Snow depth on sea ice from altimetry for 2013-2019 Arctic and Austral winters

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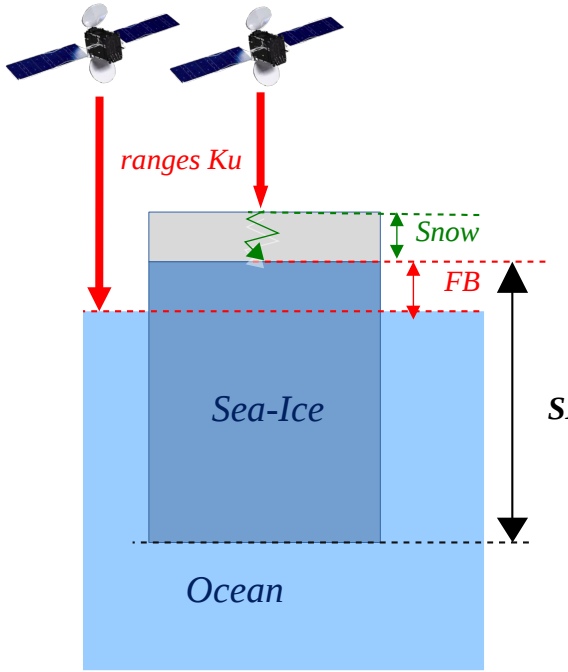
Antoine Laforge, Frédérique Rémy
and Benoit Meyssignac

Why do we need snow depth ?



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

Crucial impact...

- Sea ice growth *(insulating role)*, albedo, freshwater balance...
- Snow => Sea ice sinking + reduction of the radar echo speed propagation
- **Snow depth uncertainty => between** 30 and **100%** of error on sea ice thickness *(Hippert-2016)*

...but snow depth is poorly known !

- Warren-99 climatology *(In situ data from 1957-90 !)*
- From space : AMSR and IceSat x Envisat, bi-frequency **KA/KU**
- Models

Summary

1) Bi-frequency altimetric Snow depth measurement

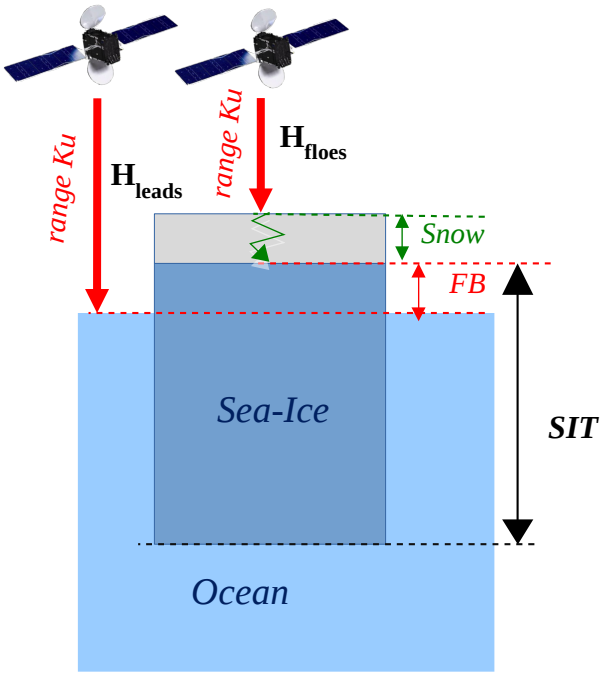
2) Comparisons with OIB and AMSR in Arctic

3) First comparisons in Antarctica

4) Towards the CRISTAL mission ***(Sinead Farrell presentation this morning)***

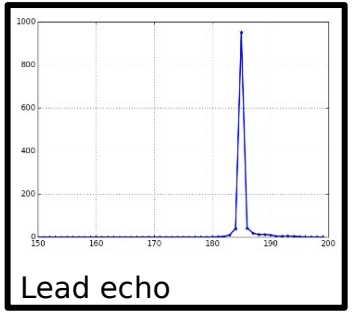
1) Bi-frequency altimetric Snow depth measurement

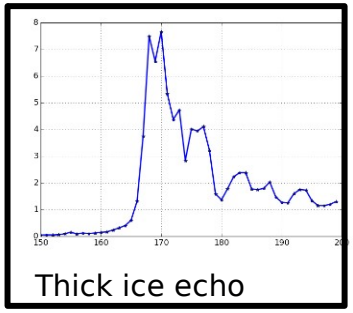
The freeboard methodology (Laxon, *2003)*

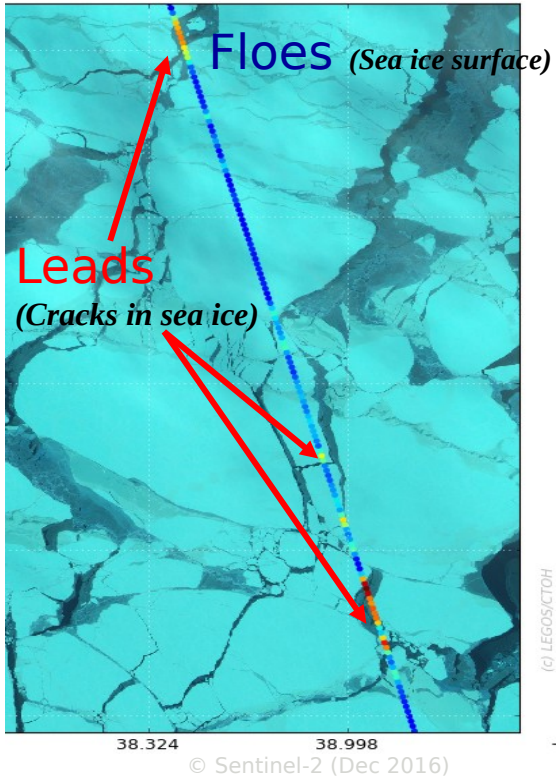


3 steps

1. **Identification of Leads and Floes**
   (Pulse Peakiness)
   $$PP = \frac{Max\ (WF)}{\sum_i WF_i}$$
2. **Retracking on Leads/Floes *(TFMRA)***
3. **Radar Freeboard = $H_{floes} - H_{leads}$**

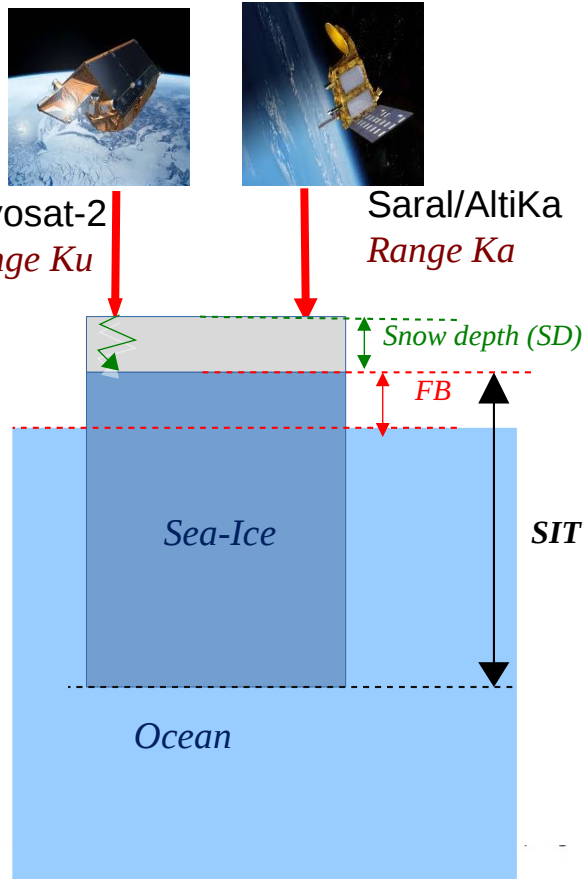






1) Bi-frequency altimetric Snow depth measurement

Based on the difference of penetration between Ka (*35.7 Ghz*) and Ku (13.5 Ghz) frequencies
(Guerreiro et al 2016, Armitage et al, 2015)



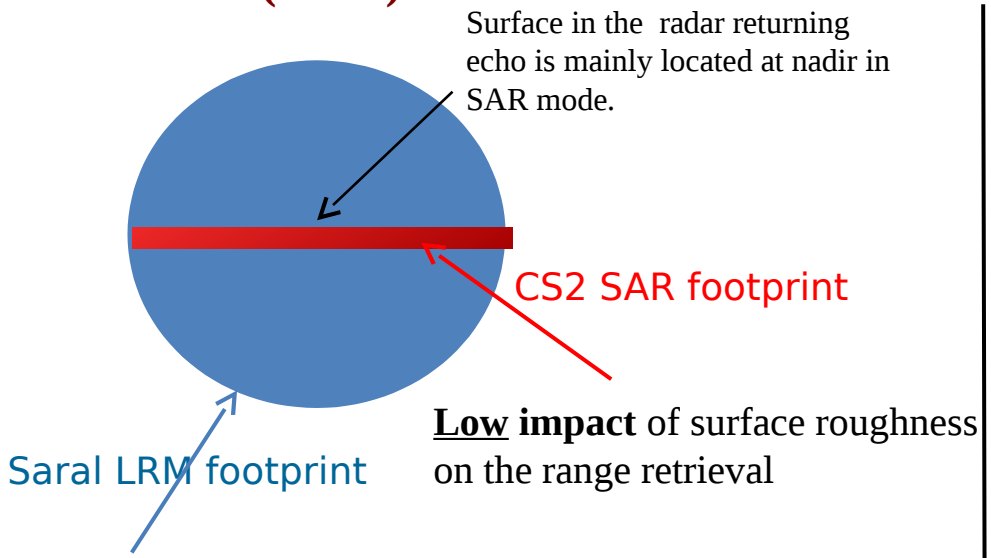
➡ $SD = FB_{Saral/altika} - FB_{Cryosat-2}$

Time period : 2013-now

But be careful of the methodology !!

1) Bi-frequency altimetric Snow depth measurement

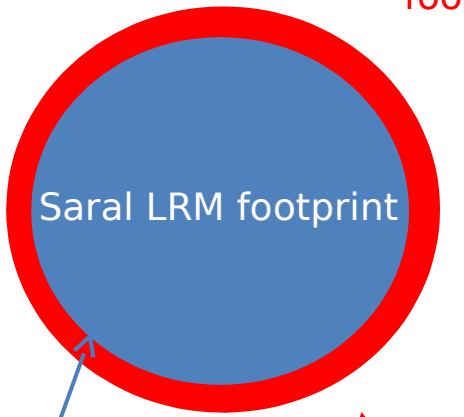
Footprint differences between SAR (CS-2) and LRM (Saral)



Low impact of surface roughness on the range retrieval

High impact of surface roughness on the range retrieval

Ka – Ku = penetration depth + roughness



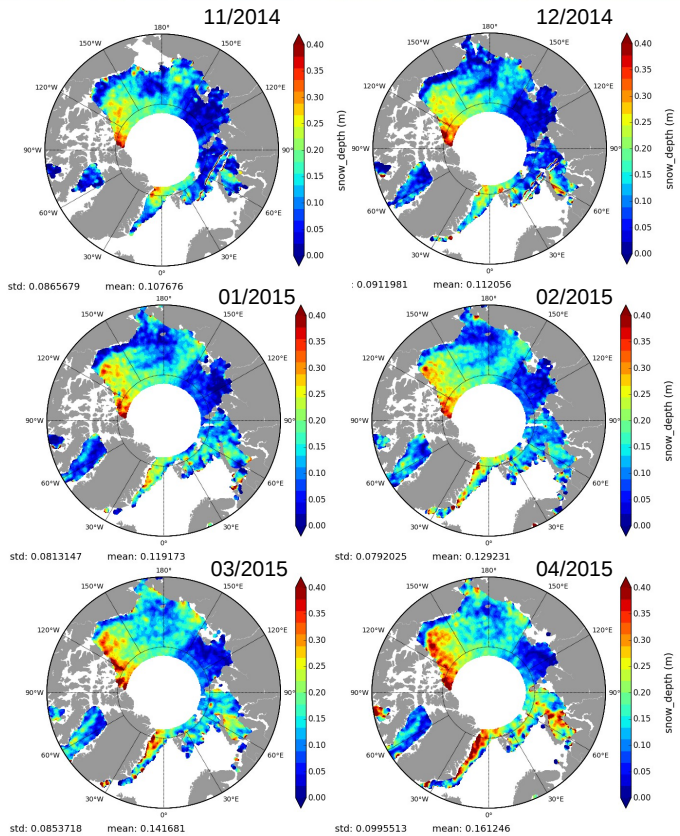
High impact of surface roughness on the range retrieval on both CS-2 and Saral can compensate each other

Ka – Ku ≈ penetration depth

1) Bi-frequency altimetric Snow depth measurement

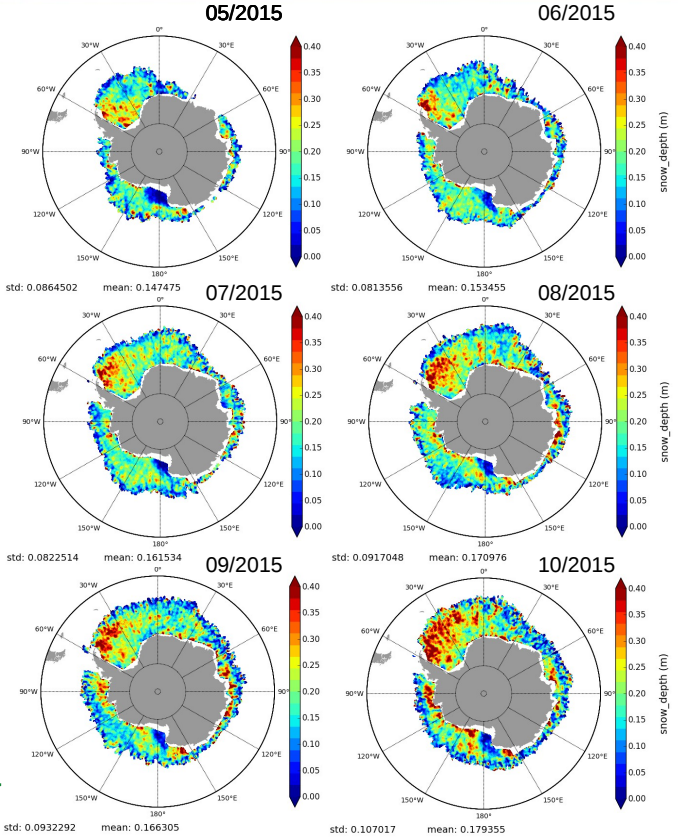
To calculate snow depth from SARAL/Altika and Cryosat-2
We need CS-2 SAR/PLRM data

1) Bi-frequency altimetric Snow depth measurement



Saral/Altika *:*
SGDR AVISO L2
Cryosat-2 :
ESA (B-C)GOP PLRM L1b

The Snow Depth data will be on the CTOH by the end of 2019 in NetCDF
http://ctoh.legos.obs-mip.fr



Antarctica

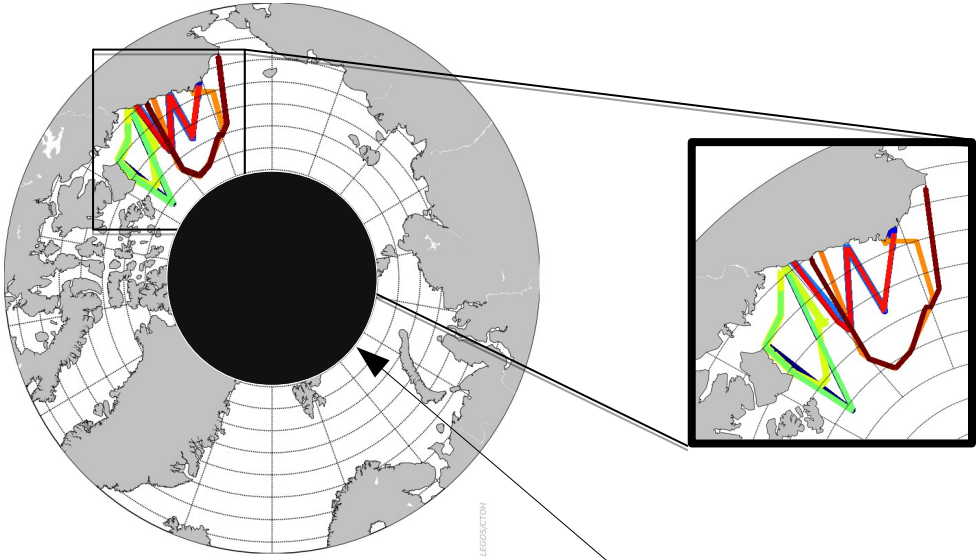
Arctic : *2013-2019*

Contact: ***Florent.garnier@legos.obs-mip.fr***

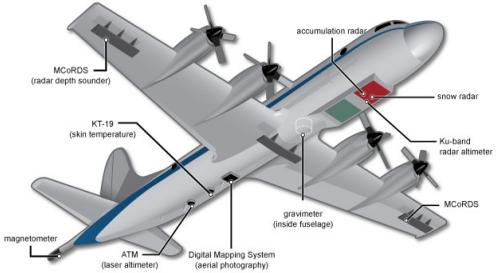
2015 (ongoing Antarctica+ ESA)

2) Comparisons with OIB and AMSR-2

Validation with **OIB**: **O**peration **I**ce **B**ridge airbone data



2013-2017 OIB tracks



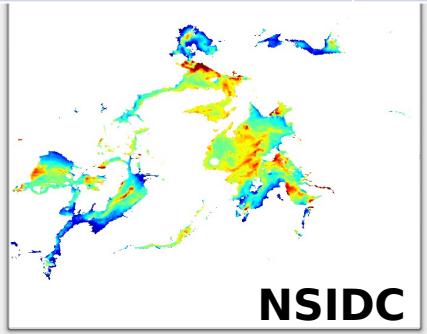
Campaigns every year
In Arctic between March and April

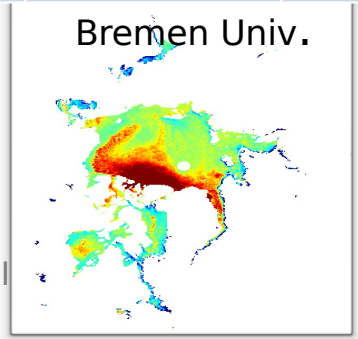
Saral < 81,5°N

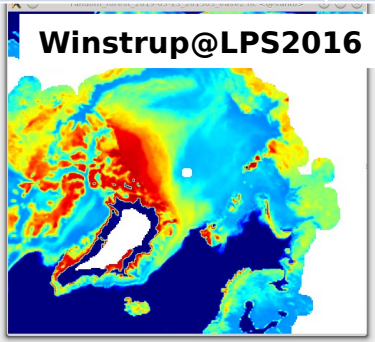
2) Comparisons with OIB and AMSR-2

AMSR :
Advance **M**icrowave **S**canning **R**adiometer data

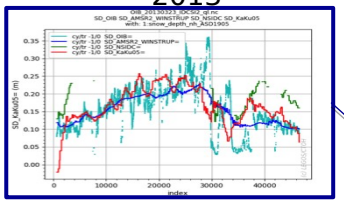
		AMSR-E (Aqua)		AMSR-2 (GCOM-W1)	
		June 2002– Sept 2011		July 2012 - now	
		NH	SH	NH	SH
NSIDC	*Cavalieri et al./ Meier et al.*	only FYI	yes	**on FYI only**	yes
Bremen Univ.	*Rostosky et al.*			Nov-May	
Danish Met. Inst.	*Winstrup et al. @LPS2019*			**March/April (OIB calib.)**	

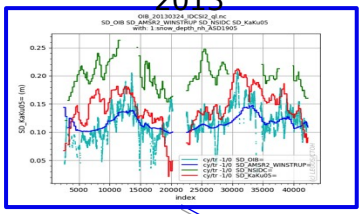


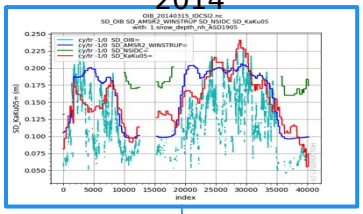


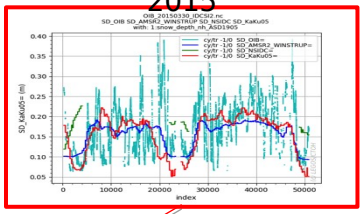


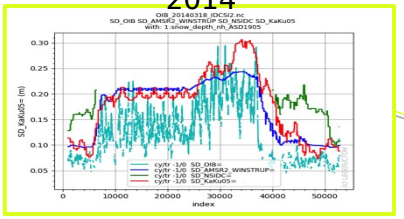
Comparisons with OIB and AMSR-2

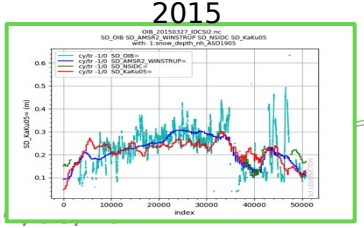


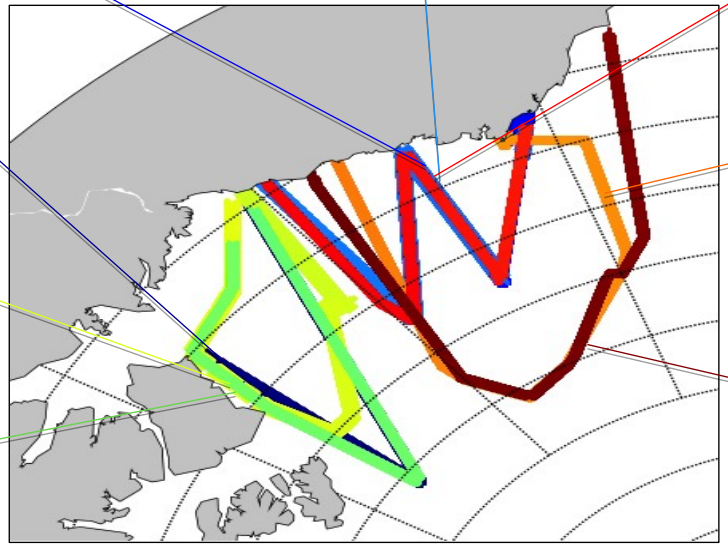


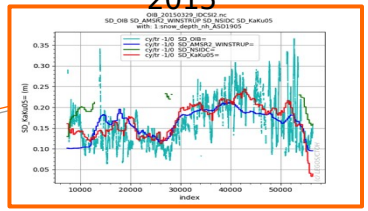


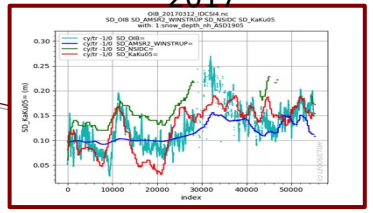






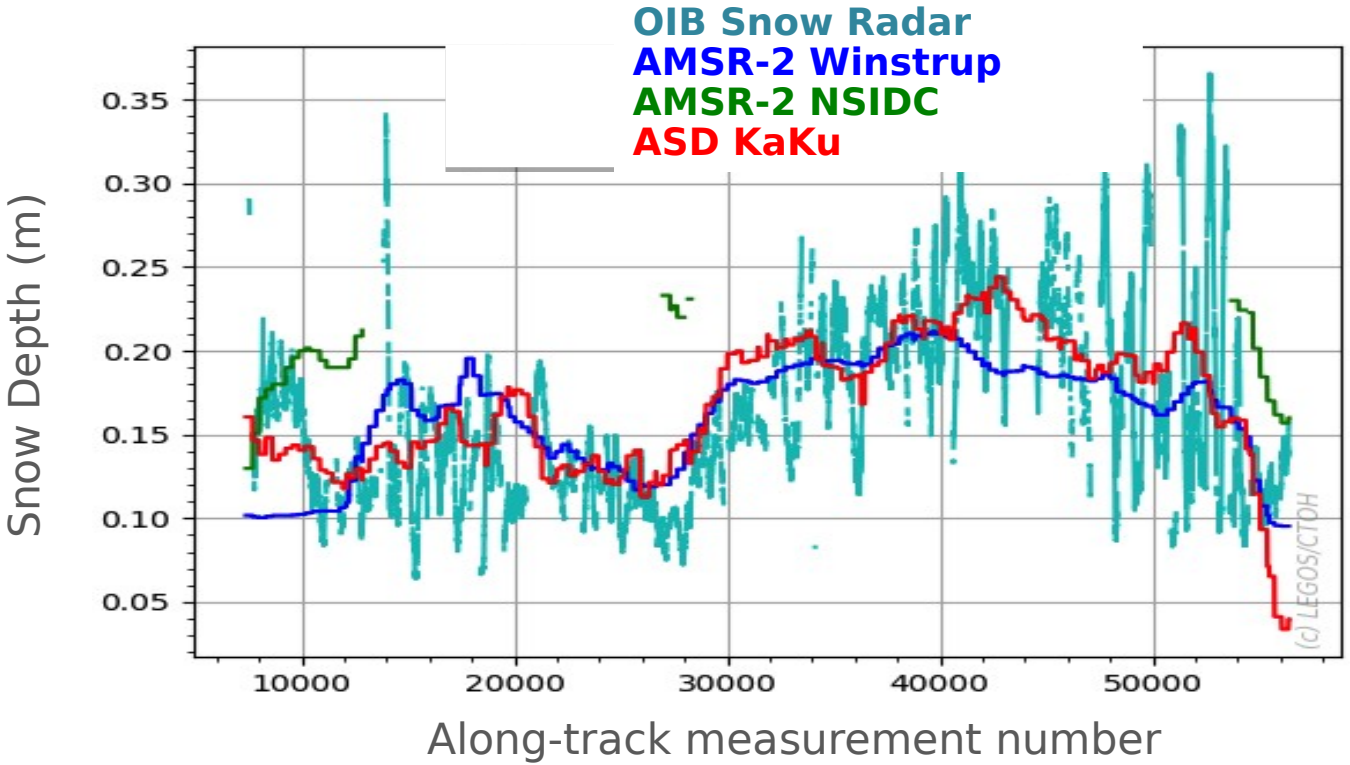






Comparisons with OIB and AMSR-2

OIB trajectory 2015/03/29



Windstrup data ~ KaKu

But

Windstrup recalibrated on OIB

NSIDC AMSR tend to overestimate SD compare to OIB

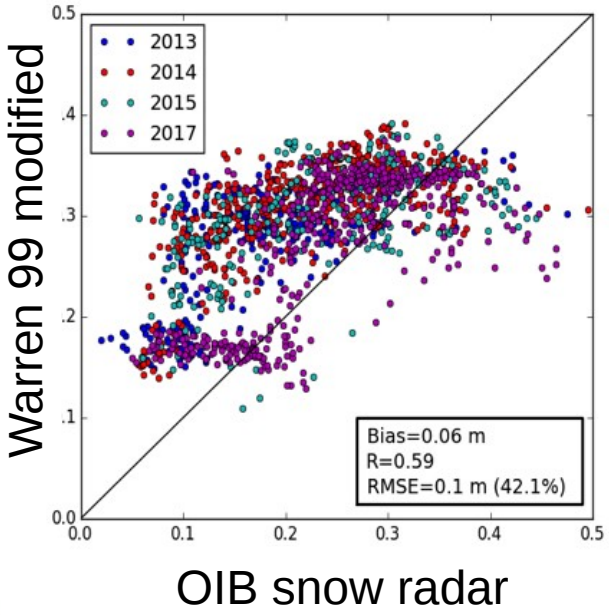
Comparisons with OIB and AMSR-2

Good consistency between KA/KU snow depth data and OIB

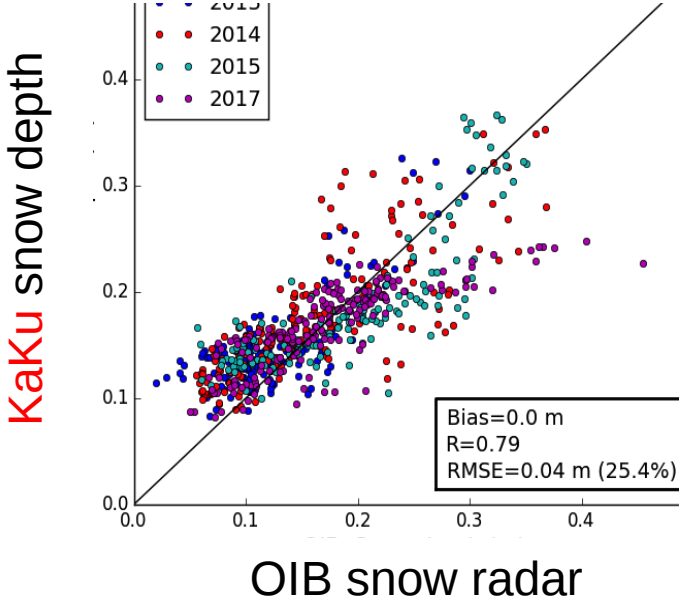
Snow depth altimetric measurement :Arctic

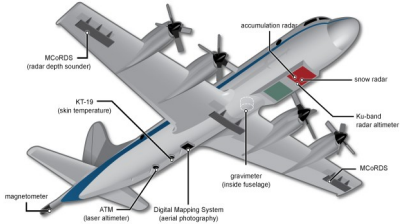
Validation with Operation Ice Bridge (OIB) airbone data

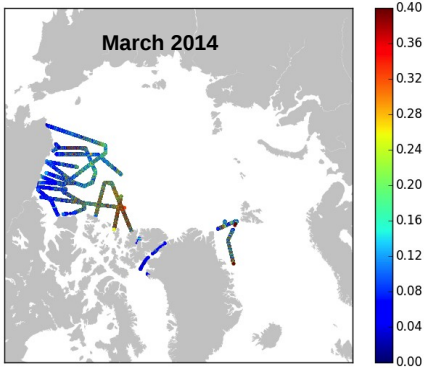
Warren-99



Ka/Ku data





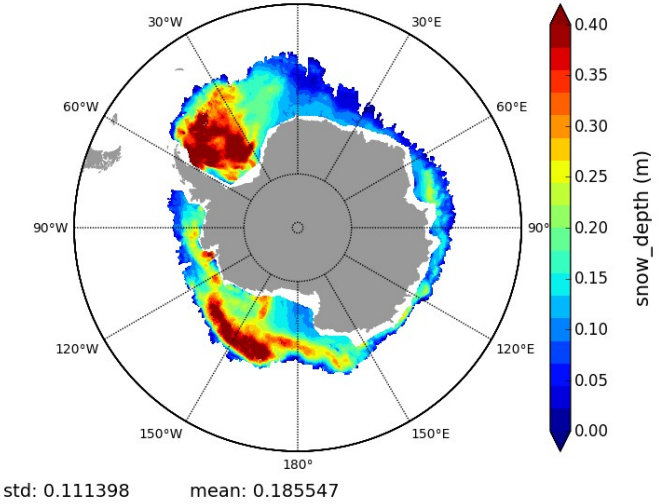


Snow depth altimetric measurement :Antarctic

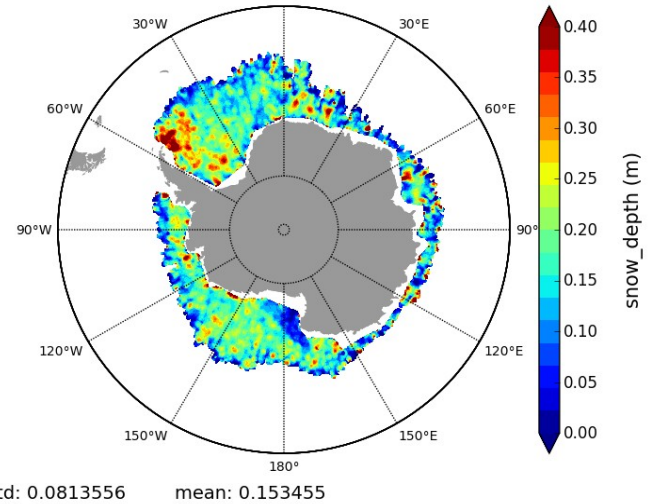
NSIDC AMSR

2015/06

KaKu



std: 0.111398 mean: 0.185547



std: 0.0813556 mean: 0.153455

~ Comparable spatial distributions

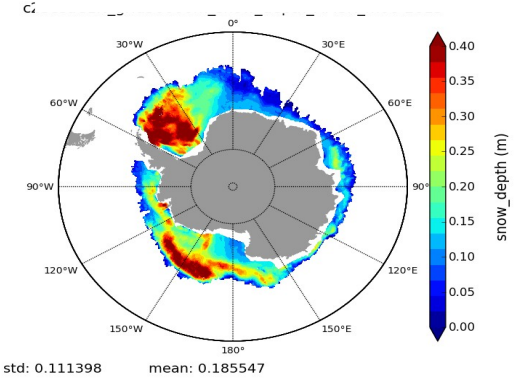
- Stronger patterns of depth snow in AMSR data.

- AMSR tend to overestimate (as in Arctic)

ongoing in the ESA Antarctica+ project

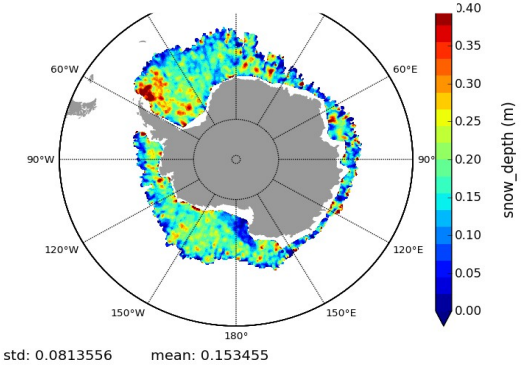
Snow depth altimetric measurement :Antarctic

NSIDC AMSR

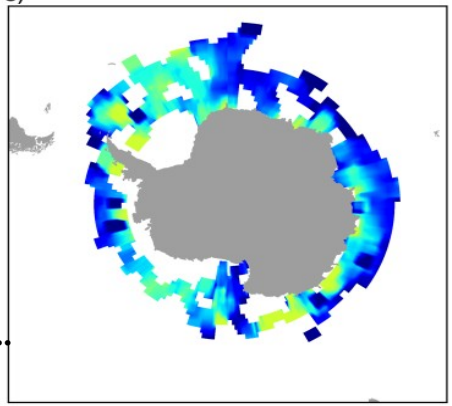


STRONG LACK OF IN-SITU MEASUREMENTS

KaKu



c) Aspect



ASPeCt campaign on the 1980-2004 period....

ongoing in the ESA Antarctica+ project

CRISTAL: Towards and Ice and Snow Satellite

CRISTAL: Copernicus Radar for Ice and Snow Topographic Altimeter

Preselected high priority Copernicus Mission (HPCM)

- Bi-frequency Ka/Ku SAR/SARin Polar Altimeter

- Primary objectives : Sea ice, Polar Caps and Glaciers survey
- Secondary objectives : Polar ocean topography ; coasts, rivers and Lakes ; permafrost

- Measure simultaneously Snow depth and freeboard → **SIT**

- **Only project to ensure the continuity of altimetric measures** over polar regions (*CS-2 orbit*)

- If selected, should be launched in mid 2020-2030 (*hopefully before the end of CS-2*)

Conclusion

- **Snow depth is a strong limitation for SIT**

- **Already KaKu snow depth time series since 2013 with consistent results in Arctic.**

- Soon in Antarctica (end 2019-early 2020)

- Still open questions:

  Doesn't Ka penetrate the snow at all ?

  Does Ku always penetrate the entire the snow cover ?

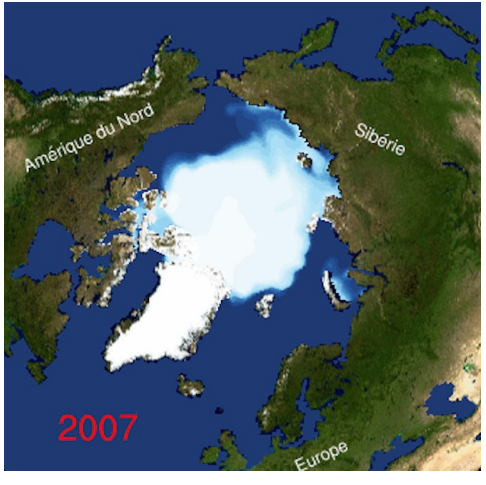
  → CryoVex airborne Ka/Ku with Karen/ASIRAS *(ESA CryoSea-NICE)*

  → IceSat2 *(~ 1 year of data)*

  → MOSAIC *(started september 2019)*

- **Preparation for Ka/Ku CRISTAL satellite**

Thanks you for your attention !!!!!



CONCLUSION

Snow depth is a strong limitation for SIT thickness estimation

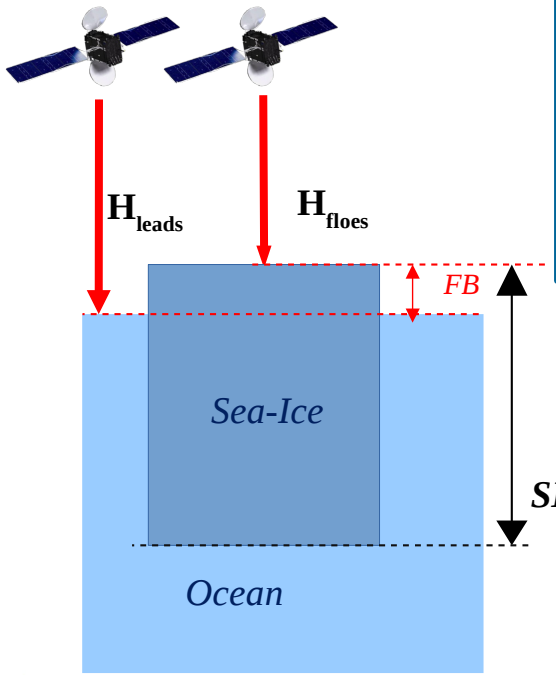
- The altimetric measurment of snow depth from Ka/Ku bi-frequency is a promising approach

  - already quite demonstrated in Artic (Guerreiro et al, 2016)
  - with applications in Antarctica

-

Altimetric Sea Ice thickness measurement

The Freeboard methodology (ESA SI-CCI project, *Ridout and Tonboe*, 2012)



Freebord (FB) : sea ice emerged height

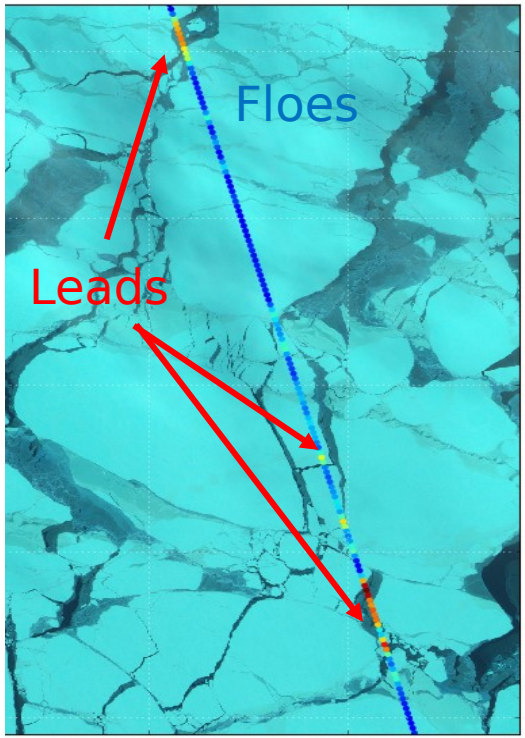
$FB = H_{floes} - H_{leads}$

Floes : sea ice surface

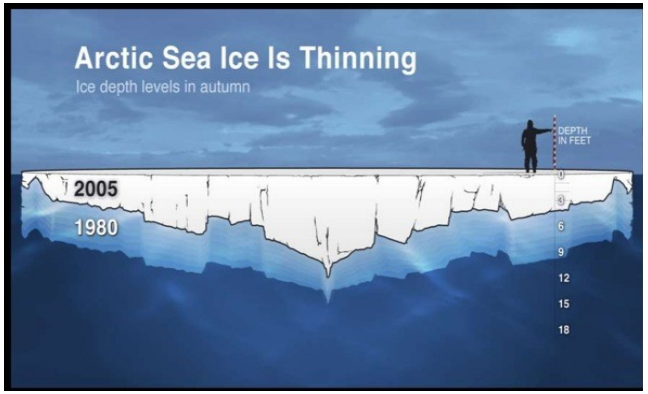
Leads : sea ice cracks

Hydrostatic equilibrium :

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



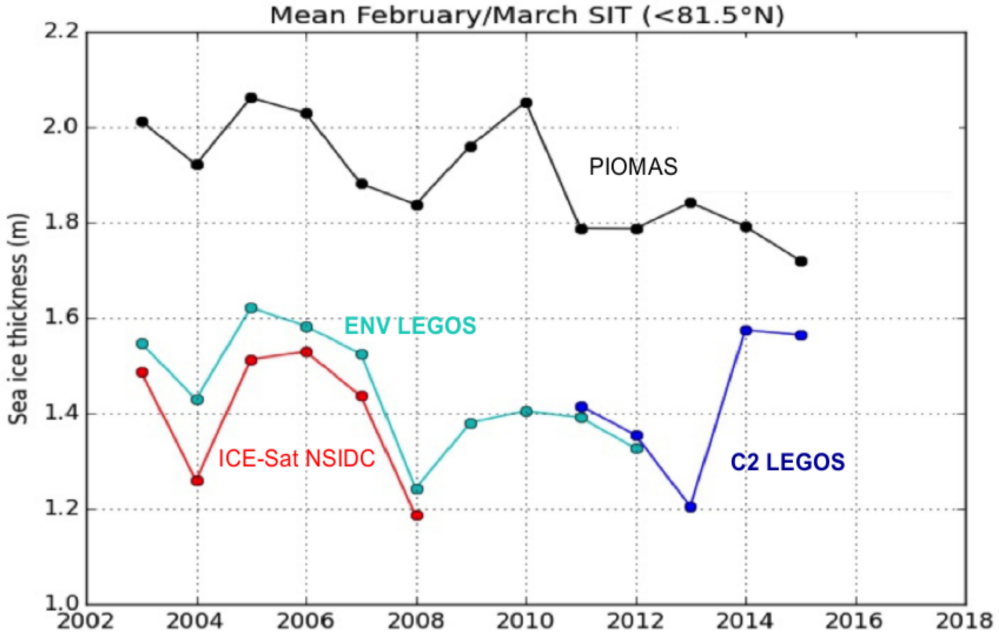
Context: why observing sea ice thickness ?



Thermodynamic weakening (*melting*)

Méchanical weakening
(*fracture and export*)

Sea Ice thickness is still poorly known



Sea ice thickness time series in Artic coming from ICESat, the PIOMAS model and from the satellite Envisat and Cryosat-2 *(source : guerreiro et al, 2017)*