
# Uncertainties in sea ice freeboard products from altimetry. Towards new methods

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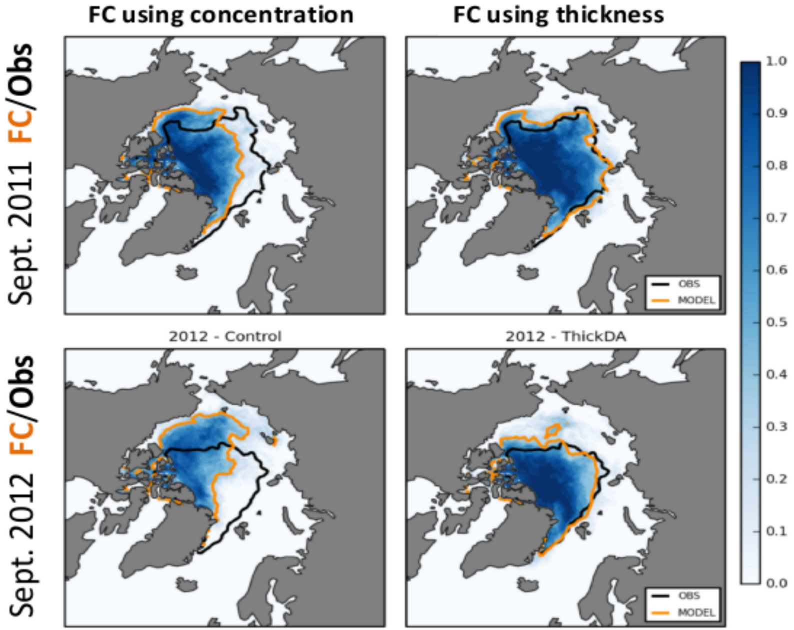
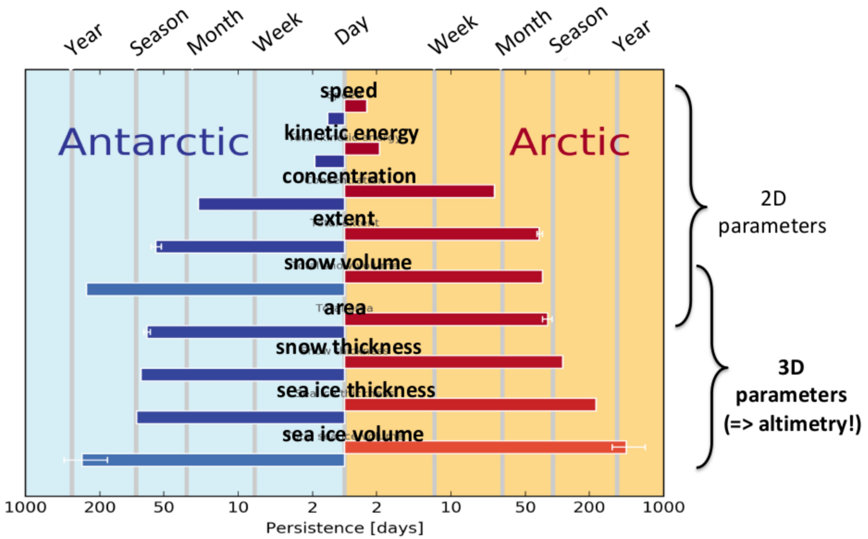
Antoine Laforge, Frédérique Rémy
and Benoit Meyssignac

# Context




4 month (may to september) forecasts (in orange) of sea ice extent performed with **sea ice concentration observations (left panels)** and with **sea ice thickness observations (right panels)**. Results are shown for 2011 (top panels) and 2012 (bottom panels). (*Source Blockley et al, 2018).*




Persistence of state variables caracterising sea ice in models
*(source : Chevallier et al,2018)*

**Sea ice thickness observations are crucial for model forecasts**

# Summary

1) Sea Ice Thickness from altimetry

2) Main sources of uncertainties

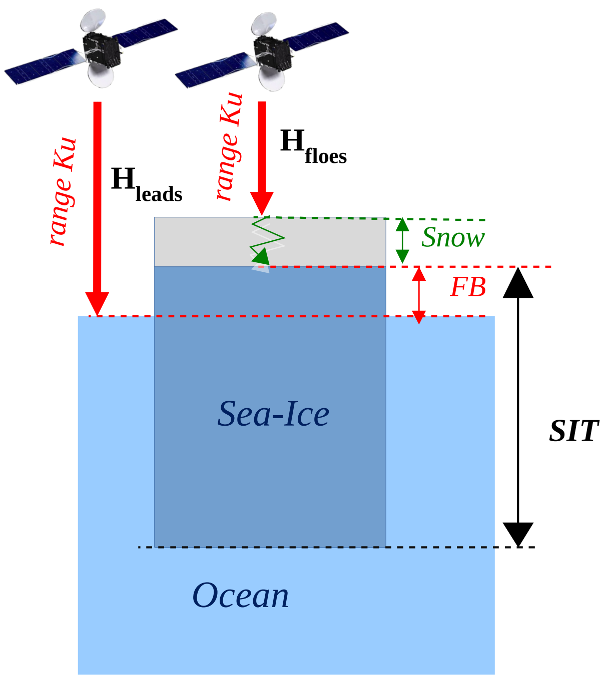
3) Uncertainties in Sea Ice Thickness products

4) Towards new quantification of uncertainties based on random numbers

5) Conclusion

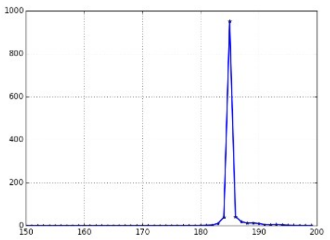
# 1) Sea Ice Thickness from altimetry

## The freeboard methodology (Laxon, *2003)*

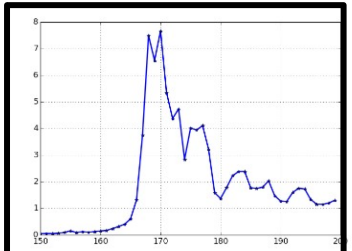



### 3 steps

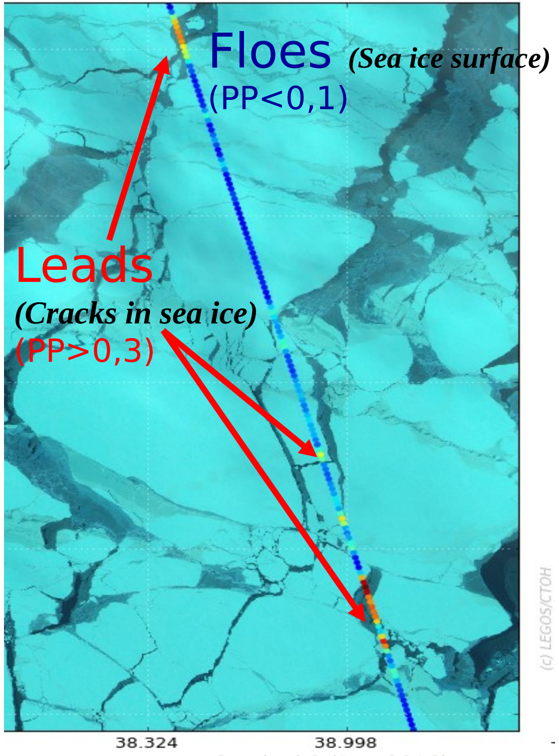
1. **Identification of Leads and Floes**
   **( Pulse Peakiness )**
   $$PP = \frac{Max\,(WF)}{\sum_i WF_i}$$
2. **Retracking on Leads/Floes**
   ***(TFMRA)***
3. **Radar Freeboard = $H_{floes} - H_{leads}$**
   **=> SIT** *(hydrostatic equilibrium)*



Lead echo



Thick ice echo




© Sentinel-2 (Dec 2016)

# 1) Sea Ice Thickness from altimetry

SIT | Freeboard | Decreasing of radar speed velocity in snow | snow

$$H_g = \frac{\rho_e((H_{floe} - H_{lead}) + h_n(1+0.51\rho_n)^{-1.5}) + \rho_n h_n}{\rho_e - \rho_g}$$

**hydrostatic equilibrium**

From the litterature

$$\epsilon_{H_g}^2 = \sum_{i=1}^{n} \frac{\partial f}{\partial x_i}^2 \epsilon_{xi}^2$$

**Uncorrelated gaussian error hypothesis**

$$\epsilon_{H_g}^2 = [-\frac{((H_{floe} - H_{lead}) + h_n(1+0.51\rho_n)^{-1.5})\rho_g + \rho_e h_n}{(\rho_e - \rho_g)^2}]^2 \epsilon_{\rho_e}^2$$
$$+[\frac{\rho_e((H_{floe} - H_{lead}) + h_n(1+0.51\rho_n)) + \rho_n h_n}{(\rho_e - \rho_g)^2}]^2 \epsilon_{\rho_g}^2$$
$$+[\frac{\rho_e(1+0.51\rho_n)^{-1.5} + \rho_n}{(\rho_e - \rho_g)}]^2 \epsilon_{h_n}^2$$
$$+[\frac{\rho_e(-1.5)(0.51)(1+0.51\rho_n)^{-2.5} + h_n}{(\rho_e - \rho_g)}]^2 \epsilon_{\rho_n}^2$$
$$+[\frac{\rho_e}{(\rho_e - \rho_g)}]^2 \epsilon_{H_{floe}}^2$$
$$+[-\frac{\rho_e}{(\rho_e - \rho_g)}]^2 \epsilon_{H_{lead}}^2$$

Freeboard uncertainties

# 2) Main sources of uncertainties (on freeboard)

- Radar echo reflexion

- *Speckle noise*

- *Geophysical corrections (Atmospheric and ocean level)*

- *Satellite altitude*

- *Mean Sea Surface*

- *Interpolated SLA under floes*

- *Lead/floe classification*

- Waveform sampling

- TFMRA retracker fixed threshold

- Distance to leads freeboard calculation

# 2) Main sources of uncertainties (on freeboard)

- ~~Radar echo reflexion~~ → considered at the snow/ice interface *(in Ku band)*

- *Speckle noise*

- *Geophysical corrections (Atmospheric and ocean level)*

- *Satellite altitude*

- *Mean Sea Surface*

- *Interpolated SLA under floes*

- *Lead/floe classification*

- Waveform sampling

- TFMRA retracker fixed threshold

- Distance to leads freeboard calculation

# 2) Main sources of uncertainties (on freeboard)

- ~~Radar echo reflexion~~ → considered at the snow/ice interface

- *Speckle noise* → Interferences in resolution cells $\sigma_{L1b}$= 0.10 m *(Ricker et al, 2014)*

- *Geophysical corrections (Atmospheric and ocean level)*

- *Satellite altitude*

- *Mean Sea Surface*

- *Interpolated SLA under floes*

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- ~~*Geophysical corrections (Atmospheric and ocean level)*~~ → *(Ricker et al, 2016)*

- *Satellite altitude*

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# 2) Main sources of uncertainties (on freeboard)

- ~~Radar echo reflexion~~ → considered at the snow/ice interface !
- *Speckle noise* → Interferences in resolution cells $\sigma_{L1b}$= 0.10 m *(Ricker et al, 2014)*
- *~~Geophysical corrections (Atmospheric and ocean level)~~* → *(Ricker et al, 2016)*
- *~~Satellite altitude~~* → *a few mm*
- *Mean Sea Surface*
- *Interpolated SLA under floes*
- *Lead/floe classification*
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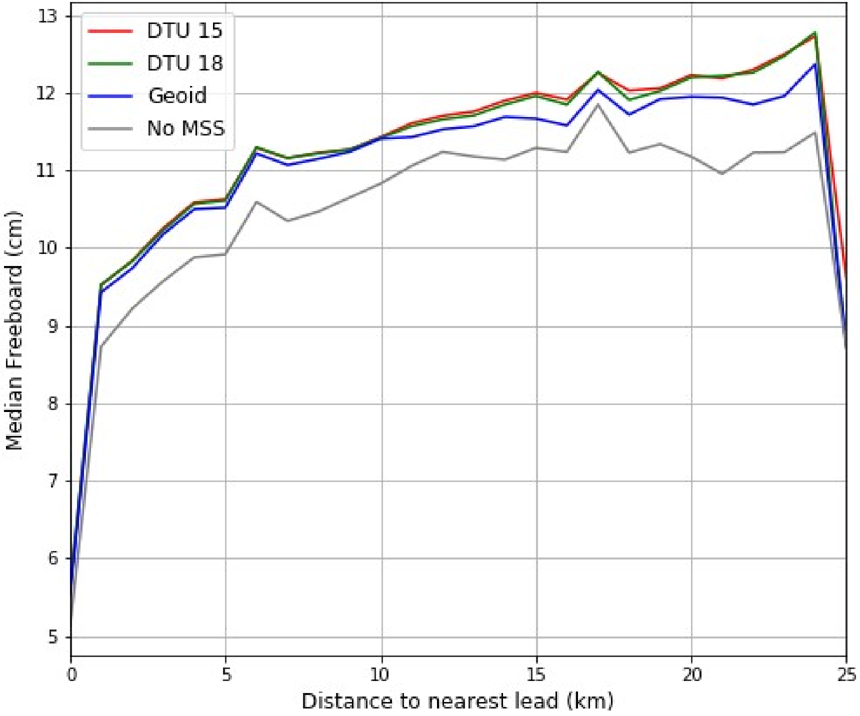
# 2) Main sources of uncertainties (on freeboard)

**-** Distance to lead **and Mean Sea Surface (MSS)**




Difference between red and green curves ~ 0

**MSS : small impact on freeboard**

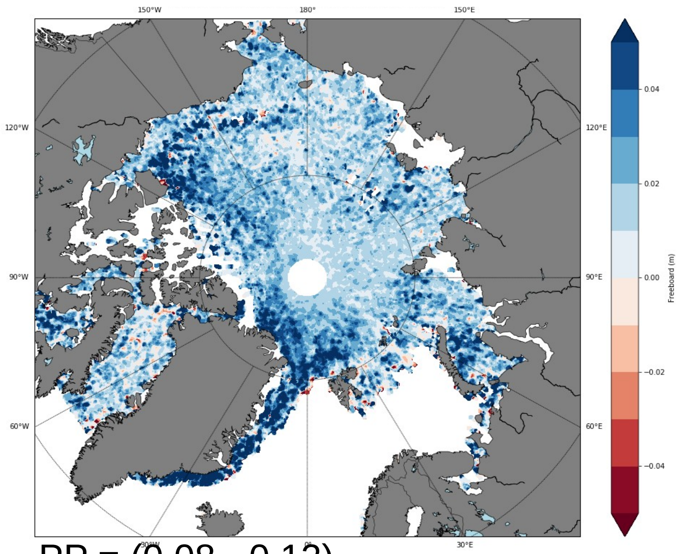
# 2) Main sources of uncertainties (on freeboard)

- ~~Radar echo reflexion~~ → considered at the snow/ice interface !
- *Speckle noise* → Interferences in resolution cells $\sigma^2_{L1b}$= 0.01 m *(Ricker et al, 2014)*
- ~~*Geophysical corrections (Atmospheric and ocean level)*~~ → *(Ricker et al, 2016)*
- ~~*Satellite altitude*~~ → *a few mm*
- ~~*Mean Sea Surface*~~
- *Interpolated SLA under floes* → *???*
- *Lead/floe classification*
- Waveform sampling
- TFMRA retracker fixed threshold
- Distance to leads freeboard calculation

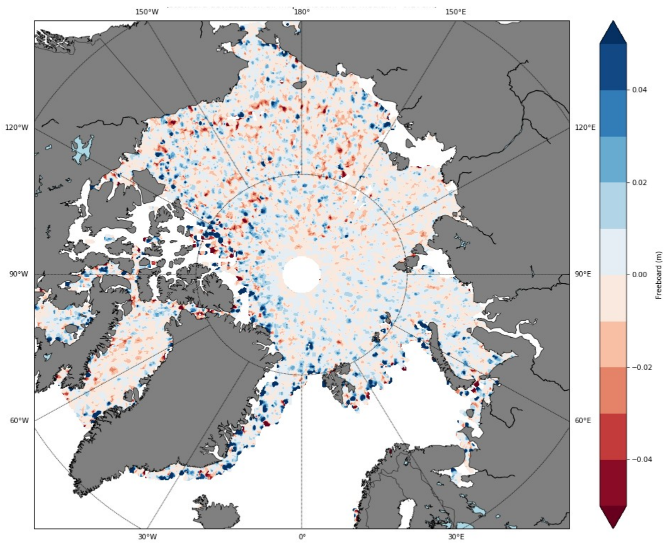
# 2) Main sources of uncertainties (on freeboard)

**- Classification lead/floes**

a) Pulse Peakiness threshold




PP = (0,08 - 0,12)




PP = (0,28-0,32)

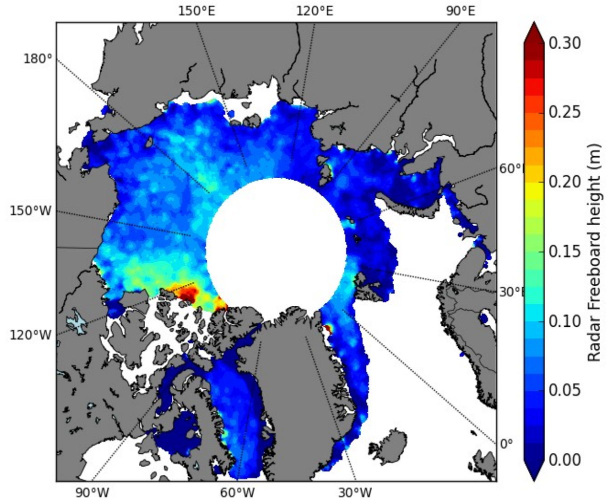
**Floes** : 1,5 cm mean bias et 4 cm std

**Leads** : 4 cm std

# 2) Main sources of uncertainties (on freeboard)

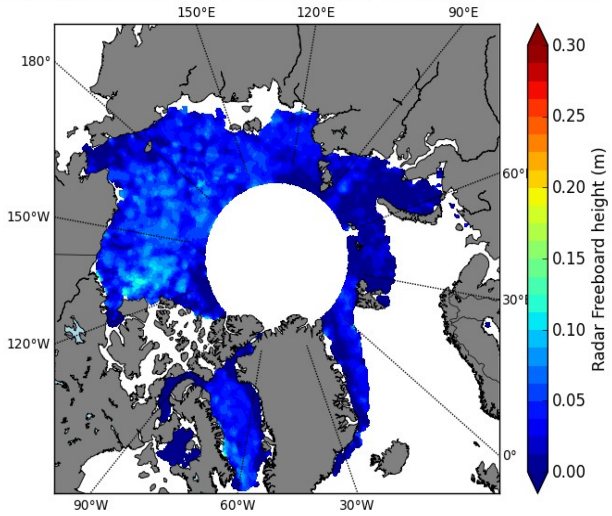
## - Classification lead/floes

FB_LEGOS




std: 0.0517958 mean: 0.0454543

FB_classif_ neuronal_network




std: 0.0353236 mean: 0.0216681

Main explication : an insufficient **floe density** in the classification

# 2) Main sources of uncertainties (on freeboard)

- ~~Radar echo reflexion~~ → considered at the snow/ice interface !
- *Speckle noise* → Interferences in resolution cells $\sigma_{L1b}$= 0.10 m *(Ricker et al, 2014)*
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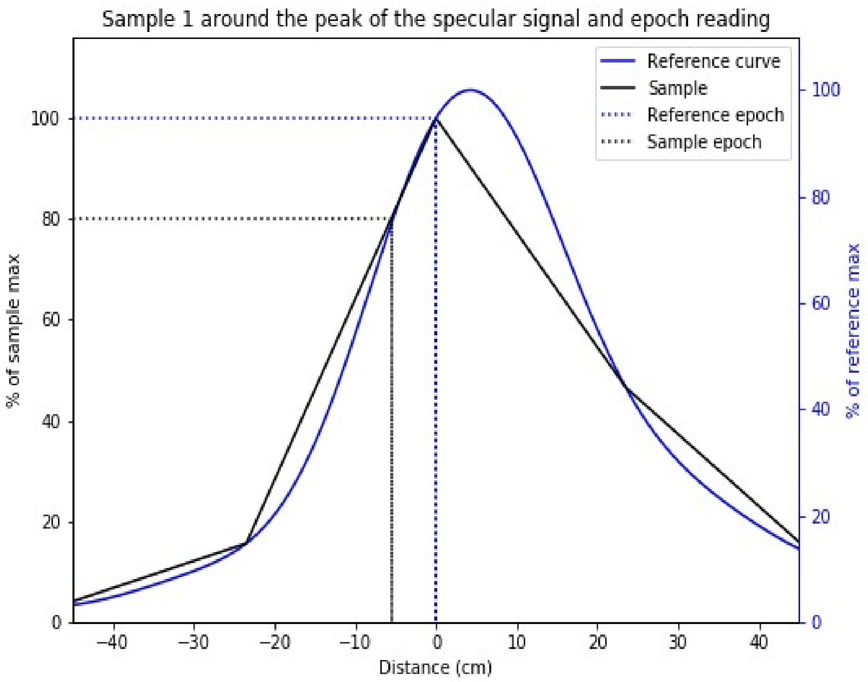
- *~~Satellite altitude~~* → *a few mm*
- *~~Mean Sea Surface~~*
- *Interpolated SLA under floes* → *???*
- *Lead/floe classification* → *bias* + *random error*
- Waveform sampling
- TFMRA retracker fixed threshold
- Distance to leads freeboard calculation

# 2) Main sources of uncertainties  (on freeboard)

**- Waveform sampling :** TFMRA → range is a fixed % of the max of the waveform




**TFMRA**
**60 %**

→ ***Lead :*** bias = -15 cm ; std = 4cm
***Floes***: bias = –30 cm ; std = 7cm

# 2) Main sources of uncertainties (on freeboard)

- ~~Radar echo reflexion~~ → considered at the snow/ice interface !

- *Speckle noise* → Interferences in resolution cells $\sigma_{L1b}$= 0.10 m *(Ricker et al, 2014)*

- ~~*Geophysical corrections (Atmospheric and ocean level)*~~ → *(Ricker et al, 2016)*

- ~~*Satellite altitude*~~ → *a few mm*

- ~~*Mean Sea Surface*~~

- *Interpolated SLA under floes* → *???*

- *Lead/floe classification* → *bias + random error*

- Waveform sampling → *bias + random error*

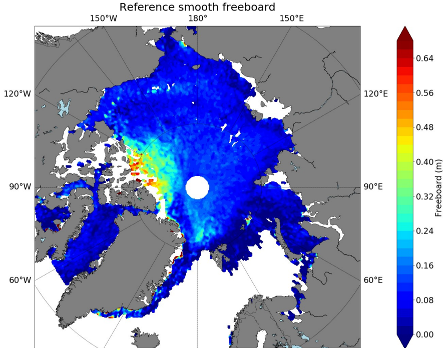
- TFMRA retracker fixed threshold

- Distance to leads freeboard calculation

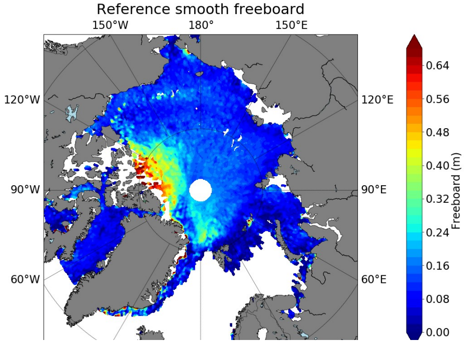
# 2) Main sources of uncertainties (on freeboard)

## - TFMRA Threshold

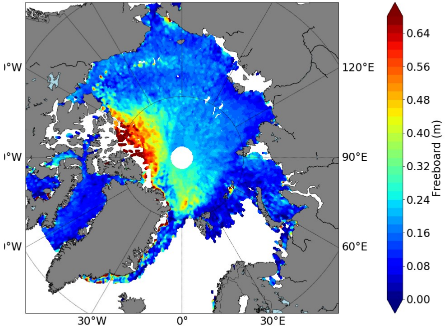
*60*



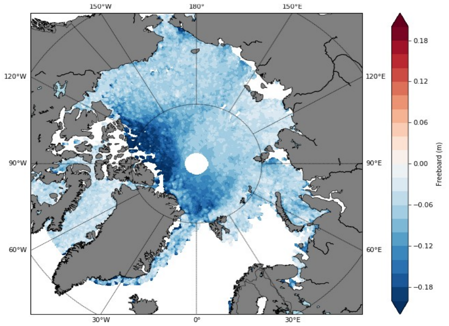

*50*



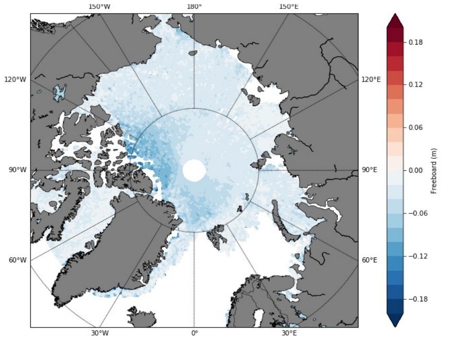

*40*




*60 - 40*




*50 - 40*




**threshold => bias**

# 2) Main sources of uncertainties (on freeboard)

- ~~Radar echo reflexion~~ → considered at the snow/ice interface !
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- ~~*Mean Sea Surface*~~
- *Interpolated SLA under floes* → *???*
- *Lead/floe classification* → *bias + random error*
- Waveform sampling → *bias + random error*
- TFMRA retracker fixed threshold → bias
- Distance to leads freeboard calculation → Thinner ice near leads ?

# 3) Uncertainties in sea ice thickness products

**Actually we do not explicitely consider these sources of uncertainties**

# 3) Uncertainties in sea ice thickness products

## Uncertainties on Freeboard at LEGOS:

Gaussian and unbiased *(some techniques are previously used to correct resulting bias)*

$$\epsilon_{H_{floe}} = \frac{\sigma_{SLA}}{\sqrt{Nobs_{floe}}}$$

$$\epsilon_{H_{lead}} = \frac{\sigma_{SLA}}{\sqrt{Nobs_{lead}}}$$

*In 25 km along track sections*

~ equivalent to other product

Ex : AWI $\sigma_{F_R}^2 = \underbrace{\sigma_{l1b}^2}_{} + \sigma_{\mathrm{SSA}}^2$

*Speckle = 0,01*

# 3) Uncertainties in sea ice thickness products

## Uncertainties on Freeboard at LEGOS:

Gaussian and unbiased *(some techniques are previously used to correct resulting bias)*

$$\epsilon_{H_{floe}} = \frac{\sigma_{SLA}}{\sqrt{Nobs_{floe}}}$$

$$\epsilon_{H_{lead}} = \frac{\sigma_{SLA}}{\sqrt{Nobs_{lead}}}$$

*In 25 km along track sections*

| | CryoSat-2 | Envisat |
|---|---|---|
| $\sigma_{SLA}$ | 0.037 m | 0.093 m |

***Freeboard uncertainty is very likely too weak***

~ equivalent to other product

Ex : AWI $\sigma_{F_R}^2 = \underbrace{\sigma_{l1b}^2}_{} + \sigma_{SSA}^2$

*Speckle = 0,01*

# 4) Towards new quantification of uncertainties

- These methods are based on **strong hypothesis** and can not characterize each sources of uncertainties in the « waveform to freeboard » process

- **Synergy** with models (data assimilation) is **difficult**

- **Idea** : produce an **ensemble** of observation (EnKF stochastic, *Evensen, 2003 ; Burgers et al, 2018*) :

# 4) Towards new quantification of uncertainties

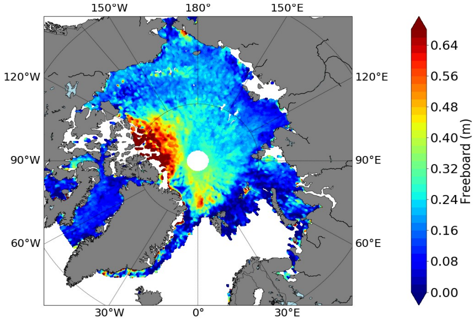
## We introduce Gaussian noises to simulate :

| | |
|---|---|
| - **Radar echo reflexion** | std = 5cm on epoch |
| - ***Interpolated SLA under floes*** | *std = 2cm on $SLA_{under\ floes}$* |
| - ***Lead/floe classification*** | std = 20 % on PP threshold |
| - **Waveform sampling** | std = 20 % on $wvf_{max}$ |
| - **TFMRA retracker fixed threshold** | std = 10 % on TFMRA50 threshold |

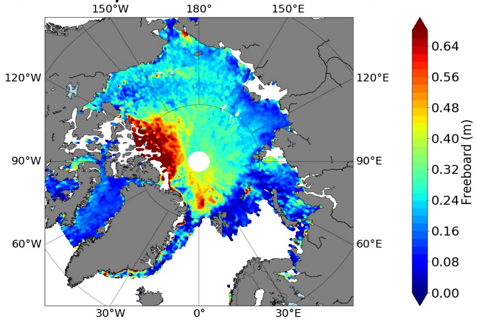
# 4) Towards new quantification of uncertainties

***30 members***

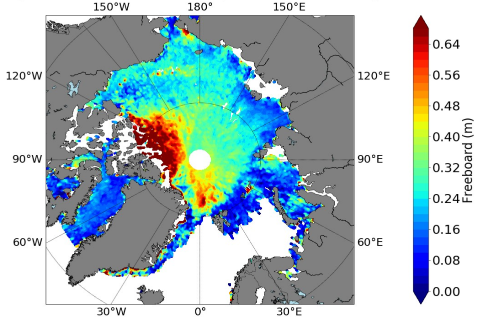
*Min*



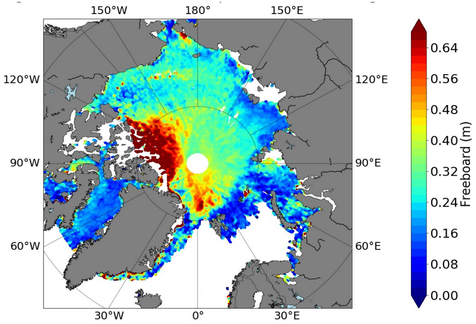

*25 % percentile*



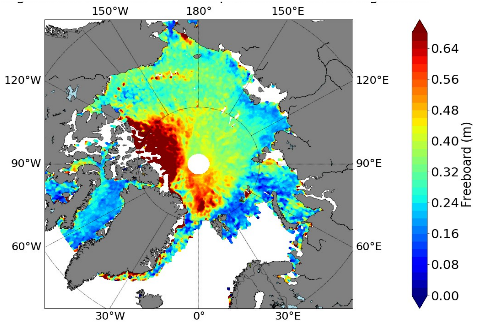

*Median*




*75 % percentile*




*Max*

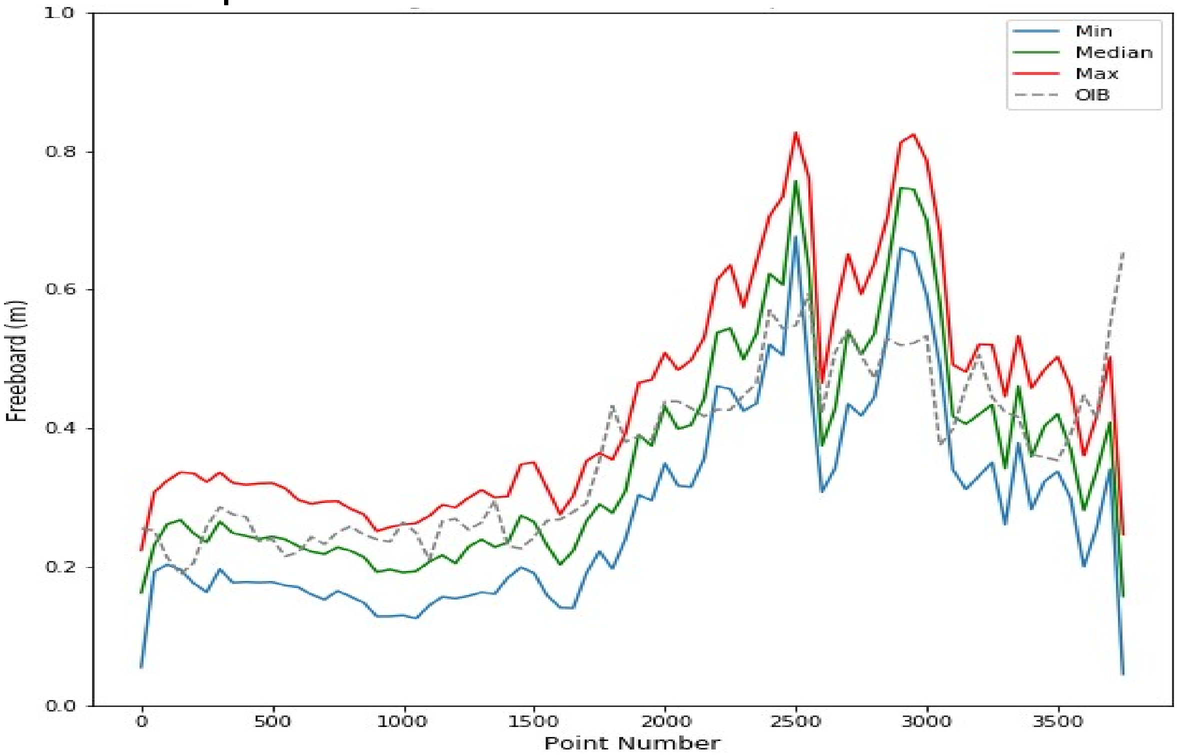


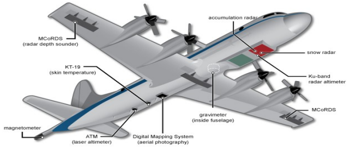

*Freeboard March 2015*

*(TFMRA 50)*

# 4) Towards new quantification of uncertainties

Comparison with OIB in 2015




**OIB:** Operation IceBridge airborne data

# Conclusion

- Sea Ice thickness observation is subject to various sources of uncertainties

- Actual methods tend to underestimate freeboard uncertainies

- Crucial to better characterize the uncertainties → forecast, reananlysis

- We intent to develop « ensemble of observation» approach

Thank you !

Questions ?

# 3) Uncertainties in sea ice products

## Uncertainties on SIT at LEGOS:

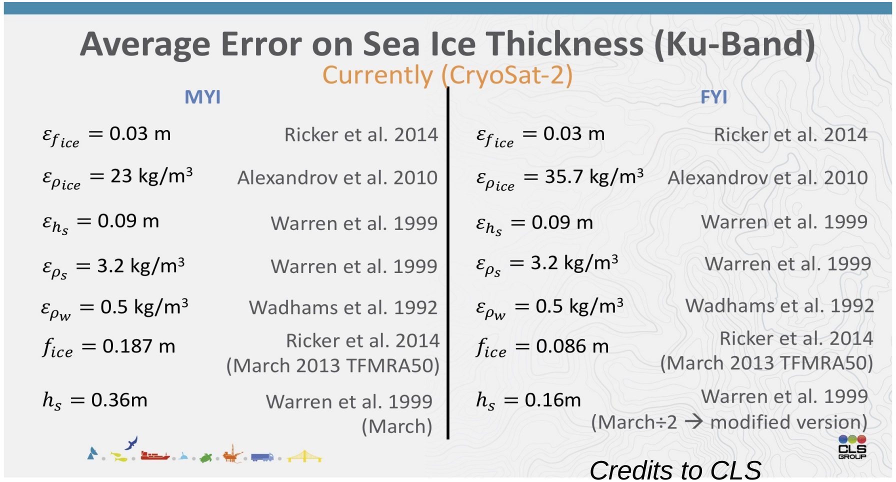
Gaussian and unbiased *(some techniques are previously used to correct resulting bias)*

$$\epsilon H_{floe} = \frac{\sigma_{SLA}}{\sqrt{Nobs_{floe}}}$$

$$\epsilon H_{lead} = \frac{\sigma_{SLA}}{\sqrt{Nobs_{lead}}}$$

*In 25 km along track sections*

+



Average Error on Sea Ice Thickness (Ku-Band)

Currently (CryoSat-2)

| MYI | | FYI | |
|---|---|---|---|
| $\varepsilon_{f_{ice}} = 0.03$ m | Ricker et al. 2014 | $\varepsilon_{f_{ice}} = 0.03$ m | Ricker et al. 2014 |
| $\varepsilon_{\rho_{ice}} = 23$ kg/m³ | Alexandrov et al. 2010 | $\varepsilon_{\rho_{ice}} = 35.7$ kg/m³ | Alexandrov et al. 2010 |
| $\varepsilon_{h_s} = 0.09$ m | Warren et al. 1999 | $\varepsilon_{h_s} = 0.09$ m | Warren et al. 1999 |
| $\varepsilon_{\rho_s} = 3.2$ kg/m³ | Warren et al. 1999 | $\varepsilon_{\rho_s} = 3.2$ kg/m³ | Warren et al. 1999 |
| $\varepsilon_{\rho_w} = 0.5$ kg/m³ | Wadhams et al. 1992 | $\varepsilon_{\rho_w} = 0.5$ kg/m³ | Wadhams et al. 1992 |
| $f_{ice} = 0.187$ m | Ricker et al. 2014 (March 2013 TFMRA50) | $f_{ice} = 0.086$ m | Ricker et al. 2014 (March 2013 TFMRA50) |
| $h_s = 0.36$m | Warren et al. 1999 (March) | $h_s = 0.16$m | Warren et al. 1999 (March÷2 → modified version) |

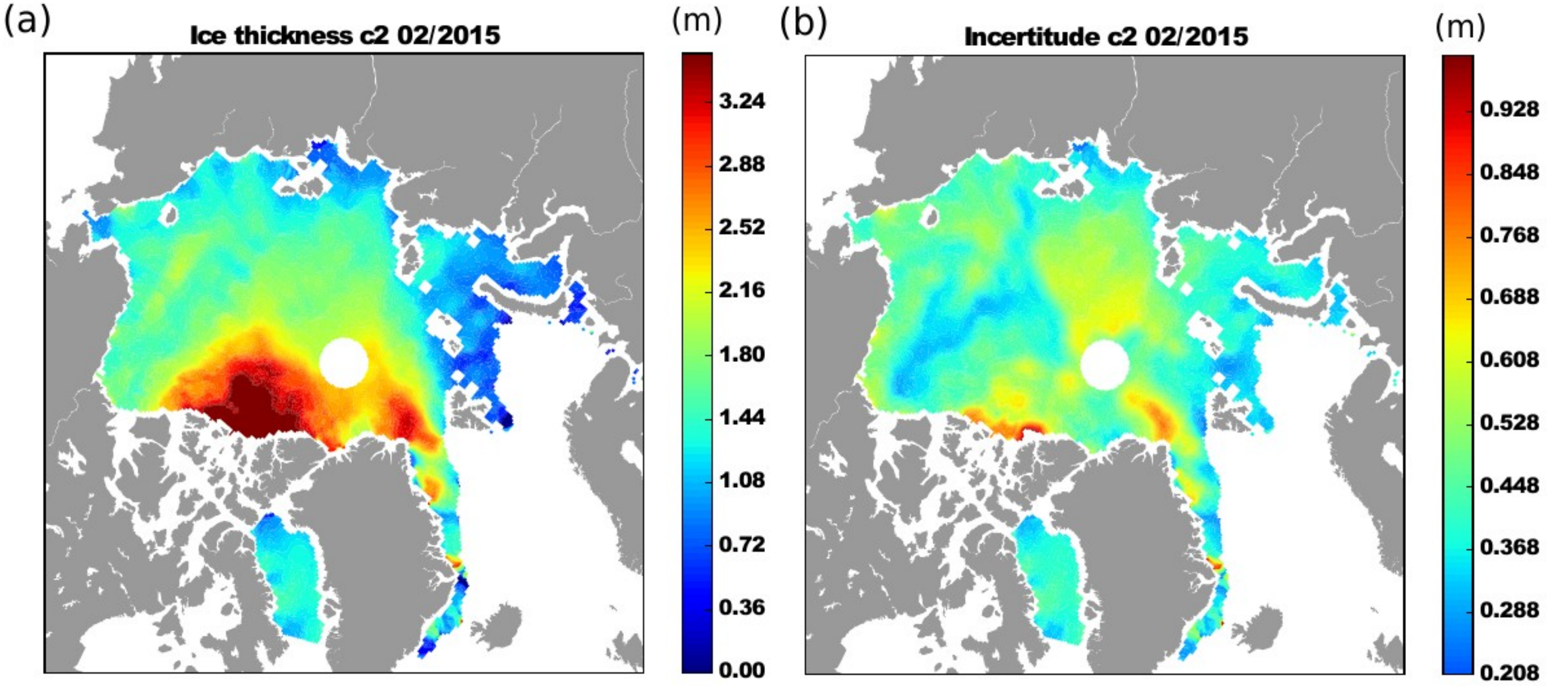
*Credits to CLS*

~ equivalent to other product

Ex : AWI $\sigma^2_{F_R} = \underbrace{\sigma^2_{l1b}} + \sigma^2_{SSA}$

*Speckle = 0,01*

# 3) Uncertainties in sea ice products




**Uncertainties are very likely underestimated**