NASA IceBridge:
Scientific insights from airborne surveys of the Arctic sea ice cover

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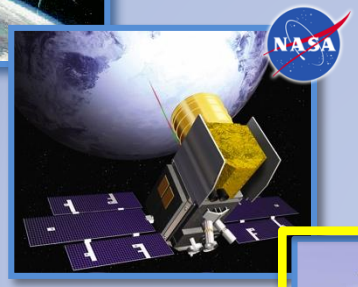
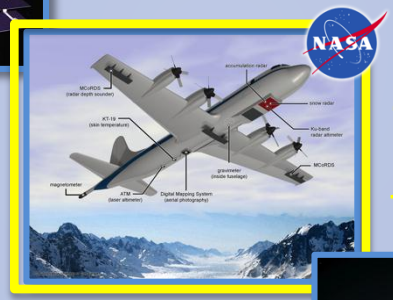
Two Decades of Polar Altimetry

ERS-1 and -2: 1991- 2000, 1995 – 2003 RA-2 Radar Altimeter

Envisat: 2002 – 2012 RA-2 Radar Altimeter



ICESat: 2003 – 2009 GLAS Laser Altimeter



Operation IceBridge (OIB): 2009 - 2018

CryoSat-2: 2010 – present
SIRAL Radar Altimeter

ICESat-2 Launch: ~ 2017

OIB: Bridging a gap between satellite missions

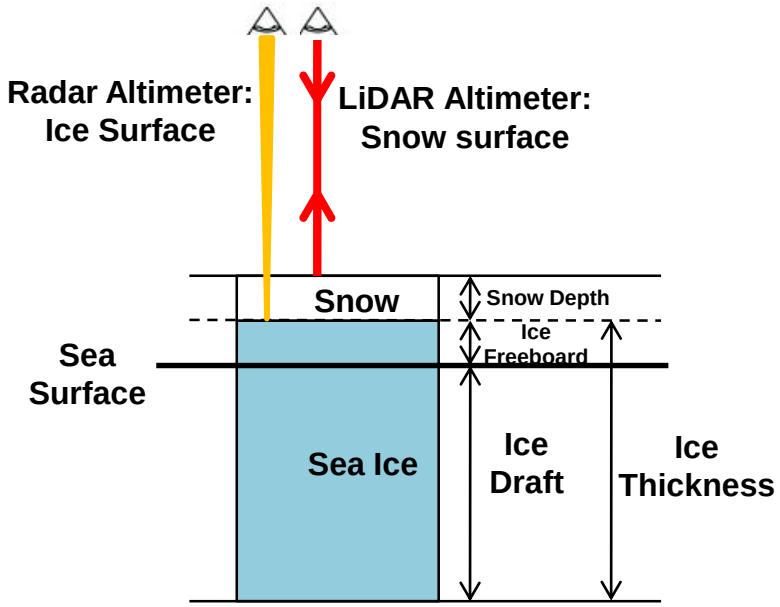
IceBridge Sea Ice Mission Goals

- ***Document spatial and interannual changes in mean sea ice thickness*** ***and the thickness distribution in the Arctic and Southern Oceans between ICESat and ICESat-2, in support of climatological analyses and assessments.***

- ***Improve sea ice thickness retrieval algorithms*** ***by advancing technologies for measuring sea ice surface elevation, freeboard, and snow depth distributions on sea ice.***

Sea Ice Thickness: Airborne and Satellite Altimetry

An inferred measurement



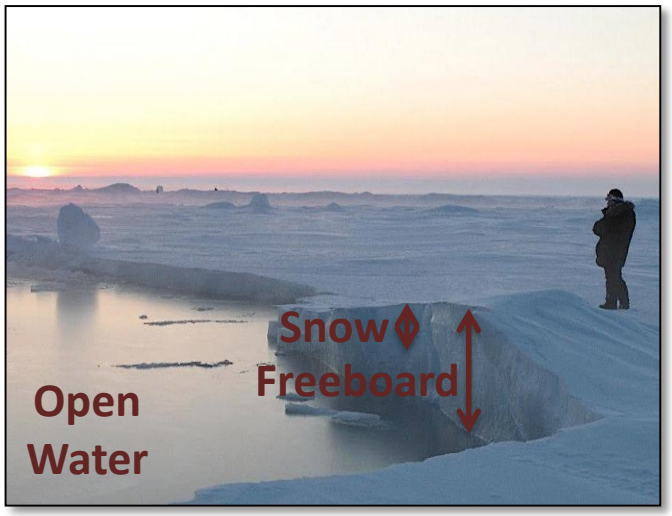


Photo Credit: Andrew Roberts, SEDNA 2007

- Measure surface elevation of snow, ice and open water
- Derive sea ice freeboard
- Assume equilibrium of floating ice cover
- Infer ice thickness, a function of:
  - Snow, ice and water density
  - Snow depth
  - Ice freeboard
- Ice thickness uncertainty primarily influenced by errors snow depth

Sea Ice Thickness: Airborne and Satellite Altimetry

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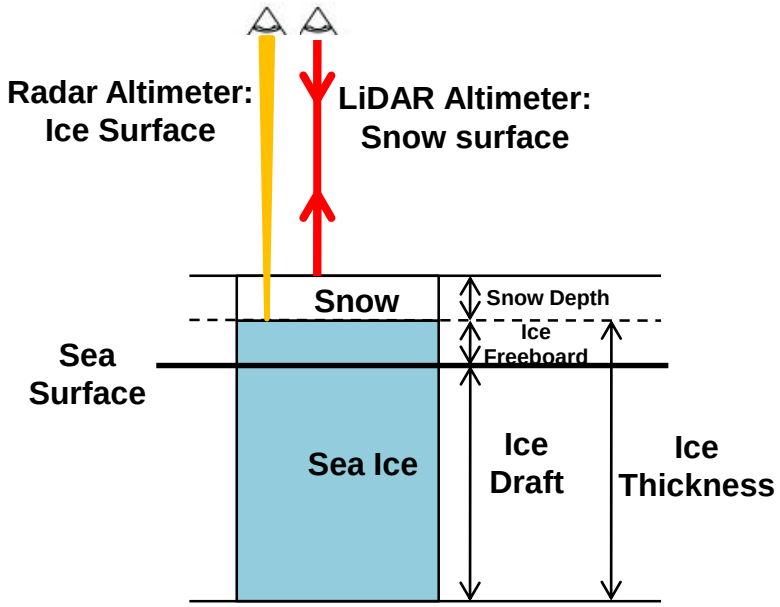

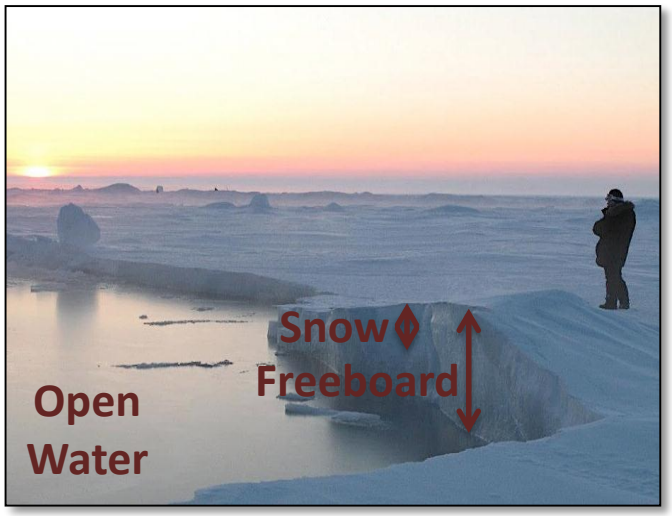

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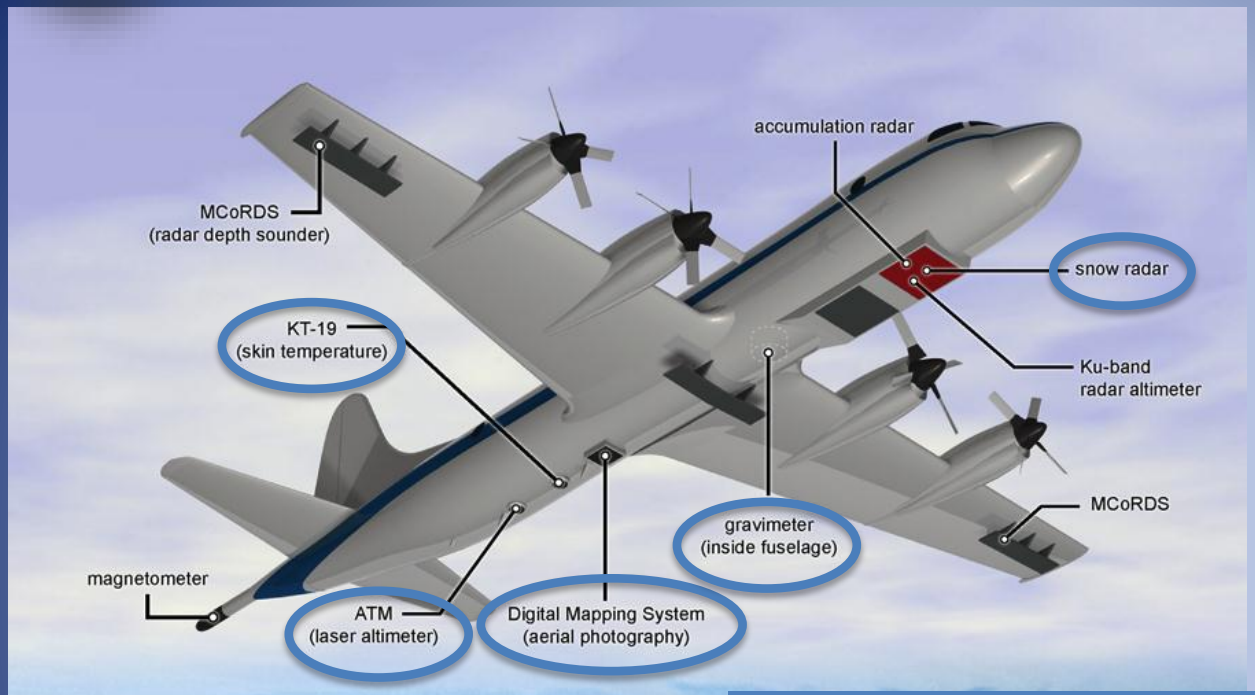
Concentrated area of research to define and reduce uncertainty

NASA Operation IceBridge



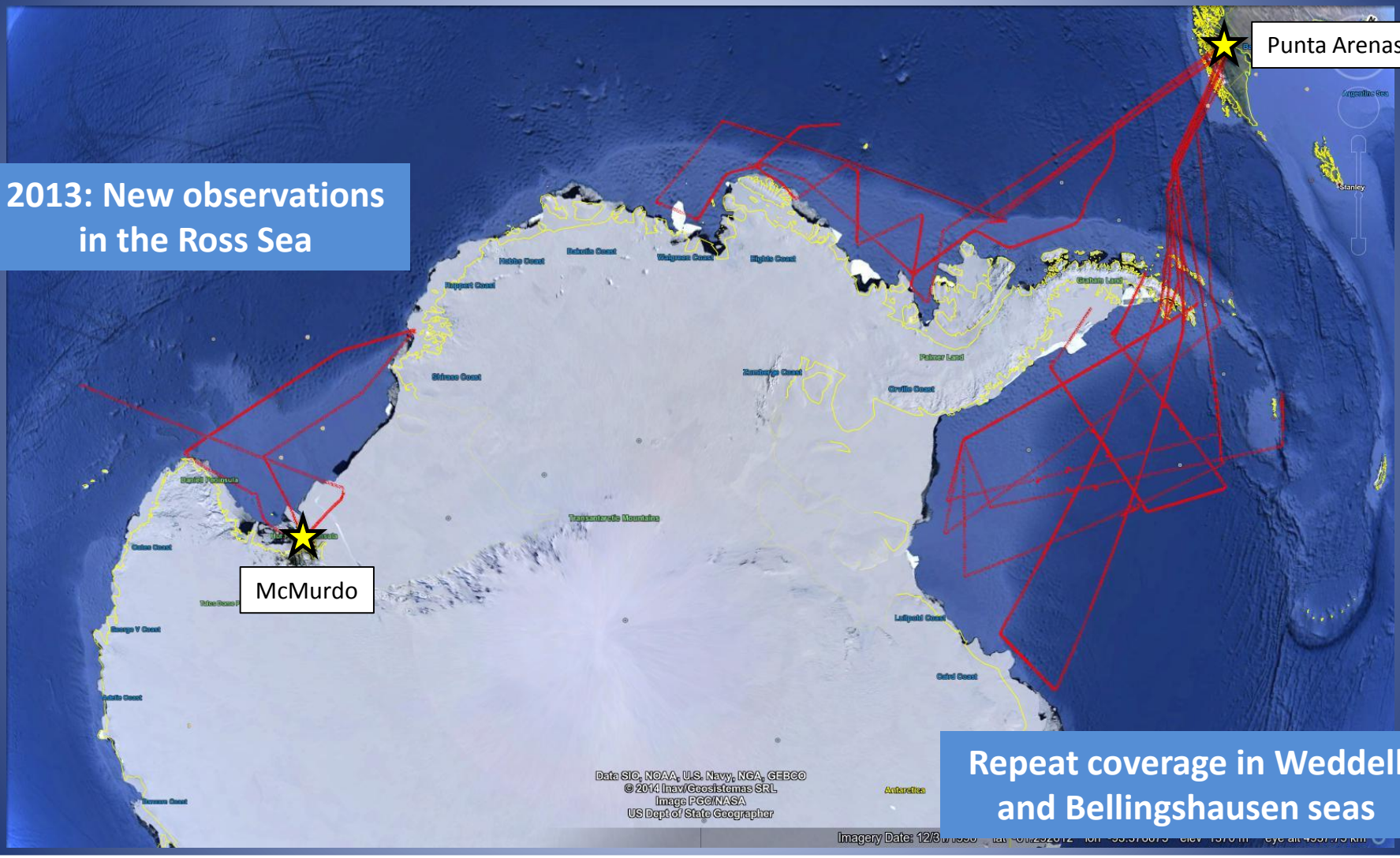
Sea Ice Data Sets: Instrumentation

- Surface Topography: ATM Laser Altimeter
- Snow Depth: Snow Radar
- Sea Ice Morphology: High res. digital photography
- Gravity field: LDEO Gravimeter
- Surface temp/lead detection: Thermal imager (KT19)

More info: icebridge.gsfc.nasa.gov & nsidc.org/data/icebridge/

Antarctic Sea Ice Flights

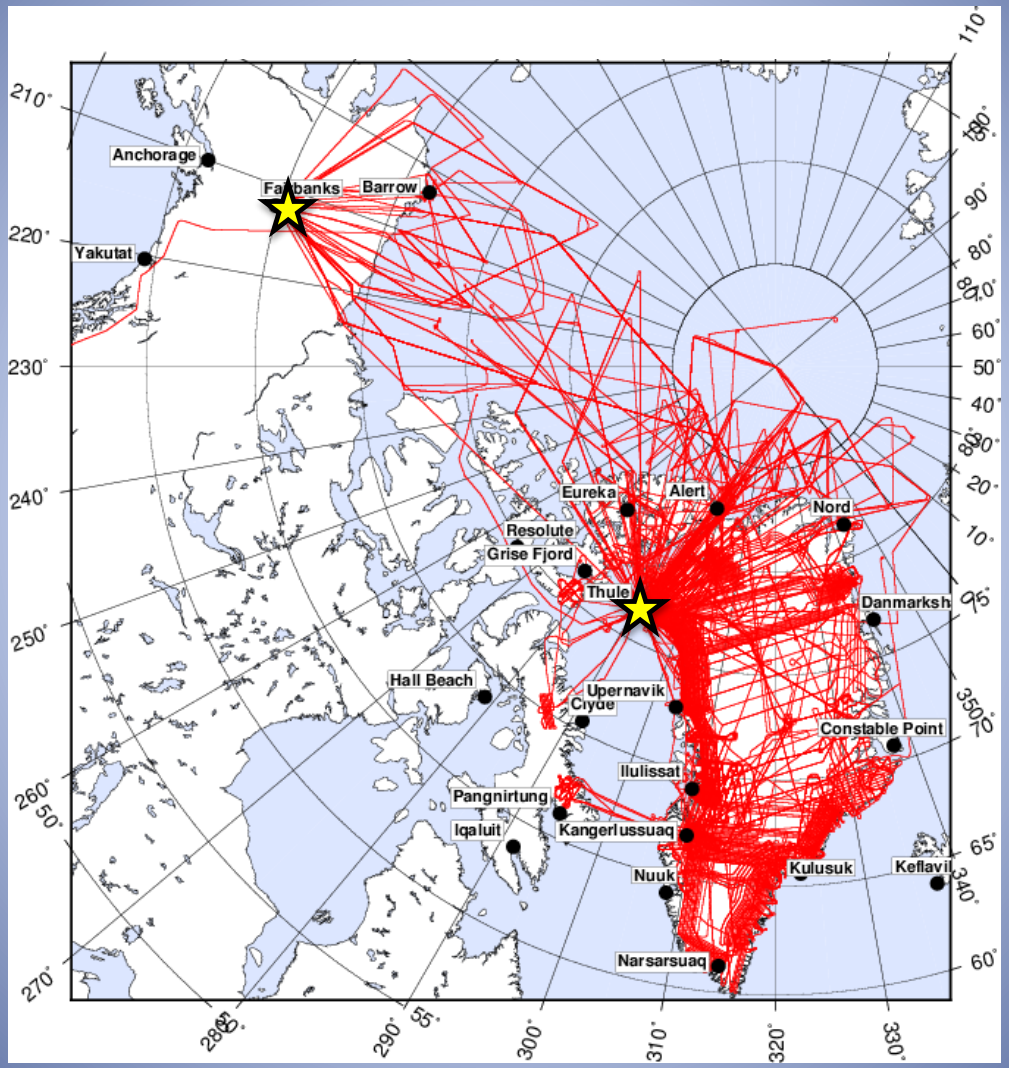
October/November 2009-2014



Complicated by flooding of sea ice surface due to heavy snow loads

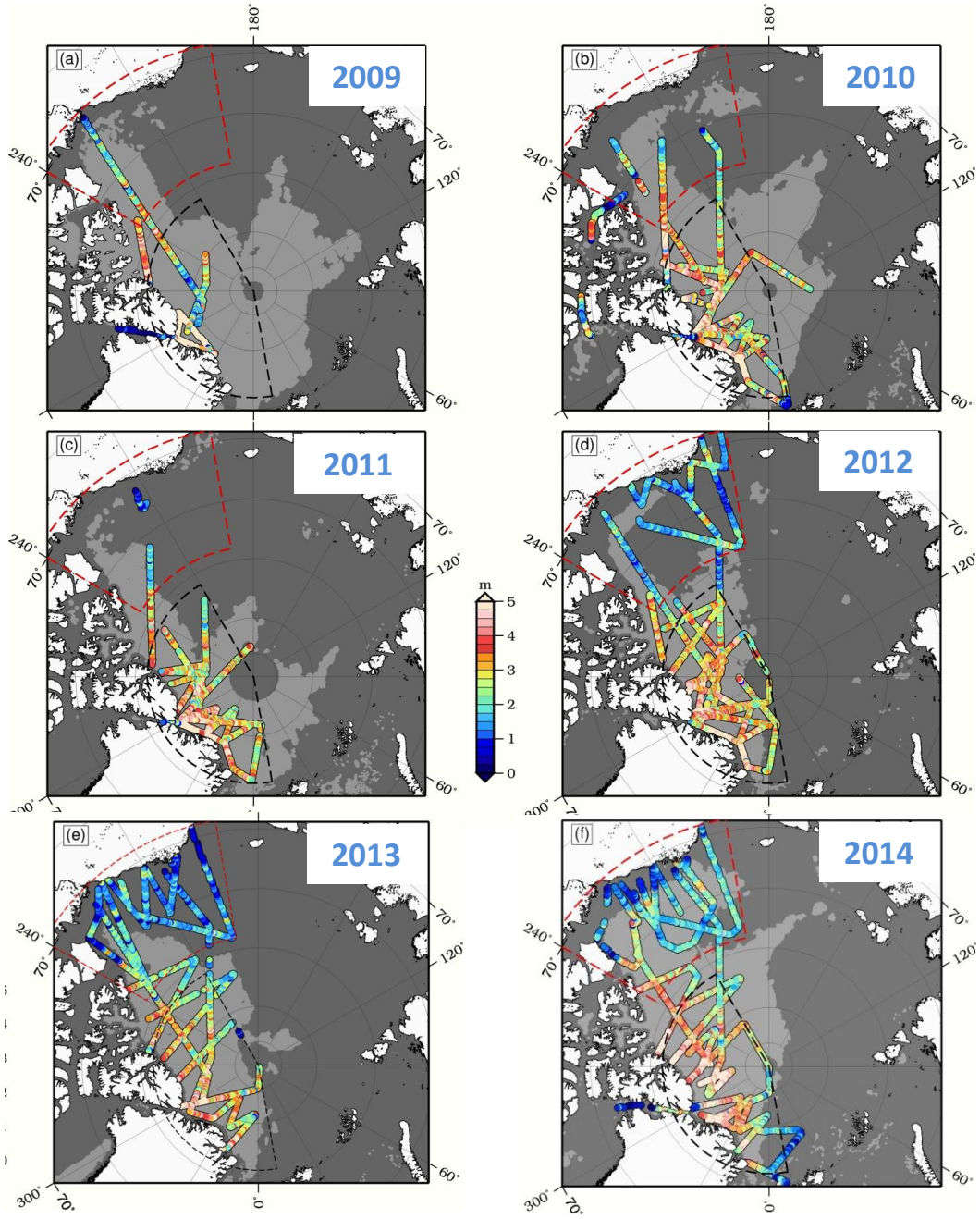
Arctic Sea Ice Flights

March/April 2009-2015



Extensive coverage over the Western Arctic Ocean

Sea Ice Thickness in the western Arctic

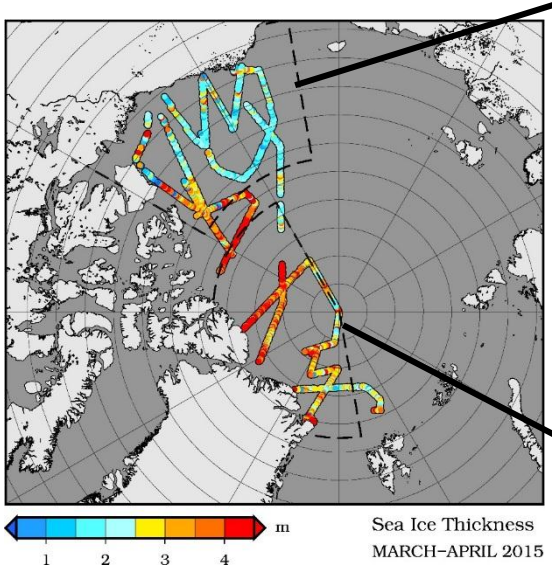


- Observations collected in March/April: near end of winter growth season
- Response to community input:
  - Increased coverage in Beaufort and Chukchi seas and Canada Basin
  - Thule and Fairbanks-based operations
  - Quick look product: available ~1 month after campaign
- Ice thickness gradients apparent
- Product support for seasonal forecasting: Summer melt evolution

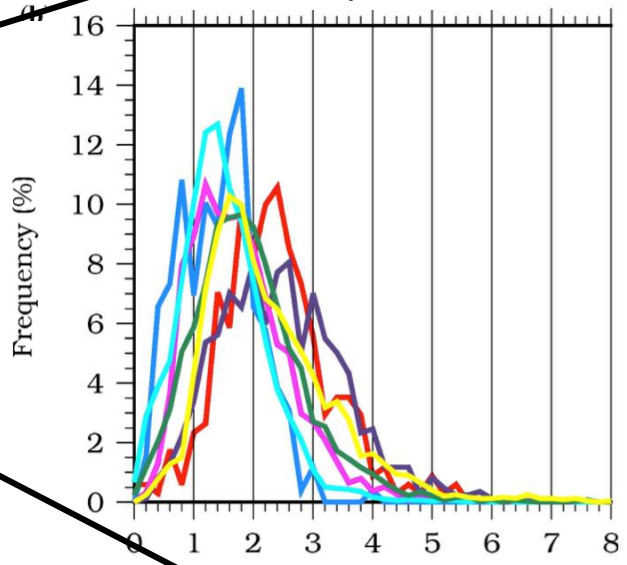
Updated from: *Richter-Menge and Farrell* (2013), GRL

Sea Ice Thickness: Interannual Variability

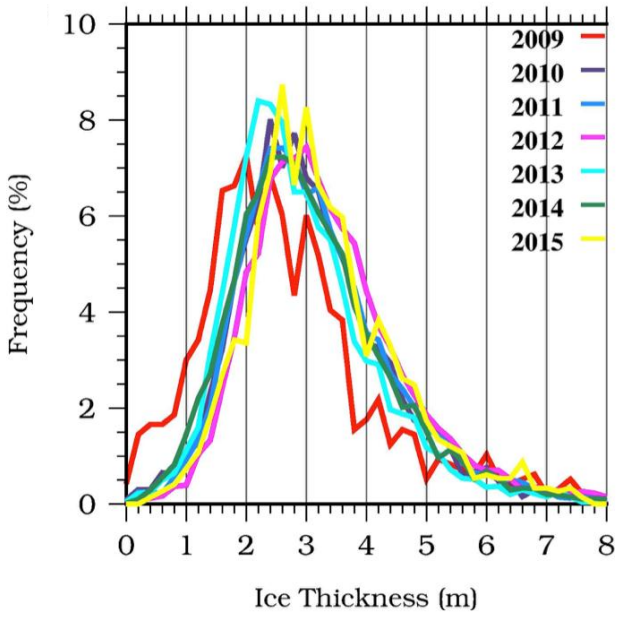
March/April 2009-2015



Beaufort/Chukchi



Central Arctic



Central Arctic:

- Predominantly multi-year
- Stable mean and modal ice thickness
- Mean: 3.2 m, mode: 2.5 m

Beaufort/Chukchi seas:

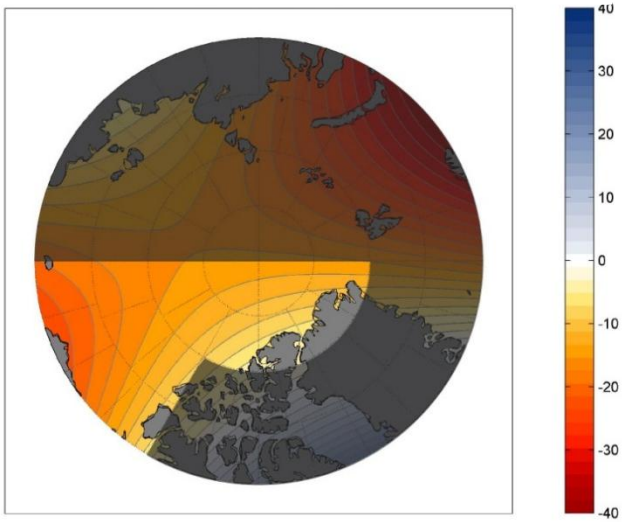
- More seasonal in nature
- Mix of multiyear (~25 %) and first-year ice (~75 %)
- Ice thickness distribution more variable
- Mean: 2.1 m, mode 1.8 m
- Inter-annual variability primarily related to the presence and location of a band of multi-year sea ice in the southern Beaufort Sea

Richter-Menge and Farrell (2013) GRL, updated

NASA IceBridge

Snow depth on sea ice a key stand-alone product

OIB snow depth (2009-2013)
compared to Warren et al. (1999)

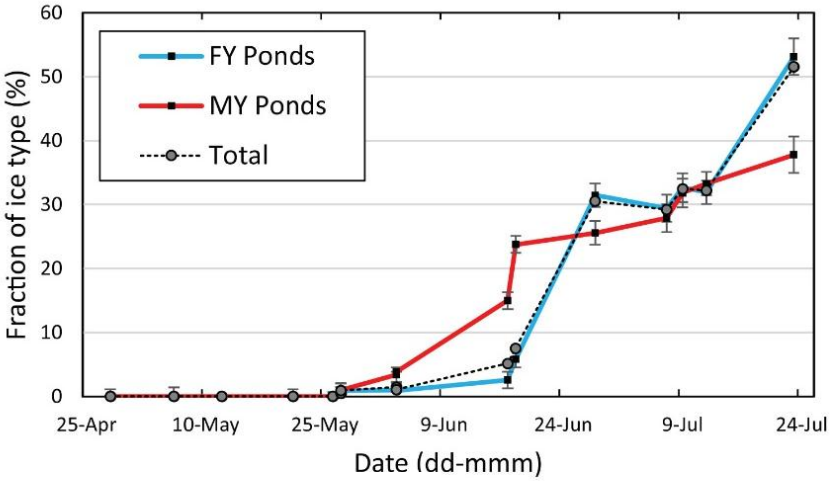


Webster et al., 2014

2011

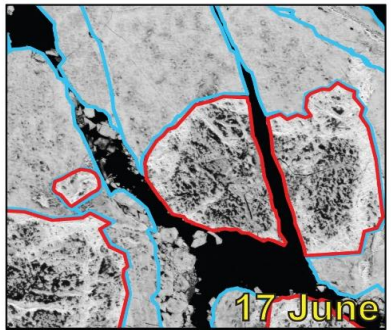
Evolution of surface conditions

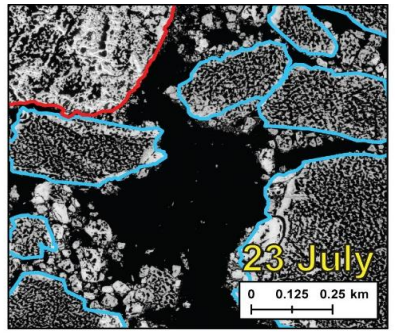
- Pond formation function of ice types
- Ponds formed on MYI before FYI
- Snow depth distributions drive timing and progression of melt



Snow climatology

- Snow depth decline in western Arctic
- Most pronounce in Beaufort and Chukchi seas region
- Thinning negatively correlated with the delayed onset of fall freezeup

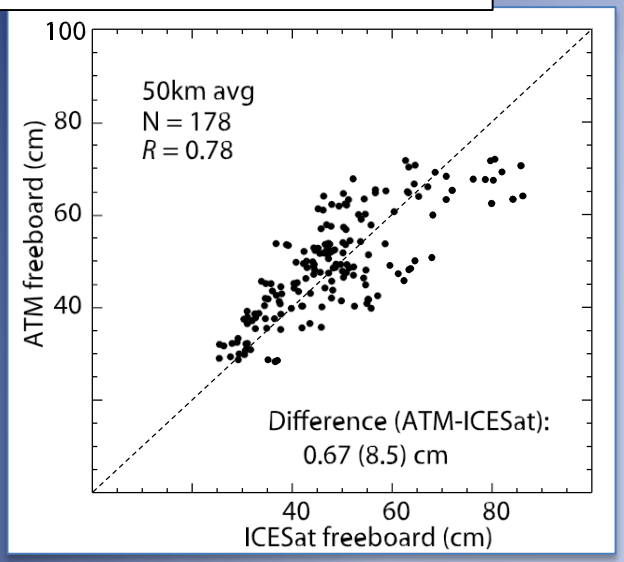




Webster et al., 2015

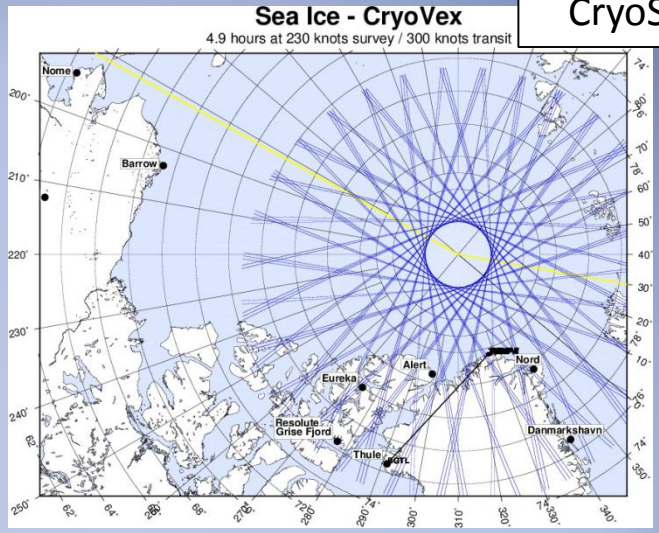
Advancing satellite observations

Comparison with ICESat obs

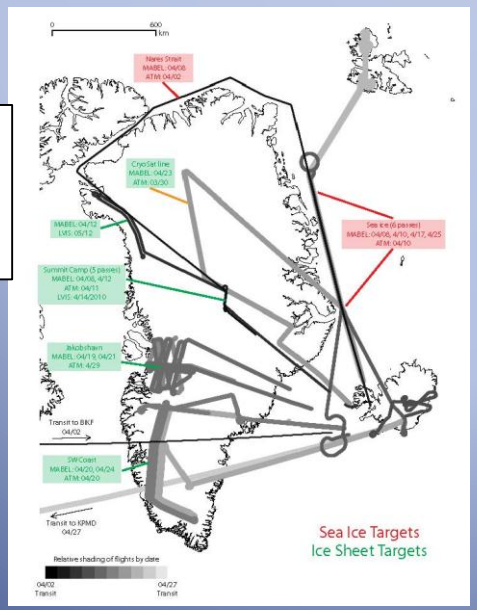


Kwok et al., 2012,JGR

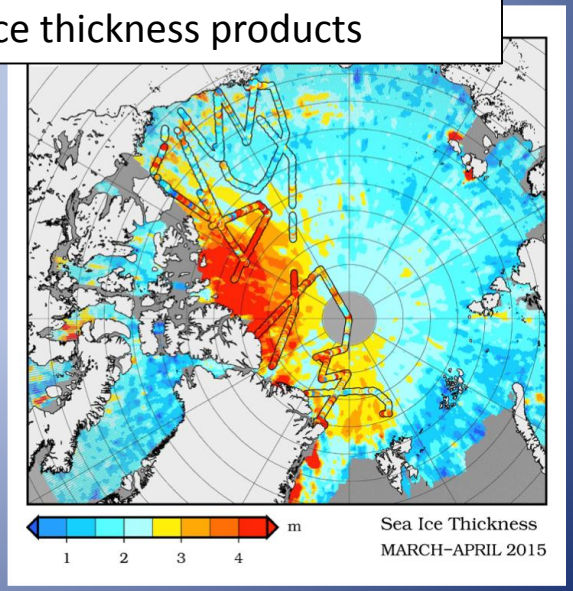
CryoSat-2 under flights



Coordination with ICESat-2 airborne simulators

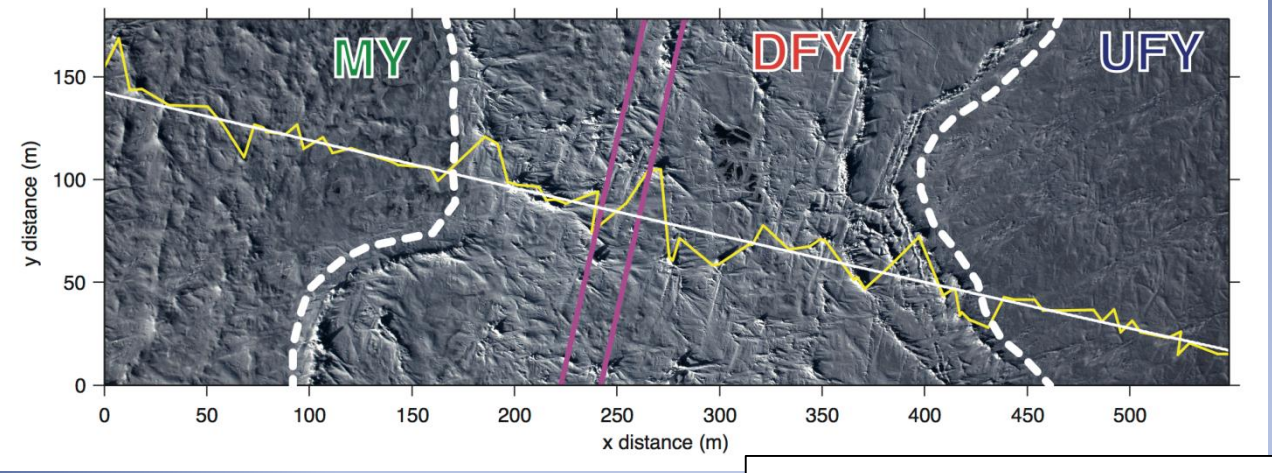


Comparing IceBridge and CryoSat-2 ice thickness products



Provided by S. Farrell

Improving in situ observations

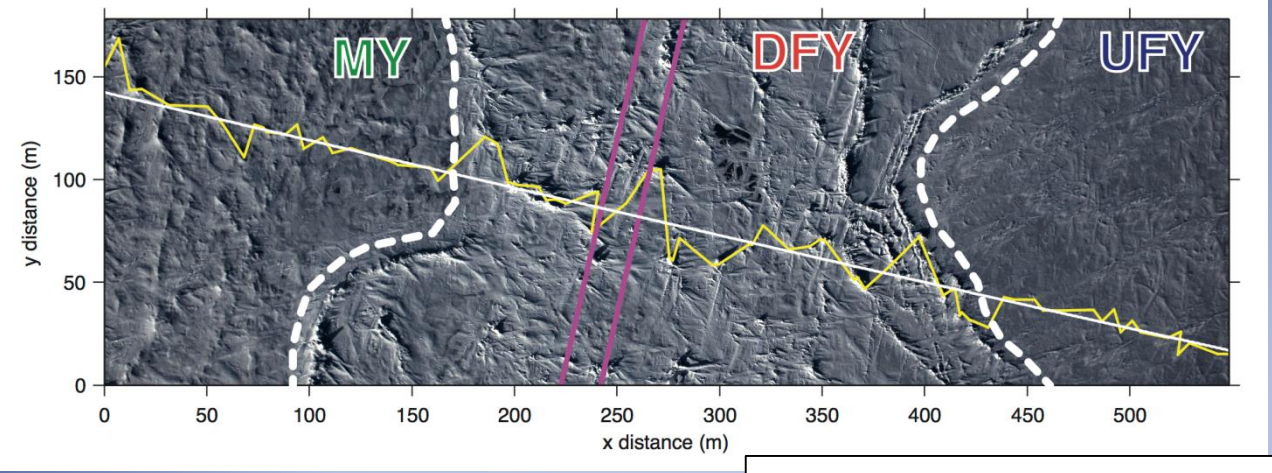


Newman et al., 2014,JGR

March 2011: 9k-long survey line @ 5m spacing

Results show the impact of surface roughness on snow radar return signal

Improving in situ observations



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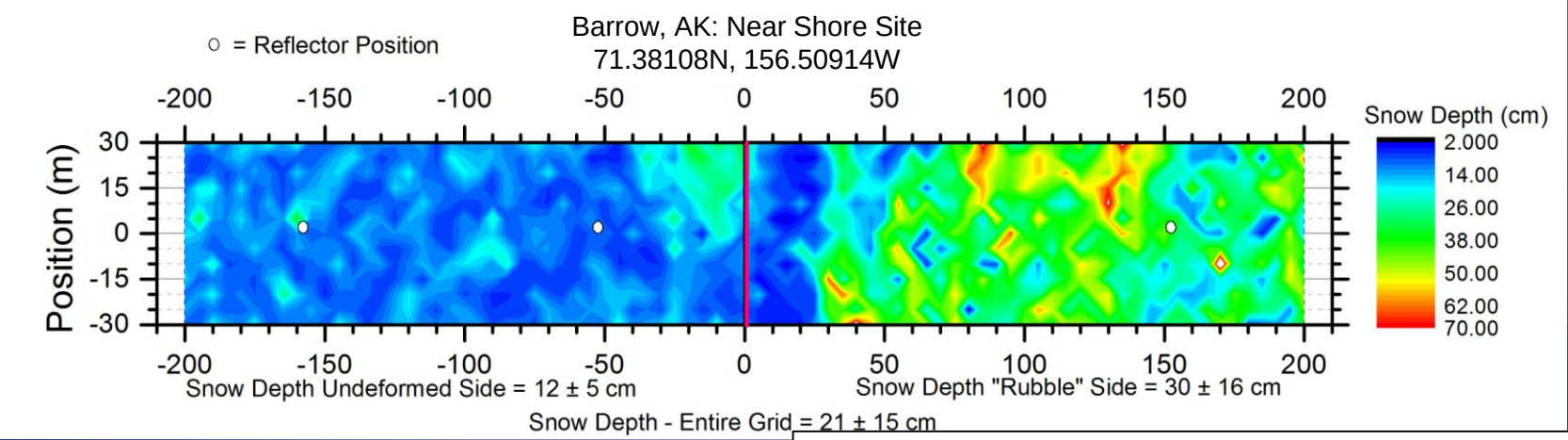
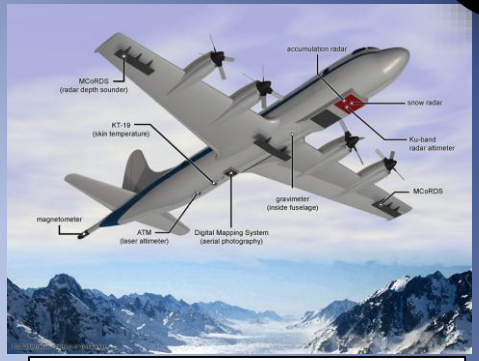


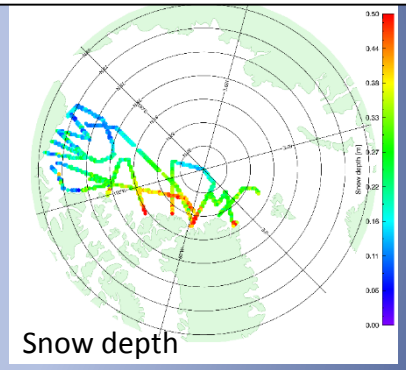
March 2014: 400m x 60m grid @ 5m spacing

Summary

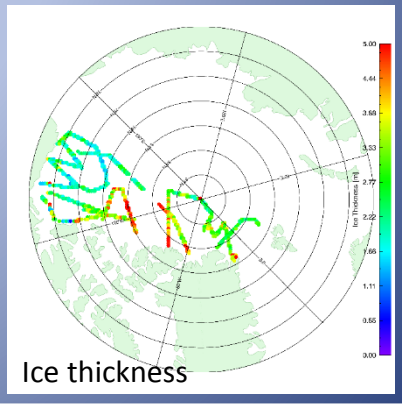
- NASA Operation Ice Bridge filling important observational gap, complementing satellite records
- 7-year record of Arctic sea ice thickness in western Arctic: 2009-2015
- Scheduled to continue through 2018
- Novel data on snow depth, surface roughness and surface conditions
- Leading to improved interpretation of satellite observations and technology development
- Contributing to significant scientific advancements in understanding processes governing observed change
- All data available to community



2015 Quick Look Products



Snow depth



Ice thickness

More info: icebridge.gsfc.nasa.gov & nsidc.org/data/icebridge/