Interannual Variability in Contemporaneous Measurements of Arctic Snow and Sea Ice Thickness from Airborne Altimetry

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Outline

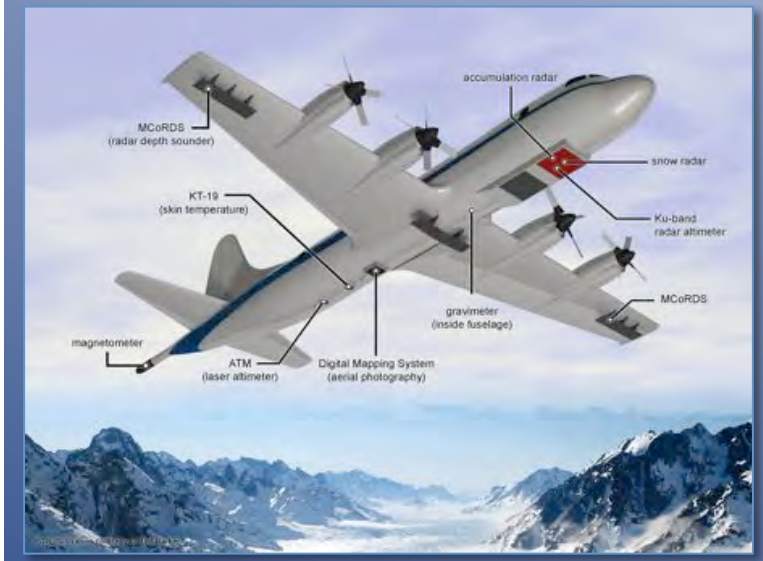
- **Contemporaneous Arctic Sea Ice Thickness & Snow Depth Observations**

  6 years of measurements: NASA's Operation IceBridge (2009-2014)
- Region of Coverage: Beaufort Sea, Canada Basin and Central Arctic
- Tracking interannual variability in first-year and multi-year sea ice types
- Use of model predictions for annual IceBridge Flight Planning:

  NRL "Arctic Cap Now-cast/Forecast System" (ACNFS)
- ACNFS sea ice model vs. IceBridge 2014: Quick Look thickness estimates
- A brief look ahead: Launch of NASA ICESat-2 and MABEL airborne simulator

NASA Operation IceBridge

Airborne mission with a suite of remote sensing instruments, launched in March 2009 to bridge gap between ICESat and ICESat-2



Instruments for snow depth and sea ice thickness:

- ATM Laser Altimeter (lead / floe elevation, surface topography, freebaord)
- FMCW Snow Radar (snow depth)
- High resolution digital camera (lead locations)
- Gravimeter (gravity field)
- KT19 Thermal imager (surface temp)

More info at:

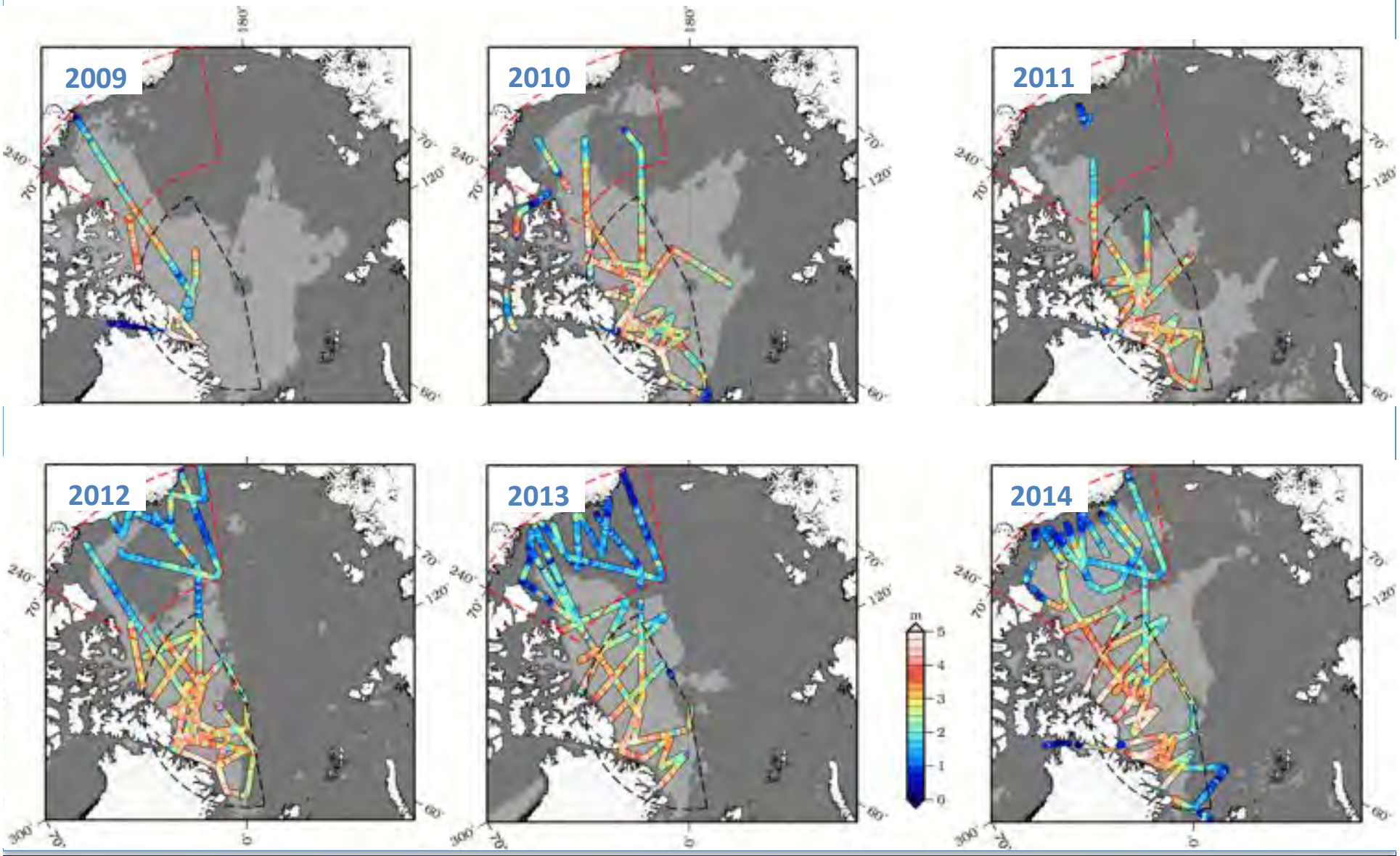
icebridge.gsfc.nasa.gov
nsidc.org/data/icebridge/
nasa.gov/mission_pages/icebridge/
@NASA_ICE

Current sea ice conditions
Southern Weddell Sea
Oct 20th 2014!

Photo Credit: J. Yungel, NASA IceBridge

Sea Ice Thickness Observations

Western Arctic: 2009 – 2014



Sinéad Louise Farrell

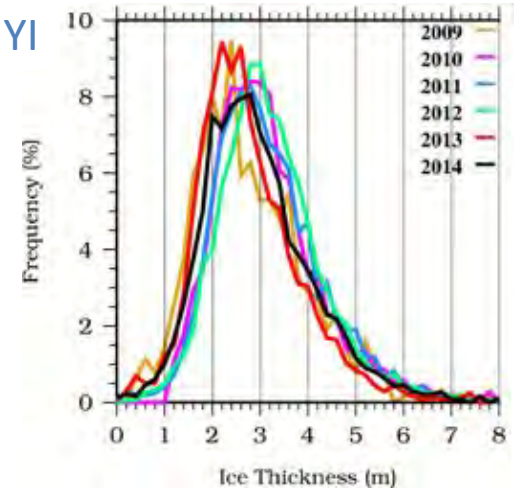
Updated From: *Richter-Menge and Farrell* (2013)

Six-Year Sea Ice Thickness Time Series (2009-2014)

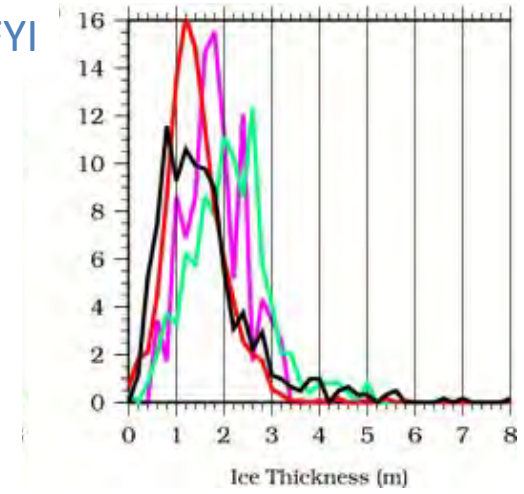
Variability in first-year vs. multi-year ice thickness

	Multi-year Sea Ice Thickness				First-year Sea Ice Thickness			
	Mean (m)	St Dev (m)	Mode (m)	Median (m)	Mean (m)	St Dev (m)	Mode (m)	Median (m)
2009	2.87	1.15	2.5	2.67	NaN	NaN	NaN	NaN
2010	3.27	1.17	2.9	3.09	1.91	0.61	1.9	1.87
2011	3.28	1.15	2.9	3.11	NaN	NaN	NaN	NaN
2012	3.35	1.20	3.1	3.20	2.22	0.83	1.2	2.10
2013	*2.86*	*1.12*	*2.3*	*2.69*	*1.51*	*0.64*	*1.3*	*1.43*
2014	3.07	1.18	2.9	2.90	1.71	1.07	0.9	1.52
6 YR AVG	**3.12**	**1.16**	**2.8**	**2.94**	**1.84**	**0.79**	**1.3**	**1.73**

MYI



FYI

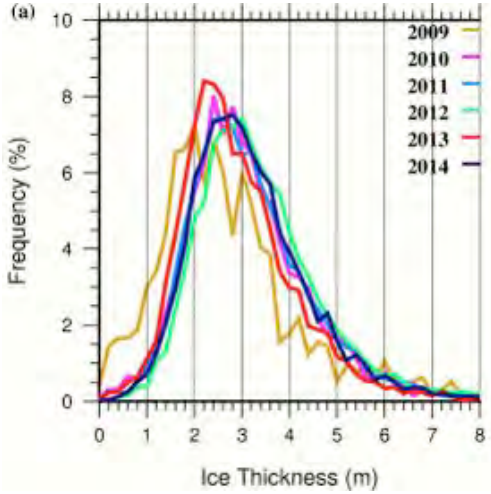


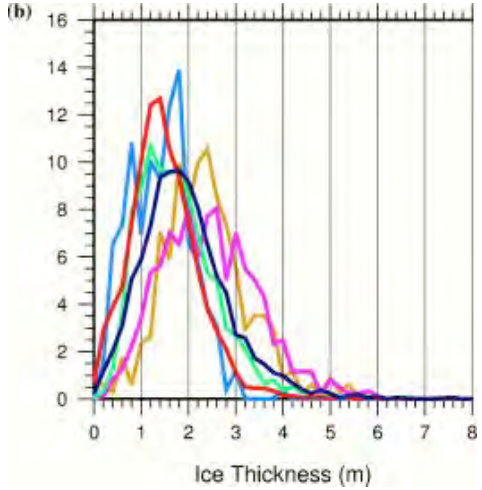
Updated From: *Richter-Menge and Farrell* (2013)

Six-Year Sea Ice Thickness Time Series (2009-2014)

Regional Analysis

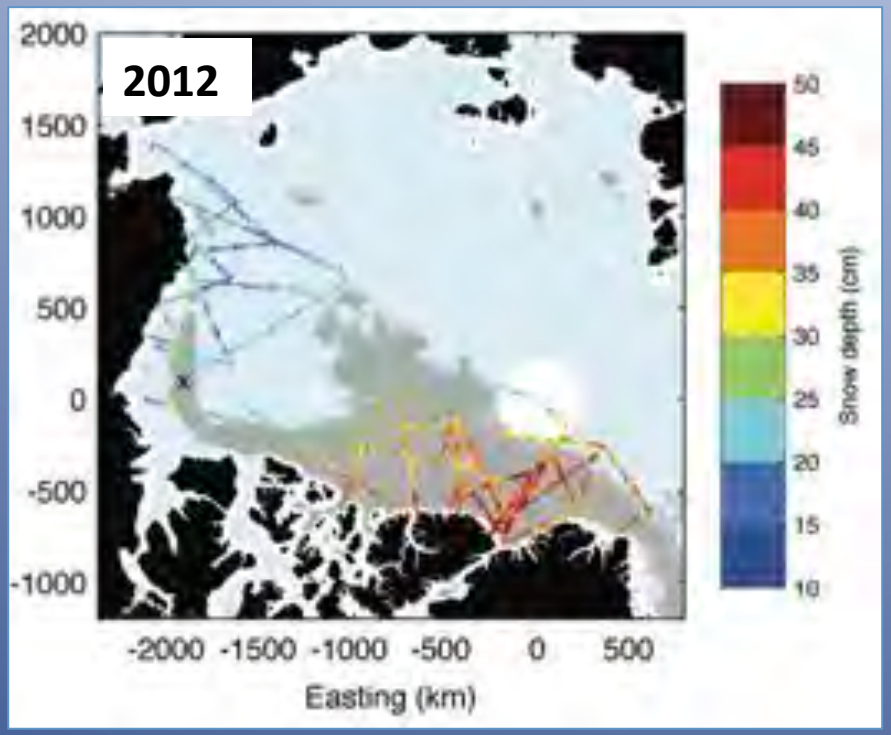
	Central Arctic				Beaufort/Chukchi Seas			
	Mean (m)	St Dev (m)	Mode (m)	Grid Cells (#)	Mean (m)	St Dev (m)	Mode (m)	Grid Cells (#)
2009	2.90	1.69	2.0	965	2.49	1.01	2.4	341
2010	3.23	1.35	2.4	4595	2.57	1.09	2.6	856
2011	3.27	1.32	2.6	6871	1.52	0.65	1.8	259
2012	3.50	1.46	3.0	10670	1.88	0.91	1.2	2152
2013	*3.04*	*1.25*	*2.2*	*5429*	*1.60*	*0.75*	*1.4*	*3729*
2014	3.28	1.27	2.8	5877	2.04	0.95	1.8	3190
6YR AVG	**3.20**	**1.39**	**2.5**	**-**	**2.02**	**0.89**	**1.9**	**-**

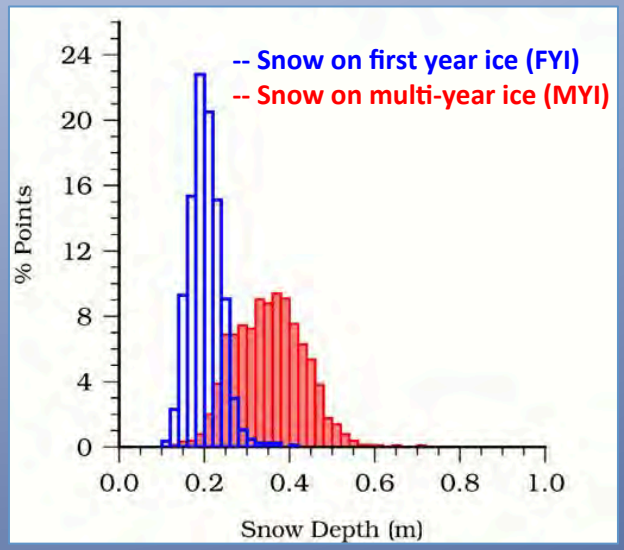




Updated From: *Richter-Menge and Farrell* (2013)

Arctic Snow Depth Estimates
IceBridge Snow Radar



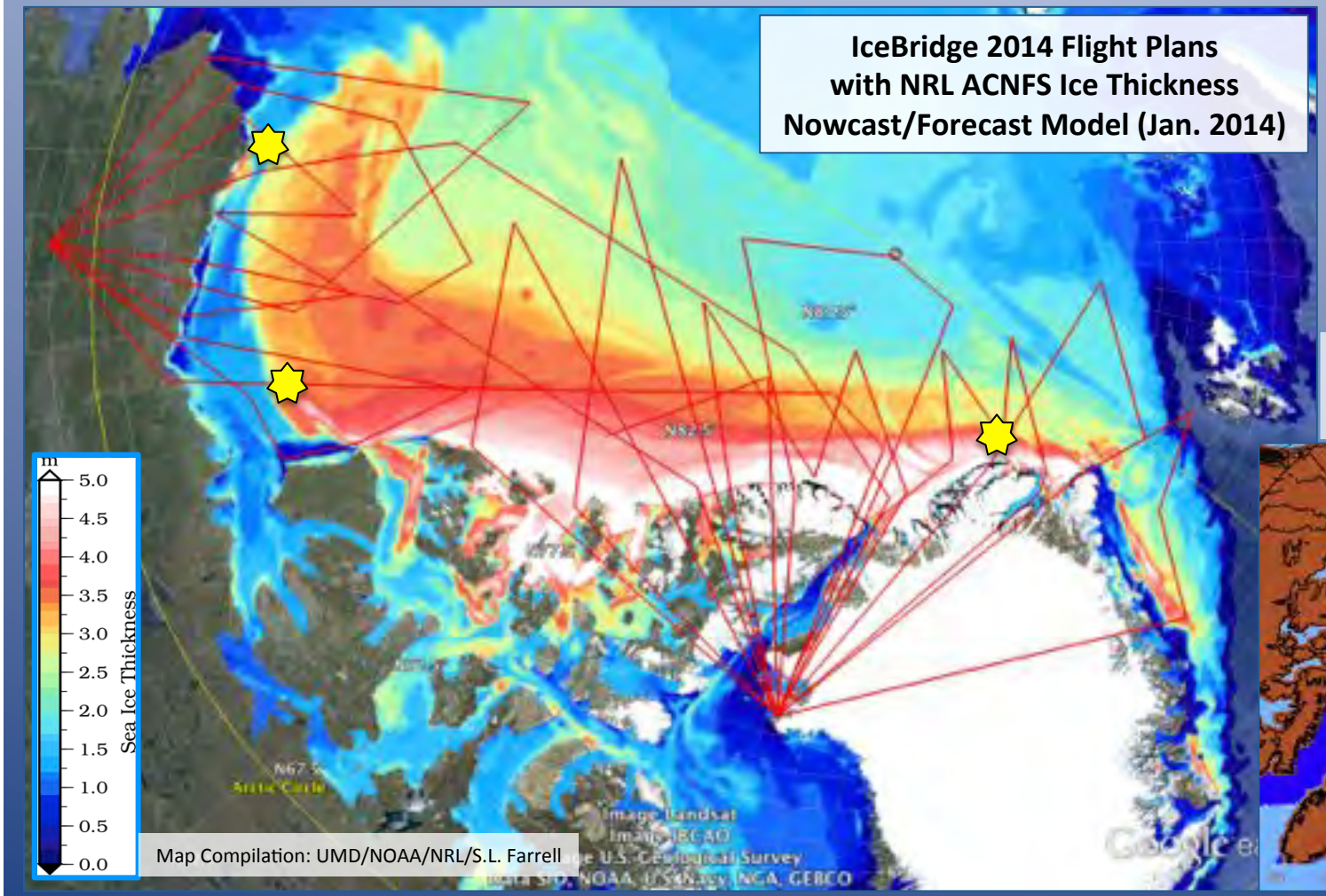


From: Newman et al., under review (2014)

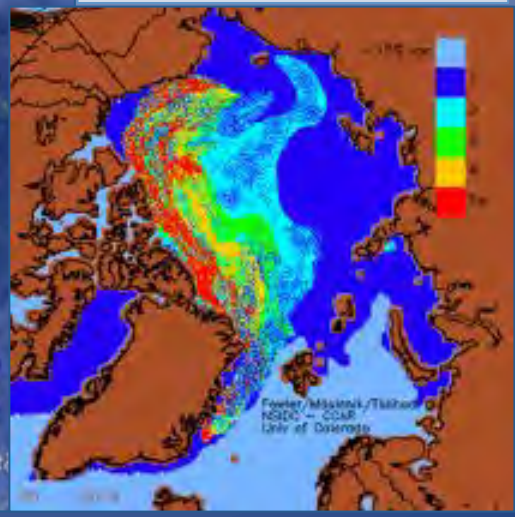
	Mean (cm)	Uncertainty (cm)	St Dev Unc (cm)	Mode (cm)	Bin Size (cm)	Median (cm)	St Dev (cm)
Newman et al. (2014): **Wavelet Technique**							
FYI: level floes (Mar-Apr 2012)	21	6	1	19	2	20	4
MYI: level floes (Mar-Apr 2012)	35	5	1	37	2	35	8

- Snow on MYI in Central Arctic consistent with snow climatology (Warren et al., 1999)
- Snow on FYI zones in the Beaufort and Chukchi Seas is ~ 60 % thinner than climatology

Arctic 2014 IceBridge Sea Ice Campaign – Mission Planning



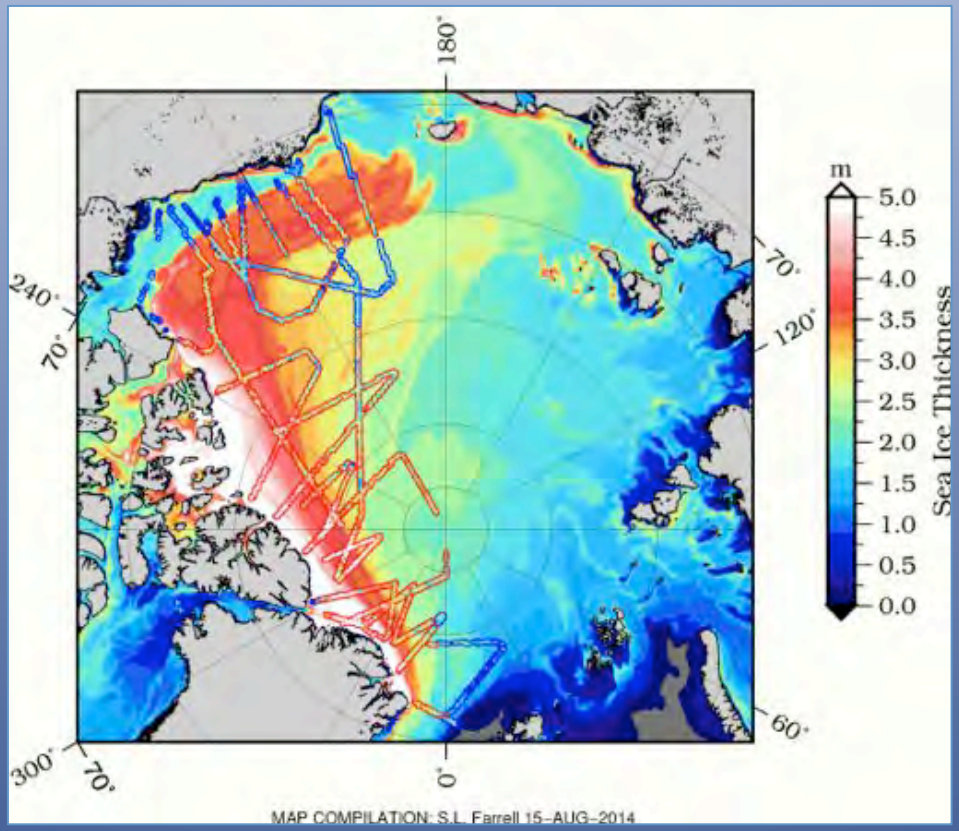
Sea Ice Age Jan 2014
Courtesy: M. Tschudi



2014 OIB campaign: multiagency effort with US & International Partners: **6 sea ice field sites**
nasa.gov/icebridge

Sea Ice Thickness: ACNFS vs. OIB Quick-Look

March – April 2014



	Operation IceBridge		NRL ACNFS		DIFF (ACNFS-OIB)	
	Mean (m)	Mode (m)	Mean (m)	Mode (m)	Mean (m)	Mode (m)
First-year Ice	**1.53**	1.75 ± 0.25	**2.44**	2.75 ± 0.25	**0.91**	1.00
Multi-year Ice	**3.19**	2.75 ± 0.25	**3.35**	3.75 ± 0.25	**0.16**	1.00

A look ahead: ICESat-2 and MABEL

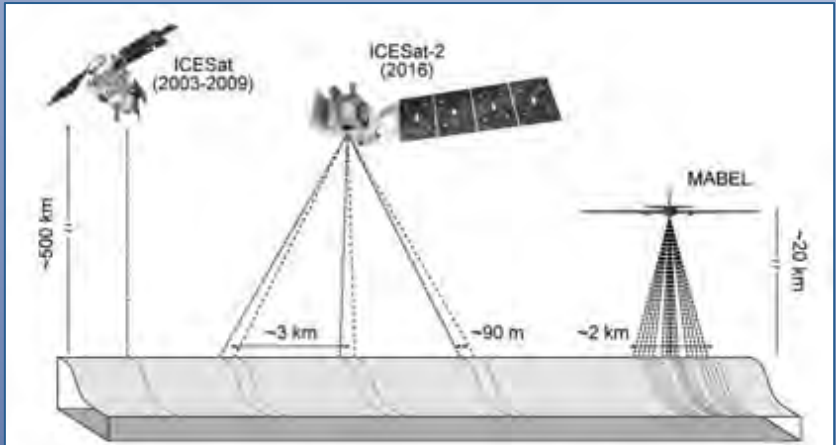


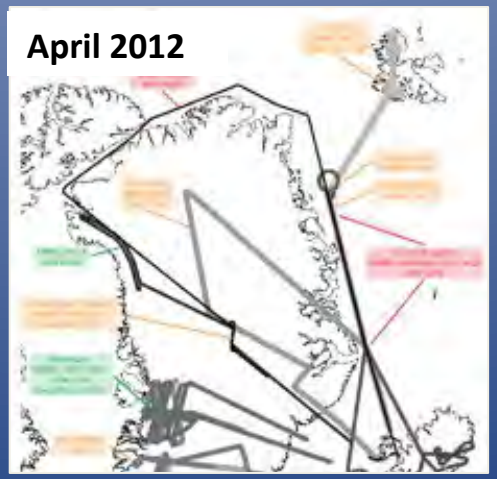
Fig. 1. (Left) Schematic ICESat, (center) ICESat-2, and (right) MABEL (dashed lines) beam geometry and (gray lines along ice-sheet surface) reference ground tracks. MABEL allows for beam-geometry changes with a maximum ground spacing of ±1 km at 20 km.

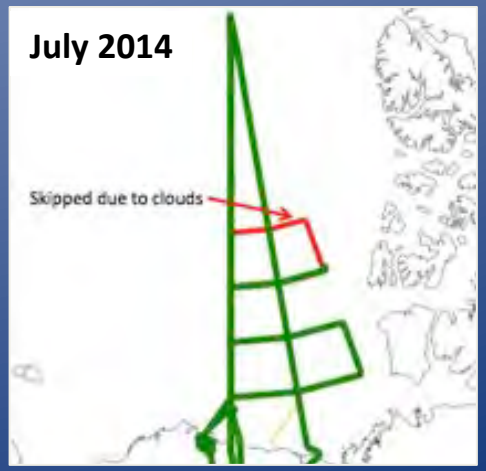
Brunt et al., IEEE GRSL, 2014

- NASA will launch ICESat-2 in 2017:
  ICESat-2 will continue key observations of Arctic sea ice through the end of this decade.
- MABEL is an airborne simulator for ICESat-2 to collect data for prelaunch algorithm development and testing.

Two major deployments over Arctic sea ice thus far:

- 2012: Wintertime sea ice conditions in Fram Strait, Nares Strait and Central/high Arctic
- 2014: Summertime sea ice conditions in the Southern Beaufort Sea and Canada Basin





Map Credits: K. M. Brunt, NASA GSFC

Sea Ice and Melt Ponds: July 2014

Digital photon-counting laser altimetry data (and coincident imagery) freely available at:
icesat.gsfc.nasa.gov/icesat2/data/mabel/mabel_docs.php

Summary

- Sea Ice Thickness in western Arctic has remained generally consistent over last six yrs after dramatic drop in winter 2007/08 (*Kwok et al.* 2009; *Giles et al*., 2009)
- Mean thickness decreased slightly in winter 2013, after record min. in Sept 2012: ~ -0.25 m (MYI) and ~ -0.33 m (FYI)
- Persistent MYI tongue in Beaufort and Chukchi Seas in winter 2014 and slight rebound in ice thickness after winter 2013
- Snow depth estimates from IceBridge now available for western Arctic
  - Snow on multi-year ice consistent with snow climatology
  - Snow on first-year ice ~60 % of snow climatology
- A look ahead – ICESat-2 due for launch in late 2017 → A digital photon-counting laser altimeter system ("ATLAS") with coverage to 88° N/S

Arctic 2015 IceBridge Sea Ice Campaign

Save the date!

Annual Sea Ice Science Workshop
27 – 28 January 2015
NASA Goddard Space Flight Center, Greenbelt, MD, USA

- Approx. 1.5 – 2 day meeting with presentations and discussions on coordination of airborne, *in situ*, satellite measurement campaigns in western Arctic: March-April 2015
- Workshop to be held in conjunction with the Program for Arctic Regional Climate Assessment (PARCA) meeting and the Operation IceBridge (OIB) Science Team meeting.
- Please contact Jackie Richter-Menge (Jacqueline.A.Richter-Menge@usace.army.mil) for further details, and if you wish to attend. (Badges required for site access)
- Further information about these meetings will be posted at:
  http://neptune.gsfc.nasa.gov/csb/index.php?section=268