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

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Outline

- NOAA/CICS-MD Sea Ice Research Group - Activities
- Measurement techniques – utility of altimetry to derive sea ice thickness
- Brief overview of Operation IceBridge and sea ice data products
- Arctic sea ice fieldwork in 2014
- Review of Arctic wintertime sea ice conditions
- Arctic Sea Ice Thickness Observations: 2009-2014
  - Assessing interannual variability of first-year and multi-year sea ice
- Summary and future work

CICS – MD / NOAA LSA Sea Ice Research Group

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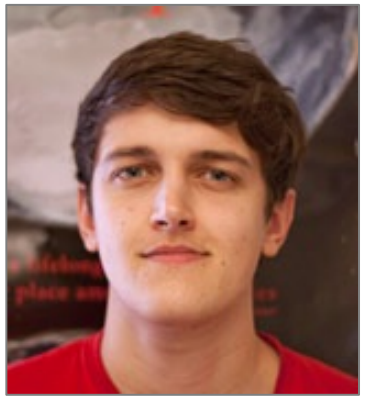

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NOAA Federal Sponsor:

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NOAA Sea Ice Team Lead: Dr. Larry Connor

Collaborations with:

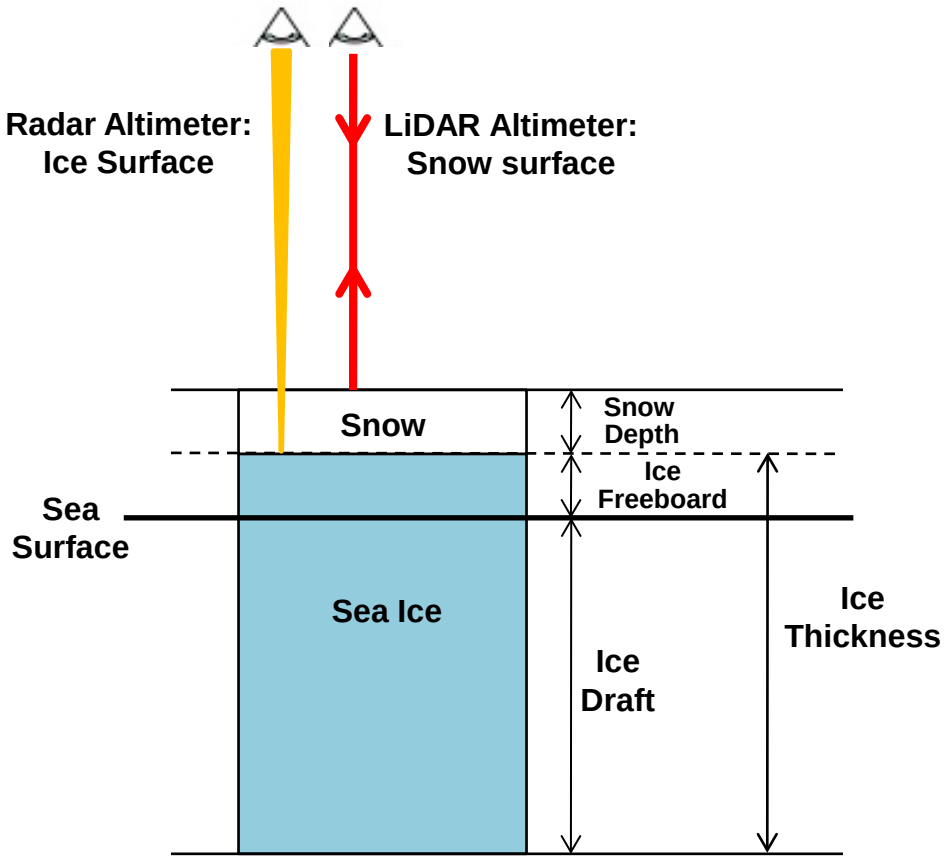
- **NASA GSFC/Cryospheric Sciences Branch**
- **US Army Cold Regions Research and Engineering Laboratory (CRREL)**
- **US Naval Research Laboratory (NRL)**
- **European Space Agency (ESA)**
- **Office of Naval Research (ONR)**
- **Oregon State University, University of Washington**
- **University College London, University of Reading, York University**

Research Activities

- Assessment of **decadal time-series of Arctic sea ice thickness** from satellite altimeters (ICESat, Envisat, and CryoSat-2) and related parameters incl. reanalysis data, satellite imagery, sea ice drift datasets
- **Data synthesis** to improve seasonal-to-decadal predictions of Arctic sea ice
- **Validation of airborne altimeter measurements** using *in-situ* field data sets, assigning accuracy estimates with respect to sea ice type
- **Validation of satellite altimeter data** via coincident airborne campaigns
- Deliver key observational datasets for **model validation / initialization**
- Derive novel, high-resolution sea ice parameters (ice type and morphology) for input to next-generation sea ice models (**model parameterizations**)
- **Team Members** of IceBridge and ICESat-2 science teams: mission support and planning, algorithm development, support Early Adopter Scheme

Sea Ice Thickness from Airborne and Satellite Altimetry

An inferred measurement



- Measure surface elevation
- Discriminate leads from floes
- Open water required for calibration
- Derive freeboard
- Assuming hydrostacy:

  Infer ice thickness, which is a function of:

  – Snow, ice and water density
  – Snow depth
  – Ice freeboard

- Ice thickness uncertainty influenced by errors freeboard and snow depth
- Uncertainty of 11 cm in snow depth => contributes ~ 50 cm to the total ice thickness unc. from laser altimeter system

Sea Ice Thickness from Airborne and Satellite Altimetry

An inferred measurement

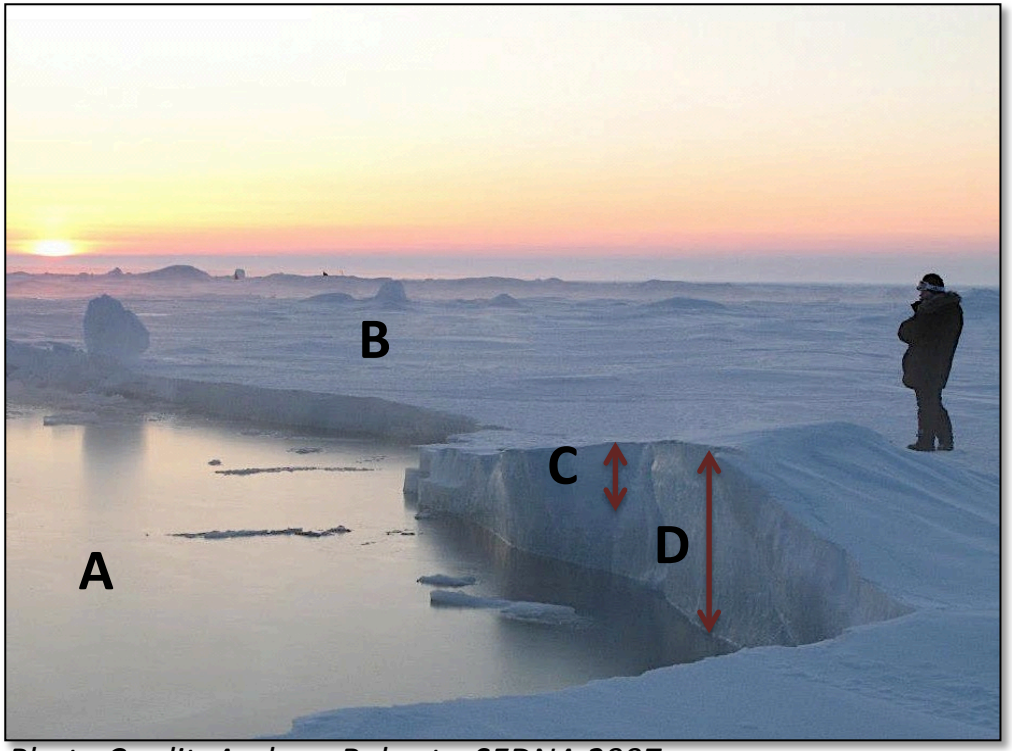


Photo Credit: Andrew Roberts, SEDNA 2007

Measurements

- Lead locations
- Lead Elevation **(A)** => sea surface height
- Floe Elevation **(B)** => sea-ice surface topography and roughness
- Snow Depth **(C)**

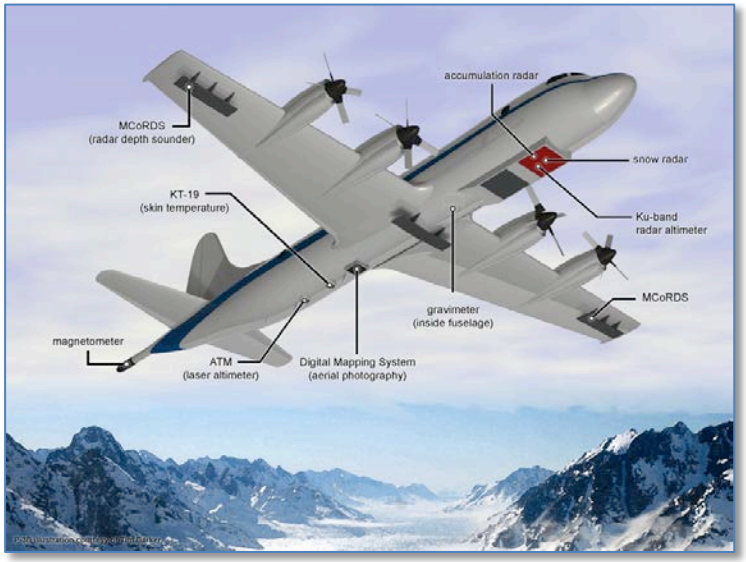
Derived Products

- Mean Freeboard (& uncertainty) **(D = B-A)**
- Snow Depth (& uncertainty) **(C)**
- Ice Thickness (& uncertainty) **(*f* (C, D))**

Examples of missions employing this technique: ERS-1, -2; Envisat; ICESat; IceBridge; CryoSat-2; ICESat-2

NASA Operation IceBridge

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



More info at:

icebridge.gsfc.nasa.gov

nsidc.org/data/icebridge/

nasa.gov/mission_pages/icebridge/

@NASA_ICE

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)

Sea ice conditions
Southern Weddell Sea
Oct 20th 2014!

Photo Credit: J. Yungel, NASA IceBridge

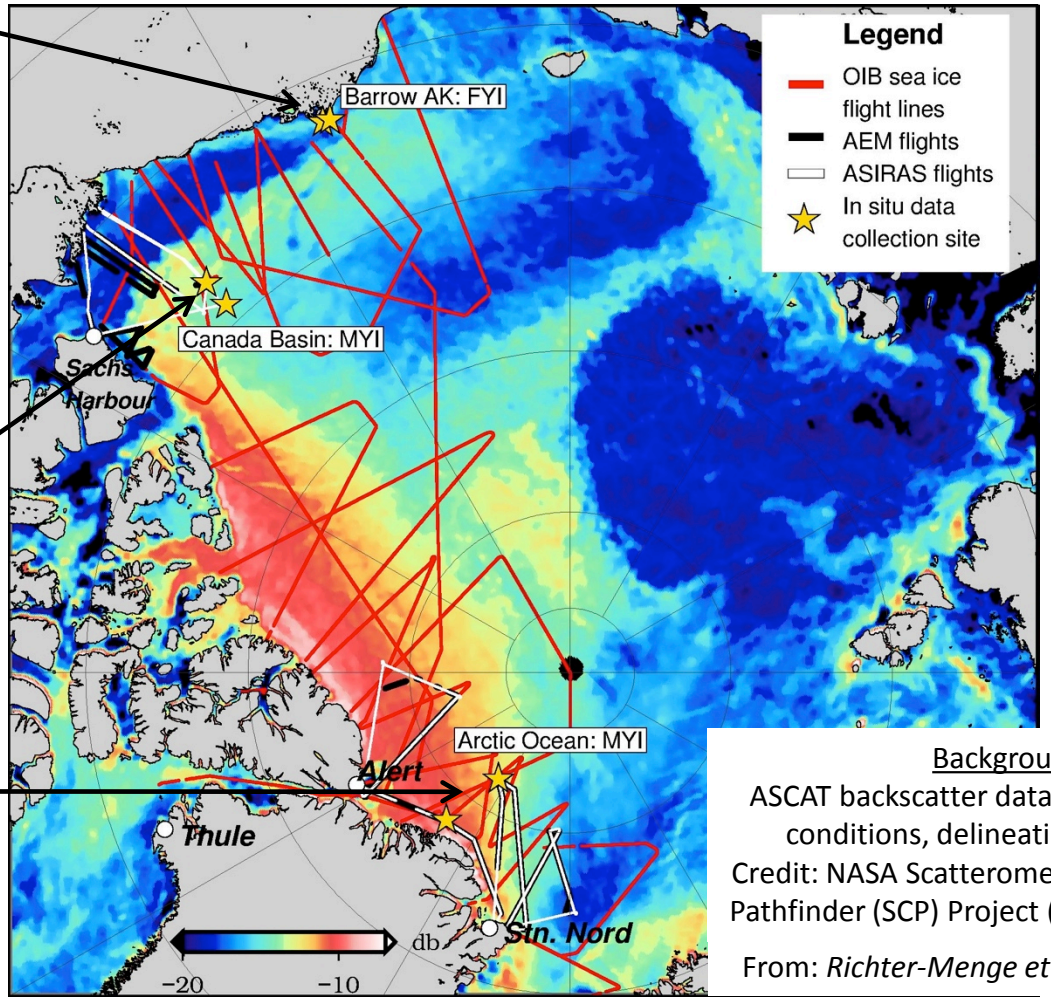
Coordinated Field Experiments, March 2014

Goal: *Characterize snow depth on Arctic sea ice in a range of locations and varying snow conditions. Multiple field teams validate a suite of airborne radar and laser sensors*

17 March, Barrow, AK: first year undeformed and deformed ice

18 March, Sachs Harbor: multiyear ice; lighter snow cover

30 March, Stn. Nord: Older, multiyear ice; heavier snow cover

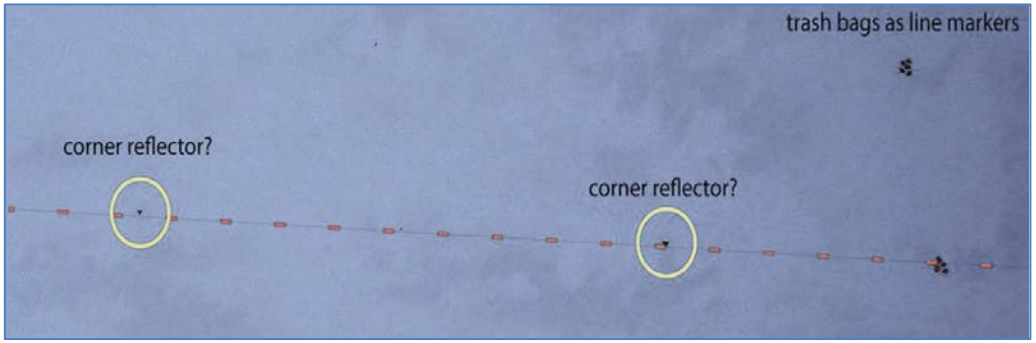


Background:
ASCAT backscatter data indicates surface conditions, delineating FYI and MYI
Credit: NASA Scatterometer Climate Record Pathfinder (SCP) Project (www.scp.byu.edu)

From: *Richter-Menge et al.* (2014, in prep)

Arctic Field Work – 2014

Barrow, Alaska: March 2014

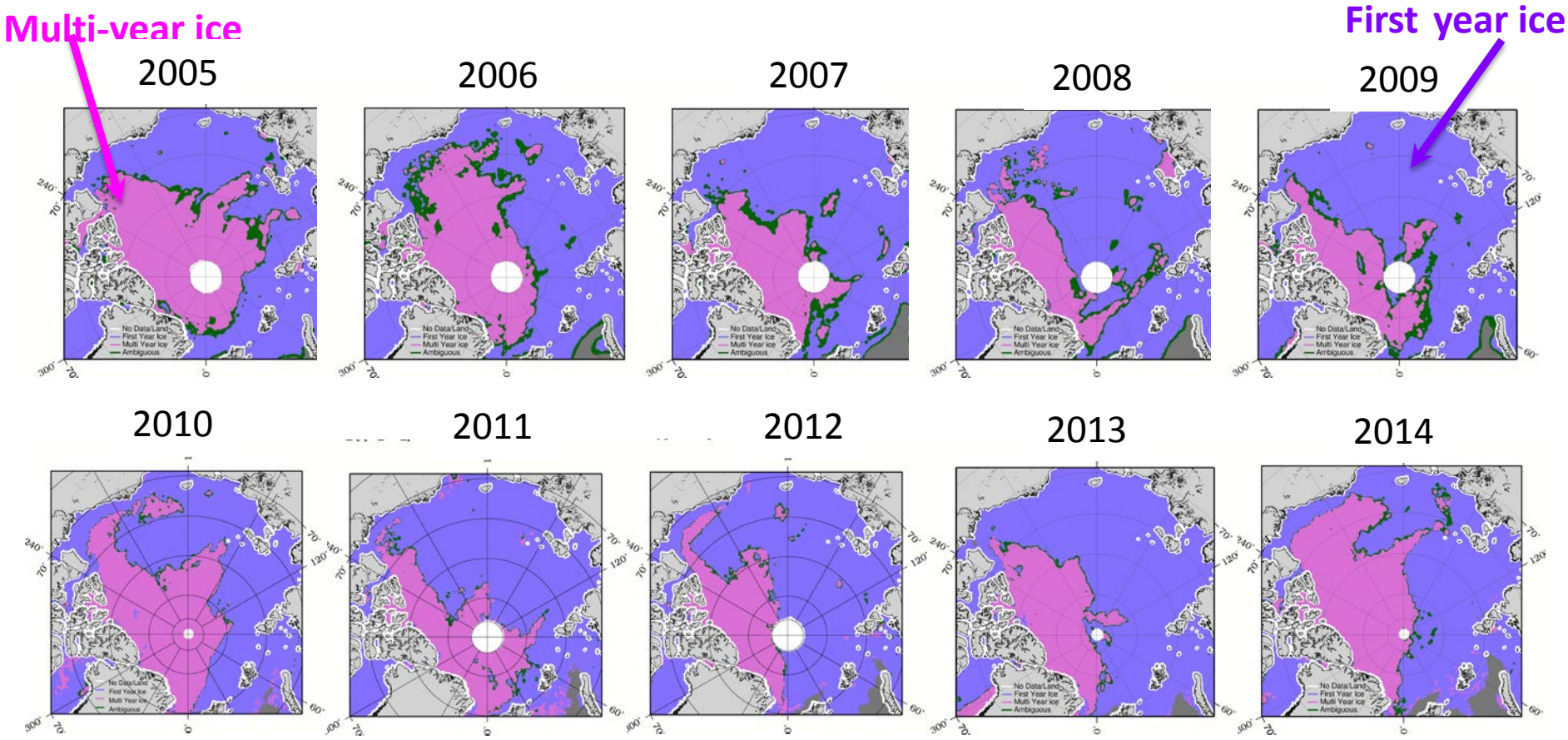


Tom Newman participated in the *NRL "DISTANCE" airborne project*, 13-27 March 2014. NRL aircraft conducted surveys above field teams and underflights of CryoSat-2

Arctic Ocean: October 2014

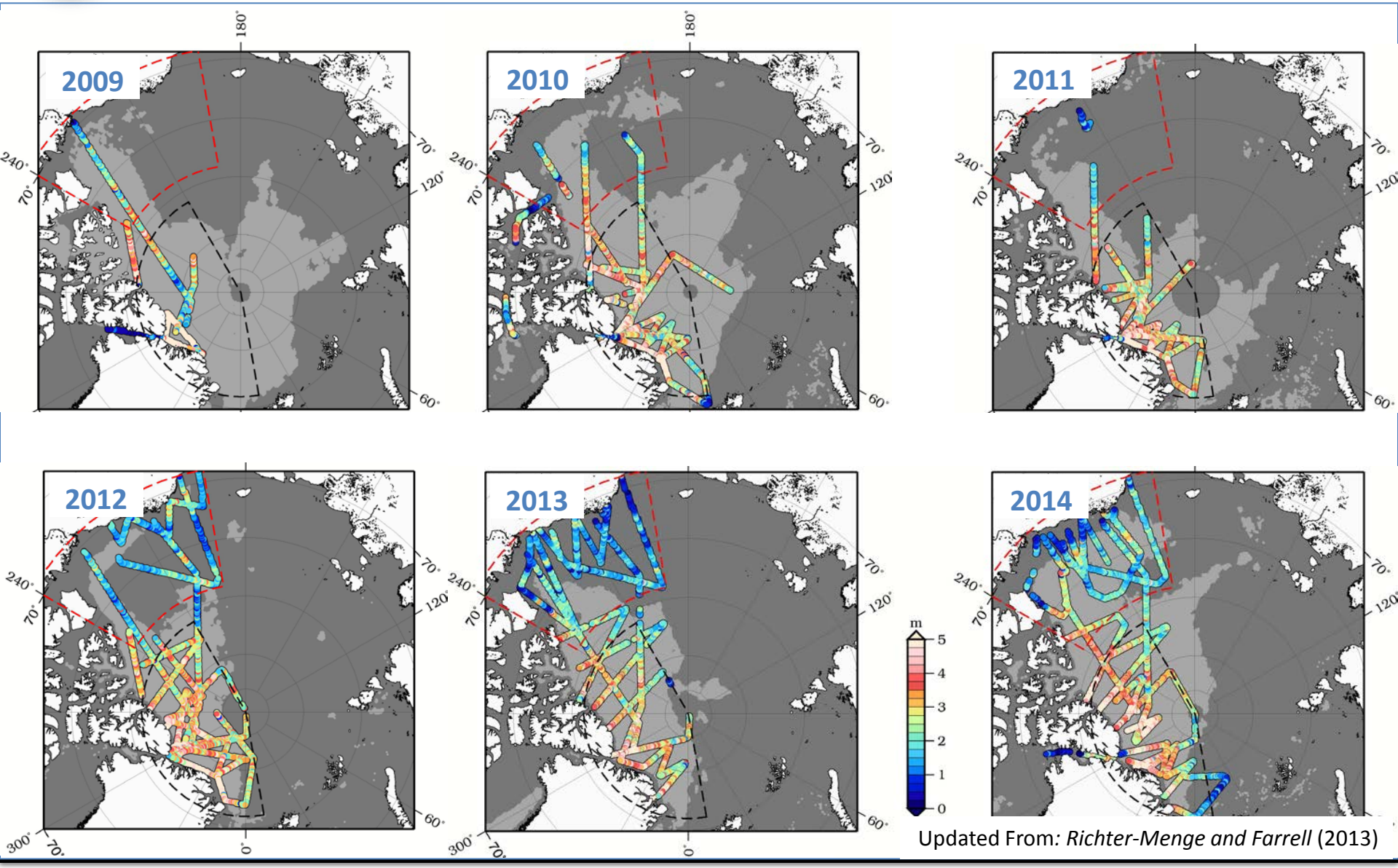
Alek Petty participated in the *JOIS/Beaufort Gyre Exploration Project research cruise* in the Beaufort Sea on board the CCGS Louis S. St Laurent, Sept/Oct 2014

Winter Sea Ice Conditions over Last Decade



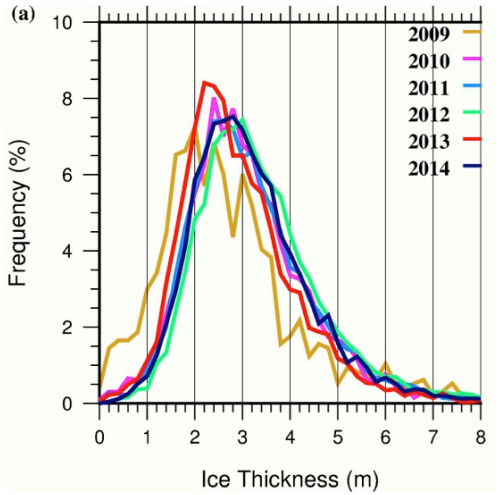
- EUMETSAT Ocean and Sea Ice –Satellite Application Facilities (OSI-SAF) sea ice type product (http://saf.met.no/p/ice/)
- *Maslanik et al.* [2011] reported that MY ice extent in the Arctic Ocean reached record minimum in March 2008.
- Loss of MY ice was particularly dramatic in the western Arctic, including the Beaufort Sea and the Canada Basin
- March 2013 and 2014: Return of MY ice in Canada Basin – reverting to 2005/2006 levels

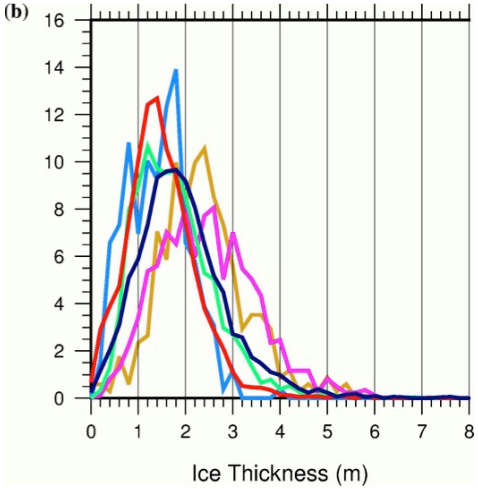
Sea Ice Thickness in Western Arctic: 2009 – 2014



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

Regional Variability in Arctic Sea Ice Thickness



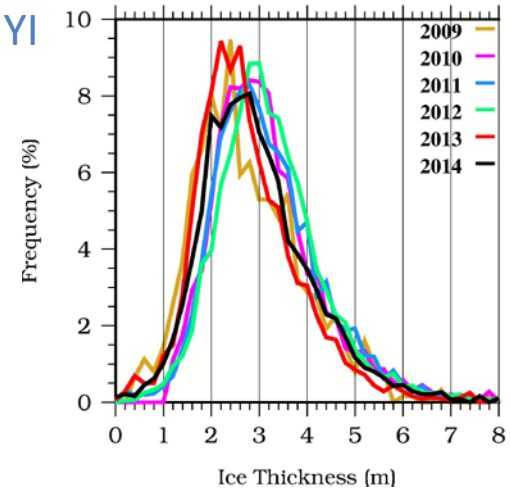


	Central Arctic				Beaufort/Chukchi Seas			
	Mean (m)	St Dev (m)	Mode (m)	Grid Cells (#)	Mean (m)	St Dev (m)	Mode (m)	Grid Cells (#)
2009	2.90	1.69	2.0	965	2.49	1.01	2.4	341
2010	3.23	1.35	2.4	4595	2.57	1.09	2.6	856
2011	3.27	1.32	2.6	6871	1.52	0.65	1.8	259
2012	3.50	1.46	3.0	10670	1.88	0.91	1.2	2152
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**	**-**

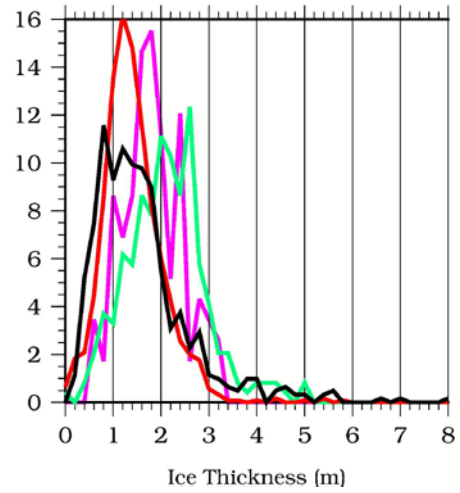
Updated From*: Richter-Menge and Farrell* (2013)

Variability in Multi-year/First-year Ice Thickness

MYI



FYI



	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**

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

Summary and Future Work

- 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:

  ~ -0.26 m (MYI) and ~ -0.33 m (FYI)
- Central Arctic: Dominant multiyear ice (MYI) zone: 90% +
- Beaufort /Chukchi Sea (BC) Region: Mix of MYI and first-year ice: ~ 25 %: 75 %
- Persistent MYI tongue in Beaufort and Chukchi Seas in winter 2014
- 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 of Warren et al. (1999)
  - Snow on first-year ice ~60 % of snow climatology
  - *See Tom Newman's presentation later today!*
- A look ahead – NASA's ICESat-2 due for launch in late 2017 with coverage to 88^{o}N/S