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Understanding the behavior of altimetric measurements of Laser and Ku-band over sea-ice

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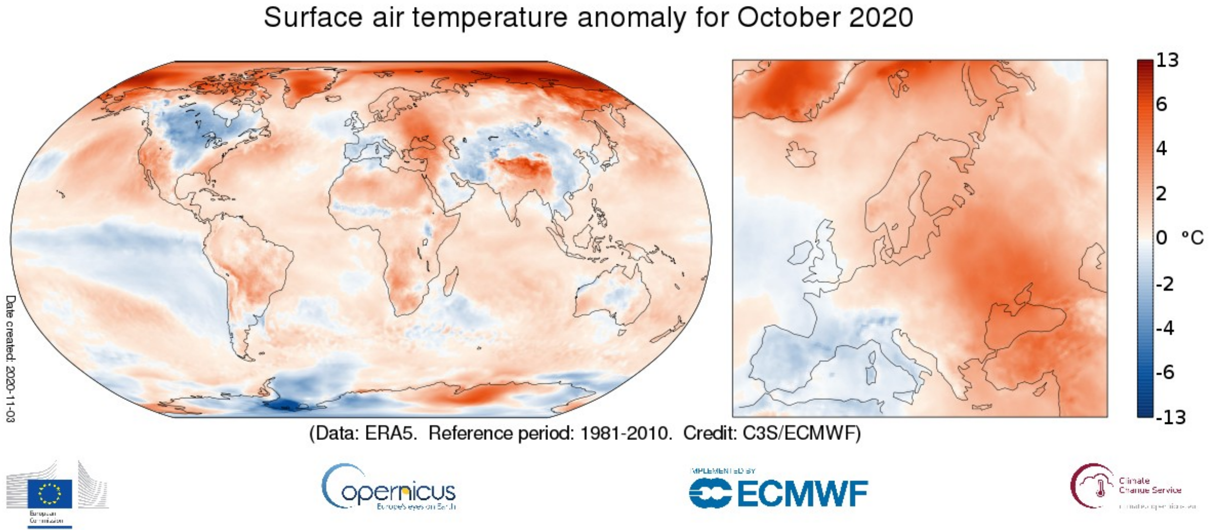
Introduction : Sea ice thickness

Why do we observe the sea ice thickness ?

1. It is the first witness and actor of global warming



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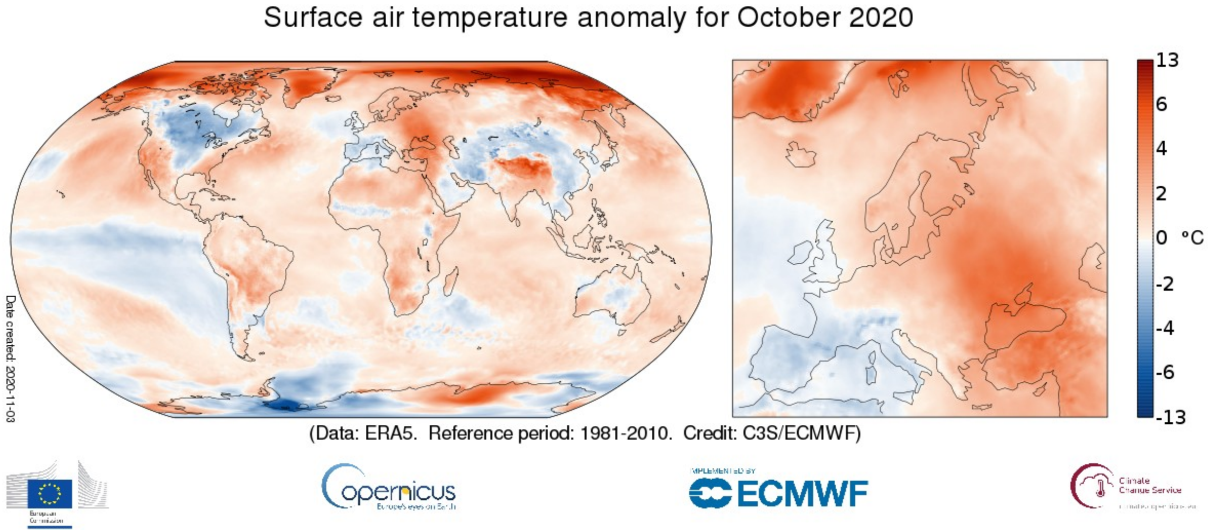

2. To understand the sea ice dynamics

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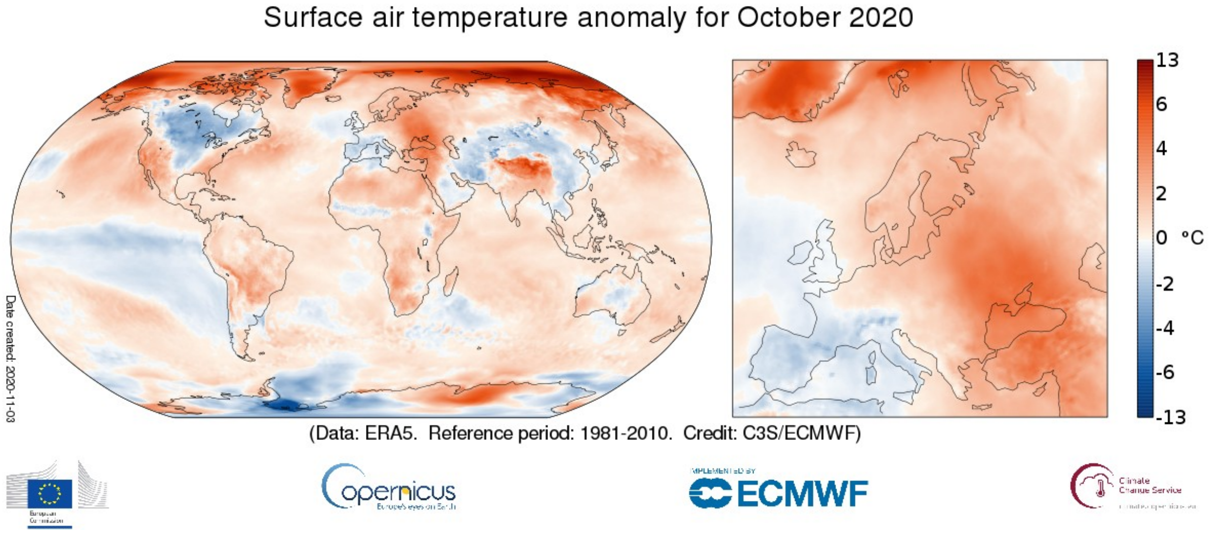
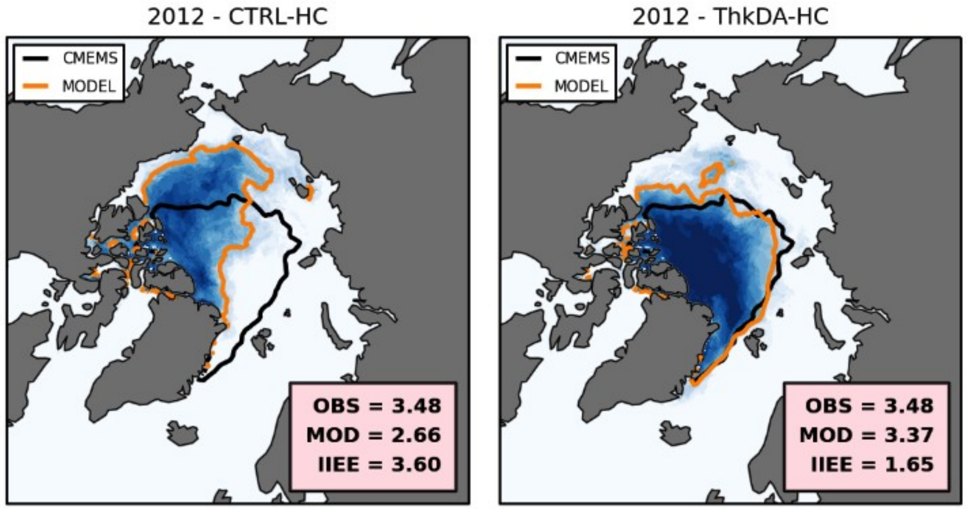


2. To understand the sea ice dynamics

3. To realise better projections taking into account thickness

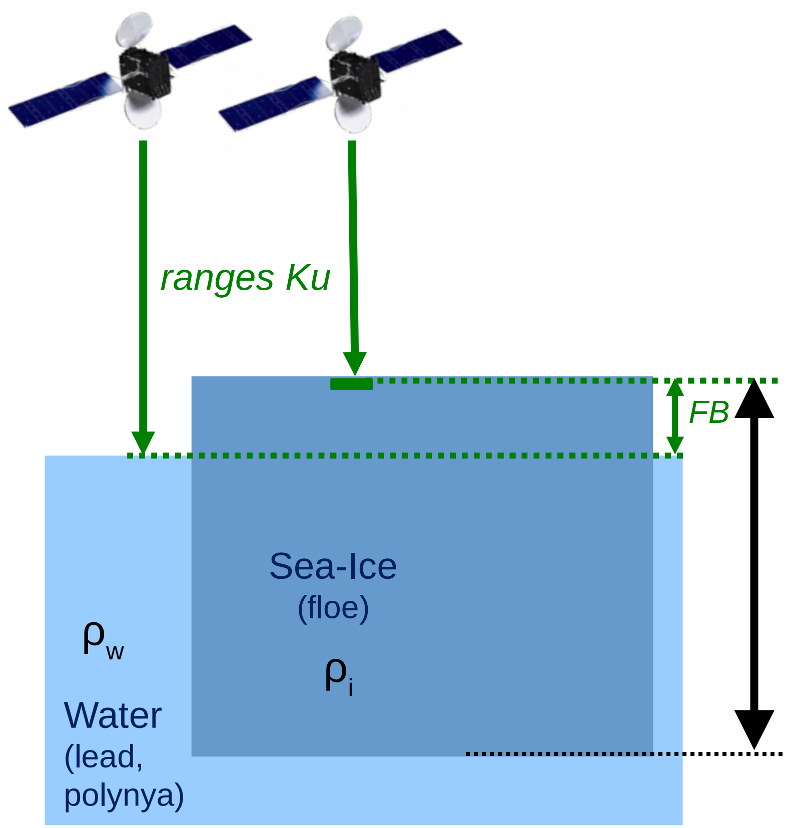
What was actually observed — 4-month forecast from observations



Blockley and Peterson, 2018

Introduction : Observation by altimetry

How do we observe the sea ice thickness by altimetry ?

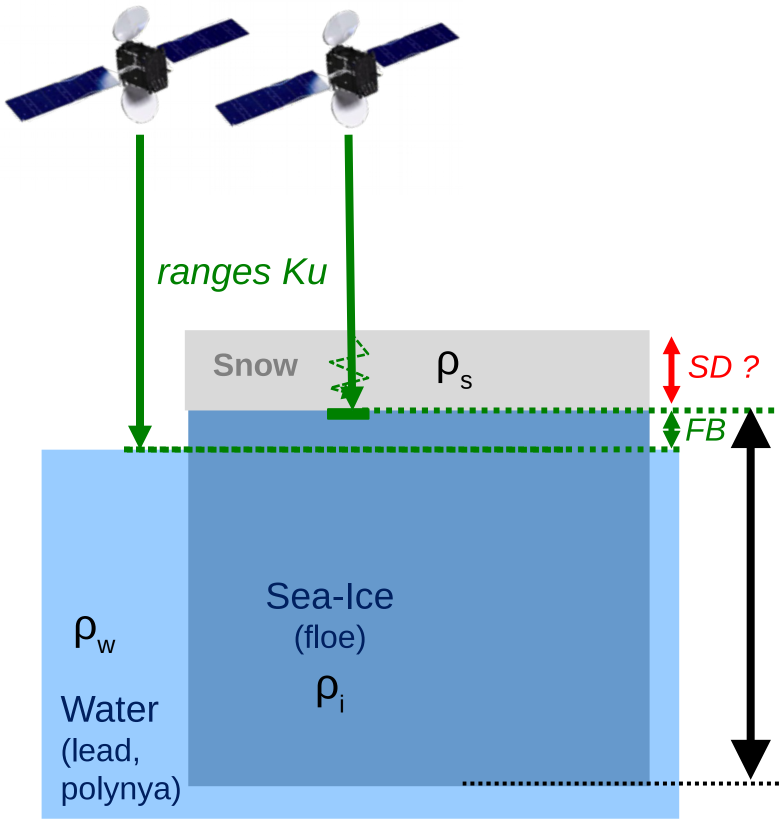


FB: FreeBoard

SIT: Sea Ice Thickness

$$SIT = \frac{\rho_w}{\rho_w - \rho_i} FB$$

Introduction : Observation by altimetry



FB: FreeBoard

SIT: Sea Ice Thickness

SD: Snow Depth

→ Key geophysical variable

$$SIT = \frac{\rho_w}{\rho_w - \rho_i} FB + \frac{(1-c_s/c)\rho_w + \rho_s}{\rho_w - \rho_i} SD$$

Mallett et al., 2020

Introduction

ERS1

ERS2

Envisat

CryoSat-2

SARAL

Introduction

ERS1

ERS2

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SARAL

- 10 years of service
- Capabilities to observe sea ice thickness

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ERS1

ERS2

Envisat

CryoSat-2

SARAL

- 10 years of service
- Capabilities to observe sea ice thickness

What are the effects of ice roughness in the footprint ?

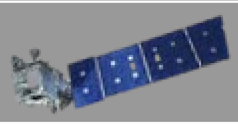
What is the Ku frequency penetration level in the snow cover ?

Methodology: CRYO2ICE project

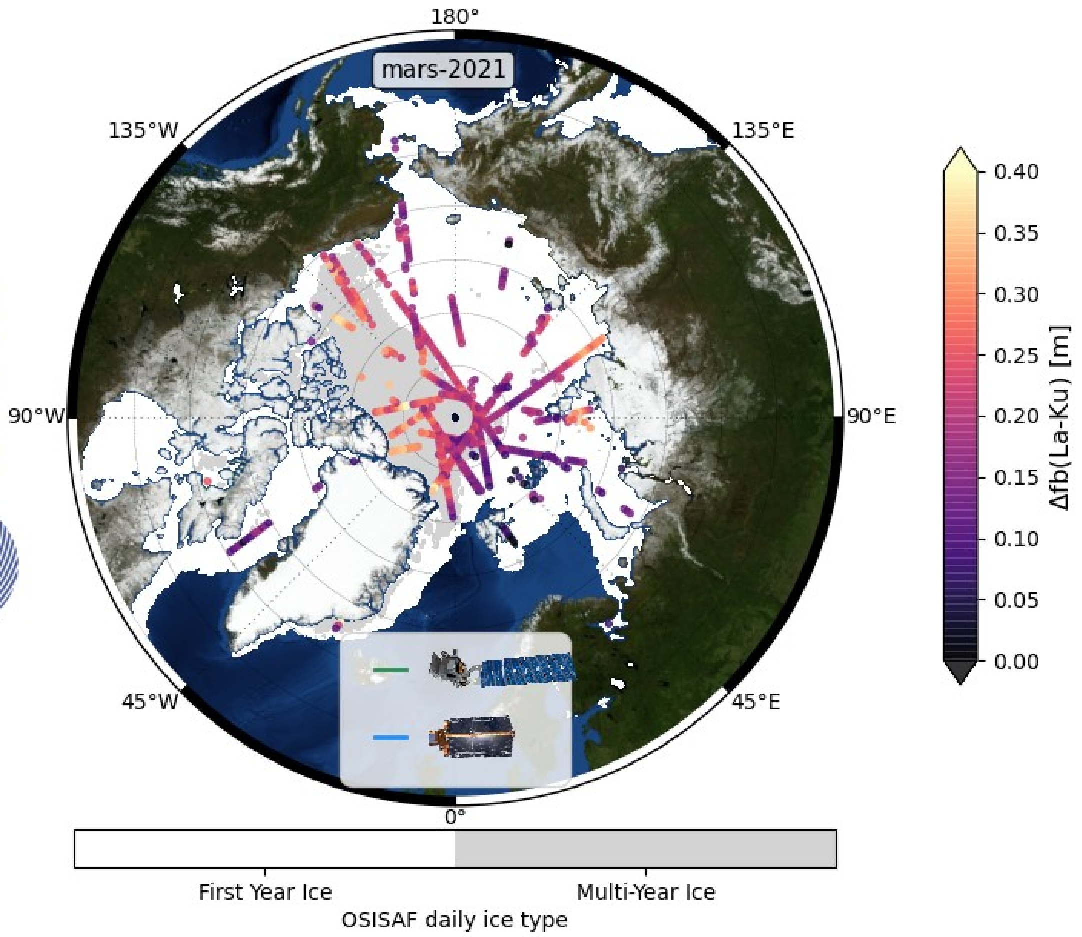
On July the 16th 2020, CryoSat-2's orbit was raised in order to periodically align ICESat-2 orbits over the Arctic ocean every 20/19 orbits (IS2/CS2).

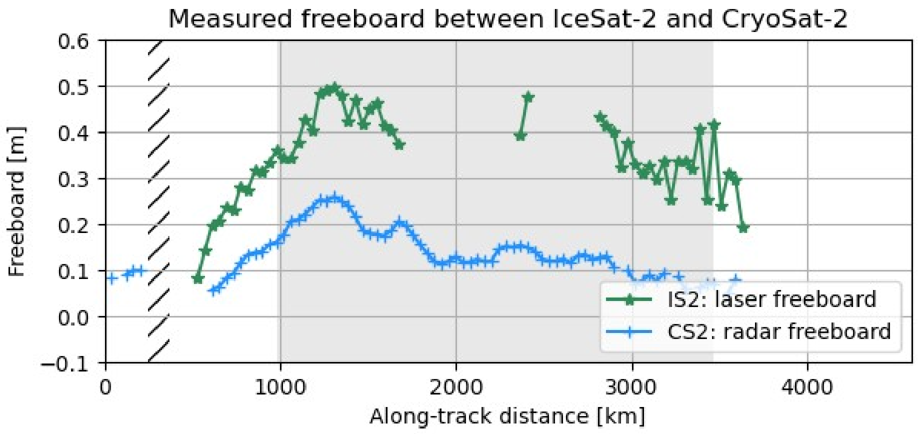
- 20 tracks of coincidental measurements per month
- With a 2-3 hours delay
- Thousands of kilometers transects

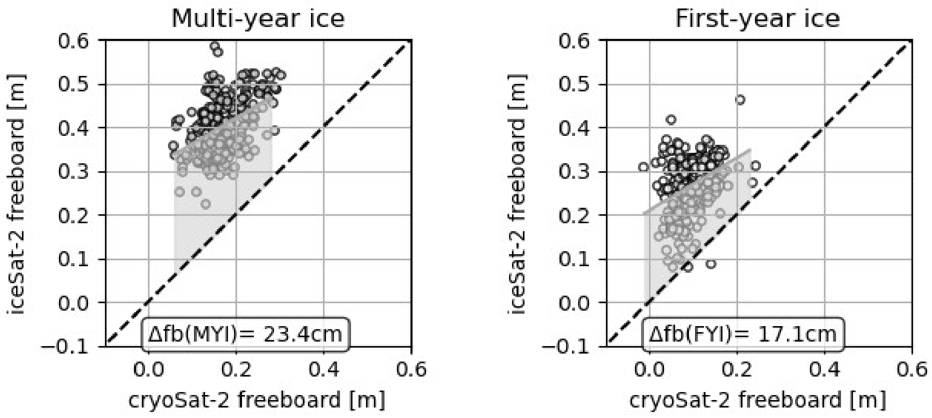
✔ Monitoring same surface (same sea-ice conditions)
✔ Enabling direct comparison of Laser vs Ku-band
✔ Evaluate the characteristics of each sensor

Missions		Launched	Expected end	Main Payload
CryoSat-2		April 2010	2023-2025 (15y)	Ku-band SAR (SIRAL)
IceSat-2		Sept 2018	2023 (3-5y)	6 beams LIDAR (ATLAS)

Results: CRYO2ICE project

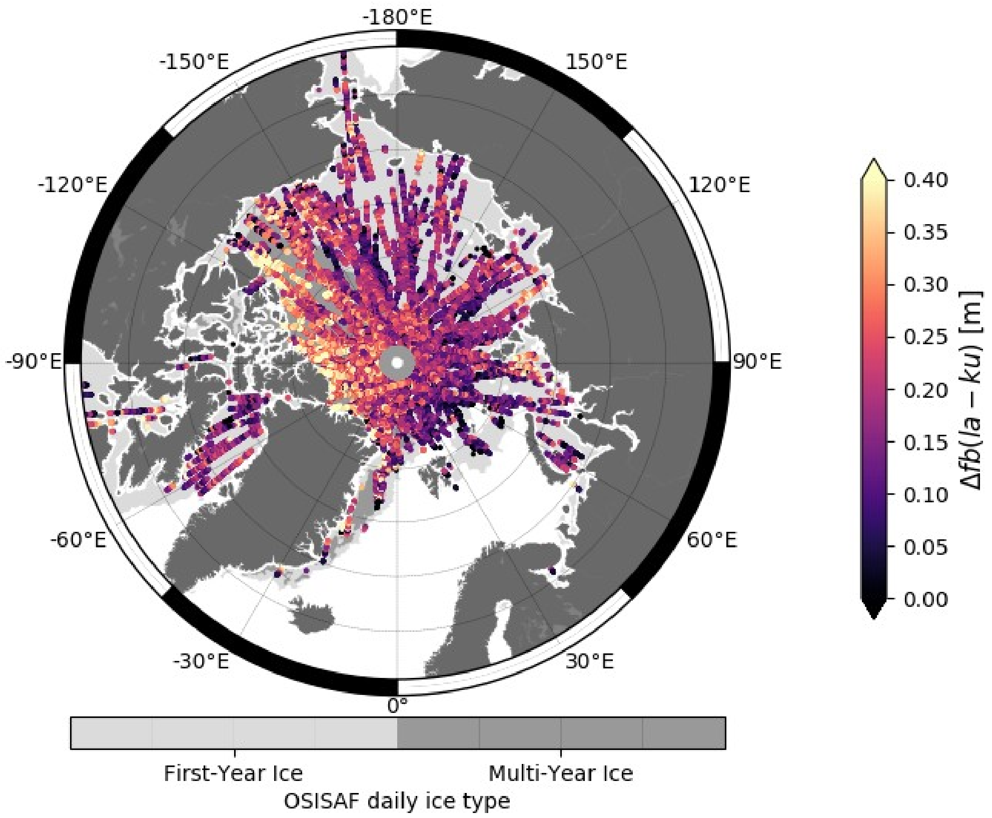


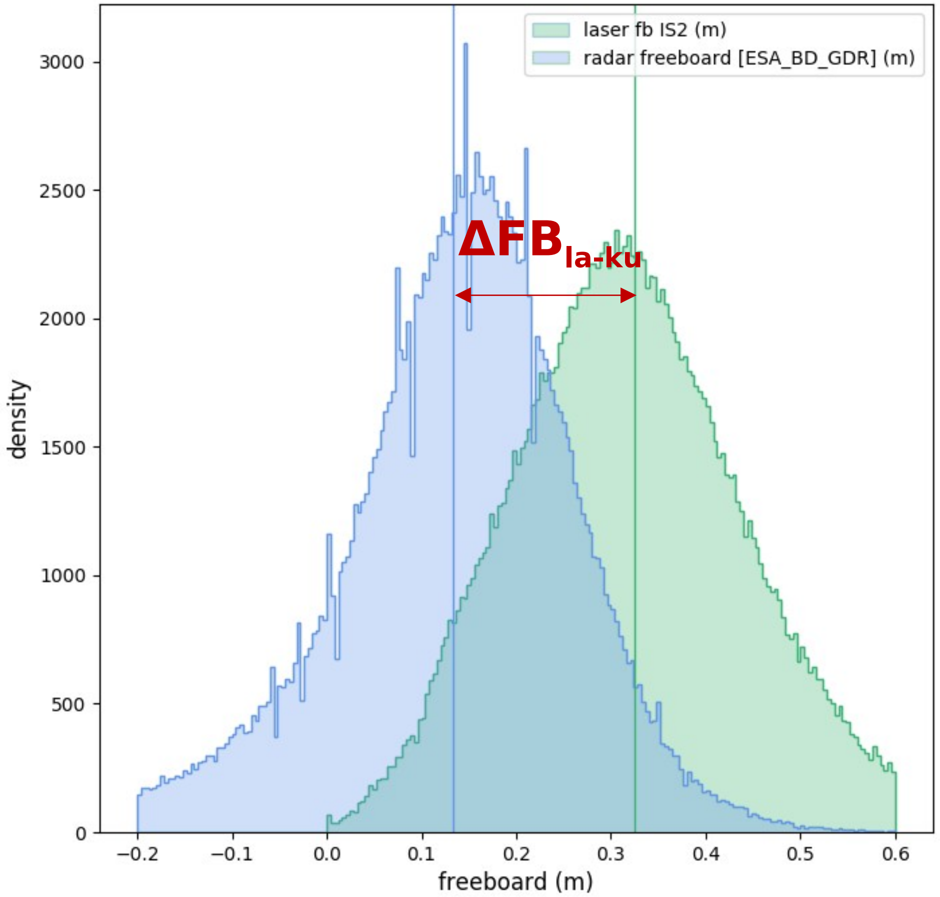




Results: CRYO2ICE project

7 months (Oct 20 – April 21) of CRYO2ICE winter collocated tracks





Interpretation of the signal

How can we interprete this $\Delta FB_{la\text{-}ku}$ signal ?

Is it:

- **Snow depth?**

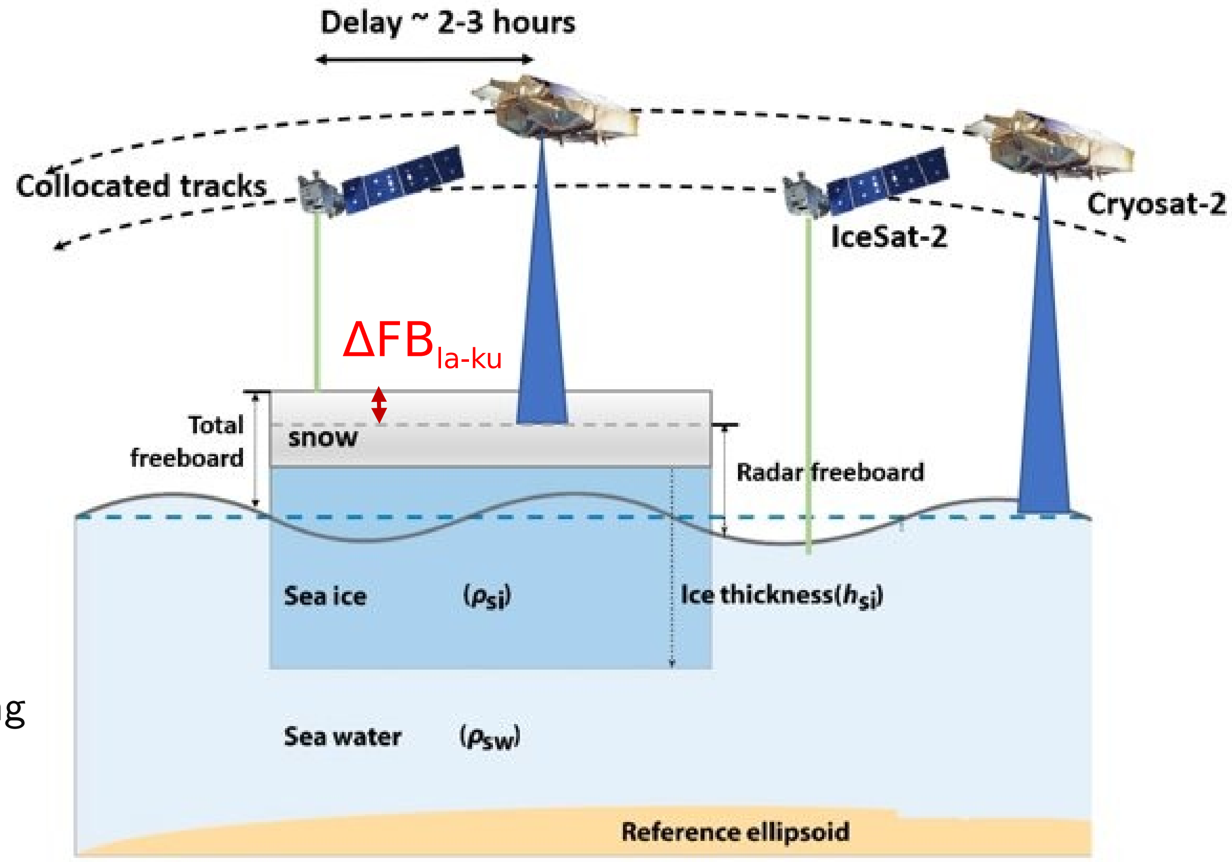
Assuming full penetration of Ku-band radar

- ❑ Penetration depends on snow properties (brines.. etc) (*Nandan et al, 2020*)

- **Surface roughness?**

A sea-state like bias height difference due to the effect of roughness on CS2 large footprint

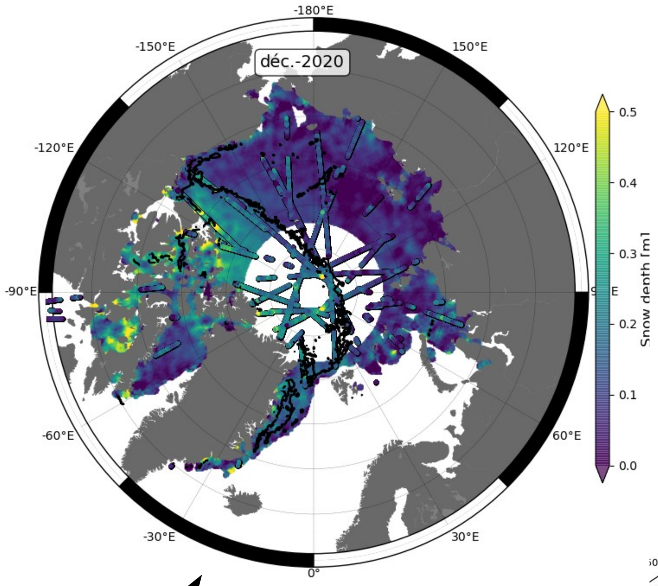
- ❑ KaKu ground altimeter shows a dominant scattering from the surface in ku-band (*Willatt et al, 2021*)



--> Most likely a mixture of both !

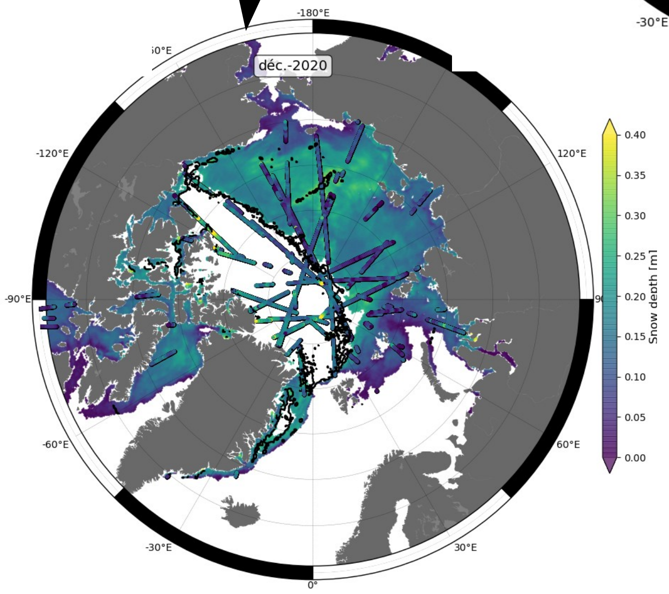
Hypothesis 1: Ku-band penetrates all the way to the snow-ice interface

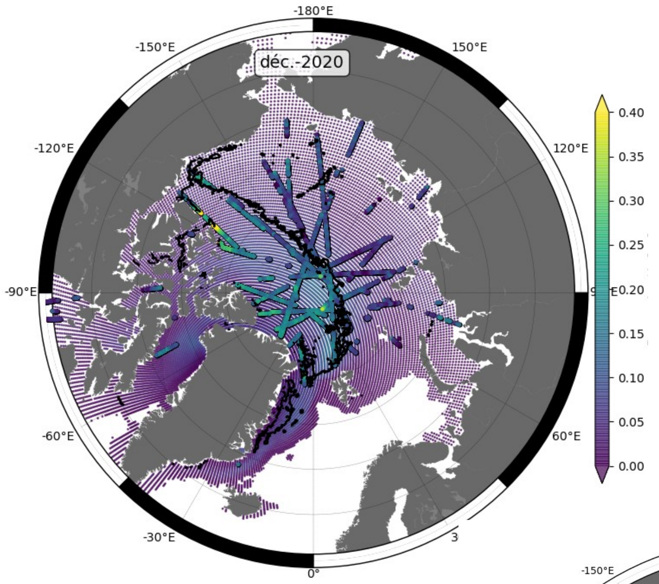
Interpretation: comparison to other snow products



ASD (monthly)
Ka (Saral) -
Ku (CryoSat-2 –pLRM)
(Garnier et al, 2021)

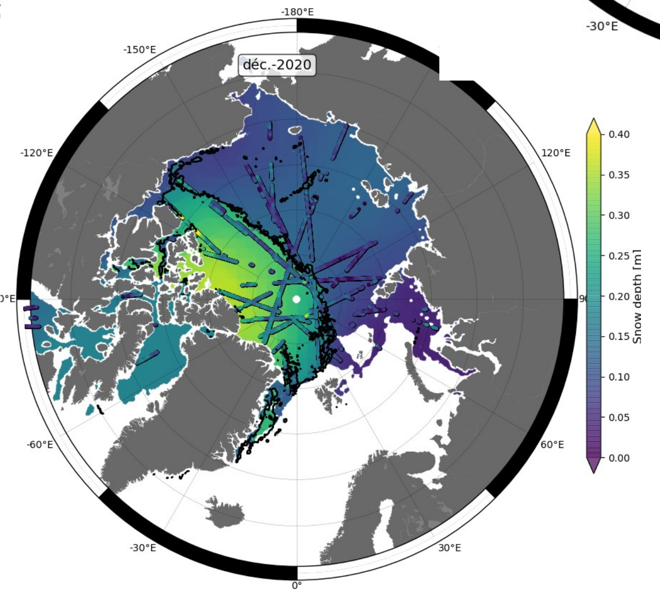
AMSR (daily)
*NSIDC microwave product (*Markus et al. 2018*)*

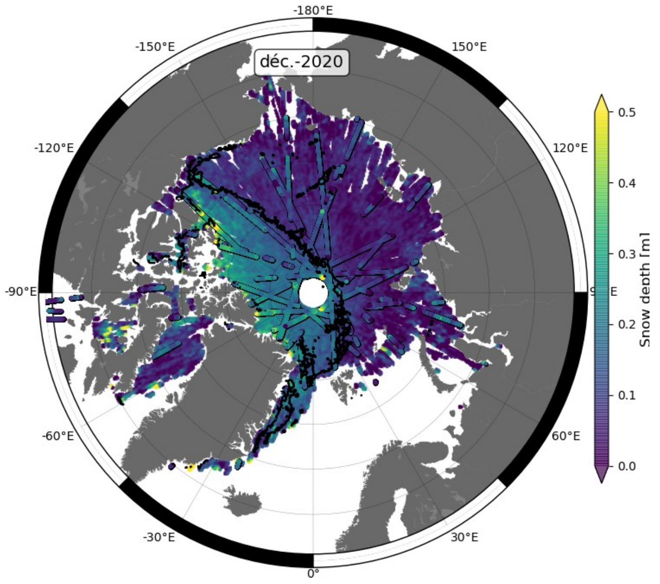




PIOMAS
(monthly)
UW assimilated model
(Zhang et al. 2003*)*

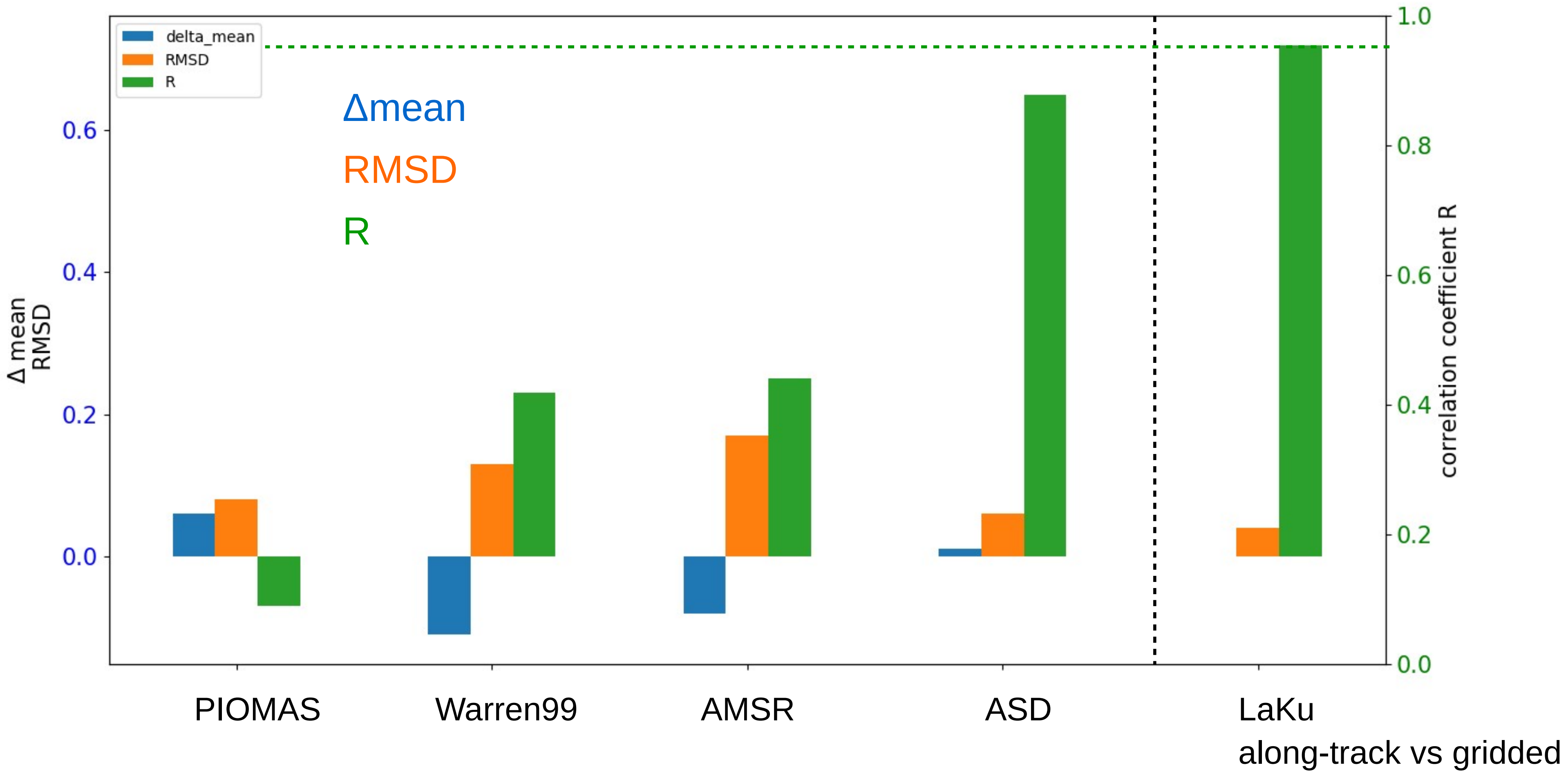
W99m
(monthly)
Modified Warren climatology (Warren et al. 1999*)*





LaKu (monthly)
La (IceSat-2) -
Ku (CryoSat-2)

Interpretation: comparison to other snow products



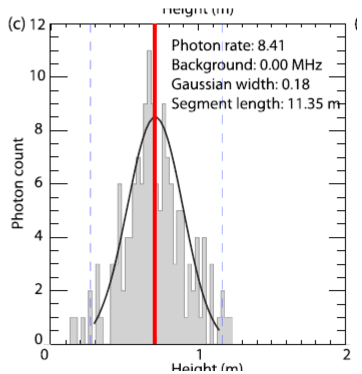
Best correlation with ASD (KaKu, Garnier et al., 2021)

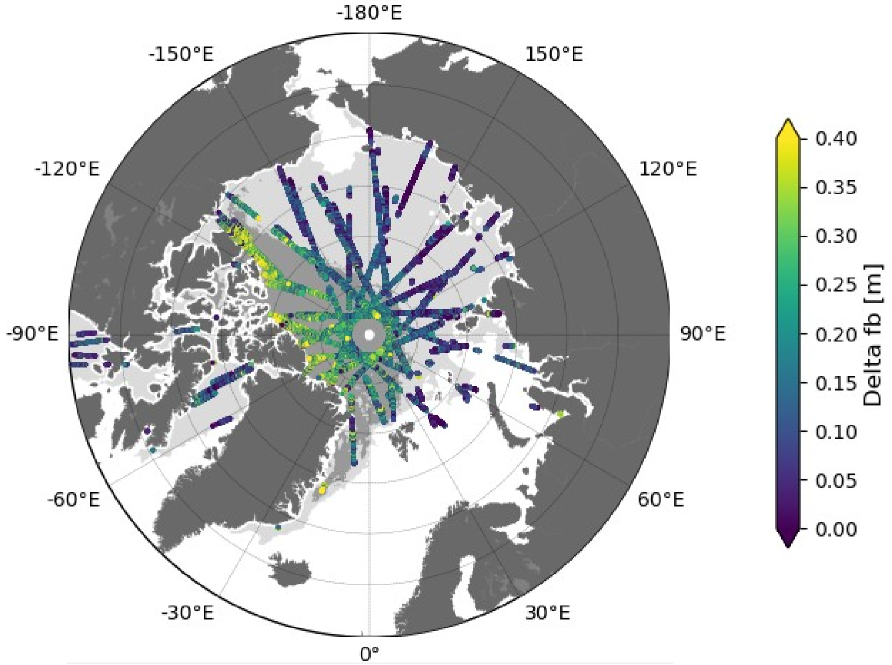
Interpretation: comparison to surface roughness

Hypothesis 2: Surface roughness has an impact on the measures

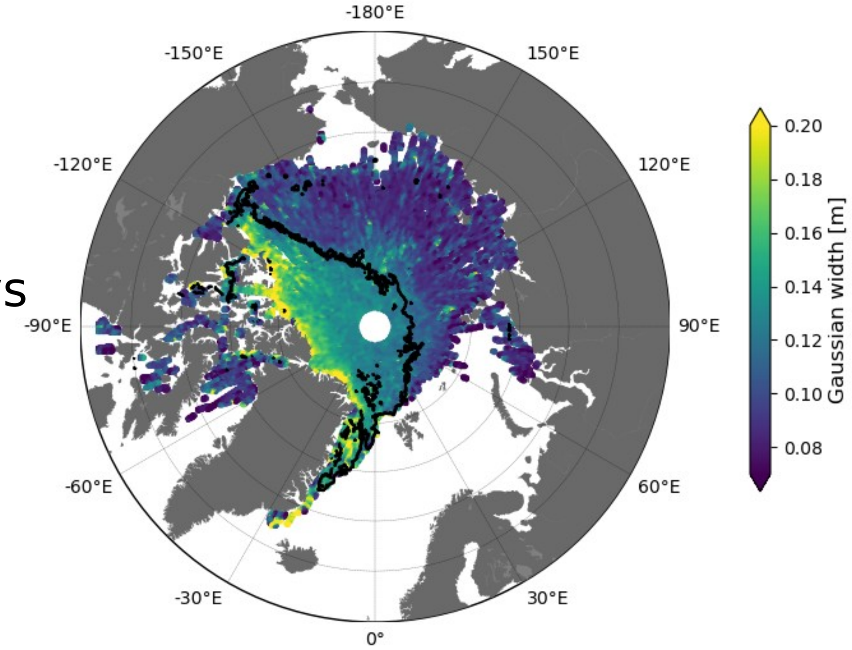
The Gaussian width is the best Gaussian fit of 150 photon aggregates distribution

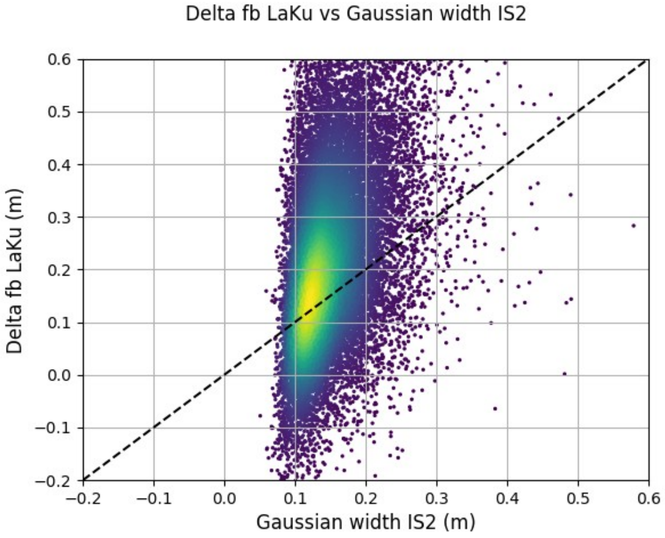
"The Gaussian width parameter provides a measure of the surface roughness [...]" Kwok et al. 2020





vs



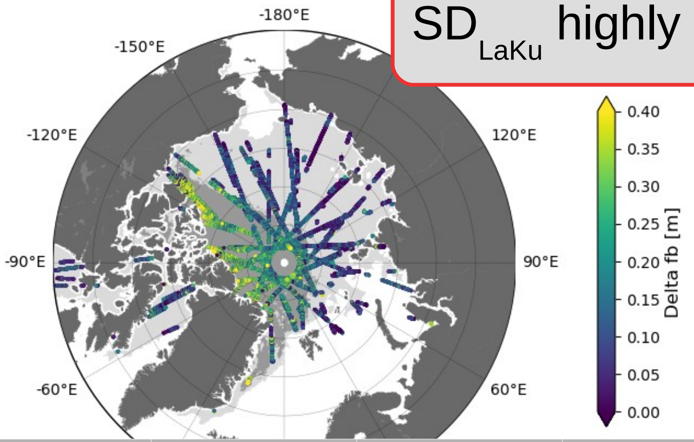


Interpretation: comparison to surface roughness

The Gaussian width is the best Gaussian fit of 150 photon aggregates distribution

"The Gaussian width parameter provides a measure of the surface roughness [...]" Kwok et al. 2020

SD_{LaKu} highly correlated to surface roughness



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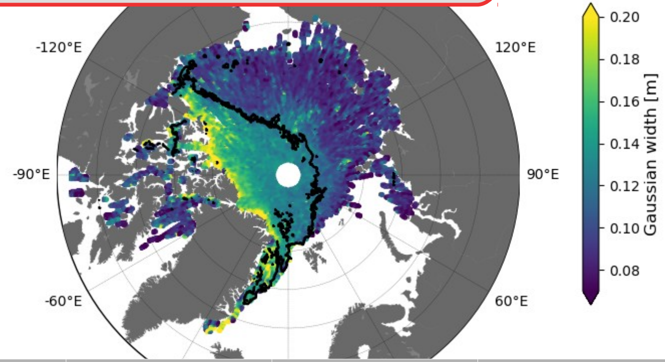
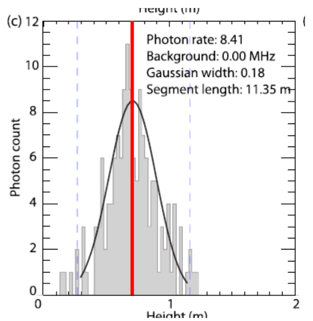
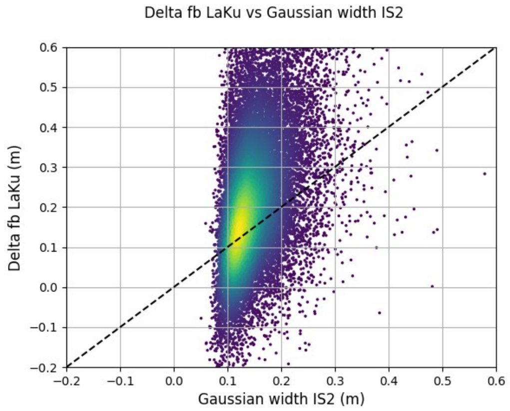






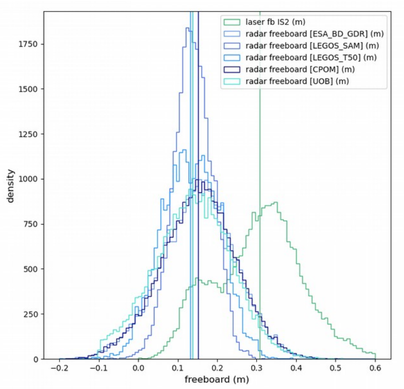
	Oct	Nov	Dec	Jan	Feb	Mar	Apr
R	0.54	0.62	0.57	0.42	0.41	0.46	0.43
R FYI	0.1	0.19	0.32	0.25	0.32	0.39	0.24
R MIY	0.51	0.47	0.45	0.17	0.29	0.33	0.47

Interpretation: impact of the processing

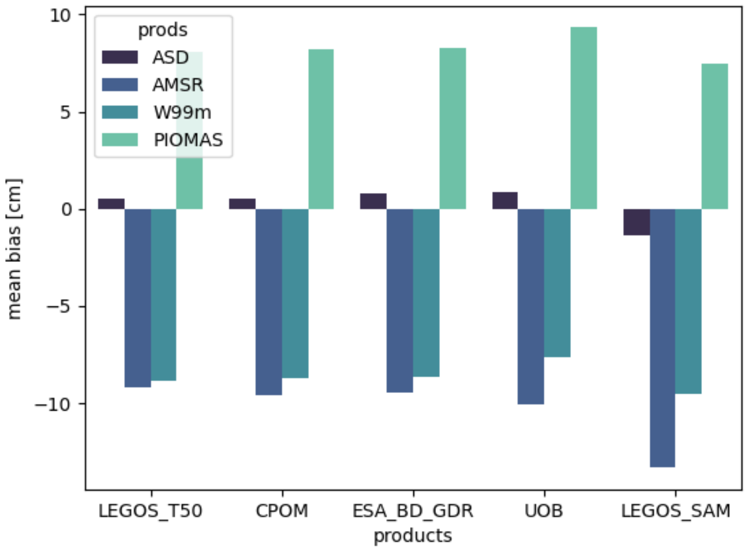
What is the impact of L2 CS2 sea-ice processing ?

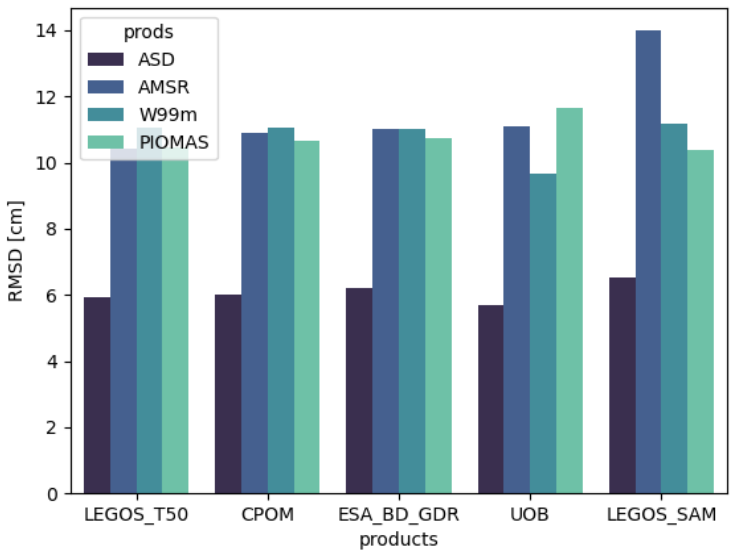
Data collected from various L2 sea-ice processors: ESA Baseline-D, AWI, LEGOS, CPOM, UoB **for collocated tracks**

Product		Retracker	Mean [m]	Std [m]
IS2	ATL10	x	0.31	0.12
CS2	Baseline-D	Emp (floes) - fit (leads)	0.15	0.09
	LEGOS (SAM+)	Phy – SAM+	0.14	0.05
	LEGOS (T50)	Emp – TFMRA50	0.13	0.07
	UOB	Phy - LARM	0.14	0.10
	CPOM	Emp (floes) - fit (leads)	0.15	0.09



SD_{Laku}(CS2 prod) vs SD products





- Limited inter-product variability
- Better match with ASD and UoB

Conclusions

Does the Ku-band radar wave penetrate all the way to the snow-ice interface ?

- The Cryo2Ice project enables to compare coincidental measurements and to provide a snow depth product LaKu

- The $\Delta FB_{la\text{-}ku} \sim 15$ cm depends on :

  - Snow layer properties (*Nandan et al, 2020*): saline snow limits penetration / Better penetration on cold/dry snow

  - Footprint size / Surface roughness

  - L2 CS2 processing

Perspectives

- Investigate the FreeBoard uncertainties
- Airborne observations needed for validation
- Prepare the CRISTAL mission (bi-frequency altimeter)
- Improve the gridding methods

Thanks for your attention