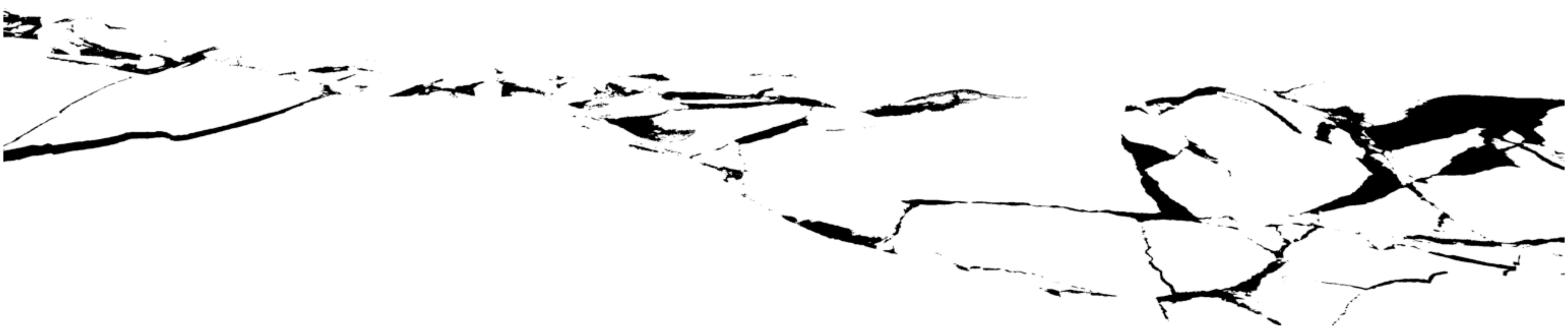
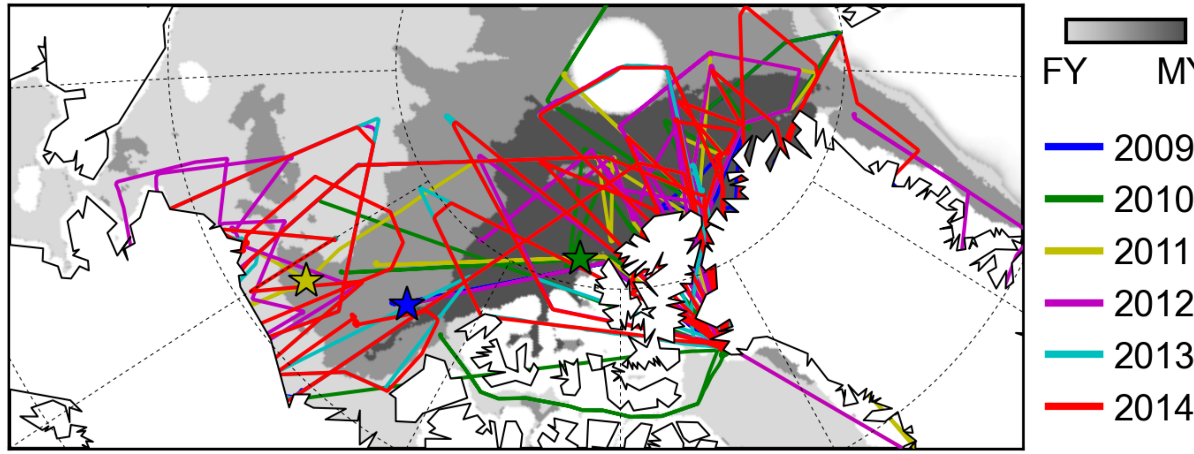
Characterizing Arctic sea ice topography using high-resolution IceBridge data

Alek Petty, Michel Tsamados, Nathan Kurtz, Sinead Farrell, Thomas Newman, Jeremy Harbeck, Jacqueline Richter-Menge and Daniel Feltham



[Petty et al., 2015, The Cryosphere Discuss]

Operation IceBridge – Arctic sea ice

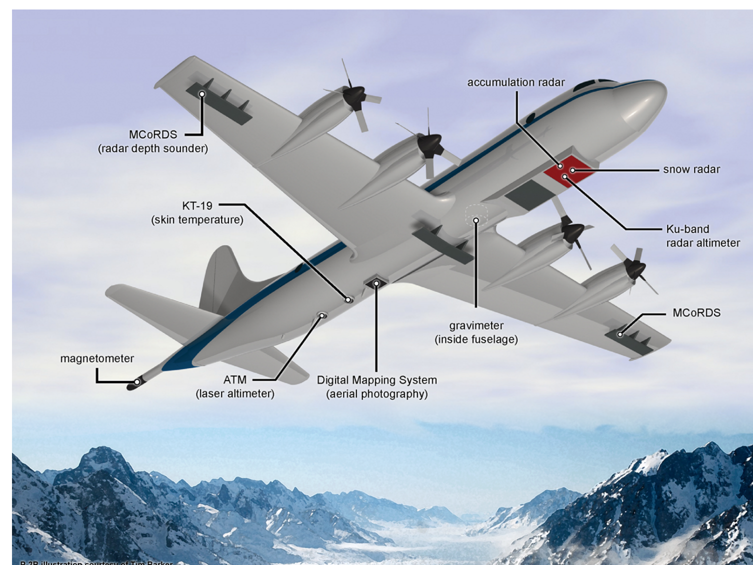


IceBridge L4 Sea Ice Freeboard, Snow Depth, and Thickness

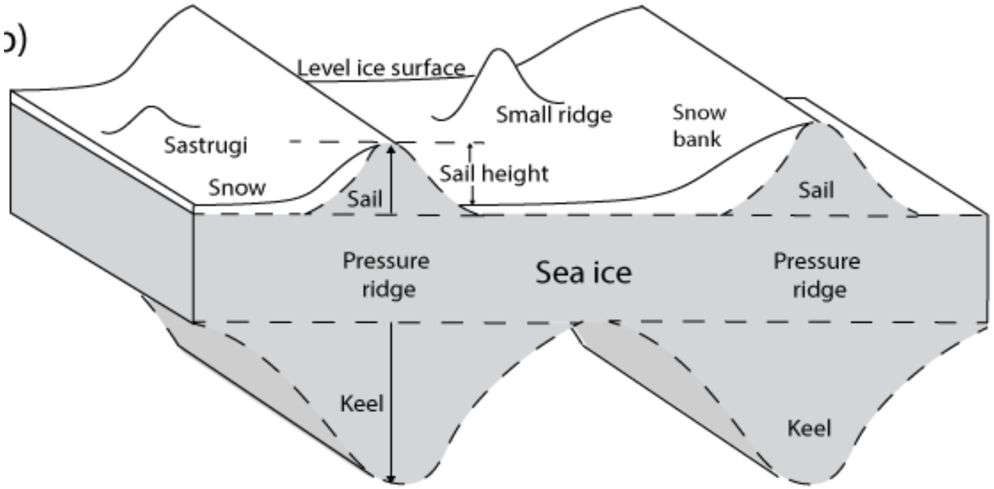
This data set contains derived geophysical data products including sea ice freeboard, snow depth, an
IceBridge Snow Radar, Digital Mapping System (DMS), Continuous Airborne Mapping By Optical Tra
data were collected as part of Operation IceBridge funded campaigns.

http://nsidc.org/data/docs/daac/icebridge/idcsi4/

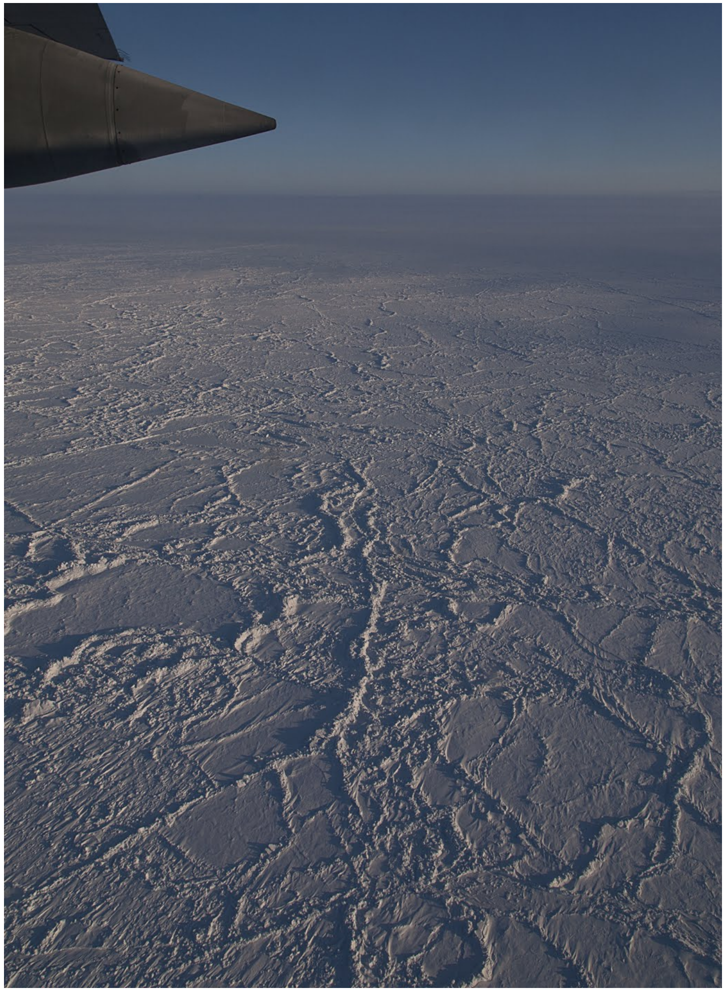
Nathan Kurtz et al., Talk (Wednesday)
Jeremy Harbeck et al., Poster (Friday afternoon)



Sea ice surface variability

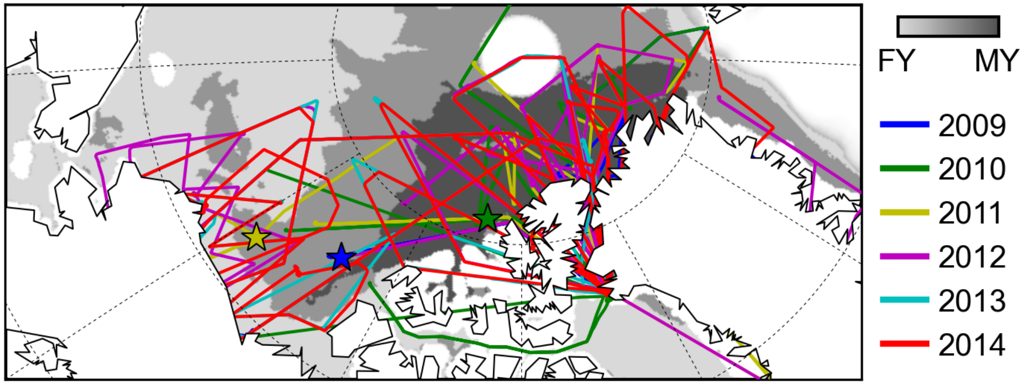


- Sea ice is, in-fact, a heterogeneous medium, which varies regionally and temporally.
- Pressure ridges (sails) often dominate the ice surface variability.
- Sastrugi, dunes, hummocks also likely to feature. A potential complication.



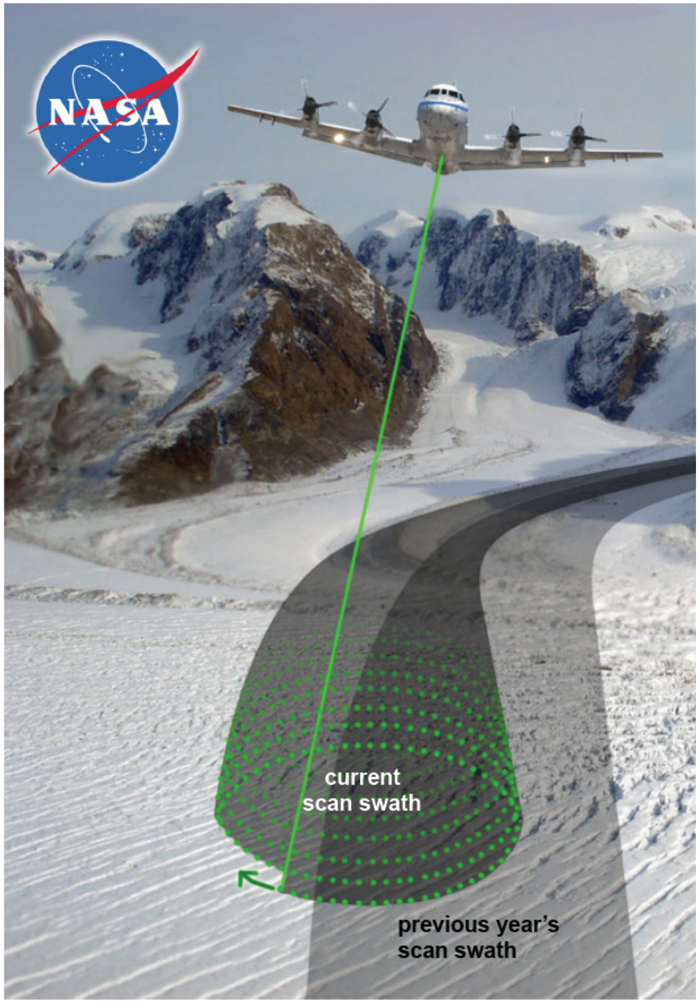
(Photo by Jeremy Harbeck, taken during an IceBridge sea ice flight)

The Airborne Topographic Mapper (ATM)

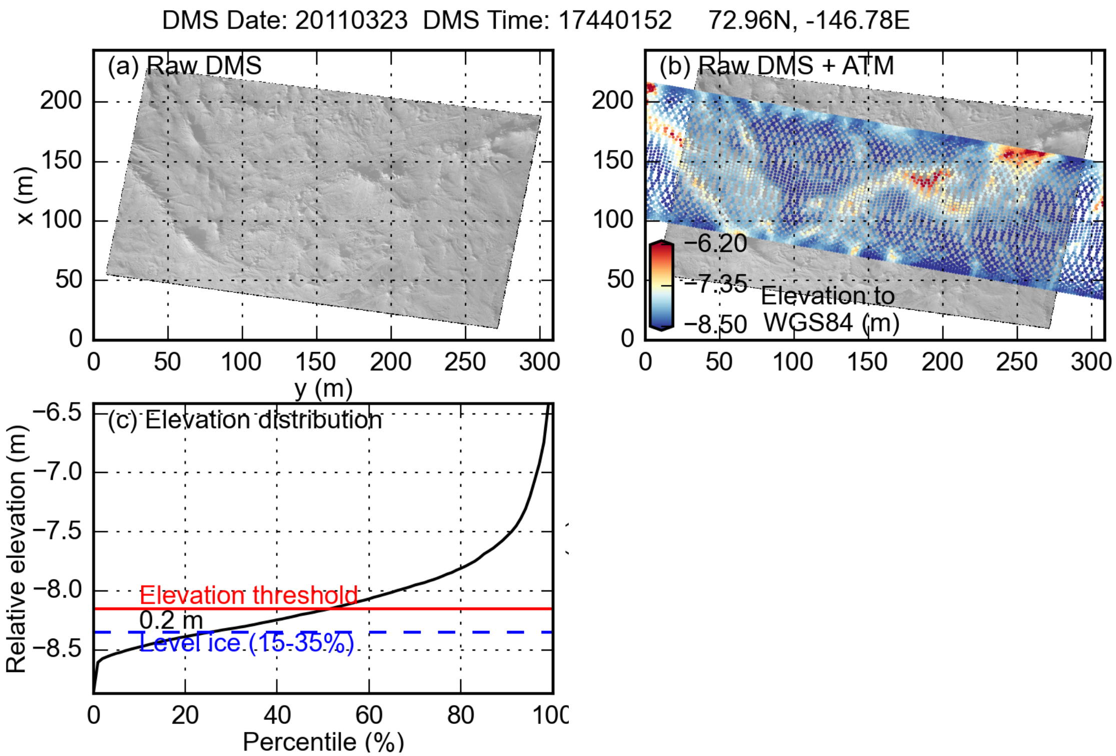


Year	2009	2010	2011	2012	2013	2014
Along-track coverage (km)	8,762	14,505	10,080	24,625	18,092	21,028
ATM swath area (km^2)	2,216	5,043	2,432	6,284	4,614	5,232

- Doubling of the 'good' sea ice coverage since 2009.
- High data coverage in the Central Arctic
- Good coverage in the Beaufort Sea, a region of rapid sea ice decline.
- Can increasingly start to investigate interannual variability.

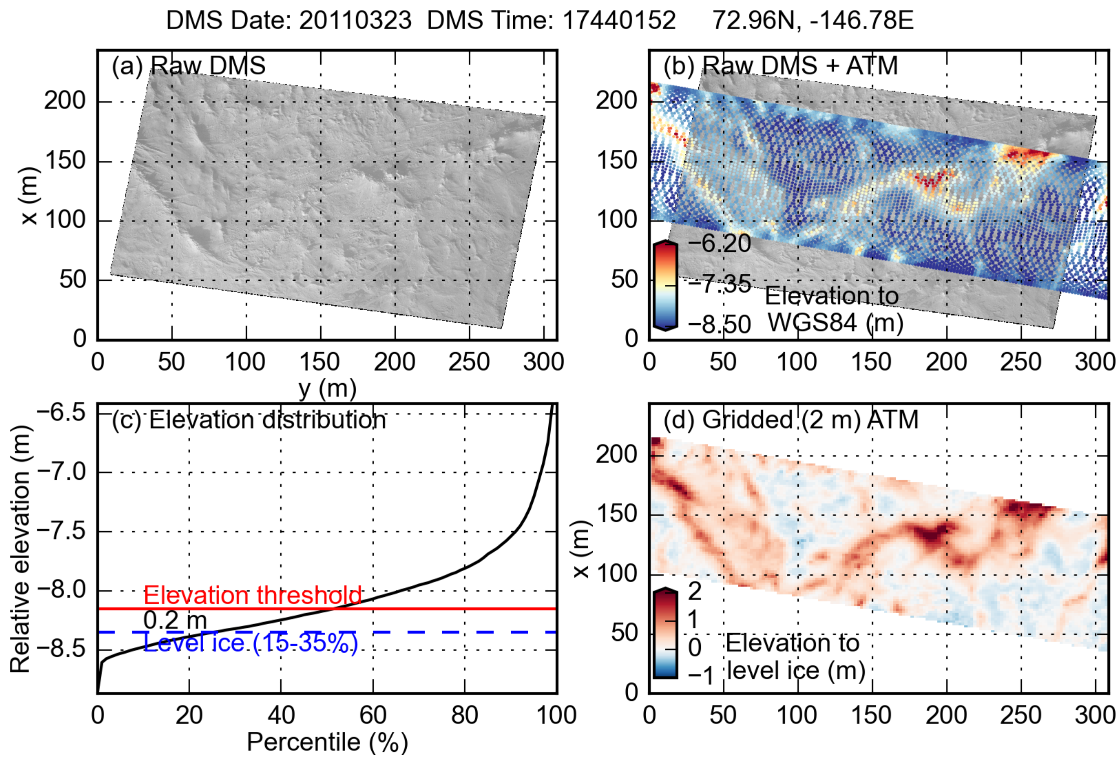


Sea ice surface profiling



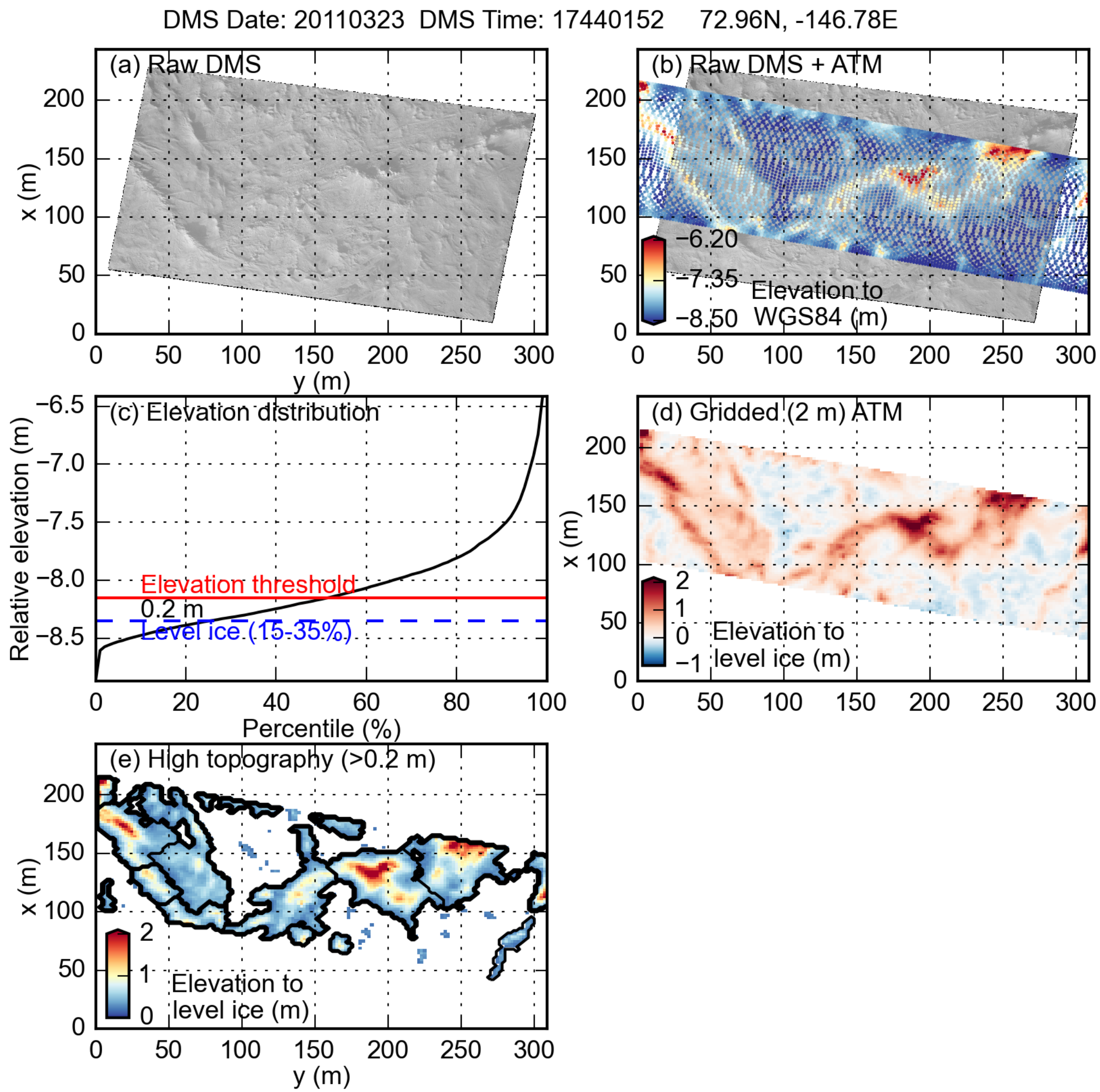
1. Find the lowest surface elevation gradient (modal elevation bin).

Sea ice surface profiling



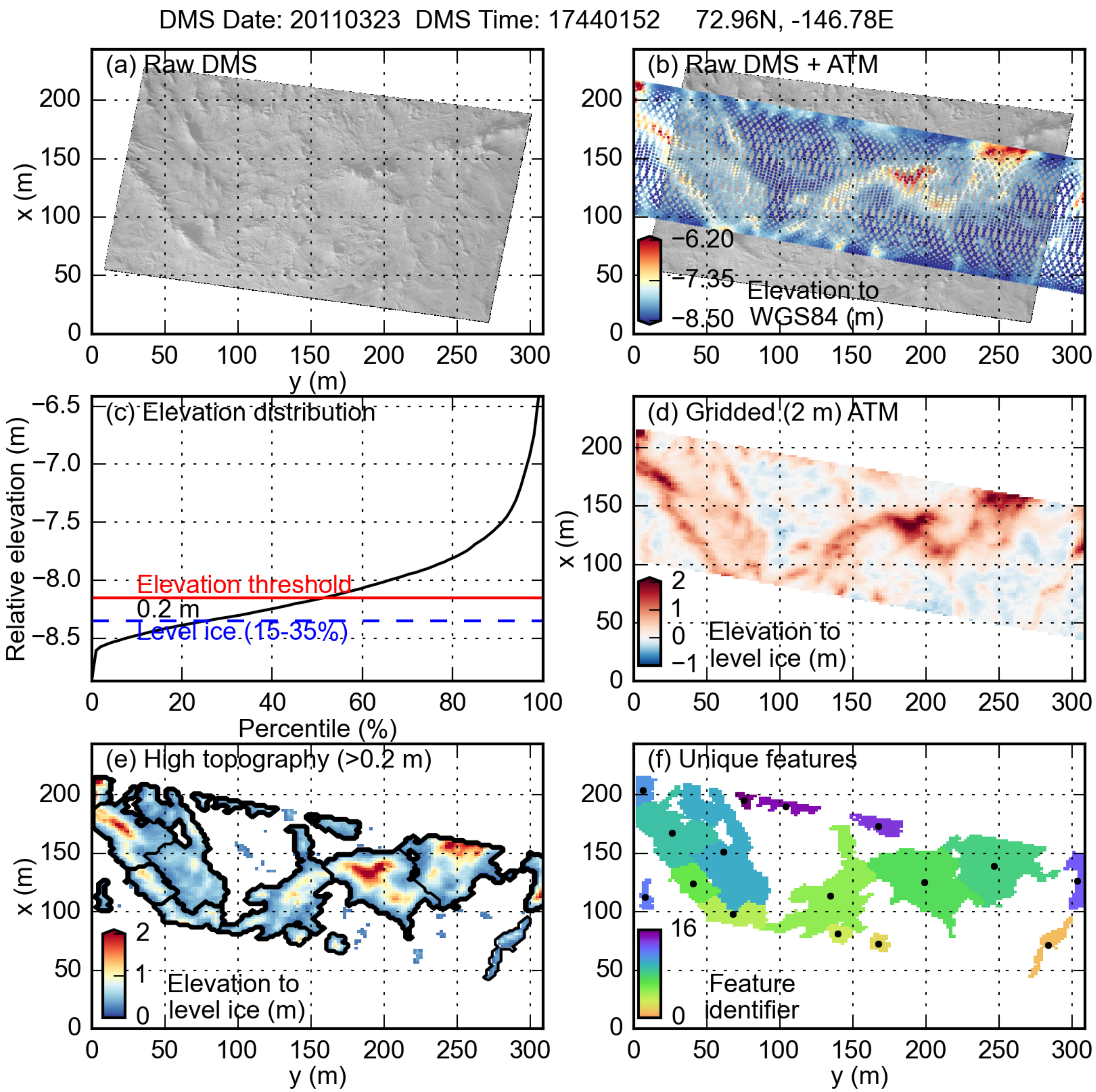
1. Find the lowest surface elevation gradient (modal elevation bin).
2. Grid the data using a simple linear interpolation scheme.

Sea ice surface profiling



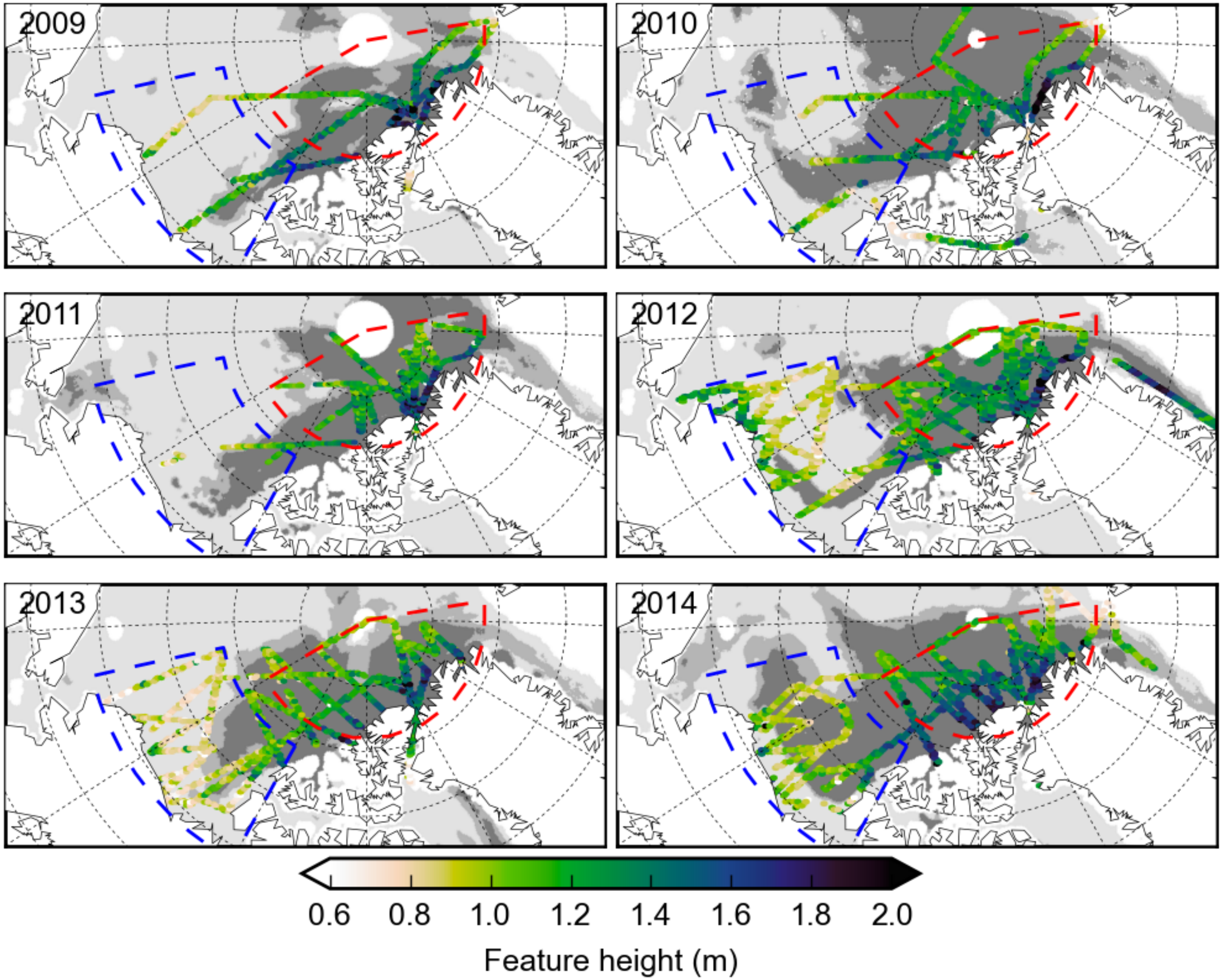
1. Find the lowest surface elevation gradient (modal elevation bin).
2. Grid the data using a simple linear interpolation scheme.
3. Keep data above a given elevation threshold (e.g. 20 cm).
4. Find local maxima and apply watershed filter to separate `unique' features.

Sea ice surface profiling



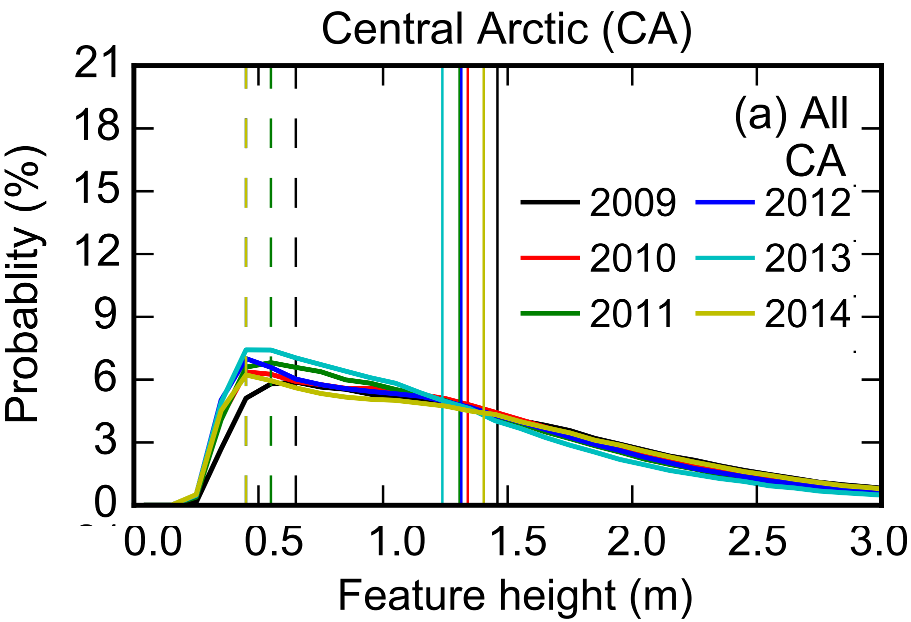
1. Find the lowest surface elevation gradient (modal elevation bin).
2. Grid the data using a simple linear interpolation scheme.
3. Keep data above a given elevation threshold (e.g. 20 cm).
4. Find local maxima and apply watershed filter to separate `unique' features.
5. Output individual statistics (e.g. height/ orientation) and bulk statistics (mean height/ volume).

Results: Surface feature height



Dark grey =MY, light grey=FY, from OSI-SAF ice type product

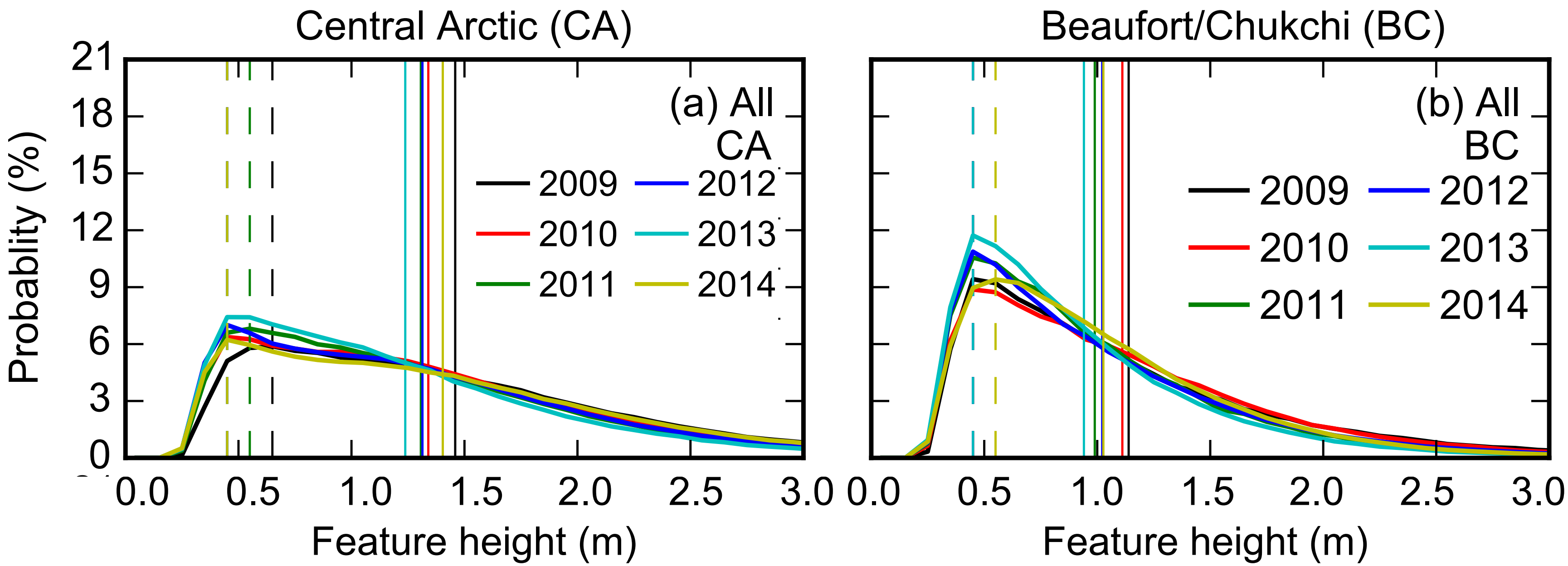
Feature height distributions



	Year	Mean (m)	Mode (m)
ALL	2009	1.46 (0.87)	0.65
	2010	1.34 (0.78)	0.45
	2011	1.31 (0.78)	0.55
	2012	1.31 (0.79)	0.45
	2013	1.24 (0.76)	0.45
	2014	1.40 (0.85)	0.45
	All	1.34 (0.81)	0.45

- Decrease in feature height from 2009 to 2013.
- Increase from 2013 to 2014.
- Results in-line with increased ice covergence through summer 2013, estimated in *Kwok, 2015, GRL.*

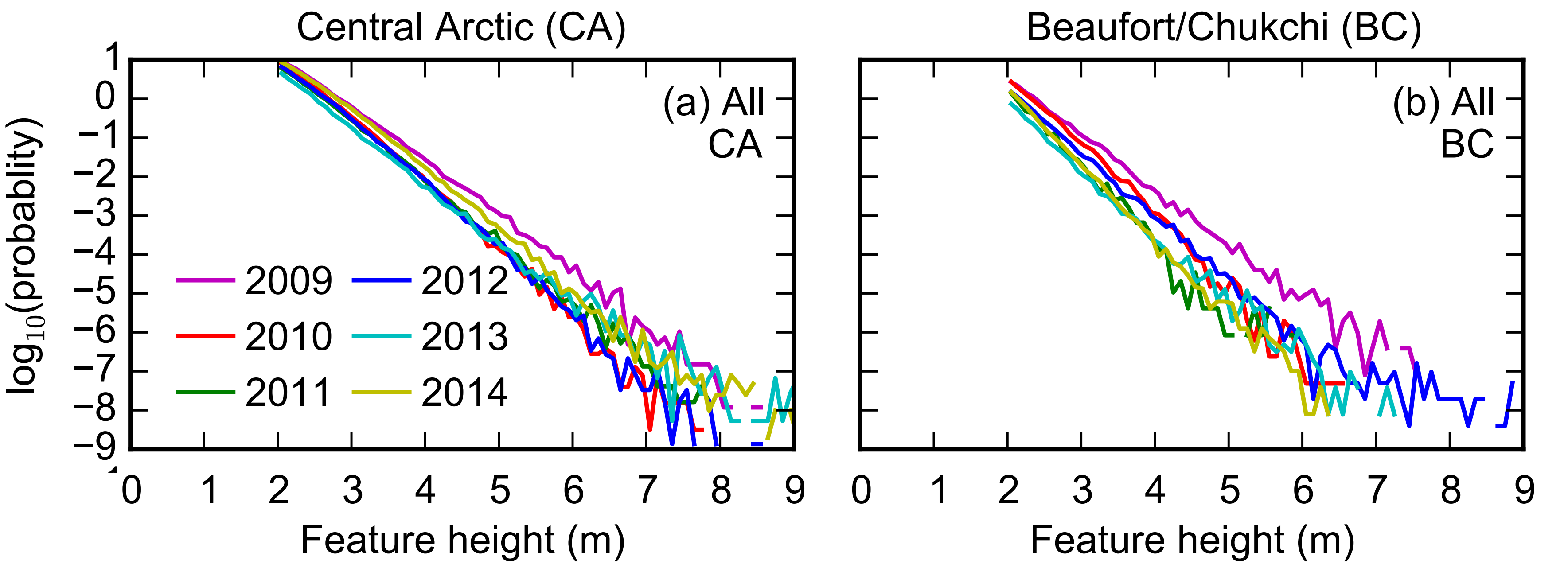
Feature height distributions



	Year	Mean (m)	Mode (m)
ALL	2009	1.46 (0.87)	0.65
	2010	1.34 (0.78)	0.45
	2011	1.31 (0.78)	0.55
	2012	1.31 (0.79)	0.45
	2013	1.24 (0.76)	0.45
	2014	1.40 (0.85)	0.45
	All	1.34 (0.81)	0.45

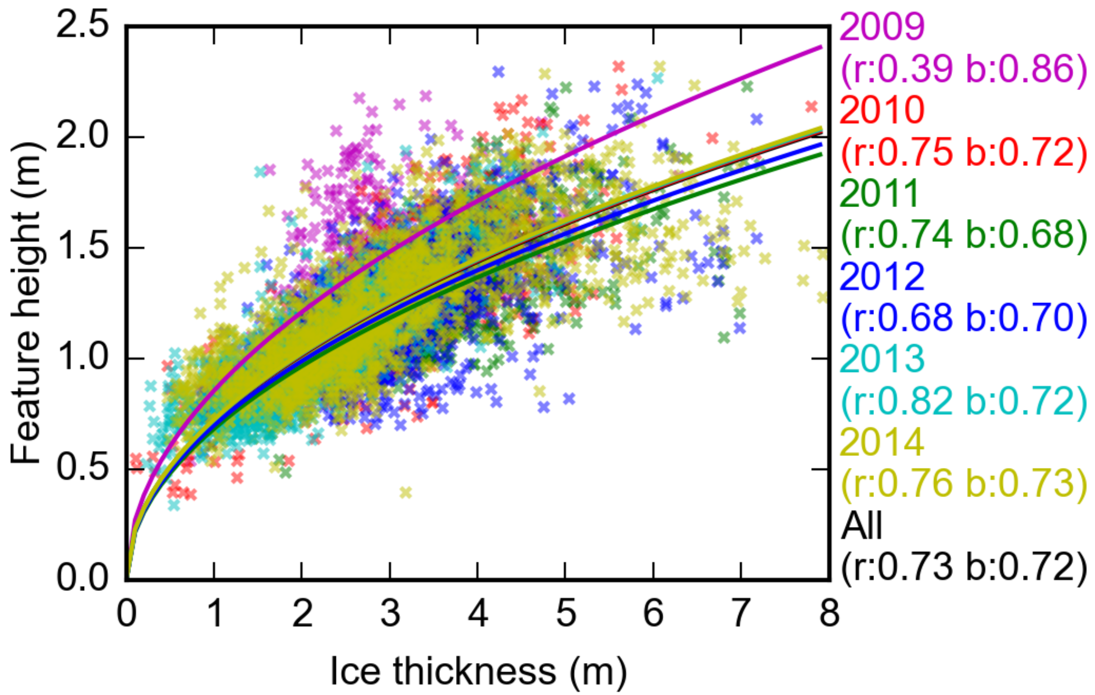
	Year	Mean (m)	Mode (m)
ALL	2009	1.14 (0.74)	0.45
	2010	1.11 (0.67)	0.45
	2011	0.99 (0.58)	0.45
	2012	1.02 (0.64)	0.45
	2013	0.94 (0.57)	0.45
	2014	1.03 (0.58)	0.55
	All	1.02 (0.63)	0.45

Feature height distributions (tails)



- Plot on a log-linear scale to highlight extremes.
- Feature heights follow a simple exponential distribution.
- Clear interannual variability in feature height extremes (2009 has more significant tail, although beware sampling issues).
- Of interest to Arctic sea ice navigation/off-shore ops?

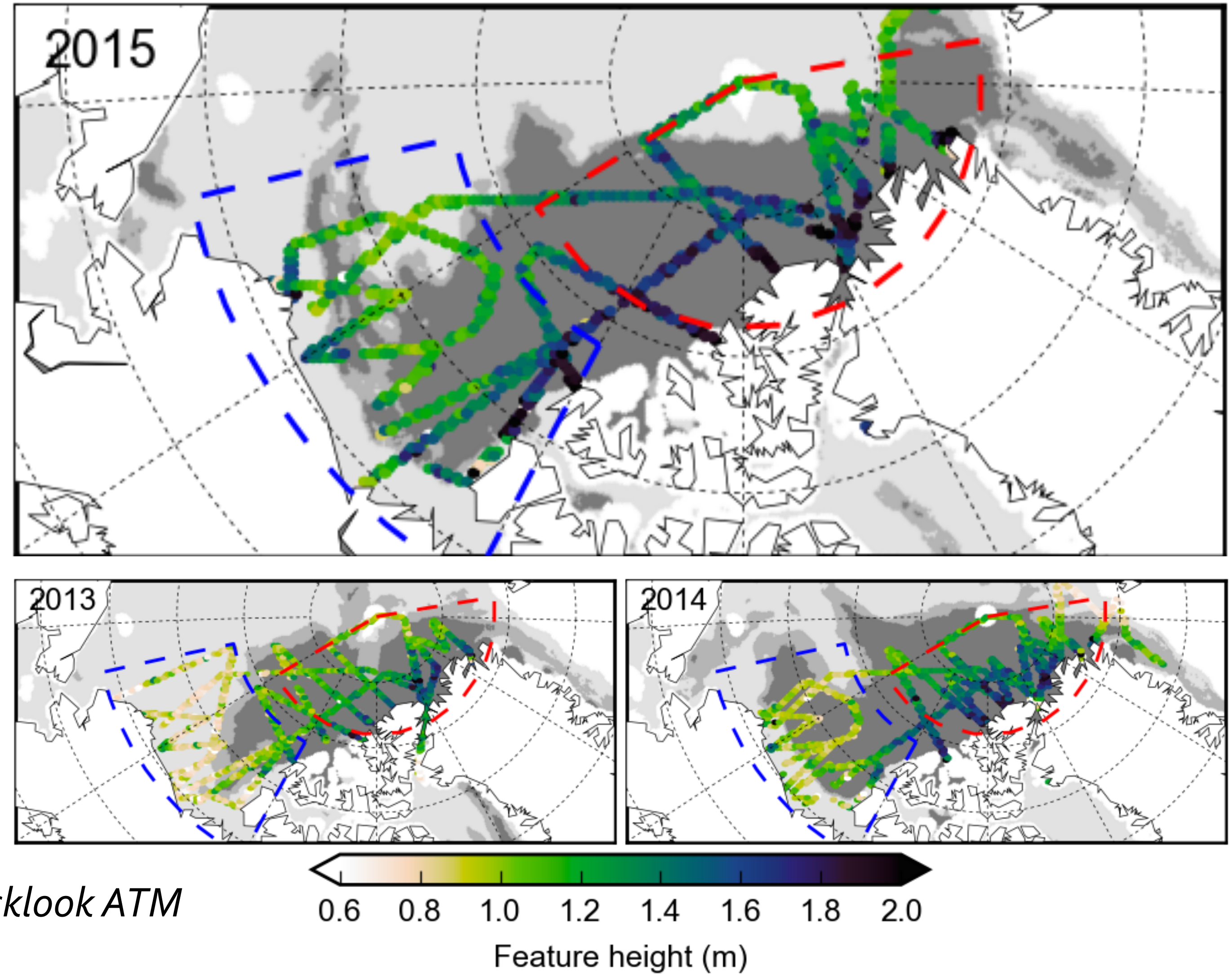
Feature height – total ice thickness



$$h_f = b\sqrt{H_i}$$

- Correlate feature heights (10km mean) with sea ice thickness.
- Strong relationship and consistent regression coefficient (except in 2009).
- Useful proxy of ice thickness?

Results: Surface feature height



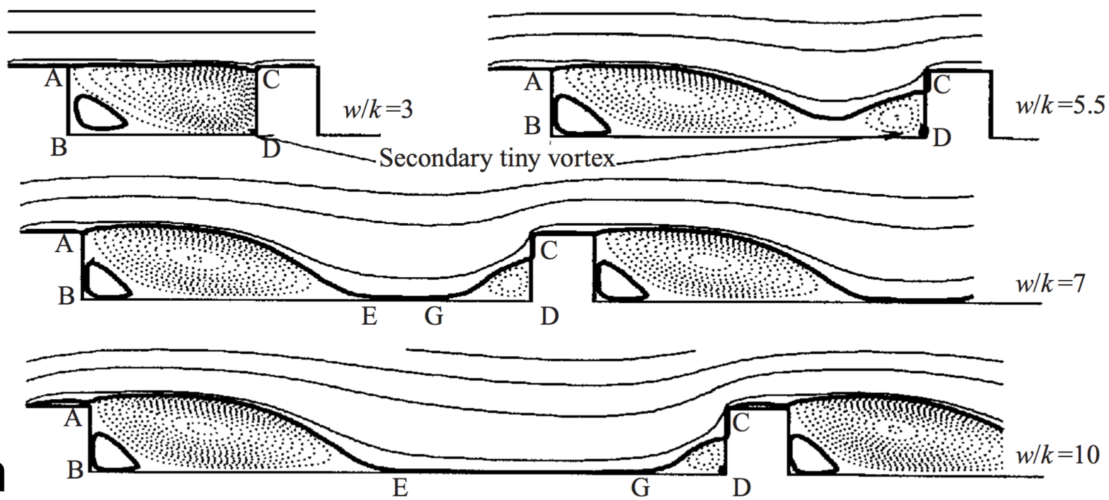
Dark grey =MY, light grey=FY, from OSI-SAF ice type product

2015 Quicklook ATM data

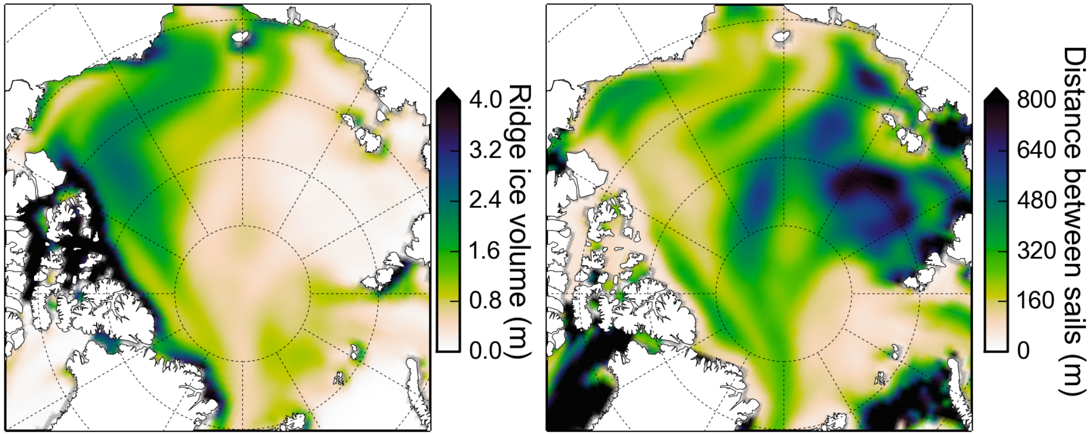
Exciting future work…

Atmospheric form drag over sea ice

- Form drag can be calculated explicitly using existing parameterizations.
- Drag recently incorporated into a sea ice climate model component (CICE).
- Model is still poorly constrained, due to a previous lack of observational data.

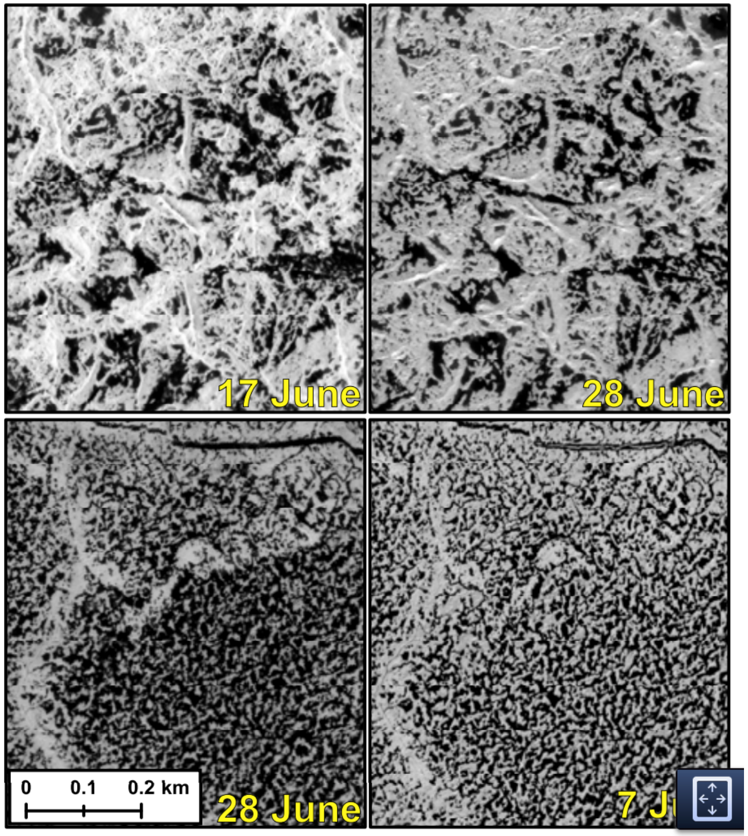


(Form drag parameterizations, taken from Leonardi et al., 2003)



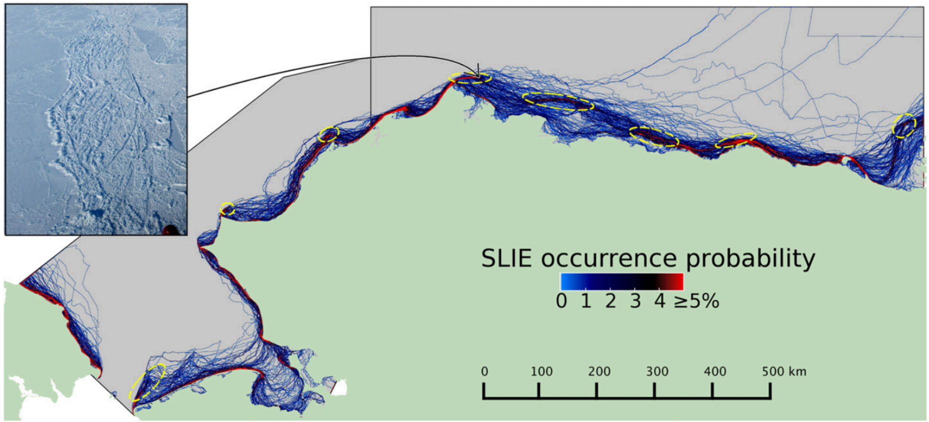
(Example (March 2012) modeled ridging behavior in the new CICE drag parameterization)

Melt ponds



[Webster et al., 2015, JGR]

Fast Ice regimes



[Mahoney et al., 2014, CRST]

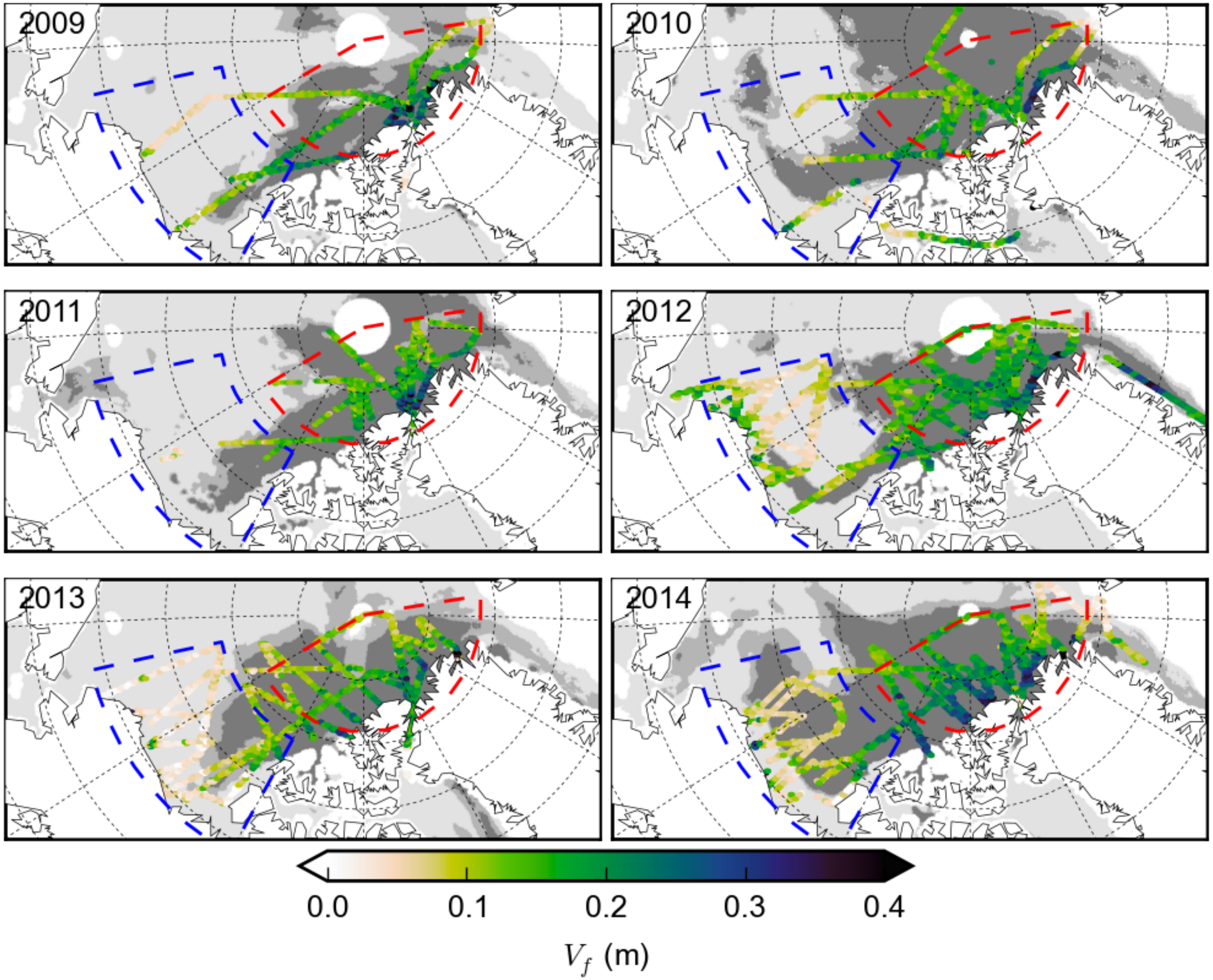
Arctic/Antarctic sea ice differences?

Summary

- A novel sea ice feature picking algorithm has been developed, suitable for 3D ATM data.
- Obtained detailed information regarding the regional and temporal variability in surface features.
- Exciting prospects for future applications, including form drag, melt pond formation, fast ice.
- Working with the IceBridge project office to characterize the entire sea ice thickness distribution.

Questions?

Results: Surface feature volume (per unit area)

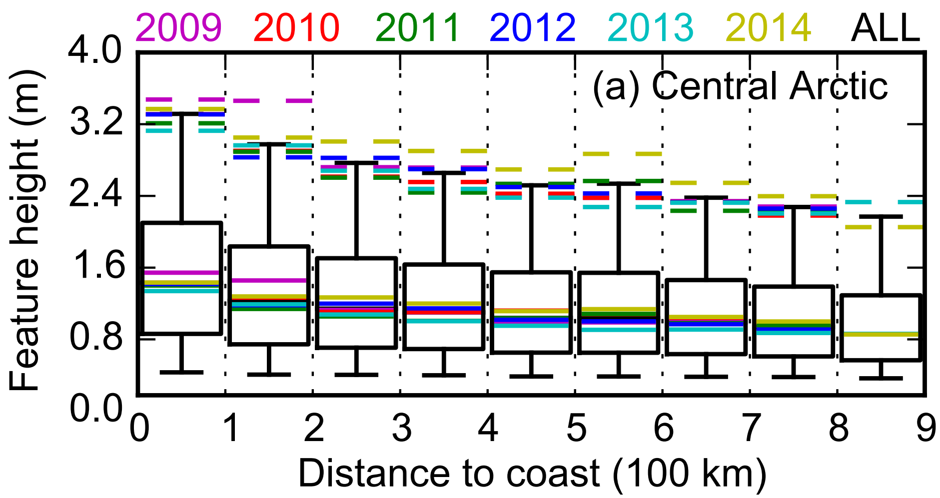


Dark grey =MY, light grey=FY, from OSI-SAF ice type product

Fast ice/melt ponds

Coastal sea ice deformation and fast ice regimes

- 100 km coastal proximity bins
- Individual flight line analysis needed for more detailed insight



Melt ponds and ice topography

- e.g. Flatter ice promotes shallow but extensive melt ponds to form.