1. ICESat Observations over the Arctic Ocean: Recent Results

2. An Arctic Sea Ice Thickness Field Experiment During April 2009

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1. Five Years of ICESat Observations over the Arctic Ocean: Recent Results

Polar Geodesy - Marine Gravity

Cryospheric Studies - Trends in Sea Ice Freeboard

Sinéad Farrell, NOAA Laboratory for Satellite Altimetry

Seymour Laxon, CPOM, University College London

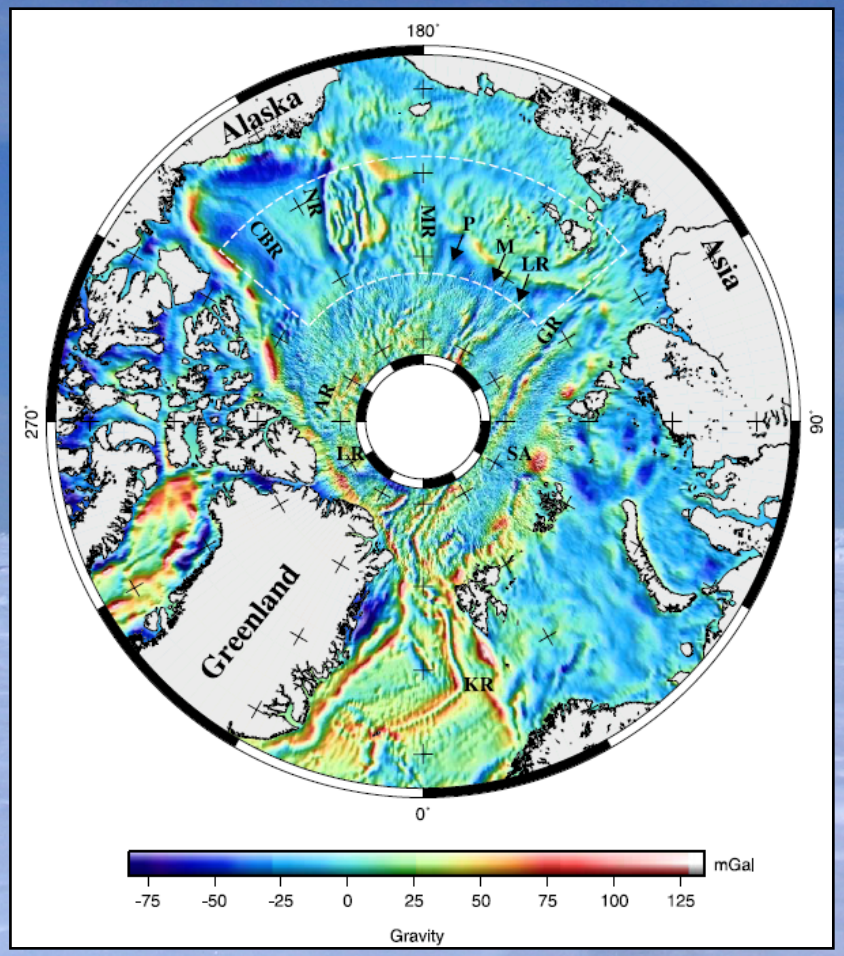
David McAdoo, NOAA Laboratory for Satellite Altimetry

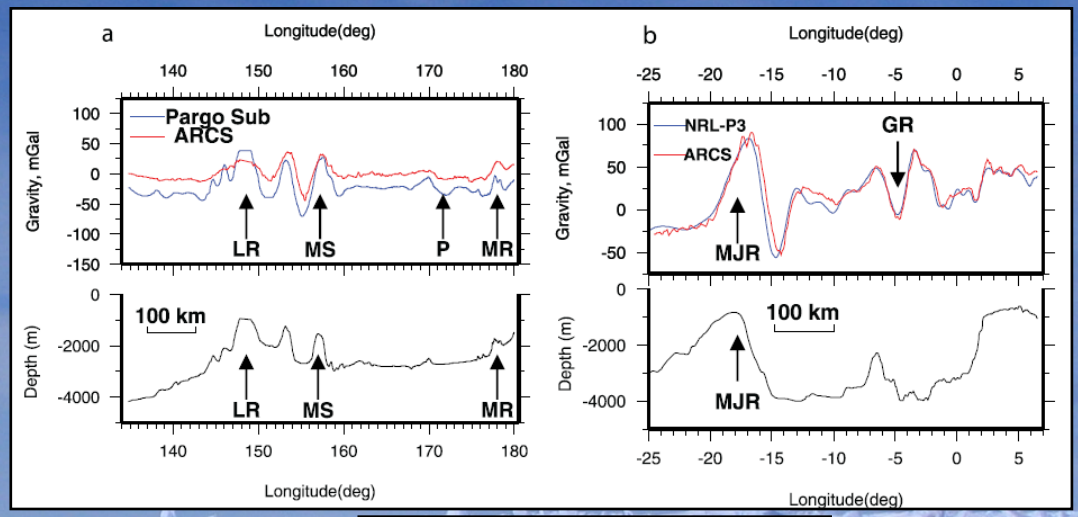
Jay Zwally, NASA Goddard Space Flight Centre

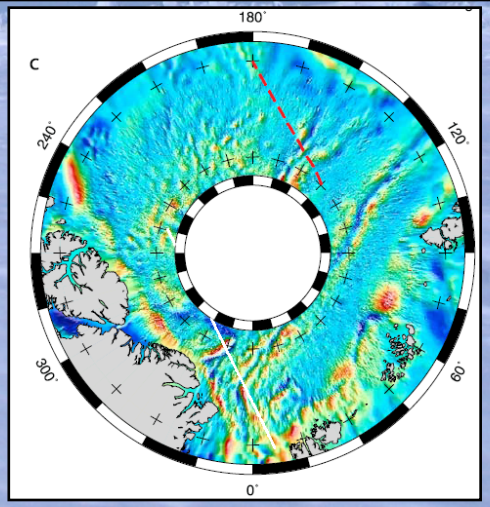
Donghui Yi, SGT Inc., NASA Goddard Space Flight Centre

ARCtic Satellite-only (ARCS) Marine Gravity Field

5 ICESat Campaigns + 8-yrs ERS-2 data [*McAdoo et al.*, JGR, 2008]







Plan to update field to include all 14 ICESat campaigns
Will improve resolution of short wavelength features

ICESat over Arctic Sea Ice:

Developing an algorithm to derive sea ice freeboard on basin scales

GLA01 and GLA06 Data Products Used

Varibale	Product Name	Product File	Description
Latitude	i_lat	GLA06	Geodetic latitude in degrees North
Longitude	i_lon	GLA06	Geodetic longitude in degrees East
Transmit Time	i_UTCTime	GLA06	Transmit time in seconds UTC referenced to noon on Jan 1, 2000 (J2000)
Surface Elevation	i_elev	GLA06	Surface elevation in meters with respect to the ellipsoid at the spot location
Transmit Pulse Waveform	i_tx_wf	GLA01	Transmit Pulse
Received Pulse Waveform	i_rng_wf	GLA01	1064 nm laser received echo
Received Pulse Energy	i_RecNrgLast_EU	GLA01	Energy in fJoules of the 1064 nm laser pulse
Received Pulse Gain	i_gainSet1064	GLA01	Receiver gain measured in counts
Reflectivity	i_reflctUncorr	GLA06	Reflectance (not corrected for atmospheric effects)
Saturation Range Correction	i_satRngCorr	GLA06	Saturation range correction in meters

Filtering Scheme

Discard data where:

SSMI sea ice concentration < 35 %

Elevation deviates from the geoid by ±5m

Reflectivity > 1

Gain > 30 counts

Waveforms with surface returns at the very start/end of the range window

Waveforms with no signal above the noise floor

Additional Waveform Shape Analysis

Tx and Rx Full-Width Half-Maximum (FWHM) Waveform Widths

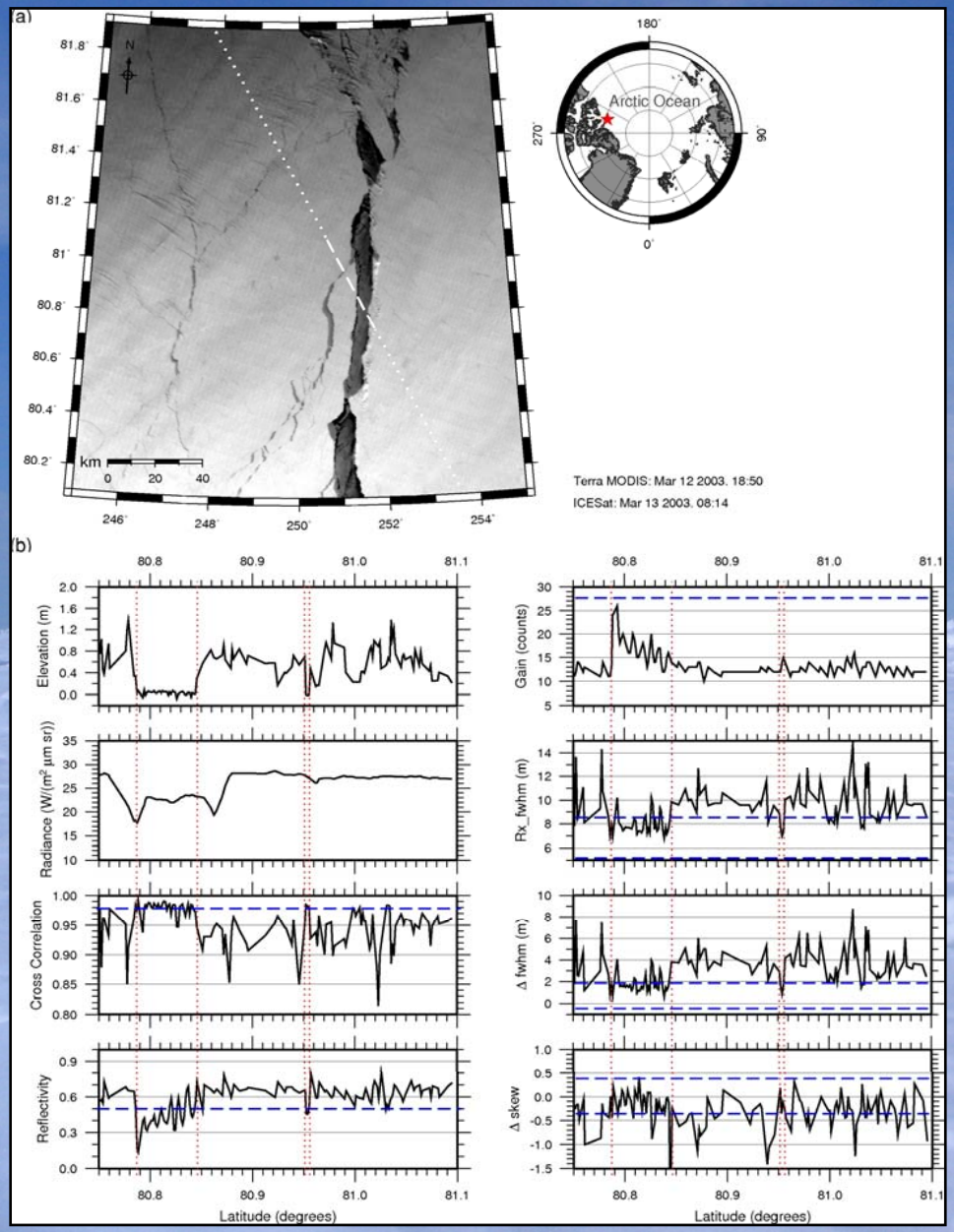
Skewness of the Rx waveform

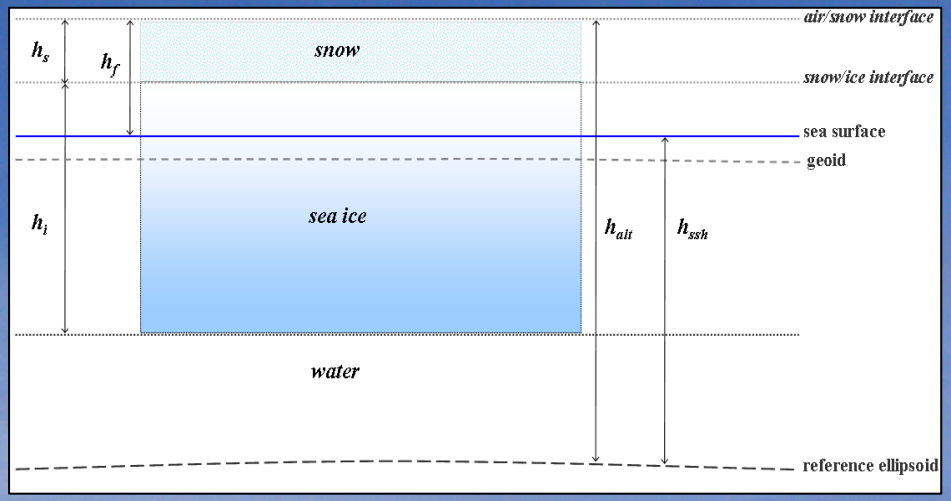
Cross-correlation between the Tx and Rx waveforms

From Farrell, Ph.D. Thesis, 2007

Deriving Arctic Sea Ice Freeboard

1. Discriminating Leads



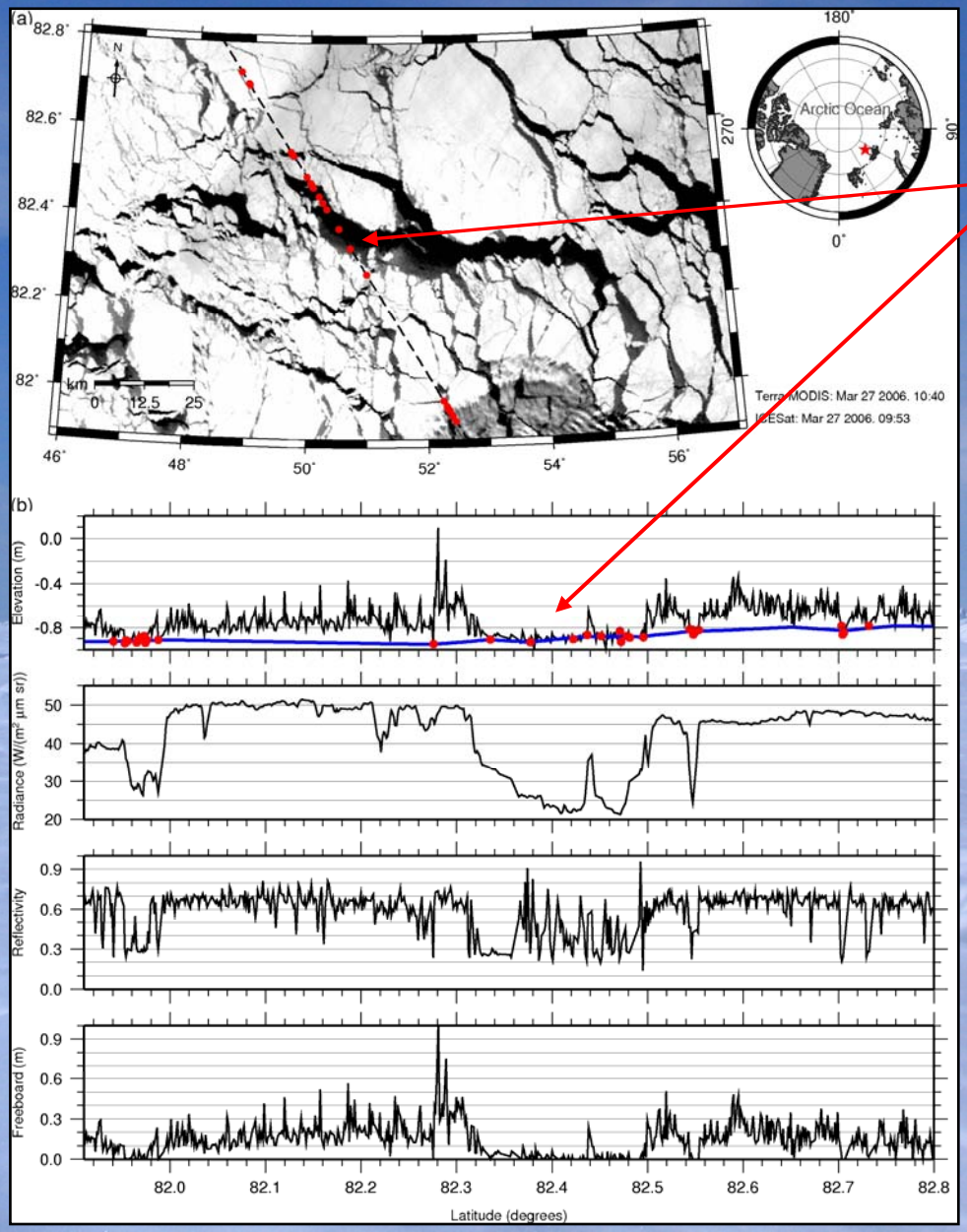


Criteria for discriminating leads in Arctic pack ice. All criteria must be met for pulse to be classified as a return from a lead.

Criterion	Threshold
Cross-correlation	$0.975 \leq Xcorrel_{TxRx} \leq 1$
Reflectivity	$0 \leq i_reflctUncorr \leq 0.5$
Gain	$13 \leq i_gainSet1064 \leq 28$
Rx_fwhm	$5.3 \leq Rx_fwhm \leq 8.5$
Δ fwhm	$-0.5 \leq \Delta fwhm \leq 2.0$
Δ skew	$-0.3 \leq \Delta skew \leq 0.3$

Deriving Arctic Sea Ice Freeboard

2. Calculating local sea surface height and estimating sea ice freeboard



Example of Coincident MODIS and ICESat overpass – north of Franz Josef Land

- Lead within the ice pack discriminated by algorithm

ICESat elevation

Lead locations and elevation

Interpolated sea surface height

MODIS Radiance (Time difference between MODIS image acquisition and ICESat overpass ~ 50 minutes)

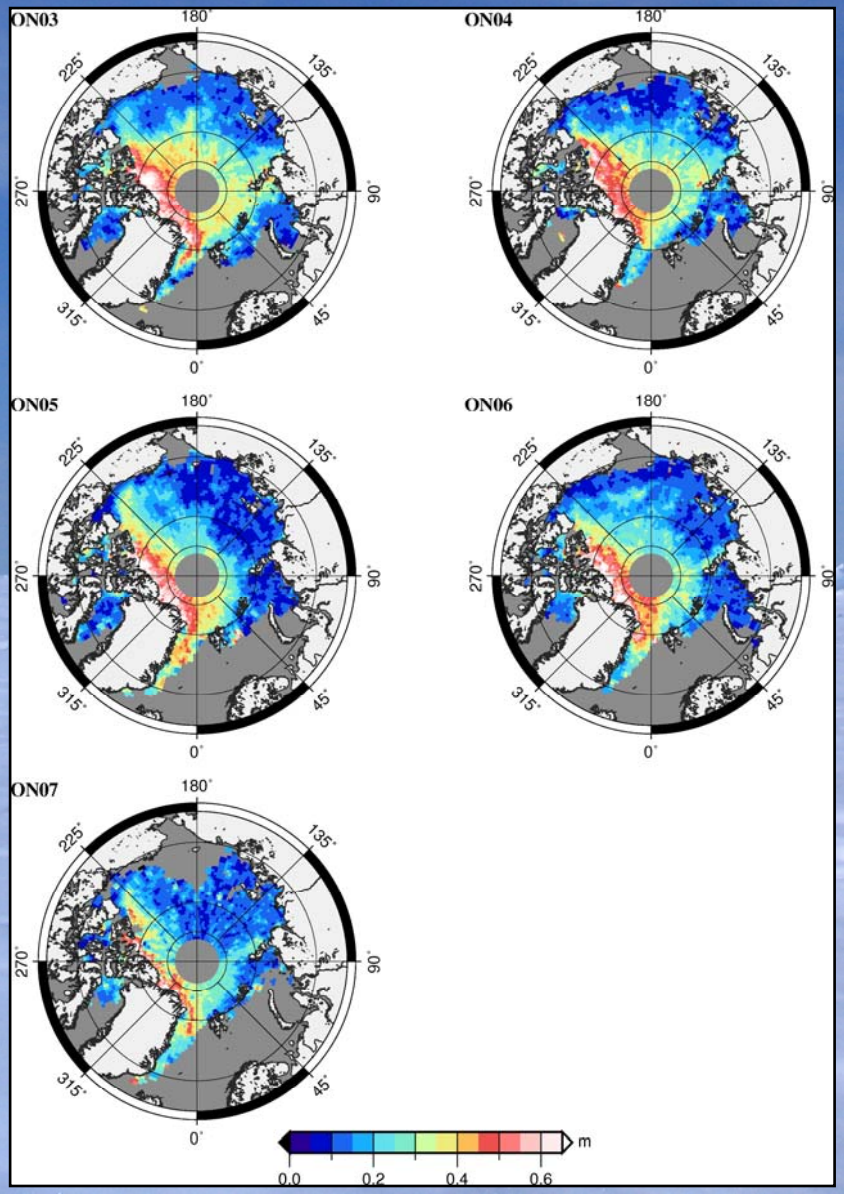
ICESat Reflectivity

Derived Freeboard

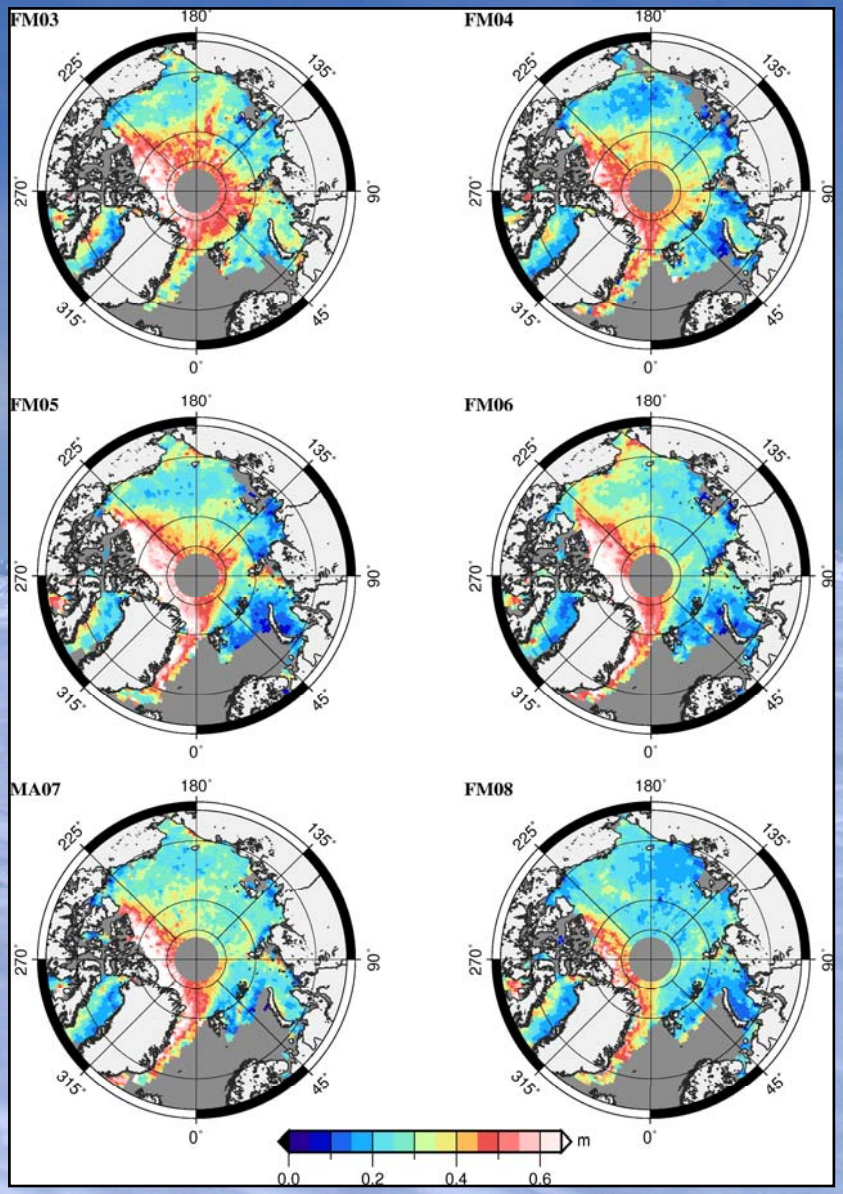
Analysis of Arctic Sea Ice Freeboard over 11 ICESat Campaigns (2003 – 2008)

Change in spatial distribution of thicker, multi-year ice

Fall Campaigns (2003-2007)



Winter Campaigns (2003-2008)



Decline in sea ice freeboard – reduction of thick ice

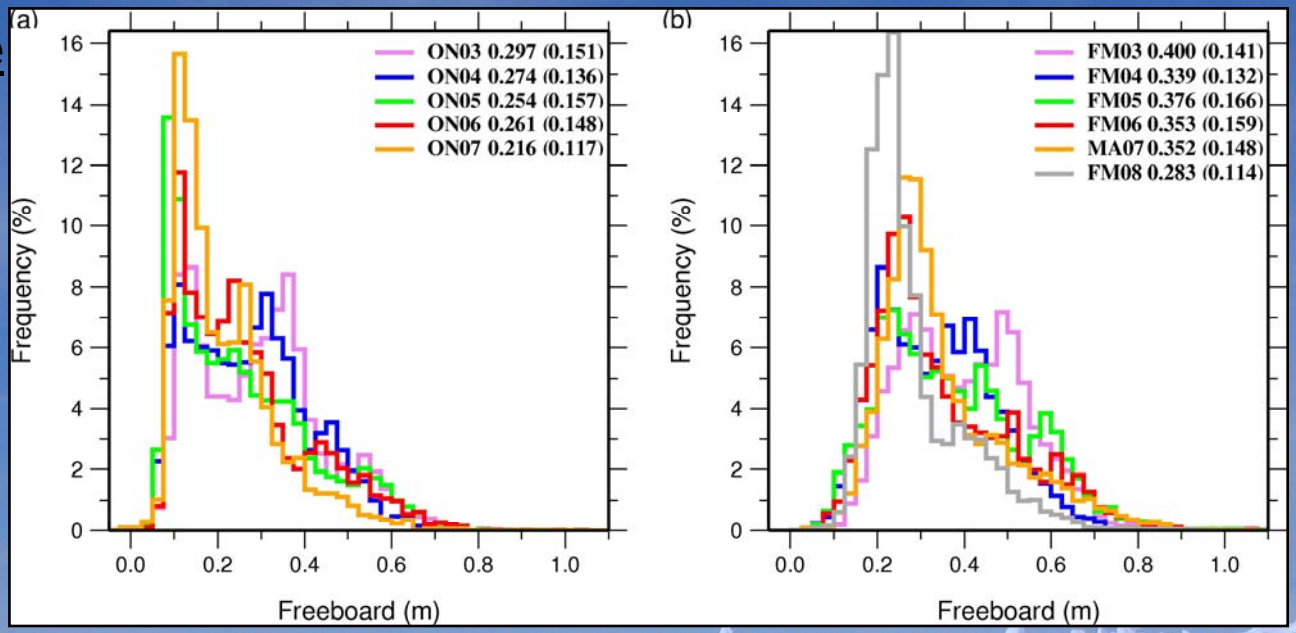
(Trends in snow depth are unresolved)

Fall Decline

2003 30 cm FB
2007 22 cm FB

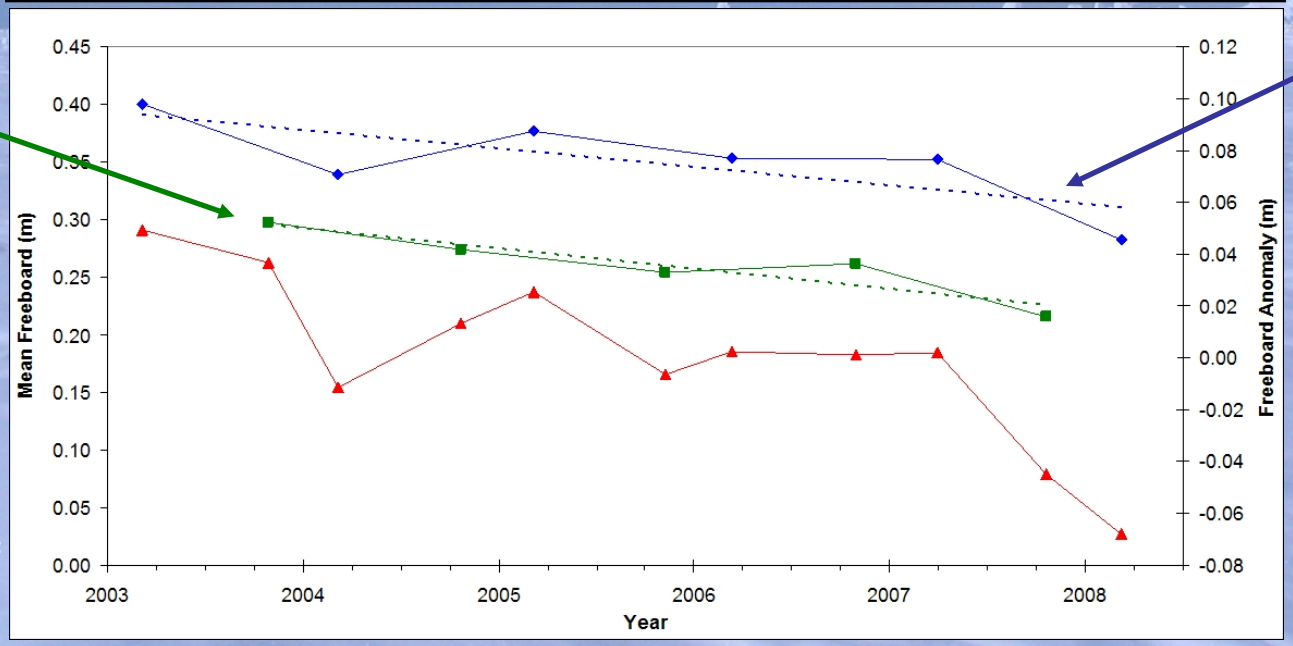
Winter Decline

2003 – 40 cm FB
2008 – 28 cm FB



-1.8 cm /yr

-1.6 cm /yr



2. An Arctic Sea Ice Thickness Field Experiment During April 2009

- Plans for April 2009 NASA P-3 Airborne Campaign
- Comparison of Laser Altimetry from Satellite and Airborne Platforms during March 2006 Campaign

Thorsten Markus, NASA Goddard Space Flight Centre

David McAdoo, NOAA Laboratory for Satellite Altimetry

Bill Krabill, NASA Wallops Flight Facility

Sinéad Farrell, NOAA Laboratory for Satellite Altimetry

Larry Connor, NOAA Laboratory for Satellite Altimetry

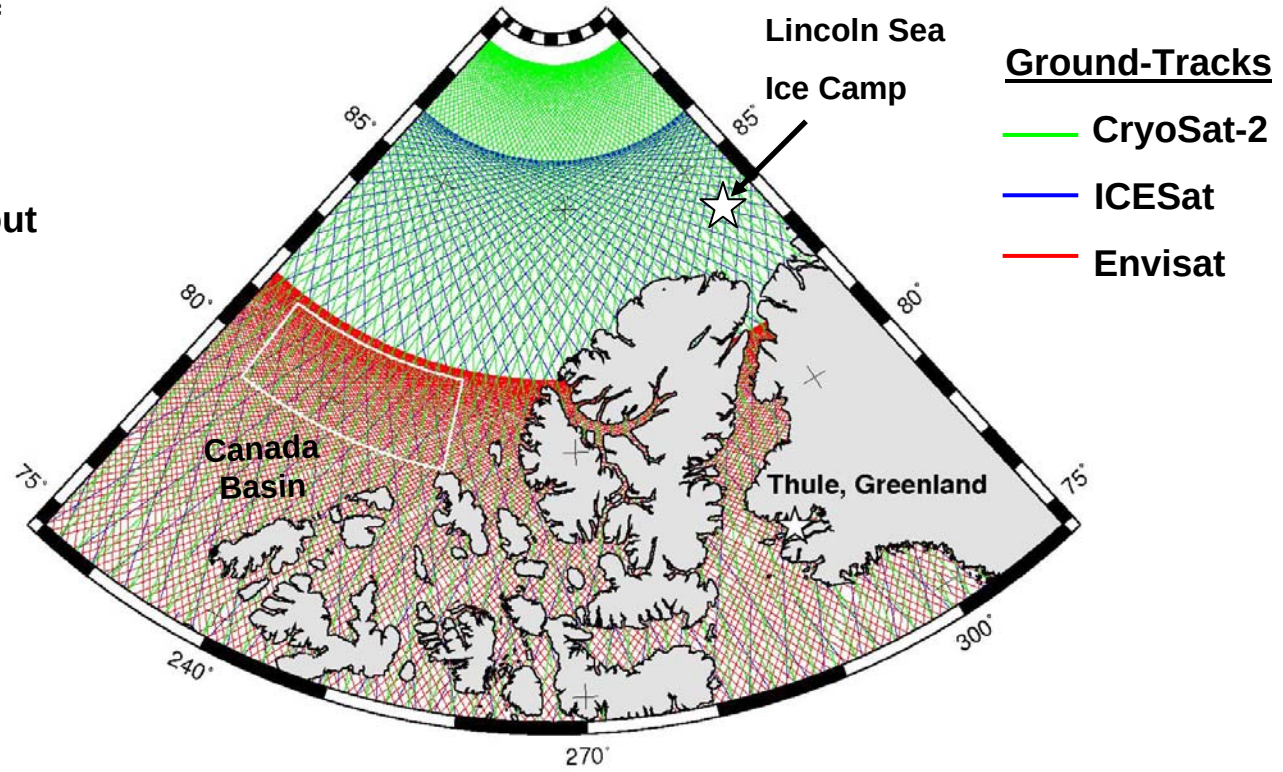
Carl Leuschen, University of Kansas

Seymour Laxon, CPOM, University College London

Canada Basin Sea Ice Thickness (CBSIT) Experiment

April 2009 – During ICESat 3L?

- NASA P-3 operating out of Thule, Greenland
- Ice-sheet and sea ice campaigns to be carried out April 6th – 24th 2009
- 3 days of sea ice flights
- Priority for 6th – 12th April for sea ice surveys



Instrumentation

NASA Scanning Airborne Laser Altimeter (ATM-4) for measuring surface elevation (Krabill / NASA Wallops)

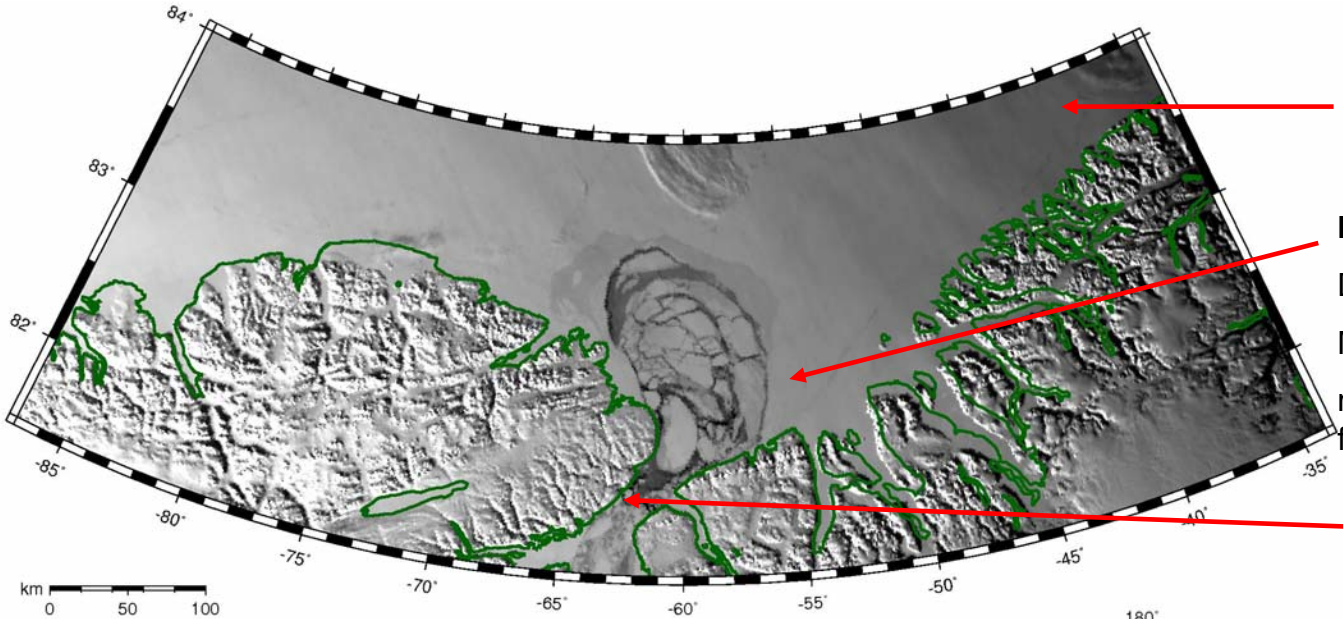
Digital cameras and video to help identify sea ice regime, morphology, leads

New Ultra-Wideband Snow Radar for measuring snow thickness (Leuschen / University of Kansas)

ESA ASIRIS Instrument (Cryo-Sat-like) for measuring sea ice freeboard (Wingham, Laxon / UCL, ESA) ??

Ground Segment

Collaborating with R. Forsberg, P. Clemente-Colon, J. Richter-Menge, C. Haas, P. Wadhams



Lincoln Sea Ice Camp

Lincoln Sea Polynya

Dynamic Region

Mix of fast ice near shore, multi-year ice and newly formed first-year sea ice

Nares Strait

- **In situ observations** at the Danish Sea Ice Camp – Rene Forsberg (National Space Inst., Denmark)

  Lincoln Sea - 84N 40W 16th April – 1st May 2009

  Sea Ice & Snow Thickness, Morphology, Physical Properties

- **Garvia Autonomous Underwater Vehicle** (AUV) - Peter Wadhams (University of Cambridge, U.K.)

  Sea Ice Draft & Bottom Topography

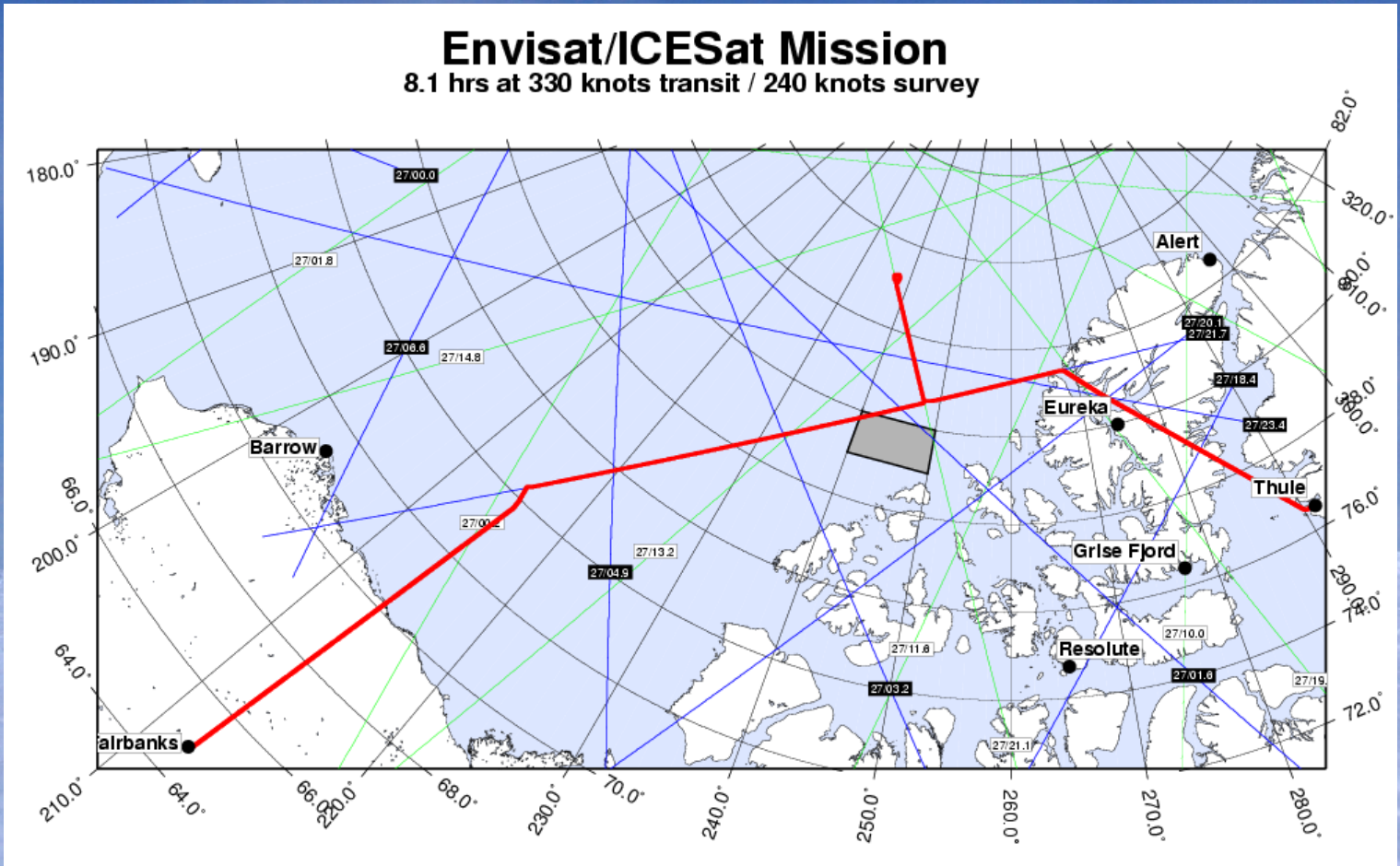
- **EM-bird Systems** – Christian Haas (University of Alberta, Canada)

  Deployed on Polar 5A - possibility to conduct a tandem flight over the northeastern Beaufort Sea and Deployed on Helicopter operating out of Danish Ice Camp

  Sea Ice Thickness Profiling

Arctic Aircraft Altimeter (AAA) Experiment

27 March 2006



Instrumentation

ATM -4 (Scanning Laser Altimeter)
Nadir-Looking Digital Cameras
D2P (Ku-band Radar Altimeter)
Snow Radar

ICESat Underflights

2-way ICESat Flight Track
300 km Coincident Elevation Data
Time delay of 30-90 minutes between ICESat and ATM surveys

Arctic Aircraft Altimeter (AAA) Experiment

27 March 2006

ATM-4 scanning laser altimeter
532 nm green laser with a 5 kHz PRF
Off-nadir scan angle of 22°
Accuracy ~ 10 cm or better
1-m footprints; 300-m swath width

Complete overlap between ICESat and ATM-swath along most of the track

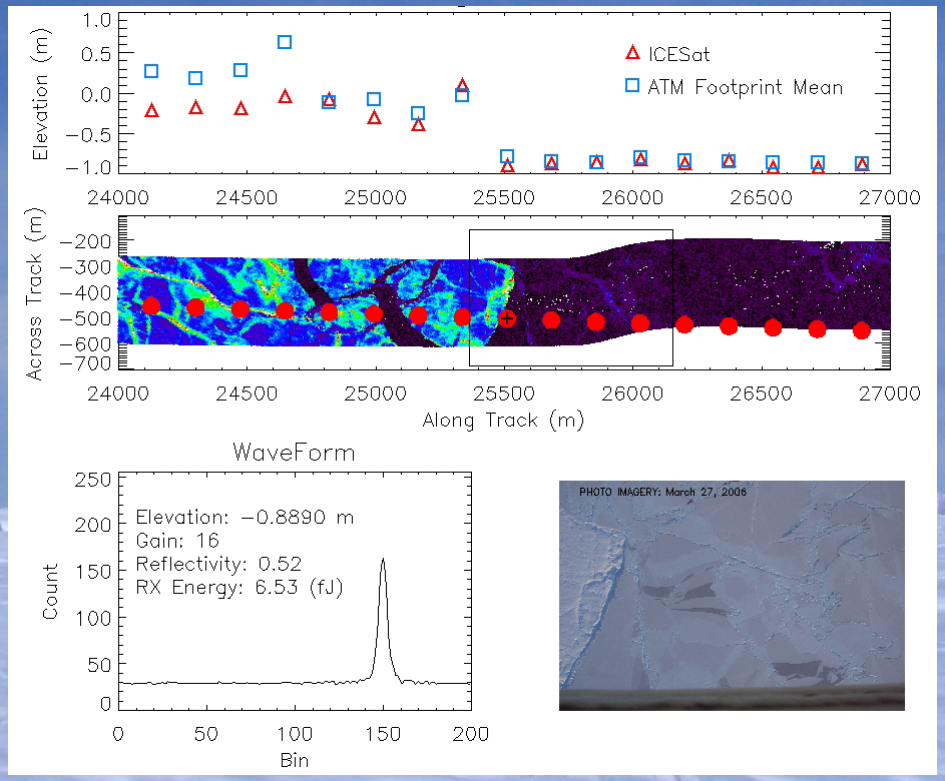
30 -90 minute delay between ICESat and P-3 aircraft overpasses

ATM and ICESat measurements both converted to WGS-84 ellipsoid

Arctic Geoid Removed from elevations

Consistent tidal corrections applied to both datasets

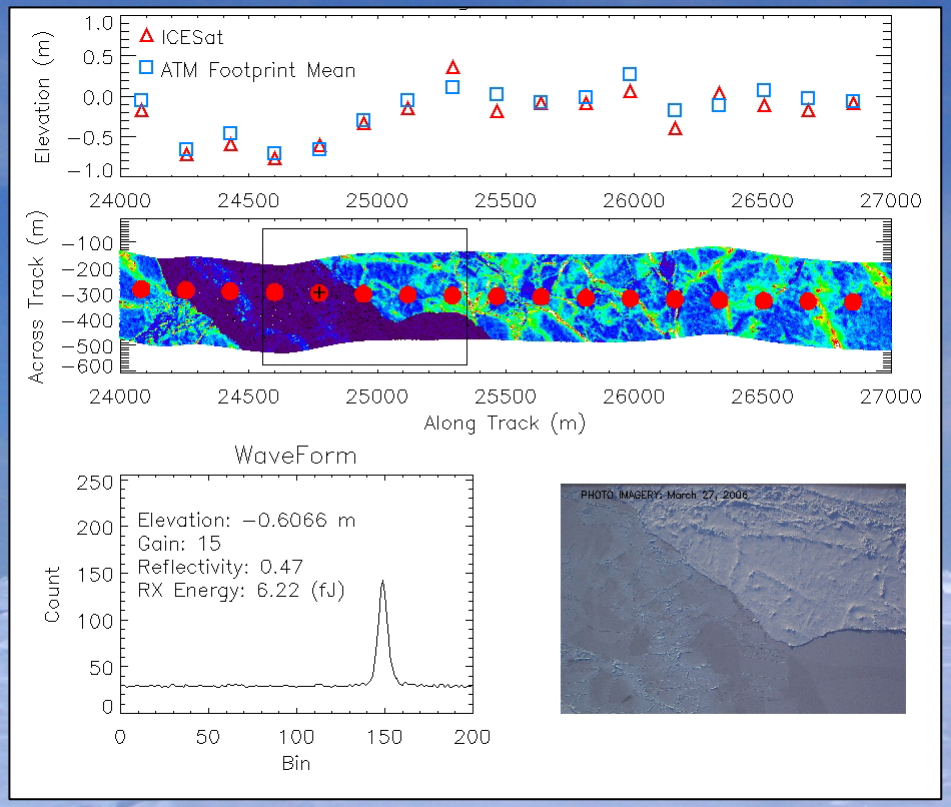
Elevations calculated using a 53.5 m diameter footprint to average ATM data beneath the ICESat footprint

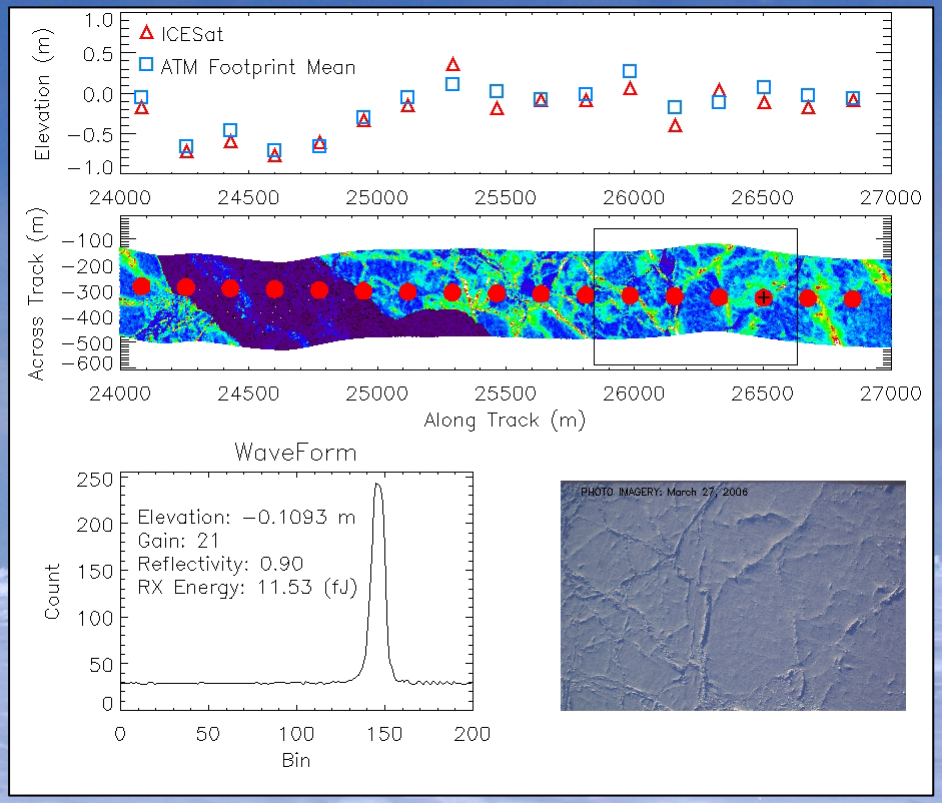


Figures courtesy of Larry Connor, NOAA

Arctic Aircraft Altimeter (AAA) Experiment

27 March 2006





- Apply correction for sea ice drift to reduce variability of elevation residuals (ATM- ICESat)
- Calculate statistics on elevation residuals along entire 300-km track
- Analysis of areal photography and waveform shapes
- Analysis of D2P radar measurements to investigate snow thickness along track

Figures courtesy of Larry Connor, NOAA

Questions?