IDEAS-QA4EO Cal/Val workshop #4: Cryosphere Cal/Val

Satellite-based altimetry for Sea Ice monitoring

01/03/23

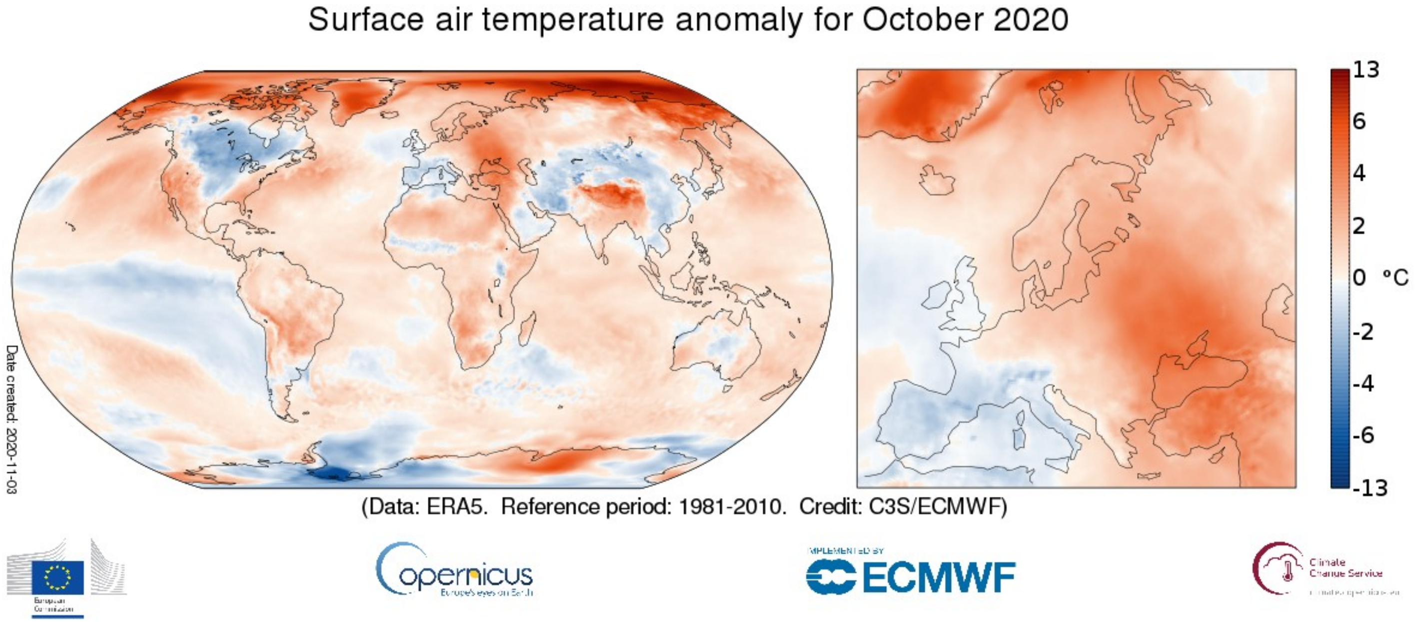
Alice Carret

sea ice observation issues

Context

Why do we observe the sea ice thickness ?

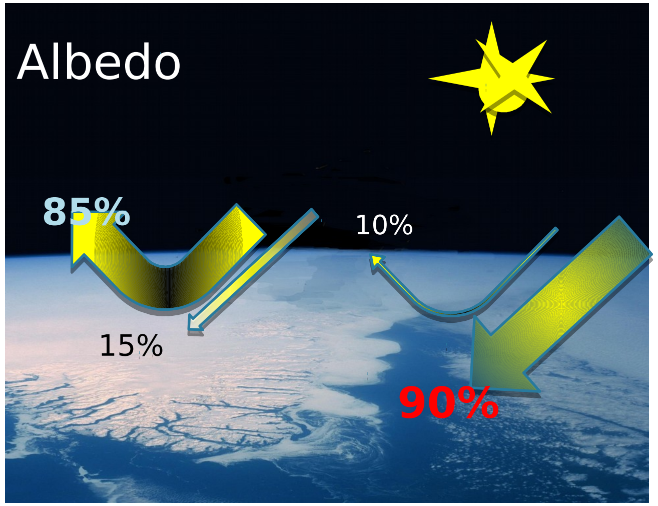
1. It is the first witness and actor of global warming



↘ albedo

⟷

Arctic amplification



Sea ice thickness ⟶ Sea ice extent ⟶ albedo

Context

Why do we observe the thickness of sea ice ?

1. It is the first witness and actor of global warming
2. To understand the sea ice dynamics

Context

Why do we observe the thickness of sea ice ?

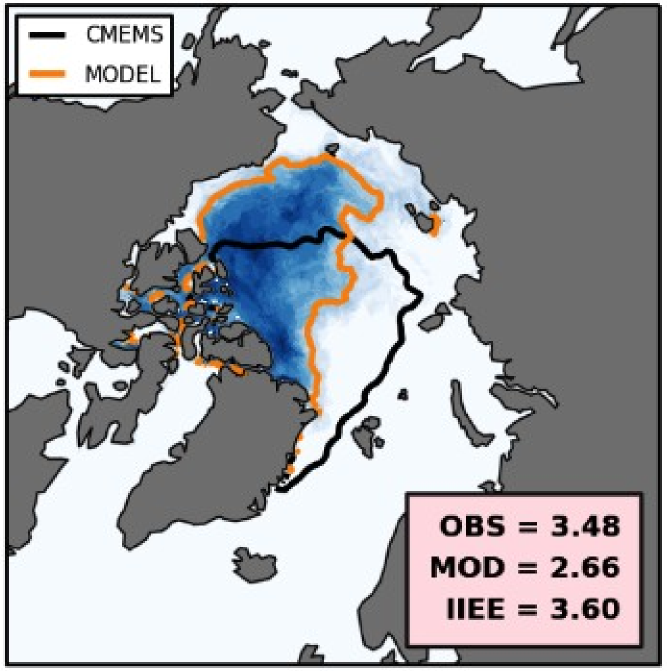
1. It is the first witness and actor of global warming
2. To understand the sea ice dynamics
3. To realise better projections taking into account thickness

Sea ice extent

— 4-month forecast from observations (concentrations)

— What was actually observed

2012 - CTRL-HC



September mean

Blockley and Peterson, 2018

Context

Why do we observe the thickness of sea ice ?

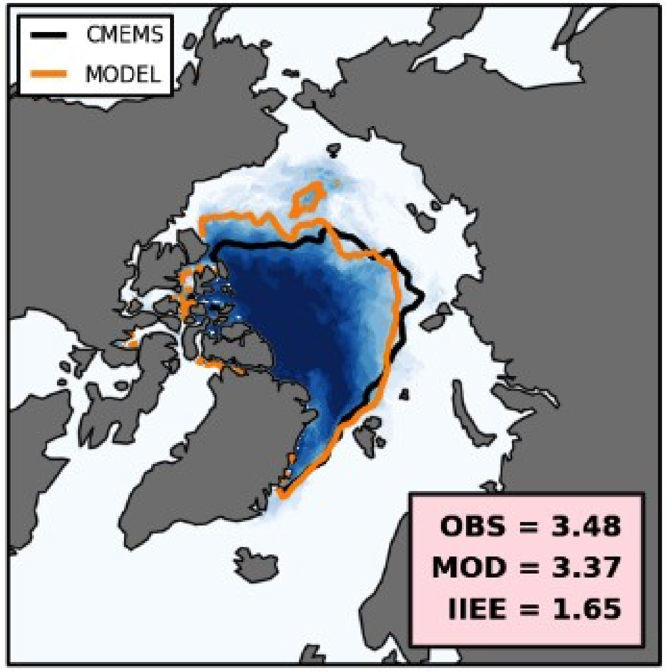
1. It is the first witness and actor of global warming
2. To understand the sea ice dynamics
3. To realise better projections taking into account thickness

Sea ice extent

— 4-month forecast from observations (thickness)

— What was actually observed

2012 - ThkDA-HC



September mean

Blockley and Peterson, 2018

Context

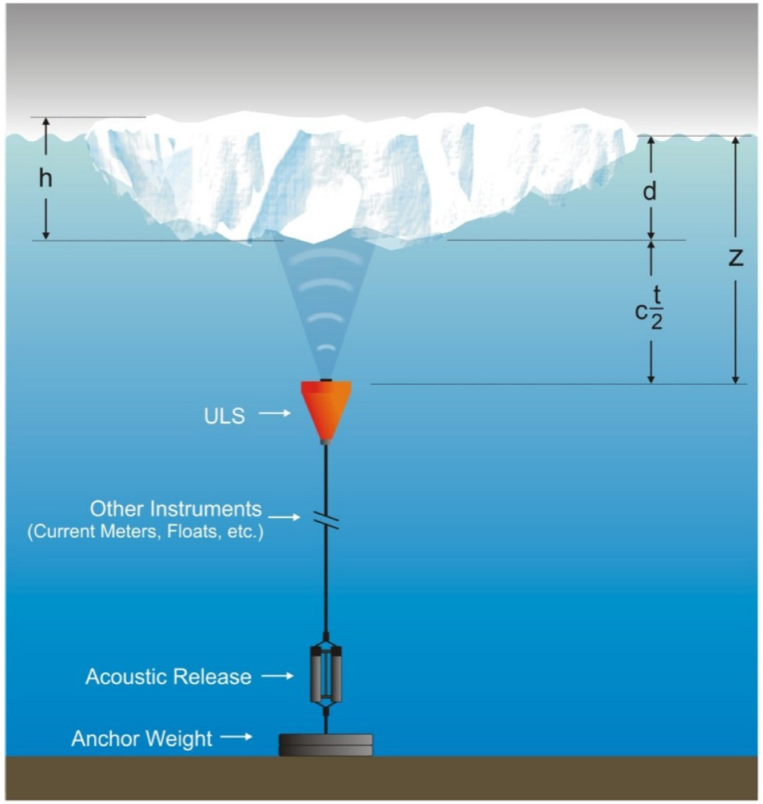
How do we observe the thickness of sea ice ?

Local scale

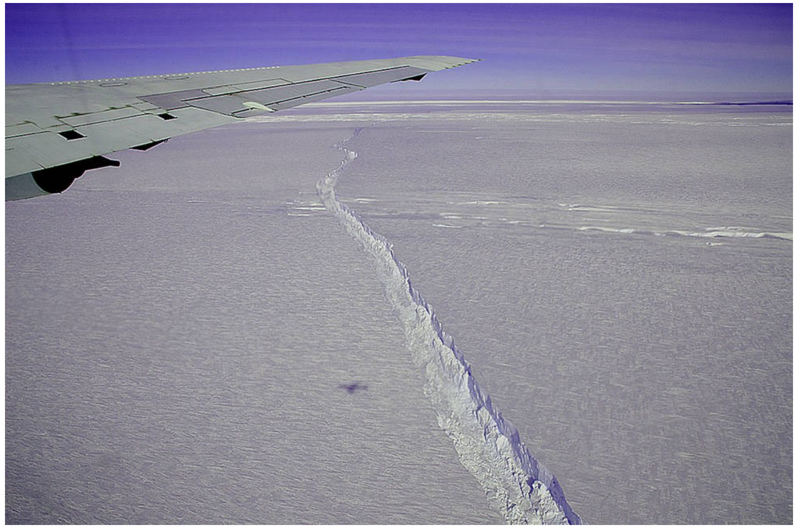
Buoys

Field measurements

Moorings



Airborne observations
(OIB, CryoVEx)



Context

How do we observe the thickness of sea ice ?

Global scale

Passive microwave radiometer

SMOS

Altimetry

CryoSat-2

Context

How do we observe the thickness of sea ice ?

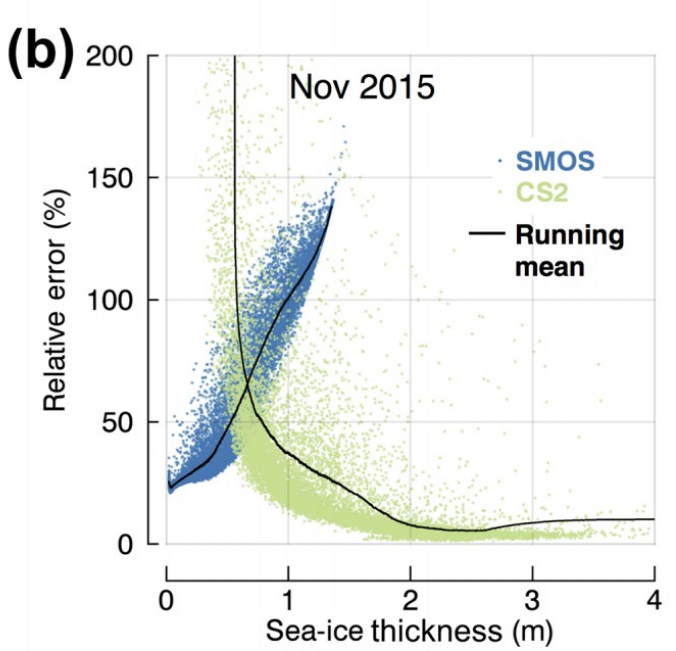
Global scale

Passive microwave radiometer

SMOS

No sensitivity over thick ice

Complementarity between the methods



Ricker et al., 2017

Altimetry

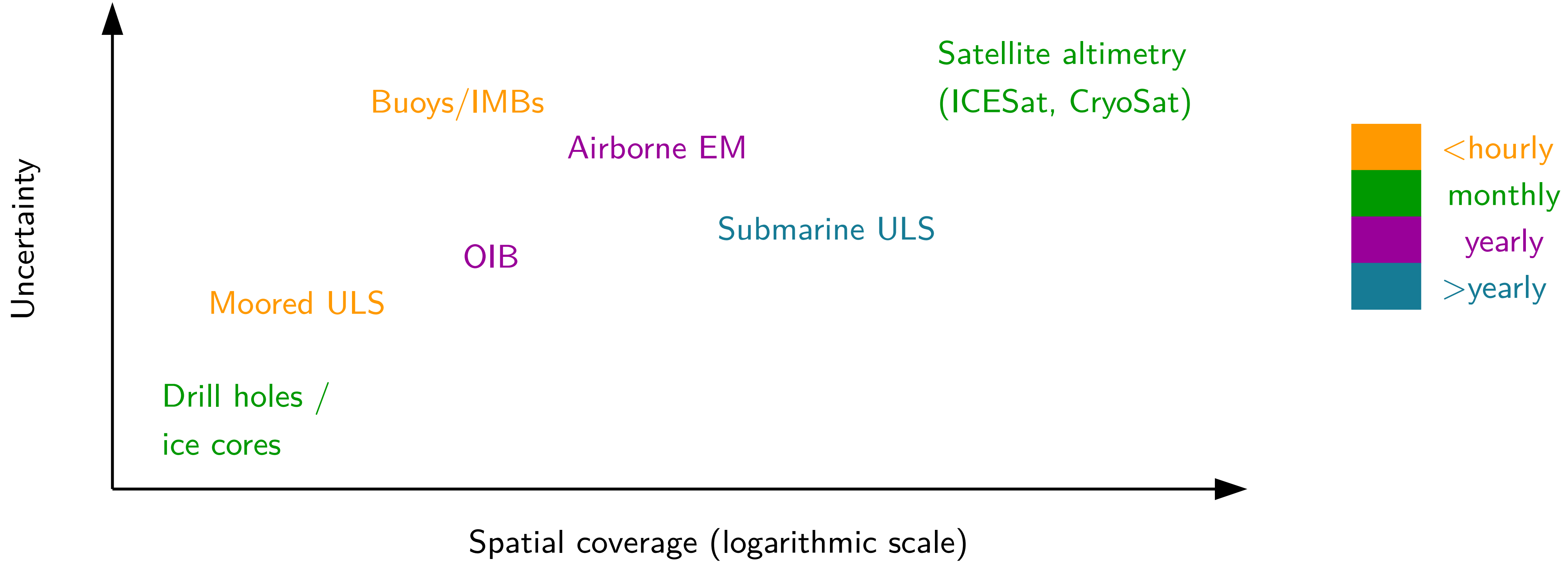
CryoSat-2

Large uncertainties over thin ice

Context

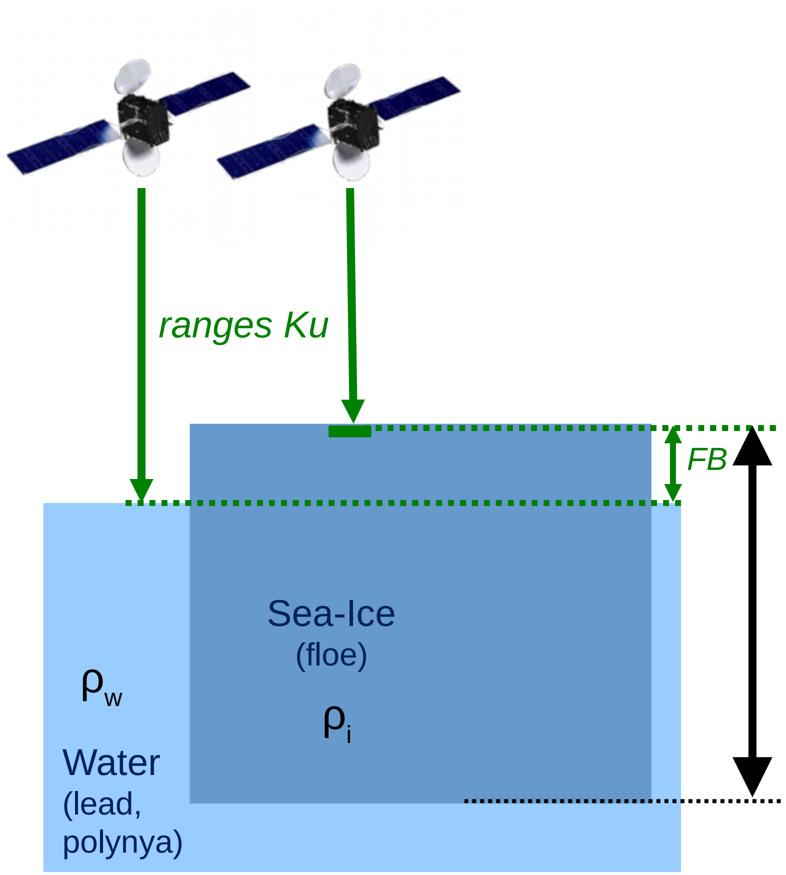
How do we observe the thickness of sea ice ?

Advantages and drawbacks of all instruments → Need all the scales !



Context

Measurement of sea ice thickness by altimetry



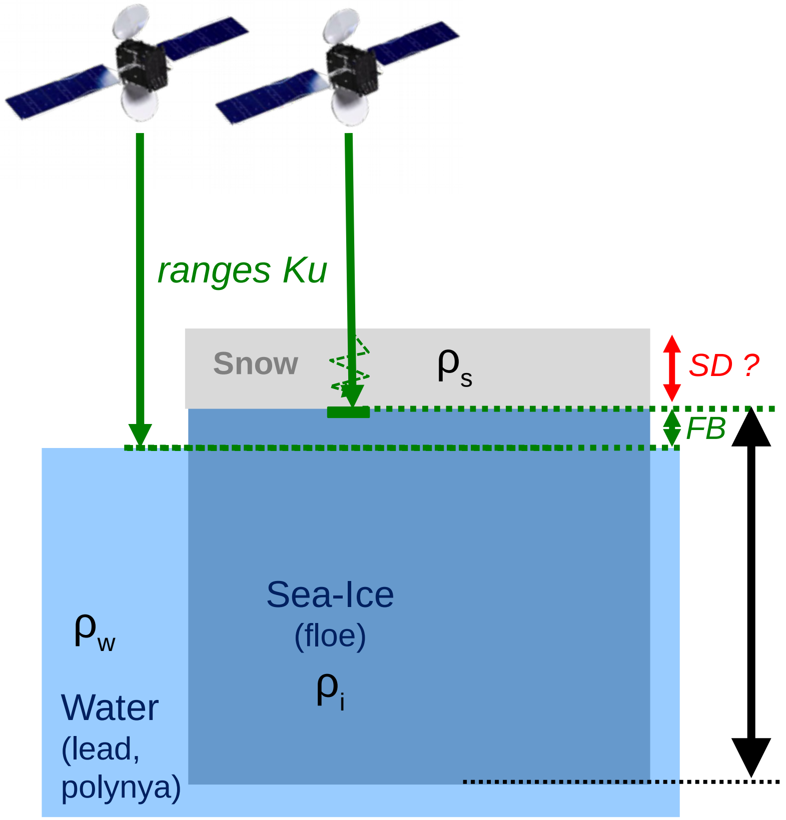
$$SIT = \frac{\rho_w}{\rho_w - \rho_i} FB$$

FB: FreeBoard

SIT: Sea Ice Thickness

Context

Measurement of sea ice thickness by altimetry



FB: FreeBoard

SIT: Sea Ice Thickness

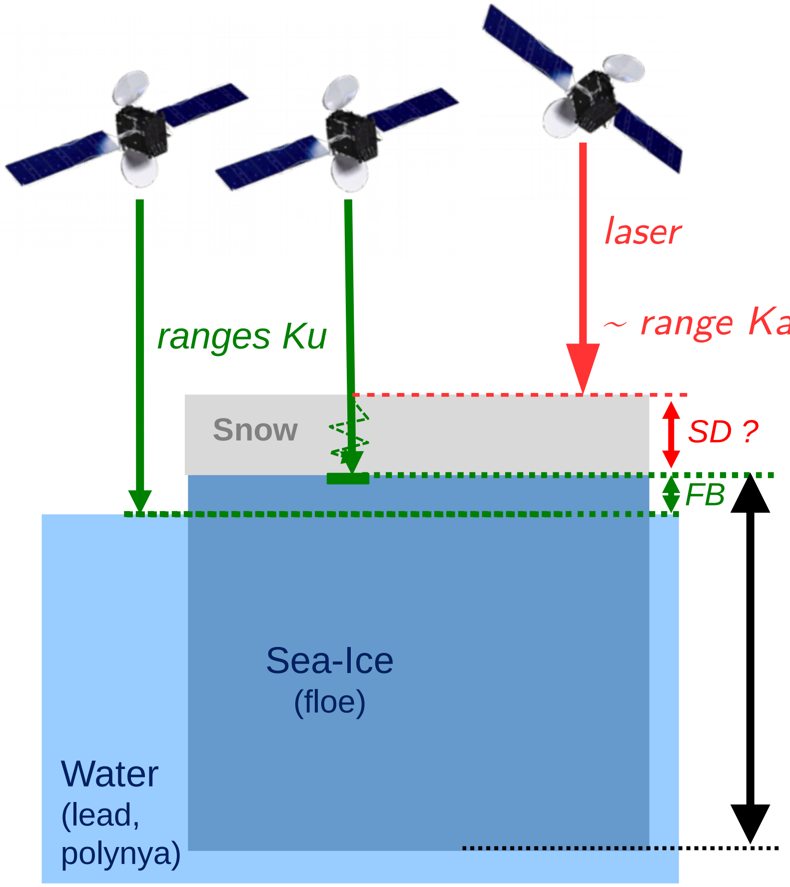
SD: Snow Depth

→ Key geophysical variable

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

Context

Measurement of sea ice thickness by altimetry



FB: FreeBoard

SIT: Sea Ice Thickness

SD: Snow Depth

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

SD = range_Ku - laser

Need to know the snow depth !

Context

Uncertainties in sea ice thickness estimation

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

Error propagation equation

$$\varepsilon^2_{SIT} = \varepsilon^2_{FBku}\left[\frac{\rho_w}{\rho_w - \rho_i}\right]^2 +$$
$$\varepsilon^2_{SD}\left[\frac{\rho_w(1 + 0.00051\,\rho_s)^{1.5} - \rho_w + \rho_s}{\rho_w - \rho_i}\right]^2 +$$
$$\varepsilon^2_{\rho s}\left[\frac{1 + 0.000765\,\rho_w(1 + 0.00051\,\rho_s)^{0.5}}{\rho_w - \rho_i}\,SD\right]^2 +$$
$$\varepsilon^2_{\rho w}\left[-\frac{\rho_i FB_{Ku} + SD\left(\rho_s - \rho_i + \rho_i(1 + 0.00051\,\rho_s)^{1.5}\right)}{(\rho_w - \rho_i)^2}\right]^2 +$$
$$\varepsilon^2_{\rho i}\left[\frac{\rho_w FB_{Ku} + SD\left(\rho_s - \rho_w + \rho_w(1 + 0.00051\,\rho_s)^{1.5}\right)}{(\rho_w - \rho_i)^2}\right]^2$$

Context

Uncertainties in sea ice thickness estimation

$$\varepsilon^2_{SIT} = c^2_{FBku}\varepsilon^2_{FBku} + c^2_{SD}\varepsilon^2_{SD} + c^2_{\rho s}\varepsilon^2_{\rho s} + c^2_{\rho i}\varepsilon^2_{\rho i} + c^2_{\rho w}\varepsilon^2_{\rho w}$$

	FYI				MYI			
	mean	ε	c^2	$c^2\varepsilon^2$	mean	ε	c^2	$c^2\varepsilon^2$
FB (m)	0.10	0.05	91.59	**0.23**	0.20	0.05	52.00	**0.13**
SD (m)	0.15	0.15	24.11	**0.54**	0.35	0.15	13.69	**0.31**
ρ_i (kg/m³)	917	36.0	25.05 10^{-5}	**0.32**	882	23.0	37.15 10^{-5}	**0.20**
ρ_s (kg/m³)	290	3.2	66.50 10^{-7}	**0.00**	290	3.2	20.55 10^{-6}	**0.00**
ρ_w (kg/m³)	1024	0.5	21.23 10^{-5}	**0.00**	1024	0.5	29.93 10^{-5}	**0.00**
ε_{SIT}				1.05				0.80

→ ρ_s and ρ_w uncertainties have negligible effects

FB_{ku}, SD and ρi uncertainties are of some order of magnitude

CRYO2ICE project

CRYO2ICE project: Presentation

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

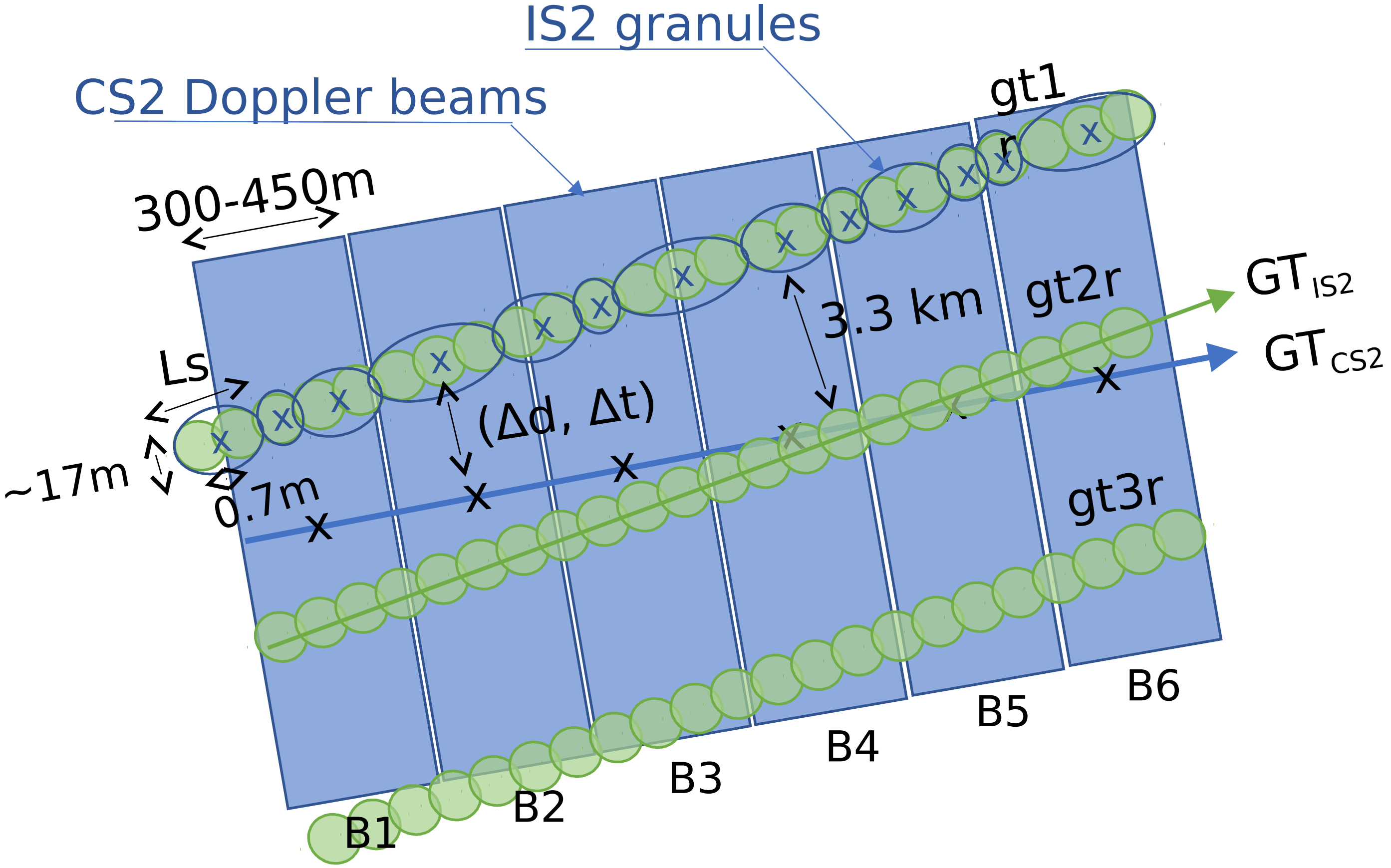
✔ Monitoring same surface (same sea-ice conditions)
✔ Enabling direct comparison of Laser vs Ku-band
✔ Evaluate the characteristics of each sensor

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)

CRYO2ICE project: Method of comparison

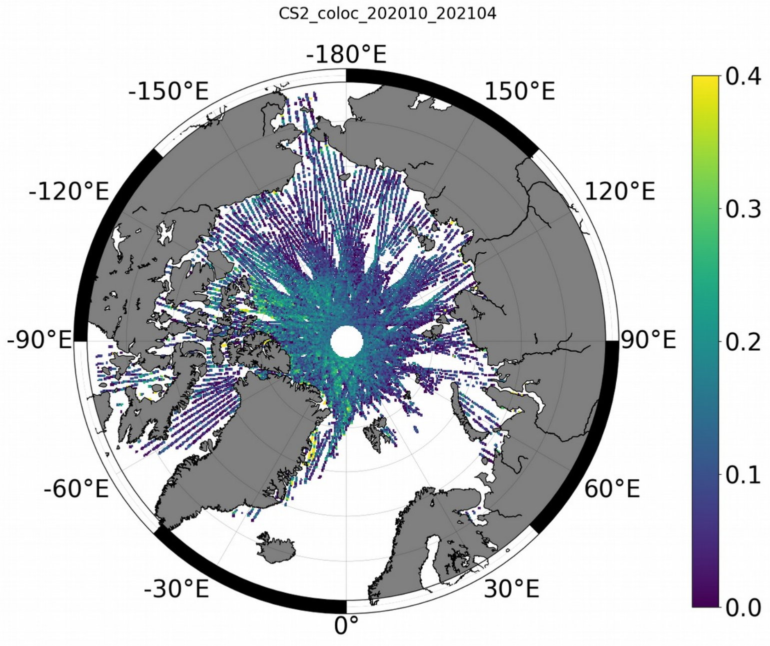
Satellite footprints:

- **CryoSat-2:** 
  - Doppler beam: (300-450)m x 1.5 km
- **IceSat-2:** 
  - Granules: Ls x 17m ,
    Ls ϵ [10m,150m]
  - Swath: 6.6 km x 10 km

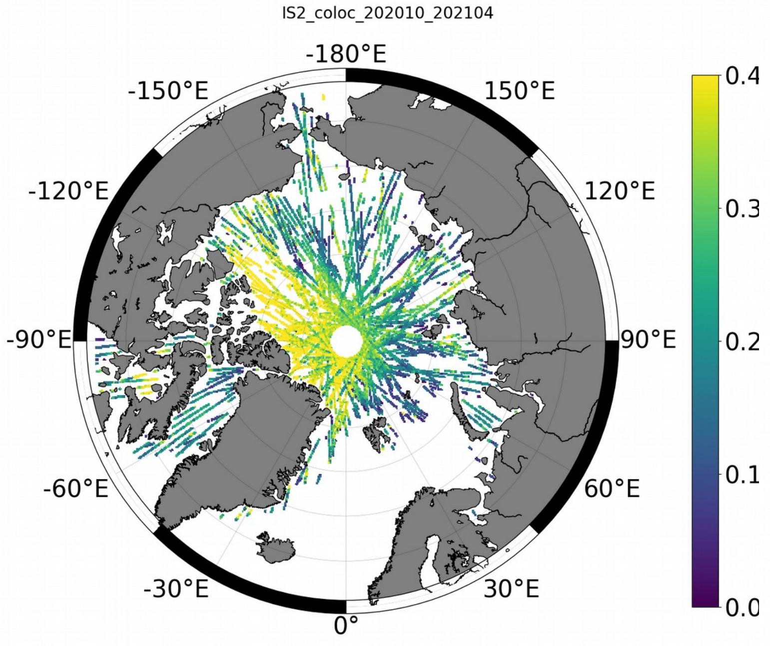


CRYO2ICE project: product

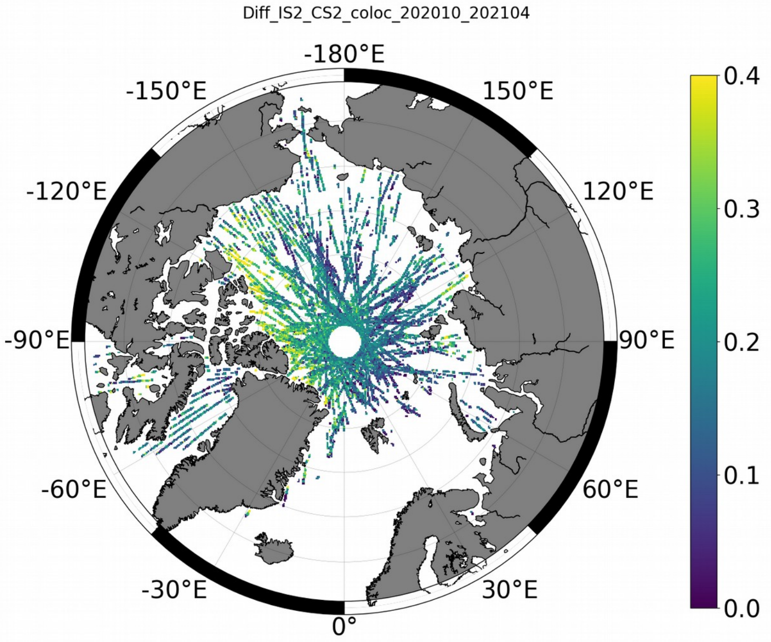
CryoSat-2 FB



ICESat-2 FB



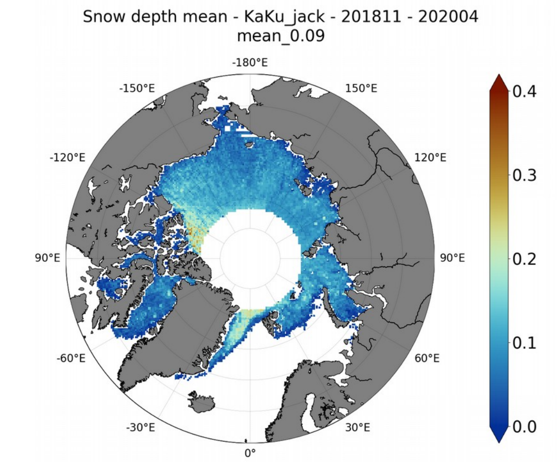
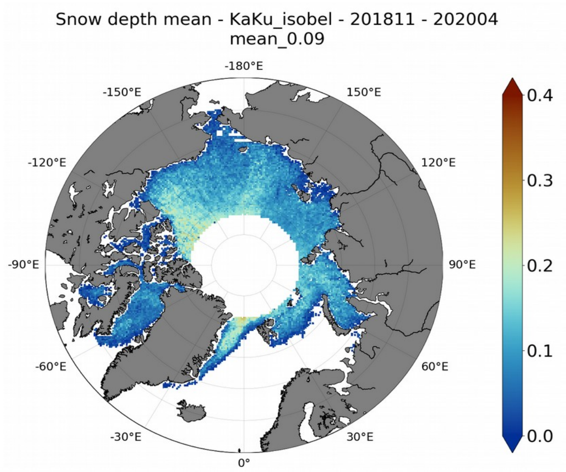
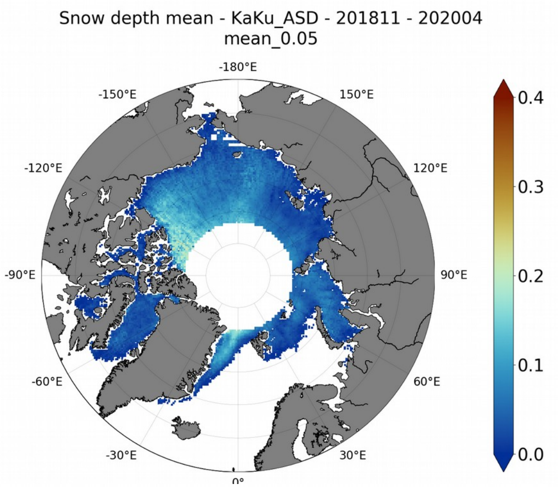
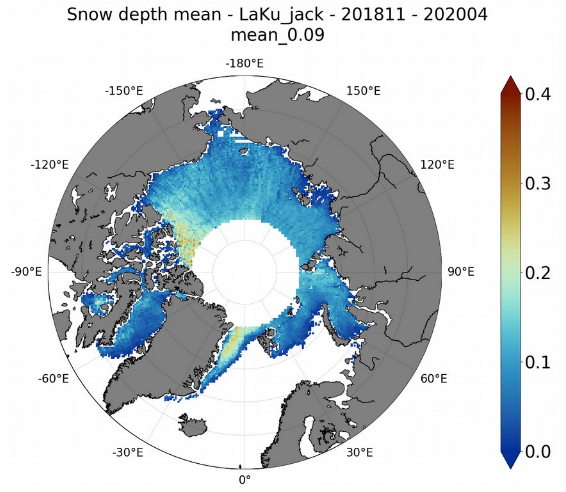
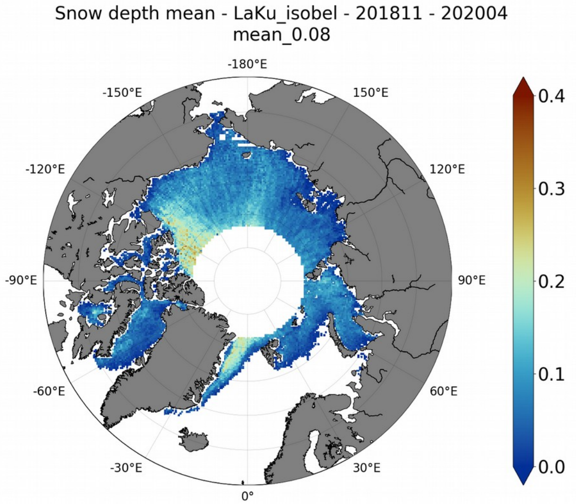
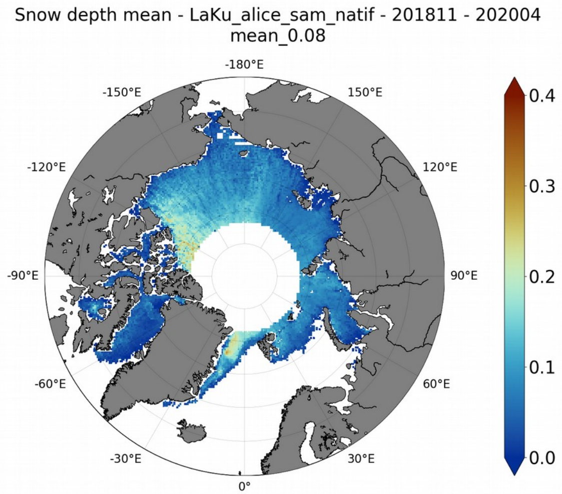
ICESat-2 – CryoSat-2



→ The difference between Laser and Ku-Band altimetry leads to a snow depth product hereafter called $\text{LaKu}_{\text{LEGOS}}$

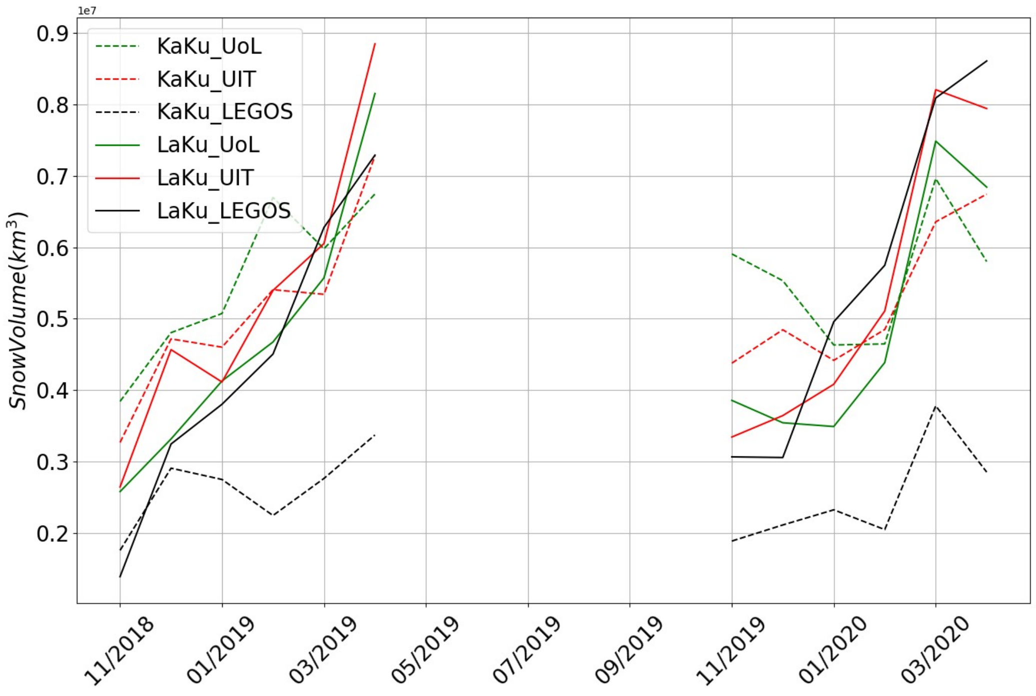
Comparison and validation of the snow depth product

CRYO2ICE project: $SD_{la\text{-}ku}$ vs other snow products

	University of Tromso Waveform methodology		University of Leeds Calibration methodology		LEGOS Bias correction	
KaKu		11/2018 – 04/2020		11/2018 – 04/2020		11/2018 – 04/2020
LaKu		11/2018 – 04/2020		11/2018 – 04/2020		11/2018 – 04/2020

CRYO2ICE project: $SD_{la\text{-}ku}$ vs other snow products

Snow depth volume

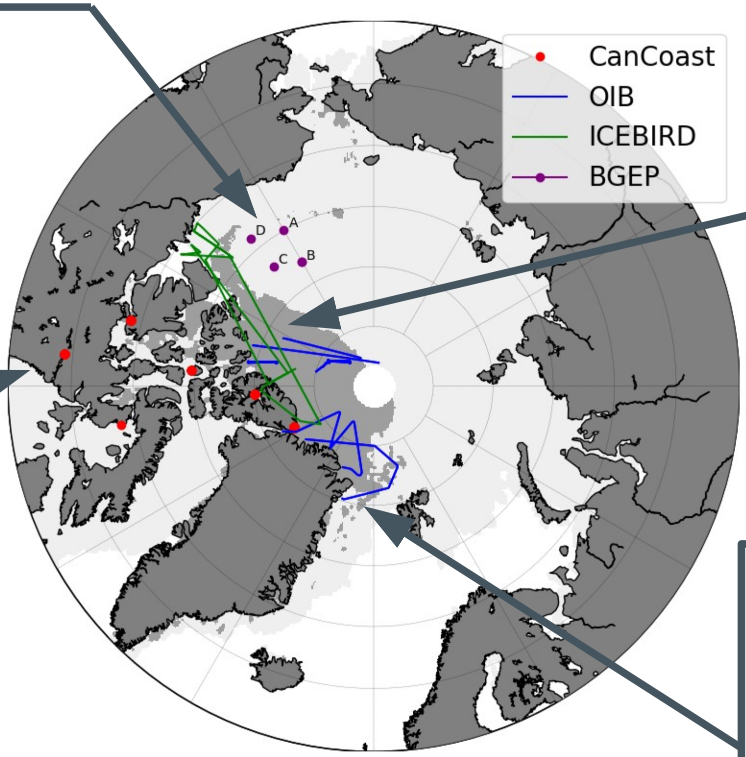


		LaKu			KaKu		
		UoL	UIT	LEGOS	UoL	UIT	LEGOS
LaKu	UoL	-	0.82	0.76	0.50	0.32	0.55
	UIT	-	-	0.79	0.36	0.35	0.41
	LEGOS	-	-	-	0.37	0.35	0.35
KaKu	UoL	-	-	-	-	0.35	0.43
	UIT	-	-	-	-	-	0.38
	LEGOS	-	-	-	-	-	-

CRYO2ICE project: $SD_{la\text{-}ku}$ vs in situ products

BGEP
- 4 moorings in the Beaufort Gyre with an upward-looking sonar
- Daily data since 2003
- Variable measured: draft

ICEBird
- Airborne survey with an ElectroMagnetic induction
- Campaign in winter and in summer since 2009
- Variable measured: snow depth

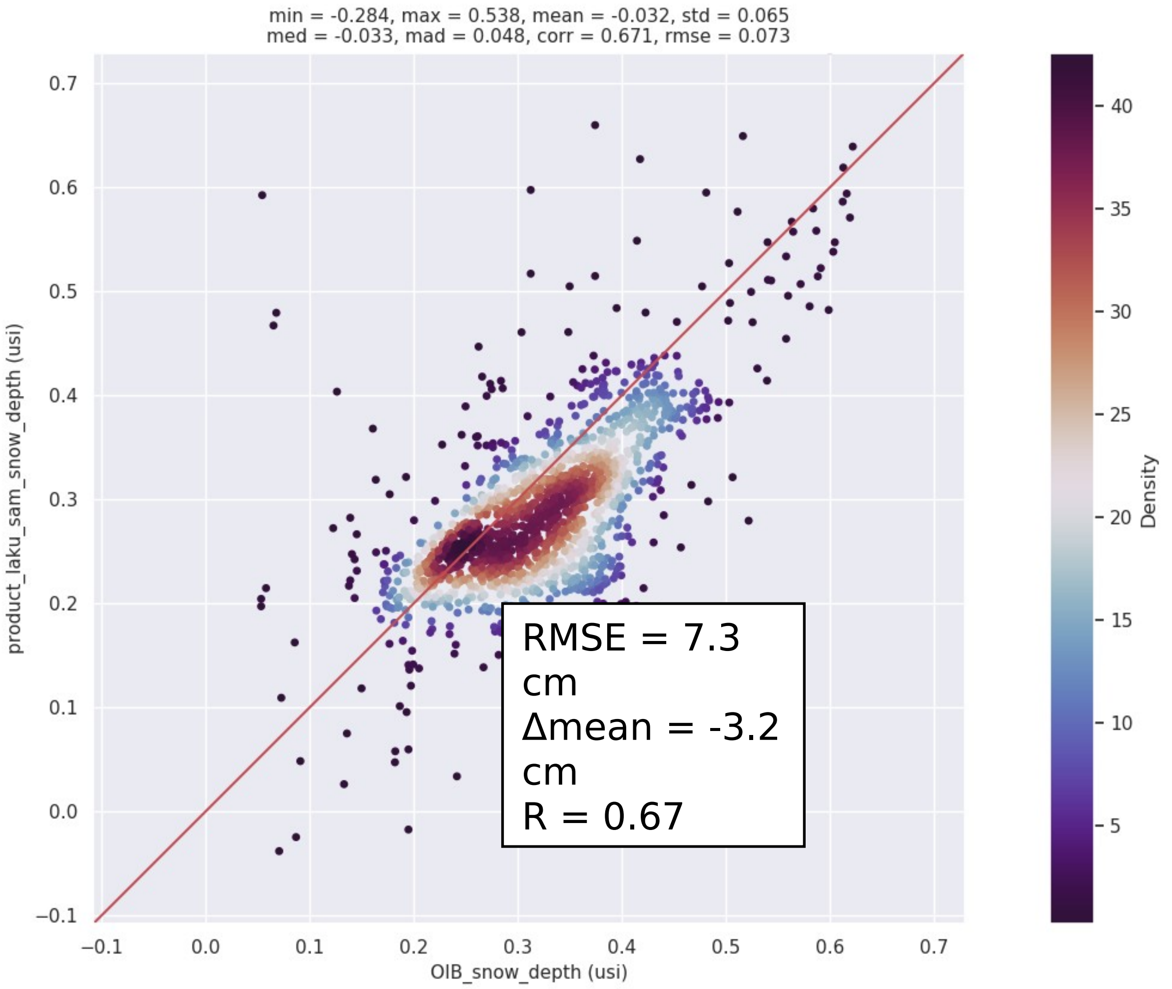


CanCoast
- Stations along the Canadian Coast
- Weekly data since 1947 for some stations
- Variable measured: snow depth

Operationnal IceBridge
- 10-year mission to collect polar data between ICESat and ICESat-2
- Airborne measurements
- Period of campaign: April 2019
- Variable measured: snow depth

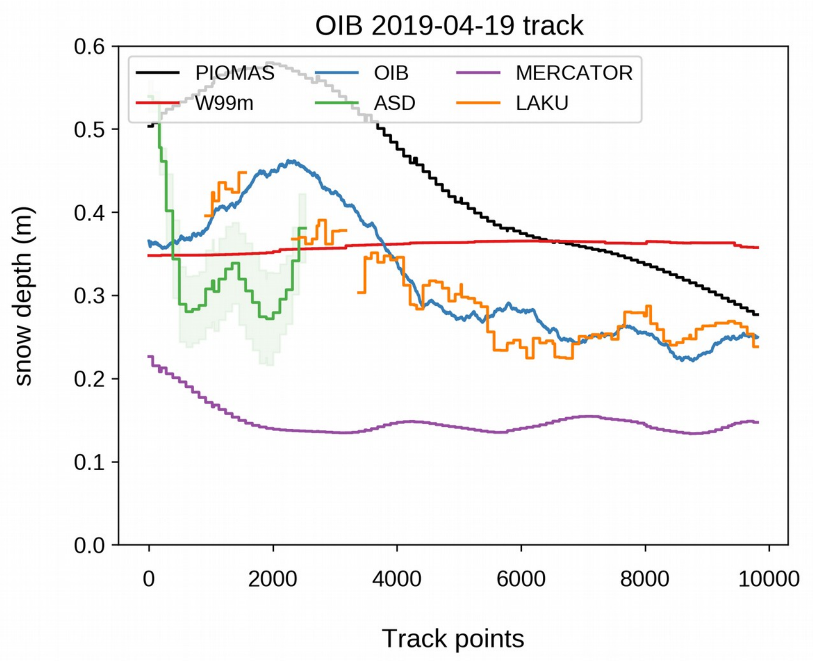
La-Ku gridded: SD LaKu vs OIB

Comparison with OIB 2019 campaign



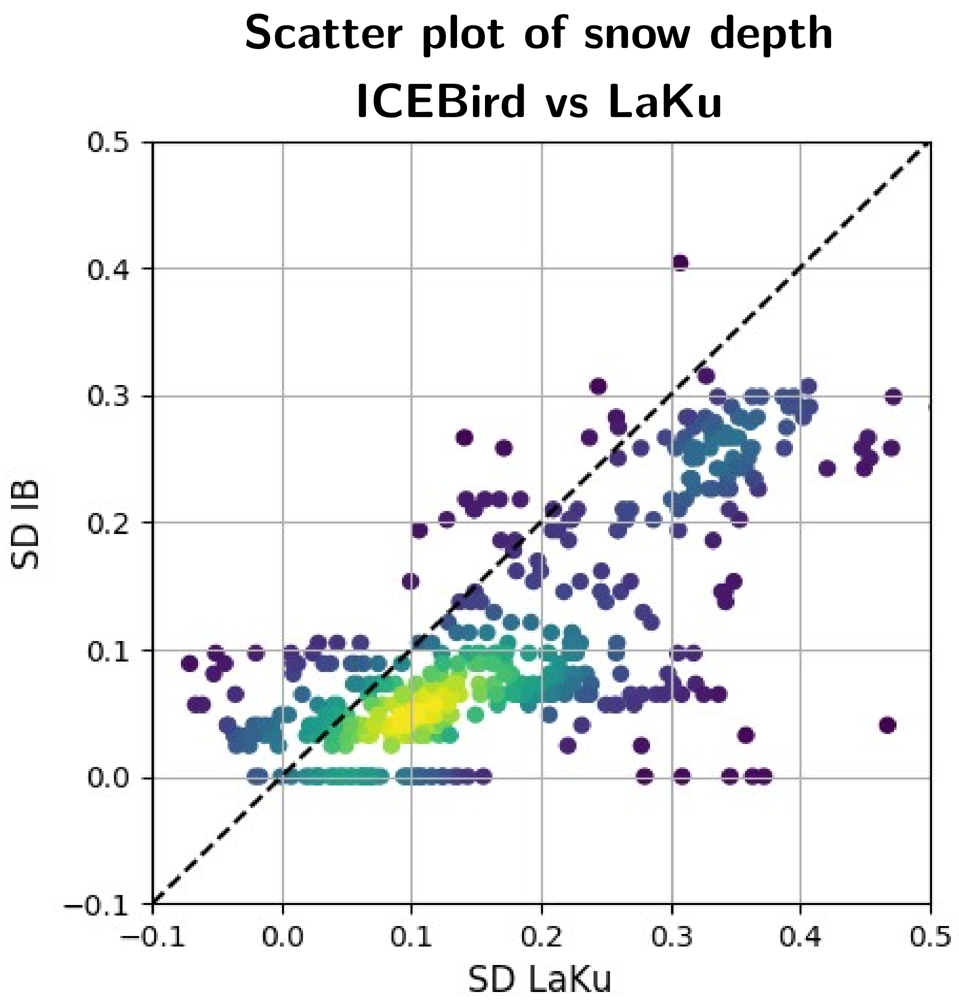
Gridded OIB vs Gridded LaKu

PIOMAS
MERCATOR
W99m
ASD
LAKU



- Good agreement with OIB
- Bias between OIB and LaKu

La-Ku gridded: SD LaKu vs ICEBird

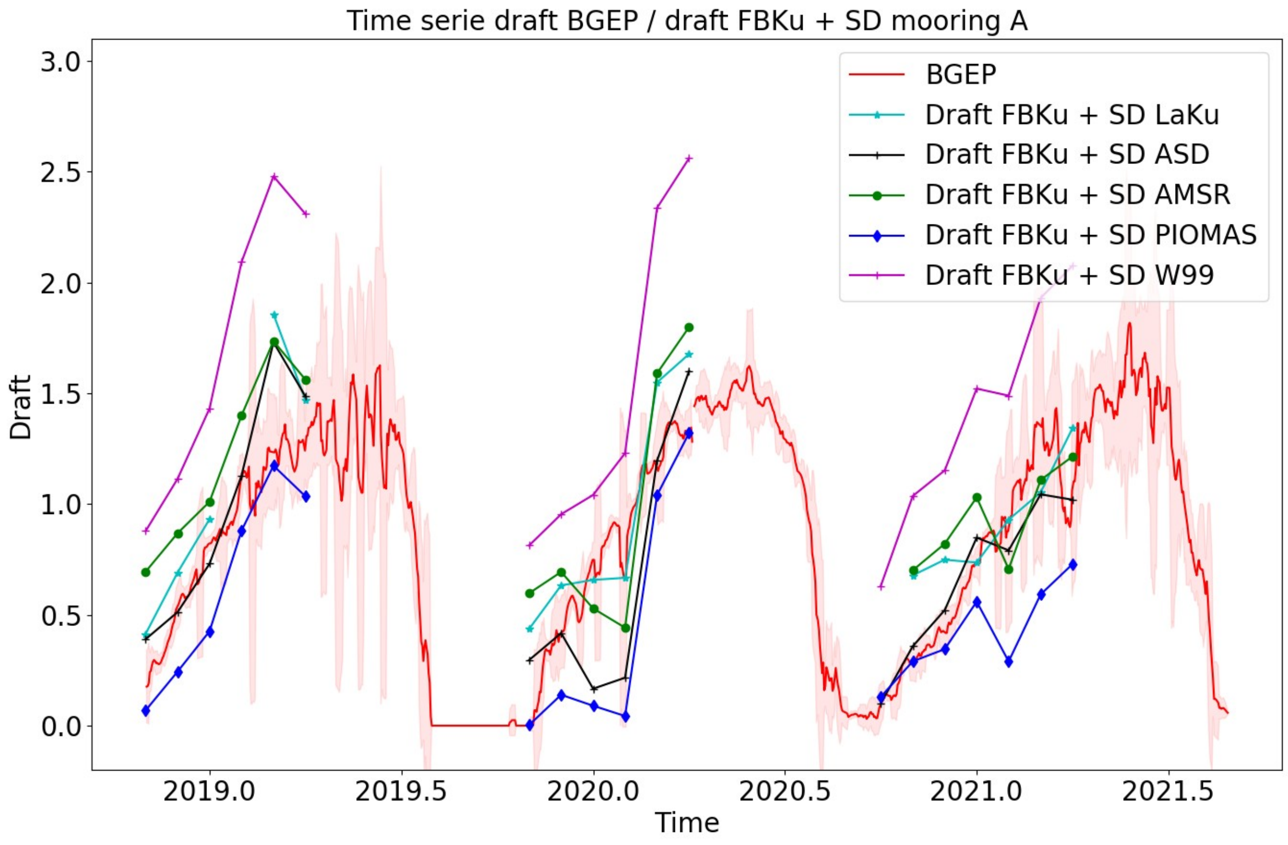


Corr	RMSD	dmean	slope
0.76	0.11	-0.07	0.54

- Good agreement between the products
- Compared to other snow depth product $LaKu_{LEGOS}$ performed well

La-Ku gridded: SD LaKu vs BGEP

$$SIT = Draft + FBKu + SD\times(c/c_{snow} - 1)$$



	Corr	RMSD	dmean	slope
Mooring A	0.84	0.25	-0.05	0.74
Mooring B	0.94	0.29	-0.23	0.88
Mooring D	0.73	0.36	-0.07	0.72

- Our LaKu product performed well
- Some strong events shown by the use of daily BGEP data

Conclusion & recommendations

Conclusions

- The Cryo2Ice project enables to compare coincidental measurements and to provide a snow depth product LaKu
- The LaKu product shows good agreement with in situ products
- The combination of different snow depth products could help to improve the snow depth understanding
- There is a need for future in-situ campaigns which must be well prepared in order to remove the remaining ambiguity (need for snow radar)

Perspectives

- Prepare the CRISTAL mission (bi-frequency altimeter)
- Integration of SARAL mission with its Ka-Band to investigate the surface roughness
- Correction to implement to account for the effect of surface roughness

Thank you for your attention