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

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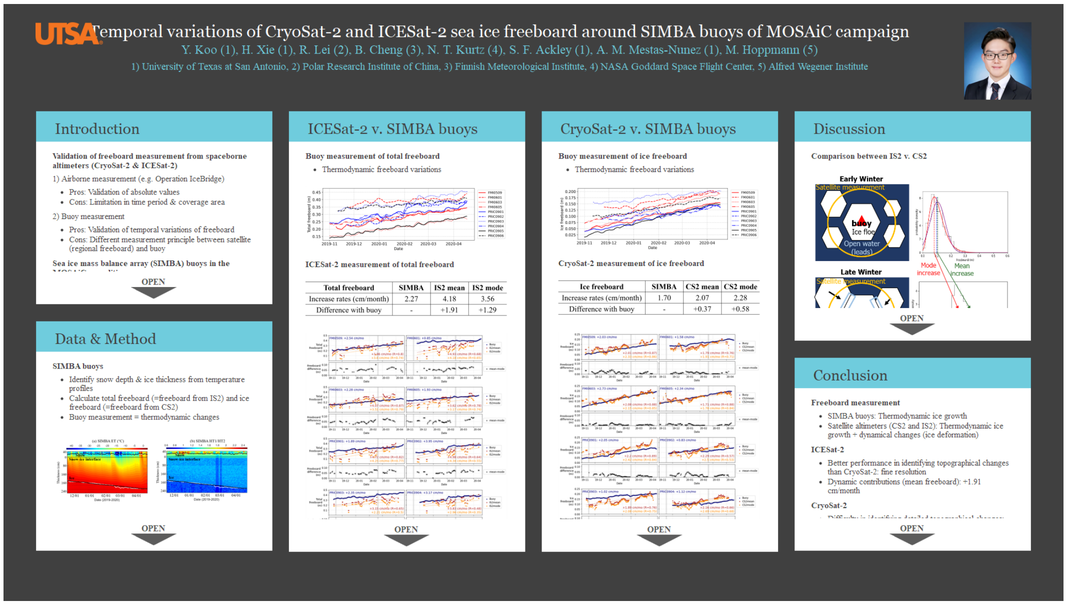
**Abstract**

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 temperature profiles of the buoy. 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. CryoSat-2 ice freeboard shows a good correspondence with the buoy ice freeboard: increase rate of ~2 cm/month, correlation coefficient (R) greater than 0.7 ($P < 0.001$), and RMSE of 3-4 cm. Meanwhile, ICESat-2 also shows a significant correlation: increase rate of 2-4 cm/month, $R > 0.7$, and RMSE of 8-12 cm. CryoSat-2 generally overestimates the ice freeboard and the lognormal estimations show the least biases. On the contrary, ICESat-2 underestimates the total freeboard and the mean estimations show the least biases. This result should be associated with various sources of uncertainties: formation of snow ice at the buoys, variations of snow/ice density, freeboard retrieval algorithms of the satellite altimeters, and spatial/temporal variations between buoy and satellite data.

# 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)

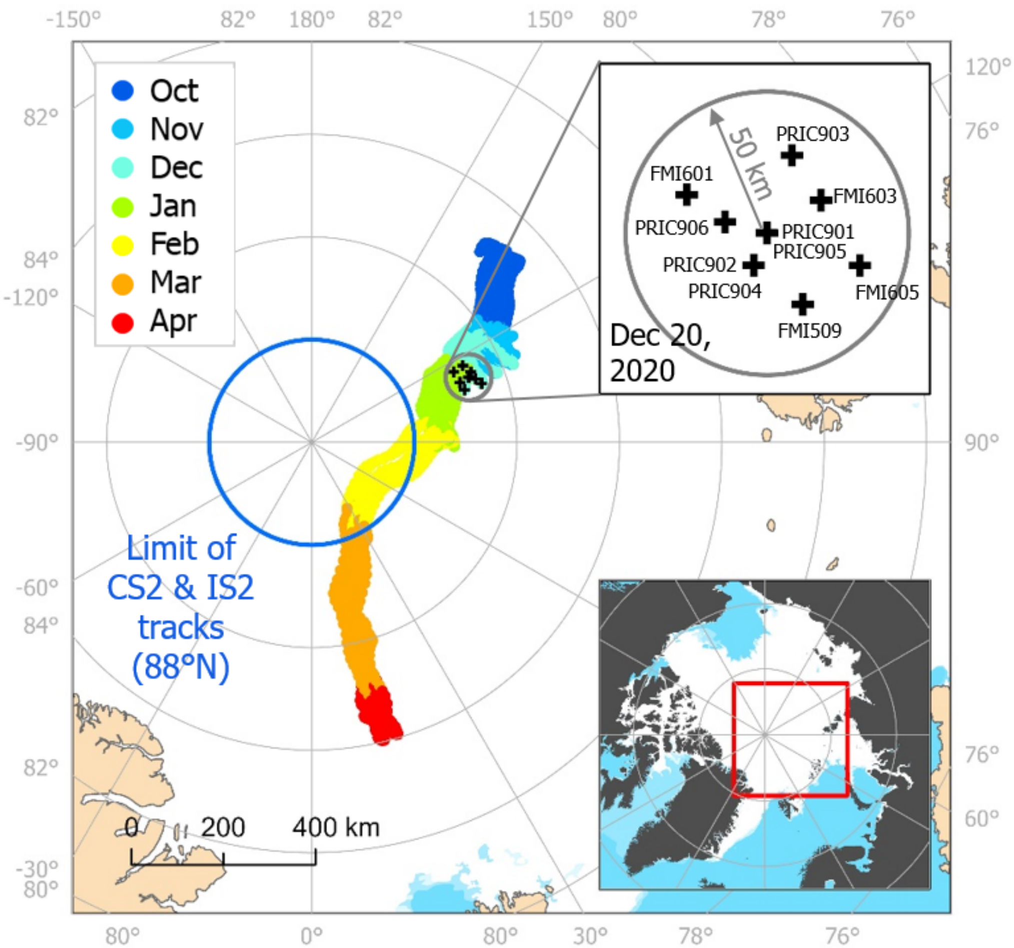
- Pros: Validation of absolute values
- Cons: Limitation in time period & coverage area

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 surrouding ice floes (spatial scale in ~ 50 km)



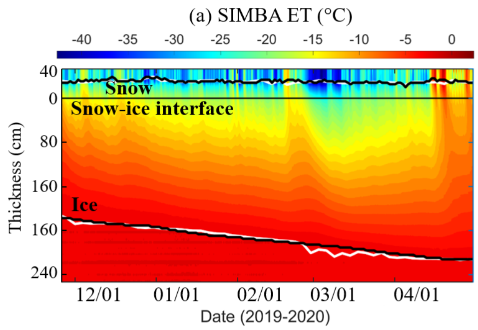

**Purpose**

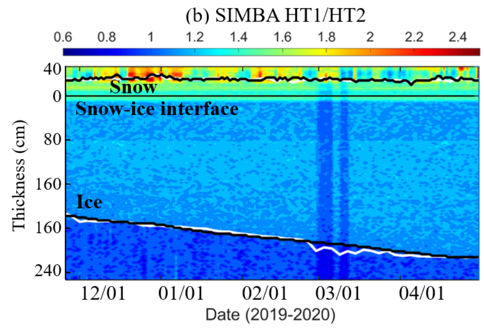
- Validate temporal variation (increase rates) of sea ice freeboard measurement of CS2 and IS2
- Compare the result from CS2 and IS2

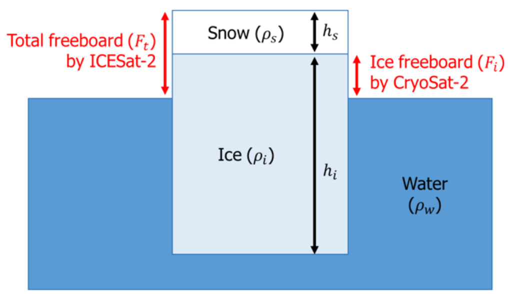
# DATA & METHOD

**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



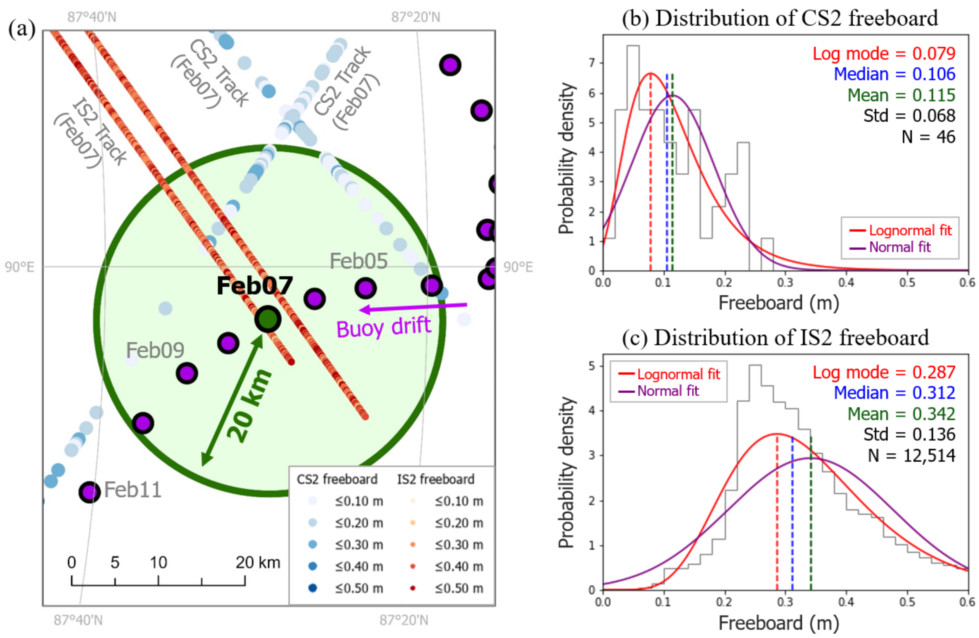




$$F_i = \frac{\rho_w - \rho_i}{\rho_w} h_i - \frac{\rho_s}{\rho_w} h_s \quad (1)$$

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

**Compare satelilte v. buoy measurement**

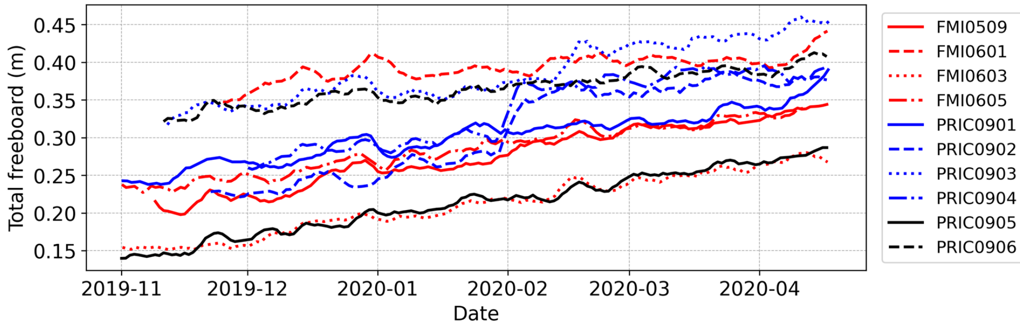
- ICESat-2: ATL10 sea ice freeboard
- CryoSat-2: SAR Level 2 product
- Compare satellite points within 20 km from buoys
- Calculate mean / median / mode of the satellite measurements in the 20 km buffer area
  - Mean freeboard: affected by sea ice deformation (ridged ice, sea ice leads)
  - Mode freeboard: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


(a)
87°40'N
87°20'N
90°E
CS2 Track (Feb07)
CS2 Track (Feb07)
IS2 Track (Feb07)
Feb05
Feb07
Feb09
Feb11
Buoy drift
20 km
0 5 10 20 km
CS2 freeboard
IS2 freeboard
≤0.10 m
≤0.20 m
≤0.30 m
≤0.40 m
≤0.50 m
(b) Distribution of CS2 freeboard
Log mode = 0.079
Median = 0.106
Mean = 0.115
Std = 0.068
N = 46
Lognormal fit
Normal fit
Probability density
Freeboard (m)
(c) Distribution of IS2 freeboard
Log mode = 0.287
Median = 0.312
Mean = 0.342
Std = 0.136
N = 12,514
Lognormal fit
Normal fit
Probability density
Freeboard (m)

# ICESAT-2 V. SIMBA BUOYS

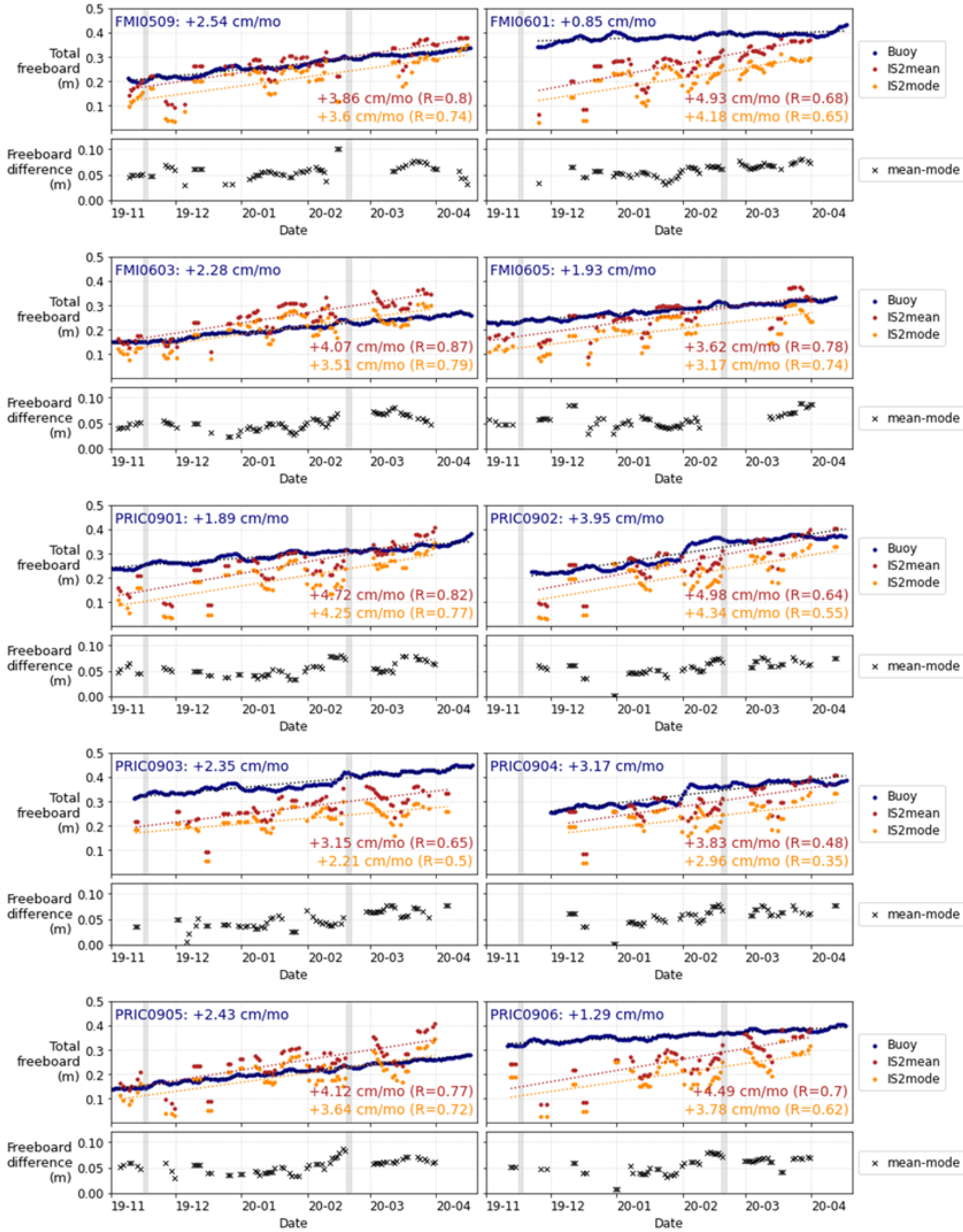
**Buoy measurement of total freeboard**

- 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 |

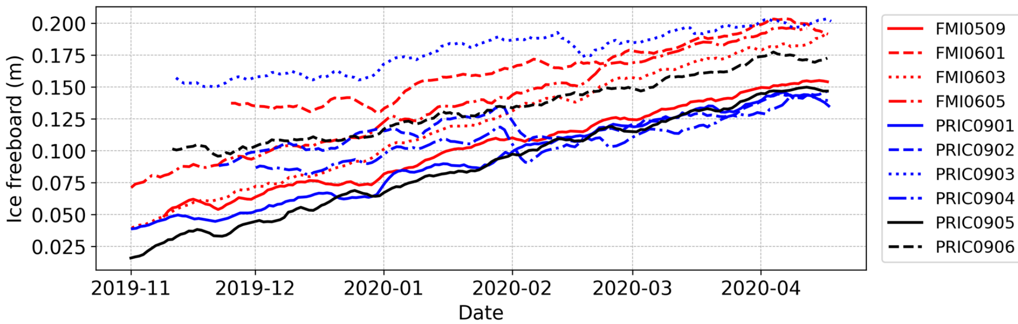



- Freeboard increase rates from ICESat-2 > Increase rates from buoy measurement
- ICESat-2 measurement includes sea ice dynamics (formation of ridged ice, sea ice leads) as well as thermodynamic ice growth
- Increase rates: Mean freeboard > Mode freeboard

# CRYOSAT-2 V. SIMBA BUOYS

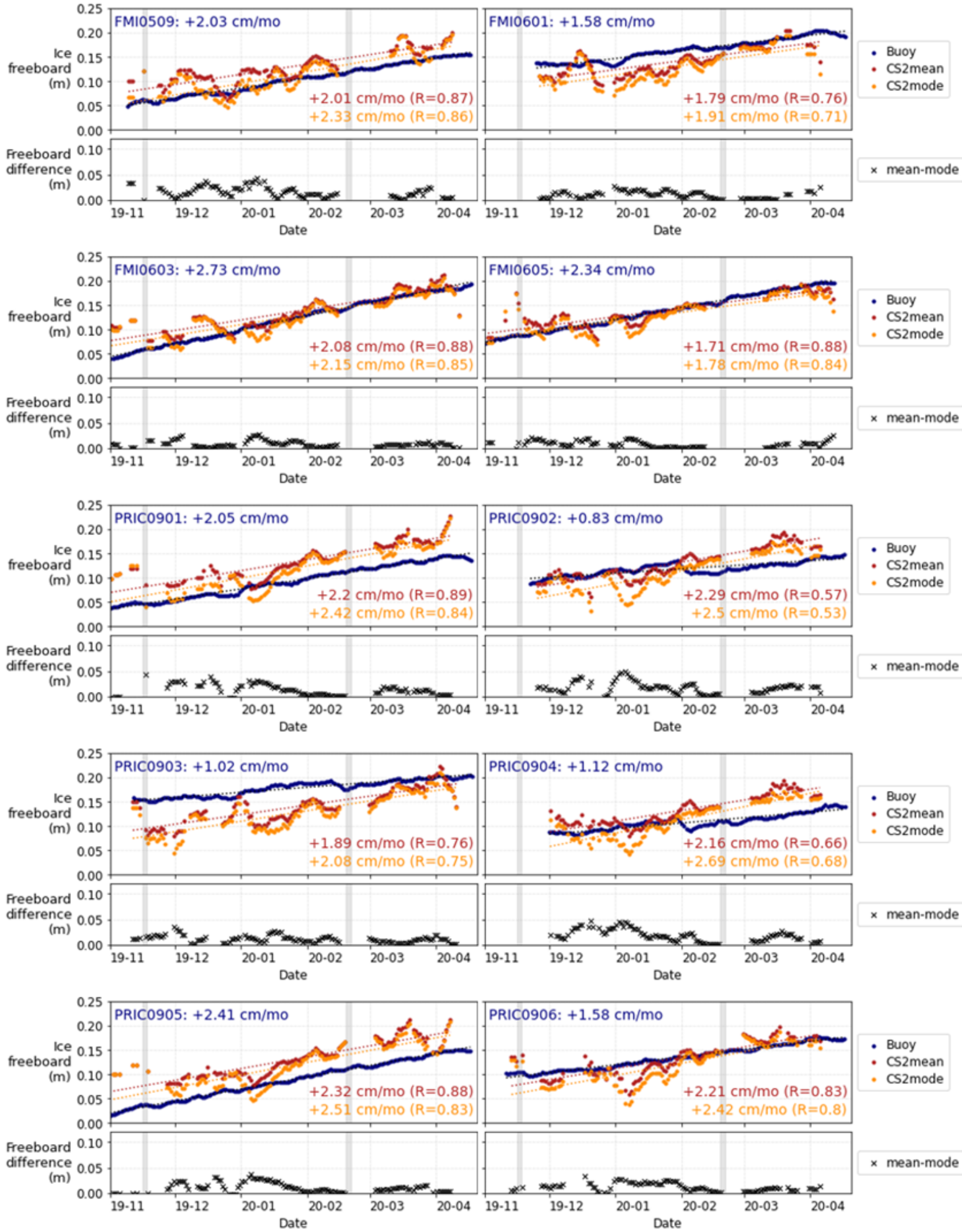
**Buoy measurement of ice freeboard**

- Thermodynamic freeboard variations




**CryoSat-2 measurement of ice freeboard**

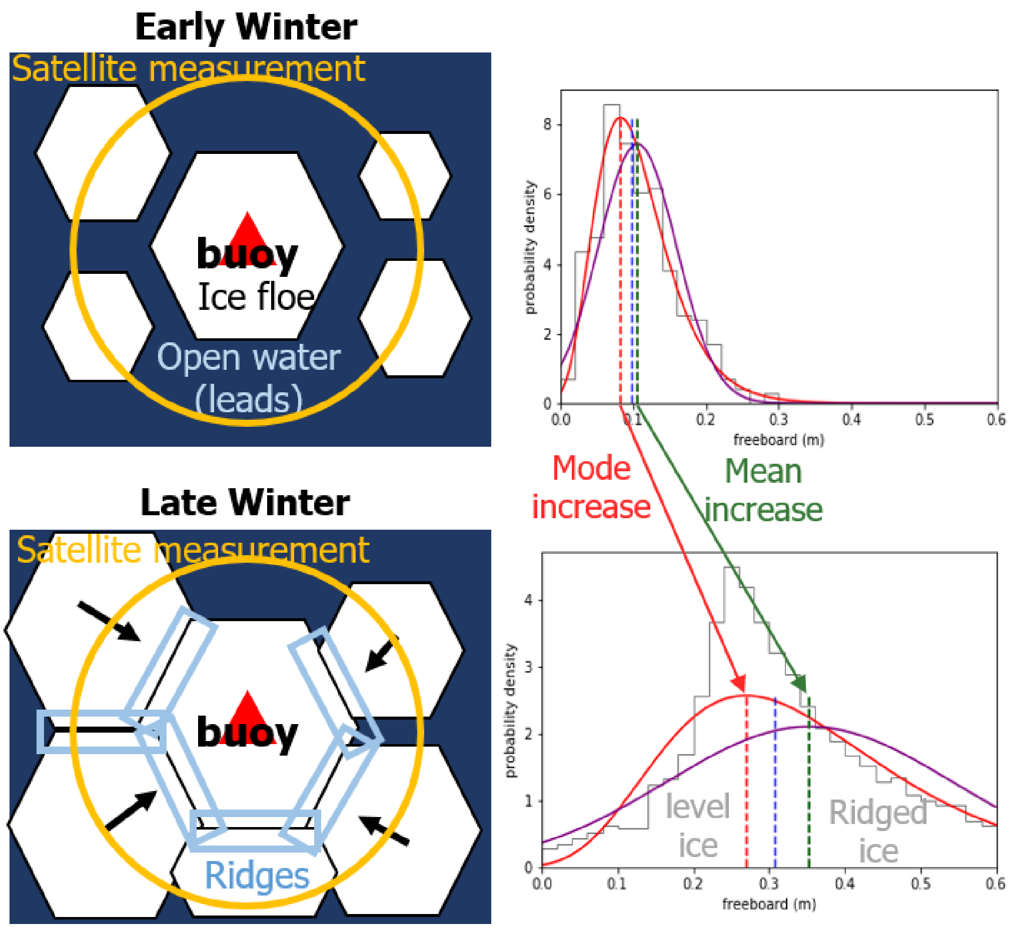
| Ice freeboard | SIMBA | CS2 mean | CS2 mode |
|---|---|---|---|
| Increase rates (cm/month) | 1.70 | 2.07 | 2.28 |
| Difference with buoy | - | +0.37 | +0.58 |




- 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 difficult 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**

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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.