US NAVAL RESEARCH LABORATORY FIVE YEAR RESEARCH OPTION

Determining the Impact of Sea Ice Thickness on the Arctic's Naturally Changing Environment (DISTANCE)

Co-PI's for NRL

John Brozena, Joan Gardner **(Marine Geosciences Division)**

Li Li, Peter Gaiser, Justin Bobak **(Remote Sensing Division)**

Richard Allard, Pamela Posey, Alan Wallcraft, Joseph Metzger, Erick Rogers **(Oceanography Division)**

Co-PI's for ERDC-CRREL-NH (Cold Regions Research and Engineering Lab)

Jackie Richter-Menge, Don Perovich, Bruce Elder

PI for Arctic Submarine Lab

Jeff Gossett

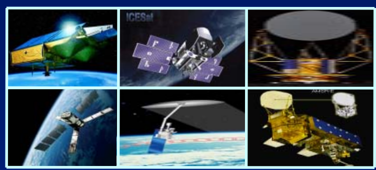
- **Objective:** Understand the changing Arctic environment, characterized by reduced ice volume, using new techniques for deriving accurate multi-sensor snow and ice thickness information and coupled ice-ocean models to explore the new Arctic dynamics.

- **Payoff:** Provide the Navy with an improved forecast capability that accurately describes these changing conditions in the Arctic and provide new global fields of snow and ice thickness for data assimilation.

Approach

- Develop new algorithms from satellite and aircraft measurements to determine Arctic-wide satellite-derived ice and snow thickness;
- Validate/calibrate these new measurements with an Arctic in-situ/airborne field program;
- Utilize the Navy's coupled ice-ocean model and these *new data types* to better understand the impact of ice and snow volume on Arctic dynamics and thermodynamics;
- Evaluate ocean processes that now play a larger role in the prediction of the reduced volume ice-ocean system, e.g., wave dynamics.

An Integrated Multi-Discipline Program

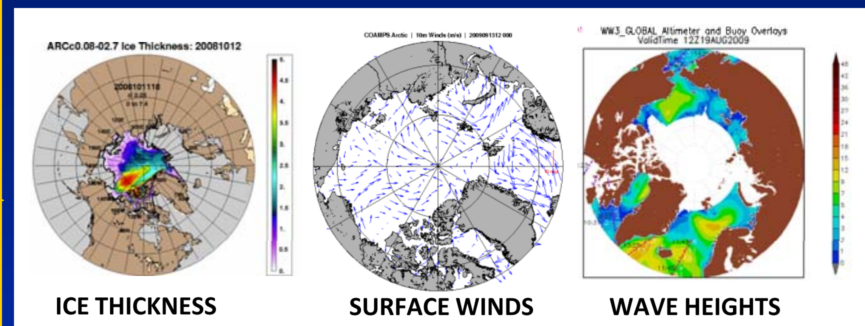


Code 7220
Satellite Algorithms

Code 7320
Arctic Modeling

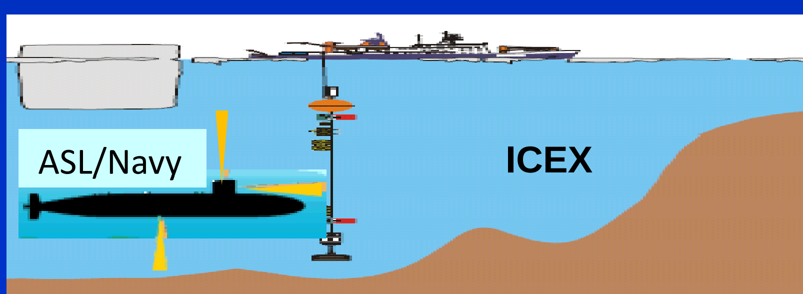
NRL

Code 7420
Airborne Campaign



boreholes

NRL, CRREL
In-situ



Strategy

Remote Sensing Synergism

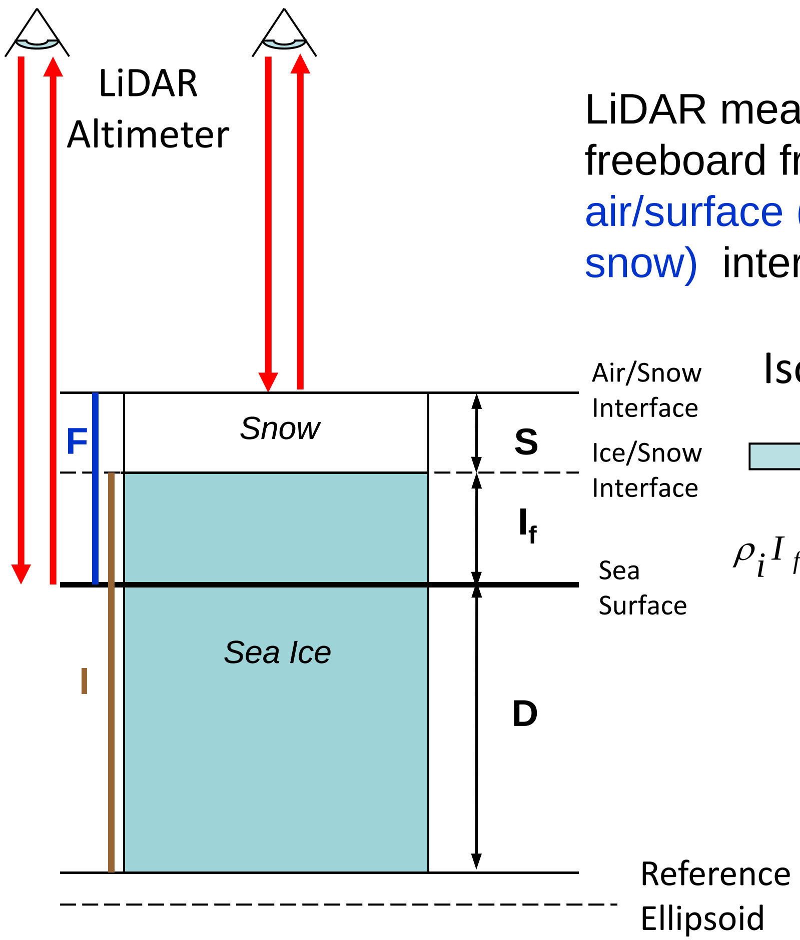
–Collect in-situ data (ice/snow thickness)
–Develop airborne algorithm from in-situ data
–Utilize airborne data to derive satellite algorithm

Ice-Ocean Modeling Scheme

–Validate model ice thickness against new satellite/airborne data
–Simulate snow forcing on ice distribution

Leverage existing Arctic programs

LiDAR Altimetry of Sea Ice Thickness



LiDAR measures freeboard from the air/surface (ice or snow) interface

Isostatic Balance

$$\rho_i I_f + \rho_s S = (\rho_w - \rho_i) D$$

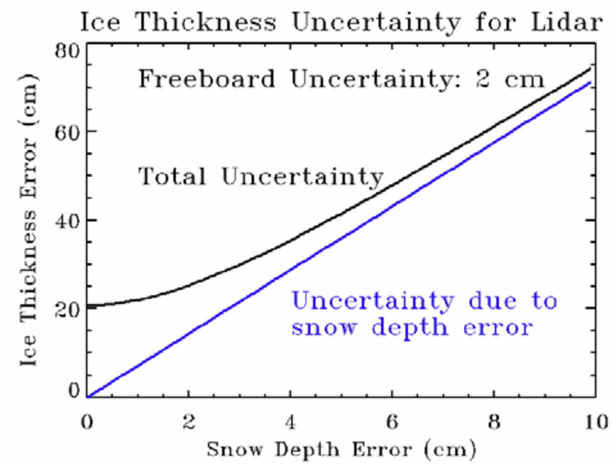
For LiDAR Altimeter,

freeboard $F = I_f + S$

Ice thickness $I = I_f + D$

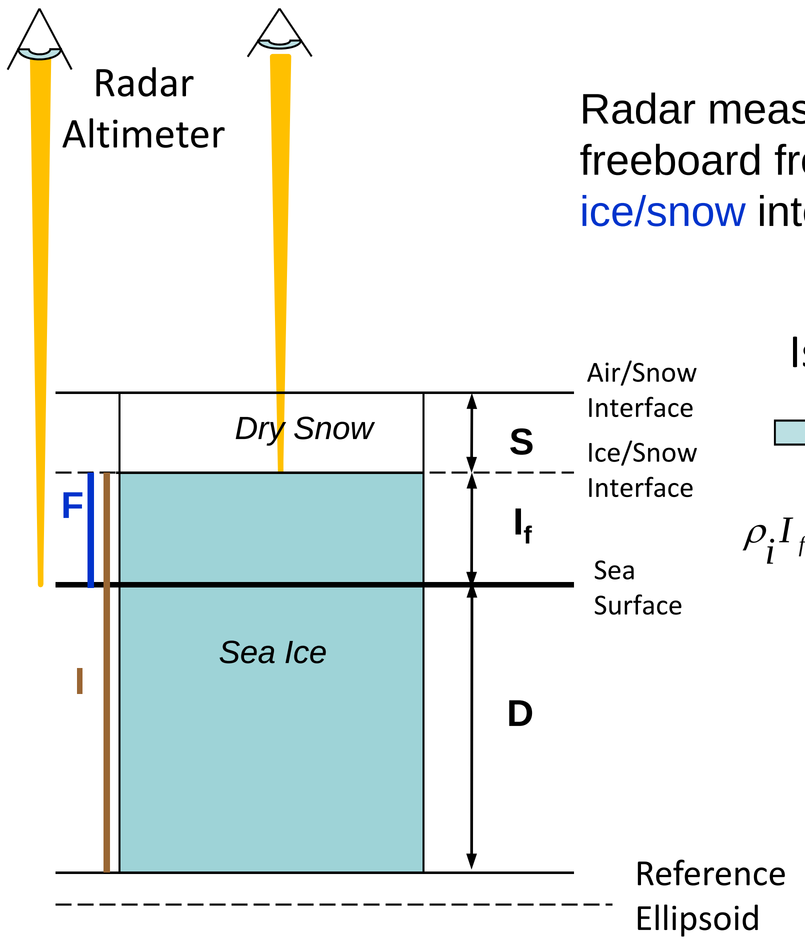
$$I = \frac{\rho_w}{\rho_w - \rho_i} F + \frac{\rho_s - \rho_w}{\rho_w - \rho_i} S$$

$$\approx 10.4F - 7.2S$$



Sea ice thickness measurements are highly sensitive to errors in snow depth data

Radar Altimetry of Sea Ice Thickness



Radar measures freeboard from the ice/snow interface

Isostatic Balance

$$\rho_i I_f + \rho_s S = (\rho_w - \rho_i) D$$

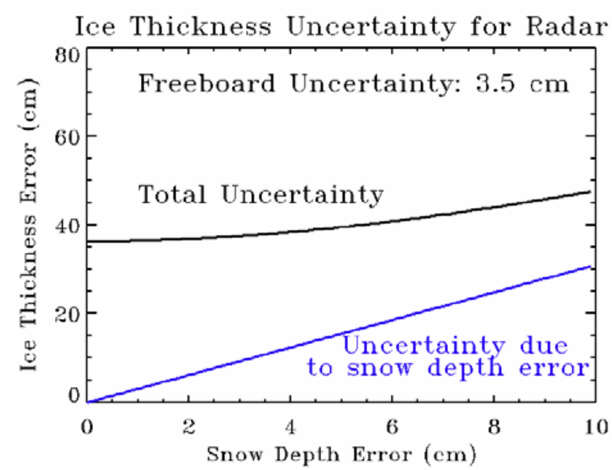
For Radar Altimeter,

freeboard *F=I_f*

Ice thickness $I=I_f + D$

$$I = \frac{\rho_w}{\rho_w - \rho_i} F + \frac{\rho_s}{\rho_w - \rho_i} S$$

$$\approx 10.4F + 3.1S$$



Sea ice thickness measurements are highly sensitive to errors in snow depth data

The NRL Field Program:
Combined LiDAR/Radar Airborne Instrumentation

10 GHz High-Power, Pulse-Limited Radar Altimeter

- ~3nsec pulse-width => 32m diameter footprint @300m altitude
- Wave-form digitization for mixed (lead & ice) returns < 1 cm vertical resolution of features @ 10 kHz

18 GHz High-Power, Pulse-Limited Radar Altimeter

- Similar parameters as 10 GHz unit
- Dual frequency radars provide degree of wet-snow discrimination

Scanning Topographic LiDAR

- < 1 cm range resolution
- Wave-form digitization for mixed (lead & ice) returns

Digital True Color Photogrammetry

- Lead discrimination

Previous Campaigns

- Skagit Bay, Afghanistan, Arctic, Greenland, etc

NRL Flight CONOPS

- Twin Otter aircraft will be based in Barrow and will perform daily flights either along satellite tracks or in a grid pattern. Flights will take place between March 18 and April 1.
- Approximate length of each flight will be 3-4 hours on site.
- Flight altitude will be ~2000 ft.
- VHF and Satellite Phone Comms available from the aircraft.

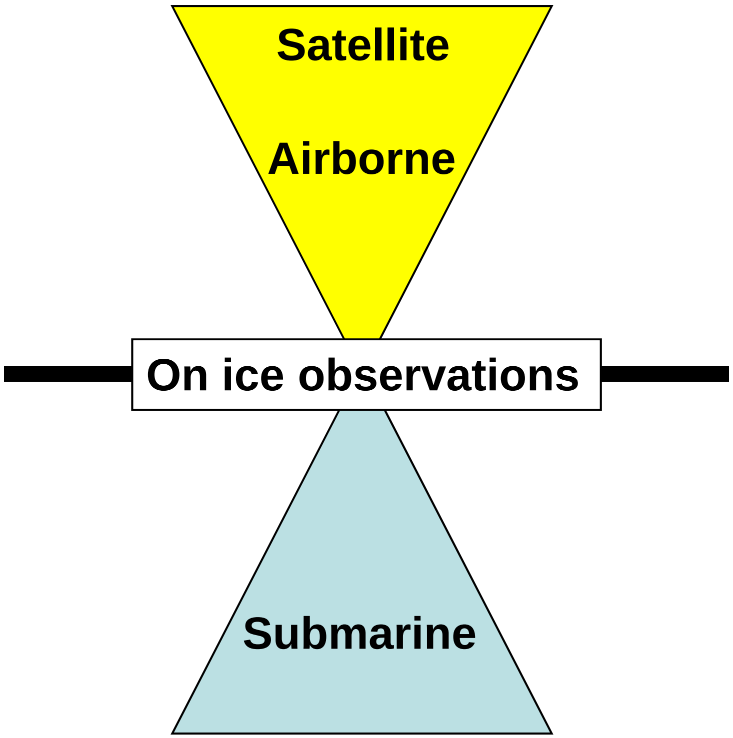
In-Situ Measurements with Joint 2011 CRREL/NRL/ASL Polar Expedition

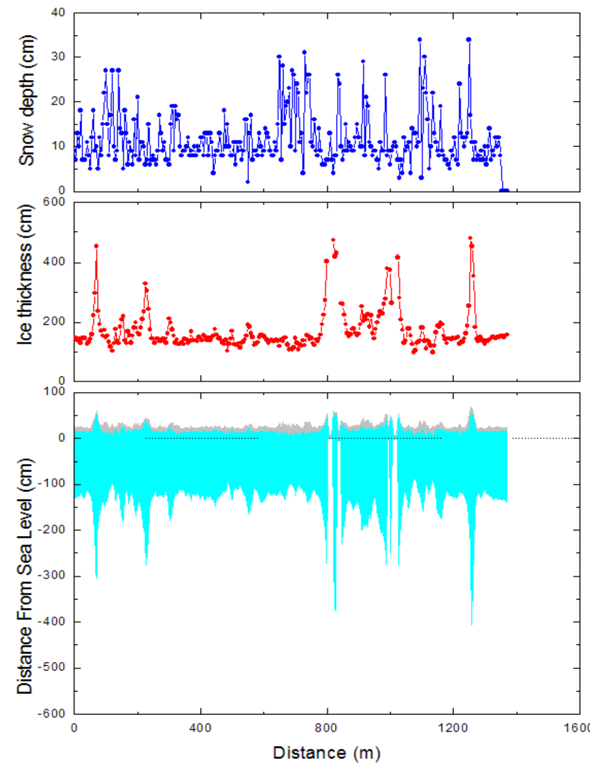
- Leverage ASL 2011 ICEX Ice island camp and submarine transits
- Coordinate with airborne and satellite measurements
- Perform surface characterization of sea ice and snow on ice
  - Install three survey lines with a total length of 10 – 15 km
  - Measure snow depth and ice thickness at meter resolution along survey lines
  - Ice thickness profile of a ridge
  - Snow characterization including vertical profiles of grain size, grain type, density, water equivalent at several sites
  - Ice characterization include vertical profiles of ice temperature, salinity, brine volume, density, and crystallography at several sites
- Upward Looking Sonar (ULS) on submarine lines

Airborne measurements, validated by *in-situ* measurements, will provide regional ice thickness and snow-depth-on-ice;
These data will aid development of satellite retrieval

Sea Ice Thickness Observations

Ice-based survey

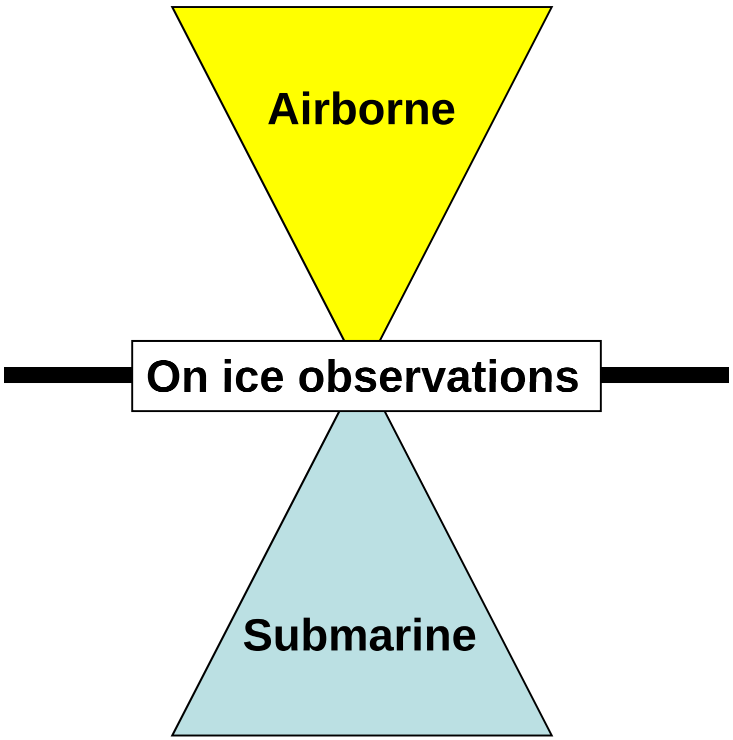




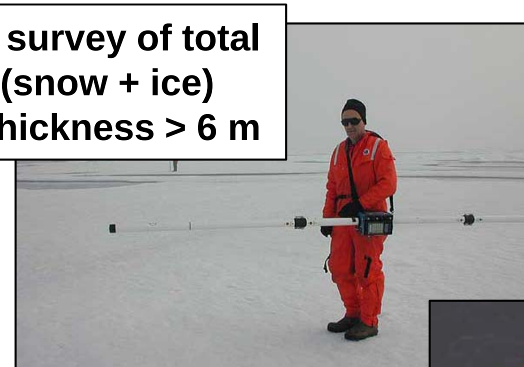
- **Ice-based survey of snow depth and ice thickness to evaluate submarine and airborne instruments**
- **Coordination key to success: Transect line and timing**

Sea Ice Thickness Observations

Ice-based survey



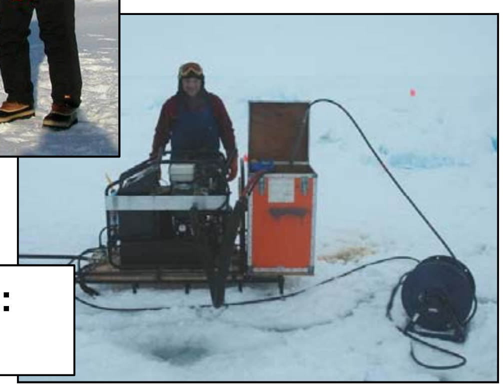
- 4-Person Team: 2 CRREL, 2 NRL
- Based in ice camp
- 20-25 March



EM31: Rapid survey of total thickness (snow + ice)
Limitation: Thickness > 6 m

MagnaProbe: Rapid survey of snow depth

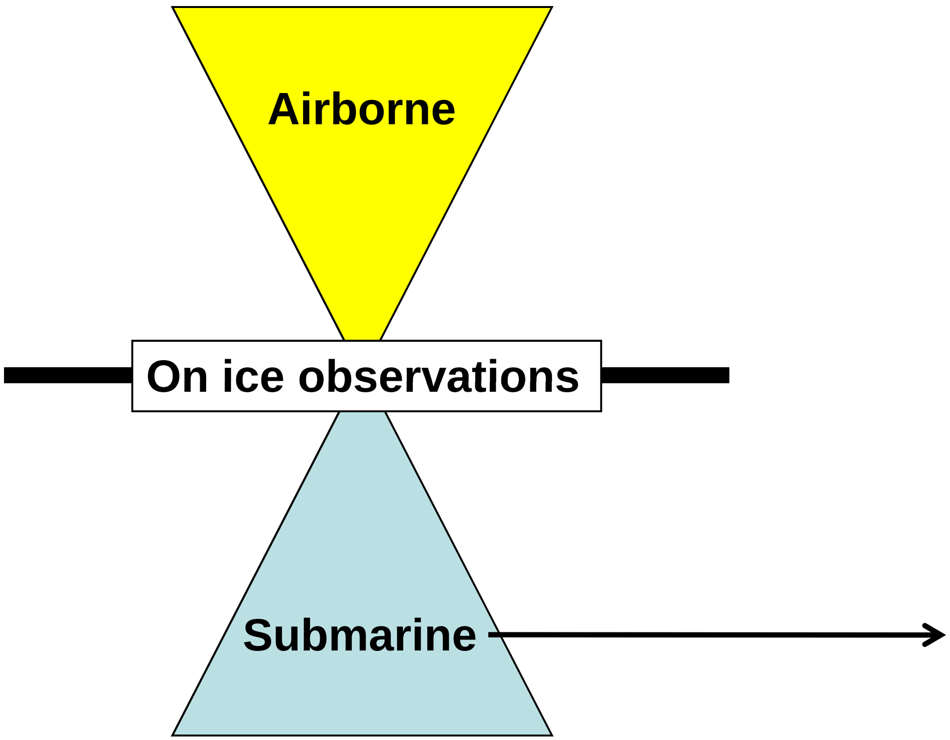
Mechanical Drilling: 0-3m thick ice



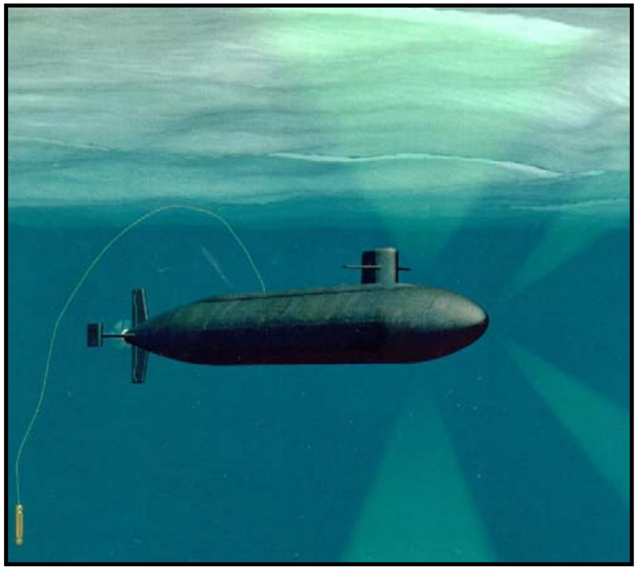
Hot Water Drilling: > 3m thick ice

Sea Ice Thickness Observations

US Navy Arctic Submarine Science Program (SCICEX)



- **Topsounder**
- **Measure ice draft**
- **Estimate ice thickness**
- **Coordinated by ASL**
- **March 2011**

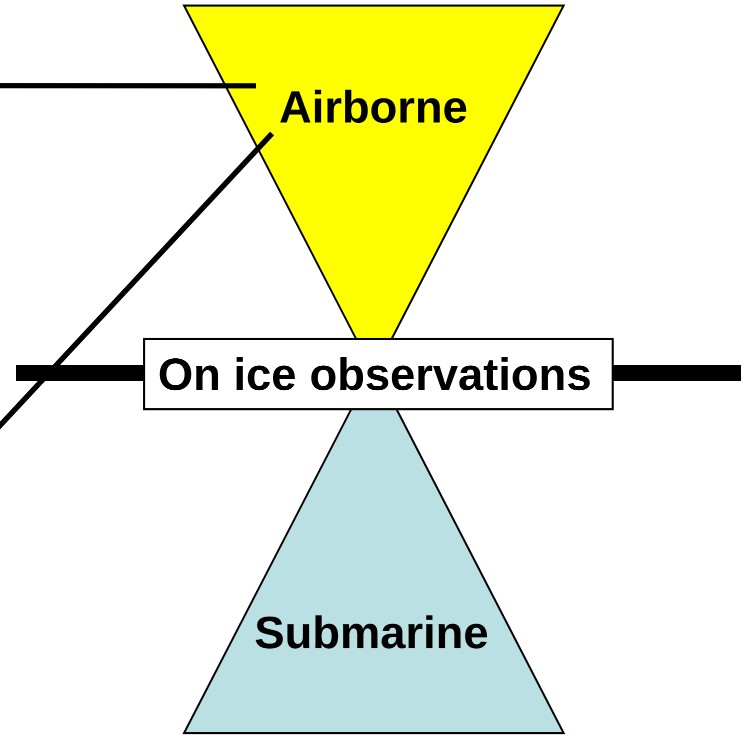


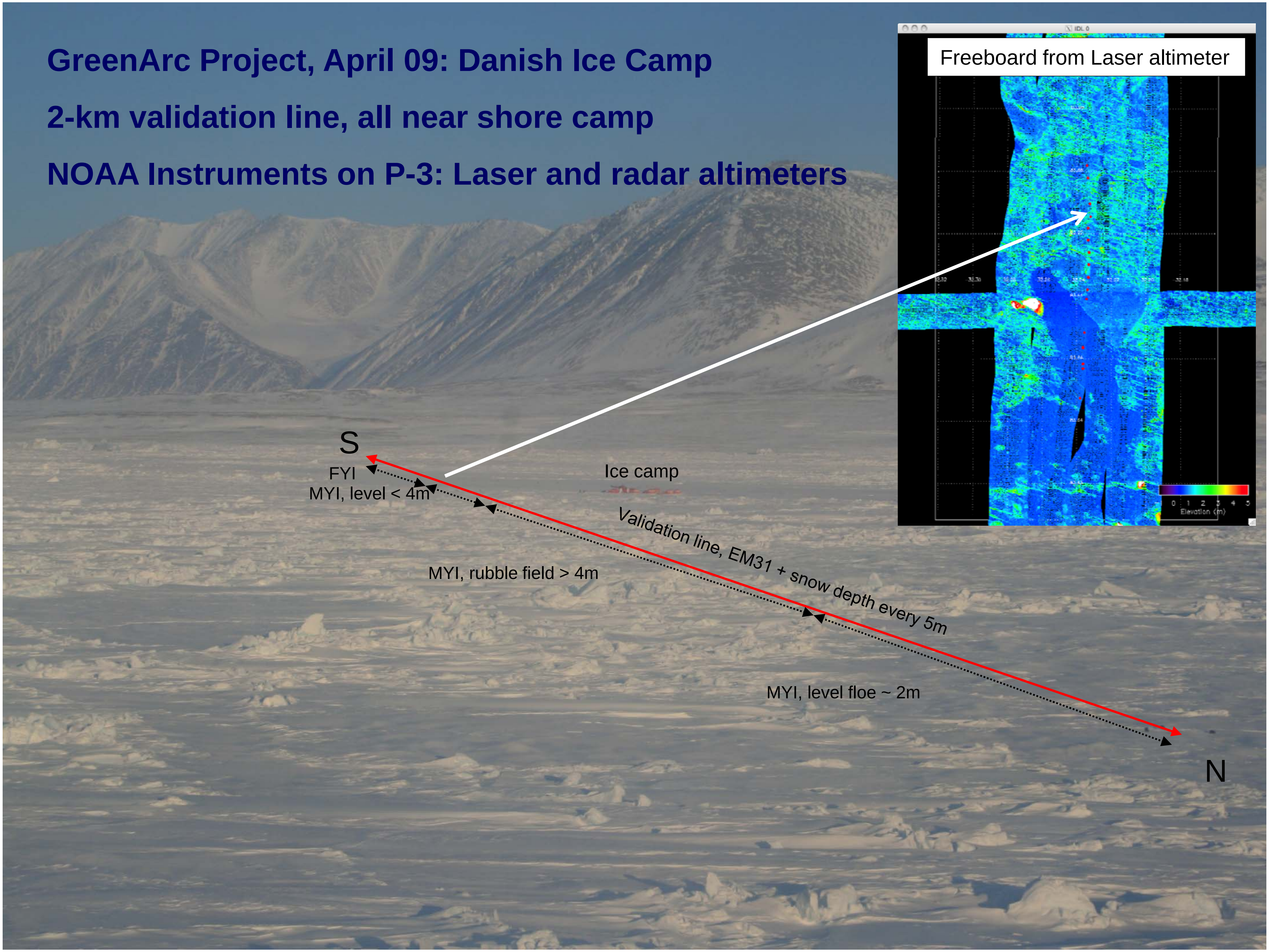
Sea Ice Thickness Observations

NASA IceBridge and AWI Polar 5

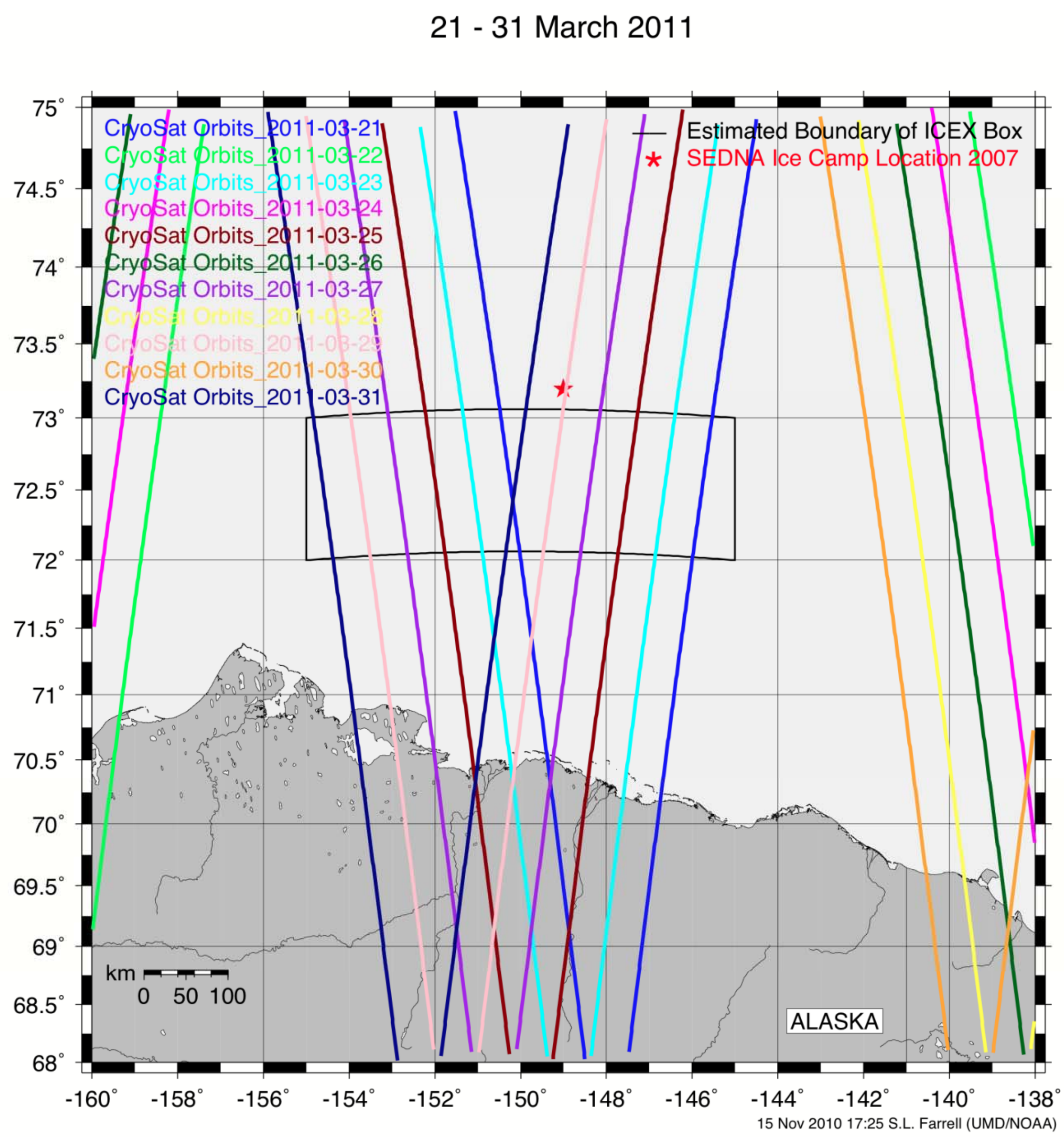
NASA P3
- Altimeter
- Snow radar
- Digital camera

AWI Polar 5
- EM31
- Lidar

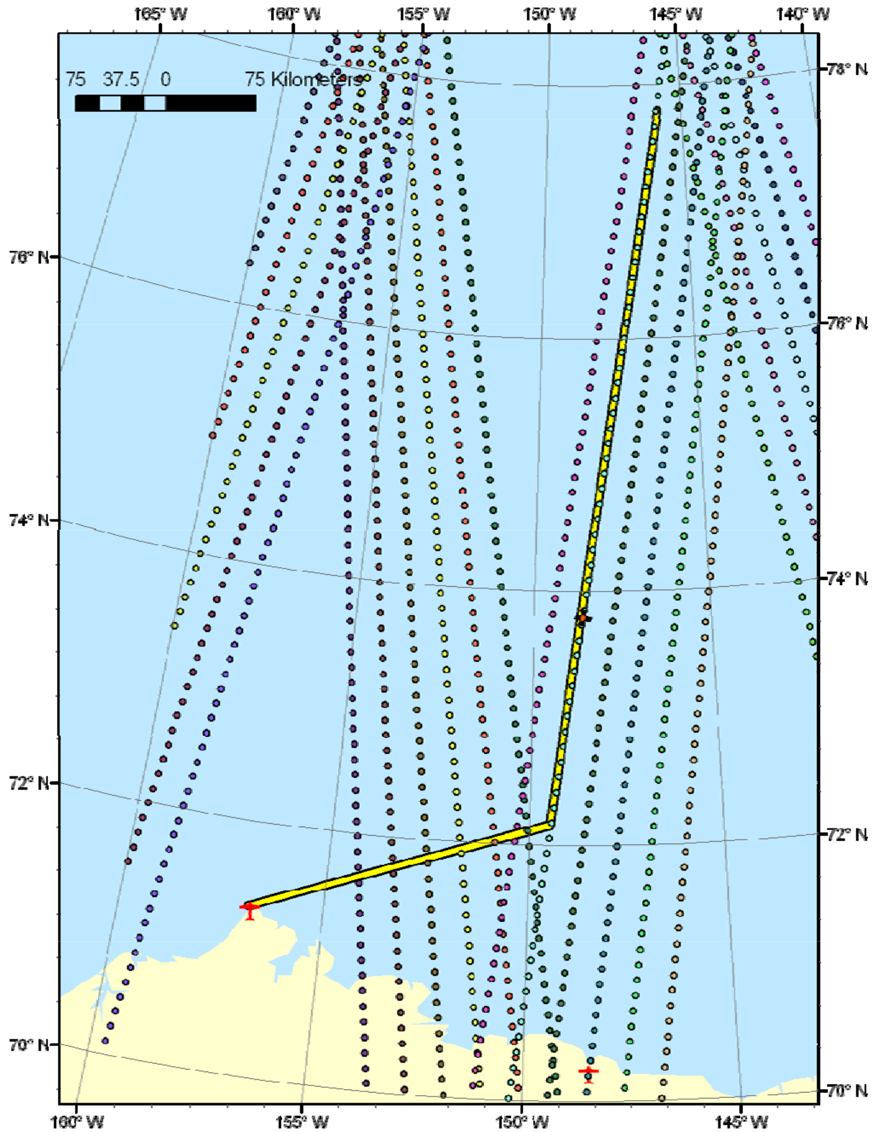



GreenArc Project, April 09: Danish Ice Camp
2-km validation line, all near shore camp
NOAA Instruments on P-3: Laser and radar altimeters
Freeboard from Laser altimeter
0 1 2 3 4 5
Elevation (m)
S
FYI
MYI, level < 4m
Ice camp
MYI, rubble field > 4m
Validation line, EM31 + snow depth every 5m
MYI, level floe ~ 2m
N

Cryosat2 Satellite Orbit Tracks



Up and Back Flight Along Satellite Track



Notional Grid Flight Profile Over Ice Camp