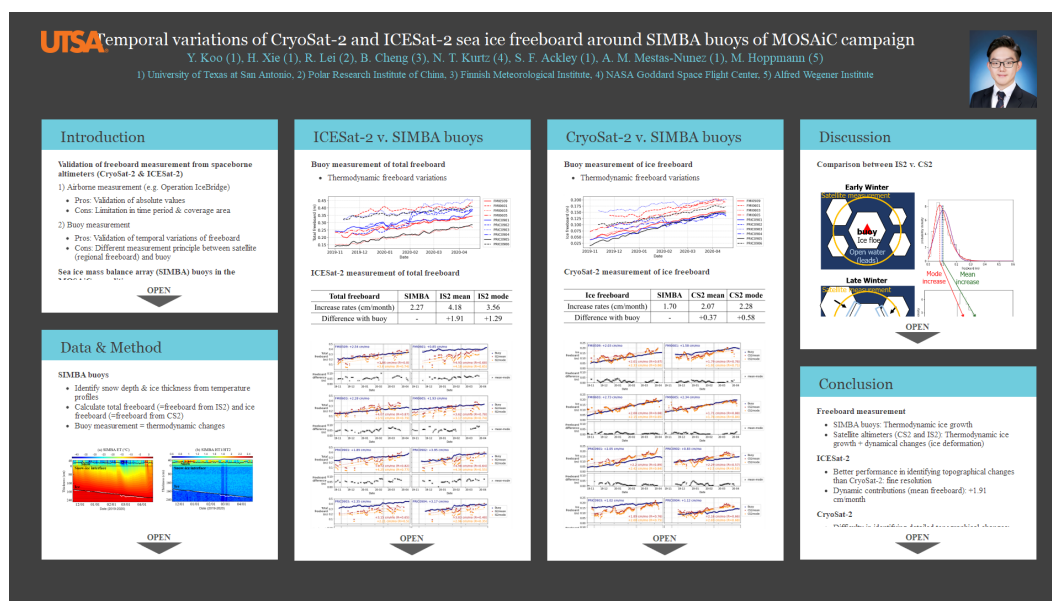


# Temporal variations of CryoSat-2 and ICESat-2 sea ice freeboard around SIMBA buoys of MOSAiC campaign



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PRESENTED AT:



# INTRODUCTION

## Validation of freeboard measurement from spaceborne altimeters (CryoSat-2 & ICESat-2)

### 1) Airborne measurement (e.g. Operation IceBridge)

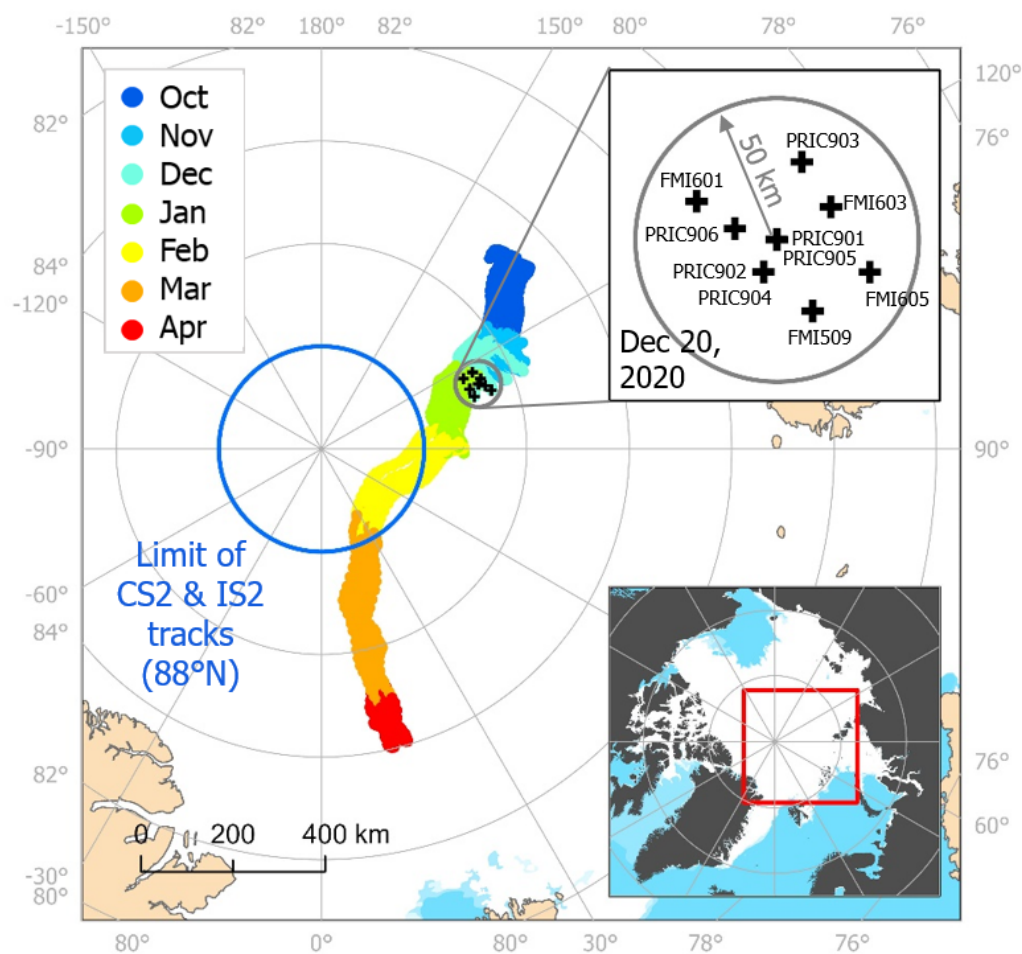
- Pros: Validation of absolute values
- Cons: Limitation in time period & coverage area

### 2) Buoy measurement

- Pros: Validation of temporal variations of freeboard
- Cons: Different measurement principle between satellite (regional freeboard) and buoy

## Sea ice mass balance array (SIMBA) buoys in the MOSAiC expedition

- 10 SIMBA buoys around the main site
- Freezing season (Nov 2019 - Apr 2020)
- Homogeneous in-situ observations for surrounding ice floes (spatial scale in ~ 50 km)



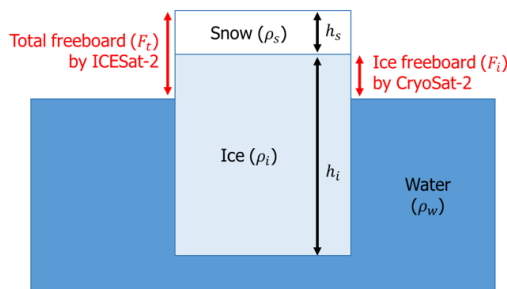
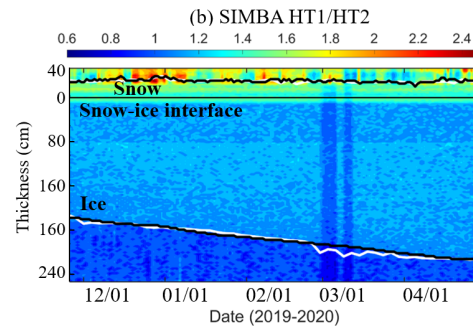
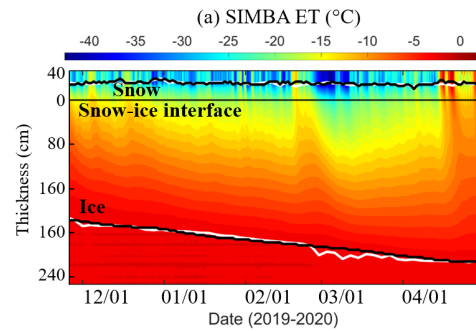
## Purpose

- Validate temporal variation (increase rates) of sea ice freeboard measurement of CS2 and IS2
- Compare the result from CS2 and IS2

## DATA & METHOD

### SIMBA buoys

- Identify snow depth & ice thickness from temperature profiles
- Calculate total freeboard (=freeboard from IS2) and ice freeboard (=freeboard from CS2)
- Buoy measurement = thermodynamic changes

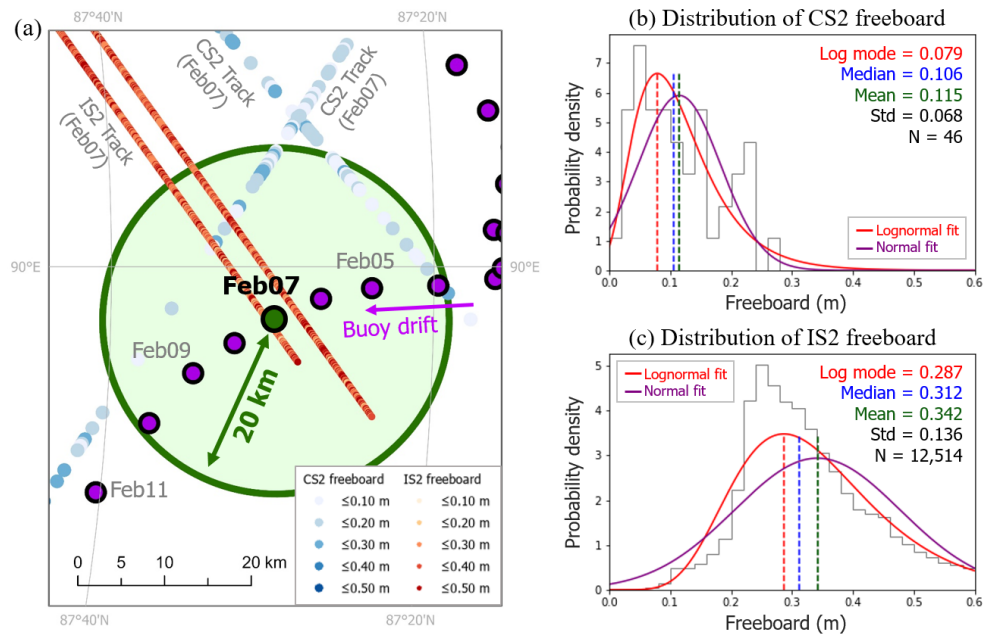


$$F_i = \frac{\rho_w - \rho_i}{\rho_w} h_i - \frac{\rho_s}{\rho_w} h_s \quad (1)$$

$$F_t = \frac{\rho_w - \rho_i}{\rho_w} h_i + \frac{\rho_w - \rho_s}{\rho_w} h_s \quad (2)$$

### Compare satellite v. buoy measurement

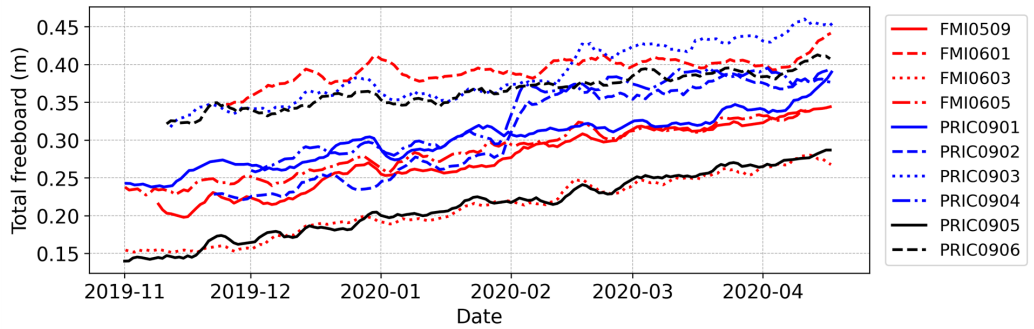
- ICESat-2: ATL10 sea ice freeboard
- CryoSat-2: SAR Level 2 product
- Compare satellite points within 20 km from buoys
- Calculate mean / median / mode of the satellite measurements in the 20 km buffer area
  - Mean freeboard: affected by sea ice deformation (ridged ice, sea ice leads)
  - Mode freeboard: representing level ice



# ICESAT-2 V. SIMBA BUOYS

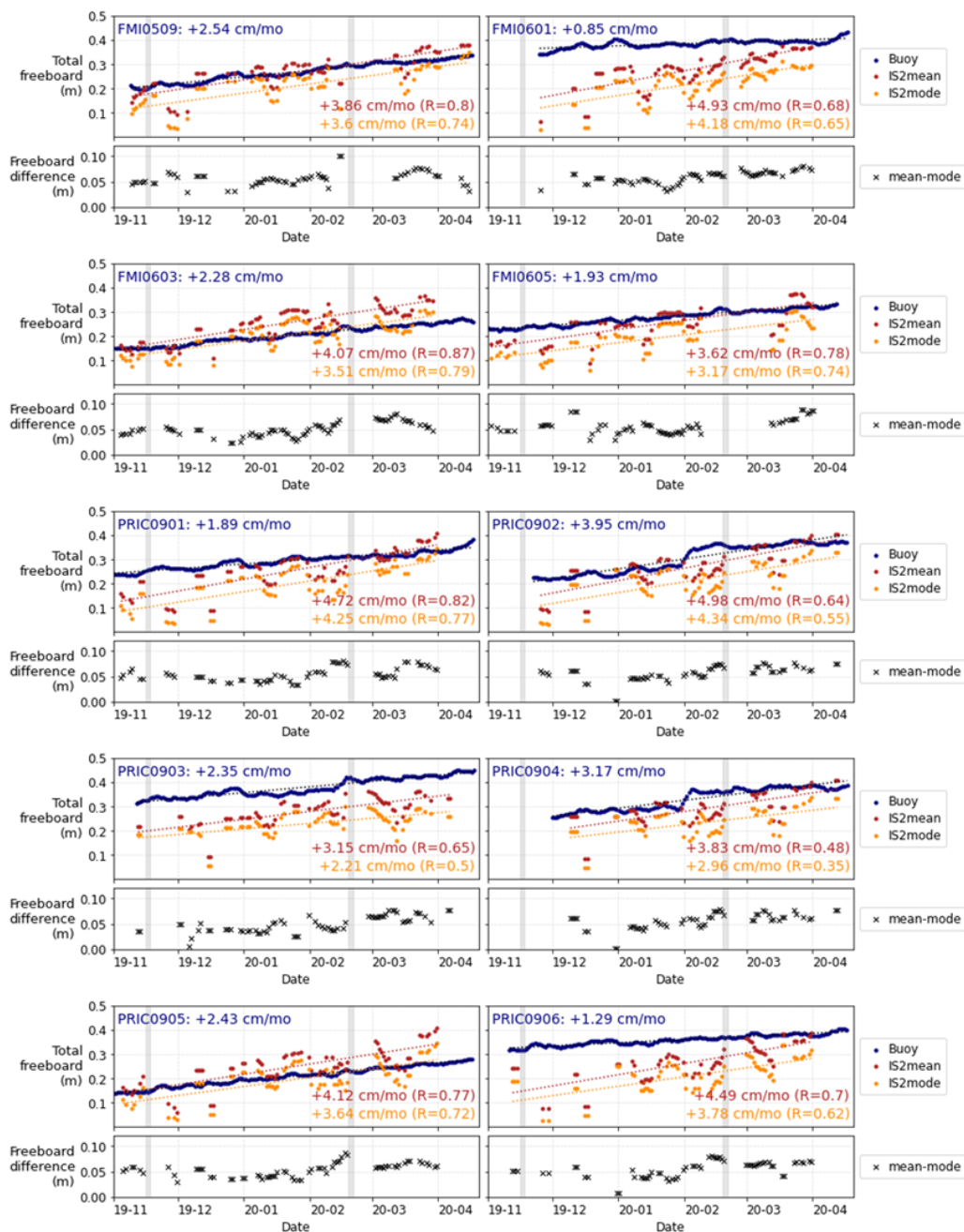
## Buoy measurement of total freeboard

- Thermodynamic freeboard variations



## ICESat-2 measurement of total freeboard

Total freeboard	SIMBA	IS2 mean	IS2 mode
Increase rates (cm/month)	2.27	4.18	3.56
Difference with buoy	-	+1.91	+1.29

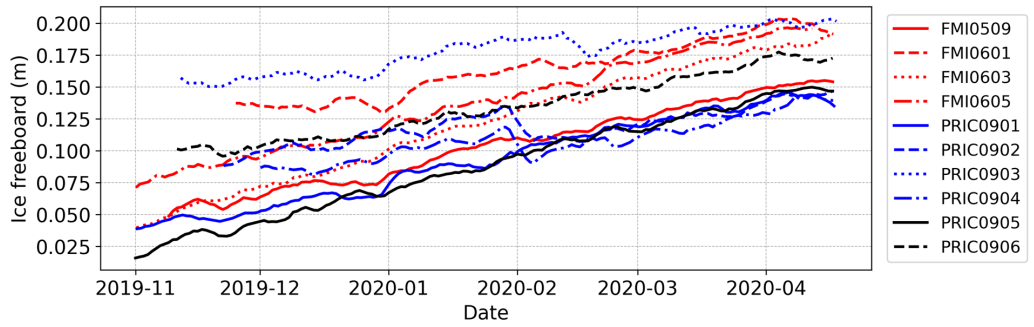


- Freeboard increase rates from ICESat-2 > Increase rates from buoy measurement
- ICESat-2 measurement includes sea ice dynamics (formation of ridged ice, sea ice leads) as well as thermodynamic ice growth
- Increase rates: Mean freeboard > Mode freeboard

# CRYOSAT-2 V. SIMBA BUOYS

## Buoy measurement of ice freeboard

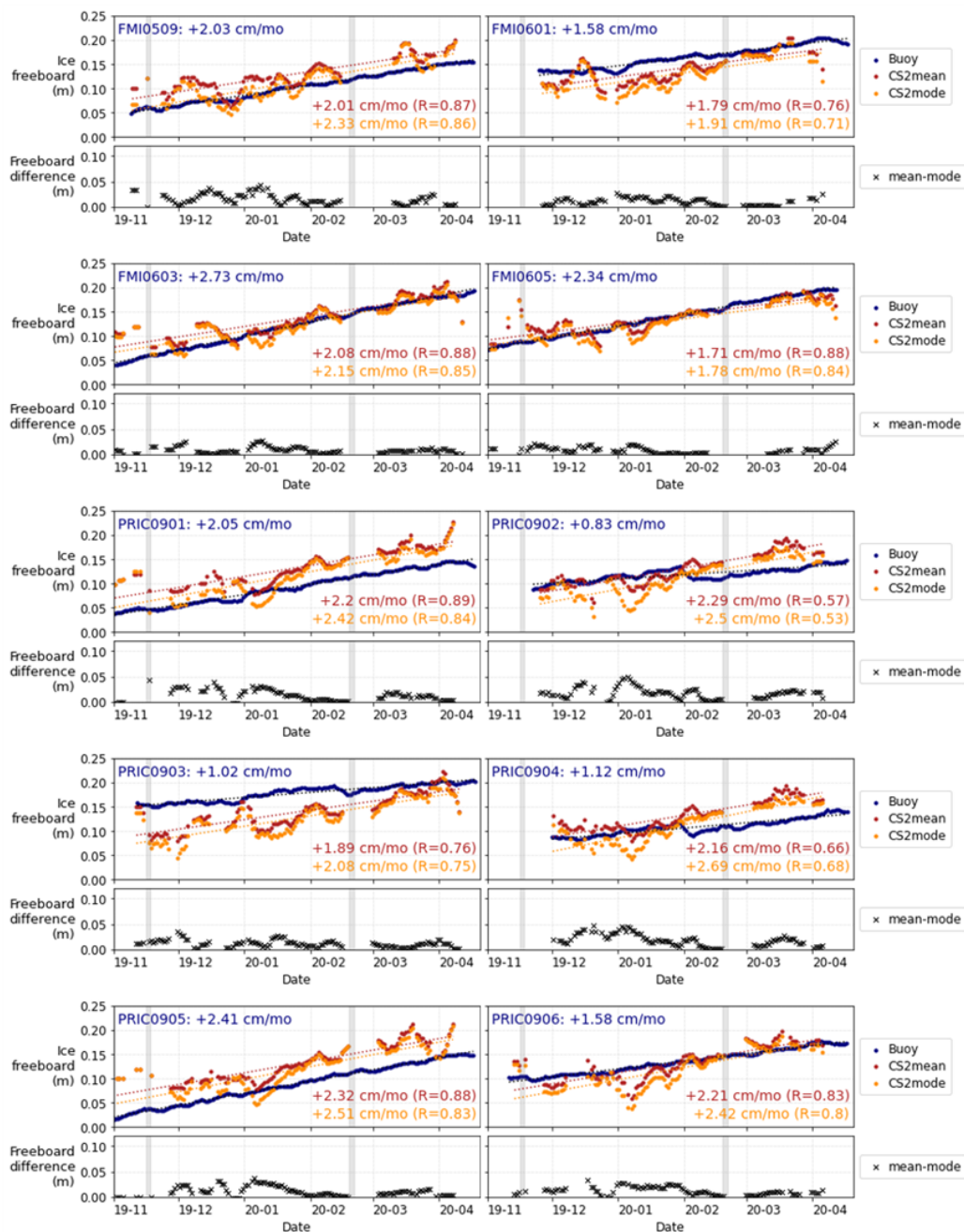
- Thermodynamic freeboard variations



## CryoSat-2 measurement of ice freeboard

Ice freeboard	SIMBA	CS2 mean	CS2 mode
Increase rates (cm/month)	1.70	2.07	2.28
Difference with buoy	-	+0.37	+0.58



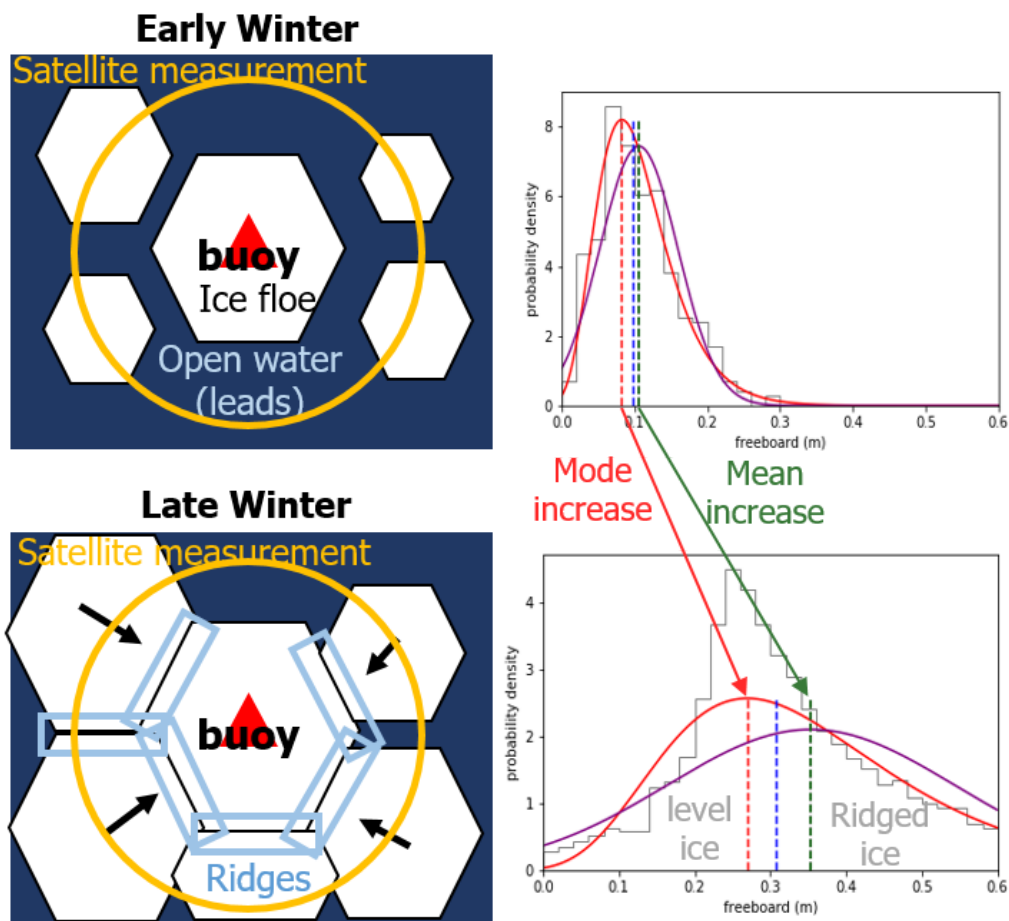


- Freeboard increase rates from CryoSat-2 > Increase rates from buoy measurement
- CryoSat-2 measurement includes sea ice dynamics (formation of ridged ice, sea ice leads) as well as thermodynamic ice growth
- Increase rates: Mode freeboard > Mean freeboard



## DISCUSSION

Comparison between IS2 v. CS2



- Mean-mode differences: ICESat-2 > CryoSat-2
  - IS2: increase during Nov-Apr
  - CS2: decrease during Nov-Apr
- Mean freeboard should have higher increase rates than mode freeboard because the mean freeboard represents freeboard increase by ridged ice
- ICESat-2 detects detailed topographical changes & ice deformation because of its fine resolution (~30 m)
- CryoSat-2 has difficulty in detecting detailed topographical changes & ice deformation
  1. Coarse spatial resolution (~400 m)
  2. Impact of snow conditions (e.g. snow density, snow depth, snow temperature, ...): variable snow conditions in early winter

# CONCLUSION

## Freeboard measurement

- SIMBA buoys: Thermodynamic ice growth
- Satellite altimeters (CS2 and IS2): Thermodynamic ice growth + dynamical changes (ice deformation)

## ICESat-2

- Better performance in identifying topographical changes than CryoSat-2: fine resolution
- Dynamic contributions (mean freeboard): +1.91 cm/month

## CryoSat-2

- Difficulty in identifying detailed topographical changes: coarse resolution
- Impacts by snow conditions in early winter
- Dynamic contributions (mean freeboard): +0.37 cm/month

# DISCLOSURES

## Acknowledgements

Buoy data used in this manuscript were produced as part of the international Multidisciplinary drifting Observatory for the Study of the Arctic Climate (MOSAiC) with the tag MOSAiC20192020. All data are archived in the MOSAiC Central Storage (MCS) and will be available on PANGAEA after finalization of the respective datasets according to the MOSAiC data policy. We would like to thank the European Space Agency (ESA) for processing and providing CryoSat-2 data, and the National Aeronautics and Space Administration (NASA) for processing and providing ICESat-2 data. Funding supports to Y. Koo, H. Xie, S. Ackley, A. Mestas were from U.S. NSF (1835784) and NASA (80NSSC18K0843 and 80NSSC19M0194) grants. R. Lei was supported by the National Key Research and Development Program (2018YFA0605903 and 2016YFC1400303); B. Cheng was supported by the European Union's Horizon 2020 research and innovation programme (727890 – INTAROS). We give special thanks to cruise leader Thomas Krumpen, all the crew and pilots of the Akademik Fedorov, and the entire science team of the MOSAiC expedition.

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## ABSTRACT

String based sea ice mass balance array (SIMBA) buoy is a good data source to figure out the temporal variations of sea ice freeboard or thickness over the polar oceans. In particular, SIMBA buoys operated as a part of MOSAiC expedition provide relatively homogeneous measurements of snow depth and ice thickness nearby MOSAiC distributed regional network. Therefore, by using 10 SIMBA buoys from MOSAiC expedition, we assess the ability of CryoSat-2 and ICESat-2 in estimating the temporal variations of the sea ice freeboard over the freezing season. We first calculate the ice freeboard and total freeboard at each SIMBA buoy from the vertical temperature profiles. Then the mean, median, and lognormal mode of the CryoSat-2 ice freeboard and ICESat-2 total freeboard are calculated within 20 km buffer from the buoy. Both CryoSat-2 and ICESat-2 detect the freeboard increases with significant correlations with the SIMBA buoys ( $R \sim 0.7$ ,  $P < 0.001$ ). However, increasing rates of the satellite freeboards are greater than that of the buoy freeboards, which indicates that the satellite freeboards include topographic variations (i.e. ice dynamics) as well as thermodynamic growth. The mean-mode differences of the satellite freeboards also demonstrate that the topographic changes have a larger impact on ICESat-2 freeboard because of its finer spatial resolution. In this study, CryoSat-2 overestimates ice freeboard by 1-3 cm, and ICESat-2 underestimates total freeboard by 3-9 cm compared to the buoy measurements. These differences may be associated with the different measurement principles between the buoys and the altimeters.