

# Detecting Change in Arctic Sea Ice Using Satellite Altimetry

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STAR Science Seminar  
Friday, 11<sup>th</sup> September, 2009

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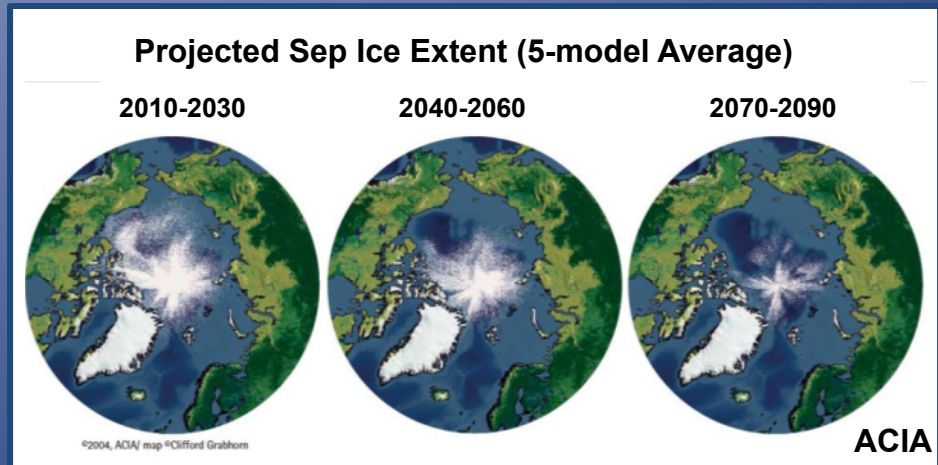
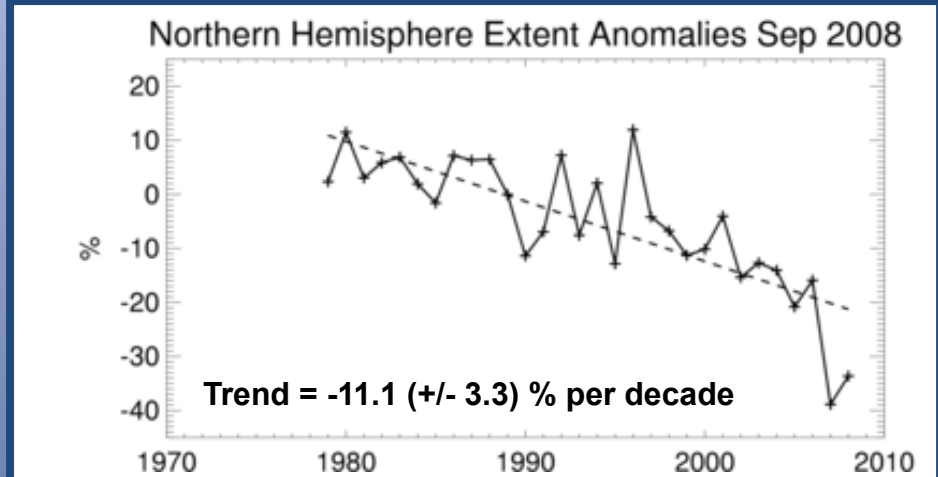
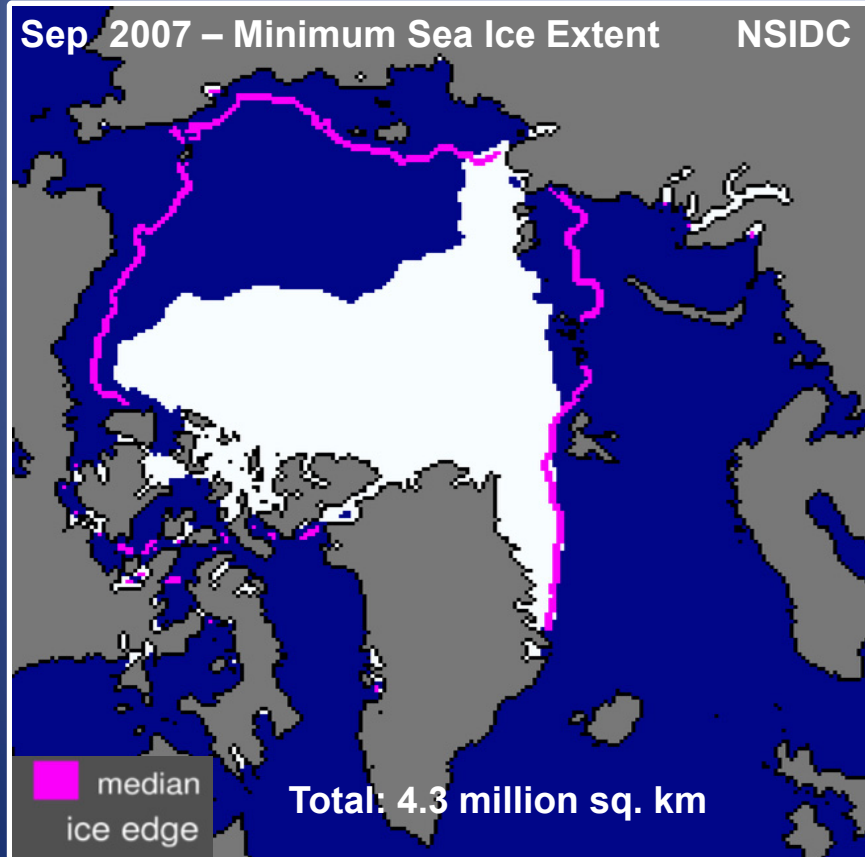


# Outline

- The changing Arctic Ocean
- Altimetry principle and measurement of sea ice freeboard
- Detecting Sea Ice Thickness Change using Satellite Data
- Validation Experiments
  - LaRA –FASIT (2002)
  - AAA (2006)
  - CBSIT (2009)
  - BESIE (2011)
- Future Work and Conclusions



# The Changing Arctic Ocean: Diminishing Sea Ice Extent



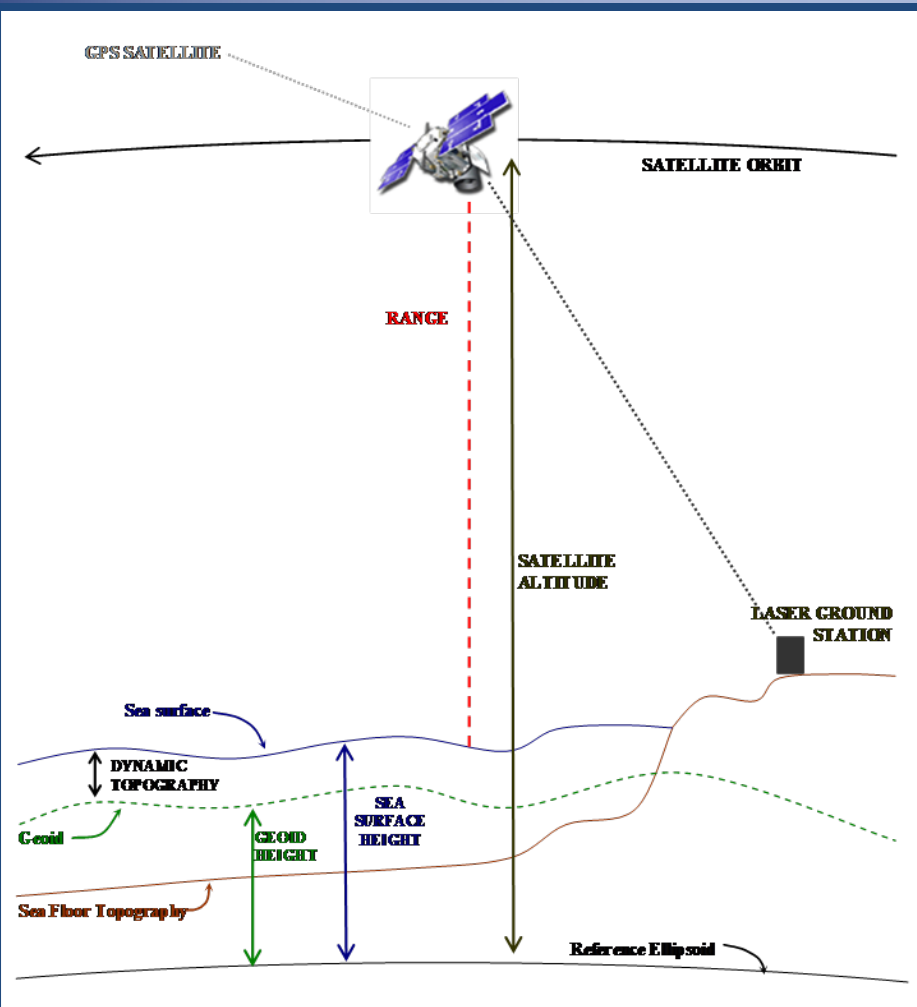
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# Using Satellite Altimetry to Measure the 3<sup>rd</sup> Dimension



Measuring Surface Elevation (h):

$$R = ct / 2$$

R = range measured by satellite altimeter

c = speed of light

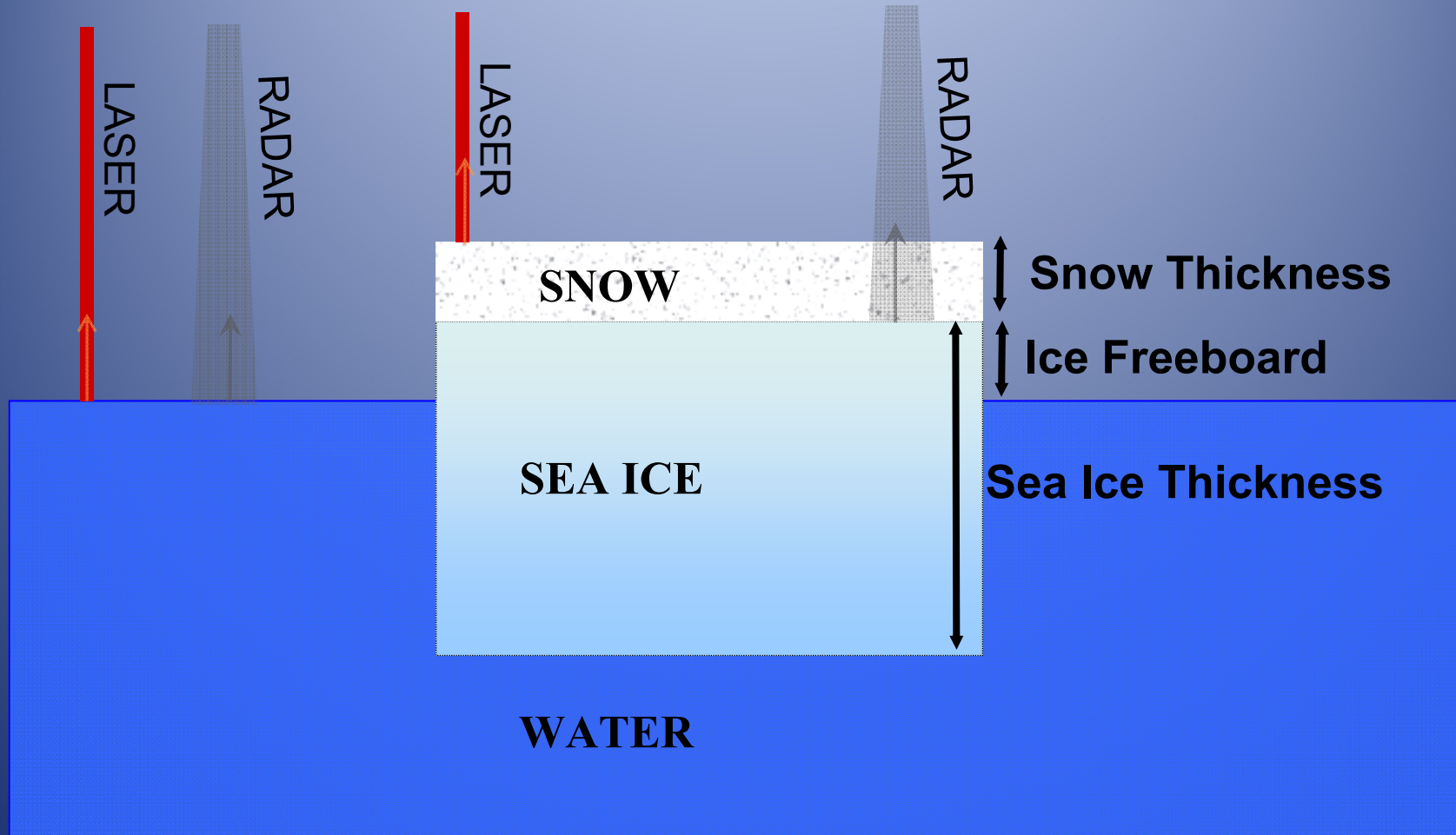
t = round-trip travel time

$$h = H - R$$

h = sea surface height  
relative to reference ellipsoid

H = satellite altitude  
above reference ellipsoid

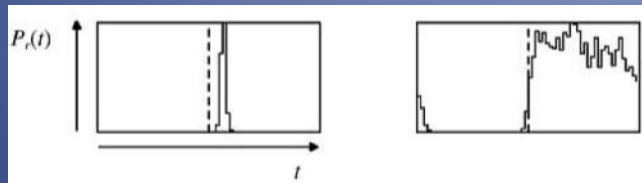
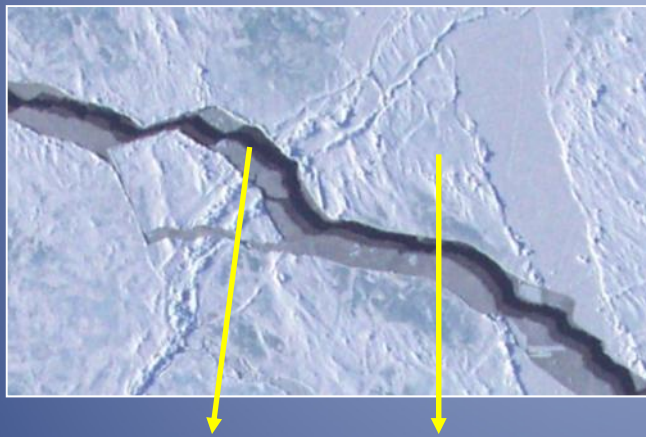
# Satellite Altimetry Measurements over Sea Ice



Altimeters provide basin-scale data over the Arctic Ocean

# Ice - Water Discrimination: Detecting Leads

## Satellite Radar Altimetry (ERS-2)



### Specular Echo (Leads)

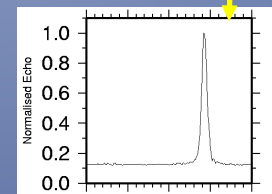
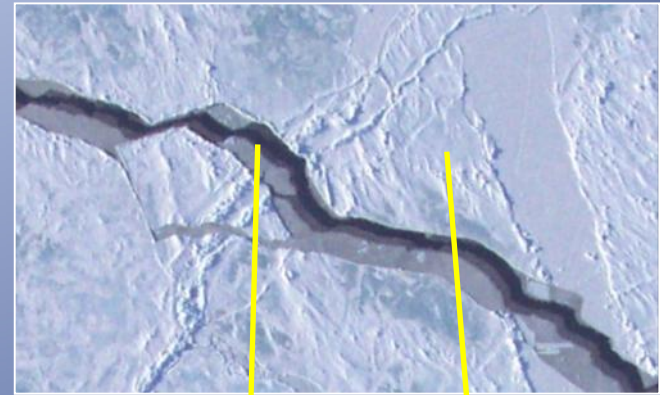
### Diffuse Echo (Ice Floes)

Provides unambiguous detections of leads for sea surface height measurements

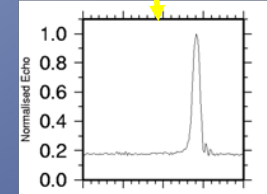
Large footprint means returns from “mixed” surfaces have to be discarded

(e.g. Peacock & Laxon, 2004)

## Satellite Laser Altimetry (ICESat)



### Leads



### Ice Floes

Highly specular reflections from leads

Difficult to distinguish leads from ice floes

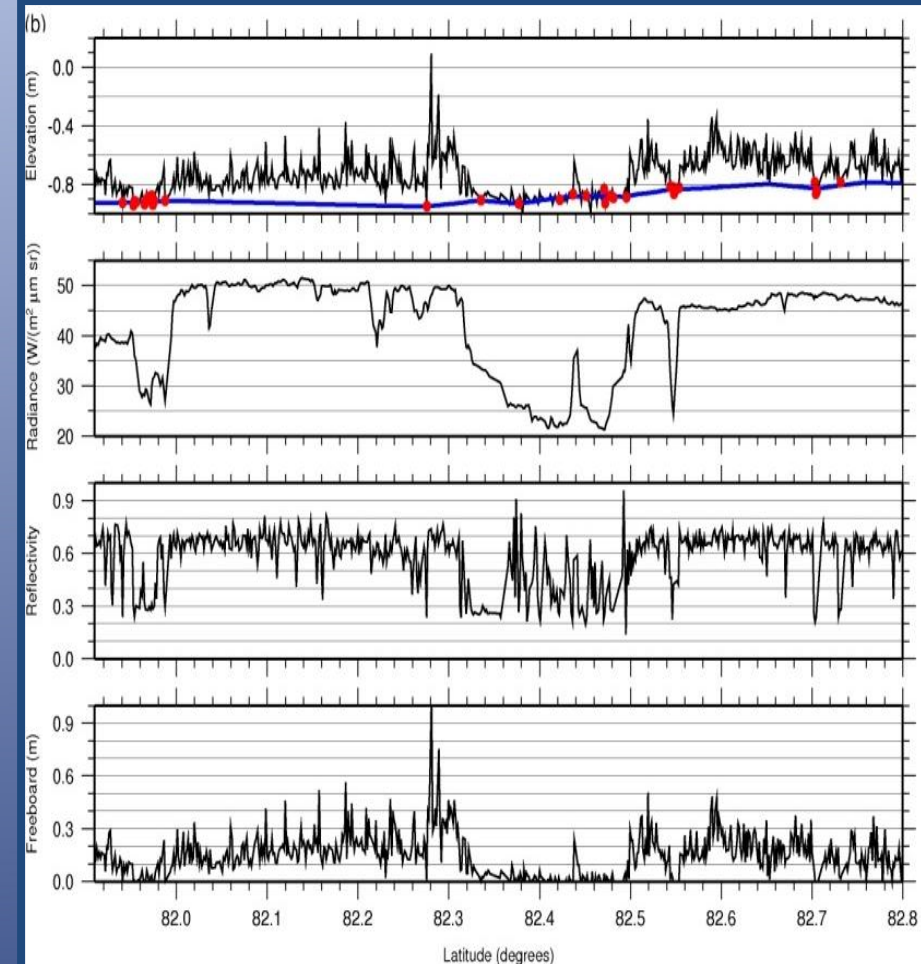
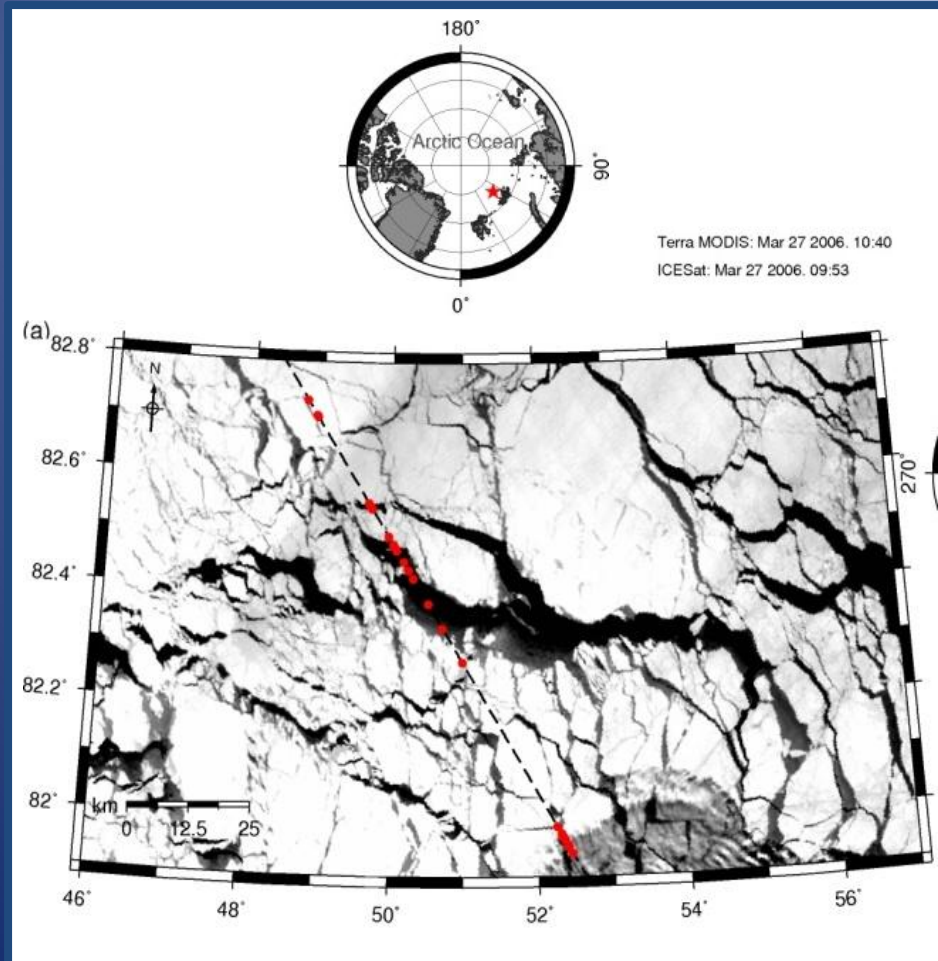
Several methods for determining SSH

(e.g. Kwok *et al.* 2007; Zwally *et al.*, 2008 ;

Farrell *et al.*, 2009)



# Echo Discrimination – ICESat Sea Surface Height (SSH)



From Farrell et al., JGR, 2009



# Outline

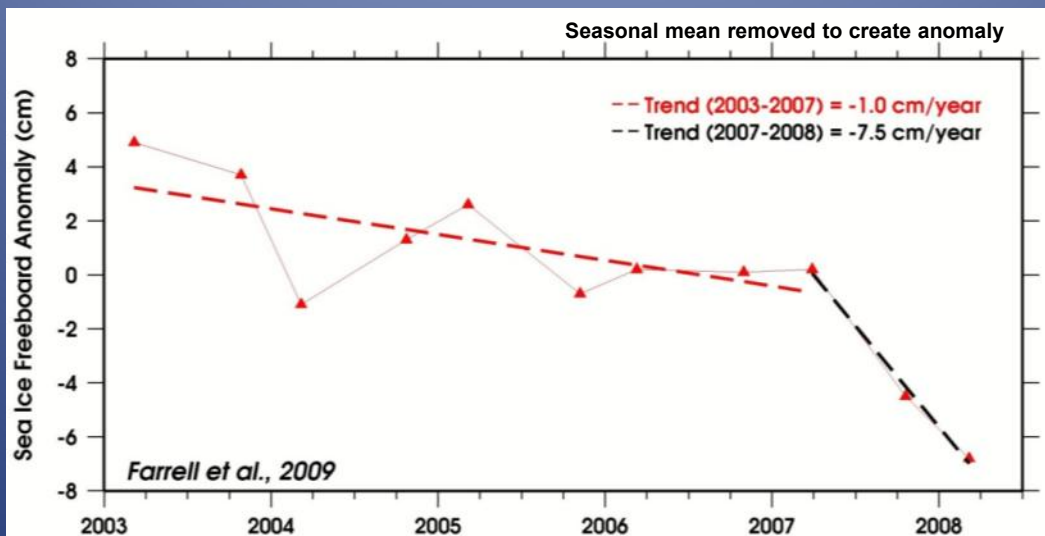
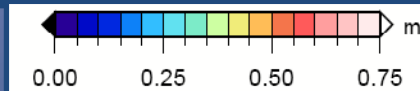
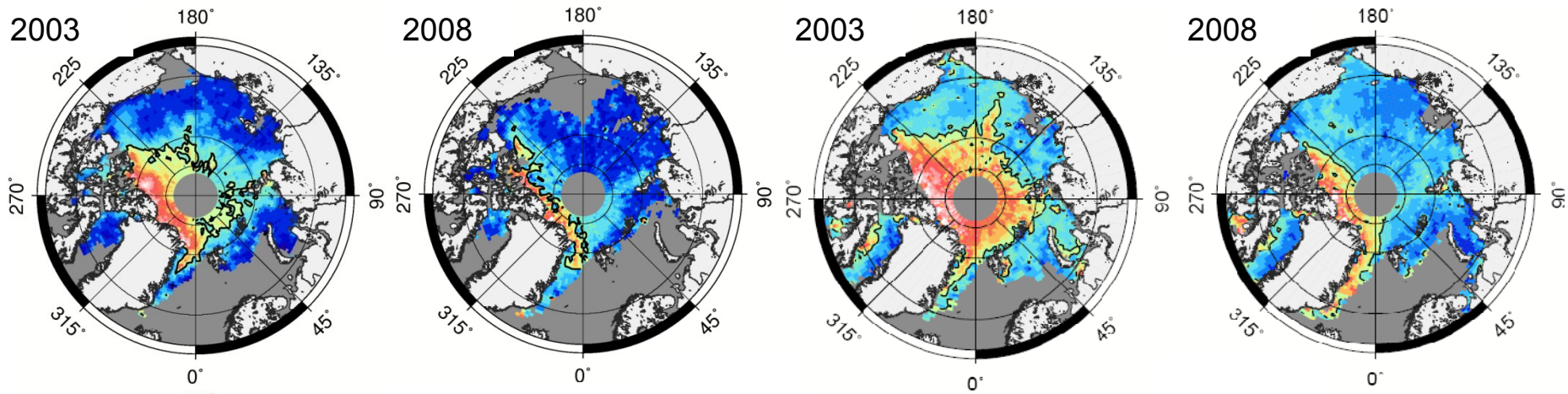
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# Change in Arctic Sea Ice Freeboard from ICESat: 2003 – 2008

Fall (Oct-Nov)

Winter (Feb-Mar)



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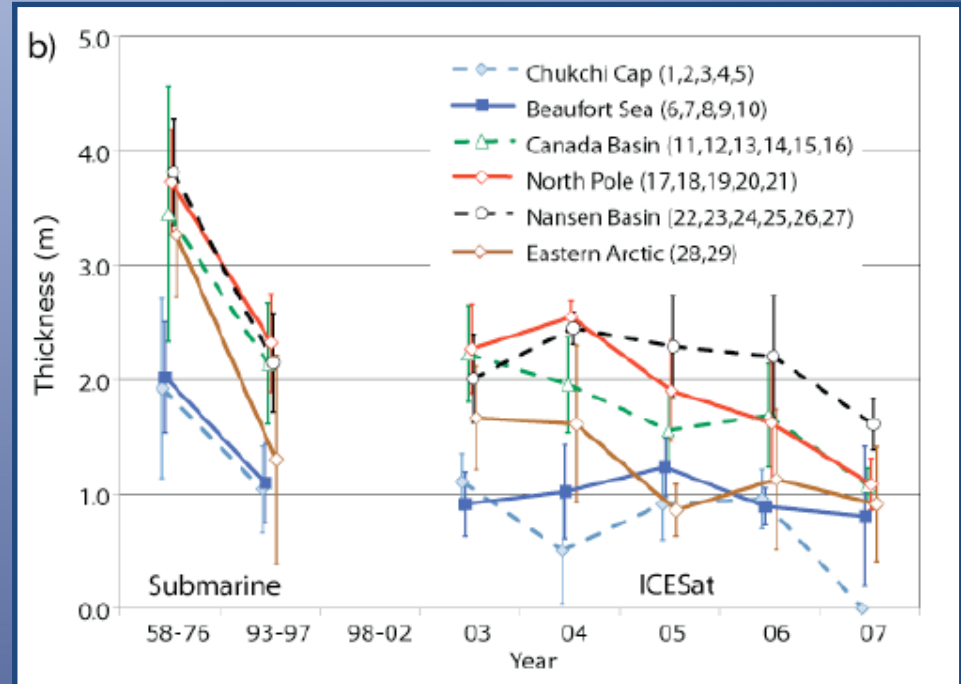
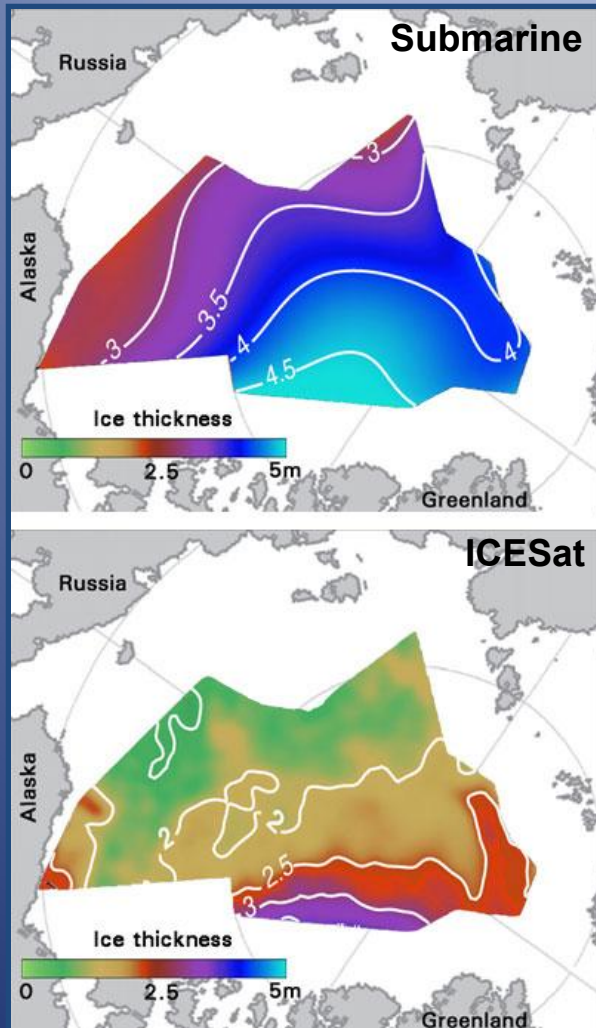
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# Change in Arctic Sea Ice Thickness:

## Comparing Submarines and ICESat



*From Kwok and Rothrock, GRL, 2009*

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# Validating Satellite Data over Sea Ice

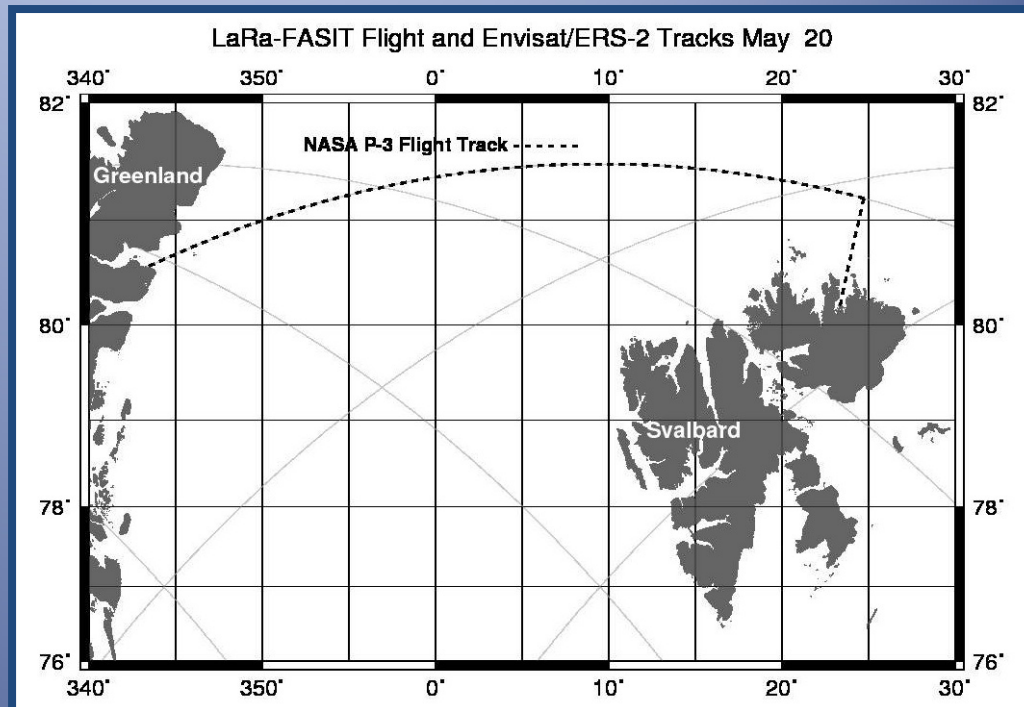
- *In-situ* measurements on ice
- Airborne surveys above ice
- Submarine (& AUV) surveys beneath ice

# NOAA/LSA Aircraft Missions

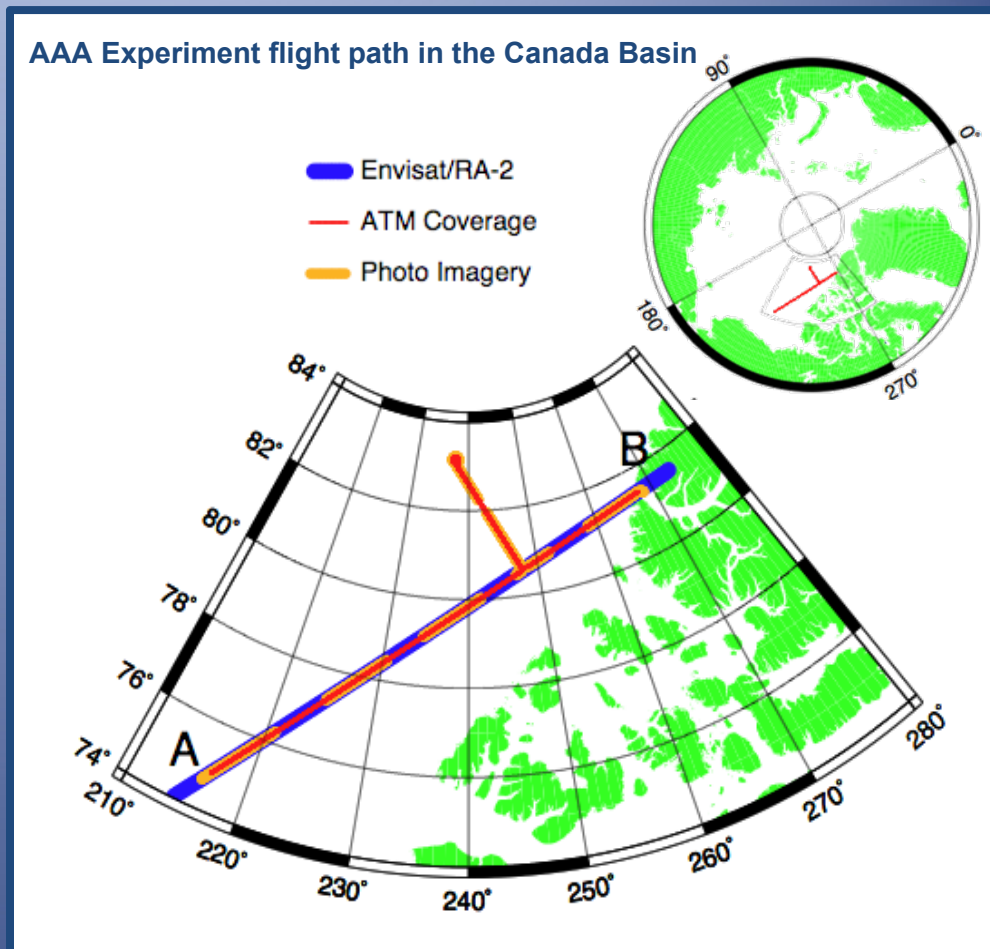
- 2002 - Laser Radar Altimetry (LaRA-FASIT) Experiment  
Fram Strait / Greenland Sea
- 2006 - Arctic Aircraft Altimeter (AAA) Experiment  
Canada Basin
- 2009 - Canada Basin Sea Ice Thickness (CBSIT) Experiment  
Canada Basin and Lincoln Sea
- 2011 – BEaufort Sea Ice Experiment (BESIE)  
Canada Basin / Beaufort Sea



- ERS-2 Underflights
- Instrumentation
  - ATM (laser altimeter)
  - D2P Radar
  - Digital Photography
- NOAA, NASA, and ESA Support
- First demonstration of simultaneous airborne/satellite altimetry data collection
- Detailed Analysis: *Giles et al., RSE, 2007*



- Envisat and ICESat underflights
- NOAA & NASA Support
- Instrumentation
  - ATM (laser altimeter)
  - D2P Radar
  - Digital Photography
- Envisat and ICESat Validation over Sea Ice



*From Connor et al., RSE, 2008*

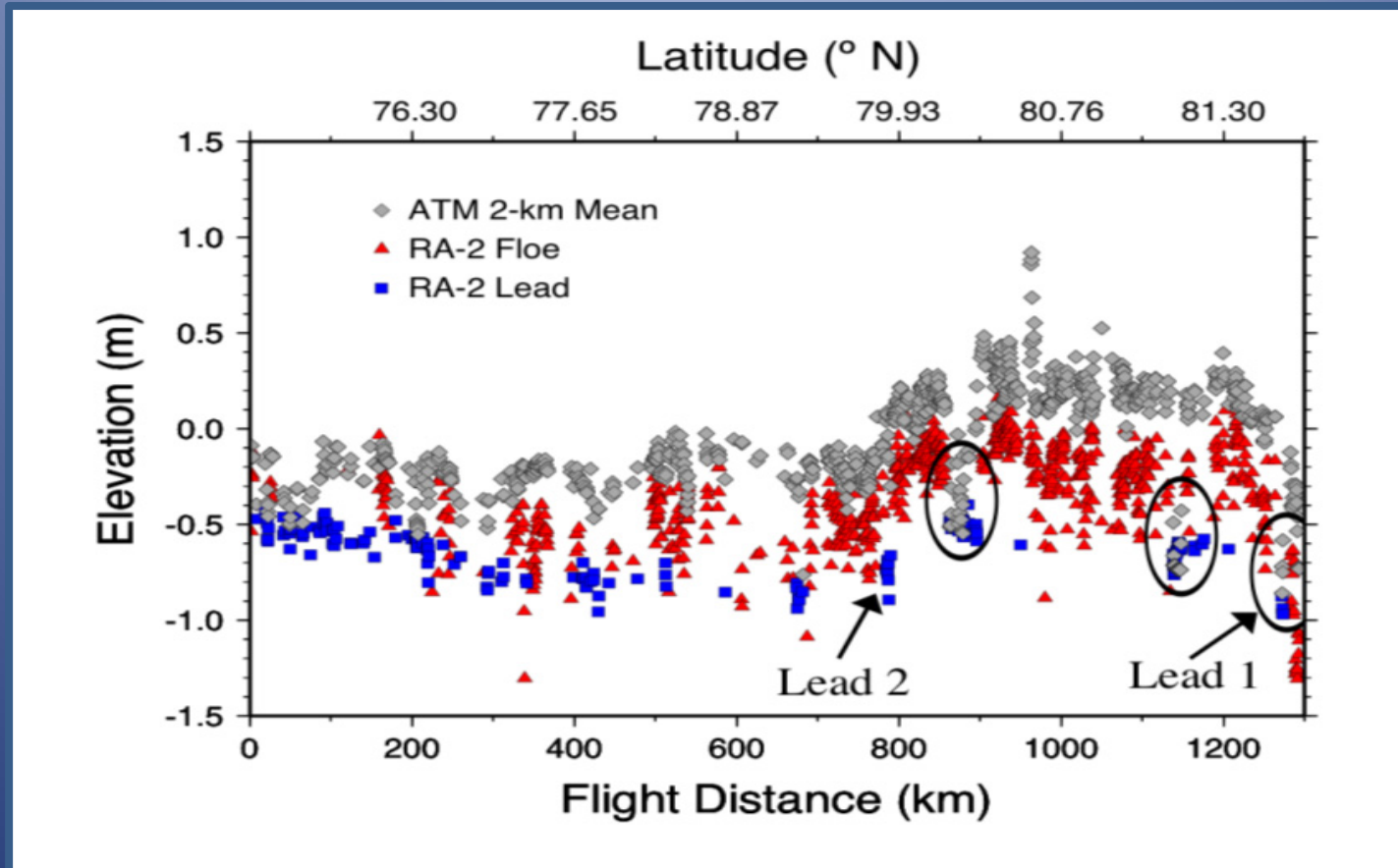




# AAA 2006: Envisat Track Analysis

## Sea Ice Surface Elevation

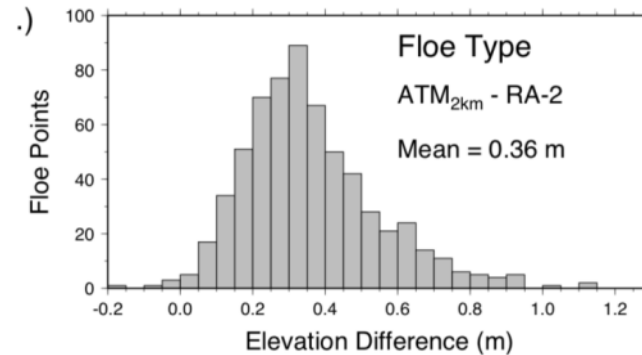
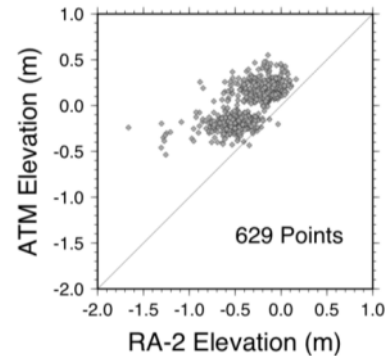
Airborne Laser Altimetry (grey) vs. Satellite Radar Altimetry (RA)



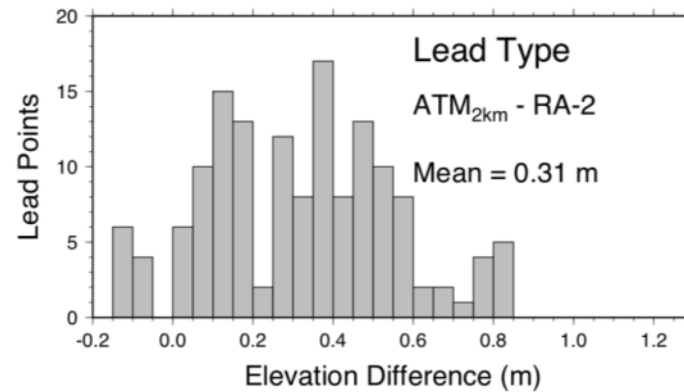
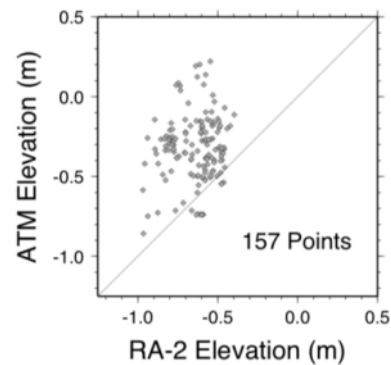


# AAA 2006: Envisat Track Analysis

## RA-2 Floe Points



## RA-2 Lead Points

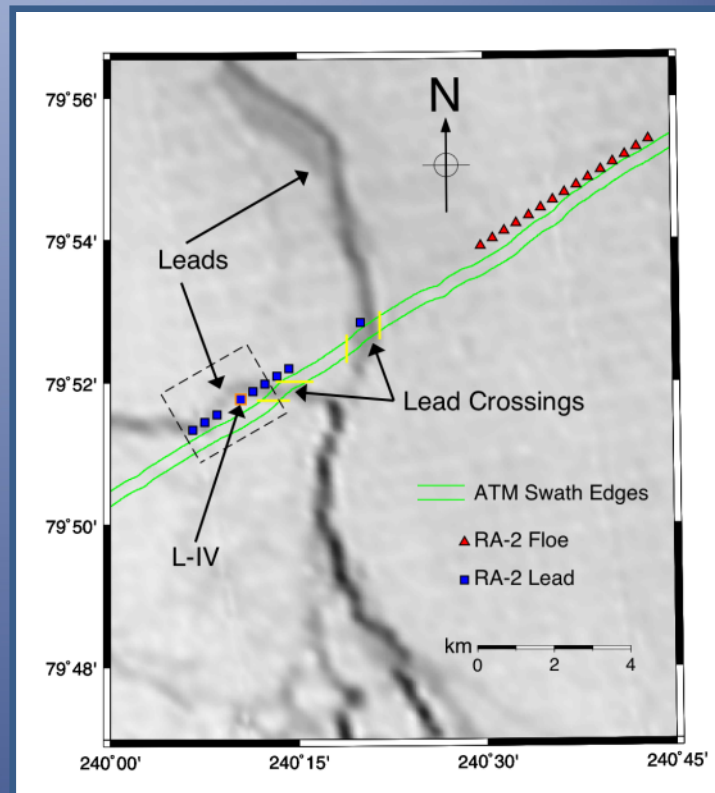
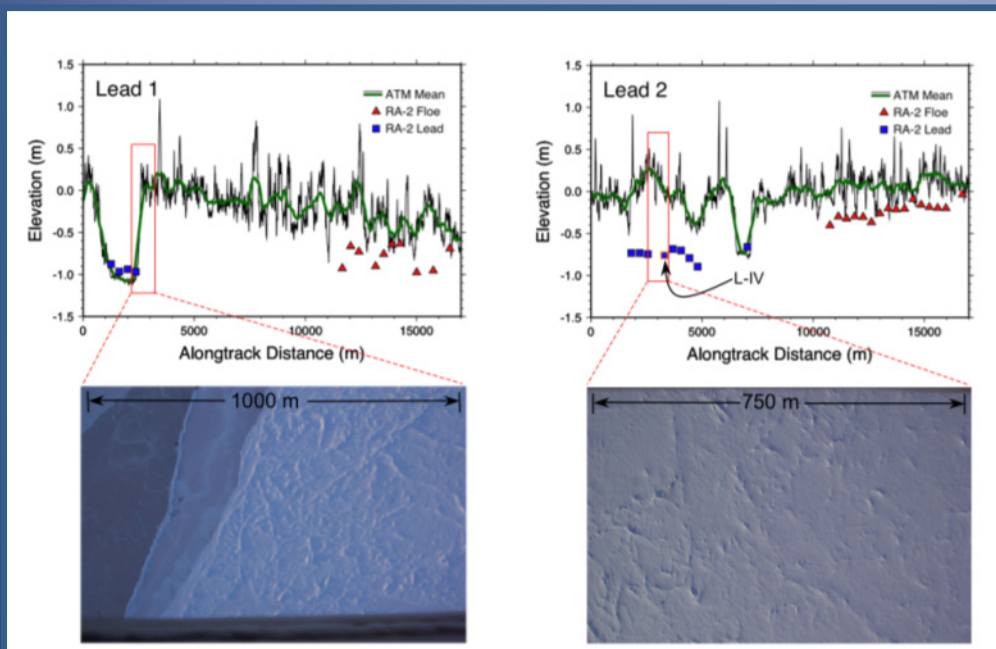




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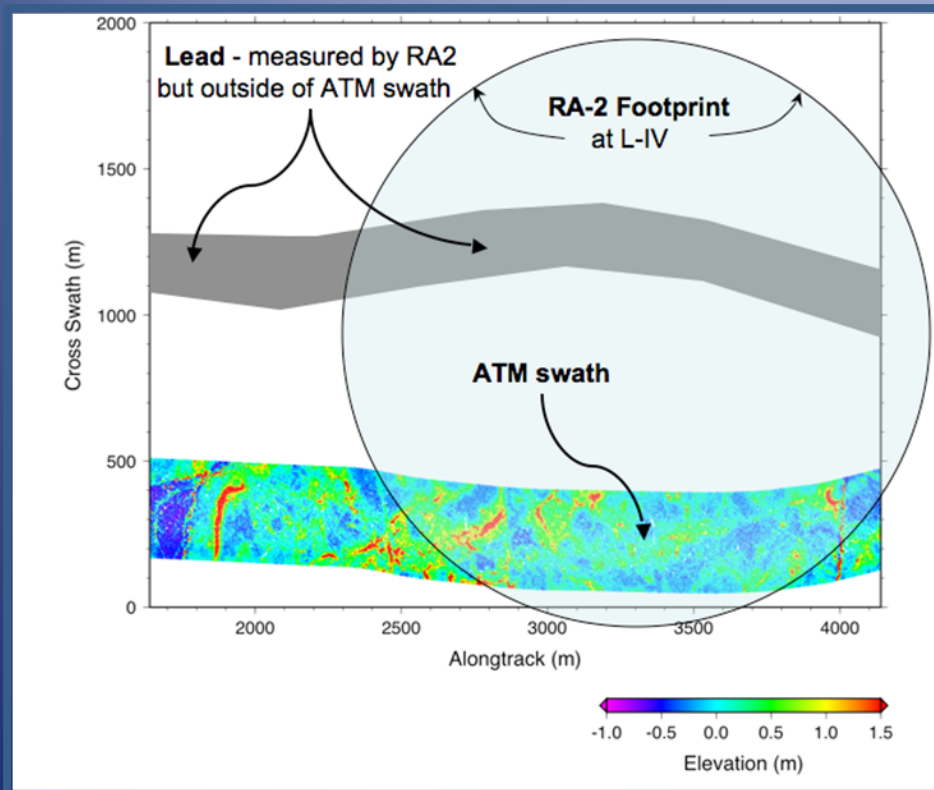
Satellite: Radar Altimetry & MODIS Visible Imagery

## Airborne: Laser Altimetry & Photography

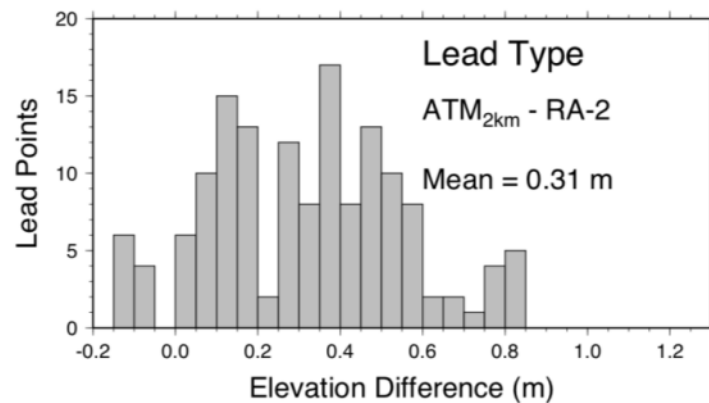
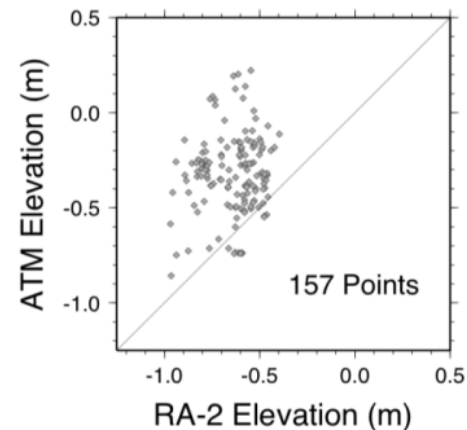




# AAA 2006: Envisat Track Analysis



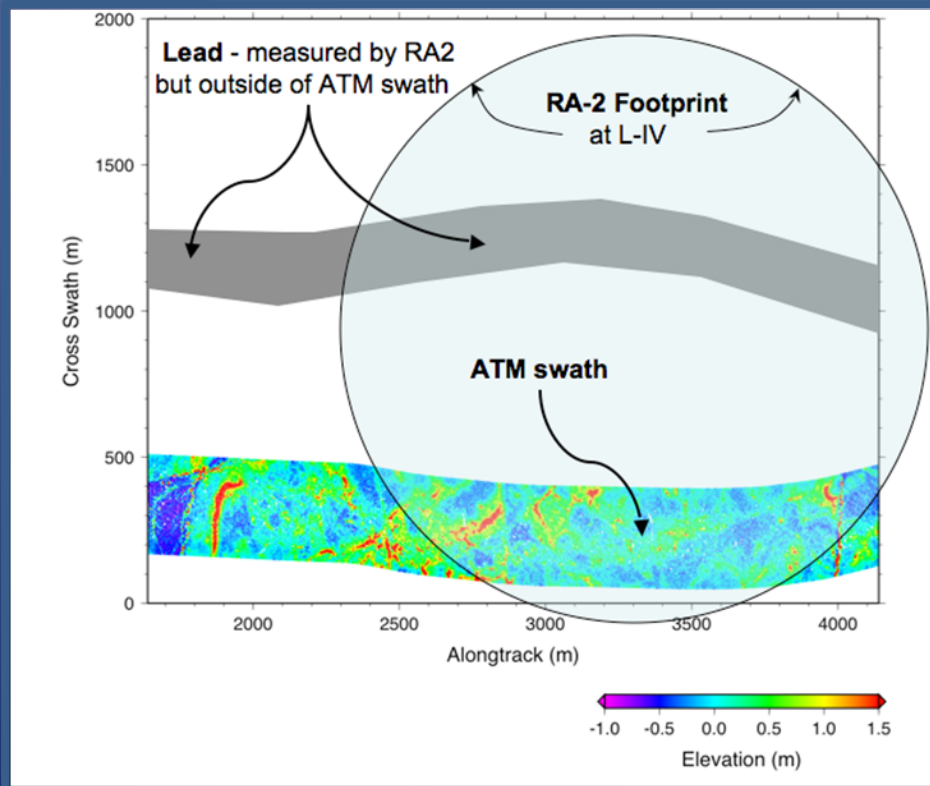
## RA-2 Lead Points



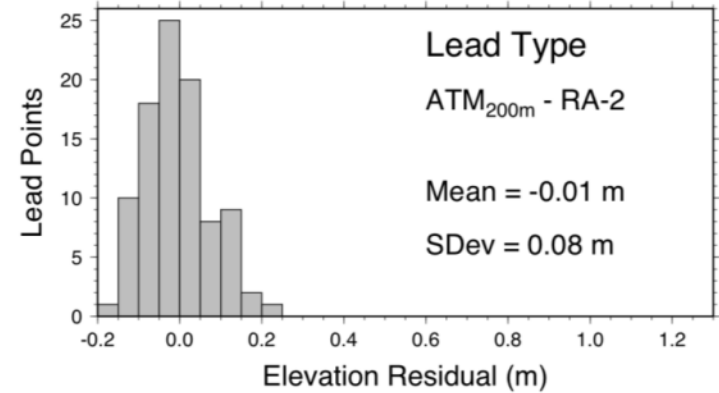
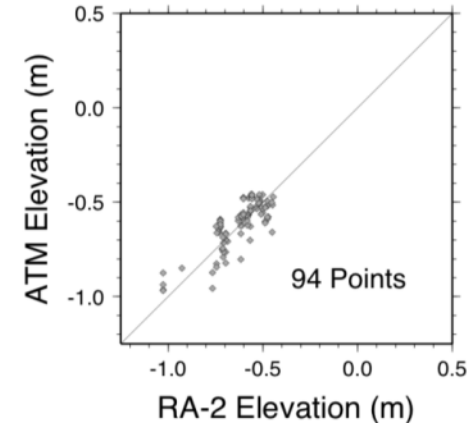




# AAA 2006: Envisat Track Analysis



## RA-2 Lead Points with ATM Lead Detection



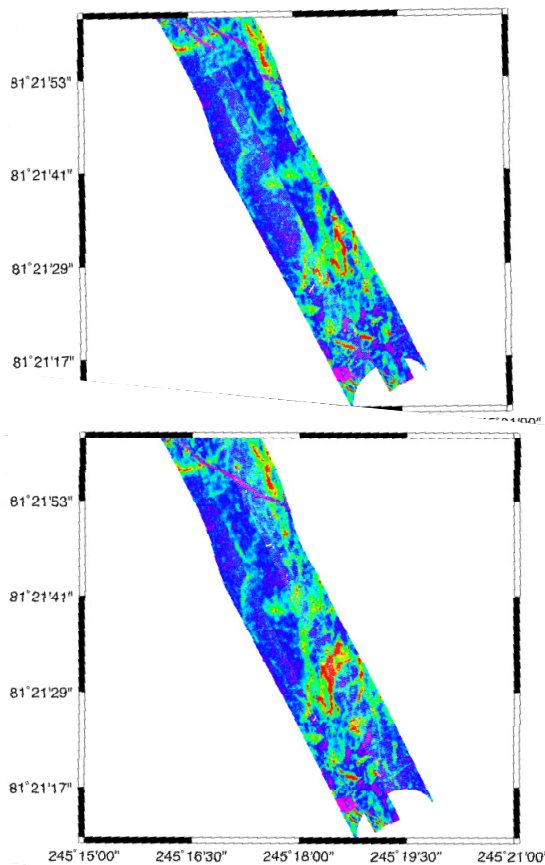
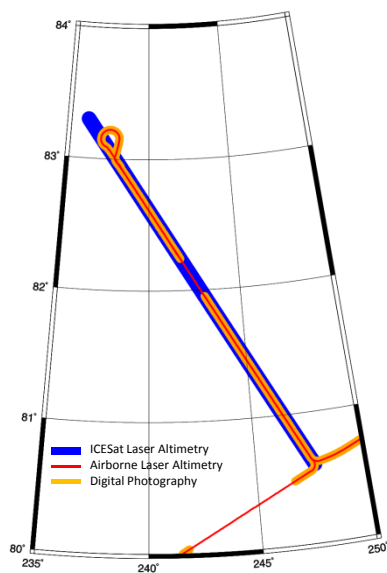
From Connor et al., RSE, 2009



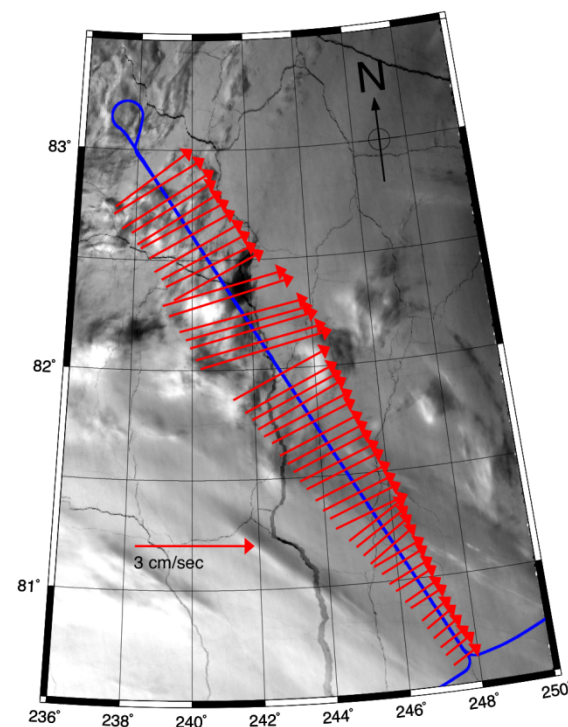
# AAA 2006: ICESat Track Analysis

## Sea Ice Drift Correction and Velocity Estimates

Correcting for sea ice drift between time of satellite overpass and acquisition of airborne data



Ice Velocity Vectors overlain on MODIS vis. imagery

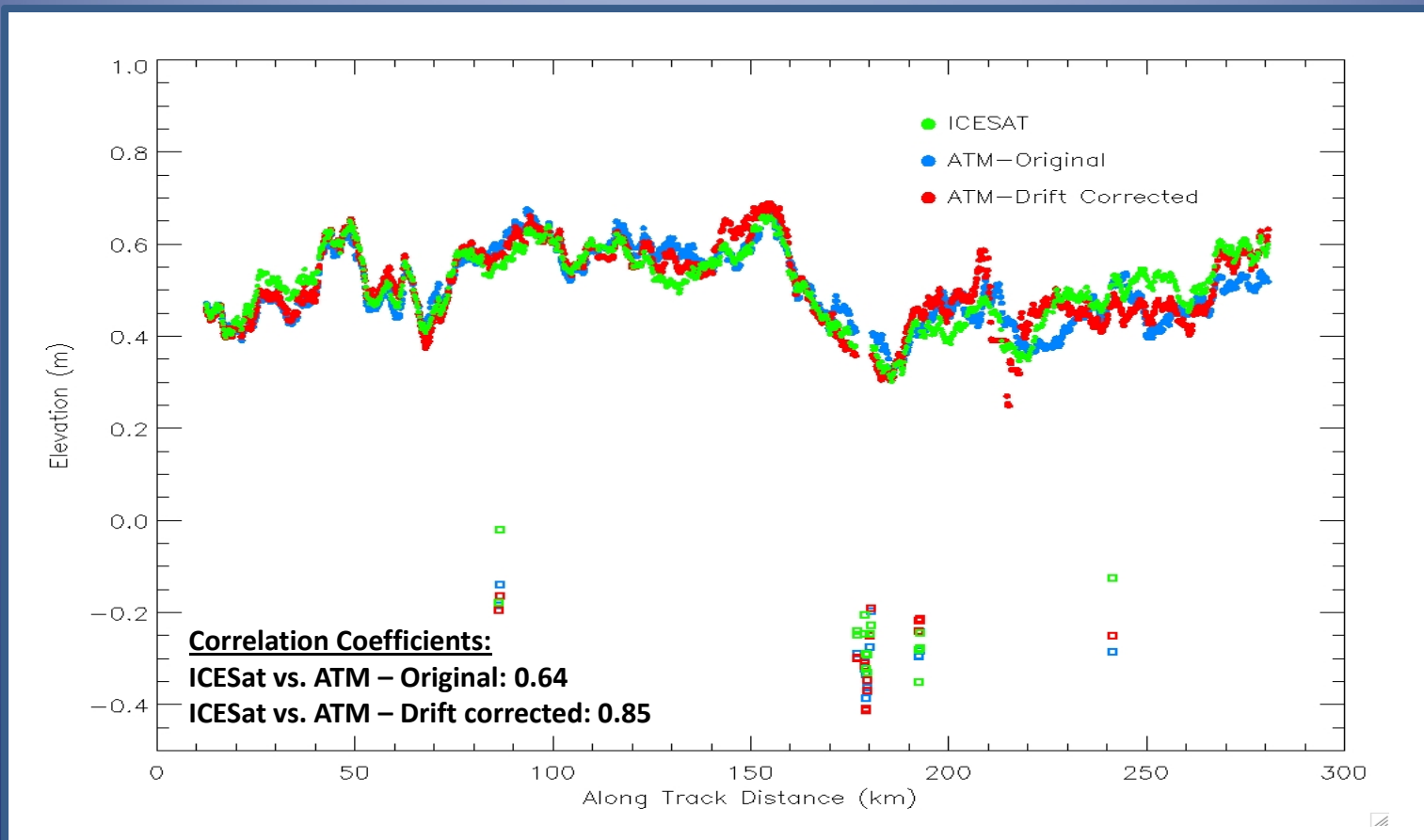




# AAA 2006: ICESat Track Analysis

## Sea Ice Surface Elevation

Airborne Laser Altimetry (blue/red) vs. Satellite Laser Altimetry (green)

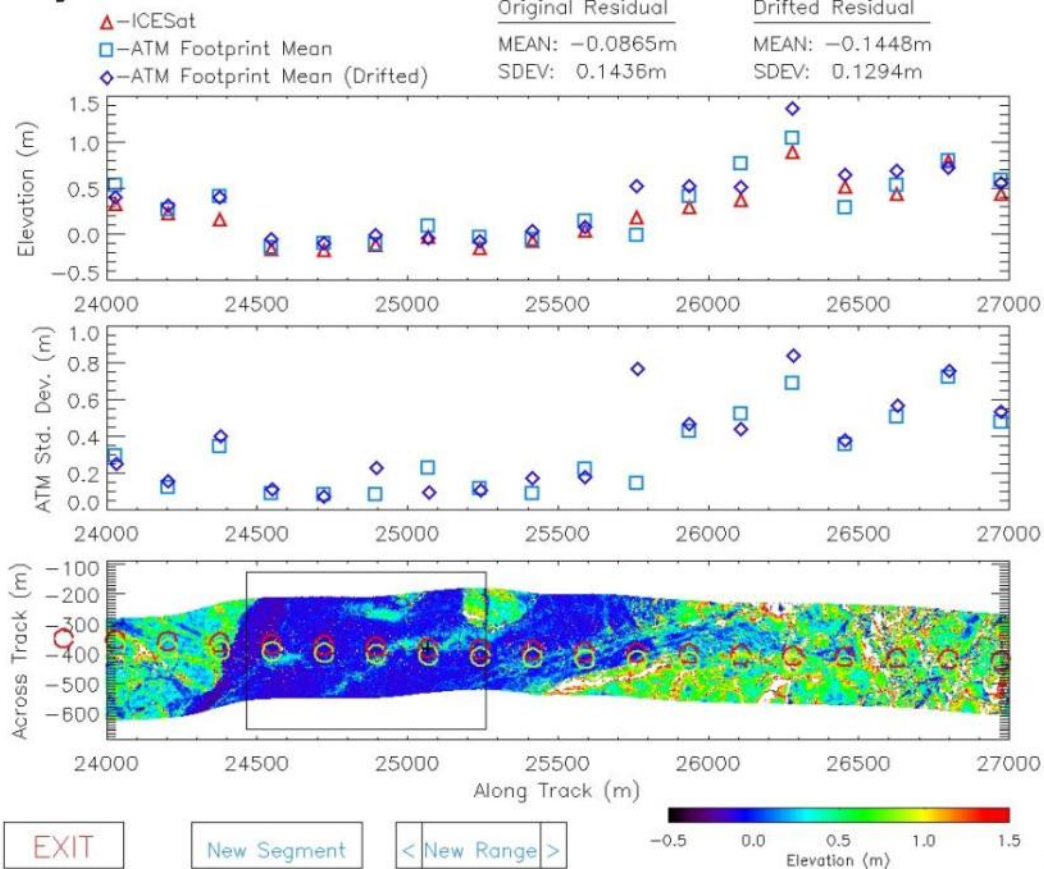




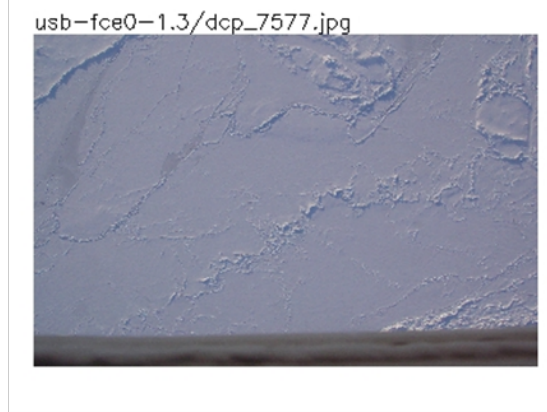
# AAA 2006: ICESat Track Analysis

## Analysis of Individual ICESat Footprints

Segment: 33



ICESat Time: 21.1538 hr  
 Longitude: 246.2911 °  
 Latitude: 81.0696 °  
 Elevation: -0.0311 m  
 Gain: 13  
 Reflectivity: 0.61  
 RX Energy: 8.52 (fJ)

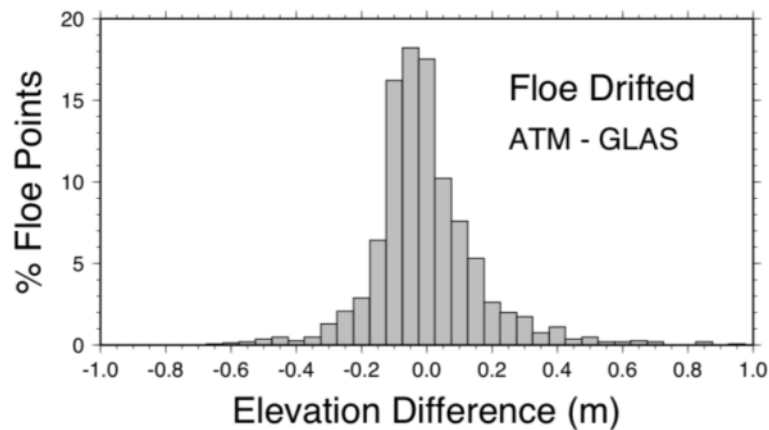
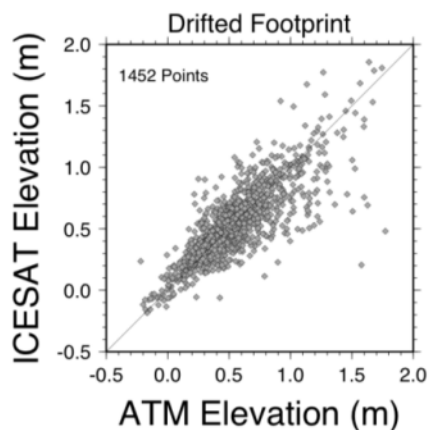
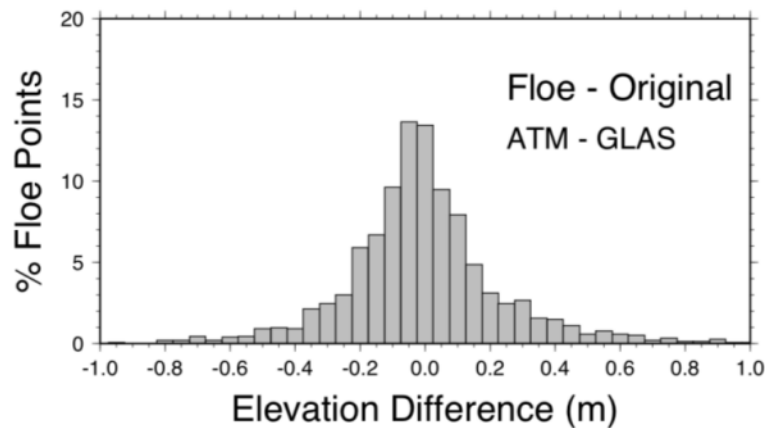
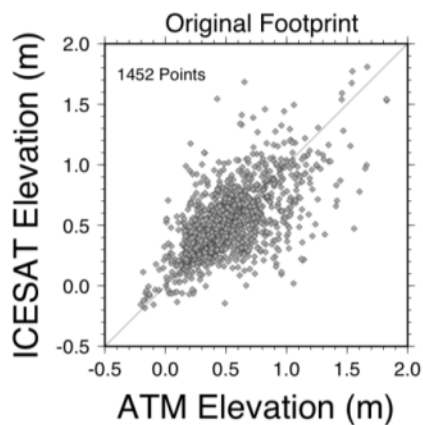






# AAA 2006: ICESat Track Analysis

## Airborne vs. Satellite Laser Altimetry Elevation Difference

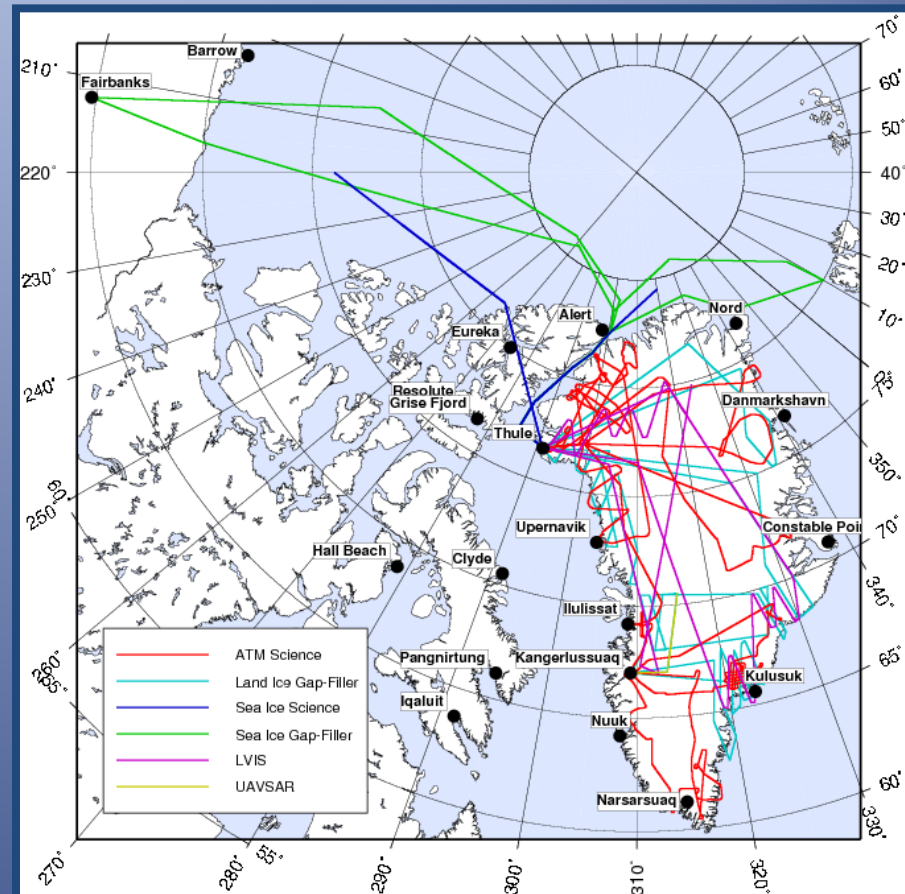




# CBSIT: 2009



- Envisat Underflight
- Danish “GreenArc” Ice Camp Overflight
- Instrumentation
  - ATM (Laser Altimeter)
  - Snow Radar
  - Digital Photography
  - LVIS (high alt.) laser
- NASA’s Operation Ice Bridge



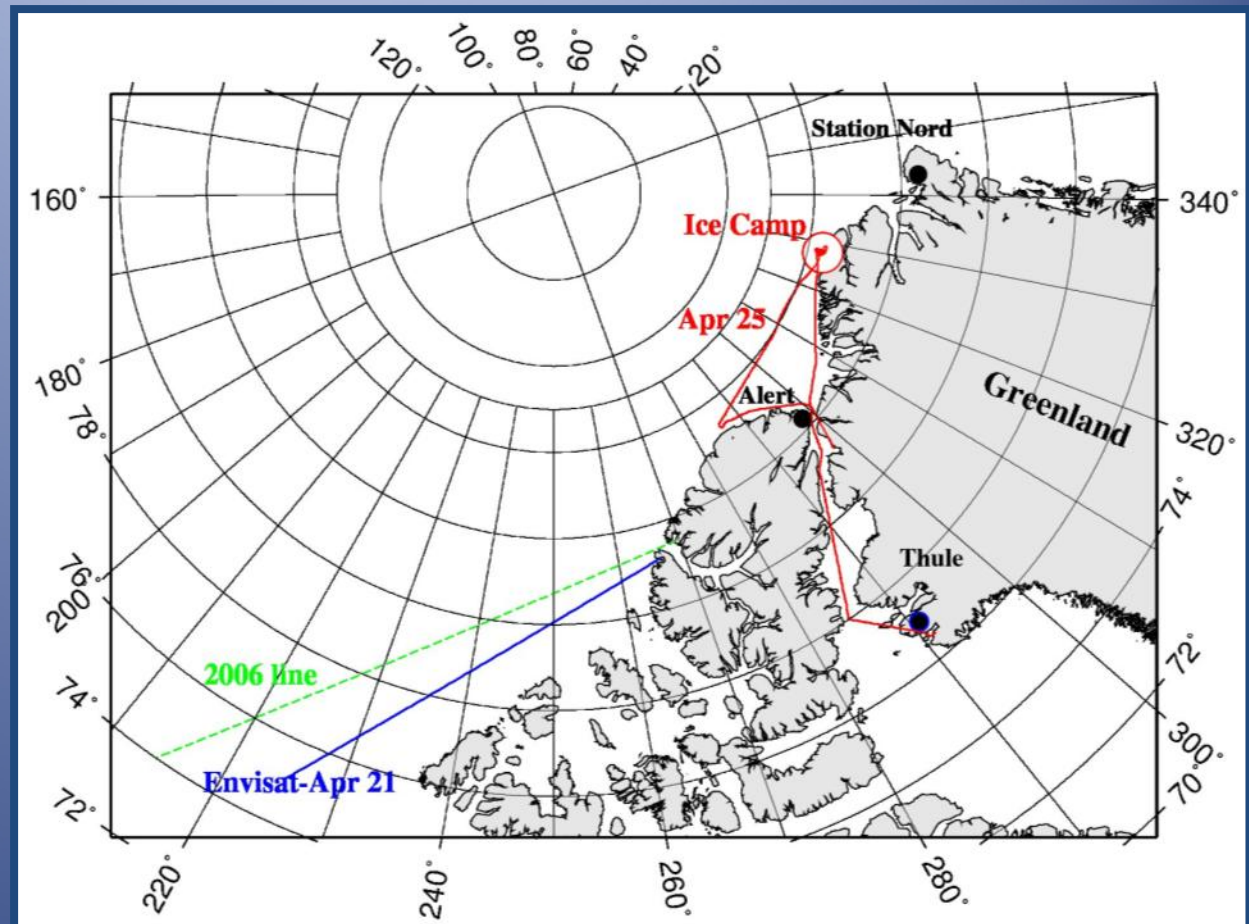
# CBSIT Experiment: April 2009

## Envisat Under-flight

- April 21 2009
- Canada Basin
- Near 2006 survey line
- Thick MY ice to FY ice

## Ice Camp Over-flight

- April 25 2009
- GreenArc Ice Camp
- Thick, Old MY ice
- Nares Strait





# GreenArc Ice Camp



Courtesy GreenArc/DNSC



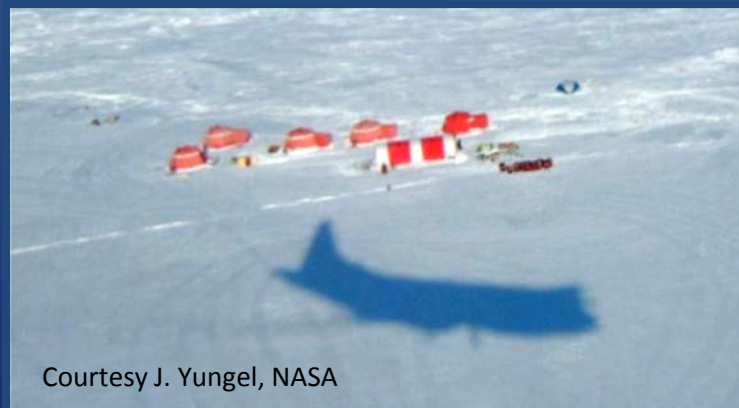
Courtesy M. Linkswailer, NASA



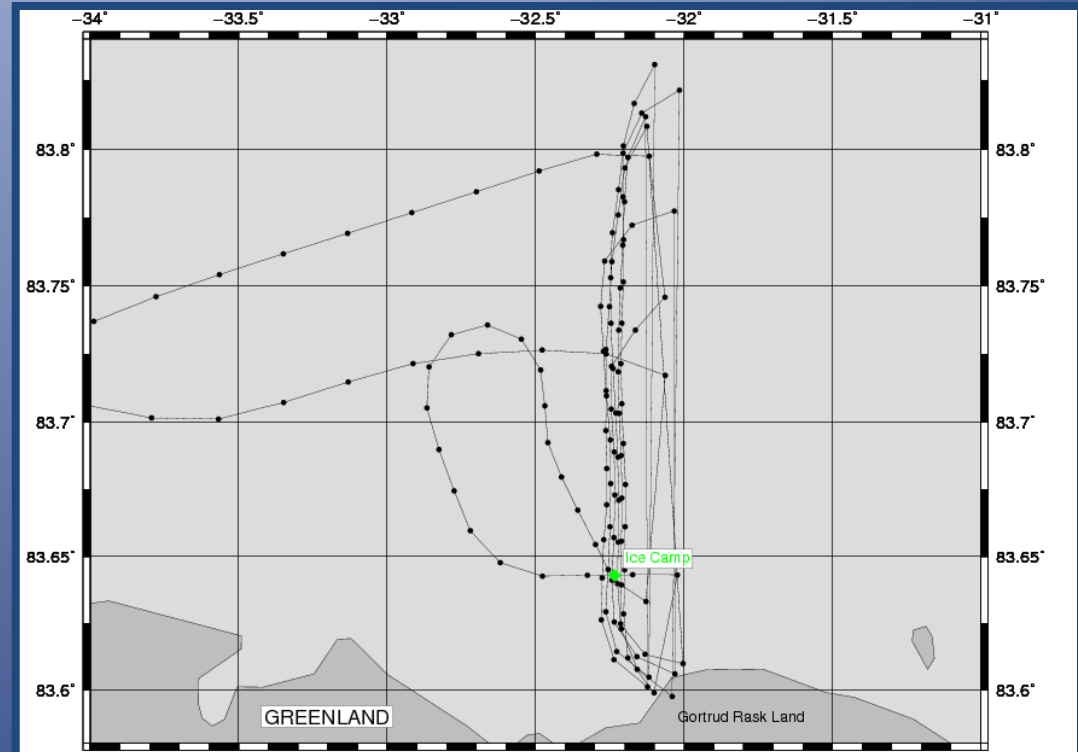
# GreenArc Ice Camp Over-Flight

## *In Situ* Measurements:

- EM-31 Ice thickness profiling
- Snow depth
- Snow pits
- Drill holes for calibrations



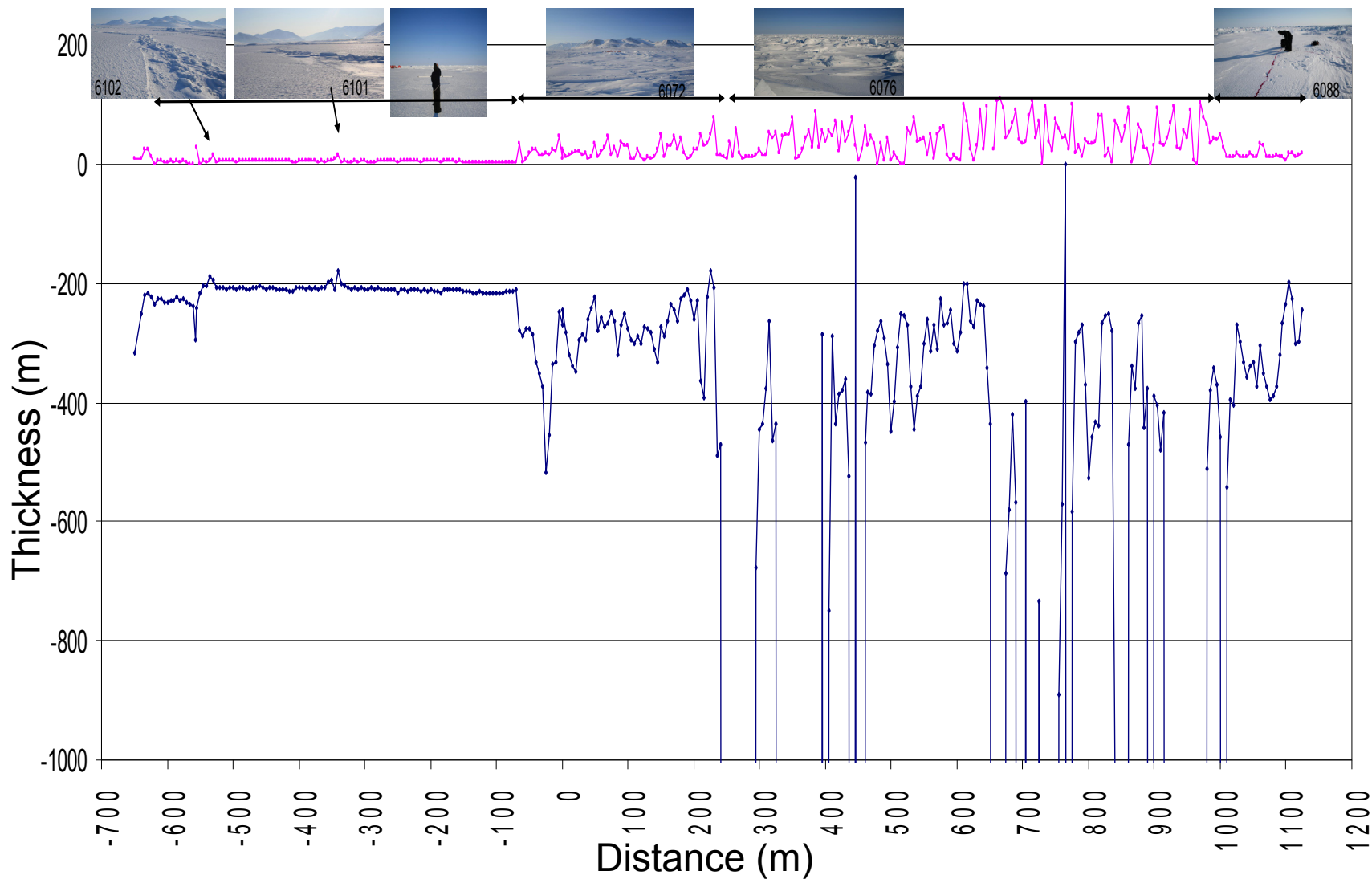
Courtesy J. Yungel, NASA



# Validation Line Overview



# Preliminary Ice Thickness along Validation Line



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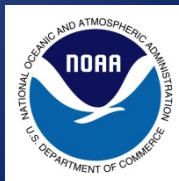
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# The Future

- Finalize AAA-2006 Data Analysis – prepare 2<sup>nd</sup> publication
- Analyze CBSIT (2009) Data Sets:
  - ATM Laser Altimeter Data
  - Kansas Univ. Snow Radar
  - *In Situ* / GreenArc Ice Camp Data Sets
  - Coincident Satellite laser and radar altimetry data
- Preparations for BESIE 2011 - Beaufort Sea Ice Camp
- Advisors to NASA's OIB Airborne Campaigns taking place in the Antarctic (2009) and Arctic (2010)
- Prepare for CryoSat-2 launch and initial data assessment



# Looking Ahead

- **GOCE** – Gravity Field and Steady State Ocean Circulation Explorer  
Launched March 17<sup>th</sup> 2009  
Measure the geoid to 1 cm accuracy at 100 km length-scales



- **CryoSat-2** – Launch Dec. 2009



- **ICESat-2** – Launch 2015/16

Questions?

LSA Sea Ice Team Website:  
<http://ibis.grdl.noaa.gov/SAT/SeaIce/index.php>



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