UP-TO-DATE PERFORMANCES OF THE SWIM NADIR RETRACKER AND POSSIBLE IMPROVEMENTS

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15 MARS 2021

Plan

1 - Introduction : Global status of the ground segment retracker

2 - Analysis of the new retrieved parameter : the pseudo-mss

- Theoretical background
- Results on ocean
- Results on sea-ice

3- Perspectives of improvement : benefits of the waveform classification

- Global ocean
- Sea-Ice
- Coastal areas
- … And more

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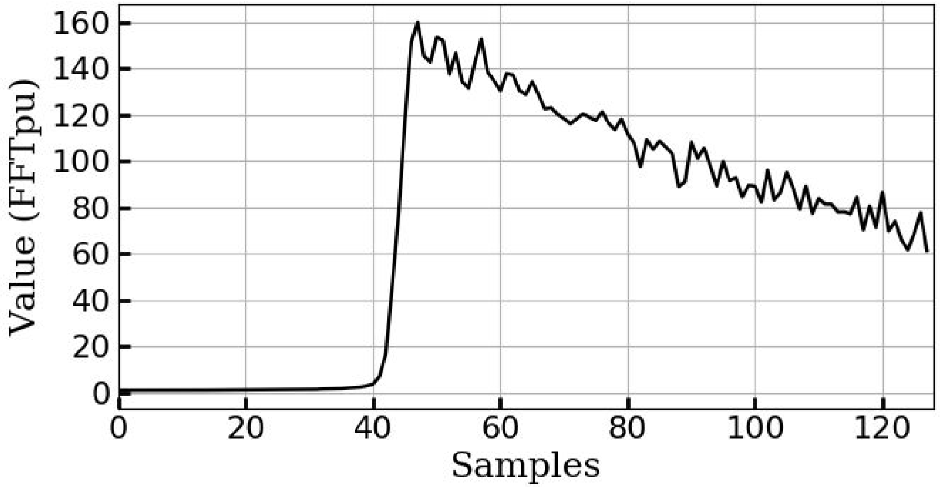
1- Introduction : Reminders about the ground segment retracker



Retracking = Algorithm estimating geophysical parameters by fitting a **model** on the nadir **echoes**

In conventionnal altimetry and for several years, the ground-segment reference algorithm for retracking nadir echoes have been the **MLE4 retracking** (Jason-2/3, SARAL/AltiKa, …)

For SWIM ground-segment, the retracking method was upgraded, by implementing a novel algorithm, called "Adaptive" retracker.

Since then, the Adaptive retracker has been chosen to be part of the new version of the Jason GDR products, along with the historic MLE4 → Is is already available for Jason-3 GDRF since the beginning of 2021

1- Introduction : Publication

- The ground segment algorithm to retrack nadir echoes, the Adaptive retracker, have been thoroughly described in a peer-review publication, accepted for submission in February 2021. It will be published in the next issue of IEEE Transactions on Geoscience and Remote Sensing (TGRS)

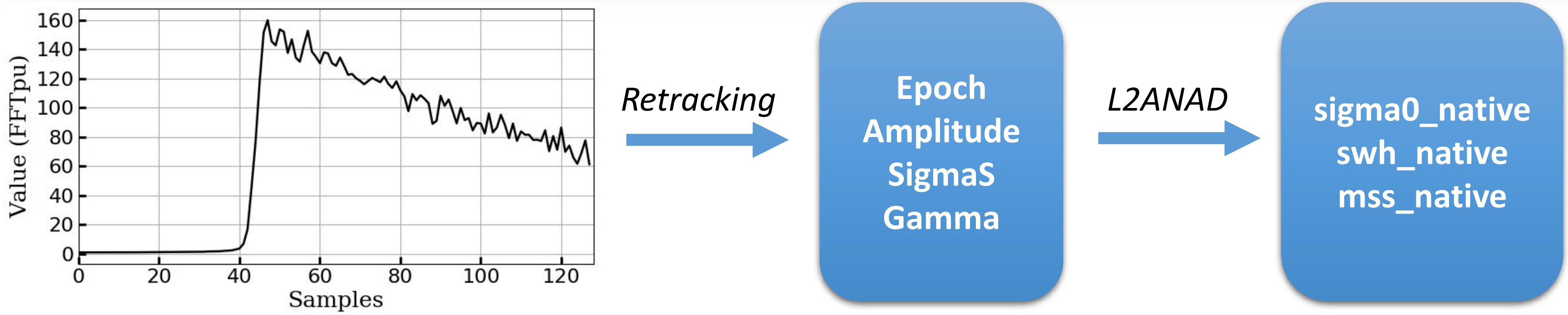
Benefits of the Adaptive algorithm for retracking altimeter nadir echoes: results from simulations and CFOSAT/SWIM observations

(*Tourain C., Piras F., Ollivier A., Hauser D, Poisson JC., Boy F., Thibaut P., Hermozo L., Tison C.*)

- After a detailed description and theoretical background, it presents a global assessment of the retracker on global ocean, with comparisons to the current reference algorithm (MLE4) and to models. It also shows its benefits on sea-ice and rain events.

- The first publication about the Adaptive algorithm → To be read to have more details about it !

1- Introduction : Overview of the retrieved parameters



- The epoch is one of the model's parameter. Since CFOSAT does not provide topography information, this parameter is not used (no range parameter in the L2ANAD)

- The SigmaS becomes the Significant Wave Height (SWH) via a simple formula. This is the main parameter for the mission and it has been described in the peer-review publication

- The amplitude is used to compute the Sigma0. Also a very important parameter, it has been described in the peer-review publication as well

- **The Gamma is used to compute the Pseudo-mss parameter. Linked to the real mean square slope (mss) of the surface, it hasnt been assessed yet → The first part of this presentation aims at describing this parameter's behaviour on global ocean and on sea-ice**

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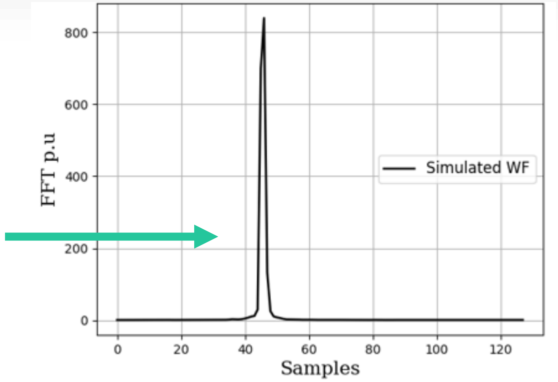
2- The nadir pseudo-mss : Theoretical background

One of the evolutions in the Adaptive model is that surface characteristics effects are taken into account through the *mss* parameter in the exponential parameter (and not only through the amplitude of the signal), allowing a far greater flexibility to adapt to specular echoes like this one



Indeed, contrary to the Haynes model that constrains its trailing edge with the off-nadir angle only, this approach allows the trailing edge of the echo to be also constrained by the surface roughness.

$$\sigma^0(\theta) = \sigma^0(0)\exp\left(-\frac{sin^2(\theta)}{mss}\right)$$

Sigma0 modelling used in the Adaptive

- The Adaptive retracker estimates the Gamma paramater defined as such :

$$\Gamma = \frac{4\gamma\ \mathrm{mss}}{4\mathrm{mss}\ \cos 2\xi + \gamma} \Rightarrow mss = \frac{\gamma\Gamma}{4(\gamma - \Gamma\cos(2\xi))}$$

Where γ is a fixed parameter related to the antenna aperture and ξ the mispointing

2- The nadir pseudo-mss : Theoretical background

- On surfaces where the roughness dominates the trailing edge of the waveform, this parameter is theoretically the **real mean square slope of the surface.** → Valid for highly specular surfaces like sea-ice or blooms

- On surfaces where the roughness **doesn't** dominate the trailing edge of the waveform, this parameter absorbs other effects affecting the trailing edge : mispointing, etc …. On those surfaces, the speckle noise is stronger and the mss doesn't vary a lot

- Theoretically, on ocean, the variations of this pseudo-mss might be hidden under the noise due to the speckle. Negative values will also appear due to this noise (similarly to SWH<0 or ksi<0) → Not physical but explained by the estimation process

  → We don't expect this pseudo-mss to be exploitable on ocean like the real mss (especially for high waves) but it might reveal some "extreme" events, to be assessed

  → On sea-ice, this parameter could be non-noisy and fully exploitable, just like the Sigma0 as first described in the publication

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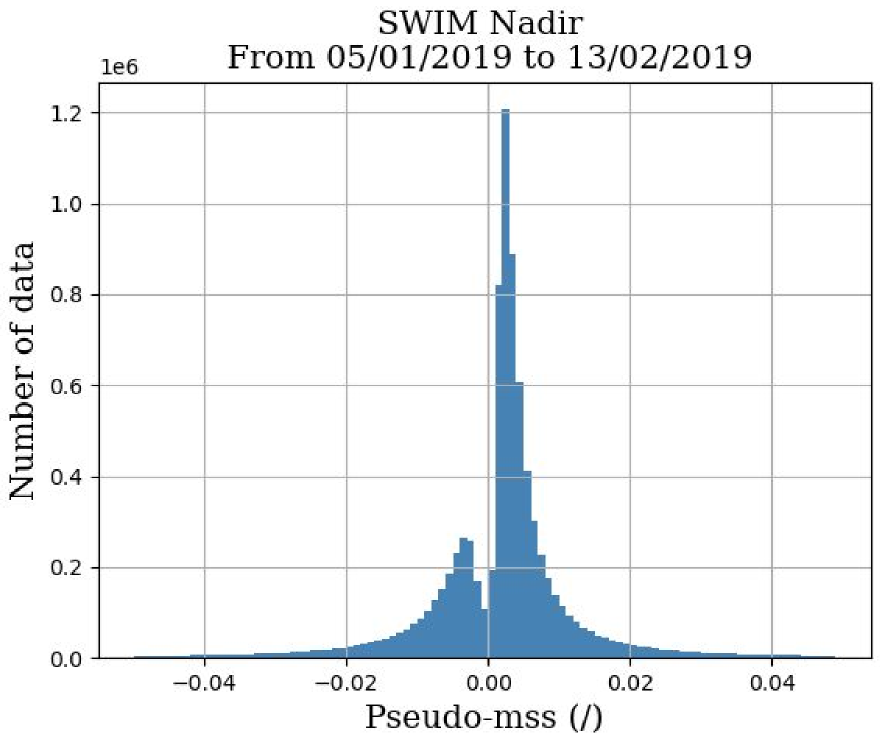
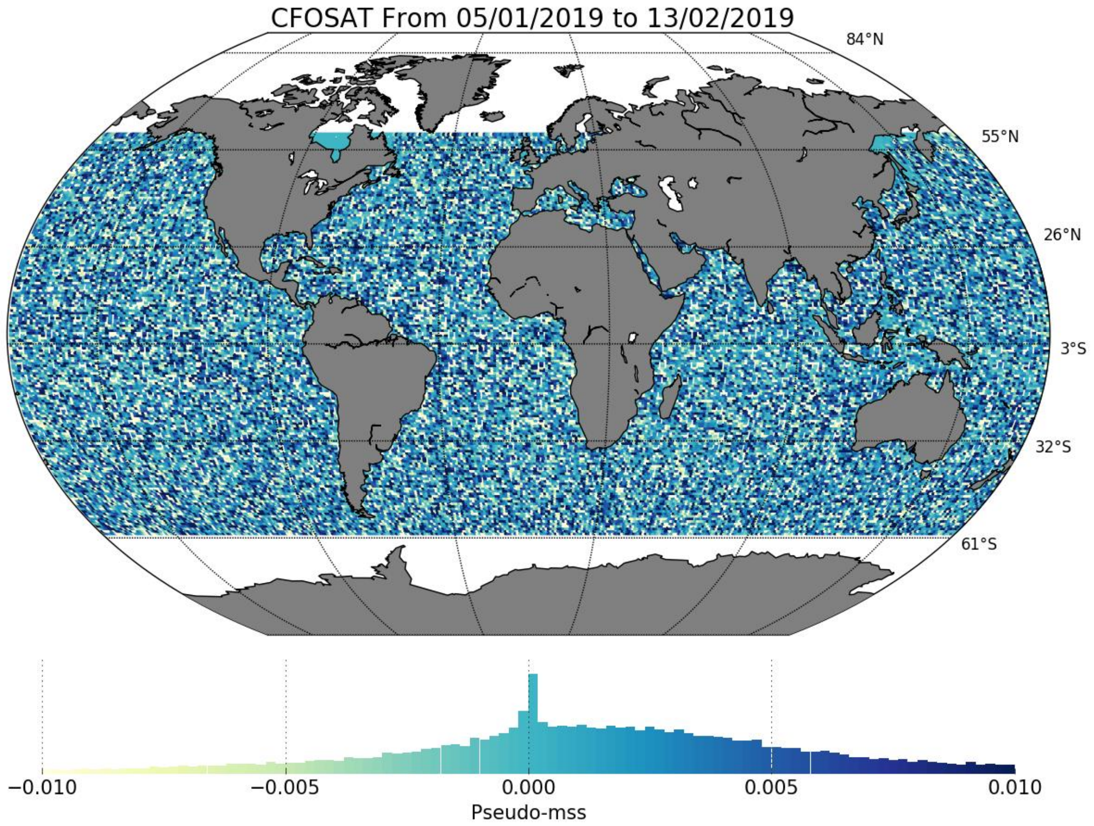
2- The nadir pseudo-mss : Global behaviour on ocean : raw values

Dataset : L2ANAD, mss_native on ~ 1 month of data | Selection : abs(LAT)<60 and Distance to shoreline > 20km





Gridded map of 1° (lat,lon) boxes

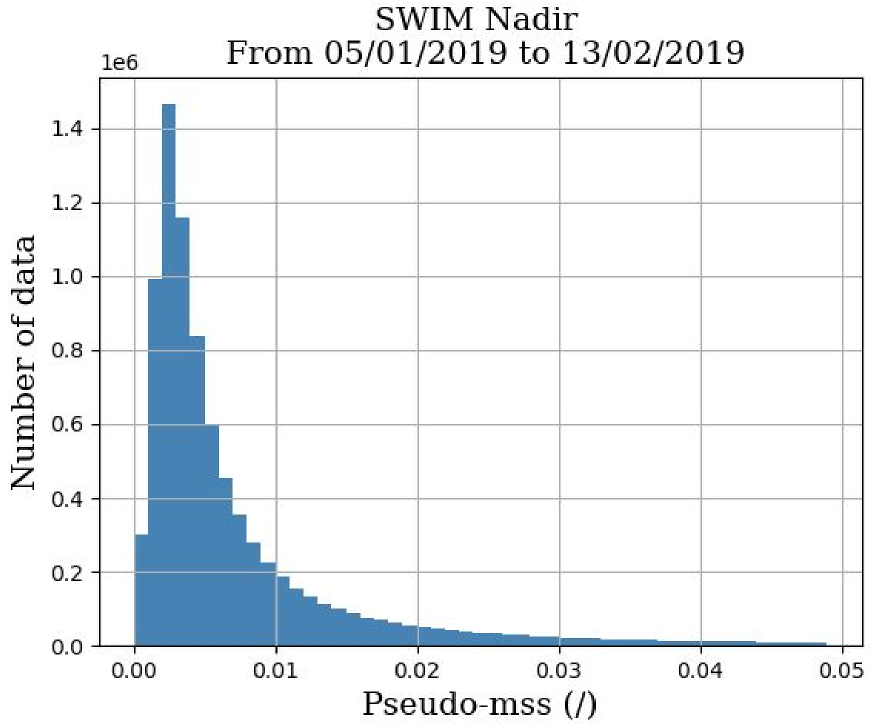
Many negative values → not physical but expected, due to the speckle noise and the estimation process

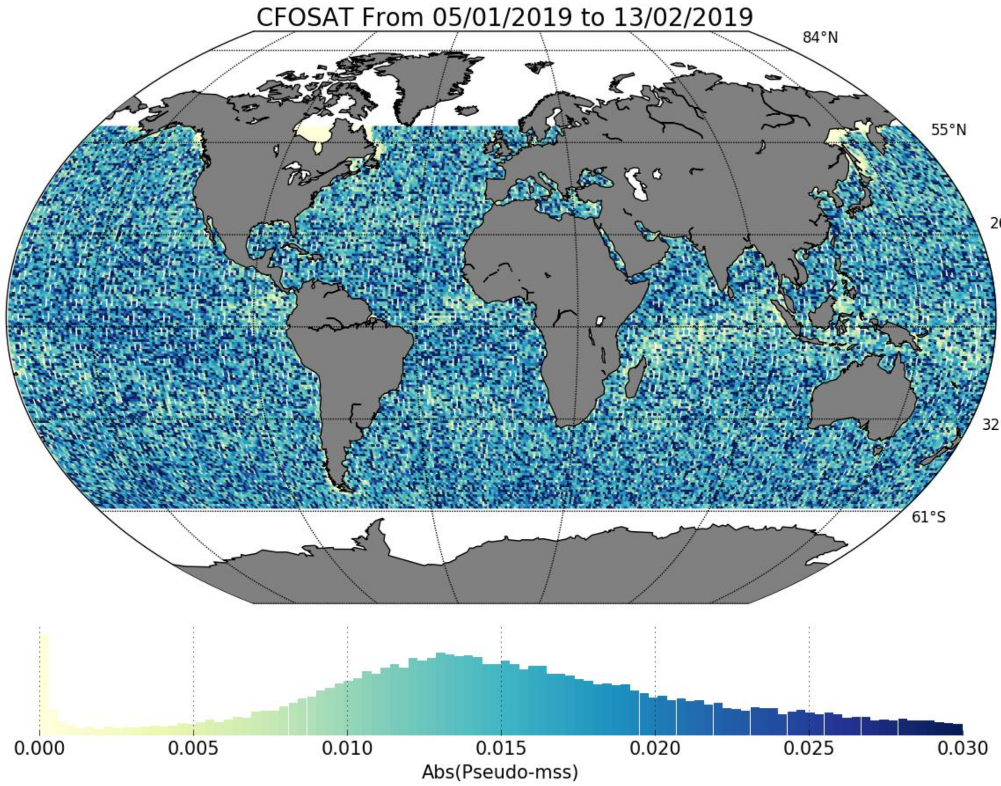
2 distinct populations : negative and positive

No geophysical patterns → Seems to be only noise !!!

2- The nadir pseudo-mss : Global behaviour on ocean : absolute values

Dataset : L2ANAD, ABS(mss_native) on ~ 1 month of data | Selection : abs(LAT)<60 and Distance to shoreline > 20km





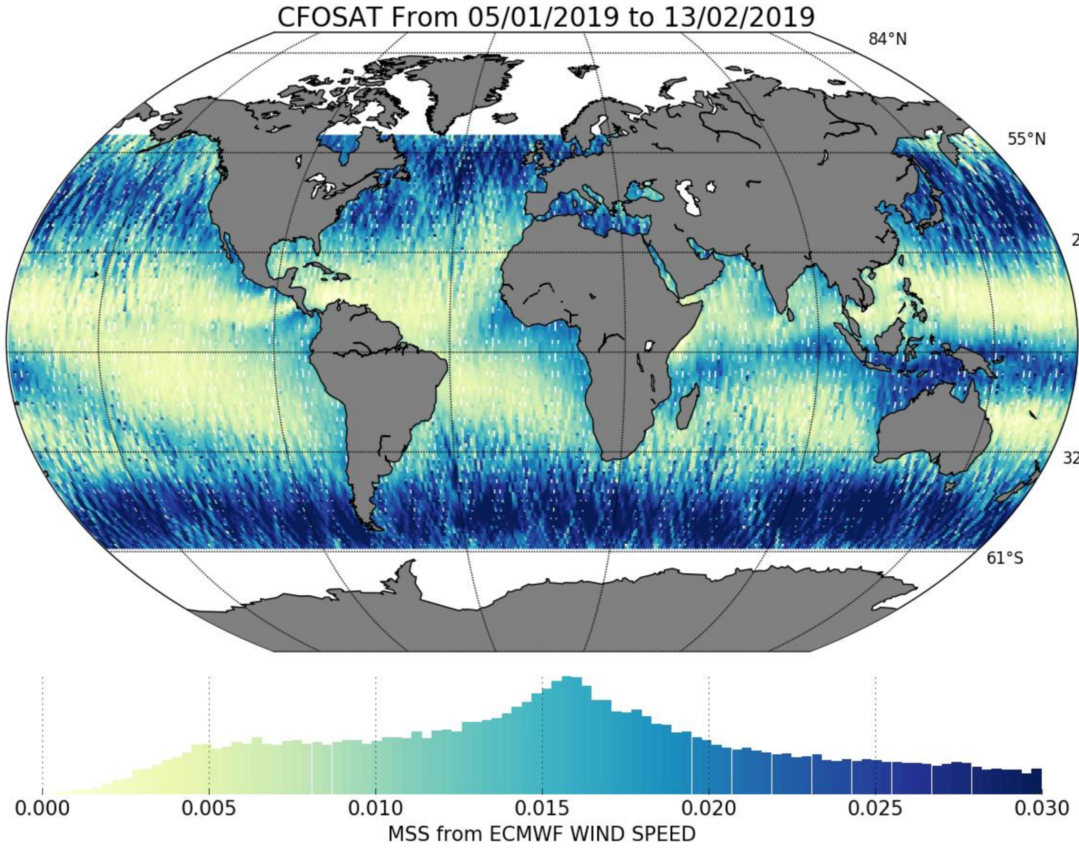
Gridded map of 1° (lat,lon) boxes

Absolute values : small patterns appear under the important noise that seems to be correlated to the surface roughness

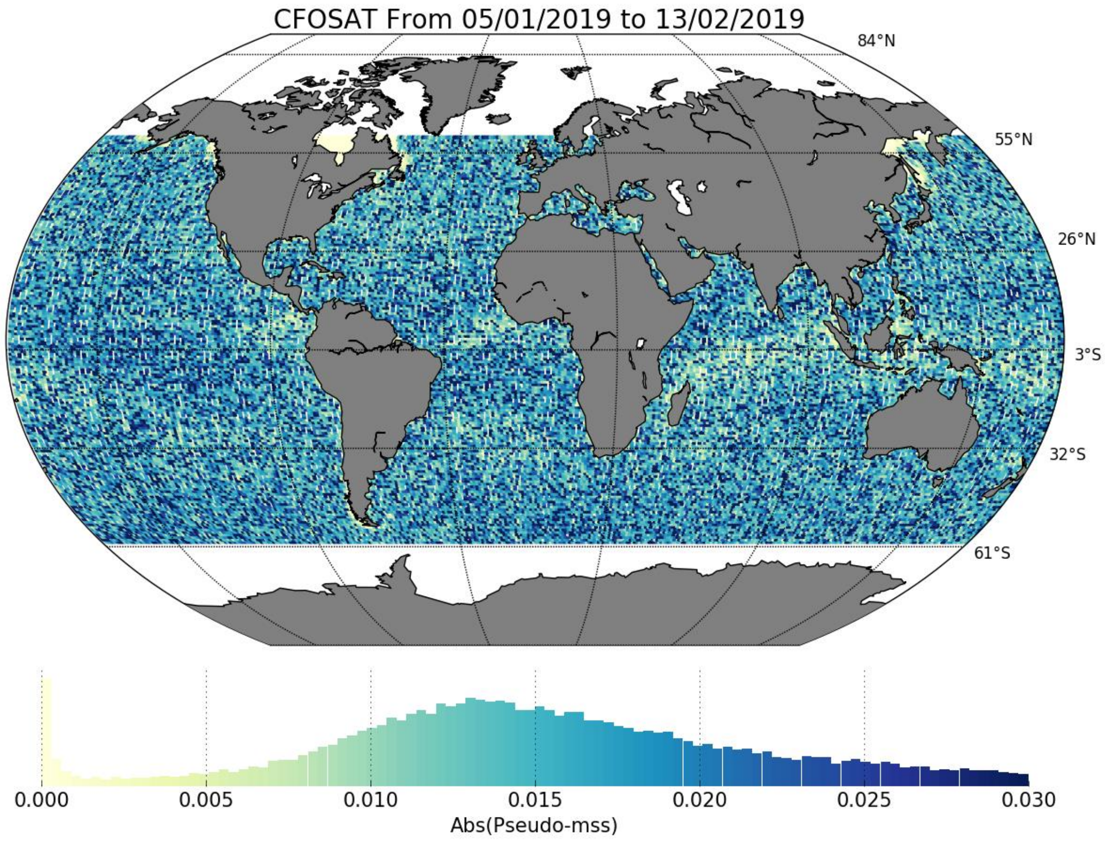
→ Maybe this parameter can be used on ocean after all ?

<u>2- The nadir pseudo-mss</u> : Global behaviour on ocean : comparison to MODEL

<u>**Dataset**</u> : L2ANAD, ABS(mss_native) on ~ 1 month of data | Selection : abs(LAT)<60 and Distance to shoreline > 20km



MSS = 0.0016 U_{10}(Nadir) + 0.016 [Freilich and Vanhoff (2003)]



Gridded map of 1° (lat,lon) boxes

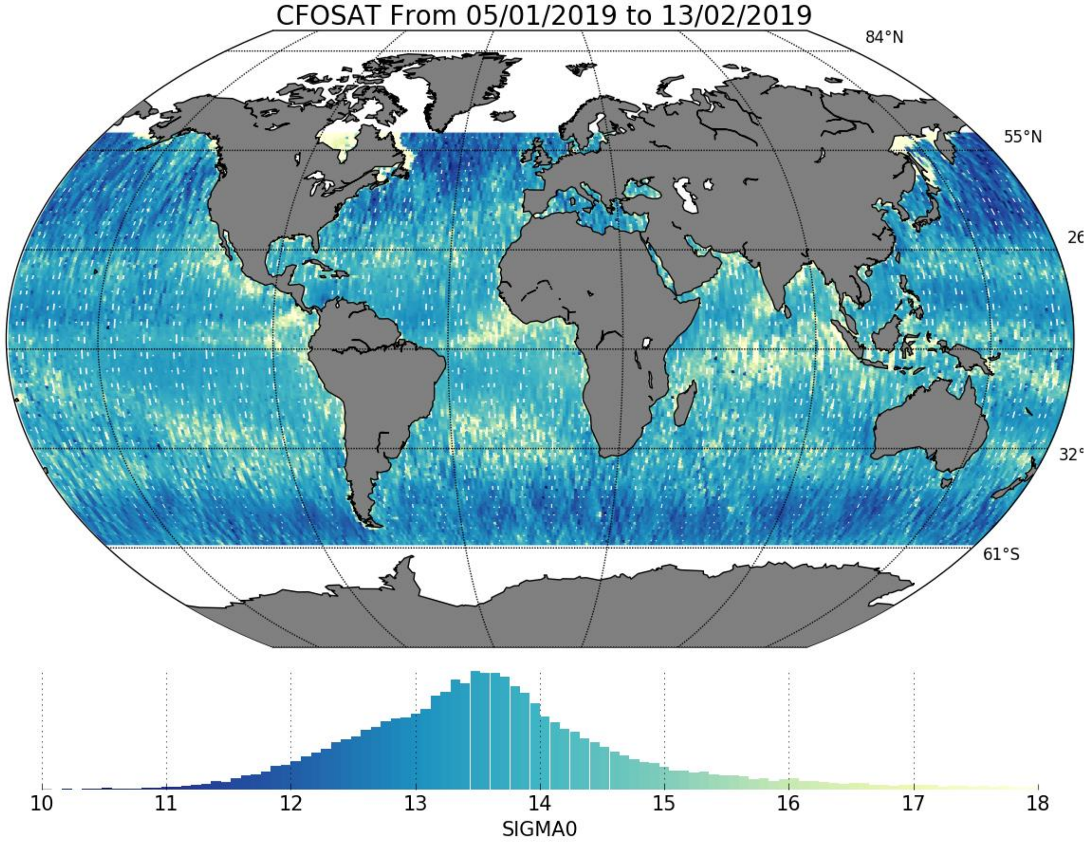
→ The range of variation is comparable to the mss computed from ECMWF wind speed

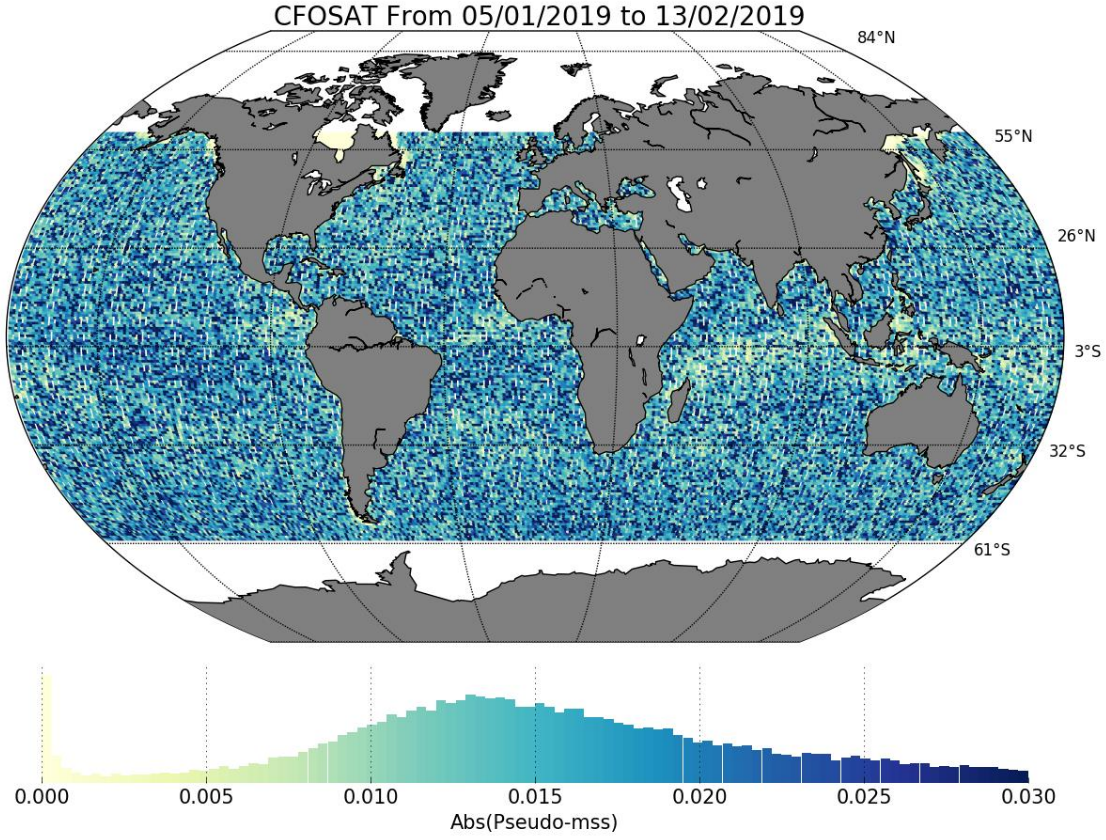
→ Few patterns seem to be comparable but in general, the two datasets don't seem highly correlated

→ As expected, this parameter seems to contain only information on low-state areas (nothing on the circumpolar for instance)

2- The nadir pseudo-mss : Global behaviour on ocean : comparison to Nadir Sigma0

Dataset : L2ANAD, ABS(mss_native) on ~ 1 month of data | Selection : abs(LAT)<60 and Distance to shoreline > 20km



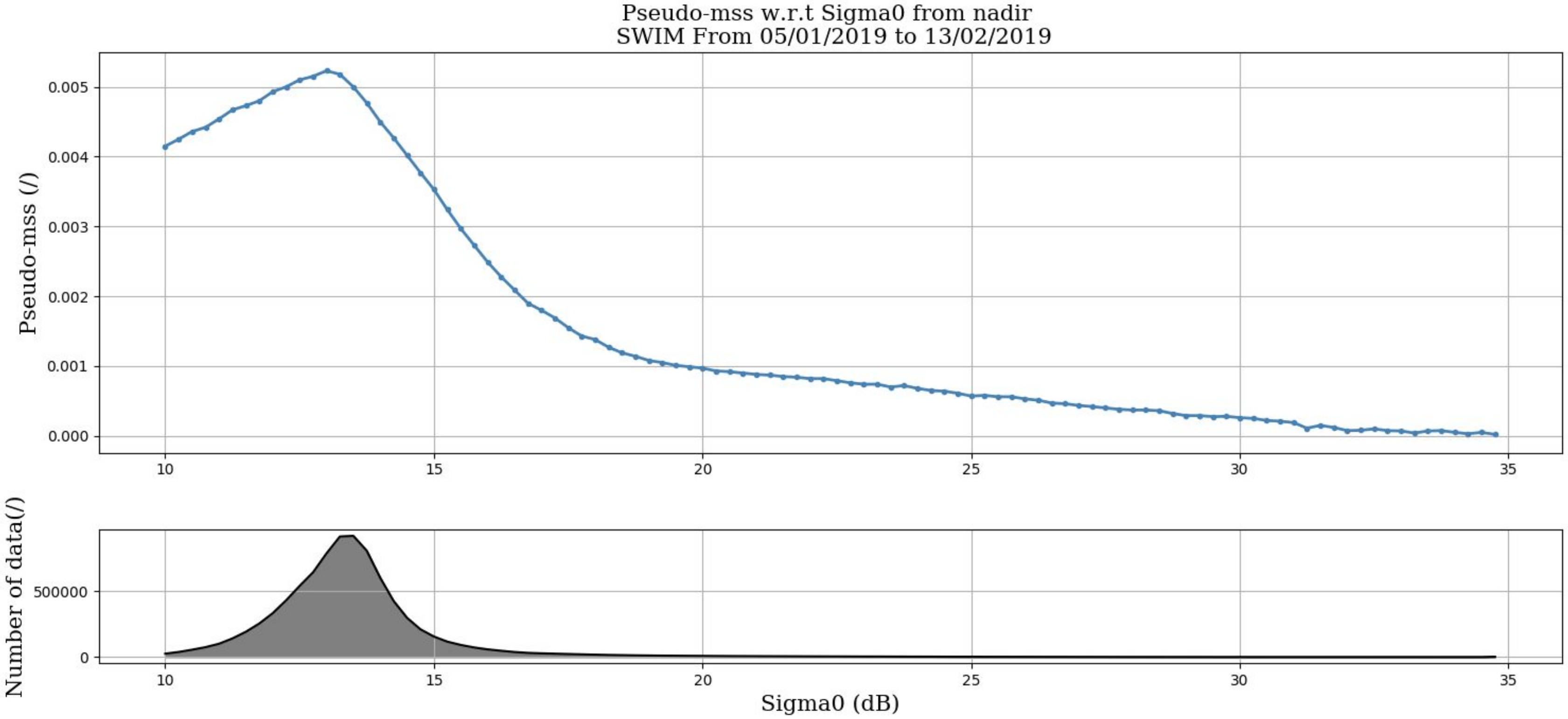


→ Apparent correlation between high Sigma0 and low mss values

→ As expected, no obvious information on high-state areas (low Sigma0 values) where the speckle noise is dominant compared to the pseudo-mss variability

2- The nadir pseudo-mss : Global behaviour on ocean : comparison to Nadir Sigma0

Dataset : L2ANAD, ABS(mss_native) on ~ 1 month of data | Selection : abs(LAT)<60 and Distance to shoreline > 20km



Median of pseudo-mss per boxes of 0,25 dB

The pseudo-mss decreases when the Sigma0 increases which is totally expected → specular surfaces are characterized by low mss and high Sigma0 values (at nadir)

<u>2- The nadir pseudo-mss</u> : Global behaviour on ocean : Perspectives

- Raw pseudo mss values from L2ANAD do no seem to be exploitable on ocean

- By taking the absolute values, some geophysical pattern appear on low state areas where the speckle noise is less important on the waveform, allowing the pseudo-mss variations to be visible
  - No clear correlation with the mss computed from the ECMWF wind speed
  - Interesting dependency to the nadir Sigma0 : the pseudo-mss is lower when the sigma0 is higher, which suggests that this parameter may contain useful information in some areas

  → **Preliminary recommendation : use the absolute values and not the raw values of this parameter**

- It might be interesting to smooth/filter the pseudo-mss to reduce this very high noise and have a more exploitable parameter on ocean

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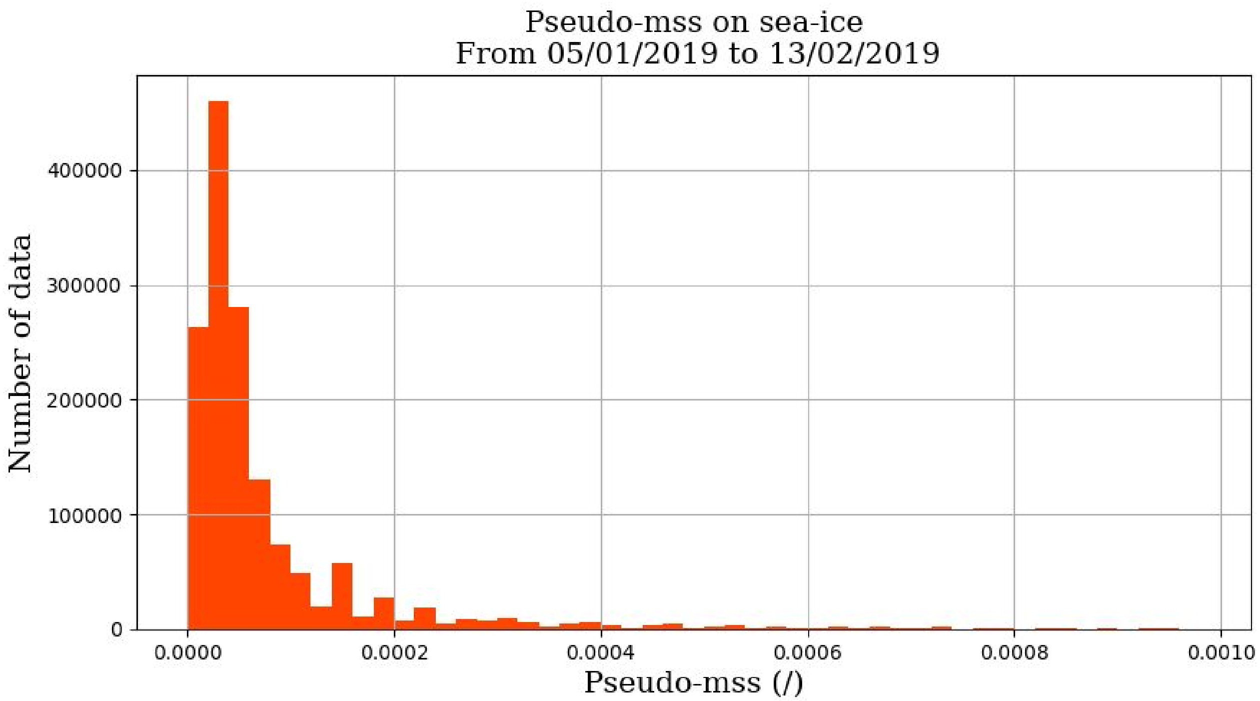
2- The nadir pseudo-mss on sea-ice : range of value

Dataset : L2ANAD, ABS(mss_native) | Selection : Sea Ice Fraction from OSISAF > 10%



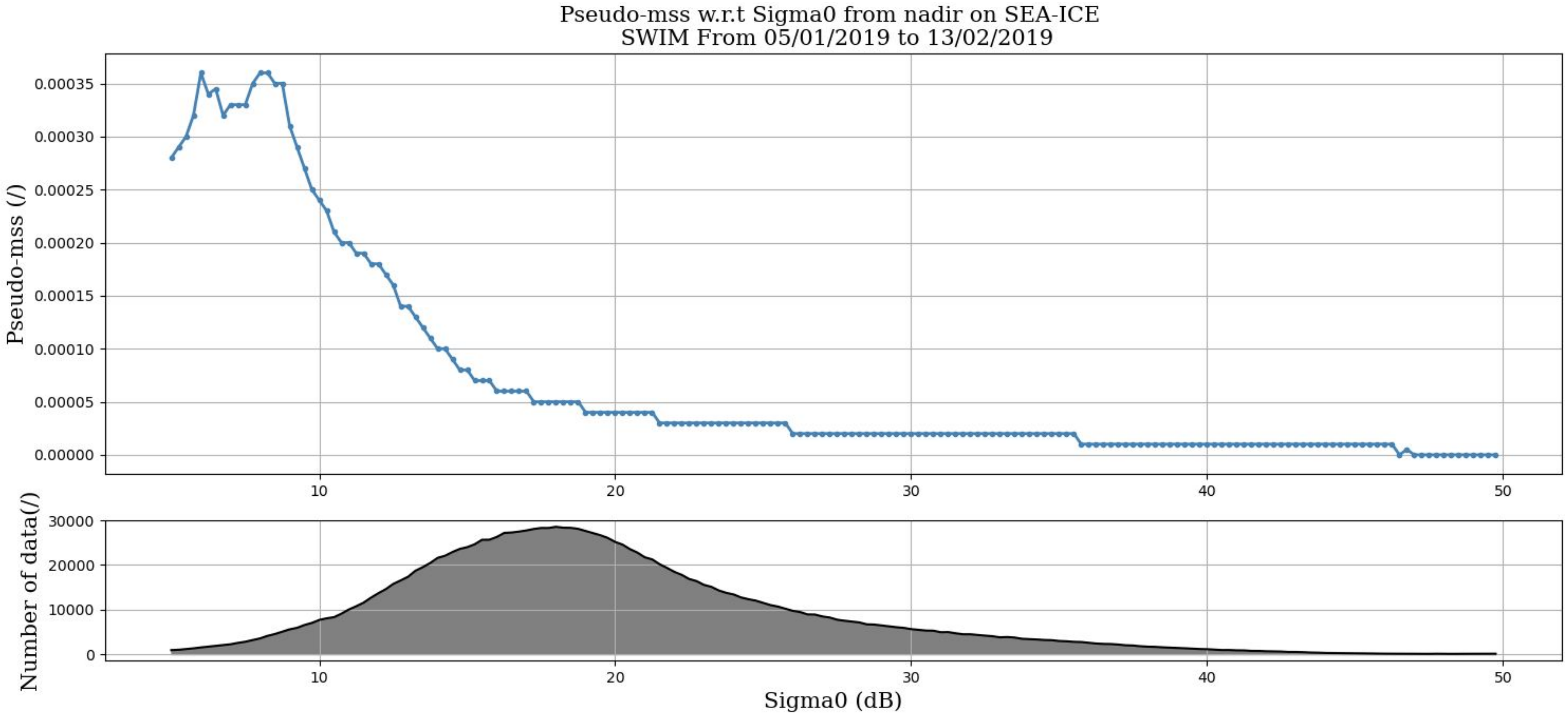
- The pseudo-mss parameter can be exploitable on sea-ice areas because of the low roughness of the sea-ice

→ No speckle noise hiding the pseudo-mss variations

- As expected, the range of values is much lower on sea-ice (more specular surfaces)

2- The nadir pseudo-mss on sea-ice : correlation to nadir Sigma0

Dataset : L2ANAD, ABS(mss_native) | Selection : Sea Ice Fraction from OSISAF > 10%

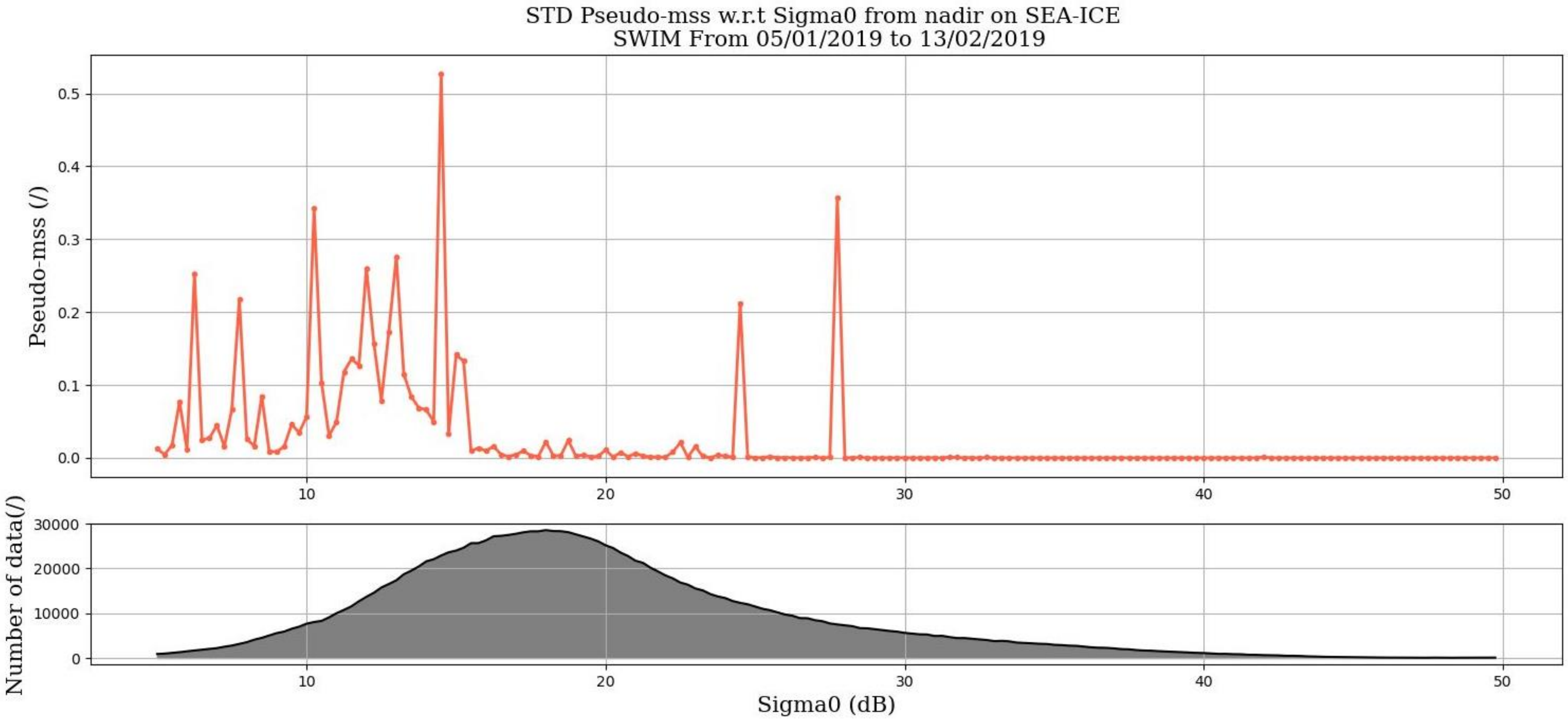


Median of pseudo-mss per boxes of 0,25 dB

- The pseudo-mss decreases when the Sigma0 increases → Totally expected and normal, they are linked in the model

2- The nadir pseudo-mss on sea-ice : correlation to nadir Sigma0

Dataset : L2ANAD, ABS(mss_native) | Selection : Sea Ice Fraction from OSISAF > 10%



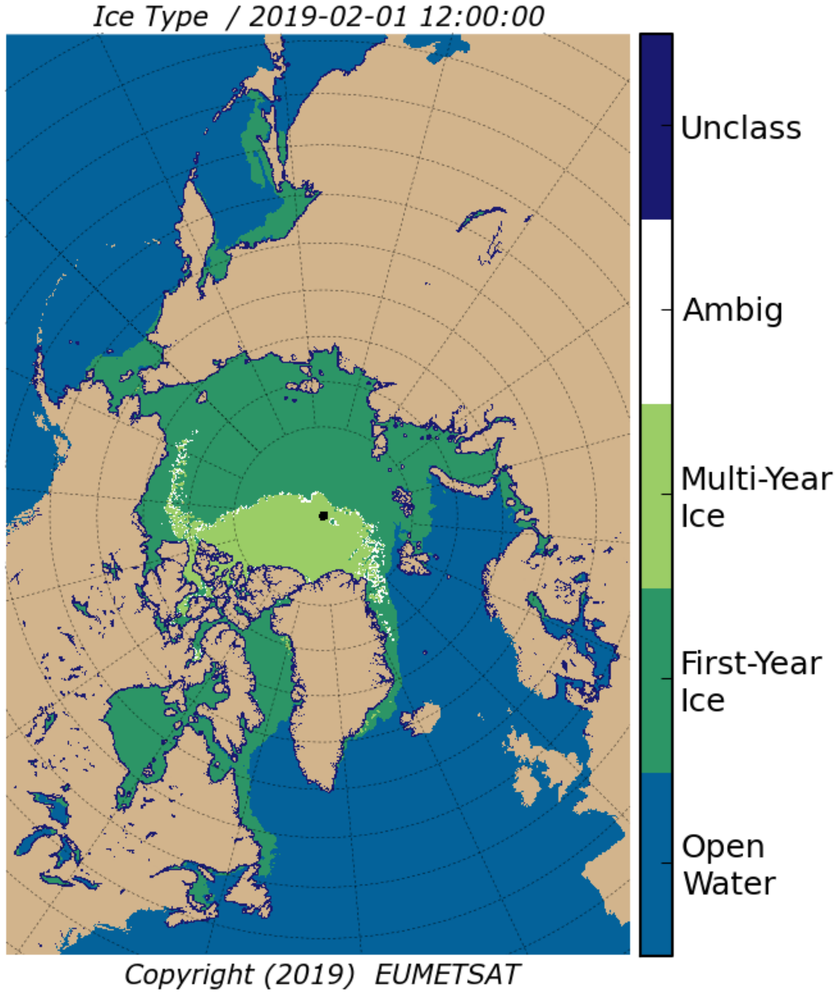
Standard Deviation of pseudo-mss per boxes of 0,25 dB

- As expected, very high STD on rougher surfaces (low sigma0 values) like open water**. Significantly lower STD** for more specular regions like sea ice → Signal should be indeed visible for these surfaces
- In the publication, it is explained that the Sigma0 is well correlated to the different ice types in the Arctic Area

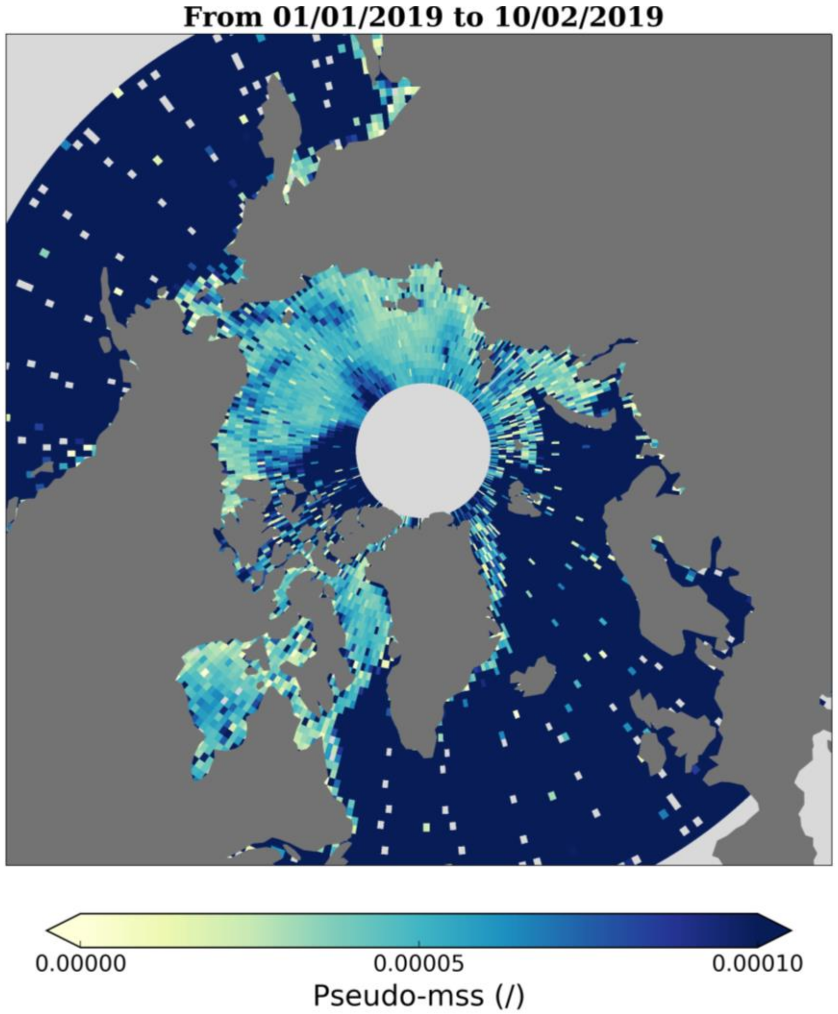
→ What about the pseudo- mss ?

2- The nadir pseudo-mss on sea-ice : qualitative comparison to OSISAF Ice-Type

Dataset : L2ANAD, ABS(mss_native) | Selection : abs(LAT)>55 and Distance to shoreline > 20km



Daily sea-ice type map extracted from the OSI-SAF quick-look website



Gridded map of pseudo-mss over 40 days of data

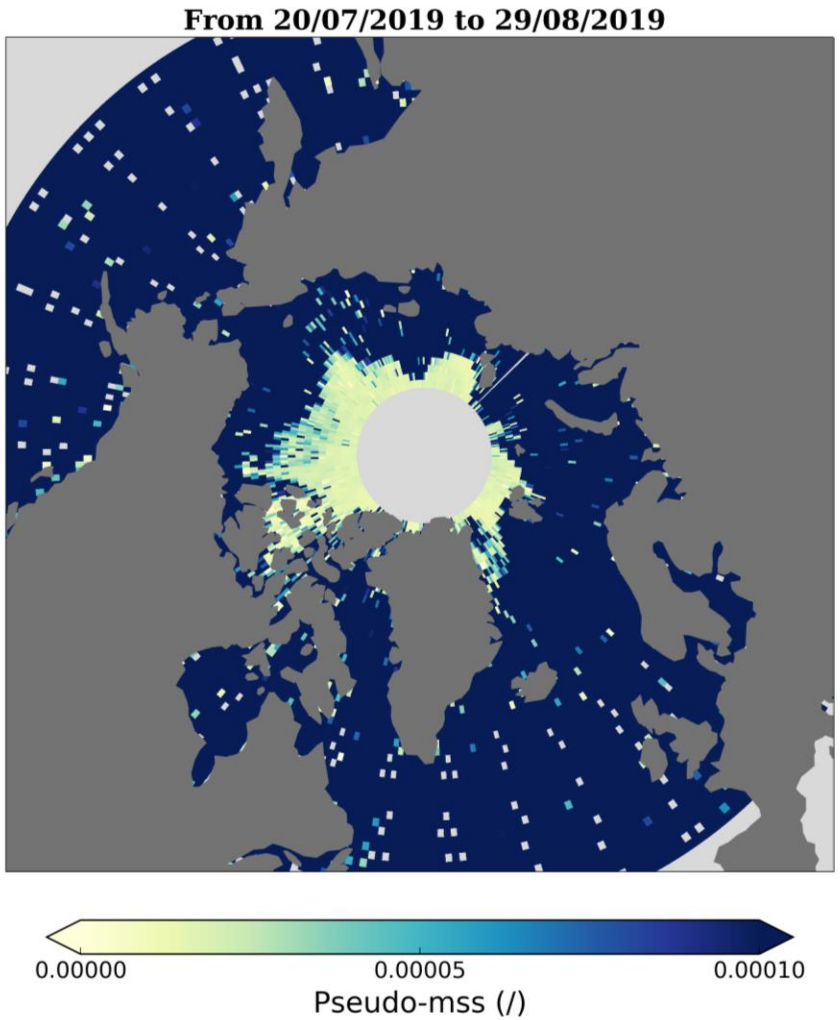
- The pseudo-mss **is totally consistent to OSISAF products** in terms of **sea-ice extension**
- We can see the **Multi-Year Ice** patch and the « tail » north of the Alaska, where the pseudo-mss is higher

→ Consistent with MYI roughness

2- The nadir pseudo-mss on sea-ice : qualitative comparison to OSISAF Ice-Type

Dataset : L2ANAD, ABS(mss_native) | Selection : abs(LAT)>55 and Distance to shoreline > 20km

Daily sea-ice type map extracted from the OSI-SAF quick-look website

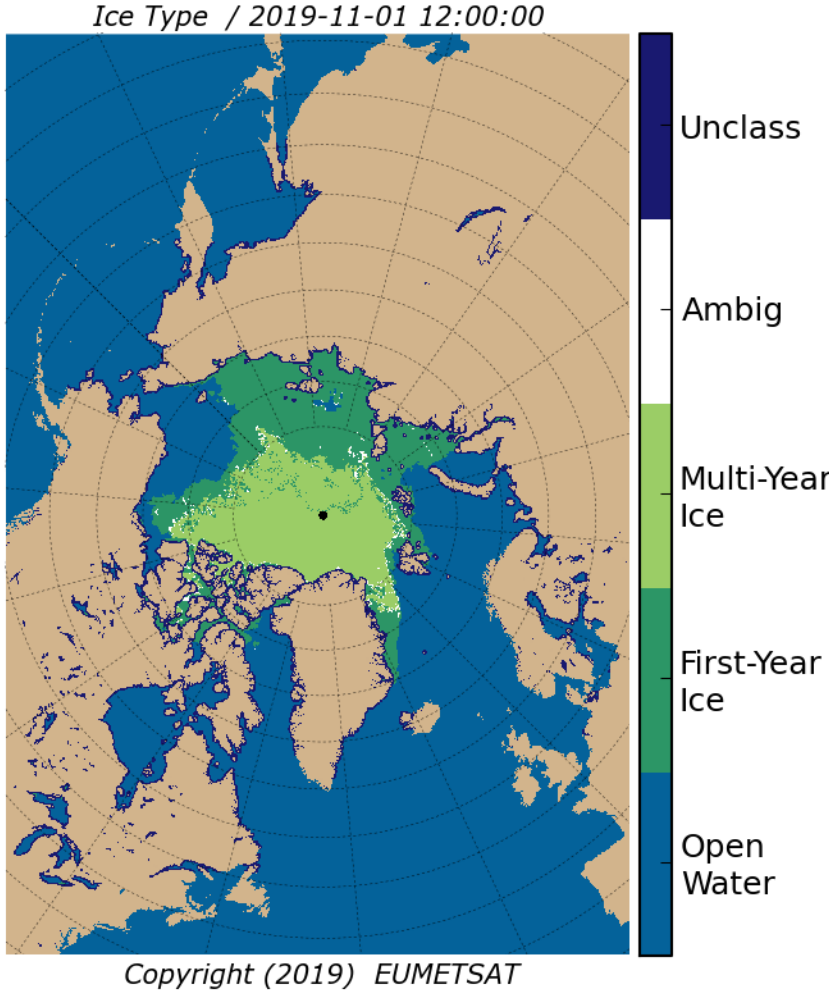


Gridded map of pseudo-mss over 40 days of data

- The pseudo-mss is again **totally consistent to OSISAF products** in terms of **sea-ice extension**
- We can see very low values of the pseudo-mss, typical of very reflective surfaces, consistent with the roughness expected at this time of the year
- During the summer in the Arctic Basin, the ice melts, creating highly specular surfaces

2- The nadir pseudo-mss on sea-ice : qualitative comparison to OSISAF Ice-Type

Dataset : L2ANAD, ABS(mss_native) | Selection : abs(LAT)>55 and Distance to shoreline > 20km



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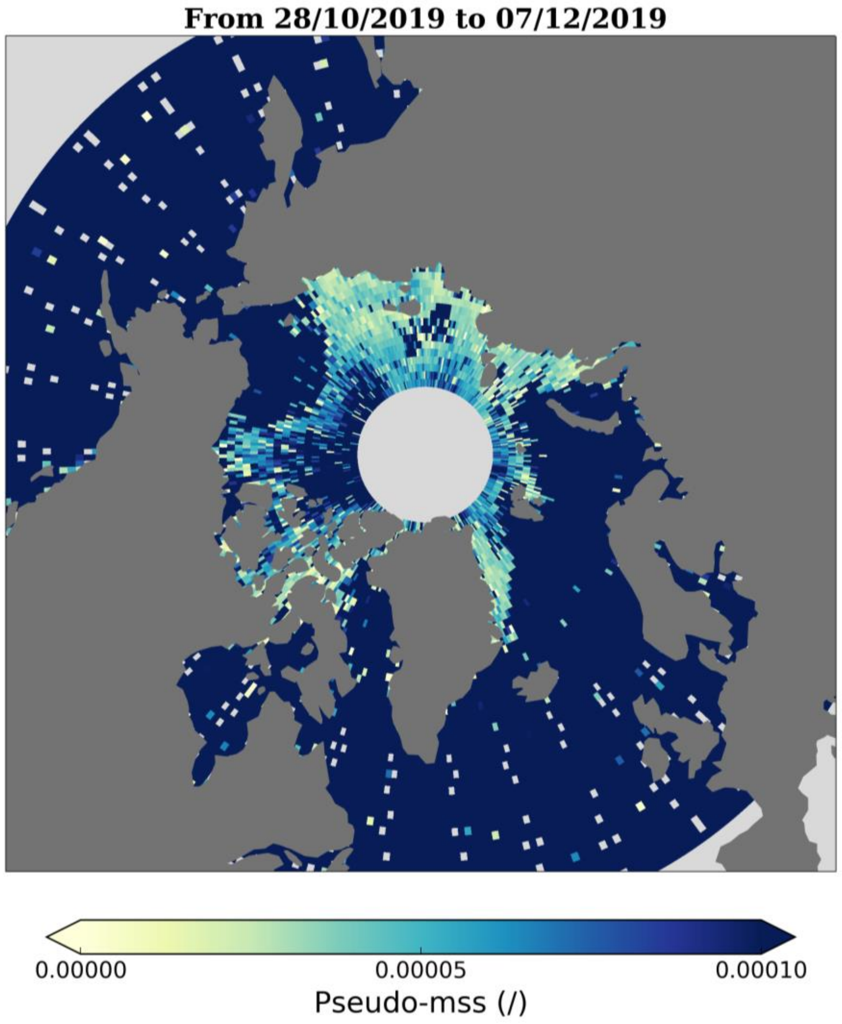

Gridded map of pseudo-mss over 40 days of data

- The pseudo-mss is again **totally consistent to OSISAF products** in terms of **sea-ice extension** (especially the Bering strait)
- We can see the **Multi-Year Ice** patch where the pseudo-mss is higher

→ Consistent with MYI roughness

2- The nadir pseudo-mss on sea-ice : conclusions

- The pseudo-mss parameter is much less noisy on sea-ice areas compared to open ocean, and is totally exploitable

- Just like the Sigma0, it is very well correlated to the sea-ice extent and the variations of the difference ice types from external data (OSISAF)

→ **It can be a complementary information to the peakiness and Sigma0 parameters for sea-ice application**

→ **On sea-ice, we also recommend to use the absolute values and not the raw values**

To go further

- Compare this pseudo-mss to the **other SWIM off-nadir beams** outputs.

- The retrieval of the geophysical parameter on sea-ice might be improved (see next part of the presentation)

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3- The waveform classification: description

- To improve the performances of the the Adaptive retracker, a **waveform classification** could be implemented for SWIM echoes

- Used as an input in the algorithm, this could allow the retracker to adapt its processing to perform more accurately, especially on surfaces **other than open ocean**.

- This algorithm developped by **CNES/CLS** is based on a neural-network approach to classify waveform depending on their shape.

- It has been already developped for LRM missions (Jason, SARAL) and SAR mission (Sentinel-3, Cryosat-2) and is currently used in the **Jason-3 GDR Adaptive algorithm**.

- Because each mission is different, the waveform classification **must be developped for each mission.**

- In a nutshell, this consists in constructing a learning database of **several thousands of echoes,** identify the most relevant **geometric parameter** for the mission to put them in the neural network, and then adjust and analyse to have the most optimal neural network → It takes some time to be developped !

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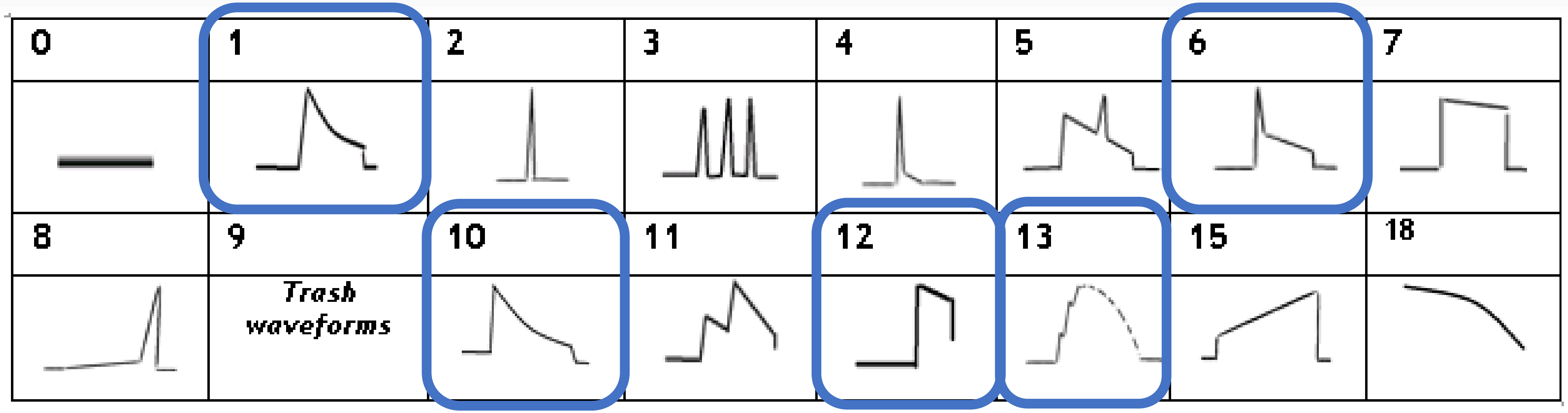
3- The waveform classification: description based on the Jason-3 classes



Class 1 : Brownian waveforms, typical from oceanic surfaces. Can also be found on big lakes or rough sea-ice. Represents the large majority of the echoes (>95%).
Class 6 : Diffuse echoes with a peak on the leading edge or with a steep trailing edge →sea ice with an average roughness (MYI)
Class 10, 12,13 : Less common waveforms, can be found on land or exotic events

→ On these waveforms, the Adaptive processes the whole waveform with a real MLE likelihood function

→ This is how the current SWIM algorithm processes **all waveforms**

→ **No improvements possible for these waveforms, the SWIM algorithm is already optimal**

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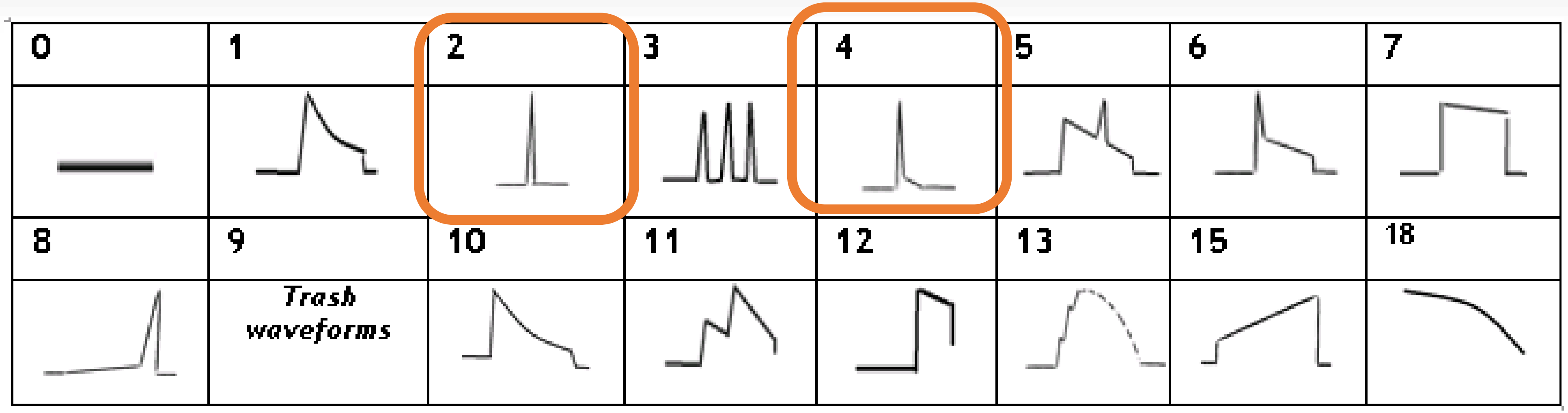

Class 2 : Very peaky waveforms, found on sea-ice leads, narrow rivers and small lakes

Class 4 : Specular return with a trailing edge → High reflective sea ice or rivers

→ On these classes, the Adaptive could apply a **reduced windowing** (a few gates after the maximum) and a **LSE** likelihood criterion (not MLE) because of the absence of speckle noise

→ Currently, the SWIM retracker processes the echoes on a full analysis window and a MLE likelihood criterion

→ Even though the performance of the algorithm seems already satisfying, **there is room for improvement for SWIM nadir on sea-ice areas**

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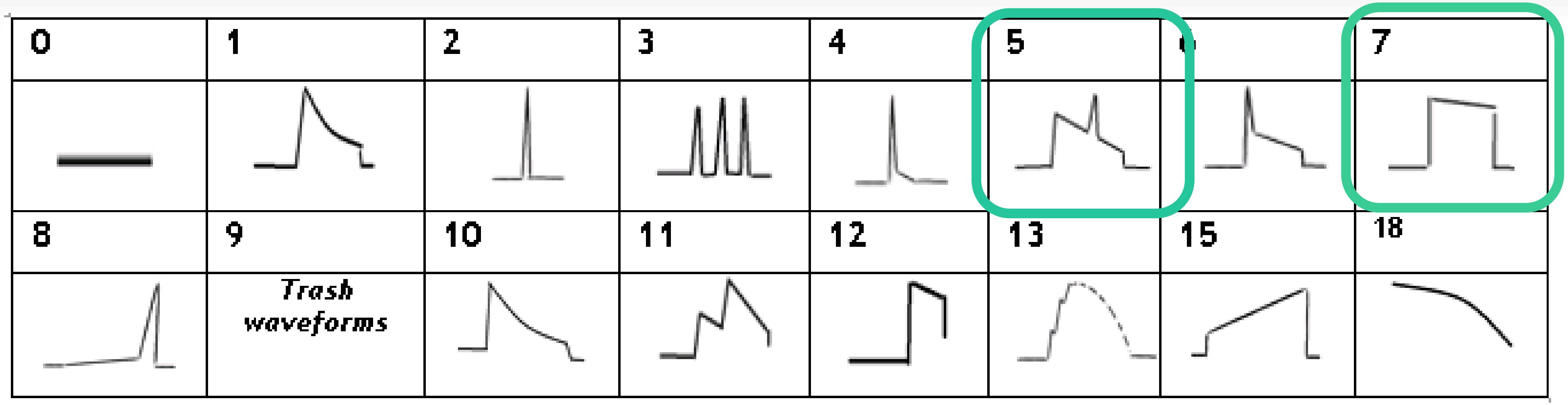


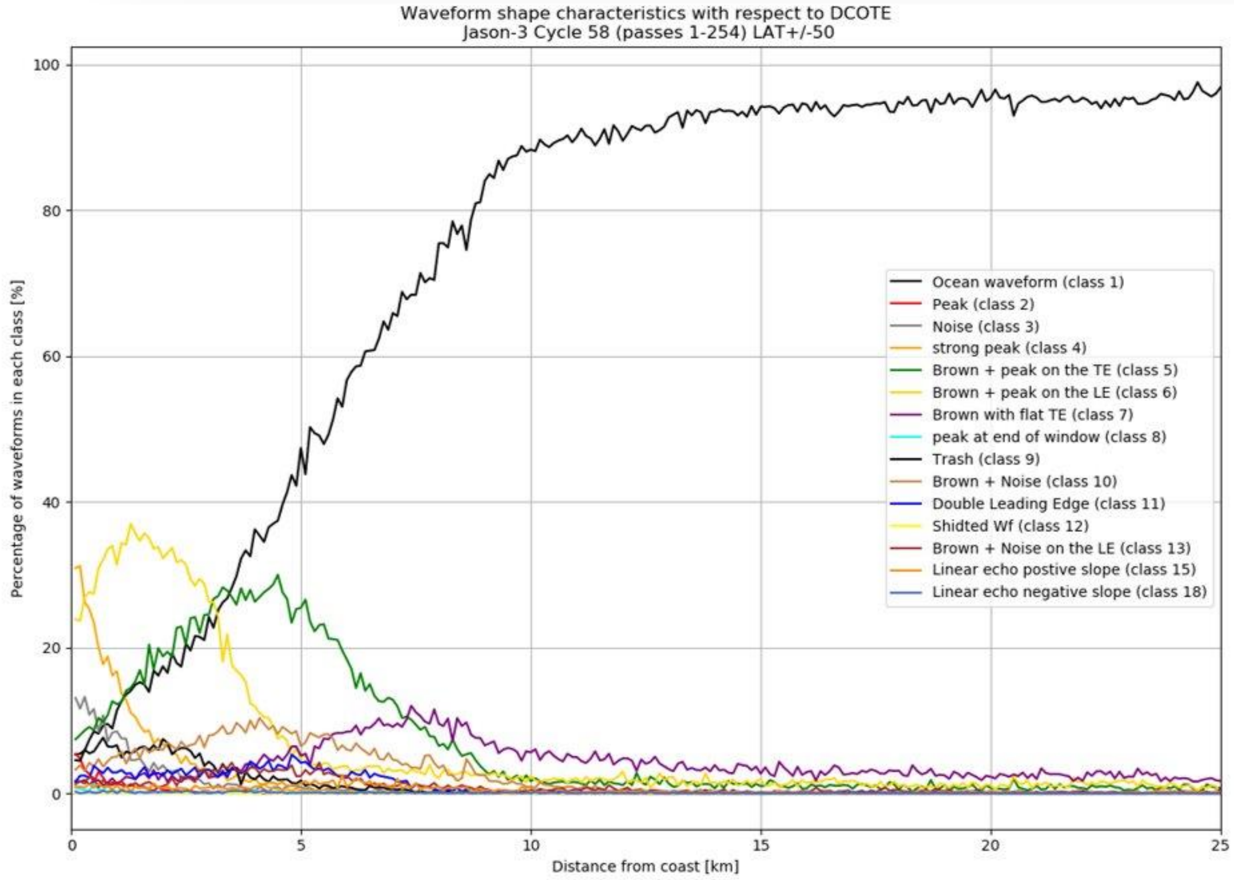
Class 5 & 7 : Echoes with a disruption on the trailing edge, typically found on land but also in the **coastal areas,** when the footprint encounters land.

→ On these classes, the Adaptive could apply a **reduced windowing** ([0,64] instead of [0,128]) allowing to fit the model on the « useful » part of the signal

→ This static windowing is not optimal but studies are on-going to improve the processing on coastal areas

→ This could really help to go **closer to the coast**

3- The waveform classification: description based on the Jason-3 classes



Percentage of the different Jason classes depending on the distance from the coast

→ When the distance to coast is <10km, the percentage of typical oceanic waveform decreases drastically

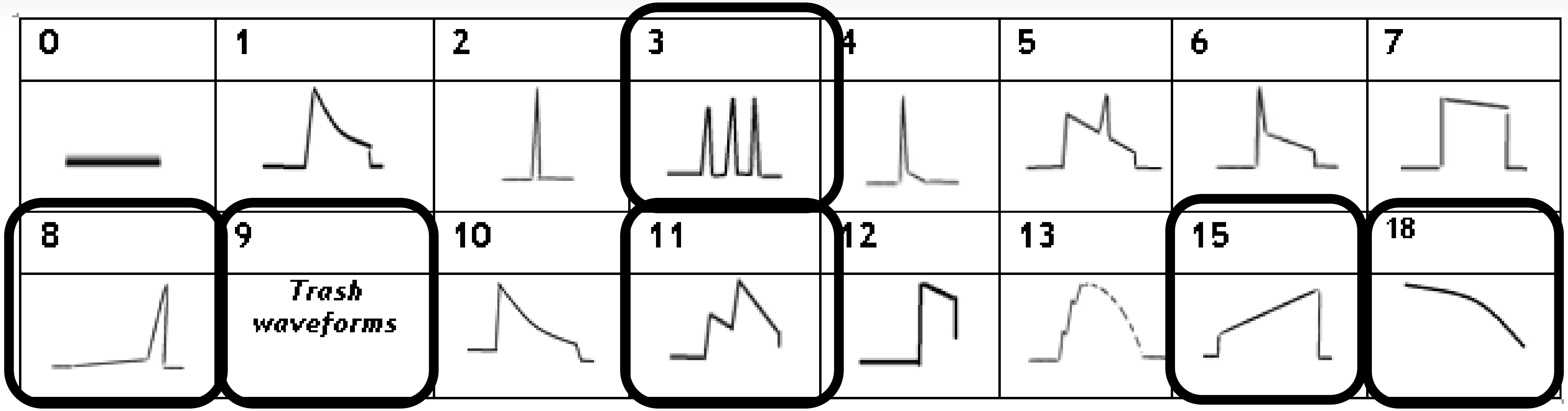
→ Close to the coast, other classes appear.

→ This shows that a processing based on a static reduced window (as implemented currently on Jason) could really help the performances in the **coastal regions**

→ **A dynamic windowing might also be considered to go further**

→ **Processing tends to go more and more towards high resolution (5Hz), so it's important to improve the processing close to the coast !**

3- The waveform classification: description based on the Jason-3 classes



Other classes: Complex echoes that can be found on land, land-ice, inland water

→ On these classes, the Adaptive could choose **not to process those echoes** as they are too complex to be retracked for the moment.

→ Nevertheless, the class information can be really useful to edit data, gain CPU time and maybe understand more about the data to be able to process them in the future .

Conclusions & perspectives (1)

- The excellent performances of the ground segment retracker called the Adaptive have been detailed in a peer-review paper accepted for submission in the next issue of IEEE Transactions on Geoscience and Remote Sensing (TGRS)

- This retracker estimates a new parameter correlated to the mean-square-slope of the surface, called the **pseudo-mss**. This presentation aimed at performing a first description of this parameter based on what was expected from the theory :

  - On open ocean, this parameter is extremely noisy, but by taking the **absolute values**, some signatures are showing for low-state areas where the surface is more specular → smoothing the parameter could be a good idea to reduce the noise

  - On the Arctic region, the pseudo-mss is very well correlated to the sea-ice type from OSISAF. It is very less noisy and can be exploitable for sea-ice application, complementary to the Sigma0 that shows similar trends. → It would be interesting to compare it to off-nadir parameters.

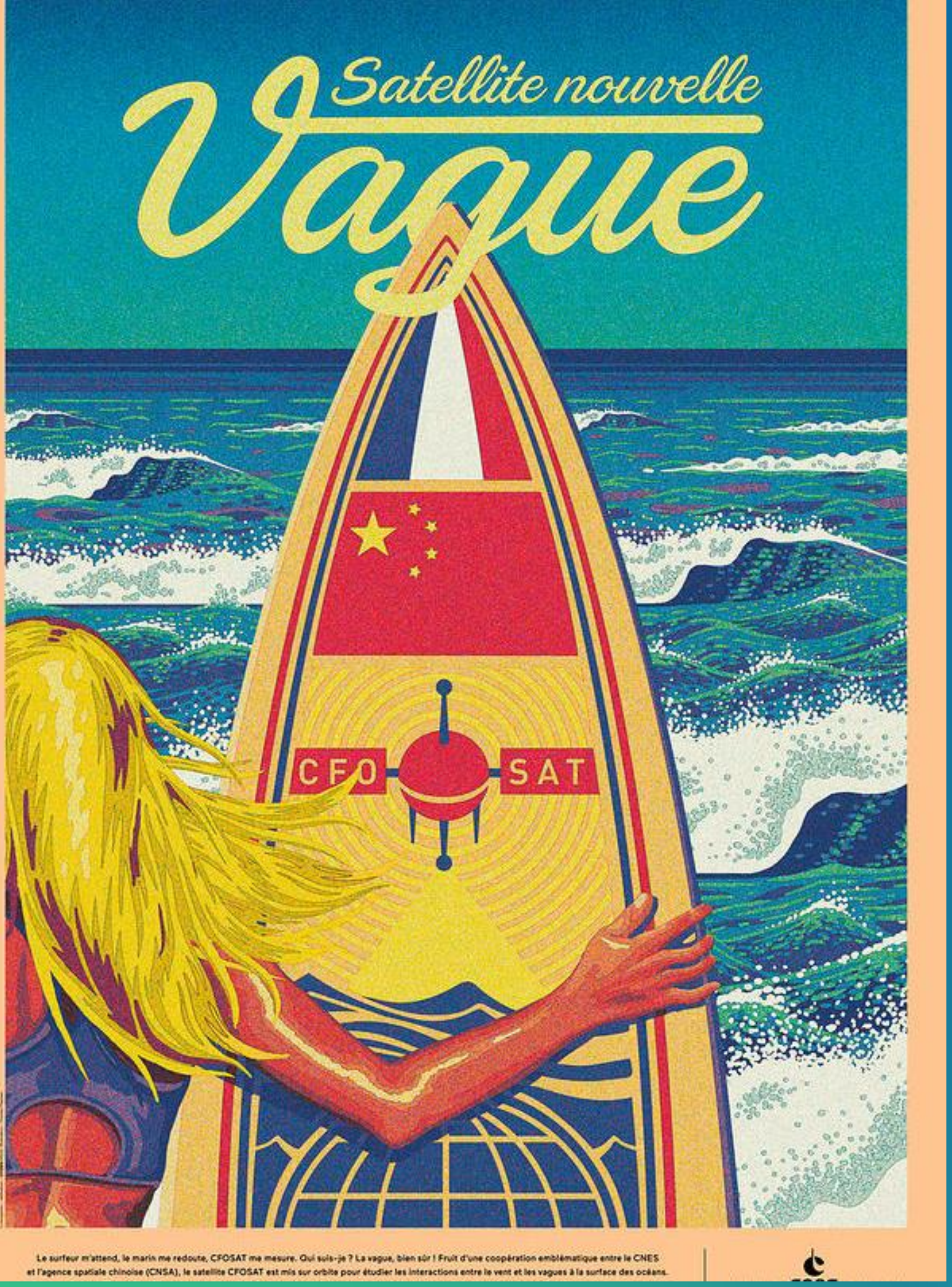
  - To go further, a detailed analysis and comparison of the parameter could be performed to assess its possible added-value compared to the Sigma0

Conclusions & perspectives (2)

- The Adaptive algorithm performs in an optimal way on the majority of the waveforms (open ocean), but it could be improved on heterogeneous surfaces thanks to the implementation of a **Neural-Netword waveform classification**. Is has already been developed for several altimetric missions (Jason, SARAL, Sentinel-3, Cryosat-2) and is currently implemented in the Jason-3 GDR-F products.

    - On sea-ice, this could help the algorithm to converge more often and more accurately
    - On coastal areas, this could help to go closer to the coast and be less disturbed by the land in the footprint
    - It could help to edit the "non useful" data

→ In a more general way, this classification could really be an added-value and and be used in a large variety of applications



THANK YOU ! ☺

I'm available to answer your online questions

fpiras@groupcls.com