SWOT
Science Team Meeting
www.swot2025.org
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Sea Ice Characterization from KaRIn HR data and Application to S3NG-T

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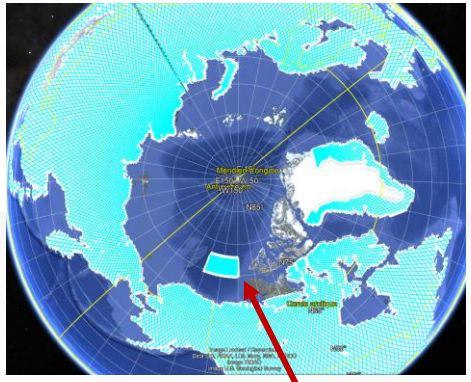
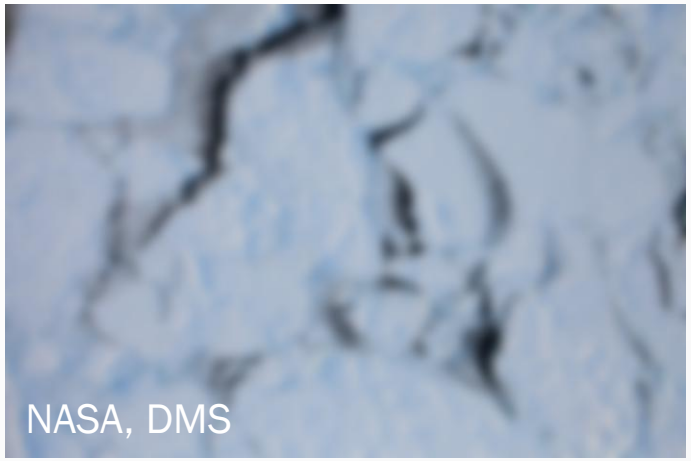
[1] CLS, [2] CNES, [3] LEGOS

SWOT data types



There are three types of official products:

LR

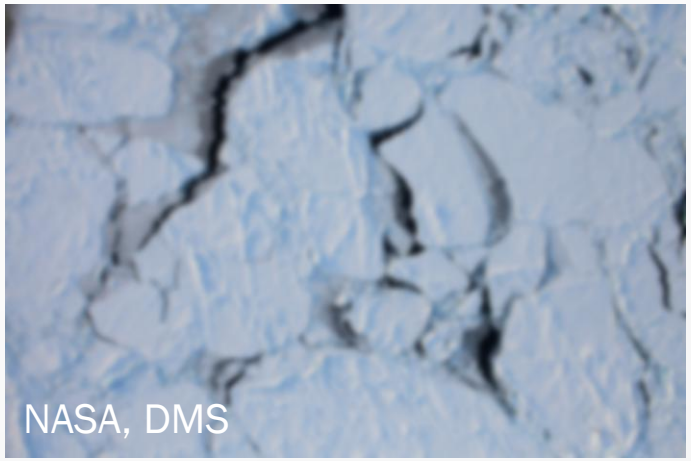


Resolution 2 km

Everywhere

Designed for the ocean

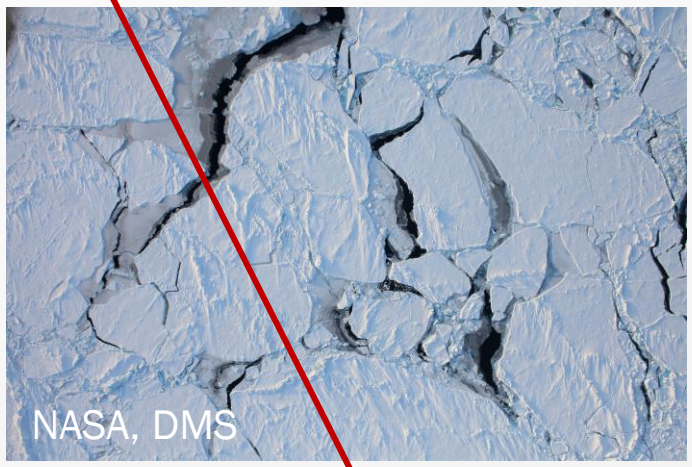
LR Unsmoothed



Resolution 500 m, posting rate 250 m

Everywhere

HR PIXC



Resolution ~ 10—60 m, 60 km tiles

Only on land + small seasonal patch of Arctic Ocean in winter + patches over the ocean in the calval phase

Designed for hydrology

None of these products are designed for sea ice, but there is signal

SWOT data types: HR sea ice patch(es?)

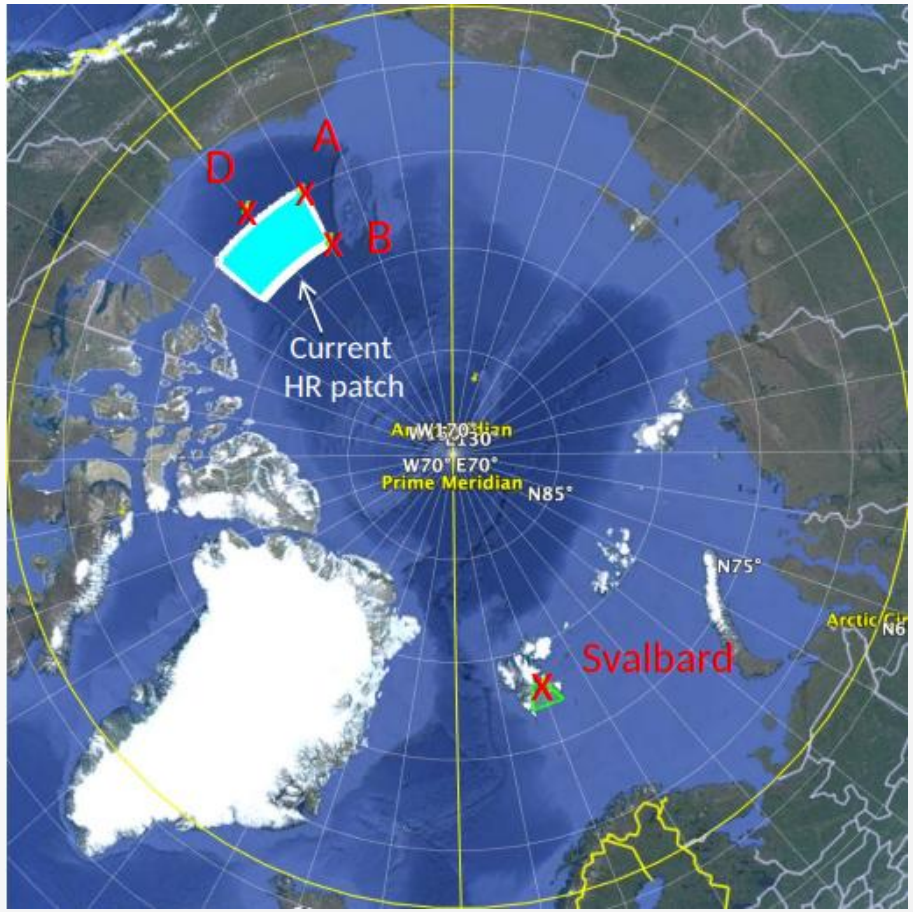
Moorings

4 permanent moorings for freeboard and sea ice thickness validations:

- 3 BGEPs: A, B and D
- 1 LOCEAN in Svalbard

Positions

	Latitude	Longitude
A	75 °N	150 °W
B	78 °N	150 °W
D	74 °N	140 °W
LOCEAN	77.97 °N	20.2 °E



SWOT Cryo-WG: HR masks over Arctic moorings

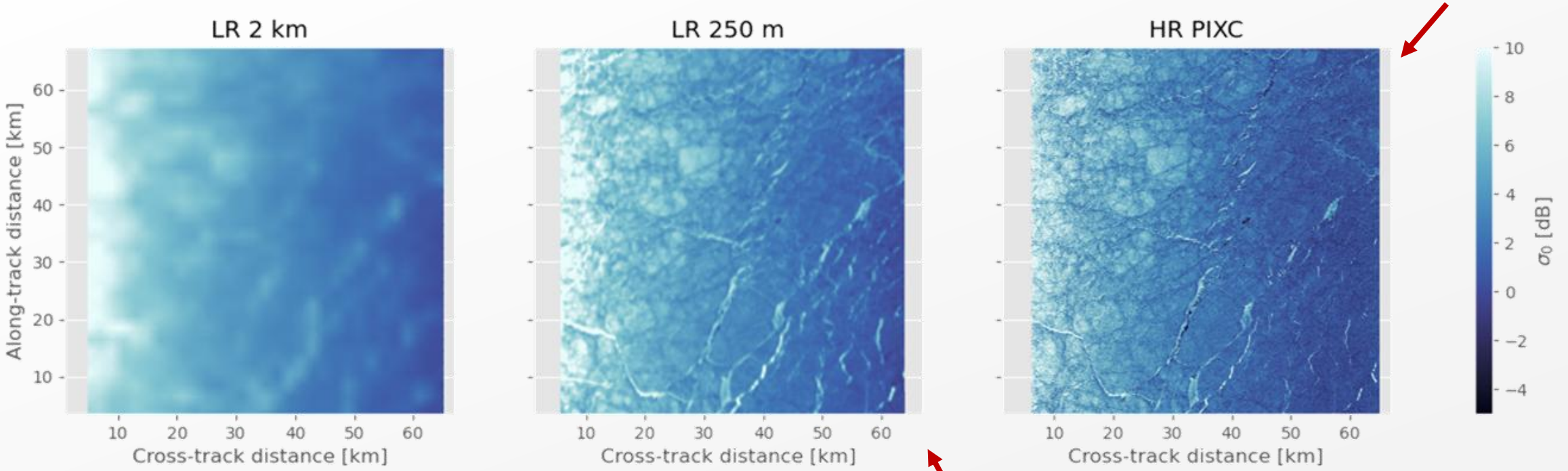
Periods

The current HR patch is active from **December to March**. We would like to survey the sea ice **full year-round** over the 3 BGEP moorings. In Svalbard, the sea ice is present 6 months from January to June.

What does sea ice look like in SWOT data?

SWOT: Three data resolutions: LR 2 km, LR 250 m and HR

High level of details!

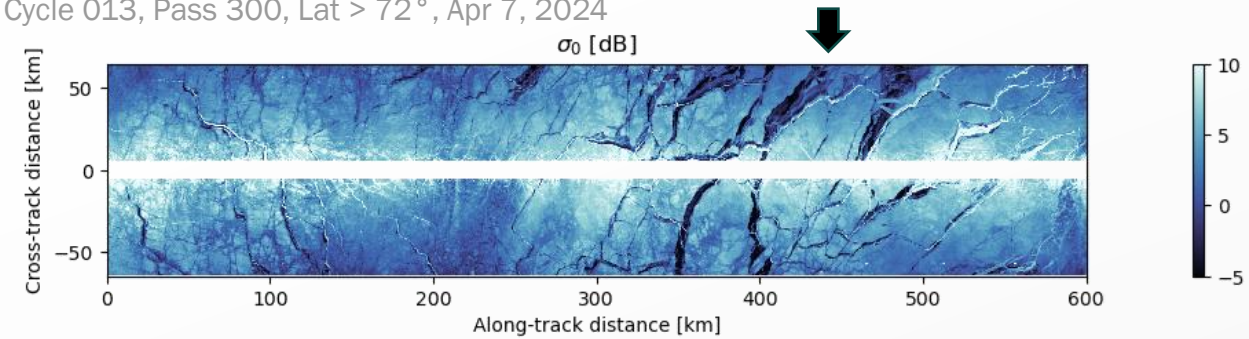


This resolution is currently used for floe-lead classification (Jestin et al. 2025)

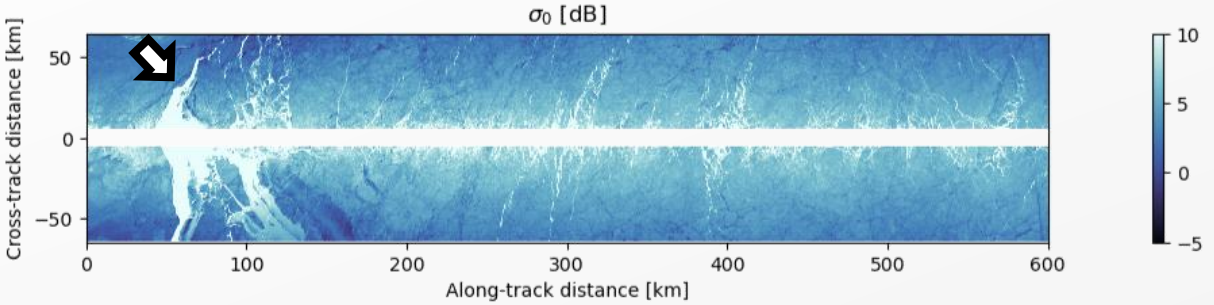
What does sea ice look like in SWOT data?

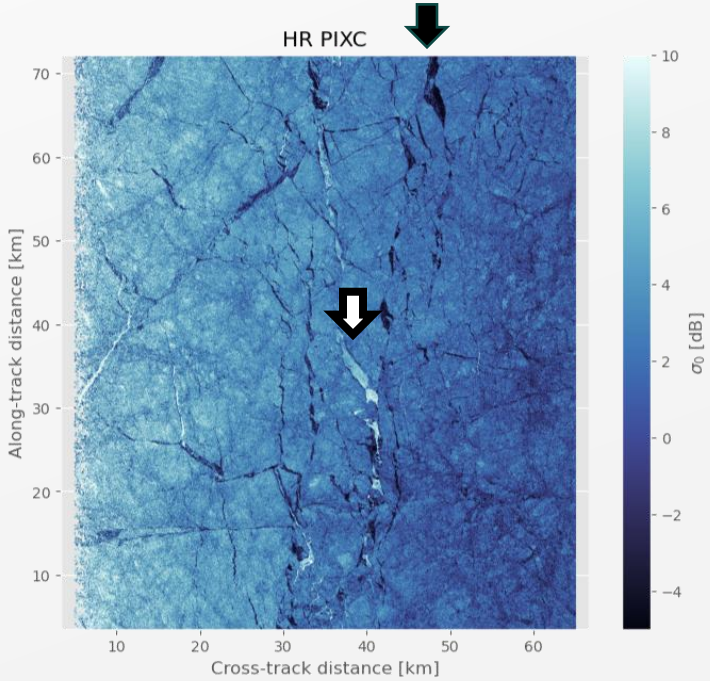
LR Unsmoothed data

Cycle 013, Pass 300, Lat > 72°, Apr 7, 2024



Cycle 013, Pass 519, Lat > 70°, Apr 15, 2024





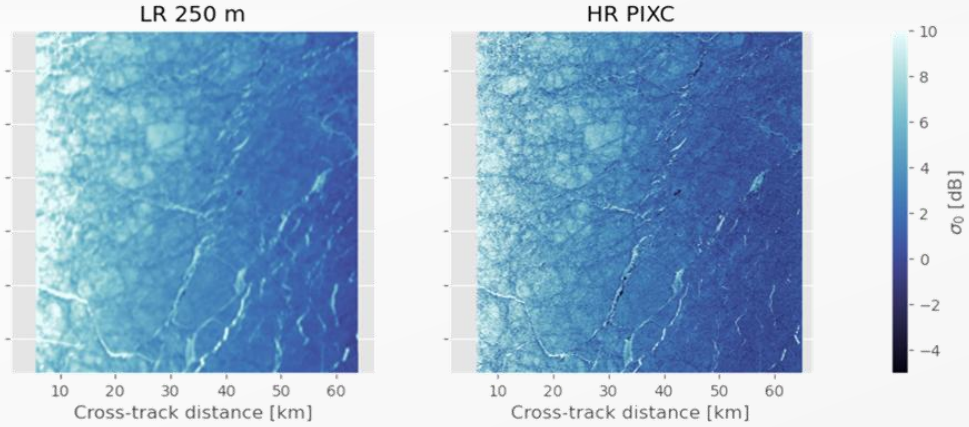
Leads can be seen as **black** or white in an ice background, both in LR and HR data

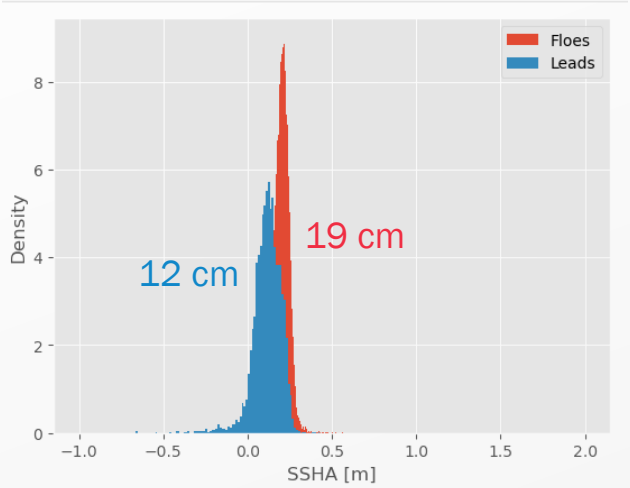
→ Backscattering varies with incidence angle, but also with roughness (wind, waves, frost), leads sizes and orientations

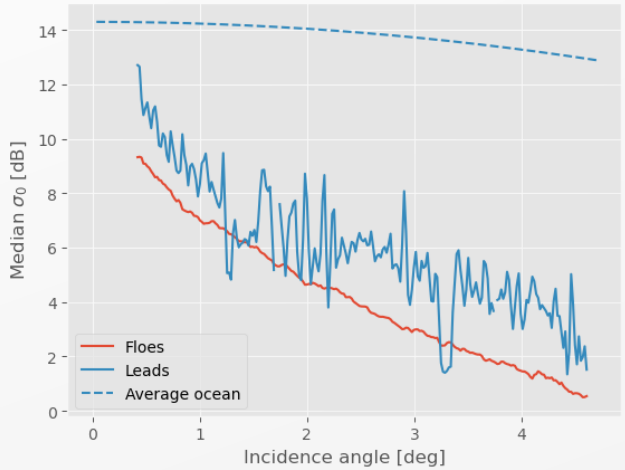
This is a challenge for the classification algorithms!

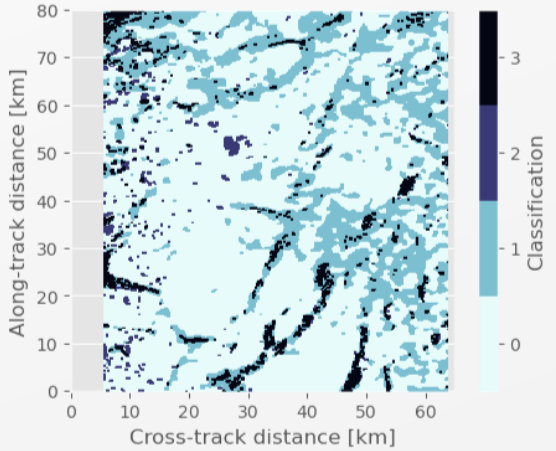
SWOT HR classification?

Let us use LR unsmoothed data co-located with a PIXC.





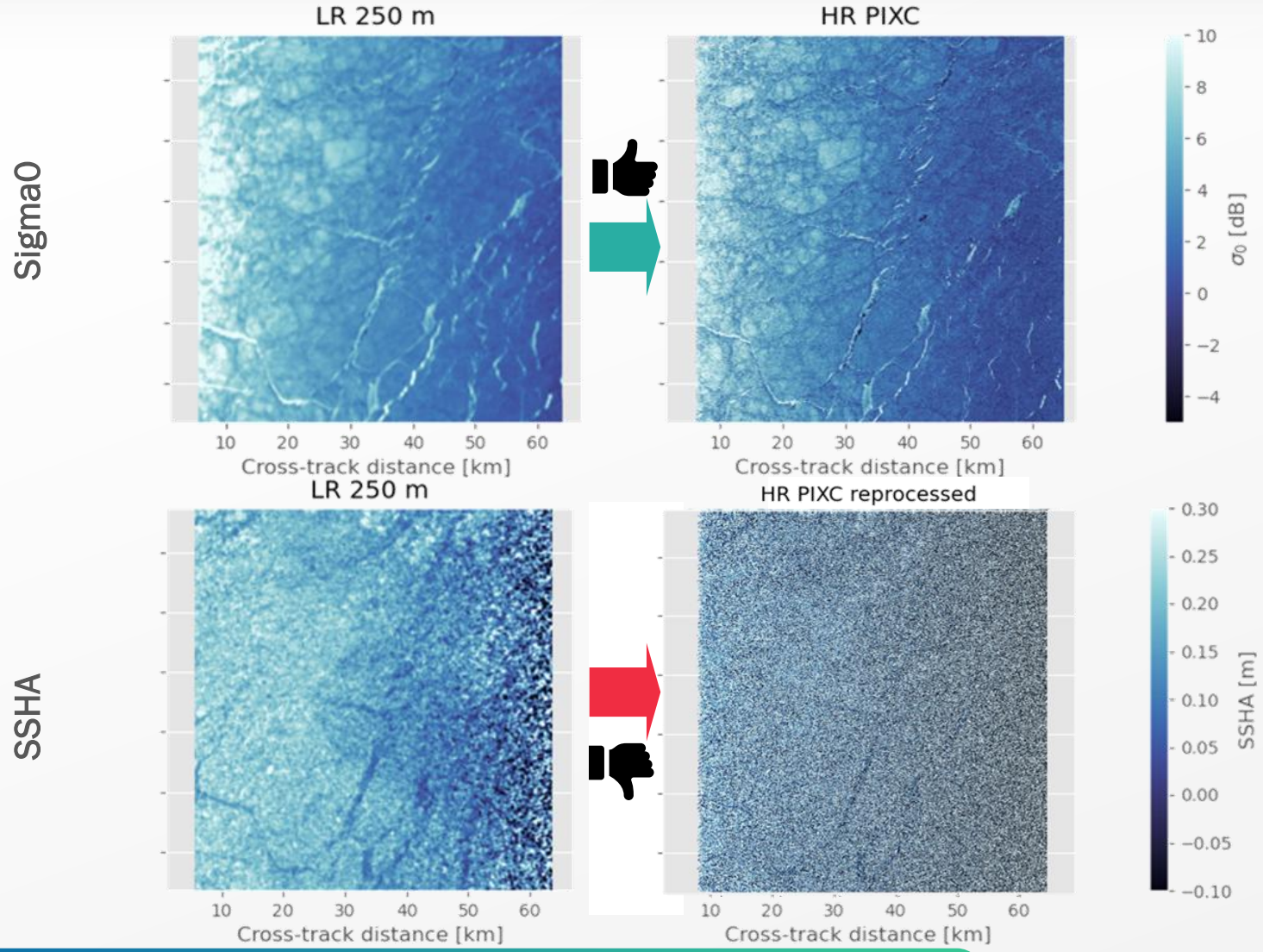




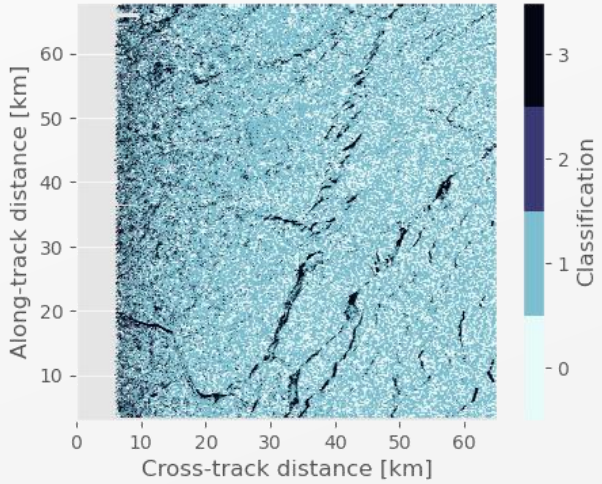
3 Leads (certain)
2 Leads (probable)
1 Floes (probable)
0 Floes (certain)

The unsmoothed LR classification gives a freeboard of ~7 cm, bright leads and a classification map.
Can we reproduce these results with HR data?

SWOT HR classification?



The LR classification algorithm requires a full pass of data, and gives **equal weight to σ_0 and SSHA**



Applied on HR data, this leads to unsure classification and biased freeboard.

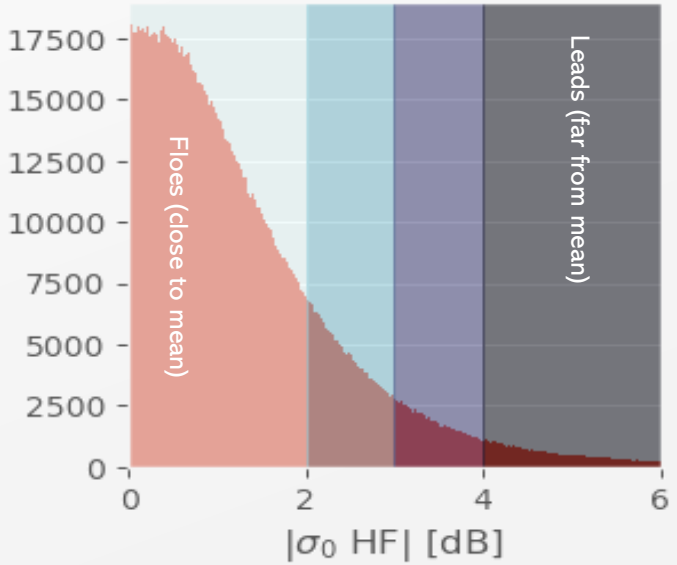
SWOT HR classification?

We suggest to use solely the σ_0 for the classification, looking for the contrast between leads and floes:

- Remove the along-track averaged to each point.
- Compute the low-frequency part of the obtained map with a large Gaussian kernel
- Remove it and take the absolute value to obtain the high-frequency straightened relative
- Label each point depending on their value.
- Convolve the obtained classification with a small Gaussian kernel

Set-back:

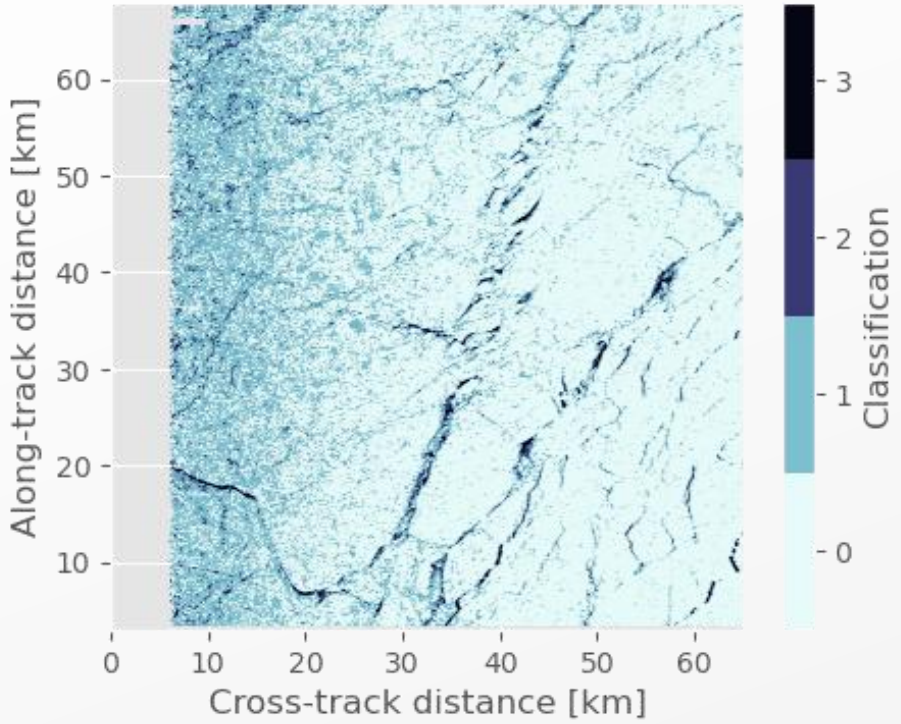
- Fixed relative sigma0 threshold? → Should depend on cross-track and location



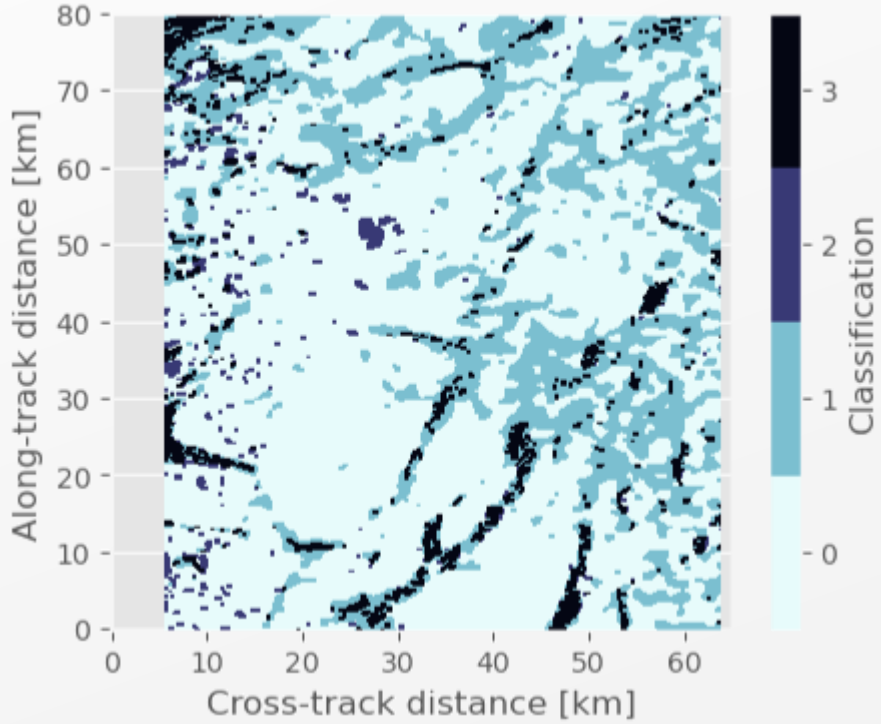
SWOT HR classification?

We suggest to use solely the σ_0 for the classification. Results:

3 Leads (certain)
2 Leads (probable)
1 Floes (probable)
0 Floes (certain)



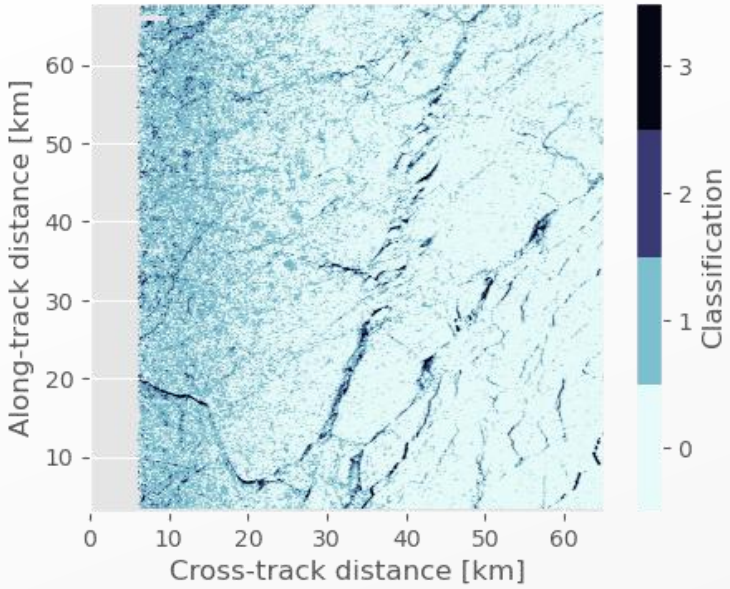
HR PIXC

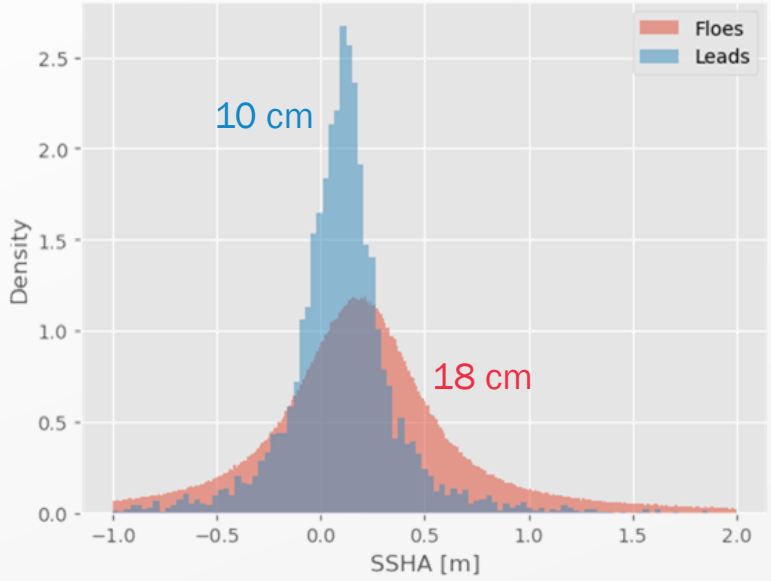


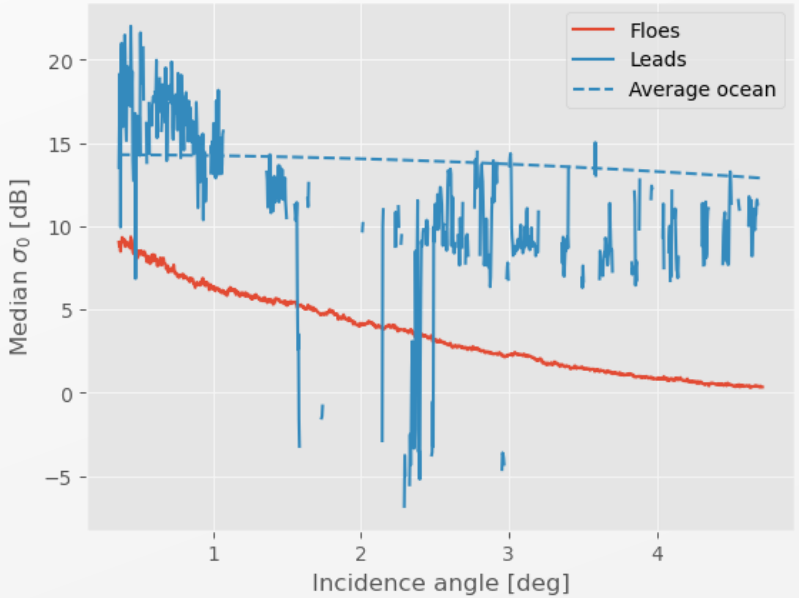
LR unsmoothed

SWOT HR classification?

We suggest to use solely the σ_0 for the classification. Results:







We retrieve a consistent classification, freeboard and radiometric profile!

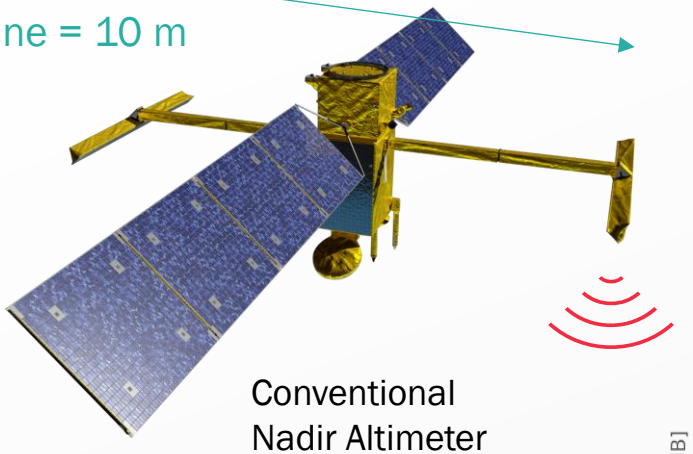
S3NG-T: similarities and differences from SWOT

Launching: 2022

Launching: 2034

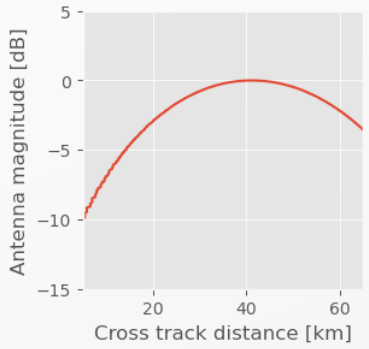
SWOT

Baseline = 10 m



KaRIn (Ka)

Conventional
Nadir Altimeter
(Ku, Poseidon 3C)

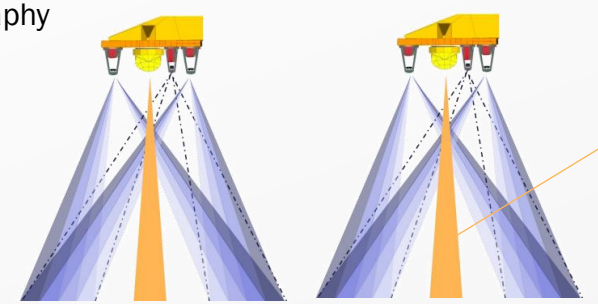


Two modes: LR and HR

Goals :
Hydrology
Oceanography (topography)

S3NG-T: Two-satellite constellation

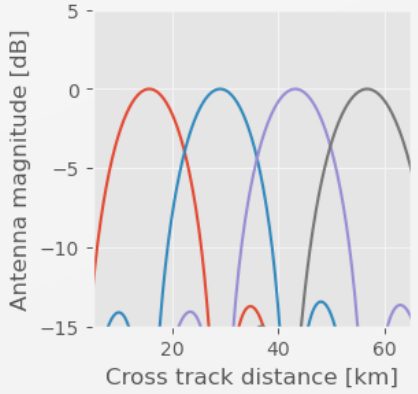
Baseline = 3 m (non deployable)
→ cheaper, but noisier topography



SAR Nadir Altimeter
(Ku, Poseidon 5)

SAOOH (Ka): 4 receiving antenna beams each side
→ same footprint size, but more power near and far-range

Three modes: LR, HR and HR-FF (one side only)

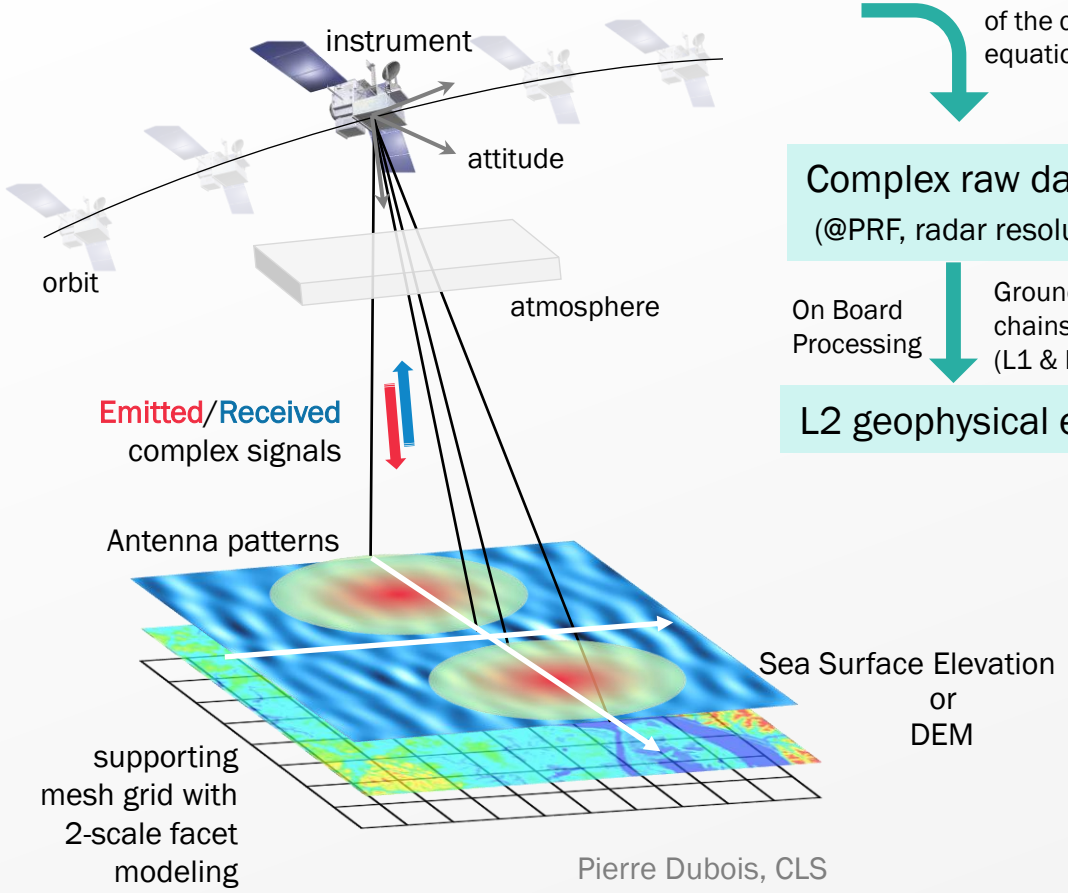


Maximum latitude: 78° 81.5°

Goals :
Hydrology
Oceanography (topography + waves)
Cryosphere

Simulations

We use an end-to-end S3NG-T simulator (SIRS) and processor (S3NGproto):



Pierre Dubois, CLS

Numerical spatial integration of the complex radar equation

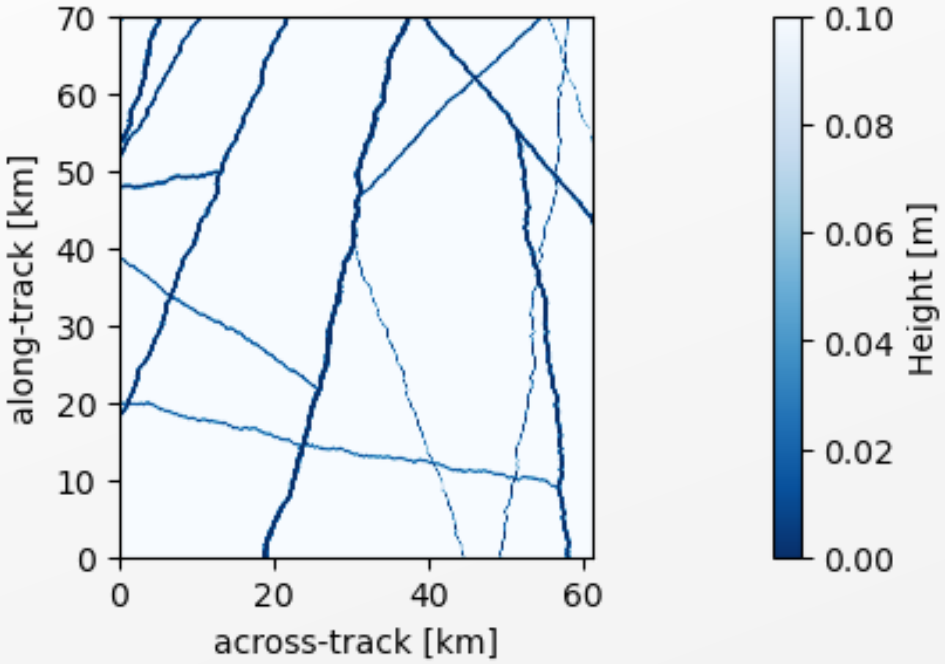
Complex raw data
(@PRF, radar resolution)

On Board Processing

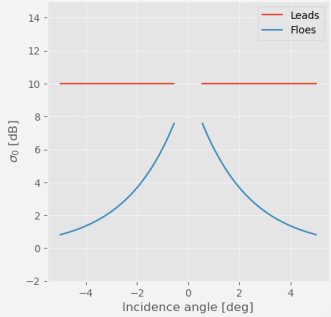
Ground Processing chains prototypes (L1 & L2)

L2 geophysical estimates

Input: simplified digital elevation model with two surface types and 15 leads from 25 to 500 m wide



Radiometric model:
bright leads

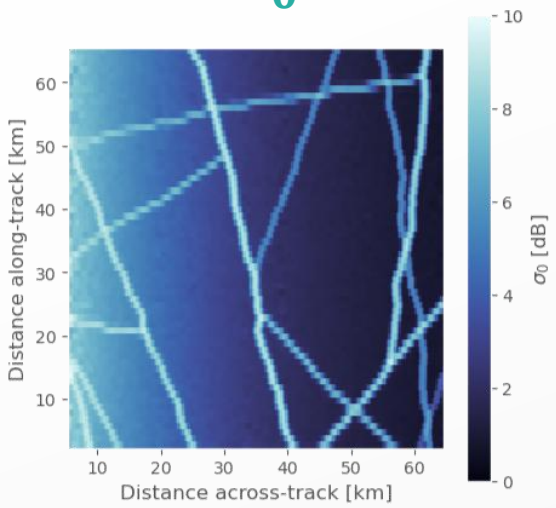


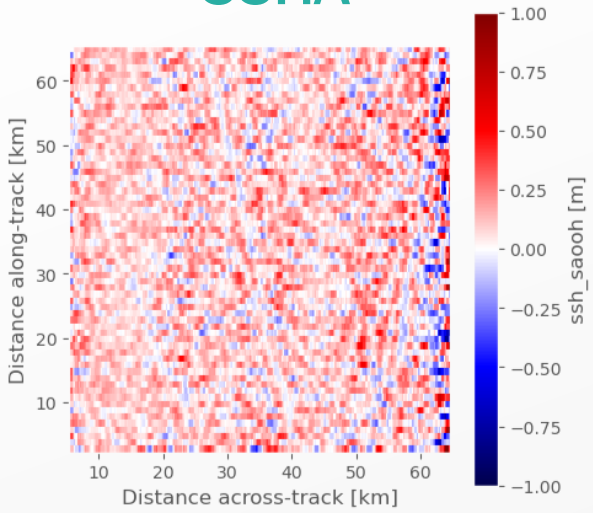
Simulation: first look

σ_0

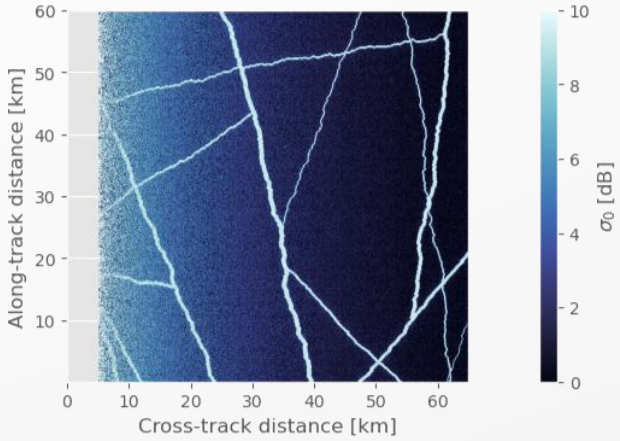
SSHA

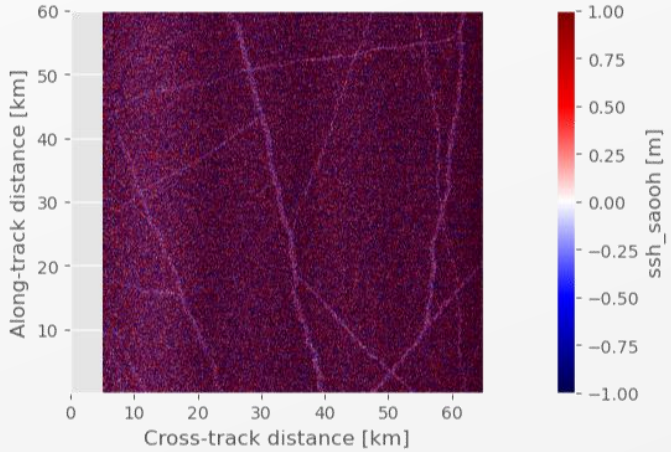
LR



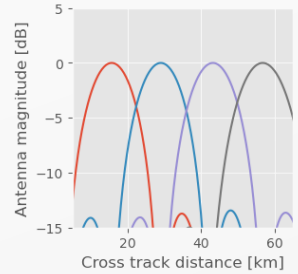


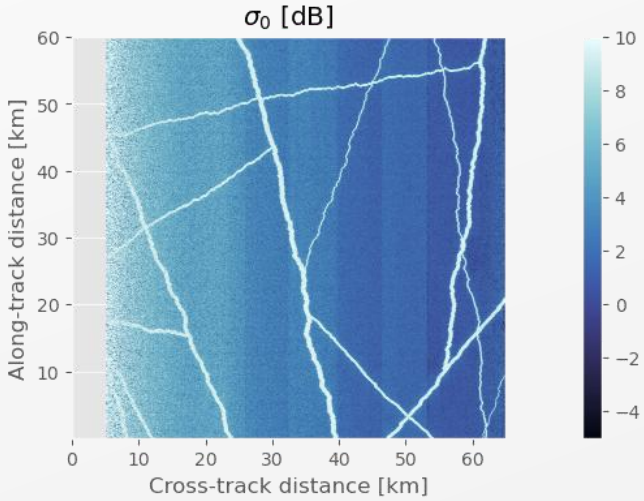
HR





Because of the four independent receiving antennas, σ_0 calibration is critical to avoid artefacts

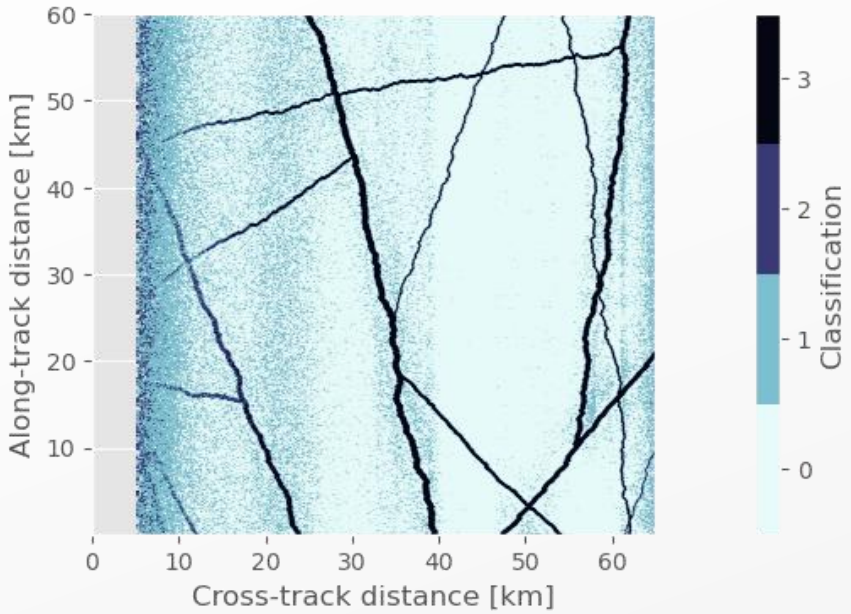




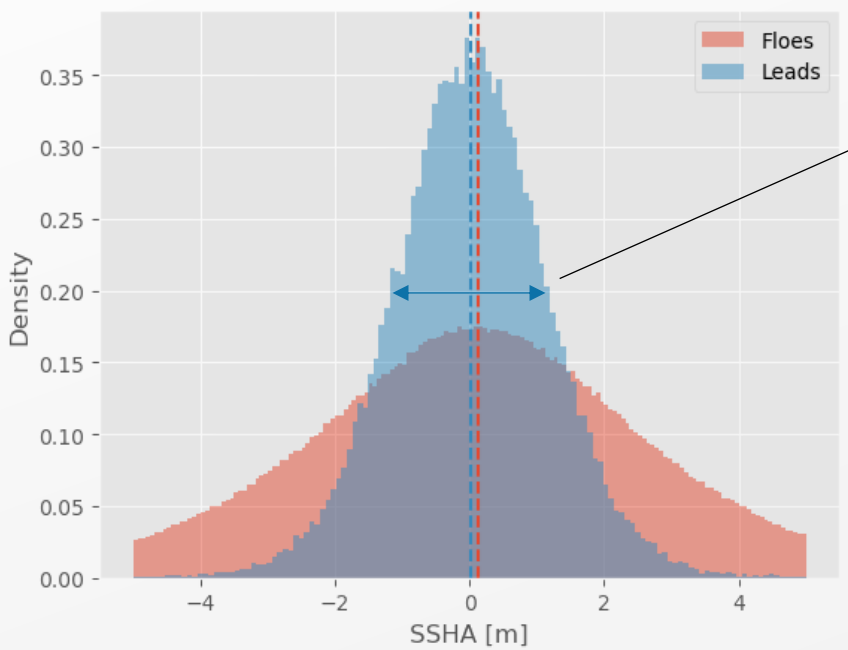
The BFPQ impact in the HR processing chain depends on the average signal, inducing a calibration discrepancy between antennas

Simulation: Classification

SWOT-like classification from LR data would require an entire simulated pass. However, we can apply the HR classification:

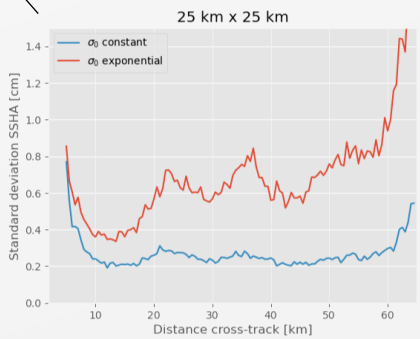


10 cm freeboard retrieved



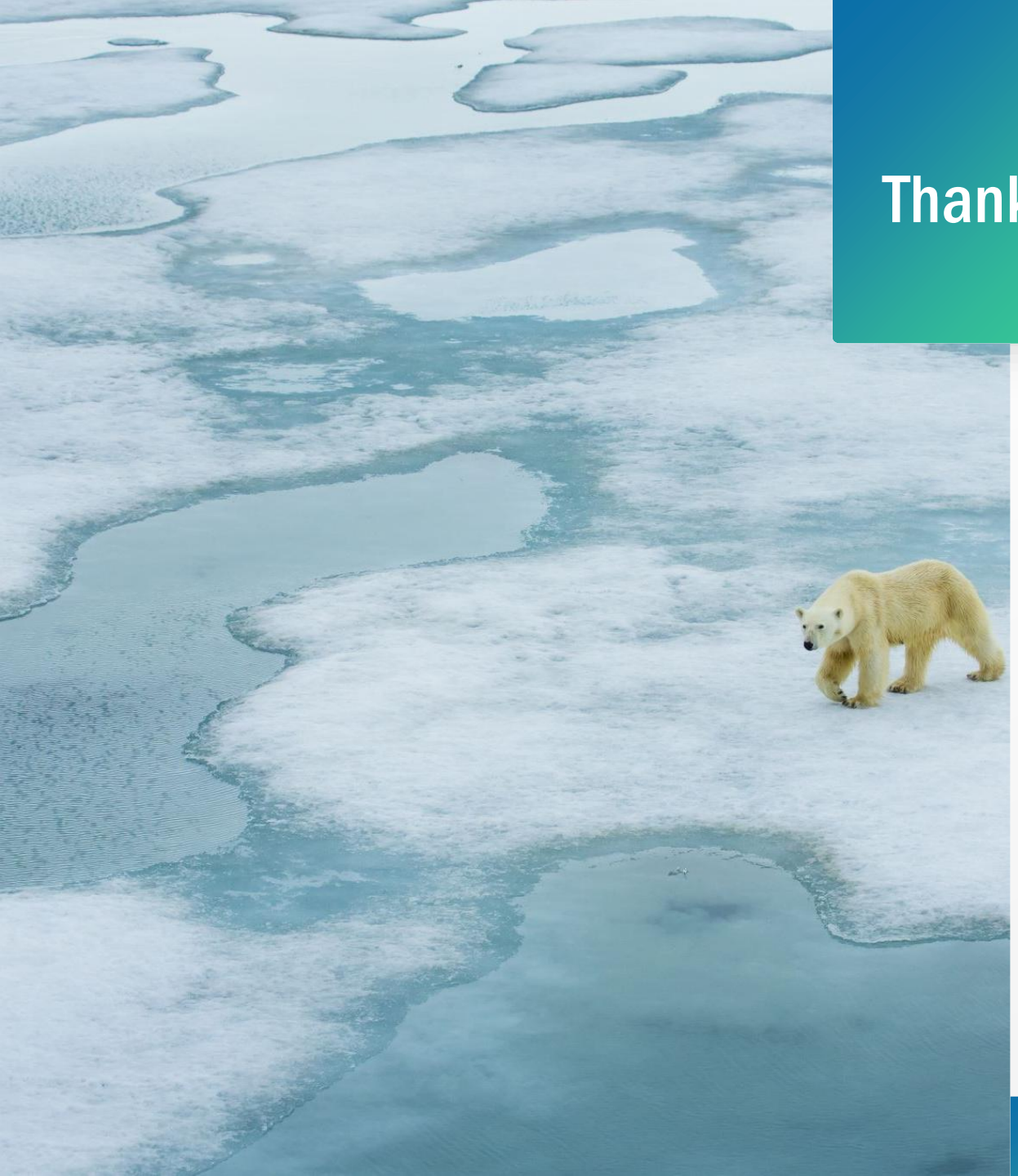
SSHA Precision at 10 dB

- 1.25 m over 50 m x 50 m area
- 2.5 mm over 25 x 25 km area



HR Simulation, bright leads, 50 m x 50 m boxes

→ Need averaging over ~4 km² area for 3 cm precision goal

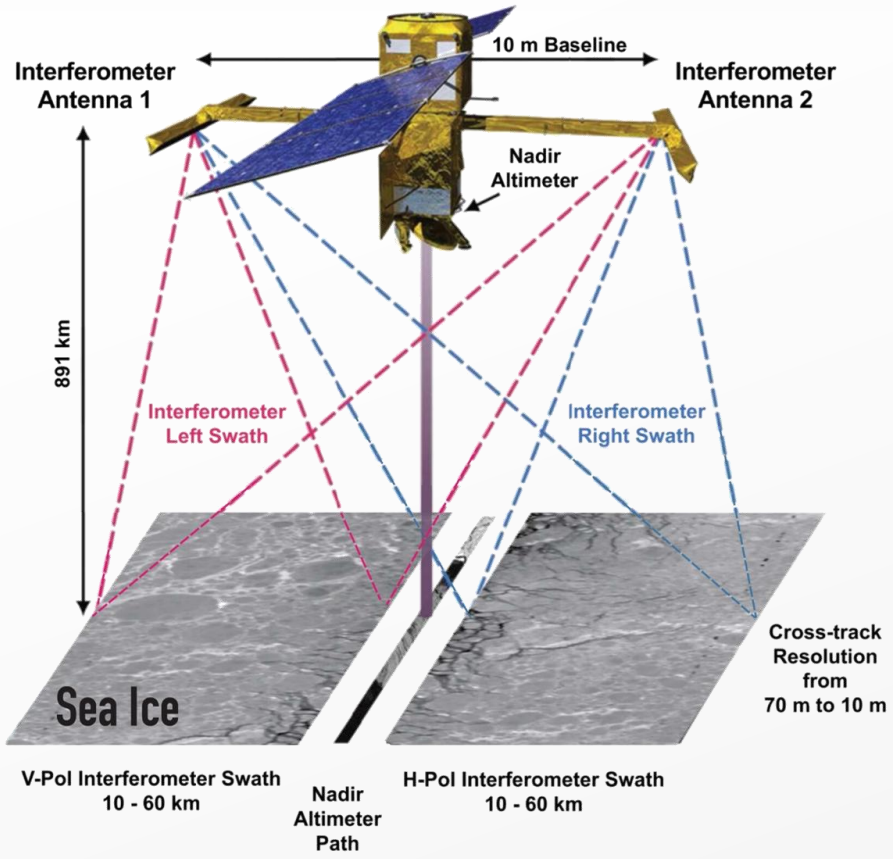


Thank you

- Despite no requirements or goals for sea ice in the **SWOT mission**, promising results pave the way for swath altimetry to **characterize sea ice concentration and thickness**.
- **HR can improve lead-floe classifications** despite the noisy height estimates.
- **S3NG-T has a mission requirement** for freeboard and sea height measurements in the cryosphere.
- Swath altimetry has expanded our possibilities for sea ice characterization from space!

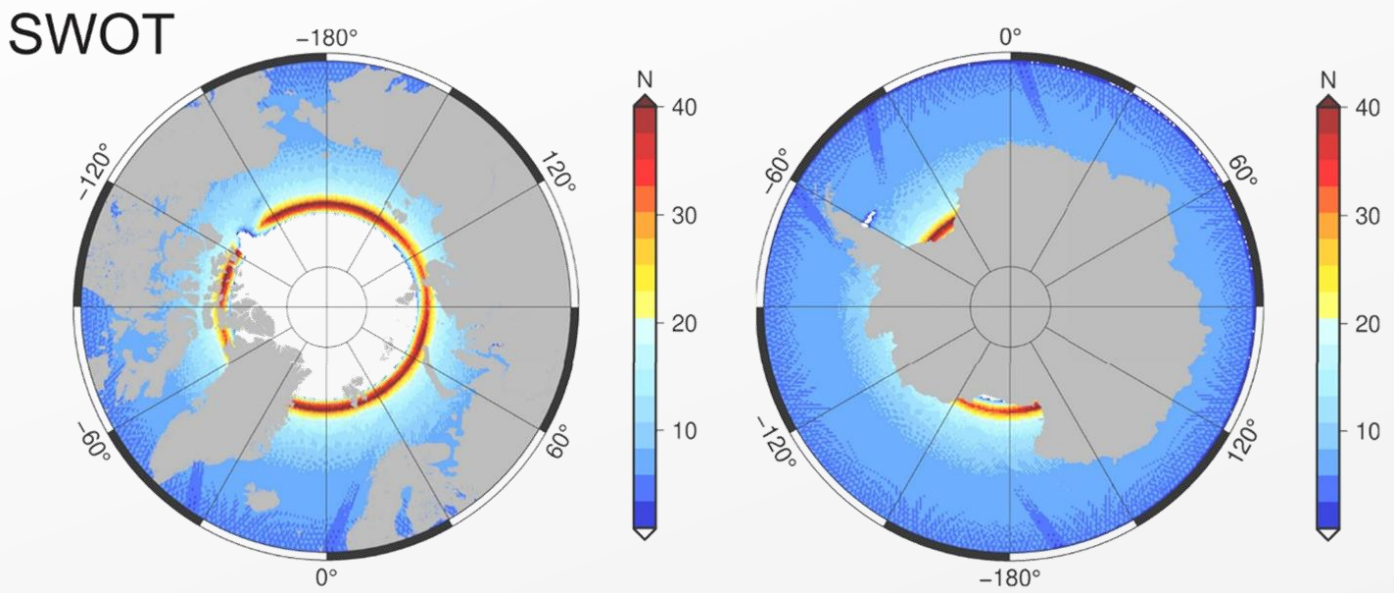
Contact: lrodet@groupcls.com

Swath altimetry: SWOT



Launching 2022

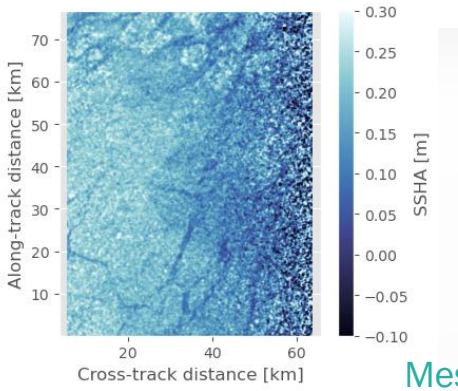
Number of orbital revisits over a given 25-km grid cell in a 21-day period

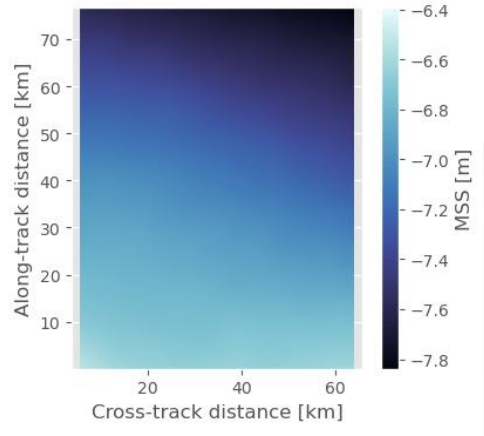


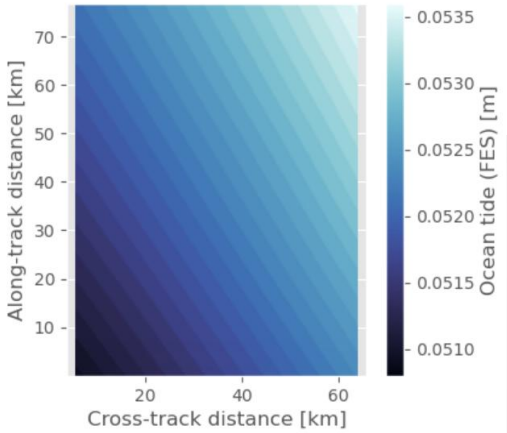
Maximum latitude: 78°

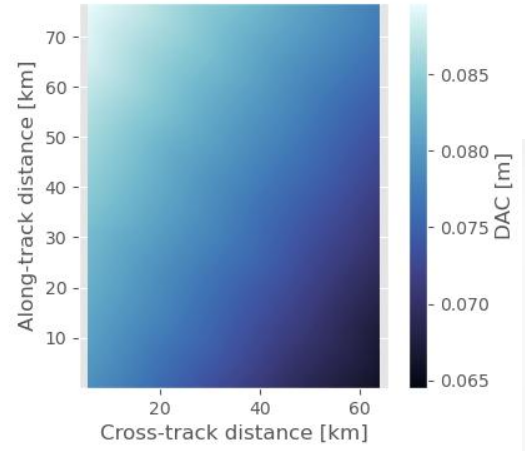
Kacimi et al. 2025

SSHA









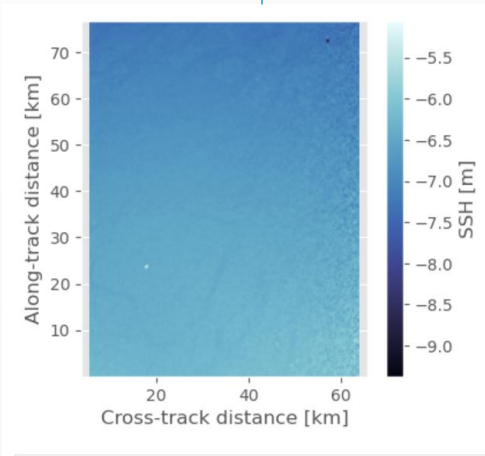
Mesurés à partir de l'ellipsoïde

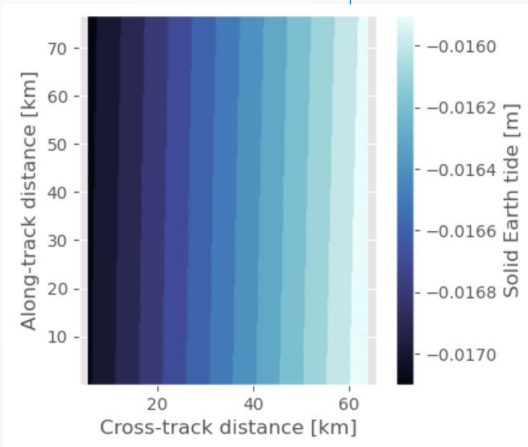
Corrections physiques

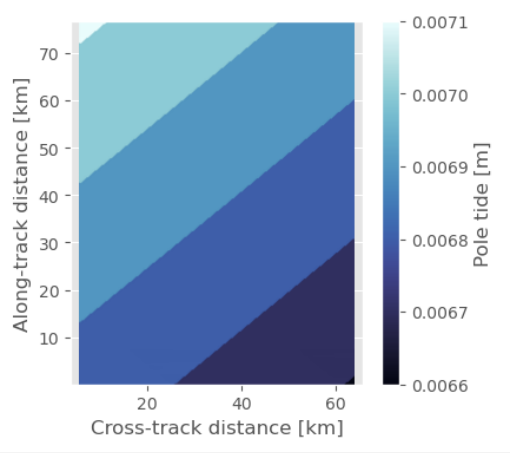
Correction instrument

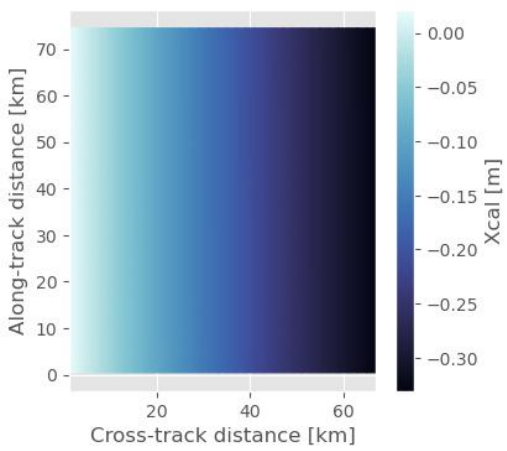
SSHA = (SSH or height) – MSS – Solide Earth tides – Ocean tides – Internal tides – Pole tides – dac + xcal

Δ sur 60 km: ~ 10 cm ~ 1.4 m ~ 1 mm ~ 2 mm = 0 ~ 0.5 mm ~ 2 cm ~ 30 cm





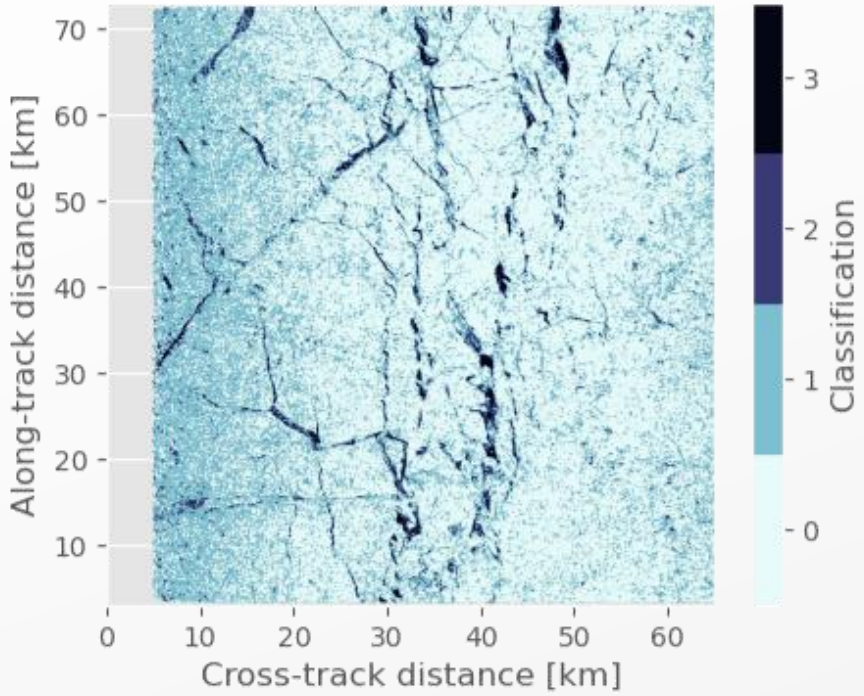


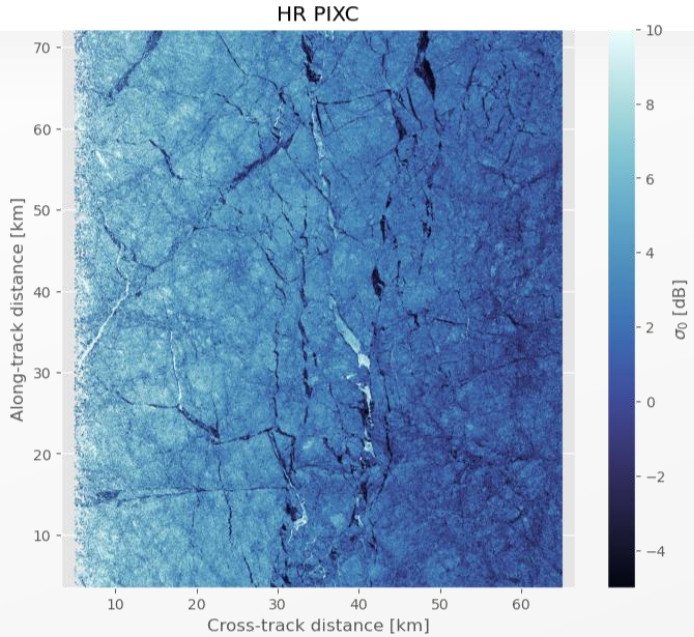


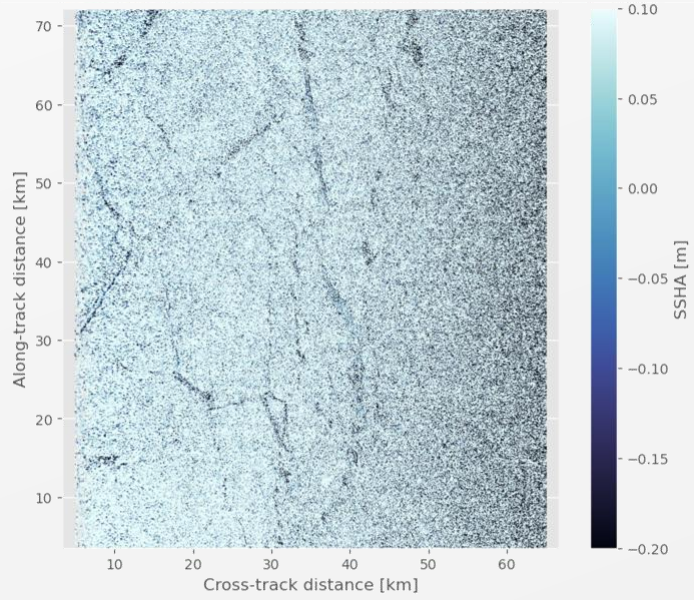
We interpolate the LR unsmoothed reference surface to compute the SSHA for every pixel in the pixel cloud.

SWOT HR classification?

Applications over other PIXC:



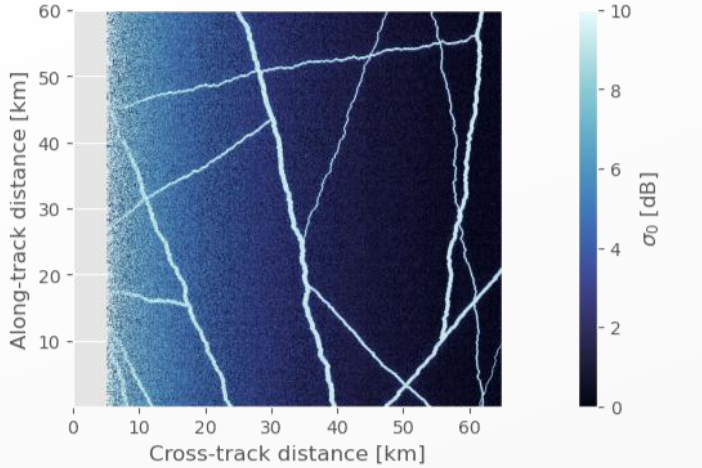


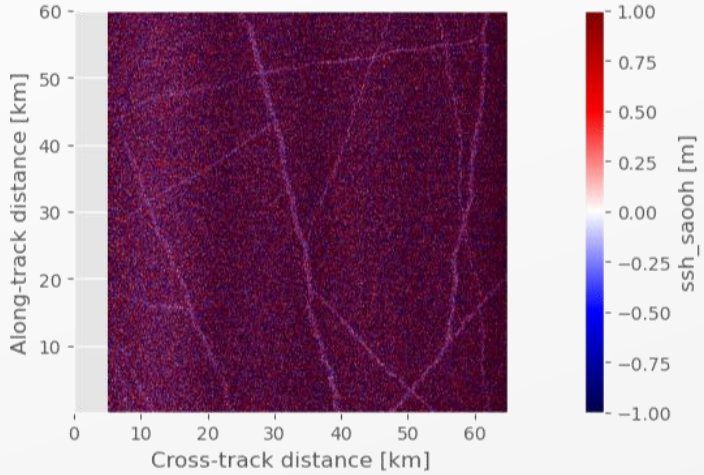


Simulation: Impact of the Fully-Focused mode

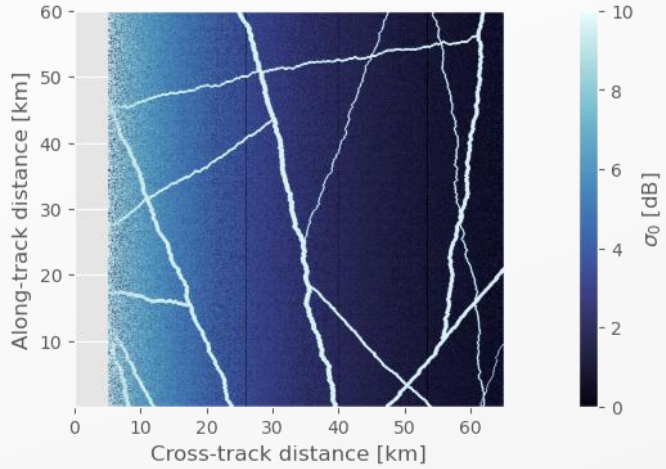
The HR-FF mode focuses on one side of the swath for a larger effective illumination time.

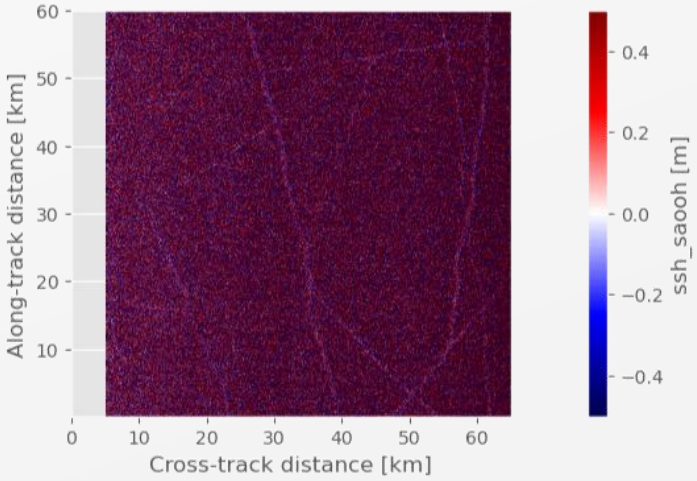
HR





HR-FF

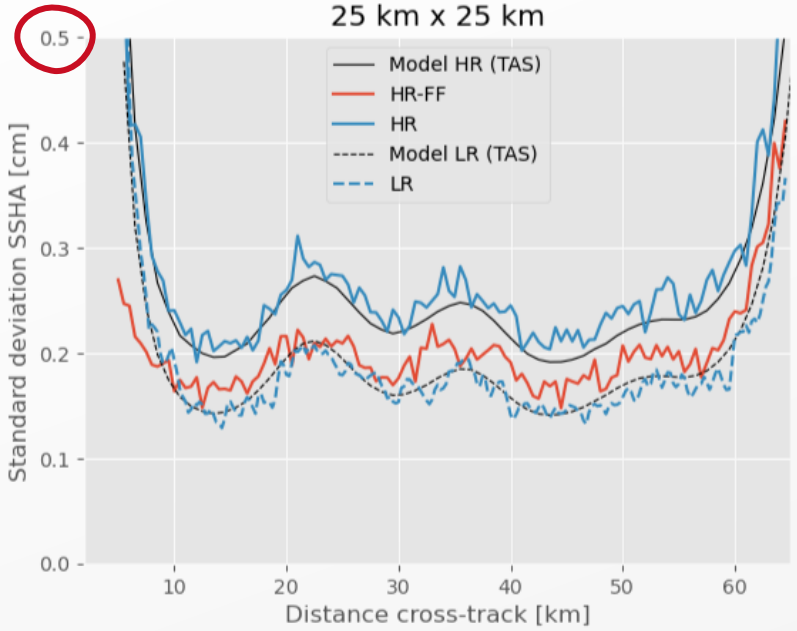




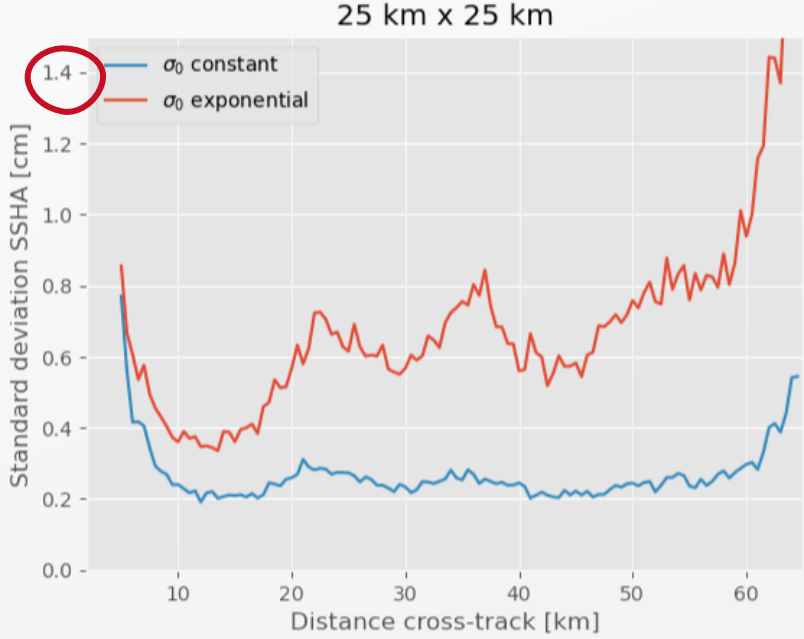
Simulation: Performance

The mission requires a minimal precision of **3 cm** on the freeboard in a 25 km x 25 km region during winter months, as well as **4 cm** in the SSHA of the leads.

SSH of ice and water within 2 cm precision on all swath!



Constant sigma0 = 10 dB



Simplified ice profile sigma0 = 10 dB $e^{-\frac{\theta}{2^\circ}}$