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A merged CryoSat-2 Sentinel-3 freeboard product, its sensitivity to weather events, and what it can tell us about Ku-band radar penetration

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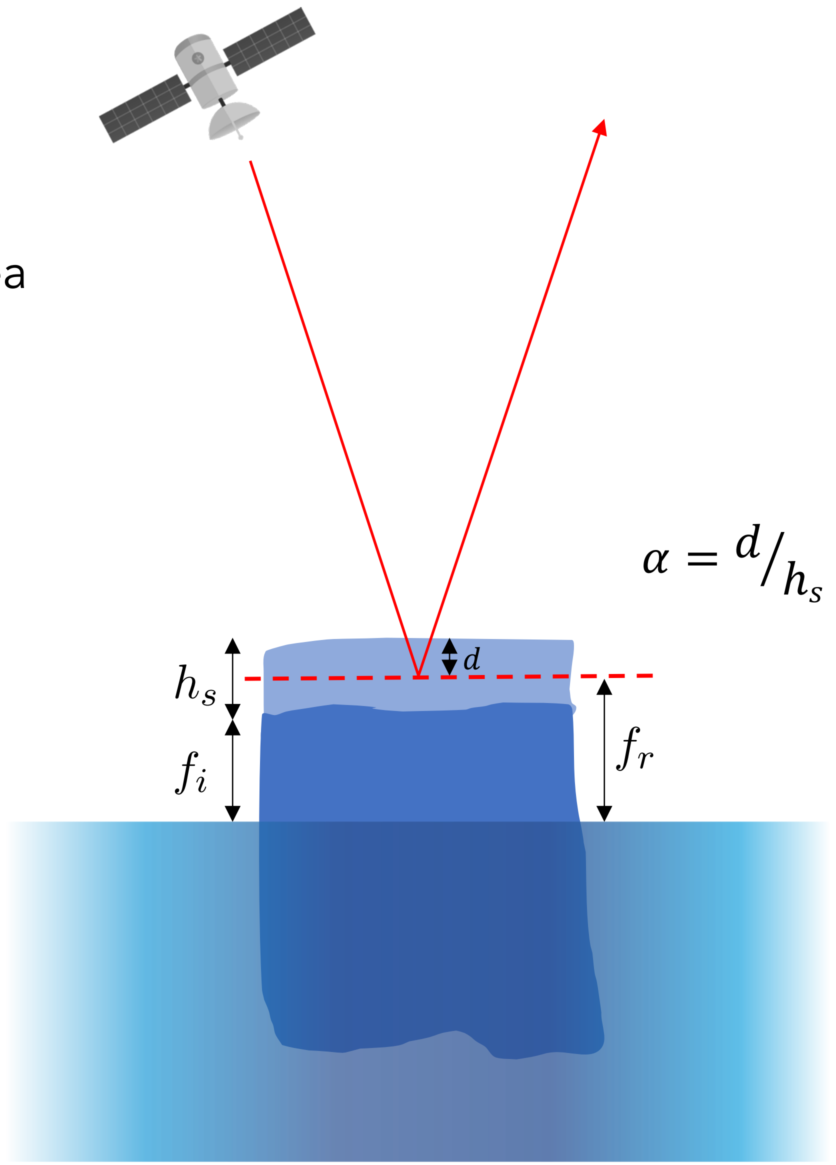
Background

- **Radar freeboard** is the difference between the elevation of the sea surface (measured in leads) and the radar elevation retrieval over a sea ice floe.
- An assessment of (e.g. the seasonal variability of) radar freeboard requires no a-priori knowledge of radar penetration or snow cover.
- In order to convert radar freeboard (f_r) to sea ice freeboard (f_i, the elevation of the snow/ice interface above the water surface), an assumption about the radar penetration (α) must be made and knowledge of the snow depth is required.

$$f_i = f_r + h_s(\alpha \frac{c}{c_s} - 1)$$



Our previous study demonstrated good agreement between CryoSat-2 (2010-present) and Sentinel-3A (2016-present) radar freeboard….

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Extending the Arctic sea ice freeboard and sea level record with the Sentinel-3 radar altimeters

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Following the method outlined in Lawrence et al. (2019), we further estimate radar freeboard from Sentinel-3B (2018-present) data. We find a good agreement (mean freeboard within 3mm) between CS2, S3A and S3B for the 5-months (December 2018-April 2019):

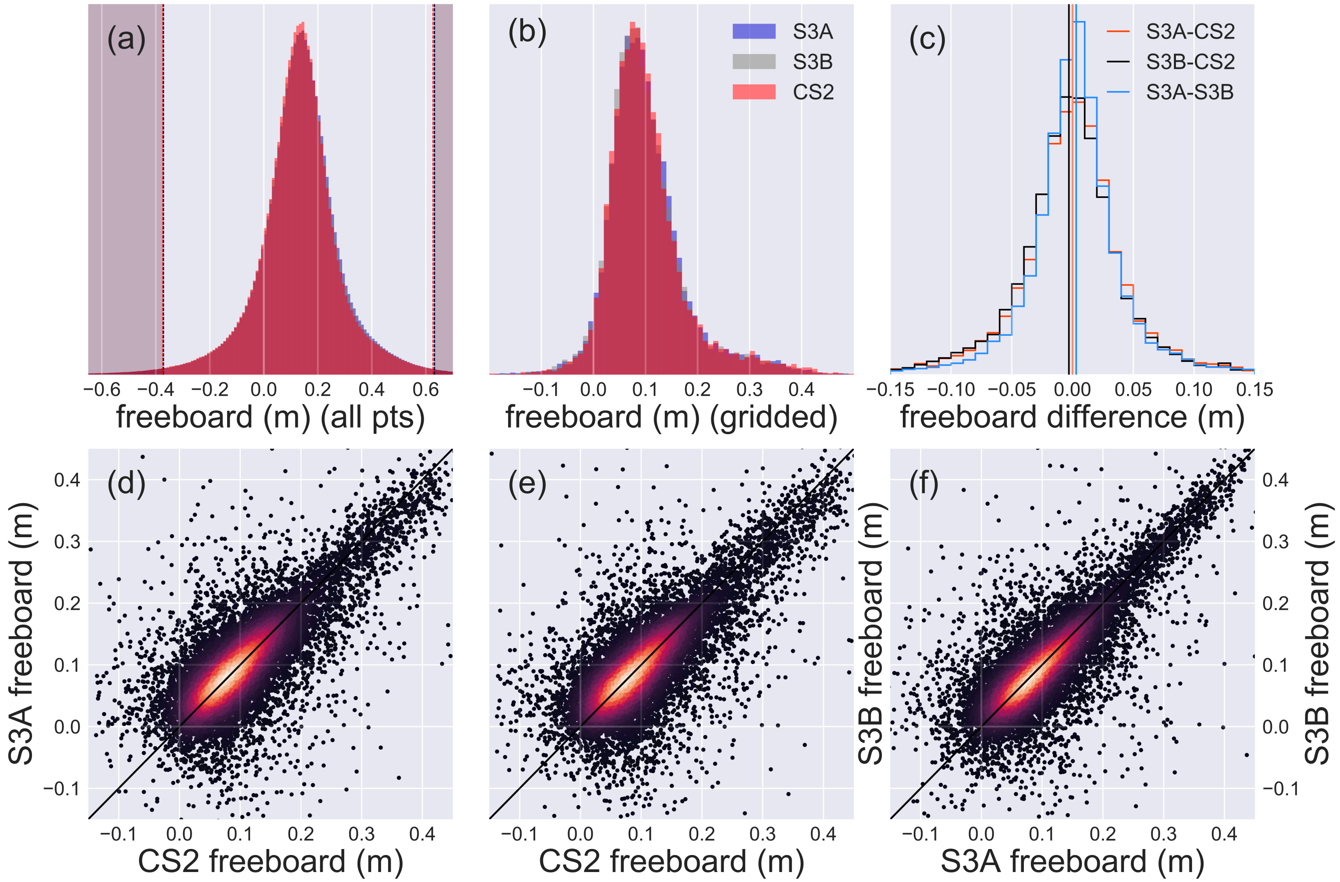
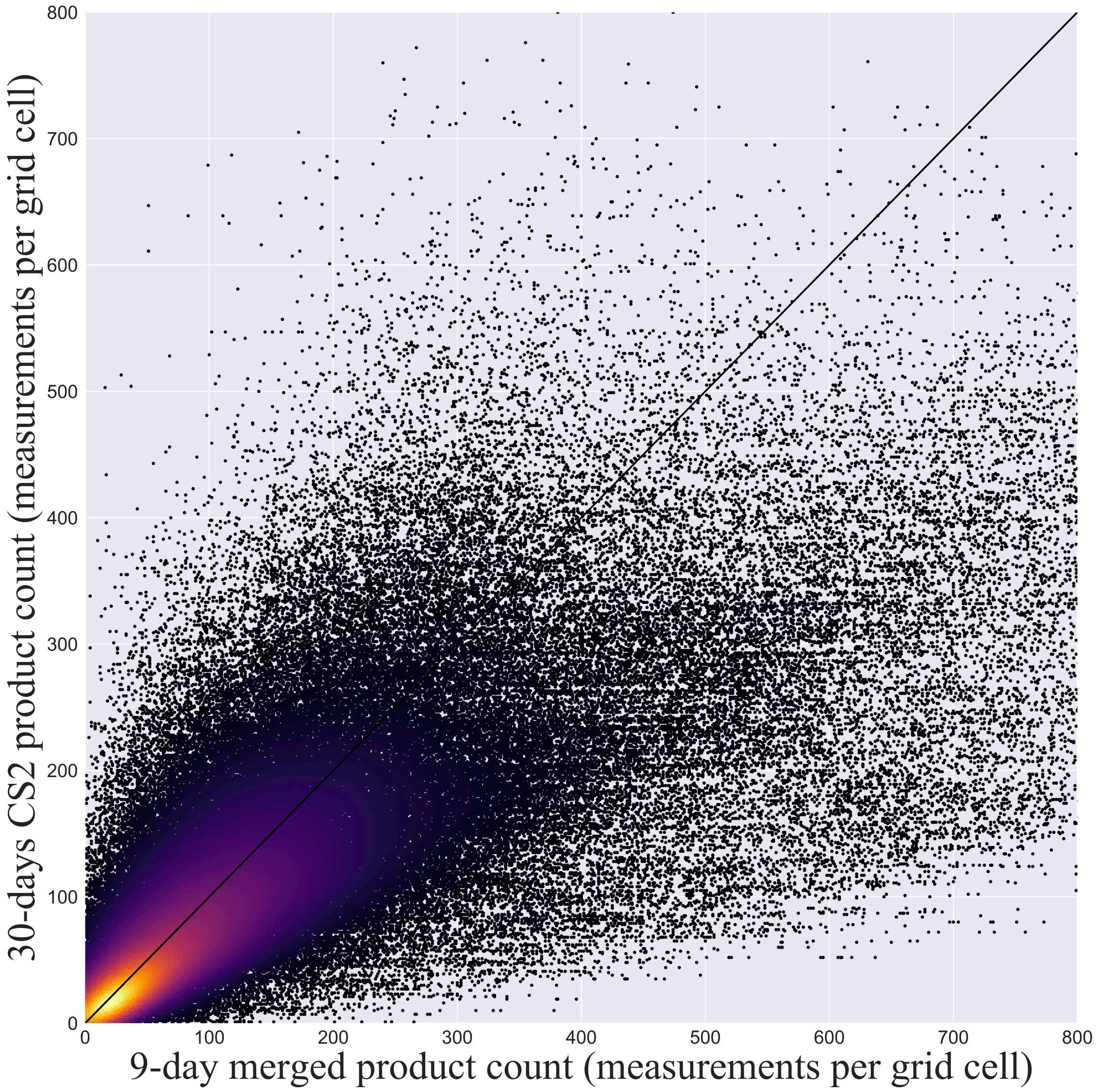


Table 1: CS2, S3A and S3B comparison

	S3A	S3B	CS2
Mean radar freeboard (m)	0.095	0.093	0.096

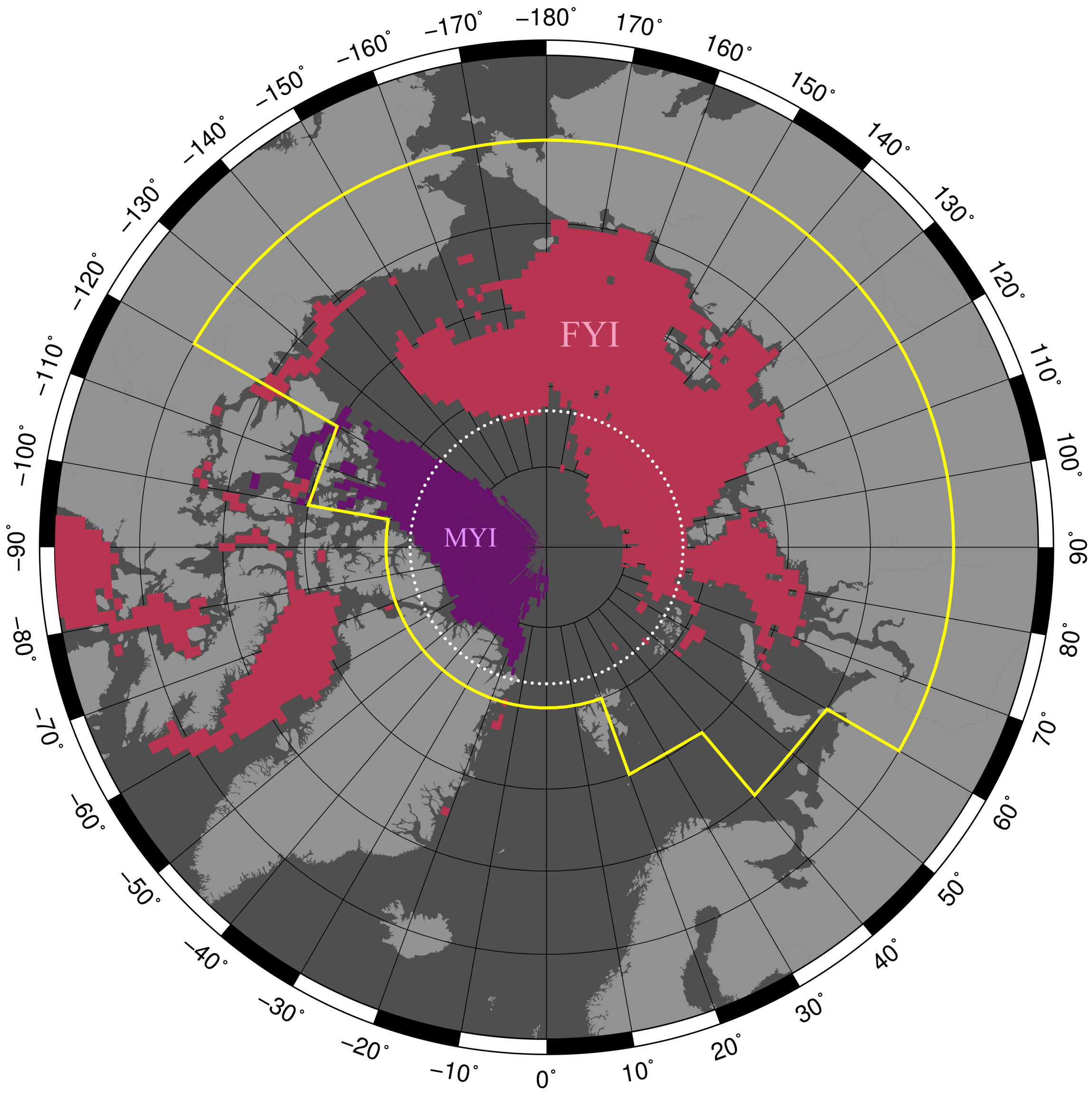
	S3A−CS2	S3B−CS2	S3A−S3B
Mean radar freeboard difference (m)	0.000	−0.003	0.003
SD on mean difference (m)	0.060	0.060	0.059
Pearson Correlation Coefficient	0.730	0.732	0.757

This good agreement permits a merging of data from the three satellites into a single dataset. The merged dataset achieves comparable spatial coverage in 9-days as CryoSat-2 achieves in 30 days:



We can use this 9-day freeboard product to look at radar freeboard variability over synoptic timescales.

We choose to assess radar freeboard over multi-year ice (MYI) and first-year ice (FYI) independently. We select grid cells that are classified as either MYI or FYI for every day of the 5-month period to limit the influence of ice dynamics on radar freeboard variability:



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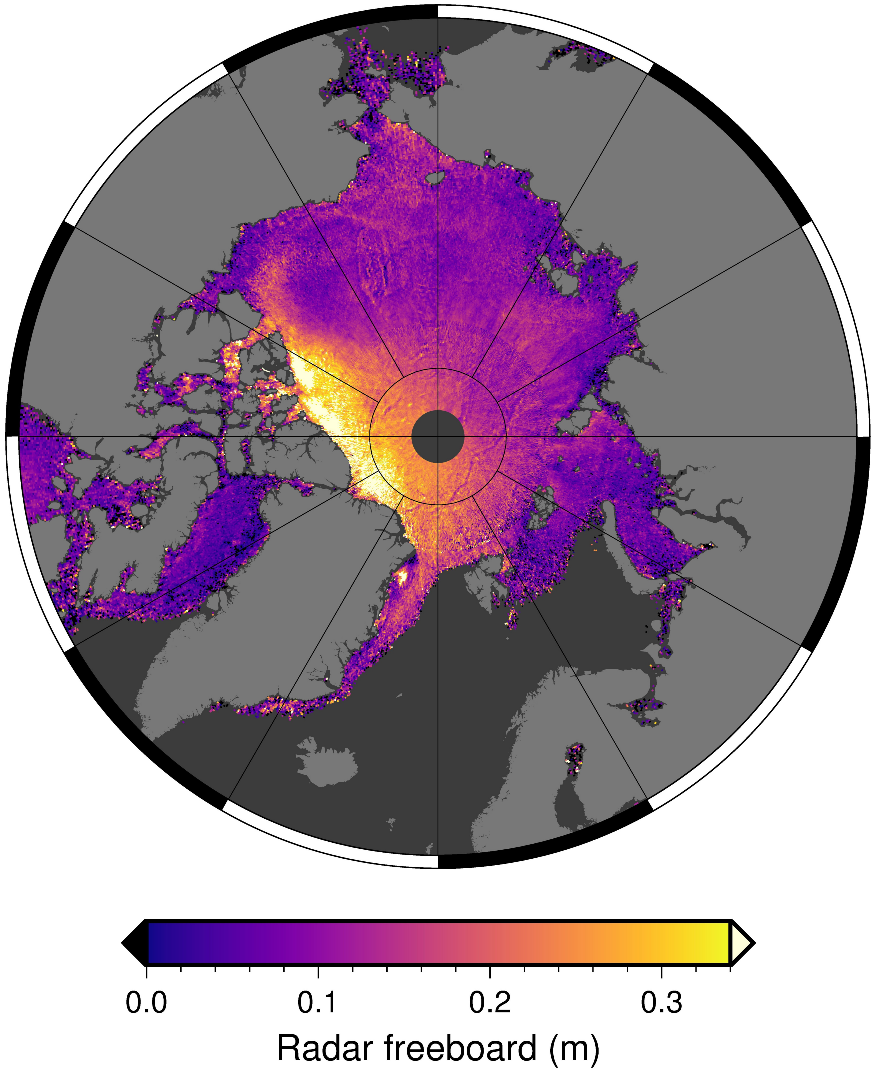
Since the same ground tracks are not being sampled every 9 days, it is important to separate variability due to sampling location from the real physical change in radar freeboard. To do this, we generate a high resolution grid of 'typical' radar freeboard (shown) and then sample this grid along the tracks for each 9-day window.

High-resolution radar freeboard grid



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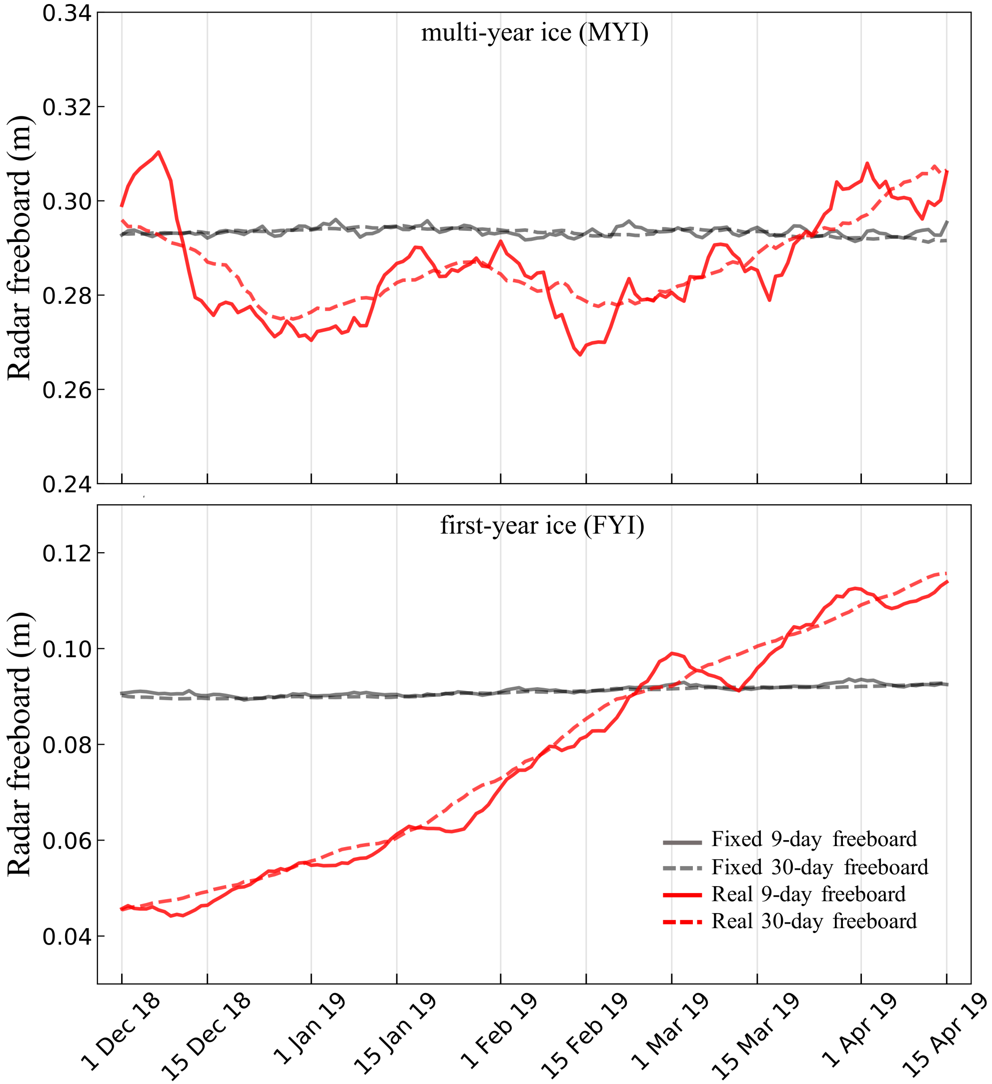
Results

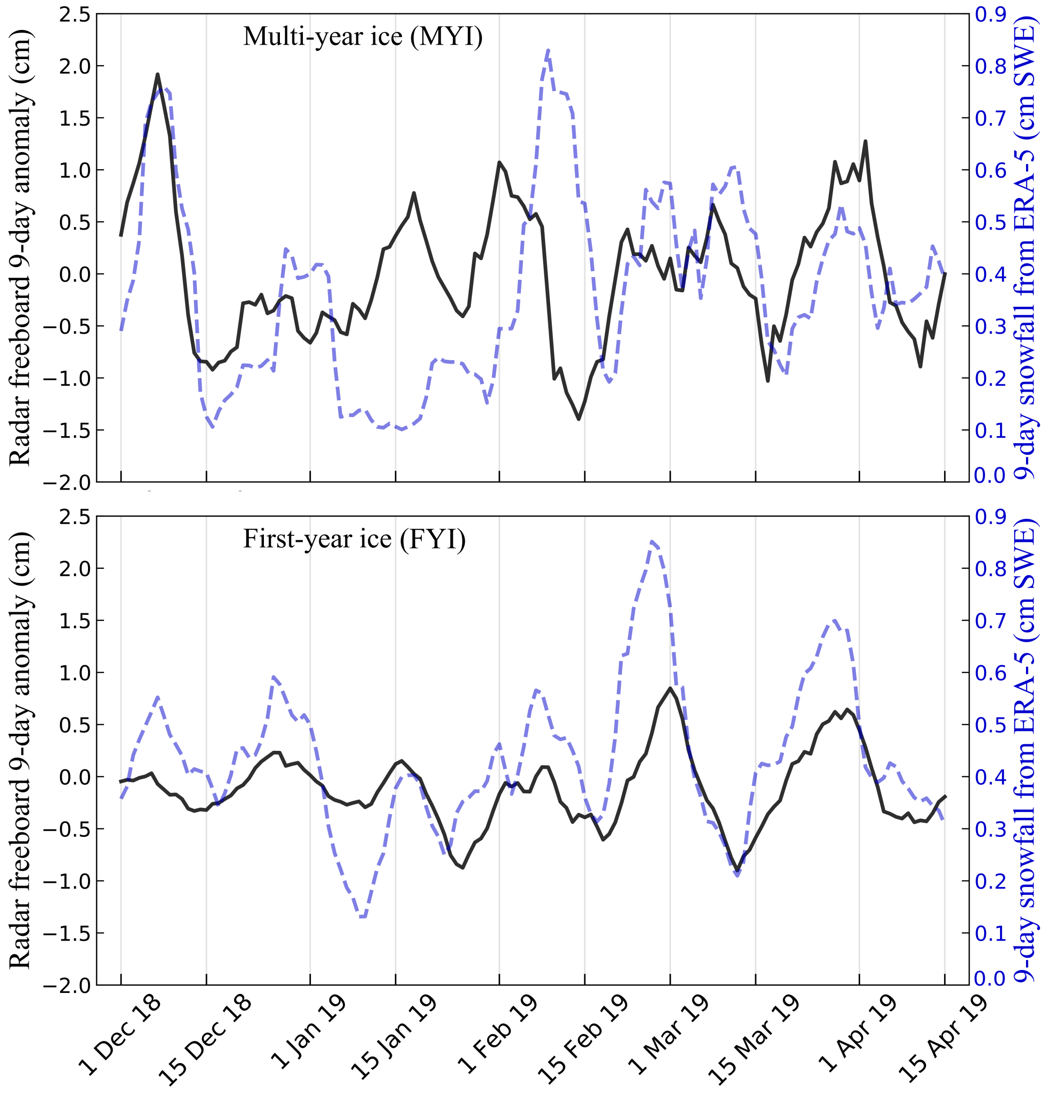
- Grey lines show the 'fixed' radar freeboard. Any variability is the result of sampling the fixed grid at differing locations.
- Red lines show the 'real' radar freeboard variability.
- The variance of the 'fixed' freeboard time-series accounts for only 3% of the variance of the 'real' signal, therefore we can conclude that the radar freeboard variability has a physical significance and is not just a result of sampling bias.



Results

- To investigate potential drivers of the variability, we compared our results against (9-day total) ERA5 snowfall over the predefined MYI and FYI regions.
- We find a strong correlation (PCC=0.72, p-value=0) between ERA5 snowfall and radar freeboard for FYI.
- By performing a first-order Taylor expansion of the equation for radar freeboard (below), we find that the influence of increasing snowfall on radar freeboard is positive if snow penetration is less than roughly half the snow pack ($\alpha < 0.55$).

$$f_r = \frac{h_i(\rho_w - \rho_i)}{\rho_w} + h_s\left(1 - \alpha\frac{c}{c_s} - \frac{\rho_s}{\rho_w}\right).$$



Summary

- We created a radar freeboard dataset combining data from CryoSat-2, Sentinel-3A and Sentinel-3B. This merged dataset achieves pan-Arctic coverage in 9 days.
- Radar freeboard was separated into multi-year and first-year ice regions to look at the 9-day radar freeboard variability over each ice regime.
- Comparing radar freeboard variability with snowfall from ERA5 reanalyses over the same regions, we found a high correlation (PCC=0.72, p-value=0) between snowfall and radar freeboard over FYI.
- A first-order Taylor expansion suggests that the influence of increasing snowfall on radar freeboard can only be positive if penetration of the snowpack is less than roughly half.
- Further investigation is needed, including repeating the analysis for winter 2019-20, since this result appears to contradict traditional assumptions of full snow penetration at Ku-band.