I = T_1 + T_2$) is a function of Freeboard ($F = T_S + T_1$) and Snow Cover (T_S and ρ_S):

$$T_I = \rho_W/(\rho_W - \rho_I) \times F - (\rho_W - \rho_S)/(\rho_W - \rho_I) \times T_S$$

$$T_I = 9.411 \times F - 6.653 \times T_S$$

for $\rho_S = 0.30$, $\rho_W = 1.0239$, and $\rho_I = 0.9151$

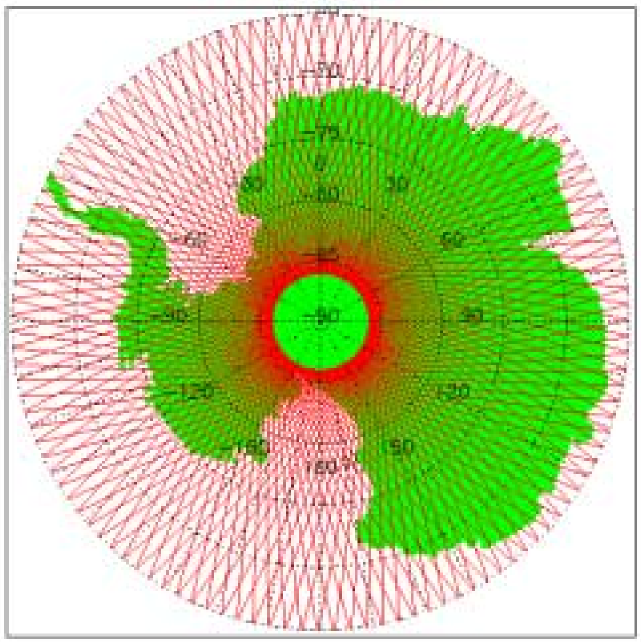
CryoSat: Snow/Ice boundary and Air/Water boundary

ICESat: Air/Snow boundary and Air/Water boundary

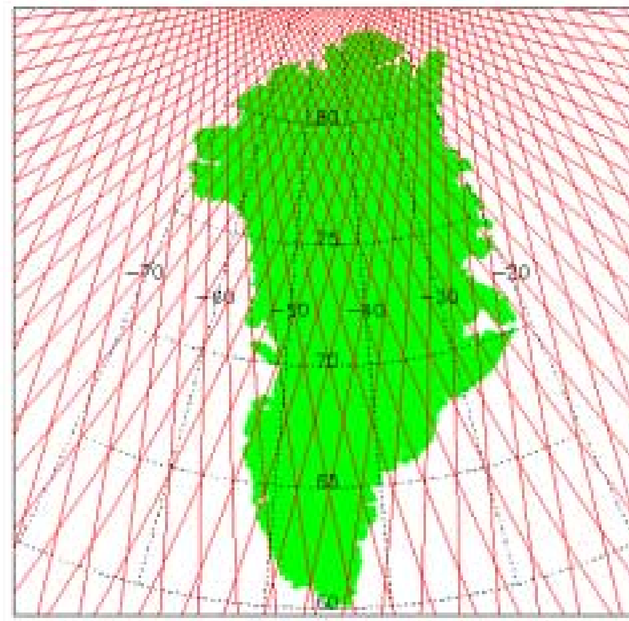
AMSR-E: Snow Thickness

8-day orbit over Antarctica and Greenland

Antarctica



Greenland

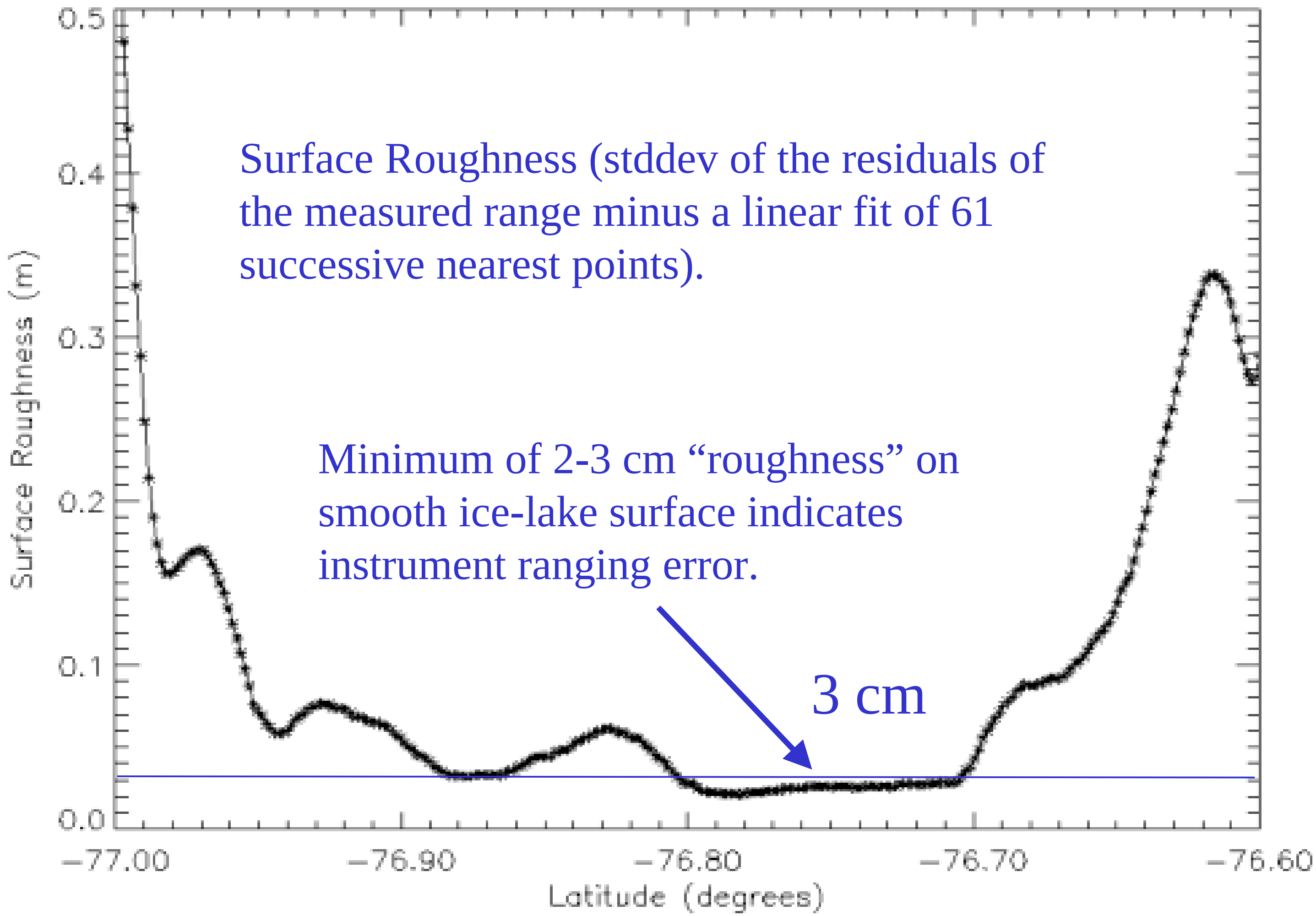


ICESat 91-day orbit is ~ 11 times denser than its 8-day orbit.

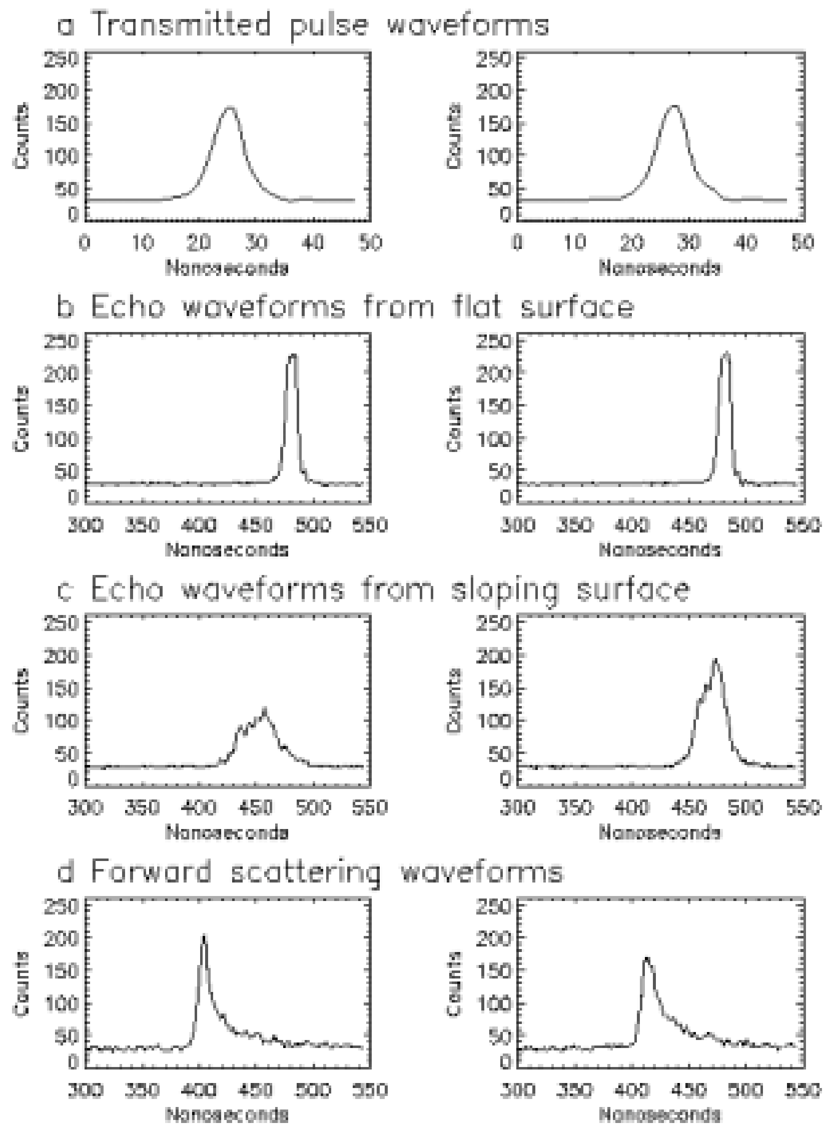
A month of the 91-day orbit is ~ 4 times denser than the 8-day orbit.

Precision of ICESat Elevation Measurement

A Track Passes Lake Vostok, Antarctica

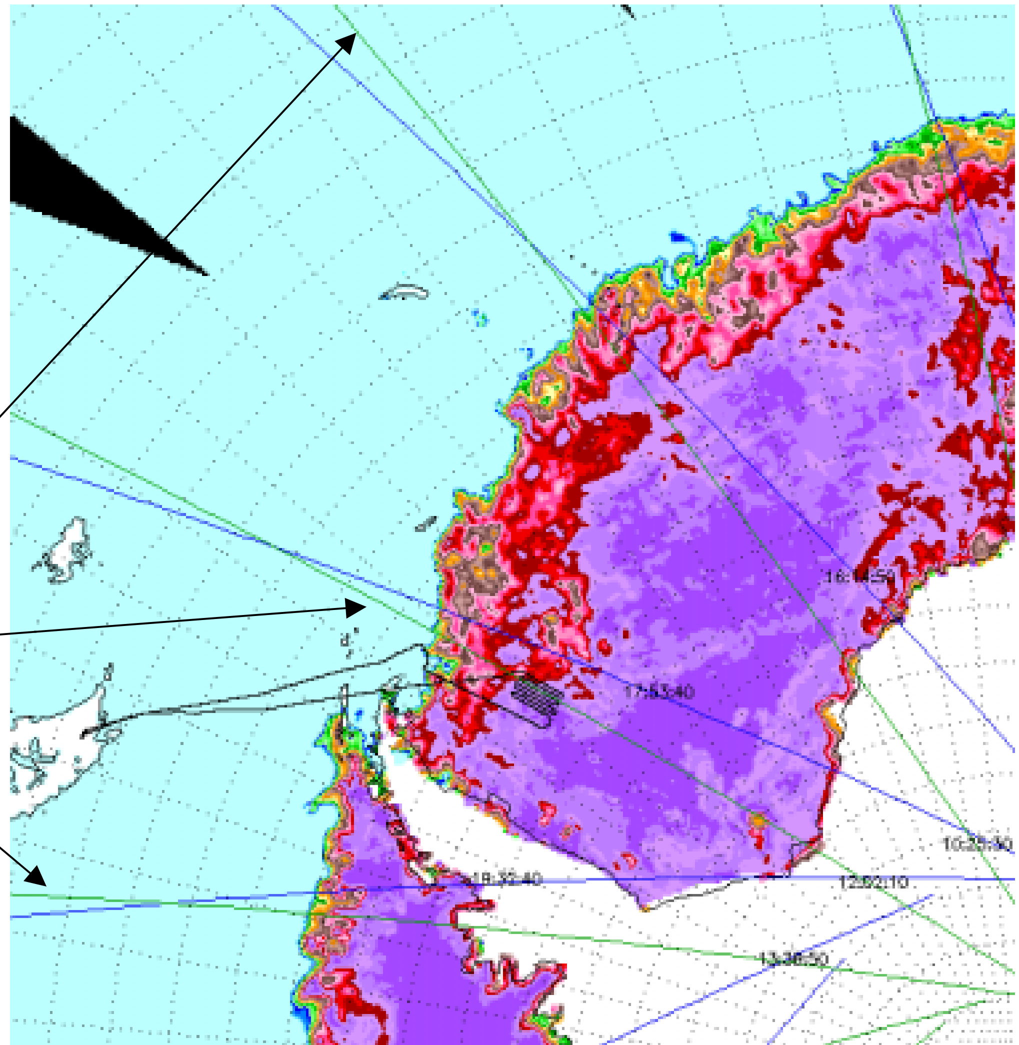


Typical GLAS Waveforms



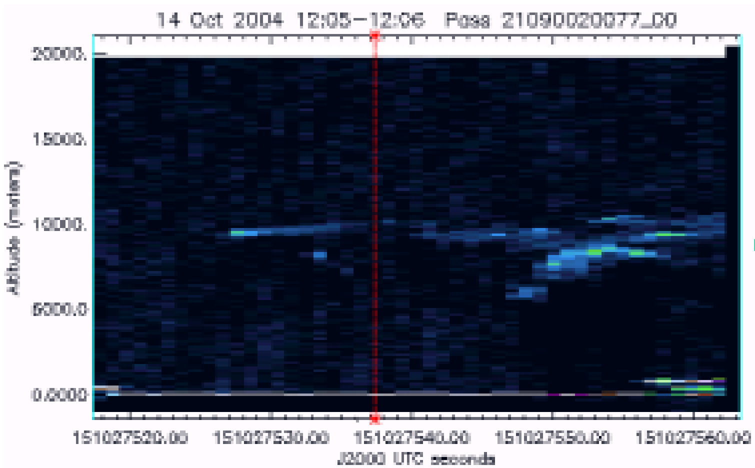
Oct 14, 2004, Field Campaign (Map from J. Comiso)

ICESat
Track

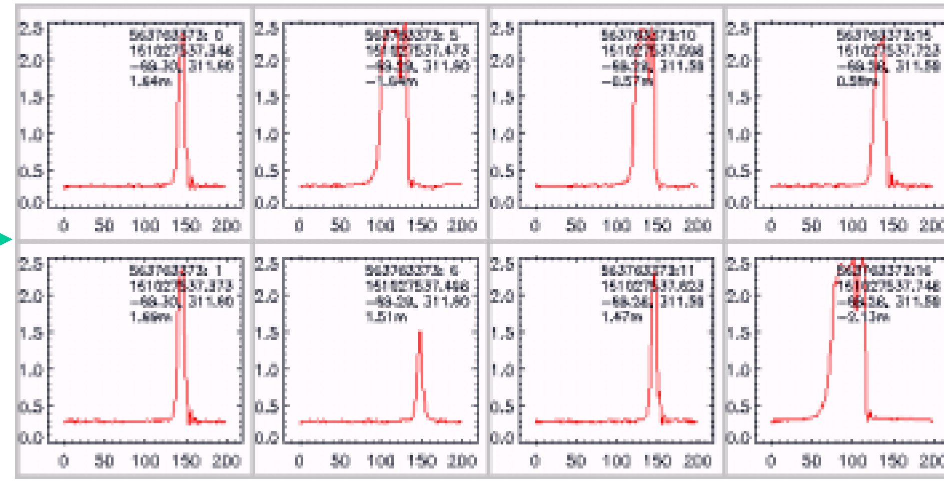


Echo Waveforms with/without Clouds

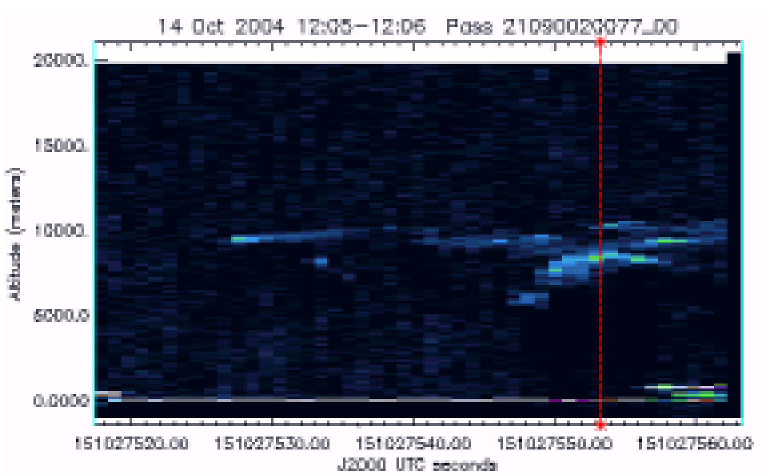
No Clouds



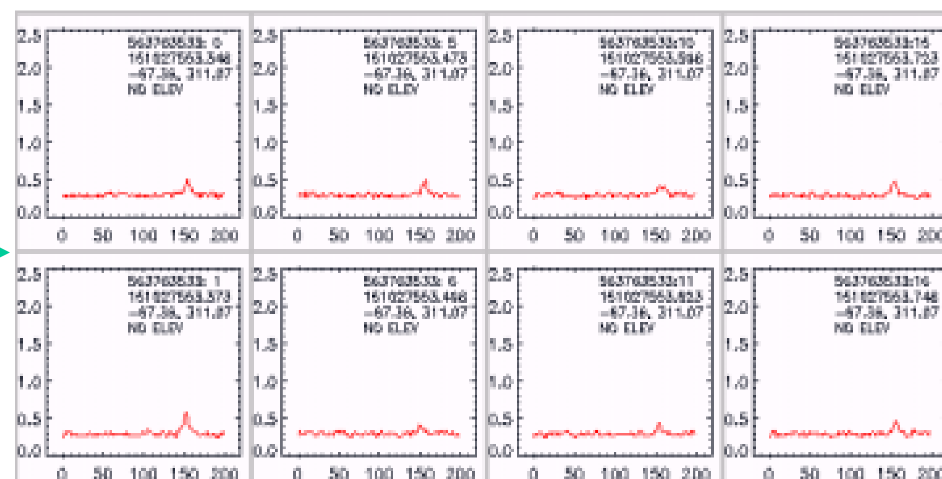
Echo Waveforms



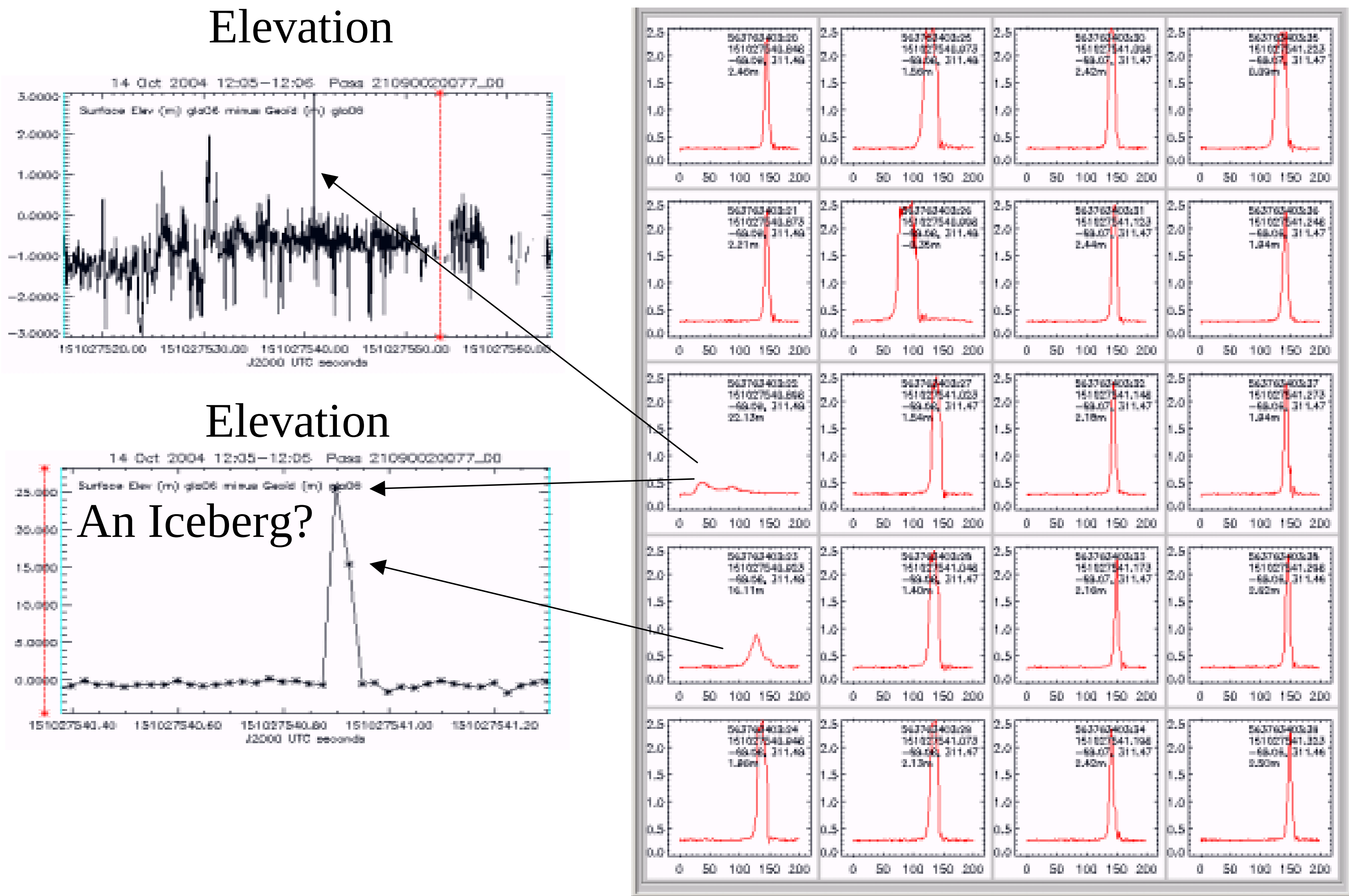
With Clouds



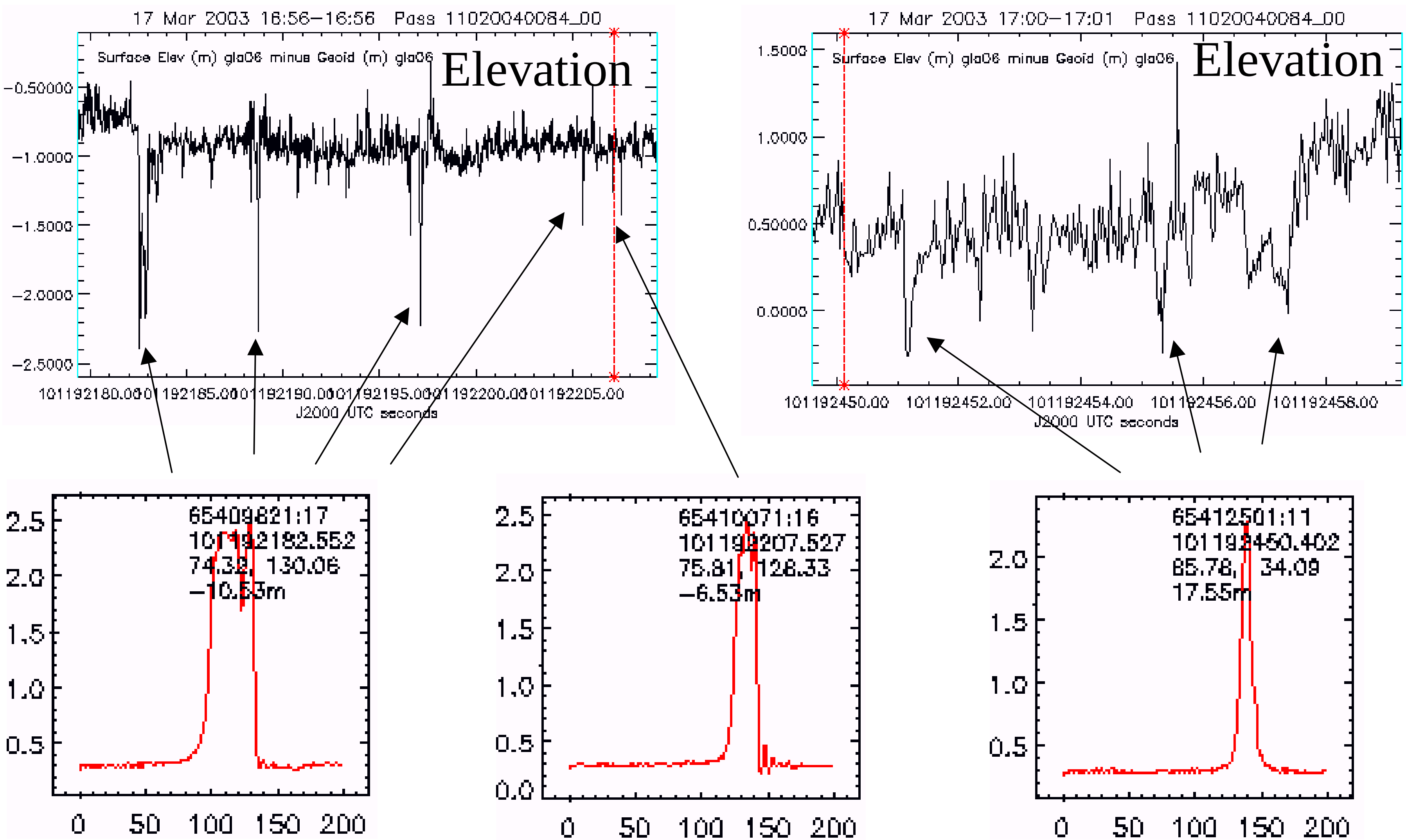
Echo Waveforms



An Iceberg shown in a profile



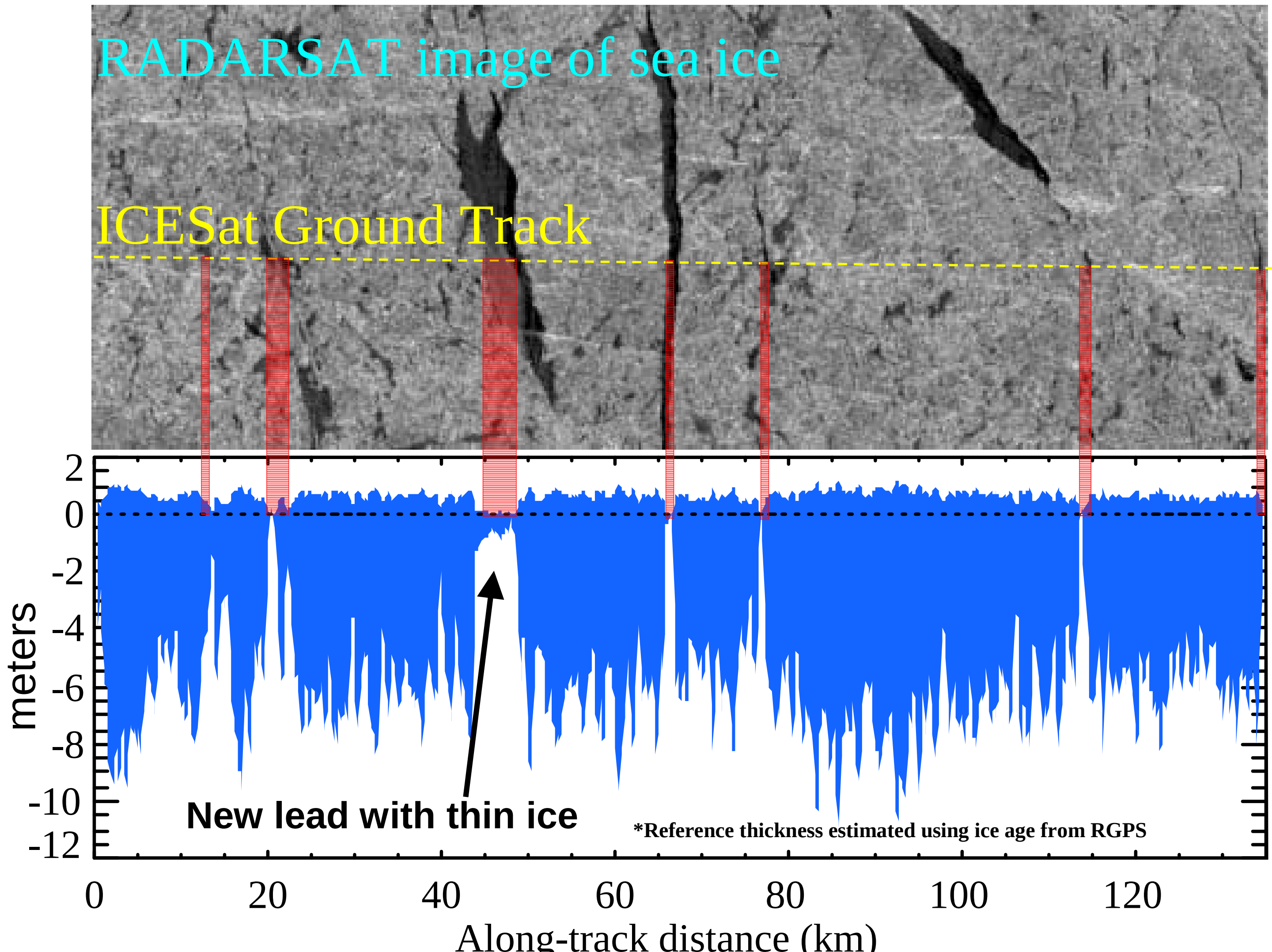
Elevation and Waveforms

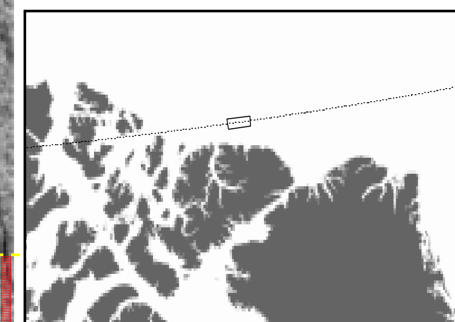


Significantly Saturated Waveforms

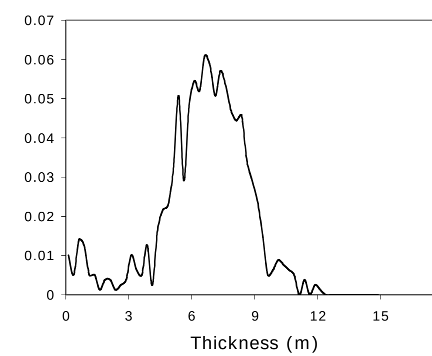
Regular Waveform

Near-coincident ICESat and RADARSAT Data Over Arctic Sea Ice



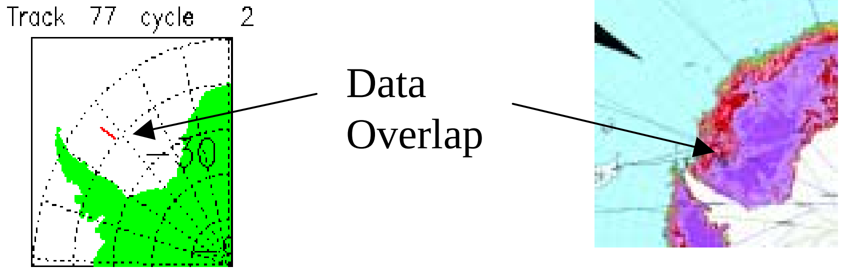


Δt = 1.2 days

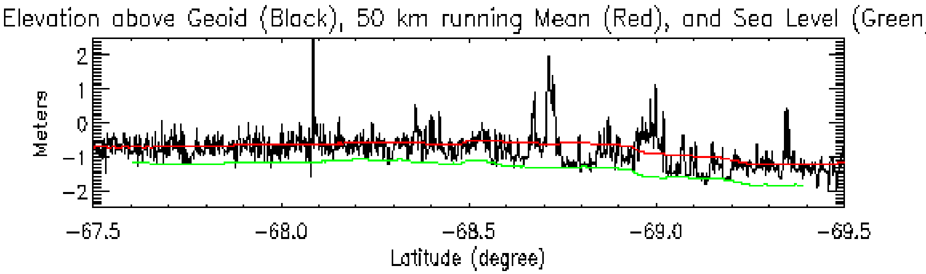


Kwok, Zwally, & Yi, GRL Aug. 2004

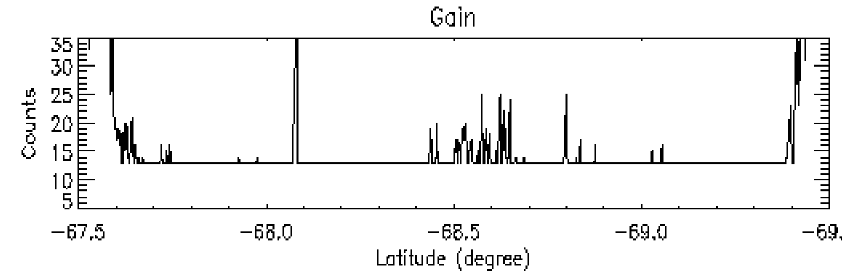
Oct 14, 2004



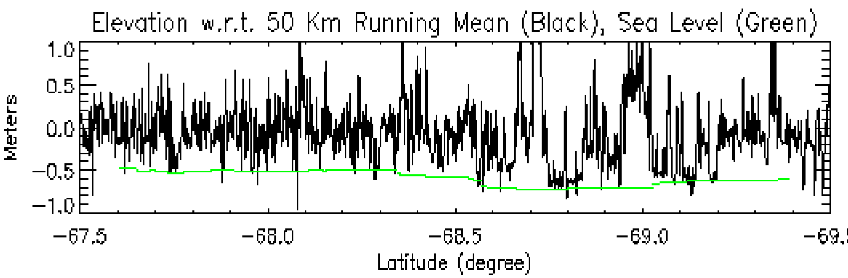
Track 77 cycle 2
Data
Overlap



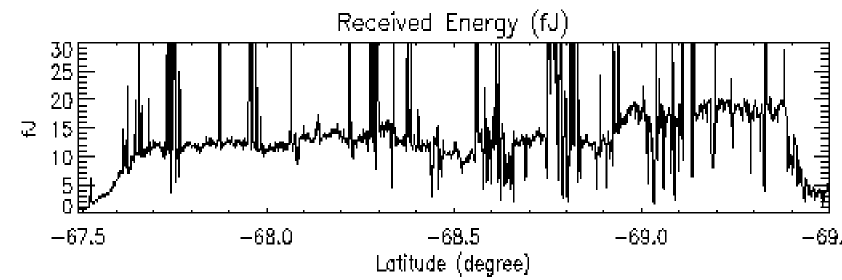
Elevation above Geoid (Black), 50 km running Mean (Red), and Sea Level (Green)
Meters
Latitude (degree)



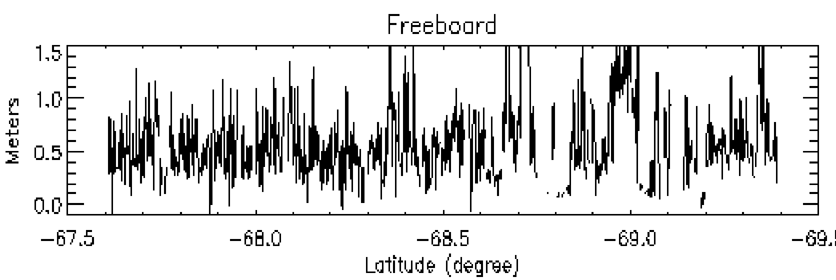
Gain
Counts
Latitude (degree)



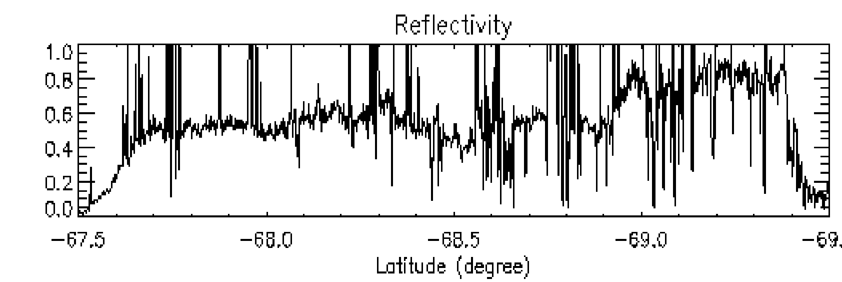
Elevation w.r.t. 50 Km Running Mean (Black), Sea Level (Green)
Meters
Latitude (degree)



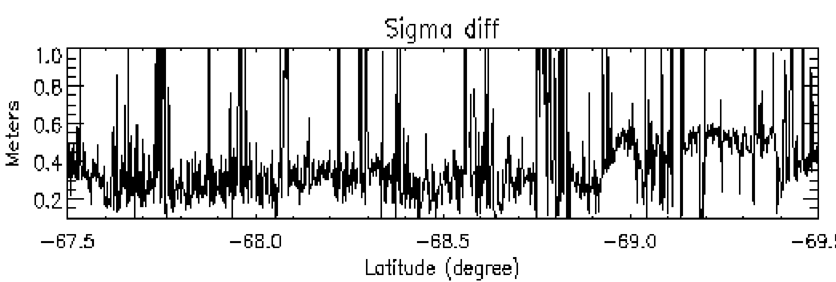
Received Energy (fJ)
fJ
Latitude (degree)



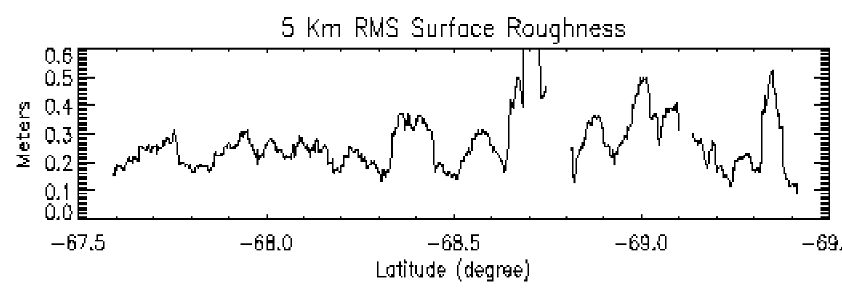
Freeboard
Meters
Latitude (degree)



Reflectivity
Latitude (degree)



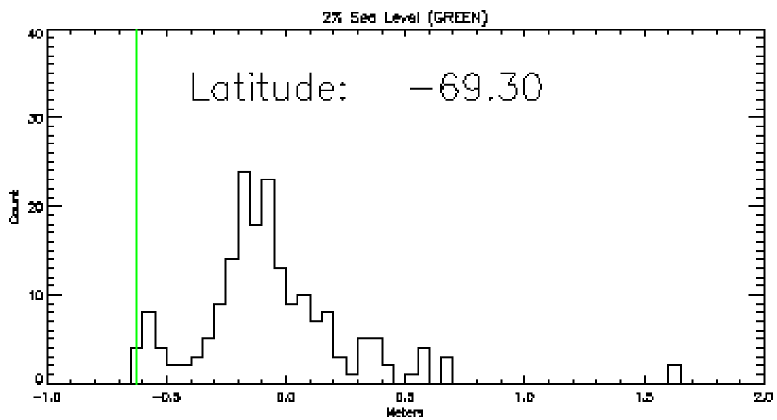
Sigma diff
Meters
Latitude (degree)

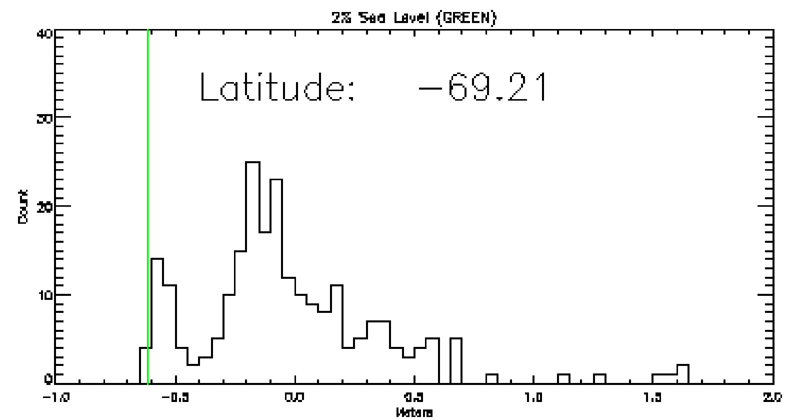


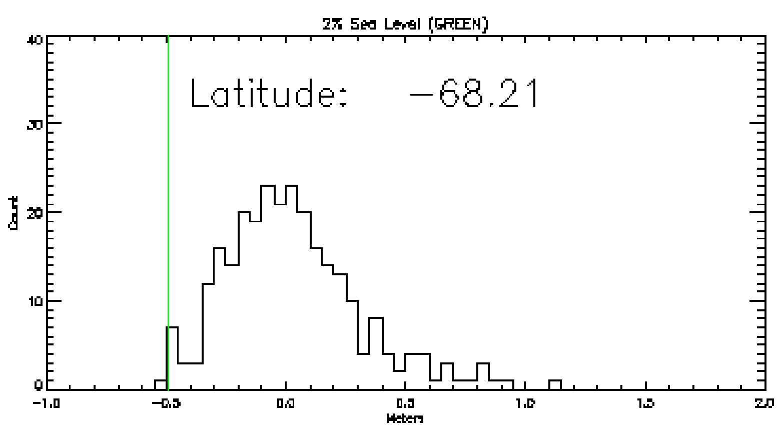
5 Km RMS Surface Roughness
Meters
Latitude (degree)

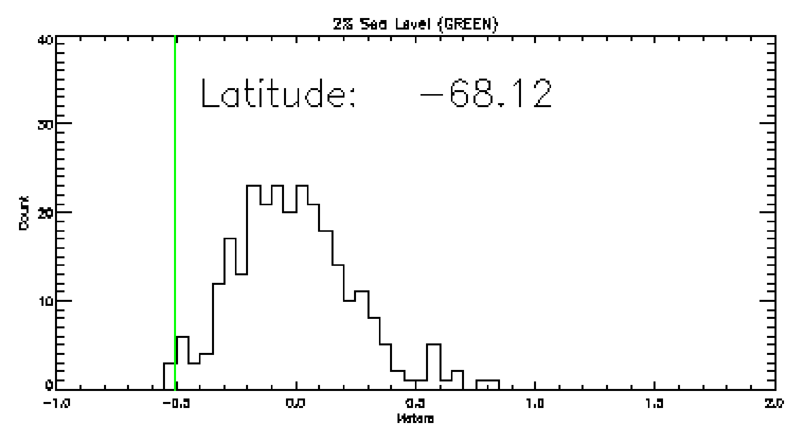
Elevation Histograms for each point

Using 50 km (300 points) to find lowest 2% (6 points) to calculate sea level









Conditions used over Antarctica

Saturation corrected,   Gain aligned,   Reflectivity corrected

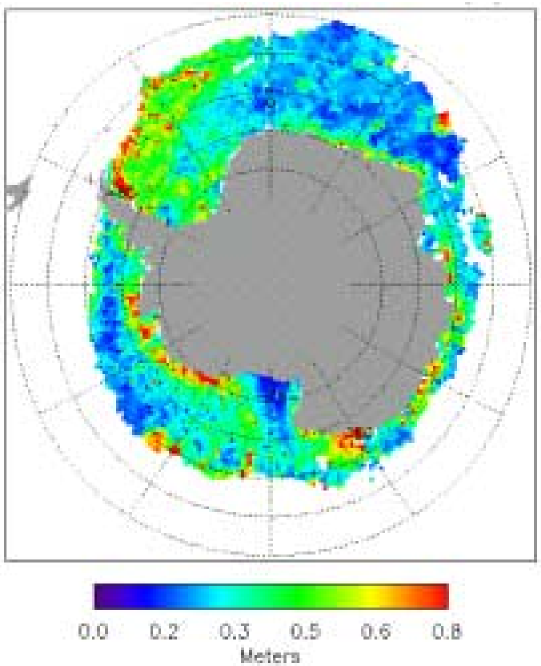
Laser2a (release 18), Laser2b (release 16/17), Laser2c (release 17):

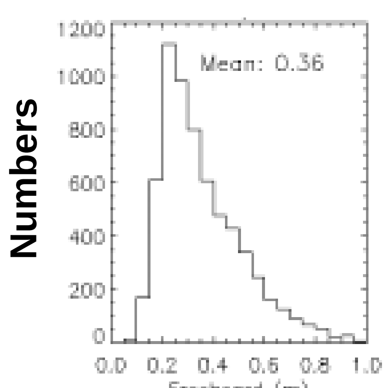
- Gain limit: < 31 (< 81 for laser 2c)
- Pulse broadening limit: S < 0.8
- 0.1< reflectivity <0.9
- -4< elevation above sea level <4m,   -1 < elevation above mean < 1 m
- Freeboard limit: Fi=0, if Fi < 0
- Snow thickness limit: Ts=Fi, if Ts > Fi

Using 50 km (300 points) to find lowest 2% (6 points) to calculate sea level. Ice Concentration (SSMI) < 50% data has been filtered out when plotting the grids. Cap size used are 35, 100, 200, 300 km.

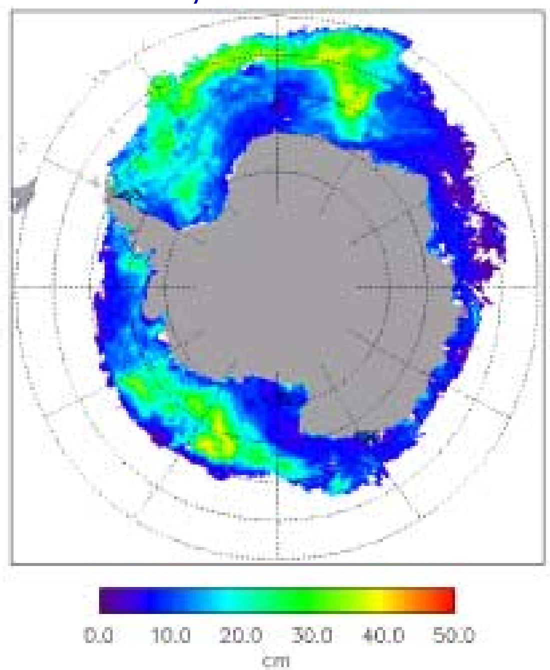
First Sea Ice Thickness Maps From Satellite Laser

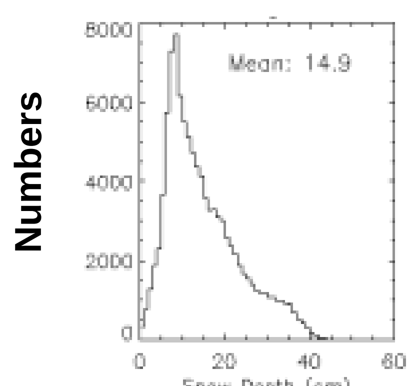
Freeboard
Oct 4 - Nov 18, 2003



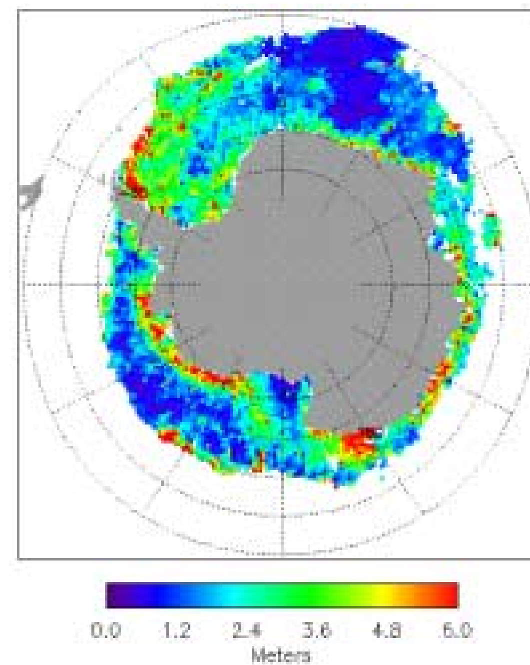


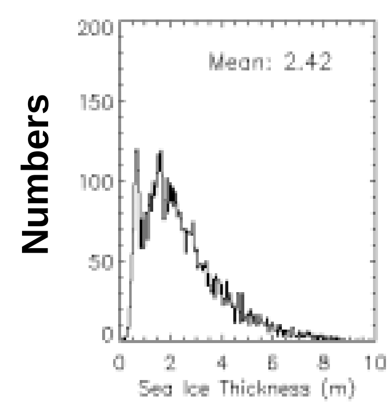
Snow cover Nov 11, 2003
Aqua-AMSR: Markus & Cavalieri, AGU Res. 1998



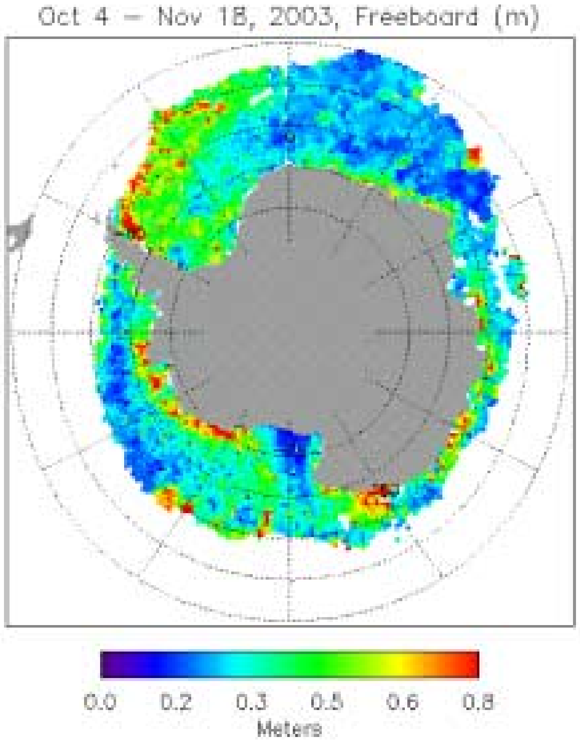


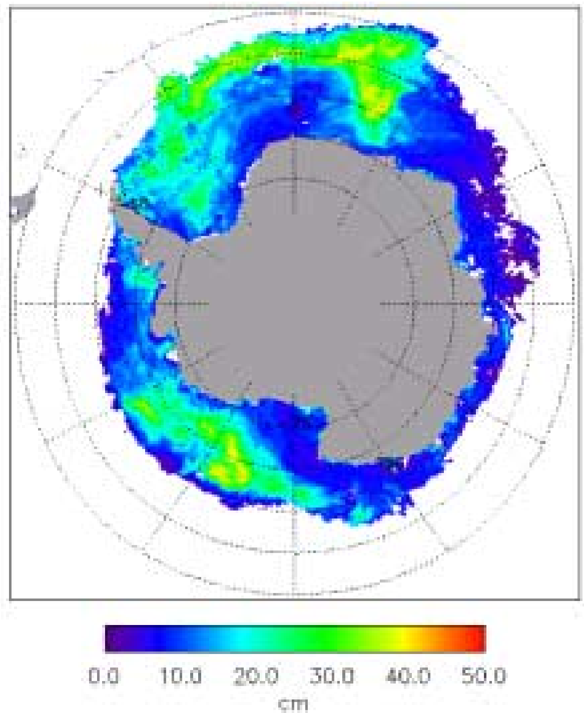
Sea Ice Thickness
Oct 4 - Nov 18, 2003

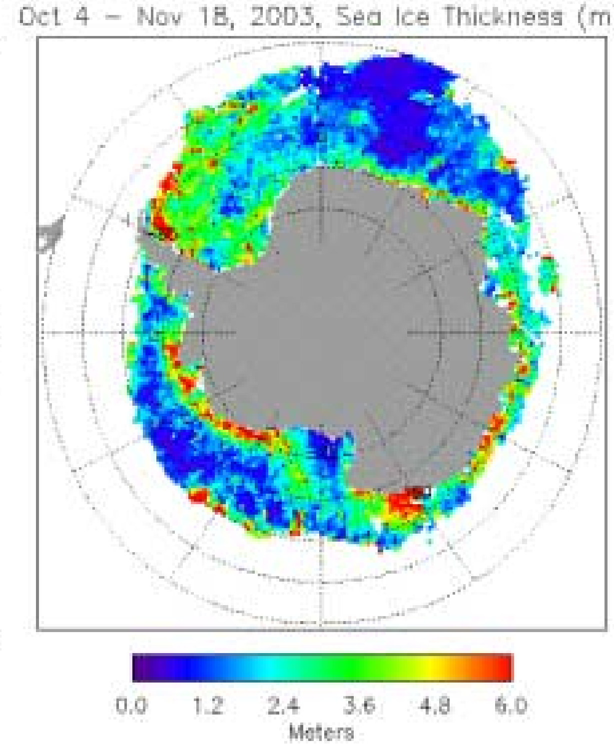


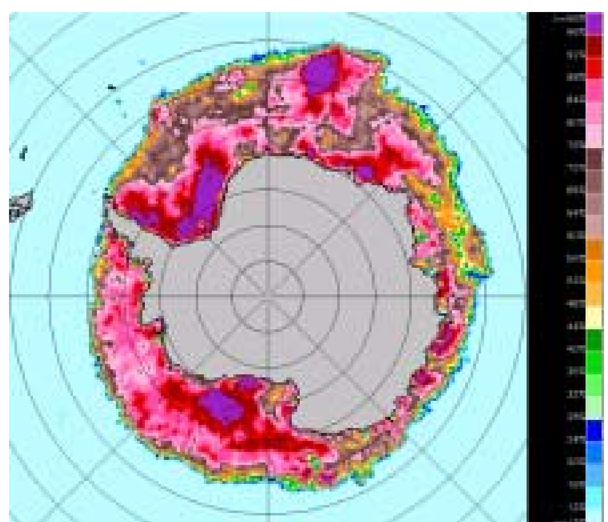


Freeboard AMSR-E Snow Depth Thickness



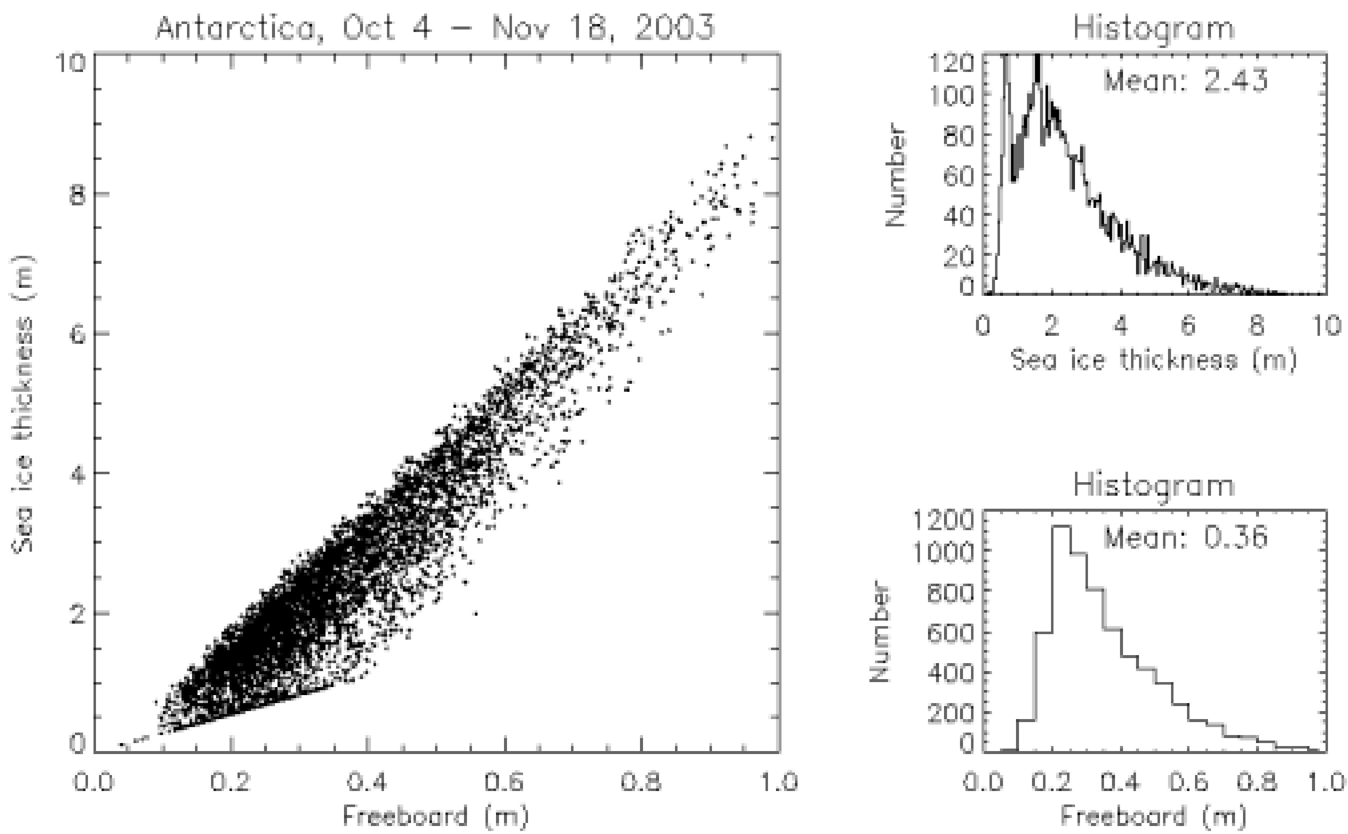




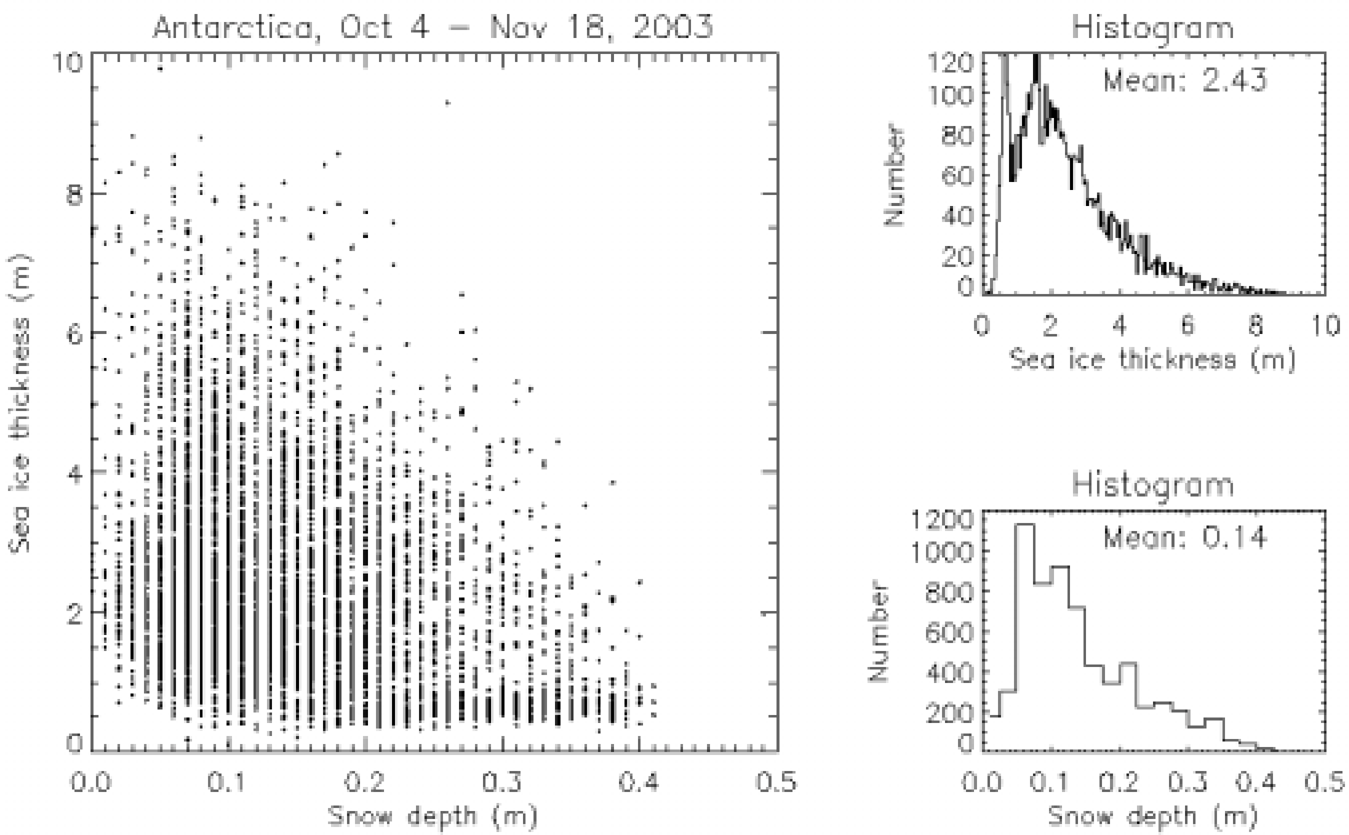


SSMI Sea Ice Concentration Oct 31, 2003

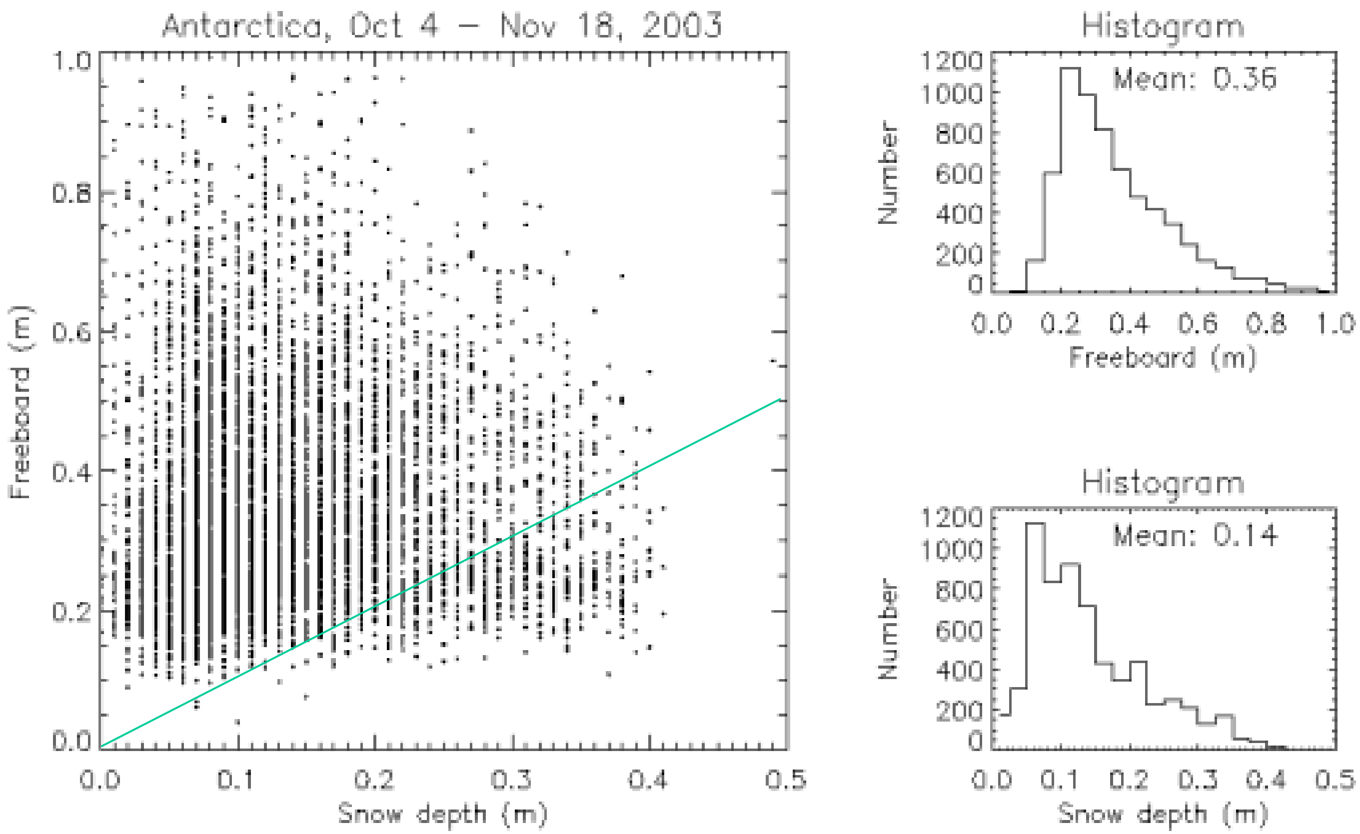
Freeboard and Sea Ice Thickness



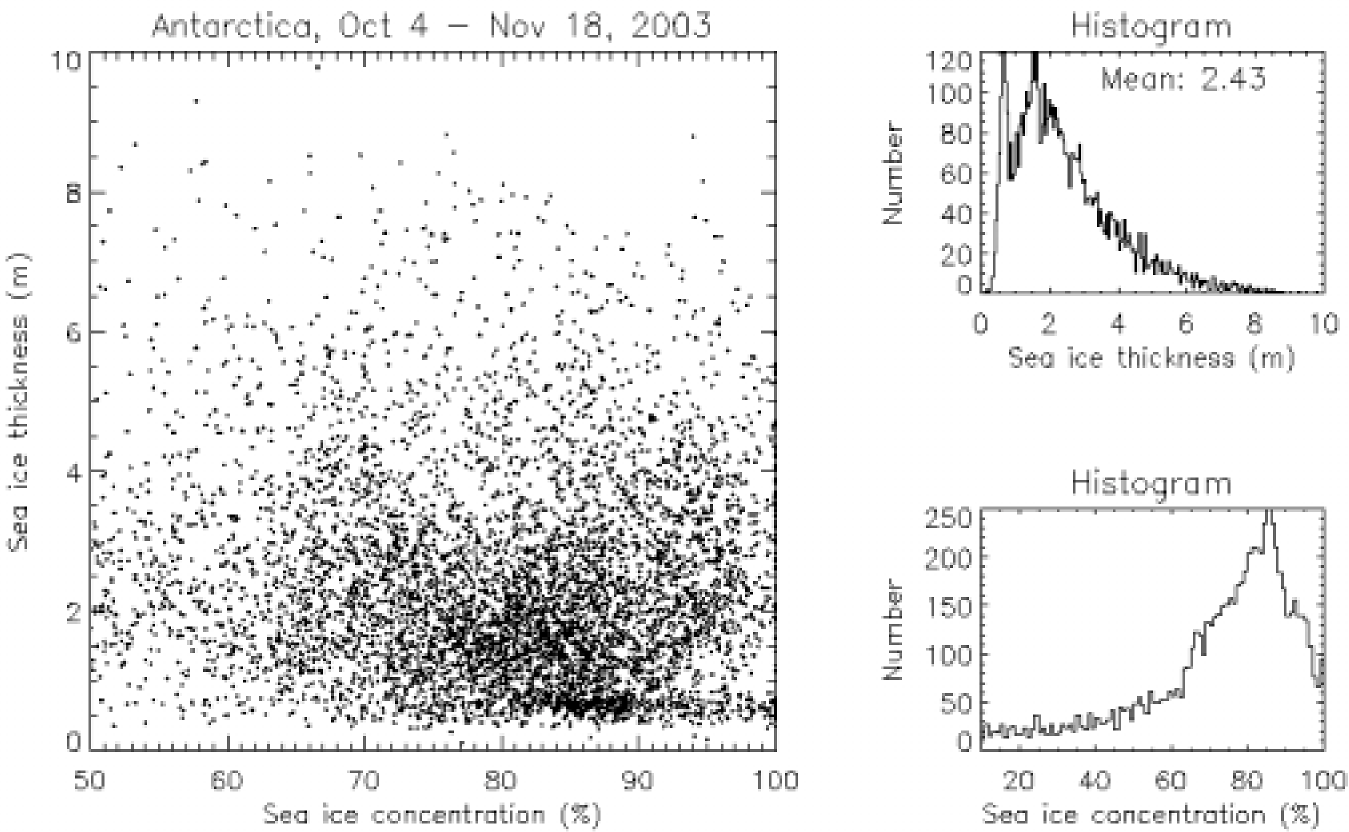
Snow Depth and Sea Ice Thickness



Snow Depth and Freeboard

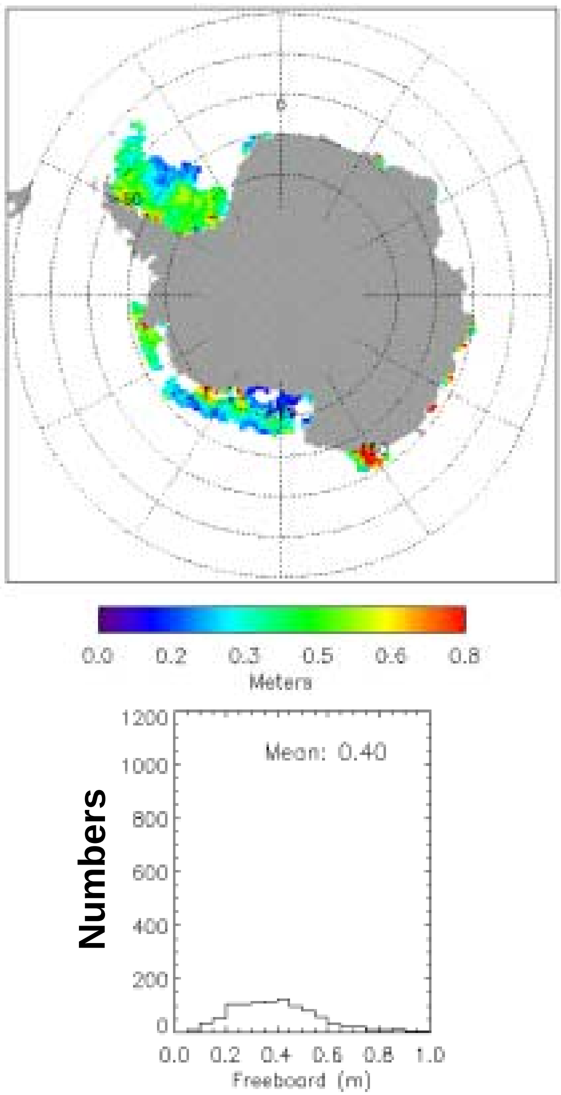


Sea Ice Concentration and Sea Ice Thickness

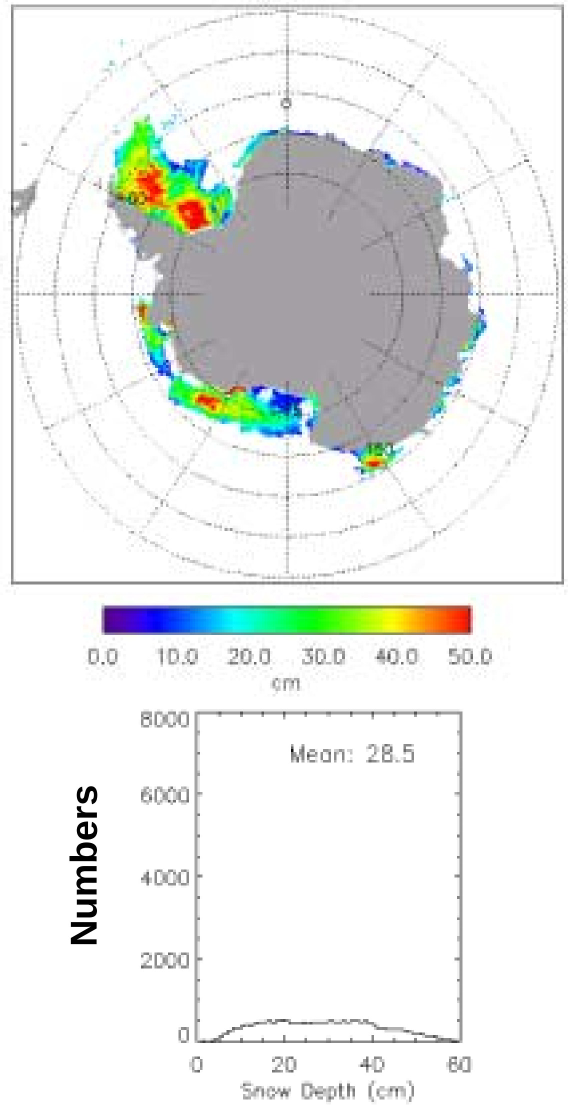


First Sea Ice Thickness Maps From Satellite Laser

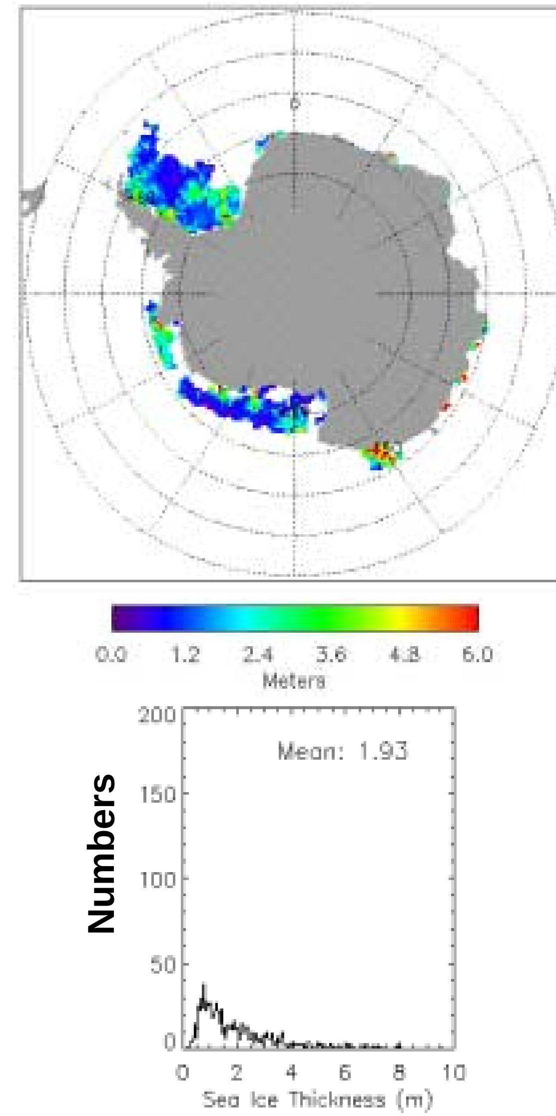
Freeboard
Feb 18 - Mar 21, 2004



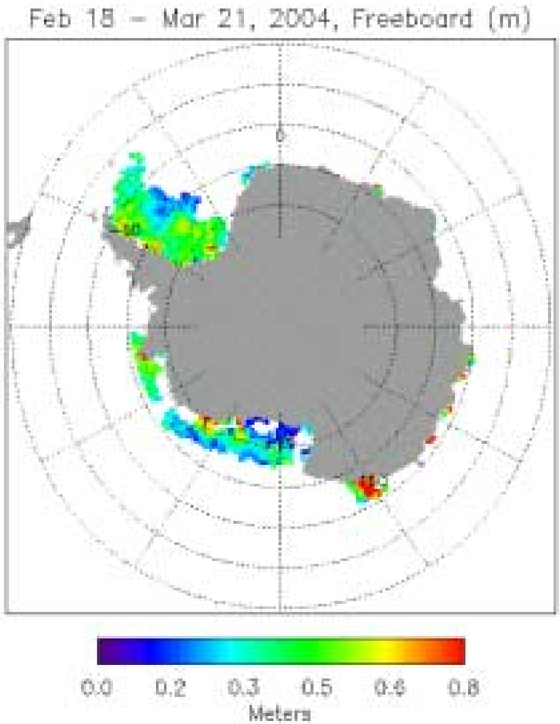
Snow cover Mar 1, 2004
Aqua-AMSR: Markus & Cavalieri, AGU Res. 1998



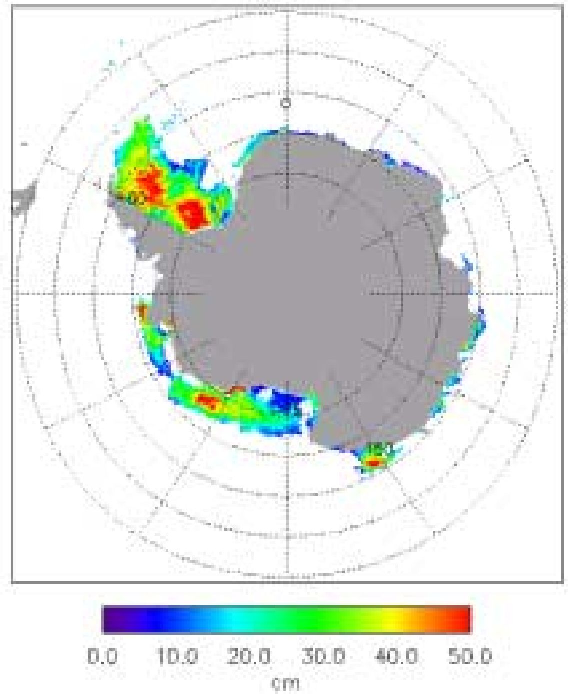
Sea Ice Thickness
Feb 18 - Mar 21, 2004



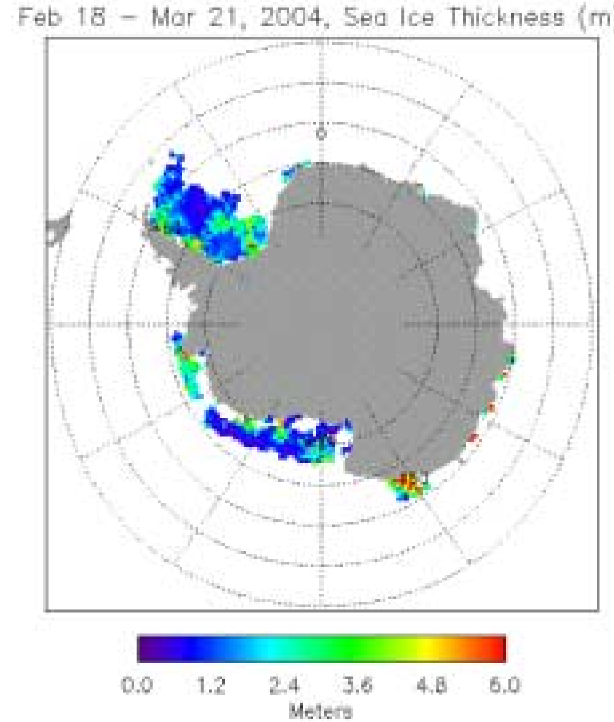
Freeboard

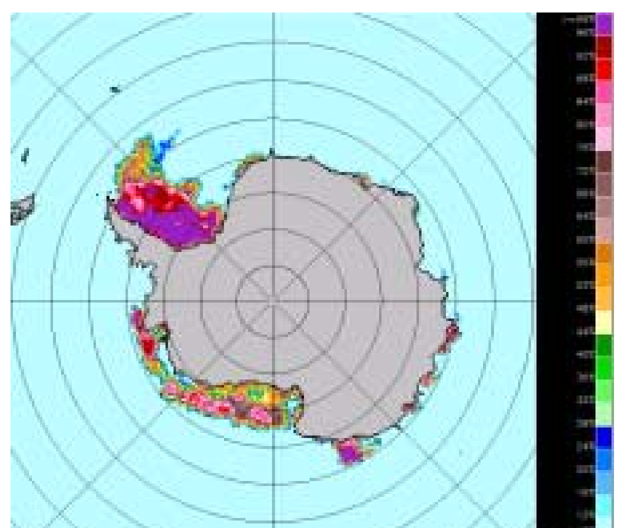


AMSR-E Snow Depth
3/1/2004



Thickness

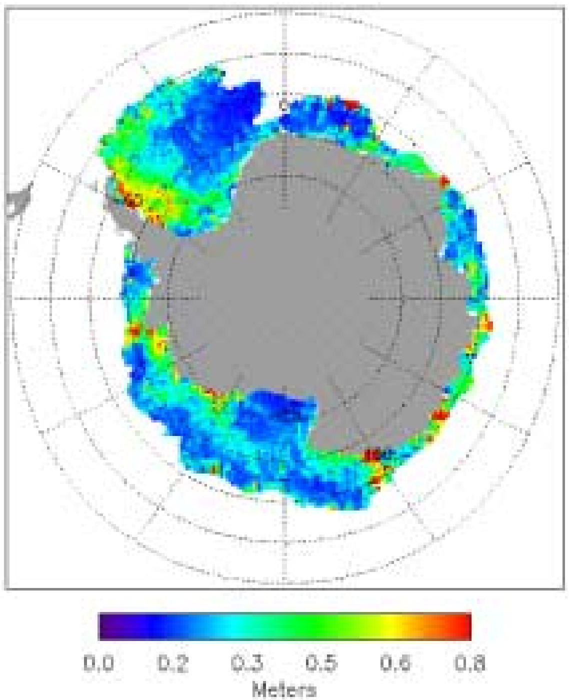


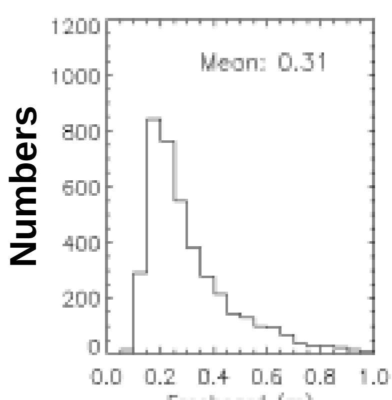


SSMI Sea Ice Concentration March 1, 2004

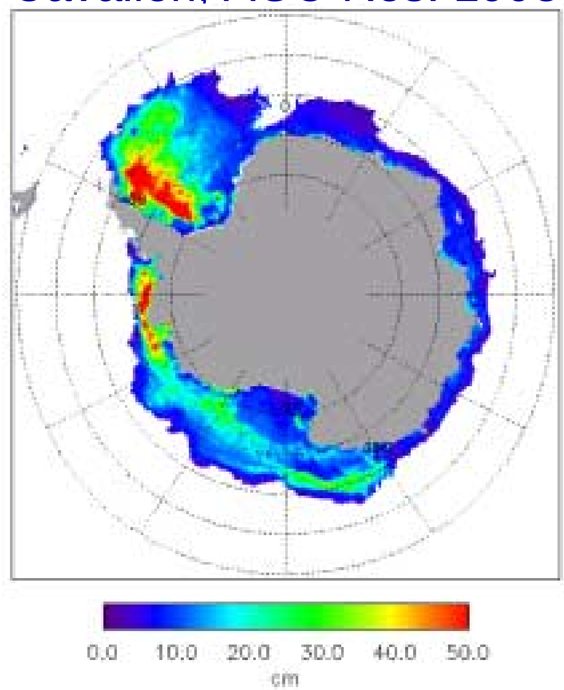
First Sea Ice Thickness Maps From Satellite Laser

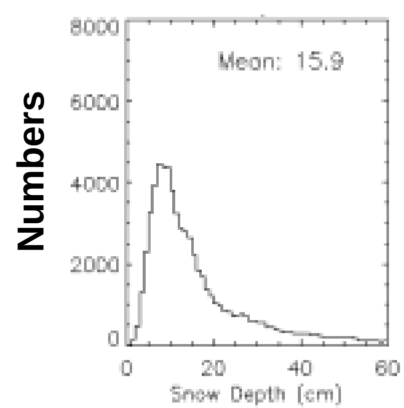
Freeboard
May 15 – Jun 20, 2004



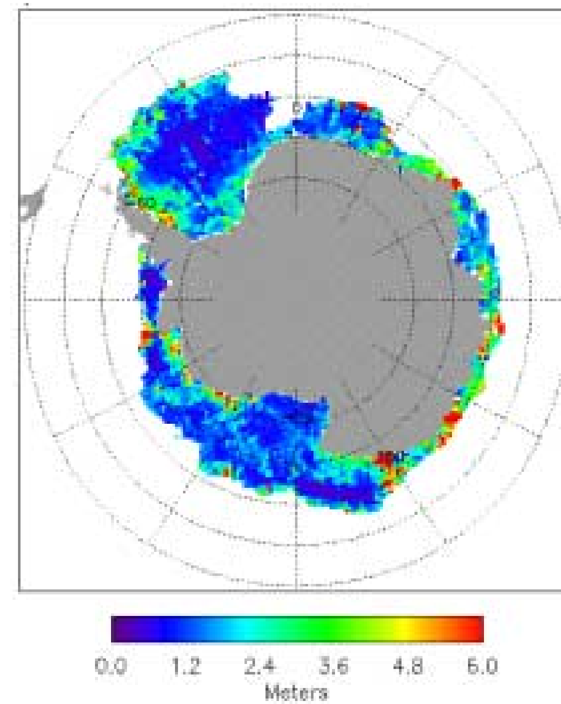


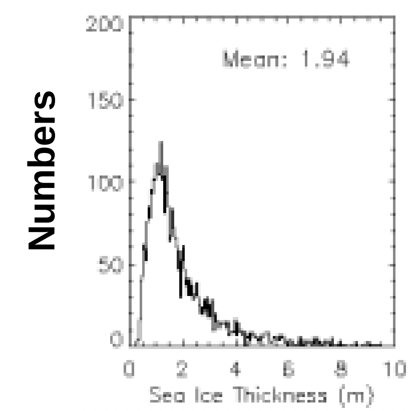
Snow cover May 23, 2004
Aqua-AMSR: Markus & Cavalieri, AGU Res. 1998



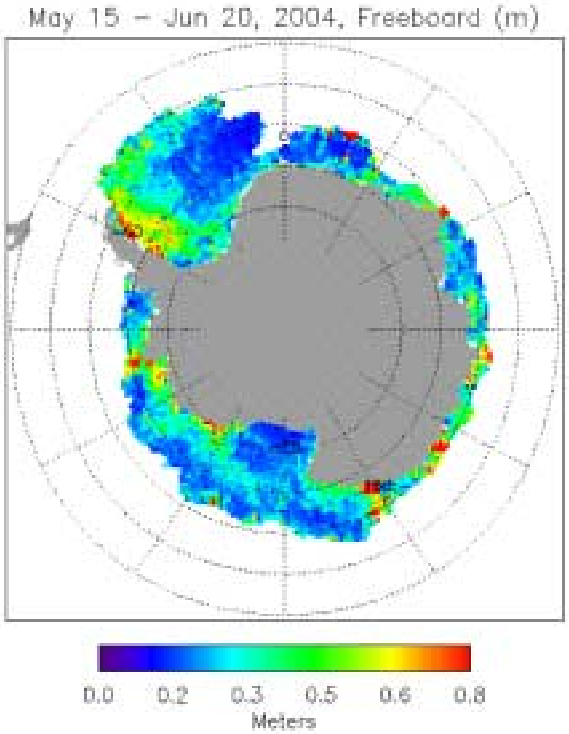


Sea Ice Thickness
May 15 – Jun 20, 2004

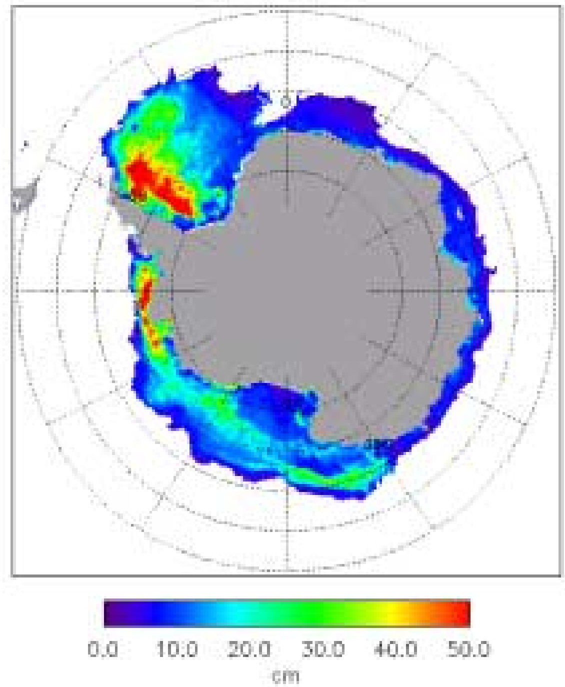




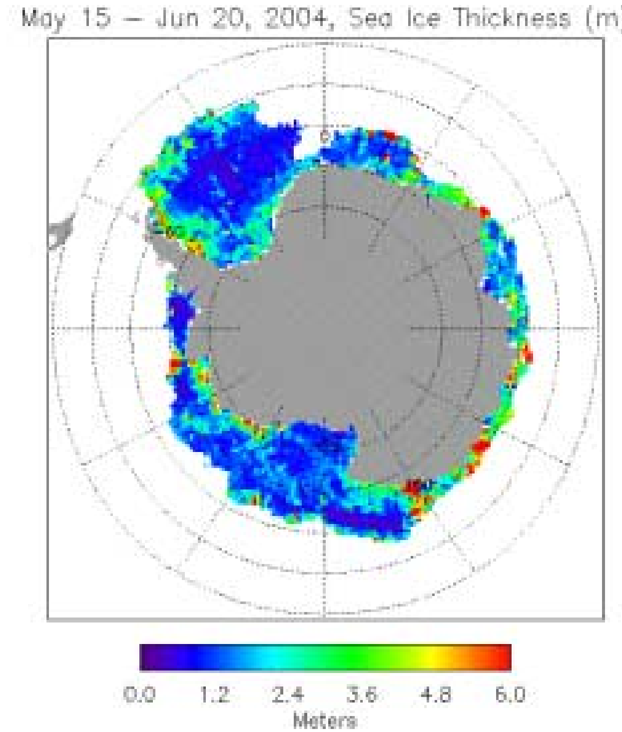
Freeboard

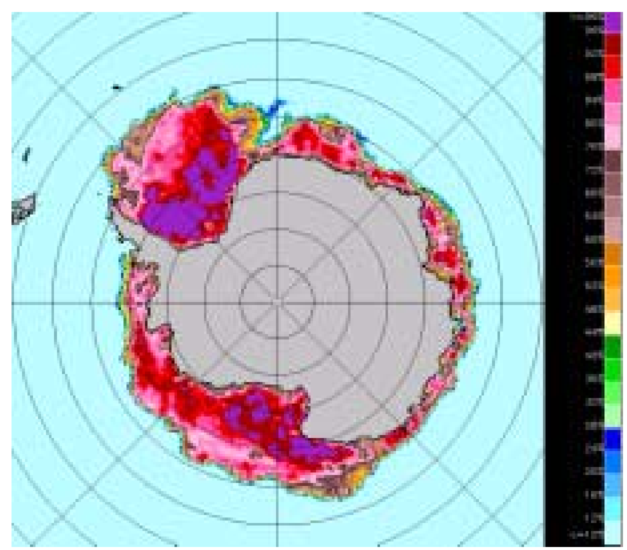


AMSR-E Snow Depth
5/23/2004



Thickness

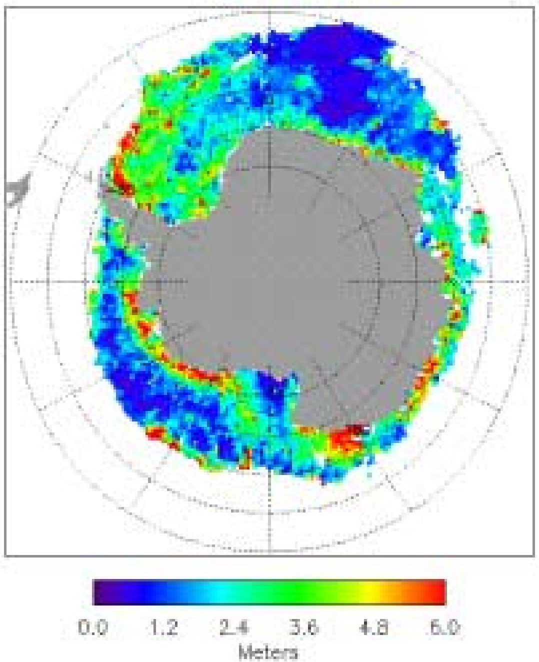


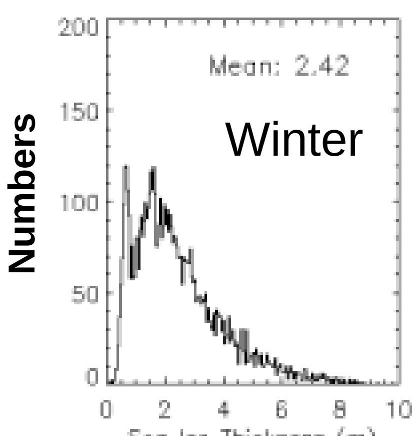


SSMI Sea Ice
Concentration
May 24, 2004

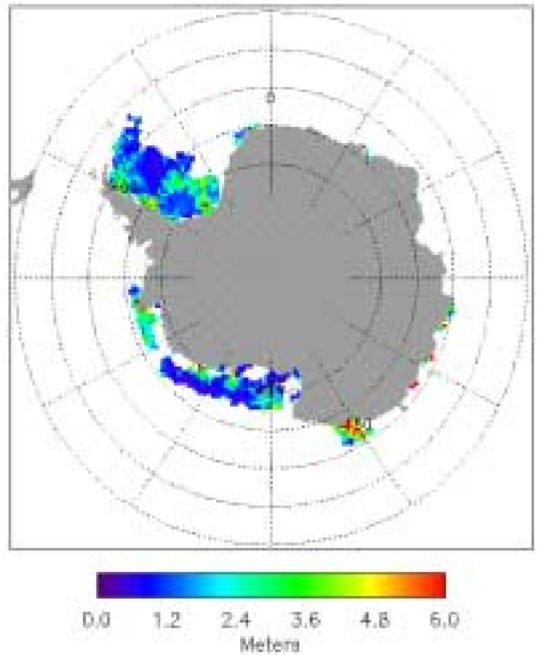
First Sea Ice Thickness Maps From Satellite Laser

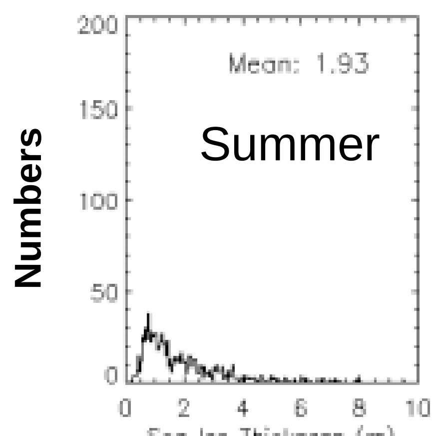
Sea Ice Thickness
Oct 4 – Nov 18, 03



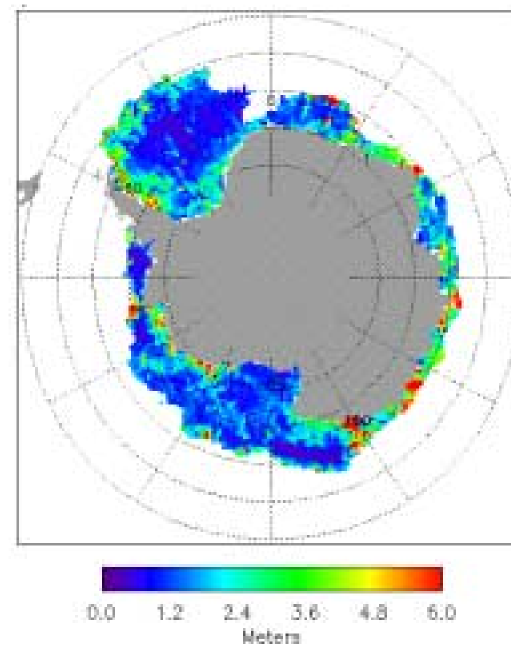


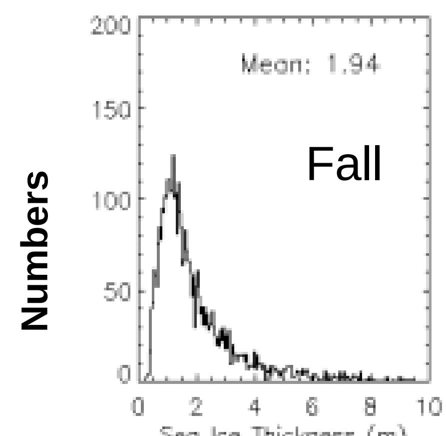
Sea Ice Thickness
Feb 18 – Mar 21, 04



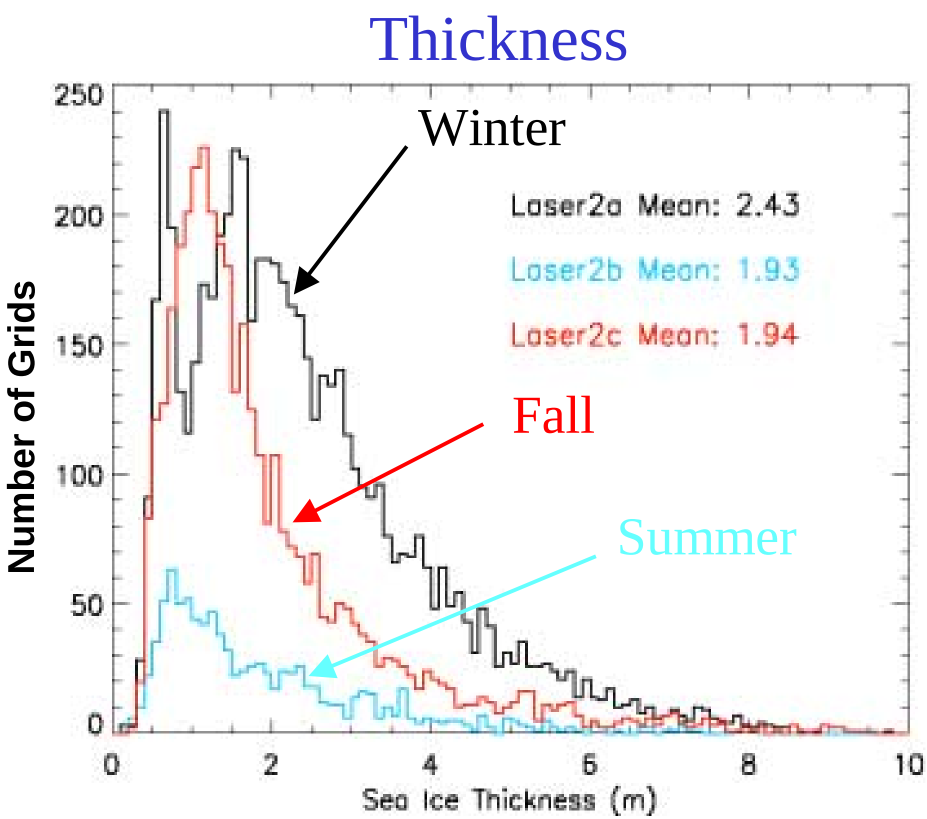


Sea Ice Thickness
May 15 – Jun 24, 04





Seasonal Variation of Sea Ice Freeboard and Thickness



Measuring sea ice thickness distributions (& mean ice thickness) globally has been a major challenge in sea ice science.

- need over entire ice pack.
- monthly or less time scales.
- 50 –100 km spatial scales.

❑ Summer: Thinner ice has melted

❑ Fall: Large increase in amount of new-thinner ice

❑ Winter: Growth in thickness to seasonal maximum.

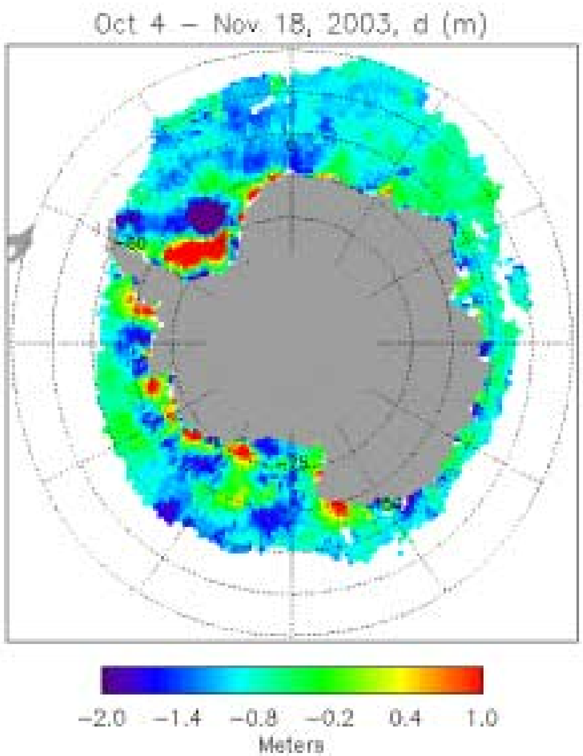
❑ Similar to regional-scale description in Worby et al, AGU Res Series, 1999.

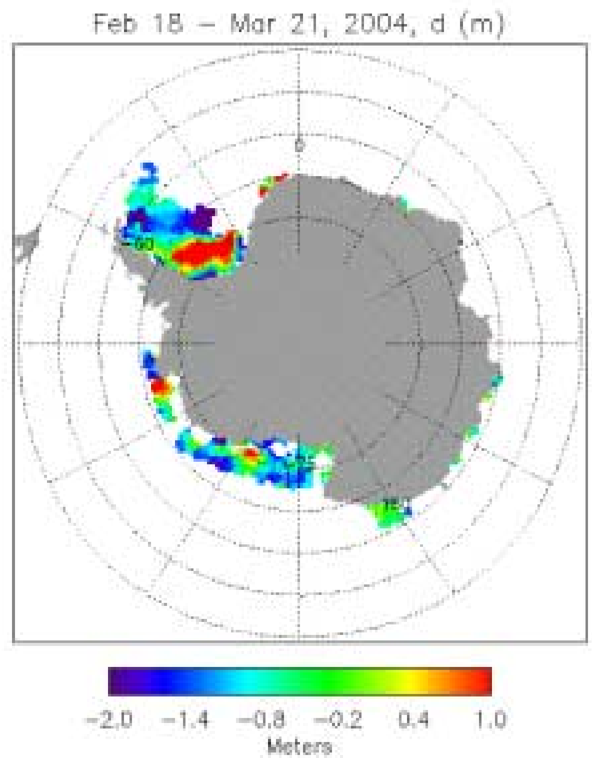
Sea thickness distributions as a function of time (over spatial scales such as 50 km by 50 km) provide a fundamental characterization of the state of a sea ice pack, giving information on:

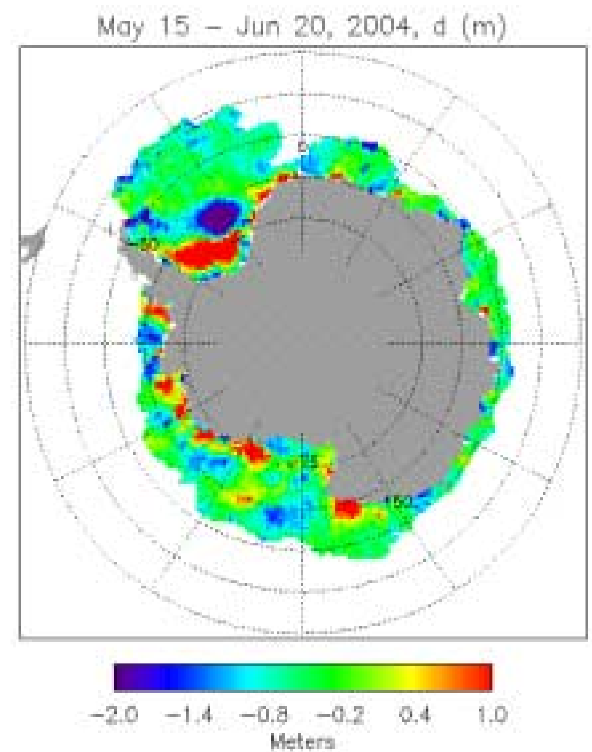
- freezing and melting
- divergence and lead formation convergence and ridging
- mean ice thickness
- ratio of new/first-year ice to multiyear ice

Difference Between ICESat Sea Level and EGM96 Geoid

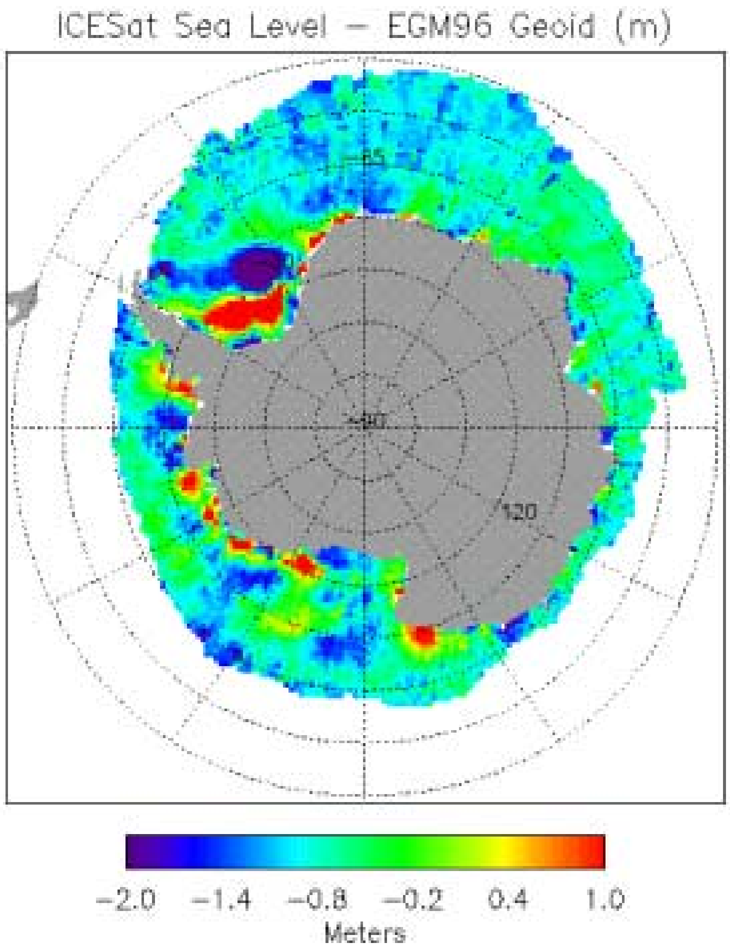
Laser2a, 2b, 2c

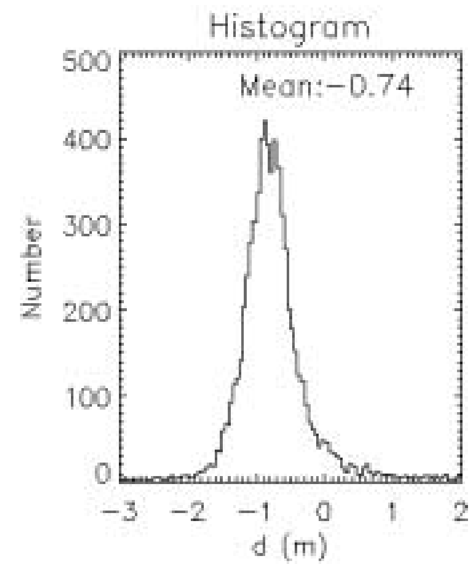






Difference Between ICESat Sea Level and EGM96 Geoid





Summary

1) ICESat is providing a novel capability to measure sea ice freeboard. With AMSR-E measured snow thickness and estimated snow and water densities, sea ice thickness can be derived from the freeboard.

2) Near-coincident ICESat and CryoSat measured freeboard and sea ice thickness can be compared for precise calibration for both satellites.

3) Snow thickness can be derived from the ICESat and CryoSat elevation difference and can be used to compare with AMSR-E snow thickness.

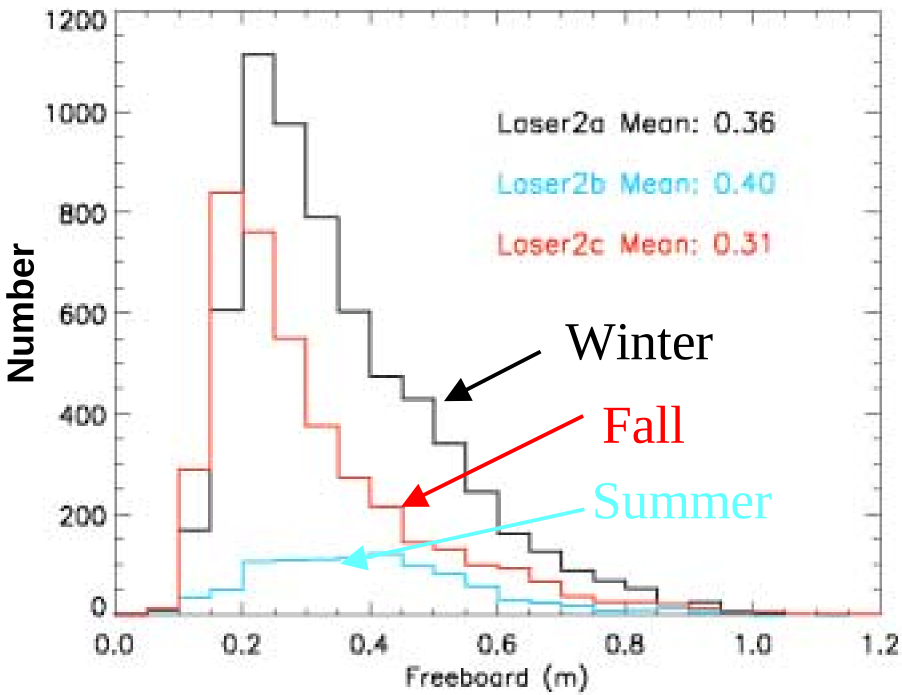
Summary

4) ICESat determined sea level can improve geoid. Improved geoid can help improve sea level determination therefore improving ICESat measured freeboard accuracy.

5) The techniques of determining sea level will be improved in the future. Improved ICESat cloud data and surface reflectivity will be added to the process.

Seasonal Variation of Sea Ice Freeboard and Thickness

Freeboard



Thickness