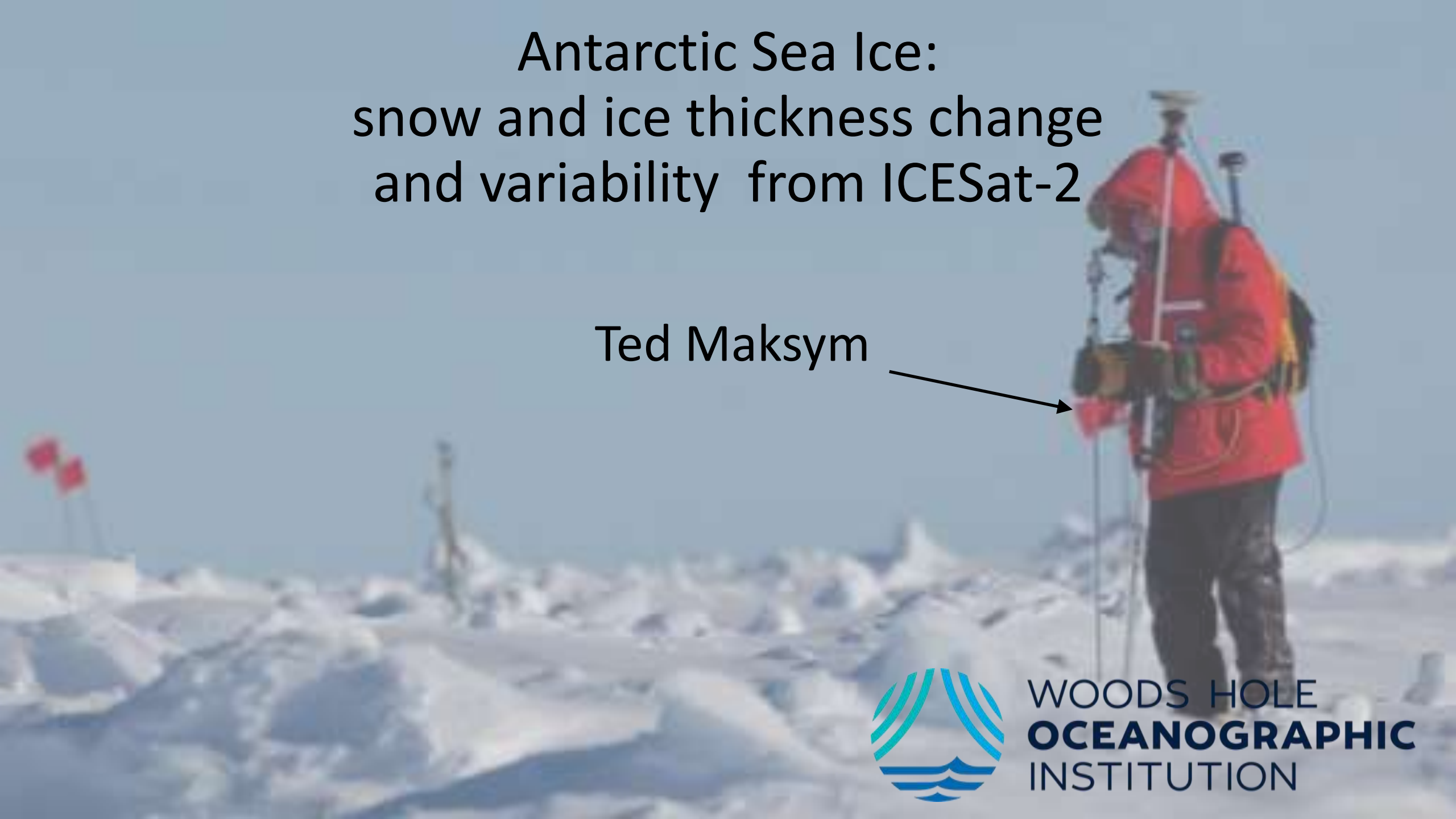
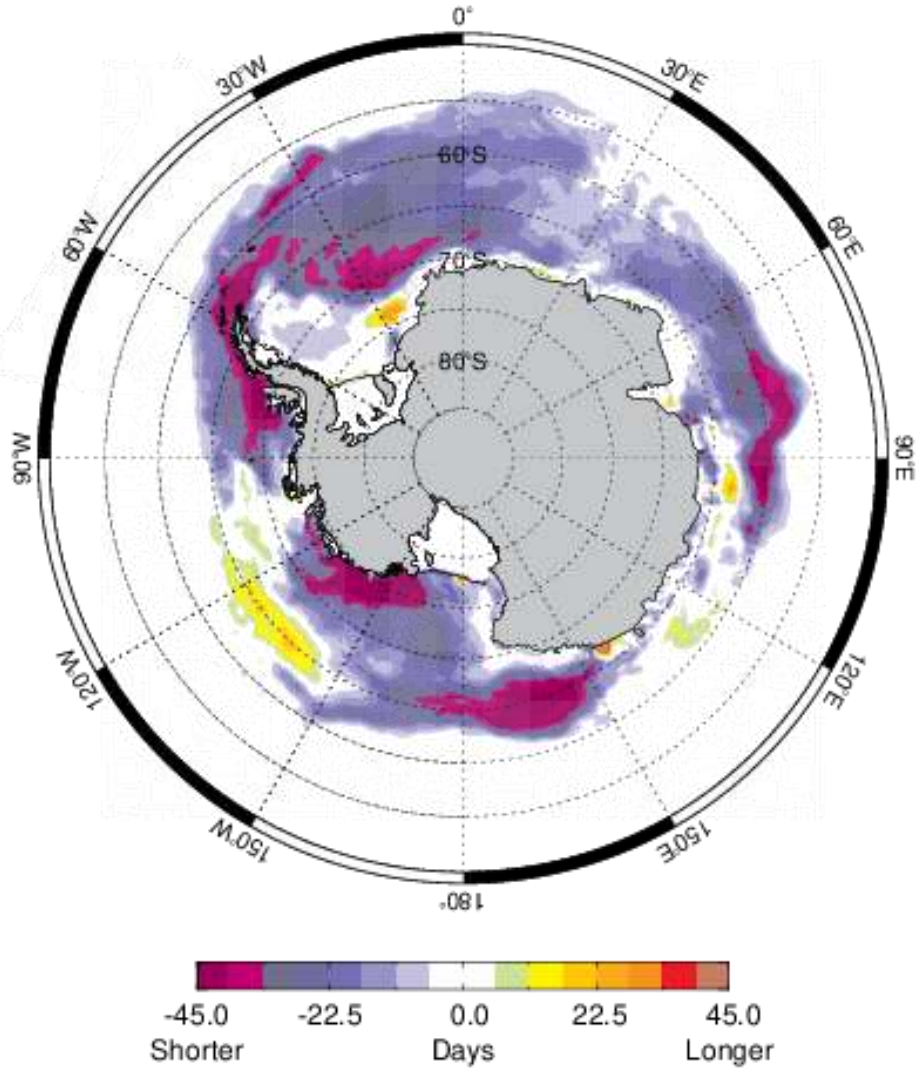
Antarctic Sea Ice: snow and ice thickness change and variability from ICESat-2

Ted Maksym



WOODS HOLE OCEANOGRAPHIC INSTITUTION

Change in Ice Covered Season 1979-2015 to 2016-2023

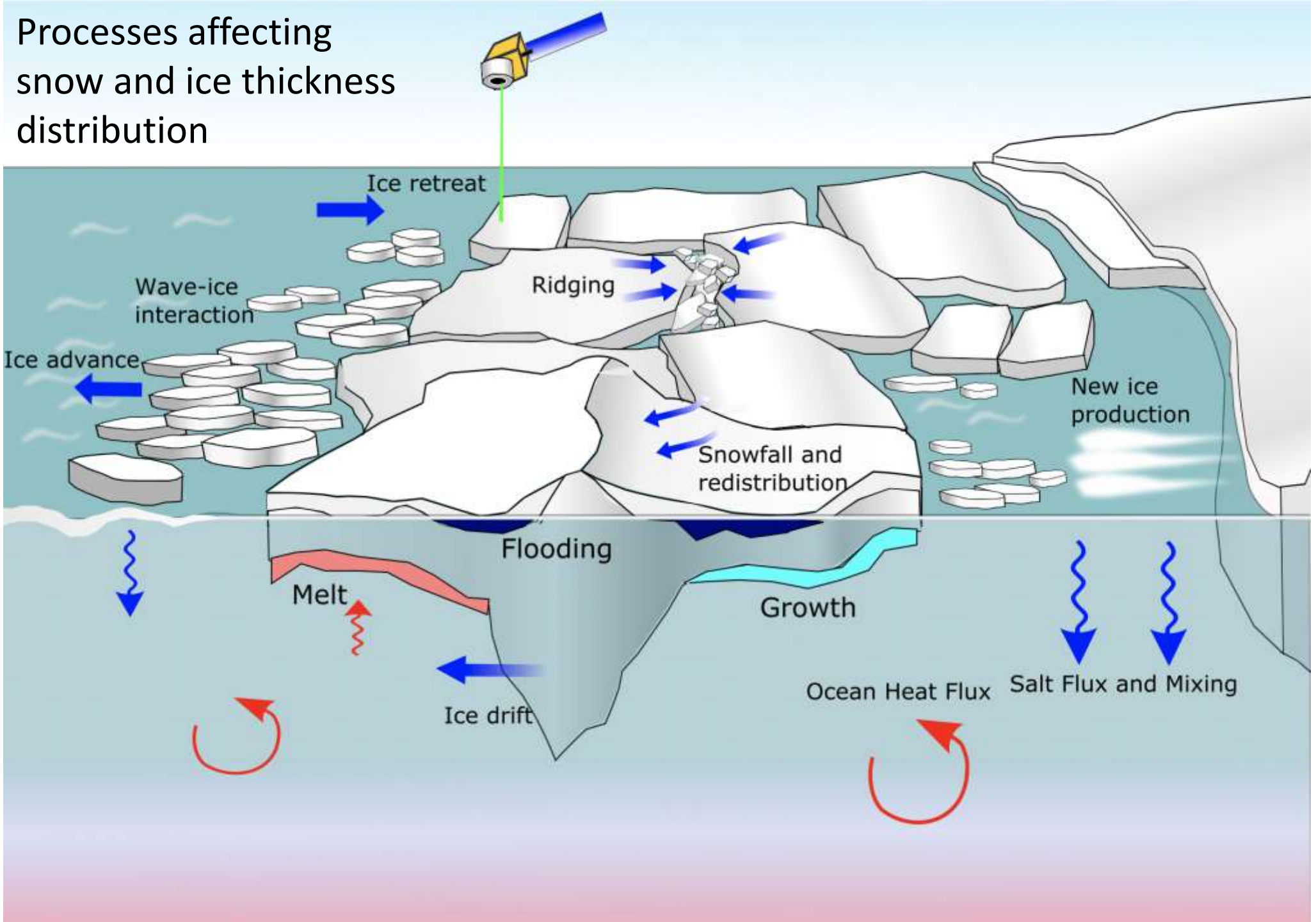


Ice Season is substantially shorter almost everywhere

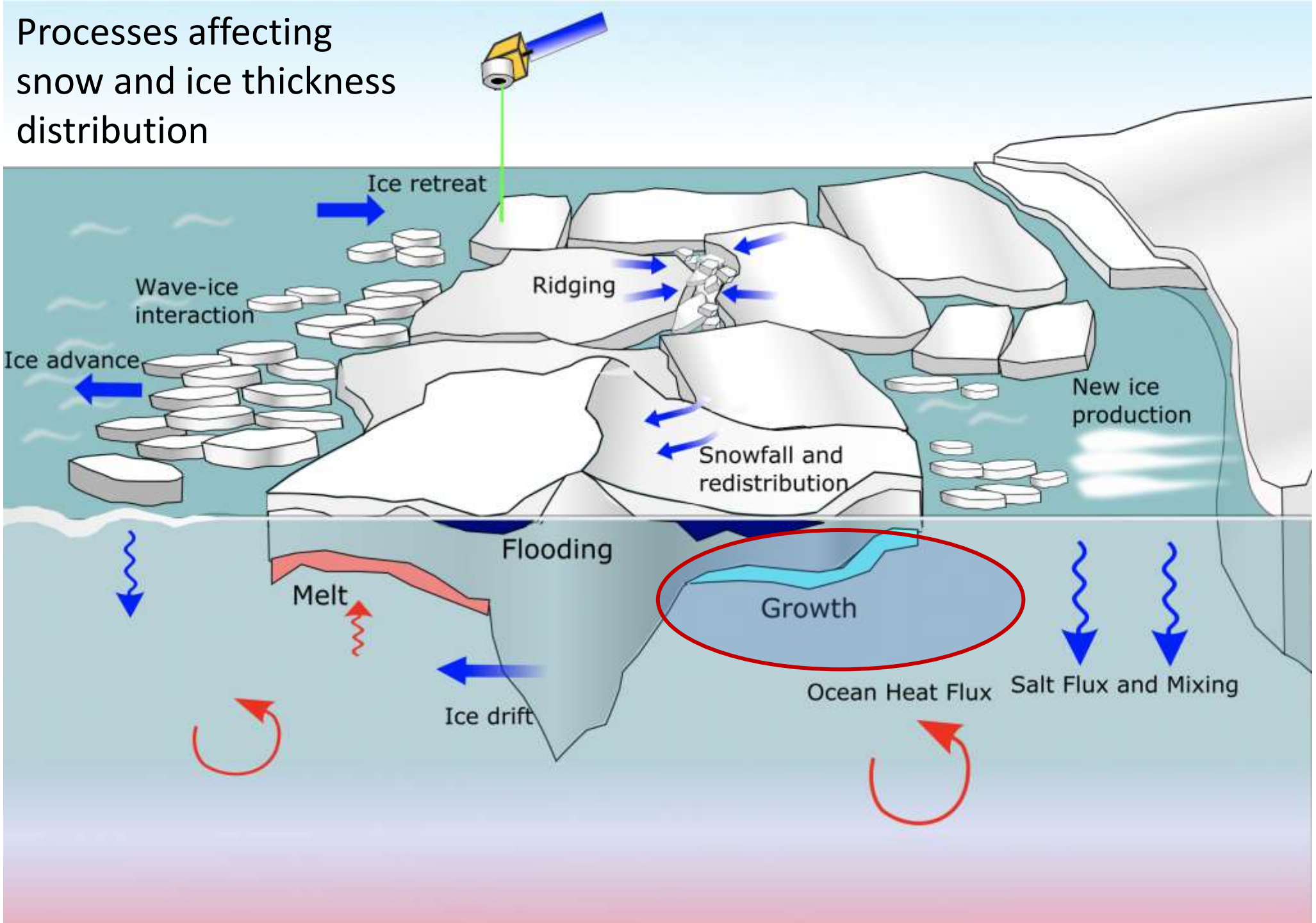
Anomaly persistence increased due to ocean forcing and/or feedback

Is this linked to ice thickness change?

Processes affecting snow and ice thickness distribution



Processes affecting snow and ice thickness distribution



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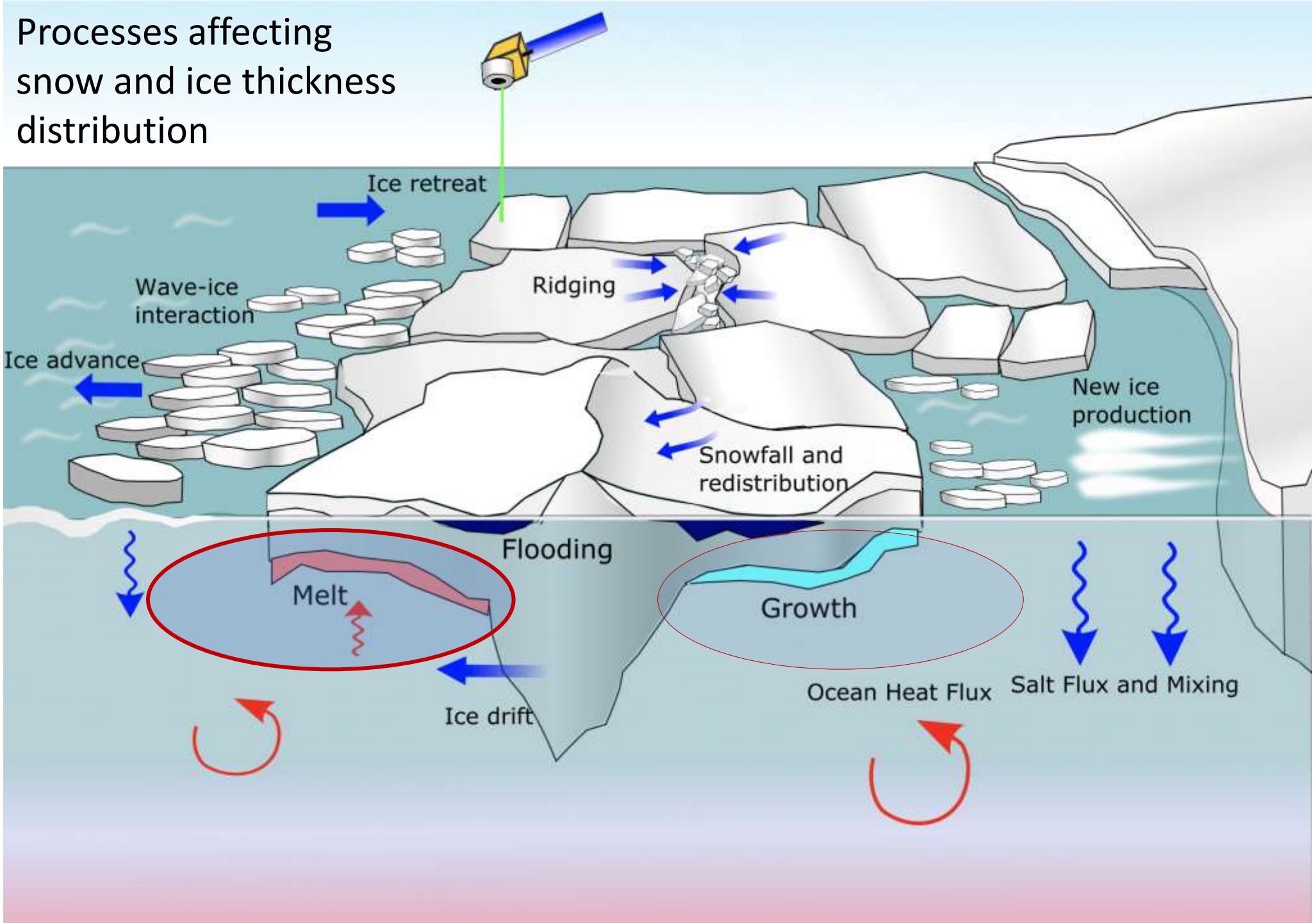

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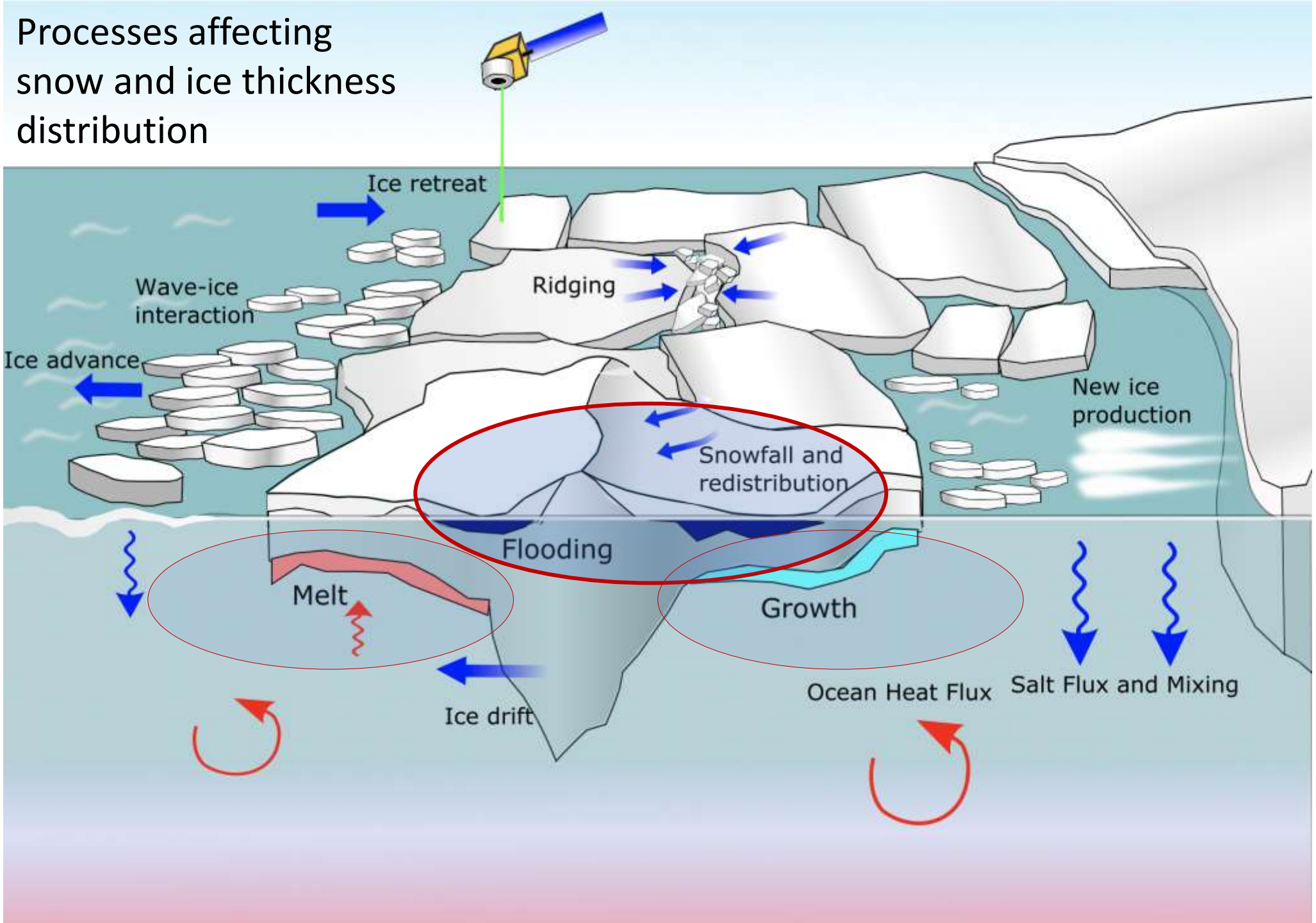
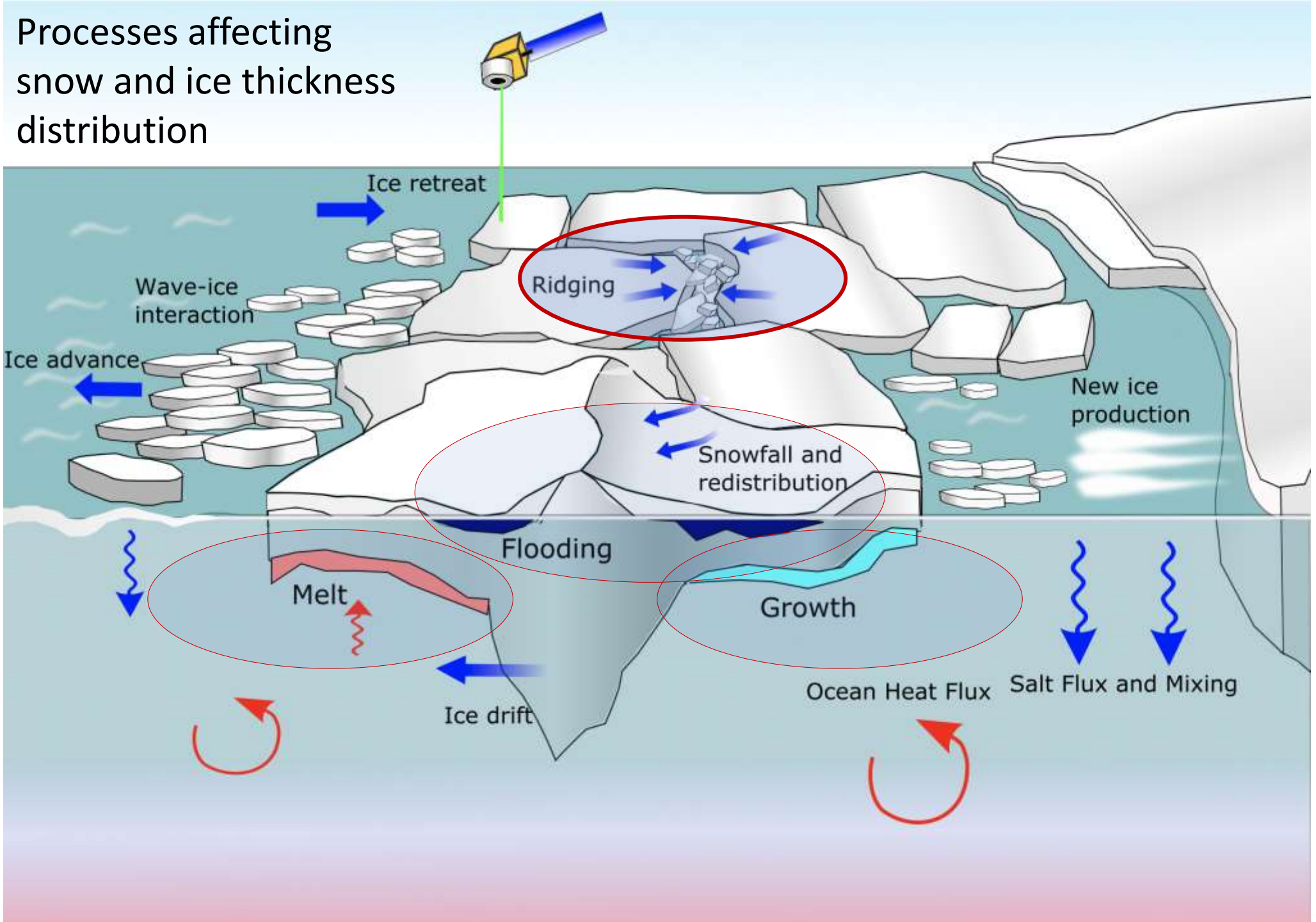
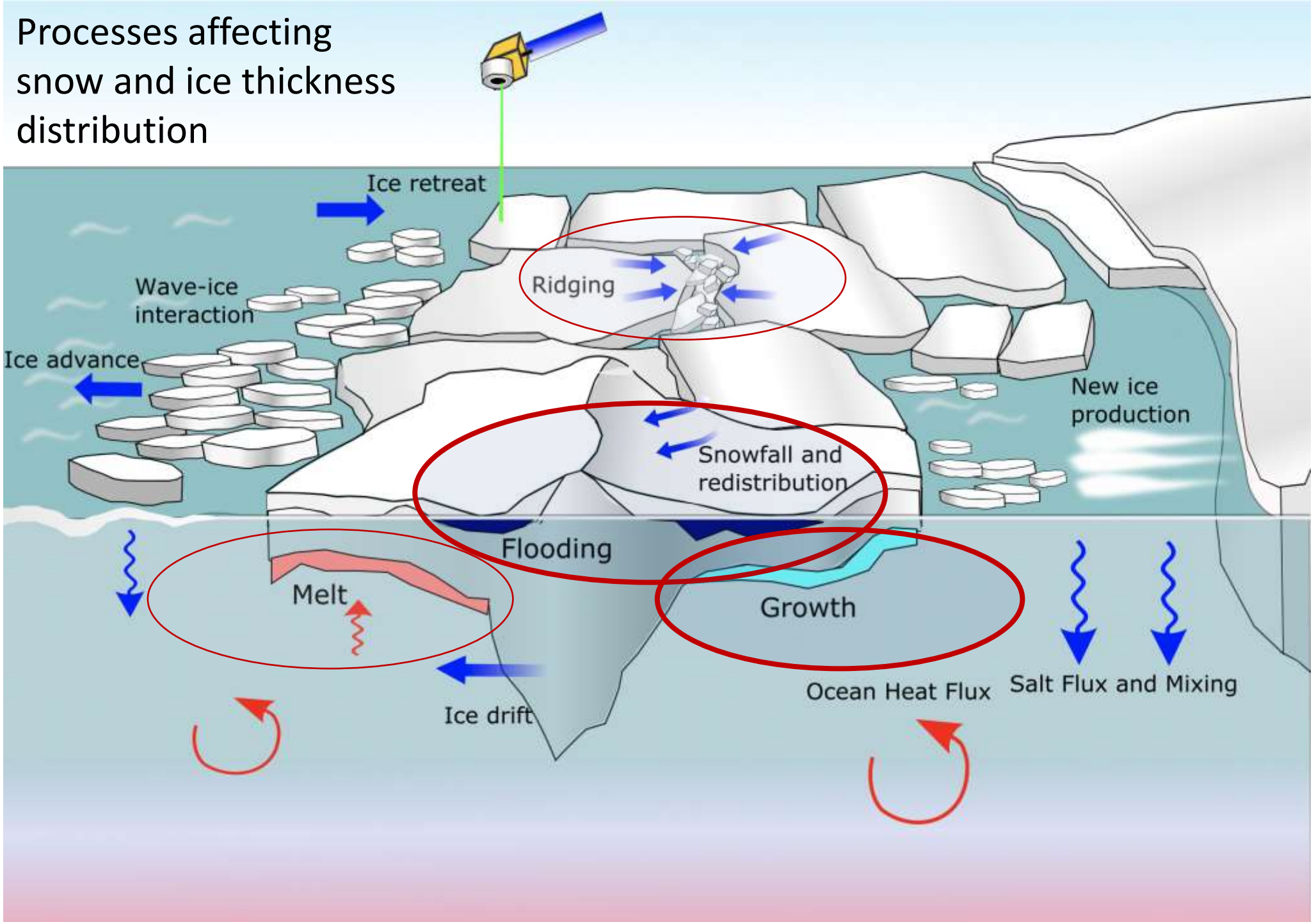


Processes affecting snow and ice thickness distribution



Processes affecting snow and ice thickness distribution



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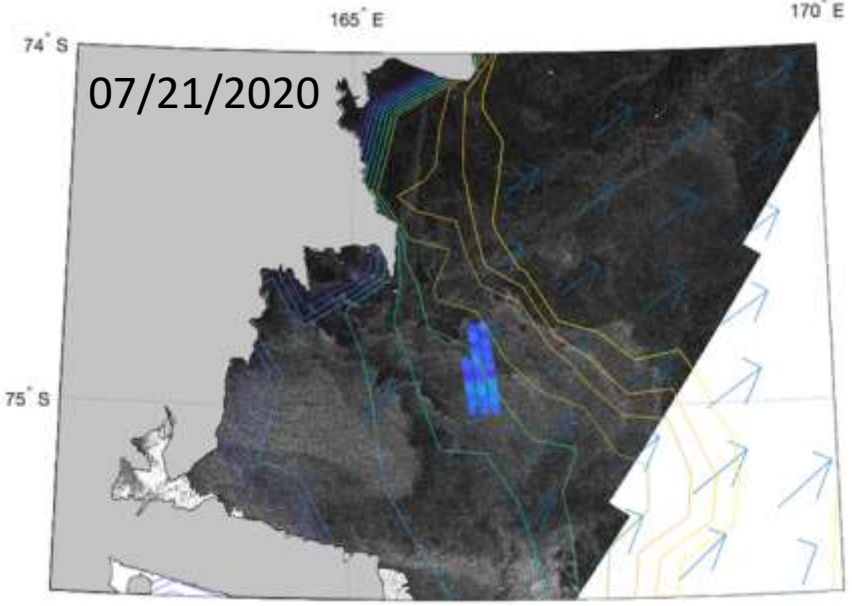
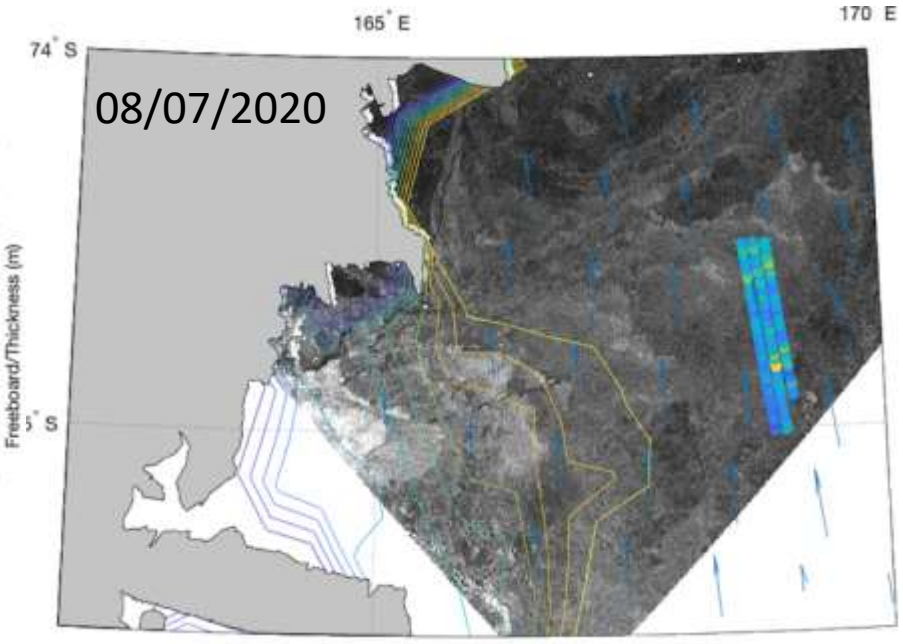
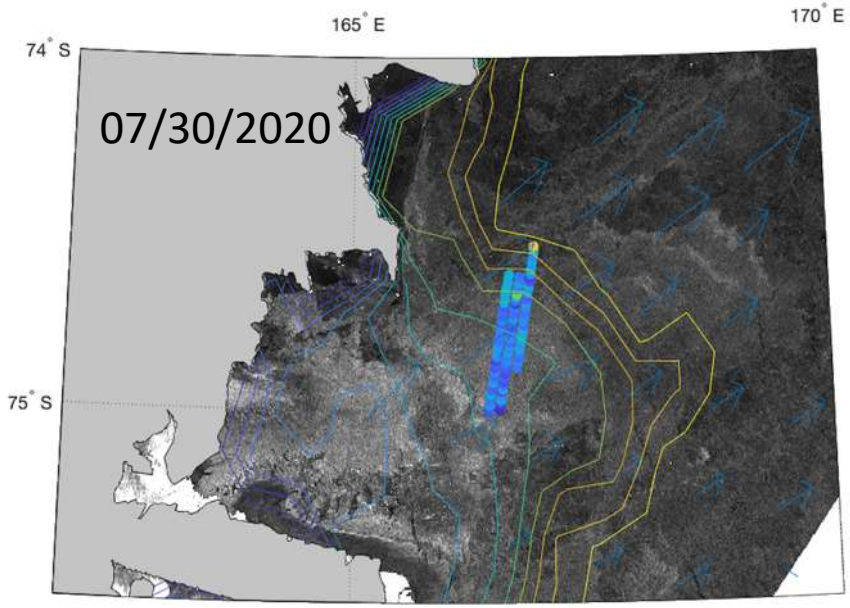
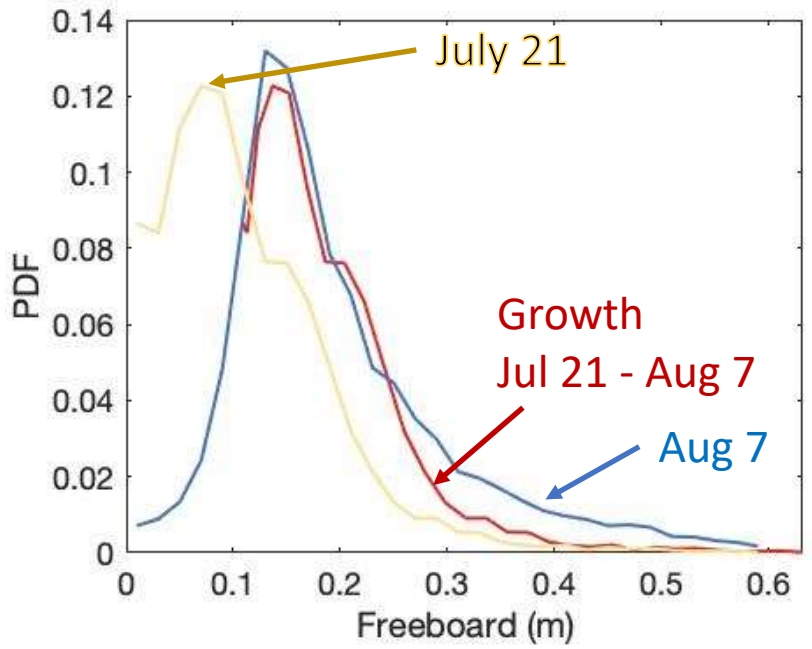
How can we estimate snow depth?

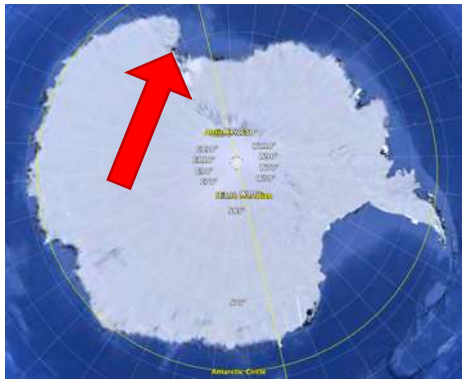
Ice evolution in polynya outlet plume



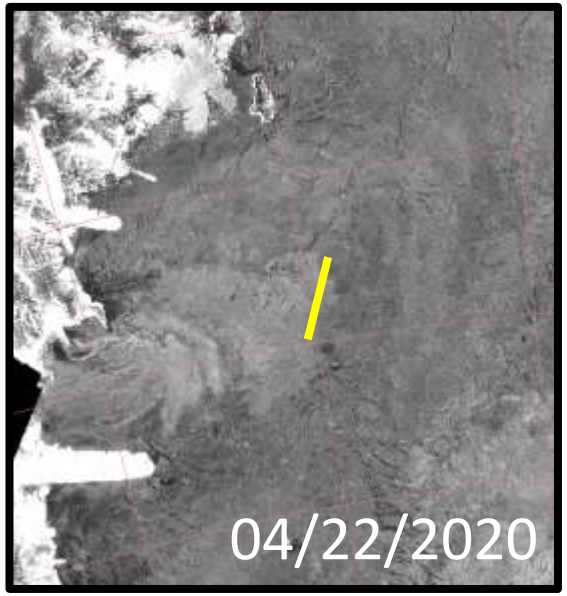


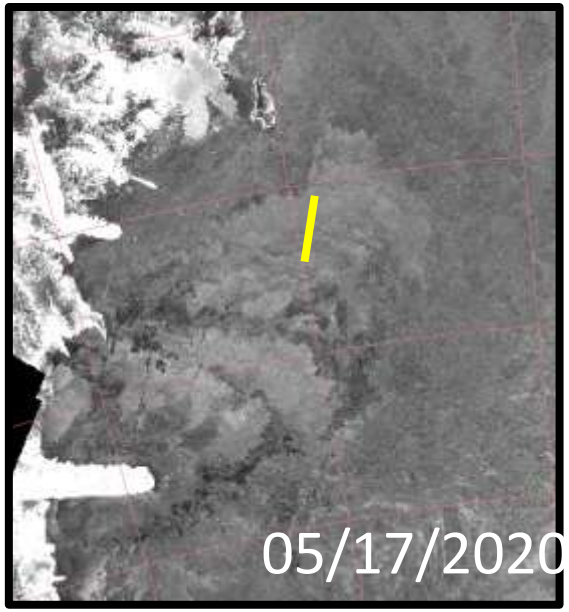




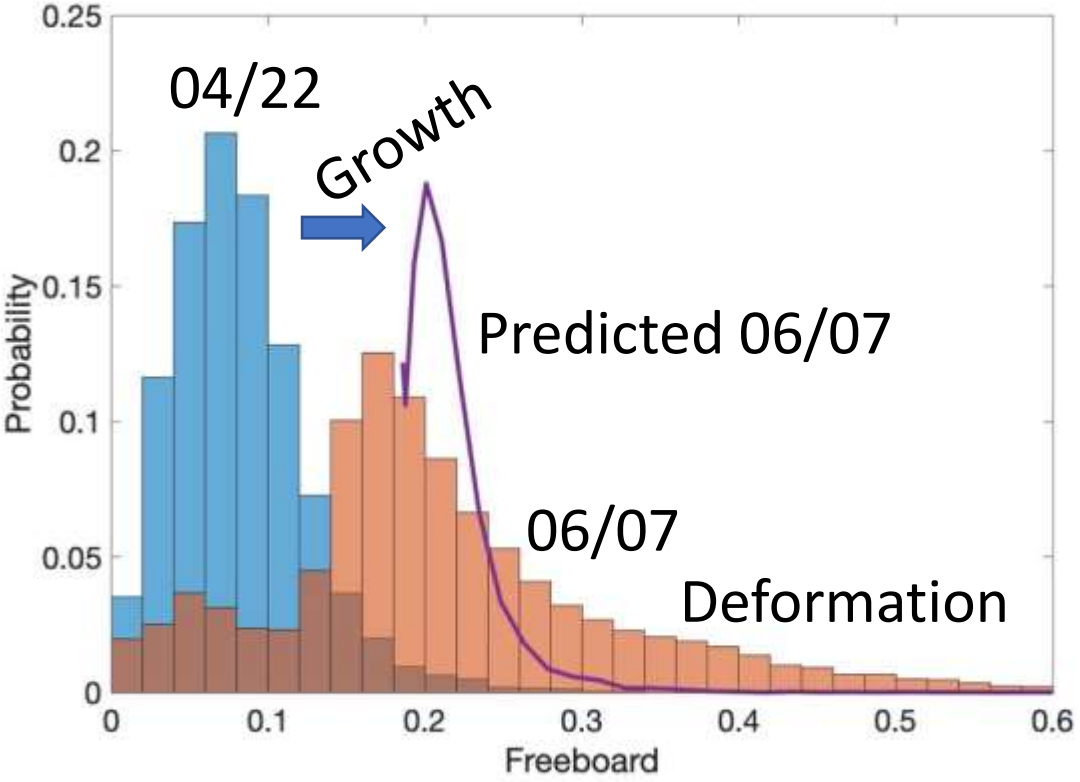


- 1D thermodynamic model (Maksym and Jeffries, 2000)
- ”No” Snow accumulation (but use ERA5 just in case)
- ICESat-2 freeboard distribution evolved over time
- No ocean heat included (should be ~nil here)





Tracking ice evolution



- 'Ice Patch' tracked across multiple ICESat-2 tracks
- Growth predicted well
- Snow accumulation is small (~5 cm)
- Ice deformation apparent in peak broadening (new ice and thick ice)

What if there’s lots of snow?

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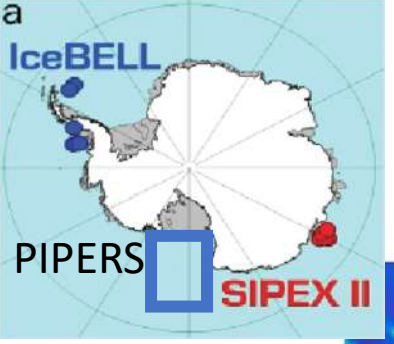
Can we classify snow and freeboard based on surface roughness?



Surface Freeboard

Snow Depth

Ridges

Dunes

Elevation (m)

Snow Depth (m)

May (PIPERS – Ross Sea)

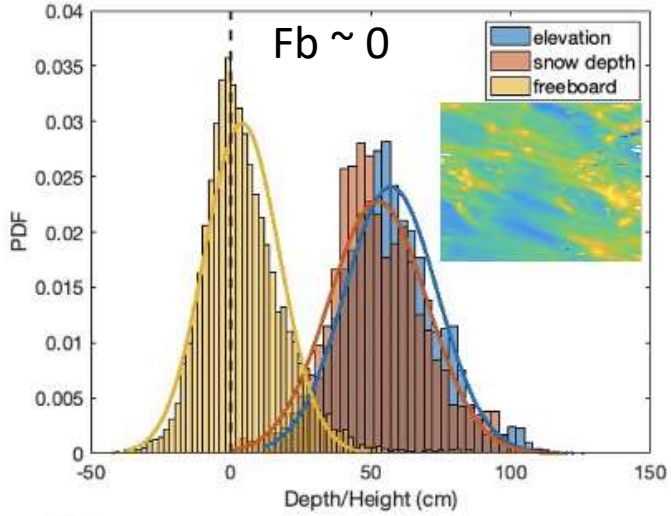
Dunes

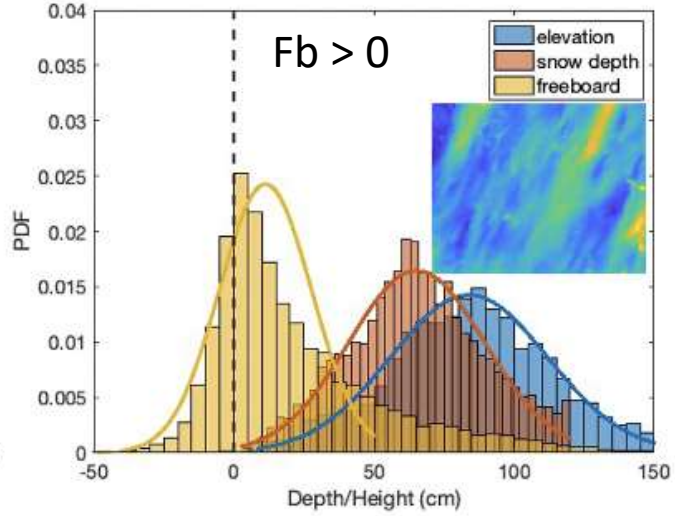
Few Ridges

Freeboard (cm)

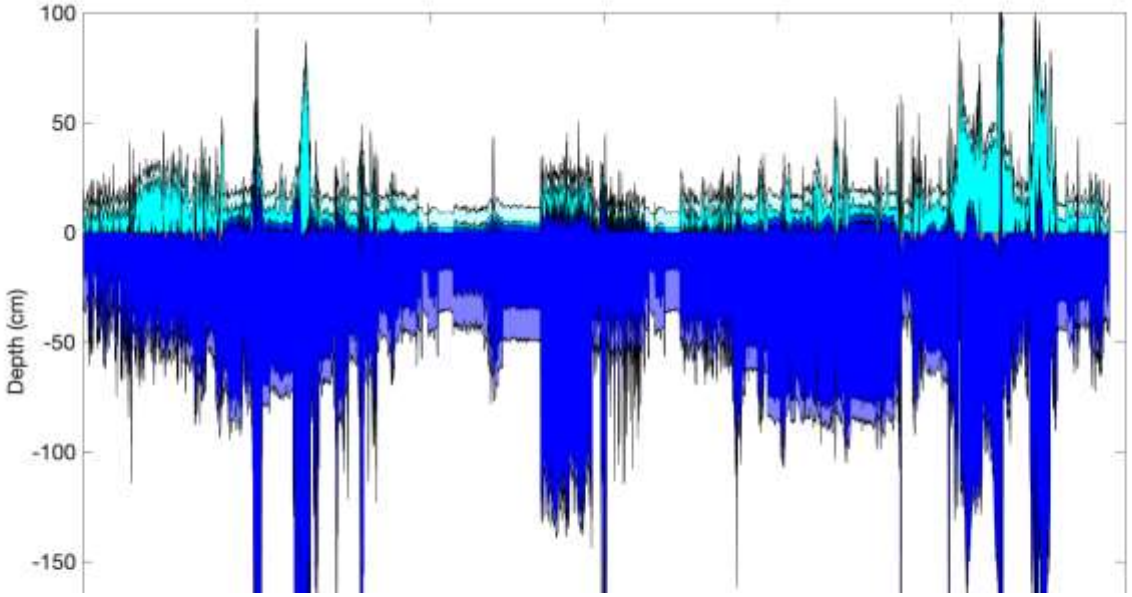
Snow Depth (cm)

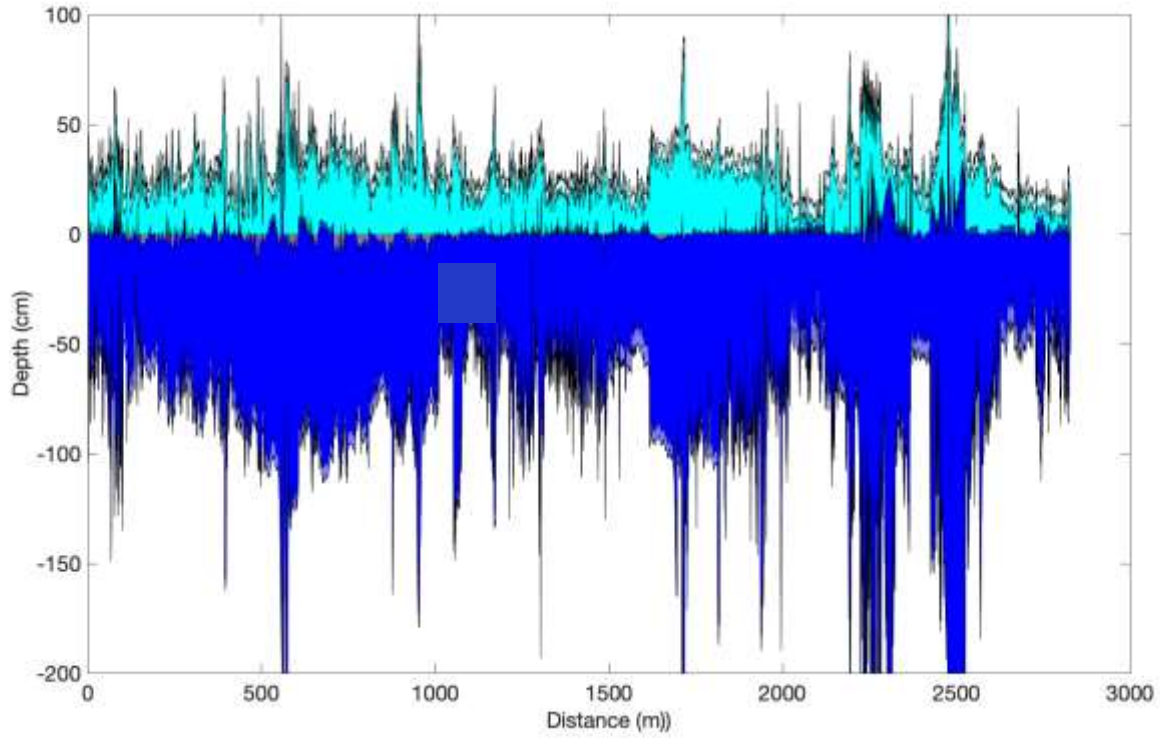
Sep (SIPEXII – E. Antarctic)





Deformed Very Thick, E. Antarctica





How much do properties change during growth?

Drilling data from ~80 floes in the Ross Sea

Floe evolution over 30 days with 10 cm accumulation

Change in Freeboard = -1.4 cm
Change in Snow Depth = + 8.5 cm
Change in Thickness = + 9 cm

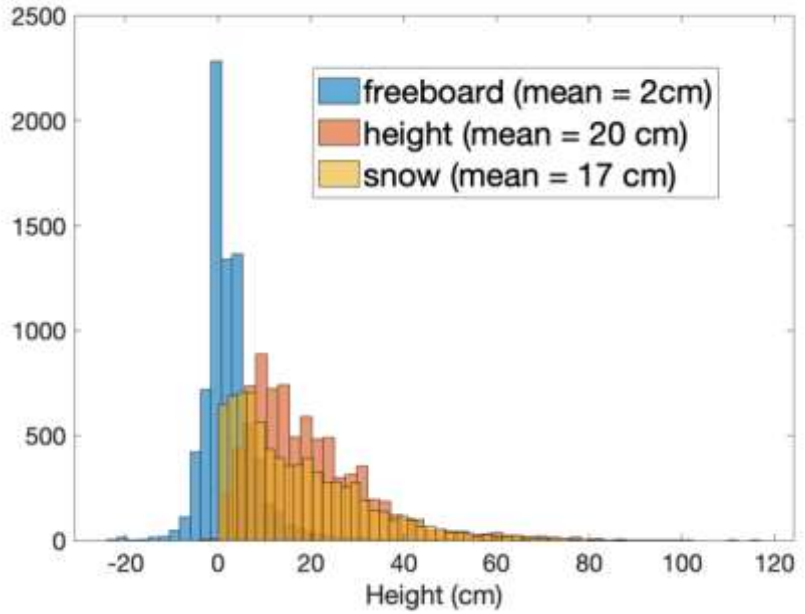
Change in Freeboard = -0.1 cm
Change inSnow Depth = +7 cm
Change in Thickness = +7 cm

Ice freeboard changes are negligible
Elevation changes are consistently ~65-70% of accumulation

This ignores deformation!

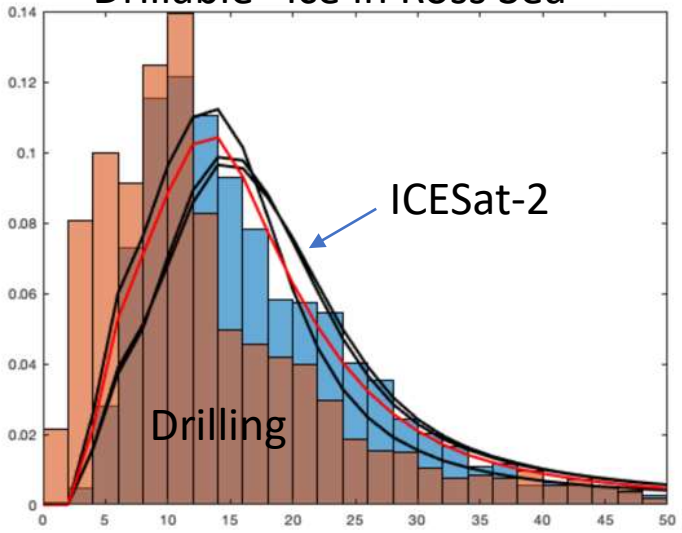
BUT – we have high-resolution roughness from ICESat-2

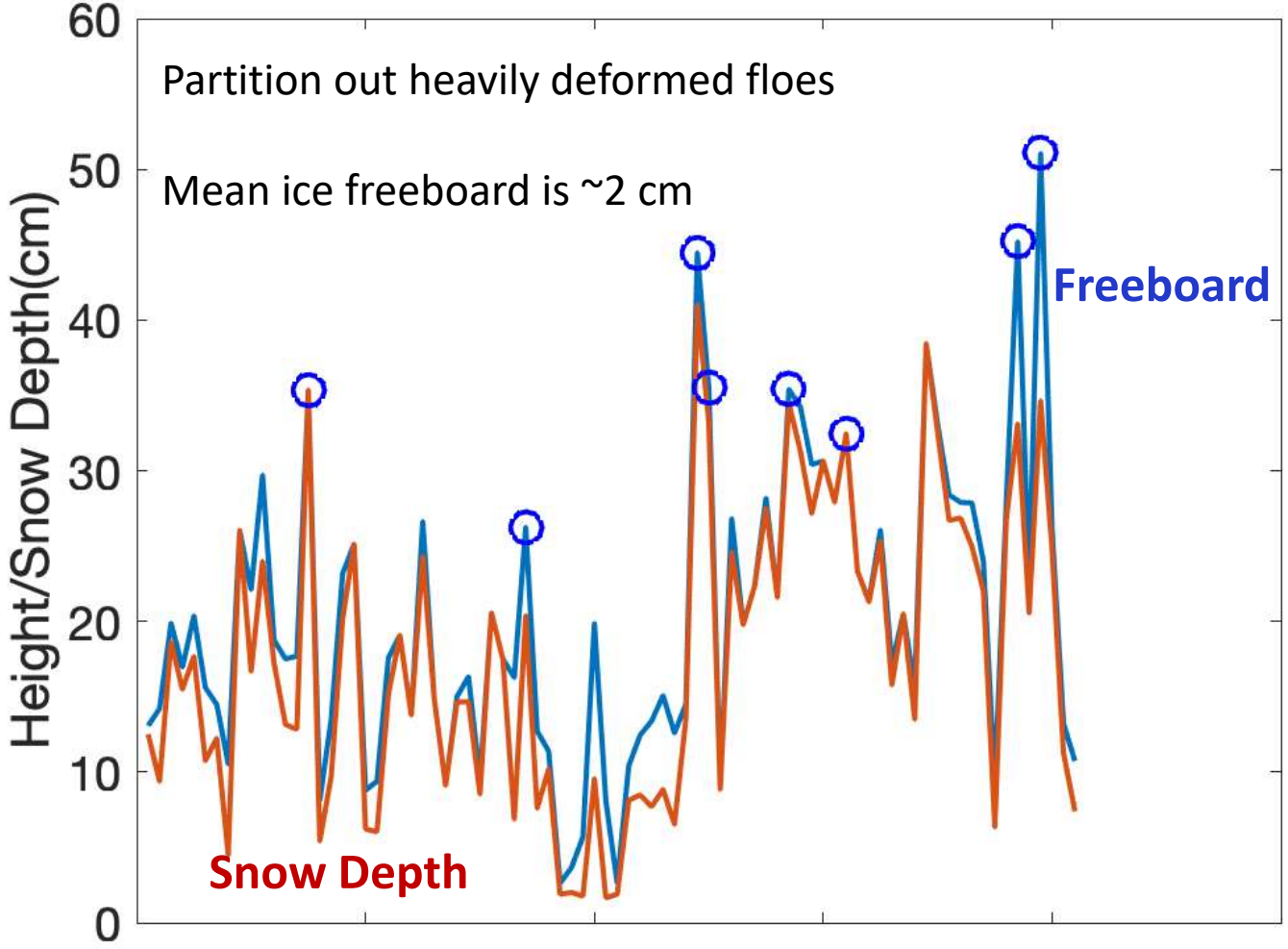
Snow Depth ≅ Freeboard
(when ice is not too thick and deformed)



Distributions from drilling data in Ross, Amundsen, Bellingshausen Seas

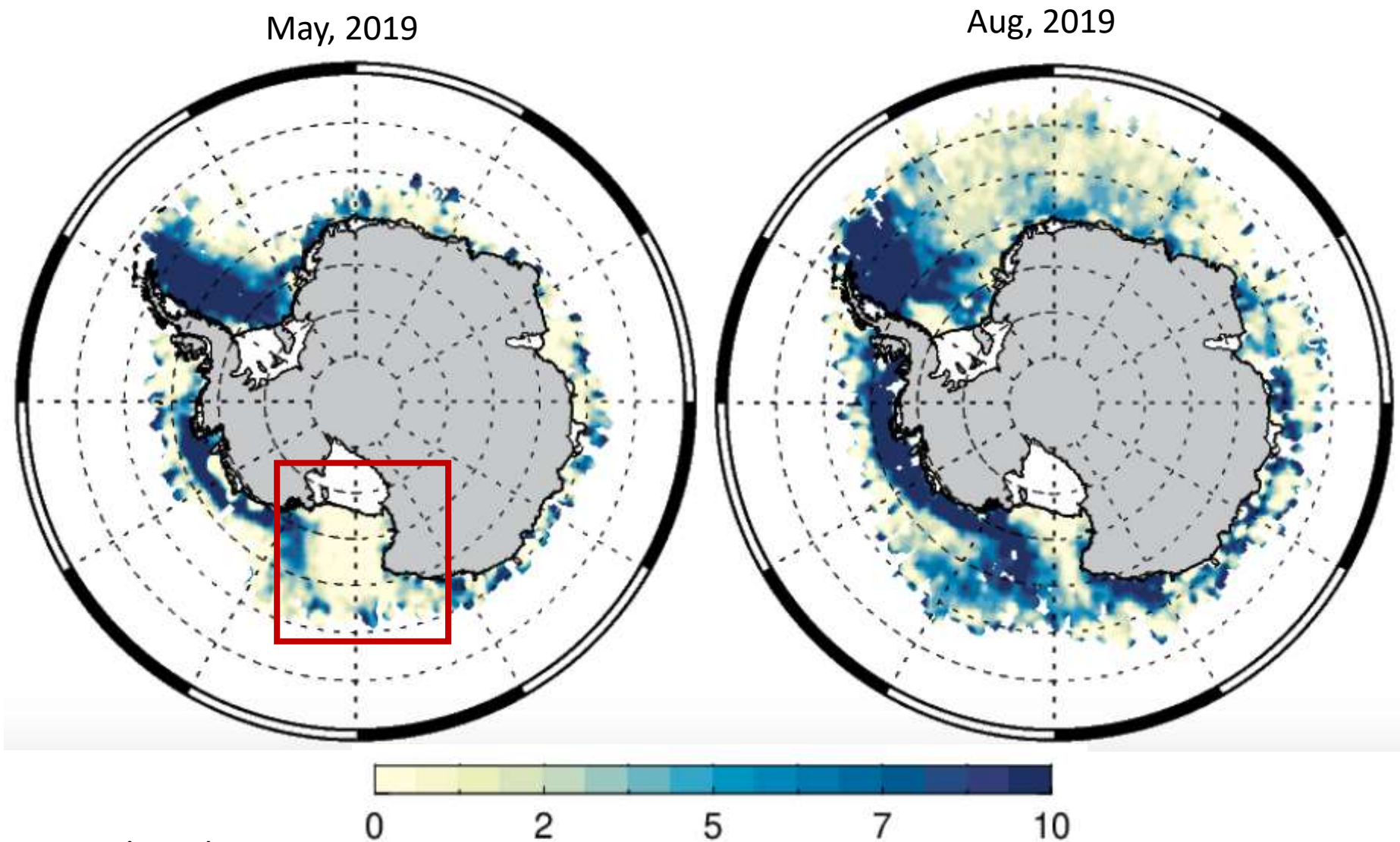
"Drillable" ice in Ross Sea





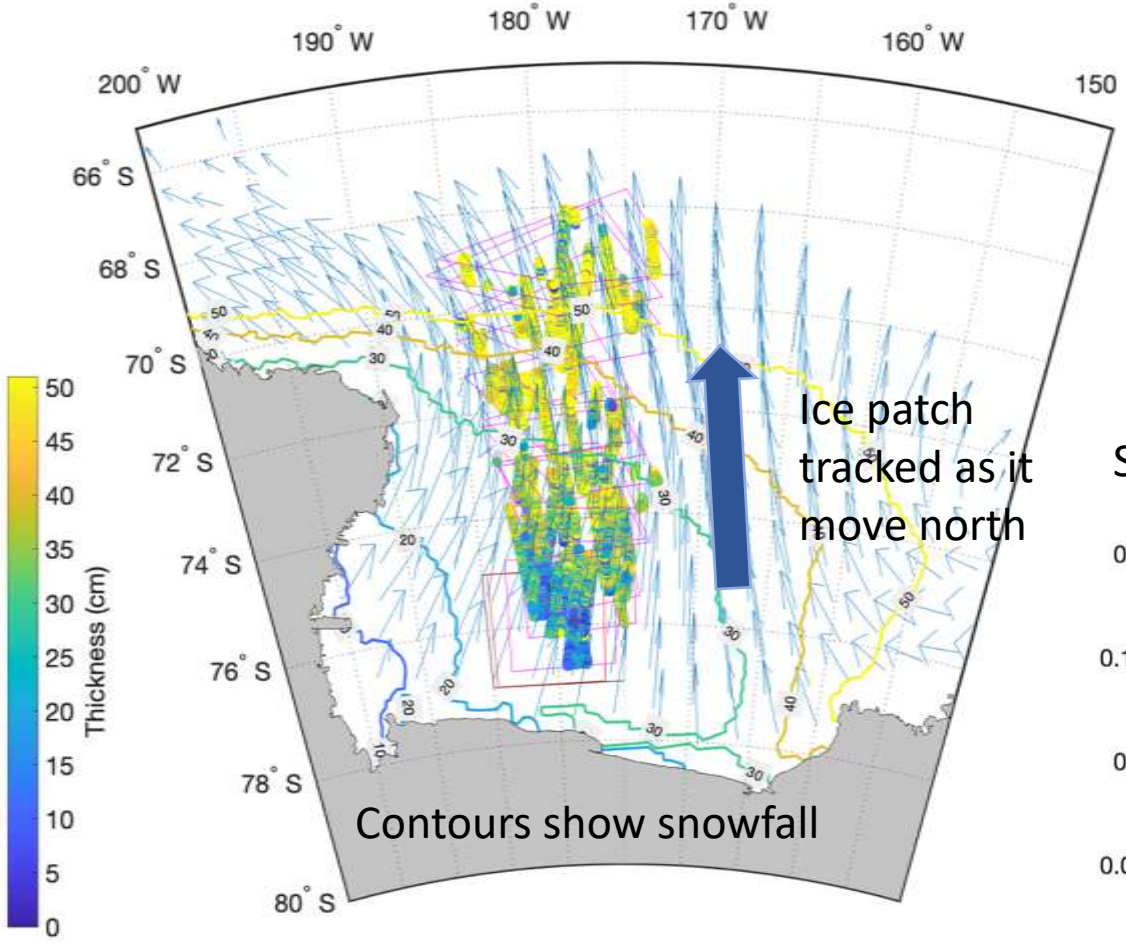
Mean floe freeboard and snow depth for ~80 floes in Ross Sea Sector

Ice Freeboards

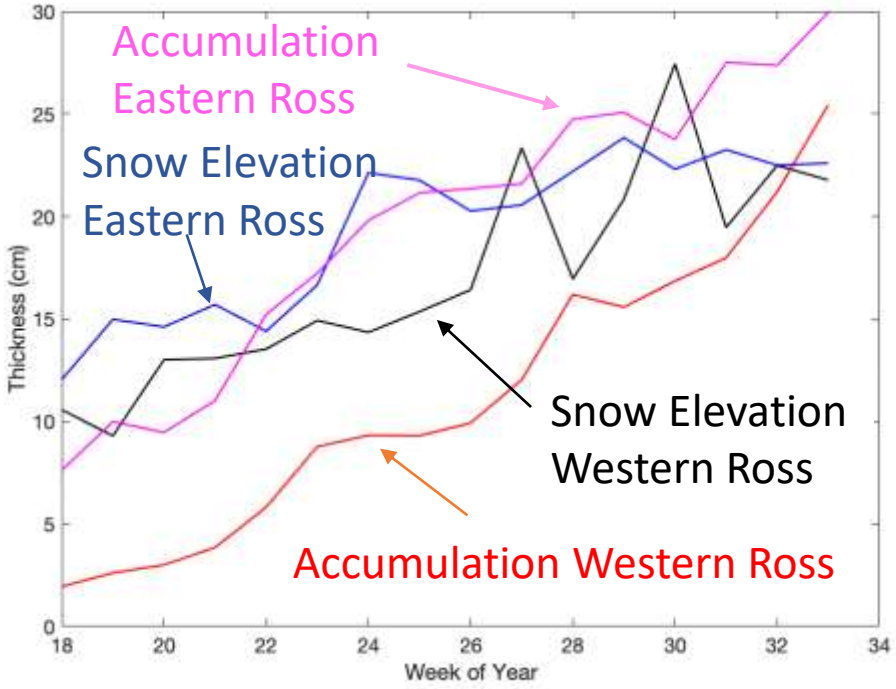


Based on Kacimi and Kwok, 2022

Winter ice evolution in Ross Sea

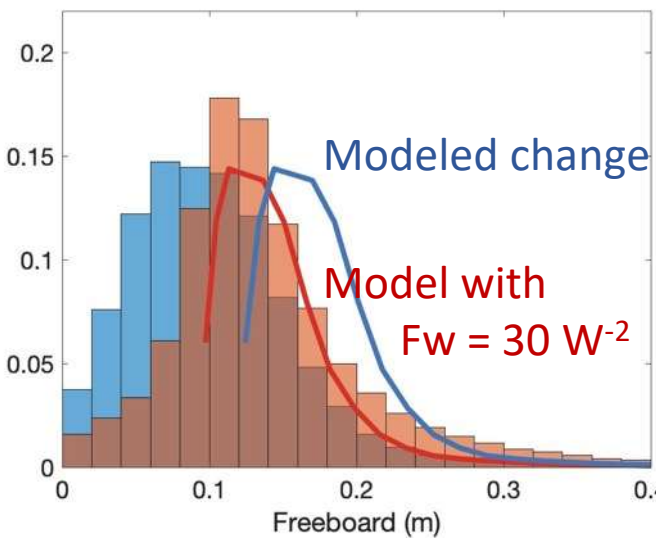


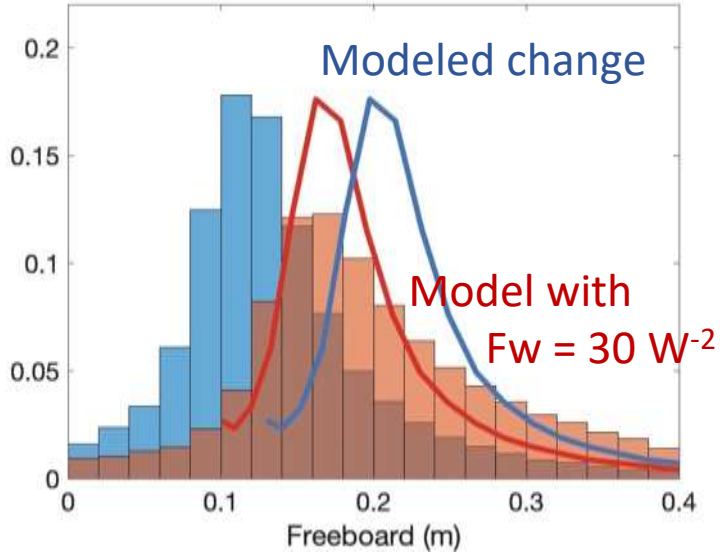
Selected ice patch repeatedly sampled by IS2 during drift



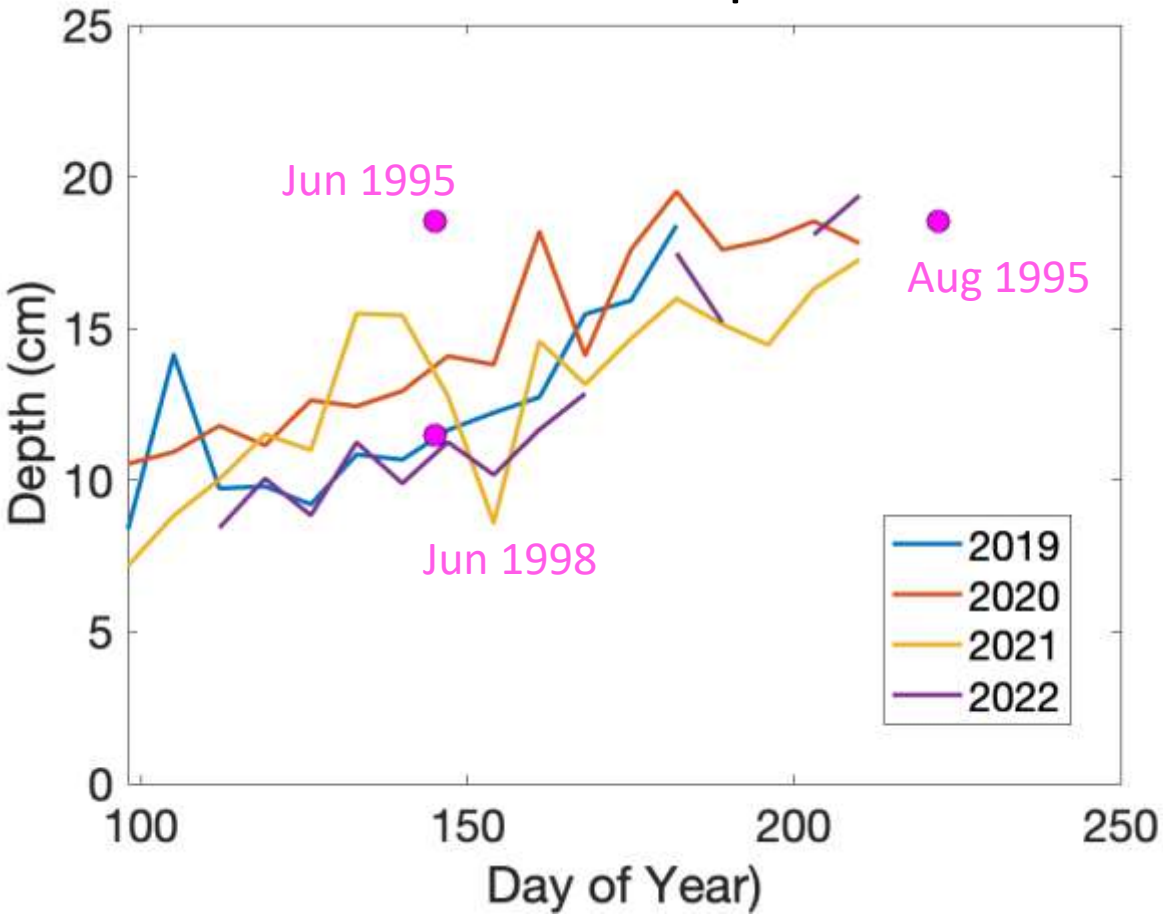
ERA5 accumulation tracks freeboard change well

Snow Elevation evolution over two separate 5 week periods during drift

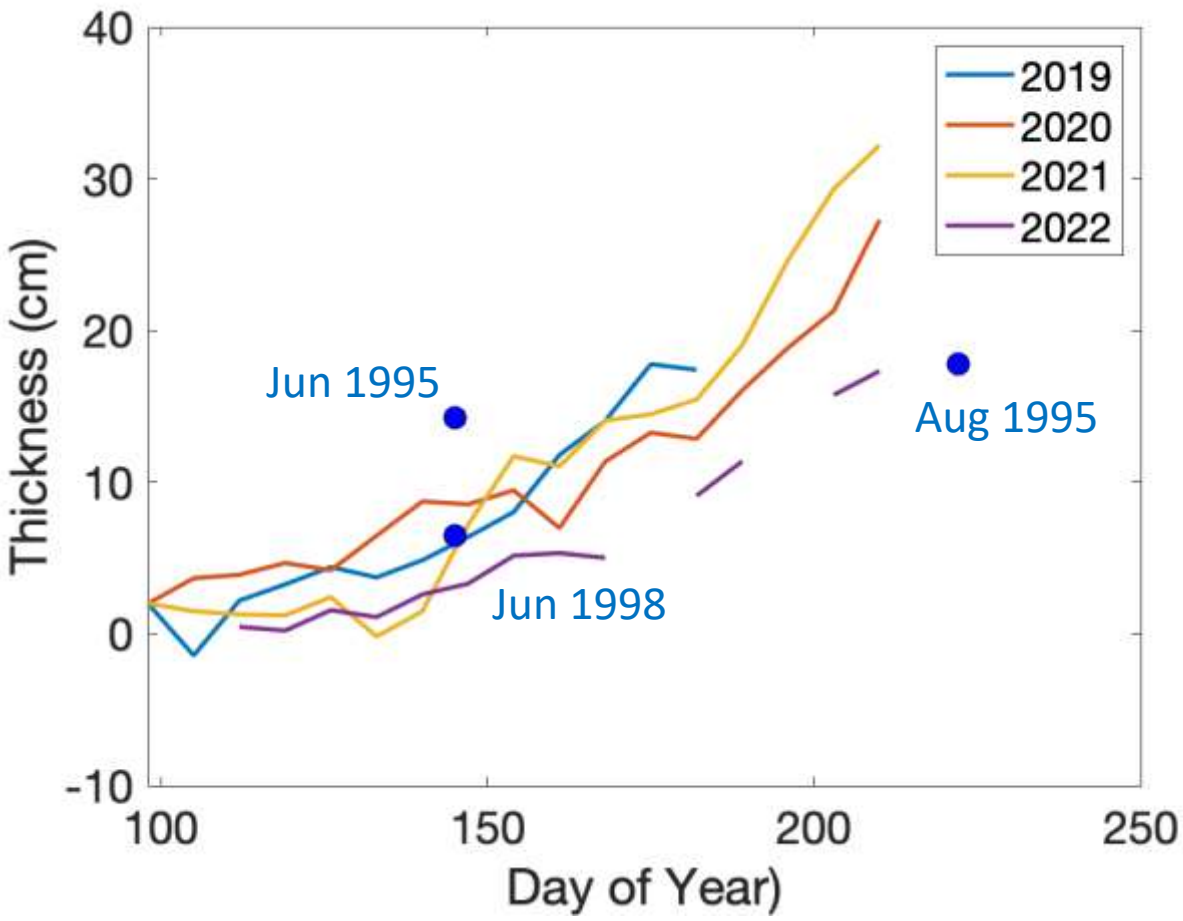




Snow depth



Snow ice production

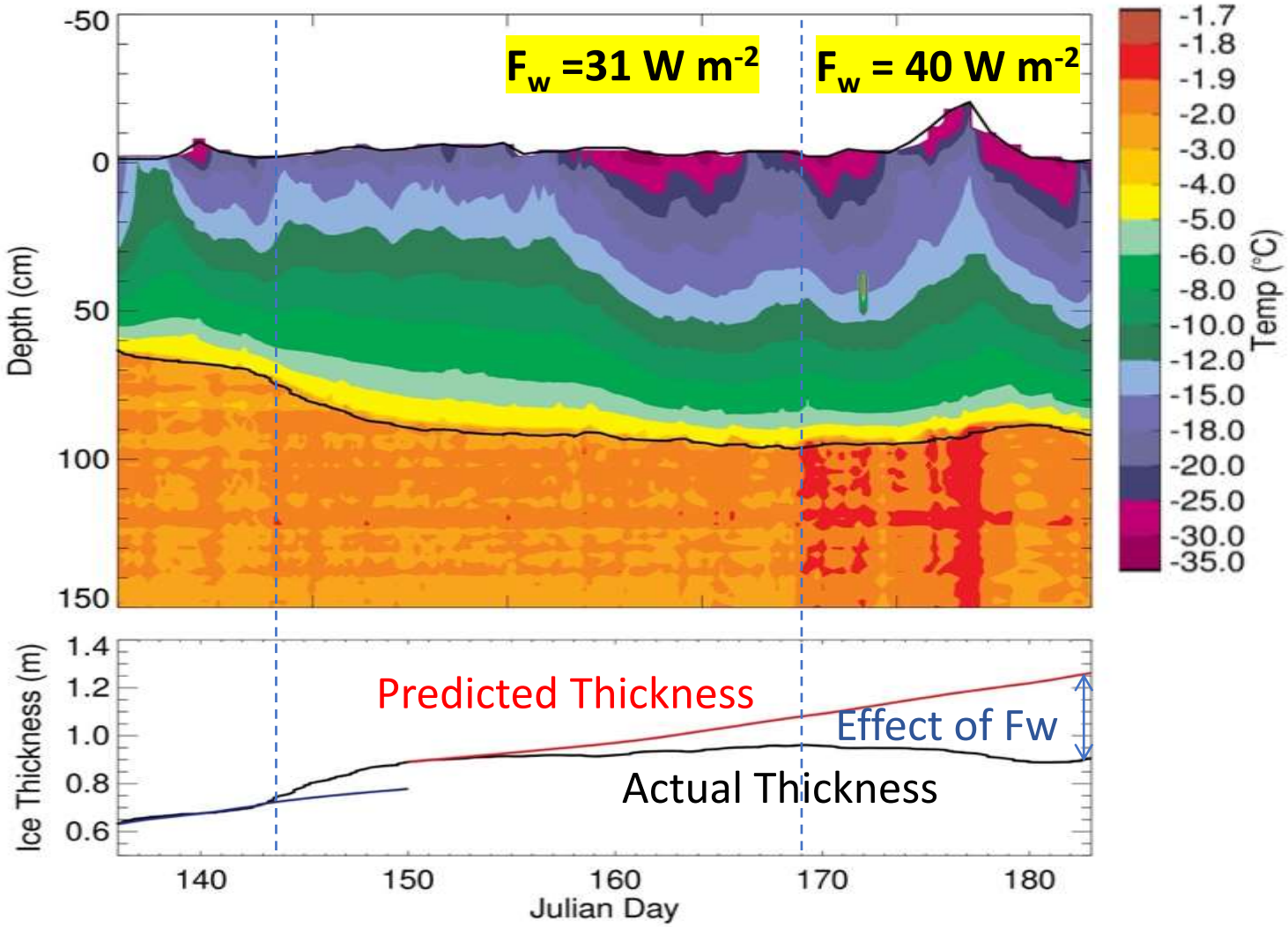


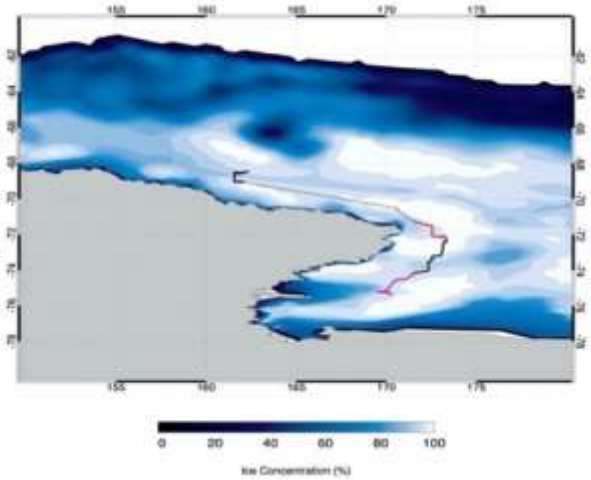
- Track ‘level’ ice by excluding ‘rough, thick ice’
- Snow depth and snow ice production compare well with prior observations – variability is modest

Are we detecting ocean heat?

Wrong year, though

Ice Mass Balance Buoy (IMB) deployed in 2017





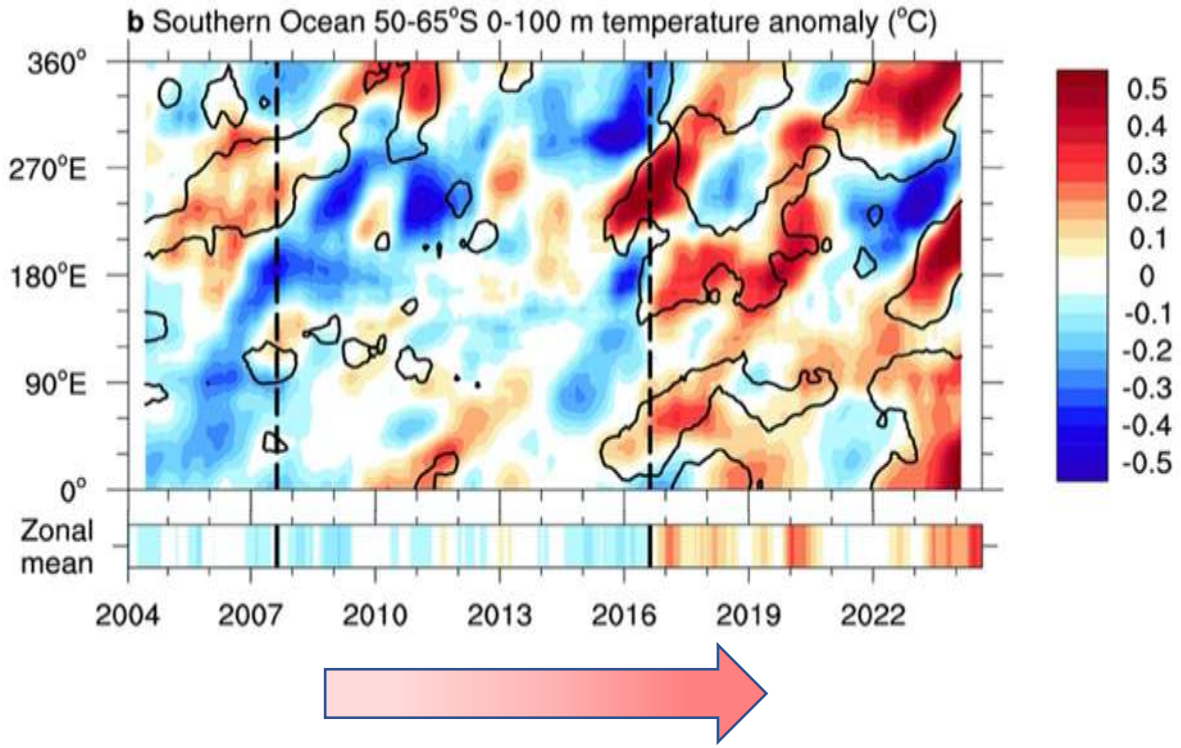
Monitors growth along central Ross drift track

…Maybe?

Ocean heat is determined from lack of expected growth

Is there more ocean heat?

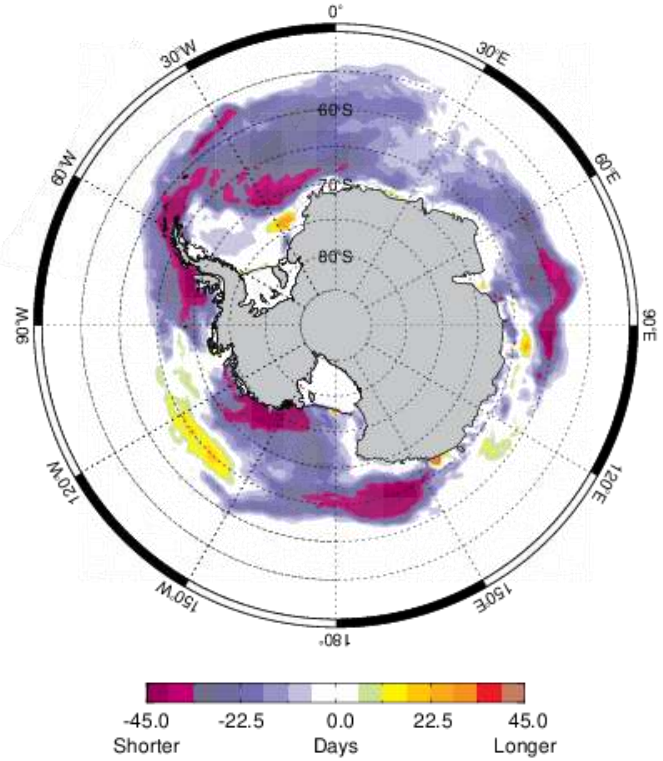
Upper Ocean Heat Anomaly



More heat

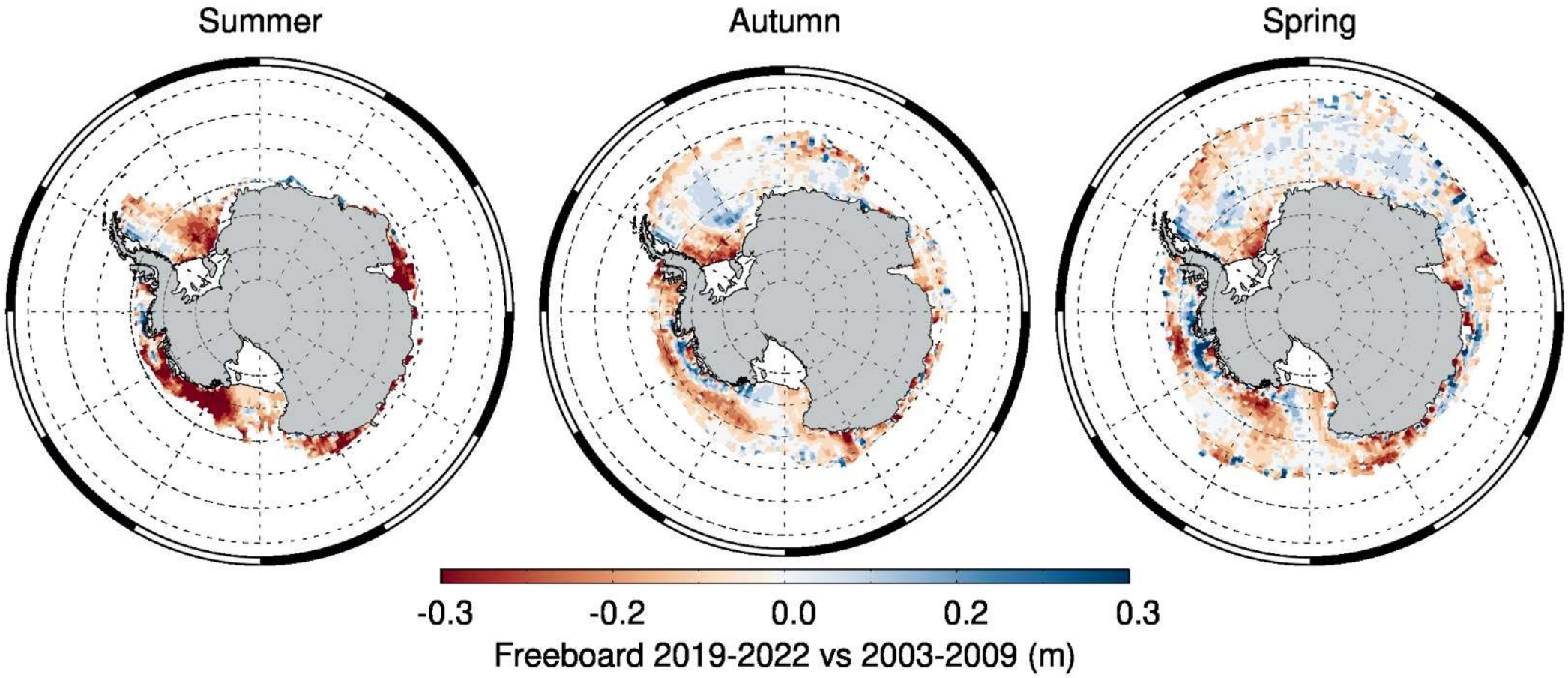
Updated from Purich and Doddridge, 2023

Change in Ice Covered Season
1979-2015 to 2016-2023

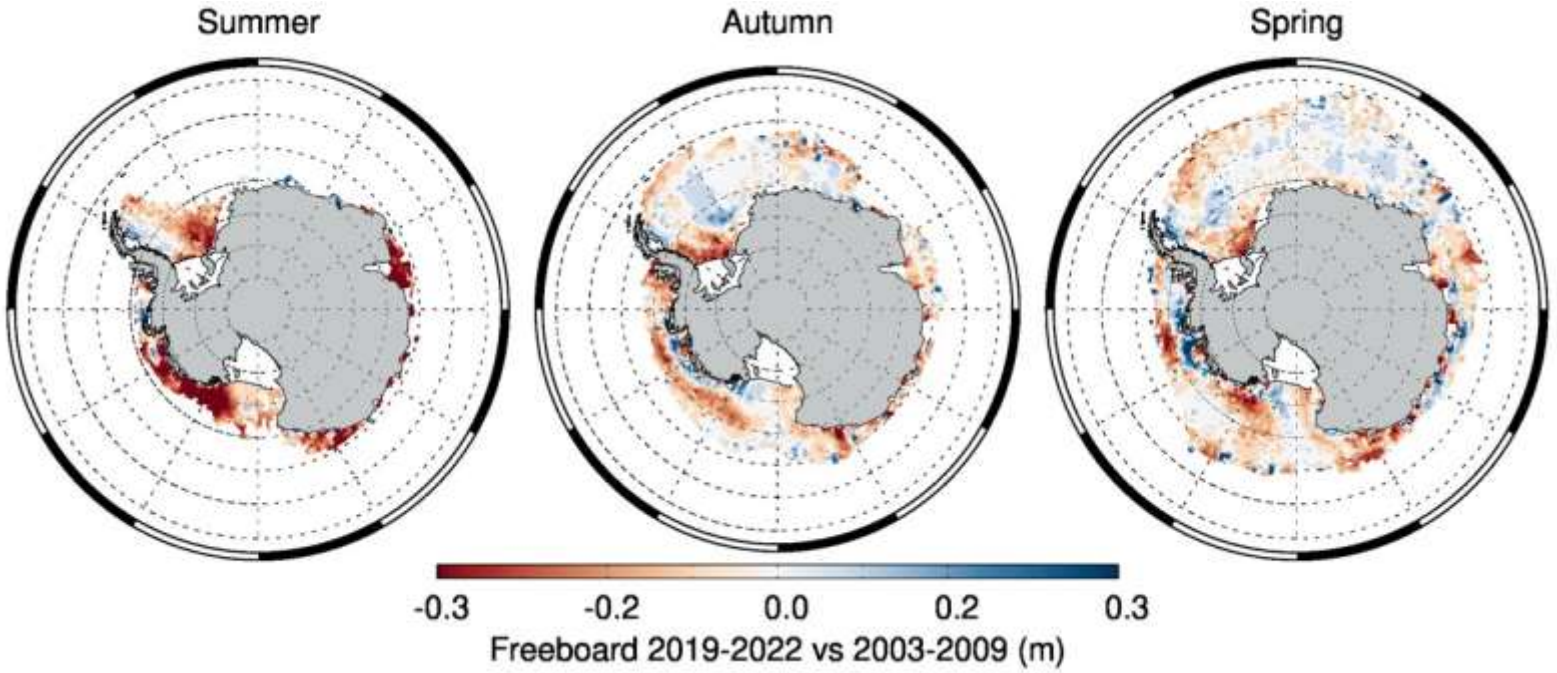


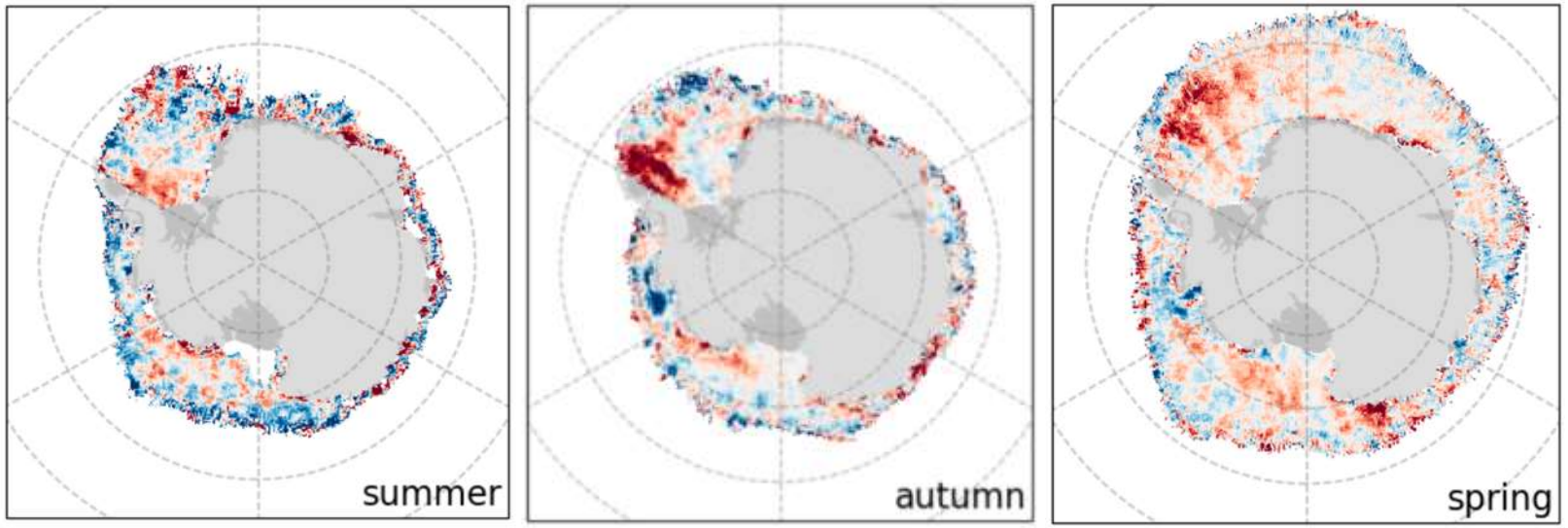
Ice season has decreased, has ice thickness, too?

ICESat-2 – ICESat Freeboards



- Major decline in summer freeboards: consistent with ice retreat
- No mean change in freeboard in Autumn/Spring!





Fons et al., 2023

2010-2021 trends

- IS2 snow freeboard changes consistent with CS2 ice thickness trends (Ross, Amundsen, and Bellingshausen)
- Some differences in Weddell
- Ice thickness trends are small, so ice freeboard trends are even smaller
- Suggests major snow freeboard changes are due to snow cover changes

Summary and Next Steps

- Lagrangian tracking of freeboard distribution changes can be used to identify role of key processes if we can effectively partition ice types
  - Better discriminate deformed ice with high-resolution product

- Snow depth is easier than ice thickness
  - Level ice freeboard change is mostly snow depth change
  - Deformation is a challenge
  - In situ observations do not compare well with satellite

- Is ice growth/advance being limited by high ocean heat flux?
  - Maybe, but thickness may not have substantially changed

- Summer sea ice has “thinned”, BUT likely less snow.
  - Next step is to better constrain snow depth in the thicker, rough ice

Need to go do more In Situ obs!

Maria Stenzel