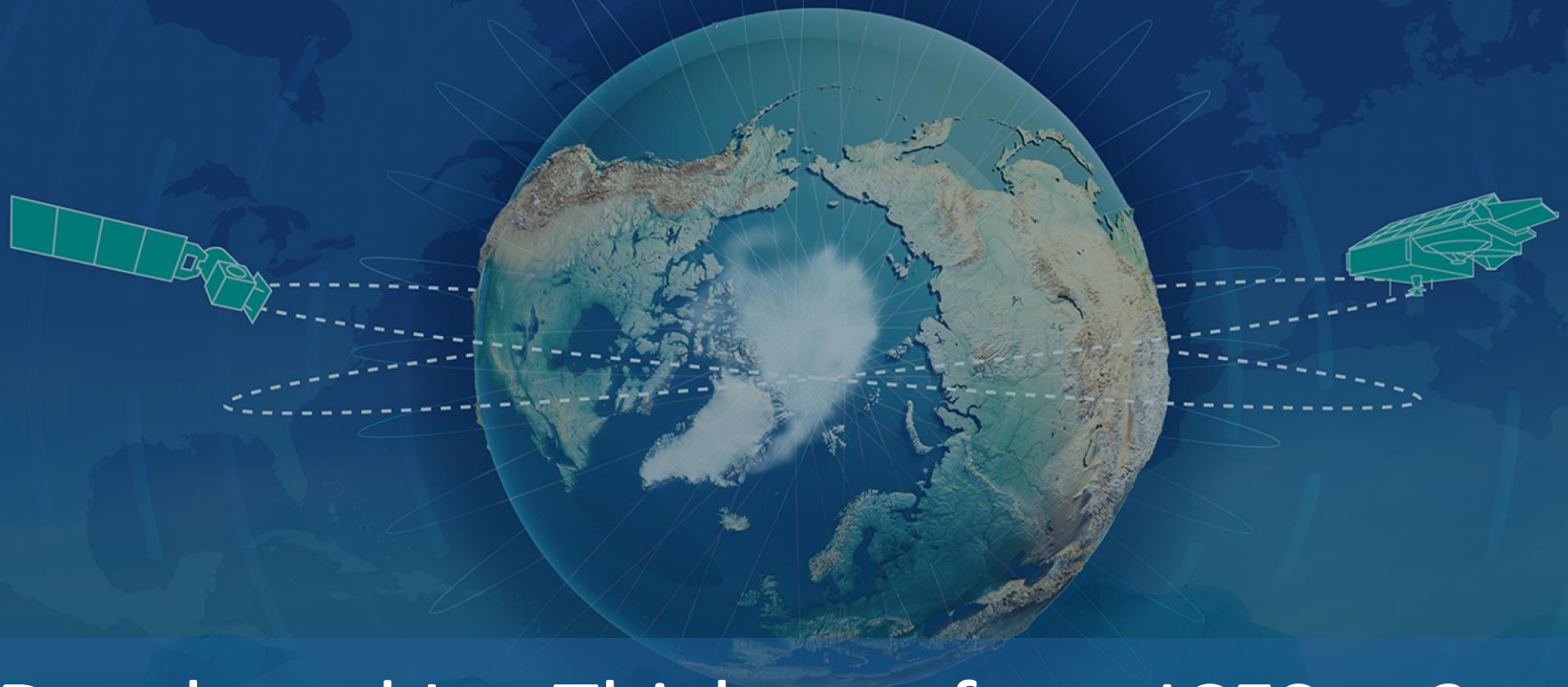

Snow Depth and Ice Thickness from ICESat-2 and CryoSat-2: Findings from 5 Years of Observations

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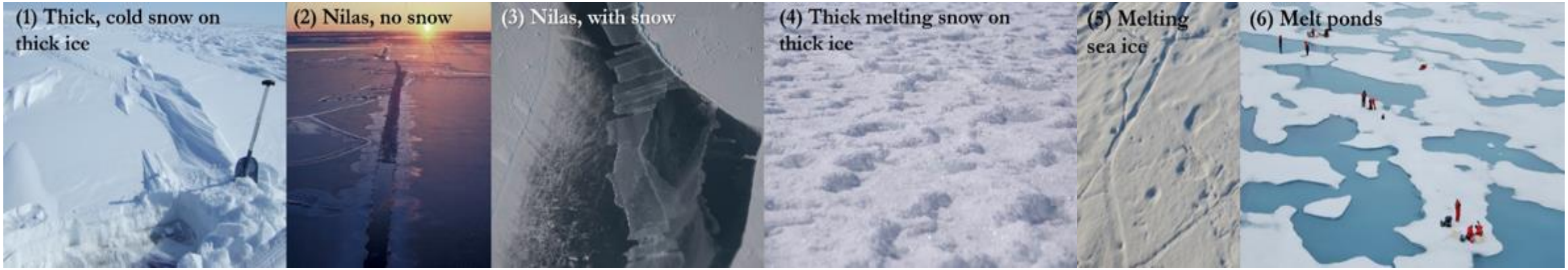
Motivation

Ice Thickness estimates are essential to better understand and predict the response of sea ice to global warming

- Snow depth is required to derive sea ice thickness from altimetry
- Typically prescribed using a climatology in the Arctic (derived from Soviet stations between 1954 and 1991)
- Snow is a critical component of Earth's climate (high albedo)
- Snow controls the growth and decay of the underlying ice



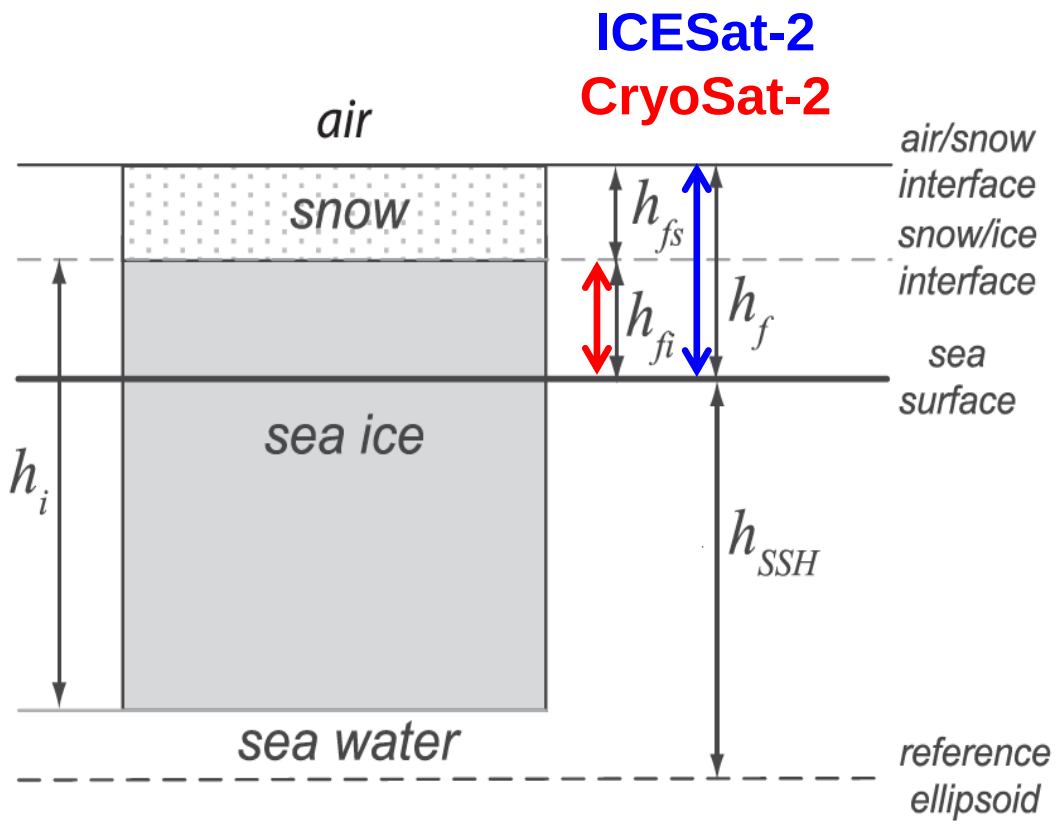
Snow Depth Retrieval from Altimetry

Snow depth is equal to the freeboard differences:

$$h_{fs} = \frac{(h_f^{IS2} - h_{fi}^{CS2})}{h_s}$$

with $h_s = c / c_s(r_s)$

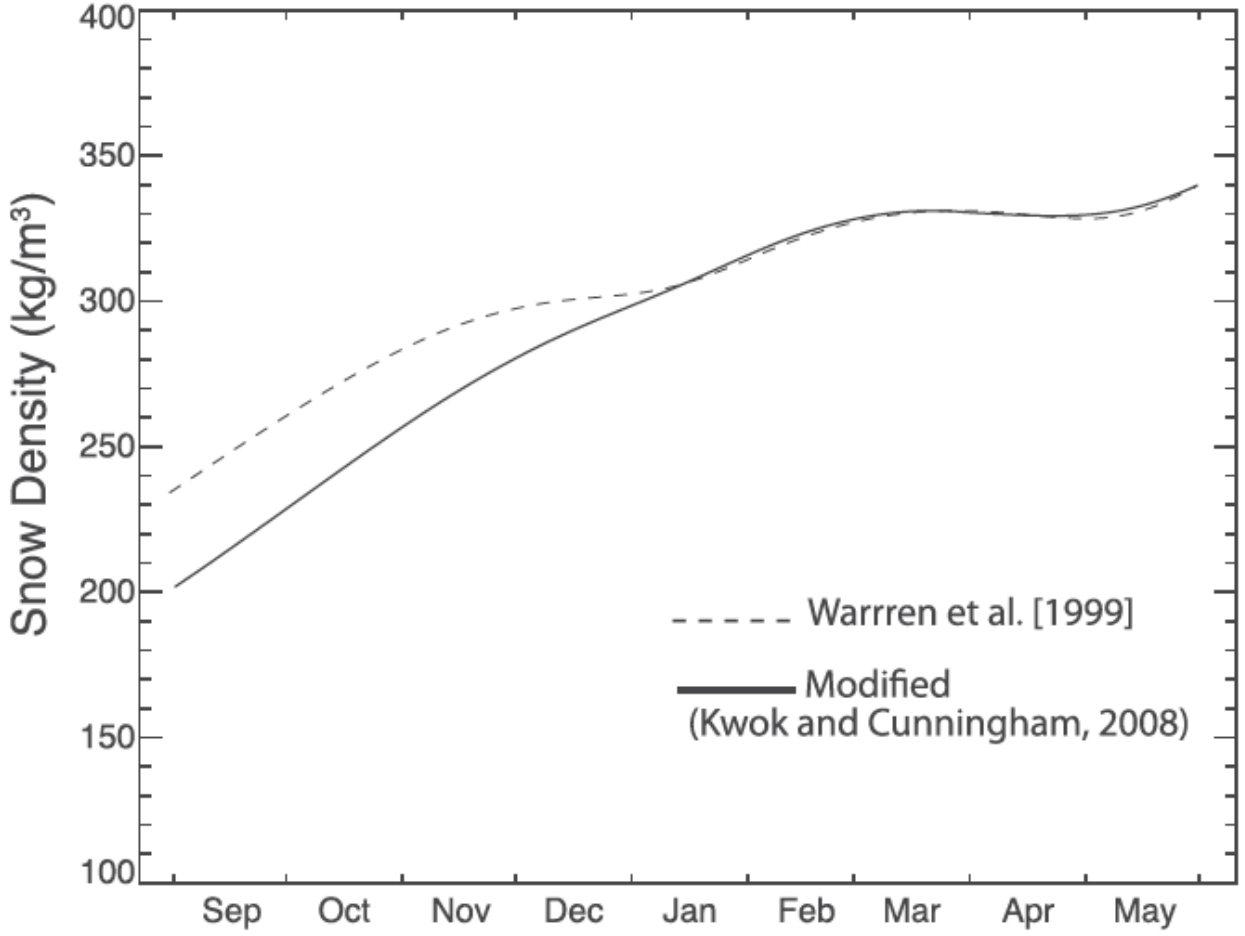
to account for propagation delay through the snow layer



Kwok et al., 2020

Snow Density

- Warren climatology provides estimates of snow depth and density
- Modified climatology to reflect the later freeze-up in the past decade.



Kwok and Cunningham, 2008

Sampling Strategy

- No coincident measurements
- Start with daily gridded fields (25-km) of ICESat-2 and CryoSat-2 freeboards
- 6 sampling configurations (variability in snow depth <1cm)

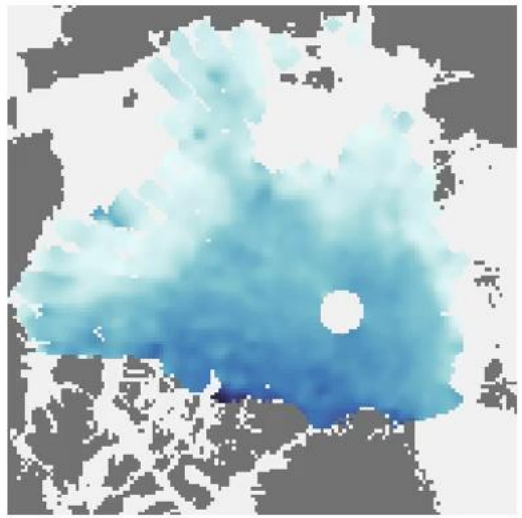
Space/ time	25 km/1 day	25 km/ 10 day	25 km/ 15 day	75 km/ 1 day	75 km/ 10 day	75 km/ 15 day
October	7,217	8,248	8,238	7,924	8,226	8,197
November	9,860	10,039	10,071	9,982	10,073	10,072
December	8,914	8,974	8,992	8,888	9,001	9,002
January	10,017	10,636	10,678	10,410	10,737	10,747
February	9,710	10,506	10,536	10,242	10,663	10,671
March	9,638	10,413	10,484	10,226	10,602	10,663
April	9,478	10,280	10,358	10,082	10,452	10,474

Number of samples for different sampling configurations

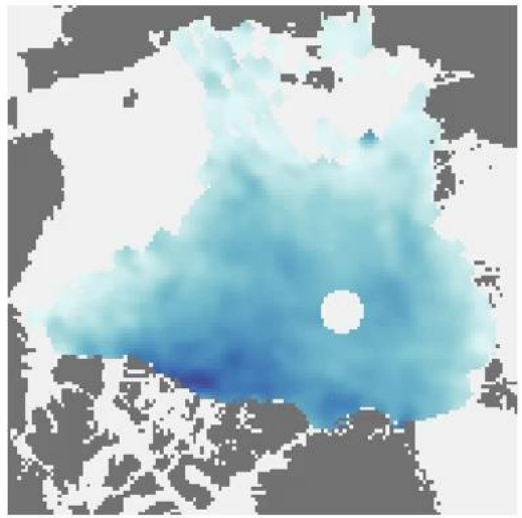
Kwok et al., 2020

OCTOBER

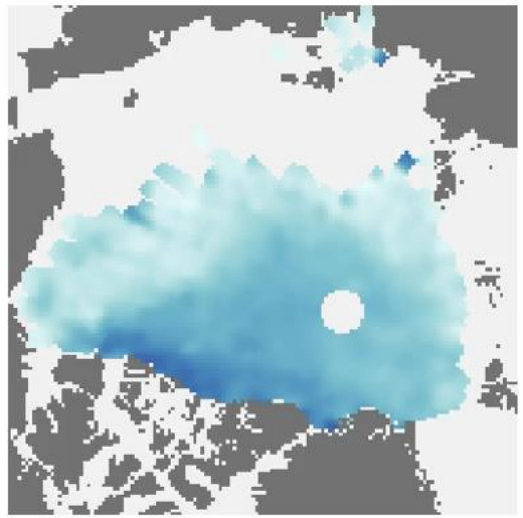
2018



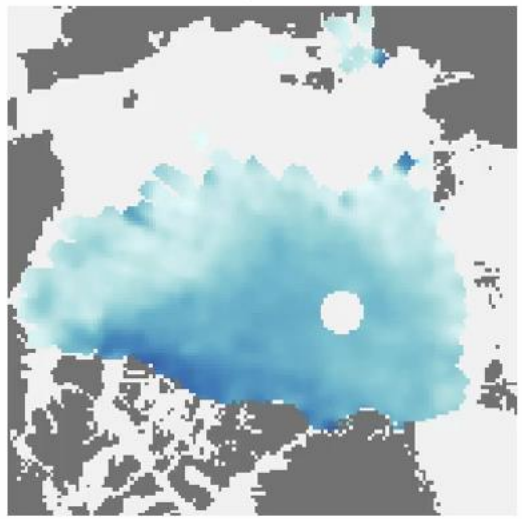
2019



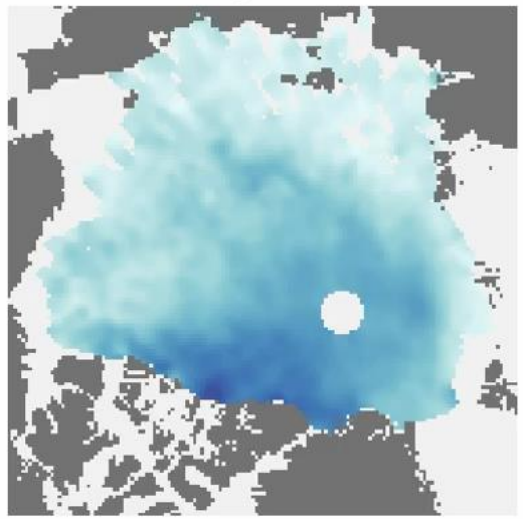
2020

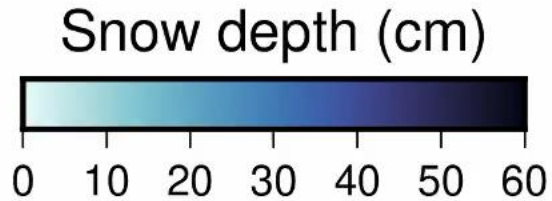


2021

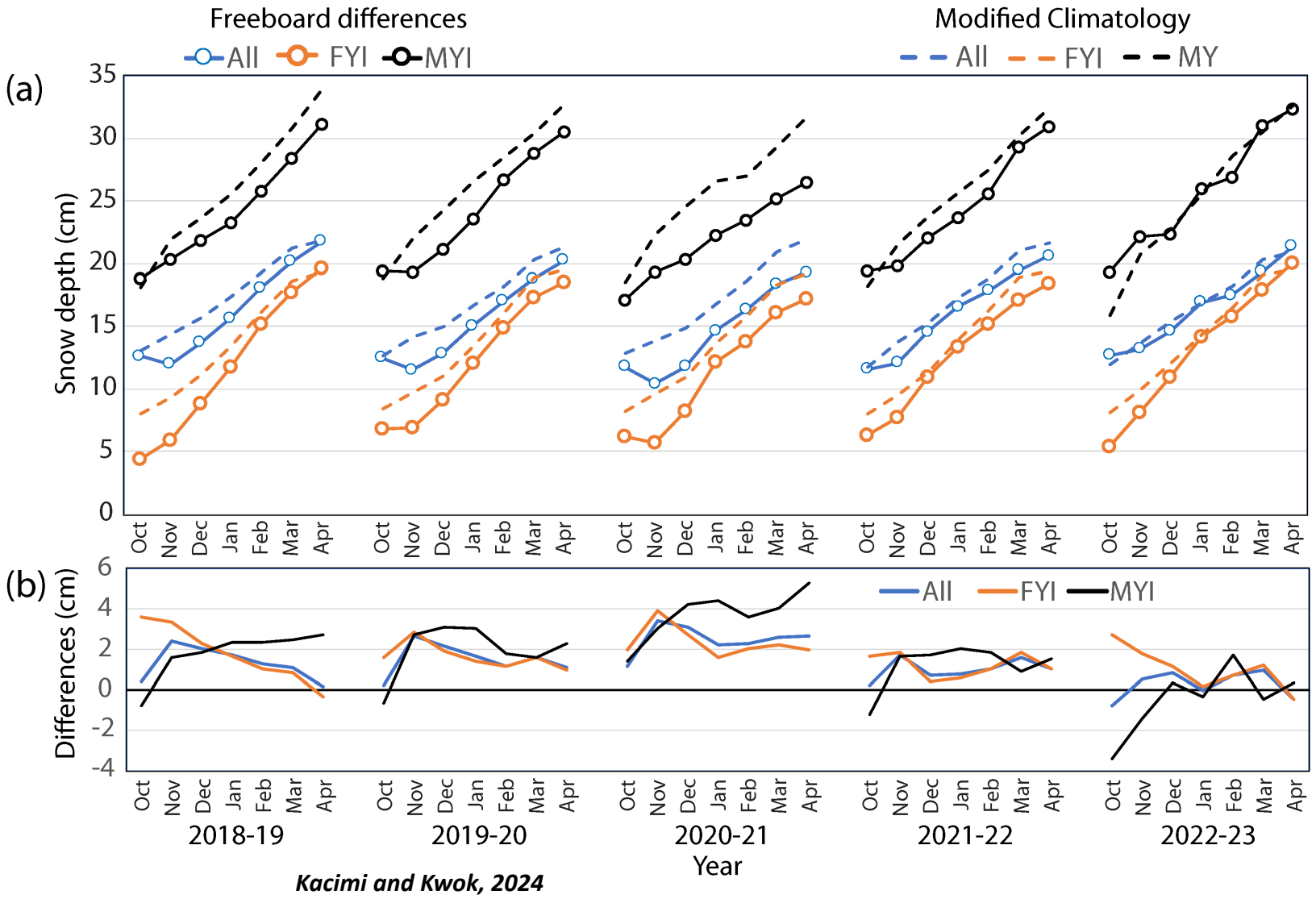


2022





Arctic Snow Depth (2018-2023)

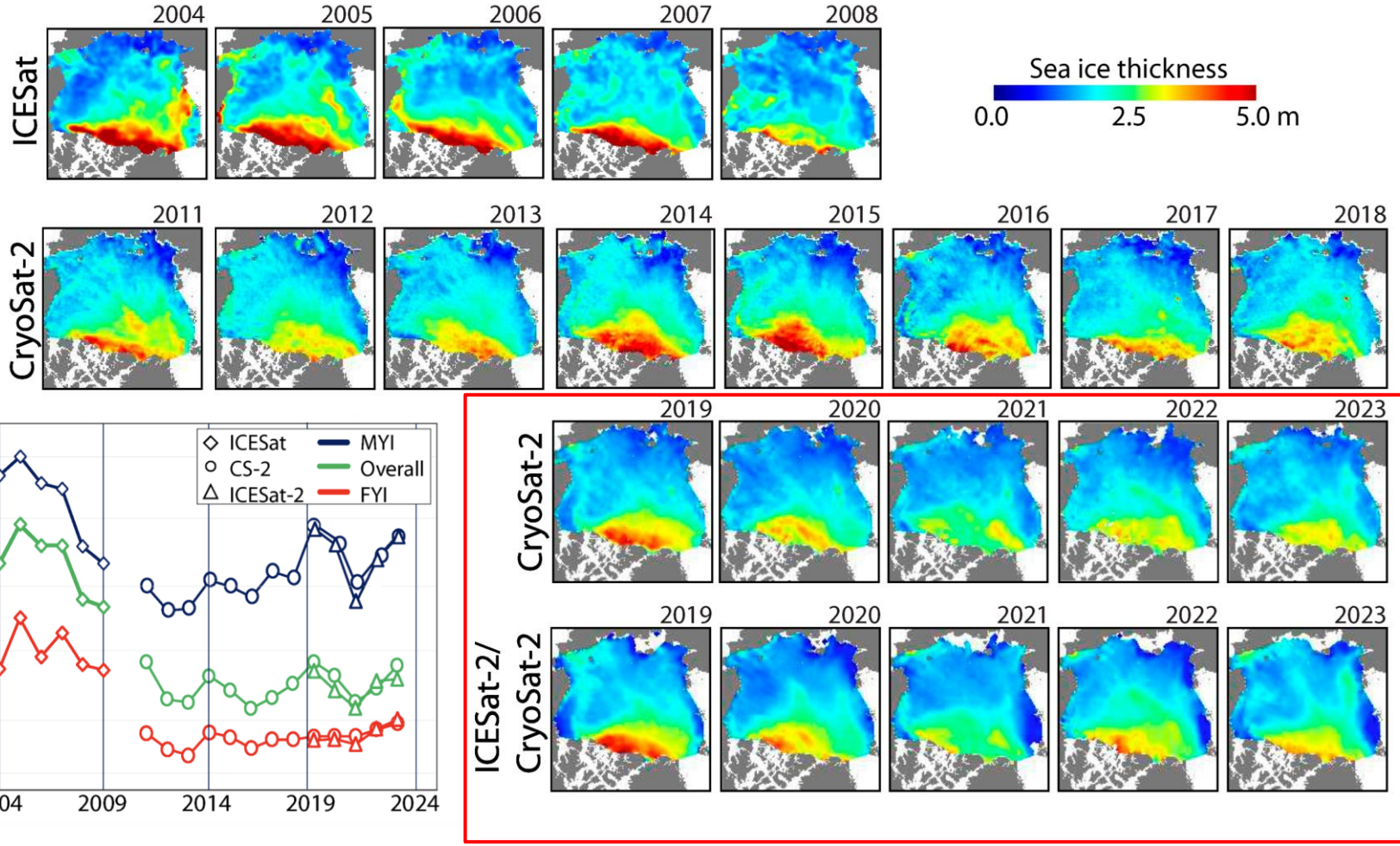


Kacimi and Kwok, 2024

- Similar seasonal behaviors between climatology and altimetry-derived snow depths
- **Differences for all ice types are < 5 cm**

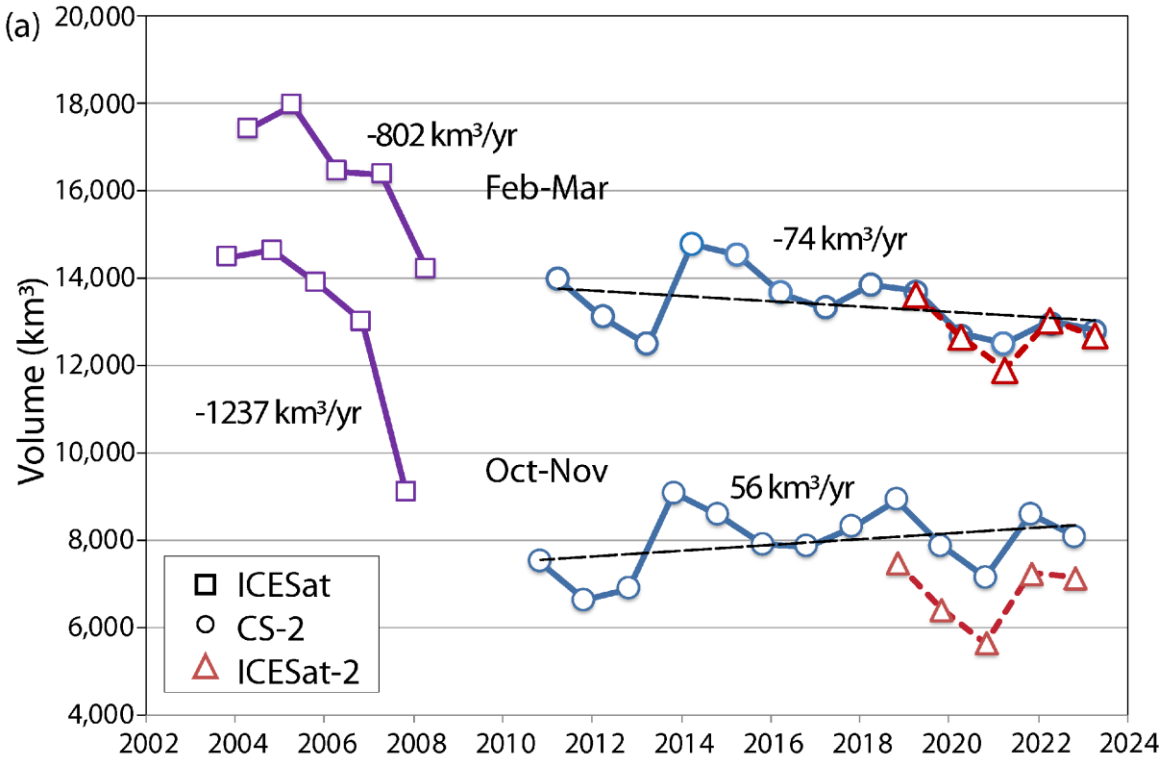
Arctic Sea Ice Thickness (2003-2023)

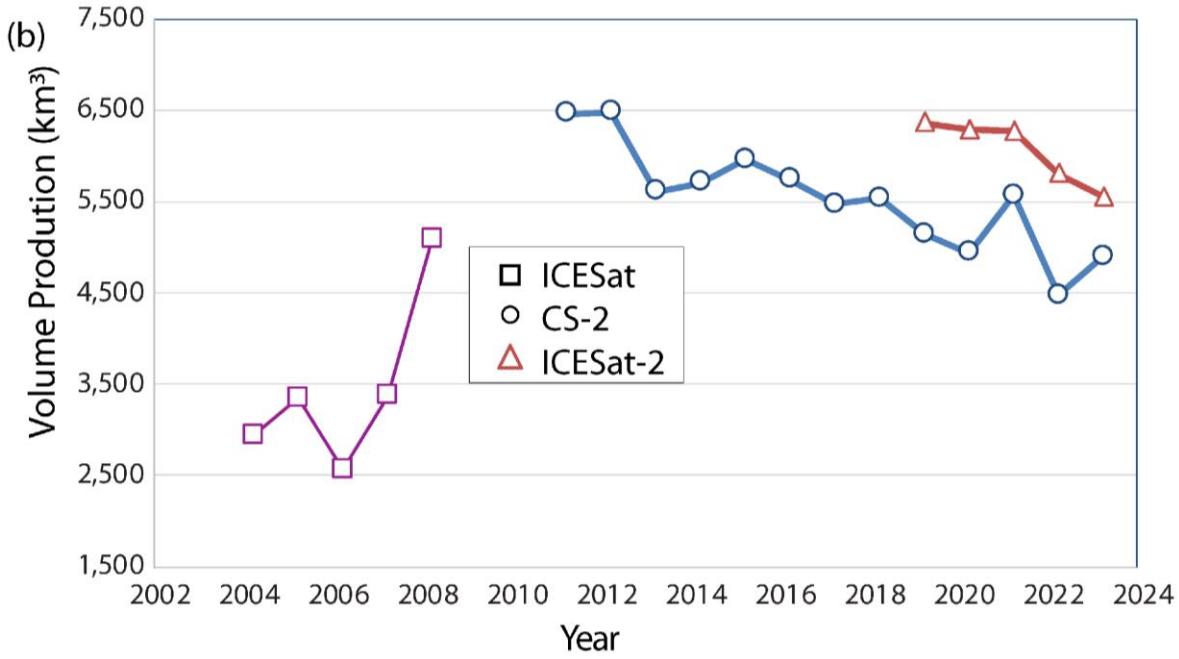
- Ice thicknesses from climatological and altimetric snow depths are comparable (within 0.2 m)
- **Thinning of ~1.2 m** from the 3 m peak thickness in the ICESat record



Kacimi and Kwok, 2024

Arctic Sea Ice Volume (2003-2023)

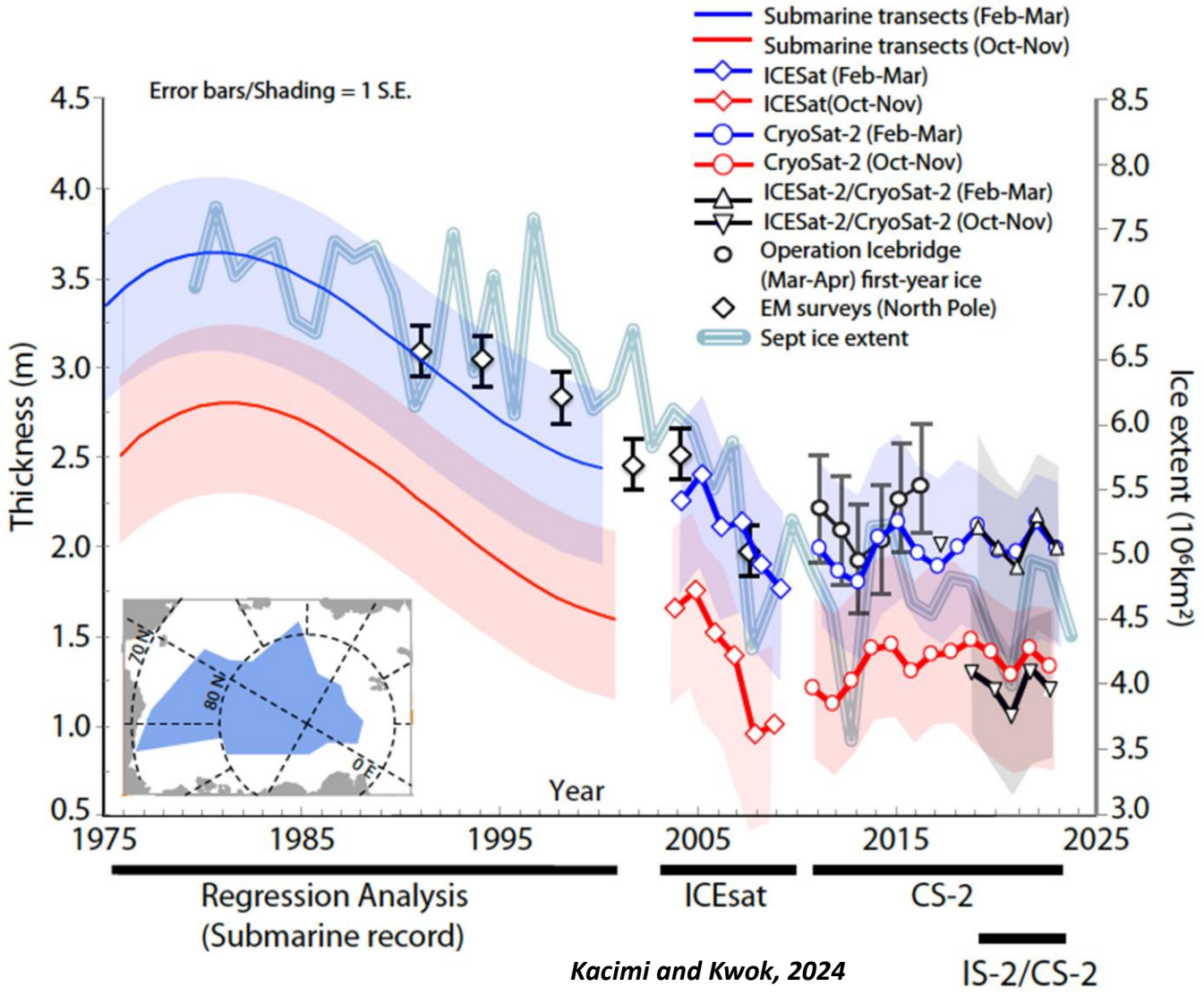




Kacimi and Kwok, 2024

- The dramatic volume loss (5500 km³) captured by ICESat has slowed
- Greater differences in the fall between IS-2 and CS-2 volume estimates
- Seasonal ice production has doubled (more seasonal ice)

Arctic Sea Ice Thickness (1975-2023)

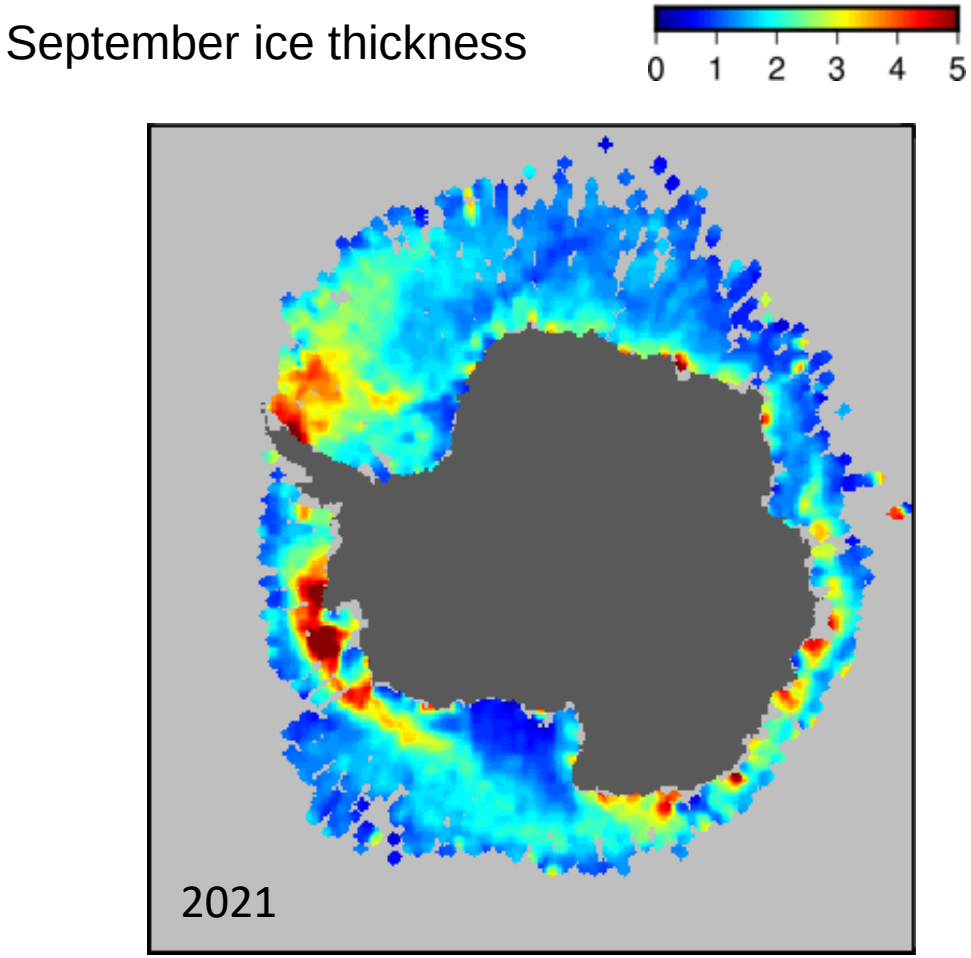


Kacimi and Kwok, 2024

- Thicknesses from declassified submarine ice-draft data sets in the Data Release Area (DRA covers ~38% of Arctic Ocean)
- Changes in the CryoSat-2 and ICESat-2 records are expected to be smaller (seasonal ice cover).

Antarctic (2018-2023)

- Increased complexity of the snow layer (flooding, high basal salinity)
- First results point to biases in the CS-2 freeboards in the order of ~7cm
- 5-year interannual variability linked to changes in large scale atmospheric circulation and air temperature



Summary and Next Steps

- Differences between climatological and satellite derived snow depths are small (< 5cm). Differences in resulting ice thicknesses are ~0.2m
- Between 2003 and 2023, results show a slow-down in the thinning of the sea ice cover and an increase in sea ice volume production
- Little variability in the DRA ice thickness over the CryoSat-2 period, explained by a shift to a seasonal ice cover
- Work towards modern snow depth and snow density climatologies
- Extend the retrievals to the melt season (2022 summer campaign)

Airborne / ICESat-2	Ice	Open water/lead	Melt pond
Lead candidate	**17.1%**	**82%**	**0.9%**
Pond/ice mixture	84.3%	5%	10.7%
Specular lead/pond	14.4%	73.7%	11.9%