

An update on Arctic sea ice thickness conditions from airborne and satellite altimetry

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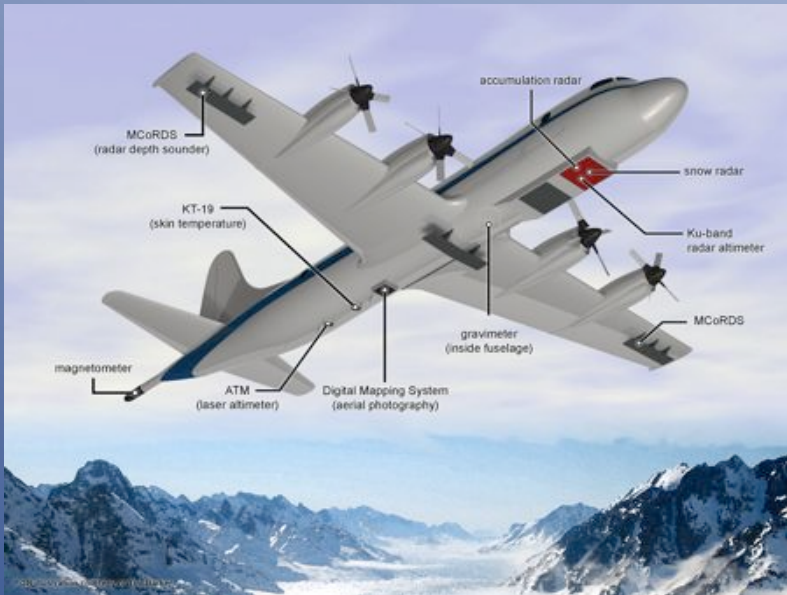


Outline

- Brief recap of airborne sea ice data products (IceBridge)
- Results for 2013 – snow depth, sea ice thickness, and thickness uncertainty
- Review of 5-year sea ice thickness data set (2009 – 2013)
- Basin-scale sea ice thickness (ICESat and CryoSat-2)
- Review of 10-year change in thickness and volume (2003 – 2012)

Arctic Airborne Altimetry

- **Operation IceBridge:** NASA airborne mission, multi-instrument suite, launched in March 2009 to bridge gap between ICESat and ICESat-2



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

Arctic Sea Ice Campaigns

Flights

2009: 6

2010: 8

2011: 9

2012: 14

2013: 10

Instrumentation – Data Sets

- Surface Topography – (ATM Laser Altimeter)
- Snow Depth (Snow Radar)
- Sea Ice Morphology (High res. digital photography)
- Gravity field - gravimeter

Sea Ice Thickness – Data Products

Sea Ice Data from IceBridge:

Measurements:

- **(A)** Lead Height – sea surface elevation (& uncertainty)
- **(B)** Snow Depth
- **(C)** Mean Freeboard (& uncertainty)

Derived Product:

- Thickness
- Thickness Uncertainty
- Available at 40 m resolution
- Stored at NSIDC

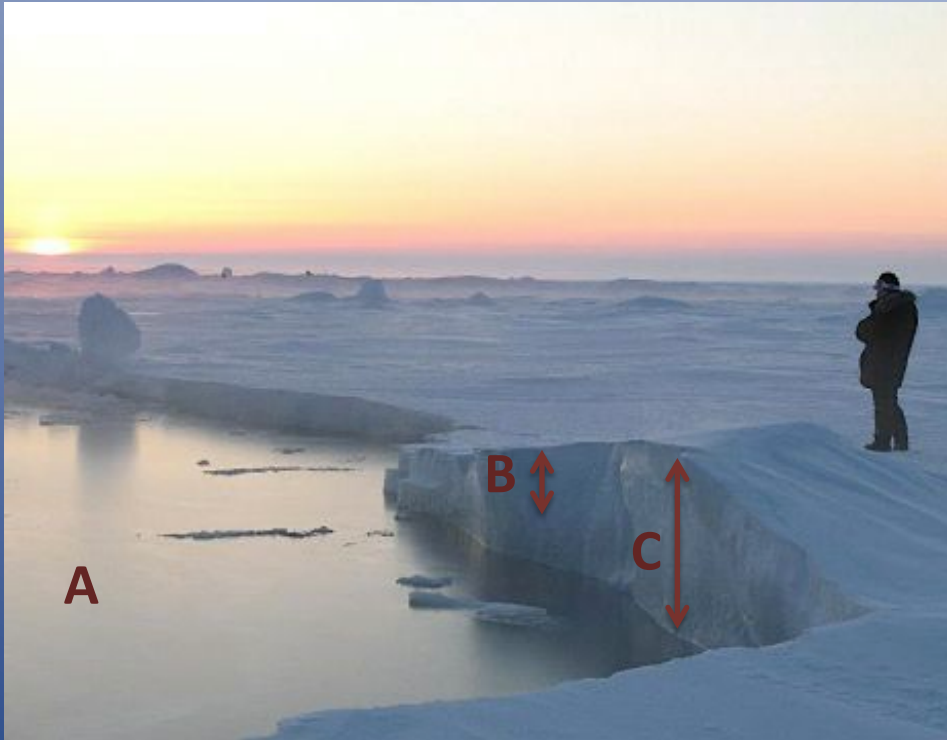
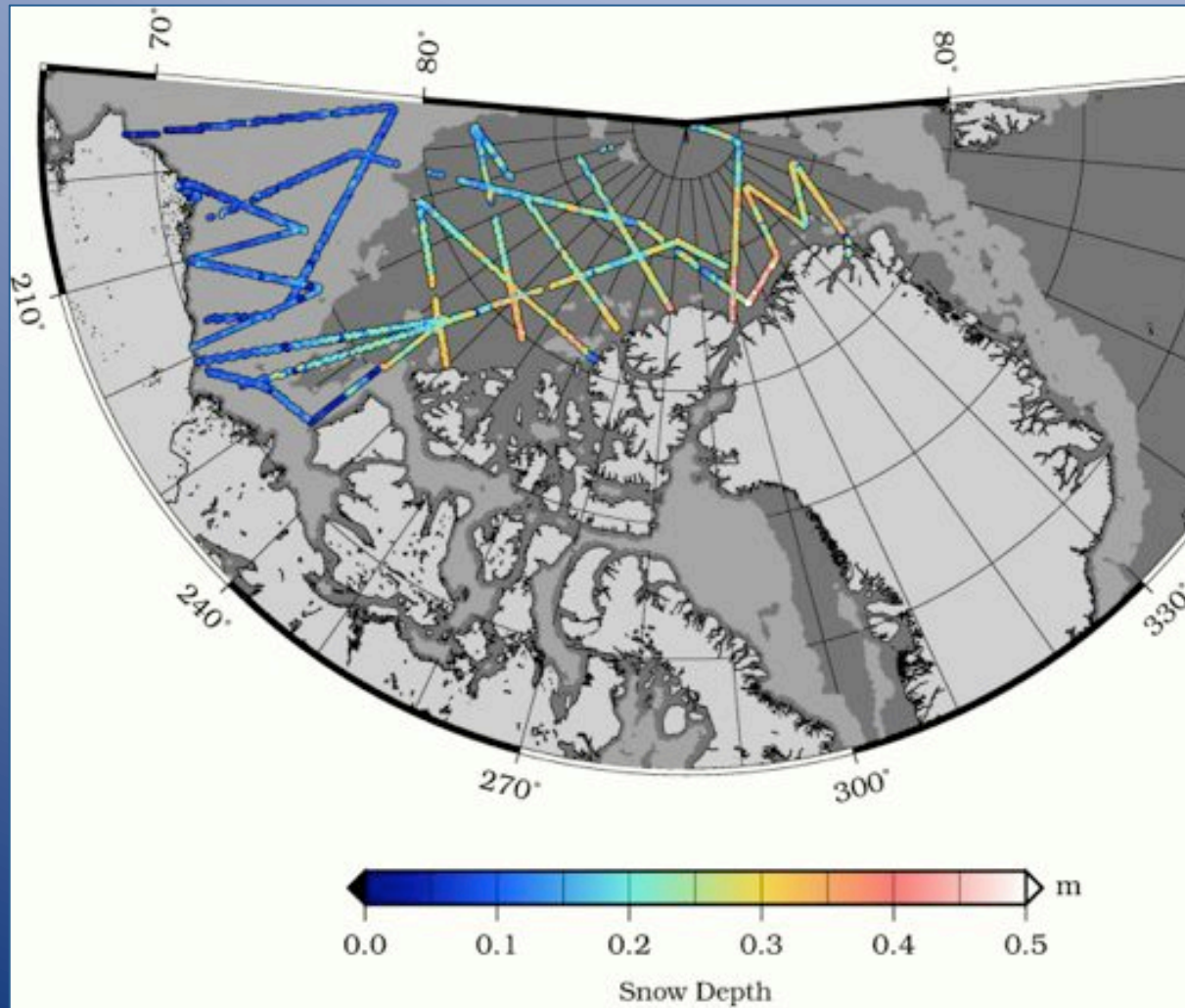


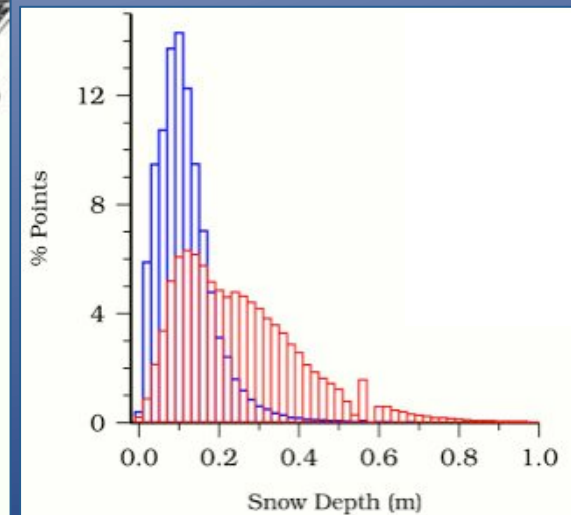
Photo Credit: Andrew Roberts, SEDNA 2007

Snow Depth (h_s) – March/April 2013



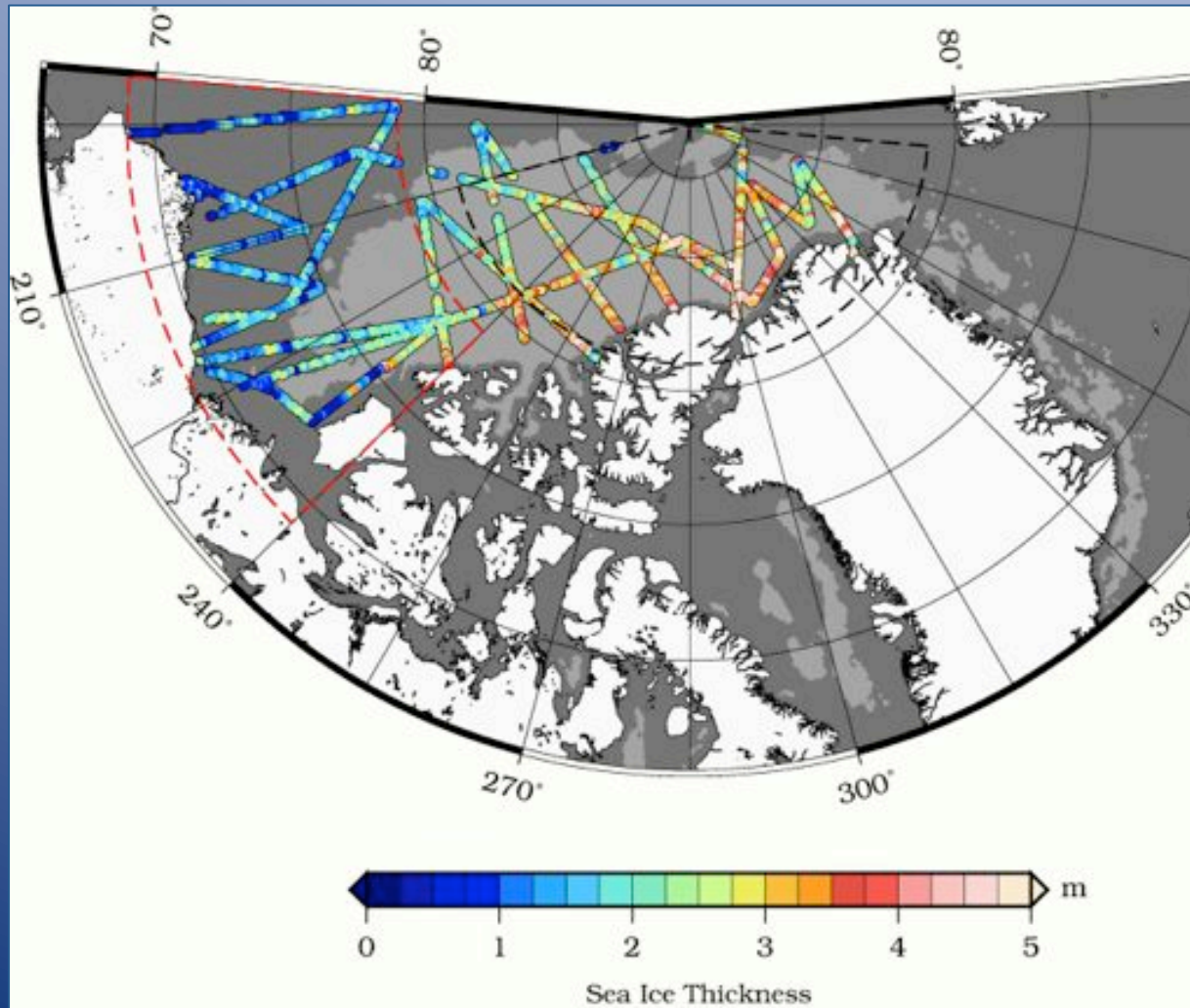
First Year Ice:
Mean Snow Depth: 0.12 ± 0.08
Modal Snow Depth: 0.12 m

Multi-Year Ice:
Mean Snow Depth: 0.26 ± 0.16
Modal Snow Depth: 0.14 m



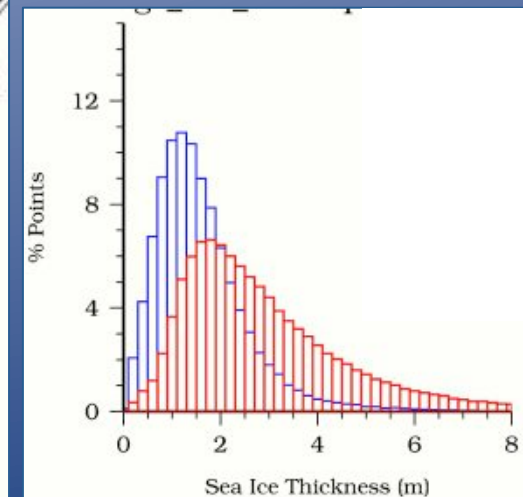
nsidc.org/data/docs/daac/icebridge/evaluation_products/sea-ice-freeboard-snowdepth-thickness-quicklook-index.html

Sea Ice Thickness (h_i) – March/April 2013



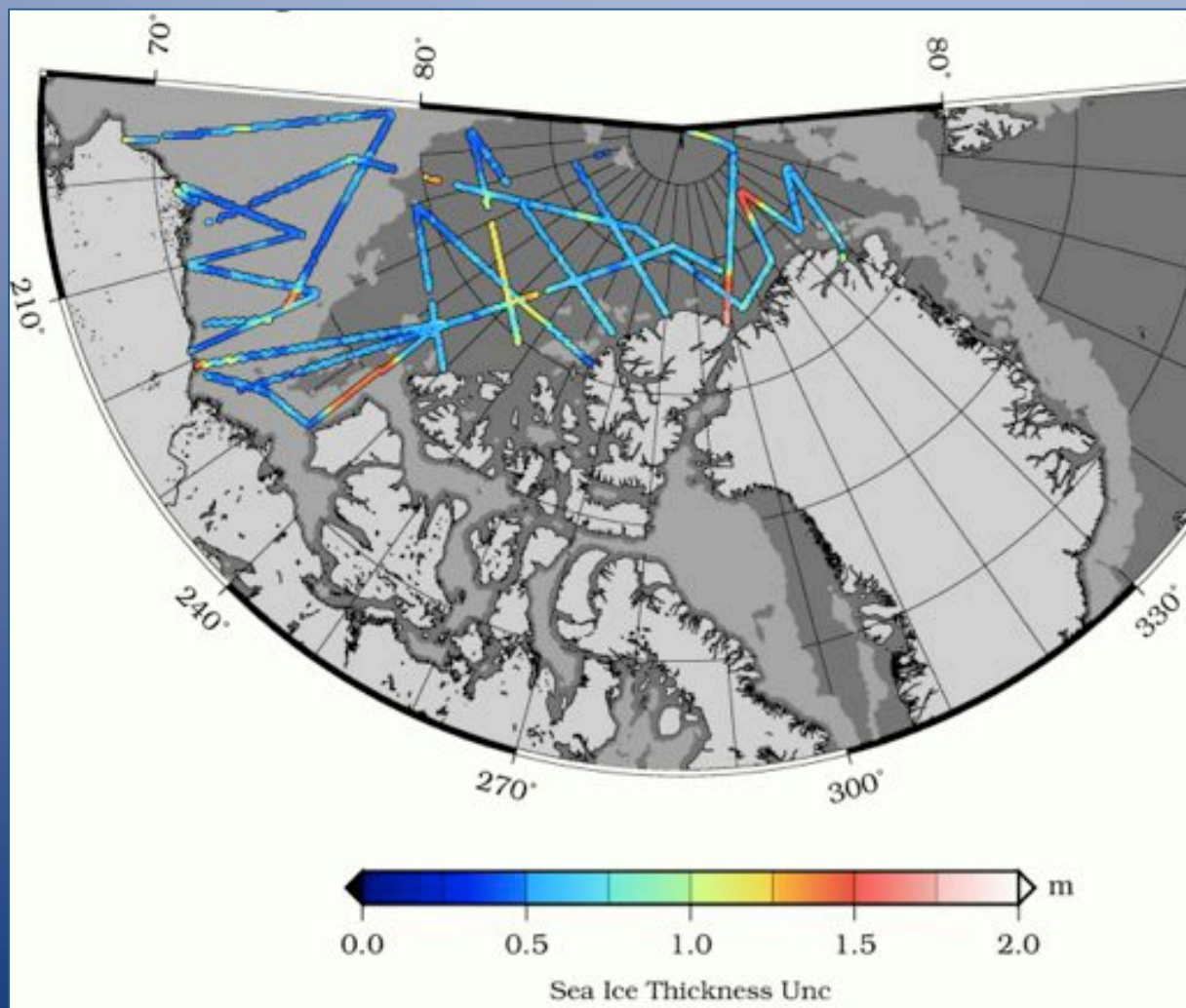
First Year Ice:
Mean Thickness: 1.63 ± 1.04
Modal Thickness: 1.20 m

Multi-Year Ice:
Mean Snow Depth: 3.00 ± 1.93
Modal Snow Depth: 2.00 m



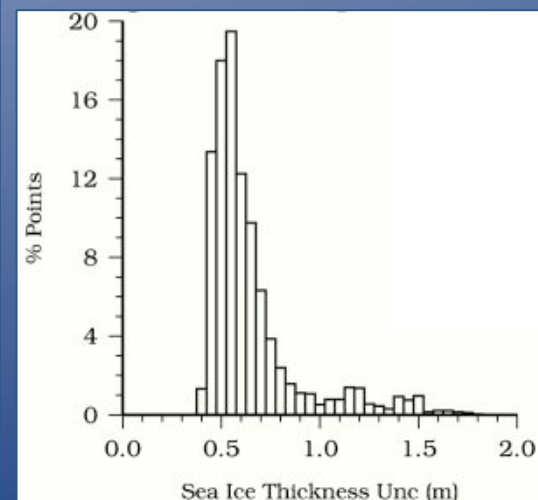
nsidc.org/data/docs/daac/icebridge/evaluation_products/sea-ice-freeboard-snowdepth-thickness-quicklook-index.html

Sea Ice Thickness Uncertainty (σ_{h_i}) – March/April 2013



- Varies Spatially

Mean Ice Thickness Uncertainty:
 0.65 ± 0.24 m



nsidc.org/data/docs/daac/icebridge/evaluation_products/sea-ice-freeboard-snowdepth-thickness-quicklook-index.html

Ice Thickness Uncertainty (σh_i)

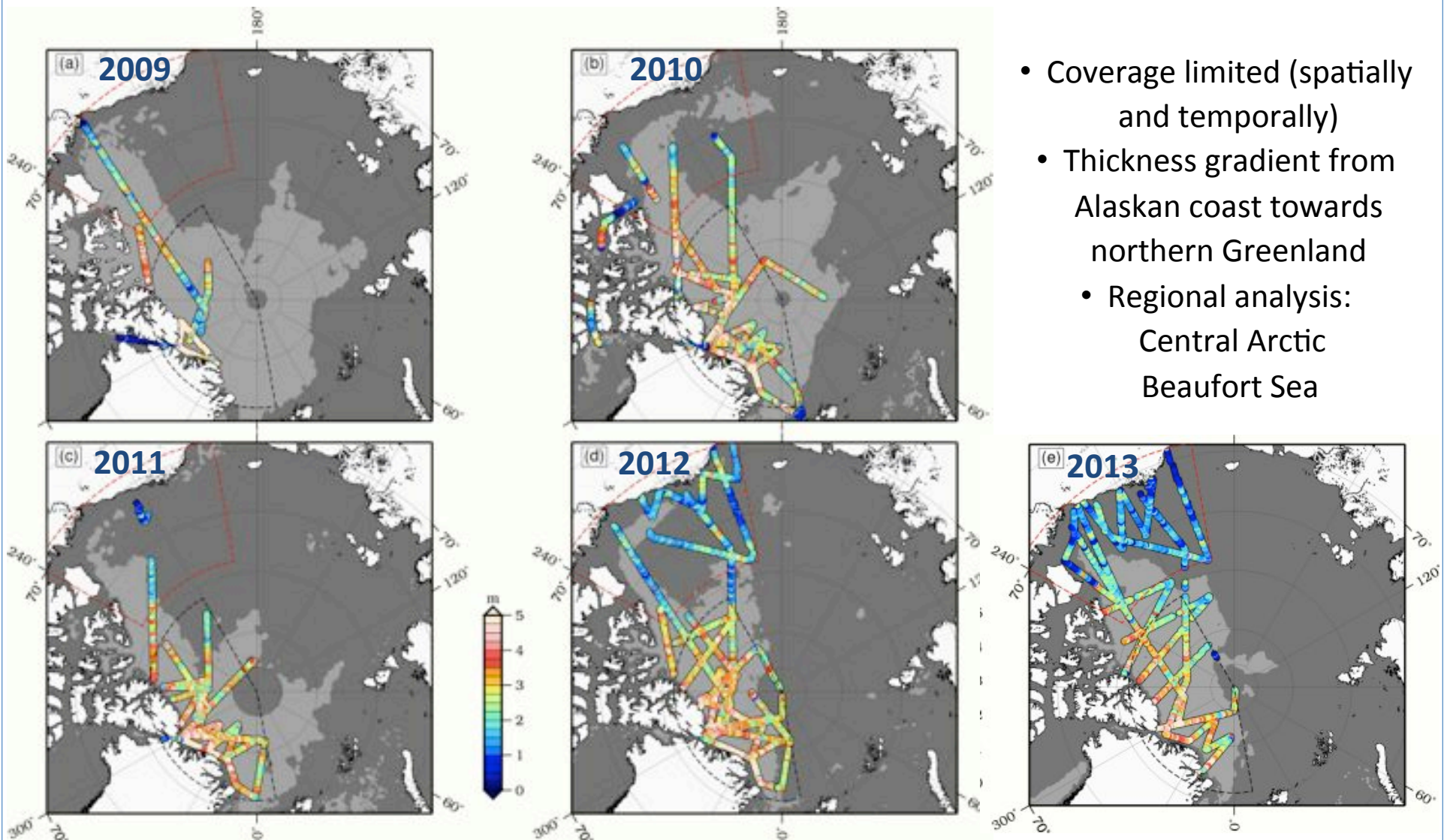
- Average ice thickness uncertainty ~ 0.65 m
- Formally calculated via inclusion of all error terms, Eqn. 1
 - including freeboard & snow depth – prevalence of leads major contributing factor

$$\sigma_{h_i} = \left[\left(\frac{\rho_w}{\rho_w - \rho_i} \right)^2 \sigma_{h_f}^2 + \left(\frac{\rho_s - \rho_w}{\rho_w - \rho_i} \right)^2 \sigma_{h_s}^2 + \left(\frac{h_s(\rho_s - \rho_w) + h_f \rho_w}{(\rho_w - \rho_i)^2} \right)^2 \sigma_{\rho_i}^2 + \left(\frac{h_s}{\rho_w - \rho_i} \right)^2 \sigma_{\rho_s}^2 \right]^{\frac{1}{2}} \quad (\text{Eqn. 1})$$

- Uncertainty has decreased over time
 - improvements in instrumentation and processing techniques
 - discarding data with a freeboard uncertainty of > 0.1 m.
- See Kurtz et al., 2013 (The Cryosphere) for detailed description of uncertainty estimation

IceBridge Campaign	Mean (m)	Mode (m)	Range (m)	Discarded %
2009	0.71 ± 0.19	0.66	0.38 - 3.54	48
2010	0.66 ± 0.18	0.55	0.37 - 2.00	37
2011	0.66 ± 0.17	0.56	0.38 - 2.39	20
2012	0.70 ± 0.17	0.63	0.38 - 2.60	16
2013	0.59 ± 0.15	0.50	0.38 - 2.58	9

Sea Ice Thickness: 2009 - 2013



From: *Richter-Menge and Farrell, 2013, GRL*

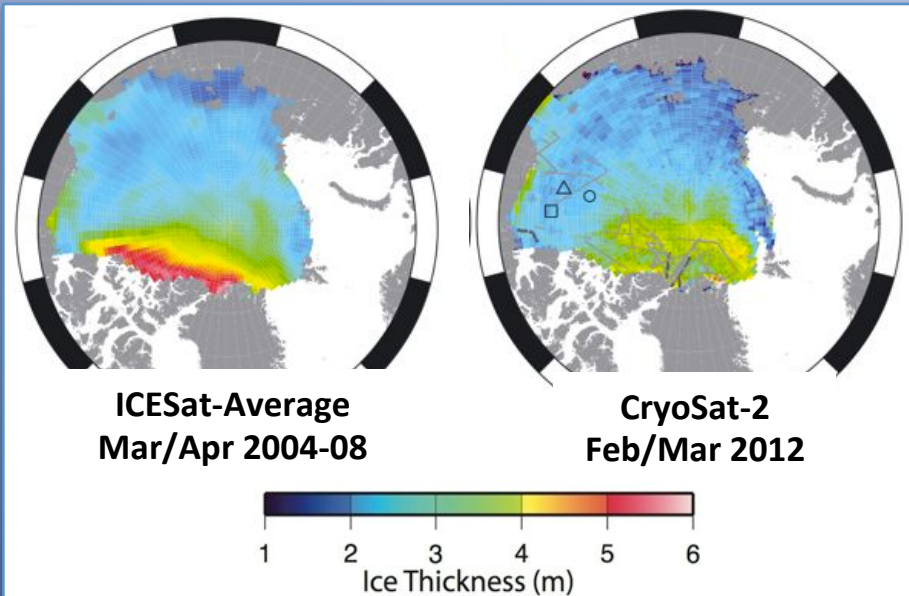
Regional Ice Thickness (2009 – 2013)

IceBridge Campaign	Central Arctic		Beaufort Sea + Eastern Chukchi Sea	
	Mean \pm 1 σ (m)	Mode (m)	Mean \pm 1 σ (m)	Mode (m)
2009	2.90 \pm 1.69	2.0	2.49 \pm 1.01	2.4
2010	3.23 \pm 1.35	2.4	2.57 \pm 1.09	2.6
2011	3.27 \pm 1.32	2.6	1.52 \pm 0.65	1.8
2012	3.50 \pm 1.46	3.0	1.88 \pm 0.91	1.2
2013	3.04 \pm 1.25	2.2	1.60 \pm 0.75	1.4
5 Year Mean	3.19 \pm 1.41	2.4	2.01 \pm 0.88	1.9

- Central Arctic: Dominant multiyear (MY) ice zone: 90% +
- Beaufort /Chukchi Sea (BC) Region: Mix of MY and first-year (FY) ice: ~ 25 % MY ice, distribution varies
- Decrease in MY in both sectors in 2011 that persisted
- Mean Sea Ice Thickness in Central Arctic is **3.2 m** and obs show interannual variability
- Mean ice thickness in B/C Region is **2.0 m**, but decrease observed after 2011.
- Very thin ice observed in Chukchi Sea: 0 – 1 m, following Feb. breakout event

From: Richter-Menge and Farrell, 2013, GRL

ICESat and CryoSat-2 Thickness Record

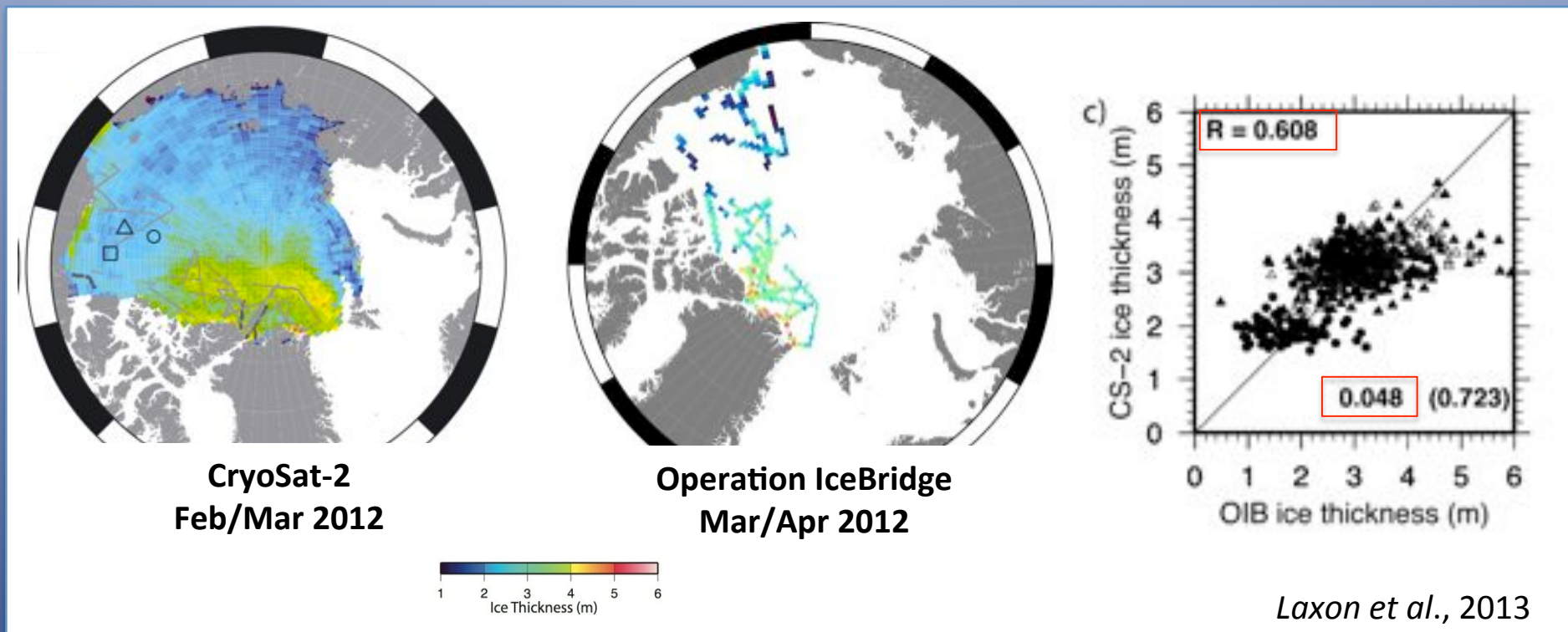


Dates	Volume (adjusted)		PIOMAS	
	Oct/Nov	Feb/Mar	Oct/Nov	Feb/Mar
2003–2008	11,852	16,299	9119	15,451
2010–2011	8283	15,424	6846	13,429
2011–2012	6838	14,215	6104	13,290
Change ^a	–4291	–1479	–2644	–2091

From: *Laxon et al., 2013, GRL*

- Combining ICESat and CryoSat-2 records: Basin Scale coverage
- Decadal variability and trends in thickness and volume of pack.
- Observations indicate decline in ice thickness and volume over last 10 yrs
- Between 2003 and 2012 volume of winter pack decreased by 9 % (1479 km³).
- Average volume loss (autumn and winter) was ~500 km³/yr
- Equivalent to a loss of 0.075 m/yr in ice thickness

IceBridge vs CryoSat-2 Ice Thickness



- Cross calibration - independent estimates of sea ice thickness (airborne, sat., in situ sources)
- Example shown here: IceBridge vs. CryoSat, Spring 2012 data
- Spatial patterns in thickness gradient agree; correlation 0.61; mean thickness difference 0.05 m
- On-going efforts to understand source of scatter and major differences
- Effort underway to provide a consistent time series of data with consistent auxiliary inputs

IceBridge/CryoSat-2 Sea Ice Thickness Data Availability

- NASA IceBridge Airborne Sea Ice thickness data product:
<http://nsidc.org/data/idcsi2.html>
- IceBridge “quicklook” Data:
<http://nsidc.org/data/icebridge/evaluation-products.html>
- CryoSat-2 sea ice thickness and uncertainty @Alfred Wegener Institut (AWI)
http://www.meereisportal.de/de/datenportal/karten_und_datenarchiv/
(Contact Stefan Hendricks, R. Ricker, V. Helm at AWI)

