ARCUS Session 2.1

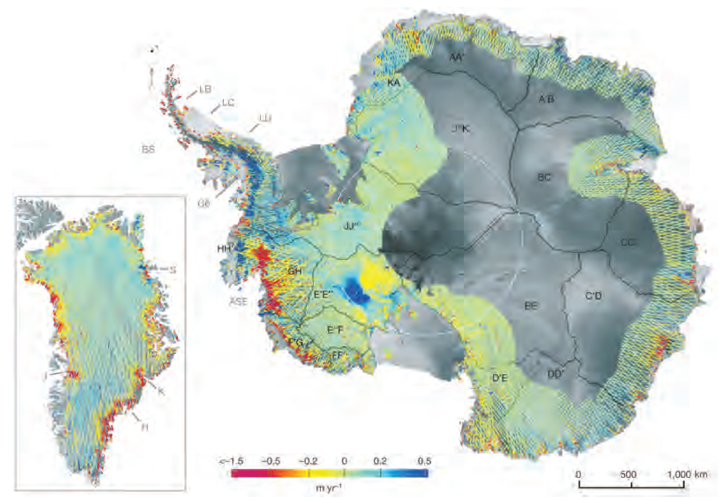
Operation IceBridge: Using instrumented aircraft to fill the observational gap between ICESat-1 and ICESat-2

Seelye Martin, University of Washington; Lora Koenig, GSFC; Michael Studinger, UM

The ICESat-1 satellite, which provided laser altimeter measurements of ice sheet elevations and sea ice freeboard, failed in 2009. Because its replacement, ICESat-2, is not scheduled for launch until about 2015, NASA began in 2009 a five year series of instrumented aircraft polar experiments under the name IceBridge, that are designed to fill the observational gap between the two satellites. The observations began in spring 2009 with a series of flights over the Arctic Ocean and the Greenland ice sheet that in many cases followed ICESat lines. The aircraft instruments include two scanning laser altimeters, a snow thickness radar that measures snow depth on sea ice, an ice penetrating radar that determines bedrock depth through ice as thick as 4 km, and a gravimeter. In fall 2009, the observations continued with flights over the Antarctic Peninsula, West Antarctica and the Antarctic sea ice. The second Arctic experiment will begin in March 2010. Use of the gravimeter, laser altimeters, and ice penetrating radar over the ice sheets allow for airborne mapping of the bedrock topography beneath the ice sheets and glaciers, as well as the size and shapes of the cavities beneath ice shelves and ice tongues. Examples include the pre-IceBridge discovery of a Grand Canyon scale trench beneath the Jacobshavn glacier outlet, and a sinuous channel under the Antarctic Pine Island Ice Tongue. IceBridge will have strong interaction with the ice sheet numerical modeling community, with a goal to provide Greenland bottom topography at the resolution required by the modelers. For the sea ice cover, the aircraft observations permit simultaneous measurements of the sea ice freeboard and of the snow thickness. These two measurements permit determination of sea ice thickness along the aircraft lines, which in the Arctic are designed to cover regions of first and multi-year ice. For the future, plans are being made to carry out some IceBridge observations from the un-manned Global Hawk aircraft. In summary, the five year ICE BRIDGE program continues the ICESat observations over the rapidly changing features of the ice sheets and sea ice, and through use of systematic gravity and ice-penetrating radar measurements, will provide the necessary bedrock and bottom topography measurements required by the numerical ice sheet models.

Background

As of October 11, 2009, Laser 2 of the Geoscience Laser Altimeter System (GLAS) onboard the ICESat satellite stopped emitting light pulses. Since this time, no new science data have been returned. The replacement, ICESat-II will not be ready until 2015. To fill the observational gap between ICESAT-1 and ICESat-2, NASA is carrying out a series of aircraft experiments under the name IceBridge.



ICESat-I measurements of the change in the Greenland and Antarctic ice elevations for the period 2003-2007. White dashed line (at 81.5°S) shows southern limit of radar altimetry measurements, white solid lines show the ICESat tracks. Labels are for sites and drainage sectors. The figure shows the regions of loss in the coastal areas of the two continents (from Pritchard et al., Nature 461, 971-975, 15 October 2009).

Science Objectives

1) Make airborne laser altimetry measurements over the ice sheets and sea ice to fill in the data gap between the failure of ICESat-1 in 2009 and the launch of ICESat-2 planned for 2015.

2) Link measurements made by ICESat, ICESat-2, and CryoSat-2 to allow their comparison and the production of a long-term, ice sheet altimetry record.

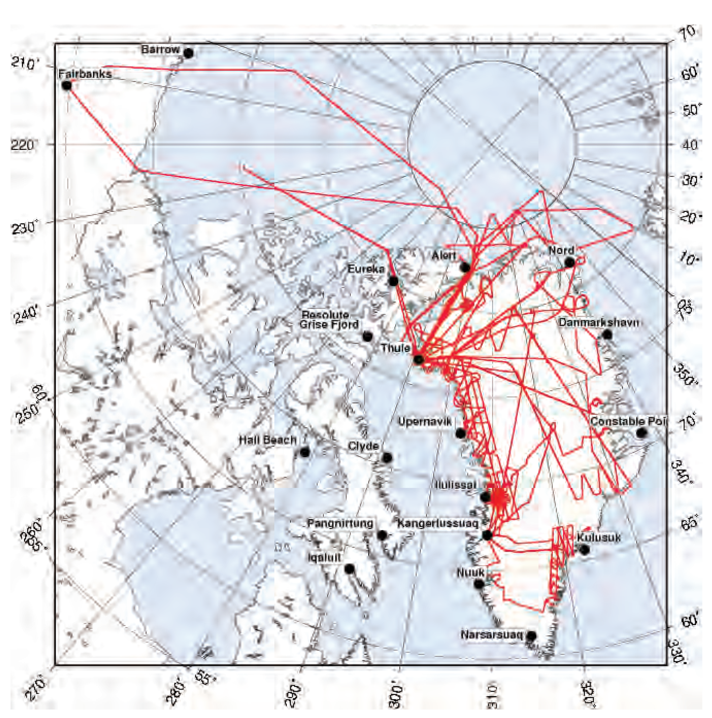
3) Use airborne altimetry and radar to monitor key, rapidly changing areas of ice, including sea ice, ice sheets and glaciers, in the Arctic and Antarctic to maintain a long term observation record, improve understanding of glacial dynamics, and augment predictive models of sea level rise and sea ice cover.

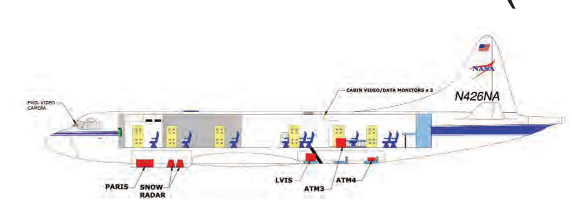
4) In conjunction with altimetry measurements, collect other remotely sensed data including the following:

Ice sheet thickness, structure and extent;
Bed topography underlying land-based ice;
Bathymetry beneath floating ice shelves;
Snow accumulation and firn structure.

Flight Lines and Instruments 2009

Greenland Instruments (P-3)



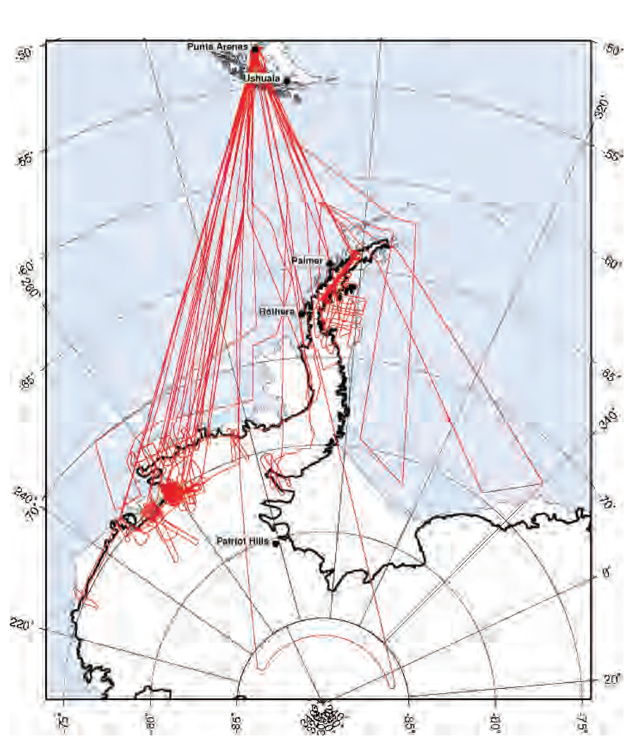


LVIS: Laser Vegetation Imaging Sensor
ATM: Airborne Topographic Mapper
PARIS: Pathfinder Airborne Radar Ice Sounder
Kansas Snow Radar: Sea ice snow depth radar

Highlights of Greenland survey (150 hrs):
Sea Ice Flights:
* Determine the ice thickness and snow depth along tracks extending across first year, multiyear ice. The Thule-Fairbanks and the Fram Strait tracks will be repeated in the coming years.

Ice Sheet Flights:
*Determine the ice sheet elevation and bedrock topography for the coastal glaciers, and fly ICESat lines for intercalibration between ICESat-1 and ICESat-2.

Antarctic Instruments (DC-8)



Lines represent 21 missions, or 227.4 flight hours, or 83,858 nautical miles, or 96,564 statute miles, or 155,137 km flown (about 4 times around the Earth at the equator)

LVIS: Laser Vegetation Imaging Sensor
ATM: Airborne Topographic Mapper
PARIS: Pathfinder Airborne Radar Ice Sounder
CReSIS Suite
- Sea ice snow depth radar
- Ku-band altimeter
- MCoRDS ice penetrating radar

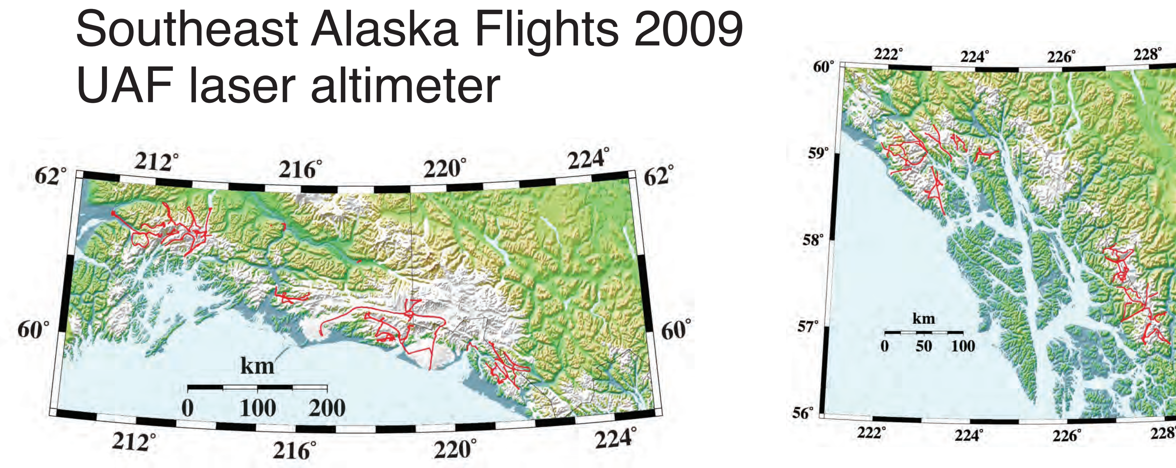
DMS: Digital Mapping Camera
Gravimeter

Highlights of Antarctic survey (250 hrs):

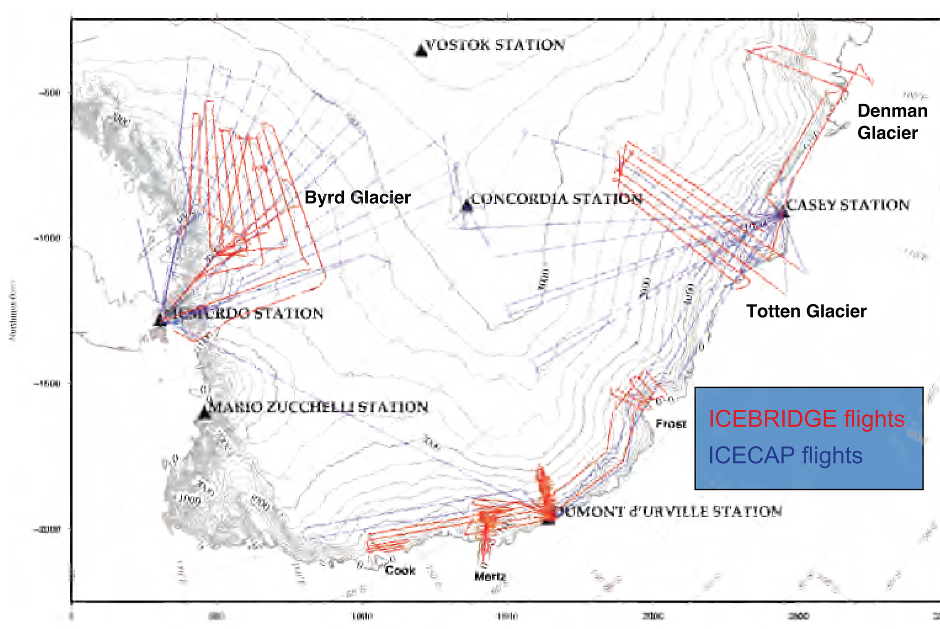
Sea Ice Flights:
* First successful aircraft sea ice flights in the Weddell Sea

Ice Sheet Flights:
*LVIS DEM over northern Antarctic Peninsula
*Determination of bottom topography beneath Pine Island Ice Tongue from gravity anomaly measurements
*Repeat of ICESat tracks over Pine Island Bay region;
*Mapping of Larsen C iceshelf.

Southeast Alaska Flights 2009
UAF laser altimeter

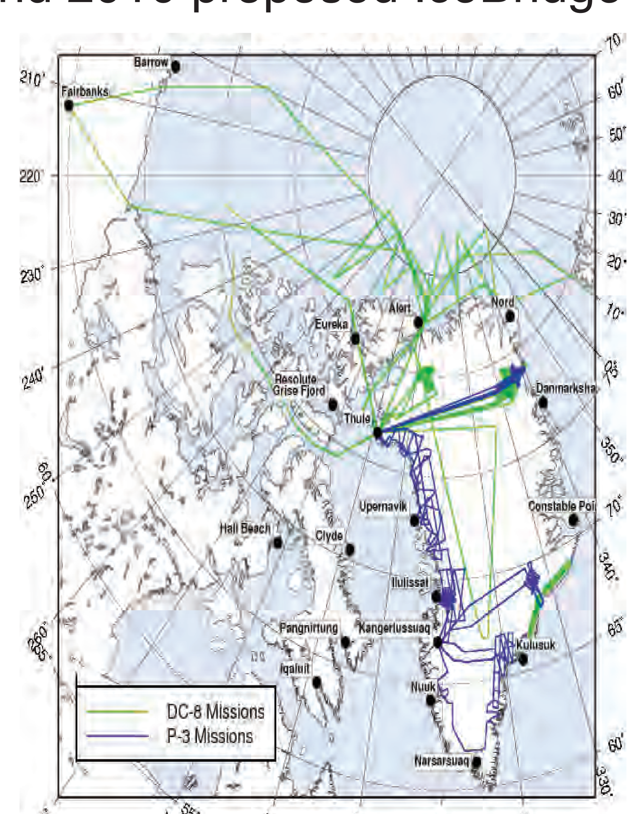


ICECAP/IceBridge Flights 2009-10 (some lines were funded by IceBridge)



Courtesy BBC

Greenland 2010 proposed IceBridge flights

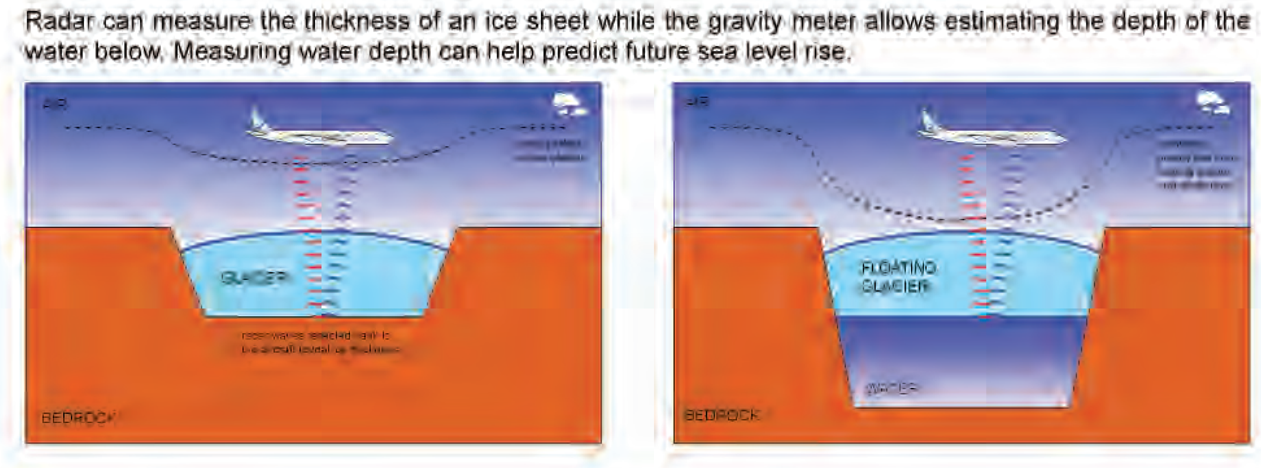


- 125 Hours on the DC-8
- 100 Hours on the P-3
- Break down
  - 8 Sea Ice flights (1 LVIS)
  - 15 Ice Sheet flights (3 LVIS)

- March 22- April 28, 2010 DC-8 in Thule, Greenland
- May 3- May 16, 2010 P-3 in Kangerlussuaq, Greenland
- May 17-May 28, 2010 P-3 in Thule, Greenland

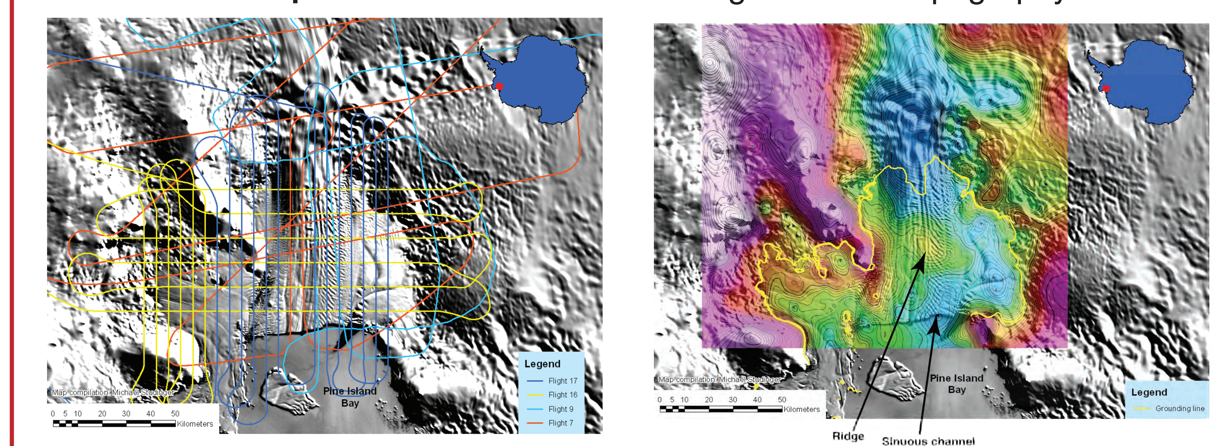
Measurement of ice thickness and topography beneath ice shelves by aircraft

Radar can measure the thickness of an ice sheet while the gravity meter allows estimating the depth of the water below. Measuring water depth can help predict future sea level rise.



Data Examples

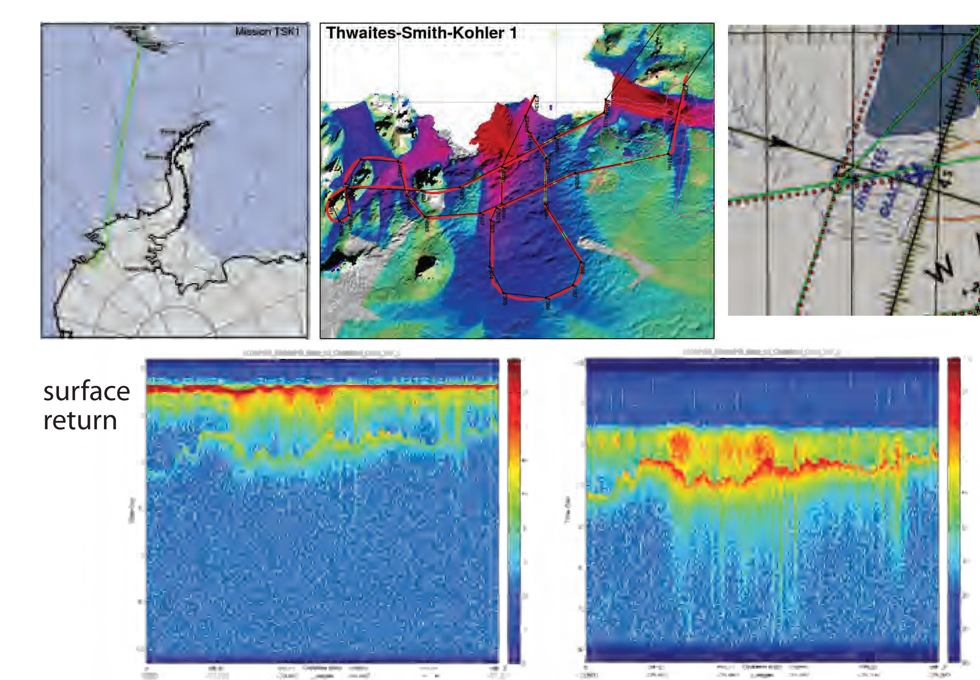
Pine Island Ice Tongue bottom topography



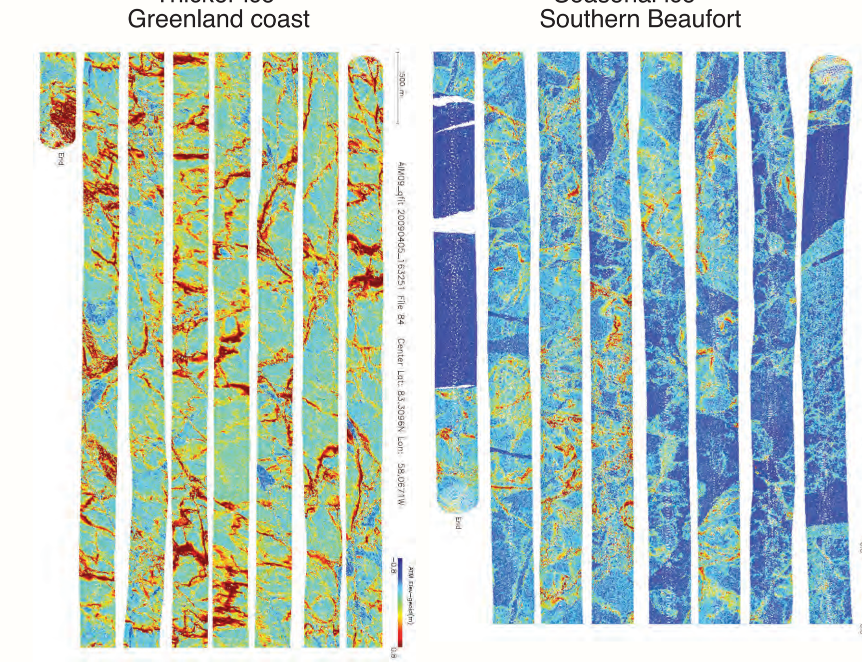
Flight lines over Pine Island Tongue (superimposed on MODIS image)

Topography determined from flights: blue shows the deep sinuous channel; green and yellow mark the ridge.

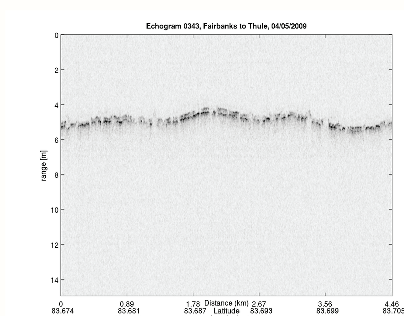
Thwaites example of CReSIS ice penetrating radar Nov 2, 2010



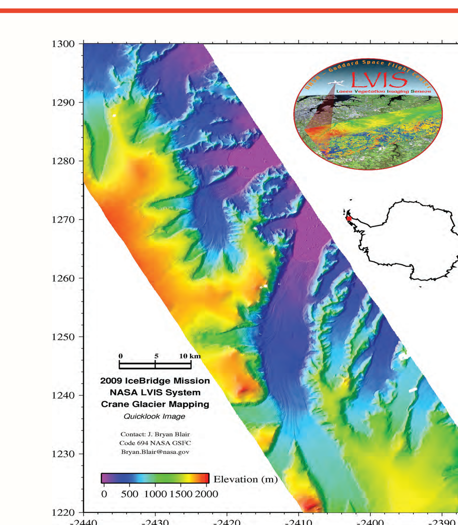
Results from scanning ATM laser images of sea ice



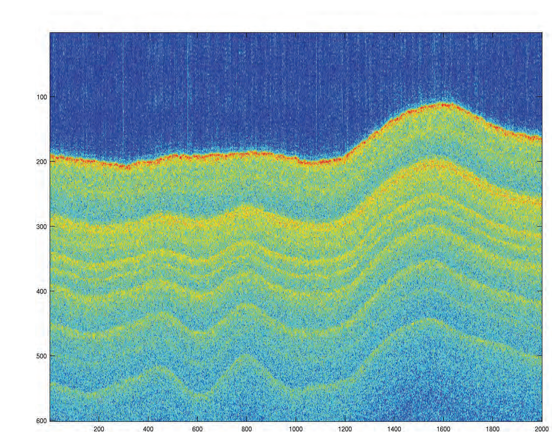
(red is pressure ridges, dark blue is open water)



Snow thickness radar results Arctic Ocean, Fairbanks-Thule (oscillation is due to variation in tides and geoid)



LVIS DEM of Crane Glacier



Ice Sheet internal layering revealed by CReSIS radar

For Additional Information:

- www.nasa.gov/icebridge
  - Education and Outreach
- http://www.espo.nasa.gov/oib/
  - Logistics and Data Meeting Presentations
- http://neptune.gsfc.nasa.gov/csb/
  - Cryospheric Science Branch for telecon notes, etc.