Thinning of Arctic multiyear and ridged sea ice in Fram Strait 1990-2011

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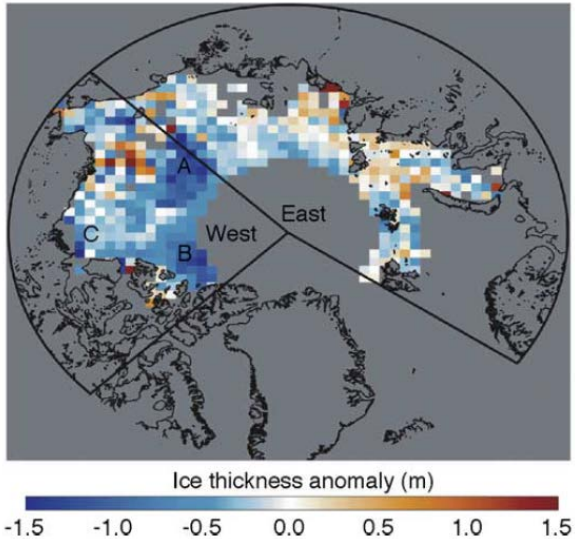
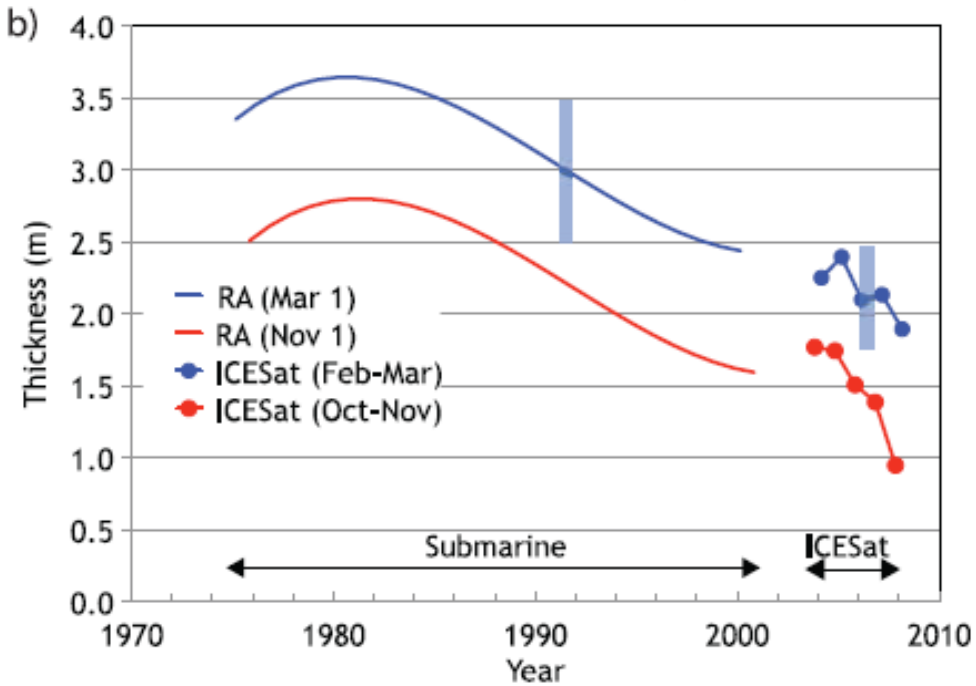
Arctic sea ice thicknesses

Arctic Ocean, S of 82 N (2003-08)



Giles et al. 2008

Arctic Basin, Beaufort Gyre & Transpolar drift



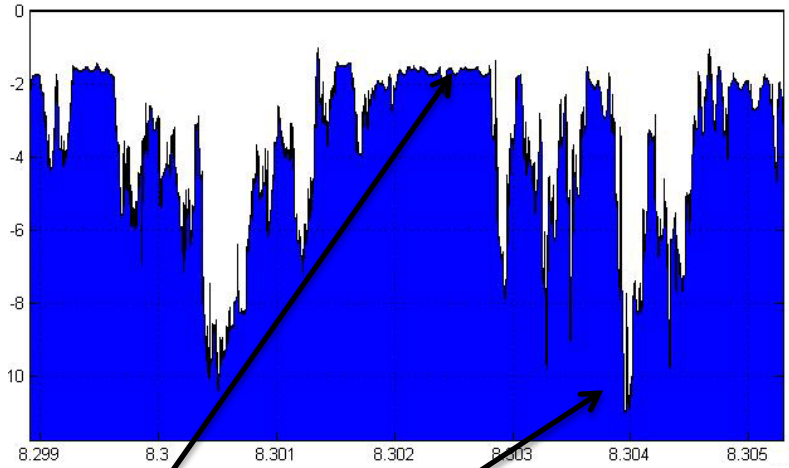
Kwok and Rothrock 2009

What is ice thickness?

How can the parameter be observed & quantified?

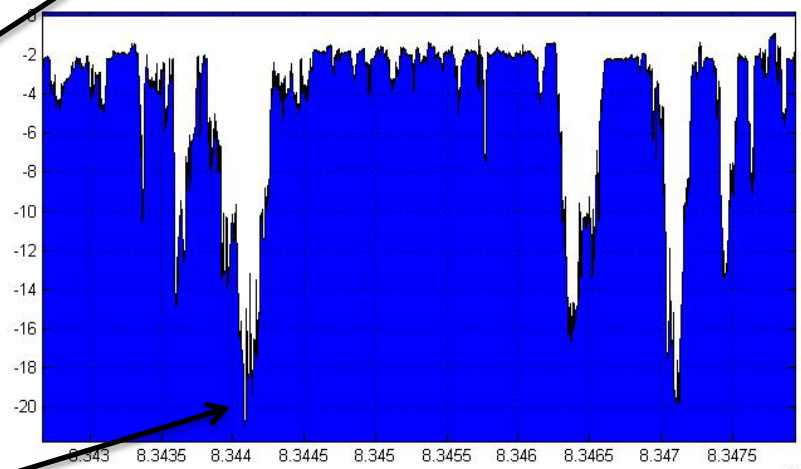
Is the mean a good summary statistic?

- The sea ice thickness feature a range of scales
- Different physical mechanisms govern how the thickness change in different ends of the scale
- Need information about thickness over the entire range: What changes, and why?



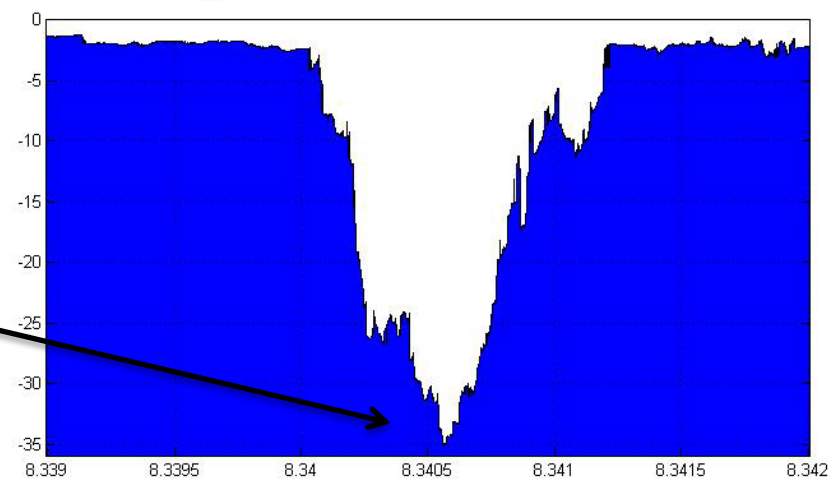
2 meter

10 meter



20 meter

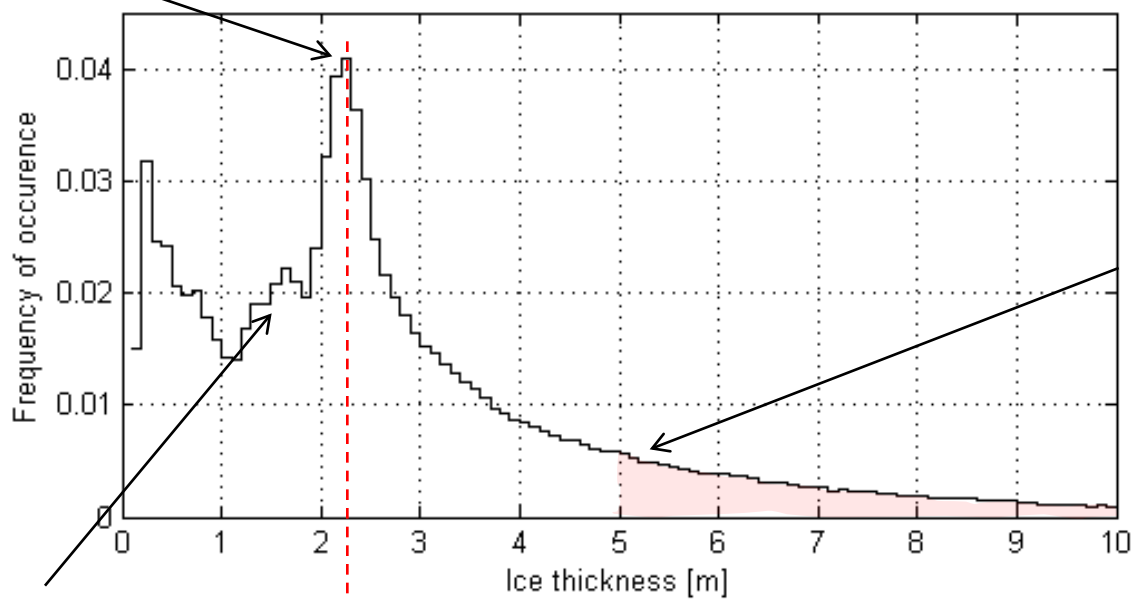
35 meter



Ice thickness distribution

MY – Multi year ice
FY – First year ice
Deformed ice (ridging)

MY mode – level MY ice
(controlled by thermodynamics)



Tail – deformed ice
(controlled by dynamics)

- Maintained by ridging
- Effectively eroded by ocean heat

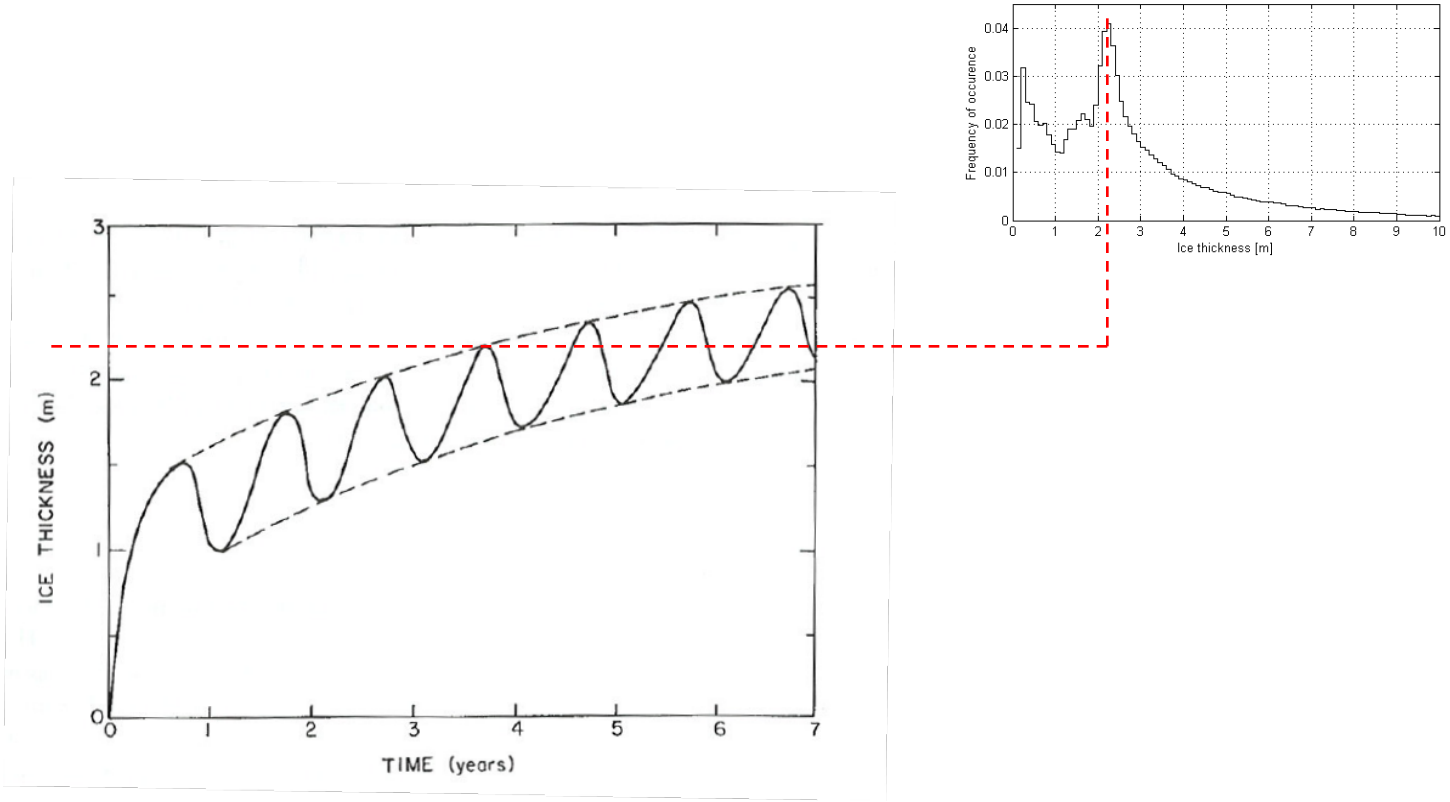
FY mode – level FY ice

MY modal thickness

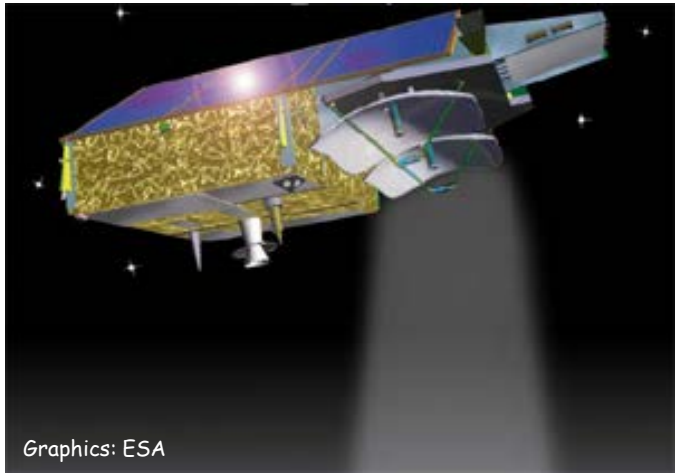
Statistical textbooks: ”If the distribution is skewed, bimodal or have a heavy tail, other summary statistics than the mean should be considered”

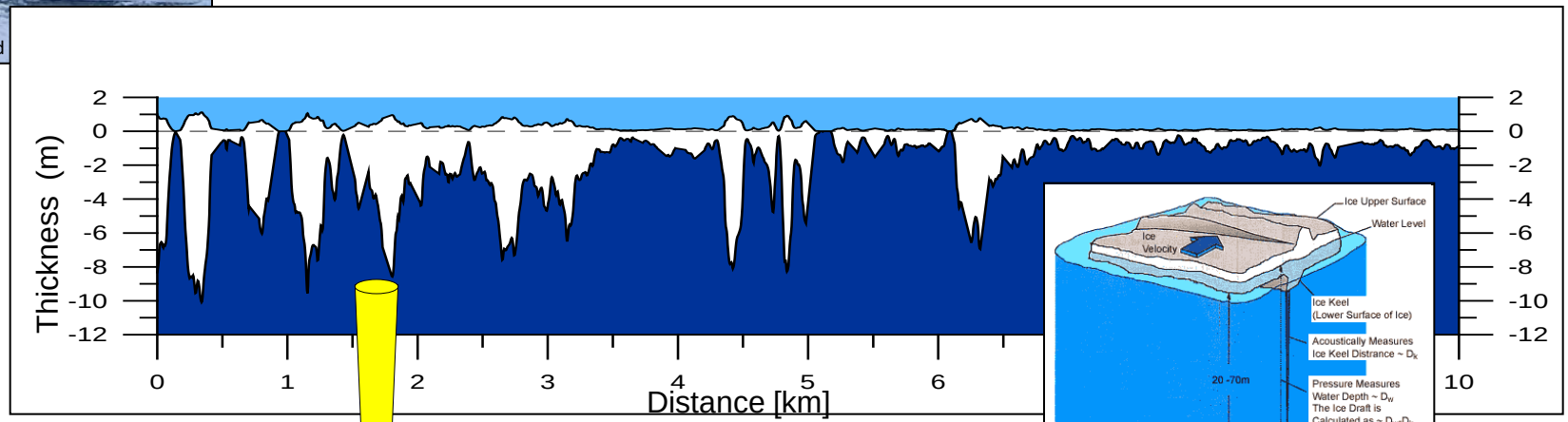
Thermodynamic equilibrium thickness (Maykut,1986):

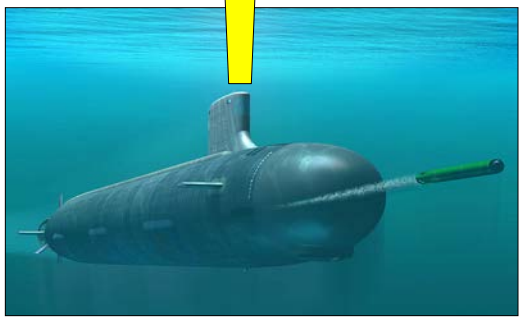
- Simplified model to understand the underlying physics
- Stationary ice, thermodynamic forcing only
- ~3 meter after 8-9 years (during the 80s-90s)
- Controlling the level ice thickness (not deformed)

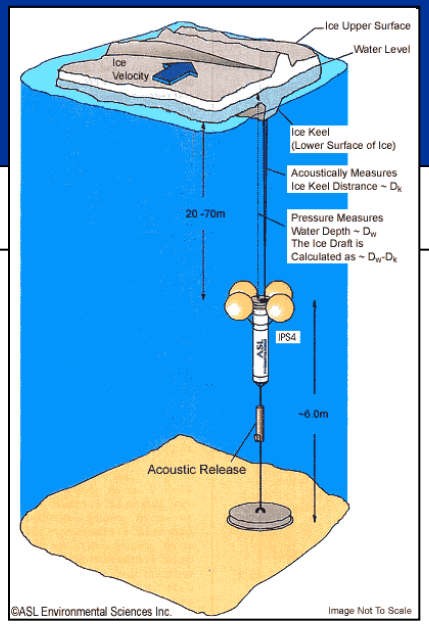


Measuring ice thickness is hampered by methodological challenges



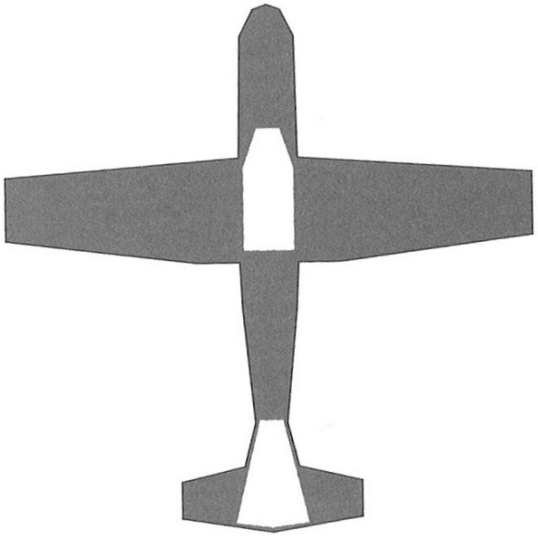






Interpreting the mean: Be careful.
Physical *insight* arises only through correct *interpretation*

Example 1:
- WW2 aircraft armour programme to protect planes
- Registering bullet holes in fighter planes returning from combat missions
- Shaded area: Took hits. White area: No hits
- Statistics tell us where to put extra armour. Where?



Where there where no hits. If you took hits in the white areas, the planes never returned - *survivorship bias*.

Example 2:
- Air temperatures increasing, cloud cover reduced - the sea ice starts to melt.
- So the sea ice is melting and thinning. What happens to the mean value?

It will increase. Since the thin ice is melting away first, the surviving thick ice pulls the mean up - *survivorship bias*

Interpreting the mean: Be careful.
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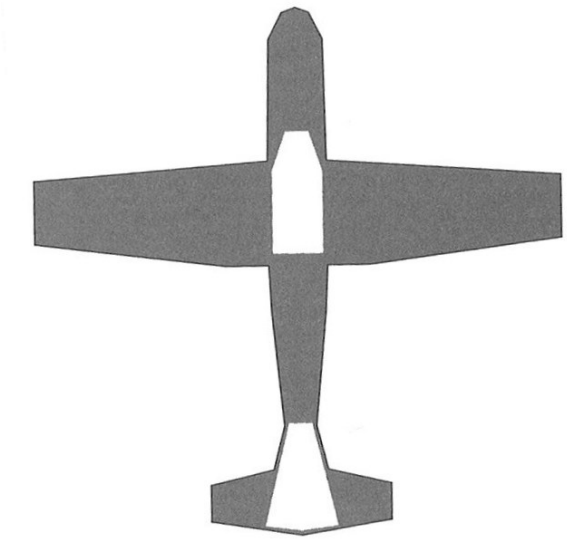


Where there where no hits. If you took hits in the white areas, the planes never returned - *survivorship bias*.

Example 3:
- We are entering the freeze up season after summer. Its very cold, much ice freezes up.
- So the sea ice thickness is increasing. What happens to the mean?

The mean will decrease. All the new, thin ice is pulling the mean down.

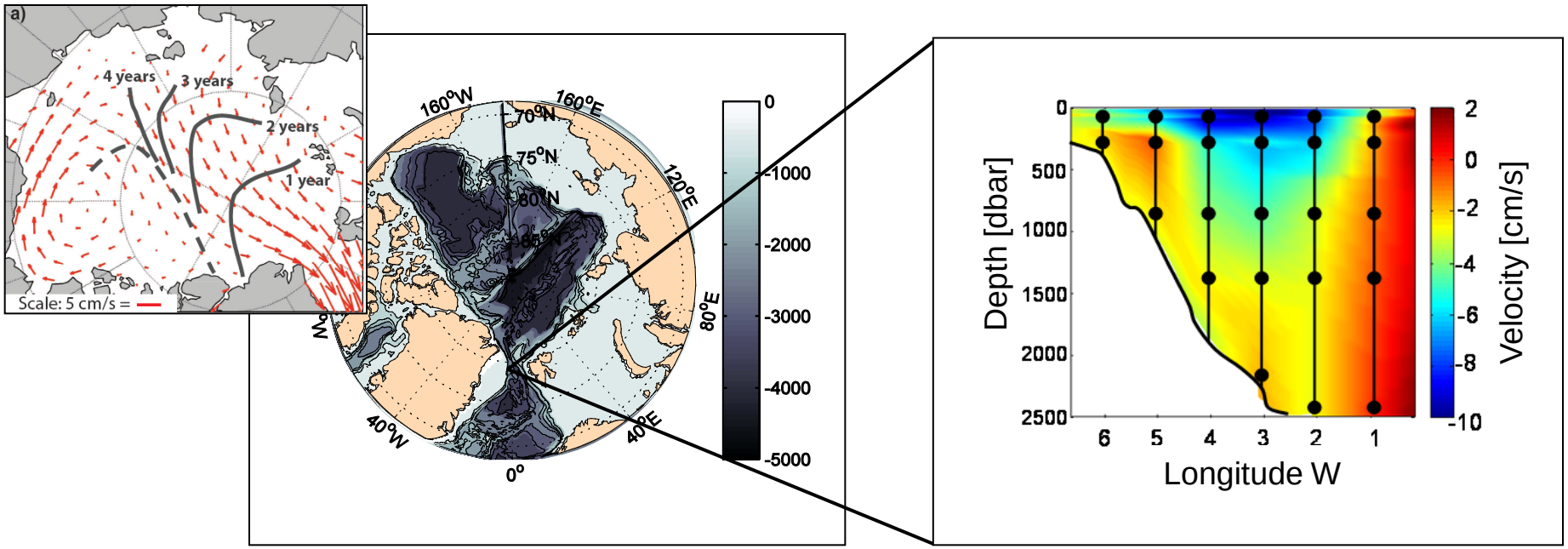
Results

20 years of ULS observations in Fram Strait
Detailed monthly ice thickness distributions
(as opposed to mean values only)

Arctic Ocean Outflow Observatory (AOBS) – NPI & AWI

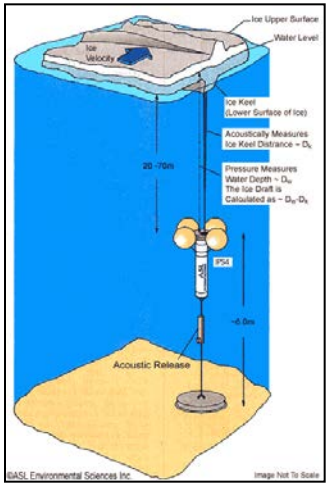
Observing Arctic change in depth

- Moorings (timeseries of T, S, currents, ice thickness, ice drift)
- Annual/biannual CTD and LADCP sections (high resolution snapshots)
- Annual/biannual tracer sections (oxygen isotopes, nutrients)
- Annual/biannual sections of ice thickness (EM31, Helicopter EM), spectral/optical properties, snow parameters

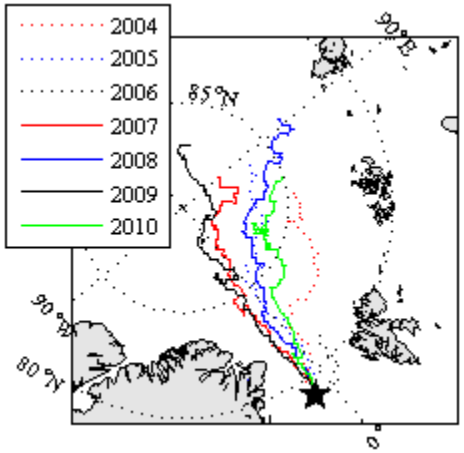


AOBS observes an integrated signal of Arctic Ocean change

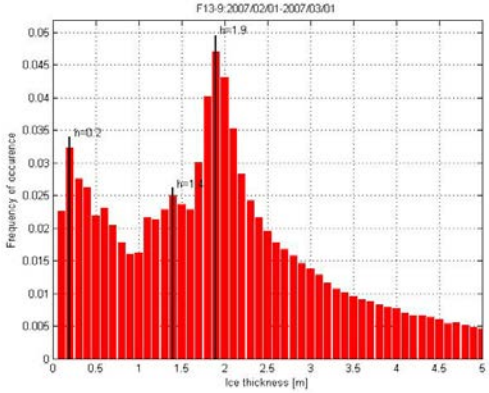
•Upward looking sonars at ~50 m depth
•Footprint ~1.5 m
•Sampling period 4 min (1990-2005)
•Sampling period 2 s (2006-)



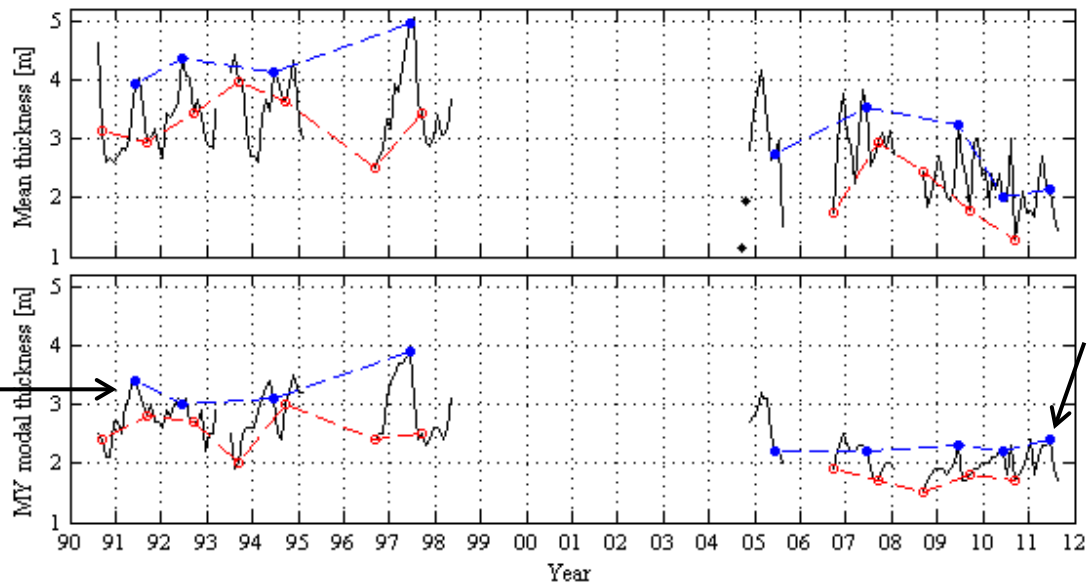
•Use instruments at the same location to construct timeseries (79 N 5 W)
•Use data from ice originating north of 85 N



•High resolution monthly ice thickness distributions
•An integrated signal of ice thickness change



What does the data tell us: MY modal thickness 1990-2011



2010-2011:
2.0 m

MY mode 90s:
3.4 0.4 m

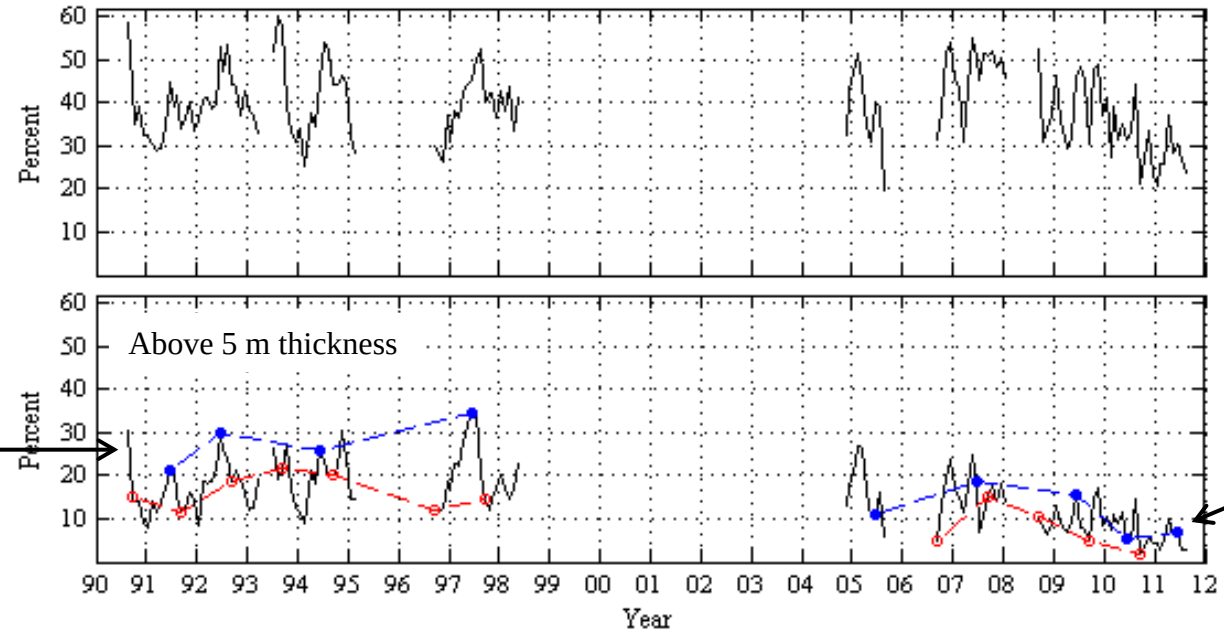
MY mode 2000s:
2.2 0.1 m

- 2010: MY modal thickness down with 38 percent since the 90s
- MY mode is approaching what used to be FY modal thickness; 1.5-2 m
- Due to the data gap, we do not know if this was a jump or a gradual transition
- Mean thickness at the end of winter 2010-2011 was 2 m: Down with 50 percent since the 90s

What does the data tell us: Changes in deformed ice

Fraction of deformed ice

Above 5 m:
28 6 %

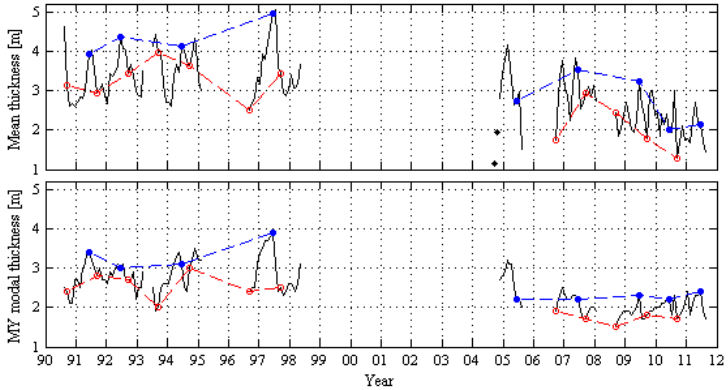


6 %

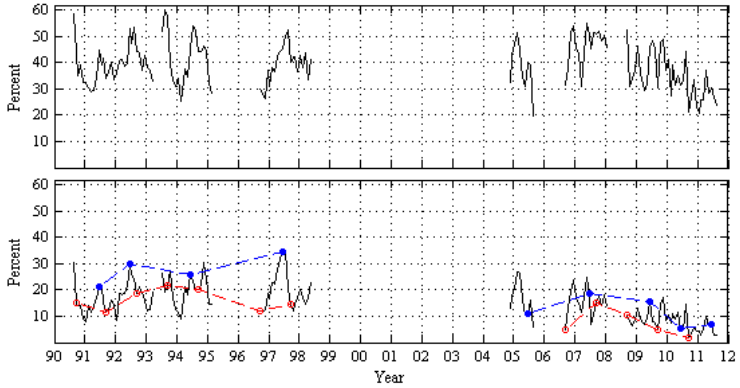
•Relative amount of ridged ice dropped with 80 percent from the 90s to 2010

Changing mean ice thickness

Mean and MY modal thickness



Deformed ice



1990s-vs2000s:

•Change in mean is due to change in both MY mode and deformed ice

•A range of processes/factors may contribute

During 2000s:

•MY modal thickness constant

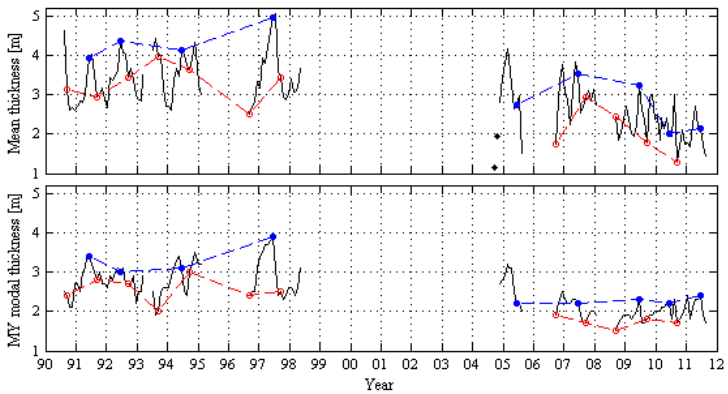
•Change in mean is due to change in deformed ice

•Rules out SAT and radiation

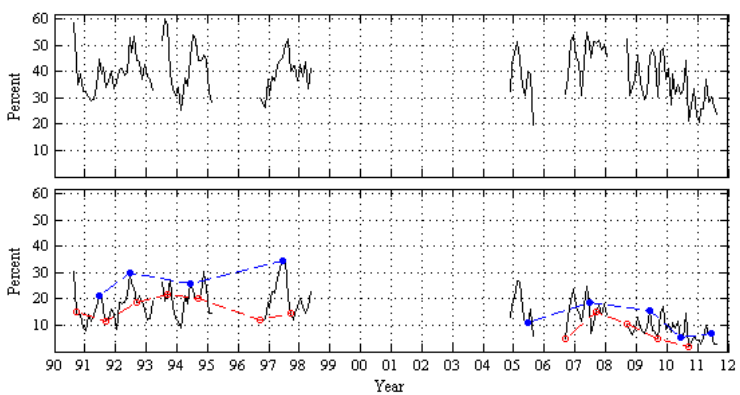
•Increased ocean heat flux?

Changing mean ice thickness

Mean and MY modal thickness



Deformed ice



One apparant implication of this combination:

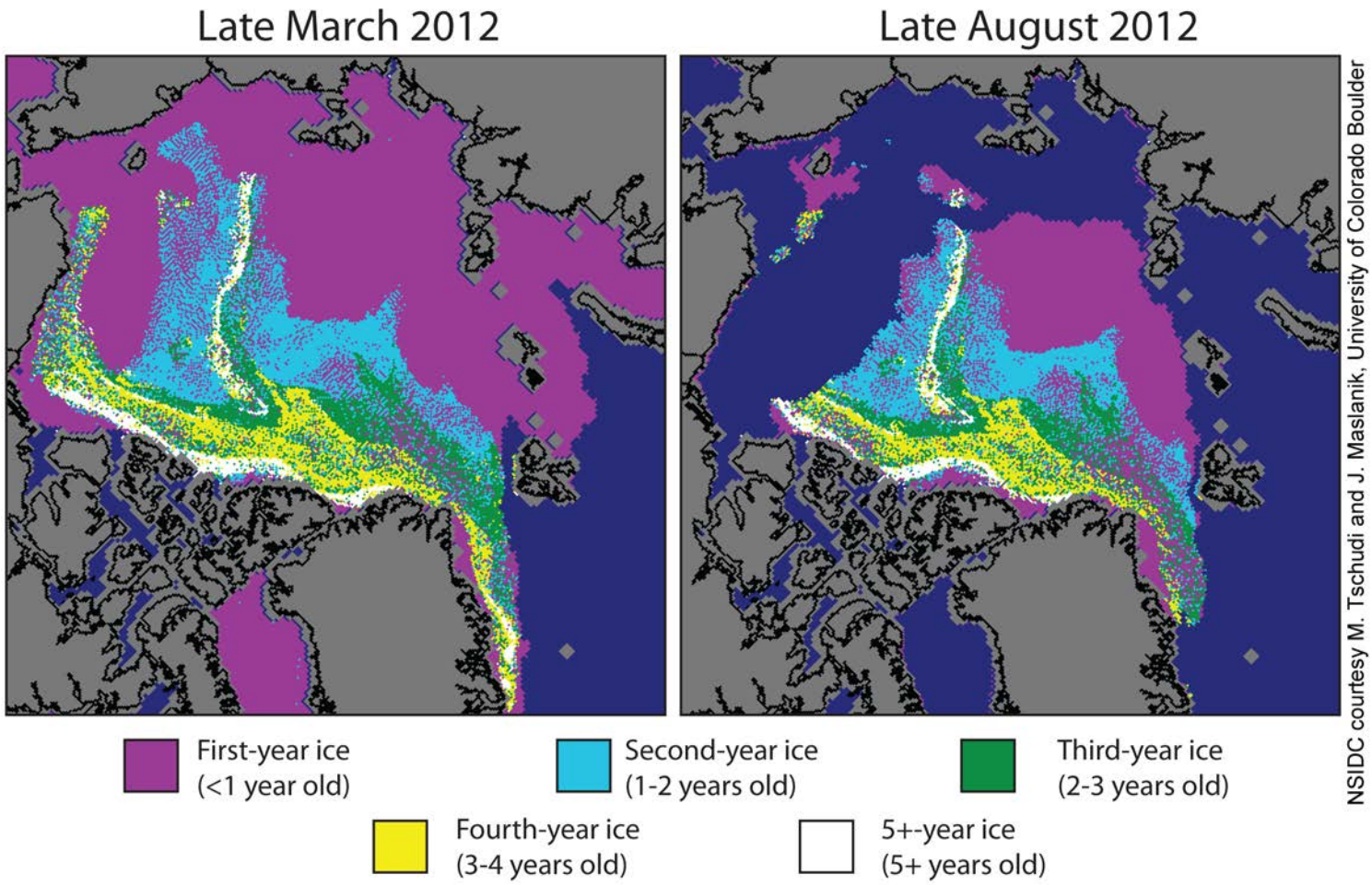
•The thick, deformed ice is nearly gone
•The MY mode is approaching FY values

•Remaining ice cover could melt away over one season – like FY ice

•The threshold for an ice free summer season in the Arctic is **not mean ice thickness = 0 m**

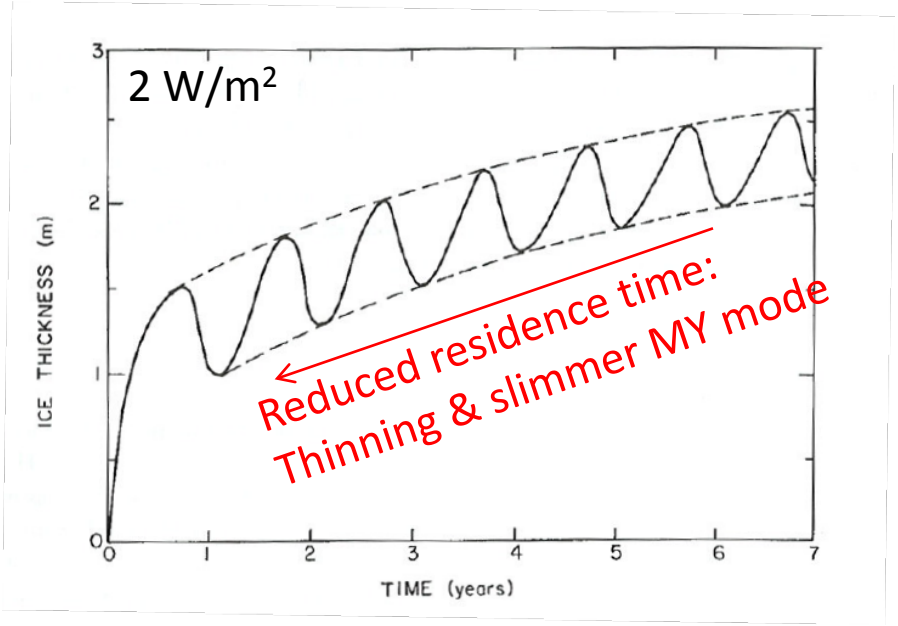
•The thickest, deformed ice is not there anymore:

•The threshold is **MY modal thickness = FY thicknesses = 1.5-2 m**


Late March 2012
Late August 2012
First-year ice
(<1 year old)
Second-year ice
(1-2 years old)
Third-year ice
(2-3 years old)
Fourth-year ice
(3-4 years old)
5+-year ice
(5+ years old)
NSIDC courtesy M. Tschudi and J. Maslanik, University of Colorado Boulder

Causes of thinning….

•Many factors contribute
•The uls data provide new insight:
•The MY mode and the tail have shifted towards lower thickness values + slimmer MY mode
•Which processes could cause this?



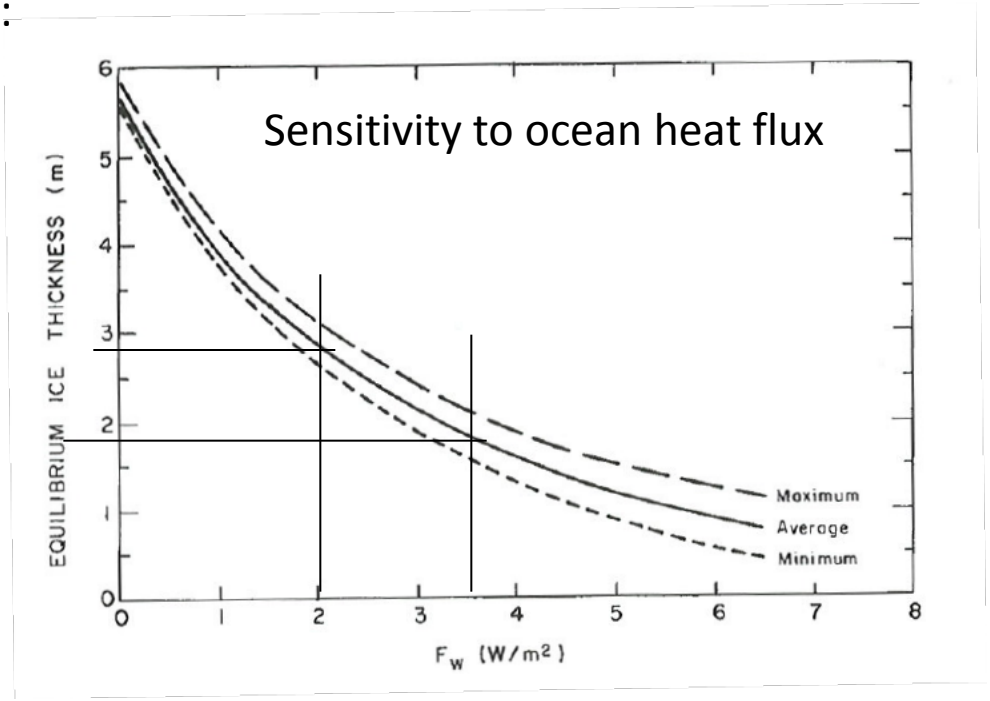
Thermal equilibrium thickness (Maykut,1986):

• Particularily sensitive to ocean heat flux

•Ocean heat flux: Will change MY thickness even with small perturbations

•Polyakov et al (2011): 3-4 W/m^2 for the early 2000s, peaking to 7 W/m^2 in 2007

•Most efficient in the tail of the distribution: Thickest ice melt first



Conclusions

•Fram Strait ULS observations provide year round, high resolution observations of Arctic sea ice thickness distributions – more info than just the mean

•MY modal thickness down with 38 % since the 90s

•Relative amount of ridged ice down with 80 % since the 90s

•**Remaining ice cover may melt away over a few seasons?**

•Increased ocean heat flux and accelerated ice drift velocities are wildcards in the balance

•Export through Fram Strait maintained due to increased area flux?